Integrated Wireless Optical Networking

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Abstract: The interoperability of wireless and PON topologies is investigated to reduce deployment expenditure by means of centralised network management while providing ubiquitous access connections and mobility. In addition, the application of extended wavelength band overlay has been proposed to enhance scalability in the converged platform with the slightest modification in network hardware. To that extent, network modelling in the physical layer of WiMAX channel transmission based on FDM over single- and multi-wavelength power-splitter PONs has demonstrated EVMs below -30dB and worst-case 1E-4 transmission in multipath fading channels.

1 Introduction.

Although the escalating demand in bandwidth provision at close subscriber proximity could be widely met by optical networking solutions, next generation access networks should also provide end users with great flexibility and mobility at ease of last-mile implementation [1]. To that extent convergence of optical and the rapidly developing by means of deployment and standards wireless networking, e.g. WiMAX and LTE, represents the challenge for ubiquitous broadband multimedia communications. A novel architectural platform demonstrating the transparent transmission of radio signals over standardized passive optical network (PON) topologies has been investigated in that direction [2]. In particular the application of Radio over Fibre (RoF), for enhanced network redundancy and capacity through centralised management, has been in the focus by means of accessing each remote Optical Network Unit/BaseStation (ONU/BS) from the optical line terminal (OLT) by frequency division multiplexing (FDM). To enhance scalability and overcome bandwidth limitations of electrical and optical components in the single wavelength hybrid network, a multi-wavelength extension over power-splitting GPON infrastructures is proposed in this paper requiring the slightest modifications in network hardware. Consequently, this would result in reduced network upgrade and components costs.

2. WiMAX over GPON Integrated Architectural Platform.

The network architecture, depicted in Fig. 1, consists of a standard GPON with novel wireless-enabled OLT and ONUs. At the OLT after WiMAX symbols are generated by multiple transmitters they are upconverted to a subcarrier for each wireless-enabled ONU. The FDM technique was used to ensure signal transparency for

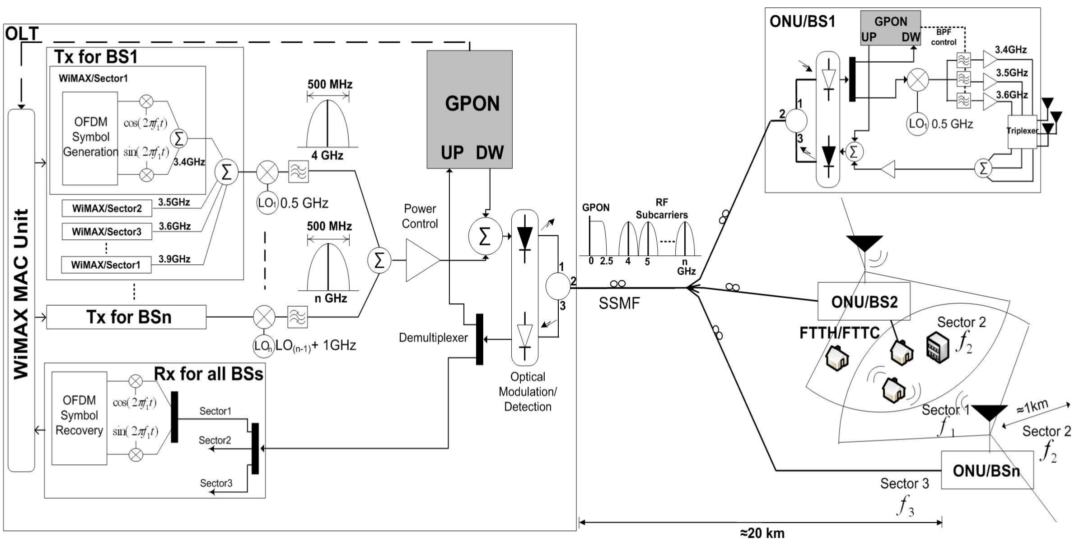


Figure 1. WiMAX over GPON architectural platform

various radio signal formats and to avoid interference with the GPON spectrum [2]. Each WiMAX transmitter at the OLT is serving a typical single sectorised radio cell at an ONU/BS. The ONU/BSs are therefore responsible only for down-conversion of received channels.

The key feature of the proposed architecture is the creation of overlapping cells, e.g. between Sector 2 and Sector 1 of ONU/BS2 and ONU/BSn respectively in Fig. 1, operating at different frequency channels enabled due to the centralised processing in the OLT [2]. Therefore, users that are in the overlapping regions can have simultaneous wireless support from multiple ONU/BSs, thus increasing the capacity of the WiMAX network and providing redundancy in case of fibre failure between a distribution node and an ONU. Furthermore, the development of smaller radio cells, as a result of the application of RoF, enables much higher spectral efficiency than in traditional WiMAX deployment, and on-demand bandwidth provisioning by means of additional WiMAX channels fed to a particular sector from the OLT. Finally, the use of time division multiple access (TDMA) in upstream minimises the optical beat interference in the OLT receiver reducing the overall design complexity through a single photoreceiver and WiMAX demodulator.

2.1. Network Performance Evaluation.

In order to demonstrate the capability of the architecture to transmit WiMAX channels successfully over combined GPON and radio-cell links a physical layer simulation test-bed was implemented using Virtual Photonic Inc. (VPI) and MATLAB complying with the network standards [2]. It has been previously established that non-linear effects of the optical modulators can degrade RoF transmission in terms of error vector magnitudes (EVMs) and bit error rates (BERs) [2]. Fig. 2 displays EVMs for five WiMAX channels as a function of the RF drive power into the Mach-Zehnder modulator (MZM) in the OLT, to indicate if the maximum allowable RF drive power into the MZM complies with the WiMAX transmitter requirements at an ONU/BS antenna.

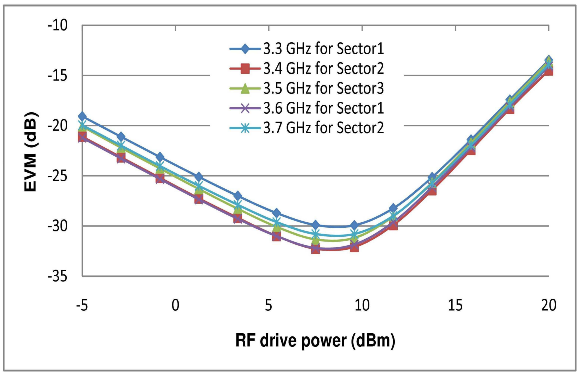
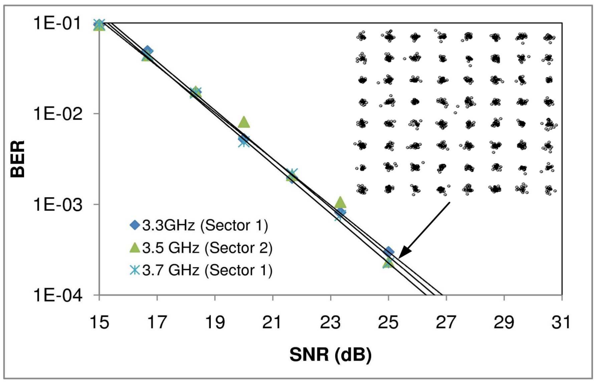


Figure 2. EVM versus RF drive power for downstream WiMAX channels

For low input power levels into the MZM the performance is limited by noise, while for high power levels, nonlinear distortions of the MZM increase EVMs. For the 64-QAM WiMAX OFDM downstream transmitters an EVM of -31 dB was obtained at distinctive drive powers, matching closely the performance figure of the WiMAX standard [3].



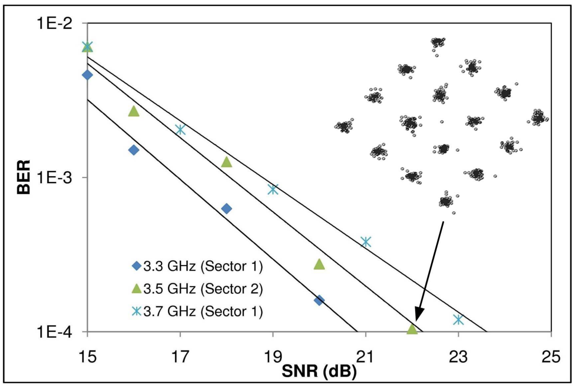


Figure 3. BER versus SNR for 64-QAM (left) and 16-QAM (right) OFDM channels bidirectionally

To demonstrate bidirectional signal transmission across GPON and standard multipath radio links, the BER plots of three WiMAX channels are shown in Fig. 3. The proposed architecture has displayed BER figures of 1E-4 downstream, representing error free transmission for IPTV and online gaming services [4], at an SNR requirement of at least 26 dB with -30 dBm fixed received power at the APD [5]. The application of wireless channel coding techniques is expected to reduce the recorded worst-case SNRs. Similar results were obtained for the other channels. Furthermore, this demonstrates 50 Mbit/s aggregate downstream capacities at transmission links extended to 21 km as opposed to relatively short distances achieved with standard WiMAX deployment. The wireless channel at 3.7 GHz deployed from the OLT could be used for on-demand bandwidth provisioning or for redundancy in case of fibre failure through overlapping cells. In upstream, for WiMAX channels, comprising 16-QAM OFDM modulation, the BER responses displays power penalty of 3 dB at 1E-4 between the 3.3 GHz and 3.7 GHz channels due to laser chirp introduced by direct modulation laser (DML). The constellation diagrams, shown as insets in Fig.3, represent the obtained data points where upstream channel DML caused constellation rotation.

3. Extended Wavelength Band Overlay.

Scalability of the presented topology to larger splits by means of additional ONU/BSs, would result in extended RF spectrum occupancy, exceeding bandwidth specifications of electrical and optical devices and imposing high dispersion penalty. In addition, this would increase the polling waiting time for wireless users in upstream due to the TDMA approach.

To that extent, the application of multi-wavelength transmission over a power-splitting GPON is demonstrated in Fig. 4, allowing for each BS upconverted wireless channels downstream to be dynamically multiplexed on different wavelengths attaining bandwidth demand. Therefore, the total number of required RF subcarriers is reduced leading to lower cost in optical and electrical components at the requirement of tuneable optical filters and low-cost vertical cavity surface emitting laser (VCSEL) arrays in the ONU/BSs. The centre frequency of the filter can be adjusted by the OLT by means of a controller circuit. Consequently any wavelength of the selected operating spectrum could be partly or exclusively assigned to different ONU/BSs, providing in the latter service level similar to WDM-PONs.

The key feature of this approach is the use of low-cost VCSEL arrays [6] in upstream demonstrating colourless terminations with simple coupling optics, not limited by Rayleigh backscattering. The VCSEL array approach in combination with TDMA, when multiple ONU/BSs are sharing a single wavelength, would also significantly reduce optical beat interference in the upstream receiver. The upstream emission wavelength is adjusted by the same controller circuit used for setting the filter's centre frequency.

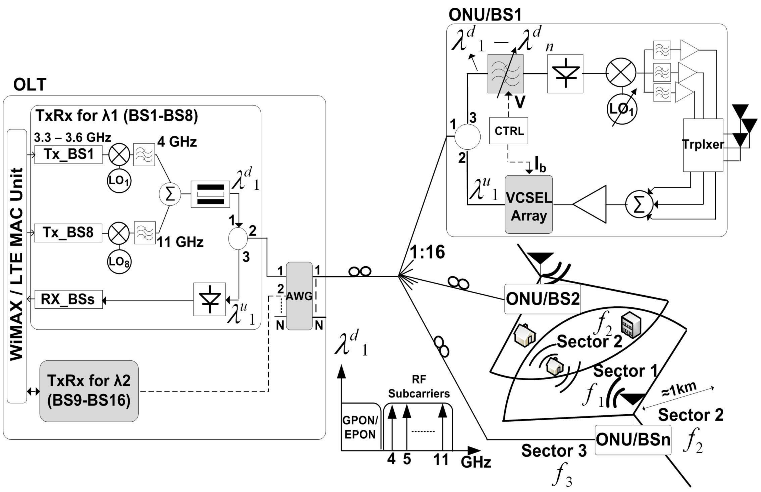


Figure 4. WiMAX over multi-wavelength, splitter PONs

In order to demonstrate the capability of the network to transmit the same RF subcarrier to multiple ONU/BSs on different wavelengths, a physical layer modelling with the same simulation platforms as before was devised. The WiMAX channels are generated individually by Tx for BS1 and Tx for BS9, as shown in Fig. 4 and up-converted to the same 4 GHz RF subcarrier. Subsequently the 4 GHz bandpass signal is modulated on both λ^d_1=1553.33 nm and λ^d_2=1554.13 nm and after application over the corresponding circulators for bidirectional transmission the modulated wavelengths are multiplexed at the AWG and routed to the destination PON through 20km of SSMF. After they have been broadcasted to ONU/BS1 and ONU/BS2, a tuneable optical band-pass filter, shown in Fig. 4, with 50 GHz bandwidth is used to select each wavelength. The resulting wavelength is then detected by an avalanche photodetector (APD) followed by RF subcarrier down-conversion to result to the transmitted WiMAX channels.

Upon WiMAX channels reception at ONU/BS1, EVM characteristics are plotted in the same manner as before. The obtained EVM performance for BS1, shown in Fig. 5, displays a figure below the -30 dB limit at distinctive drive powers. Similar results were obtained for the WiMAX channels transmitted on λ^d_2=1554.13 nm.

Significantly, in upstream, following reception at ONU/BS1, direct VCSEL modulation at λ^u_1=1553.33 nm with a constant output power level of +1.4 dBm [5, 6] is performed prior to transmission over the 20km SSMF. The optical signal is then routed through the same I/O port of the AWG as in downstream and through the corresponding circulator to the destination Rx in the OLT.

As demonstrated in Fig. 5, BER performance of 1E-4 in upstream is achieved at around 14 dB. Although this depicts acceptable performance for conventional services, increased VCSEL array powers and the application of wireless channel coding techniques are expected to significantly enhance system performance. Similar results to single-wavelength approach were obtained for downstream channels.

Finally the inset in Fig. 5 show the rotation observed in upstream modulation format constellation due to the optical filter phase response and DML respectively.

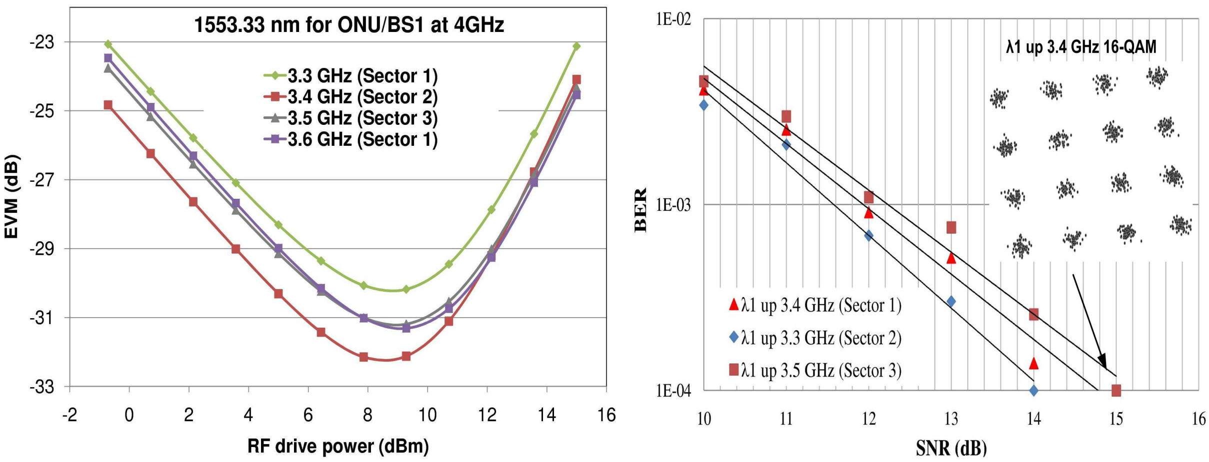


Figure 5.EVM vs. RF drive power at ONU/BS1 antenna (left) and BER with constellation (right)

4. Conclusions.

The innovative architectural platform described in this paper exploits the merits of standard GPON and WiMAX technologies to facilitate ubiquitous connections with low deployment cost and mobility. The centrally controlled ONU/BSs, in comparison with distributed control in a typical WiMAX deployment, has allowed for the formation of overlapping cells which have enabled GPON redundancy in case of fibre failure between a distribution point and an ONU and enhanced WiMAX capacity. To that extent, a highly-transparent network topology is demonstrated featuring wireless transmission by means of FDM over single-wavelength splitter PONs. In addition, the extended wavelength band overlay for higher network scalability has been presented requiring only the slightest modification in hardware through the use of a multiplexer and low-cost VCSEL arrays in the OLT and ONU/BS respectively. As a result, management of the FDM scale leads to reduced-cost optical and electrical components, decreased dispersion and dynamic assignment of ONU/BSs to wavelengths. The obtained results demonstrate maximum EVMs of -30 dB in downstream to comply with typical WiMAX transceivers while error-free transmission of standard WiMAX rates have been demonstrated bidirectionally for extended link lengths up to 21 km for both single- and multi-wavelength architectural platforms.

References.

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