Issues and Solutions in Mobile WiMAX and Wired Backhaul Network Integration

Luca Valcarenghi*, ***Member, IEEE,*** **Paolo Monti**[+], ***Member, IEEE***, **Isabella Cerutti***, ***Member, IEEE***
Piero Castoldi*, ***Member, IEEE,*** **Lena Wosinska**[+], ***Member, IEEE***
**Scuola Superiore Sant'Anna, Pisa, Italy*
[+]*Royal Institute of Technology (KTH), Kista, Sweden*
e-mail: luca.valcarenghi@sssup.it

ABSTRACT
This paper surveys the issues in implementing a wired backhaul optical network that supports mobility of broadband wireless access network users. In particular, the focus is on the functionalities and the performance in terms of delay, throughput, and reliability that the backhaul network must guarantee.
Keywords: mobile WiMAX, EPON, optical network.

1. INTRODUCTION

The IEEE 802.16 (WiMAX) protocol was developed to provide fixed broadband wireless access to IP-based users [1]. The need for providing broadband wireless access not only to fixed (or nomadic) users but also to mobile users led to the standardization of Mobile IEEE 802.16e [2], [3], that defines the air interface between Mobile Stations (MS) and Base Stations (BS). The functionalities of the backhaul network to support mobility in WiMAX and the definition of the Mobile WiMAX End-to-End Network Architecture are beyond the scope of the family of IEEE 802.16 standards. These issues are considered by the WiMAX Forum, an industry-led non-profit organization built with the aim of promoting and certifying interoperable WiMAX products. To achieve this goal, in 2005, the WiMAX Forum established the Network Working Group (NWG) that is working towards the specification of the architecture and of the interfaces for an End-to-End all-IP WiMAX Network [4].

The straightforward choice for supporting upper-layer mobility in Mobile WiMAX is MobileIPv4 (MIPv4) (and currently MobileIPv6 – MIPv6) [5], [6]. While the WiMAX Forum focuses on the architectural definition and the product compatibility, an IETF working group on "IP over IEEE 802.16 Networks" (16ng) [7] has been created with the purpose of investigating WiMAX and IP networking integration.

Nevertheless, in this scenario, the issue of which transport network must support the end-to-end all-IP WiMAX architecture is still open. Given the potential high-rate of WiMAX wireless interfaces (up to tens of Mb/s per user for distances above 1 km) [8], optical networks appear to be the most suitable solution for backhauling the end-to-end all-IP WiMAX Network [9]. Indeed, a number of architectural solutions currently proposed foresee the integration of Passive Optical Network (PON) and Optical Metropolitan Area Network with WiMAX broadband access. However few of them analyze the proposed solutions from the viewpoint of efficiently supporting Mobile WiMAX. For example, how they support handover related communication and guarantee Quality of Service (QoS) to mobile users.

This paper presents some of the issues that must be addressed while implementing an optical backhaul network for supporting fast-moving mobile WiMAX users. Special attention is focused on how the optical backhaul can meet the delay, throughput and reliability constraints required for supporting Mobile WiMAX.

2. END-TO-END ALL-IP WiMAX NETWORK

This section briefly outlines the end-to-end all-IP WiMAX network as defined in [4] and the functionalities supported by MIPv6 [5][6]. *Figure 1* shows one example of an end-to-end all-IP WiMAX network defined by the WiMAX Forum NWG. In this case the Mobile Station (MS) (i.e., the user equipped with an 802.16e network interface card – NIC) can roam between different Access Service Networks (ASNs) belonging to the same Network Access Provider (NAP) while its home agent resides in the Connectivity Service Network (CSN) of the Home Network Service Provider (NSP). ASN comprises network elements such as one or more Base Station(s) (BS) and one or more ASN Gateway(s) (ASN-GW). The ASN is responsible of providing the MSs with radio access, layer-2 connectivity, and relay functionality for establishing Layer-3 connectivity [10]. The NAP "is a business entity that provides WiMAX radio access infrastructure to one or more WiMAX Network Service Providers (NSPs)". A Home NSP is the business entity that supports roaming services of the WiMAX subscribers with which it has Service Level Agreements. The Home NSP may also have roaming relationships with other (visited) NSPs. The CSN provides IP connectivity services to the MSs. Some functionalities offered by CSN are Internet Access, Authentication Authorization, and Accounting (AAA), ASN-CSN tunnelling support, Inter-CSN tunnelling for roaming, and Inter-ASN mobility. Network Elements belonging to the CSN are routers, AAA proxy/servers, user databases, Interworking gateway, MSs. A CSN may be deployed anew by

978-1-4244-4826-5/09/$25.00 ©2009 IEEE

a Greenfield WiMAX NSP or it can be part of an incumbent WiMAX NSP sharing the network with other services (e.g., quadruple-play).

The functional architecture of MIPv6 to support MS mobility is displayed in *Figure 2*. To be ensured IP-connectivity when moving, the MS is assigned a Care of Address (CoA) by the ASN Gateway (ASN-GW) responsible of the BS to which the MS is currently connected. The CoA is registered in the Home Agent's (HA) Binding Cache (BC) that maps the MS Home Address (HoA) (i.e., the MS address in its Home-CSN) to the current CoA. In this way, a Correspondent Node (CN) located in another network can communicate with the MS by sending IP packets addressed to the MS HoA. Packets are received by the HA that, in turn, forwards them to the MS CoA, through IP tunnelling. Similarly, the MS can communicate with the CN by tunnelling packets through the HA that then forwards them to the CN (i.e., *reverse tunnelling*). Other optimized route communications can be implemented where the MS communicates directly with the CN and the CN communicates directly with the MS (i.e., *Route Optimization*). The MS may roam between different BSs but also between different ASNs. When the MS roams between two BSs that are connected to the same ASN Gateway (ASN-GW) (i.e., when they belong to the same sub-network to which the ASN-GW belongs), MIPv6 leverage the Layer-2 mobility functions provided by the ASN to support user mobility. In this case the MS does not need to change its IP Care of Address (CoA) and, thus, Layer 3 operations are not utilized. On the other hand, when the MS roams between BSs belonging to different sub-networks (i.e., connected to a different ASN-GW), a new CoA is assigned and a binding cache update is triggered. The binding cache update allows to change the entry CoA-HoA in the HA binding cache [6].

In the case of a fast moving MS, the binding update procedure is triggered frequently. To reduce the high signaling overhead, a solution, called *Hierarchical Mobile IPv6* (HMIPv6) [11], has been proposed by IETF. With the HMIPv6 protocol, a mobility anchor point (MAP) is introduced to act as a proxy of the HA. The MAP is used to handle, in a localized manner, binding update (BU) exchange procedures when the handoffs are within the same MAP domain. According to the HMIPv6 protocol, the MS configures two CoA: a regional Care of Address (RCoA), i.e., the MS address in the MAP subnet, and a Link Care of Address (LCoA) i.e., a local CoA for the MS interface. The MAP acts as a local HA. It receives all packets on behalf of the MS and it re-tunnels them to the MS current address. If the MS changes its current address within a local MAP domain, it only needs to register the new LCoA with the MAP. The RCoA does not change as long as the MS moves within the same MAP domain. This makes the MS mobility transparent to the CNs and the HA and it reduces both latency and signaling overhead. The aforementioned procedures are typical of MIPv6 and HMIPv6, but can be mapped to the WiMAX ASN-anchored mobility and CSN-anchored mobility [4].

In both architectural scenario (i.e., hierarchical and not), a backhaul network connects the ASN gateways bith among themselves and to the NSP that, in turn, provides connectivity services to the public internet network. Such backhaul network needs to efficiently support all the messages exchanged between the functional entities, as well as the data communications taking place between the MSs and the CN. To support the required Quality of Service (QoS) (e.g., high-bandwidth requirements) and to facilitate the interconnection with public internet network, backhaul networks based on optical technology are preferred but they call for an efficient wireless-wired integration.

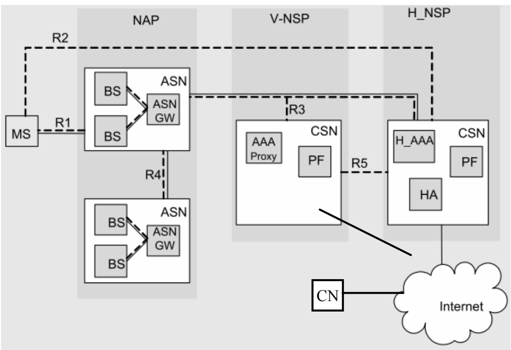

Figure 1. End-to-end all-IP WiMAX network architecture.

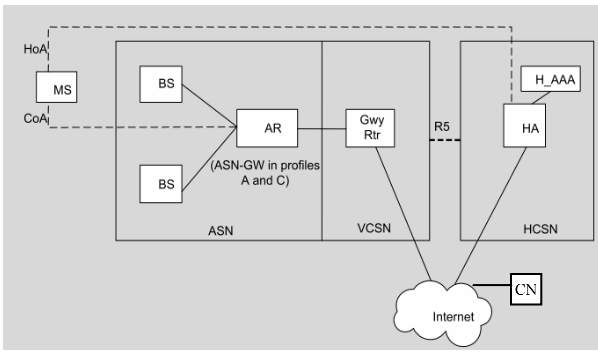

Figure 2. Functional architecture of MIPv6 [4].

3. ISSUES IN SUPPORTING MOBILITY AND QoS IN INTEGRATED WiMAX AND OPTICAL NETWORKS

The integration of wireless and optical networks has recently attracted the interest of many researchers and a number of different solutions have been proposed in literature [12]-[16]. The proposed solutions can be divided in two main categories: the ones that interface the wireless and the optical networks at the *physical level* (i.e., radio-over-fiber) by transporting the wireless signal through an optical carrier and the ones interfacing the two network segments at the *packet level* by receiving and retransmitting the data packets based on the protocol utilized in the two segments. Most of the studies related to the former category have addressed physical layer issues, such as modulation and coding techniques [14][15]. The studies belonging to the latter category have addressed the issue of designing packet-level interfaces between different wireless and optical technologies. In addition they also developed methods to interface MAC and network layer access and control protocols, that were independently developed in the two network segments [12][13] [15][16].

While physical level integration could be suitable for connecting BS to one or more ASN-GWs, to ensure all-IP connectivity to the MSs, packet level integration is required at the ASN. In addition, packet level integration must guarantee the requested level of throughput, QoS, reliability, and latency for the data and signalling transmissions towards and from the MSs. These requirements along with the high-mobility of MS impose some challenges to the architectural design that the HMIPv6 is potentially capable to address.

Minimizing *latency* during handover message exchange is of paramount importance and, in HMIPv6, it is affected by the MAP placement and selection. Especially in a large-scale network, multiple MAPs may be used to provide scalable and robust mobile IP services. In the HMIPv6 specifications [11], two MAP selection schemes are suggested. The first one is a distance-based selection scheme, where an MS chooses the farthest MAP. This scheme is particularly efficient for fast moving MSs performing frequent handovers but may not be an appropriate solution for some MSs (e.g., slowly moving MSs). In addition the most distant MAP may also become the bottleneck, causing longer processing latency. The second scheme in [11] suggests to announce MAP information (e.g., traffic load on the MAP) as part of the process, so that an MS can choose a MAP by considering its mobility characteristics and MAP current state. In addition to the above approaches, mobility-based MAP selection schemes are proposed in [17][18][19][20]. In these schemes, an MS selects its MAP based on its mobility (a fast MS selects a remote MAP, while slow MSs chooses a close MAP). Another adaptive MAP selection scheme, where an MS selects the serving MAP by estimating also its IP session characteristics (e.g., amount of traffic and session arrival frequency), was proposed in [21].

The MAP selection solutions presented above focus mainly on the latency offered by the wireless access segment. However, the optimal placement and the effect of the distribution of the MAP functionality within the overall backhaul integrated network are not considered. MAPs, although excellent in handling micro mobility, slow down the service times in the user traffic domain. This is due to both the creation of the forwarding paths (to/from the MS), and encapsulations (a MAP has to unpack the packets from one tunnel and to put them into another tunnel). This is a critical drawback in terms of the user traffic delay requirements. Network operators need to balance both handover latency and *user traffic delay*. A study in this direction is presented in [22] where a mathematical method for selecting the optimal number and the placement of MAPs supporting micro mobility functionality for telecommunication networks was proposed.

Another important aspect to consider, when looking at the end-to-end all-IP WiMAX network, is *reliability*. The choice of one MAP over another may impact differently end-to-end connections. One MAP selection approach, although efficient in reducing the signaling overhead, may not be the best choice in terms of reliability (e.g., the farther the MAP from the MS, the worse the reliability of the connection). In addition the communication between the CN and the MS may require some degree of diversity (e.g., node, SRLG), thus requiring the MS to be connected to more that one MAP, one for each disjoint end-to-end path. In turns, this impacts the way MAP should be placed in the optical backhaul network. However the MAP selection and the MAP placement schemes proposed so far, do not consider network reliability as part their objectives.

Additional work is needed in order to study and combine all these aspects into one single framework. In particular, the available MAP selection schemes need to be evaluated in terms of (fixed) network reliability. Also, the trade off between reliability and signalling/tunnelling overhead needs to be assessed. In addition, reliability should be considered as an objective to be maximized by the algorithms for MAP placement in the optical network backhaul segment.

4. CONCLUSIONS

In this study some challenges in providing a wired network backhaul to Mobile WiMAX have been outlined. GMPLS-based optical networks appear as the most promising candidate for providing such backhaul services because of their bandwidth and their flexibility but several issues in integrating Mobile WiMAX and optical networks to build an end-to-ed all-IP WiMAX Network must be addressed. In particular Mobile IPv6 (MIPv6) or Hierarchical Mobile IPv6 (MIPv6) functionalities must be supported while minimizing handover message delay, user traffic delay, and reliability.

ACKNOWLEDGEMENTS

The work described in this paper was partially carried out with the support of the BONE-project ("Building the Future Optical Network in Europe"), a Network of Excellence funded by the European Commission through the 7th ICT-Framework Programme.

REFERENCES

[1] IEEE Std 802.16-2004, "IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems", Oct. 1, 2004.

[2] IEEE Std 802.16e, "IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems; Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands; and Corrigendum 1", Feb. 28, 2006.

[3] H. K. Sabat, "The evolving mobile wireless value chain and market structure", *Telecommunications Policy*, vol. 26, no. 9-10, Oct./Nov. 2002, pp. 505-535

[4] WiMAX Forum End-to-End Network Systems Architecture Stage 2–3, Release 1.0.0, March 2007 (http://www.wimaxforum.org/resources/documents/technical/release1) [accessed on May 1, 2009].

[5] D. Johnson, C. Perkins, and J. Arkko, RFC 3775, "Mobility Support in IPv6", Jun. 2004.

[6] R. J. Koodli and C. E. Perkins, "*Mobile Inter-Networking with IPv6: Concepts, Principles, and Practice*", John Wiley & Sons, 2007.

[7] IP over IEEE 802.16 Networks (16ng) WG, http://www.ietf.org/html.charters/16ng-charter.html

[8] I. Koffman, V. Roman, "Broadband wireless access solutions based on OFDM access in IEEE 802.16", *IEEE Communications Magazine*, vol. 40, no. 4, Apr. 2002, pp. 96 – 103.

[9] I. Cerutti, L. Valcarenghi, P. Castoldi, D. Marabissi, F. Meucci, L. Pierucci, E. Del Re, L. S. Ronga, R. Tka, F. Kamoun, "IEEE 802.16: Enhanced Modes of Operation and Integration with Wired MANs", chapter in *Current Technology Developments of WiMax Systems*, Ma Maode (Ed.), pp. 265-300, Springer, Jan. 2009.

[10] "WiMAX Forum Network Architecture (Stage 2: Architecture Tenets, Reference Model and Reference Points) [Part 1] – NWG_R1_V1-2-Stage-2-Part 1", Release 1, Version 1.2, Jan. 11, 2008.

[11] H. Soliman, C. Castelluccia, K.E. Malki, L. Bellier, "Hierarchical Mobile IPv6 Mobility Management (HMIPv6)", IETF RFC 4140, Aug. 2005.

[12] G. Shen, R.S., Tucker, C.-J. Chae; "Fixed mobile convergence architectures for broadband access: Integration of EPON and WiMAX**"**, *IEEE Communications Magazine*, vol. 45, no. 8, Aug. 2007, pp. 44-50.

[13] W.-T. Shaw, S.-W. Wong, N. C., L. G. Kazovsky,. "MARIN Hybrid Optical-Wireless Access Network"**,** *in Proc. OFC/NFOEC 2007*, 25-29 March 2007, pp 1 – 3.

[14] T. Ismail, C.-P. Liu, J. E. Mitchell, A. J. Seeds, "High-dynamic-range wireless-over-fiber link using feedforward linearization", *IEEE/OSA JLT*, vol. 25, no. 11, Nov. 2007.

[15] S. Sarkar, S. Dixit, and B. Mukherjee, "Hybrid wireless-optical broadband-access network (WOBAN): A review of relevant challenger", *IEEE/OSA JLT*, vol. 25, no. 11, Nov. 2007.

[16] L. G. Kazovsky, W.-T. Shaw, D. Gutierrez, N. Cheng, and S.-W. Wong, "Next-generation optical access networks", *IEEE/OSA JLT*, vol. 25, no. 11, Nov. 2007.

[17] K. Kawano, K. Kinoshita, K. Murakami, "Multilevel hierarchical distributed IP mobility management scheme for wide area networks", in *Proc. IEEE ICCCN 2002*, Oct. 2002.

[18] K. Kawano, K. Kinoshita, K. Murakami, "A mobility-based terminal management in IPv6 networks", *IEICE Transactions on Communications* E85-B (10) (2002) 2099.

[19] Y. Xu, H.C.J. Lee, V.L.L. Thing, "A Local mobility agent selection algorithm for mobile networks", in *Proc IEEE ICC 2003*, May 2003.

[20] V. Thing, H. Lee, Y. Xu, "Designs and analysis of local mobility agents discovery, selection and failure detection for mobile IPv6", in *Proc. IEEE MWCN 2002*, Sept. 2002.

[21] S. Pack, M. Nam, T. Kwon, Y. Choi, "An adaptive mobility anchor point selection scheme in hierarchical mobile IPv6 networks", *Computer Communications*, vol. 29, no. 16, pp. 3066-3078, 2006.

[22] L. Florian, B. René, M.-T. Andreas, "Optimal placement of anchor points within large telecommunication networks", in *Proc. 4th international conference, WWIC 2006*, Bern, Switzerland, May 10-12, 2006.