Design and Development of Essential Use-Cases for Self-management in Future Internet Wireless Networks

Ioannis P. Chochliouros[1], Evangelos Sfakianakis[1], Apostolis Kousaridas[2], Jens Modeker[3], David Wagner[3], Anastasia S. Spiliopoulou[4], George Agapiou[1], Andrej Mihailovic[5], Dev Pramil Audsin[5], Maria Belesioti[1], Andreas Rigas[1], Konstantinos Chelidonis[1], Evangelos Gazis[2], Gerard Nguengang[6], Nancy Alonistioti[2], Christos Mizikakis[1], Dimitrios Katsaros[1], and Tilemachos Doukoglou[1]

[1] Hellenic Telecommunications Organization (O.T.E.) S.A.,
Research Programs Section, Labs & New Technologies Division,
Pelika & Spartis Street, 15122 Maroussi, Athens, Greece
{ichochliouros,esfak,gagapiou,mbelesioti,arigas,khelidon, xmizikakis,dimkatsar,tdouk}@oteresearch.gr
[2] Dept. of Informatics and Communications, University of Athens,
15784, Panepistimioupolis, Ilissia, Athens, Greece
{akousar,gazis,nancy}@di.uoa.gr
[3] Fraunhofer FOKUS, Competence Center Network Research, Sankt Augustin, Germany
{Jens.Modeker,David.Wagner}@fokus.fraunhofer.de
[4] Hellenic Telecommunications Organization (O.T.E.) S.A.,
General Directorate for Regulatory Affairs,
99, Kifissias Avenue, 15124 Maroussi, Athens, Greece
aspiliopoul@ote.gr
[5] King's College London (KCL)
Centre for Telecommunications Research, London, UK
{andrej.mihailovic,Dev.audsin}@kcl.ac.uk
[6] Thales Communications France
Gerard.nguengang@thalesgroup.com

Abstract. The paper discusses and describes several selected use-cases for autonomic/cognitive management purposes in the scope of the Future Internet (FI) evolution, as these have been identified upon the original context of the EU-funded Self-NET Project effort. The essential aim is to "delimit" new paradigms for the management of complex and heterogeneous wireless network infrastructures and systems, by proposing the operation of self-managed FI elements around a novel feedback-control cycle, known as the MDE cognitive cycle. Thus, the paper intends to "identify" an integrated validation environment for the prototyping and the assessment of relevant concepts and artifacts, via the establishment of appropriate use-cases and corresponding scenarios of use and the explicit description/set-up of relevant test-beds and/or implementation platforms, towards network and node management. The three proposed use-cases have been selected as "proper drivers" for the design and the validation of Self-NET architecture and concepts.

Keywords: Autonomic communications, cognitive networks, Future Internet, generic cognitive cycle model, mobility management, network capacity optimization

P. Chatzimisios et al. (Eds.): MobiLight 2010, LNICST 45, pp. 318–333, 2010.

routing adaptation, self-configuration, self-management, routing adaptation, traffic management, wireless access network coverage.

1 Introduction

The Internet world as we know it today has undergone far reaching changes since its early days while becoming a critical communications infrastructure underpinning our economic performance and social welfare. Rapid technological and social changes, together with the bewildering emergence of numerous new services and the increasing number and complexity of access technologies have created a complex environment for network operators/service providers and a challenging situation for end-users [1]. The enhancement of existing information and communication technologies (ICT) and the development of new systems will even further increase this complexity. The Internet architecture and its protocols are currently the targeted technology for future operator business [2]. As the Internet has actually moved from a research curiosity to a recognized component of mainstream society [3], new requirements are continuously emerging and they implicate completely new design principles.

According to the international practice, in a re-design of the current communication environment, a number of requirements have to be considered to have an excellently running and easy to manage system: (a) Security, by also taking into account end-user satisfaction through hidden transmission and safeness of the communication equipment, in order to ensure that the network is sufficiently protected from unauthorized users; (b) Reliability (i.e. protection from network interrupts) and making sure the network is available to users and responding to hardware and software malfunctions; (c) Network management and self configuration ability, i.e. automatic provisioning of services and dynamic adaptations of resource requests; (d) Self-healing ability, i.e. automatic identification of sources of failures and reconfiguration of the network; (e) Scalability, for an efficient management of millions of end-users, network devices, sensors and their networks; (f) Quality of Service (e.g. delay, jitter, bandwidth) and Quality of Experience (end-to-end QoS), and; (g) Support of mobility feature (inter-technology, intra-technology, inter-operator domain, and intra-operator domain), when possible. The current Internet plane environment is complex and not always capable to provide such services in an easy way. Therefore, fundamental new techniques have to be invented to decrease the complexity and to exploit all potential benefits [4], thus creating a fully innovative "*complex*" entity (including network and facilities-services). Research initiatives are being created directed on Future Internet (FI) evolutions and many approaches have been analysed and challenges for evolution have been presented [5], [6]. In this context are performed the targeted activities of the Self-NET Project effort [7], aiming to specify and evaluate new paradigms for the management of complex and heterogeneous network infrastructures and systems, such as cellular, wireless, fixed and IP networks, and taking into consideration the next generation Internet environment and the convergence of Internet and mobile networks. The essential idea is "*to bring more intelligence*" at the network element level in order to enable the network to "*self-pilot its behaviour*" within the constraints of high level business goals. With Self-NET nodes, administrators will focus more on the definition of high levels constraints and less on root cause analysis and low level devices configuration process; the management process will be simplify by automating and distributing the decision-making process involved in the network operation optimization. Powerful management capabilities will be embedded in the network elements thanks to an innovative feedback control cycle, i.e. the *"Monitoring, Decision-Making and Execution (MDE) cognitive cycle*". The MDE cycle will enhance the network element (NE) functionalities by allowing each network device to understand what is happening in its environment, deduce from this understanding the relevant set of actions required to solve the encountered abnormal situation within the constraints of business goals and enforce the corresponding configuration to recover from the anomaly [8].

Self-NET system architecture aims to incorporate the innovative aspects related to the related specific Future Internet topics, i.e., autonomic networking, network management, knowledge management, self-configuration and optimisation, and native Internet themes. In order to design the Future Internet network elements, Self-NET has identified several scenarios and thirteen use-cases have been defined [9]. Based on these use-cases, the Project has extracted FI functional requirements and has designed a knowledge framework that introduces cognitive capabilities at various level of the network ranging from the network element level to the domain level. Dynamic and flexible forwarding mechanisms have been designed to allow more adaptability of the protocols stack [10]. Based on the addressed technical areas, the relevance with respect to the work achieved in the wider Self-NET context and the availability of involved equipments, the Project has selected the following four use-cases as the "drivers" for testing and validation activities: (a) Coverage and capacity organization in wireless environments; (b) Traffic management, re-routing and forwarding to support mobility, QoS and routing adaptation, (c) Dynamic spectrum re-allocation for efficient use of traffic, and; (d) Adaptable routing and mobility management in dynamic self-managed wireless mesh topologies.

The paper provides a description of the selected three use-cases, as the latter have been proposed by several Self-NET partners. A strong emphasis is made on the integration of the knowledge framework that implements all the aspects of the MDE cycle. For each separate use-case we consider a brief description providing clarifications and/or informative data about: the background of the specific use-case; the detailed description of the corresponding test-bed and the role of each segment; the monitoring protocols that will be used to retrieve information from network elements; testing and validation perspectives, and; finally a briefing of the introduced innovative features.

2 Description of Use-Case 1: Coverage and Capacity Optimization in Modern Wireless Networking Environments

In current practice, wireless network planning is a difficult and challenging task that involves expert knowledge and profound understanding of the factors affecting and determining the performance of the wireless system. Several monitoring parameters should be taken into account for the optimal coverage and capacity formation, while different configuration actions are available that in many cases are interrelated, as regards the consequences. In established approaches, frequency planning is conducted as part of the deployment procedure for entire network segments or domains.

The assignment of operating frequencies and/or channels to wireless network elements is also a part of the frequency planning procedure. To eliminate conflicts in frequency assignment, the procedure is centrally coordinated in a procedure that assumes and requires global knowledge and control over the concerned network segment or domain. In this context, global knowledge and control implies that the administrative entities are fully aware of the channel assigned to each individual network element and are fully capable of adjusting such assignments to their liking in a centrally coordinated manner. As a result, conflicts in frequency assignment may be avoided or, *at least*, minimized, provided that a central entity coordinates the entire procedure. Apart from the optimal channel allocation, the load balancing and the distribution of the users to the available access points, in the context of a multi-RAT (Radio Access Terminal) environment is an another key issue for next generation communication networks that will be studied through this use-case. In a large-scale distributed setting, where multiple independent stakeholders operate one or more network infrastructures offering wireless access, central planning and control are neither realistic, nor "feasible" options. The independence of each stakeholder suggests that peer approaches are more suitable in this setting, either in a cooperative or a non-cooperative manner. Hence, a technical approach based on the locally available state information and the interaction with peers through explicit or implicit approaches is favored in this setting.

Existing standards for popular wireless access technologies do not provide the capacity to interact with peers on the basis of local and exchanged information for purposes of improving coverage and capacity [11]. Each wireless access system or network segment comprising multiple access systems is configured independently of all others. As a result, in cases where technical expertise falls short of the complexity involved in efficient frequency planning for an infrastructure free -or at least one with a controlled level- intra-band and inter-band interference, system performance is seriously degraded due to inefficient channel assignment. Addressing this problem on the basis of coordination among different administrations may work only for large scale installations where network management personnel is skilled in solving frequency planning problems through a set of established procedures. This is the case for cellular network operators where frequency bands are typically allocated for prolonged time periods (i.e., decades) according to some form of auction. In these settings, radio network planning is a well-structured process that leverages skilled technicians to ensure the most efficient use of the expensive spectrum resource.

However, in the huge mass consumer market segment targeted by modern WLAN (Wide Local Area Network) technologies this approach is not realistically feasible, for a number of reasons. First and foremost, the typical consumer does not possess the technical expertise required to fully comprehend and efficiently solve such frequency planning problems. Even if that was the case, achieving an efficient coordination among a large number of consumers where each controls a single wireless access system (e.g., a residential broadband gateway with an embedded WLAN access point) would be extremely difficult.

Therefore, the introduction of an autonomic mechanism that undertakes the discovery of conflicting frequency plans in-situ and initiates reactive measures to adapt frequency and/or channel assignments in a collaborative manner among the concerned network elements is necessary. In addition to being purely reactive in nature, such a mechanism may also possess additional intelligence that enables it to record adaptation decisions and correlate them to temporally collocated observations regarding the context in which those observations were made. These correlations are to be exploited in the future as part of and to improve the decision making process for similar adaptation situations [12].

The scenario considered assumes access network segments with Wireless LANs. The target problems are perceived as follows: Resource (Channel) allocation conflicts causing primarily poor resource (spectrum band) utilization and, as a consequence, delay in medium access, congestion due to inference limiting channel throughput, inability to support QoS-sensitive and real-time applications efficiently and, at a wider scope, increased capacity requirements. No protocol or standard is available and operator's intervention is necessary. In particular, if considering the network topology that is described in Fig.1, four phases have been considered for the scenario description and thus the demonstration of the developed mechanisms: (i) Activation of an access point at an already established network topology and demonstration of the self-configuration process; (ii) De-activation of an access point and network topology self-organization; (iii) Self-Optimization of the network topology due to the identification of a fault, demonstrating thus the full aspects of the decision making module, and; (iv) Improvement of the deduction and decision making mechanisms, exploiting the available feedback loops. For the actual use-case, two specific test-bed facilities have been taken into account (as discussed in the following sub-clauses 2.1 and 2.2) and are integrated in order to increase the configuration capabilities and enrich the situations that the Self-NET cognitive plane may address.

2.1 Description of Test-Bed 1 (Proposed by the University of Athens-UoA)

The essential structure of the first test-bed that is also depicted in Fig.1 is analyzed, briefly, as follows:

- *Infrastructure:* A WLAN access network segment with Network Address Translation (NAT) access to Internet and port forwarding for specific services.
- *Involved technologies:* IEEE 802.11b/g, static routing tables in the access network segment (no routing protocol in effect), and SNMP (Simple Network Management Protocol). For the realization of the "added" intelligence and cognition of the NECMs/NDCMs (Network Element Cognitive Managers/Network Domain Cognitive Managers) in the network nodes (i.e. Soekris devices [13]) and, more specifically for the decision making part, the fuzzy logic technique has been used for the inferences as well as specified objective functions for the channel allocation problem. Furthermore, neural networks and the K-Means methods have been utilised for the identification of patterns for network observations as well as for the feedback/learning process.
- *Monitoring tools:* All SNMP primitives using the SNMP protocol (port forwarded over the NAT), SSH (secure shell) remote command execution. SNMP (which is used as *monitoring protocol*) is intended to used locally as a standardized monitoring protocol (local monitoring actions), by the NECMs without the existence of a central SNMP manager that collects and re-distributes the monitoring data. A CACTI [14] installation mainly used for visualization purposes, exists in the WLAN network segment for local monitoring purposes using a dedicated network segment.

- Proposed *monitored parameters* are: Link quality, Signal level, Noise level, Rx invalid nwid, Rx invalid crypt, Rx invalid frag, Invalid misc, Channels occupied.
- *Prerequisites:* Ability to place the MiniPCI WLAN card on the Soekris boards on master mode so as to support the software-based access point daemon.
- *Initial conditions:* Soekris access points using a channel allocation pattern with at least one conflict. In fact, this requirement stems from the scenario in question.
- *Assumptions and constraints:* Local NECMs should be able to communicate directly; thus a 2nd wired interface is used for the exchange of control information.

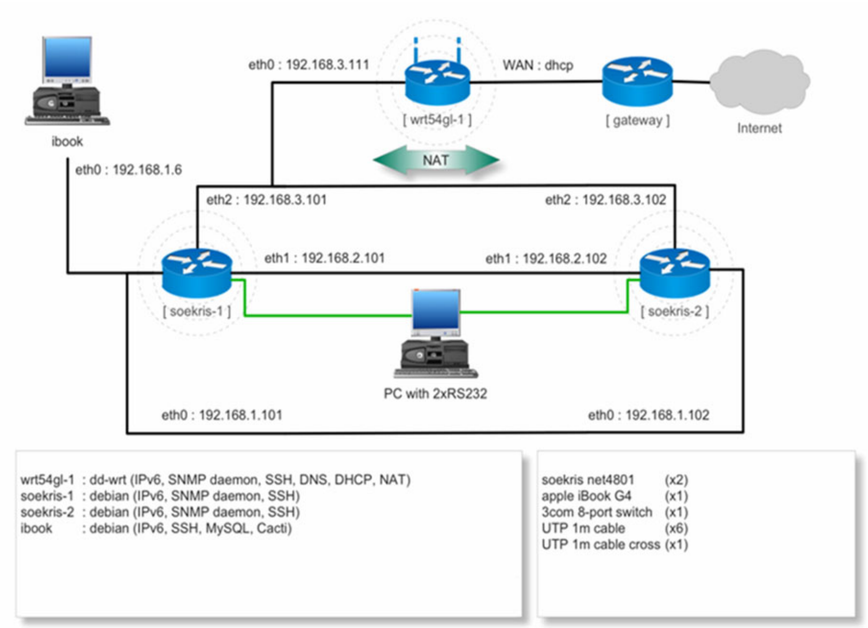


Fig. 1. Use-case 1: Topology of the *University of Athens* Test-bed

Experimental setup:

- *Fault or network anomaly generation:* Interference is caused by spectrum overlap in WLAN defined channels. This may involve only a minimal level of interference, which, however, is detected by proximal WLAN access points and thus serves as a trigger for the induction of processes in the MDE cycle. Optionally, traffic generators may be employed to induce traffic over the Soekris access points and, *thus*, heavy interference in selected WLAN channels.
- *Anomaly detection:* Primarily, a mathematical formula is used to assess metrics related to channel overlap based on specific variables retrieved over the SNMP and/or SSH protocols and concerning "key WLAN parameters" (e.g., channel in use, mode in use, transmission power, etc).
- *Configuration protocols and parameters:* The SNMP and/or SSH protocols support configuration, along with static configuration in non-volatile local storage.

2.2 Description of Test-Bed 2 (Proposed by the Hellenic Telecommunications Organization S.A.-OTE)

The proposed test-bed considers a laboratory setting, where a WiMAX base station (BS) resides, operating at 3.5GHz and serves the surrounding area. A potential example concerning the operation of the test-bed may arise if we also consider a small campus nearby the lab premises where, *during some experiments*, a young researcher unaware of all the lab settings, approaches the BS very closely with his laptop, and starts to cause a lot of interference, forcing the BS to start scanning for a another channel. Then a potential operation of the cognitive plane (based on the description previously discussed in the clause 2 of the present work) can be as follows: The situation, due to the interference caused, is also reported to NDCM and after some scanning, the NDCM aware that there are no similar BSs operating nearby, orders the BS to "change" frequency [16]. The essential "drawback" lies upon the fact that even though the band is licensed, interference deteriorates system performance, resulting in reduced channel throughput, limited support of QoS and delay sensitive applications. Therefore, causing increased capacity demand. The proposed approach implicates that a proper radio planning is required, which is mostly static and its handling also requires human management. Interference is measured in various channels and another one is selected for use in the cell/sector. Then both the CPEs (Customer Premises Equipment) and BS move to the selected frequency with less interference. In case of

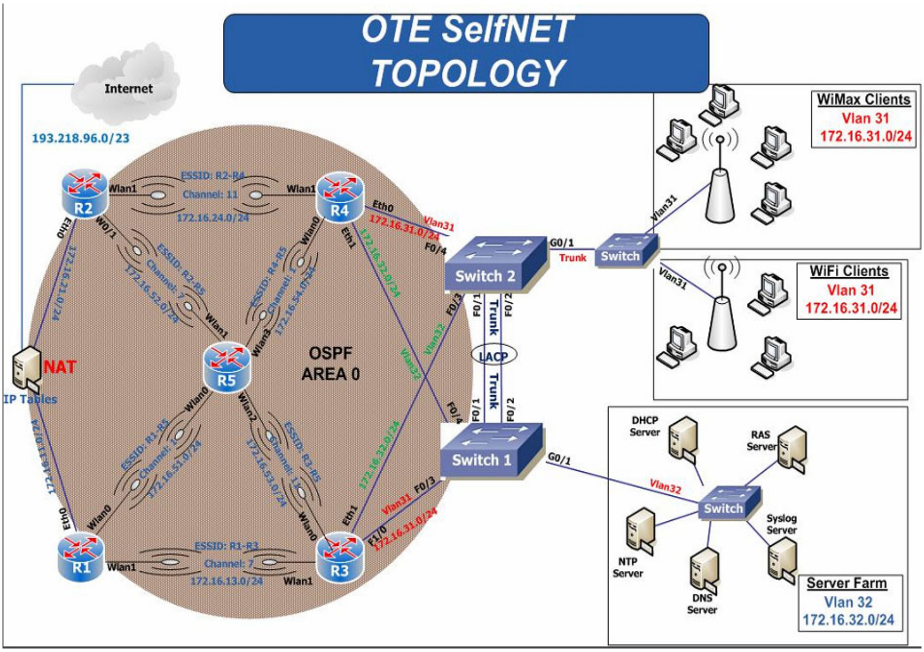


Fig. 2. Use-case 1: Topology of the *OTE (Hellenic Telecoms Organization SA)* Test-bed

increased interference (e.g. low Signal-to-Noise ratio, SNR), the NDCM will be responsible for changing the frequencies of both the BS and the Subscriber Unit (CPE). Additionally, when NDCM detects high Signal-to-Noise ratios for all subscribers and hence good transmission environment, the long cyclic prefix used in multipath environments could be changed to short cyclic prefix, improving thus the total throughput of the system.

The essential structure of the second test-bed (as illustrated in Fig.2) is as follows:

- *Infrastructure:* WiMAX network segment interconnected with Ethernet infrastructure consisting of Cisco and Linux-PCs, operating as switches and routers, providing also a few virtual LANs. Access to Internet is provided through NAT. Another wireless segment using Wi-Fi, which is operating at 2.4 GHz, is connected to the core network.
- *Involved technologies:* IEEE 802.16d, OSPF (Open Shortest Path First) is used in the routers and LACP (Link Aggregation Control Protocol) and STP (Simple Transfer Protocol) by the switches, SNMP for management purposes; SSH remote command execution; DNS (Domain Name System), DHCP (Dynamic Host Configuration protocol), NTP (Network Time Protocol) services running in the network.
- *Monitoring protocol:* SNMP.
- *Routing/Switching protocols*: OSPF (L3), LACP and STP (L2).
- *Monitored parameters (at the 802.16 segment):* SNR, Signal Modulation, CRC (Cyclic Redundancy Check) Errors, Channels occupied.
- *Monitoring Tool:* Redline Monitoring Tool in the WLAN network segment for local monitoring. SNMP, IPtables, SNORT, Syslog for all monitoring purposes.
- *Prerequisites:* Ability to connect Redline BS with a PC hosting the software-based access point daemon (hostapd). The daemon needs to support SNMP commands for the Redline BS management. Necessary sensors and other NEs are to be placed throughout the network.
- *Initial conditions:* Redline WiMAX Base Station (IEEE 802.16d) with an initial channel allocation pattern, according to the corresponding scenario's description.
- *Assumptions and constraints:* NEs issue commands understandable by the underlying network equipment (i.e., in particular from the Redline BS and the Cisco switches and routers). Since most of the network equipment is proprietary, it provides limited configurability in certain aspects and especially in real time changes of configuration. Additionally, there will be a (possible direct) connection maintained between the NDCM, NEs for the communication between them.

Activities of the cognitive framework integration under the consideration of the MDE approach:

- *Monitoring:* Monitoring is supported by the SNMP daemon on the Soekris systems (IEEE 802.11) as well as on the WiMAX BS (IEEE 802.16d) and complemented by the capacity to execute any operating system command over the SSH protocol and intelligently parse the command's output, *if necessary*. Furthermore, monitored data may also be collected and concentrated by a dedicated software established on an involved network element e.g., a network element that hosts Nagios.

- *Situation Awareness (SA):* It is supported as part of, and within the cognitive management framework instrumentation, where a loosely coupled mode of interaction is based on events and subscription to event topics of interest.
- *Decision Making:* Initially, the Fuzzy logic algorithms and utility functions have been selected for the first part of the corresponding use-case. Both placed at the decision making engine of the NECM and the NDCM.
- *Learning:* Supervised and Semi-supervised machine learning approaches (e.g., neural networks, k-means) are initially studied and developed using also WEKA libraries [15] for the off-line improvement of the decision making process.
- *Execution:* It is supported by the SNMP daemon on the Soekris systems and is "identical" to the relevant *Monitoring* activity. Similarly the SNMP daemon of the Redline WiMAX BS systems is used for the configuration actions that are issued by the NECM or the NDCM towards the WiMAX subsystem.

The target functionalities arising from the scope of the use-case 1 are summarized as follows:

- *Dynamic optimization capability through local NECMs collaboration and NDCMs hints/recommendations:* The system "*optimizes itself*" in case of a sub-optimal channel allocation while considering wireless link status and conditions.
- *Dynamic auto-configuration capability:* The system detects a significant change in its operational context (e.g., the introduction of additional network elements requiring access to the wireless resource). In response to this event, it undertakes the configuration of the proper resource assignment plan to accommodate both existing and new NEs. In particular, planning involves the assignment of a wireless channel and, optionally, the adjustment of radio transmission parameters.

The main innovations of the above contextual "approach" are listed as follows: (i) *Automation:* Compute/perform reconfiguration solutions to solve context problems; (ii) *Detection of problematic situation:* The system autonomously monitors aspects of its operational context and detects significant deviations from the set of states that determine "optimum" or "optimal" performance; (iii) *Optimization based on local interactions:* The system approaches or reaches an optimum mode of operation by exploiting local state and information exchange with peers. A scoping mechanism confines signalling and avoids scaling problems; (iv) *Self-optimization* in case of sub-optimal resource assignment or performance; (v) *Adaptability capabilities* in the face of unknown network topology and wireless conditions, and; (vi) *Distribution of decision mechanisms* by involving local/global interaction at the level of information management and dissemination.

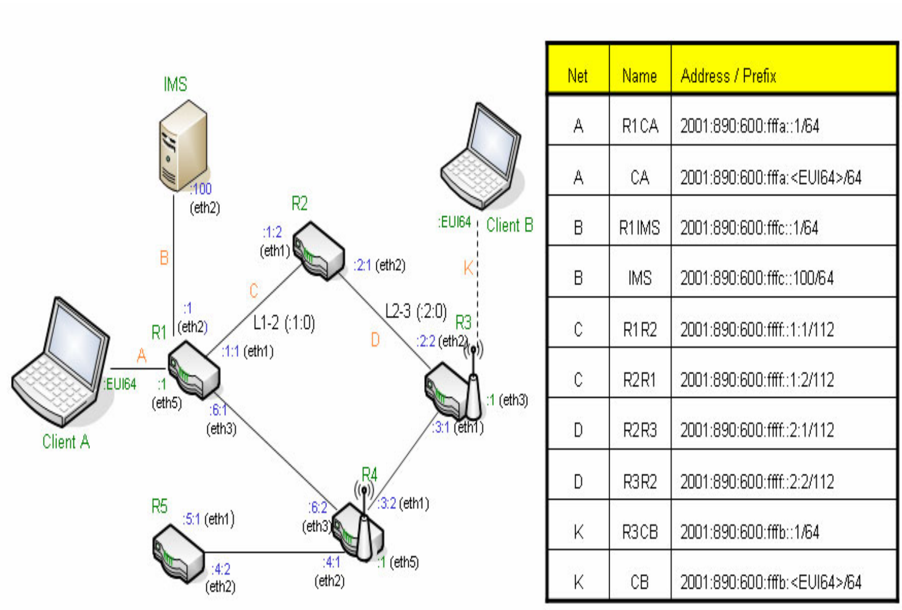
3 Description of Use-Case 2: Traffic Management, Re-Routing and Forwarding to Support Mobility, QoS and Routing Adaptation

When packet loss occurs, today's network management cannot always provide multiple options: it is possible to "change" routes and/or the deployment of nodes may be changed as a whole, but this is normally quite expensive and therefore it is usually avoided. When this comes to be the case in wireless networks (also including wireless backhauls), it would be appropriate to have the ability to "*modify*" several link characteristics like modulation, FEC (Forward Error Correction) or retransmissions on-the-fly and maybe temporary only. This would allow "tailoring" the wireless network to the "*normal case*" rather than the "*worst case*" and the use of cheaper (e.g. WiFi-based) equipment. This is an area where the capability to "*dynamically*" adopt network functionality could be extremely beneficiary, for the entire network behavior. The present use-case targets packet loss avoidance for a wireless link and incorporates the control of the DPC (Dynamic Protocol Composition) framework – the latter is a novel execution capability. The NECM derives that the monitored packet loss is due to bad link quality and decides to activate on its own ARQ (Automatic Repeat Request) to the next Self-NET node using Functional Protocol Elements (FPEs) in the DPC framework.

This affects part of the path of a video streaming flow which in return will improve significantly. The relevant test-bed is depicted in Fig.3. The use-case targets general network performance improvement by the means of activation of FPEs. It includes several possible adaptations for controlling traffic, e.g. diverting traffic or changing functionality like ARQ for flows of packets. Focus in the execution part of this use-case is the usage of functionality composed by several FPEs which may establish or change specific functions in the network e.g. changing a route or adding a protocol function like ARQ. Since the set of potential options and combinations is huge, the case is restricted to two triggers, namely an overloaded node and losses on a specific link. Current protocols and networks provide means neither to the receiver nor the sender to handle or alleviate such situations. In Fig.3 we illustrate the topology of the relevant test-bed.

Test-bed description (proposed by Fraunhofer Fokus):

- *Involved technologies:* The test-bed consists of the core routers (5PCs with Ubuntu 8.10 server), the Open IMS (IP Multimedia Subsystem) Core [17] (1 Ubuntu 8.10 server), the WLAN access point and two Clients (Linphone, SIP Communicator, or Monster).
- *Infrastructure:* Open IMS Core reconfigured to enable IPv6, Router advertisement daemon (radvd) [18] sending periodically Router Solicitation message which is required for IPv6 stateless auto-configuration (installed on R1, R3 and R4), Netem [19] (emulates variable delay, loss, duplication and re-ordering), Iperf (network testing tool that can create TCP (transmission control protocol) and UDP (user datagram protocol) data streams and measure the throughput of the network [20]), Ipv4 for management purposes.
- *Monitoring tools:* bwm-ng (Bandwidth Monitor NG) [21] installed on all routers, Network protocol Analyser TShark [22] installed on the Open IMS Core and on the layer 3 components. (There are no *monitoring protocols*).
- *Monitored parameters:* Bandwidth, load and loss detection on all nodes.
- *Prerequisites:* Clients registered at the OPEN IMS Core.
- *Initial conditions:* A SIP (Session Initiation Protocol) session is established and video is being streamed from A to B.



Net	Name	Address / Prefix
A	R1CA	2001:890:600:fffa::1/64
A	CA	2001:890:600:fffa:<EUI64>/64
B	R1IMS	2001:890:600:fffc::1/64
B	IMS	2001:890:600:fffc::100/64
C	R1R2	2001:890:600:ffff::1:1/112
C	R2R1	2001:890:600:ffff::1:2/112
D	R2R3	2001:890:600:ffff::2:1/112
D	R3R2	2001:890:600:ffff::2:2/112
K	R3CB	2001:890:600:fffb::1/64
K	CB	2001:890:600:fffb:<EUI64>/64

Fig. 3. Use-case 2: Topology of the *Fraunhofer Fokus* Test-bed

- *Assumptions and constraints:* The ability to implement the FPEs and the protocol function (e.g. ARQ) into routers. Furthermore to label the RTP (Real-Time Transport Protocol) packages and to change the routing table entries.

Experimental setup:

- *Fault or network anomaly generation:* Interference is caused by Netem (emulates variable delay, loss, duplication & re-ordering) and Iperf/Multi-Generator (MGEN) [23] (generates overload).
- *Anomaly detection:* Threshold based and statistical analysis of current throughput, packet loss and also correlation of multiple inputs including static information (like max. bandwidth), technology.
- *Configuration protocols and parameters:* SSH protocol support configuration.

Activities under the consideration of the MDE approach:

- *Monitoring* of packet loss is performed by reading retransmission using tshark.
- *Decision Making:* Using the monitored data together with a certain threshold will be utilized to derive decision making techniques.
- *Execution:* Reconfiguration of the DPC framework by enabling Link Local ARQ.

The introduced use-case can demonstrate the benefits of in-network protocol functionality that can be dynamically (and transparently) reconfigured by cognitive network management activities.

The main innovations of the proposed consideration are given, in brief, as follows: (i) *Enabling the network to interpret flow specifics*, by the provision of generalised Information Elements; (ii) *Recognition/identification* of "where packet loss has happened in the network, and compute appropriate reaction by enabling ARQ at network segment; (iii) *Introduction of fine-grained protocol functionality* to the network nodes that do not act as end-nodes, and; (iv) Unlo*ad of the network* by reducing the amount of retransmissions traffic, by rather focusing retransmissions at the hop where the packet losses are caused.

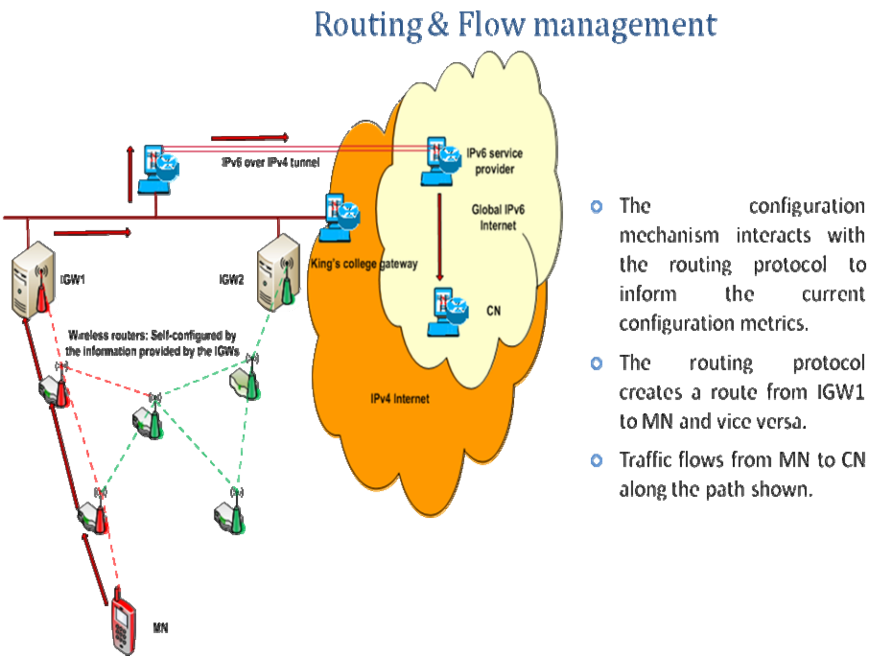
4 Description of Use-Case 3: Adaptable Routing and Mobility Management in Dynamic Self-managed Wireless Mesh Topologies

This use-case provides a mechanism for the provision of network connectivity, handover and flow re-directions for mesh networks. This use-case provides a path for the intelligent network elements by implementing some of the characteristics of self-management. The scenario concentrates on the self-X methods for the provision of the Internet, by establishing mechanisms for the NEs in order: to configure themselves with optimal information; to monitor the network dynamics, and; to adapt themselves by re-configuring the needed information. This will result in the changes to the mobile node's configuration making the mobile node to do a handover. On the other hand, NEs' re-configuration to maintain optimal configuration affects the routing protocol configuration and the operations leading to the re-direction of the packet flows.

The developed protocols in action will function during the initial bootstrapping phase as well as re-configuration phase of the NEs. The target problem areas include dynamic configuration of NEs with optimal metrics taking into account of network dynamics, such as deployment of additional nodes, network element failure, topology changes and mobility resulting in the re-direction of traffic flows. Fig.4 illustrates the topology of the relevant test-bed.

Test bed description (proposed by the King's College London-KCL)

- *Infrastructure:* WLAN, access networks, wired LANs, mesh (or "*mesh-like*") networks, with ability to connect to global IPv6 Internet.
- *Involved technologies:* IEEE 802.11 b/g, Link state routing protocol, SNMP, self-configuration and mobility management.
- *Monitoring tools:* POSIX system functions, Linux primitives.
- *Monitored entities:* Link state and characteristics, network interface, routing protocol and IPv6 configuration elements.
- *Prerequisites:* Ability to re-compile the Linux kernel, development and debugging libraries / tools, WLAN card drivers support for de-centralized communication.
- *Initial conditions:* The initial condition arises from the proposed scenario and the requirement for Internet's provision that is adaptable to the network dynamics with optimal configuration and mobility with ease and minimal network planning and human intervention.



Routing & Flow management

- The configuration mechanism interacts with the routing protocol to inform the current configuration metrics.
- The routing protocol creates a route from IGW1 to MN and vice versa.
- Traffic flows from MN to CN along the path shown.

Fig. 4. Use-case 3: Topology of the *King's College of London-KCL* Test-bed

Experimental setup:

- *Fault or network anomaly generation:* Network induced changes to optimal configuration caused by network topology variations and the NE's dynamics.
- *Anomaly detection:* A self-aware mechanism is used to determine the deviation from optimal configuration. NEs maintain an information base, supporting their configuration mechanism. The configuration methodology should select an optimal configuration for the specified performance metric and is based on a function. The decision is made considering the current configuration, set of available upstream routers, gateway preference. The optimal configuration process is triggered by a NE under two circumstances, namely the bootstrap state and changes to network conditions or, in general, the dynamics of the network environment. In the latter case, the NE should re-configure to provide optimal configuration for the Internet connectivity and traffic flows. NE failure or addition of a NE is a representative example that triggers a network dynamics and eventually changes to the configuration of the NEs. Since, the above mentioned events introduce network dynamics, a gateway with better Internet connectivity is necessary. Each NE, after the trigger for configuration selection or update selects an optimal configuration. The network area or environment for a NE includes all the routers up to the Internet gateway.
- *Configuration protocols and parameters:* SSH protocols to execute operating system and user-defined protocols, applications/commands over the network.

- A description of the mechanisms involved in that directs the monitor the information and the methods that describe the re-configuration are described in Fig.4, where the configuration mechanism interacts with the routing protocol to inform the optimal configuration metrics.

Activities under the consideration of the MDE approach:
The integration of the cognitive manager requires the input such as the address of the Internet gateway, routers and the preference of the configuration element for the decision making process which results in the selection of the optimal configuration, i.e.: routing adaptations, handover of the mobile node and flow re-directions. The action component performs the re-configuration of the NE with optimal configuration, routing protocol adaptations, handover functionality and routing re-directions enhances device's capability.

- *Monitoring* is performed by POSIX system functions, SNMP. The self-management of the network system is achieved by monitoring the network elements such as the routers, mobile node, packet flow paths and redirections and Internet gateway. The monitoring system includes configuration information, traffic flow context, cumulative traffic flow directions and state, collective packet flow information in the network.
- *Decision Making:* The monitored configuration data or parameter is utilized to "derive" decision making techniques, methodologies and processes. This is a functionality of collective analysis and involves methods and functions for the "optimum" decision making and evaluation criteria applied. One relevant process is when a configuration element is to be selected from a set of possible/candidate configuration elements as the most appropriate configuration choice. Another process involves packet redirections constrained with regards to routing and handover mechanisms.
- *Execution:* Execution is supported by Linux system calls, SSH remote execution and SNMP primitives. This implicates optimal initial configuration and re-configuration of network elements, handover trigger, routing protocol re-configuration and adaptations, route table flush and re-establishment, route recalculations, and traffic flow path alterations for handover support.

The target functionalities arising from the scope of this use-case are as follows:

- *Hot reconfiguration of network elements* including routers and mobile nodes with optimal configuration and the *capability to react in case of NE failures*, including the *addition of new NE.*
- *Routing protocol can "adapt" itself to the new configure* and calculates path with respect to the new configuration; this results in the traffic re-routing.

The main innovative features are summarized as follows: (i) Dynamic optimal configuration of network elements with regards to network dynamics; (ii) Routing protocol adaptations and traffic re-routing; (iii) Distributed decision making mechanisms, and; (iv) Decision procedure into multiple levels (NECM, NDCM, etc).

5 Conclusion

The main objective of Self-NET Project is to design and validate new paradigms for the management of complex and heterogeneous network infrastructures and systems, by taking into consideration the next generation Internet environment and the convergence of Internet and mobile networks. Self-NET aims to "engineer" the FI, based on cognitive behavior with a high degree of autonomy, by proposing the operation of self-managed FI elements around a novel feedback-control cycle, the MDE cognitive cycle. This paper aims to provide an integrated validation environment for the prototyping and the assessment of relevant concepts and artefacts, via the establishment of appropriate use-cases and the detailed set-up of relevant test-beds and/or implementation platforms towards efficient network and node management, when anomalies are detected. The paper addresses the issue of scenarios' refinements by providing a detailed description of three use-cases (i.e.: (i) wireless access networks coverage and capacity optimization; (ii) traffic management, re-routing and forwarding to support mobility, QoS and routing adaptation, and; (iii) adaptable routing and mobility management in dynamic self-managed wireless mesh topologies), that have all been selected as essential "drivers" for the validation of Self-NET architecture and concepts.

Acknowledgments. The present work has been performed in the scope of the *Self-NET* ("*Self-Management of Cognitive Future Internet Elements*") European Research Project and has been supported by the Commission of the European Communities - *Information Society and Media Directorate General* (FP7, Grant Agreement No.224344).

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