

HOWRAN: An Hybrid Optical Wireless Radio Access Network for WiMAX Antennas Backhauling

Maurice Gagnaire and Tony Youssef*

Telecom ParisTech (ENST), Institut Telecom,
46 rue Barrault, 75013 Paris, France
{maurice.gagnaire, tony.youssef}@telecom-paristech.fr

Abstract. In comparison to existing 3G or 3G+ wireless systems, fourth generation (4G), long-term evolution (LTE) or mobile Wimax are characterized by higher bit rates, highly fluctuant traffic matrices and higher antenna's density. Current backhauling techniques federating radio antennas are not suited to these new characteristics. Several investigations are carried out for the design of new generation radio access networks (NG-RAN) in charge of concentrating radio cellular traffic from the base stations to the core network. In this paper, we propose an original approach based on an Hybrid Optical Wireless Radio Access Network (HOWRAN) exploiting the benefits of radio-over-fiber technologies and of recent advances in the field of optical devices and systems. As an illustration, we apply the HOWRAN concept to the backhauling of fixed or mobile WiMAX base stations. The two main innovative aspects of HOWRAN are depicted: its hardware architecture and its control plane.

Keywords: New Generation RAN (NG-RAN), Radio-over-Fiber (RoF), SCM, reflective modulator, control plane, radio cell planning, WiMAX, AWG, VCSEL.

1 Introduction

In this paper, we propose another innovative RAN architecture that relies on Radio-over-Fiber (RoF) technology. The basic principle of RoF is to transport modulated millimeter radio frequencies via an optical carrier onto an optical fiber. In the context of broadband wireless communications, the main advantage of RoF is to enable a mutualization of the radio equipment traditionally installed close to each antenna by allowing their co-location at a remote site (for instance at Node-B in UMTS). In existing wireless systems (GSM, GPRS, UMTS), two local oscillators need to be installed at each BS, one for building the radio multiplex at an intermediate frequency (IF) and another one for shifting

* This work has been carried out in the context of the Work Package WP13 of the BONE European network of excellence. The HOWRAN architecture and control plane are under the process of a patent.

this multiplex at the radio frequency (RF). Various modulation techniques can be adopted for RoF. The simplest one consists in using the internal modulation of a laser diode by means of an RF signal. In that case, it is possible to remove all the signaling and data processing equipment usually installed at the BSs to the RNC.

This paper is organized as follows. In Section 2, we recall the main characteristics of the WiMAX technology. We then describe in Section 3 the global HOWRAN architecture. A detailed analysis of the hardware architecture of the HOWRAN head-end node is presented in Section 4. The optical network units of an HOWRAN system are qualified of hybrid since they deal with radio-frequency and optical modulation/demodulation. The hardware architecture of an Hybrid Optical Network Unit (HONU) is depicted in Section 5. In Section 6, we discuss the rationale of the HOWRAN control plane. In Section 7, we outline through simple examples how practically an HOWRAN system can be used to facilitate Wimax cell planning.

2 WiMAX Basics

These recent years, several commercial implementations of fixed WiMAX (Worldwide Interoperability for Microwave Access) cellular systems (also known as the IEEE 802.16d standard) have been proposed by the carriers. As mentioned in our introduction, WiMAX is a non-line-of-site wireless (NLOS) system based on Orthogonal Frequency Division Multiplexing Access (OFDMA). Figure 1 depicts the frequency bands reserved for either licensed or unlicensed WiMAX systems. Today, fixed WiMAX uses in Europe either the 3.5 GHz licensed band or the 5.8 GHz unlicensed band. According to the WiMAX Forum [8], the 2.5 GHz band is today proposed in many countries for fixed broadband wireless under licensed WiMAX. In the USA, the most recent FCC (Federal Communications Commission) rules specify a total available spectrum ΔF of 195 MHz including guard-bands between

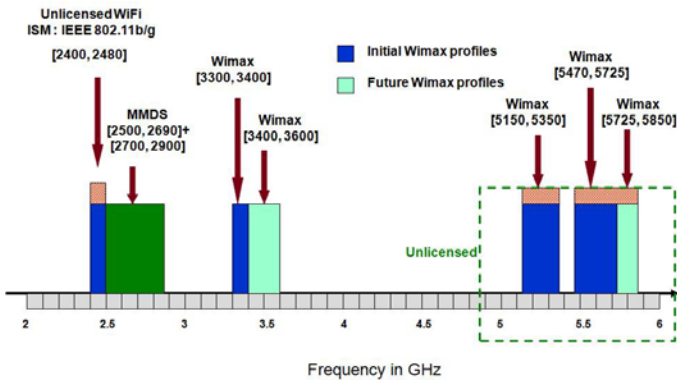


Fig. 1. Licensed and unlicensed WiMAX channels bandwidth

2.495 GHz and 2.690 GHz. Fixed two-way or broadcast communications are possible, in using either Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD).

The design of HOWRAN systems takes into account some of the characteristics of future mobile WiMAX. Mobile WiMAX characteristics are specified in the 2005 revised version of the IEEE 802.16e standard. Although multiple channels bandwidths are considered for mobile WiMAX, a consensus between the vendors and the operators focuses on a 10 MHz bandwidth (BW). In terms of modulation, mobile WiMAX uses an extended version of OFDMA called Scalable OFDMA (SOFDMA). Similarly to Discrete Multitone modulation used in ADSL, fixed and mobile WiMAX uses OFDM. The main objective of OFDM consists in reducing the negative impact of propagation disparity (due to multipath phenomenon) by spreading data flows onto multiple narrowband channels called subcarriers. Due to their very limited bandwidth, these subcarriers are not subject to propagation disparity. In order to optimize the available BW, these subcarriers are orthogonal. The capacity in bit/s of each subcarrier is evaluated according to the quality of the radio channel in the considered frequency band. The Fast Fourier Transform (FFT) algorithm enables to assign the optimum capacity to each subcarrier in order to maximize the global data rate, either upstream or downstream. Both fixed and mobile WiMAX rely on three types of subcarriers: data subcarriers, pilot subcarriers (for operation and maintenance) and null subcarriers (used as guard bands). Data and pilot subcarriers are logically associated to form subchannels. A subchannel represents the capacity assigned to a given user. In practise, the subcarriers associated to the various subchannels are interleaved in the frequency domain. For each channel bandwidth (BW) specified for mobile WiMAX, various numbers of OFDM subcarriers referred as N_{FFT} can be used. Among the N_{FFT} subcarriers, $N_{data-DL}$ and $N_{data-UL}$ are used for downlink transmission from the BS to the mobile terminal and for uplink transmission from the mobile terminal to the BS respectively. The values of $N_{data-DL}$ and $N_{data-UL}$ are specified in the standard as maximum values for downstream and upstream transmission isolately. In other terms, the sum of these two terms may be greater than N_{FFT} , each of them remaining lower than N_{FFT} . Another figure called N_{used} is specified in the standard. It is equal to the sum of the effective number of used data subcarriers N_{data} , the number of pilot subcarriers N_{pilot} and the Direct Current (DC) carriers used for hardware purposes. Finally, $N_{SubchDL}$ and $N_{SubchUL}$ correspond to the maximum number of subchannels (that is of users) that may share some of the $N_{data-DL}$ and of the $N_{data-UL}$ subcarriers respectively. Table 1 summarizes the typical values of N_{FFT} , N_{used} , $N_{data-DL}$, $N_{data-UL}$, $N_{SubchDL}$ and $N_{SubchUL}$ for different values of BW [6].

If one considers the transmission window ΔF of 195 MHz between 2.495 GHz and 2.690 GHz mentioned above, we have then the possibility to create up to 9 WiMAX channels each with a 20 MHz bandwidth. In OFDM, a test sequence enables to evaluate the quality of the radio channel in each subcarrier. For each subcarrier, the FFT algorithm determines the size of the QAM constellation

Table 1. Mobile WiMAX OFDMA parameters

BW	N_{FFT}	N_{used}	$N_{data-DL}$	$N_{data-UL}$	$N_{SubchDL}$	$N_{SubchUL}$
1.25 MHz	128	85	72	56	3	4
5 MHz	512	421	360	280	15	17
10 MHz	1024	841	720	560	30	35
20 MHz	2048	1681	1440	1120	60	70

enabling to maximize the global data rate on the air interface, either in the upstream or in the downstream direction. Once the WiMAX link has been initiated, the FFT algorithm computes on the fly on the basis of a common symbol duration and for each subchannel, a set of samples of the modulated signal. At each symbol duration, a cyclic prefix corresponding to redundant information is added to the set of the samples obtained over all the active subcarriers. The aim of this prefix is to reduce the impact of multipath effect on BER. According to the fluctuations of the air interface observed by each end-user, mobile WiMAX uses an adaptive modulation. The better the quality of the air interface, the higher the size of the adopted QAM constellation. In WiMAX, mainly three basic modulations are considered: QPSK, 16-QAM and 64-QAM. For each modulation, different coding rates may be used depending on the adopted Forward Error Correction (FEC) technique. FEC introduces redundant bits that consume some of the user data bits in the QAM constellations. The coding rate r corresponds then to the ratio of the number of data bits per symbol to the sum of the number of data bits per symbol and of redundant bits per symbol. The number of information bits per symbol is then equal to $r \log(M)/\log(2)$ where M stands for the number of bits per symbol. For instance, in the case of 64-QAM ($M=64$) with a coding rate $r = 3/4$, we have $r \log(M)/\log(2) = 4.5$ bits per symbol. In [7], the author determines the admissible Signal-to-Noise Ratio (SNR) in presence of Additive White Gaussian Noise (AWGN) assuming the usage of Reed-Solomon techniques and convolution codes to prevent erroneous bits. In this context, Table 2 extracted from [7] shows typical values of required SNR in order to guarantee a BER lower than 10^{-6} .

In OFDM, one defines a frame that groups a certain number of successive symbols with their associated additive cyclic prefixes. The WiMAX Forum sets the

Table 2. Example of SNR values for Mobile WiMAX

Modulation scheme	SNR
QPSK 1/2	5 dB
QPSK 3/4	8 dB
16-QAM 1/2	10.5 dB
16-QAM 3/4	14 dB
64-QAM 1/2	16 dB
64-QAM 2/3	18 dB
64-QAM 3/4	20 dB

duration T_{frame} of this periodical frame to 5 milliseconds. During T_{frame} , a total of N_{symbol} OFDM symbols are generated with among them $N_{data-symbol-DL}$ OFDM symbols corresponding to data symbols. In [9], a WiMAX cell capacity evaluation is carried on the basis of the above mentioned parameters. The downlink data rate Φ_{DL} observed at the physical layer per WiMAX carrier is given by:

$$\Phi_{DL} = \frac{N_{data-DL} \times N_{data-symbol-DL}}{T_{frame}} \times r \frac{\log(M)}{\log(2)} \quad (1)$$

As an example, in the case of $BW = 10$ MHz (see Table 1), we have $N_{data-DL} = 720$. If we consider a 64-QAM modulation with coding rate $r = 3/4$, knowing from [9] that in that case, $N_{data-symbol-DL} = 44$, we obtain numerically $\Phi_{DL} = 28.51$ Mbps. In the case of an uplink WiMAX carrier operating under the same conditions, we have to replace $N_{data-DL}$ by $N_{data-UL} = 560$ and $N_{data-symbol-DL}$ by $N_{data-symbol-UL} = 42$. We get $\Phi_{UL} = 21.17$ Mbps. The WiMAX carrier range has been investigated in [7] under different types of modulation, error correction techniques and radio propagation models. Due to space limitation, we simply provide in Table 3 interesting figures in this matter that will also be useful for the remaining of our study.

Table 3. Typical ranges in meters of fixed WiMAX cells in urban areas

Up/Down	QPSK 1/2	QPSK 3/4	16-QAM 1/2	16-QAM 3/4	64-QAM 1/2	64-QAM 3/4
Downlink	1150	970	850	700	620	500
Uplink	770	720	660	610	550	480

We notice that the maximum cell size in urban areas is 770 meters. This corresponds to an antenna's density at least four times higher than in current systems. SOFDMA consists in searching in a cell the users that could communicate with the BS at the highest rate (64-QAM with 3/4 coding rate) under acceptable BER. Once the potential users have been served (they are probably located close the BS), another search is carried out for users that could communicate at a lower data rate (64-QAM with 2/3 coding rate). The operation is repeated recursively until the cell capacity has been fully utilized. As it will be outlined in Section 3, HOWRAN systems are particularly designed for urban areas rather than for rural areas.

3 Global HOWRAN Architecture

Figure 2 depicts the global configuration of an HOWRAN system in which four main sections can be distinguished: the head-end node, an Arrayed Waveguide Grating (AWG) router, several feeder WDM loops and several WiMAX BSs. The head-end node is in charge of supervising the behavior of the whole infrastructure. It can be assimilated to an Hybrid Optical Line Termination (HOLT) since it manages both radio and optical carriers. The main role of the head-end

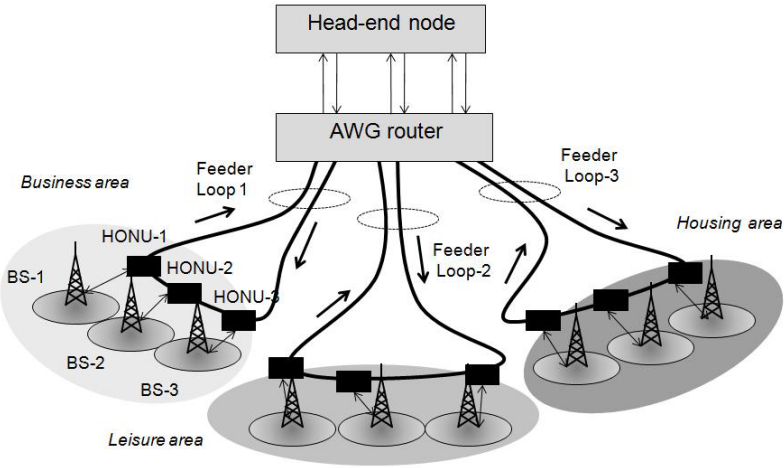


Fig. 2. The HOWRAN configuration

node is to generate continuous millimeter frequencies for upstream traffic and modulated millimeter frequencies for downstream traffic. Each of these radio frequencies modulate continuous tunable optical carriers by means of Sub-Carrier Modulation (SCM). The head-end node is in charge of the supervision of the whole HOWRAN system by means of an innovative control plane. This control plane aims to distribute dynamically upstream and downstream radio frequencies to the various WiMAX BSs of the system. An out-of-band optical channel λ^* is used to coordinate this supervision. The head-end node is interfaced with a low-cost Arrayed Waveguide Grating (AWG) router. The flexibility of such a router is mainly provided by the tunability of the continuous optical carriers. Let $\Delta_o = \{\lambda_1, \lambda_2 \dots \lambda_n\}$ be the pool of these n optical carriers. If N stands for the number of HONUs in the system, we assume that $n \leq N$. This means that, according to the maximum number of radio frequencies that can be transported by a same optical channel, a single optical channel has the capacity to feed a WiMAX BS under its maximum load.

The third section of an HOWRAN system is made of multiple WDM optical loops connected to the output ports of the AWG. As illustrated in the figure, the AWG is inserted into each loop via two distinct of its output ports. Once they have been routed to their dedicated loop, the downstream continuous optical carriers generated at the head-end node pass through successive Hybrid Optical Network Units (HONU) inserted in the lower part of each loop. The HONUs represent the fourth main section of an HOWRAN system. As described in the figure, a single WiMAX BS is connected to an HONU. In a first approach, we can assimilate an HONU to a Reconfigurable Optical Add-Drop Multiplexer (ROADM) in charge of extracting the right downstream optical channel, and from this optical channel, the right radio frequencies. In parallel, the out-of-band signaling channel λ^* is demodulated. In order to reduce the best as possible the cost of an HONU, no laser diodes is necessary for the upstream

transmission of the radio channels, a Reflective Semiconductor Optical Amplifier (RSOA) being used for that purpose. In addition, no costly local oscillator is necessary at the HONUs. Indeed, all the radio frequencies used for both upstream and downstream transmissions are located at the head-end node thanks to RoF technique. The technical feasibility of such a hardware configuration has been demonstrated in [10]. In parallel, the signaling channel uses at each HONU a low-cost VCSELs (Vertical Cavity Surface Emitting Laser) instead of a laser diode. The way the RF frequencies are used at the HONUs is depicted in Section 5. As an illustration, we consider in Figure 2 three WDM loops corresponding to three different zones of a same urban area. These three zones cover a business area, a leisure area and a housing area respectively. Our motivation for such an architecture aims to a mutualization of the radio resources since the same population is supposed to move every day from one zone to another one depending on the hour of the day. In other terms, instead of serving these three areas in installing three times the same radio resources, we want to exploit the intelligence of the HOWRAN control plane to shift dynamically the same radio resources from one zone to another one.

4 Head-End Node Hardware Architecture

Figure 3 details the internal configuration of the head-end node. A pool of n continuous tunable lasers is used to transport radio frequencies to the BSs thanks to RoF technique. In HOWRAN systems, we have adopted the most simple RoF transmission technique based on intensity modulation at the sender and direct detection at the receiver. As it is illustrated, the tunable continuous laser sources may be eventually modulated by one or several radio frequency (RF) signals by means of SCM. These RF signals can themselves be pre-modulated or not by user data. In Figure 3, we have assumed an internal modulation of the laser sources. In practise, external modulation by means of Mach-Zender modulators should provide better performance but at a higher cost. A direct detection is used at the HONUs to get-back the transmitted RF signals which are then simply amplified by WiMAX BSs. It is recalled in [7] that intensity modulation coupled with direct detection is easy to implement. It can be used for multi-level modulation formats such as QAM or SCM. The set of the RF oscillators is divided into two subsets. A first subset $\Delta_{RF1} = \{f_1, f_2 \dots f_m\}$ of pre-modulated RF signals is used for downstream radio traffic. A second subset $\Delta_{RF2} = \{f_{m+1}, f_{m+2} \dots f_{2m}\}$ of continuous RF signals is used for upstream radio traffic. The HOWRAN control plane supervises via the control channel λ^* a matrix of $n \times 2m$ OADMs in order to activate RoF modulation of the optical carriers with the desired RF signals. Similarly to the RoFnet architecture introduced in 5, Optical Single Sideband (OSSB) modulation is preferred to Optical Double Sideband (ODSS) modulation because it is less sensitive to chromatic dispersion effects.

Due to space limitation, we do not describe in this paper the configuration of the HOWRAN head-end node receiver configuration.

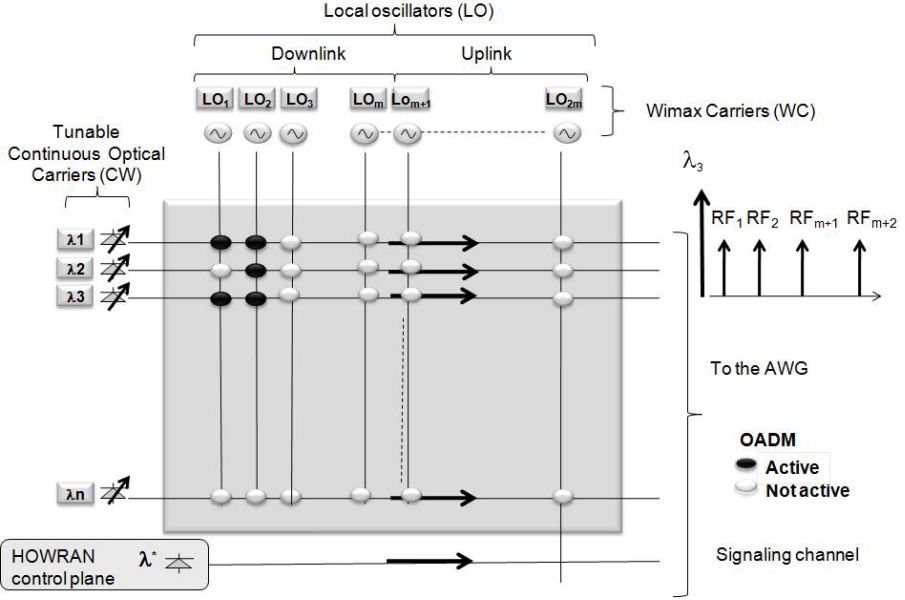


Fig. 3. Head-end node transmitter configuration

5 HONU Hardware Architecture

The internal architecture adopted for an HONU, let us say ONU-#k, is depicted in Figure 4. It is strongly inspired by the architecture proposed in [10] for the RoFnet network. The incoming section of the loop transports a subset Δ'_o of Δ_o optical channels and λ^* . After demultiplexing, λ^* is directed to a photo-detector. The signaling information transported on λ^* is analyzed in the electrical domain by the HONU control plane. For instance, the HONU is informed by the head-end node of the index i of the optical channel that must be extracted, the other optical channels by-passing this HONU. This extraction is carried out by means of a MEMS switching fabric. Once it has been isolated, channel λ_i is directed by means of an optical circulator to both an high bandwidth tunable photo-detector and to an RSOA.

Thanks to the high bandwidth tunable photo-detector, the two subsets Δ_{RF1} and Δ_{RF2} of RF signals are extracted. The m downstream modulated RF signals of Δ_{RF1} are amplified before being transmitted by BS-#k to the mobile users. The m continuous RF signals of Δ_{RF2} are used as local oscillators in order to convert the upstream radio channels coming from the antenna to intermediate frequencies (IF) within the electrical band of the RSOA (1.2 GHz). These m modulated signals at intermediate frequency are multiplexed. The resulting signal modulates the RSOA. The obtained optical signal centered on λ_i is Optically Double Sideband (ODSB) modulated. Figure 5 illustrates the shape of λ_i when it is inserted in the output multiplexer.

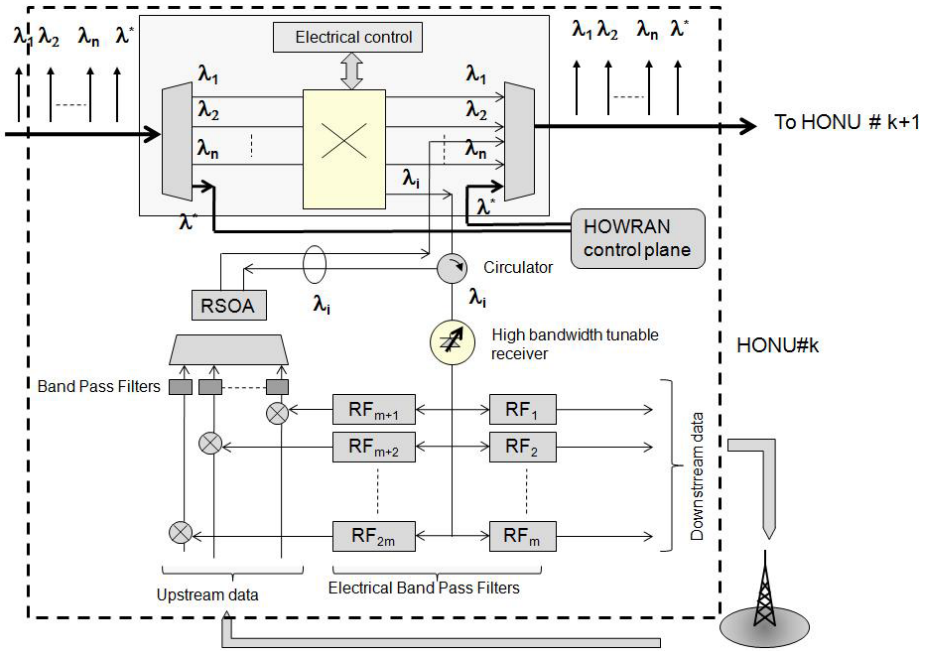


Fig. 4. HONU configuration

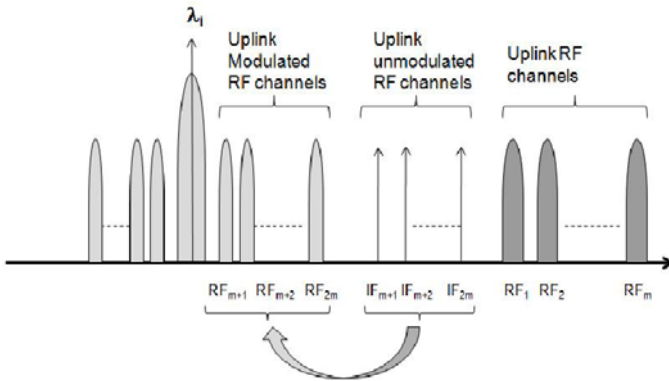


Fig. 5. Global signal on an optical loop

6 HOWRAN Control Plane

The aim of the HOWRAN control plane is to dynamically assign radio carriers to the various WiMAX BSs spread out over the multiple loops according to the upstream/downstream traffic of the WiMAX cells. The main complexity and originality of this control plane concerns upstream traffic. Upstream traffic is

viewed either as the global traffic generated within each cell, or the global traffic generated by the set of BSs belonging to a same loop. The HOWRAN control plane is then MAC agnostic since it does not see the packet level. Thus we assume that the standardized WiMAX MAC protocol is applied at layer 2. The HOWRAN control plane operates at two timescales: microscopic and macroscopic. At the microscopic timescale, one assumes that the number of optical carriers assigned to an optical loop is fixed, for instance w . Let us recall that at most N optical channels serve a same loop made of N HONUs ($w \leq N$). At this timescale, the control plane is in charge of reallocating the RF carriers belonging to the w subsets Δ_{RF1} to such or such BS belonging to the same loop. At the macroscopic timescale, if the utilization ratio of these radio frequencies becomes greater than a given threshold, the head-end node activates a wavelength reallocation procedure between the loops. For instance, one or several optical channels assigned to a loop with low loaded BSs are retrieved by the control plane to the benefit of the BSs suffering of starvation and belonging to another loop. In reference to Figure 2, let us consider that around 9am, the subscribers of a WiMAX operator leave their homes to go to work. Automatically, the HOWRAN control plane shifts progressively some of the radio resources focused on the housing area to the business area. The same type of operation should occur several times every day between the housing area, the business area and the leisure area. The rationale of the HOWRAN control plane is inspired from a similar tool we have proposed for Next-Generation WDM-PON access systems [13]. Due to space limitations, we cannot describe into details how this control plane is adapted to the cellular context. Let us simply say that the HOWRAN control plane is based on two bin-packing optimization algorithms, one being activated on the fly at the microscopic timescale, the other one being used at the macroscopic timescale.

7 Wimax Cell Planning with HOWRAN

Figure 6 illustrates an example of loop configuration adapted to the hexagonal WiMAX cell planning. According to Table 3, the smallest radius of a WiMAX cell equal to 480 meters is obtained under 64-QAM modulation with a 3/4 coding rate. In [11], the feasibility of a 10 Gbps OSSB modulation using SCM in the C-band has been demonstrated. In this study, the microwave frequencies used for SCM are distributed between 3.6 GHz and 10 GHz. According to the adopted sub-channel spacing, it is shown experimentally in this paper that the global required bandwidth around 1550 nm is 20 GHz. In reference to Section 2, we can notice that this 20 GHz bandwidth is largely greater than the 195 MHz bandwidth ΔF reserved around 2.5 GHz for WiMAX systems. Let us recall that up to 9 WiMAX carriers may be included in ΔF . This corresponds to the maximum capacity of a WiMAX cell. We can conclude that there is no problem at all to transport in practice 9 WiMAX carriers modulated with the highest bit rate (64-QAM with 3/4 coding rate) on a same optical channel operating in the C-band. In practise, up to M BSs can be connected to a same loop and up to K loops (in our scenario, $K = 3$) can be connected to the AWG. In this case, the

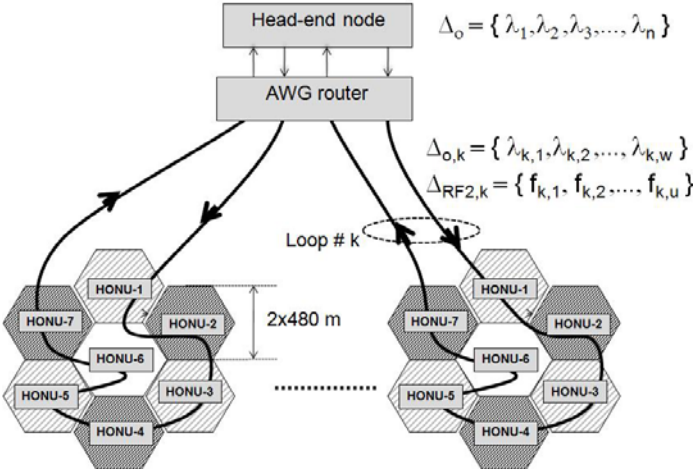


Fig. 6. Wimax frequency planning

number n of optical carriers available at the head-end is such as $n \leq K \times M$. These n optical carriers transport a maximum of $n \times 9$ WiMAX carriers. We can assume that, whatever the hour of the day, at least 10% of the population remains geographically in each loop. For instance, between 9am and 12am, 80% of the population are located in the business area whereas 10% are in the housing area and 10% are in the leisure area. The value of n must then be such as:

$$\left\lceil \frac{M}{10} \right\rceil \times 9 \times (K - 1) + \left\lceil \frac{8 \times M}{10} \right\rceil \times 9 \leq n \leq K \times M \quad (2)$$

In [12], the problem of interference avoidance for frequency planning in cellular mobile WiMAX is investigated. In this paper, the concept of Partial Usage Subchannel (PUSC) is exploited. It enables a subscriber to use only fractions of the subchannels (see Section 2). Considering a decomposition of each hexagonal cell into three sectors of 120 degrees each, the basic idea is to enable the users close to the antenna to consume all the available subchannels. The users located at the periphery of the cell can only use a fraction of the available subchannels as it is illustrated in Figure 7.

To validate the basic operation of the HOWRAN control plane, let us consider the same type of scenario as the one considered in [14] which corresponds to realistic WiMAX deployment. We assume that 80% of the WiMAX subscribers use 64-QAM evenly split with a coding rate 3/4 or 2/3, 10% of the WiMAX subscribers use 16-QAM evenly split with a coding rate 3/4 or 1/2, and 10% of the WiMAX subscribers use QPSK evenly split with a coding rate 3/4 or 1/2. In using equation 1, we determine an average bit rate per WiMAX carrier of 17.76 Mbps. Thanks to PUSC, the minimum bandwidth allocation granularity corresponds to a single WiMAX subchannel. Knowing from Table 1 that for 10 MHz WiMAX, we have $N_{SubchUL} = 35$, this minimal granularity is then $17.76/35 = 0.507$ Mbps. In the remaining of this section, we illustrate the characteristic

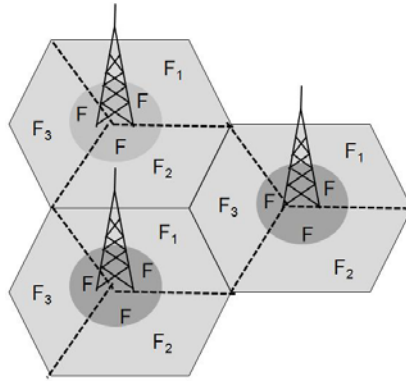


Fig. 7. Principle of Partial Usage Subchannel in WiMAX

instants at which the microscopic and the macroscopic behavior of the control plane are activated. For that purpose, we consider a very simple scenario with $K = 3$ and $M = 3$, the three cells of each loop forming the same pattern as in Figure 7.

As a reference scenario, Figure 8 depicts the successive activations of the WiMAX carriers provided by a single optical channel to a given cell. We assume the other cells of the same loop are inactive. When the offered traffic increases linearly with time, the number α of activated WiMAX carriers increases as a step function with 0.507 Mbps gaps. The HONU sends to the head-end an alarm via λ^* when α reaches a threshold α_{th} ($\alpha_{th} = 8$ in the figure) at instant t_0 . The value of α_{th} is chosen such as, in the worst case, the signaling message may arrive at the head-end, may be interpreted, and the control plane may send to the HONU a confirmation signaling message specifying that an additional optical channel has been routed to the considered loop before α reaches 9.

Figure 9 illustrates an example of the macroscopic behavior of the control plane when the three BSs of the same loop are active. The offered load in each

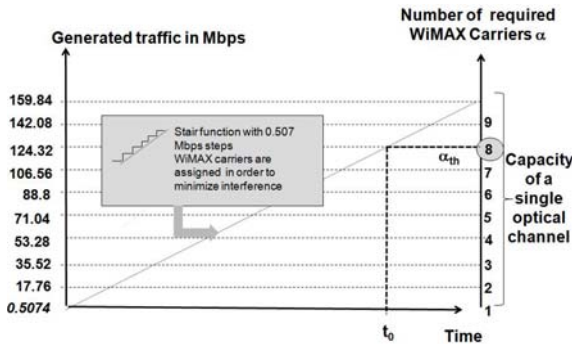


Fig. 8. Principle of WiMAX carrier's assignment

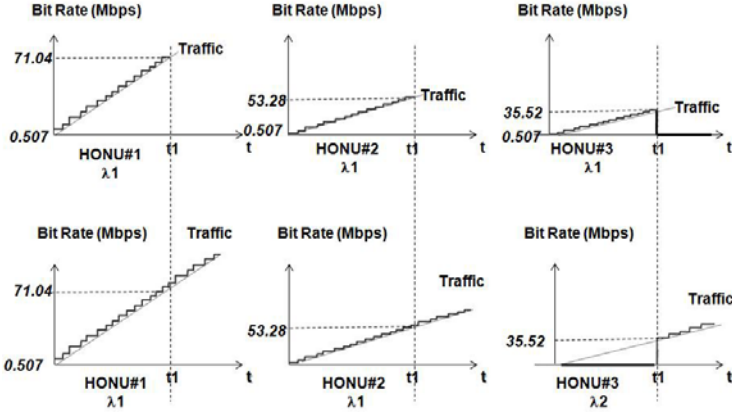


Fig. 9. Macroscopic behavior of the HOWRAN control plane: example 1

cell increases linearly. We have plotted the evolution of α proper to each HONU of the loop. When the three cells are under loaded, they use WiMAX carriers provided by a same optical carrier λ_1 . One notices that at instant t_1 , the global offered load (71.04 Mbps + 53.28 Mbps + 32.52 Mbps = 160 Mbps) reaches the maximum capacity that can be provided by 9 WiMAX carriers. In this case, by convention, the HONU with the lowest load sends an alarm to the head-end in order to require for another λ . This second λ is provided, if possible, from another loop. One notices that after t_1 , HONU1 and HONU2 still operate on λ_1 whereas HONU3 starts to operate on λ_2 . By simplification, we have not considered in this scenario an anticipation threshold that should be applied to HONU3 in the same spirit as the threshold mentioned in our previous example.

Figure 10 illustrates a second example of macroscopic behavior of the control plane. At instant t_0 , let us assume that HONU1, HONU2 and HONU3 are served by the same optical channel λ_1 . They use 4, 3 and 2 WiMAX carriers respectively. Each HONU increases its offered load progressively, like in the previous example.

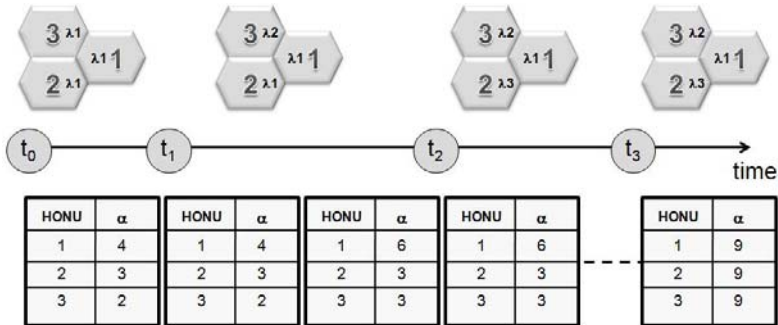


Fig. 10. Macroscopic behavior of the HOWRAN control plane: example 2

At instant t_1 , one notices that the 9 WiMAX carriers of λ_1 are used. Via the signaling channel, the head-end assigns to HONU3 a new optical channel λ_2 . At instant t_2 , the 9 WiMAX carriers of λ_1 are consumed by HONU1 and HONU2. Via the signaling channel, the head-end assigns to HONU2 a new optical channel λ_3 . The three cells are potentially saturated at instant t_3 when the 9 WiMAX carriers of λ_1 , λ_2 and λ_3 are consumed. Again, by simplification, we have not considered in this scenario an anticipation threshold. Due to space limitation, we cannot describe the microscopic behavior of the control plane. It is mainly activated to solve the inter-cell interference problems.

8 Conclusion

In the paper, we have proposed an innovative RAN architecture well suited to fixed or mobile WiMAX cellular networks. The HOWRAN network originality covers two aspects: the physical topology and the control plane. Multiple advanced devices (MEMS, RSOA, AWG) and modulation techniques (SCM, RoF, OSSB) are judiciously exploited in order to facilitate a great flexibility in terms of frequency planning. To the best of our knowledge, the HOWRAN control plane is the first one that enables a mutualization of the radio resources in dense urban areas. Our coming studies are focused on the design of a simulator of an HOWRAN system from which realistic scenarios will be investigated.

References

1. Otsu, T., et al.: Network Architecture for Mobile Communications Systems beyond IMT-2000. *IEEE Wireless Commun.* 8(5), 31–37 (2001)
2. Ghosh, S., Basu, K., Das, S.K.: What a Mesh! An Architecture for Next-Generation Radio Access Networks. *IEEE Network Magazine*, 35–42 (September/October 2005)
3. Koonen, T., Ng'oma, A., Smulders, P.F.M., Boom, H.P.A., Tafur Monroy, I., Khoe, G.D.: In-House networks using Multimode Polymer Optical Fiber for broadband wireless services. *Photonic Network Communications* 5(2), 177–187 (2003)
4. Park, Y.H., Okada, M., Komaki, S.: The Performance of Fiber-Radio Road Vehicle Communication System with Macro-Diversity. *Wireless Personal Communications* 14, 125–132 (2000)
5. Lannoo, B., Colle, D., Pickavet, M., Demeester, P.: Radio-over-Fiber-Based Solution to Provide Broadband Internet Access to Train Passengers. *IEEE Communications Magazine*, 56–62 (February 2007)
6. Lannoo, B., Verbrugge, S., Ooteghem, J.V., Quinart, B., Castteley, M., Colle, D., Pickavet, M., Demeester, P.: Business scenarios for a WiMAX deployment in Belgium. In: *IEEE Mobile Wimax Conference, Orlando-FL, USA* (2007)
7. Lannoo, B.: Study of access communications networks for heterogeneous environments. PhD Dissertation, University of Gent, Belgium (2008)
8. Wimax Forum. Considerations for Fixed Wireless Access in the 2.5 and 3.5 GHz Licensed Bands (June 2005)
9. Mobile WiMAX part 1: a technical overview and performance evaluation, The WiMAX Forum (August 2006), <http://www.wimaxforum.org/home/>

10. Medeiros, M.C.R., Avo, R., Laurencio, P., Correia, N.S., Barradas, A., da Silva, H.J.A., Darwazeh, I., Mitchell, J.E., Monteiro, P.M.N.: Radio over Fiber Access Network Architecture Employing Reflective Semiconductor Optical Amplifiers. In: IEEE ICTON Conference (2007)
11. Hui, R., Zhu, B., Huang, R., Allen, C., Demarest, K., Richards, D.: 10-Gb/s SCM Fiber System using Optical SSB Modulation. *IEEE Photonics Technology Letters* 13(8) (August 2001)
12. Jias, H., Zhang, Z., Yu, G., Cheng, P., Li, S.: On the performance of IEEE 802.16 OFDMA system under different frequency reuse and subcarrier permutation patterns. In: IEEE ICC Proceedings (August 2007)
13. Gagnaire, M., Koubaa, M.: A new control plane for Next-Generation WDM-PON access systems. In: IEEE Accessnets Proceedings, Ottawa-Canada (2007)
14. Wimax capacity White Paper, Chapter 7 “Capacity Scenarios”, SR Telecom, Canada (August 2006)