Flexible next generation communication networks

Konstantinos DEMESTICHAS
Institute of Communication and Computer Systems (ICCS)
Zografou 15780 - Athens, Greece
cdemest@cn.ntua.gr

ABSTRACT

The increasing bandwidth demand of the end-users makes the need for efficient resource management more compelling in next generation communication networks. Nowadays, the mobile communications scenery is characterized by the continuous growth of new services, the provision of which poses the need for higher data rates to guarantee satisfactory quality of experience for the end-users. The advent of evolved mobile communication networks (such as LTE - Long Term Evolution) promises to encounter this demand by offering increased capacity, high data rates, seamless mobility and low latency. Nonetheless, during this evolutionary process, the backhaul part of mobile networks has received less attention. This paper discusses on ways for further evolution of mobile networks by rendering backhaul connectivity more flexible, robust and self-aware.

Keywords: mobile networks, long term evolution, converged infrastructure, backhaul connectivity, cognitive all-IP networks.

1. INTRODUCTION

As demand for wireless access to the Internet and Internet-based services is expanding, competitive advantages in the mobile business can be gained by offering enhanced user experience through cost-effective broadband mobile access. A promising, **twofold approach** is to **maximise network performance** (so as to offer enhanced wireless access), and additionally **enable efficient network operation and maintenance (O&M)**. This paper discusses on ways to adopt and realise this approach, by innovating and implementing technologies and functionalities that shall equip next-generation wireless Base Stations (BSs), advancing both their degree of performance as well as their ability for self-organisation and self-management.

To this end, this paper focuses on the **backhaul part of Next Generation Mobile Networks (NGMN)** [1]-[2], by proposing a novel and highly flexible backhaul solution[1]. The main motivation stems from the fact that the backhaul part [3] is one of the most crucial blocks to enable NGMN form the blueprint of an innovative platform suited for the competitive delivery of wireless broadband services to the benefit of users. Without designing, developing and deploying cost-effective and bandwidth-efficient transport solutions, users will not be able to experience high broadband access everywhere, anytime, and it will become infeasible to realize the vision of **Future Internet**.

To this end, this paper proposes a mobile network architecture **evolution** based upon the design, specification and implementation of a wireless BS equipped with **flexible backhaul solutions**, as well as relevant **cognitive and self-organising** [4]-[5] functionalities targeted for optimal transport load-balancing. An integral part of the proposed concept is the introduction of a new, dual backhaul solution that delivers a great degree of flexibility by comprising two branches:

(i) the **legacy backhaul branch** of the BS;

[1] The backhaul portion of a hierarchical communication network comprises the intermediate links between the core (or backbone) network and the “edge” nodes (or sub-networks) of the entire network. Traditionally, a backhaul solution is defined as the transport network that allows: (i) in evolved networks, the connection of a NGMN Radio Access Network (RAN) node (e.g., eNodeB) to the core network (e.g., Serving GW); (ii) in legacy mobile networks (GSM/UMTS), the connection of the RAN’s base station (e.g., NodeB) to the RAN’s controller (e.g., RNC).

(ii) a new, wireline **broadband access branch**, either installed and operated by the same network operator or, more commonly, provided by a third-party wireline (fixed network) operator or Internet Service Provider (ISP).

The latter branch can, for instance, be based on Digital Subscriber Line **(DSL)** technology, since this is readily available in most urban environments (thus, representing a cost-effective approach), or on Passive Optical Network **(PON)** technology, since this constitutes a high-capacity solution with many reconfiguration capabilities.

Although this paper focuses its study on 3rd Third Generation Partnership Project (3GPP) communication technologies (such as GSM/UMTS, EPS), the discussion is also of interest to 3GPP2-standardized technologies (such as CDMA2000).

2. PROPOSED EVOLVED NETWORK ARCHITECTURE AND BENEFITS

The proposed generic concept architecture is illustrated in Figure 1. An exemplification of this architecture using the Evolved Packet System (EPS) [6]-[10] as a reference is provided in Figure 2.

As might be apparent, this **hybrid** solution allows for the **offloading** of the mobile Core Network (CN) from non-critical Mobile Internet traffic, leading to positive repercussions with respect to the provision of critical applications (i.e., with strict QoS constraints in terms of guaranteed bandwidth, delay, jitter, etc.) through the mobile network. Apart from this clear advantage, the full potential of the proposed architectural evolution can be released by **innovating and integrating** advanced functionalities inside the BS, that will allow for **optimal traffic-balancing between the two branches**. This intelligent traffic forwarding and balancing mechanism should employ **traffic measurement and analysis tools, versatile scheduling algorithms, as well as learning and reasoning functions** that will capitalise on the accumulated knowledge and experience, towards the vision of next-generation BSs **infused with cognition and self-organisation**. Parameters that must be taken into account during optimisation include the current traffic load on the radio access network, the anticipated (predicted) traffic load in near-term, the availability of resources in the two branches, the number of active and of idle users, the types of services that are being transported, the number of service data flows and the QoS level associated to each service data flow, the accumulated past knowledge and experience, and others.

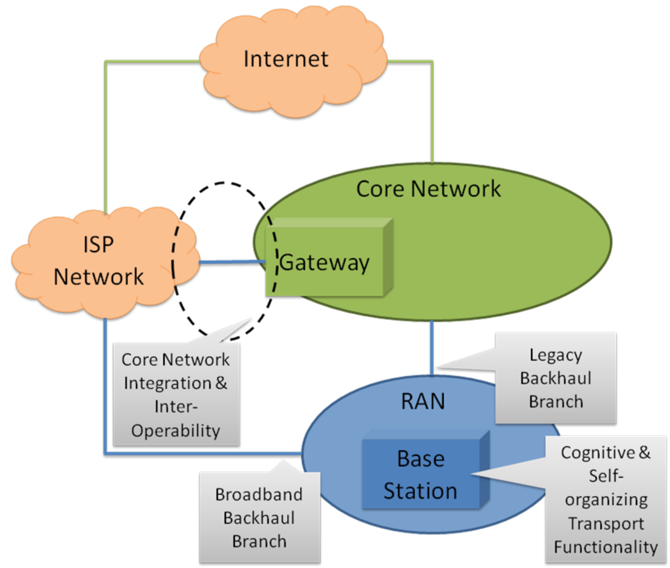

Figure 1. The proposed generic concept architecture

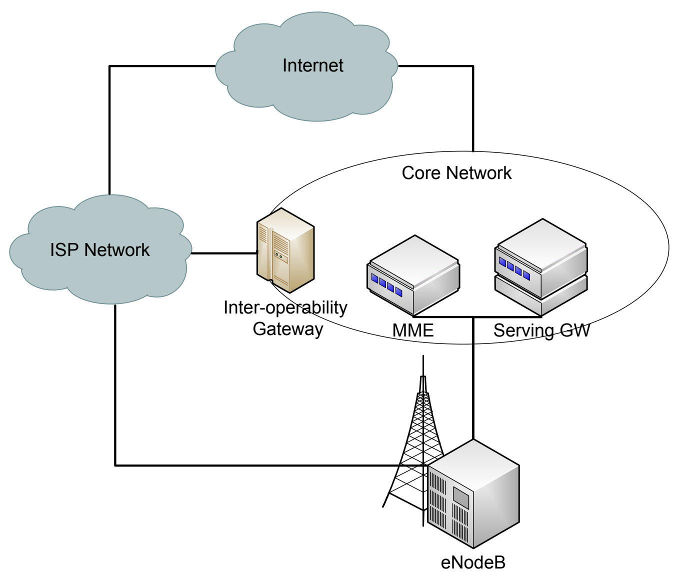

Figure 2. Exemplification of the proposed architectural model for Evolved Packet System (EPS)

Moreover but equally importantly, the broadband backhaul branch can be **shared** among many neighbouring BSs, raising opportunities for **flexible and dynamic bandwidth allocation schemes** (among different neighbouring BSs), which again improve the perceived QoS and reduce the operational expenses (compared to static schemes).

Apart from dynamic, optimal and cognitive traffic distribution on the user plane, another major associated research challenge is **the transport of the control plane** through this evolved architecture. More specifically, in the proposed architecture, the control plane now has the option of being transported through:

- **(i)** solely the legacy backhaul branch;
- **(ii)** both the legacy and the broadband backhaul branch, in a balanced manner (optimisation functions are again needed, as for the case of the user plane);
- **(iii)** solely the broadband backhaul branch, especially in cases of failure (or non-existence) of the legacy branch.

As can be derived, particularly the last two options represent a nothing but trivial research matter. The realisation of the third option mandates **seamless integration and interoperability** of the BS with the CN, in a regime of complete absence of the legacy backhaul branch. This suggests that appropriate entities and functionalities must be placed at the boundary between the ISP and the Core networks, undertaking the responsibility of **mirroring** the CN signalling functions towards the BS, and vice versa. For illustration purposes, in Figure 1 and in Figure 2, an **Inter-operability Gateway** is assumed to undertake this role.

In general, options and approaches on how to efficiently achieve this seamless BS-to-CN connectivity on the control plane may constitute a significant part of future research efforts. Security aspects must be taken into careful consideration so as to specify relevant solutions. For instance, since traffic from the BS can potentially traverse through public IP networks, for security reasons Internet Protocol Security (IPSec) can be used for encryption. Furthermore, a fundamentally breakthrough feature is to preserve the proposed solution as **agnostic** to the particular Radio Access Technology (RAT) employed by the base station at the radio interface as possible, rendering it applicable to a wide range of wireless networking systems, both legacy and future. Additionally, by being agnostic of the particular RAT used at the radio interface, this approach suggests that seamless integration can be achieved between any type of connected base station and an evolved Core Network, such as the Evolved Packet Core (EPC), over the broadband backhaul access.

Of equally primary importance is the second transport option (option ii) regarding the control plane, as specified above. This actually represents the most generic case of all, in which the BS must not only be seamlessly interconnected to the CN, but must also optimally, continuously and dynamically **balance the signalling load** between the two available backhaul branches. This in turn calls for **intelligent** forwarding and balancing functionalities, as in the case of the user plane. Signalling functions that will be subject to study and investigation include mobility management, session and QoS management, and identity and security management.

As can also be deduced, the joint utilisation of the two branches, both on the user and the control plane, leverages **network resilience**, rendering the network infrastructure more robust and reliable against operational failures and load escalations. Balanced traffic distribution also allows for efficient exploitation of backhaul resources and leads to **enhanced service provisioning** and improved user experience, whereas the proposed self-organising functionality enables efficient network **O&M** at the BS level. Regarding the enhanced service provisioning, the proposed methodology is expected to have particularly positive impact to the delivery of resource-demanding services to the end-users, such as High-Definition (HD) and 3D **IPTV**.

The **direct expected impact and benefits** that the proposed architecture introduces can be summarised as follows:

- **Improved network and application performance:** The proposed evolved architecture is capable of significantly improving the delivery of mobile broadband applications to the end-users, thanks to its advanced and flexible backhauling functionality. This enhanced flexibility also provides the basis for efficiently **overcoming structural limitations** of the current architectures arising from an increasingly larger set of applications, of devices and edge networks to be supported. Thus, the proposed approach helps **support the emergence of Future Internet**, and also, in particular, allows for the provision of resource-intensive services and applications, with various and diverse QoS requirements, in an optimised manner.
- **Sustainable market growth:** The proposed evolved architecture introduces a cost-effective solution for expanding the capacity, flexibility and performance of the backhaul network part. At the BS level, the exploitation of existing wireline technologies, that are often readily deployed and available in urban

areas, is a viable evolution path that requires small Capital Expenditures (CAPEX). This facilitates not only enhanced QoS support, but also the introduction of improved and attractive pricing models for the end-users, lowering the Digital Exclusion barrier for users that are not able to enjoy broadband services on mobile, due to economic restrictions. This in turn is expected to leverage sustainable market growth of mobile broadband access and Future Internet.

- **Flexible and efficient network O&M:** The proposed self-organising functionalities at the BS reduce the workload for site survey and analysis of network performance, and can thus diminish Operational Expenditures (OPEX). This is aligned to the Self-Organising Network (SON) principles in vendor roadmaps and the 3GPP standardisation process.

3. MOTIVATION AND PATH THAT LED TO THE PROPOSED NETWORK ARCHITECTURE

By concentrating on cognitive and cost-efficient BS backhauling solutions, this paper's proposed approach can be considered as a significant architectural evolutionary step from various points of view.

The proposed approach as an evolutionary step inspired from EPS concepts and needs

In 3GPP Release 8, the standard does not enforce any physical architecture for EPC node implementation. For example, it may be possible that the Serving and Packet Data Network (PDN) Gateways are supported by a single node, or that the Mobility Management Entity (MME) and Serving Gateway are implemented in one physical node. These two options are described in Figure 3. This model shows the interface S1, which transports both signalling (the S1-C part) and User plane data (the S1-U part) between E-UTRAN and EPC. In other words, S1 is the interface at the **backhaul** part of the E-UTRAN.

Option (a) of the picture (where the MME and the Serving Gateway are combined) may be seen as a simpler solution to operate a Packet Core network, since it does not require implementing and operating the S11 signalling interface between the MME and Serving GW. However, implementing separate MME and User plane functions allows for further **flexibility** in terms of deployment, enabling **independent scalability** between the signalling load on the Control plane and traffic handling on the User plane. *The proposed cognitive, dual backhaul solution intends to **further expand** this scalability potential, by providing ground both for S1-C and S1-U traffic optimisation.*

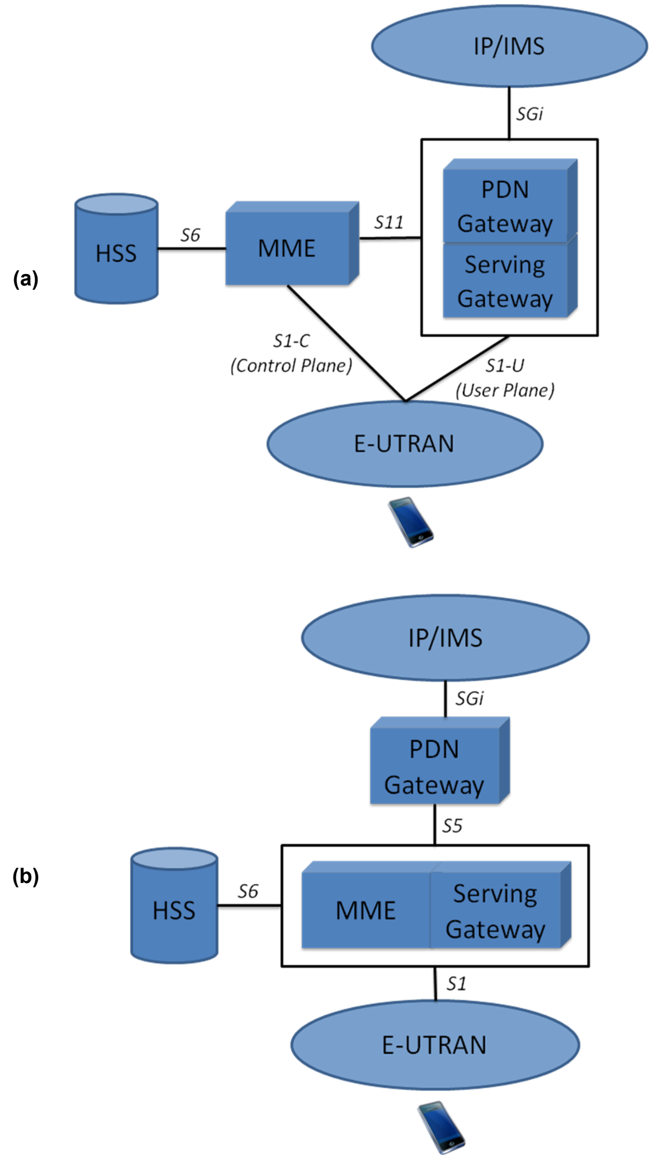

Figure 3. Different options for merged EPC physical node implementation – (a) Merging the two gateways; (b) Merging S1 Control and User planes

Furthermore, the 3GPP standard allows two modes of roaming. The default one is the 'home-routed traffic', a situation in which the home network still provides the access to external networks, possibly including IMS-based services (Figure 4(a)). The second one **('local breakout')** brings a great enhancement, since it allows the possibility of the user traffic to be routed via a visited PDN GW, as an optimisation (Figure 4(b)). This may be very beneficial in the example of public Internet access –as routing the traffic to the home network does not add any value to the end-user – and even more in the case of an IMS session established between a roaming user and a subscriber of the visited network. In the latter case, local traffic routing avoids a complete round trip of user data through the home network packet gateways. *The local breakout mechanism reveals the need to route the user data traffic to the IMS/Internet* ***as directly as possible****, a concept adopted and further evolved by this paper.*

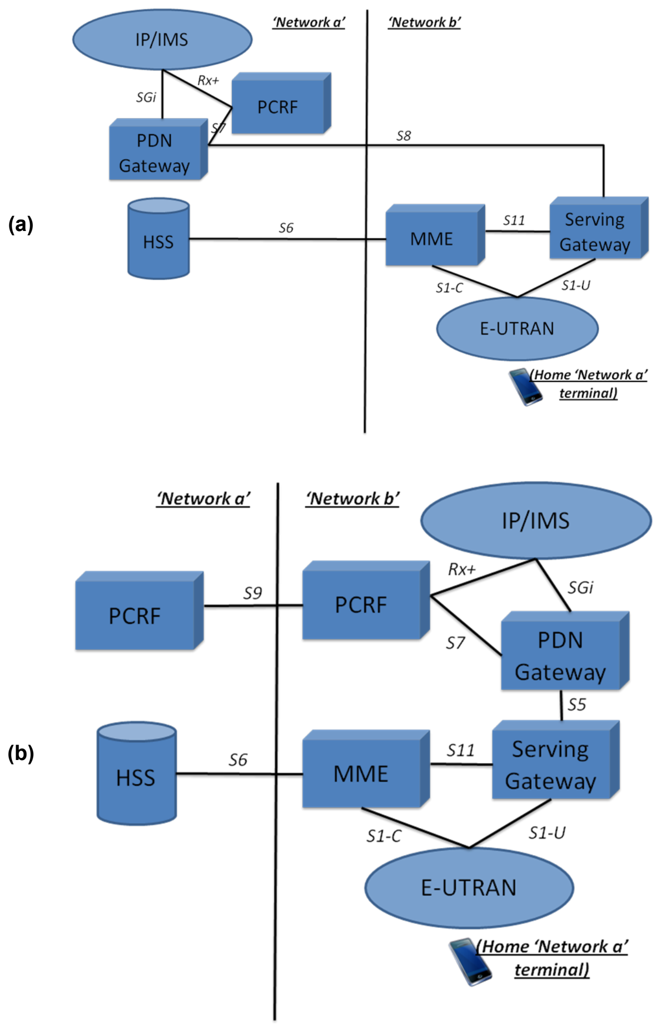

Figure 4. The EPC roaming architecture – (a) home-routed traffic; (b) local breakout

In traditional 2G and 3G cellular networks, the connectivity between the Core and the Access Network was defined as a one-to-multi hierarchical relationship: a Core Network node (either the Mobile Switching Centre (MSC) on the Circuit domain or the Serving GPRS Support Node (SGSN) in the Packet domain) serves a set of radio Controllers (the 2G BSC or the 3G RNC), and a given controller is only assigned to one Core Network node within a domain. In other words, each Core Network node is connected to its own set of radio Controllers, having no intersections with other sets.

In Release 5 of the 3G/UMTS standard, a new feature was introduced, allowing for more flexibility in the inter-connection between Access and Core nodes, breaking the usual network hierarchy. This feature has also been introduced from the beginning in the EPS standard and is known as **S1 flexibility** (Figure 5). Among others, S1 flexibility has some advantages as regards to capacity upgrade and network load management. Opening the possibility for an eNodeB to be connected to more than one MME allows **balancing and possibly redistributing** the load, by directing incoming terminal connection requests to less loaded Core Network nodes. *The concept of S1 flexibility reveals the need for additional robustness and load-balancing mechanisms in the backhaul part of current and future mobile networks.*

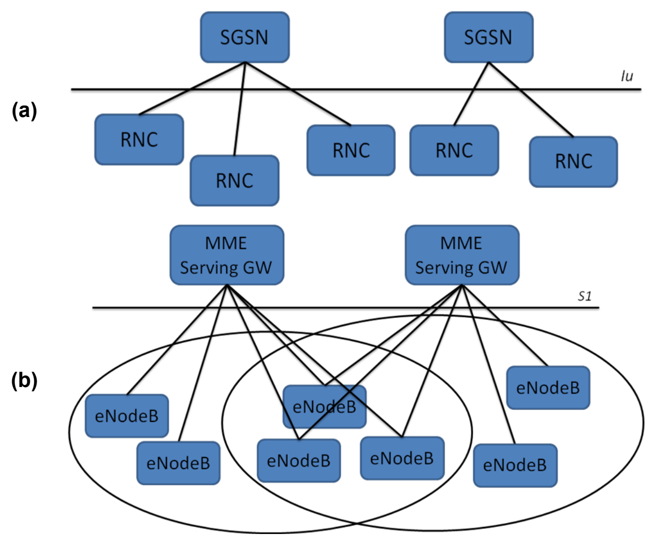

Figure 5. Traditional Access-Core connectivity and S1-flexibility – (a) The 1-to-n connectivity; (b) S1-flexibility

The proposed approach as an evolution to IP/MPLS and all-IP backhaul solutions

GSM Base Stations and 3G Node B's at cell sites have traditionally been connected to Base Station Controllers and Radio Network Controllers using a combination of PDH (Plesiochronous Digital Hierarchy) and SDH (Synchronous Digital Hierarchy). This has been responsible for **backhauling** network signalling and traffic using standard E1 TDM circuits or ATM virtual circuits. This approach has served mobile service providers well in the past, but the growth of mobile broadband traffic across HSPA networks, and the ever increasing requirement for bandwidth in the backhaul is now causing problems.

In the near term, service providers are employing hybrid solutions that include a mixture of PDH/SDH and IP/MPLS (Multi Protocol Label Switching). This means that some traffic, such as speech and signalling, is being backhauled using the PDH/SDH network, while other traffic such as HSDPA IP traffic is being backhauled using the IP/MPLS network. It is also worth noting that besides IP traffic, some voice and signalling is also being transported using IP/MPLS. Over time, a greater proportion of traffic is being backhauled using IP/MPLS, as network capacity increases and old equipment is being phased out.

Evolved technologies such as LTE and WiMAX are all-IP technologies, with signalling and traffic based on native IP. This means that IP extends from the eNodeB or WiMAX Base Station to the core network. ***This paper's proposed approach*** *paves the way for further evolution in the backhaul by expanding the all-IP backhaul to a novel, cognitive, dual backhauling solution.*

The proposed approach as an evolutionary step for mobile/fixed convergence

The proposed approach can be regarded as a convergence step between mobile/fixed architectures at the BS level. Broadband access can be considered as the driving enabler for the evolution of telecommunication networks. On the one hand, mobile broadband access has become a reality through the introduction and realisation of the 3G/HSPA roadmap, while the evolution towards LTE provides the ability to meet the need for even more bandwidth demanding applications. On the other hand, the introduction of xDSL (e.g., ADSL, VDSL) and xPON (e.g., EPON, GPON) have boosted fixed broadband access penetration, while the evolution towards Next Generation Access (NGA) architectures highlights the path towards continuously higher access rates that will become available to the user. In the area of services, the capability for broadband access enables the provision of advanced multimedia services becoming a driving force for the evolution of Internet towards the Future Internet.

In this environment, a clear trend is emerging in the form of **fixed and mobile** (telephony) **convergence (FMC)**. *Hence, it becomes reasonable to investigate and pursue the convergence of the two technologies at the BS level, on the ground that this joint utilisation can leverage network performance, flexibility and resilience.*

4. CONCLUSIONS

This paper discussed on a way for further evolution of mobile communication networks, following the principles of self-organization and increased cognition. More specifically, the paper has focused on the backhaul part of a next-generation network, which has received little research attention so far, proposing a dual backhaul solution at the wireless Base Station that takes advantage of a legacy backhaul branch (e.g., based on microwave technology) and a broadband wireline branch (based on xDSL or xPON technologies). The benefits of the proposed solution have been articulated, and the path and motivation leading to this new evolutionary step has been presented. The new proposed approach has the potential to offer increased robustness, scalability, flexibility, enhanced service provisioning, and reduced operational and maintenance costs.

Acknowledgment: This work has been performed under the Greek National project CONFES (2010 ΣΕ 01380022), which has received research funding from the Operational Programme "Competitiveness & Entrepreneurship" of the National Strategic Reference Framework NSRF 2007-2013.

REFERENCES

[1] Next Generation Mobile Networks Beyond HSPA & EVDO, A White Paper by the NGMN Alliance, Dec. 2006

[2] NGMN Optimised Backhaul Requirements, A Requirement Specification by the NGMN Alliance, Aug, 2008

[3] I. Panayotopoulos, K. Stamatis, K. Avgeropoulos, A. Valkanas, A. Maltsev, R. Maslennikov, A. Khoryaev, A. Lomayev, "Testbed for Wireless Mesh Backhaul Networks - MEMBRANE Demonstrator," ISWPC 2008, Santorini, Greece, 7-9 May 2008

[4] 3GPP TR 36.902, "Self-configuring and self-optimizing network use cases and solutions"

[5] Self Organizing Network "NEC's proposals for next-generation radio network management", White Paper, NEC Corporation, Feb. 2009

[6] P. Lescuyer and T. Lucidarme, Evolved Packet System (EPS), The LTE and SAE Evolution of 3G UMTS, John Wiley & Sons Ltd., 2008

[7] 23.401, "GPRS Enhancements for E-UTRAN Access"

[8] 23.402, "Architecture Enhancements for Non-3GPP Accesses"

[9] 36.300, "E-UTRAN Overall Description: Stage 2"

[10] 36.401, "E-UTRAN Architecture Description"