

TABLE OF CONTENTS

I.Introduction.....	1
Section I.1 – Background and motivations.....	1
1st Introduction to active and programmable networks.....	3
2nd Introduction to Policy-based Network Management.....	10
Section I.2 – Objectives of this Thesis.....	15
Section I.3 – Document structure.....	17
II.Requirements for the management of active networks.....	19
Section II.1 – Introduction.....	19
Section II.2 – Requirements derived from the management of active and programmable networks.....	19
Section II.3 – Other requirements.....	25
Section II.4 – Conclusions.....	27
III.State of the art in management of active networks.....	29
Section III.1 – Introduction.....	29
Section III.2 - Non policy-based management of active and programmable networks.....	29
1st ABONE Management.....	29
2nd ABLE.....	30
3rd AVNMP.....	30
4th Smart Packets.....	32
5th SENCOMM.....	34
6th VAN.....	35
Section III.3 - Policy-based management of active and programmable networks.....	36
1st Ponder.....	36
2nd Jasmin.....	37
3rd Seraphim.....	38
4th ANDROID.....	39
5th Policy eXtension by Policy (PxP).....	41
6th Active Policy-Based Management (A-PBM).....	43

TABLE OF CONTENTS

7th	Policy networking using active networks	44
8th	Polynet	45
9th	Policy specification for programmable networks	45
10th	FAIN.....	46
	Section III.4 - Trends and expected evolution	47
	Section III.5 – Conclusions.....	48
	IV.Proposed Model	53
	Section IV.1 - Introduction.....	53
	Section IV.2 - Use cases description	54
1st	Policy-triggered Use Case.....	57
2nd	Signalling-triggered Use Case	66
3rd	Event-triggered Use Case.....	69
4th	Bootstrap Use Case.....	70
5th	Add/Remove node Use Case.....	72
6th	Summary of components and tasks	74
	Section IV.3 – Description of the MANBoP components	77
1st	Policy Editor.....	77
2nd	Policy Consumer Manager.....	88
3rd	Authorisation Check Component	120
4th	Policy Conflict Check	123
5th	TE Manager.....	154
6th	Decision-making Monitoring system.....	175
7th	Monitoring Meter	186
8th	Policy Consumer.....	193
9th	SigDemux.....	198
10th	Database	203
	Section IV.4 – Conclusions.....	208
	V.Proof of concepts implementation description.....	211
	Section V.1 - Introduction.....	211
	Section V.2 – Naming Convention	211
1st	MANBoP packages naming convention.....	211
2nd	Database directory naming convention.....	213

3rd	Naming Service registration naming convention	216
4th	Dynamically installable files naming convention	218
Section V.3 – Information Model.....		219
1st	Policy Information Model.....	220
2nd	Information Model Objects (IMOs).....	235
Section V.4 – Implemented Code.....		248
1st	System Bootstrap.....	248
2nd	Policy Processing: Policy Reception and Policy Group Processing.....	257
3rd	Policy processing: Task coordination and Policy checking	266
4th	Policy processing: Monitoring.....	272
5th	Policy processing: Policy enforcement and result processing....	276
6th	Adding a node to the managed topology.....	288
7th	Domain-dependant components.....	289
Section V.5 – Proof-of-concepts demonstration description.....		296
1st	Introduction.....	296
2nd	Functional assessment scenario (first scenario)	296
3rd	Scalability assessment scenario (second scenario)	309
Section V.6 - Conclusions		313
VI.Evaluation.....		317
Section VI.1 - Introduction.....		317
Section VI.2 – Evaluation criteria.....		317
1st	Functional Criteria.....	318
2nd	Statistical Criteria	320
Section VI.3 – Evaluation results.....		320
1st	Functional Criteria.....	321
2nd	Statistical Criteria	348
Section VI.4 – Conclusions.....		355
VII.Conclusions.....		361
Section VII.1 – Summary		361
Section VII.2 – Assessment and analysis of the work developed.....		363
Section VII.3 – Future work.....		367

TABLE OF CONTENTS

REFERENCES.....	369
A. Implemented interfaces in IDL.....	379
B. Managed Topology and Underlying Interface files structure	395
Section B.1 – Managed Topology file	395
Section B.2 – Underlying Interfaces file	396
C. XML policy syntax.....	399
D. Implemented tools	407
Section D.1 - XPolicySender	407
Section D.2 – UserCreator	407
Section D.3 – SchemaCreator.....	408
Section D.4 – MultiPS.....	408
Section D.5 – Manager.....	409

TABLE OF FIGURES

Figure 1 - 1. Active and Programmable Networks Problem Space.....	4
Figure 1 - 2. The P1520 Reference Model and the L-Interface abstraction model.....	5
Figure 1 - 3. ForCES Architectural Representation of NE.....	7
Figure 1 - 4. The Active Node Architecture	9
Figure 1 - 5. Policy-based network management framework	12
Figure 1 - 6. MANBoP objectives.....	17
Figure 2 - 1. Dynamic extensibility requirement	20
Figure 2 - 2. Delegation requirement.....	22
Figure 2 - 3. Use of active and programmable technologies for enhancing management.....	25
Figure 2 - 4. Different management infrastructures example.....	26
Figure 3 - 1. AVNMP Prediction algorithm	32
Figure 3 - 2. Smart packet encapsulation on IP and ANEP.....	33
Figure 3 - 3. SENCOMM architecture.....	34
Figure 3 - 4. VAN Management Architecture	35
Figure 3 - 5. Jasmin Script MIB based management architecture.....	38
Figure 3 - 6. Seraphim security architecture.....	39
Figure 3 - 7. ANDROID Active Architecture.....	40
Figure 3 - 8. Policy Extension by Policy basic architecture.....	42
Figure 3 - 9. – Architecture of interdomain A-PBM.....	43
Figure 3 - 10. APES architecture.....	44
Figure 3 - 11. FAIN management architecture	46
Figure 4 - 1. MANBoP framework.....	55
Figure 4 - 2. MANBoP Use case diagram	56
Figure 4 - 3. Policy-triggered activity diagram	58
Figure 4 - 4. Policy-triggered sequence diagram.....	61
Figure 4 - 5. Policy Group Processing Activity diagram.....	65
Figure 4 - 6. Signalling-triggered use case Activity Diagram.....	67
Figure 4 - 7. Signalling-triggered use case Sequence Diagram.....	69

TABLE OF FIGURES

Figure 4 - 8. Bootstrap use case activity diagram	70
Figure 4 - 9. Add node activity diagram.....	73
Figure 4 - 10. Remove node activity diagram	74
Figure 4 - 11. GUI-initiated activity diagram	79
Figure 4 - 12. Signalling-initiated activity diagram	81
Figure 4 - 13. Policy Editor component class diagram	82
Figure 4 - 14. GUI-initiated Policy Editor behaviour sequence diagram	87
Figure 4 - 15. Signalling-initiated Policy Editor behaviour sequence diagram.....	87
Figure 4 - 16. XML Policy-initiated Policy Editor behaviour sequence diagram.....	87
Figure 4 - 17. Policy processing inside the PCM component: activity diagram.....	94
Figure 4 - 18. Signalling processing inside the PCM component: activity diagram.....	96
Figure 4 - 19. Policy enforcement trigger: activity diagram.....	98
Figure 4 - 20. Policy Consumer Manager class diagram	100
Figure 4 - 21. PFWCnt class: Policy triggered activity diagram.....	102
Figure 4 - 22. PFWCnt class: Enforcement result triggered activity diagram.....	103
Figure 4 - 23. PCMCORE class: Policy processing activity diagram	106
Figure 4 - 24. PCMCORE class: Signalling processing activity diagram	108
Figure 4 - 25. PCMCORE class: Policy uninstalling activity diagram.....	109
Figure 4 - 26. Policy Consumer Manager: Policy processing sequence diagram.....	119
Figure 4 - 27. Policy Consumer Manager: Signalling processing sequence diagram.....	119
Figure 4 - 28. Policy Consumer Manager: Trigger Enforcement Sequence Diagram	120
Figure 4 - 29. Policy Consumer Manager: Policy uninstalling sequence diagram.....	120
Figure 4 - 30. Authorisation Check Component Activity diagram.....	121
Figure 4 - 31. Authorisation Check Component class diagram.....	122
Figure 4 - 32. Authorisation Check Component sequence diagram	123
Figure 4 - 33. Policy checking activity diagram.....	125
Figure 4 - 34. Dynamic conflict checking activity diagram	127

Figure 4 - 35. Policy Conflict Check class diagram.....	130
Figure 4 - 36. PCCore class: findResources activity diagram.....	132
Figure 4 - 37. PCCore class: sumResources activity diagram.....	135
Figure 4 - 38. PCCore class: checkRAv activity diagram.....	137
Figure 4 - 39. RICnt class: Reservation Schedule activity diagram	141
Figure 4 - 40. RICnt class: Allocation schedule activity diagram	143
Figure 4 - 41. RpProc class: Reports processing activity diagram.....	150
Figure 4 - 42. Policy Conflict Check: Policy conflict checking (predictable enforcement interval)	151
Figure 4 - 43. Policy Conflict Check: Policy Conflict Checking (unpredictable enforcement interval)	152
Figure 4 - 44. Policy Conflict Check: Dynamic conflict checking	153
Figure 4 - 45. Policy Conflict Check: Removal of policy related data.....	153
Figure 4 - 46. A network topology example.....	155
Figure 4 - 47. TEManager: Cost re-calculation activity diagram.....	167
Figure 4 - 48. TEManager: Resource request activity diagram.....	169
Figure 4 - 49. TEManager class diagram	170
Figure 4 - 50. TEManager: findRoute sequence diagram.....	174
Figure 4 - 51. TEManager: estimateCosts sequence diagram	174
Figure 4 - 52. TEManager: updateTop sequence diagram	175
Figure 4 - 53. DmMs: Policy condition monitoring request activity diagram	178
Figure 4 - 54. DmMs: Unregistration of a policy condition monitoring request activity diagram	179
Figure 4 - 55. DmMs: Policy Condition monitoring activity diagram.....	180
Figure 4 - 56. DmMs: Managed topology update processing activity diagram.....	181
Figure 4 - 57. Decision-making Monitoring system class diagram	182
Figure 4 - 58. Decision making Monitoring system: regCond sequence diagram.....	185
Figure 4 - 59. Decision making Monitoring system: unregCond sequence diagram.....	185
Figure 4 - 60. Decision making Monitoring system: ISValue sequence diagram.....	186

TABLE OF FIGURES

Figure 4 - 61. Monitoring Meter: Monitor Individual Statement activity diagram.....	188
Figure 4 - 62. Monitoring Meter: Stop Individual Statement (IS) monitoring activity diagram.....	188
Figure 4 - 63. Monitoring Meter class diagram.....	190
Figure 4 - 64. Monitoring Meter: monIS sequence diagram.....	192
Figure 4 - 65. Monitoring Meter: sMonIS sequence diagram.....	193
Figure 4 - 66. Monitoring Meter: RValue sequence diagram.....	193
Figure 4 - 67. Policy Consumer components class diagram.....	196
Figure 4 - 68. Policy Consumer: enforceP sequence diagram.....	198
Figure 4 - 69. Policy Consumer: sigRequest sequence diagram.....	198
Figure 4 - 70. SigDemux: Signalling request processing activity diagram.....	200
Figure 4 - 71. SigDemux: Policy Consumer registration activity diagram.....	200
Figure 4 - 72. SigDemux class diagram.....	201
Figure 4 - 73. SigDemux: regPC sequence diagram.....	203
Figure 4 - 74. SigDemux: Signalling request detection sequence diagram.....	203
Figure 5 - 1. MANBoP Packages structure.....	212
Figure 5 - 2. Database directory structure.....	214
Figure 5 - 3. Representation of the MANBoP Information Model Objects.....	236
Figure 5 - 4. WebTV Service topology.....	298
Figure 5 - 5. Managed network topology before re-routing through the backup route.....	307
Figure 5 - 6. Managed network topology after re-routing through the backup route.....	307
Figure 5 - 7. Testbed topology with the network-level only management infrastructure.....	308
Figure 5 - 8. Testbed topology with the network-level over element-level managed topology.....	308
Figure 5 - 9. Scalability scenario testbed for the network-level only management infrastructure.....	312
Figure 5 - 10. Scalability testbed scenario for the network-level over element-level management infrastructure.....	312
Figure 6 - 1. Distribution of components at the end of the first half of the scenario.....	324
Figure 6 - 2. Distribution of components at the end of the first scenario.....	325

Figure 6 - 3. Download time statistics for the telnet test.....	335
Figure 6 - 4. Polling time statistics	336
Figure 6 - 5. Policy over CISCO time statistics	337
Figure 6 - 6. Size of the used heap statistics	338
Figure 6 - 7. Generated management traffic statistics	338
Figure 6 - 8. Download time statistics.....	339
Figure 6 - 9. Polling time statistics	340
Figure 6 - 10. Policy enforcement time on a CISCO router statistics.....	340
Figure 6 - 11. Used heap statistics.....	341
Figure 6 - 12. Policy enforcement on a CISCO router statistics.....	342
Figure 6 - 13. Network-level only Used Heap.....	352
Figure 6 - 14. Network-level over Element-level Used Heap.....	353
Figure 6 - 15. Element-level Used Heap.....	353
Figure 6 - 16. Database size occupied when running the first scenario.....	354
Figure 6 - 17. Traffic generation statistics	354

TABLE OF TABLES

Table 1 - 1. Summary of existing policy based management tools properties.....	14
Table 4 - 1. Table of components and interfaces.....	76
Table 4 - 2. PECore interface description table	84
Table 4 - 3. AuthenticationModule interface description table	85
Table 4 - 4. XMLBuilder interface description table	86
Table 4 - 5. The PFWCnt class interface description table	105
Table 4 - 6. The PCMCORE class interface description table.....	112
Table 4 - 7. The GraphBuilder class interface description table	113
Table 4 - 8. The PCCCnt class interface description table.....	114
Table 4 - 9. The PCCnt class interface description table.....	116
Table 4 - 10. The LfCnt class interface description table	118
Table 4 - 11. The ACnt class interface description table	122
Table 4 - 12. The ACkr class interface description table	123
Table 4 - 13. The PAn class interface description table.....	131
Table 4 - 14. The PCCCore class interface description table.....	139
Table 4 - 15. The RICnt class interface description table.....	145
Table 4 - 16. The PFetch class interface description table	146
Table 4 - 17. The ConsCh class interface description table	147
Table 4 - 18. The ResolvC class interface description table.....	148
Table 4 - 19. The RpProc class interface description table	151
Table 4 - 20. The TECORE class interface description table	172
Table 4 - 21. The Routing class interface description table.....	173
Table 4 - 22. The CostCalc class interface description table.....	173
Table 4 - 23. The DLgc class interface description table.....	183
Table 4 - 24. The MMCnt class interface description table	184
Table 4 - 25. The MFact class interface description table	191
Table 4 - 26. The Meter class interface description table	192
Table 4 - 27. The Mapper class interface description table.....	197
Table 4 - 28. The SignaRq class interface description table	197

TABLE OF TABLES

Table 4 - 29. The PCDmx class interface description table.....	202
Table 4 - 30. The Listener class interface description table	202
Table 4 - 31. The Database interfaces description table	207
Table 5 - 1. MANBoP policy information fields.....	221
Table 5 - 2. VANSitesInfo condition values	226
Table 5 - 3. VANFlowCond condition values.....	227
Table 5 - 4. UserCredential condition values	228
Table 5 - 5. IFBWCond values	229
Table 5 - 6. QoSAlloc action values.....	229
Table 5 - 7. Element-level QoSAlloc action values	230
Table 5 - 8. newUser action values	230
Table 5 - 9. FDRestriction action values	231
Table 5 - 10. ServiceDeployment action values.....	232
Table 5 - 11. ServiceConfiguration action values	233
Table 5 - 12. QoSRouteThrough action values	233
Table 5 - 13. QoSNHRouting action values	234
Table 5 - 14. MonReporter action values	234
Table 5 - 15. The User object attributes	237
Table 5 - 16. The Group object attributes.....	238
Table 5 - 17. The Schema object attributes.....	239
Table 5 - 18. The PRI object attributes.....	239
Table 5 - 19. The GblTop object attributes	240
Table 5 - 20. The Node object attributes.....	241
Table 5 - 21. The Link object attributes.....	242
Table 5 - 22. The NResources object attributes	242
Table 5 - 23. The ManagerInstance object attributes	244
Table 5 - 24. The Device object attributes	245
Table 5 - 25. The Component object attributes	246
Table 5 - 26. The PCC object attributes	246
Table 5 - 27. The PC object attributes	247
Table 5 - 28. The MM object attributes	248
Table 5 - 29. Methods implemented for the system bootstrap	249

Table 5 - 30. Methods implemented for policy group processing.....	258
Table 5 - 31. Methods implemented for task coordination and policy checking	267
Table 5 - 32. Methods implemented for monitoring functionality.....	273
Table 5 - 33. Methods implemented for policy enforcement and result processing.....	277
Table 5 - 34. Methods implemented for the node addition mechanism	288
Table 5 - 35. Domain-dependant methods implemented	289
Table 5 - 36. Testbed-nodes properties	309
Table 5 - 37. Testbed nodes properties.....	313
Table 6 - 1. Times for managing different types of network nodes	321
Table 6 - 2. Comparative table between monitoring using ABLE facilities or not.....	323
Table 6 - 3. Policy group processing statistics	327
Table 6 - 4. Component downloading time statistics.....	329
Table 6 - 5. Policy validation time statistics.....	332
Table 6 - 6. Time statistics for delegation tasks.....	332
Table 6 - 7. Summarised data for the scalability test with the NL over EL management infrastructure	343
Table 6 - 8. Policy processing times summary.....	349
Table 6 - 9. MANBoP components with higher processing times in average	349
Table 6 - 10. Processing times in the FAIN NMS.....	350
Table 6 - 11. Processing times in the FAIN EMS	350
Table 6 - 12. Processing times in the FAIN EMS for a VE and delegation.....	351
Table A - 1. MANBoP interfaces in IDL.....	388
Table A - 2. MANBoP exceptions.....	388
Table A - 3. CIA component interfaces.....	389
Table A - 4. MANBoP IMOs.....	393
Table A - 5. Generic interface.....	394
Table B - 1. Managed topology file example.....	396
Table B - 2. Underlying interfaces file example.....	398
Table C - 1. Main policy structure.....	399
Table C - 2. PRVP element structure	400
Table C - 3. PG element structure	401

TABLE OF TABLES

Table C - 4. ActEnf element structure	401
Table C - 5. Cond element structure	403
Table C - 6. Act element structure	404
Table C - 7. XML policy example	405