Backhauling Wireless Broadband Traffic over an Optical Aggregation Network: WiMAX over OBS

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Abstract—**This paper focuses on next generation ubiquitous networks supporting the Future Internet. In this context, it proposes an architecture and an integration framework of wireless and wired network technologies supporting a variety of services with differing service requirements. More specifically the integration of WiMAX wireless broadband access network with an aggregation metro network solution based on Optical Burst Switching (OBS) is discussed and analyzed. A proof-of-concept simulation model realizing the proposed scheme and some preliminary results are also presented.**

Wired/Wireless Integration; Optical-Wireless; Wireless Broadband; WiMAX; Optical Burst Switching; Access Networks; Broadband Networks

I. INTRODUCTION

The traffic carried by telecommunications networks has grown enormously over the past few years. This is mainly because of increased data and IP traffic, specifically traffic generated by emerging applications such as e-science, e-business, e-learning, e-health and e-government, as well as business services (such as IP VPN, VoIP and IP videoconference) and residential services (such as triple play and IPTV). It is also almost certain that this traffic growth will continue both in the near future and in the longer term, through the availability of numerous new services to the end user, with demanding requirements in terms of network accessibility, capacity, functionality and interoperability between different network segments and domains. These requirements are being addressed through the development and deployment of new wired and wireless network technologies. However, the need for service creation and continuity across composite network technologies, and also ubiquitous access not only from any network, but from any technological or administrative domain, introduces the immediate need for convergence at the service-level between network segments employing distinct technologies.

Emerging wired broadband access technologies such as VDSL (Very High Speed Digital Subscriber Line) and Passive Optical Networks (PONs) are able of provisionally or in the long term sustain the growth in traffic requirements in the access segment. However, there are specific deployment scenarios that render wireless broadband access solutions more competitive in terms of capitalization and operational expenses compared to wired counterparts. This is for example the case where deploying a wired access network infrastructure maybe too costly or for various reasons undesirable. In addition there may be cases requiring provisioning of high-rate access to sparsely populated areas or in regions with relatively under-developed networking infrastructure. It is also straightforward that specific network access patterns, namely nomadicity [1] and mobility, and at high data rates can be only achieved through wireless broadband. Obviously, this emerging increase in capacity in the access segment has to occur in accordance with a growth of the capacity in the metro/core segment, currently addressed through technologies such as Long-Reach PONs [2].

Motivated by the points above, this paper focuses on the seamless integration of two technologies that exhibit the potential of constituting integral parts of the architecture of the Future Internet supporting convergence of wired and wireless network segments at the service level. These are a wireless broadband access technology and more specifically WiMAX [3] integrated with an aggregation metro network solution based on Optical Burst Switching (OBS). In this context, we propose a sample architecture employing this composite network solution and elaborate in various issues that need to be addressed for such an integrated approach to meet service-level requirements. Beyond architectural specification, we implemented a proof-of-concept simulation model realizing the proposed scheme. Using this simulation model, we present preliminary results on the benefit of matching standard WiMAX service class specifications with service differentiation in OBS burst assembly.

II. WIRELESS BROADBAND-OPTICAL METRO INTEGRATION

A. *Related Work*

To the best of our knowledge, the aggregation of WiMAX service flows using a sub-wavelength optical transport like OBS has not been studied in detail before. Instead, prior work [4] has mainly focused on integrating wireless access technologies with PON standards (e.g. EPON, GPON). The WOBAN (Wireless Optical Broadband Access Architecture) [5] architecture proposed the use of PON ONUs (Optical Network Units) as the transport mechanism of Wi-Fi or WiMAX traffic towards the core of the network. Various issues that arise in the context of this integration scheme have been identified and discussed, while also presenting and evaluating ONU placement algorithms. Assuming a similar architecture, [6] elaborates in scheduling of service flows traversing wireless

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access (WiMAX, Wi-Fi or UMTS) and PON networks and evaluates its effect to Quality of Service (QoS). Beyond the hierarchical separation between wireless and optical access technologies, Wang et al. [7][8] proposed a hybrid access network architecture comprising PON and WiMAX infrastructure, whereby an integrated metro/core node poses functionality of aggregating traffic from both access technologies. Specifically to using OBS in the metro/core segment for backhauling wireless access traffic, [10] has evaluated the impact of data unit drops in a 802.11 WLAN over OBS scenario to the throughput of TCP flows.

B. Proposed Architecture

Fig. 1 illustrates the architecture of an integrated WiMAX/OBS network, whereby WiMAX broadband is transported over OBS to/from the core network. For the sake of simplicity, WiMAX Base Stations (BS) have been placed in the center of each cell, although this is one of the various placement options. Each BS connects via PMP (Point-to-Multipoint) wireless connections to various Subscriber Stations (SS), while a wired physical connection (e.g. Fast Ethernet) is used to connect each BS to one or more OBS Edge Routers. In turn, OBS Edge Routers aggregate traffic incoming from adjacent BSs and/or legacy access networks (e.g. xDSL) via supported interfaces (e.g. PPP or Ethernet), create bursts comprising multiple IP packets and forward them through the OBS metro network towards the core following conventional OBS routing mechanisms. The same process is followed in inverted order for traffic that is incoming from the core towards WiMAX Subscriber Stations.

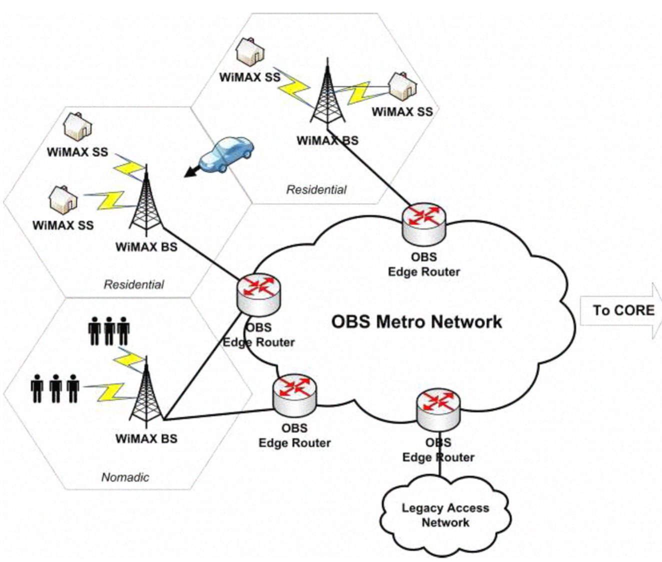

Figure 1. Architectural Diagram for using OBS as metro transport for WiMAX access

III. Convergence Issues

Despite the proposed architecture being rather straightforward, there are still various critical issues that need to be resolved towards a carrier grade converged WiMAX over OBS access/metro network that is able of satisfying the - potentially disparate - service requirements posed by WiMAX users. In this section we identify and discuss relevant issues. Without neglecting the importance of satisfying end-to-end service requirements, we limit the discussion to the WiMAX and OBS segments and we leave out of the scope of this paper other network segments that a service may traverse.

A. Integrated QoS Support

Meeting the QoS requirements of a service that is either initiated or terminated from/at a WiMAX SS requires orchestrated admission control and reservation of resources along both the WiMAX and the OBS network. Essentially, this requires matching of the QoS service-flow parameters defined in the Convergence Sublayer (CS) of the WiMAX MAC (Medium Access Control) with the parameters of the QoS classes available at each OBS Edge Router.

Due to the inherently different "perception of a flow" between a WiMAX BS and an OBS Edge Router – the former can apply QoS on a per-service basis, while the latter applies QoS to multiple services sharing the same QoS class and destination. Due to this "conventional" class-based burst forwarding may not be sufficient, especially if highly-granular QoS provisioning is a requirement. To overcome this, extensions to existing OBS schemes [10][11] could be applied to realize reservation of resources (e.g. bandwidth reservation or guaranteed maximum delay) on a per service basis, closely matching the QoS level requested by a service when entering the WiMAX MAC Convergence Sublayer (CS). In addition to this, all the above end-to-end QoS provisioning (from the requesting SS up to the egress OBS Edge Router that leads to the core) should be transparent to the user and be realized only through well-defined protocol interfaces and real-time optimization of resources between a WiMAX BS and its neighboring OBS Edge Router.

Bandwidth reservation should be fundamental in this QoS matching process, guaranteeing per service throughput not only in isolated network segments but across the boundaries of WiMAX and OBS. Having service flows in the OBS part receive available bandwidth without any reservation capability and thus without guarantees may significantly limit the benefit of MAC-level QoS differentiation applied in the WiMAX part (through bandwidth reservation in the uplink/downlink and adaptive frame times/duplexing both in the uplink/downlink). Similarly, delay and delay variation guarantees should be provided and enforced cooperatively across segment boundaries, e.g. by matching the MAC scheduling mechanism used for a service flow with the burst-assembly/optical channel scheduling mechanisms applied to the bursts formed to carry the frames of the service flow in the OBS metro part.

B. Service Continuity and Mobility

The cooperation between WiMAX edge nodes with OBS edge nodes implies the creation and maintenance of per-service state for traffic classification and mapping, especially for non-best-effort services. Even if OBS does not apply traffic handling on a per-service basis but instead applies some type of aggregation to reduce state requirements, the issue of newly reserving state at OBS Edge Routers as an SS moves

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between adjacent WiMAX cells that are served by distinct OBS Edge Routers remains. This situation is depicted in Fig. 1 through a mobile user (represented by a moving car) crossing the border of two adjacent WiMAX cells served by distinct OBS Edge Routers.

An obvious solution to this issue would be to extend the WiMAX handover mechanism, such for a handover not only to shift state between Base Stations, but also to ensure that resources are automatically reserved (respectively released) at OBS Edge Routers as the service moves and respectively switches between edge routers.

Another approach to ensure service continuity would be to reduce the need for switching between OBS Edge Routers as SS's move between adjacent cells through appropriate network planning and dimensioning measures. Specifically, given a Base Station X and the set S of all BS's serving cells adjacent to the cell served by X, the need for handover support in the OBS domain vanishes, if all BS's in $S \cup X$ are served by the same OBS Edge Router. It is straightforward that if such an approach is followed, OBS metro routers should be dimensioned accordingly to be able to sustain traffic from multiple cells. On the other hand, it is obvious that this scheme is less dependable, since the failure of a single OBS Edge Router would lead to the disconnection of a larger number of cells. In any case, the cost of cooperative WiMAX/OBS handover and its impact to user satisfaction on the one hand and the mitigation of the need for cooperative handover through careful planning on the other creates interesting techno-economic trade-offs that remain to be resolved.

C. *Nomadicity and Load-Balancing*

Nomadic access patterns may in some cases be bursty in nature, requiring a large number of users to be served via a WiMAX cell for a short period of time (e.g. serving a crowd attending a concert). In this case, dedicating a properly dimensioned OBS Edge Router to the respective BS('s) would be very inefficient, given the low utilization ratio of the resource invested. Instead, using ad-hoc load-balancing mechanisms between WiMAX and OBS seems economically more attractive, albeit requiring extensions to carry out real-time load monitoring and balancing between adjacent OBS Edge Routers.

IV. SIMULATION STUDY

A. *Simulation Setup*

As a first proof-of-concept approach, but also to quantitatively evaluate performance issues, we have implemented a simulation model of an OBS Edge Router employing the JET (Just-Enough-Time) [12] reservation scheme in the OPNET Modeler [13] simulation framework and integrated it with the standard WiMAX models available in Modeler. Fig. 2 depicts the topology of the simulation scenario, which essentially intends to showcase and evaluate end-to-end communication over the WiMAX/OBS network. For the purpose of focusing on the edge part of the integrated architecture, our simulation scenario employs a certain level of abstraction. More precisely, the OBS network is abstracted by a single optical link, assuming a lightly loaded OBS networks without burst losses or delay variation due to delayed reservations. Also, the core part of the network, as well as the metro/access part of the P2P client and eastbound IP Phone are abstracted by single serial links. Last, for the purpose of evaluating only the contribution of WiMAX and OBS-Edge delay to total end-to-end application delay, the delay of all wired links shown in Fig. 2 are virtually set to zero. Table 1 lists the values assigned to main parameters of the simulation experiment.

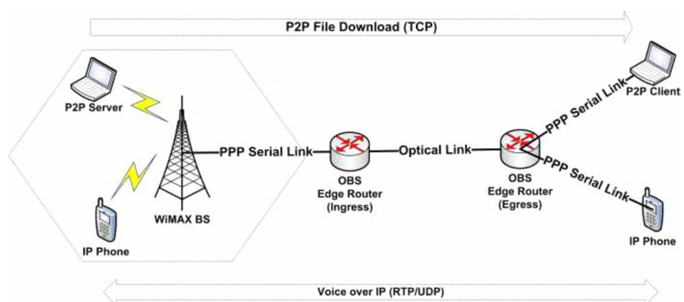

Figure 2. Simulation Topology

TABLE I. SIMULATION PARAMETERS

Parameter Name	*Parameter Value*
Reservation Scheme (OBS)	JET
Burst Assembly (OBS)	Time-based
Offset Time (OBS)	1.8E-6s
Channel Scheduling (OBS)	Longest Queue First
PHY Profile (WiMAX)	OFDMA (20MHz)
Frame Duration (WiMAX)	2.5ms
Symbol Duration (WiMAX)	102.86μs
Duplexing Mode (WiMAX)	TDD
Modulation (WiMAX)	QPSK 1/2
Optical Link Rate	2.5Gbps
PPP Serial Link Rate	OC-3

Using this simulation setting, we initiate a VoIP call (RTP over UDP) between the two IP Phones; also, we initiate a large

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file download from the Peer-to-Peer Server (P2P) residing in the WiMAX network to the P2P Client. In the WiMAX segment, each of the two service flows (VoIP and P2P) are assigned two distinct service parameter specification sets. The two sets differ mainly in the scheduling scheme used (UGS vs. Best-Effort for VoIP and P2P respectively), as well as in the value assigned to the maximum latency field.

B. Simulation Results

Fig. 3 shows the average WiMAX delay experience by the two Subscriber Stations over time. Evidently, the IP Phone experienced on average three times less delay than the P2P station due to the service differentiation applied in the WiMAX segment.

To maintain service differentiation in the metro part, where the contribution to end-to-end delay is higher compared to the WiMAX access, we applied class-based burst assembly to the two flows as they traverse the westbound OBS Edge Router, using timer values of 10ms and 25ms for VoIP and P2P respectively. Fig. 4 shows average end-to-end delay over time for the two applications, showcasing that orchestrated service differentiation between WiMAX and OBS is required to maintain traffic priority, while not wasting network resources.

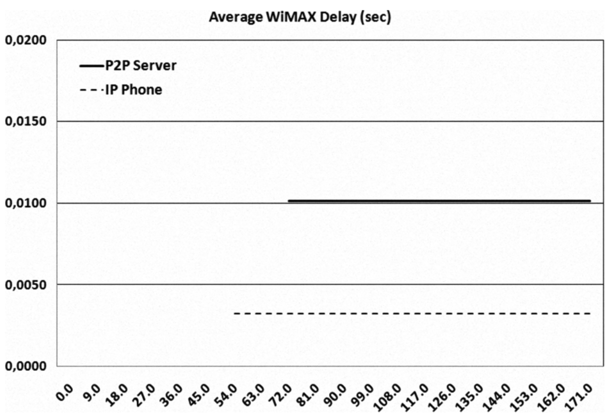

Figure 3. Average Delay experienced by WiMAX Frames over time

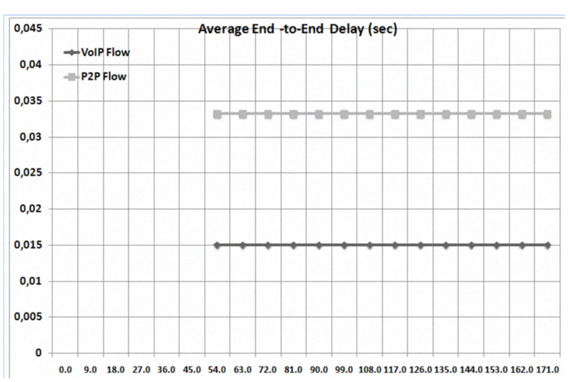

Figure 4. Average End to End Delay for each of the two service flows

V. Conclusions

Given the unfolding migration towards a service-centric Future Internet, the convergence of emerging wireless broadband technologies with hierarchically higher network segments needs to be seen from a service-level perspective. This paper discussed various issues associated with the service-level convergence of WiMAX over a sub-wavelength routing capable optical aggregation network. A first proof-of-principle simulation prototype showing viability of the proposed architecture has been implemented. Preliminary results show that inter-segment cooperation at the service-layer and below is required to satisfy end-to-end service requirements.

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