Universitat Autònoma de Barcelona

Departament d'Enginyeria de la Informació i de les Comunicacions

Triage applications and communications in emergency scenarios

Submitted to Universitat Autònoma de Barcelona
in partial fulfillment of the requirements for the
degree of Doctor of Philosophy in Computer Science

by Abraham Martín Campillo

Bellaterra, July 2012

Advisor: Dr. Ramon Martí Escalé
Professor Universitat Autònoma de Barcelona

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a dissertation for the degree of Doctor of Philosophy.

Bellaterra, July 2012

Dr. Ramon Martí Escalé
(Advisor)

External advisor:

Dr. Jon Crowcroft

Committee:

Dr. Jordi Herrera Joancomartí
Dr. Ricardo João Cruz Correia
Dr. Jaime María Delgado Mercé
Dr. Josep Rifà Coma (substitute)
Dr. Carles Garrigues Olivella (substitute)

A la meva familia

Abstract

Triaging victims is the first and foremost task in an emergency scenario. This process priorizes victim s attention based on their injuries, very important for an e cient and effective resource allocation in mass casualty incidents which large amount of victims. Traditional triage process used paper triage tags as victim s injury level indicator, a solution that had some drawbacks: first responder had to go to the each victim to see their injury level on the paper triage tag, loss of the triage tag, etc. On today emergencies, an electronic triage tag is essential for a faster coordination and attention to victims. However, emergency scenarios are usually characterized by the lack of wireless networks to rely on. Infrastructure based wireless networks as mobile phone networks or Wi-Fi networks are usually destroyed or overused due to the very nature of the emergency. Some solutions propose the use of sensors, creating a wireless sensor networks to transmit the injury level and position of the victim or deploying repeaters to create a fully connected MANET. However, in large emergencies this may not be possible and the time required to deploy all the repeaters could be not worth. This thesis analyses emergencies from the communication point of view. It proposes a system for the electronic triage of victims and emergency management to work even in worst cases scenarios from the network communications perspective thanks to the use of opportunistic networks and mobile agents. It also analyses the performance of several forwarding protocols in disaster areas and proposes some improvements to reduce energy consumption.

El triatge de víctimes és una de les primeres i més importants tasques a realitzar en arribar a un escenari d emergència. Aquest procés prioritza l atenció mèdica a les víctima en base al nivell de les seves lesions. Aquest procés és molt important per a una assignació de recursos eficient i eficaç, sobretot en emergències de gran abast amb un gran nombre de víctimes. El procés de classificació de víctimes tradicional utilitza etiquetes de triatge com a indicador de l estat de la víctima, una solució que comporta alguns inconvenients: Els metges han d acostar-se a la víctima per veure el seu estat en l etiqueta de paper, la pèrdua de l etiqueta de triatge, etc. Avui dia, la informatització de les etiquetes de classificació és essencial per a una coordinació i atenció a les víctimes més ràpida. No obstant això, els escenaris d emergència usualment es caracteritzen per la falta de xarxes sense fils disponibles per al seu ús. Xarxes sense fils basades en infraestructura com les xarxes de telefonia mòbil o les xarxes Wi-Fi solen destruir-se o saturar-se a causa d un gran intent d utilització o per la mateixa naturalesa de l emergència. Algunes solucions proposen l ús de sensors i la creació d una xarxa de sensors sense fils per transmetre l estat i la posició de les víctimes o el desplegament de repetidors per crear una MANET completament connectada. No obstant això, en grans emergències, això pot no ser possible a causa de l extensió d aquesta o pot no ser viable a causa del temps requerit per desplegar els repetidors. Aquesta tesi analitza les situacions d emergència des del punt de vista de xarxes i comunicacions. Es proposa un sistema per a la classificació electrònica de víctimes fins i tot en casos sense cap tipus de xarxa disponible gràcies a la utilització de xarxes oportunistes i agents mòbils. També s analitza el rendiment dels protocols de forwarding a les zones de desastre i es proposen algunes millores per reduir el consum d energia.

El triaje de víctimas es una de las primeras y más importantes tareas al llegar a un escenario de emergencia. Este proceso prioriza la atención médica a las víctima en base al nivel de sus lesiones. Este proceso es muy importante para una asignación de recursos eficiente y eficaz, sobretodo en emergencias de gran abasto con un gran número de víctimas. El proceso de clasificación de víctimas tradicional utiliza etiquetas de triaje como indicador del estado de la víctima, una solución que con algunos inconvenientes: Los médicos tienen que acercarse a la víctima para ver su estado en la etiqueta de papel, la pérdida de la etiqueta de triaje, etc. Hoy en día, la informatización de las etiquetas de clasificación es esencial para una coordinación y atención a las víctimas más rápida. Sin embargo, los escenarios de emergencia usualmente se caracterizan por la falta de redes inalámbricas disponibles para su uso. Redes inalámbricas basadas en infraestructura como las redes de telefonía móvil o las redes Wi-Fi suelen destruirse o saturarse debido un gran intento de utilización o a la misma naturaleza de la emergencia. Algunas soluciones proponen el uso de sensores y la creación de una red de sensores inalámbricos para transmitir el estado y la posición de las víctimas o el despliegue de repetidores para crear una MANET completamente conectada. Sin embargo, en grandes emergencias, esto puede no ser posible debido a la extensión de esta o puede no ser viable debido al tiempo requerido para desplegar los repetidores. Esta tesis analiza las situaciones de emergencia desde el punto de vista de redes y comunicaciones. Se propone un sistema para la clasificación electrónica de víctimas incluso en casos sin ningún tipo de red disponible gracias a la utilización de redes oportunistas y agentes móviles. También se analiza el rendimiento de los protocolos de forwarding en las zonas de desastre y se proponen algunas mejoras para reducir el consumo de energía.

Acknowledgements

Primer de tot voldría donar les gràcies al major responsable d aquesta tesi, el meu director de tesi, el Dr. Ramon Martí, per la seva dedicació i esforç durant tots aquests anys, i per compartir el seu coneixement amb mi.

I would also like to thanks my external advisor, Jon Crowcroft, for sharing with me his amazing knowledge and opinions. I would also thank him for giving me the great opportunity of working within the NetOS group in the University of Cambridge where I learned a lot working with extraordinary people. Special thanks to Eiko Yoneki and Narseo Vallina, members of the NetOS group, for their help and share of knowledgment with me.

També voldria agrair als meus companys del departament d Enginyeria de la Informació i de les Comunicacions, amb una menció especial als companys becaris, que no han estat només companys de feina sino també amics. Moltes gracies pels bons moments, moments que et treien un somriure en el moment que més ho necesitaves. Us trobaré molt a faltar.

Per acabar, també voldria agrair a la meva familia, els meus amics i la meva parella pel seu amor i suport incondicional; per haber aguantat derrotes i celebrat victories; us estimo molt.

En definitiva, gracies a tots aquells que heu fet aquesta tesis posible ja sigui de manera directa o indirectament.

Preface

This dissertation shows much of the work that I had done during my PhD degree in the Departament d Enginyeria de la Informació i les Comunicacions at the Universitat Autònoma de Barcelona. It is presented as a compendium of publications, thus the contributions are appended to this document in the form of publications to conferences, books and/or journals.

This work has been partially supported by the Spanish Government MEC grants TME2008-00865 and AP2008-03149, by the Spanish MICINN under the projects TSI2006-03481 and TIN2010-15764, and by the Comissionat per a Universitats i Recerca del DIUE de la Generalitat de Catalunya 2009SGR1224.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

Emergencies have been in the spotlight in recent years. Some of the most important events in the last decade have been natural disasters or mass casualties incidents. We have seen major disasters in several countries: the earthquake in Japan in 2011, the tsunami in Indonesia in 2004, the hurricane Katrina in United States in 2005, the eartquake in Haiti in 2010, in the region of L Aquila in Italy in 2009 or in the north of Italy in 2012, among others. In all cases victims have been numerous, fact that highlights that not only it is necessary to put efforts in preventing potential disasters but also in improving its management in order to reduce the number of casualties. These major incidents have made us rethink the way emergencies must be managed and coordinated, and some authors have proposed a variety of solutions in order to improve these situations and to take advantage of new technologies.

A fast recovery from an emergency situation can save a lot of lives but this is a complex task, especially in mass casualty disasters. Rescue teams dedicated to search, triage and rescue victims do not have the technological tools to help accomplish these tasks and in the case of having them, often these are not prepared to withstand extreme conditions such as lack of a pre-set communication channel.

The triage process is a standard process worldwide. It consists in performing a series of actions for getting fast medical condition information about the victim.

These actions can be a measure of the pulse or respiratory rate of the victim, or a test in order to know if the victim responds to simple questions or actions. A flowchart is followed after the information has been gathered from each test and it gives as a final result the seriousness of their injuries. It is normally used a color scale to indicate the injury level of the victim: green for good condition, yellow for delayed medical attention needed, red for urgent medical attention needed and black for no medical attention needed (victim is dead or nothing can be done to save her live).

While one team is in charge of triaging the victims another is in charge of providing medical care to those victims in worst conditions. This team has to know where the victims are and their medical condition in order to attend first those most in need. When the emergency is small this is an easy task as the team only has to look around and see the color of their triage tag. But when the emergency scenario is large the coordination becomes more difficult. More victims and their unknown locations are a challenge for the coordinators of the emergency.

Some authors proposed as solution the use of electronic triage tags sensors. These sensors are attached to the body of the victim and they retriage the victim constantly during the emergency and indicate wether the victim has changed its medical condition (from one color state of the triage to another). These sensors provide improvements over the traditional methods: constant retriage, GPS position of the victim, data availability, etc. But they also suffer from some problems: high cost of the sensors and the requirement of a fully connected mesh network in order to work. The first problem has been lowered over the years. When this thesis started back in 2009, the price of a single triage sensor was too high for a big emergency with a lot of victims. Nowadays the price of this type of sensors (with GPS, biomedical sensors, network, etc) is lower but it is still high as a single unit may cost above 100 €.

The second problem was proposed to be solved deploying Wi-Fi repeaters or hotspots all over the emergency scenario. This is a task that needs to be done by the first responders arriving to the emergency scenario in order to have all the sensors sending its data to the coordination center. But in large emergency scenarios this task could take a lot of time and cost (of all the repeaters). Furthermore, having people dedicated to deploy nodes in an emergency scenario can be seen as a waste of valuable resources available at the beginning of the aftermath of the emergency.

Communications in emergency scenarios is also a complex problem. Usual methods of communication as mobile phone networks or Wi-Fi hotspots are usually destroyed or become unavailable during mass casualties incidents. Natural disasters as earthquakes or tsunamis usually destroy network infrastructures. Even if these are not destroyed or if the disaster has another origin, users tend to overuse this networks to communicate with their families, or receive news or status updates. This fact produces an overload that makes networks unusable. Recent disasters as the earthquake in the north of Italy in May of 2012 destroyed a lot of 3G network antennas. This pushed some operators to publicity ask citizens with DSL connections still working to open their Wi-Fi hotspots to facilitate communications in the region [3].

Another problem in disaster scenarios is the energy consumption of mobile devices and sensors used, which have limited battery capacity. The emergency situation may be ongoing for some time, hence systems may have to stay usable for extended periods. Works from different authors show that Wi-Fi network is one of the most consuming power elements of a mobile device [6][50][9]. For this reason, the use of energy-e cient mechanisms is a must.

The objectives of the thesis are focused on solving disaster area communication problems. The goal is to have a triage system that does not require a fully connected mobile ad-hoc network (MANET) to route the information generated in the emergency scenario, being able to work even in worst cases scenarios: no networks with large disaster areas. Furthermore, a study about performance (delivery ratio, latency or energy consumption) should be carried in order to know which parameters of a disaster scenario impact in the performance.

Objectives

After the description of the objective of the thesis we summarize them in the following lines:

- Analyze the emergencies to deeply understand how they work and what elements can be improved or taken into account for the rest of the objectives.
- Propose a system to provide an electronic triage solution capable of working under extreme conditions (no network communications, big disaster areas, few personnel, etc).
- Propose a mechanism able to deliver the information collected in the emergency scenario (triage information, victim s information, etc) to a coordination point even in situations without any network available.
- Propose a solution for the lack of network infrastructure in emergency situations.
- Analyze the performance (delivery ratio, delay, delivery cost and energy consumption) of existing forwarding methods in emergency scenarios.
- Analyze how the characteristics of a disaster scenarios impact in the performance of different forwarding protocols in emergency scenarios.
- Analyze new forwarding schemes to improve the performance of existing routing protocols.

Structure

This thesis is presented as a compendium of publications. After this first chapter of introduction, chapter 2 follows explaining the related work of the thesis. This includes understand how emergency works, describing the recovery process, what is a triage process and how is performed and the technologies that are involved in the further proposals. It follows chapter 3 that introduces the publications taking part of the thesis presented as a compendium, summarizes the main contributions, and discusses their applicability. Finally, chapter 4 concludes the thesis and show future open lines of research.

Chapter 2

Related work

2.1 Classification of victims

The triage process is used by first responders in emergencies or disasters to prioritize victims assistance based on their level of injuries or condition and it is used afterwards to allocate medical resources more efficiently. The triage process consist in following a protocol or algorithm that is responsible for deciding the injury level of the victim based on a series of tests performed to her. This protocol is designed to obtain a confident result as fast as possible (usually from 30 to 60 seconds) by using quick and reliable tests.

Triage tags usually are a piece of paper recovered in plastic (or similar) that are used to indicate visually the condition of the victim. There is no universal agreement in the design or form of triage tags, hence there exist some different implementations. Some examples are given in figure 2.1 and 2.2. The example in figure 2.2 is placed in the wrist of the victim and only indicates their condition. The other example in figure 2.1 is usually placed around the neck or wrist of the victim and can contain more information about her.

The main purpose of a triage tag is to be a simple way to identify at a glance the condition of a victim.

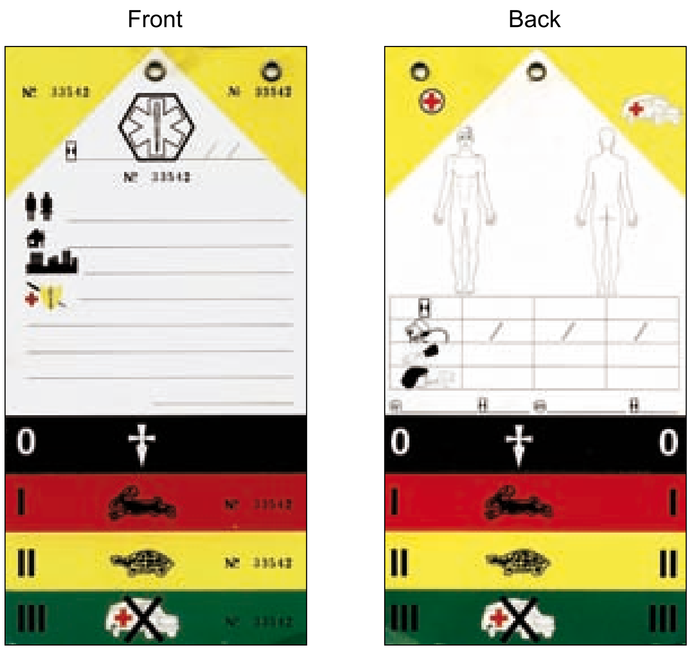

Figure 2.1: Triage Tag

2.1.1 Triage protocols

There exist several classification protocols nowadays, these are the most common.

START

Simple Triage and Rapid Treatment (START) is nowadays the most commonly used triage protocol. It was originally developed in 1983 by the Hoag Hospital and Newport Beach Fire Department in California, United States [57]. It follows four tests: autonomy (can walk away the emergency scene), respiration rate, perfusion rate (or capillary refill test) and mental status check. The process can be seen in figure 2.3 and it can be usually performed in less than 60 seconds.

First, the first responder looks if the pacient can walk. If the victim can walk

Figure 2.2: Triage wristband

without any problem or movement restriction, she will be tagged with a *green* triage tag and will be ordered to evacuate the disaster area to a safer place. Victims in this group are usually advised to go by themselves to hospital.

In case of patients with reduced or no mobility, it will be checked if the victim can breathe. If she can not breathe, the first responder will try to open an airway and check again if the victim can breathe. If she still can not breathe, she will be tagged with a *black* triage tag, meaning that the victim is deceased. If the victim has recovered her breath, she will be tagged with a *red* triage tag, meaning that she needs *immediate* attention.

In case the victim is found with reduced or no mobility but she is able to breathe, a respiration tests will be done. If the respiration rate is above 30, the victim will be classified as *immediate*, if not the first responder will perform a radial pulse test. If the radial pulse is absent in the victim, she will be tagged with a *red* triage tag. An alternative test, (perfusion test) can be done instead of the pulse test.

If the radial pulse is present in the victim, the last test will be performed: the mental status check. If the victim can follow simple commands, she will be tagged with a *yellow* triage tag, meaning that her medical attention can be *delayed* up to two hours. If the patient can not follow simple commands, she will be classified for *immediate* attention.

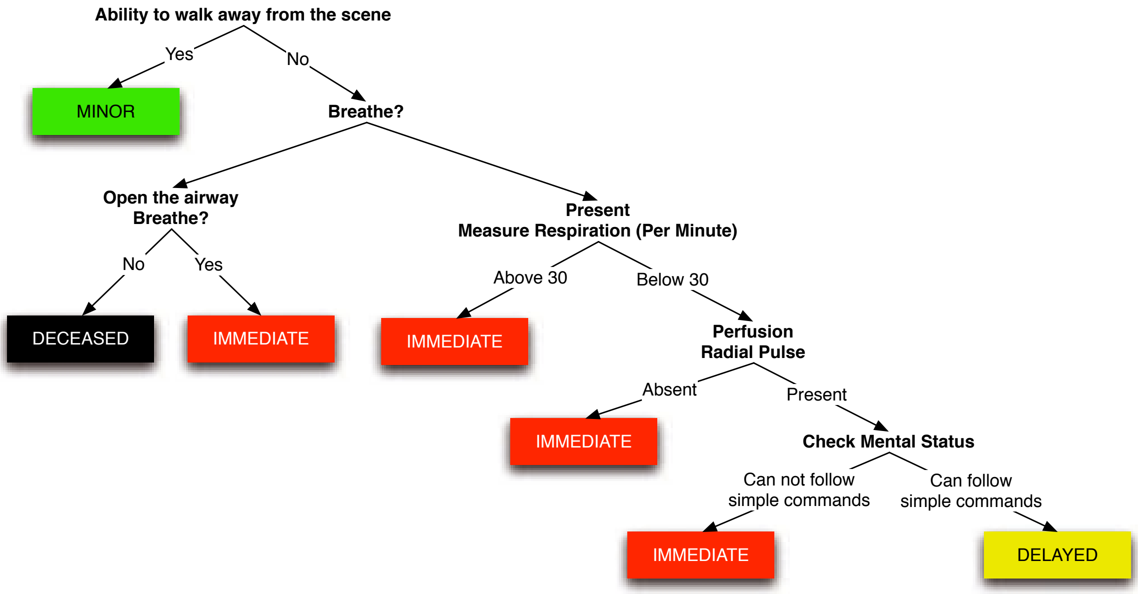

Figure 2.3: Simple Triage and Rapid Treatment protocol

As can be seen in figure 2.3, START uses 4 colors to distinguish the different possible conditions of a victim.

The green color (or MINOR) identifies the victim as low priority or delayed attention.

The yellow color (or DELAYED) identifies the victim as urgent attention.

The red color (or IMMEDIATE) identifies the victim as immediate attention.

The black color (or DECEASED) identifies the victim as dead or mortally wounded.

Triage Sieve and Sort

This triage protocol[57] is most commonly used in United Kingdom. It consist in two sub-protocols: *Triage Sieve* and *Triage Sort*. The *Sieve* protocol is used for classifying the victims in the emergency area. It uses the same four injury levels of the START protocol and the following tests: autonomy (patient can walk away), respiration rate and pulse rate (or capillary refill test). The only difference from the START protocol is that the mental status is not tested. The pulse rate test (the last one) classifies the victim into the DELAYED group if the result is between 40 and 120, or into the IMMEDIATE if not.

Once the victim is at a casualty clearing station the *Triage Sort* is performed in order to retriage the victim. It uses several *Trauma Scores* tests that have numerical results. Score from each test are added and the victim classification is based on this result. The tests are: respiratory rate, systolic blood pressure and Glasgow Coma Scale (GCS)[58]. The last one is in charge of measuring the neurological damage of the victim.

Other protocols

There exist other protocols as the *Manchester Triage System (MTS)* [12] or the Injury Severity Score (ISS) [5]. These protocols have many similarities as most of them use the same tests but with a few changes in the protocol, less populars (only used in some part of the world) or with differences in the triage tags used. For instance, the *Cruciform triage* [13], uses the START protocol but the triage tag contains more information: radiation data, toxicity, etc.

2.2 Disasters recovery process

The disaster recovery process is similar to all type of emergencies: triage, stabilization of victims and transportation of victims. Worst emergency scenarios usually are mass casualty incidents (MCIs). The main characteristic of MCIs is the large number of victims.

The triage of the victims is always the first and foremost in an emergency scenario and it is done by the first response personnel arriving at the emergency scene. Casualties are sort into groups based on their medical condition. Consequently, medical personnel arriving later know which victims need more urgent attention. Victims are attended and stabilized in triage order before they are evacuated to the hospital field or to the advanced medical post where they will be treated widely.

The most common triage protocols used in emergency scenarios usually create four groups of victims based on their medical condition. The first group, from worst to best condition order, is the deceased or black one (sometimes the color used is blue). Those victims are those who are clinically dead or with obvious mortal injuries with no significant chance of a successful outcome. The second group, immediate or red, are casualties who need immediate attention because they have life-threatening injuries. The victims in the third one, urgent or yellow, cannot walk due to mental or traumatic injuries but do not need immediate but urgent medical attention, hence they can wait for a short period of time up to two hours. And finally, the minor or green group, is for casualties with minor injuries who need help less urgently.

Once the triage is complete, rescue teams extract those victims who are trapped or cannot move from the disaster area to a safe place. The incident location is also known as zone 0. In this area the medical personnel cannot work because of a risk of danger such as explosion or contamination. Because of this, it is important for everybody to evacuate this area and for the rescue teams to extract the victims that cannot move. While rescue teams are doing their job, the medical personnel treat those victims in the red group that have already been evacuated and are in the patients waiting for treatment area, also known as zone 1.

If Advanced Medical Posts (AMPs) or casualties clearing stations are installed, the victims are evacuated there (see figure 2.4). An AMP is a mobile hospital to treat the victims before they can be moved to an hospital. In MCIs, where it is necessary to treat lots of victims in a serious condition, AMPs are essential and have to be installed near but in a reasonable distance from the zone 0 to be a safe place.

Zone 0 can have two types of nodes, transportation nodes and non-transportation nodes. The first ones are in charge of moving victims from the zone 0 to the zone 1, the patients waiting for treatment area. The second ones are in charge of triaging victims in zone 0, the incident location. Hence, a transportation node goes periodically from zone 0 to zone 1 and vice versa during the disaster (acting like a data mule) and a non-transportation node looks for victims and triage them in zone 0 without coming back to the zone 1 until required.

The main objective of the medical personnel in the AMP is to stabilize the patients. Once the stabilization is done, the ambulance, helicopter or other rescue vehicle is called to pick up each victim to transfer them to the hospital. After the red victims are treated, the yellow ones are followed. Regarding the green ones, they are arranged together and then transferred with low priority to other hospitals or medical institutions using any available transportation.

The Advanced Command Post (ACP) is where the coordination team is, and where all the decisions about actions to be carried out by rescue and medical teams are taken.

2.2.1 Node mobility in disaster areas

Node movement in disaster areas cannot be completely predicted because the emergency scenario is different in each case, victims have different location and the number of first responders working on the emergency is different. Some parts can modeled though, the disaster scenario can be divided into areas as can be seen in figure 2.4. These areas have entry and exit points and nodes behave different in each of them. Furthermore, there exist different type of nodes in some areas. In the zone 0 there exist transportation nodes and non-transportation nodes as explained in the last section. Taking into account all these concepts about disaster areas, Aschenbruck et al.

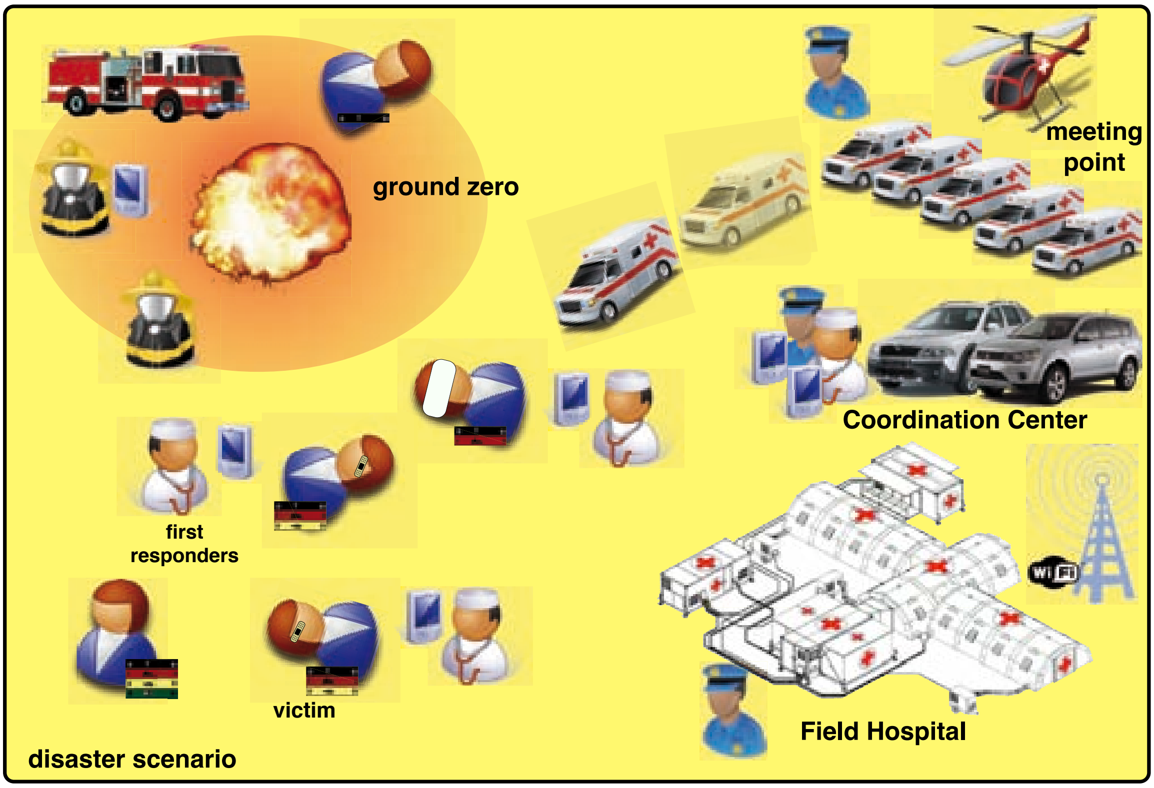

Figure 2.4: Emergency Scenario

[4] made an analysis of disaster scenarios and proposed a mobility model. It allows to create node traces based on realistic emergency scenarios. This traces generator is included in BonnMotion [48], a mobility scenario generation tool.

2.3 Communications in the emergency scenario

Traditionally emergency communications were focused on voice, but advanced communications mechanisms are being adopted. The low price of Internet enabled mobile devices using Wi-Fi or mobile phone network as mobile phones have eased this process. In most of the emergency cases tough, like hurricanes, terrorist attacks, earthquakes, etc., these networks become unstable, inaccessible, overused or even destroyed. As a consequence, emergency personnel cannot rely on the use of existing network infrastructure and may deploy and use their own or look for another solutions.

Some of this solutions may have shortcoming. For example, if the area of emergency is large, it is possible that some solutions as MANETs could not work because the impossibility of creating a fully connected network. Thus, an attempt to communicate from one point of the network to another may be unsuccessful as an end-to-end communication path is needed.

Having Internet connection is very important for coordination or information purposes (e.g. with another coordination point or with hospitals). For this reason, it is assumed that some part of the emergency, as AMPs or ACPs, have persistent Internet connectivity even if the network infrastructure is destroyed or unusable. Deploying satellite connections for in the ACPs is usual.

2.4 Triage applications and communication solutions in emergency scenarios

Some authors propose to improve current triage processes in emergency scenarios with the use of electronic triage tags or sensors. Some of them also propose solutions for the lack of network infrastructures in disaster areas. In this section we see some of them.

CodeBlue [54][23] is based on the use of sensors for the triage of victims and the wireless transmission of the sensor data. The wireless transmission is done using the wireless sensor network created by the sensors. It also integrates an RF-based localization system to track the location of patients. In the case of scarce sensors and therefore not enough to create a fully connected wireless sensor network, CodeBlue proposes the deployment of repeaters.

Decentralized Electronic Triage System This proposal [42] also aims to use sensors to triage victims. The results from the triage and the sensors information are transmitted to a mobile device carried by the first responder using Zigbee. The first responder can transmit this information to the emergency response information center using Wi-Fi or mobile phone network. The system also combines with traditional paper triage tag with a barcode that is scanned and provides a unique identification of the victim. The mobile device has a GPS receiver that allows to locate the victims once triaged with the sensor.

ARTEMIS (Automated Remote Triage and Emergency Management Information Integrated System) [43] also uses sensors to monitor victims. The information of the sensors are transmitted to PDAs that store this information in the form of agents and transmit them through a wireless ad hoc network.

TacMedCS, Tactical Medical Coordination System [46] uses RFID based triage tags to identify victims. The RFID is read using a mobile device that stores the ID, the victim s data and his GPS position. It sends all the data collected to a central server using a satellite connection. Furthermore, mesh communications are established between mobile devices in the disaster area to share data. TacMedCS is complemented with MASCAL [21], a system in charge of hospital s resources management.

The **WIISARD** architecture [31] consist of three main components. The first one is a mobile device for first responders with triage capabilities [28]. The second one is an electronic triage tag [30]. The triage is done using the mobile device of the first responder and the data generated is stored in an electronic triage tag that is attached to the victim. This electronic device provides signal alerts and can transmit its location through a wireless network connection. The third component consist of sensors to monitor a victim s vitals.

WIISARD also proposes the use of a mesh network to transmit data between mobile devices, electronic triage tags and sensors. It includes the deployment of CalMesh nodes to create a wireless infrastructure needed to support these devices. The mesh network is also used by electronic triage tags to communicate their location.

All the data is transmitted to the coordination center, that is powered with a software in charge of the emergency management and coordination [17]. This software keeps an updated list of all resources available in the hospitals nearby, together with the location of victims, the location of the first responders, victim s conditions, etc. Thus, providing a better resource allocation. All data received in the coordination center is automatically forwarded to all devices in the emergency scenario (to keep them updated) and also to the hospitals network.

IMPROVISA, Minimalist Infrastructure for service PROVISioning in Ad-hoc networks [60] focuses on the communication aspects in emergency situations. It proposes the use of Mobile Ad hoc Networks (MANETs) in disaster areas using self-organizing mobile nodes interconnected through wireless. IMPROVISA provides context-aware networked information systems and decision support tools based on agent technology.

A Situation-Aware Mobile System to Support Fire Brigades in Emergency Situations [34] proposes the use of mesh networks for emergency scenarios. The mesh network is composed of heterogeneous nodes: mobile devices carried by firefighters, nodes in firetrucks, and in case of lose of network coverage, the repeaters deployed. This mesh network is used by firefighters for voice communication or video streaming in the disaster are. Furthermore, firefighters are equipped with sensors that monitor their vitals that are sent over the mesh network to inform the rest of the team about their health status.

2.5 Mobile agents

Mobile agents [63] are a technology that have its origins in the fusion of two differentiated concepts. The former is the concept of intelligent agents [64] created by the artificial intelligence community in 1995. The latter is the code mobility [22] concept, created by the distributed systems community in 1998. The fusion of these two disciplines created the accepted definition of a mobile agent: an intelligent software entity with the ability to stop, move and resume its execution in different locations. The intelligent and mobile adjectives given to mobile agents define their properties:

- Mobility: Mobile agents are composed of three main components: code, data, and state. They can suspend their execution, move their code, data, and state to another location, and resume it there.

- Autonomy: The code of an agent is developed to give him autonomy to complete their tasks. Agent actions are performed exclusively by their code. Agents can freely move through different locations while they carry out the assigned tasks.

- Reactivity: Agents perceive environment changes and react by adapting their behavior to them [51].

- Proactivity: Agents take initiatives to complete their tasks.

- Sociability: Agents can interact with other agents. They can exchange messages, share information or even take actions together.

Agents are stored and interact with the rest of the environment within an agent platform. An agent platform can be present in several places (servers, routers, mobile devices, etc) and one single node can have more than one platform.

The most extended agent standards are the ones proposed by *IEEE Foundation for Intelligent Physical Agents (IEEE-FIPA)*, an organization focused on the management and communication of intelligent agents. The specifications standardized by IEEE-FIPA define the basic components of an agent platform, an agent identification scheme, a complete communication infrastructure, and several agent management services.

2.5.1 Agent migration

There exist two types of agent migration [22]: strong and weak. The difference between them is that strong mobility allows agents to move code, data, and state (variable/registry contents), while weak migration only moves data and code. Although strong migration seems the most convenient it is complex to implement and is highly dependent with the underlying hardware or software architectures, making more di cult the interoperability between systems.

Weak mobility does not move the execution state, as a consequence the code is always resumed from the first line of code. Although this can seem a major drawback, the agent state can be stored as agent data, thus moving this information in the migration and being able to restore it once in the destination platform. This migration type requires more effort from the developer but it is the most exible.

When a node migrates from a platform A to a platform B, it realizes a copy of him in the destination platform. Only when the copy in the platform B have been resumed and is working properly, the original copy in the platform A is destroyed. This provides fault tolerance to mobile agents [29].

2.5.2 Agent forwarding

Mobile agents decide for themselves (using their code) whether to move to another platform and what platform. The migration process is a forwarding algorithm that is coded in all mobile agent and that can be different in each one. A mobile agent could be seen as messages/data being forwarded in a network but with a very different paradigm (apart from the agent being able to execute actions and perform tasks). Mobile agent not only carries the data/message but also the forwarding algorithm (code). In traditional message forwarding, the routing protocol is executed by the node. With mobile agents is the data/message (the mobile agent) who carries and execute the forwarding method in each node/platform visited. This allows, for instance, execute forwarding algorithms unknown by the platform. Furthermore, each mobile agent is able to use its own forwarding algorithm regardless other mobile agents or the platform.

Mobile agents are routed in two different ways. In the first way, the route that the mobile agent will follow its decided when the agent is created, this is known as *static itinerary*. The second method is called *dynamic itinerary* and it is not established when the agent is created. In this case, the route followed is decided during the agent life based on its requirements.

2.6 Opportunistic Networks

Opportunistic networks is one of the existing subcategories of wireless networks. Wireless networks can be divided into ad-hoc networks or infrastructure based networks; following we will see a definition of them and their subcategories.

2.6.1 Infrastructure based wireless networks

This category is the most common one, we found examples in street and homes: mobile phone networks or Wi-Fi DSL connections. In wireless networks based in an infrastructure, nodes connect to base stations that are connected to a backbone network or interconnected with other base stations. Thus, the network topology and the routes are usually static. Messages created by nodes are sent to the base stations and then routed to the backbone network or other nodes in the network.

2.6.2 Wireless ad-hoc networks

In wireless ad-hoc networks all nodes in the network act as routers and clients. A node can be the source or the destination of a message, and they create, send, receive or forward messages. Nodes create links between them without the need of a base station or other type of infrastructure. One example of this is a Wireless Sensor Network (WSNs), where spatially distributed autonomous sensors detect each other wirelessly and connect between them. This connection can be one to one or one to several.

Mobile Ad-hoc Network (MANET)

If the nodes can move, the wireless ad-hoc network is called Mobile Ad-hoc Network (MANET). In this type of network nodes move in the scenario, reconnecting with other nodes when they move. This causes a change in the topology of the network, thus routing methods need to update their routing tables and discover new nodes to take into account these changes. Routing methods in wireless ad-hoc networks require an end-to-end path, hence routing protocols are in charge of discovering and calculating the cost of the possibles paths.

Delay (and Disruption) Tolerant Networks (DTN)

Delay (and Disruption) Tolerant Networks or DTNs [20] are wireless ad-hoc networks with a special characteristic: intermittent connectivity or equivalent (high error rate or long delay). DTNs have two main differences regarding wireless ad-hoc networks. The first one is that wireless ad-hoc networks protocols do not allow delay nor disruptions, giving an error message as a result. The second one is that while wireless ad-hoc networks routings protocols require an end-to-end path, DTNs usually do not always have one.

DTNs began with the need for a wireless ad-hoc network able to support high delays or disruptions (intermittent connectivity) in intraspace satellite communications [8] but it was rapidly adapted for other scenarios with the same needs: communications in rural areas [53], sensor networks [62], vehicular networks (for bus routes f.e.) [65] or emergency scenarios (proposed in this thesis). Furthermore, a IETF group was created to standardize all the DTN protocols and architecture, the Delay Tolerant Networking Research Group (DTNRG) [26].

The rapid growth in real use cases of DTNs and the support of an entirely dedicated IETF research group [10] made DTNs very popular in a few years [33]. While MANETs also became very popular [33] in terms of research, they never found *the killer app* for the technology with very few cases of real and viable MANET uses due to the need of a end-to-end path without high delays or disruptions.

The DTNRG proposed the Bundle protocol [52], an application layer with the objective of providing equivalent functionality of a Network Layer but allowing different technologies underneath (figure 2.5). For instance, the bundle protocol can be used with subnets that work with TCP/IP. The message, also called bundle, waits in one of the nodes until it can continue the path, also known as store-carry-forward protocol. Thus providing an end-to-end connection without the need of a fully connected network. Bundle layer has its own nodes ids that are independent of the underlaying network protocol. This ids are later used by the forwarding methods or DTN applications. Messages can be delivered even if a route between the source and the destiny have never existed before the creation of the message.

The bundle protocol have strong similarities with mobile agents. Mobile agents provide also the same features: delivery without previous knowledge of the route, they can wait in a node or they can be used with different technologies underneath. Mobile agents also provide additional advantages as proactivity or reactivity.

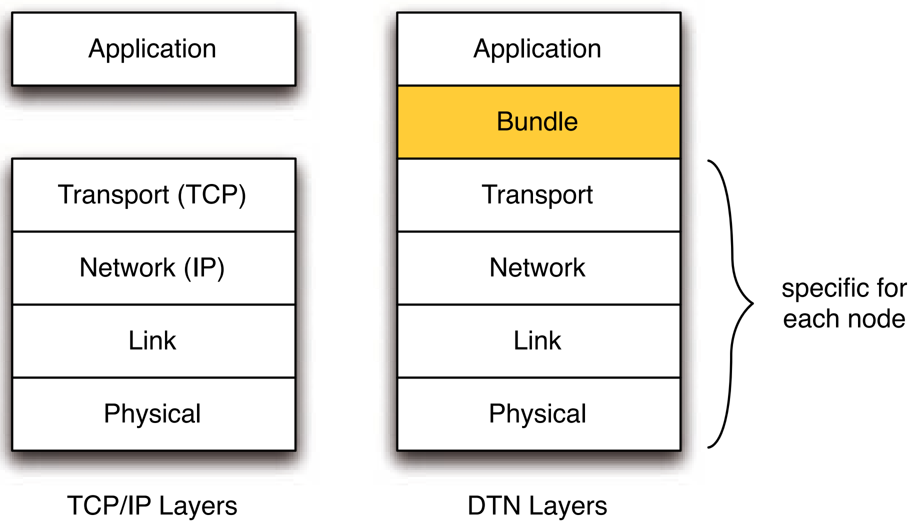

Figure 2.5: TCP/IP Layers vs DTN Bundle Protocol Layers

Opportunistic Networks

Opportunistic networks [49] are a subset of DTNs where the movements of the nodes are unpredictable, therefore they are a delay and disruptions tolerant MANET [11]. As node movements are unpredictable, the network topology also is. This means that nodes do not know the network topology, thus they can not build routes to the message destination. Therefore, routes are built dynamically in each message hop. It is also usual that the message is routed only to the next hop, ignoring which will be their next hop/node. This means that the next hope calculation is done in each node when the message arrives based on the metrics of the chosen forwarding method.

Opportunistic and delay tolerant networks not only deal with disruptions but also with heterogeneity. Heterogeneity is one of the most prominent characteristics of these type of networks. It ranges from different devices, different network protocols underneath or different density of nodes.

2.6.3 Opportunistic networks forwarding

As we have seen with the bundle protocol, the forwarding decisions are made at the application layer. Thus, allowing the forwarding protocols to use application data for forwarding decision. This can include: network data, contacts history data or even more high level data as social networks data or location data.

Epidemic forwarding [59] is the most evident forwarding algorithm for opportunistic networks. It consist in relaying a copy of each message in the buffer to all the nodes encountered. It causes network ooding because of its greediness but it has always the best delivery delay as a result. It is very used to compare other opportunistic forwarding methods.

New forwarding algorithms that calculate the delivery probability using the contact history have also been proposed. The forwarding decision is taken based on this delivery likelihood. Some examples of this type of forwarding are PRoPHET (Probabilistic Routing Protocol using History of Encounters and Transitivity) [32] or

MaxProp [7].

Another type of forwarding protocols very popular in opportunistic networks are those based on social networks. Some examples are PeopleRank, BUBBLE Rap or SimBet. PeopleRank [45] is based in the social relation between nodes. It gives a weight to each relationship that is later used to make a ranking. Forwarding decisions are taken from this ranking. BUBBLE Rap [25] is based on communities. It tries to forward messages to the destination community and once there to the destination node inside the community. And the last one of the examples, SimBet [16], uses node centrality in the social networks to decide the next hop of the message.

Opportunistic networking can also use DTN forwarding protocols, for example, those based on data mules. Data mules are nodes which movements can be predicted. These are usually used, for instance, for collecting data from wireless sensors scattered around a large area.

2.6.4 Haggle

Haggle [47][56] is a networking architecture for opportunistic communications. Haggle is composed by a kernel that communicates with several managers that are in charge of different tasks (figure 2.6). Haggle provides, with this modular architecture, a complete framework with a set of managers that ease the use of opportunistic networking from applications.

The managers include the functionalities for neighbor discovery, resource management, name resolution, or forwarding between others, thus removing the need to implement such features in applications. Using the libhaggle API, developers can create applications that use opportunistic networks without the hassle of developing all the underlying communications. Haggle is in charge of managing connections coming from different interfaces (bluetooth, Wi-Fi, etc) or protocols (TCP, UDP, etc), or using different forwarding algorithms.

The network architecture has a data-centric approach. This means that, when a node creates data and want to send it, the data (in the form of data objects) is published in the Haggle network using a publish-subscription system. Nodes interested in this data request a subscription and receive it. Therefore, the network architecture is not host-centric in where data have a host (or hosts) destination.

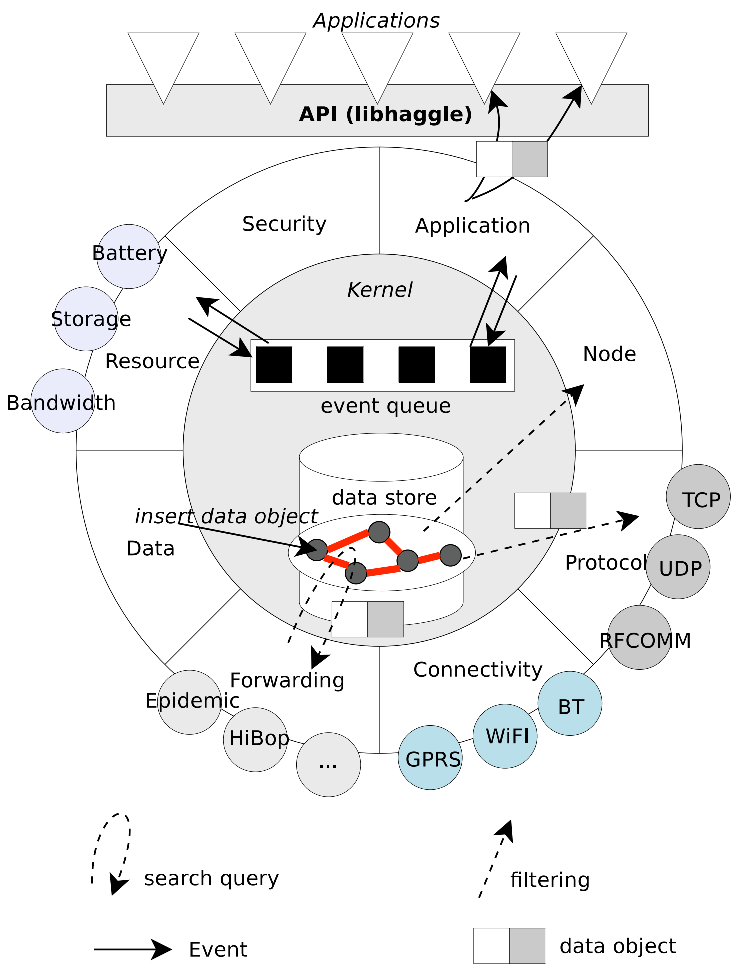

Figure 2.6: Haggle architecture from [47]

Chapter 3

Contributions and discussions

In this chapter we present and discuss the contributions of the thesis and the results obtained. This thesis is presented as a compendium of articles, hence the contributions are introduced referencing the corresponding article.

3.1 Contributions

There are five main contributions in the thesis.

- **Mobile Agent Electronic Triage Tag (MAETT)**: The first contribution is a proposal of system for creating and forwarding electronic triage tag in the emergency scenario with a technology based on mobile agents. This system combines other technologies (RFID, GPS, mobile devices, etc) to achieve its proposal: create a virtual version of the traditional triage tag and be able to forward it to the coordinator center even in worst emergency scenarios (those without network connectivity).

- **Virtual Electronic Medical Record from emergency scenario**: The second contribution aims to extend the use of MAETT not only for triage tags but also for collecting other type of information data in emergency scenario. One of this data is the ID of the victims. This ID can be forwarded to the coordination center in the same way that mobile agent based electronic triage tags are forwarded. Once in the coordination point, the mobile agent will be able to move to the hospitals network thanks to the network connection available. In combination with other systems working in the hospitals network [61], it would be possible to collect the medical record of the victim and forward it to the hospital where she would be taken. Thanks to this information the victim could be treated faster (some tests may not be necessary, as blood type test) or better resource allocation caould be made.

- **Haggle based Electronic Triage Tag (HaggleETT)**: Besides the much advantages of mobile agents, they have some drawbacks too. The most relevant is the slowness it takes to forward a big (in terms of weight/bytes) mobile agent, due to internal processes required to fulfill the FIPA standards. To fill this gap we proposed the use of Electronic Triage Tags using the Haggle platform. The Haggle platform is based in opportunistic networks and can provide a faster forwarding using DataObjects.

- **Opportunistic networks in disasters**: The movement of the nodes in an emergency scenarios cannot be predicted. Disaster areas can be very different from one emergency to another: location of victims, size of the scenario, number of first responders, etc. The fourth contribution is targeted to discover how the performance is impacted based on the different characteristics of an emergency scenario: Number of victims, number of first responders, etc. This tests and analysis are done using some of the most popular opportunistic forwarding methods in order to see how the performance impact is different between them based on their characteristics.

- **PropNTTR**: The last contribution of the thesis is the proposal of a new forwarding protocol based on two existing ones: MaxProp and TTR. It takes advantage of the high delivery ratio of MaxProp and the low energy consumption of TTR. The proposal aims to mix different forwarding protocols in opportunistic networks to improve delivery ratio, latency or energy consumption.

3.1.1 Publications

The compendium is composed by the following five publications:

- **Appendix B**: Martín-Campillo, A.; Martí, R.; Robles, S.; Martínez, C. *Mobile agents for critical medical information retrieving from the emergency scene.* In 7th International Conference on Practical Applications of Agents and Multi-Agent Systems. Springer, Springer Berlin / Heidelberg, April 2009. ISBN: 1615-3871. DOI: 10.1109/TIT.2011.2119465. [37]

- **Appendix C**: Martín-Campillo, A.; Martínez, C.; Cucurull, J.; Martí, R.; Robles, S.; Borrell, J. *Chapter 4: Mobile Agents in Healthcare, a Distributed Intelligence Approach* In book Computational Intelligence in Healthcare 4. Springer Verlag, August 2010. ISBN: 978-3-642-14463-9. DOI: 10.1109/TIT.2011.2119465. [40]

- **Appendix D**: Martín-Campillo, A.; Crowcroft, J.; Yoneki, E.; Martí, R.; Martínez, C. *Using Haggle to create an Electronic Triage Tag.* In The Second International Workshop on Mobile Opportunistic Networking - ACM/SIGMOBILE MobiOpp 2010. ACM Press, pp:167 - 170. February 2010. ISBN: 978-1-60558-925-1. DOI: 10.1109/TIT.2011.2119465. [36]

- **Appendix E**: Martín-Campillo, A.; Martí, R.; Yoneki, E.; Crowcroft, J. *Electronic Triage Tag and Opportunistic Networks in Disasters*. In Special Workshop on the Internet and Disasters at ACM CoNEXT 2011 (WoID at CoNEXT 2011). December 2011. [39]

- **Appendix G**: Martín-Campillo, A.; Martí, R. *Energy-e cient forwarding mechanism for wireless opportunistic networks in emergency scenarios*. Computer Communications, May 2012. DOI: 10.1016/j.comcom.2012.04.028. [41]

Additionally there are two more publications, not part of the compendium, but part of the research work done during the PhD:

- **Appendix A**: Martí, R.; Robles, S.; Martín-Campillo, A.; Cucurull, J. *Providing early re- source allocation during emergencies: the mobile triage tag*. Journal of Network and Computer Applications. November 2009 vol. 32. no. 6, pp: 1167-1182. ISSN: 1084-8045. DOI: 10.1109/TIT.2011.2119465. [38]

- **Appendix F**: Martín-Campillo, A.; Crowcroft, J; Yoneki, E.; Martí, R. *Evaluating Opportunistic Networks in Emergency Scenarios.*

3.2 Mobile Agent Electronic Triage Tag (MAETT)

As stated in the introduction of the thesis, the first part of the thesis was dedicated to research for a solution for a triage application to minimize the network problems in the solutions proposed until that moment. Traditional schemes of triage in emergency scenarios use a standard paper-made tag placed on the victim. The paper triage tag is widely accepted and used, but this method suffers from two main problems. The former is that the tag is a physical element placed on some part of the body of the victim. This can make location of the victim after it has been triaged a di cult task. The location of the victim is communicated per radio giving an approach using known elements as addresses, buildings, etc. And this takes us to the second problem:

the task of triaging the victims, and the task of locating them for further assistance and transportation are independent. Triaged victims cannot be traced to verify if they have all been picked up. Furthermore, not having this information electronically available makes very di cult to extract valuable statistical information as whether if there is a higher concentration of critical victims in a specific place.

Some authors propose the use of Barcodes or RFIDs [21][27][46][28] to identify and track victims or materials. An RFID provides some advantage over the Barcodes. The most evident is the availability of the RFID over situations when the QR or the barcode in the tag is not visible (caused by blood or mud). RFID has been accepted widely as a good solution for victim tracking.

Some proposals have made relevant the problem of the lack of a network infrastructure in which relay for communication of triage information or emergency management. The existing network infrastructures in an emergency scenario are usually destroyed (by the nature of the emergency) or they become overused causing their unavailability. There are some alternatives proposals, ranging from using mesh networks [54], to a full infrastructure deployment [18][23]

MAETT is the first contribution of the thesis, a mobile agent system that proposes a low cost solution for mass casualty incidents and is able to work even in large disaster scenarios lacking network infrastructures.

See Appendix A Providing early resource allocation during emergencies: the mobile triage tag [38] and Appendix C Mobile Agents in Healthcare, a Distributed Intelligence Approach [40] for all the details about this contribution.

MAETT uses triage tags with RFID as a method of uniquely identification of victims. Triage personnel or first responders carry handheld devices that allow them to create electronic triage tags. When a victim is found, the triage personnel have the option of follow a wizard (or assistant) in the mobile device that will help her complete the S.T.A.R.T. (Simple Triage and Rapid Treatment) process. This assistant can be skipped if the personnel wants to carry out another triage method or if she wants to introduce directly the condition of the victim. Once the triage process is finished an electronic triage tag (ETT) is created. An ETT is created in the form of mobile agent, it contains the medical condition of the victim, its GPS position, and the id of the RFID triage tag used with the victim. It can also contain other data considered necessary or helpful for the recovery of the emergency as photos of the victim or the scenario. The GPS position is retrieved through the mobile device (that has to support GPS system) at the time the victim is triaged. The system is fully compatible with more traditional methods of victim triage, since traditional paper colored tags are still used. This allows coexistence with other systems and, therefore, a progressive deployment that facilitates its adoption.

This mobile agent containing all the triage information of the victims has been coded to jump from agent platform to agent platform until it arrives to the command (or coordinator) center. The agent platforms are situated in each mobile device carried by first responders and in the command center. These agent platforms allow agents to jump from one device to another.

One of the main advantages of this scheme is that it does not require any network infrastructure neither a fully connected MANET or mesh network to transmit the triage information from the disaster scenario to the coordinator center. Mobile agents allow asynchronous transportation of this information, therefore a direct connection or a complete route from the device that generates the electronic triage tag to the coordinator center is not required. A temporal link between two devices is enough to transmit the ETTs.

Other proposals [54][23] that require a MANET, or mesh network, need an end to end communication established. This may not be feasible in large disaster scenarios because the MANET or mesh network will not cover all the area in the emergency scenario. Furthermore, deploying relay stations to achieve areas without network coverage is expensive and require time. Time is very valuable at the first stage of the disaster when everybody has to focus its efforts in discovering, triaging and evacuating victims. For these reason, we believe that MAETT offered a great innovation and improvements over existing solutions at the moment.

Mobile agents allows to have an asynchronous method of relying information from node to node. Traditional routing network methods as those based on TCP/IP require an end to end connection form the origin to their destiny. Mobile agents use the application layer to make forwarding decisions. They can take decisions based on which route they want to use, which node they want to jump or simply wait in one node until a better node opportunity arises. The movements of the first personnel working in the disaster scenario are unpredictable which makes impossible to establish a fixed route from the generation of the triage tag to the coordinator center. The routes will dynamically change and a mobile agent is able to support that feature. Using a forwarding algorithm that recovers information about delivery probabilities of each node, a mobile agent can decide if it is better to jump to the next node or wait in the current node until a better opportunity arises.

Knowing which is the best forwarding protocol (in terms of performance) for emergency scenario is complex decision. Mobile agents are autonomous and reactive pieces of code that are able to move from different platforms or nodes and interact with the environment obtaining data or making decisions. They can also clone themselves to maintain a copy of them in the current platform while the other one jumps to another platform. The way they make forwarding decisions can be based on a well know forwarding algorithm, a new one, or a selection of them, as mobile agents can react to environment changes and therefore use the best forwarding algorithm in each situation.

This algorithms can be replaced at any time, or even coexist with different protocols, strategies, or interfaces. This is a direct advantage of using mobile agent technology, where the code of the system is not static in the devices, but is carried by the mobile agents. But this features and characteristics will be widely taken into consideration later in that document when we talk about the fourth contribution.

Emergency scenarios may be dangerous (in cases of fire, earthquake, tsunami, etc) even for first response personnel that have been trained for these cases. Because of this, some coordinator team leaders assign a return time to the base to each one of the members of the first response personnel. This time to return (TTR) is for safety purposes, in dangerous places the team leader has to have control over all their team and propose them to return to the base periodically. If anyone is missing after a time to return has finished, a rescue team will go to search for him. TTR forwarding protocol is based on this time to return. It uses this value as a decision making.

As a sum up we can say that one of the strongest points of this contribution is the improvement on information transmission with respect to other triage proposals thanks to the to the autonomy, reactivity, and proactivity of the mobile agents which allow them to move from different platforms asynchronously without the need for an end to end path. This contribution provides a low cost system because the only need of handheld devices carried by first personnel instead of a large set of sensors or wireless network repeaters. Furthermore, this solution is exible as it allows the use of different forwarding methods and it works in all the different network environments that could happen (with or without network infrastructure available).

Even if the contribution has good points, it also has a few drawbacks in regards to other proposals. CodeBlue [54] is one of the systems that propose deploying repeaters in case the sensor network is not enough for a fully connected mesh network. As we have commented before, this has an expensive cost and requires a very valuable time at the beginning of the aftermath of an emergency. But this provides an advantage that MAETT does not have: live information. With MAETT the triage information will have to be transmitted throughout different nodes or devices (and wait until the mobile agent can jump to another platform) until it arrives to the coordination center, delaying the delivery of this information. In cases where a fully connected MANET is deployed this does not happen as there exist an end to end path that connects the generation point of the triage information with the coordination center.

3.3 Virtual Electronic Patient Medical Record from emergency scenario

In the aftermath of an emergency, the first responder personnel arrive first to the scenario. They triage the victims to establish a medical attention order. Once triaged, the victims in worst conditions are assisted first, they are stabilized and evacuated to an hospital where they will be widely attended. Evacuate victims before stabilizing them elevates the risk of death. Hence, only after stabilized, victims are transferred to an hospital.

While the victim is being stabilized or transferred, medical personnel can search for victim s personal items; documents or cards that could identify them. Identify the victim can improve the medical treatment given in the hospital or provide a faster response in the attention of the victim, specially if the hospital has implemented a Virtual Electronic Patient Medical Record (VEPMR) solution [61][35][19].

A VEPMR system provides the full medical record of a patient from any medical institution. Every time a patient visits the doctor, or has a surgery, or performs her a medical test, this information is recorded in the local database of the medical institution. If this institution is part of a VEPMR system network, a complete medical record can be build afterwards from any institution that is part of this network. Having all the medical information about a victim before she arrives can provide a faster and better diagnosis, thus a better treatment may be given [24].

Virtual Electronic Medical Record from emergency scenario is the second contribution of the thesis, it proposes the use of MAETT to forward information about victim identification to the medical network from the emergency scenario with the aim of retrieving her Virtual Electronic Medical Record and provide to the hospital with better information about the victim for a more effective and e cient resource allocation.

See Appendix B Mobile agents for critical medical information retrieving from the emergency scene [37] and Appendix C Mobile Agents in Healthcare, a Distributed Intelligence Approach [40] for all the details about this contribution.

Once an ID of the victim s is found this can be associated to her RFID generating a new mobile agent with this information that can follow the same path as the electronic triage tag mobile agents. Hence, this mobile agent will arrive to the coordination point where it will be relayed to the hospital network using the infrastructure network deployed in the coordination point (usually satellite communications).

Once in the medical network, the mobile agent can request the whole VEPMR of the victim from a VEPMR system and therefore have all the medical information about the victim before she arrives to the hospital assigned. This information can be used for different purposes. For example, with the VEPMR we can know the blood type of the victim. This information is useful for the hospital allowing to reserve units of this blood type before the victim arrives. Or for example, if the hospital runs out of units of this type of blood, the victim could be redirected to another hospital with stock.

Besides the example of the blood type, the VEPMR can contains more valuable information for the urgent attention of the victim: chronic and contagious diseases, past medical tests, allergies, etc. All these data will be available to the medical test without the need of performing any test (saving time and money) and even before the victim arrives, improving the medical assistance of the victim. This information can be used to make a better resource allocation, to improve diagnosis, or to avoid hazardous treatments, for instance in the case of drug allergic victims.

3.4 Haggle based Electronic Triage Tag (HaggleETT)

MAETT provides a good way to solve the lack of network infrastructures in the emergency scenario. The implementation we carried out used JADE (Java Agent

Size (KB)	5	10	25	50	100	250	500	1000
Time (ms)	133	148	227	499	1760	11546	39869	141939

Table 3.1: Agent migration performance in a 100 Mb/s LAN network

DEvelopment Framework), a software framework fully implemented in Java language that complies all the IEEE FIPA standard specifications. The FIPA standard specifies that all agent and platforms communications have to be done using FIPA-ACL (Agent Communication Language), this includes the mobility. Hence, when a agent has to jump from one platform to another, the process has to be done using FIPA-ACL [14].

The main problem is that this process requires a lot of processing time because each mobile agent has to be serialized and sent inside a FIPA-ACL message [15] as can be seen in Table 3.1 (extracted from paper [15]). It shows a mobile agent transfer performance between two hosts connected through a Local Area Network (LAN). The network has a response time of less than 1ms, does not present packet loss, and has a bandwidth of 100 Mb/s. The set of test, measures the performance of different agents with data of different sizes and a fixed small code size of 5KB.

Communication between nodes in emergency scene are short in time. First personnel run from victim to victim, hence nodes are in contact a small amount of time. The time required to transfer a mobile agent of 250KB of data and 5KB of code is of 1.76 seconds, and 11 seconds for a mobile agent of 500KB of data and 5KB of code in a 100Mb/s LAN network with less than 1ms of response time: Table 3.1

In a real disaster scenario the bandwidth between nodes is of a theoretical maximum of 54 Mb/s. We measured the real maximum speed rate using two iPhone 3GS (indoor and outdoor) and we obtained an average result of 6,4 Mb/s (figure 3.1). We also measured the average contact time in an emergency scenario using BonnMotion which generates disaster area traces. We performed several runs for each number of nodes which gave us the results shown in figure 3.2. Furthermore, mobile devices required more time to compute the serialization of the mobile agent. With these results we can see that some opportunities of relaying mobile agents will be lost as

Figure 3.1: Traces of the speed tests performed

for example if a node has several triage tags. For solving these problems we looked for an alternative solution to mobile agents.

Haggle Electronic Triage Tag (Haggle-ETT) is the third contribution of the thesis, an application based on Haggle [2] for the triage of victims in emergency scenarios. It is able to work in scenarios where there is no network infrastructure and the nodes have to communicate in opportunistic mode.

See Appendix D Using Haggle to create an Electronic Triage Tag for all the details about this contribution.

MAETT and HaggleETT have the same purpose but they are based on different platforms. MAETT uses mobile agents as Electronic Triage Tags. The mobile agent contains the triage information about the victim and the forwarding is done through migration of the agent between agent platforms in mobile nodes. On the other hand, HaggleETT allows to do the same tasks as MAETT but having a better performance when transferring messages between nodes, thus losing less relay opportunities. Haggle uses *Triage DataObject* as Electronic Triage Tags. HaggleETT also uses TTR as a forwarding method which is convenient in this situation. We will talk more about forwarding in emergency scenarios in next section.

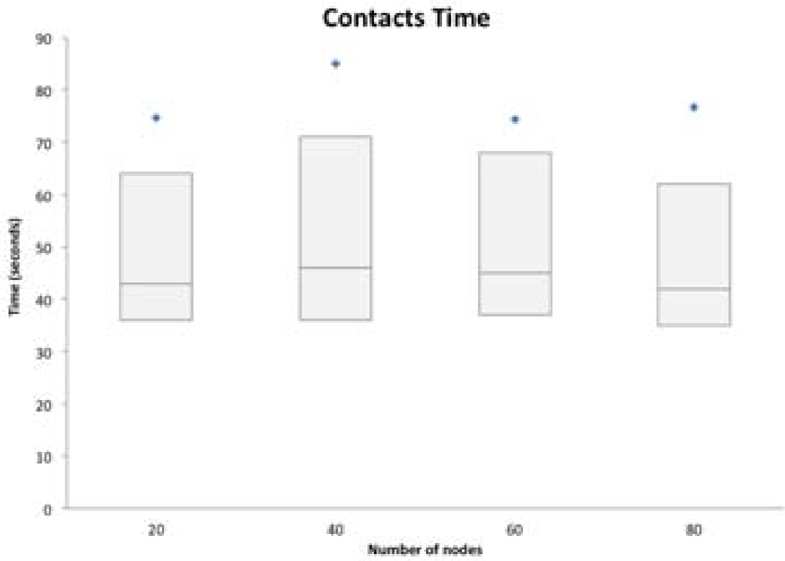

Figure 3.2: Contacts time in an emergency scenario simulation

HaggleETT, as well as MAETT, is not limited only to scenarios without network infrastructures but can also scenarios where end to end connections are available. In this case, the node destination of the message is seen as a neighbor, hence the message is relayed directly to it. If the network infrastructure becomes unavailable, or if there are delays and disruptions in the fully connected MANET or mesh network, the system will go on working. This makes the proposal useful in any situation.

HaggleETT can provide better performance than MAETT but it also has some drawbacks. Mobile agents not only contain the data they are carrying but they also carry their code. Thanks to this characteristics, they can introduce new functionalities and algorithms once the nodes are deployed in the field. A mobile node can be created and sent from a *platform A* with algorithms that a *platform B* does not know. This allows to execute new actions that other platforms are not able to perform because they are not programed to do so. Hence, this mobile agent jumps to different nodes executing their actions (code) without the need that the platform has to know them.

In cases of emergencies this can be an advantage if there is the need to deploy a new algorithm that has to perform some action that has not been coded in the nodes/platforms already present in the disaster scenario.

3.5 Opportunistic networks in emergencies

As we have discussed in previous sections, in cases where no network infrastructures are available, other types of networks have to be used. Some authors [54][18][23] proposed the following alternatives:

- Deploy repeaters to supply a network infrastructure: It is a high resource consuming solution because it requires repeaters and people to deploy them. In large disaster areas it may not be feasible.
- A fully connected MANET or mesh network using the nodes (mobile devices) in the emergency scenario. It is not possible in large geographic areas.
- A fully connected Wireless Sensor Network (WSN). Also not possible in large geographic areas where victims can be far enough from each other. Hence, sensors attached to victims may not have enough communication range to cover all the disaster scenario.

All solutions are based on the on the assumption that all nodes are interconnected all the time. Assuming end-to-end connectivity in disaster scenarios can be very risky. Large emergency areas cannot be covered with few nodes and even if covered nodes could be moved or destroyed ending with the fully connected network.

Opportunistic networks are a good alternative to solve the problem of intermittent connectivity, delay and disruptions. This type of networks use the store-carry-forward paradigm. Nodes store and carry data when they are disconnected from other nodes or their neighbors are not eligible for forwarding. When they met a node that is eligible based on the routing algorithm, they forward the data they carry.

Although opportunistic networks seem a good choice in emergency scenarios, there exist many forwarding algorithms that can be used. One of the most populars routing methods is Epidemic. When two nodes met in an encounter transmit a copy of the messages in their buffer to the other node if it does not have a copy yet. Despite this simplicity, it produces a low delivery latency in scenarios with low number of messages or nodes. But when those numbers increase, its greediness produces poor results as a consequence of the high resource allocation, ooding the network. With buffers filled up with messages, they cannot be forwarded to other nodes and delivery opportunities are lost. The same can happen when more than one node are met at the same time and the contact time is short.

Forwarding protocols with better performance exist in opportunistic looking to reduce the overhead produced by epidemical protocols. Some of them use social relations between nodes, trough social networks, as a forwarding decision (PeopleRank[45], BUBBLE Rap[25] or SimBet[16]). Others calculate the delivery probability, based on the contact history, to decide to relay messages or not (PRoPHET[32] or MaxProp[7]). There are also more simpler forwarding protocols as Spray-and-wait [55] that relay copies of messages to some randomly selected nodes (not all nodes that encounter) reducing the epidemic overhead but without the probabilistic advantage of other protocols.

All these existing forwarding protocols (and many more in literature) make very di cult to decide which one to use in emergency situations. For this reason we carried out a set of tests based on emergency scenarios simulations. The objective of this study is to test the performance of the most populars forwarding protocols for opportunistic networks in disaster areas. These results provides information about which characteristics of an emergency scenario (number of people involved, number of victims, etc) impact the most in the performance of the algorithms in terms of delivery ratio, delay or energy consumption. Furthermore we give details of how the tests were performed to provide other researchers to test their own protocols with the same testbed and therefore compare them.

See Appendix E Electronic Triage Tag and Opportunistic Networks in Disasters [39], and Appendix F Evaluating Opportunistic Networks in Disaster Scenarios for all the details about the fourth contribution.

MAETT and HaggleETT require an opportunistic forwarding to work. In MAETT, the mobile agent contains the forwarding algorithm and decides whether if the mobile agent electronic triage tag has to jump to another neighbor platform or remain in the node where it is. In HaggleETT the forwarding algorithm is in the Haggle platform and decides whether if relay the DataObject (or a copy) to a neighbor or not.

3.5.1 TTR

As a first solution for MAETT forwarding, the Time To Return (TTR) was proposed. TTR aims to use a time to return to the coordination point, or base, for all the nodes in the emergency. This is something that sometimes is already used in some emergency scenarios. Each first responder in the emergency scenario is given a time to return to the base for security purposes. Emergency scenarios are usually dangerous places, hence a method to control the personnel has to be set. This metric is set the device when the node leaves the coordination point, setting the time it will return. Figure 3.3 show how the TTR protocol works.

Although TTR is a *delegation forwarding* protocol because it uses the TTR metric to decide whether to forward or not an electronic triage tag, it is also based on data mules. The destiny of the messages is a point where nodes goes which collect messages from the disaster area.

3.5.2 Opportunistic networks in emergencies

From the results obtained from the tests and analysis, we can say that MaxProp is the forwarding protocol tested with best results in terms of delivery ratio and delay

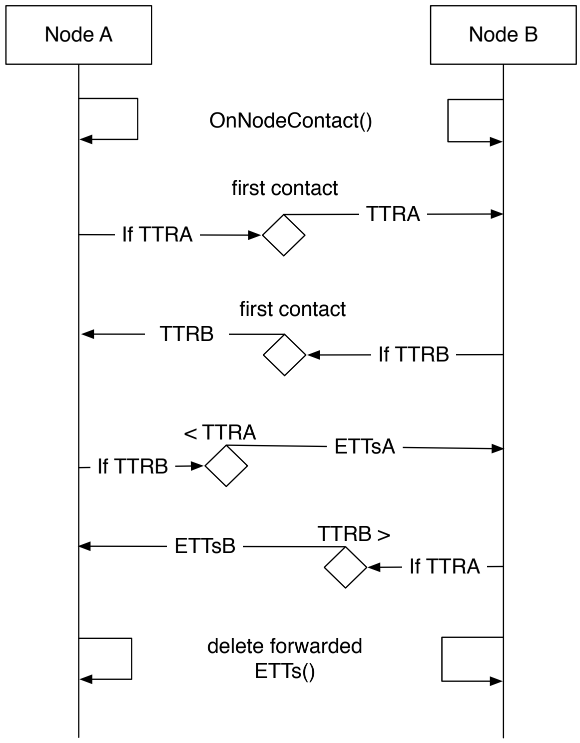

Figure 3.3: TTR protocol

performance. In almost every test MaxProp is the routing protocol that delivers more message and the one that delivers messages fastest. All other forwarding protocols tested have significantly poorer results in terms of delivery ratio and delay with few exceptions.

Making electronic triage tags and information created in the disaster area arrive fast to the coordination point is essential. Therefore, the use of MaxProp is a good solution for the opportunistic forwarding in emergency scenarios. However, if we consider energy consumption, in some scenarios MaxProp could exhaust the battery of some devices. In scenarios with lots of messages or nodes MaxProp increases its energy consumption due to the replication of messages. In this cases the use of forwarding methods that use less replication (like TTR that only keeps one copy of each message generated throughout the network) is the solution for not exhausting the battery. As a drawback, TTR has less delivery ratio, not achieving more than 50% of messages delivered in any case. Furthermore, TTR is twice slower than MaxProp in terms of delivery delay.

Taking into account these results, emergency scenarios with a high density of nodes or a lot of victims (a lot of message created) will cause a high energy consumption for MaxProp and therefore will drain the battery fast. If one of these cases is foreseen, a solution could be provide a better (or extra) battery to the nodes if a fast and high delivery ratio is wanted. Otherwise TTR can be used that will produce the battery last longer (in some cases up to 10 times more) but a lower delivery ratio and slower delay.

3.6 Improving forwarding in disaster areas

As we have seen in the previous chapter, energy consumption is one of the key points in emergency scenarios with large number of messages or nodes. Routing methods, like MaxProp, with high delivery ratio and fast delivery are the most desired in disasters, but they produce an elevated message replication to achieve this, leading to a high energy consumption.

According to recent works Wi-Fi is one of the most consuming power elements of a mobile phone device [6][50], consuming up to 725 mW transferring data at full capacity [9]. Furthermore, when a mobile device is using its Wi-Fi network in opportunistic mode, it cannot enter in PSM (Power Safe Mode) because it looks constantly for nodes and so it spends a lot of energy scanning the network. Not only the scanning but also the association between nodes spends a lot of energy [6]. We cannot reduce the amount of energy consumed by the scan and association processes in opportunistic networks at application level but we can save energy by using forwarding methods that transfer less data. To achieve this we propose an hybrid routing protocol between MaxProp and TTR. This is the fifth contribution of the thesis.

See Appendix G Energy-e cient forwarding mechanism for wireless opportunistic networks in emergency scenarios [41] for all the details about this contribution.

MaxProp approximates delivery probability as the likelihood of an existing delivery path and replicates messages to the nodes with higher probability. This achieves a good delivery ratio and a low delay but with a high energy consumption due to a lot of relays of message copies. TTR only maintains one copy of each message in the network and is forwarded to the node with lesser TTR value. This provides a good delivery per energy consumption ratio but a poor delivery ratio due to a lot of lost better-forwarding opportunities. For example, if we have a *message M* in *node A* and it contacts with a *node B* with lesser TTR value than theirs, *node A* will forward the *message M* to *node B*. It is likely that *node A* will contact later on with another node with lesser TTR than node B. Therefore, *node A* would have lost a better-forwarding opportunity as it does not keep a copy of the *message M*.

Using the hybrid forwarding proposed, called PropTTR, we wanted to have a forwarding method that achieves a compromise between delivery ratio and energy consumption. PropTTR solves these lost opportunities caused by keeping only one copy of the message. PropTTR uses MaxProp protocol for the first hop of the message and TTR for the rest. Thus, the message is distributed using MaxProp algorithm based on delivery probability in the first hop and TTR for the rest. In PropTTR messages have a hop count property because it is used to decide whether to use MaxProp or TTR. This property is updated in each messages at each forward.

This property of the message will be read when the node is going to start the forwarding decision in order to know which forwarding protocol to use. The property will be written when the message is forwarded to another node, the receiver will add one to its value. For all the message in a node with a hop count of 0, the forwarding decisions is made using the MaxProp algorithm, if not, using the TTR protocol. The owchart of the PropTTR algorithm can be seen in figure 3.4.

A node using PropTTR that creates a *message m* will distribute *n+1* copies of

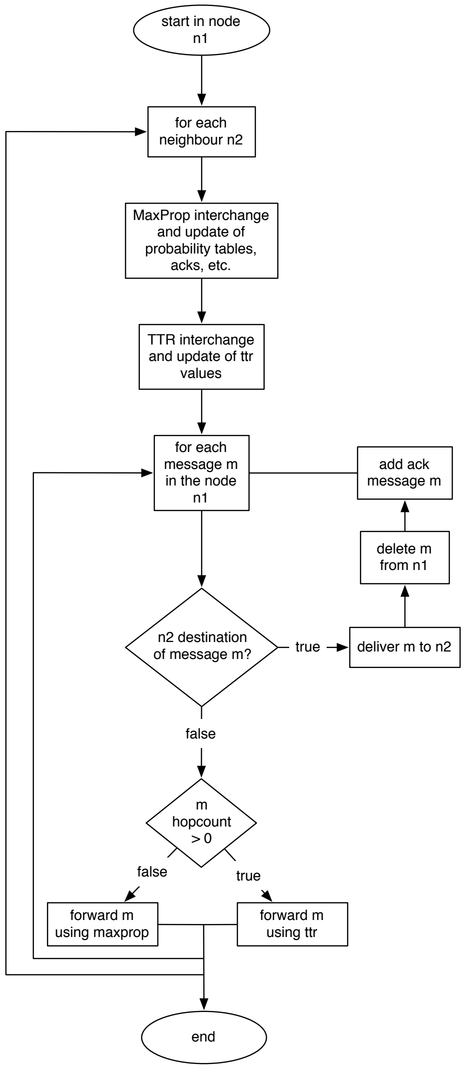

Figure 3.4: PropTTR algorithm in owchart format

that message in the network, where n is the number of different nodes contacted. These $n+1$ copies will increase the energy consumption if compared with TTR but this better distribution of the message produces lesser better-forwarding lost opportunities, thus improving the delivery ratio although latency is penalized in return.

A distribution of n more copies of each message improves the delivery ratio up to 10% in the tested disaster scenarios. We also wanted to see how an step by step wider distribution will affect on the performance results. We did an analysis incrementing the distribution of the message using PropNTTR.

PropNTTR works in the same way that PropTTR does but uses a variable N as threashold. For example, if we use N=2 this means that MaxProp will be the forwarding protocol used for messages with a hop count smaller than 2 and TTR for the rest.

We tested N in PropNTTR for 2, 3 and 4. For N=3 and N=4 we see that the performance results are very similar to MaxProp in terms of delivery ratio or energy consumption for the scenarios tested. We extracted information about hop count in a set of simulations to analyze the value of N in PropNTTR. In figure 3.5 we see that the value of N determines the average hopcount. The change from MaxProp (replication forwarding) to TTR (non-replication forwarding) stops messages from being replicated which have effect on the average hopcount. Although we can see that for 85 nodes MaxProp has an average hopcount of 6 and Prop4TTR an average hopcount of 4, the difference in energy consumption is insignificant. Hence, we cannot say that there is a direct correlation between the average hopcount and the energy consumption. As a conclusion, we can say that in Prop4TTR the use of TTR instead of MaxProp greatly impacts in the average hopcount of the messages but not significantly in the energy consumption.

Prop3TTR produced a very similar results in terms of delivery ratio regarding Prop4TTR but it reduced the average hopcount from more than 4 to 3,5 for 85 nodes. In this case, Prop3TTR also reduced the energy consumption an 18% while having the same delivery ratio as Prop4TTR. But the most relevant results were those of Prop2TTR.

For the same simulations compared in the last paragraphs, Prop2TTR delivers 75% of the messages created: a 10% less than MaxProp and a 30% more than TTR. In terms of energy consumption, Prop2TTR consumes 1200 Joules while MaxProp 6500 and TTR 500. This huge gap in energy consumption between MaxProp and Prop2TTR while delivering only 10% less messages demonstrates that Prop2TTR is

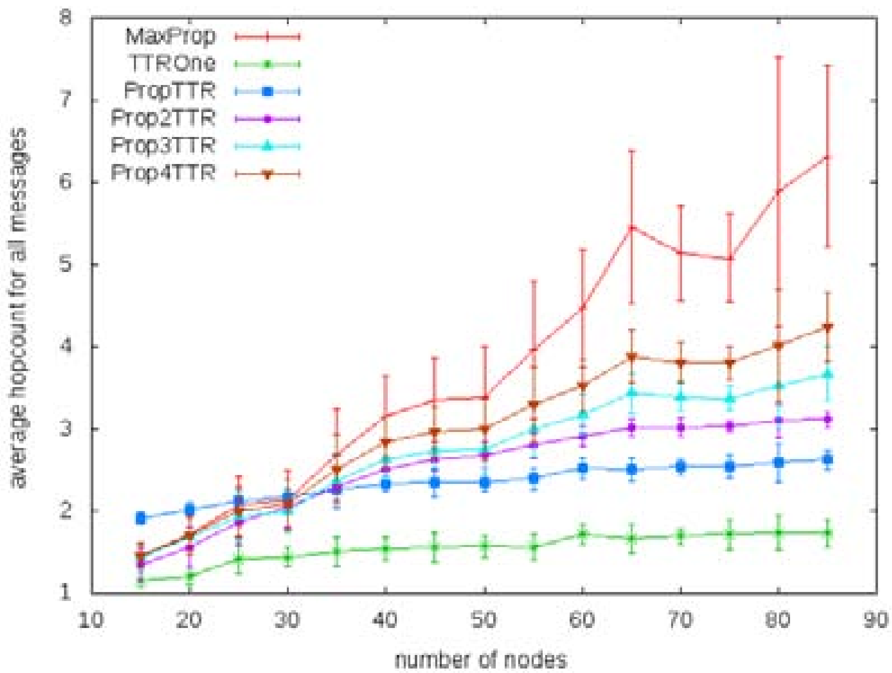

Figure 3.5: Average hop count of all messages vs. number of nodes

much more energy e cient that MaxProp.

For the rest of simulations of scenarios with different characteristics, we can say as a general conclusion that in almost all situations Prop2TTR is more energy e cient than MaxProp, defining as energy e ciency, the energy consumed by the delivery ratio. The reduction of delivery ratio from using MaxProp to Prop2TTR is much smaller than the reduction in energy consumption. As a drawback, latency is slightly increased.

As a sum up, we can extract two main conclusions. The former, PropTTR provides a better delivery ratio than TTR slightly increasing the energy consumption but producing a higher delivery delay. The latter, Prop2TTR proves between 5% and 15% lower delivery ratio than MaxProp and a much lower energy consumption (up to 6 times less), in the tests performed, without a high increase in delivery delay.

This proposal can be generalized to other types of scenarios and forwarding protocols. The main idea is to reduce unnecessary message duplications of too greedy forwarding protocol (reducing the energy consumption), thus producing a lesser energy consumption. This is achieved mixing the greedy forwarding protocol with a single copy forwarding protocol in scenarios with presence of data mules. The latter routing method have a good energy consumption but low delivery ratio due to the loss of better-forwarding opportunities.

Chapter 4

Conclusions

This thesis began with the aim of improving how the triage was done in disasters. At that time, triage were only though as a paper attached to the victim without any electronic information associated with it. This traditional system has some evident problems, the first one is that a paper triage tag can be lost once attached to the victim losing the time that the paramedic spend triaging the victim. This can be solved by using a triage wrist but some of the information gathered by the paramedic will also be lost as the wrist only indicates the color of the triage. Another problem is that the first responder has to approach the victim to see her triage tag, losing a very valuable time. The first proposal of this thesis was the Mobile Agent based Electronic Triage Tag system (MAETT). MAETT provides an Electronic Triage Tag (ETT) that not only can be used as a backup in case the paper triage tag is lost but also for improving the rescue process thanks to the added ETT fields (GPS position of the victim).

MAETT creates an Electronic Triage Tag with the information gathered in the form of a Mobile Agent. This Mobile Agent can jump from one device to another until it reaches the Coordination Center where the information will be unload and processed. All the information gathered by all the Mobile Agent Triage Tags allow to draw in a map showing where the victims are, together with their condition, giving the possibility of tracing ambulance routes to pick up victims or sending paramedics to those more needed.

We also proposed a Virtual Electronic Patient Medical Record (VEPMR), a link between the MAETT system and a Mobile Agent system to get an Electronic Patient Medical Record [61] if the victim has been previously identified. If the medical record of the victim is available, the hospital system can foresee the equipment needed to take care of the patient. For instance, book units of blood of the blood type of the victim before the patient arrives to the medical center.

But forwarding information in an emergency scenario to a coordination center is not an easy task. Mobility of paramedics in the disaster zone in emergency scenarios is almost unpredictable. The Electronic Triage Tags are carried in mobile devices which are transported by first responders who look for victims. These victims are located in different uknown places making the movement of the first responders different for each emergency. But there is something that can be predicted, the first responders have a time to return to the coordination center, hence they can act as data mules. The trace of the data mule can not be foreseen but the time at which the first responder will come back to the coordination center can be. With this information a new routing protocol was proposed, the TTR.

Mobile Agents support opportunistic networks. They can discover new platforms and jump to them, but the process may require some time. Mobile Agents have to freeze their processes, have to be serialized and have to move to the new platform. Furthermore, they carry all the code and data. All of these can penalize performance in some emergency scenarios with short contact time between nodes or with long distance contacts with a low bandwidth. We proposed an Electronic Triage Tag based on the Haggle architecture, a complete framework prepared for opportunistic networks, to solve these problems.

Emergency scenarios can vary a lot from one to another: location and number of victims, number of first responders, size of the disaster area, etc. For this reason we performed a deep analysis about emergency scenarios and opportunistic networks in order to uncover which characteristics of the emergency scenarios have more impact in the performance of a set of routing protocols. MaxProp showed a very good performance in terms of delivery ratio in almost any scenario but also at a high energy cost that could exhaust the battery of a mobile device. On the other hand, TTR showed a very good energy performance but its delivery ratio was much lower than MaxProp. In order to have an intermediate solution we proposed PropNTTR, a solution based on data mules together with probabilistic routing. Tests showed very good results in terms of delivery ratio (although below MaxProp) with a low energy consumption. This routing method could improve the duration of the battery while having a good delivery ratio.

4.1 Future research lines

At this end stage of the thesis, future research lines arise. In the following we describe some of them.

- **Dynamic Routing in Opportunistic Networks in Disasters** We propose the use of PropNTTR dynamically. This means that the value of N can change dynamically under some conditions. For example, if a node is using Prop2TTR and its battery is getting exhausted, the N can be dynamically changed to 1 to save even more energy. Hence, the node will start to use PropTTR instead of Prop2TTR which will lower its energy consumption. One of the advantages of PropNTTR is that each node is independent from the other: one can use Prop3TTR and other can use PropTTR and both will be able to communicate with each other and exchange they messages between them. With PropNTTR with N dynamically a node could start with a high value of N and decrease its value as the battery runs out. This can be implemented using bundle protocol (which is at application level and can read application level data) or using Haggle which provides a resource manager that informs about the remaining battery, RAM, CPU, etc. Thus, allowing the forwarding manager to take decisions after consulting the resource manager.

- **Social Networks for Triage Collaboration and Victim Discovery** The power of internet in disaster information dissemination has become very important in the lasts emergency situations. Google Crisis Response [1] is one example of how people use internet to be informed and to inform about elements of an emergency (points of interest, people missing, etc). Social Networks also are growing every day. People use them to discuss about daily news and events almost instantly while they are happening. We can remember how that egyptian revolution started in great part by the in uence of the social networks or how a Pakistani citizen related the CIA capture of Osama Bin Laden while it was happening. This heavy use of social networks could be used in disaster scenarios to organize information related to the emergency posted by users and use them by the first responders.

- **Electronic Triage Tag using Sensors** Using the application architecture described in MAETT, sensors can be added to it to retriage victims in real time and send any change in their condition (from yellow triage to red triage for instance) using mobile agents. Thanks to this, during the entire emergency the triage is eventually updated, providing a more effective resource allocation. Some of this work is under development [44].

- **MaxProp with Spray and Wait** *Spray and Wait* [55] is a forwarding protocol that consist in two parts. The first part, *Spray*, is in charge of message dissemination based on probabilities. This probability can be calculated by using different algorithms. Hence, the message is copied and distributed from the node where it has been generated to encountered nodes. Once the *Spray* part is finish, the *Wait* part comes along. It only consist in waiting until one of the nodes that have a copy of the message encounters the destination node of it, taking into account that nodes have mobility. MaxProp face a similar problem. It has a very good *spray* algorithm based in probabilities but it doesn t have a *wait* part, thus consuming a lot of energy. PropNTTR has shown that possibly a *wait* part in MaxProp will slightly reduce the delivery ratio but significantly reduce the energy consumption. A further research about creating a *Spray with MaxProp and Wait* could produce good results.

Bibliography

[1] Google crisis response. [Online]. Available: http://www.google.com/crisisresponse/

[2] Haggle, http://code.google.com/p/haggle/. [Online]. Available: http://code.google.com/p/haggle/

[3] Terremoto nord italia. come rendere accessibile wifi di vodafone station e vodafone station, 2012, http://goo.gl/WmWhV.

[4] N. Aschenbruck, E. Gerhards-Padilla, M. Gerharz, M. Frank, and P. Martini, Modelling mobility in disaster area scenarios, in *MSWiM*. ACM, 2007, pp. 4 12.

[5] S. Baker, B. o Neill, W. Haddon Jr, W. Long *et al.*, The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care, *J Trauma*, vol. 14, no. 3, pp. 187 196, 1974.

[6] N. Balasubramanian, A. Balasubramanian, and A. Venkataramani, Energy consumption in mobile phones: a measurement study and implications for network applications, in *Proceedings of the 9th ACM SIGCOMM conference on Internet measurement conference*, ser. IMC 09. New York, NY, USA: ACM, 2009, pp. 280 293. [Online]. Available: http://doi.acm.org/10.1145/1644893.1644927

[7] J. Burgess, B. Gallagher, D. Jensen, and B. N. Levine, Maxprop: Routing for vehicle-based disruption-tolerant networks, in *In Proc. IEEE INFOCOM*, 2006.

[8] S. Burleigh, A. Hooke, L. Torgerson, K. Fall, V. Cerf, B. Durst, K. Scott, and H. Weiss, Delay-tolerant networking: an approach to interplanetary internet, *Communications Magazine, IEEE*, vol. 41, no. 6, pp. 128 136, 2003.

[9] A. Carroll and G. Heiser, An analysis of power consumption in a smartphone, in *Proceedings of the 2010 USENIX conference on USENIX annual technical conference*, ser. USENIXATC 10. Berkeley, CA, USA: USENIX Association, 2010, pp. 21 21. [Online]. Available: http://portal.acm.org/citation.cfm?id=1855840.1855861

[10] S. H. A. T. L. D. R. S. K. F. K. Cerf, V.; Burleigh and H. Weiss, Delay-Tolerant Networking Architecture, RFC 4838 (Informational), Internet Engineering Task Force, 2007. [Online]. Available: http://www.ietf.org/rfc/rfc4838.txt

[11] M. Conti and M. Kumar, Opportunities in opportunistic computing, *Computer*, vol. 43, pp. 42 50, 2010.

[12] M. Cooke and S. Jinks, Does the manchester triage system detect the critically ill? *Emerg Med J*, vol. 16, no. 3, pp. 179 181, 1999. [Online]. Available: http://emj.bmj.com/cgi/content/abstract/16/3/179

[13] Cruciform, Cruciform, Online, Web, last checked on 18th May 2012. [Online]. Available: http://www.cwc-services.com/products-services/triage

[14] J. Cucurull, R. Martí, S. Robles, J. Borrell, and G. Navarro-Arribas, Fipa-based interoperable agent mobility, in *CEEMAS07*, ser. LNAI, vol. 4696. Springer Verlag, September 2007, pp. 319 321.

[15] J. Cucurull, R. Martí, G. Navarro-Arribas, S. Robles, J. Borrell, and G. Suades, Fragment transfer protocol: An ieee-fipa based e cient transfer protocol

for mobile agents, *Computer Communications*, vol. 33, no. 18, pp. 2203 2214, 2010. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0140366410003622

[16] E. M. Daly and M. Haahr, Social network analysis for routing in disconnected delay-tolerant manets, in *Proceedings of the 8th ACM international symposium on Mobile ad hoc networking and computing*, ser. MobiHoc 07. New York, NY, USA: ACM, 2007, pp. 32 40. [Online]. Available: http://doi.acm.org/10.1145/1288107.1288113

[17] B. Demchak, T. C. Chan, W. G. Griswold, and L. A. Lenert, Situational awareness during mass-casualty events: command and control, *AMIA Annu Symp Proc*, p. 905, 2006, times Cited: 0.

[18] R. B. Dilmaghani and R. R. Rao, A reliable wireless mesh infrastructure deployment at crisis site. in *IPCCC*. IEEE Computer Society, 2007, pp. 579 581. [Online]. Available: http://dblp.uni-trier.de/db/conf/ipccc/ipccc2007.html#DilmaghaniR07

[19] K. B. Eden, R. Messina, H. Li, P. Osterweil, C. R. Henderson, and J.-M. Guise, Examining the value of electronic health records on labor and delivery, *American Journal of Obstetrics and Gynecology,*, vol. 199, no. 3, pp. 307.e1 307.e9, 9 2008.

[20] S. Farrell, V. Cahill, D. Geraghty, I. Humphreys, and P. McDonald, When tcp breaks: Delay- and disruption- tolerant networking, *IEEE Internet Computing*, vol. 10, no. 4, pp. 72 78, 2006.

[21] E. A. Fry and L. Lenert, Mascal: Rfid tracking of patients, staff and equipment to enhance hospital response to mass casualty events, in *AMIA Annual Symposium Proceedings*, 2005, pp. 261 265.

[22] A. Fuggetta, G. P. Picco, and G. Vigna, Understanding code mobility, *IEEE Trans. Softw. Eng.*, vol. 24, no. 5, pp. 342 361, 1998.

[23] T. Gao, C. Pesto, L. Selavo, Y. Chen, J. Ko, J. Lim, A. Terzis, A. Watt, J. Jeng, B. rong Chen, K. Lorincz, and M. Welsh, Wireless medical sensor networks in emergency response: Implementation and pilot results, in *In Proc. 2008 IEEE International Conference on Technologies for Homeland Security. IEEE*, 2008.

[24] J. Hippisley-Cox, M. Pringle, R. Cater, A. Wynn, V. Hammersley, C. Coupland, R. Hapgood, P. Horsfield, S. Teasdale, and C. Johnson, The electronic patient record in primary care - regression or progression? a cross sectional study, *British Medical Journal*, vol. 326, pp. 1439 1443, 2003. [Online]. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=162256

[25] P. Hui, J. Crowcroft, and E. Yoneki, Bubble rap: Social-based forwarding in delay-tolerant networks, *Mobile Computing, IEEE Transactions on*, vol. 10, no. 11, pp. 1576 1589, nov. 2011.

[26] IETF, Delay tolerant networking research group, http://www.dtnrg.org/.

[27] S. Inoue, A. Sonoda, K. Oka, and S. Fujisaki, Emergency Healthcare Support: RFID Based Massive Injured People Management, in *Proc. Pervasive Healthcare Workshop in Ubicomp 2006 (UbiHealth)*, 2006, p. 9.

[28] J. P. Killeen, T. C. Chan, C. Buono, W. G. Griswold, and L. A. Lenert, A wireless first responder handheld device for rapid triage, patient assessment and documentation during mass casualty incidents, *AMIA Annu Symp Proc*, pp. 429 33, 2006, times Cited: 0.

[29] G. S. Kim and Y. I. Eom, Domain-based mobile agent fault-tolerance scheme for home network environments, in *Information Security Practice and Experience, LNCS*, ser. LNCS, vol. 3903, February 2006, pp. 269 277.

[30] L. Lenert, D. Palmar, T. Chan, and R. Rao, An intelligent 802.11 triage tag for medical response to disasters, in *AMIA Annual Symposium Proceedings*, 2005, pp. 440 444.

[31] L. Lenert, T. C. Chan, W. Griswold, J. Killeen, D. Palmer, D. Kirsh, R. Mishra, and R. Rao, Wireless internet information system for medical response in disasters (wiisard), in *AMIA Annual Symposium Proceedings*, 2006, pp. 429 433.

[32] A. Lindgren, A. Doria, and O. Schelén, Probabilistic routing in intermittently connected networks, 2004, pp. 239 254. [Online]. Available: http://www.springerlink.com/content/9xt3904hd05fxmjf

[33] A. Lindgren and P. Hui, The quest for a killer app for opportunistic and delay tolerant networks: (invited paper), in *Proceedings of the 4th ACM workshop on Challenged networks*, ser. CHANTS 09. New York, NY, USA: ACM, 2009, pp. 59 66. [Online]. Available: http://doi.acm.org/10.1145/1614222.1614233

[34] K. Luyten, F. Winters, K. Coninx, D. Naudts, and I. Moerman, A situation-aware mobile system to support fire brigades in emergency situations, *On the Move to Meaningful Internet Systems 2006: Otm 2006 Workshops, Pt 2, Proceedings*, vol. 4278, pp. 1966 1975, 2006.

[35] P. M. V. Marques, A. Cunha, L. Antunes, R. C. Correia, and A. da Costa Pereira, A first approach for a regional wide vepr, in *HEALTHINF (1)*, L. Azevedo and A. R. Londral, Eds. INSTICC - Institute for Systems and Technologies of Information, Control and Communication, 2008, pp. 215 218.

[36] A. Martín-Campillo, J. Crowcroft, E. Yoneki, R. Martí, and C. Martínez, Using haggle to create an electronic triage tag, in *The Second International Workshop on Mobile Opportunistic Networking - ACM/SIGMOBILE MobiOpp 2010*. ACM Press, February 2010, pp. .

[37] A. Martín-Campillo, R. Martí, S. Robles, and C. Martínez-García, Mobile agents for critical medical information retrieving from the emergency scene, in *7th International Conference on Practical Applications of Agents and Multi-Agent Systems*, ser. Advances in Intelligent and Soft Computing, S. B. . Heidelberg, Ed. Springer, 2009.

[38] R. Martí, S. Robles, A. Martín-Campillo, and J. Cucurull, Providing early resource allocation during emergencies: the mobile triage tag, *Journal of Network and Computer Applications*, vol. 32, no. 6, pp. 1167 1182, November 2009.

[39] A. Martín-Campillo, R. Martí, E. Yoneki, and J. Crowcroft, Electronic triage tag and opportunistic networks in disasters, in *In Special Workshop on the Internet and Disasters at ACM CoNEXT 2011 (WoID at CoNEXT 2011)*, December.

[40] A. Martín-Campillo, C. Martínez, J. Cucurull, R. Martí, S. Robles, and J. Borrell, *Computational Intelligence in Healthcare 4*, bichindaritz, i.; jain, l.c.; vaidya, s.; jain, a. ed., August 2010, ch. Mobile Agents in Healthcare, a Distributed Intelligence Approach.

[41] A. Martín-Campillo and R. Martí, Energy-e cient forwarding mechanism for wireless opportunistic networks in emergency scenarios, *Computer Communications*, no. 0, pp. , 2012. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0140366412001636

[42] T. Massey, T. Gao, M. Welsh, J. H. Sharp, and M. Sarrafzadeh, The design of a decentralized electronic triage system, in *AMIA Annual Symposium Proceedings*, 2006, pp. 544 548.

[43] S. McGrath, E. Grigg, S. Wendelken, G. Blike, M. D. Rosa, A. Fiske, and R. Gray., ARTEMIS: A Vision for Remote Triage and Emergency Management Information Integration, in *Dartmouth University*. Dartmouth University, November 2003, pp. .

[44] E. Mercadal, S. Robles, R. Martí, C. Sreenan, and J. Borrell, Double multiagent architecture for dynamic triage of victims in emergency scenarios, *Progress in Arti cial Intelligence*, pp. 1 9, 10.1007/s13748-012-0016-8. [Online]. Available: http://dx.doi.org/10.1007/s13748-012-0016-8

[45] A. Mtibaa, M. May, C. Diot, and M. Ammar, Peoplerank: Social opportunistic forwarding, in *INFOCOM, 2010 Proceedings IEEE*, march 2010, pp. 1 5.

[46] U. Navy, Tactical medical coordination system (tacmedcs), http://www.namrl.navy.mil/clinical/projects/tacmedcs.htm.

[47] E. Nordström, P. Gunningberg, and C. Rohner, A search-based network architecture for mobile devices, Department of Information Technology, Uppsala University, Tech. Rep., 2009.

[48] U. of Bonn, Bonnmotion: A mobility scenario generation and analysis tool, http://net.cs.uni-bonn.de/wg/cs/applications/bonnmotion/, 2002-2011.

[49] L. Pelusi, A. Passarella, and M. Conti, Opportunistic networking: data forwarding in disconnected mobile ad hoc networks, *Communications Magazine, IEEE*, vol. 44, no. 11, pp. 134 141, 2006.

[50] A. Rice and S. Hay, Measuring mobile phone energy consumption for 802.11 wireless networking, *Pervasive and Mobile Computing*, vol. 6, no. 6, pp. 593 606, 2010, special Issue PerCom 2010. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1574119210000593

[51] I. Satoh, Building reusable mobile agents for network management, *Systems, Man and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 33, no. 3, pp. 350 357, Aug. 2003.

[52] K. Scott and S. Burleigh, Bundle Protocol Specification, RFC 5050 (Experimental), Internet Engineering Task Force, Nov. 2007. [Online]. Available: http://www.ietf.org/rfc/rfc5050.txt

[53] A. Seth, D. Kroeker, M. Zaharia, S. Guo, and S. Keshav, Low-cost communication for rural internet kiosks using mechanical backhaul, in *Proceedings of the 12th annual international conference on Mobile computing and networking*, ser. MobiCom 06. New York, NY, USA: ACM, 2006, pp. 334 345. [Online]. Available: http://doi.acm.org/10.1145/1161089.1161127

[54] V. Shnayder, B. rong Chen, K. Lorincz, T. R. F. F. Jones, and M. Welsh, Sensor networks for medical care, in *SenSys 05: Proceedings of the 3rd international conference on Embedded networked sensor systems*. New York, NY, USA: ACM, 2005, pp. 314 314.

[55] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, Spray and wait: an e cient routing scheme for intermittently connected mobile networks, in *Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking*, ser. WDTN 05. New York, NY, USA: ACM, 2005, pp. 252 259. [Online]. Available: http://doi.acm.org/10.1145/1080139.1080143

[56] J. Su, J. Scott, P. Hui, J. Crowcroft, E. De Lara, C. Diot, A. Goel, M. Lim, and E. Upton, Haggle: Seamless networking for mobile applications, in *Proceedings of the 9th international conference on Ubiquitous computing*. Springer-Verlag, 2007, pp. 391 408.

[57] G. Super, *START: A Triage Training Module*. Newport Beach, California: Hoag Memorial Hospital Presbyteriand, 1984.

[58] G. Teasdale and B. Jennett, Assessment of coma and impaired consciousness. a practical scale. *Lancet*, vol. 2, no. 7872, pp. 81 84, 1974. [Online]. Available: http://view.ncbi.nlm.nih.gov/pubmed/4136544

[59] A. Vahdat, D. Becker *et al.*, Epidemic routing for partially connected ad hoc networks, Technical Report CS-200006, Duke University, Tech. Rep., 2000.

[60] J. R. Velasco, M. A. López-Carmona, M. Sedano, M. Garijo, D. Larrabeiti, and M. Calderon, Role of multi-agent system on minimalist infrastructure for service provisioning in ad-hoc networks for emergencies, in *Proceedings of AAMAS 06*, 2006, pp. 151 152.

[61] P. M. Vieira-Marques, S. Robles, J. Cucurull, R. Cruz-Correia, G. Navarro, and R. Martí, Secure integration of distributed medical data using mobile agents, *IEEE Intelligent Systems*, vol. 21, no. 6, pp. 47 54, 2006.

[62] Y. Wang and H. Wu, Delay/fault-tolerant mobile sensor network (dft-msn): a new paradigm for pervasive information gathering, *Mobile Computing, IEEE Transactions on*, vol. 6, no. 9, pp. 1021 1034, 2007.

[63] J. E. White, Telescript technology: Mobile agents, in *Software Agents*, J. Bradshaw, Ed. Menlo Park, CA: AAAI Press/MIT Press, 1996.

[64] M. Wooldridge and N. R. Jennings, Intelligent agents: Theory and practice, *Knowledge Engineering Review*, vol. 10, no. 2, pp. 115 152, 1995.

[65] X. Zhang, J. Kurose, B. N. Levine, D. Towsley, and H. Zhang, Study of a bus-based disruption-tolerant network: mobility modeling and impact on routing, in *MobiCom 07: Proceedings of the 13th annual ACM international conference on Mobile computing and networking.* New York, NY, USA: ACM, 2007, pp. 195 206.

Appendix A

"Providing early resource allocation during emergencies: the mobile triage tag"

Journal of Network and Computer Applications 32 (2009) 1167–1182

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

Providing early resource allocation during emergencies: The mobile triage tag

R. Martí *, S. Robles, A. Martín-Campillo, J. Cucurull

Department of Information and Communications Engineering, Universitat Autònoma de Barcelona, 08193 Cerdanyola, Spain

ARTICLE INFO

Article history:
Received 10 December 2008
Received in revised form
23 April 2009
Accepted 15 May 2009

Keywords:
Mobile agents
Triage tag
Emergency system

ABSTRACT

Quick response is critical during an emergency situation. This paper describes a system based on mobile electronic triage tags that makes victim information available at the base of operations as soon as possible, thus allowing an early medical resource allocation and immediate action. The cornerstone of the system is mobile agent technology, which allows information to be transported asynchronously and reliably from terminal to terminal and not requiring any network infrastructure at all. This novel approach is ready to be used in the worst case scenario, where only small handheld devices carried by the emergency personnel are available, but also integrates well when synchronous connections are possible, for instance when a mesh network can be created. The system has been successfully implemented, showing the feasibility of the proposal. By using this low-budget system, the number of casualties during the triage stage of an emergency is expected to drop off.

1. Introduction

When there is an emergency situation, for instance after a terrorist event or a meteorological disaster, immediate action is required. Communication networks are normally disrupted in these cases, and this obviously is an obstacle for quick and coordinated assistance.

One of the most important tasks after an emergency has occurred is sorting the victims on the basis of need for, or likely benefit from, medical treatment (Super, 1984; Mackway-Jones, 2006). After this, aid is allocated based upon the severity of each victim. Traditional schemes to achieve this urgent triage use a standard physical tag which is placed on the person, normally around their neck. This tag usually has a color code concerning the severity of the case, and it is used afterwards to allocate medical resources more efficiently. Although this approach is widely accepted and used, it shows some shortcomings that hinder the final goal of optimizing the medical aid provision. There are two main issues for this. Firstly, the tag is a physical element placed on the body of the victim; this can make location a difficult chore, for it depends on visual skills and direct eye contact (what if the wind has moved the tag and it is hidden behind the body!). Secondly, the task of sorting the victims and locating them for further assistance and transportation are decoupled; tagged victims cannot be traced to verify if they have all been collected, and it is not possible to find out where in the geographic landscape there is a higher concentration of critical victims.

Electronic systems have often been proposed to solve these problems. Ranging from quick infrastructure deployments (Dilmaghani and Rao, 2007) to barcode or Radio Frequency Identification (RFID) based solutions (Inoue et al., 2006), all these approaches have tried to solve the main issues of emergency management, including victim triage. Most existing approaches, unfortunately, fail to provide a feasible low-cost answer to actual problems, and especially to early resource provision.

As in many other scenarios where distribution and coordination is of utmost importance, agent technology (Wooldridge and Jennings, 1995) has also been applied to emergency management (Fry and Lenert, 2005). In this case, though, no advantage has been taken of agents for the particular purpose of triage. Still, the introduction of agents has meant an important betterment in emergency systems, and the number of applications in related areas such as eHealth is growing by the minute (Hendler, 2006). Far from being a silver bullet, agent technology allows us, hitherto, to face the design of complex systems in a sensible manner.

This paper aims for providing a novel approach to solve the problem of triage in emergency situations—the Mobile Agent based Electronic Triage Tag System (MAETTS)—that overcomes the issues of the traditional schemes described above. The basis of our proposal is mobile agent technology. Mobile agents (White, 1996) are reactive and communicative pieces of software that, unlike traditional static agents, can move between execution platforms in a proactive fashion, roaming the whole system to accomplish their goal. Platforms run a middleware used by agents to interact with other agents and with the system.

There are two main physical components in this proposal. Firstly, a triage tag with medical status, embedding a contact-free,

* Corresponding author. Tel.: +34 93 581 4835; fax: +34 93 581 4477.
E-mail address: ramon.marti.escale@uab.es (R. Martí).

1084-8045/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jnca.2009.05.006

low-range RFID device emitting a unique identification. This identifier will be associated with a victim, and will represent them through all the system. Secondly, a handheld device with an integrated Global Positioning System (GPS) receiver, a touch screen, a RFID reader, and wireless communications. This device is attached to the high visibility vest worn by the triage personnel. When a victim is found, a triage tag is placed on them, and the basic information in the tag about their status is filled in using the device. The very handheld device reads the tag identification and a mobile agent is created, carrying the medical status information, the tag identification, and the geographical position. This agent will hop from member to member of the emergency staff since all handheld devices form a large wireless mobile ad hoc network. Asynchronous agent migration makes it unnecessary any extra communication infrastructure. An ingenious routing protocol allows agents to reach the base of operations. Once there, and with all the information about the condition and whereabouts of the victims, resources such as vehicles or food can be optimally managed and used to aid the higher prioritized persons first.

Our agents in handheld devices show as simple, intuitive visual interfaces, in which triage personnel can easily indicate the victim's condition and vital signs by touch. In our proposal, the agent providing the user interface is different from the agent which keeps and transports the triage tag information. The first one is always residing in the handheld device, while the second one is mobile and moves through several devices. In this way, mobile agents become smaller and faster to move, as well as the information able to be easily displayed in agents providing user interfaces adapted to each type of device.

This system avoids some of the issues of current schemes lag far behind, and the number of casualties during the triage and medical evacuation is expected to drop significantly. Moreover, the Mobile Agent Electronic Triage Tag System can be easily integrated into existing Electronic Patient Record Systems, such as the one presented by Vieira-Marques et al. (2006). This will make critical information such as allergies and chronic or infectious diseases available to be imported to the very emergency scene, in an analogy to a virtual medical tag pendant.

The rest of the paper is structured as follows. The next section is devoted to related work and background. Sections 3 and 4 describe the RFID electronic tag based on mobile agents, and an implementation of the scheme, including a routing mechanism used to reach the coordination point, respectively. A discussion on the advantages of this proposal with respect to other existing systems, and the conclusions drawn, conclude the paper.

2. Related work and background

Our proposal is focused on the medical triage stage in emergency situations. This section analyzes the existing work on medical triage and emergency systems, and provides a basic background on the technologies supporting the proposal, namely mobile agents, wireless networks and Bluetooth.

2.1. Medical triage related work

There are three topics closely related to a triage system: victim identification (assigning a temporary identifier for further reference), a medical classification system (common criteria for objectively deciding the status of victims), and a physical support to make all this information available (generally, triage tags). This section will go into these aspects.

2.1.1. Victim identification

The first requirement for any emergency triage system is having a mechanism for the unique identification of victims. Barcodes have replaced plain numbers in this task, especially in medical environments, thus facilitating mechanical reading (Neuenschwander et al., 2003). Barcodes are easy to create (they can just be printed on paper using a standard printer), but the optical reader needs to be very close to get the information. Furthermore, only one barcode can be read by a reader at a time, and no additional data apart from the identifier can be stored in it.

Recently, two-dimensional barcodes are being introduced in different fields (Gao et al., 2007). This technology is based on dots instead of bars, allowing more bits of information to be included in the code. It can also be used for victim identification, and even additional information, such as patient data, can be stored on it. Unfortunately, this mechanism also requires readers to be placed in front of the barcode, only one code can be read at a time, and a new code must be printed again if the information in it has to be updated.

Radio Frequency Identification (Inoue et al., 2006) is another technology that can be used for victim identification. A unique identification number is stored in a RFID tag, and a wireless, contact-free, low-to-medium-range reader communicates with it using radio waves to get this information. Two types of tags exists, passive tags, that use the energy received from the reader to send the identifier, and active tags, that include a battery to increase its distance range.

In spite of requiring special hardware tags, this technology is very interesting for emergency systems because it supports the simultaneous identification of several elements from a medium range distance.

2.1.2. Triage systems

The first medical step in the aftermath of a crisis is the triage of the victims, which is required for an initial evaluation of their health status. This process, called triage, must observe a strict, nonsubjective procedure following standard criteria.

Several triage systems exist, such as the world-wide used Simple Triage and Rapid Treatment (START) (Super, 1984), the more complex and complete Manchester Triage System (MTS) (Mackway-Jones, 2006) widely used in UK, Europe and Australia, the points-based Glasgow Coma Scale (GSC) (Teasdale and Jennett, 1974), only centered in the conscious state of the victim, or the two-step Triage Sieve and Sort (Wallis, 2002).

Most of these systems are based on the rapid analysis of the breath status and rate, pulse rate, patient ability to follow simple commands, or eye, verbal or motor response. After the triage, victims are usually classified into four injury level categories, each one associated with a color: Minor (green), Delayed (yellow), Immediate (red), and Deceased (black). Furthermore it has recently being introduced a new category, violet, for victims in a very critical status, which are very likely to be casualties in a short time. In this paper we will use the four color system, which is the most widely used currently.

2.1.3. Triage tags

Once a victim has been triaged, one of the four colors associated with the injury level is assigned to them together with an identification number. The medical data obtained from the triage, as well as non-medical information that may be obtained from the victim, may also be vital for later treatment.

For the visualization of the color associated with the injury level, easy methods are used such as the Flagging tape, a simple color non-adhesive PVC or vinyl tape. More complex paper tags, known as triage tags, are also widely used. These triage tags

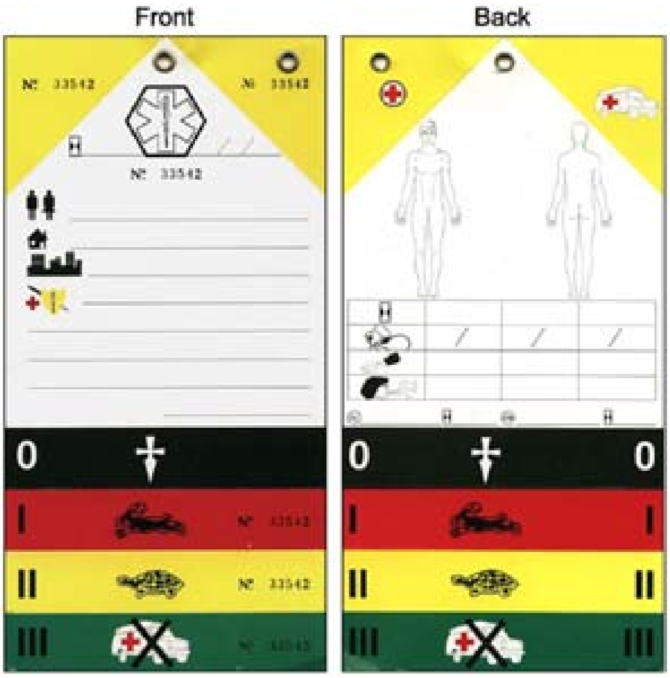

Fig. 1. METTAG triage tag.

include the color associated with the injury level, the victim identification number, and additional medical and non-medical information that may be useful for the medical personnel to assist the patient later (see Fig. 1). Examples of them are the original (METTag), the foldable Smart Tag (TSG Associates), the big-size cross-shaped foldable Cruciform tag (CWC-services), or the military Smart Incident Command System (SICS) (TSG Associates).

Using these traditional paper triage tags the information written on them remains near the patient. Nonetheless, additional steps are required for the medical personnel if this information must be received in advance to attend the patient later on, or if this information must be introduced and managed in a computer system.

2.2. Technical background

Our approach focuses on the improvement of existing triage systems through the innovative usage of technologies such as mobile agents, wireless networks, and Bluetooth. A very brief background of these technologies is described below.

2.2.1. Mobile agents

The system we propose is based on the use of mobile agents for emergency situations. Agents (White, 1996) are autonomous software entities with a set of tasks, reactive (i.e., react to their environment changes), proactive (i.e., change their environment), and social (i.e., interact with other agents). Mobile agents have the additional ability to move to different network locations. Agents dwell in agent platforms, which are frameworks where they are executed.

In order to allow agents to collaborate among themselves, when they are originated in platforms using different technologies, a standardized way to interoperate is required. Nowadays, the standards specified by the IEEE Foundation of Intelligent Physical Agents (FIPA), both for agents and for agent platforms, are the most widely used.

Several mobile agent platforms exist. We highlight the most representative ones: AgentScape (Overeinder and Brazier, 2006), a middleware layer focused on security and scalability, developed by the Department of Computer Science of the Vrije Universiteit Amsterdam; Aglets (Lange and Mitsuru, 1998), a Java-based platform and library for mobile agents support, originally developed by IBM Tokyo Research Laboratory, and currently hosted as a SourceForge open source project; Ajanta (Tripathi et al., 1999), a Java-based mobile agents platform developed at the University of Minnesota; FIPA-OS (Poslad et al., 2000) supporting the majority of the FIPA initial specifications; JADE (Bellifemine et al., 2006) an IEEE-FIPA-compliant Java-based middleware, with mobility support. Most of them are based on the multi-platform Java language, but only JADE is lately updated, is based on Java, supports agents mobility, and is IEEE-FIPA compliant.

Regarding agent mobility, it can be provided through different approaches. For this reason, some efforts have been done to standardize it, for example through FIPA-compliant (Cucurull et al. 2007a, b) or XML-based (Chen et al., 2008) protocols.

2.2.2. Wireless networks

In most emergency situations no communication infrastructures exist. It is in this case where wireless ad hoc networks have an important role. These networks are formed connecting the different systems without using any intermediate access point. A specific case of wireless ad hoc networks are mobile ad hoc networks (MANETs), where nodes move and dynamically change the structure of the network.

In MANETs, research has mainly been done on the optimization of routing algorithms, which are focused on different objectives: load balancing, energy efficiency, distance vectors, or the link state.

Another approach are Wireless Mesh Networks. These networks create routes, only as desired by the nodes, that are maintained as long as they are needed or the link is available. The standard, IEEE 802.11s draft, extends IEEE 802.11 with an architecture supporting broadcast, multicast, and unicast delivery in mesh networks at data link layer. An example of its usage is in the One Laptop Per Child (OLPC) project (OLPC).

Regarding wireless ad hoc network routing standards at network layer, the two main ones are the Ad-hoc On-demand Distance Vector (AODV) (Perkins et al., 2003), a reactive protocol which only establishes routes on demand based on distance vectors; and the Optimized Link State Routing (OLSR) protocol (Clausen and Jacquet, 2003), a proactive protocol based on link state.

2.2.3. Bluetooth

Bluetooth (Haartsen, 2000) is a radio frequency wireless technology for connecting devices in a short distance set to replace cables. It is designed to use very low power, making it suitable for portable devices, but limiting the data transfer speed. One of its features is the possibility to deal with several devices connected over a single link without being in line of sight of each other.

3. The Mobile Agent Electronic Triage Tag System

The main objective of this proposal is the specification of the Mobile Agent Electronic Triage Tag System, an innovative triage system for using in emergency situations. The system is an improvement of current electronic medical triage systems, which takes advantage of mobile agent technology to provide information mobility, autonomy, proactivity, and reactive component behavior to face up emergency situations. Moreover, the system is able to operate without communication infrastructures, permanent connections, or full network coverage through MANET

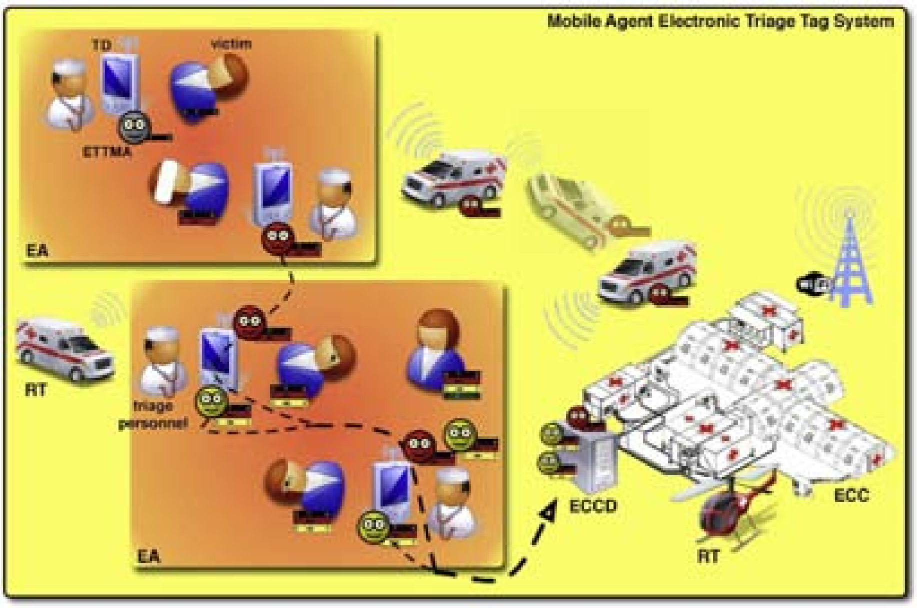

Fig. 2. Mobile Agent Electronic Triage Tag System (MAETTS).

technology. Besides, the system enables early resource allocation and integration with existing eHealth solutions, which are groundbreaker features not present in any other approaches up to date.

In the next paragraphs, there is an introduction of the scenario where the system operates. Then, there is a description of the system and the agents involved. And, finally, there is a detailed description of the the overall operation.

3.1. Scenario

Our proposal is based on a scenario with two different areas, the Emergency Area (EA) and the Emergency Coordination Center (ECC), interacting through the Electronic Triage Tags Mobile Agents (ETTMAs). See Fig. 2.

The EA is the zone where there are the victims of a Mass Casualty Incident (MCI). It is the focus of the medical attention, and there may be more than one in an emergency. Triage of the victims is done in this area by trained triage personnel, such as doctors, nurses and paramedicals. After the triage, doctors provide initial medical stabilization to victims and rescue teams (in ambulances, helicopters, and so on) take care of the transportation and evacuation.

Regarding communications, in the EA neither fixed nor permanent communication networks may be available. In some cases, although there might be a network available, such as GSM, it may be saturated, non-functional, or even disconnected for security reasons. Therefore, the solution is to use MANETs to communicate all handheld devices and computers supplied to the triage personnel, doctors, rescue teams, and the ECC. Anyway, MANET connectivity in this area is usually intermittent, and therefore permanent connection between devices, including the ECC, cannot be assured. Mobile agents travel across this network with triage information when ad hoc network coverage exists, trying to reach the ECC.

ECC is the second area in the scenario. All the information regarding the MCI (victims, doctors, specialists, volunteers, rescue teams, medical supplies, and so forth) is managed from there. Access to the non-permanent ad hoc network is available, and in some cases the access to an infrastructure network is also possible through cable or satellite communications. Usually, the ECC may also be linked to one field hospital.

Emergency personnel move from the EA to the ECC (and to field hospitals) to provide the required services, while rescue teams are in charge of victim transportation. Through the devices used by all the emergency personnel and rescue teams connected by MANET communications.

All the emergency information moves from the EA to the ECC by using the devices carried by all the emergency personnel and rescue teams connected by MANET communications, while management information moves in the opposite direction.

3.2. System description

From the initial requirements and the scenario described above, we propose the use of a hardware platform composed of several components. For the triage personnel and doctors in the EA, we propose the use of handheld devices with RFID reader, IEEE 802.11, and GPS support. For the rescue teams, in vehicles, we propose computers with IEEE 802.11 network support, GPS, and RFID reader. And for the ECC, computers with RFID reader, and network connectivity through wireless IEEE 802.11, wired ethernet, or satellite communications. Furthermore, simple paper triage tags with attached RFID tags for victim unique identification are used. In order to read tags, RFID readers with wired or wireless connection to the handheld device or computer must be available. Finally, the use of discovery and routing protocols on top of IEEE 802.11 ad hoc networking is proposed in order to link all unknown handheld devices and computers in the system.

Regarding the hardware infrastructure, MAETTS is based on three main devices: the Triage Device (TD), the Emergency Coordination Center Device (ECCD) and the Rescue Team Device (RTD). All of them run mobile agents, so they require a mobile agent platform.

3.2.1. Triage Device

The TD is the part of MAETTS used by triage personnel during the triage phase, and by doctors during the victim initial medical stabilization. It is composed of a handheld device which runs an agent platform, and a Manager Agent (MA) acting as the user interface and as a factory of ETTMAs. It also stores ETTMAs, either those created in the same device or the received from other devices.

3.2.2. Emergency Coordination Center Device

The ECCD is the part of MAETTS in charge of the emergency management. At least one ECCD is required in a MCI, usually in the ECC. Otherwise, an ECCD in the hospital can be used.

Apart from the computer, the ECCD has an agent platform installed on it, a MA to manage the agents and acting as a user interface, and a Coordination Agent (CA) providing the specific facilities for the coordination of the emergency. Moreover, the ECCD also stores all the ETTMAs arrived from the TDs in the EA, and calculates, creates and assign rescue routes to the RTDs.

3.2.3. Rescue Team Device

The RTD is the device used by every rescue team. From the architecture point of view, it is very similar to the TD, and it is composed of a computer running an agent platform, a MA, and all the ETTMAs received from the ECCD.

3.3. Agents

As seen in the previous system description, there are three different agents present in all three devices of MAETTS: the Manager Agent, the Electronic Triage Tag Mobile Agent and the Coordination Agent.

3.3.1. Manager Agent

The MA is an agent that must be present in all the platforms of the system. It is in charge of the management of MAETTS and provides the basic and common features required in all devices described above: a user interface, the creation of agents, the management of the device, and the management of the TTR.

User interface: This is the graphical user interface for all the devices in the system. It supports the introduction of all the medical information related to the victim, such as the status, the vital signs, or the medication received. It keeps a list of the ETTMAs in the device, and provides the services to visualize, modify, and add information to these ETTMAs. The touch interface is optimized for a good usability in the small-screen handheld devices used in the EA. Moreover, it is also adapted for its use in the rescue teams' computers as well as in the ECC, field hospital, or regular hospital. Other user interfaces customized for different types of specialists can also be supported by MAs.

ETTMA factory: MAs are in charge of creating new ETTMAs, and supply them with the triage information provided by the triage personnel.

ETTMA management: The MA is also the manager of ETTMAs running in the same agent platform, both the ones created in the same device as well as the ones coming from other devices.

Management of the remaining Time To Return: The routing decision algorithm for ETTMAs at the application level is based on the concept of Time To Return (TTR) to the ECC. A more detailed description of the ETTMA routing based on the TTR concept can be found in Section 3.4.2. The MA is in charge of managing its own TTR information, interchanging and storing the information of the TTR of all the devices currently accessible in the ad hoc network, and making this information available to all the ETTMAs in their own mobile agent platform.

3.3.2. Electronic Triage Tag Mobile Agent

The ETTMA is the basis of the system. The features provided by this agent are described below.

The ETTMA is able to store and visualize the victim triage color associated with the injury level, together with all relevant data obtained in the triage phase.

Apart from that, the ETTMA provides the storage of all the vital signs measured to the victim during the triage, the initial medical stabilization, and all the subsequent treatment, together with the non-medical data. The identification of the member of the medical personnel that has introduced each data, with timestamp information, is also stored.

Additionally, it stores the identification of the victims gotten through the RFID readers. Each victim is provided with a RFID tag. For backup purposes, as well as for support of systems without readers, paper triage tags with the identification number printed on it are tight to the RFID tag.

The ETTMA also supports the automatic and dynamic introduction of information regarding victim localization. This information is vital for the best management of medical transportation. For this reason, ETTMA is linked with a GPS receiver either built inside the hardware, usually in handheld devices, or an external one connected through Bluetooth, USB, or serial communication. A record with consecutive localization information is also periodically stored together with a timestamp. In case no GPS is available, localization information introduced by hand is also supported. A more detailed description of the victim localization process can be found in Section 3.5.4.

Finally, the ETTMA, as its name states, is a mobile agent, so it is able to migrate in an autonomous, proactive, and reactive way to other platforms when required. In a first step, the mobility is centered in moving from the TD of the triage personnel to other TDs until reaching the ECCD. Once there, and after a rescue team is assigned, it migrates to the corresponding RTD.

3.3.3. Coordination Agent

The CA, as previously mentioned, is in charge of the general coordination of the emergency. For this purpose, it provides the features below.

It is in charge of the management of the ETTMAs coming from the EA and stored in the ECCD.

It also provides the management of the rescue team routes, including their creation and assignment according to the rescue teams and ETTMAs present at each moment in the ECC.

Finally, the CA is also in charge of the management of the transportation and distribution of all the medical supplies from and to EA, ECC, field hospital and regular hospitals.

3.4. Electronic Triage Tag Mobile Agent features

The ETTMA is the central part of the system. Regarding data, it contains all the information related to the triage, while as for the software, it includes all the algorithms for the routing decisions to allow the mobile agent reach the ECCD as soon as possible.

3.4.1. ETTMA information

Each ETTMA contains all the victim information, most of them medical but also non-medical, required for the management of the emergency. The information must be equivalent to the one supported by the traditional paper triage tags, plus all the additional information related to the facilities provided by the hardware and software of the selected platform.

One of the advantages of using ETTMAs in front of traditional paper triage tags is that electronic triage tags may contain more information than on the reduced size of traditional paper triage tags. In this way, more information fields can be defined, and even new agents with new fields can be easily created, downloaded and used when required.

Some of this information, mainly the non-medical, is unique and it is only stored once, such as the victim identification, or the personal data. Other information, such as the medical one, may change during time, so it can be stored (overwritten or appended) as many times as required. In this later case, additional information that can be automatically obtained, such as a timestamp or the identification of the medical personnel that have introduced the information, may be added to track the changes in the ETTMA. The following list describes the information fields in the ETTMA, which can be extended as required.

Victim identification: The victim is identified using a unique identifier. Usually, this information is automatically obtained from the RFID tag stuck to the paper triage tag.

Personal data: The ETTMA includes data such as victim name, address, city, gender, and public health identifier.

Triage information: Storage of all traditional medical triage information must be supported by the ETTMA. It includes vital data such as blood pressure, pulse (full or weak; regular or irregular), or respiration. It also includes non-vital data medical status such as walking ability (yes or no), alert level (responsive or unconscious), capillary refill, or mental status (alert, verbal, pain, or unconscious). Among all the information regarding the triage, the color associated with the injury level must be remarked, which is the basis of all triage tags.

Body injuries: A front and back body diagram for the introduction of information regarding location of body injuries must also be present in the ETTMA.

Additional information: For extra medical information and/or observations, an additional text field is included.

Transportation information: Information about the transportation is also included in the ETTMA. It contains a transportation identifier, and origin and destination locations.

Medication: All the information about the medications administered to the victim is stored in this field. It includes the medication solution and dose, and whether it is intravenous or intramuscular.

3.4.2. ETTMA routing

Each ETTMA is in charge of the decision of moving from one platform to another by itself. For this purpose, a decision algorithm at application level must be included in the agent code. In this system, the decision is taken from the information carried by the ETTMA, together with information obtained from the MA in the platform where it is running.

As a first approach, we propose a simple routing decision algorithm for ETTMA based on the *Time To Return* to the ECC concept. With this approach, agents always move to the platform in the same MANET that expects to return to the ECC earlier.

Each time a user with a TD or a RTD (doctors, nurses, rescue teams, among others) leaves the ECC, he initializes, using a very simple GUI in the MA, a timer indicating when he expects to return to the ECC. This timer automatically decreases its value as time goes by. In case one of the users returns earlier or later than expected, the value may be modified in the same fashion as it is introduced. This is a realistic situation, since deployed personnel in the EA are important assets that normally are very controlled.

Each MA has a list with all the neighbor platforms and the TTR associated to the personnel carrying them. When a new accessible device is detected, both interchange their TTR, and introduce the obtained information in its own list of platforms. At that moment, all ETTMAs in the platform receive a notification of changes, and they may access the list and act in consequence. When the communication link is lost, the entry in the list is removed and the subscribed ETTMAs are notified.

The objective of the ETTMA is to reach the ECC as soon as possible. Hence, it selects the neighbor platform (P) with the lowest TTR as long as it is lower than the TTR from the current platform (TTR_c), they move to it.

$$next\ P = \{P_i | TTR_i = \min(TTR_1, \ldots, TTR_n) \wedge TTR_i < TTR_c\}$$

Since the decision is taken by the MAETT itself, other approaches could be supported simultaneously by other kind of agents with other priorities, such as agents selecting the higher TTR in order to stay in the EA as long as possible.

It should be noticed that when any member of the triage personnel, doctor, or rescue team returns to the ECC, the MA in the corresponding TD or RTD will have a low TTR value. In a normal operation in a wireless MANET, they may find other devices with higher TTRs. Thus, so during this return trip a number of ETTMAs will be received to be transported to the ECCD. When TDs or RTDs arrive to the ECC, they detect the ECCD and notify ETTMAs in their platforms in order to allow them to move.

3.5. Operation

In the mass casualties scenarios previously described a predefined set of actions are followed, by the different participating actors. Using the MAETTS does not implies to substantially modify these actions, but improve and speed them.

Below there is a description of the traditional actions and actors involved in an emergency scenario. Moreover, we provide a comparison between their behavior in a traditional scenario and with our innovative system, comprising from the victim identification to the rescue transportation of the victims.

The first event is the incident itself. The result of which is a number of victims, scattered around the EA. At this stage, no medical action is taken, and it is therefore out of the scope of our proposal.

3.5.1. Victim identification

In traditional emergencies, the barcode and identifier printed on the paper triage tag is used to uniquely identify victims and to facilitate presencial tracking.

For the victim identification, we propose instead the use of RFID technology through a RFID tag attached to a paper triage tag with the same identifier number printed on it, for fault-tolerance purposes.

The identifier is read approaching the handheld device and the RFID reader in the vest to the paper triage tag (including the RFID tag) assigned to the victim. In the triage phase, the read identification is automatically assigned to a new ETTMA. In all the other cases, such as when the victim is collected by the rescue teams, the RFID tag is also read. The display in the computer system in the ambulance may automatically show the information in the associated ETTMA. Afterwards, when the victim reaches the field hospital or the hospital, the RFID is also read by a RFID reader at the entrance, and the ETTMA, that is inside the medical transportation device, moves to the hospital system platform, where the victim information can be eventually integrated in an existing virtual patient record system.

3.5.2. Triage

The first medical action taken during emergency situations is the triage. Triage personnel look for victims and approach them. Immediately, they triage these victims, evaluating a few vital signs in a simple, fast, and predetermined way. Once evaluated, an injury level is assigned to the victim, together with the associated color in the paper triage tag. At the same time, the victim's medical values obtained during the evaluation can also be written on this triage tag.

For the management of the information in the initial triage of the victims, we propose the use of a CA running on a handheld TD, able to create ETTMAs to store victim's information. Triage and medical personnel are provided with reflectance vests that integrate a handheld device which is equipped with a touch screen, a GPS receiver, and a RFID reader.

When triage personnel reach a victim, they create a new ETTMA in their TD, and label the victim with a physical paper triage tag with a RFID tag that is placed in the neck or wrist. The triage personnel measure the victim's vital signs, evaluate the state, and introduce the triage information in the newly created ETTMA by means of the TD touch screen. Then, ETTMA suggests an injury level to the triage personnel. The color associated with the injury level is also selected in the paper triage tag. If the victim can pronounce his name or some identification documentation is found, this information is also incorporated into the ETTMA (if the triage personnel have enough time).

3.5.3. *Initial medical stabilization treatment*

After the triage, doctors provide each victim with the required emergency care in order to stabilize them before he can be rescued. All the medication and treatment administered during this phase can be written in the paper triage tag.

In our proposal, this information is entered and stored by the ETTMA, which represents this victim, by means of the user interface in the MA.

3.5.4. *Victim localization*

In order to facilitate rescue teams to find the victims, localization information may be used in traditional solutions. They require additional GPS hardware and communication mechanisms to get and transmit the information.

We also propose the use of GPS technology for the victim localization, but directly integrated into the MAETTS devices. When the ETTMA is created, it automatically retrieves its geographic position through the GPS and stores it together with a timestamp. Later, at periodical intervals, the location information with the corresponding timestamp is added to the ETTMA.

Nonetheless, there are special situations in which no GPS signal is available. In these situations, localization information can be introduced in three different ways. The first option is introducing text location information by hand. This is a very useful feature to locate inaccessible ravines for the triage personnel. The second one is done pointing the position where the victim is at a map interface in the handheld device. The third one is done automatically; when an ETTMA is submitted and there is no GPS coverage, the time since the coverage was lost and the last GPS position known is stored inside the agent. Thus, it is possible to estimate a location of the victim using the time of the last known GPS position.

3.5.5. *Medical information routing*

Traditionally, once the victim has been triaged, the triage and medical information is written on the simple paper triage tag and sent together with the victim. In some cases, and only if an infrastructure for voice or data communication is available (e.g. telephone, the TETRA system Dunlop et al., 1999), some medical information can be sent in advance, but in most of these cases information is not automatically sent or tracked, and it requires some human active participation.

In our proposal, the information is routed by the automatic and asynchronous mobility features provided by ETTMAs. The triage information of the victim is stored in an ETTMA, which moves from device to device deciding its route by itself.

The main advantage of using mobile agents for this purpose is that the communication with the final destination may be asynchronous, i.e., no direct connection is required. ETTMAs always jump to the neighbor device most likely to reach the MANET where the ECCD is. Once the ETTMA is in that network, it may jump to the final destination device.

3.5.6. *Emergency coordination*

The coordination and management of the different actors in an emergency is traditionally done from an ECC. In each emergency there is usually at least one ECC, and it is usually in, or near to, the field hospital. This center is in charge of the distribution of rescue teams, the hospital allocation when needed, the medical supplies distribution, and the actors communication.

The ECCD is the device in charge of the emergency coordination in our proposal. It is the initial destination of the ETTMAs and includes a MA and a CA. The MA provides the general management of the agents and the user interface, while the CA is in charge of the specific coordination of the emergency, including the creation and assignment of routes for the rescue teams, according to the medical status of the victims associated to the ETTMAs present in the ECCD.

When an ETTMA reaches the ECCD, it announces its presence and remains there making the victim information available to the CA and MA. When a rescue team arrives to the ECC, it also announces its presence to the CA in the ECCD. The CA creates a new rescue route, according to the ETTMAs existing at that moment in the system, and sends it to the RTD. At the same time, the ETTMAs of the victims to be transported are also requested to move to the same device. Once the ETTMAs have moved to the designated RTD, the team leaves to the EA to pick up the victims.

3.5.7. *Transportation*

After the initial triage and medical stabilization, victims must be transported out of the Emergency Area. In traditional solutions, medical personnel may request for a rescue team to perform the transportation. This request can be optional, for rescue teams may be proactive and they may look for triaged victims by they own initiative. In any case, these teams arrive to the emergency zone and look for the victims. They reach, rescue, and transport them to a normal or a field hospital.

In our proposal, the transportation of victims is provided by traditional rescue teams with the help of the route created by the ECCD, using GPS information from the ETTMA, together with the medical information also provided by the ETTMA.

Rescue teams arrive to the EA using the location information in the route. They easily find the victim and, through the ETTMA, they obtain their medical status. When the victim is collected by the rescue team the RFID tag, stucked in the paper triage tag, is read. Since the associated MAETT is already in the RTD, information of the victim triage tag may be instantly displayed and new information may be introduced. Additionally, agents representing the victims, or clones of them, arrive at the ECC, field hospital, or hospital in advance to the victims themselves and may make an early reservation of resources.

4. Implementation

MAETTS has been implemented as a proof of concept, showing that it is a valid innovative mechanism for mass casualties situations. The implementation follows the generic system proposed in the previous section, with the addition of specific details regarding the platform hardware and software described ini the next paragraphs.

4.1. System platform

The election of the hardware to implement the system was a tricky issue. After a thorough research, we decided to use handheld devices for the TD, and personal computers for the ECCD and the RTD. The main requirement for all devices in the system was the possibility to run a Java Standard Edition Virtual Machine (JAVA SE VM) able to support a mobile agent platform. For the handheld TD, an integrated touch screen, wireless Ethernet, Bluetooth and GPS were also required.

The handheld TD selected for the proof of concept is the Nokia N810, which was selected for its Linux-based Maemo/OS2008 operating system (Maemo Community) that supports all the requirements previously mentioned. The ECCD and the RTD are standard and portable personal computers, respectively. Bluetooth (Haartsen, 2000) and IEEE 802.11 is supported by all the devices of the system, while the ECCD also supports Ethernet wired network. The bluetooth "ID Blue" (Baracoda) pen RFID reader has been selected for all the devices. Finally, the Smart Rapid Aid & Treatment (R.A.T.) Pack (TSG Associates) pocket-based bandolier is used to carry all the hardware needed by the triage personnel and doctors.

A more detailed description of the components implemented in MAETTS (see Fig. 3) can be found in the next sections.

4.2. MAETTS software

Regarding software used in our implementation, MAETTS requires a mobile agent execution platform. We have selected the Java-based JADE (Java Agent DEvelopment Framework) (Caire, 2004), mainly due to its wide spread usage, its compliance with the IEEE-FIPA standards, and its extended mobility services (Cucurull). This platform has been installed in all the handheld devices and computers of the system. For the TD, since there are few Java Virtual Machines running on top of Maemo/OS2008 (Maemo Community), the operating system of the Nokia N810. We selected the Jalimo JVM (Jalimo project) for our purposes. For the ECCD and TD, Sun Java Runtime Environment (available for Windows and Linux operating systems) has been used. Regarding the user interface, it takes advantage of the Java open source widget toolkit SWT (Standard Widget Toolkit) (Northover and Wilson, 2004.) For the discovery of accessible devices in the MANET, and for the routing of mobile agents, the Optimized Link State Routing protocol Daemon (Tønnesen) has been used (see more details in Section 4.4).

Fig. 3. Nokia N810 handheld device and ID Blue RFID reader components used in the implementation of MAETTS.

Regarding the agents (CA, ETTMA, and MA), they have been implemented providing the functionality described in Section 3.3. Concerning the presence of these agents in the different hardware devices, the TD and RTD have been provided with a MA and the ETTMAs corresponding to the victims. The ECCD device has also been provided with a CA, a MA, and the ETTMAs.

4.3. User interface

The design of the user interface of the CA has been done according to two main objectives. The first one is usability, in the handheld device, with a small touch screen used as input mechanism, as well as in the personal computers. The second one is similarity with the existing paper triage tags, aiming to minimize the learning curve of its users, and taking advantage of its maturity. The implementation of its user interface has been done using SWT because it is one of the few graphical toolkits supported by Jalimo project Java.

The MAETTS interface eases the user access to the user functionality, which is described below (Fig. 4).

- *ETTMA creation and hand-made or wizard-based filling*: The user interface allows to create an ETTMA and fill it in through an automatic wizard (see Fig. 5), or manually through a user interface (see Fig. 6). Using the medical data introduced by the triage personnel, it also provides an automatic proposal for the color associated with the injury level of the victim.
- *ETTMA listing*: The interface is also able to display a list with all the agents in the platform together with basic information about them. To act as the interface for the RTD route list, it includes an option to sort it based on the localization information.
- *TTR manager*: The setup and real-time visualization of the remaining TTR is also provided by the MA user interface.
- *User information management*: The user interface allows the introduction and management of personal information of the members of the personnel using the handheld device or the computer.

4.4. Ad hoc network routing

Routing protocols are used to allow devices in the same MANET to discover other devices at more than one link of distance, to act as routers, and to provide the best route to send information to any device in the network.

Among the existing implementations of the two main wireless ad hoc network routing protocols (AODV, Perkins et al., 2003; OLSR, Clausen and Jacquet, 2003), we selected the Optimized Link State Routing protocol Daemon (Tønnesen) because it can run on any wireless Ethernet card supporting the ad hoc mode as well as on any device with wired Ethernet, and supports for all the devices in the system is provided. Moreover, its efficient implementation and low CPU requirements make it very suitable for portable devices.

It must be noted that although at this moment we are using OLSR and the OLSR Daemon, the proposal is open to any existing or future routing protocol, like the draft IEEE 802.11 s ESS Extended Service Set Mesh Networking, and implementation.

5. Discussion

The emergency system based on ETTMAs presents a set of advantages with respect to the traditionally used technologies and

Fig. 4. Screenshots of the user interface of the MA in the TD for the different features supported.

Fig. 5. Screenshots of the user interface of the triage wizard of the MA in the TD.

the existing emergency systems. The following sections discuss the feasibility of our system and its security features.

5.1. Feasibility

The feasibility of the proposed solution and its implementation regarding wireless communications range, power limitations, ETTMA routing decision algorithms, and GPS coverage aspects are discussed in the lines below.

5.1.1. Wireless communications range

A drawback of wireless communication technologies is that the signal level in the communications link is greatly affected by the presence of obstacles between the connecting devices, so the effective range decreases. Moreover, according to the noisy-channel coding theorem, also known as Shannon (1949) theorem, for a given channel (in our case, a data link) the signal-to-noise ratio limits the maximum transfer speed.

IEEE 802.11, the wireless communication protocol used in our implementation, supports different link speeds up to 11 Mb/s in IEEE 802.11 b and 54 Mb/s in IEEE 802.11 g. Moreover, since this wireless technology is also affected by the presence of obstacles, for a given link speed indoors range is smaller than outdoors. From the different links speeds supported by the standard, devices always use the fastest one that provides reliable communication at the given range. Fig. 7, with data extracted from (www.kioskea.net), shows the estimated range for the different link speeds supported by IEEE 802.11 b and IEEE 802.11 g standards, both for indoors and outdoors.

Due to the Medium Access Control (MAC) mechanism used in IEEE 802.11, and because the link is shared between different devices, effective data transfer can never reach the full link speed. A usual practical estimate of the maximum effective data transfer speed value, also known as throughput, is around 55% of the link speed.

We have done a set of tests using the implemented platform, which only supports IEEE 802.11 ad hoc networks at a maximum speed of 11 Mb/s. We have observed an approximate 100 m

Fig. 6. Screenshots of the electronic triage tag user interface of the MA in the TD.

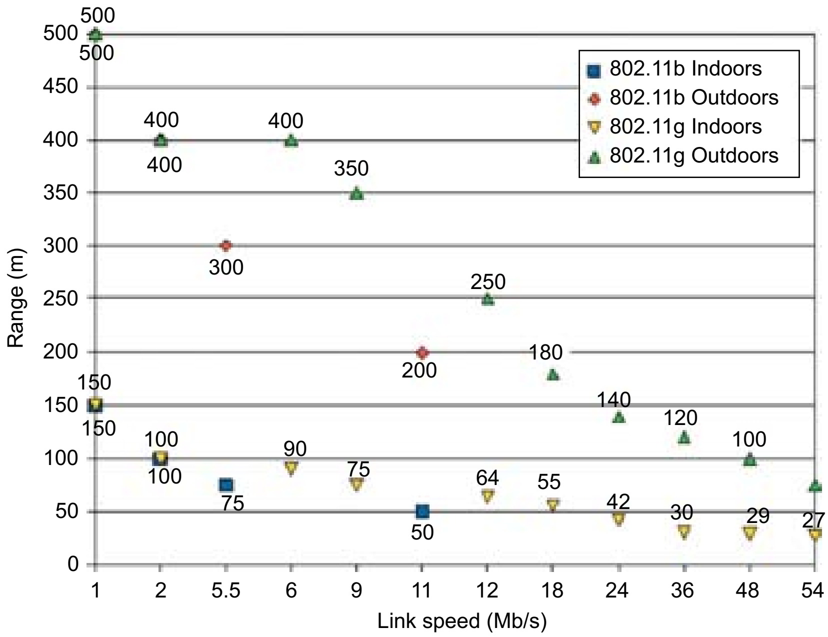

Fig. 7. IEEE 802.11b and IEEE 802.11g range and link speeds.

outdoors range with direct visibility and 50 m indoors range. It must be noticed that apart from the migration time of each ETTMA, an initial time must be considered to connect with neighbor devices in the MANET, detect if a MAETTS CA is running on them and, finally, interchange their TTR values and provide them to the ETTMA in the platform.

In these tests, the time required for an ETTMA to migrate from one platform to another has been measured. Note that ETTMAs only include the victim's data, since the user interface is provided by the MA. Moreover, when moving to the same platform, the second and following migrations will require a smaller migration time since they will seize on code cache and, depending on the implementation, also from Java optimization mechanisms. Bearing this in mind and considering a 2 m separation between devices, so with the maximum link speed of 11 Mb/s, and an effective throughput around 6 Mb/s, the migration of an ETTMA requires about 7 s for the first migrating agent, and 3 s for the following ones.

With the previous range figures, two handheld devices separated by 100 m approaching each other and then going away at an average running speed of 6 km/h, have 2 min of visibility at data link level that must be used to detect each other, connect, interchange data, and migrate the ETTMA. This time can be higher if the speed is reduced, e.g., a typical walking speed of 4 km/h, or if the real range provided by the specific IEEE 802.11 network cards is higher than 100 m. However, the time may also be reduced if the devices never physically meet, or if the actual range is smaller, as it can be seen in Table 1.

5.1.2. Power limitations

Handheld devices have a limited battery capacity, especially when wireless communications are used, due to its additional

Table 1
Data link visibility time (min:s) for a given device separation, approaching and going away, at 4 and 6 km/h walking speed.

Separation (m)	4 km/h	6 km/h
50 (both moving)	0:45	0:30
100 (both moving)	1:30	1:00
50 (one moving)	1:30	1:00
100 (one moving)	3:00	2:00

power requirements. As a consequence, the selection of a good strategy to optimize data interchanges is a really important issue.

5.1.3. ETTMA routing decision algorithms

In our proposal, the routing decision is made at the application level. The algorithm used in our proposal is based on the estimated time of arrival to an ECC (TTR). The ETTMA uses this heuristic value to intelligently reach the ECCD.

It must be noticed that the proposal is not bound to a particular routing decision algorithm, and any algorithm could be used at the application level. Notice that the algorithm itself is implemented inside the agent, and that the CA in each platform may provide the required information for making the decision. Alternative application routing decision algorithms can be proposed to improve the arrival time of the agent to the ECCD or to minimize the power consumption. With our proposal, the use of different strategies, like keeping the agent as much as possible in the EA, is also possible.

5.1.4. GPS coverage

Another issue to be considered in the discussion of the proposal is the fact that GPS technology is only usable in outdoor environments, where GPS receivers have direct, or almost direct, view of emitting satellites. GPS devices with better sensibility, and even with motion detection, allow a better management of situations where coverage is weak or almost inexistent. Once again, the system has been specified in an open way so new localization technologies can be easily integrated into ETTMAs when available.

5.2. Security

Mobile agents, and in general all kind of agents, are exposed to security threats from the platform they reside, from other agents in the platform, and from external entities. ETTMAs carry sensitive data, which integrity and anonymity should be preserved. Security mechanisms are therefore to be taken into account.

In our proof of concept system no security was provided for the kind of results we were looking for, but mobile agent security mechanism such as Self Protected Mobile Agents (Ametller et al., 2004) can be easily integrated in real applications.

Another issue to be discussed is the tolerance to errors and failures. At this moment, the implemented proof of concept system assumes agents always reach the CA in the ECCD, and they never die before arriving there. In a real situation, battery or communication problems may arise so the agent could "die" inside a device before reaching the CA.

Mechanisms for mobile agent fault tolerance (Silva et al., 2000) also exist. However, most of them are based on infrastructure networks with permanent connection. In ETTMA, fault-tolerance mechanisms can be added only if their protocols are compliant with MANET networks.

5.3. Performance evaluation

In this section we aim to evaluate the proposal in terms of performance. Due to the large number of variables involved in this calculation, we have reckoned an estimation of the performance by means of simulations.

The model used in the simulation was designed to obtain performance results that were independent of the size of the area, so they would apply to any emergency scenario regardless of its perimeter. The simulation model consists of a 1 km^2 area EA with one ECCD, partitioned into 50 m-sided hexagonal cells (100 m wide), each one surrounded by other six. At the beginning, the devices are randomly distributed among the cells, and they are assigned a TTR in the range [0 ... TTRmax] following an equiprobable random distribution (a zero TTR meaning that they are currently in the ECC). Every time step (time unit) the devices can either move to an adjacent cell or do not move at all, decreasing their current TTR. A MAETT is randomly placed in one of the devices, representing the triage of a victim. This MAETT will move to other accessible devices depending on whether they have a lower TTR.

Four simulations have been computed for different TTRmax: 30, 60, 90, and 120 time units. The simulations' results can be seen in Fig. 8. It shows how much time in average is required by the MAETT to arrive to the ECCD, depending on the density of devices.

There are some interesting conclusions drawn from the simulation's results. The number of time units required to reach the ECCD fall considerably when the density of devices in the EA increases. The reason for this is that as the number of devices rises there is more probability of finding a device with a better TTR.

It must be noticed that when there is only one device the average value is TTRmax/2 for a given TTRmax, which is exactly the same result we have in the traditional non-electronic approaches. The higher TTRmax, the better improvement of time to reach the ECCD. It can also be seen that the time needed to reach the ECCD significantly drops and then tends to flatten out to a theoretical zero. The explanation of this is that when there are devices in all the cells it is an equivalent situation of having a fully connected network. All in all, it would be as having an infrastructure enabling an end-to-end communication from the device hosting the MAETT to the ECCD, with the advantage of not needing the deployment of an infrastructure.

To put the whole matter in a nutshell, it can be said that the use of routing decisions based on TTR provides a clear improvement in the time of arrival of the triage information to the ECCD with respect to the traditional non-electronic approaches.

6. Existing emergency systems

From the Information Technology point of view, there are several systems dealing with different aspects of emergency situations, ranging from medical information management, electronic triage, victims data record and other approaches. The next sections provide a brief description of the most relevant systems, together with a final comparison with our proposal. Furthermore, Table 2 provides a summary of the main features of these systems for emergency situations, allowing a fast comparison.

6.1. Medical information management systems

Some existing systems are focused on the management of medical information. A brief description of some of them is presented.

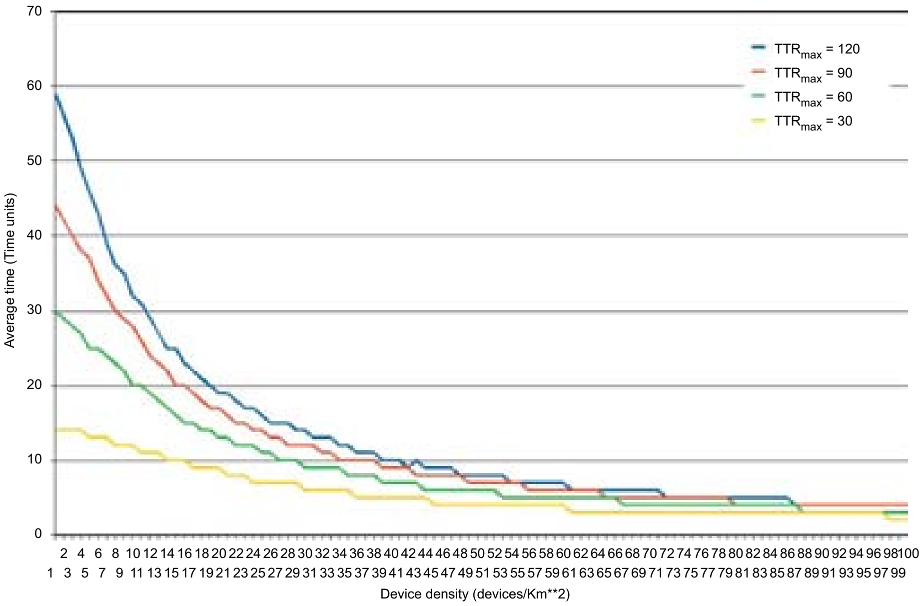

Fig. 8. Time to reach the ECCD using routing decision based on TTR.

Table 2
Emergency systems features comparison, separated following distribution in Section 6.

	Medical information management			Electronic triage				Victims Data Record			Other approaches		MAETTS
	AMBULANCE	EMERGENCY-112	DITIS	WIISARD	ARTEMIS	TacMedCS	The Decent. ETS	CodeBlue	EMTrack	Trac. Syst.	IMPROVISA	MASCAL	MAETTS
Electronic medical information management support	o	o	o	o						o		o	o
Electronic medical information transmission support	o	o	o	o	o	o	o	o	o	o		o	o
Electronic triage support				o	o	o	o						o
Wireless communications support, including MANET				o	o	o		o	o			o	o
Agents usage			o		o					o	o		o
Mobile agents usage			o		o					o	o		o
Communications deployment support											o		
Personal Data Assistants usage				o	o	o			o	o			o
Bar Code identification usage									o	o			
Radio Frequency Identification usage				o				o	o				o
Global Positioning System usage													o

6.1.1. AMBULANCE

AMBULANCE (EU-98) (Pavlopoulos et al., 1998) is a research project funded by the European Commission. Its objective was the creation of a mobile unit device for the transmission of critical vital biosignals and still images of the victims to an emergency call center from the emergency site to the consultation site using GSM, satellite, or fixed networks.

6.1.2. EMERGENCY-112

The EMERGENCY-112 (National Technical University of Athens) project is based on AMBULANCE. It is focused on the creation of an industrial prototype of an integrated emergency telemedicine system. Mobile units or ambulance stations were improved and integrated as clients of hospital server base stations.

6.1.3. DITIS, Networked Collaboration supporting Home Healthcare Teams

DITIS, Networked Collaboration supporting Home Healthcare Teams (CY-06) (Pitsillides et al., 1999), is a Cyprus research project that provides an Internet web-based group collaboration system supporting virtual collaborative medical teams for the continuous treatment of patients with chronic diseases at home and at specialist healthcare centers. From the technical point of view, it is an approach based on mobile agents that takes advantage of GPRS/GSM/WAP connectivity, and web databases with Java connectivity for storage and processing of information, including Electronic Medical Record (EMR) and coding of diagnosis and health care protocols.

6.1.4. WIISARD

WIISARD, Wireless Internet Information System for Medical Response in Disasters (Lenert et al., 2006), is a US federally funded research project at the University of California, San Diego (UCSD). From the medical information management point of view, its objective is being an integrated application that brings wireless Internet technologies from the hospital to the field treatment station. It is based on the use of wireless technology for the coordination of emergencies, providing support for real-time tracking and monitoring of the victim's condition. Moreover, it also supports technologies for the communication of the emergency teams.

6.2. Electronic triage systems

Other projects are centered in developing different types of electronic triage tag systems for emergencies. A brief description of some of them is presented following.

6.2.1. ARTEMIS

ARTEMIS (McGrath et al., 2003) is a research project sponsored in part by the US Army's Communications and Electronics Command Division. Its aim is the development of an automated remote triage and emergency management information integrated system, able to monitor victims information through sensors in a PDA, and to transmit this information to the medical services using agents that move through a reliable messaging layer in wireless ad hoc networks.

6.2.2. TacMedCS

TacMedCS, Tactical Medical Coordination System (US Navy), is a military U.S. Navy System to capture and display real-time casualty data in the field. It is based on the use of radio frequency hardware tags to identify victims and store casualty data.

A handheld unit also stores this casualty data, as well as the positioning information from the built-in GPS, and sends all the information to the central server database through its satellite (Iridium) communication facilities. Triage and Medical Information is transported with the victim in the hardware intelligent ID tag. In the central server, visual graphical user interface provide enhanced real-time situational awareness. Moreover IEEE 802.11 mesh communications can be established between the different handheld units for their collaboration.

6.2.3. The Decentralized Electronic Triage System

The Decentralized Electronic Triage System (Massey et al., 2006) is part of The Advanced Health and Disaster Aid Network (AID-N) project. It is an ultra-low power embedded hardware electronic triage tag, based on the visualization of the victim's status through colored LEDs. It also supports the gathering of vital signals through sensors, based on an extension of the CodeBlue project.

6.2.4. WIISARD Intelligent Triage Tag (ITT)

The WIISARD architecture, also includes Electronic Triage facilities through the *Wireless First Responder Handheld Device for Rapid Triage, Patient Assessment and Documentation during Mass Casualty Incidents* (Killeen et al., 2006), a Personal Digital Assistant (PDA) with non-volatile memory and IEEE 802.11 wireless transmission capabilities. Two components form this device:

- *An Intelligent 802.11 Triage Tag For Medical Response to Disasters* (Lenert et al., 2005). It is the "Intelligent Triage Tag" functionality in the PDA-based system. As a triage tag, it includes victim triage status and recording of medical data for later use, but it also provides signal alerts and support for marking patients for transport or immediate attention. All of these features are complemented with the Electronic Medical Records functionalities of the WIISARD First Responder (WFR) described below.
- *WIISARD First Responder* (Killeen et al., 2006). Its functionality is the support for EMR, together with the real-time recording of medical information in a PDA-based hardware with IEEE 802.11 wireless communications. It is complemented, in the same PDA, by the Intelligent IEEE 802.11 Triage Tag.

6.3. Victims Data Record Systems

Other systems are focused on recording victim data and sending and retrieving this data through remote communications. Some of them are described below.

6.3.1. CodeBlue

The CodeBlue system (Shnayder et al., 2005) is centered around the use of wireless sensors in emergencies. It is a project supported by the National Science Foundation, National Institutes of Health and U.S. Army among other participants. This is a combined hardware and software platform for medical wireless sensor networks that provides protocols for device discovery, publish/subscribe multihop routing, and a simple query interface. In addition to monitoring patient vital signs, it also integrates an RF-based localization system to track the location of patients and caregivers.

6.3.2. EMTrack

The EMTrack emergency system (EMSystems) is a product from EMSystem, which aims the electronic patient tracking for all-scale emergencies. It is an internet-based patient tracking application, with PDA mobile data collection units (using RFID or barcode) on a wireless, cellular (IEEE 802.11), or satellite networking system. It supports the tracking of victims during triage, treatment, and transport. A central server with a Web Services interface is provided to access stored data.

6.3.3. Traceability System for Sick and Injured in Event of Major Disasters

The Traceability System for Sick and Injured in Event of Major Disasters (Dai Nippon Printing Co. Ltd.,) is a project jointly developed by DNP, Fuji Tokoha U., and Catena Corp. This system uses triage tags that are designed to be compatible with digital pens with a mini-camera mounted on them that record the hand written patient data. A two-dimensional barcode is pre-printed on the triage tag. Additionally the system provides access, via a dedicated web site, to all patient data accumulated in the server.

6.3.4. Victims Data Record Systems Comparison

In these systems based on hardware for victims record, no ad hoc networking support exists for emergency cases with no communication infrastructure, and, as in the previous cases, the asynchronous communication and code mobility, autonomy, proactivity, or reactivity mechanisms provided by mobile agents are not supported.

6.4. Other approaches to emergencies

Other approaches to emergencies include systems focused on communication deployment or resource tracking. The description of some of them is done following.

6.4.1. IMPROVISA

IMPROVISA, Minimalist Infrastructure for service PROVISioning in Ad-hoc networks (Velasco et al., 2006) focuses on the communication aspects in emergency situations. It is a Spanish founded research project. Its research is mainly centered in Mobile Ad hoc Networks (MANETs) for emergency situations, where heterogeneous, autonomous, and self-organizing mobile nodes are interconnected through wireless technologies. In this field, it provides practical ad hoc networking, secure frameworks, improved multimedia delivery, service-oriented computing, and agent platforms that enable the deployment of context-aware networked information systems and decision support tools in the target scenario. In this project, intelligent agents technology is used to manage the ad hoc network.

6.4.2. MASCAL

MASCAL (Fry and Lenert, 2005) is a system focused on tracking resources. It is a system partially supported by the Department of the Navy, Automated Identification Technologies Office and the National Library of Medicine. It is an integrated hardware–software system designed to enhance the management of resources in hospitals during a mass casualty situation, tracking patients, staff, and equipment using the IEEE 802.11 wireless communications technology inside hospitals. It integrates the TACMEDCS triage application, which also takes advantage of IEEE 802.11 communications, providing a visual management environment, supporting different views for hospital command center, local area managers (emergency room, operating suites, radiology, and so on) or registration personnel.

6.5. Comparison of Existing Systems with MAETTS

In this section, we briefly compare the different existing emergency systems with the proposed MAETTS.

6.5.1. Comparison with Medical Information Management Systems

These projects provide electronic management and transmission of the victim's medical information, but do not provide all together, like MAETTS does, electronic triage facility (except from WIISARD); the asynchronous communication and code mobility, autonomy, proactivity and reactivity supported by mobile agents (except from DITIS); or the identification facilities of RFID technology.

6.5.2. Comparison with Electronic Triage Systems

These projects are focused on the use of electronic devices as triage tags in the EA, using RFID technology for victim identification. However, compared to our proposal based on mobile agents, they do not provide asynchronous communication and code mobility, autonomy, proactivity, or reactivity mechanisms.

6.5.3. Comparison with other approaches to emergencies

Compared to MAETTS, projects centered on providing communications in emergency situations, they do no care about the information sent through them. In the case of IMPROVISA, the use of intelligent agents without mobility is limited to the management of the ad hoc network.

Regarding systems focused on tracking resources are not meant to be used in the Emergency Area, since it lacks the features required in these situations.

6.5.4. Comparison conclusion

In conclusion, it can be said that none of the existing systems combine altogether the facilities provided by MAETTS in a single system. These features are victims data storage and asynchronous communication, code mobility, autonomy, proactivity, reactivity supported by mobile agents, remote identification technology through RFID, and location facilities offered by GPS.

7. Conclusions

In this paper we have introduced a triage system based on mobile agents which is intended to be used in emergency situations. The rationale behind the proposal is a MANET of handheld devices, which are carried by the triage personnel and doctors, and a set of mobile agents, the cornerstone of the system. When a victim is classified, their information is borne by a mobile agent which hops from one handheld device to the other within the MANET until it eventually reaches a base of operations. RFID tags are used to uniquely identify the victims, and their geographical position is retrieved using GPS.

One of the main advantages of this scheme is that it does not require any network infrastructure whatsoever, in opposition to many similar proposals in the literature. The reliable transportation of the information is totally asynchronous, and therefore a permanent connection with all devices of the system is not required. In the worst case scenario, a temporal link between two devices is enough to safely transmit mobile agents. Once the agent has moved to the next device, the application is freed. In a MANET, even when the network layer information units are transported asynchronously, reliable connections require both ends of the communication to be simultaneously active. This is a strong requirement for most emergencies aftermaths.

The triage information, obtained in the EA, is quickly made available to the base of operations, even when it is not possible to establish a direct connection from this location, and before the triage personnel physically arrives there. With all of this information, an early resource allocation can be made in the base of operation, contributing to drop off the number of casualties.

The system is fully compatible with more traditional methods of victim triage, since traditional colored tags are still used. This allows coexistence with other systems and, therefore, a progressive deployment that facilitates its adoption. This is also useful for certain situations in which electronics are forbidden, such as if remotely activated bombs are suspected.

The routing protocol and the strategy used by mobile agents in the paper, as well as other details such as the graphical interfaces, are just proposals. They can be replaced at any time, or even coexist with different protocols, strategies, or interfaces. This is a direct advantage of using mobile agent technology, where the code of the system is not static in the devices, but is carried by the very agents. Introducing changes is as easy as sending a different version of the agent. The lightweight execution environment in the devices, namely platform, is very simple and is not expected to be changed except for bug fixing. Thus, mobile agents provide to the triage system with a dynamic way for the deployment of software updates and the introduction of new protocols, strategies, or interfaces which might have been devised even during the emergency.

One of the most salient points of the proposed system is the improvement on triage information transportation with respect to other proposals, which is due to the autonomy, reactivity, and proactivity of the mobile agents involved. But on the other hand, this paper also makes an important contribution to the design of flexible, modular, low-budget emergency systems, which can be easily adapted to different scenarios and integrated with other systems.

7.1. Future work

The proposal presented in this paper is focused on the emergency scene, but the triage information and other personal data could be used by other applications outside the hot spot. Future work includes the interchange of information with other systems, such as virtual electronic patient records, or hospital resource managers, in order to take advantage of the synergies with them. Information on allergies or infectious diseases obtained from the patient record, for instance, could be of interest in case of urgent surgery required in the emergency scene.

Finally, another step in future work to be considered is the study of application level routing protocols even more suited to emergency scenarios and its implementation and performance evaluation.

8. Acronyms

CA	Coordination Agent
EA	Emergency Area
ECC	Emergency Coordination Center
ECCD	Emergency Coordination Center Device
EMR	Electronic Medical Record
ETTMA	Electronic Triage Tag Mobile Agents
MA	Manager Agent
MAETTS	Mobile Agent Electronic Triage Tag System
MCI	Mass Casualty Incident
RTD	Rescue Team Device
TD	Triage Device
TTR	Time To Return

Acknowledgments

This work has been partially funded by the Spanish Government project TSI2006-03481.

We also want acknowledge Mr. Xavier Jurado for his contribution to the implementation of parts of the system.

References

Ametller J, Robles S, Ortega-Ruiz JA. Self-protected mobile agents. In: AAMAS '04: proceedings of the third international joint conference on autonomous agents and multiagent systems. Washington, DC, USA: IEEE Computer Society; 2004. p. 362–7.

Baracoda. IDBlue—an efficient way to add RFID reader/encoder to Bluetooth PDA and mobile phones ⟨http://www.baracoda.com/baracoda/products/p_21.html⟩.

Bellifemine FL, Caire G, Greenwood D. Developing multi-agent systems with JADE. New York: Wiley; 2006.

Caire G. JADE: the new kernel and last developments. Technical Report, Telecom Italia; 2004 ⟨http://jade.tilab.com/papers/Jade-the-services-architecture.pdf⟩.

Chen B, Linz DD, Cheng HH. XML-based agent communication, migration and computation in mobile agent systems. Journal of Systems and Software 2008;91(9):1364–76.

Clausen T, Jacquet P. RFC 3626—Optimized Link State Routing Protocol (OLSR); 2003.

Cucurull J. JADE Inter-Platform Mobility Service ⟨http://jipms.sourceforge.net⟩.

Cucurull J, Martí R, Robles S, Borrell J, Navarro G. FIPA-based interoperable agent mobility. In: CEEMAS07. Lecture notes in computer science, Springer, Berlin. New York: Academic Press; 2007a.

Cucurull J, Overeinder BJ, Oey MA, Borrell J, Brazier FMT. Abstract software migration architecture towards agent middleware interoperability. In: Proceedings of the international multiconference on computer science and information technology, Wisla, Poland, 2007b. p. 27–37.

CWC-services, Cruciform Tag, CWC-services, Triage Systems, UK.

Dai Nippon Printing Co. Ltd. (DNP), T. Komura, Catena Corporation, Traceability System for Sick and Injured, Dai Nippon Printing Co. Ltd. (DNP); Fuji Tokoha University, Shizuoka city; Catena Corporation.

Dilmaghani RB, Rao RR. A reliable wireless mesh infrastructure deployment at crisis site. In: IPCCC. IEEE Computer Society; 2007. p. 579–81 ⟨http://dblp.uni-trier.de/db/conf/ipccc/ipccc2007.html#DilmaghaniR07⟩.

Dunlop J, Girma D, Irvine J. Digital mobile communications and the TETRA system. New York: Wiley; 1999.

EMSystems, LLC. EMTrack patient and evacuee tracking system. EMSystems, LLC, USA.

FIPA, Foundation of Intelligent Physical Agents (FIPA) ⟨http://www.fipa.org/⟩.

Fry EA, Lenert L. Mascal: Rfid tracking of patients staff and equipment to enhance hospital response to mass casualty events. In: AMIA Annual Symposium Proceedings; 2005. p. 261–5.

Gao JZ, Prakash L, Jagatesan R. Understanding 2d-barcode technology and applications in m-commerce—design and implementation of a 2d barcode processing solution. In: COMPSAC '07: proceedings of the 31st annual international computer software and applications conference (COMPSAC 2007), vol. 2. Washington, DC, USA: IEEE Computer Society; 2007. p. 49–56.

Haartsen J. The bluetooth radio system. Personal Communications, IEEE 2000;7(1):28–36 [see also IEEE Wireless Communications].

Hendler J, editor in chief. Special issue: intelligent agents in healthcare. IEEE Intelligent Systems 2006;21(6).

Inoue S, Sonoda A, Oka K, Fujisaki S. Emergency healthcare support: RFID based massive injured people management. In: Proceedings of the pervasive healthcare workshop in Ubicomp 2006 (UbiHealth), 2006, p. 9.

Jalimo project. Jalimo ⟨http://wiki.evolvis.org/jalimo/index.php/Main_Page⟩.

Killeen JP, Chan TC, Buono C, Griswold WG, Lenert LA. A wireless first responder handheld device for rapid triage, patient assessment and documentation during mass casualty incidents. In: AMIA annual symposium proceedings; 2006. p. 429–33.

Lange DB, Mitsuru O. Programming and deploying java mobile agents aglets. Boston, MA, USA: Addison-Wesley Longman Publishing Co, Inc.; 1998.

Lenert L, Palmar D, Chan T, Rao R. An intelligent 802.11 triage tag for medical response to disasters. In: AMIA annual symposium proceedings; 2005. p. 440–4.

Lenert L, Chan TC, Griswold W, Killeen J, Palmer D, Kirsh D, et al. Wireless internet information system for medical response in disasters (WIISARD). In: AMIA annual symposium proceedings; 2006. p. 429–33.

Mackway-Jones K, editor. M.T. Group, emergency triage; Manchester triage group. 2nd ed., Wiley, Incorporated, New York, 2006.

Maemo Community. Maemo software platform ⟨http://maemo.org/⟩.

Massey T, Gao T, Welsh M, Sharp JH, Sarrafzadeh M. The design of a decentralized electronic triage system. In: AMIA annual symposium proceedings; 2006. p. 544–8.

McGrath S, Grigg E, Wendelken S, Blike G, Rosa MD, Fiske A, et al. ARTEMIS: a vision for remote triage and emergency management information integration. Dartmouth University; 2003. Available at: ⟨http://www.ists.dartmouth.edu/library/15.pdf⟩

METTag, Medical Emergency Triage Tag, METTag, USA.

National Technical University of Athens (NTUA). EMERGENCY-112 ⟨http://www.biomed.ntua.gr/emergency112/⟩.

Neuenschwander M, Cohen MR, Vaida AJ, Patchett JA, Kelly J, Trohimovich B. Practical guide to bar coding for patient medication safety. American Journal of Health-System Pharmacy 2003;60(8):768–79.

Nokia. Nokia N810 ⟨http://www.nseries.com/index.html♯l=products,n810⟩.

Northover S, Wilson M. SWT: the standard widget toolkit: vol. 1. in: The Eclipse Series. Reading, MA: Addison-Wesley; 2004.

OLPC, One Laptop Per Child (OLPC) ⟨http://laptop.org/⟩.

Overeinder BJ, Brazier FMT. Scalable middleware environment for agent-based Internet applications. In: Proceedings of the workshop on state-of-the-art in scientific computing (PARA'04), Copenhagen, Denmark, 2004. p. 675–9 [published in Applied parallel computing. Lecture notes in computer science, vol. 3732. Berlin: Springer; 2006].

Pavlopoulos S, Kyriacou E, Berler A, Dembeyiotis S, Koutsouris D. A novel emergency telemedicine system based on wireless communication technology—AMBULANCE. In: IEEE Transactions on Information Technology in Biomedicine; 1998. p. 261–7.

Perkins C, Belding-Royer E, Das S. RFC 3561—Ad hoc On-Demand Distance Vector (AODV) Routing; 2003.

Pitsillides A, Samaras G, Dikaiakos M, Olympios K, Christodoulou E. DITIS: collaborative virtual medical team for home healthcare of cancer Patients. In: Conference on the information society and telematics applications; 1999 –.

Poslad S, Buckle P, Hadingham R. The FIPA-OS agent platform: open Source for Open Standards. In: Proceedings of PAAM 2000, 2000.

Shannon CE. Communication in the presence of noise. In: Proceedings of the institute of radio engineers, vol. 37, 1949. p. 10–21.

Shnayder V, Rong Chen B, Lorincz K, Jones TRFF, Welsh M. Sensor networks for medical care. In: SenSys '05: proceedings of the 3rd international conference on embedded networked sensor systems. New York, NY, USA: ACM; 2005. p. 314.

Silva LM, Batista V, Silva JG. Fault-tolerant execution of mobile agents. In: DSN '00: proceedings of the international conference on dependable systems and networks (formerly FTCS-30 and DCCA-8). Washington, DC, USA: IEEE Computer Society; 2000. p. 135–43.

Super G. START: a triage training module. Newport Beach, California: Hoag Memorial Hospital Presbyteriand; 1984.

Teasdale G, Jennett B. Assessment of coma and impaired consciousness: a practical scale. Lancet 1974;2(7872):81–4.

Tønnesen A. Implementing and extending the optimized link state routing protocol. University of Oslo. ⟨http://www.olsr.org/docs/report.pdf⟩.

Tripathi A, Karnik N, Vora M, Ahmed T, Singh R. Mobile agent programming in ajanta. In: Proceedings 19th IEEE international conference on distributed computing systems; 1999. p. 190–7.

TSG Associates, Smart Incident Command System, TSG Associates, UK.

TSG Associates, Smart R.A.T. Pack, TSG Associates, UK.

TSG Associates, Smart Tag, TSG Associates, UK.

US Navy. Tactical Medical Coordination System (TacMedCS) ⟨http://www.namrl.navy.mil/clinical/projects/tacmedcs.htm⟩.

Velasco JR, López-Carmona MA, Sedano M, Garijo M, Larrabeiti D, Calderon M. Role of multi-agent system on minimalist infrastructure for service provisioning in ad-hoc networks for emergencies. In: Proceedings of AAMAS'06; 2006. p. 151–2.

Vieira-Marques PM, Robles S, Cucurull J, Cruz-Correia RJ, Navarro G, Martí R. Secure integration of distributed medical data using mobile agents. IEEE Intelligent Systems 2006;21(6):47–54.

Wallis L. START is not the best triage strategy. British Journal of Sports Medicine 2002; 473.

WiFi-Introduction. ⟨www.kioskea.net⟩, WiFi—Introduction, ⟨http://en.kioskea.net/wifi/wifiintro.php3⟩.

White JE. Telescript technology: mobile agents. In: Bradshaw J, editor. Software agents. Menlo Park, CA: AAAI Press, MIT Press; 1996.

Wooldridge M, Jennings NR. Intelligent agents: theory and practice. Knowledge Engineering Review 1995;10(2):115–52 URL: ⟨citeseer.ist.psu.edu/article/wooldridge95intelligent.html⟩.

Appendix B

"Mobile agents for critical medical information retrieving from the emergency scene"

Mobile Agents for Critical Medical Information Retrieving from the Emergency Scene

Abraham Martín-Campillo, Ramon Martí, Sergi Robles, and Carles Martínez-García

Departament of Information and Communications Engineering, Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Spain
{abraham.martin, ramon.marti.escale, sergi.robles, carlos.martinez}@uab.cat

Abstract. Lacking medical information about a victim in the aftermath of an emergency makes the early treatment and the efficient allocation of resources difficult. On the other hand, communication infrastructures are normally disrupted in these situations, thus hindering the gathering of the required information. This paper presents a new application of mobile agents for retrieving partial information of medical records upon request from the emergency scene. This solution fits well when mobile ad hoc networks are in use, and it is based on the asynchronous communication provided by mobile agents. By using the proposed system, it is possible to request remote hospitals for critical information about the victims, such as allergies or infectious diseases, thus facilitating more accurate diagnosis and bringing forward decision making. An implementation of the system has been developed, showing its feasibility.

1 Introduction

When an emergency occurs, especially in mass casualty incidents, lots of victims need medical attention. When the first responder medical personnel arrive to the scene, they triage the victims they find [11] [7]. The triage consists of a protocol to sort victims according to their medical status in order to prioritize their needs for receiving medical attention. When all the victims are triaged, the medical personnel begins to treat them following the color-based prioritization.

The objective of the first responder medical personnel is to stabilize the victim before they can be evacuated to an hospital. Only after stabilized, the victim is transferred to an hospital. Normally, while the victim is being stabilized or transferred, medical personnel search for victim's personal items that could identify them. Discovering who the victim is may not seem essential but it is; with this information, personnel from the hospital where the victim has been taken to can contact with their family. Those can provide doctors with important medical information about the patient. Without the help of their family it is probable that the hospital does not have all the important medical data of the victim unless it has implemented a Virtual Electronic Patient Medical Record (VEPMR) solution.

Some research has been done about electronic patient medical records systems, a hot topic nowadays [5] [13]. A VEPMR system makes available from any medical institution all the existing medical information about a patient. To achieve this purpose,

Y. Demazeau et al. (Eds.): 7th International Conference on PAAMS'09, AISC 55, pp. 30–39.
springerlink.com

medical institutions have to be part of the medical network where every member shares the information it has. As a consequence, every time a patient visits the doctor, each surgery and each test done (f.e. scans or x-rays) is recorded inside this distributed database to be available at the whole medical network. It is clear that having all the medical information about a patient, a faster and better diagnosis is obtained, thus a better treatment may be given [6].

Our motivation is making VEPMRs available in the emergency scene. This could improve the medical assistance of the victim. Seems obvious that the knowledge of some data like blood type, chronic and contagious diseases, without the need for doing tests, could save more lives as the medical team saves time and money. Furthermore, this knowledge could prepare the hospital where the victim is assigned if special attentions are needed. The possibility to have access to a VEPMR repository in the emergency scene is not a reality nowadays.

When incidents like hurricanes, floodings or tsunamis occurs, most communication networks are normally disrupted, being an obvious handicap for quick and coordinated assistance. Some projects propose deploying antennas to have communication networks in all the emergency scene [10]. Others propose using sensor or ad-hoc networks for communication inside the emergency scene [8][12].

We could use any of these systems to make true the VEPMR retrieval from the emergency scene. But, our goal is going a step forward proposing the use of mobile agents on ad-hoc networks to forward requests of VEPMRs to the medical network. This allows the retrieval of the patient's medical record in the place where the emergency has occurred, even in the worst case scenarios that others proposals have not taken into account. As a result, our proposal does not need the deployment of a network infrastructure. Only using personal information about the victims, found in the emergency scene, our system is able to identify the victims to make the request of their VEPMR.

The rest of the paper is structured as follows. Section 2 introduces the reader to the emergency world, describing an emergency scene and its actions and actors. Section 3 presents our system proposal, its description and implementation. Finally, Section 4 contains a discussion comparing our systems with different alternatives and complementary work. Section 5 concludes the paper.

2 Emergency Scene

This paper is centred in the worst scenario emergencies which usually are mass casualty incidents (MCIs). The main characteristic of MCIs is the big number of victims. In these cases, the triage of victims is needed to sort injured people into groups based on their need for immediate medical treatment. This triage is done by the first medical personnel that arrive at the emergency scene. Consequently, the medical personnel arriving latter know those victims who need more urgent attention. The victims are stabilized and prepared, in triage color order, to be evacuated to the hospital where they will be treated widely.

The triage process usually creates four groups of victims based on their condition. The first group, from worst to best condition order, is the black one. Those victims triaged as black group are dead or in very bad condition, impossible for the medical

Fig. 1. Emergency scene and VEPMRE retrieval scheme

team to do something to save their live. The second group, red, are victims who need immediate attention. The victims in the third one, yellow, do not need for immediate but urgent medical attention so can wait for a short period of time. And finally, the green group, with victims with minor injuries who need help less urgently.

The first and foremost step is the triage because it focuses the medical attention in those victims in worst conditions. Once the triage is complete, rescue teams extract those victims who are trapped or cannot move from the hot spot to a safe place. The hot spot is a dangerous area where the emergency has happened. In this area the medical personnel cannot work because it may exists risk of danger (as explosion or contamination). Because of this, it is important for everybody to evacuate this area and for the rescue teams to extract the victims who cannot move. While rescue teams are doing their job, the medical personnel treat those victims in the red group that have been already evacuated and are in a safe place.

If an Advanced Medical Post (AMP) is installed, the victims are evacuated to this place (see Fig. 1). The AMP is a mobile hospital to treat the victims before they can be transfered to an hospital. In mass casualties, where is necessary to treat lots of victims in seriously condition, the AMP is a must that have to be installed near but in reasonable distance from the emergency, or hot spot, to be a safe place.

The main objective of the medical personnel regarding the victims in the red group is to stabilized them, to make them be ready to be transferred. Once the stabilization is done, the ambulance, helicopter or rescue vehicle in general are called to pick up each victim. Afterward, victims are transferred to the hospital assigned by the coordinator team. The coordinator team manage which victims are assigned to which hospitals.

Once all the red victims have been treated it is time for the yellow ones, that follow the same process as the red ones. The green patients are arranged together and then transfered as low priority to other hospitals or medical institutions using any available transportation.

The Advanced Command Post (ACP) is where the coordination team is. From this site, all the decisions about actions to be carried out by rescue and medical teams are taken.

It is necessary to consider that in a big emergency more than one hot spot or local emergency can exist. These local emergencies, for instance, in a hurricane each house devastated or vehicle crashed, can share the meeting point, AMP and/or ACP or have its own for each one if they are big enough. Usually, if the emergency has multiple hot spots or local emergencies, a crisis committee is created to manage and coordinate all the emergency in collaboration with different ACPs installed.

2.1 Communications in the Emergency Scene

Talking about communications in the emergency scene, on past days, it was only matter of walkie-talkie communications, but nowadays it is getting more and more important. This is due to the greater use of Internet enabled devices or mobile phones by the emergency personnel, that require mobile networks such as mobile phone network (3G) or WiMAX. In the great majority of emergency cases, hurricanes, terrorist attacks, floodings, etc, these networks become unstable, unaccessible, overused or even destroyed. As a consequence, emergency personnel cannot use existing network infrastructure and may deploy and use their own, or simply use wireless mobile ad-hoc networks (MANETs) or wireless mesh networks. These networks create routes by request of the nodes that are maintained as long as they are needed or the link is available.

Anyway, all these solutions have the same lack. If the area of emergency is big enough, could be possible that the ad-hoc network created by the medical personnel's devices is not fully connected. As a result, an attempt to communicate from one point of the network, for instance, a first responder, to another point of the network, for example, the AMP, could be unsuccessful.

The AMP and ACP always have Internet connection even if the network infrastructures are destroyed or unusable. They use their own deployed network infrastructure, for instance, satellite connections. For the AMP and the ACP, it is very important to have Internet connection for coordination or information communications (f.e. with another coordination point or with hospitals assigned to victims).

3 Critical Medical Information Retrieving System

We propose a mechanism to retrieve VEPMRs from the emergency scene. Each member of the triage and medical personnel is provided with a mobile device supporting mobile agents. With this mobile device, any member of the triage or medical personnel, anywhere in the emergency zone, can create a mobile agent with a VEPMR request when any personal document identification of the victim is found.

3.1 Retrieving System

Our proposal takes into account the three possibles scenarios in the emergency scene. The first one is the existence of a network infrastructure with Internet connection, for instance, mobile phones network infrastructure (GSM, EDGE or 3G). The second and third possible situation lack of a network infrastructure with Internet connection. In the second case, a MANET is created using all the neighbor devices of the medical and triage personnel to solve the lack problem. In this situation, all the mobile devices are close enough each other to create a fully connected MANET. Furthermore, some of the mobile devices that creates the MANET are near the AMP or ACP. As a result, all of them can access to Internet, using the network infrastructure of the AMP or ACP, and routing the packet to them using usual ad-hoc networks routing protocols. Consequently, from any part of the network it is possible to send directly the VEPMR request to the medical network. The third possible situation is similar to second one but the MANET is not fully connected, so clusters of devices are created, hence, not all the mobile devices can access to Internet directly.

Let us begin with the third situation. Our proposal is based on creating a mobile agent each time a VEPMR request is done. This mobile agent contains the identification of the victim whose VEPMR is requested. As the MANET is not fully connected, the request cannot be sent directly, thus, the mobile agent have to jump from device to device or cluster to cluster of devices until it reaches the ACP or AMP. Once the mobile agent has arrived, it can communicate the request to the VEPMR system of some hospital of the medical network.

Delay Tolerant Networks (DNTs) are one solution for this problem but the routing process in DTNs is an open issue nowadays. We wanted to go one step further and make possible a more complex routing protocol and an easy-to-change routing policy. As a consequence, we decided to use mobile agents and create a mobile agents based MANET. This MANET uses agent platforms and its services as routers for the mobile agents that are treated as packets in traditional networks. Therefore, the routing process is done in the application layer. The complex routing decision is provided by the mobile agent itself, accessing and using attributes and values available in the application layer. Furthermore, it is possible to use different routing protocols depending on the situation of the mobile agent, or the network, or even allows the user to select which routing policy wants to use.

Using this method it is possible to route a mobile agent from the point where the request is created thought the whole, not fully connected, MANET to the AMP or ACP. In traditional networks this cannot be done because a fully connected network from the origin point to the destiny point is needed. Using mobile agents based MANET, the agents can wait for a connection if there is not, in any part of the network, thus, they can cover a part of the route. Furthermore, they can use different dynamic routing protocols to reach the destiny point. The dynamic routing protocol decides if it is better for the mobile agent to jump to another platform or to stay in the platform where it is, and also deciding the best platform to jump.

Different dynamic routing protocols can be used in the mobile agents based MANET. In our case, the objective of all mobile agents is to arrive to some point where Internet connections exists. This is usually the AMP or ACP if there is no network infrastructure. So, the objective of the routing protocol is to offer the best route spending the minimum time to arrive to the AMP or ACP. Our proposal aims to use the time that the medical personnel expects to stay in the emergency scene to calculate the routing. This is an approach and one solution for the problem, but other routing policies can be used to arrive to the ACP or AMP as soon as possible. When a first responder leaves the meeting point they has to state when they will come back. This is for security reasons because they will be in a emergency scene where some disaster has occurred and it is not fully safe. Therefore, they foresee a "time to return" (TTR) that they will put into their device. So, each device stores the time when the personnel who carries it expects to return to the AMP. The mobile agent asks for this information for the service's platform of all the neighbor devices and jumps to the one that has the smaller return time value. In this way, the mobile agents arrives to the AMP as soon as possible.

Some special devices, for instance those installed in an emergency vehicle, can store an especial "time to return" value. This is especially useful when an emergency vehicle has to go to the emergency scene and come back to the AMP or ACP, or the first responder has finished their job in the emergency scene and is coming back. In these situations the "time to return" will have a low value. Therefore, all the mobile agents near the platform with low TTR will jump into it because is the fastest way to get access to Internet.

It would wrongly seem that agents are not useful in the first situation, where mobile devices can connect directly to Internet using network infrastructure available in the emergency scene, and in the second situation, where the mobile devices can access to Internet through the fully connected MANET. However, in emergency situations the network infrastructures are usually unstable or over-saturated, thus the situation can change from the first one to the second one. In the second situation it would wrongly seem that mobile agents are also not needed. Moreover, as a mobile ad-hoc network, in any moment the situation can change from a fully connected to not fully connected network, hence the third situation. In this case, we do need mobile agents to make the requests work. In emergency scenes the situations are intermittent as they can change in any moment from first to second or third, and vice versa. For this reason we always have to focus in the worst case scenario, this is, the third situation. Therefore, the mobile agents based MANET scheme is always used regardless of in what situation the emergency scene is. In conclusion, mobile agents are always launched when a requests is done and they try to reach the AMP or ACP to make the request from there, where the network infrastructure is more stable.

When the VEPMR is retrieved, a copy is saved in the AMP and ACP. The mobile agent that has made the request, looks from the ACP or AMP for the mobile device that has launched it. If this mobile device is connected to the same MANET cluster than the ACP or AMP, the mobile agent can jump to its agent platform. As a consequence, if the victim is being treated in the emergency zone or in the AMP, their VEPMR will be always available for the medical personnel treating them.

Security has also been taken into account in our system. VEPMRs consist of sensible private medical data. For this reason, this information has to be dealt with carefully

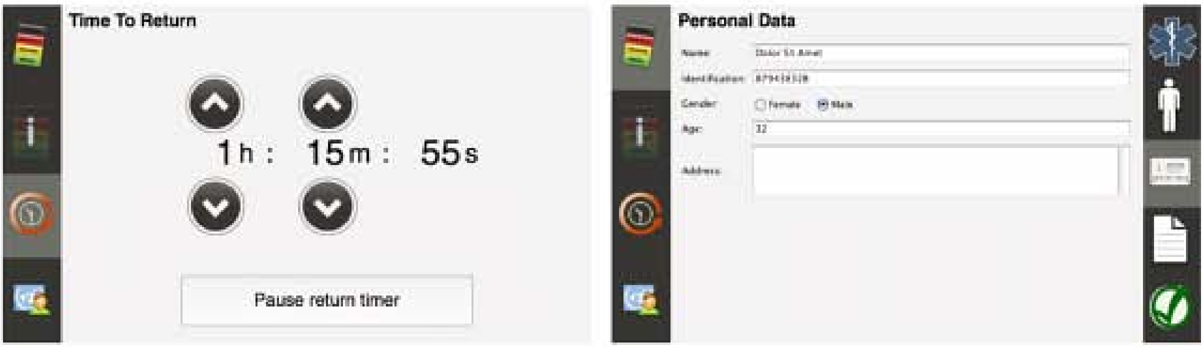

Fig. 2. Implementation screenshots

using strong security mechanisms, and the communication between ACP, or AMP, and the VEPRM system has to be secure. The problem of security in ad-hoc networks is not fully solved nowadays. Even thought, this is not an issue for our system because the very agents protect the data they carry [1]. Thus, the system can be used in insecure networks.

3.2 VEPMR for Emergencies

We also propose the creation of a special VEPMR containing only the relevant information for an emergency case. This VEPMR for emergencies (VEPMRE) contains the blood type, hepatitis, AIDS, allergies and more basic information to treat the patient in an emergency case. Thanks to this, the VEPMRE has a smaller size so it uses less network bandwidth.

An important issue is how a VEPMRE is associated with the victim. An AMP may receive many VEPMRE from requests launched by the mobile agents, so how do the medical personnel know what VEPMRE corresponds to which victim? Our proposal is adding the id number of the triage tag with each VEPMRE request inside the mobile agent. In this way, once the VEPMRE is received it is possible to identify the victim, since the triage tag is always carried by them.

3.3 Implementation

An implementation has been developed as a proof of concept. A Nokia n810 touch screen-based mobile device with a MAEMO linux distribution has been used as a hardware platform. The programming language used is Java with JADE Framework [2] as agents platform, together with its FIPA-compilant mobility services [3].

IEEE 802.11g has been used as a network interface with the handhelds. When a device leaves the AMP or ACP, a TTR value has to be added as the screenshot in the figure 2A shows. When a first responder finds an ID of the victim, it can be introduced in the system and a VEPMRE request is sent (figure 2B). At this moment a mobile agent is created containing the ID of victim and with a routing policy. The mobile agents tries to move from platform to platform following the routing policy until it reaches the AMP or ACP.

4 Discussion

Some other works have proposed some other ideas to implement in the emergency scene [10][9][8][4]. On the other hand, some researchers have proposed VEPMR solutions that complement our work [13].

"A Situation-Aware Mobile System to Support Fire Brigades in Emergency Situations" [10] proposes a network infrastructure deployment mechanism for communication between the fire brigades members. The firefighters are equipped with PDAs, for coordination, and sensors to read their vital signs. PDAs transmit data, voice over IP and video streaming through a mesh network, while the sensors create sensor networks to transport the data obtained to the PDA. The proposal for the mesh network is based on the deployment of new nodes where the coverage is lost. One or more of these nodes may be connected to Internet, allowing access to it to all PDAs. Our proposal does not deal with the deployment of new nodes in the infrastructure, but to use the mobile devices in asynchronous way in order to get VEPMREs.

The Wireless Internet Information System for Medical Response in Disasters (WIISARD) [9] project proposes a set of systems to use in the emergency scene. They provide triage personnel with PDAs to introduce the triage information of the victim [8]. The identification of the victim is done through a barcode reader. WIISARD also proposes a system in the ACP, able to receive all the triage information from the PDAs [4]. A decision making system is also included, using the triage information together with additional information about the emergency, like resources available at hospitals. Again, the deployment of a network, the existence of a network infrastructure or a fully connected MANET is needed.

Marques et al. [13] propose VEPMR mobile agents as a solution for the problems of heterogeneity and dispersion of electronic patient records in different healthcare institutions. Their paper describes an information-gathering system for securely integrating distributed, inter-institutional medical data using security-enhanced mobile agent technology into a single VEPMR. In this case, mobile agents move inside the infrastructure network in order to visit all medical institutions and departments to gather the required records. Our proposal is a step-forward, since it aims to create a significant reduced version of the VEPMR adapted to emergency situations, and use the mobility and intelligence of mobile agents to move asynchronously inside a MANET in order to reach the AMP as the entry point to the Internet.

5 Conclusions

Coordination and information gathering are hard chores to achieve during an emergency situation, especially when they involve scattered personnel and hospitals. It is particularly relevant the issue of getting critical information about a victim before arriving to a hospital for treatment. The proposal described in this paper provides a practical application of mobile agents to solve this particular problem, making it possible to asynchronously retrieve significant information, such as allergies or infectious diseases, from the patient record while the victim is still in transit. This information can be used to make a better resource allocation, such as operating rooms reservations, improve diagnosis, or to avoid hazardous treatments, for instance in the case of diabetics, or drug allergic victims. The proposed system can be used in mobile ad hoc networks, and is tolerant to network disruptions and high delays, which are common during the aftermath of an emergency. The early acquirement of this information might save lives in some cases. The system has been implemented as a proof of concept using real handheld devices, and has shown to be feasible.

There are aspects of the system that can be complemented with other technologies. As a future work, we aim to integrate this solution with a fault tolerance mechanism which is a must when sensible information is to be transmitted. Other additional functionalities we have planned to add are using the agent for bearing triage information, or inserting geographical position (GPS) of the victim's whereabouts in the agent.

Acknowledgements

This work has been funded by the Spanish Ministry of Science and Innovation through the project TSI2006-03481.

References

1. Ametller, J., Robles, S., Ortega-Ruiz, J.A.: Self-protected mobile agents. In: 3rd International Conference on Autonomous Agents and Multi Agents Systems, vol. 1, pp. 362–367. ACM Press, New York (2004)
2. Caire, G.: Jade: The new kernel and last developments. Technical report, Telecom Italia (2004), http://jade.tilab.com/papers/Jade-the-services-architecture.pdf
3. Cucurull, J., Martí, R., Robles, S., Borrell, J., Navarro-Arribas, G.: FIPA-based interoperable agent mobility. In: Burkhard, H.-D., Lindemann, G., Verbrugge, R., Varga, L.Z. (eds.) CEEMAS 2007. LNCS (LNAI), vol. 4696, pp. 319–321. Springer, Heidelberg (2007)
4. Demchak, B., Chan, T.C., Griswold, W.G., Lenert, L.A.: Situational awareness during mass-casualty events: command and control. In: AMIA Annu. Symp. Proc., p. 905 (2006) (Times Cited: 0)
5. Eden, K.B., Messina, R., Li, H., Osterweil, P., Henderson, C.R., Guise, J.-M.: Examining the value of electronic health records on labor and delivery. American Journal of Obstetrics and Gynecology, 199(3), 307.e1–e307.e9 (2008)
6. Hippisley-Cox, J., Pringle, M., Cater, R., Wynn, A., Hammersley, V., Coupland, C., Hapgood, R., Horsfield, P., Teasdale, S., Johnson, C.: The electronic patient record in primary care regression or progression? a cross sectional study. British Medical Journal 326, 1439–1443 (2003)
7. Kennedy, K., Aghababian, R.V., Gans, L., Lewis, C.P.: Triage: Techniques and applications in decisionmaking. Annals of Emergency Medicine 28(2), 136–144 (1996)
8. Killeen, J.P., Chan, T.C., Buono, C., Griswold, W.G., Lenert, L.A.: A wireless first responder handheld device for rapid triage, patient assessment and documentation during mass casualty incidents. In: AMIA Annu. Symp. Proc., pp. 429–33 (2006) (Times Cited: 0)
9. Lenert, L., Chan, T.C., Griswold, W., Killeen, J., Palmer, D., Kirsh, D., Mishra, R., Rao, R.: Wireless internet information system for medical response in disasters (wiisard). In: AMIA Annual Symposium Proceedings, pp. 429–433 (2006)

10. Luyten, K., Winters, F., Coninx, K., Naudts, D., Moerman, I.: A situation-aware mobile system to support fire brigades in emergency situations. In: Meersman, R., Tari, Z., Herrero, P. (eds.) OTM 2006 Workshops. LNCS, vol. 4278, pp. 1966–1975. Springer, Heidelberg (2006)
11. National Association of Emergency Medical Technicians U.S. and American College of Surgeons. PHTLS–basic and advanced prehospital trauma life support, 4th edn. Mosby, St. Louis (1999)
12. Portmann, M., Pirzada, A.A.: Wireless mesh networks for public safety and crisis management applications. IEEE Internet Computing 12(1), 18–25 (2008)
13. Vieira-Marques, P.M., Robles, S., Cucurull, J., Cruz-Correia, R., Navarro, G., Martí, R.: Secure integration of distributed medical data using mobile agents. IEEE Intelligent Systems 21(6), 47–54 (2006)

Appendix C

“Mobile Agents in Healthcare, a Distributed Intelligence Approach”

Chapter 4
Mobile Agents in Healthcare, a Distributed Intelligence Approach

Abraham Martín-Campillo, Carles Martínez-García, Jordi Cucurull, Ramon Martí, Sergi Robles, and Joan Borrell

Departament of Information and Communications Engineering, Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Spain
{abraham.martin,carlos.martinez,jordi.cucurull}@uab.cat,
{ramon.marti.escale,sergi.robles,joan.borrell}@uab.cat

1 Introduction

1.1 Introduction

The information in healthcare institutions is generally managed by computer applications deployed in medical centers. Usually, each organization has its own system, which is normally proprietary and makes it difficult the exchange of information with other institutions. This chapter discusses the use of mobile agent technology [51,7] as an enabler of open distributed eHealth applications. More precisely, it describes some successful experiences based on this technology: one regarding integration of medical information, and two concerning emergency scenarios. These three successful cases can be very useful at the time of designing new eHealth systems since they have already solved many of the most common issues in this domain.

The first system that will be presented is MedIGS [49], a mobile agent based application that comprises several important features of current healthcare systems, such as distributed information gathering and interoperation among medical centers. The main goal of the system is achieving a Virtual Electronic Patient Medical Record (VEPMR) [6] out of all the medical data about a patient which are spread over a set of hospitals. The system benefits from the mobile agent technology, which relies on local searches performed by roaming agents avoiding the need of a central repository.

Secondly, an application will be described for retrieving partial information of medical records upon request from an emergency scene [33]. This solution fits well when mobile ad hoc networks are in use, and it is based on the asynchronous communication provided by mobile agents. This system allows, for example, to request remote hospitals for critical information about the victims, such as allergies or infectious diseases, thus facilitating more accurate diagnosis and bringing forward decision making.

Finally, the chapter will analyse the case of the Mobile Agent Electronic Triage Tag system (MAETT) [31][32], which is based on mobile electronic triage tags for emergency situations that makes victim information available at the base of operations as soon as possible, thus allowing an early medical resource allocation and immediate action. The cornerstone of the system is mobile agent technology, which allows information to be transported asynchronously and reliably from terminal to terminal and not

I. Bichindaritz et al. (Eds.): Computational Intelligence in Healthcare 4, SCI 309, pp. 49–80.
springerlink.com

requiring any network infrastructure at all. This approach is ready to be used in the worst case scenario, where only small handheld devices carried by the emergency personnel are available, but also integrates well when synchronous connections are possible, for instance when a mesh network can be created.

The chapter concludes with a discussion of the lessons learnt from the development and deployment of these applications. This discussion includes some best practices for the effective use of mobile agents in the e-health domain.

2 Mobile Agents

2.1 Definition

Mobile agents [51] are a technology which has its origin on two different disciplines. On the one hand, the artificial intelligence community created the concept of intelligent agent [53]. On the other hand, the distributed systems community, with a more pragmatic vision of mobile agents, exploited the code mobility [12].

A valid definition for mobile agents, regarding the two mentioned disciplines, is that they are intelligent software entities that have the ability to stop and resume their execution in different network locations to accomplish a set of tasks. The agents live within environments called agent platforms, which define the boundaries of available locations, and are characterised by a set of properties:

- **Mobility:** Agent ability of suspending its execution in a specific agent platform, and resume it in another agent platform, i.e., in another location. This process is usually called agent migration.
- **Autonomy:** Each agent is driven according to a code specially developed to achieve one or more goals. The agent actions are completely decided according to this code without direct intervention of other parties.
- **Reactivity:** Agents react to the environment changes in order to achieve their goals.
- **Proactivity:** Agents change their environment and take several initiatives to achieve their goals.
- **Sociability:** It is the ability of agents to interact with other agents. This is a key feature, since some agents only can perceive their environment through communication with other agents.

2.2 Agent Architecture

A mobile agent, from an architectural point of view, is an entity with a unique identification that is composed of three main components: code, data, and state. The agents live in an environment called agent platform, which is managed by an agent middleware software layer.

2.2.1 Agent Identification

Each mobile agent has an associated identifier that distinguishes it individually. This identifier is assigned when the agent is created, it should be immutable, and it is unique within the scope of the agent authority. The agent identification is of utmost importance since it is related to the communication among agents.

2.2.2 Agent Components

The *agent code* is the core component of the agent and contains the agent's main functionality. The code is developed and compiled using a programming language and computer architecture supported by the hosting agent middlewares.

The agent code is usually interpreted code, since it must be easily separable from its local agent platform for, later, being incorporated to a remote agent platform. This is the main reason why most of the mobile agent systems run over an interpreter or a virtual machine, e.g., the Java Runtime Environment.

The *agent data* are the movable resources associated to the mobile agent, i.e., all the information used and, maybe, produced by the agent during its life, which is moved along with it. In object oriented systems this is usually associated to the object instance. How this information is encoded is completely dependent on each agent middleware, e.g., in Java mobile agent systems the Java Serialisation mechanism is typically used.

The *agent state* is the information associated to the agent execution from a operating system point of view. It comprises the program counter, the heap, and so forth. Nonetheless, most of the code interpreters used in mobile agent systems do not support access to this information.

2.2.3 Agent Standards

Since currently several agent middleware implementations exist, a number of organisations have initiated the development of agent standards in an attempt to deal with the problem of incompatibility and interoperability. The most extended agent standards are the ones proposed by *IEEE Foundation for Intelligent Physical Agents (IEEE-FIPA, http://www.fipa.org)*, which is an organisation focused on the management and communication of intelligent agents. The specifications standardised by IEEE-FIPA define the basic components of an agent platform, an agent identification scheme, a complete communication infrastructure, and several agent management services.

2.3 Agent Mobility

Agent mobility is the ability of agents to suspend their execution, move their code, data, and state to another location, and there resume their execution. The set of actions involved in the movement of an agent is called *migration process*. The complexity of this process is variable and depends on the protocols and type of mobility chosen. A mobility mechanism that allows the use of different mobility protocols, and which is based on the IEEE-FIPA standards, is the Inter-Platform Mobility Architecture (IPMA) [7].

2.3.1 Types of Agent Mobility

Not all the agent middlewares can deal with the agent state. Depending on this fact two types of agent mobility [12] can be distinguished: *strong* and *weak* mobility.

Strong mobility allows agents to suspend their execution and resume it exactly at the same point it was suspended. This is an advantage for the agent developer, who do not need to add any special code to continue the execution at the appropriate place of the code, see Algorithm 1 of Figure 1. However, strong mobility is complex to implement because of the need to capture and restore the agent state. Furthemore, this type

Algorithm 1: Strong mobility.

```
begin
    Task A
    doMove();
    Task B
end
```

Algorithm 2: Weak mobility.

```
begin
    switch state do
        case 0
            Task A;
            state = 1;
            doMove();
            break;
        case 1
            Task B;
            break;
    end
end
```

Fig. 1. Equivalent algorithms using strong and weak mobility.

of mobility is highly dependent with the underlying computer architectures or virtual machines, which hinders the achievement of interoperable systems.

Weak mobility does not capture the execution state, as a consequence the code is always resumed from the first line of code. This is not a major issue, since part of the agent execution state can be saved as agent data. An example, see Algorithm 2 of Figure 1, is the use of switch control flow statements driven by a simple variable which is updated and saved in each agent execution. Therefore, the execution can be approximately resumed in a specific block of code. This migration type is more difficult to manage by the agent developer, but it is the most flexible and portable alternative.

2.3.2 Agent Itineraries

Agent itineraries are the lists of locations that mobile agents visit during their life. The concept of itinerary was firstly introduced in the Concordia [52] agent middleware. The concept is specially important when security is introduced to mobile agents.

Two basic types of itineraries can be distinguished. On the one hand, there are *static itineraries*, which are decided when the agent is created. They comprise the set of ordered locations that the agent will visit during its life. And, on the other hand, there are *dynamic itineraries*, which are not initially preestablished and are decided during the agent life according to its necessities.

2.4 Advantages

Although there is no application that cannot be conceived without the existence of mobile agents, they ease the implementation of applications which require:

- **Task delegation:** Due to the inherent autonomy of agents and mobile agents, they can be assigned with a set of tasks which the agent performs on behalf of its owner, e.g., in Section 3 is described a medical application where the task of searching for patients information is delegated to an specific agent.
- **Asynchronous processing:** Mobile agent execution is not dependent on a continuous communication with the agent owner or the home agent platform. Therefore,

the agent can freely move through different network locations while it carries out the assigned tasks. An example of this is nomadic computing [30], where agents reside in mobile devices and migrate to other locations to perform tasks without consuming the scarce resources of the mobile device.

- **Dynamic environment adaptation:** Agents perceive environment changes and react by adapting their behaviour to them. An example applied to network management can be seen in [43], where a mobile agent is reused without modifications to manage various networks.
- **Flexible interfaces:** Since its ease of adaptability, agents can be used to interact with completely different interfaces, such as it is proposed in [50]. Even, agents can be used as improvised adaptors between two kinds of interfaces.
- **Fault tolerance:** Because of the agents capacity to adapt to changing environments, mobile agents can easily deal with computer and network faults. They are specially suitable for hostile environments, where the agent can decide to visit alternative locations in case of failure. An example of fault tolerance based on mobile agents can be seen in [20].
- **Parallelism:** The autonomous nature of mobile agents, the ability to migrate to different locations, and the capacity of interacting with other agents, make them suitable for parallel applications, where a coordinated group of several agents are used. An example, which uses them as a load balancing mechanism, can be seen in [46].
- **Local data processing:** mobile agents can process data directly where it resides without having to move it from the original location. There are two kinds of applications which benefit from this feature. Firstly, *sea-of-data* applications where there is a large quantity of distributed information to process and the movement of it has an elevated cost [16]. And, secondly, medical applications [49] where moving data from its original location is not legal.

3 MedIGS

In this section it is introduced MedIGS [49], a mobile agent based application that comprises several important requirements of current healthcare systems, such as distributed information gathering and interoperation among medical centers. The main goal of the system is the generation of Virtual Electronic Patient Records (VEPR) [6] out of all the medical data about a patient spread over a set of hospitals. The system benefits from the mobile agent technology, which relies on local searches performed by roaming agents avoiding the need of a central repository.

3.1 Introduction

Healthcare is information and knowledge driven. Good healthcare depends on taking decisions at the right time and place, according to the right patient data and applicable knowledge. Communication is of utmost relevance in today's healthcare settings, as health related activities, such as delivery of care, research and management, depend on information sharing. Indeed, the practice of medicine has been described as being "dominated" by how well information is processed or reprocessed, retrieved, and communicated [2].

As more data on patients are now recorded than ever before [54] the economical impact of their management is high. An estimated 35 to 39 percent of total hospital operating costs has been associated with patient and professional communication activities. In a single healthcare institution, information technologies usually tend to combine different modules or subsystems, resulting in a "best-of-breed" approach [24]. This leads to a great demand on creating efficient integrated electronic patient records that would facilitate the communication process. Nevertheless, centralized solutions are often infeasible and expensive. But, users will not agree on give up the legacy information systems they have been using during years. Thus, integration with these systems is a key issue in order to provide physicians with complete and reliable information. In order to integrate clinical information systems in a way that improves communication process and data use for healthcare delivery, research, and management, many different issues must be handled, e.g., data availability, integrity, and validity. The combination of data from heterogeneous sources takes a great deal of effort because the participating systems usually differ in many respects, such as functionality, presentation, terminology, data representation, and semantics [24]. Interfaces are needed in order to retrieve useful information.

Taking into consideration the intra-institutional level, and departmental systems, Virtual Electronic Patient Medical Records (VEPMR) systems approach can provide for the necessary means for departmental systems integration, enabling, at the point of care, a single integrated view of all patients' clinical information existing on the institution. We could say that at the institution level local information integration could suffice to provide doctors with all the necessary information to deliver care to a given visiting patient. However, patients are mobile entities, they visit multiple institutions during their life time and leave a trail of information scattered around laboratories, primary care units and other hospitals. The patient clinical history available to the doctor should not be resumed only to the information produced locally in the institution but also to the external data. The lack of articulation observed at the institution level, in what information systems integration is concerned, is also present when looking at the inter-institution integration level. Usually data integration relies on patients carrying their paper lab reports, x-rays, and other clinical documents themselves. In order to provide consistent and complete clinical data availability, solutions must be provided for bridging inter-institutional systems integration gap.

MedIGS is a gathering information system for securely integrating distributed medical data using mobile agent technology.

3.1.1 Why Agents in MedIGS?

MedIGS provides new clinical data discovery mechanisms which allow each institution to have access to external complementary patient clinical information. For the development of an inter-institution Virtual Electronic Patients Record system several technologies could be used, such as peer-to-peer, Web services, or mobile agents.

- Peer-to-Peer is a good technology to efficiently search through a large network in a decentralized way. Unfortunately this technology does not provide the privacy needed in medical environments, because it is based on storing some key data over many computers in the network to ease the searches.

- Web services can be a good solution, but are not flexible enough. They can contact with a set of institutions but it is difficult to dynamically increase it to reach more data. Web services do not have a pro-active nature, and it usually implies working in a synchronous way, so all systems must be available when a request is done.
- Mobile agents can stand as the most well fitted technology for MedIGS. They have pro-active nature, they can be sent to search over a set of data sources in an asynchronous way dealing with resources unavailability or heavy load. And they can choose where and when to go and also dynamically change their itinerary to visit new locations. Although one of the disadvantages of the agents is the complexity of guaranteeing their security, recent agent driven security developments [1] have solved the most important issues related to this fact.

The multi-agent paradigm has been shown to address procedural complexity issues in the health care information systems arena. It can be used with success for modeling complex communication processes, building highly distributed systems and overcoming the cost and technical demand of a central systems approach [42]. Besides all known characteristics of agents such as sociability, pro-activity and adaptive behavior, the mobility of the agents has been used in the healthcare domain in order to ease the development of data integration mechanisms and to provide data availability throughout. Mobility tends also to be used for overcoming issues originating from connectivity instability, load balancing, or complex legacy systems interfacing.

Authors point out several additional reasons as advantages for the use of mobile agents : the ability to optimize computational load distribution, and the ability to handle failure; the need to handle instable or dynamically changing communication channels [45]. Support for a more flexible peer-to-peer model, scalability and decentralization of control and data [27] is also pointed out.

3.1.2 Issues, Challenges, and Requirements

MedIGS arise for networked and distributed medical systems when considering patient mobility. Its architecture is supposed to fulfill the requirements of modern health institutions, where roaming patients contribute to a highly distributed data scenario where useful information is digitally unreachable outside each institutional island. Current situation has important drawbacks:

- Data are distributed and the location where they are actually stored is often unknown.
- A common database is often unfeasible because of its cost and technical requirements.
- Medical institutions usually prefer to keep control of their own medical data.
- Remote on-line data retrieval is not always possible, especially when considering network disruptions, high latencies or specific search procedures.

From this situation, and the need for data integration at the inter-institutional level, several questions arise:

- How to find out which institutions the patient has visited without relying in their volatile memory?
- How to deal with network disruptions, high latencies or complex institutional legacy systems interfacing?
- How to deal with resistance to share data among institutions?
- How to secure the access to stored information in a way that only authorized staff can access it?
- How to secure the data while agents are roaming through the network?

In order to answer these questions we must firstly provide effective and reliable search and interface methods, as well as an adaptive and fault tolerant system behavior. These features, along with strong security enforcement mechanisms, would increase system confidence and solve most of the above questions.

3.2 System

MedIGS is an evolution of current medical information gathering systems, overcoming the main issues described before. This proposal goes far beyond others, such as [42], addressing issues like inter-institution patient health data integration, unavailable online remote data retrieval, or secure data access and transportation. Two mainstays support the proposal: mobile agents and agent-driven security. MedIGS is based on the widely used multi-agent platform JADE [3], which is compliant with the IEEE-FIPA agent specifications, together with the JADE Inter-Platform Mobility Service [7] add-on, which allows the agents to move between different platforms. This platform provides the system with the necessary means for inter-institution data discovery, transport, and integration. Information gathering actions will be triggered by consultation appointments, and agents will direct their efforts in order to make patient clinical history available as complete as possible for that event. Integration efforts will be directed to clinical documents and not to the data themselves.

In terms of computer structures there are no major requirements besides the need for an agent platform where the broker agent resides and where mobile agents can move. Regarding existing procedures there is no need for changes on the normal execution of the central system, it is just necessary to have a specific interface behavior that can be executed by the mobile agent to provide for a document retrieval interface from which document references can be retrieved. This interface is in charge of the dynamic report generation with existing data on the fly.

3.2.1 Architecture

The MedIGS proposal defines a common set of agents that exist in all systems. These agents are devoted to event management, data discovery, and data collection. Actions are triggered by scheduled clinical episodes (interventions, outpatient visits) or upon user request. There are five agents present in each system:

- **Mobile Scheduler (MS):** This is the agent in charge of managing scheduled events and launching mobile agent instances that will go in search of patient data references.

- **Collector Agent (CA):** Mobile agent in charge of discovering and collecting document references.
- **Remote Broker (RB):** Agent in charge of attending incoming agents asking for patient references.
- **Local Broker (LB):** Agent that receives mobile agents coming back and takes the medical information provided by them.
- **Document Broker (DB):** Agent that manages the needed documentation about a patient. It will retrieve from other platforms the referenced documents provided by the CA collection actions.

Figure 2 shows an overview of the proposed mobile agent application. The main architectural functional steps are described in more detail below:

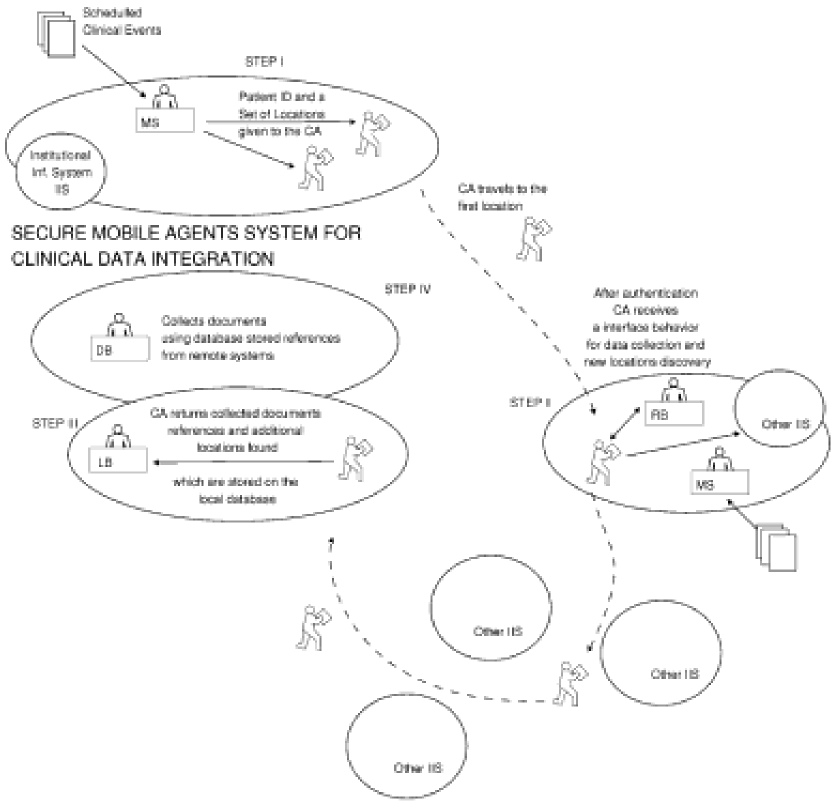

Fig. 2. Overview of the proposed mobile agent application.

Step I - A clinical episode is scheduled creating a new data collection event. This event contains patient information (identification numbers), a date, and a set of known data locations. Based on the scheduled date the MS will start in advance a CA that carries the Patient ID (the National Social Security Number for example) and a set of locations to be visited.

Step II - When the CA reaches the first location it asks for information about the patient it represents. In each institutional system there is a RB which is in charge of attending incoming agents asking for patient data. This RB authenticates the incoming agent, and provides it with the information requested. The CA can request for local patient data and for possible locations with more data. Regarding the patients' data, the agent only retrieves the references to them. Therefore, agents do not need to carry a large amount of data. Regarding the request of other platform locations with more information about the patient, it is returned as a list of new platforms which is included on the agent's itinerary for later visit. After completion, the CA will migrate to the next location and this procedure will be repeated.

Step III - Once CA completes its itinerary it returns to the origin. There all the collected information, e.g., document references and new locations, are managed and stored by the LB.

Step IV - On the home system, a DB is in charge of getting all the referenced documents collected by the CA and making them available locally for the scheduled event.

Since different institutions can communicate inconsistent facts, the system has to include a module to check for contradictory data. For example, if it is known for sure that the patient is male, then he cannot have a pregnancy report; if there is not enough information then the system should keep both facts, let the reader know there is an inconsistence and try to solve the problem by alerting information sources about the inconsistence.

3.2.2 Data Sharing Resistance

Health institutions do not usually have a natural disposition to share data, and this is precisely one issue the proposal overcomes. By using mobile agent technology, data is not directly accessed, but this task is delegated to a mobile agent which performs the actions locally under the security control of the agent platform. This mobile agent searches and collects data references about the scheduled patients, and this makes a difference with a wide and remote access to all the information. On the other hand, in MedIGS the exchange of information is symmetrical between institutions, thus creating a symbiotic relationship in which all profit in the same way. In short, there is not a simple sharing of information here, but a controlled, restricted, and symmetric exchange for which institutions are not believed to object.

As MedIGS deals with clinical information, strong security measures must be put in place in order to ensure protection for both data transportation and collection. For this purpose a set of security mechanisms described in Section 3.3 have been used.

3.3 Security

Security has a paramount importance when designing medical information gathering systems. There are sound and well-known cryptographic mechanisms to guarantee most of the basic security properties (data privacy, integrity, and authenticity). However, having agents that can move along, carrying sensitive data from one execution environment to the next, and acting on behalf of others, raise new security requirements that must be considered.

Three cryptographic techniques face some of the main threats resulting from the utilization of mobile agent technology. These techniques are specific for this type of applications, and are focused in the protection of agent's data and code integrity, and access control:

3.3.1 Self Protected Mobile Agents

In MedIGS scheme, agents protect their code and data by carrying their own protection mechanisms [1]. This approach improves traditional solutions, where protection was managed by the platform. Hence, security is no longer a rigid part of the system, but travels within the agent. Thus, each agent could use its own protection schemes, independently of those supported by the platform. This allows the coexistence of different security mechanisms at the same platform and time.

This solution is based on a public decryption function provided by the platform through a cryptographic service, which is accessed by properly structured agents. It reconciles opposing requirements by introducing a hybrid software architecture that incorporates the advantages of agent driven proposals while limiting the impact of platform driven approaches. Interoperability, code reuse and deployment flexibility concerns are also fully addressed.

3.3.2 Retrieved Medical Information Protection

Another important asset to protect is the information carried by the agent. Although the protection of the agent code is of utmost importance, if the results carried by the agent are not protected against modifications or eavesdroppers the whole security is jeopardized. MedIGS uses a scheme based on hash chains to protect agent's results. Similar mechanisms have been used before to protect agent data, as described in [13]. This type of protection prevents the results from being undisclosed or changed by unauthorized parties. Moreover they allow to check the actual itinerary that the agent has followed.

3.3.3 Access Control

MedIGS purposes a multi-domain scenario where several health institutions come together to share medical data. However, in order to regulate the access to the medical data arises the following problems:

- **Roaming agents act on behalf of unknown users:** When a local user launch a retrieval query, for the rest of the health institutions the user is unknown. However, it can be determined where the query comes from.
- **Credentials are defined locally:** Each independent health institution grants its users with local privileges which are not directly understood in the rest of the health institutions.

In order to solve the above problems, MedIGS purposes a credential conversion mechanism [34] which allows, through conversion policies, the credentials translation from one institution to another. Thus, the Collector Agent privileges are computed in each institution based on the privileges of the local user who launched the query.

4 Mobile Agents for Critical Medical Information Retrieving from the Emergency Scene

Lacking medical information about a victim in the aftermath of an emergency makes the early treatment and the efficient allocation of resources difficult. On the other hand, communication infrastructures are normally disrupted in these situations, thus hindering the gathering of the required information. In this section it is introduced a new application based on mobile agents for retrieving partial information of medical records upon request from the emergency scene. This solution fits well with a mobile ad hoc network environment with asynchronous communications provided by mobile agents. The proposed system allows to request remote hospitals for critical information about the victims, such as allergies or infectious diseases, thus facilitating more accurate diagnosis and bringing forward decision making.

4.1 Introduction

When an emergency occurs, especially in mass casualty incidents, lots of victims need medical attention. Researchers agree that the fast and accurate acquisition and analysis of data, the more effective the answer can be given. That is, the needs will be supplied as soon as possible and the affected population will be reduced. The common point in all cases is the analysis of information. Around it lies the importance of responding to the emergency. Furthermore, information revolves around all stages of disaster: preparation, planning, training, response, recovery and evaluation. [47].

The first responder medical personnel stabilizes the victim before they can be evacuated to a hospital. After it is stabilized, the victim is transferred to a hospital. Normally, while the victim is being stabilized or transferred, the medical personnel search for victim's personal items that could identify them. Discovering who the victim is it is important since with this information, important medical information about the patient can be retrieved from a Virtual Electronic Patient Medical Record (VEPMR) solution, which makes available from any medical institution all the existing medical information about a patient.

The objective of this system is to make VEPMRs available in the emergency scene. This could improve the medical assistance of the victim, since the victim's blood type, chronic and contagious diseases, and so on, can be rapidly obtained. Furthermore, the hospitals can be prepared for the victim's arrival, e.g., special attentions, resources, and so forth.

When incidents like hurricanes, floodings or tsunamis occurs, most communication networks are normally disrupted, being an obvious handicap for quick and coordinated assistance. Some projects propose deploying antennas to have communication networks in all the emergency scene [28]. Others propose using sensor or ad-hoc networks for communication inside the emergency scene [19][41].

We could use any of these systems to make true the VEPMR retrieval from the emergency scene. But, our goal is going a step forward proposing the use of mobile agents on ad-hoc networks to forward requests of VEPMRs to the medical network. This allows the retrieval of the patient's medical record in the place where the emergency has occurred.

4.2 Background

This section describes the state of the art of applications dedicated to emergency management and those that propose solutions to face the lack of infrastructure in the emergency scene.

4.2.1 Emergency Management

Coordination, information sharing, and decision-making are the three fundamental axes for the management of an emergency situation [5] [21]. Optimization of those three axes reduces the response time, one of the objectives of any system for managing the emergency. Several emergency management approaches exist.

AMBULANCE[40] aims to create medical portable devices that allow remote, medium and long distance tele-medicine specialists support. The device allows the transmission of vital signs and patient images from anywhere using the mobile phone network.

ARTEMIS [36] is based on a previous knowledge base to make decisions. It is based on an expert system that follows rules and that, according to the input parameters added, make a decision based on rules applied in other cases available in the knowledge memory.

PHERIS[26] introduces a new protocol to replace the one used in China to deal with the SARS. PHERIS consists of 4 systems: the surveillance, control, action and support. The surveillance system captures emergencies and reports to the control system. The control system decides whether to take measures to raise the alert level and make decisions to meet the emergency. The action system receives the orders from the control system and carries them out in response to the emergency. The support system is responsible for ensuring that all protocol are followed correctly and that the actions are carried out correctly. From the point of view of communication, it creates a virtual network of five layers and three layers. The layers are defined by the magnitude of the organization involved. The levels will depend on the organization.

MASCAL [11] is a system that seeks to integrate a solution based on software and hardware to improve the management of a hospital during a large scale emergency. It integrates TacMedCS (section 5.2.3) and it provides a visual management of hospital resources and their locations supporting different types of views depending on the type of medical center. It also has support for the staff registration and management of individual local areas, such as operating rooms, emergency rooms, radiology, and so on.

CWME [25] is a framework for emergency management that provides a collaborative virtual work space for the organizers of the various fields of emergency. In this way, one can communicate easily and create joint documents defining the plans to deploy.

WIISARD [23] is a project whose main objective is to use wireless networks to assist in the coordination and care of victims in large-scale emergencies. WIISARD proposes providing emergency personnel (medical personnel both in the field and coordinating staff) with medical and tracking data in real-time of all casualties that occur during the emergency. WIISARD proposes to deploy a network of nodes CalMesh as soon as arriving at the emergency scene. This network of nodes can be connected both to the medical devices as well as to classification devices (Section 5.2.3) in the entire area of the emergency. When a victim is found, a tracking and monitoring device is placed on him, and the emergency personnel introduce in it the state of the victim, the treatment and the identification data. These data will travel over the network to the emergency control and management system where they will be sent to all devices in the emergency field through the same network and to the nearest hospital via the Internet. It also shows the list of available resources (hospital beds, medicines, ambulances, and so on) in the area near the emergency. This helps in deciding where each victim must go depending on the resources of the hospital and the condition of the victim. Furthermore, it provides additional information that can help in making decisions in an emergency, such as weather reports, action plans, network status, location of the PDAs, and so forth.

4.2.2 Infrastructure in Emergency Situations

Deploying an infrastructure is something complex in emergencies which require prompt action and when the personnel is engaged in tasks that require greater attention than the deployment of a network. Many of the systems and papers propose the use of wireless networks using mesh nodes installed by first aid teams when arriving at the scene of the accident [28] [8] [17] [41].

Deploying a network is more complicated in places where communication networks are partially operating than in places where no infrastructure exists. This is due to various factors such as interference with existing signals, saturation of these networks, and so on. [29].

The alternative to deploy a network is using mobile ad hoc networks (MANET) (mesh or not) in the devices of the emergency personnel. This way they can communicate each other when they are close enough or if there are devices that behave as routers. A disadvantage is that if the devices are too far they cannot communicate, since their coverage does not reach the coverage of the another device. Several proposals to solve the problem of lack of infrastructure in an emergency scenario exist.

The project IMPROVISA [48] addresses the provision of information services in scenarios which, lacking a fixed communications infrastructure for any reason, require collaboration and performance of human resources and IT. The project provides technological solutions to this problem using MANETs that communicate with each other through wireless links. Furthermore, mobile agents are also used for the management of the deployed network.

The article "A Situation-Aware Mobile System to Support Fire Brigades in Emergency Situations" [28] describes the deployment of network and system support for emergencies, especially fires. For the network deployment, it proposes the use of mesh networks. Fire trucks are provided with wireless network in order to create a mesh network with PDAs carried by firefighters. This mesh network is interconnected to a fixed network (either wired or wireless) through one of its nodes. PDAs are provided with an indicator of the mesh network coverage. When a firefighter sees the coverage level decreases significantly and that it is about to disappear, he is responsible for installing a node to increase the mesh coverage. These nodes are small, portable, battery-operated and can be installed all around the area where necessary.

4.2.3 Decision Support Systems

They also urge the creation and use of a common language among all the teams, understood by all standard signals and of a compatible communication network between groups that help to coordinate the emergency from a decentralized point of view.

To manipulate so much heterogeneous information when designing a system, it must be carefully modeled its structure, the path followed and the decision process of the action. This will produce some tasks that have to be physically carried out by staff. The coordination of these tasks will also be important and will require the involvement of different teams and coordinators of different areas of the emergency (police, social welfare, etc.).

The actions may involve the use of non-personal but material resources. The management of these resources is something that must be taken into account in an emergency as these resources are finite. The number of blood units that are available for victims who needs urgent transfusions, ambulances available to transport the victims to the hospital, the number of beds and operating rooms available at nearby hospitals, etc. are some examples of resources that will necessary have to administer and know its quantity.

The authors of paper [10] aim to integrate the decision-making systems of all the equipment involved in the emergency. The information is automatically shared through the whole devices of the emergency scene and the decisions are based on the scope of the whole emergency.

4.2.4 User Interface

Some systems use specific interfaces on the PDA of the triage staff as a support for the management of information and triage assistance [19,44,36]. At first it seems like a good idea, but a difficult to read or non-intuitive an interface can lead to the opposite.

During an emergency everything is urgent and the staff responsible for the care of the victims cannot spend their time using a tiny keyboard on the PDA or a virtual keyboard on the touchscreen. PDA-personnel interaction should be easy, intuitive, and above all fast. The user of the PDA must comprehend, without reading a long text, what he is doing, what happened, and what the next step is. Therefore it is good to use pictures and intuitive interfaces for data input.

Paper [4] discusses the human-computer interaction related to the systems dedicated to emergency management and how this can influence the response. As a conclusion they define that a human being must be taken into account as part of the system and the hardware as part of the team. Thus, defining a communication between both is an easier task.

4.2.5 Interoperability

Response to an emergency involves different teams: rescue, firefighters, first aid, police. They have to share information and coordinate joint actions to perform. Normally, the action and communication protocols used by them are quite different. Therefore, define standard methods for communication between different emergency teams is of utmost importance if one wants an effective exchange of information and a good coordination [37].

The teams consist of an ad hoc basis by members of different teams with different roles and different priorities. These roles are well defined when these members are within their team. But in emergency situations, in which one must respond quickly and there are involved heterogeneous groups, roles are not predefined and must use improvisation. To deal with improvisation, decision support systems are used.

4.2.6 Agents

Agents can be a good resource to use for emergency management [9], since responding to an emergency requires many complex tasks performed by multiple actors under conditions of time and resource requirements.

During the emergency response agent-based systems can provide a number of important benefits:

- Agents have the ability to operate in highly dynamic environments.
- They can work in decentralized and distributed networks.
- They have the ability to search and collect distributed information, verify, process, analyze, and interpret it for later use and management.
- They are suitable for decision using the data collected by a single agent or exchanged with several agents.

Despite having these advantages, only a few emergency management systems are based on agents [9].

4.3 Communications in the Emergency Scene

The emergency scene is characterized by several zones. The first one is the Zone 0, also called the hot zone, which is the place where the disaster has happened and where the victims are at the beginning. Then there is the Zone 1, with the Advanced Medical Post (AMP) and the Advanced Command Post (ACP), which are improvised medical infrastructures for the emergency. Other zones can be considered outside of the emergency area, such as Zone 2 and Zone 3, for the hospitals which will receive the victims and the medical centers which have treated them before the incident respectively. This last comprises the data which compose the victims' medical records.

Referring to the emergency area, the AMP is the hospital that treat the victims before they can be transferred to a hospital. And the ACP is the place where the coordination team is. From this place, all the decisions about actions to be carried out by rescue and medical teams are taken.

Communications in the emergency scene are getting more and more important. This is due to the greater use of Internet enabled devices and mobile phones by the emergency personnel. Their devices require networks such as mobile phone network (3G) or WiMAX. In most of the emergency cases, hurricanes, terrorist attacks, floodings, and so on, these networks become unstable, unaccessible, overused and even destroyed. As a consequence, emergency personnel cannot use existing network infrastructure. Hence, they should deploy and use their own, or simply use wireless mobile ad-hoc networks (MANETs) or wireless mesh networks. These networks create routes by request of the nodes that are maintained as long as they are needed or the link is available.

If the emergency area is too large, it is possible that the ad-hoc network created by the medical personnel's devices would not be fully connected. As a result, an attempt to communicate between two points of the network could be unsuccessful.

The AMP and ACP always have Internet connection even if the network infrastructures are destroyed or unusable. They use their own deployed network infrastructure, for instance, satellite connections. For the AMP and the ACP, it is very important to have Internet connection for coordination or information communications (f.e. with another coordination point or with hospitals assigned to victims).

4.4 Critical Medical Information Retrieving System

In this section is explained the mechanism to retrieve VEPMRs from the emergency scene. In the context of this system each member of the triage and medical personnel is provided with a mobile device supporting mobile agents. This device allows any member of the triage or medical personnel to create a mobile agent with a VEPMR request when any personal document identification of the victim is found.

4.4.1 Retrieving System

Our proposal takes into account three possible scenarios in the emergency scene. The first one is the existence of a network infrastructure with Internet connection, e.g., cellular phones network infrastructure (GSM, EDGE or 3G). The second and third possible situation lack of a network infrastructure with Internet connection. The second one is a MANET composed of all the neighbor devices of the medical and triage personnel. In this situation, all the mobile devices are close enough each other to create a fully connected MANET and some of the mobile devices are near the AMP or ACP. As a result, all of them are connected Internet through the network infrastructure of the AMP or ACP, taking advantage of the usual usual ad-hoc networks routing protocols. Hence, from any part of the network it is possible to directly send the VEPMR request to the medical network. Finally, the third scenario is similar to the second one but the MANET is not fully connected. Thus clusters of devices without direct Internet access are created.

The application described in this chapter is focused on the third scenario. It is based on creating a mobile agent each time a VEPMR request is done. This mobile agent contains the identification of the victim whose VEPMR is requested. As the MANET is not fully connected, the request cannot be sent directly, thus, the mobile agent have to jump from device to device or cluster to cluster of devices until it reaches the ACP or AMP. Once the mobile agent has arrived, it can communicate the request to the VEPMR system of some hospital of the medical network. Mobile agents have been used to create a mobile agents based MANET. This network uses agent platforms as routers for the mobile agents, which are equivalent to packets in traditional networks. Therefore, the routing process is done in the application layer. Nevertheless, the routing decisions are taken by the mobile agents themselves, accessing and using attributes and values available in the application layer. Hence, it is possible to use specific routing protocols or policies in each agent and depending on the situation.

Using this method it is possible to route a mobile agent between two distinct points of the network despite being isolated in different clusters. In traditional networks this cannot be done because a fully connected network from the origin point to the destiny point is needed. Using mobile agents based MANET, the agents can wait for a connection if there is not, in any part of the network, thus, they can cover a part of the route. Furthermore, they can use different dynamic routing protocols to reach the destination point.

Different dynamic routing protocols can be used in the mobile agents based MANET. In this application, the objective of the mobile agents is to reach the AMP or ACP. So, the routing protocols must the best route spending the minimum time to arrive there. The protocol proposed for this application takes into account the time that the medical personnel expects to stay in the emergency scene to calculate the routing. Then, when a first responder leaves the meeting point they has to state when they will come back. So, each device stores the time when the personnel who carries it expects to return to the AMP. The mobile agent asks for this information for the service's platform of all the neighbor devices and jumps to the one that has the smaller return time value. In this way, the mobile agents arrives to the AMP as soon as possible. This is for security reasons because they will be in a emergency scene where some disaster has occurred and it is not fully safe. Therefore, they foresee a "time to return" (TTR) that they will put into their device.

Some special devices, for instance those installed in an emergency vehicle, can store a special "time to return" value. This is specially useful when an emergency vehicle has to go to the emergency scene and come back to the AMP or ACP, or the first responder has finished their job in the emergency scene and is coming back. In these situations the "time to return" will have a low value. Therefore, all the mobile agents near the platform with low TTR will jump into it because it is the fastest way to reach Internet.

It would wrongly seem that agents are not useful in the first situation, where mobile devices can connect directly to Internet using network infrastructure available in the emergency scene, and in the second situation, where the mobile devices can access to Internet through the fully connected MANET. However, in emergency situations the network infrastructures are usually unstable or over-saturated and mobile agents and the routing protocols implemented can deal with this situation.

When the VEPMR is retrieved, a copy is saved in the AMP and ACP. Then VEPMR will be already available once the victim reaches the AMP or ACP for the medical personnel treating them.

Security has also been taken into account in our system. VEPMRs consist of sensible private medical data. For this reason, this information has to be dealt with carefully using strong security mechanisms, and the communication between ACP, or AMP, and the VEPMR system has to be secure. The problem of security in ad-hoc networks is not fully solved nowadays. Even thought the very agents can protect the data they carry by using mechanisms such as [1]. Thus, the system could be used in insecure networks.

4.4.2 VEPMR for Emergencies

We also propose the creation of a special VEPMR containing only the relevant information for an emergency case. This VEPMR for emergencies (VEPMRE) contains the blood type, hepatitis, AIDS, allergies, and more basic information to treat the patient in an emergency case. Thanks to this, the VEPMRE has a smaller size so it uses less network bandwidth.

An important issue is how a VEPMRE is associated with the victim. An AMP may receive many VEPMRE from requests launched by the mobile agents, so how do the medical personnel know what VEPMRE corresponds to which victim? Our proposal is based on adding the identifier number of the triage tag with each VEPMRE request inside the mobile agent. In this way, once the VEPMRE is received it is possible to identify the victim, since the triage tag is always carried by them.

Fig. 3. Emergency scene and VEPMRE retrieval scheme

4.4.3 Implementation

An implementation has been developed as a proof of concept. A Nokia n810 touch screen-based mobile device with a MAEMO Linux distribution has been used as a hardware platform. The programming language used is Java with the JADE Framework [3] as agent platform, together with its FIPA-compliant mobility services [7].

IEEE 802.11g has been used as a network interface. When a device leaves the AMP or ACP, a TTR value is added as can be seen on the left side of Figure 4. When a first responder finds the identity of the victim, it can be introduced in the system and a VEPMRE request is sent (figure 4B). At this moment a mobile agent is created containing the identity of the victim. The mobile agents tries to move from platform to platform following the TTR routing protocol until it reaches the AMP or ACP.

Fig. 4. Implementation screenshots

5 The Mobile Agent Electronic Triage Tag (MAETT)

5.1 Introduction

Once an emergency occurs, the task of the first responder medical personnel arriving to the scene is triageing the victims they find [39] [18]. The triage consists of a protocol to sort victims according to their medical status in order to prioritize their needs for receiving medical attention. When all the victims are triaged, the medical personnel begins to treat them following the color-based prioritization.

The triage of the victims is an important issue to take into account and the implementation through electronic means must meet certain requirements:

- Data from the triage of the victims cannot be lost and its integrity must be guaranteed.
- The time spent to enter the victim information in the mobile device should be as short as possible and must not exceed the time to do it in the traditional triage.
- The triage must be possible under any condition, whether or not there are network or other technical conditions. In addition, the device must be shielded from withstand water, blood, or other fluids which may be in contact with them at the scene of the accident.
- The information should reach the control center, where the emergency is managed, as soon as possible to prepare the required resources for the victims attention on their arrival.

In this section, a system for the electronic triage of the victims using mobile agents [31,32] is explained.

5.2 Background

5.2.1 Introduction

This section describes and analyzes the main protocols for triaging victims in large scale emergency situations. Both, manual and electronic systems are discussed.

5.2.2 Traditional Victims Triage

At present there are different victims triage protocols, the most common protocol used is the START [15]. The protocol consists of the steps depicted in Figure 5. The whole procedure does not take more than 60 seconds for each victim.

As it can be seen in Figure 5 four colors are used to differentiate the possible states of the victim.

- Green color identifies the victim as delayed or low priority.
- Yellow color identifies the victim as urgent priority.
- Red color identifies the victim as immediate priority.
- Black color identifies the victim as deceased.

The triage protocol and the color labels provide an effective visual classification that allows the medical personnel to easily identify the victims which require more urgent attention. The protocol steps are described below:

First it is checked if the victim can walk. If they can, they are labeled with a green triage tag and they are asked to go by their means from the area where the accident or disaster area to where the field hospital is located. Once in the area of the field hospital, they may be treated by the medical staff. If no urgent attention is needed, they recommend the victim to go by themself to a health center where they can be attended.

If the victim has reduced mobility, or there is risk of injury in case of movement, the triage personnel do further checks. First the breathe is checked. If there is no breath, an airway is opened. If they continue without breathing, they are labeled with a black triage tag. If the victim recovers breath thanks to the actions of medical personnel he is labeled with a red triage tag.

In case the patient without mobility breathes, the number of breaths per minute are checked. If they exceed 30 or they are less than 10, the victim is labeled with a red triage tag. Otherwise, the pulse is checked.

The pulse is checked in the wrist. If no pulse is found or if it is over 120 beats per minute, the victim is labeled with a red triage tag. If it is below 120, the response of the victim to some simple commands is checked. If the patient responds correctly to the orders, a yellow triage tag is assigned, otherwise a red one is chosen.

It should be said that wrist pulse may be replaced by a capillary test. The index finger of the victim is pressed for a few seconds and how long filling of blood vessels takes, i.e., the time since the area changes from white color to red again, is measured. If it is under 2 seconds a yellow triage tag is assigned, otherwise it is labeled red.

Triage tags are placed around the neck or wrist of the victim and allow to classify the victims according to their severity, so that when medical help arrives the status of each victim can be easily distinguished.

5.2.3 Electronic Triage Systems

Some systems [35] [22] [14] use as a substitute for the traditional triage tag electronic devices with features that improve the current system. These devices have cardiac

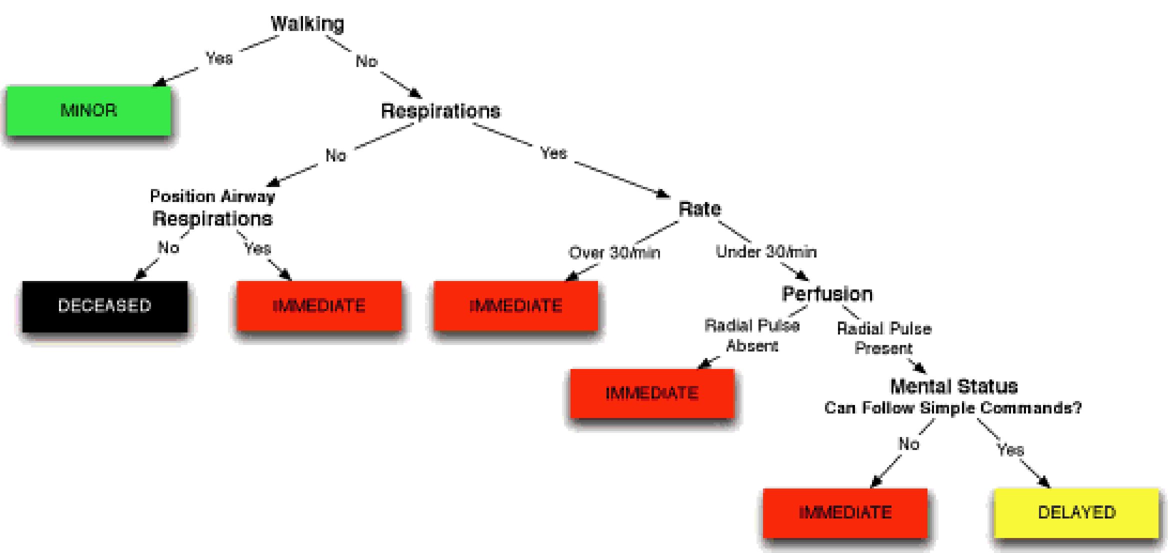

Fig. 5. START Flow

sensors, GPS, wireless network capabilities, the ability to read the data via network, and so on. These characteristics entail clear advantages with respect to paper triage tags. Nonetheless, because of the complexity of the devices and because of the fact that several of them are required, the economic cost of deployment must be carefully considered.

Nevertheless, it must be taken into account that these triage devices are reused. Furthermore, they are exposed to liquid and strokes and may be damaged. The battery of these devices is also an issue to keep in mind, since it must be checked that it is at its maximum capacity before leaving to the emergency. Some of the existing electronic systems for victims triage are described in the next lines.

ARTEMIS [36] is an automated system for the classification and management of casualties that occur in an emergency scene. It uses a network of physiological sensors that are placed on the victim for checking their vital signs and apply the START procedure. It also uses wireless sensor networks to communicate with medical personnel PDAs as well as with the control center located at the base camp.

The CodeBlue project [44] is based on a sensor network for detecting the physiological condition of the patient and transmitting this data to a remote device. With this data one can make an assessment of the patient status and classify them properly.

The Decentralized Electronic Triage System [35] is a system which goal is to create a very low power consumption hardware that emulates the operation of a paper triage tag. This device has buttons to select the patient's condition through some color LEDs for the triage tag. The device can be controlled remotely and provides telemetry to consult data connecting through a wireless network . Each device has a GPS receiver and a radio frequency transmitter to locate victims.

TacMedCS [38] is a military project from the United States to capture and display data in real-time from casualties in the battlefield. It uses radio frequency tags to identify victims and save their data. A mobile device is also used to store data of the victim together with their GPS position and to send them to the database of central server using satellite communications. The information from the victim and their triage travel along them in the RFID tag. In the central server one can check the status of the victim. Besides communications based on mesh networks are used for collaboration through the mobile devices.

The system proposed in [17] is devoted to the triage of casualties using a triage tag with an RFID. The system consists of a traditional triage tag with an attached RFID tag and a mobile device with an RFID reader. Moreover, the PDA has a wireless network interface. Nevertheless, it is required that the PDA has some type of coverage with the wireless network interface device. When the medical staff sorts the victim, he puts the triage tag and reads it with the mobile device. He performs the triage protocol and places the results, comments and processing carried out in the paper triage tag as well as in the mobile device. This information is sent through the wireless network to a central server that stores all information that is collected at the emergency scene. Data from the central server can be consulted by the coordinator of the emergency so that he knows the resources needed to meet the demand. All the equipment are provided with RFID readers and connection to the central server with data associated with the victim's ID from the RFID.

WIISARD [22] also includes an intelligent 802.11 triage tag device. It provides water and handling resistance, wireless networking support, remote operation and a battery of 8 to 12 hours of operation. Victims are triaged by staff with PDAs. After this step, personnel puts this devices on the victim and synchronizes it with the patient data entered in the PDA. The triage tag recognizes and displays the data through its color LEDs for the status of the patient's severity. The wireless network can connect to transmit the position it is. These nodes include GPS to know their position and they use ad hoc network and mesh protocols for the deployment of the network .

5.3 Emergency Zones Definition

The first step towards the definition of a new electronic triage tag mechanism is the modeling of the zones that comprise the place of an emergency and the services they offer.

5.3.1 Zones

The emergency scenario has been split in different zones (Figure 6). The zones range from Zone 0, where the emergency arises, to Zone 3, where the routine medical visits are done.

To better understand the differentiation between these zones, we will put an example. Suppose a tragedy like that of a large earthquake in a major city.

Zone 0

The natural disaster produce some hot spots of different extensions. These hot-spots are what we call Zone 0. There, network infrastructure existence is not guaranteed. Therefore it must be assumed that in practice no available networks exist.

Zone 1

The management of all zones, takes place in Zone 1. Within Zone 1 there are field hospitals, the control center (the place from where the emergency is coordinated and where its information collected), and ambulance and rescue equipment in general. Field hospitals, which are also included in this zone may be associated to one or more Zone 0.

Zone 2

The network of hospitals and medical centers close to the emergency compose Zone 2. This zone is the destination of the victims. It is characterized by having stable communication networks which connect the rest of the hospitals.

Zone 3

This zone comprise the regular medical centers that the victims have visited during their lives. In short, they compose all those actions that have recently featured in the medical record.

The integration of Zone 3 in the proposed scheme may not seem obvious, since it has no apparent direct relationship with the emergency. However, the need to have a minimum medical history for use in emergency situations is the main argument for including the zone in the diagram, as the creation and management of history is intimately linked with the entities that make up the zone. These clinical records contain the minimum basic information from a patient (blood group, chronic or contagious diseases, allergies, and so forth), which may be essential in an emergency situation, e.g., this allows more

Fig. 6. Emergency zones schema

efficient care to a patient in a state of emergency (to ask for a blood type, medication supplies, and so on) as well as protect the health team of a possible contagion. The system explained in Section 4 provides this functionality.

5.3.2 Services

A key element defining the zones are the services they offer. A list of services are offered by the system in each of them according to their specific needs.

Zone 0 offers localization, triage and basic care of the victims in the emergency.

Zone 1 manages the emergency, such as transport victims, emergency care in field hospitals, management of accidents, calculation of the optimal pathway for transport, and so on.

Zone 2 offers treatment services and basic operations with specialists such as neurosurgeons, trauma, and so forth.

And finally, Zone 3, provides information about the victims' medical records.

Services are processed and supplied by the emergency system. These services may be required from another part of the emergency system in a manual and automatic way.

5.4 The Mobile Agent Electronic Triage Tag System

5.4.1 System Description

The system aims to manage an emergency from a point of view of the victims. It takes care of managing the resources to search, attend, and transport the victims. The system deals with the tasks comprised from the triage of the victims at the emergency scene to the reservation of the resources needed at the hospital where the victims are transferred.

Let's suppose a scenario with many casualties caused by a large scale emergency, and with the victims spread over a large area. Doctors, caregivers and triage personnel are equipped with identification reflective vests. In addition, triage personnel (staff, from now on) is equipped with bandoliers integrating a PDA, with touch screen tied to an arm, and an additional high capacity battery. This PDA includes a GPS and a RFID reader. The bandoliers contain pockets with first aid equipment to facilitate the task of the emergency personnel, including electronic triage tags, later explained.

When a victim is found, he is labeled with an electronic triage tag, that is composed of a traditional paper triage tag along with a conventional RFID tag that provides the ability to be digitally identified. In this way, reading the RFID tag a unique identifier is obtained to uniquely identify the victim within the emergency. Before labeling the victim, the staff shall approach the electronic triage tag to the PDA that read the incorporated RFID. Then a software wizard to help staff to assess the state of the victim (Figure 7) is activated.

This software provides all the steps required to follow the START protocol (breathing, pulse, responds to simple questions, etc.) and perform the triage (Figure 8).

The software interface of the wizard (Figure 7) is simple, with intuitive icons, short and understandable text, and large buttons that facilitate the use of the touch screen.

Furthermore, its use is optimal for triage because it does not increase the time devoted to follow the START protocol (which must be as short as possible) and benefits from the available data already digitized.

Once the process has been completed, a recommendation of status (color) for the victim is suggested: green for *MINOR)*, yellow for *DELAYED*, red for *IMMEDIATE*, and black for *DECEASED*. This status can be accepted by the staff or may be changed to another one that the staff considers more appropriate.

After selecting the state (color) of the victim, the software will read the GPS device position where the staff, and therefore the victim, is at that time.

5.4.2 Mobile Agent Electronic Triage Tag

The mobile agent crated after the triage will include the status (color of the triage tag) of the victim, the GPS position, the unique identifier of the triage tag, and the patient's vital data (pulse, respiration, and so on).

This mobile agent will stay in the personnel PDAs waiting to arrive to the field hospital for, later, moving to the emergency control center system. During the travel from the Zone 0 to the Zone 1, the mobile agent will try to get to the emergency control center as fast as possible by jumping between the PDAs of the emergency personnel.

The decision of a mobile agent to jump or not to jump to a PDA of another staff or to a computer of an ambulance will depend on the application level routing protocol used by the mobile agent. The use of the TTR routing protocol (see Section 4.4.1) is encouraged.

5.4.3 Additional Services

Apart from the routing service, staff PDAs may offer different specific services. For example, in the event of a medical staff performing triage in Zone 0 is a specialist in any

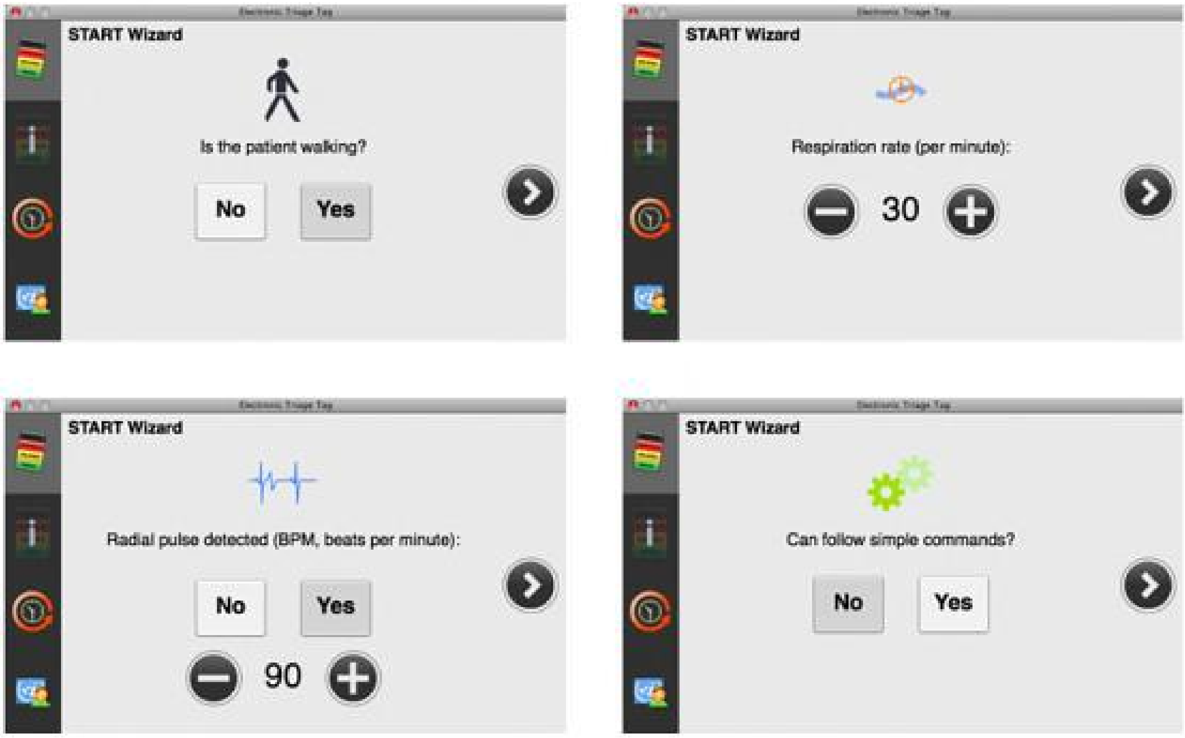

Fig. 7. Software wizard for the triage of victims

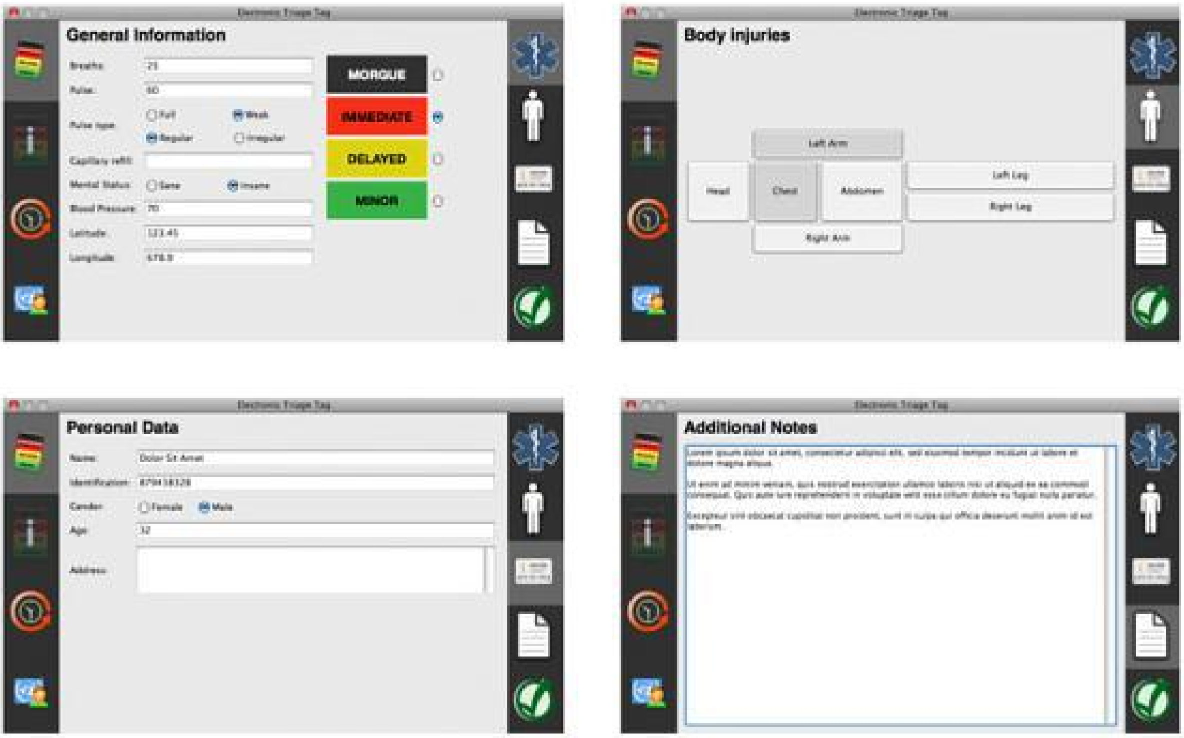

Fig. 8. Electronic Triage Tag

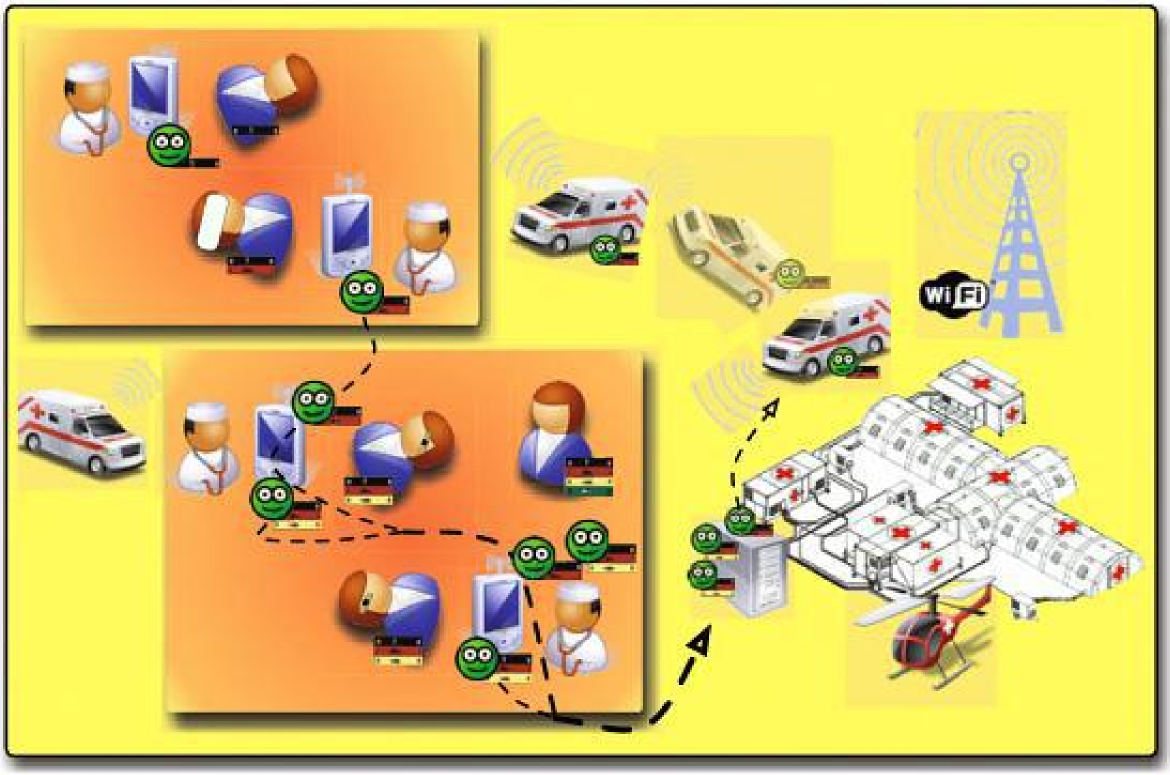

Fig. 9. Electrnic Triage Tag based on Mobile Agents

field of medicine, could provide services associated with his specialty. These may be viewed by the agents and may make requests to be booked by assigning such a victim to a particular specialist. A petition will not always be accepted and may be denied, e.g., because the resource is busy. There is also the option for example of disabling the service, when staff are returning to the control centre or the service has already been reserved by another mobile agent.

Services not only can be unitary, meaning that only pertain to or have a single staff, but there may be services offered by a group. For instance, one can define emergency rescue teams, dedicated to rescuing victims in dangerous floodings or similar. In this case would have the special feature of the service that the entity would be distributed and virtual. This service could be sued by a mobile agent in case that before launching it the staff indicate that a rescue operation to retrieve the victim is required.

5.4.4 Control Center

The control center is responsible of receiving all mobile agents coming from Zone 0. This system may be distributed, i.e., it may comprise more than one server that will be able to exchange data, since they are connected to each other. The control center have a wireless network access point to allow the communication with the arriving PDAs.

Furthermore, the control center keep all the information gathered by the mobile agents. It may know the position of the victims, their status, and whether there are special needs for each one. This eases to plan routes for the collection of the victims by placing higher priority on those that have been selected for such. There may even be a map of the affected area with color dots indicating the status (color) and the position of the victim within the map, which will help the emergency organization and management staff to have a clearer idea of the distribution of victims.

5.4.5 Medical Transportation

After the collection of the victim, personal data from him can be obtained, either because the victim was able to give any of its data or because identification documentation has been found. In this case the new data can be reported inside the agent reading the RFID of the electronic triage tag. Within the rescue vehicles there is a laptop which also allows to update the personal data and/or medicines and treatments provided to the patient.

5.4.6 Shared Medical Record

While the patient is transferred to a hospital or medical center a reservation and preparation of resources can be made. This task may be automatically done by the agent in the area of the emergency. It can contact with the agent in charge of the hospital management and establish an agreement with the institution where the victim is transferred. After the ambulance has picked the victim, the time it takes to get to the hospital may be foreseen so when the victim arrives everything will be ready with the materials and resources needed.

Moreover, if it has been able to collect patient data and added them to the mobile agent, during transit from the collection of the victim to the hospital, he may take advantage of fixed wireless networks, for example, to pass this information to the agent in the hospital.

6 Conclusions

Along this chapter, three eHealth applications using mobile agents have been described. They have shown how mobile agent technology can be successfully applied in this domain, solving some important issues such as interoperability or asynchronous communication.

The first case was based on the integration of medical information. This system provides a global integration of agent-based VEPR systems through secure and standardized mobility and communication mechanism. The system is focused towards a reliable intra-institution integration, allowing a medical doctor from a given institution to have access to all the patient information that can be spread over different medical institutions.

This system makes clear the advantages that agent mobility and agent-driven security add to medical information gathering systems, promoting free patient roaming, up-to-date distributed VEPR access, and other new functionalities such as inter-institution secure information exchange.

The second analysed scenario was a practical application of mobile agents to solve the particular problem of getting critical information about a victim before arriving to a hospital for treatment. It makes it possible to asynchronously retrieve significant information (Virtual Electronic Patients Medical Record for Emergencies, VEPMRE), such as allergies or infectious diseases, from the patient record while the victim is still in transit.

In this case, mobile agents are used to bring critical information forward to the emergency area, thus improving the treatment received by the victim.

Finally, a support system based on the use of mobile agents for the transmission of electronic triage tag information has also been presented. The most important feature of this application is that no end-to-end communication is needed at all, and therefore it can operate without any infrastructure.

All three cases showed common problems in large eHealth systems, and illustrated at the same time how mobile agents can be used to face them. One of the most important conclusions drawn is that agents have been crucial to face the high complexity of these systems. Should traditional technologies had been used to solve these problems, a greater effort in designing would have been required. Besides, the current scalability in all the systems would have been very difficult to achieve, if not impossible.

Basic interoperability problems where solved partially by using the standards defined by IEEE-FIPA (*http://www.fipa.org*). In particular, the Agent Communication Language (ACL) was of great help for designing interactions.

Mobile agents are being used more and more commonly in complex distributed applications, such as complex eHealth systems. However, there is still a long way to run to make the most of mobile agents in this domain. Currently, there are some promising lines of research going on. Integrating different applications to find out interoperability problems is one of them. Also, applying Role Based Access Control (RBAC) to mobile agents in this scenario is being explored. Although the RBAC policies provide for a good access control management, some situations might need additional mechanisms for a more flexible adaptation to sudden changes in the organization or emergency situations. Discretionary delegation of permissions could be of special interest.

The information systems described in this chapter could also be used in different domains other than eHealth, such as public administration or universities. In these scenarios, there exist heterogeneous distributed information sources that could benefit from the results of this work, showing another advantage of using the paradigm of mobile agents: re-usability.

References

1. Ametller, J., Robles, S., Ortega-Ruiz, J.A.: Self-protected mobile agents. In: 3rd International Conference on Autonomous Agents and Multi Agents Systems, July 2004, vol. 1, pp. 362–367. ACM Press, New York (2004)
2. Barnett, O.: Computers in medicine. In: JAMA, vol. 263, pp. 2631–2633 (1990)
3. Bellifemine, F.L., Caire, G., Greenwood, D.: Developing Multi-Agent Systems with JADE, January 2006. Wiley, Chichester (2006)
4. Carver, L., Turoff, M.: Human-computer interaction: the human and computer as a team in emergency management information systems. Commun. ACM 50(3), 33–38 (2007)
5. Chen, R., Sharman, R., Rao, H.R., Upadhyaya, S.J.: Design principles of coordinated multi-incident emergency response systems. In: Kantor, P., Muresan, G., Roberts, F., Zeng, D.D., Wang, F.-Y., Chen, H., Merkle, R.C. (eds.) ISI 2005. LNCS, vol. 3495, pp. 81–98. Springer, Heidelberg (2005) Times Cited: 0

6. Cruz-Correia, R., Vieira-Marques, P., Costa, P., Ferreira, A., Oliveira-Palhares, E., Araújo, F., Costa-Pereira, A.: Integration of hospital data using agent technologies - a case study. AI Commun. 18(3), 191–200 (2005)
7. Cucurull, J., Martí, R., Navarro-Arribas, G., Robles, S., Overeinder, B.J., Borrell, J.: Agent mobility architecture based on IEEE-FIPA standards. Computer Communications 32(4), 712–729 (2009)
8. Demchak, B., Chan, T.C., Griswold, W.G., Lenert, L.A.: Situational awareness during mass-casualty events: command and control. In: AMIA Annu. Symp. Proc., p. 905 (2006) Times Cited: 0
9. Fiedrich, F., Burghardt, P.: Agent-based systems for disaster management. Commun. ACM 50(3), 41–42 (2007)
10. French, S., Turoff, M.: Decision support systems. Commun. ACM 50(3), 39–40 (2007)
11. Fry, E.A., Lenert, L.: Mascal: Rfid tracking of patients, staff and equipment to enhance hospital response to mass casualty events. In: AMIA Annual Symposium Proceedings, pp. 261–265 (2005)
12. Fuggetta, A., Picco, G.P., Vigna, G.: Understanding code mobility. IEEE Trans. Softw. Eng. 24(5), 342–361 (1998)
13. Asokan, N., Karjoth, G., Gülcü, C.A.: Protecting the computation results of free-roaming agents. In: Rothermel, K., Hohl, F. (eds.) MA 1998. LNCS, vol. 1477, p. 195. Springer, Heidelberg (1998)
14. Gao, T., White, D.: A next generation electronic triage to aid mass casualty emergency medical response. In: 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS 2006, 30 2006-September 3, pp. Supplement:6501–6504 (2006)
15. Gebhart, M.E., Pence, R.: Start triage: Does it work? Disaster Management and Response 5(3), 68–73 (2007)
16. Gray, J.: Distributed computing economics. In: Herbert, A., Jones, K.S. (eds.) Computer Systems: Theory, Technology and Applications, December 2003, pp. 93–101. Springer, Heidelberg (2003), Also MSR-TR-2003-24, March 2003
17. Inoue, S., Sonoda, A., Oka, K., Fujisaki, S.: Emergency healthcare support: Rfid based massive injured people management. In: Pervasive Healthcare Workshop in Ubicomp 2006 (UbiHealth), September 2006, p. 9 (2006)
18. Kennedy, K., Aghababian, R.V., Gans, L., Lewis, C.P.: Triage: Techniques and applications in decisionmaking. Annals of Emergency Medicine 28(2), 136–144 (1996)
19. Killeen, J.P., Chan, T.C., Buono, C., Griswold, W.G., Lenert, L.A.: A wireless first responder handheld device for rapid triage, patient assessment and documentation during mass casualty incidents. In: AMIA Annu. Symp. Proc., pp. 429–433 (2006)
20. Kim, G.S., Eom, Y.I.: Domain-based mobile agent fault-tolerance scheme for home network environments. In: Chen, K., Deng, R., Lai, X., Zhou, J. (eds.) ISPEC 2006. LNCS, vol. 3903, pp. 269–277. Springer, Heidelberg (2006)
21. Kopena, J.B., Sultanik, E.A., Lass, R.N., Nguyen, D.N., Dugan, C.J., Modi, P.J., Regli, W.C.: Distributed coordination of first responders. IEEE Internet Computing 12(1), 45–47 (2008)
22. Lenert, L., Palmar, D., Chan, T., Rao, R.: An intelligent 802.11 triage tag for medical response to disasters. In: AMIA Annual Symposium Proceedings, pp. 440–444 (2005)
23. Lenert, L., Chan, T.C., Griswold, W., Killeen, J., Palmer, D., Kirsh, D., Mishra, R., Rao, R.: Wireless internet information system for medical response in disasters (wiisard). In: AMIA Annual Symposium Proceedings, pp. 429–433 (2006)
24. Lenz, R., Kuhn, K.A.: Integration of heterogeneous and autonomous systems in hospitals. In: Data Management and Storage Technology (2002)

25. Li, Y.D., He, H.G., Xiao, B.H., Wang, C.H., Wang, F.Y.: Cwme: A framework of group support system for emergency responses. In: Mehrotra, S., Zeng, D.D., Chen, H., Thuraisingham, B., Wang, F.-Y. (eds.) ISI 2006. LNCS, vol. 3975, pp. 706–707. Springer, Heidelberg (2006) Times Cited: 0
26. Liang, H.G., Xue, Y.J.: Investigating public health emergency response information system initiatives in china. International Journal of Medical Informatics 73(9-10), 675–685 (2004) Times Cited: 5
27. Oliveira, A.-I., Camarinha-Matos, L.M., Rosas, J.: Tele-care and collaborative virtual communities in elderly care. In: Proceedings of the 1st International Workshop on Tele-Care and Collaborative Virtual Communities in Elderly Care, TELECARE 2004 (2004)
28. Luyten, K., Winters, F., Coninx, K., Naudts, D., Moerman, I.: A situation-aware mobile system to support fire brigades in emergency situations. In: Meersman, R., Tari, Z., Herrero, P. (eds.) OTM 2006 Workshops. LNCS, vol. 4278, pp. 1966–1975. Springer, Heidelberg (2006)
29. Manoj, B.S., Baker, A.H.: Communication challenges in emergency response. Commun. ACM 50(3), 51–53 (2007)
30. Marsa-Maestre, I., Lopez, M.A., Velasco, J.R., Navarro, A.: Mobile personal agents for smart spaces. In: ACS/IEEE International Conference on Pervasive Services, pp. 299–302 (2006)
31. Martí, R., Robles, S., Martín-Campillo, A., Cucurull, J.: Method and system for information management and victims classification, based on its condition, in emergency situations. Spanish Patent Pending P200803741 (2008)
32. Martí, R., Robles, S., Martín-Campillo, A., Cucurull, J.: Providing early resource allocation during emergencies: the mobile triage tag. In: Journal of Network and Computer Applications (2009) (accepted)
33. Martín-Campillo, A., Martí, R., Robles, S., Martínez-García, C.: Mobile agents for critical medical information retrieving from the emergency scene. In: 7th International Conference on Practical Applications of Agents and Multi-Agent Systems, Advances in Intelligent and Soft Computing. Springer, Heidelberg (2009)
34. Martínez-García, C., Navarro-Arribas, G., Borrell, J., Martín-Campillo, A.: An access control scheme for multi-agent systems over multi-domain environments. In: 7th International Conference on Practical Applications of Agents and Multi-Agent Systems. Advances in Intelligent and Soft Computing. Springer, Heidelberg (2009)
35. Massey, T., Gao, T., Welsh, M., Sharp, J.H., Sarrafzadeh, M.: The design of a decentralized electronic triage system. In: AMIA Annual Symposium Proceedings, pp. 544–548 (2006)
36. McGrath, S., Grigg, E., Wendelken, S., Blike, G., De Rosa, M., Fiske, A., Gray, R.: Artemis: A vision for remote triage and emergency management information integration. Dartmouth University (November 2003)
37. Mendonça, D., Jefferson, T., Harrald, J.: Collaborative adhocracies and mix-and-match technologies in emergency management. Commun. ACM 50(3), 44–49 (2007)
38. US Navy. Tactical medical coordination system (tacmedcs), http://www.namrl.navy.mil/clinical/projects/tacmedcs.htm
39. National Association of Emergency Medical Technicians U.S. and American College of Surgeons. PHTLS–basic and advanced prehospital trauma life support, 4th edn., Mosby, St. Louis (1999)
40. Pavlopoulos, S., Kyriacou, E., Berler, A., Dembeyiotis, S., Koutsouris, D.: A novel emergency telemedicine system based on wirelesscommunication technology-ambulance. IEEE Transactions on Information Technology in Biomedicine 2(4), 261–267 (1998)
41. Portmann, M., Pirzada, A.A.: Wireless mesh networks for public safety and crisis management applications. IEEE Internet Computing 12(1), 18–25 (2008)
42. Costa, P., Cruz-Correia, R., Vieira-Marques, P.: Integration of hospital data using agent technologies - a case study. AICom 18, 191–200 (2005)

43. Satoh, I.: Building reusable mobile agents for network management. IEEE Transactions on Systems, Man and Cybernetics, Part C: Applications and Reviews 33(3), 350–357 (2003)
44. Shnayder, V., rong Chen, B., Lorincz, K., Fulford Jones, T.R.F., Welsh, M.: Sensor networks for medical care. In: SenSys 2005: Proceedings of the 3rd international conference on Embedded networked sensor systems, pp. 314–314. ACM, New York (2005)
45. Barnett, G.O., Murphy, S.N., Rabbani, U.H.: Using software agents to maintain autonomous patient registries for clinical research. In: Proc. AMIA Annu. Fall Symp., pp. 71–75 (1997)
46. Thant, H.A., San, K.M., Tun, K.M.L., Naing, T.T., Thein, N.: Mobile agents based load balancing method for parallel applications. In: Proceedings of 6th Asia-Pacific Symposium on Information and Telecommunication Technologies, APSITT 2005, November 2005, pp. 77–82 (2005)
47. Van de Walle, B., Turoff, M.: Decision support for emergency situations. Information Systems and E-Business Management 6(3), 295–316 (2008), M3: 10.1007/s10257-008-0087-z
48. Velasco, J.R., López-Carmona, M.A., Sedano, M., Garijo, M., Larrabeiti, D., Calderon, M.: Role of multi-agent system on minimalist infrastructure for service provisioning in ad-hoc networks for emergencies. In: Proceedings of AAMAS 2006, pp. 151–152 (2006)
49. Vieira-Marques, P., Robles, S., Cucurull, J., Cruz-Correia, R., Navarro, G., Martí, R.: Secure integration of distributed medical data using mobile agents. IEEE Intelligent Systems 21(6), 47–54 (2006)
50. De Capitani Di Vimercati, S., Ferrero, A., Lazzaroni, M.: Mobile agent technology for remote measurements. IEEE Transactions on Instrumentation and Measurement 55(5), 1559–1565 (2006)
51. White, J.E.: Telescript technology: Mobile agents. In: Bradshaw, J. (ed.) Software Agents, AAAI Press/MIT Press, Menlo Park (1996)
52. Wong, D., Paciorek, N., Walsh, T., DiCelie, J., Young, M., Peet, B.: Concordia: An infrastructure for collaborating mobile agents. In: Rothermel, K., Popescu-Zeletin, R. (eds.) MA 1997. LNCS, vol. 1219. Springer, Heidelberg (1997)
53. Wooldridge, M., Jennings, N.R.: Intelligent agents: Theory and practice. Knowledge Engineering Review 10(2), 115–152 (1995)
54. Wyatt, J.C.: Clinical data systems, part 1: Data and medical records. Lancet 344, 1543–1547 (1994)

Appendix D

"Using Haggle to create an Electronic Triage Tag"

Using Haggle to Create an Electronic Triage Tag

Abraham Martín-Campillo*
Department of Information and Communications Engineering
Universitat Autònoma de Barcelona
08193 Bellaterra, Spain
abraham.martin@uab.cat

Jon Crowcroft, Eiko Yoneki
Systems Research Group
University of Cambridge
Cambridge, UK
{jon.crowcroft, eiko.yoneki}@cl.cam.ac.uk

Ramon Martí † and Carlos Martínez-García ‡
Department of Information and Communications Engineering
Universitat Autònoma de Barcelona
08193 Bellaterra, Spain
{ramon.marti.escale, carlos.martinez}@uab.cat

ABSTRACT

Forwarding data in scenarios without connectivity, Pocket Switched or Opportunistic networking can be difficult without a mobility model, or a history of node contacts. One of these scenarios is a disaster, where forwarding victim's medical information to a coordination point is critical for the good and fast intervention. "Time To Return" (TTR) forwarding was used in combination with mobile agents in MAETTS to provide early resource allocation during such emergencies. In this paper, we propose to apply TTR forwarding in Haggle to create an Electronic Triage Tag. This approach allows us to take advantage of short connectivity opportunities between nodes.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless Communication*; C.2.2 [**Computer-Communication Networks**]: Network Protocols—*Routing protocols*

General Terms

Design

Keywords

Delay Tolerant Networks, Pocket Switched Networks

*Supported by the Spanish Ministerio de Educación y Ciencia (FPU grant AP2008-03149)

†Partially supported by the Catalan DURSI Grant 2009SGR1224.

‡Supported by Universitat Autònoma de Barcelona (PIF grant 472-01-1/07)

1. INTRODUCTION

When a mass casualty incident occurs, many rescue personnel are involved in caring for victims. The coordination of these personnel is vital to speed up the rescue process and to minimise the loss of lives. Having information about the number of victims, their location, and their injury level is essential to prioritise individual treatment.

Medical aid for victims must be prioritised based on their condition. For this reason, the medical personnel arriving early to the emergency scene perform triage, to determine injury levels. As a result, victims are sorted into groups based on their need for immediate or urgent medical treatment. Consequently, medical personnel arriving later know those victims who need more attention. The victims are stabilised and prepared, in injury level order, to be evacuated to hospital, where they can be treated more thoroughly.

In the great majority of mass casualty incidents, infrastructure becomes unstable, inaccessible, overused or is even destroyed. Hence, communications in the emergency area cannot rely on existing wireless network infrastructures. In consequence, emergency personnel may deploy and use their own infrastructure, for example using a wireless mobile adhoc networks (MANETs), to transmit triage information. However, if the area is too large, it may not be feasible to have a fully connected MANET.

The aim of this paper is to present a system based on Haggle to triage victims in a mass casualty incident, transmitting this information to the emergency Coordination Point (CP) from the emergency area, without relying on unstable communication infrastructure, nor on the deployment of a new infrastructure or the a fully connected MANET.

2. BACKGROUND

The proposed system is based on various existing technologies, including: triage protocols; Haggle; and DTN forwarding schemes. We present background information on these next.

2.1 Triage

There exist several triage protocols for emergency situations. The START protocol [9] is the most widely used. This classifies victims into one of four groups depending on their condition. In order of from worst to best condition, the first group is black. Victims triaged in the black group are deceased, or in such bad condition that it is impossible for the medical team to do anything to save them. The second group, red, contains victims who need immediate attention. The victims in the third one, yellow, do not need immediate medical attention, and can wait for a short period of time. Finally, the green group is for victims with minor injuries, who need help less urgently.

Handheld devices are frequently used in emergency scenes by rescue personnel to triage victims [5][3].

2.2 Haggle

Haggle [7] is an autonomic networking architecture designed to exploit opportunistic communications (i.e., in the absence of end-to-end communication). When an application wants to send some data, a direct connection to the receiver or receivers is not required, and even the identities of the receivers can be unknown. Haggle implements improvements over classic communications architecture by using a data-centric communication model with a publish-subscribe API. The representation of data in Haggle is as DataObjects, which are made up of attributes with corresponding values. An application can subscribe its interest to DataObjects with a specified attributes, or to only these DataObjects with a specified value of an attribute. When an application subscribes to one or more interests, it will receive all DataObjects matching these interests. This is known as interest based forwarding.

Furthermore, Haggle provides underlying functionality for neighbour discovery, resource management and resolution, thus removing the need to implement such features in applications. The architecture of a Haggle platform is composed by a kernel and a group of managers. Each manager performs dedicated tasks in parallel sharing data with the other managers as the neighbours list, the opening sockets and the data send by the applications. Managers can be added or deleted from the kernel any without negative impact on, or complex interaction with other managers.

2.3 Pattern based forwarding

In PSNs or DTNs scenarios, data about social networks, node contacts and the history of movements between places, are commonly used to support decisions for forward packets. Some examples of different forwarding approaches are given next.

2.3.1 Social attraction

Musolesi et al [6] proposed a forwarding method based on a mobility model founded on social network theory. The authors propose to use the social relations between individuals to create a matrix. Each relation is associated with a weight depending of the strength of the social relation. This weight will be later used to take forwarding decisions.

2.3.2 Levy walks

Levy walks [8] consist of routes that a creature follows during over some period. During a week, an individual usually does the same movements each day: commuting from home to work, from work to restaurant, from restaurant back to work, and then, back to home. These walks or *flights* can be modelled, and later on used as routing information, predicting individuals' contacts.

2.3.3 Time To Return (TTR) forwarding

In *Martí, R. et al* [4], a new routing protocol, Time To Return (TTR), is proposed. Medical personnel in an emergency scenario are coordinated by a leader. The leader, or a group of leaders, tells personnel where to go to, or in which area to work [4]. When they leave the coordination point, a maximum time to return to the base is assigned to them. They are required to return to base for security reasons, before this time has passed.

2.3.4 Delegation forwarding

TTR forwarding is an example of Delegation forwarding [1]. *Vijay Erramilli et al.*, a proposed generalisation of forwarding methods such as BUBBLE Rap [2] or TTR. This generalisation applies to mobile opportunistic networks with unpredictable mobility, heterogeneity of contact rates and lack of global information. Achieving delivery of messages without flooding in such network is challenging. In Delegation forwarding, each node has an associated value which is created using a metric that represents the quality of the node as relay. The metric used depends of the scenario where it will be used.

3. HAGGLE ELECTRONIC TRIAGE TAG

In this paper we present Haggle Electronic Triage Tag (Haggle-ETT), an application dedicated to the triage of victims in emergency scenarios where there is no infrastructural network, and a fully-connected MANET is not feasible due to the large geographical extent of the scene. Our application uses Haggle as middleware. Haggle allows the application to run in Pocket Switched Networks (PSN) or Delay and Tolerant Networks (DTN) without relying on the state of the network. Haggle is in charge of managing the network, connectivity, contacts, neighbours and more. Because of these features, Haggle was chosen as the base architecture for our system.

The default forwarding method in Haggle is simply sending DataObjects that match the interest of the target whenever a node contact occurs. This forwarding method is effectively epidemic in our emergency scenario, since all nodes have interest in delivering this information to the coordination point. However, sending data in an epidemic way in emergency scenarios may not be efficient. Battery has to be preserved as much as possible and, furthermore, sending data in an epidemic fashion may waste opportunities for forwarding data to better choices of nodes who could deliver the data sooner to the coordination point. For instance, if two node contacts occur at the same time, and both contacts are short in duration, it is possible that the sender node only has time to forward the data via one of these nodes. Data sent in this manner will go via the first node contacted in an epidemic manner, and not the second; but in our scheme for TTR forwarding, data is sent to the node that will deliver the data soonest to the coordination point.

TTR forwarding is a novel method for forwarding[4], using Haggle. It can provide faster delivery of triage information to the coordination point, and therefore accelerate the treatment of victims. We have developed a Haggle manager to implement TTR forwarding support, together with an application that is in charge of creating the Electronic Triage Tags (ETTs).

The aim of this whole system, the application plus the Haggle middleware with TTR forwarding, is to route triage

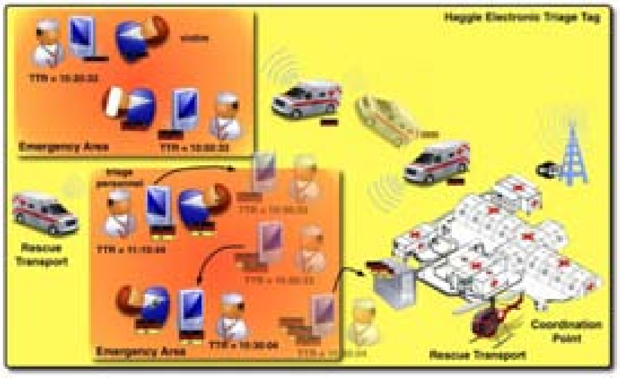

Figure 1: Haggle-ETT scenario

information of victims in the form of *Triage DataObjects* to a Coordination Point where this information will be used to treat the victims in a prioritised way according to their injury level. This system is designed to work in the worst emergency scenarios without any network connection, relying solely on node contacts, even over wide geographic areas. However, Haggle-ETT and the TTR forwarding method not only works in these type scenarios, but will also work even better where there is network connectivity.

3.1 Triage Process

Medical personnel are equipped with handheld devices, and use them to triage victims. The handheld, running the Haggle-ETT application and the Haggle middleware, displays a wizard that follows the START protocol. When the user has finished the wizard, an injury level is proposed by the application based on the data provided by the user using the wizard. The user can then accept this injury level proposal or propose another one if they think that the victim deserves it. Once the victim has been triaged and an injury level is assigned, a Triage Tag (paper Triage Tag) is attached to her, allowing a quick visual identification of the victim's injury level. This paper Triage Tag contains an RFID in order to identify uniquely the victim within the emergency scene. This RFID is read by the handheld device, which contains an RFID reader. An RFID tag is a good and fast solution to combine both Electronic and Paper Triage Tag, and identify the victim in uniquely. Next, the handheld device creates a *Triage DataObject* containing the injury level information and the GPS position of the victim provided by the handheld and the RFID of the Triage Tag. The *Triage DataObject* is a message created and formatted for the Haggle API. Once the message is created, it is handed to the Haggle middleware. Inside the Haggle system, the message is forwarded from one device to another following TTR forwarding. The destination of the *Triage DataObject* is the Coordination Point (CP) for the emergency. The CP maintains a prioritised list of victims that is updated each time a *Triage DataObject* is received. Furthermore, a map with the position and injury level of each victim can be created. As a result, routes can be traced using the map information. These routes try to take the medical personnel first to where victims with worst injury level are.

3.1.1 Haggle and the TTR manager

The TTR forwarding method [4] is implemented in Haggle. As stated before, the development of a Haggle manager (TTR manager) was needed to forward the messages using the TTR strategy. The combination of Haggle and the TTR manager provides Haggle with the functionality to look constantly for neighbours, and compare TTR values. If this node finds another node with a lower TTR, it forwards the *Triage DataObjects* via that node, with the aim of reaching the CP as soon as possible.

The TTR manager is in charge of forwarding messages between nodes using the TTR forwarding method. The first step is to set up a TTR on the platform. This value will be used later on for forwarding decision. A *TTR set up message* has to be sent by the Haggle-ETT application to Haggle in order to initialise this value. The TTR manager processes this message, and sets up the TTR value in the message as the TTR value of the platform. Once the platform has a valid TTR value, each time two nodes make contact, they exchange TTR values. Each TTR Manager (of each Haggle node) sends a message informing of the TTR value of the node and processes the TTR information message received from the other node. The TTR values are compared, and if the TTR value of the other node is lower, the *Triage DataObjects* in this node are forwarded to the other node with lower TTR. Each time a *Triage DataObject* is received from a Haggle-ETT application, it is stored in the TTR Manager. If one of the nodes in a node contact has no valid TTR value yet, there is no exchange, because there will not be any *Triage DataObject* stored yet.

The TTR values of other nodes that discovered in all contacts are saved. When recording this information, the TTR value is associated with the Haggle identifier of that node, identifying it uniquely in future contacts. Haggle maintains a list of messages sent. As a consequence, if two nodes are in contact again in the future they will not exchange TTR values again, unless the TTR values have changed since the last contact (because typically, the TTR value of a node will not change). Therefore subsequent node contacts will be faster, since *Triage DataObjects* will have be forwarded before via the node with least TTR.

It is possible that the user does not make any contact with another user during their trip. If this happens, the time that the *Triage DataObjects* would require to arrive the Coordination Point will be the TTR left when the victim is found and triaged.

3.1.2 Haggle-ETT application

The application is in charge of creating the Electronic Triage Tag, and send it using Haggle. When the application is opened, the user is prompted to set up the TTR value. Once the TTR value has been set up, a TTR set up message is sent to the platform, and then the user is able to start a triage process. This process begins with the START protocol. The wizard guides the user using the same steps that the START protocol and asks for victim's sanitary conditions. After completing the wizard assistant, a suggested triage level is shown. If agreed, the user accepts and a *Triage DataObject* is created. While the user attaches the paper Triage Tag to the victim, the handheld reads the GPS position and adds it to the *Triage DataObject*. Furthermore, before the paper Triage Tag has been placed its RFID is read by the handheld and the ID is also attached to the *Triage DataObject*. Finally, the message is passed to Haggle and the wizard's start again. An emergency scenario operational example is illustrated in figure 1.

4. IMPLEMENTATION

Our implementation is a proof of concept. All the functionalities of the TTR manager have been built, and are working within Haggle. The Haggle-ETT application has been implemented to show the performance of the TTR manager and Haggle. A series of tests have been done using this implementation to confirm the smooth running of the system. In this section we describe some of the implementation details.

- TTR Manager: The TTR Manager added to Haggle provides TTR forwarding method and is in charge of the TTR Interchange, forwarding Triage DataObjects, and the set up of TTR value on the platform.
- Haggle-ETT application: The Haggle-ETT application is written in C++ and uses the libhaggle library. It has been tested in Mac OS X (10.5 and 10.6) and Windows. This application has been used as a proof of concept to send the *TTR set up message* using the Haggle platform. Furthermore, it has also been used to create *Triage DataObjects* to test Haggle and the TTR forwarding.
- Triage DataObjects: *Triage DataObjects* in Haggle have three main attributes that can be added to the Haggle-ETT application. The injury level of the victim: black (deceased), red (immediate), yellow (urgent) or green (delayed); the GPS position of the victim (the same position as the user of the handheld when is triaging the victim) provided by the GPS module of the handheld; and the ID of the RFID attached to the paper Triage Tag assigned to the victim

5. CONCLUSIONS

Making information about the victims available within the emergency scene is essential for the prioritisation of the rescue process. However, due to the nature of the emergency scenarios, communications cannot rely in existing infrastructure, which may be unusable for various reasons. Moreover, the deployment of a fully connected MANET network may not be feasible because nodes are sparsely distributed over the emergency scene. In this paper, we have presented a system to forward triage information about victims in the emergency using Haggle. The triage is done using a GUI, following the START protocol. This process creates a *Triage DataObject* which is delivered, using Haggle with the TTR forwarding method, to the Coordination Point without relying in the communications infrastructure or the deployment of a MANET.

Mobile devices, held by the medical personnel, are in charge of keeping and forwarding the victims' triage information with the aim of reaching the coordination point as soon as possible. *Triage DataObjects* are forwarded using node contacts when the other node has a lower TTR value, which means that the other device will arrive earlier at the coordination point. Thus, routing decisions are made at the application layer. The proposed system is not limited to scenarios without infrastructure. It can also be used in scenarios where end to end connectivity is available. In this case, a Haggle node can communicate directly with the Coordination Point's Haggle node. If the network infrastructure becomes unavailable, or if there are delays and disruptions in the fully connected MANET, the system will go on working. This makes the system useful in any situation.

5.1 Future work

As future work it has been planned to carry out comparisons with MAETT: speed and minimum contact time are key features to test. Simulations of Haggle-TTR in different types of emergency scenarios are also been planned. The TTR model of communication can be viewed somehow, as like a very slow WiFi access point network, so a comparative evaluation based on 802.11 models can also be done. Furthermore, research about extend the TTR forwarding to other scenarios is anticipated.

6. ACKNOWLEDGEMENT

This research is funded in part by the EU grants for the Haggle project, IST-4-027918.

7. REFERENCES

[1] V. Erramilli, M. Crovella, A. Chaintreau, and C. Diot. Delegation forwarding. In *MobiHoc '08: Proceedings of the 9th ACM international symposium on Mobile ad hoc networking and computing*, pages 251–260, New York, NY, USA, 2008. ACM.

[2] P. Hui, J. Crowcroft, and E. Yoneki. Bubble rap: social-based forwarding in delay tolerant networks. In *MobiHoc '08: Proceedings of the 9th ACM international symposium on Mobile ad hoc networking and computing*, pages 241–250, New York, NY, USA, 2008. ACM.

[3] J. P. Killeen, T. C. Chan, C. Buono, W. G. Griswold, and L. A. Lenert. A wireless first responder handheld device for rapid triage, patient assessment and documentation during mass casualty incidents. *AMIA Annu Symp Proc*, pages 429–33, 2006. Times Cited: 0.

[4] R. Martí, S. Robles, A. Martín-Campillo, and J. Cucurull. Providing early resource allocation during emergencies: the mobile triage tag. *Journal of Network and Computer Applications*, 32(6):1167–1182, November 2009.

[5] S. McGrath, E. Grigg, S. Wendelken, G. Blike, M. D. Rosa, A. Fiske, and R. Gray. Artemis: A vision for remote triage and emergency management information integration. In *Dartmouth University*, pages –. Dartmouth University, November 2003.

[6] M. Musolesi and C. Mascolo. A community based mobility model for ad hoc network research. In *REALMAN '06: Proceedings of the 2nd international workshop on Multi-hop ad hoc networks: from theory to reality*, pages 31–38, New York, NY, USA, 2006. ACM.

[7] E. Nordstrom, P. Gunningberg, and C. Rohner. A search-based network architecture for mobile devices. Technical report, Uppsala University, 2009.

[8] M. F. Shlesinger, J. Klafter, and Y. M. Wong. Random walks with infinite spatial and temporal moments. *Journal of Statistical Physics*, 27(3):499–512, 1982.

[9] G. Super. *START: A Triage Training Module*. Hoag Memorial Hospital Presbyteriand, Newport Beach, California, 1984.

Appendix E

“Electronic Triage Tag and Opportunistic Networks in Disasters”

Electronic Triage Tag and Opportunistic Networks in Disasters

Abraham Martín-Campillo*, Ramon Martí
Dept. of Information and Communications Engineering
Universitat Autònoma de Barcelona
Bellaterra, Spain
abraham.martin@uab.cat, ramon.marti.escale@uab.cat

Eiko Yoneki and Jon Crowcroft
Systems Research Group
University of Cambridge
Cambridge, United Kingdom
eiko.yoneki@cl.cam.ac.uk, jon.crowcroft@cl.cam.ac.uk

ABSTRACT

The use of electronic devices such as sensors or smartphones in emergency scenarios has been increasing over the years with new systems taking advantage of their features: mobility, processing speed, network connection, etc. These devices and systems not only improve victim assistance (faster and more accurate) but also coordination. One of the problems is that most of these systems rely in the existence of a network infrastructures, but usually in big disasters, or mass casualties incidents, these infrastructures become saturated or destroyed by the very nature of the emergency. In this paper we present MAETT and Haggle-ETT, two applications that provide electronic triage tags (ETTs), a digital version of the classics triage tags, based on mobile agents and opportunistic networks, respectively. These systems are able to work even without network infrastructures using ad-hoc networks to forward the ETTs to a coordination point where they will be processed.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and DesignWireless Communication; C.2.2 [**Computer-Communication Networks**]: Network ProtocolsRouting protocols

General Terms

Design

*corresponding author

ACM SWID 2011, December 6, 2011, Tokyo, Japan.

Keywords

Delay Tolerant Networks, Emergencies, Triage Tag, Opportunistic Networks, Disasters

1. INTRODUCTION

With the increase in the usage of the Internet and smartphones in recent years, their role in the recovery of emergencies has become essential [22]. One of the most important elements in emergencies is the information generated during the emergency, e.g. triage data or location of a victim. Having this information helps the coordination of the emergency recovery and provides a fast response. But these data suffer from two problems. Firstly, some data are usually not transmitted, or transmitted by traditional mechanisms like voice radio or even written annotations, as is the case of paper triage tags for triage information. Secondly, some systems used in emergency scenarios rely on a network infrastructure that may have been destroyed by the very nature of the emergency or may be unstable or inaccessible due to its over usage [2]. Because of this, the use in these scenarios of ad-hoc opportunistic networks, focused on scenarios with intermittent network connectivity in the absence of end-to-end communication infrastructures, is very appropriate.

In this paper, we present MAETT (Mobile Agent Electronic Triage Tag) [13][9][21] and Haggle-ETT [14], that allow the triage data to be collected and represented in an electronic format and to be transmitted, to a coordination point where they will be processed and made available for the managers of the disaster recovery, even if no network infrastructures are present. Thus, these applications provide a collection of additional information for a better coordination and a faster response.

MAETT and HaggleETT provide the same features but are based on different paradigms. MAETT uses Mobile Agents [5] for storing the Electronic Triage Tag information. Moreover, Mobile Agents are used as the mechanism for forwarding the information. They can carry data and jump from platform to platform using different strategies in their code. Each Mobile Agent can have its own code, different from others Mobile Agents (with other algorithms, forwarding mechanisms, etc), and can carry data generated in different visited nodes. On the other hand, HaggleETT is based on Haggle [1] networking architecture for content-centric opportunistic communication. Haggle allows mobile devices to exchange content directly between themselves whenever they happen to come in close range without requiring a network infrastructure.

2. DISASTERS RECOVERY PROCESS

The two systems presented in this paper are specially useful on mass casualty incidents (MCIs), whose main characteristic is the large number of victims. In these cases, the triage of these injured victims is needed to sort them into groups based on their need for immediate medical treatment. This triage is done by the first response personnel arriving at the emergency scene, so the medical personnel arriving later know those victims who need more urgent attention. The victims are stabilised in triage colour order (black, red, yellow and red) before they are evacuated to the hospital or to the advanced medical post where they will be treated widely.

There are a number of triage protocols for emergency situations, however, the START protocol [7] and the Triage Sieve and Sort [23] are the most widely used. Both create four groups of victims based on their condition. The first group, from worst to best condition, is the black one, that is assigned to those victims that are dead or in a very bad status, impossible for the medical team to do something to save their lives. The second group, red, are victims who need immediate attention. The victims in the third one, yellow, do not need immediate but urgent medical attention, that can be delayed for a short period of time. And finally, the green group, is for victims with minor injuries who do not need urgent help.

Once the triage is complete, rescue teams extract those victims who are trapped or cannot move from the hot spot to a safe place. The incident location is also known as zone 0. In this area the medical personnel cannot work because of a risk of danger such as explosion or contamination. Because of this, it is important for everybody to evacuate this area and for the rescue teams to extract the victims that cannot move. While rescue teams are doing their job, the medical personnel treat those victims in the red group that have already been evacuated and are in the patients' waiting for treatment area, also known as zone 1.

If Advanced Medical Posts (AMPs) or casualties clearing stations are installed, the victims are evacuated to this place (see Figure 1). An AMP is a mobile hospital to treat the victims before they can be transferred to an hospital. In mass casualties, where it is necessary to treat lots of victims in a serious condition, AMPs are essential and have to be installed near but in reasonable distance from the zone 0 to be a safe place.

The main objective of the medical personnel in the area regarding the victims in the red group is to stabilise them. Once the stabilisation is done, the rescue vehicle is called to pick up the victims to transfer them to the hospital. After the red victims, the yellow ones are treated in the same way. Regarding the green ones, they are arranged together and then transferred with low priority to other hospitals or medical institutions using any available transportation.

The Advanced Command Post (ACP) is where the coordination team is, and where all the decisions about actions to be carried out by rescue and medical teams are taken.

It is necessary to consider that in a big emergency more than one hot spot or local emergency can exist. During these local emergencies, for instance in a hurricane, each house devastated or vehicle crashed, can share the meeting point, AMP and/or ACP or have its own for each one if they are big enough. Usually, if the emergency has multiple hot spots or local emergencies, a crisis committee is created to manage and coordinate all the emergency in collaboration with different ACPs installed.

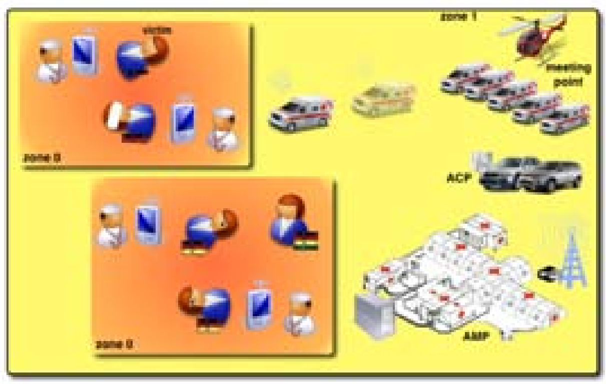

Figure 1: Emergency Scenario

2.1 Communications in the emergency scenario

Previously emergency communications were only a matter of walkie-talkie communications, but nowadays they are becoming more and more advanced. This is due to the greater use of Internet enabled devices or mobile phones by the emergency personnel, that require mobile networks such as mobile phone network (3G) or WiFi. In the great majority of emergency cases, hurricanes, terrorist attacks, flooding, etc, these networks become unstable, inaccessible, overused or even destroyed. As a consequence, emergency personnel cannot rely on the use of existing network infrastructure and may deploy and use their own [12][11], or simply use wireless mobile ad-hoc networks (MANETs) [16][20][15][11]. These networks create routes by request of the nodes that are maintained as long as they are needed or the link is available.

Anyway, all these solutions have the same lack: because of the mobility of the devices (or if the area of emergency is big enough) a continuous end-to-end connection cannot be guaranteed. As a result, an attempt to communicate from one point of the network, for instance, a first responder, to another point, for example the AMP, could be unsuccessful as this kind of networks needs an end to end communication. In these cases, opportunistic networks can be used; even if a message is required to arrive as soon as possible once it has been generated, the time to arrive to any part of the disaster area will require less time than deploying all the nodes necessary to create an infrastructure network or a fully-connected MANET

Regarding the AMP and ACP, it can be supposed that they have always Internet connection even if the network infrastructures are destroyed or unusable. They use their own deployed network infrastructure, for instance, satellite connections. For the AMP and the ACP, it is very important to have Internet connection for coordination or information communications (f.e. with another coordination point or with hospitals assigned to victims). From this point of the paper we will talk about AMPs and ACPs as coordination points, the only points of the emergency scenario where there are network connection.

3. ELECTRONIC TRIAGE TAG SYSTEM

Previously in this paper two applications have already been introduced: MAETT and Haggle-ETT. Both applications make use of the same core, our Electronic Triage Tag System, that is in charge of the creation of the Electronic Triage Tags (ETTs). MAETT and Haggle-ETT will have different methods for carrying, storing and forwarding the ETTs to a coordination point using opportunistic networks but both share the core system in charge of the creation of the ETTs.

Triage personnel is equipped with handheld devices with GPS, and a RFID reader units (Figure 2). When a victim is found, she is labeled with a paper triage tag containing an RFID tag attached that provides the ability to uniquely identify the victim within the emergency. The paper triage tag allows a quick visual identification of the victim's injury level. An RFID tag is a good and fast solution to combine both Electronic and Paper Triage Tag and identify the victim in both of them in a

Figure 2: Nokia MAEMO n810 and RFID reader

Figure 3: RFID reader software, TTR and software settings

uniquely way. Before labelling the victim, the staff shall approach the electronic triage tag to the RFID reader that will read their unique ID (Figure 3). After that, a software assistant is activated to help staff to assess the state of the victim (Figure 4). This software provides all the steps required to follow the START protocol (breathing, pulse, answers to simple questions, etc.) to perform the triage.

The software interface of the wizard (Figure 4) is simple, with intuitive icons, short and understandable text, and large buttons that facilitate the use of the touch screen. Furthermore, its use is optimal for triage because it does not increase the time devoted to follow the START protocol (which must be as short as possible) and benefits from the available data already digitalised.

Once the process has been completed, an injury level is proposed by the application based on the data provided by the user using the wizard: green for *MINOR*, yellow for *DELAYED*, red for *IMMEDIATE*, and black for *DECEASED*. This status can be accepted or may be changed to another one that the user considers more appropriate. The wizard can be turned off if the situa-

Figure 4: START protocol assistant for the triage of victims

Figure 5: Electronic Triage Tag

tion requires it to show the selection screen color (state) just to read the RFID associated with the paper triage tag.

After estimating the state (colour) of the victim, the software will read the GPS device position where the staff, and therefore the victim, is at that time, and an Electronic Triage Tag with all this information (Figure 5) will be created. Additionally, the staff will assign the same injury level colour to the paper triage tag of the victim.

3.1 Electronic Triage Tag

The electronic triage tag (ETT) created after the triage (Figure 5) will include the status (color of the triage tag) of the victim, the GPS position, the unique identifier of the triage tag, and the patient's vital data (pulse, respiration, etc). Other possibilities could include an additional photo of the situation of the victim or the victim itself.

The ETTs will be stored in the personnel smartphone for later being transferred to the coordination point. While the personnel is working in the Zone 0, the system will forward the ETTs stored in their smartphone to other emergency personnel's smartphone in order to allow the ETTs to get to the emergency coordination point as fast as possible. Mobile Agents and Haggle accept any existing opportunistic routing protocol but this is an important part of the application as it has a high impact on the message delivery performance. Hence, choosing the appropriate forwarding algorithm is critical. This algorithm will be in charge of making the decisions of relaying or not an specific ETT to another emergency personnel's smartphone in order to make it arrive sooner to a coordination point.

3.2 Coordination point

The coordination point system is where all ETTs are delivered. This system may be distributed, i.e., it may comprise more than one server that will be able to exchange data, since they are connected to each other. The coordination point has a wireless network access point to allow communication with the smartphones arriving from the emergency, as well as a wired or wireless internet connection for coordination outside the emergency area.

Furthermore, the coordination point system keeps all the information gathered by all the staff. It may know the position of the victims, their status, and whether there are special needs for each one. This eases the task of planning routes for the collection of the victims by placing higher priority on those that have been selected for such, and helps the emergency organisation and management staff to have a clearer idea of the distribution of victims.

4. FORWARDING

Smartphones usually have three network interfaces: HSPA/GSM, wifi, and Bluetooth. The first one can not be used for opportunistic networks. Bluetooth has only a range of 10 m and the transfer speed is very low. In big scenarios with a low density of nodes, nodes will not approach each other at these small distances. In mass casualty incidents there are a lot of victims and the first responders are fewer in number, hence they are far from each other. Moreover when two first responders approach each other, the contact time will be small because they usually run in those scenarios, so the faster the transfer speed, the more data will be interchanged.

Hence, even though wifi has a high energy consumption, it will be the best option for opportunistic communications in emergency scenarios. Furthermore, the wifi will be working in opportunistic mode, therefore it will not be able to enter into low energy mode. That said, in order to reduce this high energy consumption (very important in mobile devices running on battery) and also have a good delivery ratio we should use an appropriate routing algorithm.

Regarding data, one can think that using an epidemic method is the best option, but the use of broadcast-based forwarding approaches (where multiple copies of the same data is spread throughout all the network) has two problems. The first one is the energy efficiency. Since data transfer using wifi is the most energy consuming process in a handheld device [18], each data transfer consumes a lot of energy. For this reason it is important to select a forwarding algorithm that does not waste a lot of energy relaying unnecessary data. The second problem occurs in cases with a high number of messages because due to the short contact times it is not possible to forward all the data in a node, so it may also require some kind of data forwarding priority management.

But choosing the right forwarding method for the application depends also on a number of factors: the number of first responders working in the zone 0, the number of victims, the size of the ETT, the buffer of the device, and the energy consumption of the device using the network.

For these reason we created the Time To Return (TTR) routing method, a simple mechanism to forward data only once per node (energy efficient) with good delivery performance thanks to taking advantage of the use of a time that it is usually used in disasters but never used in applications.

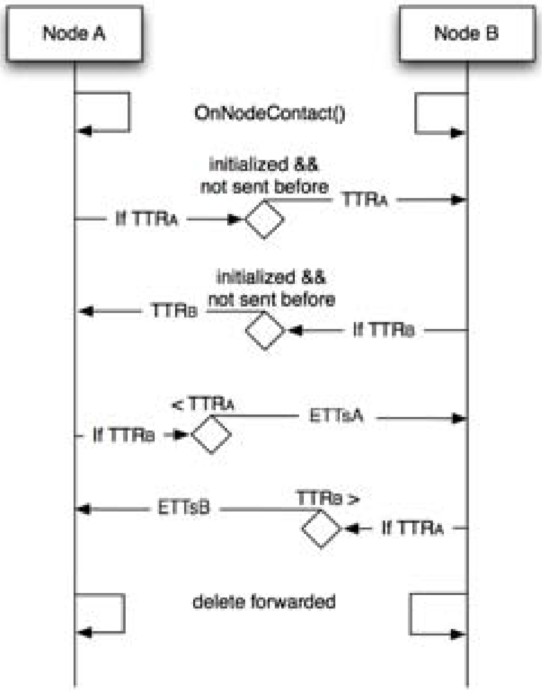

Figure 6: TTR protocol

4.1 Time To Return

Time To Return (TTR) routing protocol is based in the fact that for coordination issues, each actor in the emergency knows when she will return to the coordination point. When coordinating an emergency, the staff dedicated to the rescue must be controlled because there is a risk of danger. Therefore, protocols to follow and a time indicating when each staff must return to the coordination point are defined. This TTR is allocated by the coordinator of the emergency and set up into the smartphone rather manually or automatically from the software in the coordination point.

When a node finds several neighbours around, they will interchange their TTR. If there is one or more neighbour with lower TTR, the ETTs in the node will be forwarded to the device with the lowest TTR, indicating that this is the staff that will return to the coordination point earlier and therefore will deliver the ETTs sooner, a priority in emergency scenarios.

It is important to say that the TTR value of a node can be changed at any time if the schedule of the personnel is changed: if she has to return before than initially planned or if she has authorisation to be in the emergency scene a longer time. Furthermore, other factors can force decisions to change the TTR value, as the battery life of the mobile device. The maximum time of the TTR always has to be the maximum time of battery left. Otherwise all the data in the device will not be forwarded and they will not be communicated to the coordination point until the battery is recharged, ending up in a critical medical information delay.

4.1.1 *Protocol*

The TTR has to be set up at the beginning of the emergency in each node. Once the node has a valid TTR value, each time two nodes come into contact they interchange their TTR. The TTR values are compared and the ETTs are forwarded, if required, to the node with the lower TTR.

The TTR of the contacted nodes is stored, so if two nodes come into contact again in the future they will not interchange their TTR again except in the cases when the TTR has been modified.

It is possible that a node does not come into contact with another node during their way. If this happens, the time that ETTs would require to arrive to a coordination point would be the TTR left in the node when the victim was found and triaged. A scheme of this protocol can be found in figure 6.

4.2 Evaluation

We have tested the performance of the TTR along with other opportunistic forwarding methods in a simulated emergency scenario. We have to take into account that the delivery ratio performance will be always 100%

as eventually all the nodes will come back to the coordination point. Hence, for measurements we will use the CDF delivery delay and the delivery cost (number of messages relayed per messages created), two important metrics used to evaluate opportunistic network and routing protocols performance. The CDF delivery delay represents the difference between the time when a message is delivered and its creation time.

The traces used for the simulation have been generated by the Bonnmotion tool. BonnMotion [17] is an application that generates traces of different types of scenario. One of these scenarios is disasters. They create mobility traces based on the analysis of the disaster scenario created for the preparation of the FIFA world cup in Germany [3]. This mobility model for disasters is useful for defining zones of an emergency. The incident location where the victims are found (Zone 0); patients' waiting for treatment area (Zone 1, where coordination point is); casualties clearing stations; the ambulance parking point and the coordination, or meeting, point. The parameters for the generations of traces can be found in table 1.

Once the traces are generated with the BonnMotion, we use them as an input of the ONE simulator. The ONE simulator [10] is a simulation environment specially designed for opportunistic networks simulation. It supports different routing algorithms in the nodes and sender and receiver types (with different characteristics in interfaces for example). A link speed of 54 Mbps and a radio range of 60m are the values defined for all the nodes. The link speed is chosen using the 802.11g standard, the simulator is in charge of changing the speed rate depending of the distance between the two nodes. As for the maximum radio range, we carried tests using iPhones 3GS that gave us an average result of 60 meters. We tested the radio range outdoor with obstacles (typically for disaster scenarios). The radio range is a parameter that can change depending of the device the user is using. We also tested the maximum data transfer rate for the wifi network (802.11g) of the iPhone 3GS with a result of 6,4 Mbps. The duration of the simulation is 6000 seconds.

We have chosen a message size of 225kB. We have calculate this size for a message containing text and a small size photo. We have supposed a mass casualty incident hence a total number of 2000 messages are created during the simulation (100 minutes). The messages can be Electronic Triage Tags or messages with information about the emergency scenario. A size of 10 MB has been chosen for the buffer size of each node, so each node will be able to store up to 45 messages each node before it starts rejecting messages because the buffer is full. Each node will create an average of 33 messages throughout the simulation, so each node has buffer space to store more messages, even if it is not able of deliver any of his created messages.

Using bluetooth v2.1 + EDR included in most of today's smartphones (with a maximum practical data transfer rate of approximately 2Mbps) would require 1 second to transmit a message under optimal conditions (sender and receiver very close one each other). Using 802.11g would require 274 ms based on the maximum data transfer rate measured. But the best advantage of using wifi is that the radio range is 8 times larger than the bluetooth, so more contacts will occur. We also have to take into account that as larger the distance is between the sender and the receiver, the lower the data transfer rate is. Therefore, the average data transfer speed will usually be much lower than 6,4Mbps.

Table 1 sums up the simulation parameters.

Parameter	**Value**
Number of nodes	60
Zone 0	1300x250 m
Zone 1	100x40 m
Simulation time	6000 s
Radio range	60 m
Buffer size	10 MB
Number of messages	2000 messages
Message size	225 kB

Table 1: Default parameters

The following routing methods have been tested in the simulations: Epidemic, First contact, PRoPHET, MaxProp and TTR. Epidemic method has been chosen because of its fast message spread but also because it floods the network due to the replication of each message to the rest of the nodes. It's a reference for other routing methods. First contact is different from others methods as it only keeps one copy of the message in all the network. So, when a node sends the message to another node, it deletes its copy of the message. This in an interesting routing method for its very low delivery cost. It is very simple and follows no intelligent algorithm so we cannot expect good results. PRoPHET is a probabilistic routing method that aims to improve Epidemic routing with lower overhead and higher delivery ratio due to the use of probabilities. It is interesting to see how it works in disaster areas. MaxProp does an estimate delivery likelihood and adds some rules to the decision as to give forwarding preference to low-hop-count messages, to free up storage of delivery messages or to not forward the same packet twice to the same next hope destination. This add-ons are important as they give a congestion control to MaxProp interesting to test. This method has very good results applied to vehicular networks and we'd see if they achieve similar results in disaster areas. TTR is a routing method specific for disaster areas, so it is interesting to see its performance. It only keeps one copy of the message in all the network as First contact, hence it is important to compare its performance in delivery versus cost.

4.2.1 Results

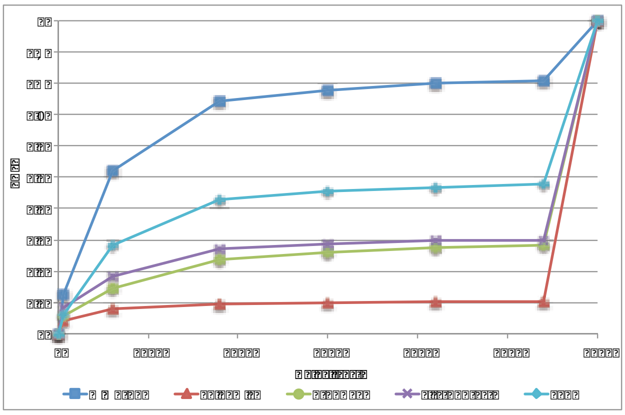

Figure 7: Delivery Delay CDF

Routing	Delivery cost
MaxProp	382
PRoPHET	121
Epidemic	100
FirstContact	9
TTR	2

Table 2: Delivery cost

The results from the tests that can be seen in the figure 7 and the table 2 show that MaxProp is clearly the forwarding method with better delivery delay but also with a very high delivery cost. The TTR have a good delivery delay and the best delivery cost from the forwarding methods compared. Hence, it will be the method with less energy consumption as it interchanges less data than others.

5. MOBILE AGENT ELECTRONIC TRIAGE TAG

Mobile Agent Electronic Triage Tag is the version of the Electronic Triage Tag System based on mobile agents. Mobile agents are software entities that can suspend their execution on a host, move to a different location and resume their execution. The agents use platforms as an run-time environment. These platforms can be distributed in different hosts or in the same. The agents will move, or jump, from platform to platform, if needed, until they have accomplished all their tasks. Mobile agents technology [24] has its origin on two different disciplines: artificial intelligence (intelligent agent) [25] and distributed systems (code mobility) [6]. The main characteristics are: Autonomy, reactivity, proactivity, sociability and mobility. Mobile agents can give the application the following advantages: task delegation, asynchronous processing, dynamic environment adaptation, flexible interfaces, fault tolerance, parallelism and local data processing.

The ETTs are created in the form of a mobile agent. The mobile agent includes all the information of the ETT: the status (color of the triage tag) of the victim, the GPS position, the unique identifier of the triage tag, and the patient's vital data (pulse, respiration, and so on).

This mobile agent will be stored in the personnel smartphone. If a mobile agent finds a neighbour with a lower TTR, it will jump to this platform. This decision is taken by the application level routing protocol used by the mobile agent, the TTR, as explained before on section 4.1.

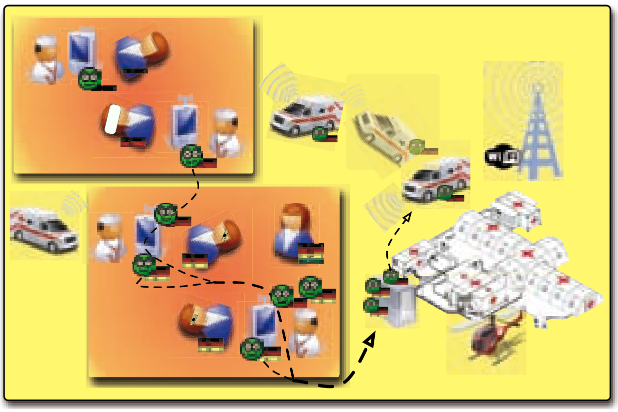

Figure 8: Electronic Triage Tag based on Mobile Agents

Routing, from the viewpoint of the mobile agent, is a decision algorithm, at application level, to decide which platform to jump from a set of platforms or devices, or whether it is better to stay on the current platform.

In the same way that the routing algorithms at network level, the initial step is to exchange information between nodes, in the case of mobile agents exchange is done through ACL messages. The platform is the agent that is responsible for providing a service for reporting information and the mobile agent to carry out a request to obtain this service.

It is worth mentioning that mobile agents can move through more than one device without having to jump one by one to all platforms agent devices from location to destination. Using the coverage of the smartphones of the staff a network can be created able to reach the

Figure 9: Android Version

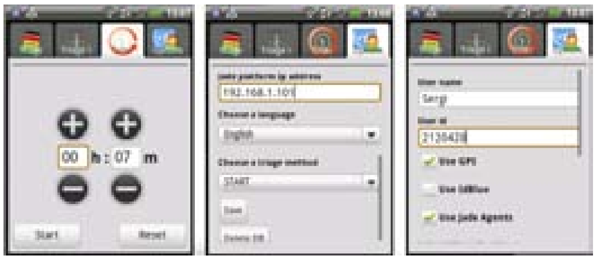

Figure 10: Android Version

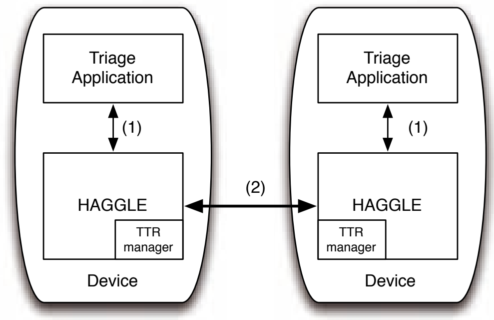

Figure 11: Haggle-ETT scheme. (1) Communications intra device between Haggle application and Haggle platform (2) Communications inter devices between Haggle platforms

coordination point.

5.1 Implementation

There are two implementations of the MAETT. Both implementations use JADE [8] platforms for the agents creation and management and JIPMS [4] for the mobility of the agents. JADE and JIMPS are written in JAVA.

The first implementation is for MAEMO devices (such as Nokia n810 in figure 2). The figures 3, 4 and 5 are screen captures from the MAEMO version of MAETT. The software is distributed under a GPL license and can be downloaded from its webpage[9].

The second implementation is for Android devices. The figures 9 and 10 show screen captures of the Android version of MAETT. It is also distributed under a GPL license and can also be downloaded from its webpage [21].

6. HAGGLE-ETT

Haggle Electronic Triage Tag (Haggle-ETT) [14] is the version of the Electronic Triage Tag System based on Haggle. Haggle [19] is an autonomic networking architecture designed to enable opportunistic communications. Haggle provides underlying functionality for neighbour discovery, resource management and resolution, thus removing the need to implement such features in applications. When some data wants to be sent by an application, it is not required a direct connection to the receiver or receivers and even it is possible that the identities of the receivers be unknown.

The representation of data in Haggle are the DataObjects. Hence, the Electronic Triage Tags are created in form of *Triage DataObjects* using the Haggle API. A *Triage DataObject* contains all the information of an ETT: injury level information, GPS position, etc. Once the ETT is created, it is sent to Haggle. Inside Haggle, the message is forwarded from one device to another following the TTR forwarding method. The destination of the *Triage DataObject* is the Coordination Point (CP) of the emergency.

The TTR forwarding method (section 4.1) is used in Haggle. Haggle is structured in managers that are in charge of carrying different tasks. The forwarding manager in charge of applying the TTR routing method is called TTR Manager.

This scheme can be seen in figure 11, where communications between the application and Haggle are presented as (1) and communication between Haggle platforms of different devices are represented as (2).

6.1 Implementation

The implementation of the proposal has been done as a proof of concept. All the functionalities of the TTR manager have been implemented and they are working within Haggle. Also the Haggle-ETT application has been implemented to proof the performance of the TTR manager and Haggle.

The Haggle platform is written in C++ and it is available for Windows, Mac OS X, Android, Windows Mobile and iPhone OS.

The Haggle-ETT application is written in C++ and uses the libhaggle library. It has been successfully tested on laptops running Mac OS X. This computers can communicate either using Bluetooth or WiFi. The implementation have also been tested on iPhones running iOS 3.0. All the devices were set up to work on Wifi network, even thought they can work on Bluetooth network in the same way. The tests confirmed the interoperation between the laptops and the smartphones and the proper use of the TTR forwarding method.

7. CONCLUSIONS

Having all the information about the victims in a digital format is essential for the prioritisation in the rescue process. However, due to the nature of the emergency scenarios, communications cannot rely in existing infrastructures because they can become unusable for different reasons. Hence, the forwarding of this data may become difficult and the data may arrive to a coordination point with an excessive delay.

In this paper, we have presented MAETT and Haggle-ETT, two applications that create Electronic Triage Tags with triage information of the victims in the emergency scene, and forward them to a coordination point using ad-hoc networking. The triage is done using an application with a GUI that follows the START protocol. This process creates an ETT which is forwarded, using the Time To Return (TTR) forwarding method, to a coordination point using opportunistic networks without relying in any communications infrastructure. The time to return to a coordination point, that is commonly used in emergencies, is assigned to each person working in the disaster in order to have a periodic security check. The TTR forwarding method uses this time as a forwarding decision: the ETTs will be forwarded to the node with the lower TTR, meaning that they will arrive earlier to a coordination point.

These applications are not only limited to scenarios without available network infrastructure, they can also be used in scenarios where end to end connections are available. In these cases, a node could communicate directly with a coordination point. If the network infrastructure becomes unavailable, or if there are delays and disruptions the applications will continue working. This fact makes the applications useful in any situation.

7.1 Future work

As future work, an extensive research about performance of opportunistic forwarding methods in emergencies scenarios is planned. Having a good method of forwarding data in disasters scenarios is critical. The characteristics of an emergency scenario cannot be predicted (density of nodes, number of messages, etc) and those elements have a big impact in the performance of the forwarding methods. Furthermore, other applications for disasters, different from ETTs, can be developed based on our research in Mobile Agents or Haggle in order to be able to use them even in worst cases scenarios where infraestructured networks are unusable.

8. ACKNOWLEDGEMENT

This research has been partially funded by the Spanish Ministerio de Educación (FPU AP2008-03149), by the Catalan DURSI (2009SGR1224) and by the Spanish Ministerio de Ciencia e Innovación (TIN2010-15764).

9. REFERENCES

[1] Haggle, http://code.google.com/p/haggle/.

[2] The-day-after networks: A first-response edge-network architecture for disaster relief, http://mobius.cs.uiuc.edu/research/phoenix/.

[3] N. Aschenbruck, M. Frank, P. Martini, and J. Tolle. Human mobility in manet disaster area simulation - a realistic approach. In *in 29th Annual IEEE International Conference on Local Computer Networks (LCN 04*, 2004.

[4] J. Cucurull. Jade inter-platform mobility service, 2008. http://jipms.sourceforge.net.

[5] J. Cucurull, R. Martí, S. Robles, J. Borrell, and G. Navarro-Arribas. Fipa-based interoperable agent mobility. In *CEEMAS07*, volume 4696 of *LNAI*, pages 319 321. Springer Verlag, September 2007.

[6] A. Fuggetta, G. P. Picco, and G. Vigna. Understanding code mobility. *IEEE Trans. Softw. Eng.*, 24(5):342 361, 1998.

[7] M. E. Gebhart and R. Pence. Start triage: Does it work? *Disaster Management and Response,*, 5(3):68 73, 0 2007.

[8] T. Italia. Jade, 2004. http://jade.tilab.com/.

[9] X. Jurado. Mobile agent based eletronic triage tag - maemo version, https://www.assembla.com/spaces/triagetag/.

[10] A. Keranen, J. Ott, and T. Karkkainen. The ONE Simulator for DTN Protocol Evaluation. In *SIMUTools 09: Proceedings of the 2nd International Conference on Simulation Tools and Techniques*, New York, NY, USA, 2009. ICST.

[11] J. P. Killeen, T. C. Chan, C. Buono, W. G. Griswold, and L. A. Lenert. A wireless first responder handheld device for rapid triage,

patient assessment and documentation during mass casualty incidents. *AMIA Annu Symp Proc*, pages 429 33, 2006.

[12] K. Luyten, F. Winters, K. Coninx, D. Naudts, and I. Moerman. A situation-aware mobile system to support fire brigades in emergency situations. pages 1966 1975, 2006.

[13] R. Martí, S. Robles, A. Martín-Campillo, and J. Cucurull. Providing early resource allocation during emergencies: The mobile triage tag. *J. Netw. Comput. Appl.*, 32:1167 1182, November 2009.

[14] A. Martín-Campillo, J. Crowcroft, E. Yoneki, R. Martí, and C. Martínez. Using haggle to create an electronic triage tag. In *The Second International Workshop on Mobile Opportunistic Networking - ACM/SIGMOBILE MobiOpp 2010*, pages . ACM Press, February 2010.

[15] T. Massey, T. Gao, M. Welsh, J. H. Sharp, and M. Sarrafzadeh. The design of a decentralized electronic triage system. In *AMIA Annual Symposium Proceedings*, pages 544 548, 2006.

[16] S. McGrath, E. Grigg, S. Wendelken, G. Blike, M. D. Rosa, A. Fiske, and R. Gray. Artemis: A vision for remote triage and emergency management information integration. In *Dartmouth University*, pages . Dartmouth University, November 2003.

[17] U. of Bonn. Bonnmotion: A mobility scenario generation and analysis tool, http://net.cs.uni-bonn.de/wg/cs/applications/bonnmotion/, 2009.

[18] A. Rice and S. Hay. Measuring mobile phone energy consumption for 802.11 wireless networking. *Pervasive and Mobile Computing*, 6(6):593 606, 2010. <ce:title>Special Issue PerCom 2010</ce:title>.

[19] P. C. J. D. C. Scott, J; Hui. haggle: a networking architecture designed around mobile users . In *The Third Annual IFIP Conference on Wireless On-demand Network Systems and Services (WONS 2006)*, January 2006.

[20] V. Shnayder, B. rong Chen, K. Lorincz, T. R. F. F. Jones, and M. Welsh. Sensor networks for medical care. In *SenSys 05: Proceedings of the 3rd international conference on Embedded networked sensor systems*, pages 314 314, New York, NY, USA, 2005. ACM.

[21] S. Solsona. Mobile agent based eletronic triage tag - android version, http://deic.uab.cat/∼amartin/amaett.zip.

[22] H. Sun. Chopper crews saved by google maps during queensland floods, http://www.heraldsun.com.au/technology/chopper-crews-saved-by-google-maps-durig-queensland-floods/story-fn7celvh-1226046611966.

[23] L. Wallis. START is not the best triage stategy. *Br J Sports Med*, 36(6):473 , 2002.

[24] J. E. White. Telescript technology: Mobile agents. In J. Bradshaw, editor, *Software Agents*. AAAI Press/MIT Press, Menlo Park, CA, 1996.

[25] M. Wooldridge and N. R. Jennings. Intelligent agents: Theory and practice. *Knowledge Engineering Review*, 10(2):115 152, 1995.

Appendix F

"Evaluating Opportunistic Networks in Disaster Scenarios"

Evaluating Opportunistic Networks in Disaster Scenarios

Abraham Martín-Campillo[a], Jon Crowcroft[b], Eiko Yoneki[b], Ramon Martí[a]

[a]*Department of Information and Communications Engineering, Universitat Autònoma de Barcelona, Bellaterra, Spain*
[b]*Systems Research Group, University of Cambridge, Cambridge, UK*

Abstract

Forwarding data in scenarios where devices have sporadic connectivity is a challenge. An example of such an scenario are disasters, where forwarding information generated in the emergency area, like the victims' medical data, to a coordination point is critical for quick, accurate and coordinated intervention. New applications are being developed based on mobile devices and wireless opportunistic networks as a solution to destroyed or overused communication networks. But the performance of opportunistic routing methods applied to emergency scenarios is unknown today. In this paper, we compare and contrast the efficiency of the most significant opportunistic routing protocols through simulations in realistic disaster scenarios. This paper will allow researchers and developers to know how the different characteristics of an emergency scenario (density of nodes, number of messages created, etc) impact in the behaviour of each one of them. Furthermore, these results will give valuable information to researchers proposing new routing opportunistic protocols or applications for emergency scenarios.

Key words: opportunistic networks, opportunistic forwarding, performance evaluation, emergency scenarios

1. Introduction

Recovery from an emergency situation is always a complex task, particularly in mass casualty disasters. In these types of emergencies a quick and coordinated response must be taken to improve the efficiency of rescue teams and save as many lives as possible. Furthermore, the emergency situation may be ongoing for some time, hence systems may have to stay usable for extended periods.

The need for these systems is real and the last mass casualty incidents in the recent years have made appear new applications [1][2][3][4][5][6] designed to satisfy these needs. These applications ease the work of first responders providing a faster victim's triage (medical status acquisition), a better coordination and communication in situations without network infrastructure.

From the communication point of view, in many cases existing network infrastructure is destroyed by the very nature of the disaster, or it is overloaded or saturated by heavy use. This produces the lack of a network for transmitting and sharing information generated within the emergency. An usual way to work around the problem is the use of Mobile Ad hoc Networks (MANET). Others [7] propose to solve this difficulty by distributing antennas in the disaster area. Although possible, this may not be feasible in large scale emergencies. Other authors [4] suggest the use of a wireless opportunistic network [8] based on mobile devices carried by emergency personnel to forward the data created and collected in the disaster area until the coordination point. The use of opportunistic networks is very appropriate for emergency scenarios as they are infrastructure-less, nodes can store, carry and forward messages, and the routes from the sender and the destination are build dinamically. This makes opportunistic networks tolerant to delays and disruptions and nodes can communicate each other even if there is not a route connecting them.

In these situations the most important objective is to ensure that the messages and data generated in the disaster area reach their destination as soon as possible without any loss as they contain valuable information for the global coordination of the emergency response, as well as information about victims. Because of these requirements, a fast and accurate forwarding strategy is required in all the applications used in a disaster area employing opportunistic communications.

However, forwarding data in opportunistic scenarios is challenging [9][10]. The length of the disaster area, the number and distribution of the victims, and the number of nodes are characteristics that could notably impact on the performance of routing protocols. Because of this, deciding which forwarding method to use in these scenarios is difficult [11].

The purpose of this research is to characterise the performance of a set of routing algorithms in disaster scenarios with different characteristics (different number of nodes, number of victims, etc) in order to uncover the performance and therefore their suitability to different situations. We have done this performance analysis carrying

Email address: `abraham.martin@uab.cat` (Abraham Martín-Campillo)

out several simulations using realistic scenarios and traces generated by BonnMotion [12]. We have also used the One simulator [13], a simulation tool specific for opportunistic networks, to generate the scenario and to simulate the forwarding process based on the traces generated by the BonnMotion tool.

This paper is structured as follows: first, the existing related work on mobile devices in emergencies and forwarding mechanisms is presented. Subsequently, the emergency scenario is depicted, followed by a description of the tests performed. Next, the results of the simulations are shown, analysed, and discussed. We close the paper with our conclusions.

2. Related Work

In order to convey the nature of the problem of communications in disaster scenarios, in this section we present related work. We include: applications in emergency scenarios using its own developed network, forwarding mechanisms in mobile opportunistic networking, and test and simulation tools available.

2.1. Applications in emergency scenarios using its own developed network

Mobile devices (PDAs, smartphones, customised, etc.) are frequently used in disaster areas by rescue personnel for different purposes, including victims triage and tracking. The usual problem in emergency situations is the lack of an infrastructured network in which rely the communications on. Solutions proposed include the use of ad-hoc networks, MANETs, DTNs or Opportunistic Networks. Some examples of applications, systems, and architectures for these purposes are described below.

2.1.1. ARTEMIS

ARTEMIS [14] is a research project sponsored in part by the US Army's Communications and Electronics Command Division. Its aim is the development of an automated remote triage and emergency management information integrated system, able to monitor victims information through sensors in a PDA, and to transmit this information to the medical services using agents that move through a reliable messaging layer in wireless ad hoc networks.

2.1.2. MAETTS

The Mobile Agent Electronic Triage Tag System [15], is a system that uses mobile devices to triage victims. Mobile agents are created to store and transport that information in an asynchronous way from node to node in a MANET. In this system, the Time To Return (TTR) to the Emergency Coordination Point is used as the decision basis for the mobile agents forwarding between nodes.

2.1.3. TacMedCS

TacMedCS, Tactical Medical Coordination System [16], is a military U.S. Navy System to capture and display real-time casualty data in the field. It is based on the use of radio frequency hardware tags to identify victims and store casualty data. A handheld unit stores this casualty data, as well as the positioning information from the built-in GPS, and sends all the information to the central server database through its satellite (Iridium) communication facilities. Triage and Medical Information is transported with the victim in the hardware intelligent ID tag. IEEE 802.11 mesh communications can also be established between the different handheld units for their collaboration.

2.1.4. HaggleETT

Haggle Electronic Triage Tag (Haggle-ETT) [4], is a system that uses Haggle [17] and mobile phones to create electronic triage tags (ETTs) and transmit them. Haggle is an autonomic networking architecture designed to enable opportunistic communications. Hence when an application wants to sent some data, it is not required a direct connection to the receiver, or receivers, and even it is possible that the identities of the receivers are unknown. Therefore, this system is able to work even without network infrastructures using opportunistic networks to forward the ETTs to a coordination point where they will be processed.

2.2. Forwarding in Mobile Opportunistic Networking

Traditional network paradigms assume an existing end to end path between the sender and the receiver. These networks don't accept excessive delays or disruptions, hence when this happens the delivery fails. But for some scenarios such as deep space communications, where nodes are not always in communication range, a type of network that supports intermittent communications is needed. These networks are called Delay and disruption Tolerant Networks (DTN)[18] and are designed to support the disruption of connectivity and/or long delivery delays. These type of networks are becoming very popular in some environments such as disasters areas or developing countries.

DTNs can have nodes acting as data mules, that is nodes going back and forth to a collection point. Data mules store, carry and forward messages until their destination. They carry the message stored in their memory while moving around and forward the messages when they find an opportunity. Plenty of routing methods have been proposed for DTNs that follow this paradigm. But DTNs can also be Opportunistic Networks.

In opportunistic networks, mobile nodes can communicate each other even if there is not a route connecting them. Like in Delay and Tolerant Networks, nodes can store, carry and forward messages. Furthermore, nodes are not supposed to possess or acquire any knowledge about the network topology (there is a lack of global information) and contacts are heterogeneous and unpredictable.

Routes from the sender and the destination of a message are built dynamically and any possible node can opportunistically be used as next hop of a message if it is more likely to bring the message closer, or faster, to the final destination. For all these reasons forwarding data in Opportunistic Networks is a challenging issue. The most significant opportunistic forwarding strategies are explained below.

2.2.1. Epidemic forwarding

Epidemic [19] is a well known forwarding strategy. It is based on the very simple idea of sending a copy of all the messages stored in a node to all the nodes that become in contact with it during its journey. This usually results in network congestion in scenarios with high number of contacts and/or nodes as there are many copies of the same message in the network. This congestion can produce that in the cases where the contact time is small not all messages can be forwarded. Nonetheless, it also increases significantly the chances of delivery the message in scenarios with low number of contacts or nodes. One of the variations for Epidemic forwarding is Epidemic with ACK. This modification eliminates all the copies of a message in the network when the ACK for this message (generated when the message is delivered to their destination) is received. Nevertheless, the ACKs generated also produce more saturation.

2.2.2. PRoPHET forwarding

PRoPHET forwarding [20] is based on the probability of future contacts between nodes to make forwarding decisions.

The probabilities stored in one node are exchanged when there are contacts with other nodes. Then, each node updates its table by increasing the probability for the nodes that have been found and by decreasing the probability for the rest. Based on these tables of probability, it is calculated which node has higher probability of delivery of the message. When one node contacts another node, if the other node has a higher probability of delivering the message, the message is sent to it, in the other case the message remains in the current node.

2.2.3. MaxProp forwarding

MaxProp forwarding [21] is based, like PRoPHET, on the use of information about probability of future contacts with nodes when deciding if a message has to be forwarded, but unlike PRoPHET, MaxProp has a priority queue. This priority queue is used to discard messages that have little chance of being delivered to its destination and to keep those which are more likely. With this method the number of copies of messages in the network is reduced and therefore there is also less saturation. Even though, the message is not deleted when relayed to another node but kept until its timeout.

2.2.4. Delegation forwarding

In Delegation forwarding [22], each node has an associated value which is created using a metric that represents the quality of the node as relay. The metric used depends on the scenario where it will be used. *Vijay Erramilli et al.* [22] propose a generalisation of forwarding methods such as BUBBLE Rap [23]. This generalisation applies to mobile opportunistic networks with unpredictable mobility, heterogeneity of contact rates and lack of global information. Achieving delivery of messages without flooding in such a network is challenging.

Time To Return (TTR) forwarding: In *Martí, R. et al* [15], a routing protocol designed for disaster scenarios is proposed: Time To Return (TTR). Medical personnel in an emergency scenario are coordinated by a leader. The leader, or a group of leaders, tells personnel where to go, or in which area to work [15]. When they leave the coordination point, a maximum time to return to the base is assigned to them. They are required to return to base for security reasons, before this time has passed. Each node has its own time to return (TTR) and therefore the forwarding protocol takes advantage of the existence of this value to use it to make forwarding decisions. If a node contacts another node with a lower TTR, it relays all its messages to this node. Afterwards if the messages have been successfully received, the sender deletes all messages relayed in order to have only one copy of the message throughout the network. Hence, TTR is a single message copy forwarding.

Traditional routing algorithms usually only maintain one copy of the message in the network. When a router forwards a message to another router, it doesn't keep a copy of the message. In opportunistic networks it is the opposite, forwarding methods usually keep a copy of the message to increase the chances of delivering the message or deliver it faster. Nevertheless, there are some exceptions in opportunistic routing like Time To Return (TTR) forwarding.

2.3. Test and simulation tools

Regarding test and simulation tools for mobile opportunistic networking, in this clause we include a brief description of BonnMotion [12], and The One simulator [13].

2.3.1. BonnMotion

BonnMotion [12] is an application that generates traces of different types of scenario. One of these scenarios is disasters. It creates mobility traces based on the analysis of the disaster scenario created for the preparation of the FIFA world cup in Germany [6]. This mobility model for disasters is useful for defining zones of an emergency: The incident location where the victims are found (Zone 0); patients' waiting for treatment area (Zone 1); casualties clearing stations; the ambulance parking point and the coordination, or meeting, point.

2.3.2. The ONE simulator

The ONE simulator [13] is a simulation environment that is capable of defining different sender and receiver types, generating node movement using different supported movement models, and routing messages between nodes with various available DTN routing algorithms. The ONE can generate its own traces based on mobility models and can import mobility data from real-world traces or other mobility generators. It can also produce a variety of detailed reports from node movement to message passing and general statistics.

3. Disasters recovery process

This work focuses on finding the behaviour of the most popular forwarding methods in opportunistic networks in disaster areas. With the results of the analysis, developers who want to create disaster area applications can know which forwarding method to use depending on the characteristics of disaster area on which their applications are focused. Furthermore, authors looking for creating new opportunistic forwarding protocols for emergency scenarios will find useful information.

For doing this analysis and extracting the results we must pass through a set of phases: understanding how the processes involved in the recovery process in the disaster areas are; knowing how the application environment is in these disaster areas; detecting the useful information in the process that can be used in the forwarding processes; finding tools to simulate those scenarios; simulating all the possible scenario cases taking into account the different values that can have all the parameters in the simulation; and extracting all these results and analyse them.

In this section, the disaster scenario will be described, including its important parts, the actors involved, and the recovery process. This is important in order to understand how the routing protocols will behave in the simulations and to interpret the results.

3.1. Disasters recovery process

This paper is centred on the worst emergency scenarios which usually are mass casualty incidents (MCIs). The main characteristic of MCIs are the large number of victims. In these cases, the triage of these victims is needed to sort injured people into groups based on their need for immediate medical treatment. This triage is done by the first response personnel arriving at the emergency scene. Consequently, the medical personnel arriving later know those victims who need more urgent attention. The victims are stabilised and prepared, in triage colour order (black, red, yellow and green), to be evacuated to the hospital or to the advanced medical post where they will be treated widely.

The triage process usually creates four groups of victims based on their condition. The first group, from worst to best condition order, is the black one. Those victims triaged as black group are dead or in a very bad condition, impossible for the medical team to do something to save their lives. The second group, red, are victims who need immediate attention. The victims in the third one, yellow, do not need immediate but urgent medical attention, so they can wait for a short period of time. And finally, the green group, is for victims with minor injuries who need help less urgently.

The first and foremost step is the triage because it focuses the medical attention on those victims in the worst conditions. Once the triage is complete, rescue teams extract those victims who are trapped or cannot move from the hot spot to a safe place. The incident location is also known as zone 0. In this area the medical personnel cannot work because of a risk of danger such as explosion or contamination. Because of this, it is important for everybody to evacuate this area and for the rescue teams to extract the victims that cannot move. While rescue teams are doing their job, the medical personnel treat those victims in the red group that have already been evacuated and are in the patients' waiting for treatment area, also known as zone 1.

If Advanced Medical Posts (AMPs) or casualties clearing stations are installed, the victims are evacuated there (see Fig. 1). An AMP is a mobile hospital to treat the victims before they can be transferred to an hospital. In mass casualties, where it is necessary to treat lots of victims in a serious condition, AMPs are essential and have to be installed near but in reasonable distance from the zone 0 to be a safe place.

Zone 0 can have two types of nodes, transportation nodes and non-transportation nodes. The first ones are in charge of picking victims in the zone 0 and take them to the zone 1, the patients' waiting for treatment area. The second ones are in charge of triaging the victims in zone 0, the incident location. So, a transportation node goes periodically from zone 0 to zone 1 and vice versa during the disaster (acting like data mules) and the non-transportation nodes go looking for victims and triaging them without coming back to the zone 1 until the emergency has finished.

The main objective of the medical personnel in the area regarding the victims in the red group is to stabilise them. Once the stabilisation is done, the ambulance, helicopter or other rescue vehicle is called to pick up each victim to transfer them to the hospital. After the red victims, the yellow ones are treated in the same way. Regarding the green ones, they are arranged together and then transferred with low priority to other hospitals or medical institutions using any available transportation.

The Advanced Command Post (ACP) is where the coordination team is, and where all the decisions about actions to be carried out by rescue and medical teams are taken.

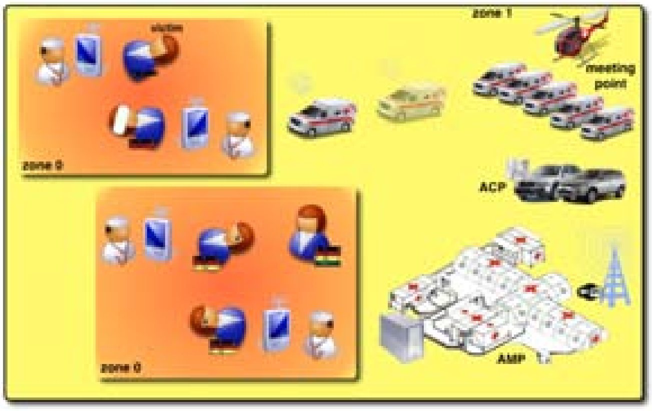

Figure 1: Emergency Scenario

3.2. Communications in the emergency scenario

Traditionally emergency communications have only been a matter of walkie-talkie communications, but nowadays more and more advanced communications mechanisms can be used. This is due to the increase of use by the emergency personnel of Internet enabled devices or mobile phones, that make use of infrastructure networks such as mobile phone network (3G) or WiFi. In most of the emergency cases, like hurricanes, terrorist attacks, earthquakes, etc., these networks become unstable, inaccessible, overused or are even destroyed. As a consequence, emergency personnel cannot rely on the use of existing network infrastructure and may deploy and use their own, or simply use wireless mobile ad-hoc networks (MANETs) or wireless mesh networks. These networks create routes by request of the nodes, that are maintained as long as they are needed or the link is available.

Anyway, all these solutions have the same shortcoming. If the area of emergency is big enough, it is possible that the ad-hoc network created by the medical personnel's devices would not be fully connected. As a result, an attempt to communicate from one point of the network, for instance, a first responder, to another point of the network, for example, an AMP, could be unsuccessful as this kind of networks needs an end to end communication.

Regarding AMP and the ACP, having Internet connection is very important for coordination or information purposes (e.g. with another coordination point or with hospitals assigned to victims). For this reason, it is assumed that they have persistent Internet connectivity even if the network infrastructures are destroyed or unusable because they can use their own deployed network infrastructure, for instance, satellite connections.

3.3. Discussion

The data generated within an emergency scenario regarding victims (e.g. triage) or coordination issues are always considered critical and cannot be lost. In some circumstances such as big disasters where no network infrastructures are available, other types of networks have to be used.

Deploying nodes to supply an infrastructure is not the best solution, since a long time may be required and even in big disaster areas it may not be feasible. Also, a fully-connected MANET is not possible due to the large geographical extension of the scenario. In these cases, the use of opportunistic networks is the appropriate solution; even if a message is required to arrive as soon as possible once it has been generated, the time to arrive to any part of the disaster area will require less time than deploying all the nodes necessary to create an infrastructure network or a fully-connected MANET.

Even though opportunistic networks seem a clear choice in these situations, different routing mechanisms can be used on top of them. The obvious, but naive choice would be to use epidemic forwarding. The information has to arrive as soon as possible to the coordination point where it will be evaluated and used, so it seems that if data is routed to all the nodes epidemically and more nodes have a message, then there are more probabilities hat one of these nodes returns early to the coordination point and delivers the message. However, this way may not be the best mechanism; Epidemic routing can lose opportunities to forward data when more than one node are in contact at the same time and the intra-contact time is short, and there are a lot of messages to be interchanged. In this case, only those with a higher probability of being delivered will be interchanged. Furthermore, Epidemic routing generates a lot of copies of the same message in the network, producing congestion and having negative influence on the rest of the messages.

In the next sections of this paper we analyse the behaviour of some routing solutions for its use in emergency scenarios. We will test the forwarding protocols in emergency scenarios with different characteristics (density of nodes, number of victims...)

4. Evaluation

Disaster scenarios are unpredictable, its area or the number of victims are data that can not be precisely predicted. Furthermore, emergencies are heterogeneous because each disaster produced have different number of victims (that is closely related to the number of messages created), different scenario area, different number of people working on the emergency, etc. As the characteristics of a disaster scenario considerably change from one to another, it is very important to carry out simulations that test the performance impact in each routing protocol of these greatly changing characteristics of disaster scenarios.

We have selected four of the most relevant opportunistic routing protocols for emergency scenarios: Epidemic, MaxProp, PRoPHET, and TTR. This evaluation, test the selected protocols through simulations in a set of emergency scenarios with different characteristics: different values of number of nodes, percentage of transportation nodes, number of messages and message size, in order to evaluate their impact on the performance.

Results are expressed as delivery delay CDF (cumulative distribution function), delivery ratio, overhead (number of messages relayed / messages delivered), and energy consumption metrics. Using this metrics we will be able to see which is the most efficient protocol in terms of delivery ratio in each situation or which is the lowest energy consuming. On one hand, users may wish to minimise the energy consumed by the network in anticipation of a long emergency situation but on the other hand they may prefer a better delivery ratio.

4.1. Routing methods

There are plenty of forwarding methods in literature but we can not test all of them, hence we have chosen those that we consider more relevant for opportunistic networks and, in this special case, for emergency scenarios. Furthermore, in this paper we provide all the data that we have used for carrying the simulations, hence, authors proposing new forwarding protocols will be able to reproduce this simulations with their own protocols and compare them.

We have chosen three popular routing methods in literature for doing the simulations: Epidemic, PRoPHET and MaxProp. Furthermore, we have chosen another forwarding method, TTR, that is special for disaster situations. In the following lines is a brief explanation of the motivation why they have been selected:

- Epidemic: This method has been chosen because of its fast message spread. It is a reference for other routing methods. It is also very well known for flooding the network because of the replication of each message to the rest of the nodes.

- PRoPHET: It is a probabilistic routing method that aims to improve Epidemic routing with lower overhead and higher delivery ratio due to the use of probabilities. This protocol is well known in opportunistic networks and it is usually used, as Epidemic, in comparisons. It will be interesting to see how it performs in disaster areas.

- MaxProp: It does an estimate delivery likelihood and adds some rules to the decision as to give forwarding preference to low-hop-count messages, to free up storage of delivered messages or to not forward the same message twice to the same next hope destination. These features are important as they give a congestion control to MaxProp interesting to test. This method has very good results applied to vehicular networks and we want to see if they achieve similar results in disaster areas.

- TTR: This is a routing method specific for disaster areas, it uses the "Time to Return" as a forwarding decision. In contrast to the others protocols, TTR only keeps one copy of the message throughout the network: when a message is relayed, it is deleted from the sender. This makes this protocol very energy saver but also penalises its delivery ratio. For all of these, it will be interesting to see its performance compared to other methods.

In the last few years a lot of forwarding protocols based on social networks have arise for opportunistic networks (SimBet [24], PeopleRank [25] or BUBBLE Rap [26]). However these routing methods can not be used in emergency scenarios because they use information that is not available under disaster situations.

4.2. Simulation set up

We use the BonnMotion tool to generate the traces used for the simulation. BonnMotion provides generation of disaster scenarios mobility traces. The trajectories created in Bonnmotion are calculated based on an analysis of disaster mobility traces extracted from an emergency simulation in May 2005 in Cologne, Germany, in preparation of the World Youth Day 2005 and the FIFA Soccer Worldcup 2006 [27]. Bonnmotion has predefined 5 zones or areas in the emergency scenario: the incident location, the patients waiting for treatment area, the casualties clearing stations, the ambulance parking point, and the technical operational command (ACP). It supports nodes moving in the same zone or moving between two zones.

We have defined for all the simulations an area of 1300m x 250m for the incident location (zone 0) and an area of 100m x 40m for the patients waiting for treatment area, the AMPs, the ACP, and the coordination or meeting point (zone 1). The situation and size of the zones is important because the nodes in zone 0 go periodically to zone 1 in order to carry victims, get more equipment or because the TTR is exhausted. The usual situation of the zone 1 is as close as possible to the zone 0 but always in a safe area. For this reason we have set up the zone 1 sharing its left edge with the upper right edge of the zone 0 (figure 2). We have not taken into account the ambulance parking lot and the ACPs in the simulations because the nodes from zone 0 (those who generate the messages) only moves between zone 0 and 1. Messages will be delivered when the nodes enter in the zone 1, that can have a wireless access point, a satellite connection or another type of network connection because is where the coordination point is.

For creating the traces we only take into account the number of nodes in zone 0 and the size and situation of the zone 0 and zone 1. Nodes in other zones won't be relevant for the simulations as they don't move to zone 0 and because messages are delivered when a node coming from the zone 0 enters in zone 1. The nodes moves at a speed from 0 m/s (stopped, when they find a victim) to 2,5 m/s (the average human running speed). The duration of the simulation is of 6000 seconds. This gives time to the simulation to be stabilised as the CDF results will show. This is important because we need to analyse the results when the simulation is stabilised, and not while its starting when no messages are circulating throughout the network and the buffers of the nodes are empty.

Four main characteristics of an emergency scenario are tested in the simulations to see how they impact in the performance of the forwarding protocols: number of nodes (density of nodes of the scenario), percentage of transportation nodes, number of messages created (that can also be interpreted as number of casualties because of its correlation) and message size.

Once the traces are generated with the BonnMotion tool, they are converted to the ONE traces format and imported into this simulator. The One simulator allows to separate nodes into groups. All the nodes belonging to the same group share the same properties.

In the scenario there exist two groups of nodes, non-transportation and transportation, both with the same attributes (link speed, radio range, etc.). Hence, it only needed the definition of one group in the One simulator because the only difference between both groups is the movement model, information that is already included in the traces provided by the BonnMotion tool. A link speed of 54 Mbps and a radio range of 60m are the values defined for all the nodes. The link speed is chosen using the 802.11g standard, the simulator is in charge of changing the speed rate depending on the distance between two nodes. The maximum radio range is a parameter that can be different depending of the device the user is using, so we carried tests outdoor with obstacles (typical for disaster scenarios) using iPhones 3GS, that gave us an average result of 60 meters. Regarding this value, in section 5.1 we have tested a disaster scenario with different density of nodes. Since having shorter radio range is similar to having less density of nodes or a larger scenario, these results can be extrapolated to know which results would be obtained for radio ranges longer, or shorter than 60 meters. The messages are originated in randomly chosen nodes (either transportation or not transportation group) and all have as destination, the zone 1. Messages are created throughout the simulation time. Regarding the size of the messages it has been done a whole set of simulations to see the performance impact of this parameter in each one of the forwarding protocols. In the other sets of simulations, testing other parameters, it has been set up a message size of 225 kB, an average size for a message with text and an image.

Table 1 sums up the main simulation parameters. The number of messages generated, number of nodes in the disaster area and the message size in each simulation will be explained in the corresponding sections.

Each routing method is evaluated in terms of delivery ratio, delay (latency), overhead and energy consumption for each parameter of the simulation tested: number of nodes, percentage of transportation nodes, number of messages and message size. We have expressed the results using four charts: delivery delay CDF (Cumulative Distribution Function), delivery ratio, overhead and energy consumption.

	Parameter	**Value**
Network	Simulation time	6000 s
	PHY data rate	54 Mbps
	Radio range	60 m
	Buffer size	5 MB
	TTL	
Scenario size	Zone 0	1300x250 m
	Zone 1	100x40 m
Mobility	Number of groups	2
	Mobility Model	Disaster [27]
	Speed	0-2,5 m/s
PRoPHET	Pinit	0,75
	β	0,25
	γ	0,99
MaxProp	Max Meeting Prob	50
	α	1

Table 1: Values for the simulation parameters

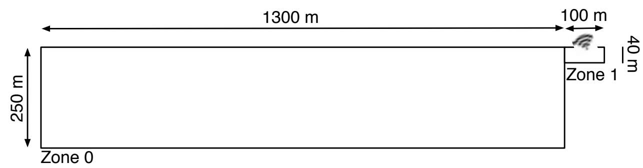

Figure 2: Simulation Scenario

4.3. Energy-efficiency

The energy-efficiency of forwarding methods in emergency scenarios is very important. This importance is mainly due to two reasons: The first one is that in these scenarios mobile devices are heavily used, and its battery is limited, so if it is drained fast the node will be off and the messages will not arrive. The second is that the duration of an emergency is unknown, hence the battery life has to be preserved against the overuse.

According to recent works wifi is one of the most consuming power elements of a mobile phone device [28][29], consuming up to 725 mW transferring data at full capacity [30]. Furthermore, when a mobile device is using its wifi network in opportunistic mode, it cannot enter in PSM (Power Safe Mode) because it looks constantly for nodes and so it spends a lot of energy scanning the network. Not only the scanning but also the association between nodes spends a lot of energy [28]. Because scanning and associating spend a lot of energy it is very important to use a low energy consuming forwarding algorithm that achieves a high delivery ratio while having a low overhead.

For the calculation of the Energy (Joules) required for the transmission of n bytes in a single connection, we have based our calculations in the equation proposed by N. Balasubramanian [31] for the use of mobile phones in WiFi networks.

Transfer Energy:

$$R(x) = 5.9 + 0.007(x)J$$

Maintenance:

$$M = 0.05J/sec$$

Total energy needed to transfer *(x)* kB:

$$R(x) + M$$

Where the *5.9 J* of the transfer energy is the energy required for the initial connection, and the *0.007(x) J* is the energy required to transmit *(x)* kilobytes. The maintenance energy is the energy required while the connection between two nodes is up.

We have adapted the previous equations, to make a calculation of the average energy consumed by each node. This calculations use the values we get from the simulation tools and takes into account all the transfers and connections a node does during the simulation. Then the equations for the calculation of the average energy consumed by each node become:

$$T(x\ nc\ ct) = 5.9(nc) + 0.007(x) + 0.05(ct)$$

Where nc is the average number of contacts per node, x is the average number of bytes relayed per node, and ct is the average total contact time per node.

5. Simulation Results

In this section we present and discuss the results obtained after performing the simulations. We want to analyze how the chosen routing methods behave in emergency scenarios with different characteristics in number of nodes, percentage of transport nodes, number of messages and messages size. We will examine the performance impact of each characteristic in each routing method using four metrics: delay, delivery ratio, overhead and energy consumption.

5.1. Number of nodes

The number of people involved in an emergency can be variable depending on many factors: personnel available, location of the emergency, etc. For this reason we have evaluated the performance of the selected routing methods with different number of nodes. Table 2 shows the values of the parameters for these simulations. 2000 messages are generated during the 6000 seconds of the simulation with a message size of 225 kB. The messages are originated in randomly chosen nodes in the transportation group. All nodes in the simulation have the role of transportation nodes.

Parameter	**Value**
Number of messages	2000 messages
Transportation nodes	100%
Message size	225 kB

Table 2: Values for parameters for "number of nodes" based simulations

Delivery ratio and delay

In terms of delivery ratio, in figure 3 we see that MaxProp performs much better than any other method, achieving up to 85% of messages delivered with 80 nodes. As the number of nodes grows, so does the performance gap between MaxProp and the second best method, TTR. TTR only gets up to 45% of message delivery. Increasing the number of nodes improves the delivery ratio of MaxProp and TTR but decreases the performance of PRoPHET and Epidemic.

Using Epidemic the buffers can become full and, in some contacts, not all messages can be relayed in the intra-contact time. Furthermore, nodes always deliver and relay messages in the same order, as they are stored in the buffer, because Epidemic does not use message prioritization. This explains the low delivery ratio of Epidemic.

PRoPHET has the same problem as Epidemic. For this reason the messages relayed are always the same: those who are first in the buffer of the node. However, PRoPHET includes probabilistic information when deciding whether a message should be relayed or not, which improves the delivery ratio of Epidemic. Nevertheless, adding probabilities to the decision making works better for few nodes.

If we look more deeply in MaxProp results, we will find that its good results are due to two main characteristics of this routing method. MaxProp deletes those message in the buffer with low probability of being delivered, freeing up space for new messages. In addition, it sends messages to other nodes in specific order that takes into account message hop counts and message delivery probabilities based on previous encounters. This two characteristics provide congestion control and make the most of short contacts. Therefore, for MaxProp, having more nodes in the emergency scenario means better results.

For TTR, its results improve those of Epidemic and PRoPHET thanks to using a data mules approach in emergency scenarios. Transportation nodes go back and forth to the coordination point where they deliver the messages. TTR takes advantage of that by using this information into the forwarding decision and thus forwarding the messages only to those nodes that have better chances of delivering the message sooner. However, its single-message policy makes this routing method lose opportunities to relay messages to better nodes, producing a delivery ratio far below MaxProp.

Figure 4 shows the delivery delay CDF for 80 nodes. Since all the delay charts show the same shape of the curves, the delivery delay CDF for different number of nodes can be obtained combining this chart with the delivery ratio chart in figure 3. It must only be taken into account that for a given number of nodes, the asymptotic value of a curve is the same as the value in the delivery ratio chart for this routing protocol.

In the case presented in figure 4 we can say that for 80 nodes, MaxProp is the fastest method, 65% of the messages created are delivered in less than 1000 seconds whereas for TTR only 33% of messages created, or 15% for PRoPHET, have a delivery delay of less than 1000 seconds. Asymptotically, we see that for 6000 seconds around 82% of MaxProp messages and 45% of TTR messages are delivered, that corresponds to the delivery ratio in figure 3.

If we want to calculate the delivery delay CDF values of MaxProp for 20 nodes, we see in the delivery ratio chart that the asymptotic value will be 45% (while for 80 nodes it is 82%). Calculating the equivalence, the value for 1000 seconds will be around 35% ($0.65 * 0.45/0.82$). The same applies for the rest of the delivery delay CDF charts in all this section.

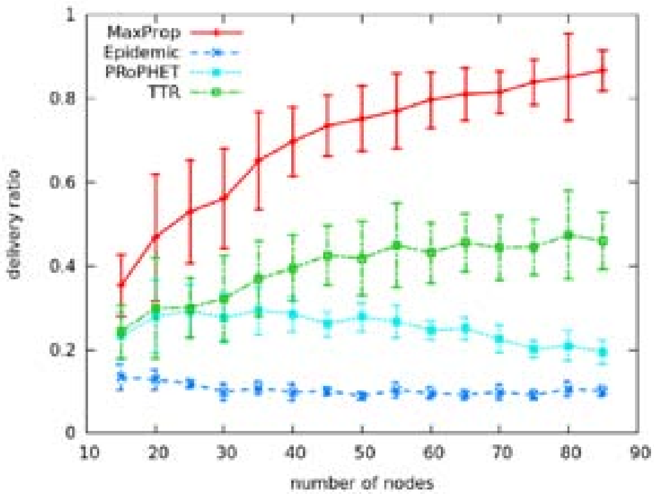

Figure 3: Delivery ratio vs. Number of nodes

Overhead

Regarding overhead, figure 5 shows that Epidemic is the routing method that produces more transmissions per message per each one delivered while TTR is the one that produces less.

PRoPHET also has a high overhead. In Epidemic, nodes exchange all the messages they have stored when they contact another node but PRoPHET only exchanges them if the delivery probability is big enough.

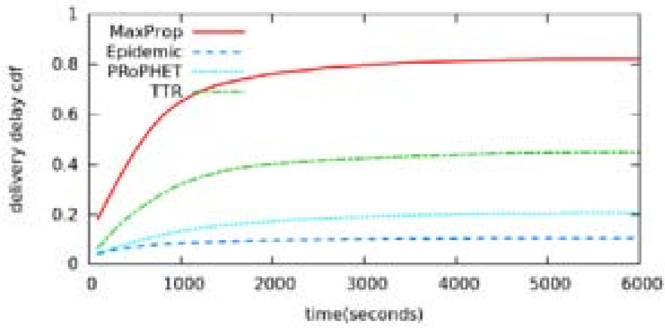

Figure 4: Delivery delay CDF vs. time for 80 nodes

MaxProp also transmits plenty of messages but the high delivery ratio gives as a result a good overhead. This is explained because MaxProp only keeps the messages most likely to be delivered and removes all the others. Hence, when two nodes exchange messages using MaxProp, they receive messages that had been received earlier and later deleted because they were unlikely to be delivered.

TTR only manages one copy of the message instead of duplicating it in each node. A node using TTR only relays the message (not a copy) to another node contacted if the second one is more likely to deliver the message to the recipient earlier than the node that has the message.

Analysing the results we can also say that as the number of nodes grows, so does the number of messages relayed in all routing methods. Hence, the number of nodes in the scenario has a big impact in the overhead performance of MaxProp, PRoPHET and Epidemic but little impact in TTR, a single copy routing method.

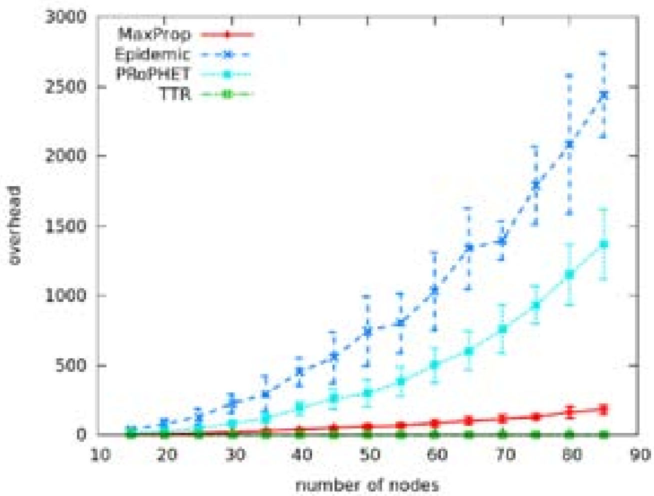

Figure 5: Overhead vs. Number of nodes

Energy consumption

Figure 6 clearly shows that when the number of nodes in the emergency scenario grows, the energy consumption of the devices is bigger as more message are relayed and more contacts are produced. The increase in energy consumption is similar to MaxProp, Epidemic and PRoPHET. TTR maintains a lower energy consumption due to its single-copy forwarding policy. In this figure, TTR shows its potential as a low consumption routing method. It consumes up to 10 times less than MaxProp for 85 nodes. The rest of methods grow linearly with a higher slope.

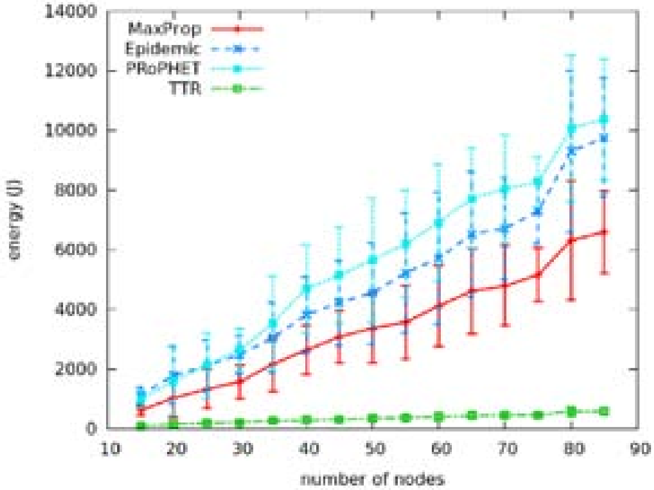

Figure 6: Average energy consumed by each node vs. Number of nodes

5.2. Percentage of transportation nodes

The organisation of an emergency makes some people working in it to have to return periodically to the zone 1, which is the destination of all the messages. We call this group of nodes "transportation group". The remaining group working in an emergency stays in the emergency scenario and only comes back to the zone 1 when the emergency has ended. This second set of simulations analyses the performance impact when the percentage of transportation nodes changes. Table 3 shows the specific parameters for these simulations. There are 60 nodes in the simulation and 2000 messages are generated during the 6000 seconds of the simulation with a message size of 225 kB.

Parameter	Value
Number of messages	2000 messages
Nodes	60
Message size	225 kB

Table 3: Values for parameters for "percentage of transportation nodes" based simulations

Delivery ratio and latency

In terms of delay and delivery ratio versus percentage of transportation nodes we see in figures 8 and 7 that MaxProp performs much better than any other method, achieving up to than 80% of messages delivered with 100% of the nodes being transportation nodes and with a density of 60 nodes. As the percentage of transportation nodes grows, so does the performance of the routing methods. For all methods, except Epidemic, increasing the percentage of transportation nodes improves the delivery ratio but for MaxProp and TTR the increase in performance is clearly remarkable. These results demonstrate that it is positive to have the highest percentage of nodes possible in the scenario behaving as transport nodes. It is notable the low performance of TTR in low percentage of transportation nodes. The delay chart also shows the dominance of MaxProp not only in terms of delivery ratio but also in delivery delay.

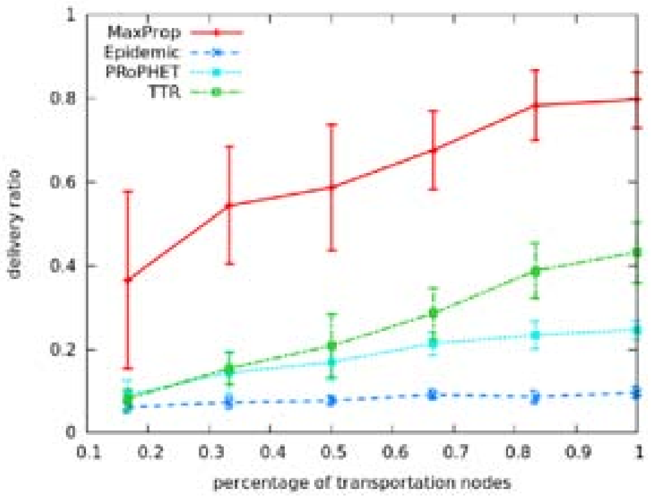

Figure 7: Delivery ratio vs. Percentage of transportation nodes

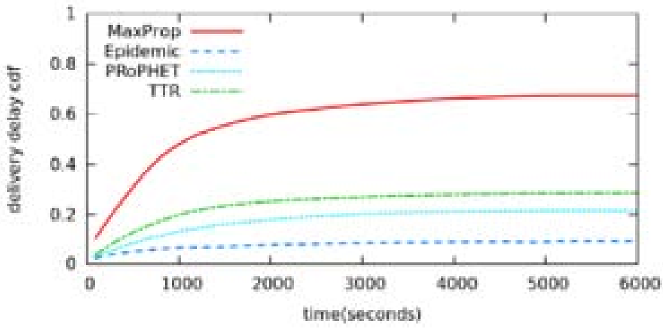

Figure 8: Delivery delay CDF vs. time for 66% of transportation nodes

Overhead

Regarding the overhead versus percentage of transportation nodes, in figure 9 we can see that the percentage of transportation nodes does not impact in the results of TTR but it is noteworthy in Epidemic and PRoPHET where the overhead decreases in case of PRoPHET because more messages are delivered in contrast with those relayed. Epidemic is also significantly affected decreasing the overhead when the delivery ratio increases, but also increasing the overhead for more than 60% of nodes as the delivery ratio becomes constant but the number of messages relayed increments. With these results, we can say that increasing the percentage of transportation nodes in the emergency scenario has a significantly impact in the overhead in Epidemic and PRoPHET but a negligible impact in the overhead in TTR.

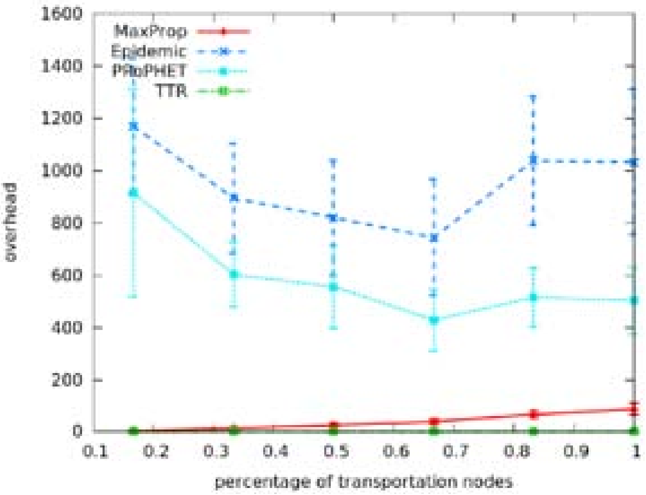

Figure 9: Overhead vs. Percentage of transportation nodes

Energy consumption

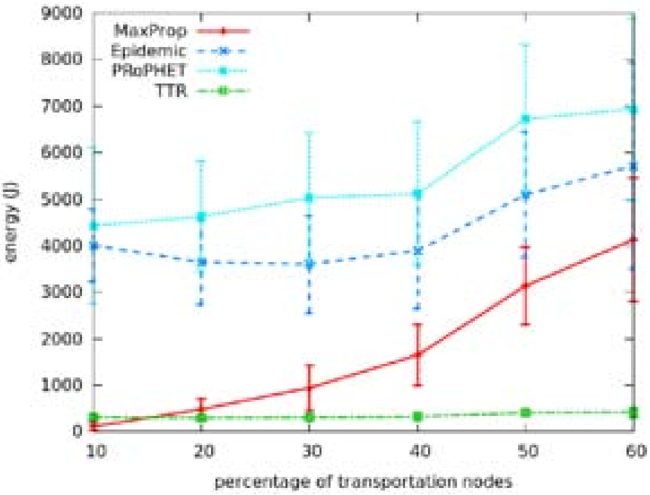

Figure 10: Average energy consumed by each node vs. Percentage of transportation nodes

In terms of energy consumption, in figure 10 we can see that the percentage of transportation nodes does not significantly impact in the results of TTR but it is noteworthy in MaxProp where the cost increases due to the big growth of the number of messages relayed. ProPHET and Epidemic are less affected than MaxProp but they also increase their energy consumption when the percentage is more than 60%. We can say that increasing the percentage of transportation nodes in the emergency scenario has a significantly impact in the energy consumption in MaxProp (as it had in delivery ratio) but a negligible impact in the overhead in TTR. This data shows how important is a good forwarding policy. While Epidemic, or PRoPHET, spends a lot of energy even in cases where only a 15% of the nodes are transportation nodes (those who go to the zone 1 and deliver the messages), MaxProp adapts its consumption to the number of this type of nodes in the scenarios. Thanks to this, it maintains a good balance between energy consumption and performance. MaxProp relays more messages to transportation nodes because they have more probability of delivery messages, producing a low energy consumption as less messages relays are wasted. This can also bee seen in figure 9. We can state similar conclusions for TTR. It loses good relay opportunities because its single-message policy, producing a lower delivery ratio than MaxProp but also a very low energy consumption.

5.3. Number of messages

Generally in emergency scenarios there is a correlation between the number of victims (or the magnitude of the event) and the number of messages generated. Usually a message is generated for each victim found, for an update of her health status, or for some critical information about the scenario. In this third set of simulations the focus is on the analysis of how the number of message impacts the routing methods performance. Table 4 shows the specific parameters for these simulations. There are 60 nodes in the scenario, the message size is 225 kB and the messages are originated in randomly chosen nodes in the transportation group. All nodes in the simulation have the role of transportation nodes.

Parameter	Value
Nodes	60
Transportation nodes	100%
Message size	225 kB

Table 4: Values for parameters for "number of messages" based simulations

Delivery ratio and delay

For the delivery ratio and delay, see figures 11 and 12, the results show that MaxProp performs much better than any other method, achieving almost 100% of messages delivered for low number of messages. PRoPHET behaves well for low number of messages and its delivery ratio decreases as the number of messages increases. This last behavior is the same for all the methods, their performance decrease when the number of message increases, the buffers of some nodes become full, hence some messages cannot be relayed. There is also a second reason for this behavior that is explained because there are a lot of messages in each buffer and in short contacts there is no time to relay all the messages from one node to another. The methods without congestion control are more affected than the others, this can be seen with MaxProp vs Epidemic.

TTR is less affected by the change of number of messages created because the nodes have fewer messages to relay or deliver in contacts. Although the delivery ratio performance is less affected by the increase of the number of message, its delivery ratio is also low.

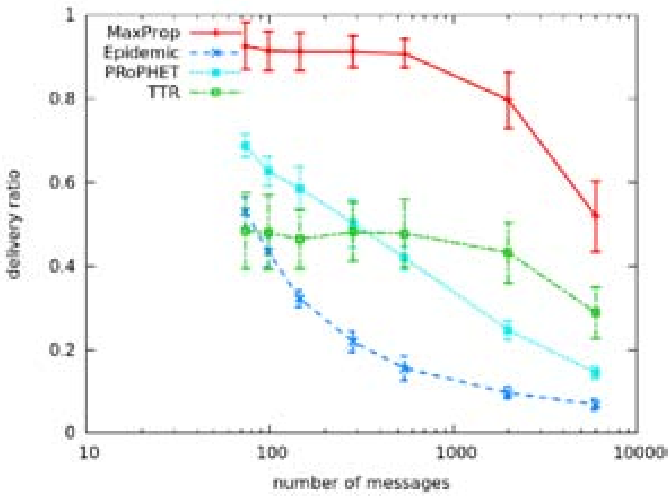

Figure 11: Delivery ratio vs. Number of messages

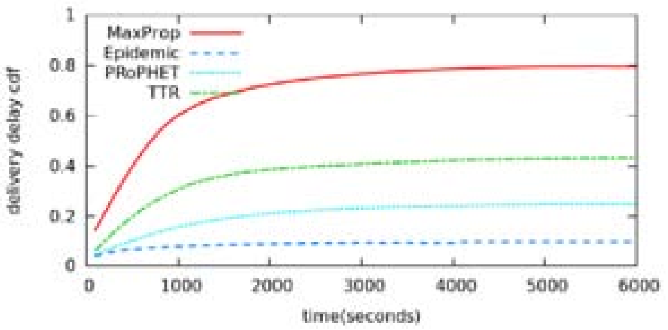

Figure 12: Delivery delay CDF vs. time for 2000 messages

Overhead

Regarding overhead, figure 13 shows that with MaxProp, PRoPHET, and Epidemic initially increase the overhead but then it start to decrease. The explanation of these results is the same as in the results of the delivery ratio: the buffers of the nodes become full and hence they start to discard messages.

PRoPHET and Epidemic decrease the overhead faster because these protocols are Epidemic (with few message they do a lot of relays) and because they do not have congestion control and buffers become full faster than other methods.

Moreover, it can also be seen that TTR also suffers from the problem of short contacts when they have a lot of messages in the buffers.

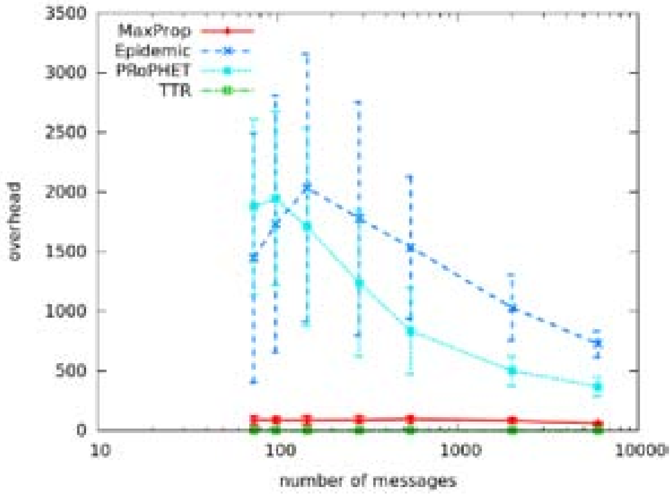

Figure 13: Overhead vs. Number of messages

Energy consumption

Figure 14 shows that MaxProp, PRoPHET and Epidemic highly increases due to the increment of relayed messages. In a difference with overhead, energy consumption takes into account those messages that fail to relay. TTR also increases but to its nature of single-message routing it only increases a bit.

5.4. Message size

In this set of simulations we test how message size impacts in the delivery ratio, delay, overhead and energy consumption performance for each routing method. Table 5 shows the specific parameters for these simulations. 2000 messages are generated during the 6000 seconds of the simulation. The messages are originated in a randomly chosen node in the transportation group. All the 60 nodes in the simulation have the role of transportation nodes.

Parameter	**Value**
Number of messages	2000 messages
Nodes	60
Transportation nodes	100%

Table 5: Values for parameters for "message size" based simulations

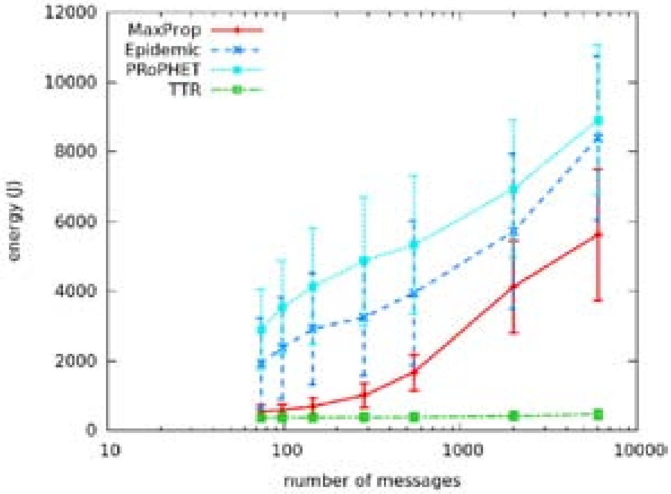

Figure 14: Average energy consumed by each node vs. Number of messages

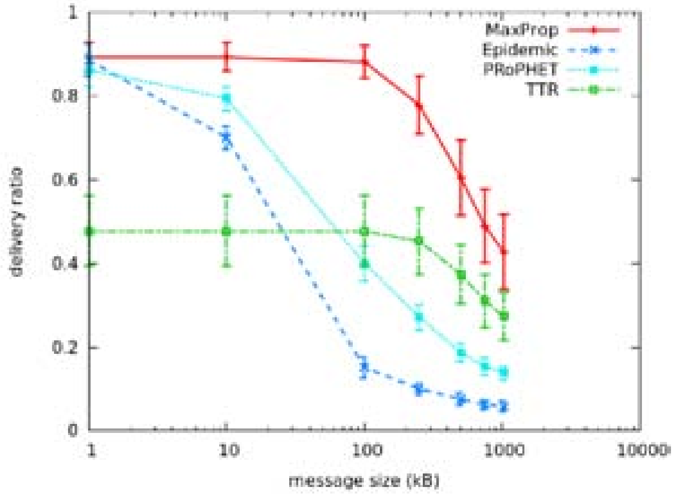

Figure 15: Delivery ratio vs. Message size

Delivery ratio and latency

In figures 15 and 16 we observe that the delivery ratio for each routing method decreases when the message size increases. The performance drop is more severe for the Epidemic and ProPHET methods. These two methods are very efficient for small messages, but they are more affected by the increment of message size than the others because of their lack of congestion control. In case of small message size there is no need of congestion control because the buffers are not full and all the messages can be relayed in short contacts.

For large messages MaxProp is also the best method, followed by TTR. When the size of the messages grows, a good congestion control is very important as the performance of Epidemic and PRoPHET shows. The same reason given for the results of the simulations based on number of messages can be given to explain those results.

Overhead

Regarding the overhead versus message size, in figure 17 we see how overhead increments due to the decrease of the delivery ratio. But for Epidemic when the buffers become full the number of messages relayed decreases faster than the delivery ratio which causes the decrement of its overhead. As well as in other charts, MaxProp and TTR are less affected.

Energy consumption

In terms of energy consumption we see in figure 18 the same problems mentioned above. When the buffers of the nodes become full, the number of messages relayed decreases and so does the energy consumption. All routing methods are affected but they seem to be affected differently.

When using Epidemic for small size messages, all the nodes have time to relay all the messages because of their size. When the size of the messages is big, specially when they are bigger than 100 kB, the nodes don't have time to relay all the messages in the buffer and so the energy consumption decreases.

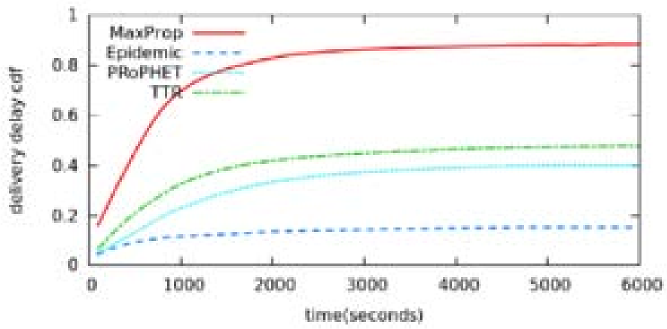

Figure 16: Delivery delay CDF vs. time for a message size of 100 kB

In the case of PRoPHET, it is less affected than Epidemic when the size of the messages is bigger than 100 kB due to the ordering by probability of the messages.

As stated before, MaxProp has a good congestion control (it deletes messages with low probability of being delivered). Therefore the number of messages transmitted between nodes increases, except for the last result.

Regarding TTR, it is also affected by the message size, although it only carries one copy of the message in all the network, the buffer also become full when it carries several heavy messages and so energy consumption drops.

We have to take into account that the initial increase in the figure 18 of the energy consumption in Epidemic and PRoPHET it is not produced because of more message relays but because messages are bigger and hence they require more time to be transmitted, consuming more energy.

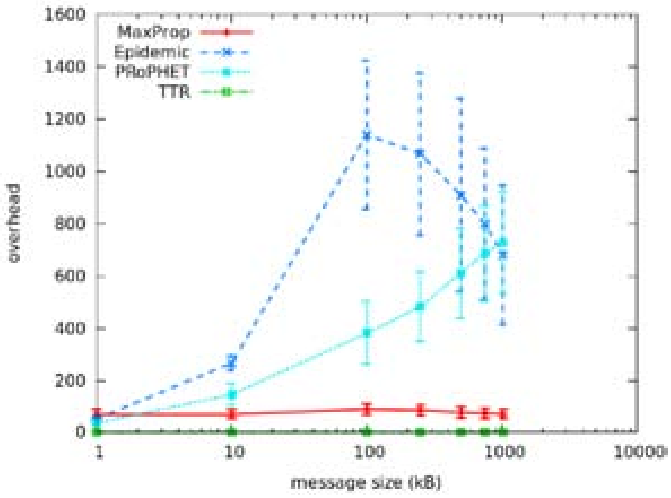

Figure 17: Overhead vs. Message size

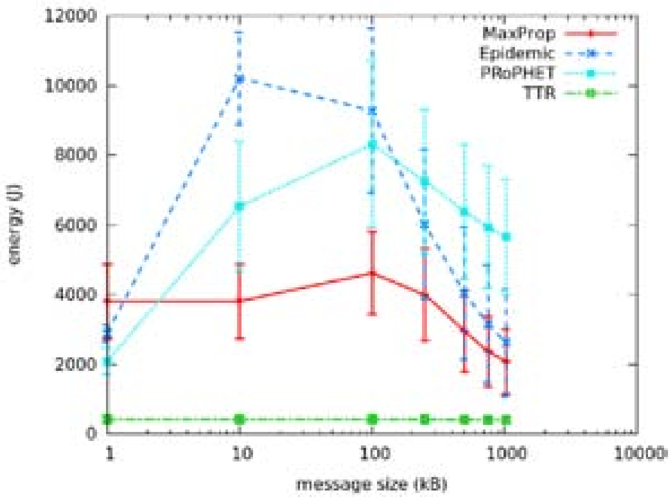

Figure 18: Average energy consumed by each node vs. Message size

6. Discussion

In this section we want to discuss the results obtained in the previous section. From these results we can say that MaxProp has a very good performance in terms of delivery ratio for almost all emergency scenarios regardless its characteristics. It is the method with most messages delivered and the one that delivers the messages fastest. All other methods are significantly worse in terms of delivery ratio and delay with few exceptions.

However, if we consider overhead or energy consumption, then the results are different. In this case, the routing method with best results is always TTR as it keeps only one copy of the message throughout the network and it is designed for emergency scenarios. This means that TTR is the most efficient (number of relays for each message delivered) forwarding method and the one that consumes less energy. In terms of delivery ratio and delay, TTR shows good results except for scenarios with few message or lightweight messages where Epidemic or PRoPHET also surpass the results of TTR.

In disaster scenarios it is also very important to make the information about victims available in the coordination point as fast as possible. In this case, MaxProp is the fastest forwarding protocol, the one with lowest delivery delay.

Taking into account these results, if in an emergency scenario where we require the fastest delivery method then we would choose MaxProp. However, choosing MaxProp will produce an elevated power consumption and will drain fast the battery. In some cases the battery will not last until the end of the emergency and another forwarding method should be used. Emergency scenarios with a high density of nodes or a lot of victims (a lot of message created) will cause a high energy consumption for MaxProp. If one of this cases is foreseen a energy efficient forwarding method should be used. If TTR is used the battery of the nodes will last much longer, in some cases up to 10 times more. This would have as a consequence a poorer delay and delivery ratio but the node will not be switched off during the emergency.

We have to remember that all nodes will eventually come back to the coordination point once the emergency will come to an end, hence all messages will be delivered at some point and no one will be lost. Furthermore, at some point, when all the victims are found, the number of messages created will approach to zero, which will allow to deliver the remain messages in the network before the emergency ends. The delivery ratio charts show how MaxProp is the fastest method followed by TTR in almost all situations, except for low number of messages created and for lightweight messages, where the Epidemic methods perform better.

The following summarises the key aspects of each of the routing protocols:

MaxProp

++ Excellent delivery ratio and good delay in almost any situation thanks to its congestion control protocol and forwarding decision algorithm

\+ Satisfactory energy performance for low number of nodes or messages

\- Elevated consumption for scenarios with high number of nodes or messages because its congestion control protocol

TTR

++ Very good energy efficiency in all situations thanks to its single message copy policy

\+ Good delivery ratio in scenarios with any number of nodes but high percentage of transportation nodes

\- Poor delivery ratio in scenarios with low message size or low number of messages

ProPHET and Epidemic

-- Elevated energy consumption due to epidemic algorithms

+ Acceptable delivery ratio only in scenarios with low message size, number of messages or number of nodes where no congestion is produced

7. Conclusions

There has been a growing interest recently in the design of systems to help managing an emergency, and triaging the victims or coordinating rescue teams are key facets of these systems. Many of these systems rely on the availability of a network infrastructure, which in a real emergency scenario may be damaged and unavailable, as we have seen in recent events such as the floods in New Zealand or the Tsunami and earthquake in Japan. There are various approaches to solve this problem: to create an ad-hoc network between all the mobile devices used in the disaster area to get a full-coverage; to deploy a full-coverage network spreading nodes in the disaster area; or to use opportunistic delay and disruption tolerant networks to provide a network of not fully connected nodes. The last option does not require time to develop nodes before using the solution and also it can be employed in widely distributed disaster areas where an ad-hoc network cannot be fully connected with only a few nodes. For the opportunistic networking approach, there are several routing methods that can be used, and it was perhaps not obvious how to decide which provides the best performance for a given scenario.

In this paper we have presented the results of an analysis of opportunistic routing performance in emergency situations using opportunistic networks. We take into account parameters regarding the characteristics of the emergency scenario (number of people involved, number of victims, etc) to see how they impact on the performance of routing methods, with regards to suitability for various performance requirements such as delivery rate or lifetime.

From our analysis, we draw two main conclusions. Firstly we find that MaxProp routing method is the best method in terms of delivery performance in almost all scenarios. Its performance surpasses the other routing methods by a wide margin in almost all the simulations, no matter the number of nodes in the emergency or the density of victims (number of messages generated). Secondly, we note the low overhead and energy consumption of the TTR routing method. While the delivery performance results of TTR are far below the performance of MaxProp its energy performance deserves consideration, if the characteristics of the emergency scenario requires it. Examples are long emergency situations, scenarios with a high density of nodes, or a lot of messages, where an energy efficient forwarding method is required for not exhausting the node's battery.

Developers working on emergency applications using opportunistic networking can see the difference between the forwarding methods applied to disaster areas and decide which scheme to use depending on the target scenario using our data and analysis, or extend the comparison to new opportunistic forwarding schemes that may arise in future.

8. Acknowledgement

This research has been partially funded by the Spanish Ministerio de Educación y Ciencia (FPU grant AP2008-03149), by the Catalan DURSI Grant 2009SGR1224 and by EU Socialnets project (217141).

References

[1] http://www.mashproject.com/, Mass casualties and health care following the release of toxic chemicals and radioactive material (mash) (2009).

[2] http://www.geo pictures.eu/, Geo-pictures (2010).

[3] I. Hikaru, M. Kenji, U. Yoichiro, I. Kazuo, M. Noriharu, Study on the evaluation of applicability of smart phones in a disaster recovery system, Proceedings of the IEICE General Conference 2011 (2) (2011-02-28) S61 S 62.
URL `http://ci.nii.ac.jp/naid/110008577631/en/`

[4] A. Martín-Campillo, J. Crowcroft, E. Yoneki, R. Martí, C. Martínez, Using haggle to create an electronic triage tag, in: The Second International Workshop on Mobile Opportunistic Networking - ACM/SIGMOBILE MobiOpp 2010, ACM Press, 2010, pp. .

[5] Google crisis response.
URL `http://www.google.com/crisisresponse/`

[6] N. Aschenbruck, M. Frank, P. Martini, J. Tolle, Human mobility in manet disaster area simulation - a realistic approach, in: Proceedings of the 29th Annual IEEE International Conference on Local Computer Networks, LCN 04, IEEE Computer Society, Washington, DC, USA, 2004, pp. 668 675. doi:http://dx.doi.org/10.1109/LCN.2004.64.
URL `http://dx.doi.org/10.1109/LCN.2004.64`

[7] Improvisa - infraestructura minimalista para la provisión de servicios en redes ad-hoc (minimalist infrastructure for service provisioning in ad-hoc networks), `http://www.gsi.dit.upm.es/ improvisa/english.htm`.

[8] M. Conti, M. Kumar, Opportunities in opportunistic computing, Computer 43 (2010) 42 50. doi:http://doi.ieeecomputersociety.org/10.1109/MC.2010.19.

[9] Q. Ye, L. Cheng, M. C. Chuah, B. D. Davison, Performance comparison of different multicast routing strategies in disruption tolerant networks, Computer Communications 32 (16) (2009) 1731 1741, special Issue of Computer Communications on Delay and Disruption Tolerant Networking. doi:DOI: 10.1016/j.comcom.2009.02.007.

[10] L. Pelusi, A. Passarella, M. Conti, Opportunistic networking: data forwarding in disconnected mobile ad hoc networks, Communications Magazine, IEEE 44 (11) (2006) 134 141. doi:10.1109/MCOM.2006.248176.

[11] M. P. Wittie, K. A. Harras, K. C. Almeroth, E. M. Belding, On the implications of routing metric staleness in delay tolerant networks, Comput. Commun. 32 (2009) 1699 1709. doi:10.1016/j.comcom.2009.02.006.

[12] U. of Bonn, Bonnmotion: A mobility scenario generation and analysis tool, http://net.cs.uni-bonn.de/wg/cs/applications/bonnmotion/ (2009).

[13] A. Keranen, J. Ott, T. Karkkainen, The one simulator for dtn protocol evaluation, in: Proceedings of the 2nd

International Conference on Simulation Tools and Techniques, Simutools 09, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), ICST, Brussels, Belgium, Belgium, 2009, pp. 55:1 55:10. doi:http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5674.
URL `http://dx.doi.org/10.4108/ICST.SIMUTOOLS2009.5674`

[14] S. McGrath, E. Grigg, S. Wendelken, G. Blike, M. D. Rosa, A. Fiske, R. Gray., ARTEMIS: A Vision for Remote Triage and Emergency Management Information Integration, in: Dartmouth University, Dartmouth University, 2003, pp. .

[15] R. Martí, S. Robles, A. Martín-Campillo, J. Cucurull, Providing early resource allocation during emergencies: the mobile triage tag, Journal of Network and Computer Applications 32 (6) (2009) 1167 1182.

[16] D. Williams, Tactical medical coordination system (tacmedcs), Naval Health Research Center, San Diego, CA. Technical report Feb 2004-Jun 2007 (November 2007).

[17] E. Nordstrom, P. Gunningberg, C. Rohner, A search-based network architecture for mobile devices, Tech. rep., Uppsala University (2009).

[18] S. Farrell, V. Cahill, D. Geraghty, I. Humphreys, P. McDonald, When tcp breaks: Delay- and disruption- tolerant networking, IEEE Internet Computing 10 (4) (2006) 72 78. doi:http://dx.doi.org/10.1109/MIC.2006.91.

[19] A. Vahdat, D. Becker, Epidemic routing for Partially-Connected ad hoc networks, Tech. rep., Duke University (Apr. 2000).
URL `http://issg.cs.duke.edu/epidemic/epidemic.pdf`

[20] A. Lindgren, A. Doria, O. Schelén, Probabilistic routing in intermittently connected networks, in: SAPIR, Vol. 3126 of Lecture Notes in Computer Science, Springer, 2004, pp. 239 254.
URL `http://www.springerlink.com/content/9xt3904hd05fxmjf`

[21] J. Burgess, B. Gallagher, D. Jensen, B. N. Levine, MaxProp: Routing for Vehicle-Based Disruption-Tolerant Networks, in: Proc. IEEE INFOCOM, 2006.
URL `http://goo.gl/hZOAw`

[22] V. Erramilli, M. Crovella, A. Chaintreau, C. Diot, Delegation forwarding, in: MobiHoc 08: Proceedings of the 9th ACM international symposium on Mobile ad hoc networking and computing, ACM, New York, NY, USA, 2008, pp. 251 260. doi:http://doi.acm.org/10.1145/1374618.1374653.

[23] P. Hui, J. Crowcroft, E. Yoneki, Bubble rap: social-based forwarding in delay tolerant networks, in: MobiHoc 08: Proceedings of the 9th ACM international symposium on Mobile ad hoc networking and computing, ACM, New York, NY, USA, 2008, pp. 241 250. doi:http://doi.acm.org/10.1145/1374618.1374652.

[24] E. M. Daly, M. Haahr, Social network analysis for routing in disconnected delay-tolerant manets, in: Proceedings of the 8th ACM international symposium on Mobile ad hoc networking and computing, MobiHoc 07, ACM, New York, NY, USA, 2007, pp. 32 40. doi:http://doi.acm.org/10.1145/1288107.1288113.
URL `http://doi.acm.org/10.1145/1288107.1288113`

[25] A. Mtibaa, M. May, C. Diot, M. Ammar, Peoplerank: Social opportunistic forwarding, in: INFOCOM, 2010 Proceedings IEEE, 2010, pp. 1 5. doi:10.1109/INFCOM.2010.5462261.

[26] P. Hui, J. Crowcroft, E. Yoneki, Bubble rap: Social-based forwarding in delay-tolerant networks, Mobile Computing, IEEE Transactions on 10 (11) (2011) 1576 1589. doi:10.1109/TMC.2010.246.

[27] N. Aschenbruck, E. Gerhards-Padilla, M. Gerharz, M. Frank, P. Martini, Modelling mobility in disaster area scenarios, in: MSWiM, ACM, 2007, pp. 4 12.

[28] N. Balasubramanian, A. Balasubramanian, A. Venkataramani, Energy consumption in mobile phones: a measurement study and implications for network applications, in: Proceedings of the 9th ACM SIGCOMM conference on Internet measurement conference, IMC 09, ACM, New York, NY, USA, 2009, pp. 280 293. doi:http://doi.acm.org/10.1145/1644893.1644927.
URL `http://doi.acm.org/10.1145/1644893.1644927`

[29] A. Rice, S. Hay, Measuring mobile phone energy consumption for 802.11 wireless networking, Pervasive and Mobile Computing 6 (6) (2010) 593 606, special Issue PerCom 2010. doi:DOI: 10.1016/j.pmcj.2010.07.005.
URL `http://goo.gl/AjQZH`

[30] A. Carroll, G. Heiser, An analysis of power consumption in a smartphone, in: Proceedings of the 2010 USENIX conference on USENIX annual technical conference, USENIXATC 10, USENIX Association, Berkeley, CA, USA, 2010, pp. 21 21.
URL `http://portal.acm.org/citation.cfm?id=1855840.1855861`

[31] N. Balasubramanian, A. Balasubramanian, A. Venkataramani, Energy consumption in mobile phones: a measurement study and implications for network applications, in: Proceedings of the 9th ACM SIGCOMM conference on Internet measurement conference, IMC 09, ACM, New York, NY, USA, 2009, pp. 280 293. doi:http://doi.acm.org/10.1145/1644893.1644927.
URL `http://doi.acm.org/10.1145/1644893.1644927`

Appendix G

“Energy-efficient forwarding mechanism for wireless opportunistic networks in emergency scenarios”

ARTICLE IN PRESS

Computer Communications xxx (2012) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Energy-efficient forwarding mechanism for wireless opportunistic networks in emergency scenarios

Abraham Martín-Campillo *, Ramon Martí

Department of Information and Communications Engineering, Universitat Autònoma de Barcelona, Bellaterra, Spain

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Energy-efficiency
Opportunistic networks
Opportunistic forwarding
Performance evaluation
Emergency scenarios

ABSTRACT

During emergency situations, the use of mobile devices and wireless opportunistic networks as a solution of destroyed or overused communication networks are vital. In these cases, the fast and reliable delivery of emergency information, together with the use of energy-efficient communication mechanisms are required. In this paper we propose PropTTR and PropNTTR, a set of forwarding mechanisms for wireless opportunistic networks in emergency scenarios that provide a high message delivery ratio together with a low energy consumption. We have set up a testbed used to compare the performance and energy-efficiency of our proposals with two other significant forwarding methods. We present the results of this analysis comparison in terms of message delivery ratio, delivery cost, latency and energy consumption, showing the improvements of our proposals.

1. Introduction

Due to the emergence of social networks and the increase in the use of Internet and smart phones in recent years, their role in the recovery of emergencies has to be taken into account. Some of the most important events in the last decade have been natural disasters or mass casualties incidents: 9/11 in New York in 2001, the tsunami in Indonesia in 2004, the hurricane Katrina in New Orleans in 2005, the earthquake in Haiti in 2010 and the earthquake and tsunami in Japan in 2011 are just some examples. These major incidents in recent years that have made us rethink the way emergencies must be managed and coordinated, and some authors have proposed a variety of solutions in order to improve these situations and to take advantage of new technologies.

One of the most important elements in emergencies is the quantity of information generated during the emergency. Nowadays with social networks and internet, everyone affected by the emergency is able to communicate information of what they see, what they know, etc. This information is very valuable for different purposes: locating victims, knowing the conditions of the area, etc. If all this information could be aggregated in a single place it would be very valuable. The problem is that all this information is distributed all over the internet and social networks (twitter, facebook, blogs, etc.). One of the efforts to centralise information is made by Google [1], they have developed an application addressed to find and to distribute information about victims.

Another problem is that this information posted in social networks, blogs, etc. cannot always be uploaded due to the destruction of the networks (cellular, DSL, telephone, etc.), or because their overusage. There are a lot of reports about this issue in all the emergencies, where people tend to call to their family and friends or to post something to internet to say they are ok. This prevents people that want to use this networks to send information about the emergency and the victims. Because of this, the use of opportunistic networks is very appropriate to transmit this information. To solve this problem, Martí et al. [2] proposed a system called MAETT (Mobile Agent Electronic Triage Tag) to be used in the emergency scenario to send triage information of the victims using opportunistic networks even when the network infrastructures are destroyed or overused.

Other studies devote their efforts to characterise [3,4] or analyse [5,6] emergencies with the aim to draw conclusions that allow to develop new applications capable of improving victim's care after an emergency, improve coordination and provide a faster response.

In all these cases where mobile devices, which have limited battery capacity, are used, the use of energy-efficient forwarding mechanisms is a must. According to recent works wifi is one of the most consuming power elements of a mobile phone device [7,8], consuming up to 725 mW transferring data at full capacity [9]. Furthermore, when a mobile device is using its wifi network in opportunistic mode, it cannot enter in PSM (Power Safe Mode) because it looks constantly for nodes and so it spends a lot of energy scanning the network. Not only the scanning but also the association between nodes spends a lot of energy [7]. Because scanning and associating spend a lot of energy it is very important

* Corresponding author. Tel.: +34 935813577.
E-mail address: abraham.martin@uab.cat (A. Martín-Campillo).

0140-3664/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.comcom.2012.04.028

to use a low energy consuming forwarding algorithm that achieves a high delivery ratio while having a low delivery cost (messages relayed per message created).

Because these main problems, in this paper we propose PropTTR and PropNTTR, a set of energy-efficient forwarding mechanisms for emergency scenarios using wireless opportunistic networks for communication between nodes.

This paper is structured in the following way. First, we present a background; then we propose the PropTTR and PropNTTR forwarding mechanisms, followed by the description of the simulation set up. Then the simulation results are showed and analysed; and finally the conclusions are presented.

2. Background

In this section we describe how communications in emergency scenarios are, a brief explanation of what an opportunistic network is, and a description of some of the existing opportunistic forwarding methods. Furthermore, we en this section with an analysis of data forwarding in emergency scenarios.

2.1. Solutions for communications in the emergency scenario

Previously emergency communications were only a matter of walkie-talkie communications, but nowadays they are becoming more and more advanced. This is due to the greater use of Internet enabled devices or mobile phones by the emergency personnel, that require mobile networks such as mobile phone network (3G) or WiFi. In the great majority of emergency cases, hurricanes, terrorist attacks, flooding, etc., these networks become unstable, inaccessible, overused or even destroyed. As a consequence, emergency personnel cannot rely on the use of existing network infrastructure and may deploy and use their own [10,11], or simply use wireless mobile ad hoc networks (MANETs) [12–14,11]. These networks create routes by request of the nodes that are maintained as long as they are needed or the link is available.

However, all these solutions have the same lack: because of the mobility of the devices (or if the area of emergency is big enough) a continuous end-to-end connection cannot be guaranteed. As a result, an attempt to communicate from one point of the network to another could be unsuccessful as this kind of networks needs an end to end communication. In these cases, opportunistic networks can be used; even if a message is required to arrive as soon as possible once it has been generated, the time to arrive to any part of the disaster area will require less time than deploying all the nodes necessary to create an infrastructure network or a fully-connected MANET.

2.2. Opportunistic networks

Opportunistic networks are an evolution of Mobile Ad-hoc NETworks (MANETs). In opportunistic networks, mobile nodes can communicate each other even if there is not a route connecting them. Like in Delay and Tolerant Networks, nodes can store, carry and forward messages. Furthermore, nodes are not supposed to possess or acquire any knowledge about the network topology. Routes from the sender and the destination of a message are built dynamically. Any possible node can opportunistically be used as next hop of a message if it more likely to bring the message closer, or faster, to the final destination.

2.3. Existing opportunistic forwarding methods

A recent work [15] compares and contrasts the use of a variety of forwarding protocols in a set of realistic disaster scenarios through simulations. The results in this comparison show that MaxProp is the forwarding method with the best message delivery performance and that TTR has the best ratio in cost per message delivered. For these reasons we have chosen these two methods as the comparison references of our PropTTR and PropNTTR proposals.

2.3.1. MaxProp

MaxProp [16] is an opportunistic forwarding protocol based on prioritising both the schedule of packets transmitted to other peers and the schedule of packets to be dropped. These priorities are based on the path likelihoods to peers according to historical data and also on several complementary mechanisms, including acknowledgments, a head-start for new packets, and lists of previous intermediaries. These probabilities are exchanged when the nodes come into contact. The tables of probabilities of each node are updated by upgrading to a higher probability the nodes that have been found and decreasing the probability of the rest. Based on these tables of probability, it is calculated which node has higher probability of delivery of the message. When one node contacts another node, if the other node has a higher probability of delivering the message, the message is sent to it, if not, the message remains in the actual node. MaxProp also has a priority queue that is used to discard messages that have little chance of being delivered to its destination and keep those which are more likely. MaxProp does an estimate delivery likelihood and adds some rules to the decision as to give forwarding preference to low-hop-count messages, to free up storage of delivered messages or to not forward the same packet twice to the same next hop destination. These add-ons are important as they give a congestion control to MaxProp. This method has shown very good results applied to vehicular networks [16] and to disaster areas [15].

2.3.2. TTR

TTR [2] is a delegation forwarding protocol designed for disaster areas. When the people leave the coordination point, a maximum time to return to the base is assigned to them. They are required to return to the base for security reasons, before this time has passed. Each node has its own time to return (TTR) that is exchanged when two nodes come into contact. This is the value used to make forwarding decisions, if a node comes into contact with another node with less TTR, it relays all its messages to this node. The TTR protocol only maintains one copy of the message throughout the network. This means that if the messages are successfully relayed, the sender deletes them all from its buffer in order to keep only one copy throughout the network. The TTR value can be changed by the user if she is coming back to the coordination point sooner than predicted. This strategy has shown a very good ratio in cost per message delivered in disaster areas but not a very high message delivery ratio [15].

2.4. Forwarding in emergencies

The smartphones we use today, usually have three network interfaces: HSPA/GSM, wifi, and Bluetooth. The first one can not be used for opportunistic networks. Bluetooth has only a range of 10 m and the transfer speed is very low. In big disaster scenarios nodes will not approach each other at these small distances. Moreover when two first responders approach each other, the contact time will be small because they usually run in those scenarios, so the faster the transfer speed, the more data will be interchanged.

Hence, even though wifi has a high energy consumption, it will be the best option for opportunistic communications in emergency scenarios. Furthermore, the wifi will be working in opportunistic mode, therefore it will not be able to enter into low energy mode. That said, in order to reduce this high energy consumption (very

Please cite this article in press as: A. Martín-Campillo, R. Martí, Energy-efficient forwarding mechanism for wireless opportunistic networks in emergency scenarios, Comput. Commun. (2012), http://dx.doi.org/10.1016/j.comcom.2012.04.028

important in mobile devices running on battery) and also have a good delivery ratio we should use an appropriate routing algorithm.

Regarding data, one can think that using an epidemic method is the best option, but the use of broadcast-based forwarding approaches (where multiple copies of the same data are spread throughout all the network) have two problems. The first one is the energy efficiency. Since data transfer using wifi is the most energy consuming process in a mobile phone [8], each message relayed consumes a lot of energy. For this reason it is important to select a forwarding algorithm that does not waste a lot of energy relaying unnecessary data. The second problem occurs in cases with a high number of messages because due to the short contact times it is not possible to forward all the data in a node, so it may also require some kind of data forwarding priority management.

But choosing the right forwarding method depends also on a number of factors: the number of first responders working in the disaster area, the number of victims, the size of the messages, the buffer of the device, and the energy consumption of the device using the network.

3. PropTTR and PropNTTR

One of the problems of the TTR protocol is that while it is positive to keep only one copy of each message in the network because it produces a very low delivery cost (messages relayed per message created) and energy consumption, it is also negative because it produces a moderate message delivery ratio. Keeping only one copy of the message produces a lot of lost opportunities. Using TTR forwarding protocol, when a node A comes into contact with another node B with less TTR than hers, the node A forwards the message to B without keeping a copy. It is likely that node A will contact another node C with less TTR than the node B. In this case, the node A will not be able to forward the message, thus losing the opportunity to forward the message to a node with more probability to deliver the message sooner.

For this reason, we propose PropTTR. PropTTR is based on TTR and MaxProp. As a solution for these lost opportunities caused by keeping only one copy of the message, PropTTR uses MaxProp protocol for the first hop of the message and TTR for the rest. MaxProp approximates delivery probability as the likelihood of a delivery path existing, thus with PropTTR, the messages are distributed in the first hop based on this delivery probability of each node. Using PropTTR, when two nodes come into contact, they exchange their probability tables based on MaxProp and their time to return values based on TTR. Consequently, PropTTR always have information about delivery probability and time to return values. If the message has a hop count of 0, the forwarding decisions is made using the MaxProp algorithm if not, using the TTR protocol.

As PropTTR uses hop count as a parameter to decide whether to use MaxProp or TTR, the message must have a hop count property. This property of the message will be read when the node is going to start the forwarding decision in order to know which forwarding protocol to use. The property will be written when the message is forwarded to another node, the receiver will add one to its value.

Usually, a node has more than one message with different hop count. In this case, PropTTR will use the MaxProp algorithm in the forwarding decision of all the messages with a hop count of 0 and will use the TTR protocol for the rest. Following is the algorithm of PropTTR.

Fig. 1 show the PropTTR algorithm in a flowchart format. Fig. 2 show the UML sequence diagram of PropTTR.

Let c be the number of nodes contacted by a peer after a message m is created by the peer. With TTR, there will be only one copy of each message created in a node. However, with PropTTR there

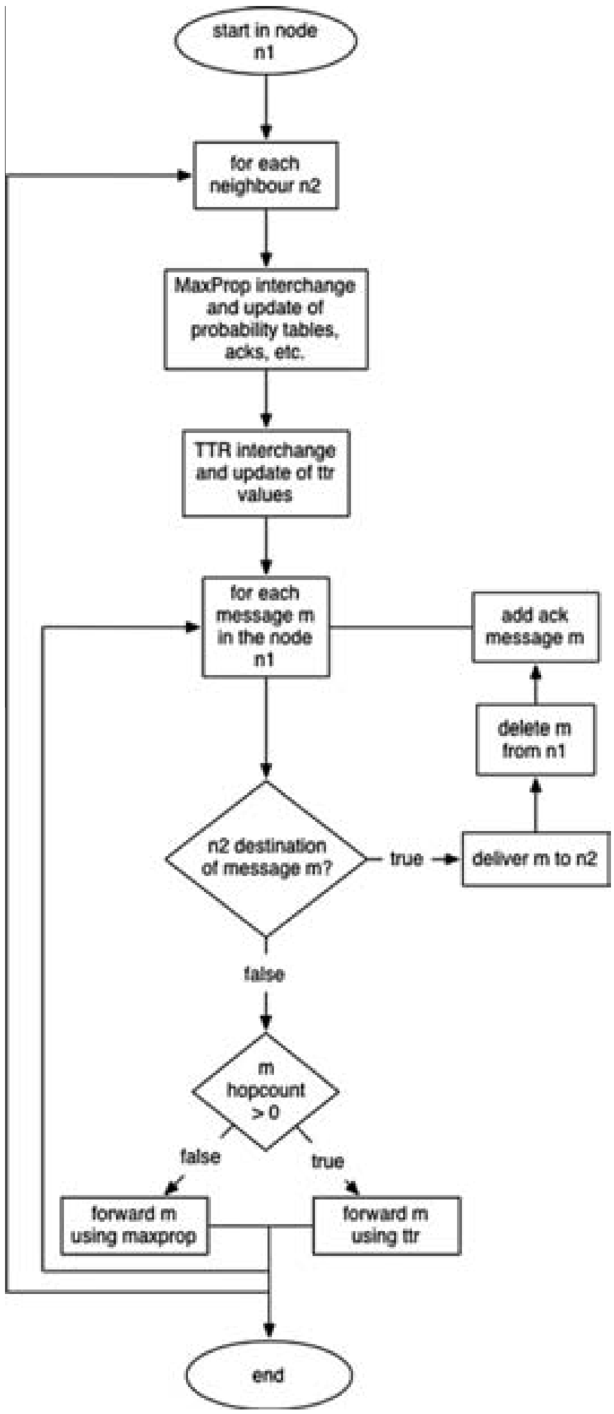

Fig. 1. PropTTR algorith in flowchart format.

will be a maximum of $c + 1$ copies: a copy will only be forwarded to a node contacted if it has better probability (using MaxProp algorithm) of deliver the message. This method increases the chances of meeting a node with a good TTR rather than the case of having only one copy of each message. Thus, this will increase the delivery ratio but will not increase in the same way the delivery cost.

Depending of the scenario (scenarios with low density of nodes), c could be a low value. For this reason, we also propose PropNTTR. PropNTTR follows the same rules as PropTTR but instead of changing the forwarding decision algorithm when the message has a hop count of 1, it changes when it has a hop count

Please cite this article in press as: A. Martín-Campillo, R. Martí, Energy-efficient forwarding mechanism for wireless opportunistic networks in emergency scenarios, Comput. Commun. (2012), http://dx.doi.org/10.1016/j.comcom.2012.04.028

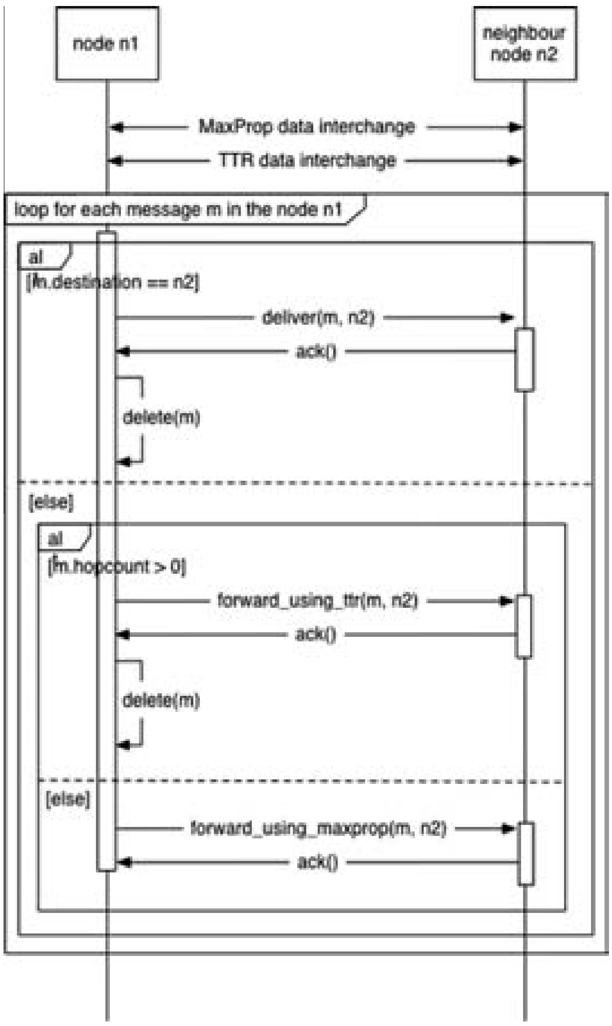

Fig. 2. UML sequence diagram of PropTTR.

of *N*. Increasing *N* will produce a better delivery ratio because of a greater distribution of the messages but the delivery cost will increase as *N* increases. Tuning the value of *N* of PropNTTR is not a simple issue, for this reason in the next chapter we do an analysis of the value of *N*.

4. Simulations

Disaster scenarios are unpredictable, its area or the number of victims are data that cannot be precisely predicted. Furthermore, emergencies are heterogeneous because each disaster produced have different number of victims (that is closely related to the number of messages created), different scenario area, different number of people working on the emergency, etc. As the characteristics of a disaster scenario considerably change from one to another, it is very important to carry out simulations that test the performance impact of these greatly changing characteristics of disaster scenarios. We have defined three basic properties of emergency situations that can define which forwarding performs better: number of nodes, number of messages and size of the messages. We carry out simulations to see the performance impact of these characteristics of the disaster area in the forwarding algorithms we have selected: MaxProp, TTR, PropTTR and PropNTTR (for $N = 2, 3, 4$). We have chosen different values for *N* (for PropNTTR) to be able to do an analysis of this value. This chapter explains how the simulations were carried: the test-bed and metrics.

4.1. Simulation test-bed set up

For the simulation set up, we have used two different tools: the BonnMotion tool [17] and the ONE (Opportunistic Network Environment) simulator [18].

BonnMotion [17] is an application that generates traces of different types of scenario. One of these scenarios is disasters. It creates mobility traces based on the analysis of the disaster scenario created for the preparation of the FIFA world cup in Germany [3]. The BonnMotion tool has been used to define the emergency scenario, and to generate the movement traces for the simulations. BonnMotion requires a set of parameters in order to specify the properties of the disaster scenario: the size and situation of the zones of the disaster scenario; the number of people in each zone; and the duration of the simulation.

The two zones of the emergency scenario are: zone 0, the incident location where the victims are found; zone 1, the area with patients' waiting for treatment, casualties clearing stations, and the coordination or meeting, point. The area of zone 0 has been defined as 1300×250 m and the area of zone 1 as 100×40 m. Regarding the situation of the zones, the upper right corner of zone 0 it is shared with the upper left corner of zone 1 (Fig. 3).

The forwarding protocols for the opportunistic networks created in disaster areas only apply for zone 0 because zone 1 can have a wireless access point, a satellite connection or another type of network connection because is where the coordination point is. Hence, for creating the traces we only take into account the number of nodes in zone 0 and the size and situation of the zone 0 and zone 1. The situation and size of the zones is important because the nodes in zone 0 go periodically to zone 1 in order to carry victims, get more equipment or because the TTR is exhausted. Zone 1 will have a number of nodes of 0. Regarding the number of nodes of zone 0, we want to test the impact of this parameter in the performance of the forwarding protocols, so it will be tested from 15 to 85. Some other parameters needed to generate a trace are included in the disaster scenario mobility model as the speed of nodes.

We have created delivery delay CDF (cumulative distribution function) over simulation time charts. Those figures have shown us that with 6000 s all the simulation results are stabilised which means that results over time (delivery ratio) do not change. Messages are created and delivered thought all the simulation and we want to extract the results when the simulation is stabilised. Hence, we have set up the duration of the simulation as 6000 s.

Three main parameters are tested in the simulations impacting the performance of the forwarding protocols: number of nodes (density of nodes of the scenario), number of messages created (that can also been interpreted as number of casualties because of its correlation) and message size.

As a second step, the ONE simulator has been used for the simulation, using as input the BonnMotion traces converted to the ONE format. The ONE [18] is a simulation environment specialised in opportunistic networks. The ONE can generate its own traces based on mobility models and can import mobility data from real-world traces or other mobility generators. It can also produce a variety of reports from node movement to message passing and general statistics. The ONE simulator allows to separate nodes into groups, and to define link speed, radio range and forwarding method are some attributes that have to be set up for each group. All the nodes belonging to the same group share its properties.

In the simulation scenario it has been defined only one group of nodes, all the nodes in this group share the same attributes (link speed, radio range, etc). A link speed of 54 Mbps and a radio range of 60 m are the values defined for all the nodes. The link speed is chosen using the 802.11g standard, the simulator is in charge of changing the speed rate depending of the distance between the two nodes. As for the maximum radio range, we carried tests using

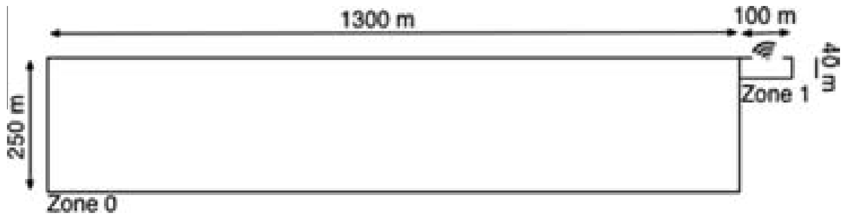

Fig. 3. Simulation scenario.

iPhones 3GS that gave us an average result of 60 m. We tested the radio range outdoor with obstacles (typically for disaster scenarios). The radio range is a parameter that can be different depending of the device the user is using. In Section 6.1 we have tested a disaster scenario with different density of nodes. These results can be extrapolated to know which results would be obtained for radio ranges longer, or shorter than 60 m, as having shorter radio range is similar to having less density of nodes or a larger scenario. The messages are originated in randomly chosen nodes and all have as destination the meeting point. Regarding the size of the messages it has been done a whole set of simulations to see the performance impact of this parameter in each one of the forwarding protocols. In the other sets of simulations, testing other parameters, it has been set up a message size of 225 kB, an average size for a message with text and an small image.

Table 1 sums up the main simulation parameters used in BonnMotion and in the ONE simulator. The number of messages generated, number of nodes in the disaster area and the message size in each simulation will be explained in the corresponding sections.

For the simulation purpose, we have selected the message delivery ratio, the delivery cost (number of messages relayed per number of messages created), and the latency as metrics to define which method is more efficient for each situation. We have performed these evaluations for different values of number of nodes, number of messages and message size, in order to see their impact on the performance.

5. Energy-efficiency

As previously noted, the energy-efficiency of forwarding methods in emergency scenarios is very important. This importance is mainly due to two reasons: The first one is that in these scenarios mobile devices are heavily used, and its battery is limited, so if it is drained fast the node will be off and the messages will not arrive. The second is that the duration of an emergency is unknown, hence the battery life has to be preserved against the overuse.

For the calculation of the Energy (Joules) required for the transmission of n bytes in a single connection, we have based our calculations in the equation proposed by Balasubramanian [7] for the use of mobile phones in WiFi networks.

Transfer Energy:

$$R(x) = 5.9 + 0.007(x)J$$

Maintenance:

$$M = 0.05J/\sec$$

Total energy needed to transfer (x) kB:

$$R(x) + M$$

where the 5.9 J of the transfer energy is the energy required for the initial connection, and the $0.007(x)$ J is the energy required to transmit (x) kilobytes. The maintenance energy is the energy required while the connection between two nodes is up.

We have adapted the previous equations, to make a calculation of the average energy consumed by each node. This calculations use the values we get from the simulation tools and takes into account all the transfers and connections a node does during the simulation. Then the equations for the calculation of the average energy consumed by each node become:

$$T(x, nc, ct) = 5.9(nc) + 0.007(x) + 0.05(ct)$$

where nc is the average number of contacts per node, x is the average number of bytes relayed per node, and ct is the average total contact time per node.

Table 1
Default simulation parameters.

	Parameter	Value
Network	Simulation time	6000 s
	PHY data rate	54 Mbps
	Radio range	60 m
	Buffer size	5 MB
	TTL	∞
	Number of runs	50 each
Scenario size	Zone 0	1300×250 m
	Zone 1	100×40 m
Mobility	Number of groups	2
	Mobility Model	Disaster [19]
	Speed	0–2,5 m/s
MaxProp	Max Meeting Prob	50
	α	1

6. Simulation results

This section shows the results of the different simulations that have been performed evaluating the impact in the performance of the following parameters: Number of nodes, number of messages and message size. This simulation have been carried out for following forwarding protocols: MaxProp, TTR, PropTTR, and PropNTTR (for $N = 2, 3, 4$).

For each of one of these sets of simulations, results on message delivery ratio, delivery cost and latency have been extracted. It has been also calculated the average energy consumption of each node following the equation in the previous section.

The following subsections include the results of each set of simulations.

6.1. Number of nodes

The number of people involved in an emergency can be variable depending on many factors: personnel available, location of the emergency, etc. For this reason, the performance of the selected forwarding methods with different number of nodes have been evaluated.

We have selected a range that goes from 15 nodes to 85 nodes. Hence, the density of nodes of the disaster area (1300×250) change radically from one to another. With the lowest density we want to test how the forwarding algorithms behave when they are out of the network range of others nodes. With this low density and a network radio range of 60 m, the nodes will have a small probability of

Please cite this article in press as: A. Martín-Campillo, R. Martí, Energy-efficient forwarding mechanism for wireless opportunistic networks in emergency scenarios, Comput. Commun. (2012), http://dx.doi.org/10.1016/j.comcom.2012.04.028

Table 2
Specific parameters for "number of nodes" based simulations.

Parameter	Value
Number of messages	2000 messages
Message size	225 kB

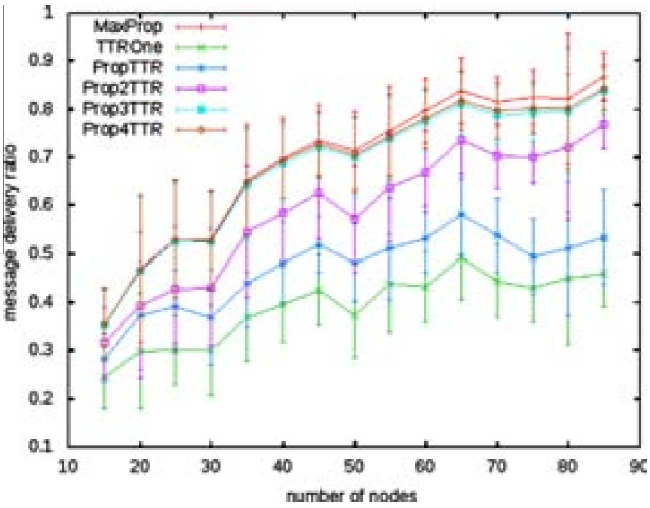

Fig. 4. Delivery ratio vs. number of nodes.

meeting other nodes. With the highest density, message will be easier to deliver because more contacts will be produced.

2000 messages are created during this set of simulations with a size of 225 kB (Table 2). The values for these parameters are chosen with the aim that they do not interfere in the simulation results. This means that we do not want these values to produce network congestion for any of the densities of nodes we test for any forwarding protocol. Hence, we can have the results under the same conditions for any forwarding protocol and measure the real impact of having different density of nodes in the disaster area. The same reasoning has been used in Section 6.2 for choosing the values of number of nodes and message size and in Section 6.3 for number of messages and number of nodes.

The results for PropTTR show, in Fig. 4, an improvement of message delivery ratio. PropTTR delivers up to 58% of the messages generated while TTR only is able to deliver up to 49% of messages. This increase in the message delivery ratio does not significantly elevate the delivery cost as it can be seen in Fig. 5. However, PropTTR has a high latency when compared to TTR or MaxProp as it shows Fig. 6.

Prop2TTR, it is able to deliver up to 74% of messages that is a substantial improvement over TTR. With these results similar to MaxProp, it can be expected a similar delivery cost, but Prop2TTR has significantly lower delivery cost than MaxProp for more than 60 nodes. In terms of latency Prop2TTR is comparable to MaxProp for 60 nodes or less. For more than 60 nodes, the latency of MaxProp decreases while the latency of Prop2TTR is constant. Prop2TTR has a 50% more latency than MaxProp for 85 nodes but MaxProp has an 800% more delivery cost than Prop2TTR for 85 nodes.

Prop3TTR and Prop4TTR are practically equal to MaxProp in terms of delivery ratio. In terms of latency both behave in the same way until 55 nodes. From 55 nodes, as the number of nodes increase, the difference between Prop3TTR/Prop4TTR and MaxProp also increases in terms of latency. Prop4TTR have the same energy consumption than MaxProp for any number of nodes but the energy consumption for Prop3TTR does not augment in the same

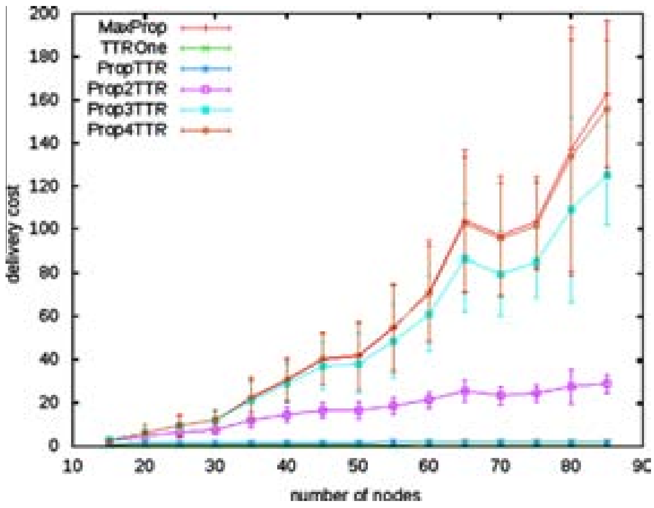

Fig. 5. Delivery cost vs. number of nodes.

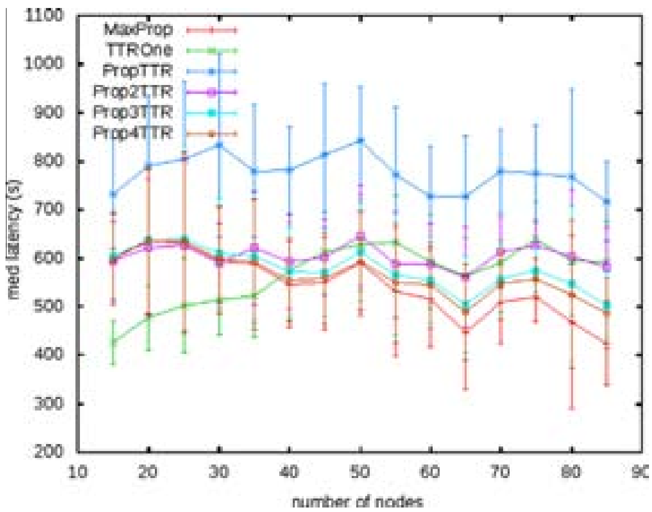

Fig. 6. Latency vs. number of nodes.

rate as MaxProp. At 85 nodes, Prop3TTR has a 25% less energy consumption than MaxProp.

These graphs clearly show the need for TTR, PropTTR or even also Prop2TTR in environments with high density of nodes if an energy-efficient forwarding method is wanted in order to allow the battery to last longer (Fig. 7). PropTTR increases the message delivery ratio of TTR but also increases the latency, important in emergency scenarios. Prop2TTR is a very good alternative, it offers low latency (TTR alike), a moderate delivery cost and energy consumption (1000 J more than TTR but 5000 J less than MaxProp for 85 nodes), and a high message delivery ratio (74%, only 9% less than MaxProp for 85 nodes).

6.2. Number of messages

Generally in emergency scenarios there is a correlation between the number of victims (or the magnitude of the event) and the number of messages generated. Usually a message is generated for each victim found, for an update of her health status, or for some critical information about the scenario. In this second set of simulations the focus is on the analysis of how the number of message impacts in the performance of the forwarding methods.

Please cite this article in press as: A. Martín-Campillo, R. Martí, Energy-efficient forwarding mechanism for wireless opportunistic networks in emergency scenarios, Comput. Commun. (2012), http://dx.doi.org/10.1016/j.comcom.2012.04.028

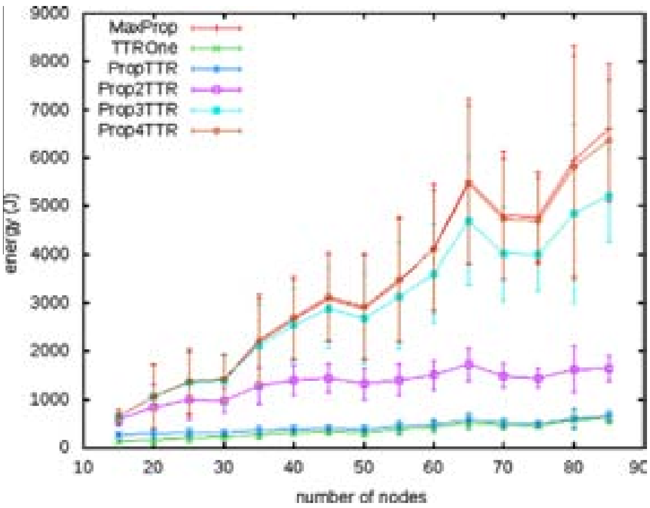

Fig. 7. Average energy consumed by each node vs. number of nodes.

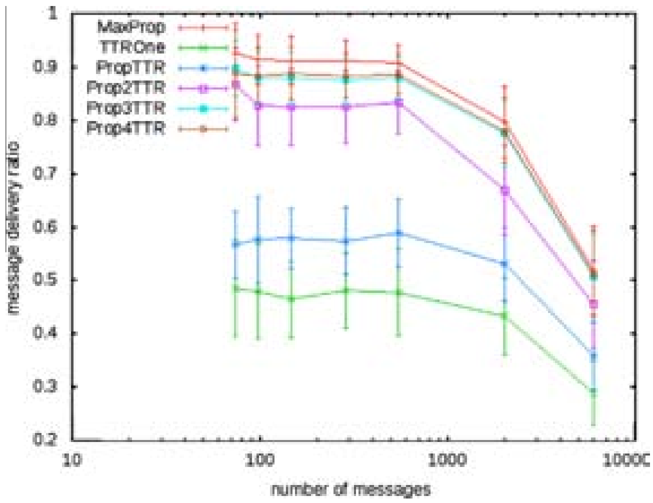

Fig. 8. Delivery ratio vs. number of messages.

Table 3
Specific parameters for the simulations to calculate the difference in performance based on the number of messages.

Parameter	Value
Nodes	60
Message size	225 kB

We have selected a range that goes from 74 to 6000 messages created during the simulation time. In combination with 60 nodes and 225 kB per message (Table 3) we can test from an easy to deliver messages situation to a situation that nodes cannot relay messages to another because buffers are full due to the number of messages that carry each node. 60 nodes produces plenty number of contacts between nodes during the simulation so it will not interfere in the simulation results: not causing lacks of contacts and hence nodes not being able to relay messages in case of choosing a low number of nodes (low density). The same for the message size, that allow the nodes to be able to forward all the messages in their buffers during the connectivity time with other nodes.

In Fig. 8, we see that MaxProp delivers up to 94% of the messages created when the number of message is low. In cases where there are few messages MaxProp is very effective and PropTTR can only deliver up to 56% of the messages created. Regarding Prop2TTR, it is able to deliver up to 85% of messages. PropTTR performs a 20% better than TTR, and Prop2TTR provides a ratio only 10% lower than MaxProp and higher than TTR (90%) and PropTTR (60%). Prop3TTR and Prop4TTR are very similar and its performance is only slightly below MaxProp.

In terms of delivery cost (Fig. 9), once again, TTR and PropTTR have a very low delivery cost, while Prop2TTR has a moderate cost in comparison with MaxProp (even 80% less delivery cost for 500 messages). Prop3TTR delivery cost is an average of the delivery cost of MaxProp and Prop2TTR. Following is Prop4TTR which shows that as we increase the *N* in PropNTTR it becomes more and more similar to MaxProp. We see how the delivery cost decrease as we increase the number of messages because the rate number of message relayed per message created drops. This is because of congestion of the network, not all messages can be relayed.

In this case, we can see the downward trend as the number of messages are higher. This is explained because the buffers of the nodes become full and messages cannot be relayed. We have set

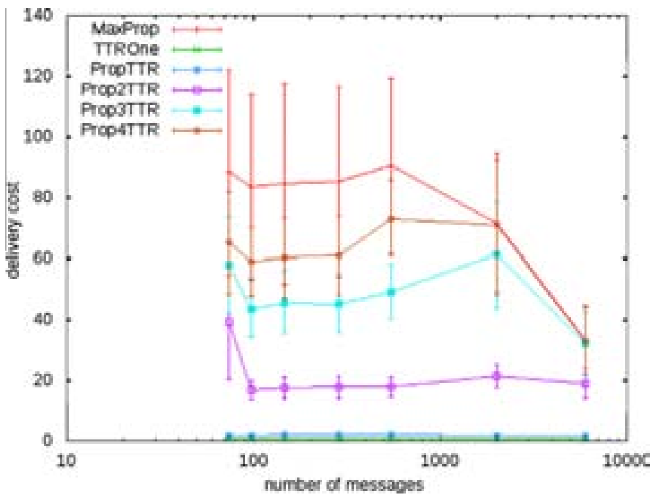

Fig. 9. Delivery cost vs. number of messages.

up a buffer size of 5 MB that can carry 22 messages of 225 kB. This is a low buffer for a real case but we wanted to see how the forwarding methods will behave in situations were the buffers are full. We can see that messages cannot be relayed (we can see this because the delivery cost drops for high number of messages). When this happens the nodes that deliver the messages are the ones who created them (all nodes eventually go to the zone 1).

Regarding latency, MaxProp has a very low value for small number of messages (Fig. 10). For more than 750 messages, latency is similar for all the methods except PropTTR that has a higher one.

In Fig. 11 can be seen how the increase of the number of messages created impacts in the energy consumption of a node as more message relays are done. This figure also shows that Prop2TTR has more than 50% less energy consumption than MaxProp for all the results of the different simulations with different number of messages created. Therefore, although Prop2TR provides a message delivery ratio of only 10% lower than MaxProp, it decreases its delivery cost by over 50%.

6.3. Message size

In this third set of simulations it has been tested how message size impacts in the message delivery ratio, the delivery cost and

Please cite this article in press as: A. Martín-Campillo, R. Martí, Energy-efficient forwarding mechanism for wireless opportunistic networks in emergency scenarios, Comput. Commun. (2012), http://dx.doi.org/10.1016/j.comcom.2012.04.028

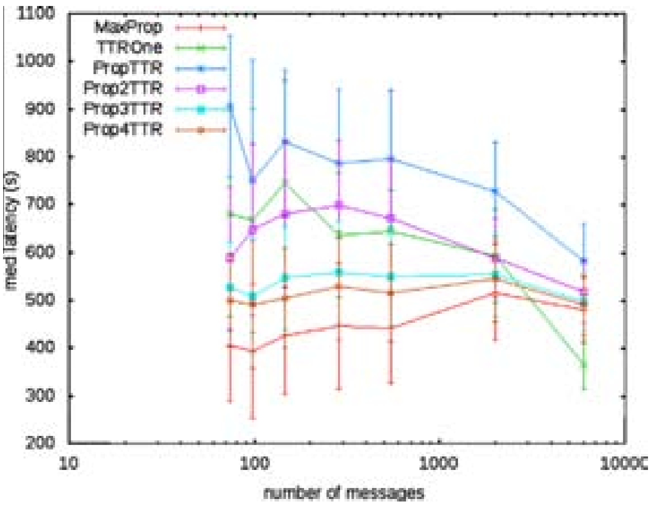

Fig. 10. Latency vs. number of messages.

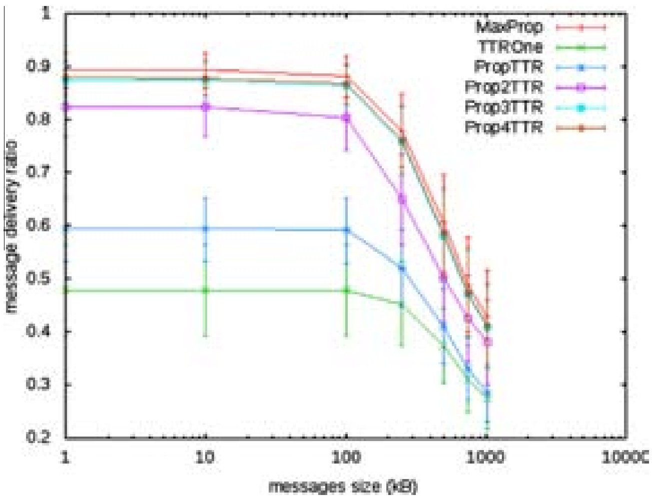

Fig. 12. Delivery ratio vs. message size.

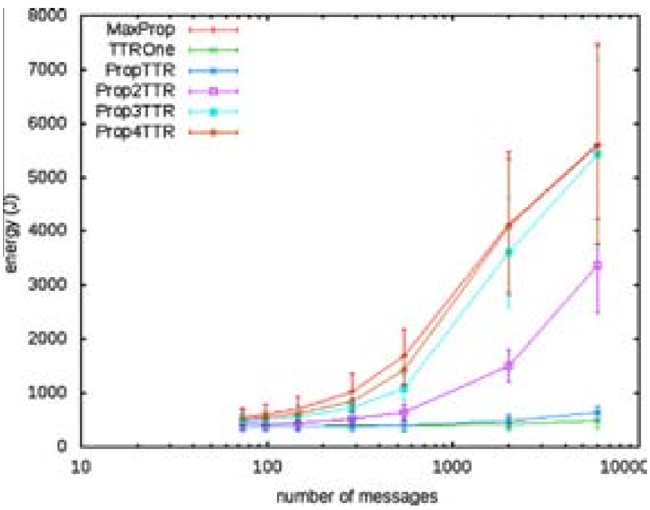

Fig. 11. Average energy consumed by each node vs. number of messages.

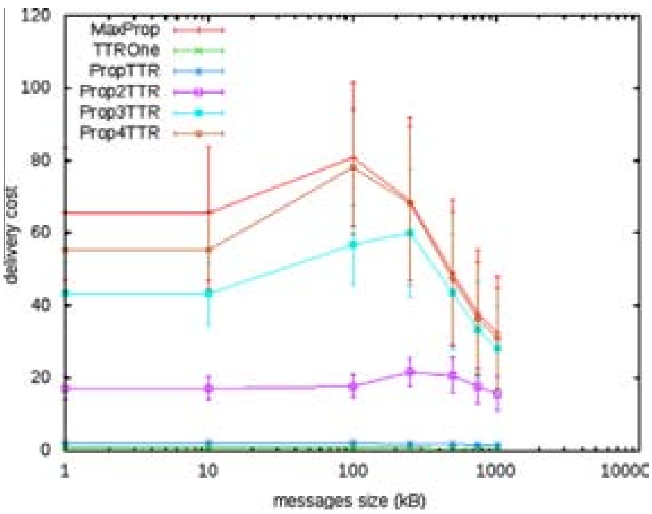

Fig. 13. Delivery cost vs. message size.

Table 4
Specific parameters for the simulations to calculate the difference in performance based on the message size.

Parameter	Value
Number of messages	2000 messages
Nodes	60

the latency performance for each forwarding method. We have selected a range that goes from 1 kB to 1 MB. In combination with 60 nodes and 2000 messages created during the simulation (Table 4) we can test from an easy to deliver messages situation to a situation that nodes cannot relay messages to another because buffers are full due to the size of those messages.

For the delivery ratio, in Fig. 12 we see that MaxProp delivers up to 90% of the messages created when the message size is under 100 kB. In cases where the size is low MaxProp is very effective and PropTTR can only deliver up to 60% of the messages created. PropTTR performs a 20% better than TTR, while Prop2TTR provides a delivery ratio only 10% lower that MaxProp while higher than TTR (up to 60%) and PropTTR (up to 30%). When the size of the messages is bigger than 100 kB MaxProp is still the best forwarding method in terms of delivery ratio but the gap with PropTTR and TTR is lower. Prop3TTR and Prop4TTR perform very similar to MaxProp in terms of delivery ratio, as it has been seen in previous set of simulations. All methods decrease their delivery ratio as the message size increases because the buffers become full and the nodes can only carry some messages.

In terms of delivery cost, Figs. 13 and 15 show, again, that MaxProp is the most expensive method. Regarding PropTTR and TTR, both have a similar behaviour with always a very low delivery cost and energy consumption compared to MaxProp. In the case of Prop2TTR, it consumes only 1/3 part of the MaxProp energy consumption. Prop3TTR have an average delivery cost between MaxProp and Prop2TTR and Prop4TTR has a similar behaviour as MaxProp.

Again, as in the others set of simulations, MaxProp shows the best latency and PropTTR the worst, except for messages size greater than 500 kB where TTR has the best latency (Fig. 14). As greater the value of N in PropNTTR is, closer to the results of MaxProp it gets.

Although the number of runs in the simulations is high, some figures have shown a big confidence interval for some results or forwarding methods. Each run in the simulations uses a different

Please cite this article in press as: A. Martín-Campillo, R. Martí, Energy-efficient forwarding mechanism for wireless opportunistic networks in emergency scenarios, Comput. Commun. (2012), http://dx.doi.org/10.1016/j.comcom.2012.04.028

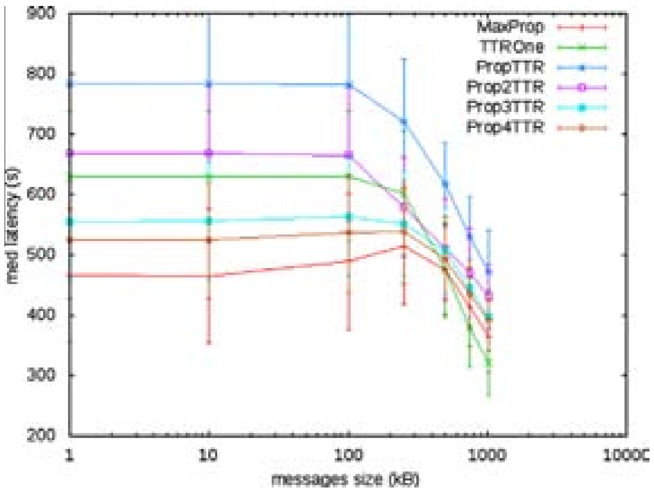

Fig. 14. Latency vs. message size.

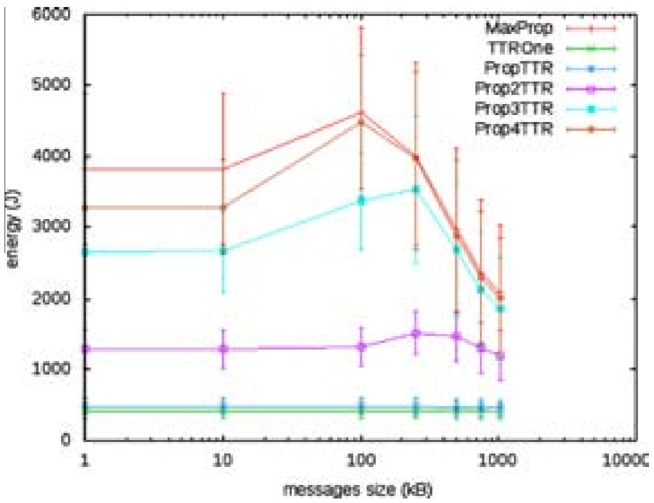

Fig. 15. Average energy consumed by each node vs. message size.

trace in order to get a valid average result. The traces of each for the same test have the same parameters (number of nodes, zones, etc.) but the trace of each nodes, and therefore the contacts between them, change a lot from one run to another. Hence, this produces a wide standard deviation.

In these sets of simulation it can be seen that MaxProp has the highest energy consumption, and TTR and PropTTR are green protocols. In between them, there is the most important one: Prop2TTR. Prop2TTR has a great energy-efficiency and also has a good message delivery ratio. The results confirm that Prop2TTR decreases the cost of MaxProp much more than it decreases the message delivery ratio. However, Prop2TTR has more latency than MaxProp but less than PropTTR and similar to TTR. In almost all cases, the use of Prop2TTR will be recommended, except for those cases where the latency is more important than the power consumption. Regarding Prop3TTR and Prop4TTR, its behaviour is the same as in delivery cost and it becomes more similar to MaxProp as the *N* in PropNTTR is higher.

7. Discussion

We believe that with the simulations carried out, we can extract conclusions for the performance of the forwarding protocols tested in the worst case scenario. The worst case situation that can occur is a disaster area with low density of nodes and a lot of big messages. With the first characteristic (low density of nodes) we have seen in Figs. 4 and 5 (with only 15 nodes) that nodes will always be out of the network range of other nodes. Hence, the nodes that will deliver the messages will be the ones who created them (all nodes eventually go to the zone 1) because they cannot relay messages to other nodes. With the second characteristic, an abundant number of big messages, we have seen in Figs. 8, 9, 12 and 13 that buffers of the nodes become full and therefore they also cannot relay messages to other nodes, causing the same problem as described for low density of nodes.

7.1. PropTTR

PropTTR only creates *c* more copies of a message than TTR, where *c* is the number of nodes contacted by the peer who created the message. These *c* more copies slightly increase the energy consumption with respect to TTR but this is almost insignificant as we can see in Figs. 7, 11, and 15. However, when we look at the figures of delivery ratio (Figs. 4, 8, and 12) we see that PropTTR delivers a 10% (of the messages created) more than TTR. This is a very important improvement that is caused because a greater distribution of the messages thanks to these *c* more copies of each one. Nevertheless, as we can observe in Figs. 6, 10, and 14, latency is the parameter that is penalised in return.

In emergency scenarios it is very important to preserve battery but it is also important to deliver messages as fast as possible (latency). Hence, we recommend to use PropTTR in scenarios where the battery has to be preserved over the latency of a message. It is a very good replacement for TTR in scenarios with those needs because for the practically the same energy consumption it can deliver more messages.

7.2. PropNTTR

We have tested *N* in PropNTTR for 2, 3 and 4. The results of simulations have been commented in the corresponding sections but we would like to globally analyse PropNTTR in this section.

The simulation results clearly show that Prop2TTR are a better solution than Prop3TTR and Prop4TTR. These two are practically identical to MaxProp except for a few cases. Comparing the energy consumption improvement over the delivery ratio decrease with respect to MaxProp, we see that 3 and 4 are not optimal values for PropNTTR. We haven't tested Prop5TTR but with these results we can predict that it will behave practically like MaxProp in the majority of simulations.

Regarding Prop2TTR, if we contrast its energy saving versus the delivery ratio decrease with respect to MaxProp we can see a great improvement over other values of *N* in PropNTTR. Prop2TTR is able to deliver 75% of the messages created spending only 1200 J while Maxprop spends 6000 Joules for a 85% of delivery ratio (results in Figs. 4 and 7 for 85 nodes). The results vary from simulations with different characteristics but in almost all situations Prop2TTR performs remarkably well, having a good delivery ratio with a low energy consumption. Furthermore, it does not have the problem that PropTTR has with latency and the latency of Prop2TTR is similar to the TTR one in most cases.

PropNTTR is an hybrid of MaxProp and TTR. For $N = 2$, it uses MaxProp for messages with a hop count smaller than 2 and TTR for the rest. This property of the protocol provides a better message distribution than TTR thanks to using MaxProp in the first two hops while keeping the energy consumption under control due to the use of TTR for the rest of the hops. With this, Prop2TTR achieves a greater distribution of each message, thus, losing less opportunities to find a node with higher possibilities of delivering a message sooner.

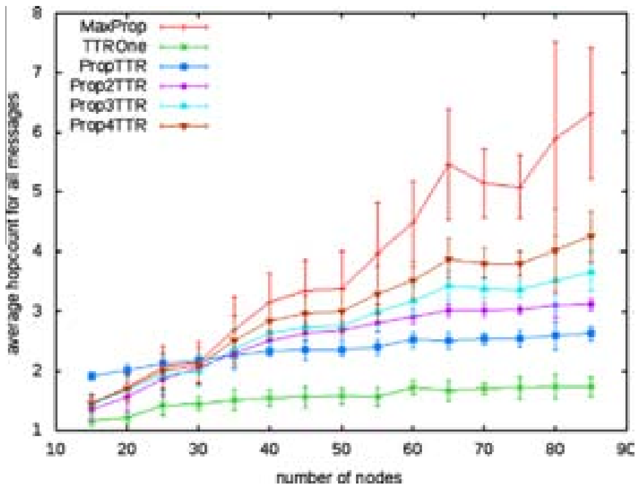

Fig. 16. Average hop count of all messages vs. number of nodes.

We have extracted information about hop count in the first set of simulations to analyse if there exist a correlation between hop count and the optimal value of N in PropNTTR (Fig. 16). Given the results in the figure we cannot say that there is a correlation.

Finally we also propose the use of PropNTTR dynamically. This means that the value of N can change dynamically under some conditions. For example, if a node is using Prop2TTR and its battery is getting exhausted, the N can be dynamically changed to 1 to save even more energy. Hence, the node will start to use PropTTR instead of Prop2TTR which will lower its energy consumption. One of the advantages of PropNTTR is that each node is independent from the other: one can use Prop3TTR and other can use PropTTR and both will be able to communicate with each other and exchange they messages between them. With PropNTTR with N dynamically a node could start with a high value of N and decrease its value as the battery runs out.

8. Conclusions

The use of opportunistic networks is very appropriate for emergency scenarios, where communication infrastructures may be unavailable.

In this paper we have proposed PropTTR and PropNTTR, two energy-efficient forwarding mechanisms for wireless opportunistic networks in emergency scenarios. This forwarding mechanisms are based on two other algorithm: MaxProp, which has demonstrated in the simulations a high message delivery ratio and very good latency but also a high delivery cost and energy consumption; and TTR, an energy-efficient algorithm but with a moderate message delivery ratio. PropTTR and PropNTTR take the best characteristics of MaxProp and TTR to get an energy-efficient forwarding methods with a high message delivery ratio. Simulations to analyse message delivery ratio, delivery cost, latency and energy consumption have been carried.

These tests show how PropTTR provides an acceptable delivery ratio with a low energy consumption but with a high latency, and how PropNTTR (for $N = 2$) provides a better delivery ratio with a low energy consumption. For this reason, the use of Prop2TTR, an energy-efficient protocol, is very suitable in all the cases where preserving the battery is very important.

PropTTR and PropNTTR can be generalised to other types of scenarios (not only emergency ones) but they must have some characteristics. First, these scenarios must have nodes that are data mules. Secondly, these data mules must have a returning (periodically or not) time to the destination of the messages.

Acknowledgements

This research has been partially funded by the Spanish Ministerio de Educación y Ciencia (FPU grant AP2008-03149), by the Generalitat de Catalunya-AGAUR 2009SGR1224 anb by the Spanish Ministry of Science and Innovation through the project TIN2010–15764.

References

[1] Google crisis response. <http://www.google.com/crisisresponse>.
[2] R. Martí, S. Robles, A. Martín-Campillo, J. Cucurull, Providing early resource allocation during emergencies: the mobile triage tag, J. Networks Comput. Appl. 32 (2009) 1167–1182, http://dx.doi.org/10.1016/j.jnca.2009.05.006. http://portal.acm.org/citation.cfm?id=1598089.1598476.
[3] N. Aschenbruck, M. Frank, P. Martini, J. Tölle, Human mobility in manet disaster area simulation-a realistic approach, in: 29th Annual IEEE International Conference on Local Computer Networks (LCN 04), 2004.
[4] Y. Shu, K. Furuta, Modelling of multi-organisation performance for emergency response, Proceedings of the 1st International Conference on Digital Human Modelling, ICDHM'07, Springer-Verlag, Berlin, Heidelberg, 2007, pp. 511–520. <http://portal.acm.org/citation.cfm?id=1784074.1784135> .
[5] A. Boukerche, M. Zhang, R.W. Pazzi, An adaptive virtual simulation and real-time emergency response system, Proceedings of the 2009 IEEE international conference on Virtual Environments, Human-Computer Interfaces and Measurement Systems, VECIMS'09, IEEE Press, Piscataway, NJ, USA, 2009, pp. 360–364. <http://portal.acm.org/citation.cfm?id=1699798.1699869> .
[6] P. Albores, D. Shaw, Responding to terrorist attacks and natural disasters: a case study using simulation, in: Proceedings of the 37th conference on Winter simulation, WSC '05, Winter Simulation Conference, 2005, pp. 886–894. http://portal.acm.org/citation.cfm?id=1162708.1162863
[7] N. Balasubramanian, A. Balasubramanian, A. Venkataramani, Energy consumption in mobile phones: a measurement study and implications for network applications, Proceedings of the 9th ACM SIGCOMM conference on Internet measurement conference, IMC '09, ACM, New York, NY, USA, 2009, pp. 280–293. http://dx.doi.org/10.1145/1644893.1644927.
[8] A. Rice, S. Hay, Me asuring mobile phone energy consumption for 802.11 wireless networking, Pervasive and Mobile Computing 6(6), 2010, pp. 593–606, special Issue PerCom 2010. http://dx.doi.org/10.1016/j.pmcj.2010.07.005. <http://www.sciencedirect.com/science/article/pii/S1574119210000593>.
[9] A. Carroll, G. Heiser, An analysis of power consumption in a smartphone, in: Proceedings of the 2010 USENIX conference on USENIX annual technical conference, USENIXATC'10, USENIX Association, Berkeley, CA, USA, 2010, pp. 21–21. <http://portal.acm.org/citation.cfm?id=1855840.1855861>.
[10] K. Luyten, F. Winters, K. Coninx, D. Naudts, I. Moerman, A situation-aware mobile system to support fire brigades in emergency situations, in: R. Meersman, Z. Tari, P. Herrero (Eds.), OTM Workshops (2), Lecture Notes in Computer Science, Vol. 4278, Springer, 2006, pp. 1966–1975.
[11] J.P. Killeen, T.C. Chan, C. Buono, W.G. Griswold, L.A. Lenert, A wireless first responder handheld device for rapid triage, patient assessment and documentation during mass casualty incidents, AMIA Annu Symp Proc (2006) pp. 429–33. (Times Cited: 0).
[12] S. McGrath, E. Grigg, S. Wendelken, G. Blike, M.D. Rosa, A. Fiske, R. Gray., Artemis: A vision for remote triage and emergency management information integration., in: Dartmouth University, 2003.
[13] V. Shnayder, B. rong Chen, K. Lorincz, T.R.F.F. Jones, M. Welsh, Sensor networks for medical care, SenSys '05: Proceedings of the 3rd International Conference on Embedded Networked Sensor Systems, ACM, New York, NY, USA, 2005, p. 314, http://dx.doi.org/10.1145/1098918.1098979.
[14] T. Massey, T. Gao, M. Welsh, J.H. Sharp, M. Sarrafzadeh, The design of a decentralized electronic triage system, in: AMIA Annual Symposium Proceedings, 2006, pp. 544–548.
[15] A. Martín-Campillo, R. Martí, E. Yoneki, J. Crowcroft, Electronic triage tag and opportunistic networks in disasters, in: In Special Workshop on the Internet and Disasters at ACM CoNEXT 2011 (WoID at CoNEXT 2011).
[16] J. Burgess, B. Gallagher, D. Jensen, B.N. Levine, Maxprop: Routing for vehicle-based disruption-tolerant networks, in: In Proceedings of IEEE INFOCOM, 2006.
[17] U. of Bonn, Bonnmotion: A mobility scenario generation and analysis tool, (2009) <http://net.cs.uni-bonn.de/wg/cs/applications/bonnmotion/>.
[18] A. Keränen, J. Ott, T. Kärkkäinen, The ONE Simulator for DTN Protocol Evaluation, in: SIMUTools '09: Proceedings of the 2nd International Conference on Simulation Tools and Techniques, ICST, New York, NY, USA, 2009.
[19] N.e.a. Aschenbruck, modelling mobility in disaster area scenarios, in: MSWIM'07.

Abraham Martín Campillo

Bellaterra, July 2012