Experimental evaluation of MPI noise mitigation effects for various modulation schemes in analog IFoF-based mobile fronthaul link

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Abstract: Effects of multipath interference (MPI) mitigation for different modulation schemes in analog IFoF link is experimentally evaluated. The results show phase-dithered and polarization-scrambled IFoF signal could tolerate 30-dB MPI for two types of external modulations.

1. Introduction

Analog Radio-over-Fiber (RoF) and analog Intermediate-Frequency-over-Fiber (IFoF) technologies have been gaining large interests as an attractive mobile fronthaul solution for beyond 5G era. This is because not only RoF and IFoF can handle a large bandwidth of radio signals compared with existing digital-based fronthaul technologies based on Common Public Radio Interface (CPRI) or eCPRI, but also it is expected to reduce power consumption especially in the antenna site by simplifying the functions in it. So far many high-capacity RoF and IFoF transmission experiments with sufficient quality compliant to 3GPP criteria have been reported [1], [2]. On the other hand, the most important and biggest issue inherent to analog RoF and IFoF technology is a performance degradation induced by an optical multipath interference (MPI) in actual deployed optical fibers with imperfect connection at the connectors. Since the RoF and IFoF transmit radio signals in an analog waveform, MPI noise significantly degrades the SNR, therefore it is required to have an enough transmission quality under the worst possible MPI conditions. Theoretical analysis and experimental evaluation of MPI impact for directly modulated laser (DML)-based IFoF signal was reported in ref [3]. Similar theoretical analysis of MPI and its reduction by phase dithering for electro-absorption modulator laser (EML)-based IFoF signal has also been reported in ref [4], [5], [6]. For system design, however, it is important to clarify MPI tolerance for different modulation schemes with various MPI reduction methods.

In this paper, the impact of MPI noise for three different analog IFoF modulation scheme, DML, EML and external modulated laser using lithium niobate Mach-Zehnder modulator (LN-MZM-LD) are experimentally compared with the same IF signal and under the same MPI conditions, and compared the impact of MPI reduction technique of phase dithering and polarization scrambling. The results show phase-dithered and polarization-scrambled IFoF signal can tolerate up to 30 dB MPI for external modulations for both EML and LN-MZM-LD.

2. Experiment setup

Fig. 1 illustrates the experimental setup. An arbitrary waveform generator (AWG) generated six frequency-multiplexed and 3GPP-compliant 5G-NR-based 64-QAM OFDM signals with 380.16-MHz bandwidth as wireless IF signal. The center frequencies ranged from 0.3 GHz to 2.3 GHz with 0.4-GHz frequency interval. Additionally, another OFDM signal with the same format as the wireless signal was generated at 6 GHz for phase dithering used in the MPI mitigation experiment. The output signals from the AWG were split into two by an RF splitter, and the IF signal and the dither ODFM signal were filtered using a low-pass filter (LPF) for up to 3 GHz and a band-pass filter (BPF) centered at 6 GHz, respectively. The wireless IF signal was amplified by an RF amplifier and input to the electrical-to-optical converter (E/O) of a transmitter. The dither OFDM signal was also amplified by an RF amplifier and input to the PM in a transmitter. For IFoF transmission, a 5-km single mode fiber (SMF) was used. After transmission, the optical signal was split into two signals by an optical splitter for emulating direct and multi-reflected signals. In the path for the multi-reflected signal, another SMF was inserted to emulate the round-trip transmission delay between two reflection points. After SMF transmission, the polarization of the optical signal was adjusted by a polarization controller (PC) to maximize the influence of MPI between direct and multi-reflected signals. Additionally, a variable optical attenuator (VOA) was used for changing the power of the multi-reflected signal and the SIR between direct and multi-reflected signals. An optical coupler combined the direct and the reflected signals, and both of the signals were simultaneously input to a photodetector (PD) with the received optical power of the direct signal of 0 dBm. The electrical IF signals from the PD were input to a 5G signal analyzer (SA), and the error vector magnitude (EVM) performance was measured after the OFDM demodulation as average values for one minute. Three types of optical transmitter were evaluated in the experiment (depicted as OTx #1 to #3 in Fig.1). The wavelength and linewidth of DML and the light source of EML and LN-MZM were 1551.2 nm and 6.2

MHz, 1553.3 nm and 3.8 MHz, and 1550.1 nm and 100 kHz, respectively. The output optical signal was amplified by an erbium-doped fiber amplifier (EDFA) to compensate for the loss of optical components in the experiment. When evaluating the effectiveness of MPI mitigation scheme, i.e. a phase dither and polarization randomization, an LN phase modulator (PM) and polarization scrambler were inserted after EDFA.

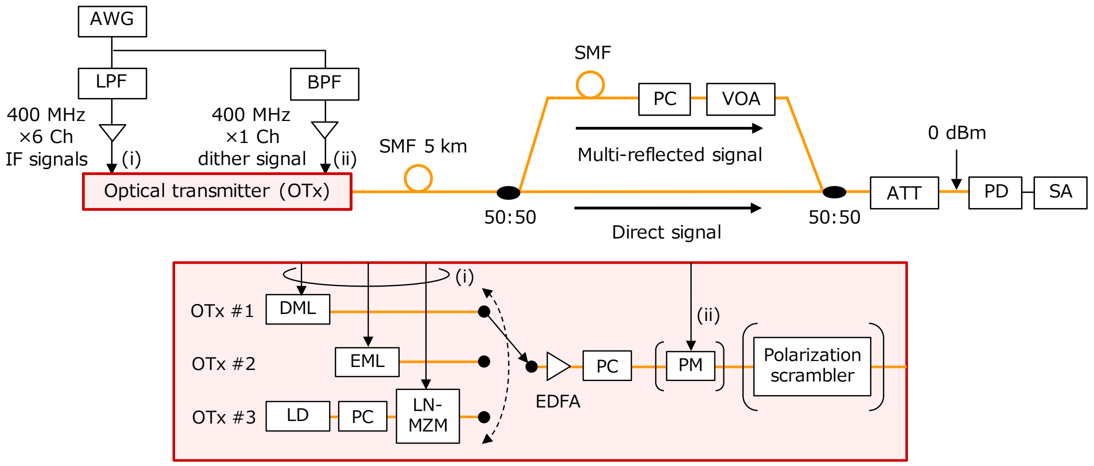


Fig. 1. Experimental setup.

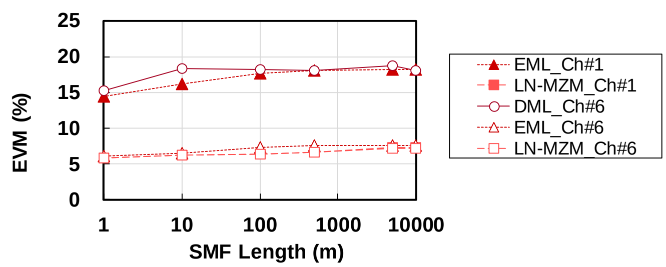


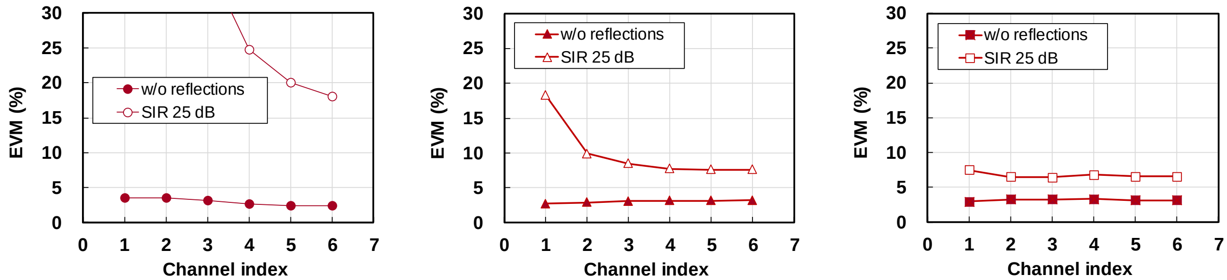
Fig. 2. EVM for different distance of reflection points. (*EVM for DML_Ch#1 was not shown (EVM>50%))

3. Results and discussion

At first, we evaluated the dependency of the MPI effect on the distance between two reflection points. Fig.2 showed the relation between the EVM and SMF length for multi-reflected signal. EVM gets worse for the longer SMF and the EVM stays at almost constant value above 5 km when the SMF length exceeds coherent length of the light source of the modulators. In the following experiment, we use 10 km SMF to consider the worst EVMs.

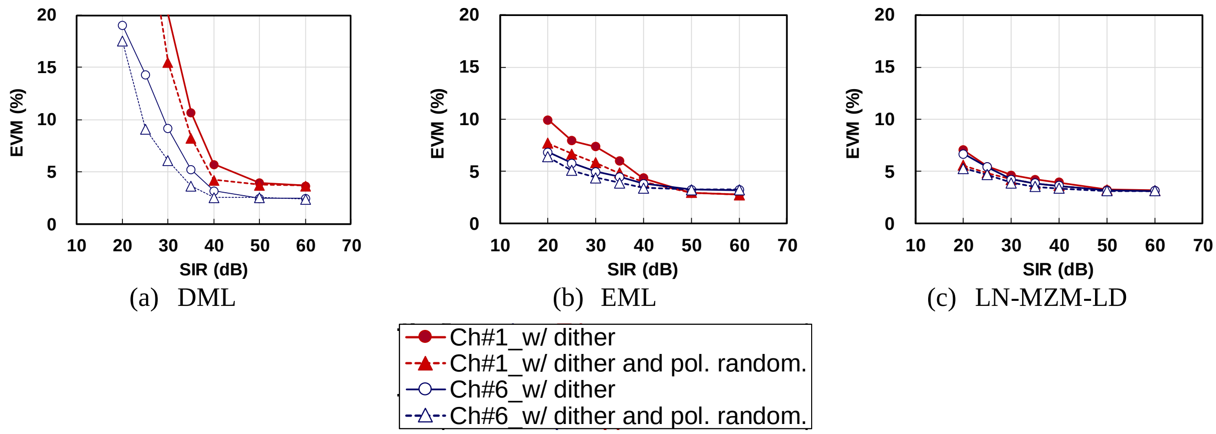
We compare the degree of the performance degradation by MPI for three modulation methods when the SIR was fixed to 25 dB, which is equivalent to the amount of maximum MPI by two Fresnel reflections at the connecter ends. Fig.3 shows the EVM for the modulation scheme of (a) DML, (b) EML and (c) LN-MZM-LD, respectively. We also put the EVMs under no MPI condition as the reference. No MPI mitigation technique was employed in this experiment. When there is no MPI, all three modulation method showed the similar EVM around 3% for all IF channels. However, when we added MPI with 25 dB SIR, significant EVM degradation was observed especially for the lower frequency in the DML case. EML showed a slightly smaller degradation than DML, and LN-MZM-LD showed the smallest degradation. The degradation was caused mainly by the laser chirp [3]. The broadened spectrum by the frequency chirp generates a large beat components especially in the lower frequency side by the direct and multi-reflected signals at the output of the PD [3]. The amount of the chirp-induced degradation was significant for all channels of DML, however, IF channel above #4 (larger than 1.5 GHz) of EML-modulated signals showed the smaller degradation. LN-MZM-LD showed almost no frequency dependency due to its low chirp characteristics.

We also evaluated the effect of MPI mitigation techniques (phase dither [4], [5], and the combination of phase dither and polarization randomization) for three modulation method when changing the SIR from 20 to 60 dB in Fig.4. Only the IF channels of lowest frequency (Ch#1, fc=0.3MHz) and the highest frequency (Ch#6, fc=2.3GHz) were shown in the figure. For all modulation methods, the phase dither effectively mitigated the degradation by MPI, and the simultaneous use of phase dither and polarization randomization showed further improvement in EVM performance. This is because the polarization relationship between direct and multi-reflected signals was randomized, and, as a result, the MPI noise was averaged and mitigated. From these results, high quality transmission fiber is required for DML case with higher SIR above 40 dB to obtain EVM values of less than 8 %, which is the 3GPP criterion for 64 QAM OFDM signal, even when the MPI mitigation techniques are introduced. However, EML and LN-MZM could have EVMs below 8% both at Ch#1 and Ch#6 for SIR of 30 dB or below thanks to the MPI mitigation techniques.



(a) DML (b) EML (c) LN-MZM-LD

Fig. 3. EVM performance for six IF signals with 25-dB SIR.



(a) DML (b) EML (c) LN-MZM-LD

Fig. 4. Effect of MPI mitigation technique for three modulation method.

4. Conclusion

The impact of MPI noise and its mitigation techniques for analog IFoF signals generated using DML, EML and LN-MZM-LD were experimentally compared. The results showed phase-dithered and polarization-scrambled IFoF signal could tolerate up to 30 dB MPI for external modulations for both EML and LN-MZM-LD.

5. Acknowledgement

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6. References

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