Hybrid 2.5G/10G Co-existing OFDMA-PON Employing Single Receiver at the OLT

Dayou Qian, Junqiang Hu, Ting Wang
NEC Laboratories America, Inc., 4 Independence Way, Princeton, NJ 08540
dqian@nec-labs.com

Abstract: A 2.5G/10G co-existing OFDMA-PON is demonstrated through 20km SSMF with 31dB loss budget. Only one receiver at the OLT and low-speed transceiver at the 2.5G ONUs are required, thereby reducing system complexity and cost.

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1. Introduction to the style guide, formatting of main text, and page layout

Multiple rates co-existing PON can bring many benefits including high flexibility and low operation cost to the carriers. As the continuing standardization work of FSAN for NG-PON and NG-PON2, a much higher data link is becoming possible for the end-users in the future optical access networks. However, it is also possible that different data speeds could be chosen as the system specification at different stages of the standardization work based on their technology difficulties and business model. A 2.5Gb/s upstream link could be deployed first, and upgraded to 10Gb/s or even 40Gb/s later. Meanwhile, ONUs with different rates may co-exist and be linked to the same central office (CO) based on their different upgrading levels [1]. On the other hand, when 10Gb/s or 40Gb/s links [2] are available, they are not deployed for residential end-users who only require Gigabit Ethernet for their interactive 3D-TV, HD-video conference/call, PtP applications, on-line gaming, etc. Those huge pipes are more desired by the commercial customers like an enterprise building, a mobile base station, a small data center or a bank branch. Because those customers usually have very different network usage hours during a day, for example, a bank branch may back-up its data only after midnight and an enterprise building would operate its network mainly during working hours, they may co-exist with residential end-users in order to optimize the system efficiency and equipment utilization. Obviously, a flexible CO which can support multi-rate ONU-s is a cost-effective solution.

In WDM-PON, each ONU uses a dedicated wavelength to transmit data. Different data rate links can co-exist easily by using WDM technologies. However, WDM-PON still requires optical AWG and multiple receivers in the OLT, and it still lacks the flexibility to dynamically allocate the bandwidth among the ONUs. In TDM-PON, dual-rate burst-mode receiver [3] has been experimentally demonstrated, but the dual-rate burst-mode receiver could be complicated and expensive, and it is also limited by the data rate beyond 10G. In OFDMA-PON [4], the total available bandwidth will be split into sub-carriers which are orthogonal to each other. The bits stream of one ONU are only mapped to its own assigned sub-carriers and the un-assigned sub-carriers would be set to zero and saved for other ONU-s, so that each ONU only uses only part of its total available bandwidth. Both downstream and upstream multi-rate transmission can be easily achieved by assigning different number of sub-carriers to different ONUs. However, for upstream transmission in a multi-rate ONUs co-existing network, when all ONUs have the same high-speed DAC, this architecture will cause significant waste of the DAC bandwidth and increase the ONU cost.

We propose and experimentally demonstrate an enhanced OFDMA-PON architecture to receive multi-rate upstream transmission with a single receiver at the OLT. In the experiment, one 5GHz signal and one 1.25GHz signal are generated by two ONUs with 20GS/s and 5GS/s DAC respectively, direct-detected by one photodiode at the OLT, and demodulated by a single regular OFDMA receiver with 20GS/s ADC. The QPSK modulation format is used, enabling 10Gb/s and 2.5Gb/s dual-rate upstream transmission. The proposed architecture can also support other or multiple (>2) data rates without any hardware modification.

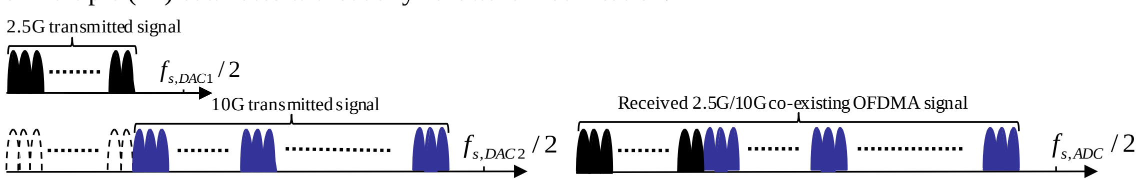

Figure 1. Transmitted and received hybrid 2.5G/10G co-existing OFDMA signal

2. Dual-rate receiving technologies for OFDMA-PON

The proposed architecture is still based on OFDMA technology. The OFDMA frames are made up of many orthogonal sub-carriers allocated in the frequency domain. Different rates can be supported by assigning different number of sub-carriers to the ONUs. When the DAC sampling rates are different, in order to use a single OFDMA demodulator to receive all the upstream signal at the same time, the sub-carrier bandwidth of all ONUs have to remain the same and orthogonal to each other as show in Figure 1. The DAC clock frequency offset among all the ONUs has to be minimized to reduce the inter-sub-carrier-interference (ICI). The upstream OFDMA frames from multiple ONUs also need to be aligned and synchronized at the receiver of OLT. Low data rate ONU only needs a low-speed DAC to generate its own OFDMA signal. The DAC bandwidth in one ONU can be fully utilized by itself and it could be much lower than the ADC speed at the OLT.

3. Experimental Setup

Figure 2 depicts the experimental setup for 2.5G/10G co-existing upstream with a single receiver. At the 2.5G ONU upstream transmitter, QPSK symbols were mapped onto baseband OFDM sub-carriers (-25th ~ -1th & 1th ~ 25th) where 0th sub-carrier was saved for DC component. Sub-carriers (-41th ~ -26th & 26th ~ 40th) were used as guard band. The FFT size was 82. The baseband I/Q signals were digitally up-converted to generate OFDM RF signal with the frame size 164. Then the RF signal was up-sampled 50/41 times to match the DAC sampling rate at 5GS/s. Similarly at the 10G ONU upstream transmitter, QPSK symbols were mapped onto baseband OFDM sub-carriers (-50th ~ -1th & 1th ~ 100th) where 0th sub-carrier was saved for DC component. Sub-carriers (-116th ~ -101th & 101th ~ 115th) were used as guard band. Sub-carriers (-100th ~ -51th) were reserved for 2.5G ONU signal. The FFT size was 232. The 10G baseband I/Q signals were digitally up-converted to generate OFDM RF signal with the frame size 464. Then the RF signal was up-sampled 50/29 times to match the DAC sampling rate at 20GS/s. Due to the short transmission distance, cyclic prefix (CP) was not used. A training sequence was added every 128 OFDM data frames. The resulting OFDM RF signals were uploaded into two Tektronix AWG 7122B (AWG1 and AWG2) operating at 5GS/s and 20GS/s with 8-bit DAC resolution. Both AWG1 and AWG2 were synchronized with a 10GHz clock signal. The upstream OFDMA frames alignment and synchronization was achieved with an external trigger signal at 10MHz.

To generate the optical signal, two distributed feedback lasers (DFB) (linewidth ~100MHz) with λ_1 = 1546.1 nm and λ_2 = 1546.9 nm were employed as the CW optical sources for two 10 GHz intensity modulators (IM1 and IM2) driven by the OFDM RF signals output from AWG1 and AWG2. The upstream optical signals were next combined with a 2:1 optical coupler and transmitted to the OLT receiver through 20 km SSMF, followed by a optical tunable attenuator (OTA) to vary the received power level. All fiber used is standard SMF-28 fiber with 17 ps/nm/km dispersion and an insertion loss of 0.2 dB/km at 1550 nm. The upstream transmitted power of each ONU was 7dBm.

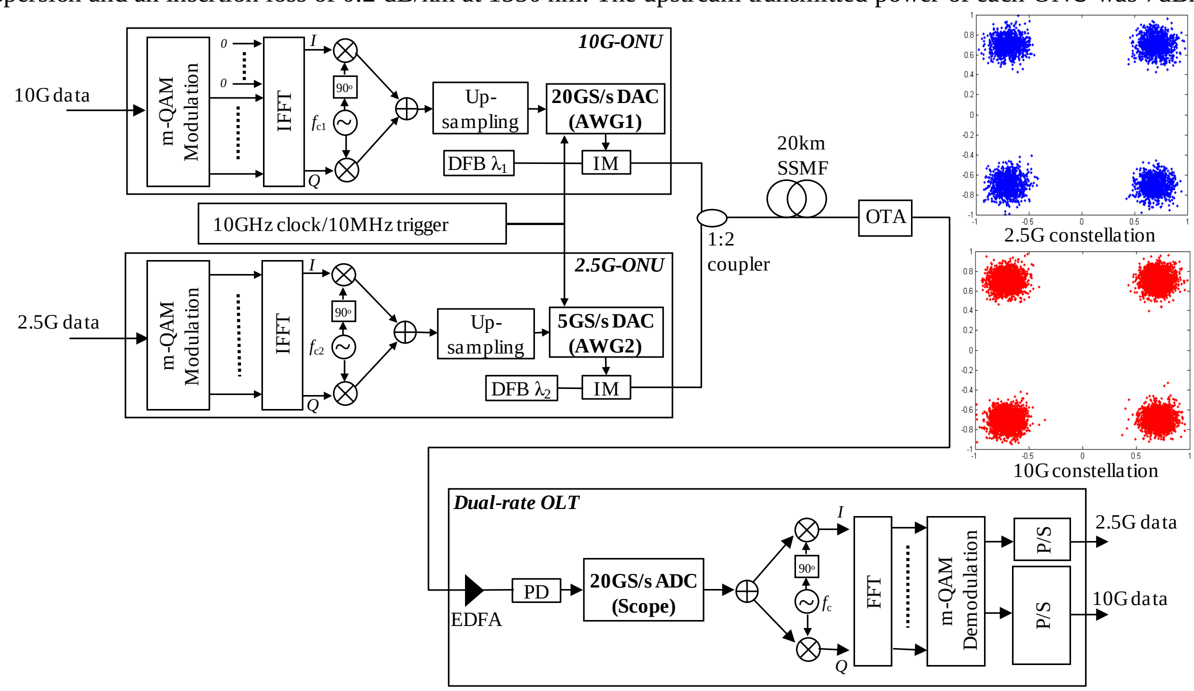

Figure 2. Experimental Setup

At the receiver (OLT), the received power was adjusted between -5dBm and -29dBm by the OTA, accounting for a 4-5dB attenuation from 20km fiber and 9~32dB attenuator loss. The received signal was amplified via an EDFA, and photodetected by one 10GHz photo diode (PD), while sampling and digitization were performed by a 20 GS/s ADC (LC830Zi-A scope). The sampled data was then processed with off-line DSP.

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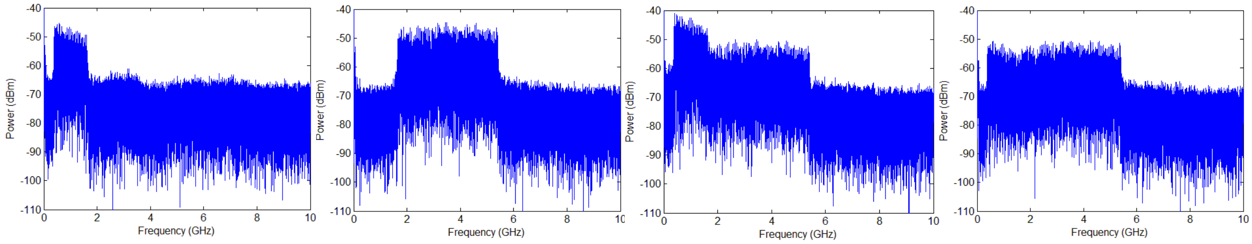
Within the off-line DSP receiver, the data was recovered through five steps: first, output from the ADC was fragmented into 800-sample segments. Next, each 800-sample segment was processed by 800-point FFT. Third, channel estimation and single-tap equalization were performed. Gray-code mapping was used to convert the data back to binary format in the subsequent step. Finally, the recovered data was separated to 2.5G and 10G binary streams for performance measurement. All the transmission Q-factor and BER measurements were calculated from 10^5 symbols and 10^6 bits.

4. Results and Discussion

The electrical spectrum of the signals is shown in Figure 3. Both 2.5G and 10G signals can be transmitted in either single or dual-rate modes. When both signals are transmitted simultaneously, the received power may be different as shown in Figure 3 (c). Equal power control was used in the experiment to balance both 2.5G and 10G signals (Figure 3 (d)).



(a) (d) (c) (d)

Figure 3. Spectral figures of received signal at the OLT

(a). Single 2.5G upstream signal; (b). Single 10G upstream signal; (c). 2.5G/10G co-existing upstream signal without power control; (d). 2.5G/10G co-existing upstream signal with power control

Figure 4 shows the Q-factor performance for single and dual-rate transmission. In single rate mode, the 2.5G and 10G transmission can achieve Q-factor above the FEC limit with the received power of -24dB and -26dB. In dual-rate mode, the 2.5G and 10G transmission can achieve Q-factor above FEC limit with the received power of -21dB and -22.5dB. The 3~3.5dB difference is caused by the power split between two optical carriers before the EDFA in dual-rate mode. Meanwhile, the power loss budget up to 31dB and 32.5dB can be successfully achieved for 2.5G and 10G data rates. The transmission penalty is negligible. The BER performance is also measured for the same setup as shown in Figure 5.

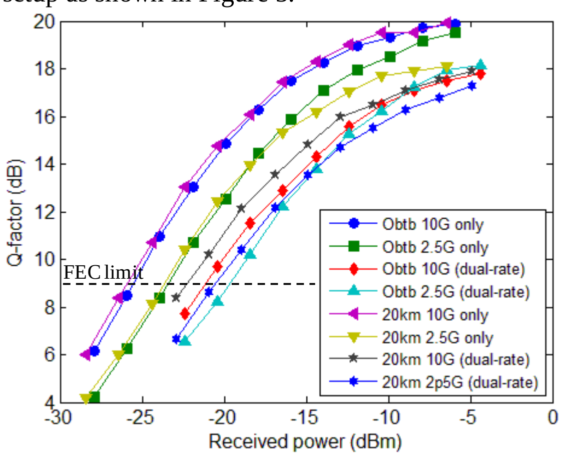


Figure 4. Single and dual-rate Q-factor performance

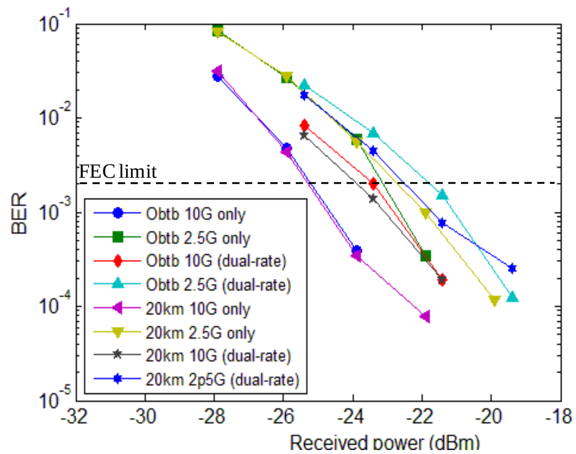


Figure 5. Single and dual-rate BER performance

5. Conclusions

This paper presents and experimentally demonstrates an enhanced OFDMA-PON using single receiver to support coexistence 2.5G/10G ONUs. BER and Q-factor performance were measured after 20 km SSMF transmission plus 8~32dB attenuation. The FEC limit can be satisfied with the power loss budget of 31dB. The introduced architecture may be viewed as a highly attractive candidate for the next-generation PON.

[1] http://www.ieee802.org/3/av/.
[2] D. Qian, ECOC 2009, PD 3.3.
[3] J. Nakagawa, OFC 2010, PDPD10
[4] D. Qian, ECOC 2007, paper Mo 5.4.1.