Multi-Wavelength Wireless-PON

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ABSTRACT

An innovative architectural platform demonstrating transparent transmission of frequency division multiplexed (FDM) WiMAX channels over multi-wavelength splitter-PONs enriched by overlapping cell functionalities has been investigated to potentially double the spectral efficiency and provide resilience. The obtained results has demonstrated EVMs below -30 dB at ONU/BS WiMAX remote antenna inputs and 4 dB downstream power penalty for 10^{-6} BERs over line-of-sight overlapping micro-cells circumference without any error coding. In addition, to accommodate various delay requirements a dynamic multi-wavelength (DMW) protocol suite is examined demonstrating a minimum of 100 Mbit/s bandwidth provision for each of 32 ONUs with a maximum 0.085 s packet delay for the worst-performing lower service level agreement (SLA) ONUs.

Keywords: WiMAX; PON; DMW; Overlapping cells; FDM;

1. INTRODUCTION

Convergence of optical and the rapidly growing by means of, deployment and standards wireless networking, represents the current challenge for ubiquitous broadband multimedia communications [1, 2]. To that extent, this paper presents an innovative architecture demonstrating transparent transmission of broadband wireless signals to remote optical network unit/base stations (ONU/BS) addressed by frequency division multiplexing (FDM) over multiple wavelengths of splitter-based PONs. In addition, a gigabit passive optical network (GPON) upstream map frame format enhancement has been developed to accommodate aforementioned dynamic multi wavelength (DMW) transmission. Accordingly network functionality has been supported by means of an algorithm, managing bandwidth allocation among utilised wavelengths in a dynamic two dimensional protocol.

2. NETWORK ARCHITECTURE

A comprehensive diagram of the proposed multi-wavelength splitter-PON, incorporating the developed modelling setup, is shown in Fig. 1. Any wavelength in the selected operating spectrum could be partially or exclusively assigned to different ONU/BSs, providing in the latter service levels similar to WDM-PONs without requiring any modifications in the remote node (RN). This is implemented by the addition of a dense array waveguide grating (DAWG) in the OLT and tuneable optical filters in ONU/BSs. On each wavelength, multiple RF WiMAX channels are arranged in a frequency division multiplexed (FDM) window to address individual ONU/BSs sharing a single wavelength. The same FDM window could be carried on multiple wavelengths relaxing bandwidth requirements of optical and electrical devices and also providing for enhanced network scalability and dynamicity.

Another significant feature of the proposed topology lays in the use of low-cost VCSEL arrays to demonstrate colourless terminations upstream with simple coupling optics. In contrast to RSOAs [3], VCSEL

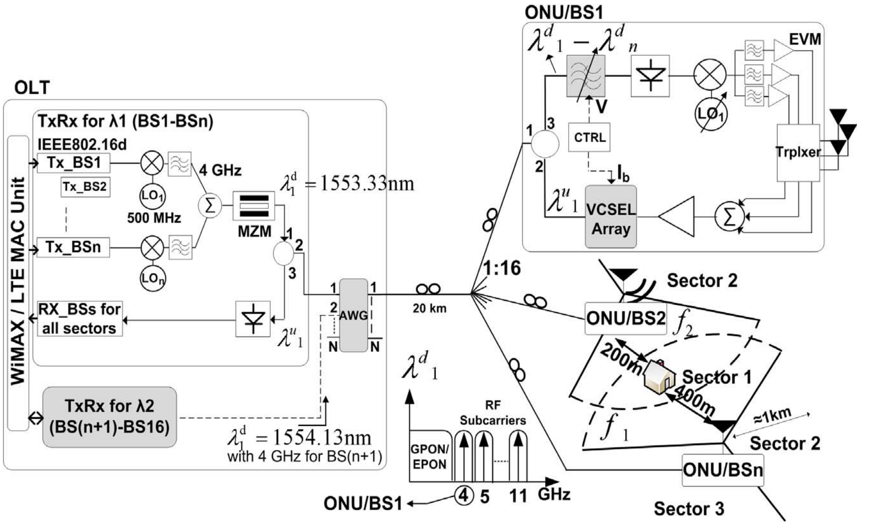

Figure 1. WiMAX over multi-wavelength, splitter PONs.

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arrays do not require upstream wavelengths transmitted downstream reducing the Rayleigh backscattering effect.

Significantly, the WiMAX user could experience higher quality of service since each transceiver in an overlapping region could be tuned to different channels depending on the bandwidth requirements. The transmission distances between ONU/BSs shown in Fig. 1, allow for higher spectral efficiency compared to traditional WiMAX deployment while could be potentially extended with the application of relay techniques.

2.1 Network Transmission Evaluation

A physical layer simulation test-bed, as shown in Fig. 1, was implemented using the industrial standard Virtual Photonics Inc. (VPI), enriched in functionalities in view of MATLAB programming, to build an integrated simulation platform [4] for the transmission of wireless channels over a multi-wavelength GPON and overlapping cell circumferences.

To that effect, three 20 MHz, 70 Mbit/s, 64-QAM, 256-OFDM downstream WiMAX channels [5] are generated individually by the transmitter for ONU/BS1 (Tx_BS1) and Tx_BS(n + 1), ranging from 3.4 to 3.6 GHz, with 100 MHz spacing. As shown in Fig. 1 they are up-converted to the same 4 GHz RF subcarrier using a 500 MHz local oscillator. Subsequently, signals from both transmitters are modulated on $\lambda^d_1 = 1553.33$ nm and $\lambda^d_2 = 1554.13$ nm and after applied over the corresponding circulators for bidirectional transmission, the modulated wavelengths are multiplexed at the DAWG and routed to the destination PON through 20 km of standard single-mode fibre (SSMF). After being broadcasted to each ONU/BS, a tuneable optical band-pass filter with 50 GHz bandwidth is used to select each wavelength which is then detected by an avalanche photodetector (APD) followed by frequency downshifting to result to the transmitted WiMAX channels.

The error vector magnitude (EVM) below -30 dB, as shown in Fig. 2 (left), have been demonstrated for standard RF WiMAX channels at ONU/BS antenna inputs for both wavelengths, matching closely the WiMAX standard [5]. Therefore, the proposed multi-wavelength xPON provides transparent pipes for WiMAX signals without any dispersion compensation techniques. In addition, the direct VCSEL array [3] laser modulation has also demonstrated successful transmission of upstream WiMAX channels over the integrated network [2].

Furthermore, to demonstrate the overlapping cell functionality, the two received radio channels at both base stations are transmitted to a single overlapping cell receiver. Typical power budget parameters, found in standard deployments, were modelled for the WiMAX transceivers. As shown in Fig. 2 (right), an initial 4 dB power penalty is observed at a BER of 10^{-6} in the presence of a LOS channel [5]. This represents a worst case scenario due to the absence of any wireless channel coding. As expected, further power penalties were monitored over NLOS. Based on the empirical path loss model for fixed WiMAX applications [6], transmitted power of +40 dBm and receiver sensitivity of -71.7 dBm, the maximum transmission distance for LOS channel was 430 m. Finally, the received constellation diagram, displayed as inset in Fig. 2 and obtained prior to gain and phase compensation, show the rotation due to the optical filter phase response.

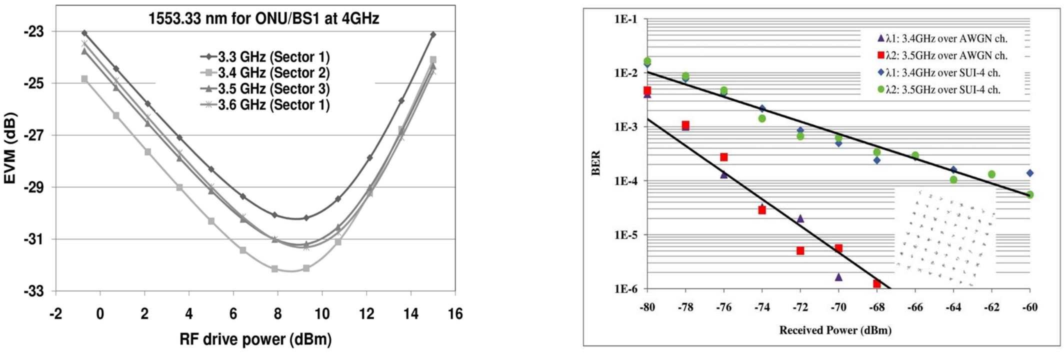

Figure 2. EVM (left) and BER (right) for the WiMAX channels in the overlapping sector downstream.

3. DYNAMIC MULTI-WAVELENGTH (DMW) PROTOCOL

The proposed multi-wavelength transmission upstream could significantly reduce the network utilisation and also increase mean packet delay. To that extent, a DMW-GPON protocol is designed to increase upstream capacity, compared to previously monitored results [4], and provide support for multi-wavelength operation over the currently deployed GPON infrastructures.

3.1 Principle of Operation

The DMW algorithm facilitates four SLAs to assign each ONU with a guaranteed minimum bandwidth, satisfying their basic service requirements, plus an additional allocation of extra bandwidth on demand based on the assigned SLA to provide greater user experience and network flexibility. In addition, extra upstream wavelengths, bringing the total to five, are introduced in a model with respect to previous DMW developments [4] to scale-up wavelength assignment in view of the ITU-T G.984.5 standard [7]. However, the performance evaluation has been drawn from three wavelengths only in order to efficiently make comparison with previous measured results [4].

As described in [4], the OLT assigns the upstream available bandwidth in each polling-cycle in three stages, bandwidth calculation, bandwidth allocation, and wavele1ngth allocation. After having received the requested bandwidth from each ONU, the OLT calculates a safety margin as shown in Fig. 3 (left) [4]. In that manner, the OLT allocates ONU bandwidth by means of the individual total network capacity depending on the time and wavelength. Random distribution of ONU traffic among the different wavelengths could potentially result in exceeding the maximum available cycle-time. Progressively the DMW OLT specifies the three highest ONU allocated bandwidths, since three wavelengths are utilised in the current implementation, and positions them at the end of each cycle as shown in Fig. 3 (left). As a result the network throughput is increased by decreasing adjacent cycle idle times, resulting from delays associated with processing the report and grant messages by the OLT and the associated round trip time (RTT). The remaining ONU bandwidths are assigned to wavelengths in order, from high to low, starting at λ_{up0} and finishing at λ_{up2}. This process allows the OLT to guarantee that the last ONU's time-slot in λ_{up2} can fit within the safety margin. This approach potentially produces a shorter polling cycle length, a reduction in the ONU upstream packet waiting-time in proceeding cycles, and hence increased network utilization.

Although the DMW algorithm deals successfully with adjacent cycle idle times, the network wavelengths are not always evenly populated resulting in idle times within each cycle, as seen primarily in Fig. 3 (left) for λ_{up0} and λ_{up2}. This is resolved in the updated algorithm by allocating any remaining available bandwidth for each wavelength from the OLT to its assigned ONUs according to their SLA, before sending the gate message. Fig. 3 (right) portrays the finalised bandwidth allocation for each ONU in orange on top of the initial allocation in yellow to demonstrate the protocol enhancement. This step leads to a better bandwidth utilisation and reduced mean packet delay of the system.

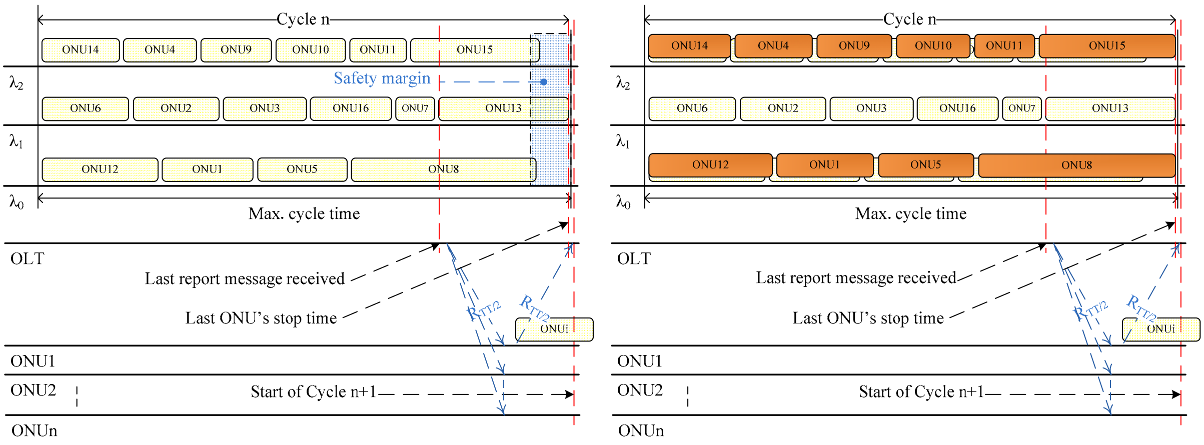

Figure 3. DMW-GPON normal bandwidth assignment (left) and with extra bandwidth assignment (right).

3.2 Simulation Results

To investigate the performance of the proposed DMW protocol a FTTH oriented GPON network was initially modelled using the OPNET platform with Pareto self-similar traffic with typical Hurst parameter of 0.8, 1.24416 Gbit/s upstream data rate, 2.488 Gbit/s downstream data rate, and 32 ONUs. The latter were organised to implement service level agreement diversity with 4 ONUs assigned at SLA0, 4 ONUs at SLA1, 8 ONUs at SLA2, and 16 ONUs at SLA3 from high SLA to low respectively, simulating progressive network usage. In particular a 96 bits GPON guard-time between ONU traffic was considered, a 2.0 ms maximum cycle time, 20 km link lengths between the OLT and ONUs, and as explained in the previous section, 3% of the maximum cycle time utilised as a safety margin.

Comparing the DMW-GPON performance, with that of the DMB-GPON [8], as shown in Fig. 4 (left), the overall network capacity of the former is confirmed to have been increased by a factor equal to the number of wavelengths employed. Although such a characteristic was rather expected, it was achieved with the simultaneous increase in each DMW wavelength throughput by 70 Mbit/s compared to the DMB network. It has also been achieved at the provision of 100 Mbit/s minimum transmission rate per ONU, for 32 ONUs, as opposed to 30 Mbit/s basic bandwidth per ONU in the DMB-GPON. This imposes a reduction in idle time between cycles. In addition, the use of the 3% safety margin has not limited the wavelengths' throughput, in contrast to the single wavelength DMB capacity, due to the more effective utilisation of the available time slots.

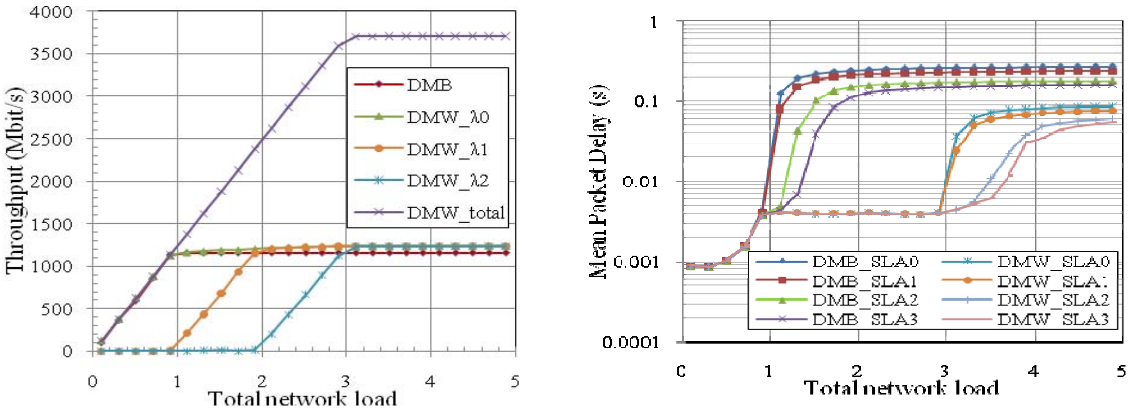

Figure 4. Throughput (left) and mean packet delay (right) versus total network load for DMB and DMW-GPON.

In another performance evaluation measure, while the mean packet delay for all SLAs utilising a single wavelength exceeds 0.1 s, when the total network load achieves one wavelength capacity at 1.24 Gbit/s, shown in Fig. 4 (right), the DMW protocol provides notably decreased packet delay. Corresponding figures indicate 0.003 s delay up to the point the total network load reaches three wavelengths capacity, allowing for the non obstructive transmission of interactive applications. Thus the DMW protocol allows for real time service provisioning at the stringiest requirements of the real time services at increased basic bandwidth to 100 Mbit/s and increased ONU volume. Even at higher network load, the lower service level DMW ONUs, displaying the greatest delay, still maintains delay figures below 0.1 s which provides the scope for further scalability to ONU provision and service advancements.

4. CONCLUSIONS

A highly-scalable network topology is described featuring wireless transmission by means of FDM over multi-wavelength splitter PONs. The network dynamicity through overlapping cells is also presented by routing multiple-wavelengths to a single user via a radio link. The 4 dB power penalty at BERs of 10^{-6} for 70 Mbits/s downstream channels respectively were obtained transmitted over standard 20 km PONs and 430 m overlapping cell circumferences in the absence of channel error coding and relay techniques. In addition, a novel DMW algorithm for the multi-wavelength operation upstream demonstrated aggregate transmission bit-rates for wired users of 3.70 Gbit/s in the presence of three wavelengths and 32 ONUs, 100 Mbit/s minimum bandwidth per ONU and a considerable reduction in mean packet delay in comparison to a resourceful single wavelength GPON topology. The obtained maximum packet delay of 0.085 s at heavy loading allows for the continuous communication of the stringiest specification interactive services.

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