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Inter-band interference suppression in multi-band OFDM-PON uplink transmission using window shaping

Chang-Hun Kim, Sang-Min Jung, Sun-Young Jung, Soo-Min Kang, Sang-Kook Han *

Department of Electrical and Electronic Engineering, Yonsei University, 50, Yonsei-ro, Sinchon-dong, Seodaemun-gu, Seoul 03722, Republic of Korea

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ABSTRACT

We propose window shaping based inter-band interference suppression technique in multi-band orthogonal frequency division multiple access (MB-OFDMA) based passive optical network (PON) system. Conventional MB-OFDMA and raised-cosine (RC) windowed MB-OFDMA were compared in QPSK transmission and adaptive modulation scenario. The effect of OFDM clipping ratio is analyzed, which is used to mitigate peak to average power ratio (PAPR) problem at the transmitter. Also, the MB-OFDMA based multiple access performance is investigated according to the different roll-off factor of RC window in terms of error vector magnitude (EVM) and effective bit rate. Compared with the conventional MB-OFDMA which is rectangular windowed, the RC-windowed MB-OFDMA shows better performance by suppressed sidelobe which leads to IBI. The maximum effective bit rate of 10 Gbps was achieved for 20 km transmission scenario at optimum roll-off factor, while it was 9 Gbps in the conventional MB-OFDMA transmission.

1. Introduction

Orthogonal frequency division multiple access (OFDMA) based passive optical network (PON) system has been spotlighted and widely researched to accommodate explosively increasing data traffic, due to its various benefits such as high spectral efficiency, fiber dispersion tolerance and two-dimensional bandwidth allocation in time and frequency domain [1–3]. Also intensity modulation with direct detection (IM/DD) based OFDM transmission provides system simplicity and cost effectiveness [4,5].

However, time synchronization is essentially required among multiple access signals to maintain the OFDM orthogonality in the OFDMA-PON system [1,2,4]. In practical, multiple access signals are generated at different time in each optical network unit (ONU), and the fiber lengths from optical line terminal (OLT) to each ONU are also different. Although this problem could be overcome through cyclic prefix (CP) extension, the effective bit rate decreases as much as CP length. Theoretically 50% CP of symbol duration is required for asynchronous multiple access of two ONUs to maintain the orthogonality, and the effective bit rate becomes a half. Thus, the time synchronization is one of the main challenges in OFDMA-PON uplink system.

On the other hand, multi-band OFDMA (MB-OFDMA) system [6,7] transmits asynchronously independent OFDM signals on the different frequency band, and it could be a suitable solution for realizing next generation of optical access network. Besides, ONU complexity and energy requirements could be relaxed in the MB-OFDM system using RF oscillator by processing the signal as much as used bandwidth without overcapacity [6]. However, inter-band interference (IBI) caused by OFDM sidelobes degrades the MB-OFDM signal performance such as in asynchronous OFDMA system. Guard band (GB) between adjacent bands is usually used to mitigate the IBI, but it leads to waste of bandwidth [6].

In this paper, MB-OFDMA PON with IBI mitigation based on raised-cosine (RC) windowing technique is experimentally demonstrated. The proposed system is compared with conventional MB-OFDMA to verify IBI mitigation effect. In order to avoid optical beating interference (OBI) issue, different wavelength optical sources are used for each ONU. The MB-OFDM signal is digitally generated using subcarrier allocation technique such as in an OFDMA scenario, and different digital sample delay between bands are applied to implement asynchronous transmission condition. Three-bands OFDM signals and two-ONUs are used for the experiment as a proof of concept. The IBI effect according to the different clipping ratio and roll-off factor of RC window are investigated. Also, adaptive modulation is applied to maximize the total throughput. The results show IBI mitigation effect of RC window which leads to improvement of error vector magnitude (EVM) and bit loading performance.

* Corresponding author. Fax: +82 2 364 4016.
E-mail address: skhan@yonsei.ac.kr (S.-K. Han).

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2. MB-OFDM uplink system architecture

Fig. 1 illustrates the proposed MB-OFDM upstream architecture with different bandwidth allocation between OFDMA and MB-OFDMA. In both cases, two-dimensional bandwidth allocation in time and frequency domain is feasible. However, the time synchronization among multiple ONU should be maintained in the OFDMA system, and it would cause system complexity for bandwidth allocation planning with higher redundancy by extended CP length. On the other hand, the MB-OFDMA is robust to asynchronous multiple access by transmitting independent OFDM bands and receiving each band individually through multiple demodulation processes without need to maintain the orthogonality among OFDM bands. However, OFDM bands affect to one another by their sidelobes, which is called IBI. In order to reduce the IBI, using broad GB between adjacent bands is the simplest solution. However, it leads to waste of bandwidth and effective only around the bands boundaries while IBI affects to overall signal bandwidth. In our study, RC-window was applied to mitigate the IBI by suppressing the OFDM sidelobe. It allows improvement of data capacity by minimizing the required GB. Hence, MB-OFDMA with windowing technique could be a suitable candidate for future PON which requires low latency network with high capacity to support internet-of-things (IoT) services such as smart grid, smart city and so on.

3. Windowed OFDM signal generation

Fig. 2 shows block diagram of windowed OFDM transmitter and frame structure used in our experiment. The windowed OFDM signal is generated by conventional OFDM signal, shaping prefix & postfix, and windowing processes [8–10]. The cyclic extension of each OFDM frame is used for SP, and usually well-known RC window [9,10] was applied in our experiment to mitigate IBI effect. To reduce the windowing overhead by SP, overlap and sum were applied in the roll-off region. As a result, effective symbol duration becomes $(1+\beta)T_s$, where T_s and β are symbol duration of conventional OFDM signal and roll-off factor, respectively. Finally, the widowed and normalized signal is clipped at clipping level A which is defined by clipping ratio (CR) as follow:

$$x_{\text{clipped}} = \begin{cases} -A, & \text{if } x < -A \\ x, & \text{if } -A \leqslant x \leqslant A, \quad A = \sqrt{10^{\frac{CR}{10}}} \\ A, & \text{if } x > A \end{cases}$$

The conventional OFDM has rectangular window corresponding to $\beta = 0$. It leads to sinc shaped spectrum which has high sidelobe level and causes IBI. The IBI could be mitigated by RC-window which has suppressed sidelobe.

4. Experiments

For the demonstration of IM/DD based MB-OFDMA-PON as a proof of concept, three bands OFDM with two ONUs were used as shown in Fig. 3. The MB-OFDM signals were generated by sub-carrier allocation with 512 subcarriers from DC to 2 GHz. The bandwidth ratio of three OFDM bands was set to 1:1:2 with guard band (GB) as 1 subcarrier at both side of each band. That is, digital up-conversion based MB-OFDM signal was used for a simple experimental configuration, and focused on the IBI mitigation effect by RC window in the MB-OFDMA-PON system. The FFT/IFFT size of 2048 was used for Hermitian symmetry and oversampling factor of two. The CP length was 1/64 of symbol duration. In addition, different digital sample delay was applied to different bands in order to implement asynchronous scenario. The asynchronous MB-OFDMA signals for ONU 1 and ONU 2 were generated by MATLAB and extracted by an arbitrary waveform generator (AWG: Tektronix 7122B) sampling at 8 Gsample/s. Two lasers with 20 GHz spacing were used for uplink sources in order to avoid OBI issue. The 1st and 3rd bands of OFDM signals were modulated by 10 GHz MZM1 at quadrature point for intensity modulation, and 2nd band was modulated by MZM2. Two launched optical powers were fixed and monitored at −3 dBm by variable optical attenuator (VOA) and in-line optical power monitor (PM). Then, two optical signals were combined by 3 dB optical coupler and transmitted to OLT. The VOA and PM were used to control the optical power

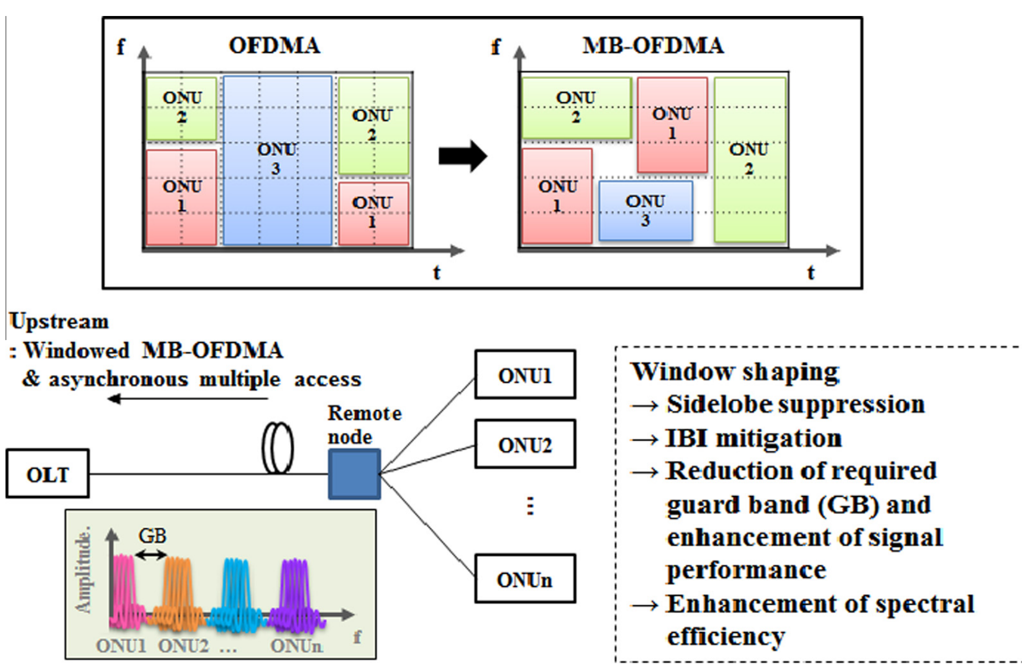

Fig. 1. Network architecture and difference between OFDMA and MB-OFDMA for the uplink transmission.