Polarization Sensitivity Mitigation for AM-CO-OFDMA PON Uplink Transmission

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Abstract— A novel technique for mitigating the polarization sensitivity between the uplink multiple access signals was proposed in the AM-CO-OFDMA PON uplink transmission. To provide uplink multiple access on the orthogonal frequency division multiplexing (OFDM) based optical access network, the polarization difference between the uplink optical signals are unavoidable issue which degrades a transmission performance severly. By using symple digital signal processing with Pythagorean identity, we experimentally demonstrated stable transmission performance of various polarization states of uplink multiple access signals.

1. INTRODUCTION

In recent years, coherent optical transmission is moved down to the area of optical access network with its attractable advantages likes high receiver sensitivity, fineness of its spectral selectivity and dense spectral efficiency [1, 2]. Especially, with orthogonal frequency division multiplexing, the coherent orthogonal frequency division multiple access passive optical network (CO-OFDMA PON) has tremendous attention because of its easy of multiple access with dynamic bandwidth allocation (DBA) on the same nominal wavelength and high spectral efficiency with the adaptive modulation on the individual subcarriers of OFDM signal frame [3]. But, to realize OFDMA based PON system, there are some critical issues which come from the de-correlation of the uplink optical fields which transmitted from each optical network unit (ONU). Because the uplinks signals are carried on the same nominal wavelength, it generates optical beating interference (OBI) effects which related with the optical phase difference of uplink optical fields when it detected at the photo diode [4]. We already solved the OBI problems with the balanced detection of coherent receiver [5]. But, there is another issue in the practical system, the received uplink optical fields couldn't have same polarization states each other because of its different transmission path and responses of the devices in the link. These variously polarized optical fields lead to the signal fluctuation after photo-detection and crosstalk between the multiple access user signals.

In this paper, we proposed polarization sensitivity mitigation technique in CO-OFDMA uplink multiple accese and experimentally demonstrated it. By using Pythagorean identity with the intensity modulation for uplink multiple access, we eliminated unwanted phase fluctuations of received optical fields of uplink multiple access signals.

2. SCHEMATICS

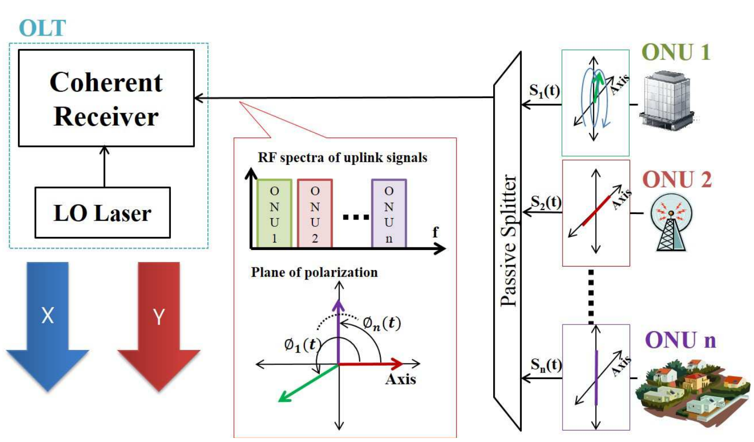

Figure 1: CO-OFDMA uplink transmission.

Figure 1 shows the CO-OFDMA uplink transmission link conceptually in view of RF spectrum and the plane of polarization. In the OFDMA PON, the multiple access can be easily provided by allocating subcarrier sub-bands of OFDM signal frames to each users. In this scheme, especially in uplink transmission, uplink multiple access signals are carried on the optical fields with same nominal wavelength but different transmission paths. These different transmission paths which has different birefringence and channel response in the link cause different polarization responses for each arrived optical fields at the receiver. Because coherent detection uses the optical beating between received signals with local oscillator laser (LO), the polarization mismatch between optical fields of received signals with optical field of LO laser cause unwanted signal fluctuations and signal crosstalk between each polarization output of the coherent receiver. As a result, the received signals at each polarization output of coherent receiver can be described as

$$X(t) = S_1(t)\cos(\phi_1(t)) + S_2(t)\cos(\phi_2(t)) + \ldots + S_n(t)\cos(\phi_n(t)). \tag{1}$$

$$Y(t) = S_1(t)\sin(\phi_1(t)) + S_2(t)\sin(\phi_2(t)) + \ldots + S_n(t)\sin(\phi_n(t)). \tag{2}$$

where $X(t)$ and $Y(t)$ are two orthogoanl polarization componenets, the parallel with reference polarization axis 'X-polarization' and orthogonal polarization componenets with it 'Y-polarization', respectively, and $S_n(t)$ and $\phi_n(t)$ are the n-th uplink signal and polarization angle with respect to the reference polarization axis in each detection moment. We note here, even though the uplink optical fields are arbitrary polarized, at the received moment, it can be considered as linear polarization with each polarization angles. To eliminate the effect of the polarization mismatch, we use trigonometric features of the sinusoidal function which called Pythagorean identity with additional DC bias because the signals have bipolar amplitude.

$$\begin{aligned} U(t) &= \sqrt{X'^2(t) + X''^2 + Y'^2(t) + Y''^2} \\ &= \sqrt{DCs + 2\sum_{k=1}^{n-1}\sum_{j=k+1}^{n} S_k(t)S_j(t)\cos\{\phi_k(t) - \phi_n(t)\} + 2\left\{S_1^2(t) + S_2^2(t) + \ldots + S_n^2(t)\right\}} \end{aligned} \tag{3}$$

where $X'(t) = DC + X(t)$, $X''(t) = DC - X(t)$, $Y'(t) = DC + Y(t)$ and $Y''(t) = DC - Y(t)$. By using the Pythagorean process, it generates unwanted DC components and the beating components between the ONU signals. But, because the ONU signals basically have orthogonality each other, during the FFT process of the OFDM demodulation process, the beating components are vanished and the DC components could not have influence on the subcarriers.

3. EXPERIMENTS AND RESULTS

Figure 2 shows the experimental setup for the proposed scheme. In this experiment, we used self-homodyne detection to avoid carrier frequency offset (CFO). An external cavity laser (ECL) with a center wavelength of 1550.223 nm and linewidth of 50 kHz was used as an optical source. And we used 3 dB coupler to split the launched optical source to the signal carrier and the LO source. And there were additional 3 dB coupler to modulate different user signals by using mach-zehnder modulator (MZM) which droved by arbitrary waveform generator. We used polarization controllers (PCs) before the MZM to maximize the modulation efficiency. Between the uplink signal modulators, we used additional polarization controller and polarization scrambler to generate all the possible polarization state between the uplink optical fields. Before the coherent receiver, additional PCs were used to control the optical field to maximize receiver performance. In the experiments, we used DMT as a modulation format. The calculated DMT signal was loaded into an 8 Gs/s arbitrary waveform generator. The number of FFT size was 512 with Hermitian symmetry. So, the number of effective subcarriers was 256 ranging from DC to 4 GHz and each subcarrier were mapped with 4 QAM. Between each ONU subcarrier subbands, we gave the guard band of 8 subcarriers to reduce the inter-user-interference. As a result, the usable subcarriers for ONU 1 were ranging from 5 to 124 and ONU 2 were ranging from 133 to 252, total transmission throughput was 7.38 Gb/s. The received DMT signal was captured by a digital phosphor oscilloscope with sampling rate of 25 Gsample/s and evaluated by offline processing.

Figure 3 shows the RF spectra of the received signal in each experiment. To analyze the effect of the Pythagorean process to the polarization mismatch in the OFDMA PON uplink transmission, we compare the BER for each case. Without the Pythagorean process, the received signal for uplink ONU signals go through the serious fluctuation because of the polarization mismatch between

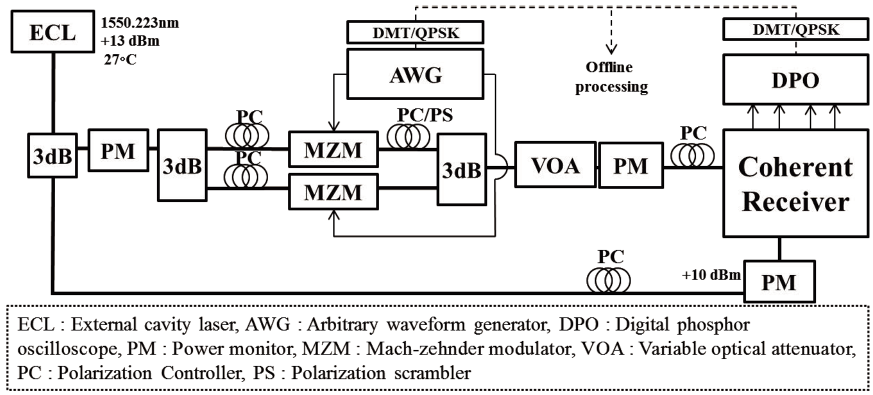

Figure 2: Experimental setup.

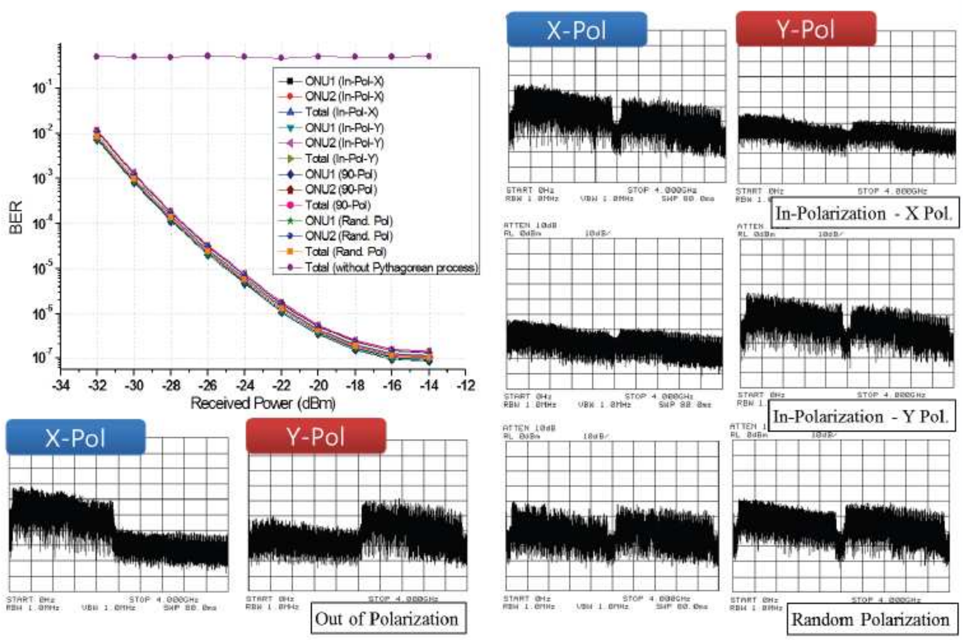

Figure 3: BER and RF spectra of multiple access signals for input optical power of the receiver in case of in-polarized to X between the ONU, in-polarized to Y between the ONU, out of polarized each other, and random polarization with polarization scrambling.

the LO laser and uplink optical fields. As a result, the BER of demodulated DMT frame was almost 0.5 in each received optical powers, this is because the signal fluctuation interferes the synchronization process before the FFT process of the DMT during the demodulation which is very critical to the performance. However, by using Pythagorean process, we could get stabilized the signal performance in each polarization states which means that the average BER among the entire DMT frame was less than 10^{-3}, when the input optical power was higher than $-29\,\mathrm{dBm}$. This shows that it was able to transmit the DMT signal even in randomly polarized uplink signals with satisfying the forward error correction (FEC) limit.

4. CONCLUSION

We have demonstrated a polarization insensitive CO-OFDMA PON uplink transmission with two ONU multiple access by using a simple Pythagorean process. By virtue of this technique, the polarization mismatch issue in coherent optical transmission can be significantly reduced, and as a result, we can stabilize the transmission performance. This concept would be useful for relaxing the critical polarization mismatch problem in the uplink transmission of the CO-OFDMA PON which can provide flexible bandwidth usages.

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