Impact of RF Noise on Transmission Performance of Multiband OFDM UWB over Fiber Systems

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Abstract: We investigate the performance of multiband OFDM ultra wideband (UWB) signal over fiber system considering the impact of RF noise. A compensation technique is proposed to reduce RF noise impact.
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1. Introduction

Multiband orthogonal frequency division multiplexing (MB-OFDM) ultra wideband (UWB) is considered as a low cost solution for radio over fiber communications [1-4]. In MB-OFDM, 480 Mb/s data can be transmitted over 528 MHz of RF bandwidth. MB-OFDM UWB wireless chips can be cheaply produced using current CMOS technology at a cost of a few dollars with all the front ends, filters, RF amplifiers, up/down mixers, ADC/DAC, and digital signal processing included in the chip. The WiMedia alliance which is responsible for the standardization of MB-OFDM technology has recently unveiled the proposal for a new physical layer which suggests the use of advanced LDPC codes to increase the bit rate to 1 Gb/s [1]. Due to very low power, wide bandwidth and high frequency signals of the UWB, distribution of UWB over coaxial cable is pretty expensive. On the other hand, optical fiber offers low loss, low cost and wide bandwidth characteristics which make radio over fiber the perfect choice for UWB transmission. The added advantage of MB-OFDM UWB is that it can be transmitted using legacy passive optical network (PON) transceivers. A two-dollar RF transceiver combined with a 10-dollar transmitter/receiver optical sub assembly (TOSA/ROSA) brings the cost of radio over fiber down enabling its commercialization. The performance of UWB over fiber was studied extensively when considering optical modulation-demodulation effect [2] and fiber dispersion [3]. Transmission performance of MB-OFDM UWB over fiber for mm wave application was also analyzed [4].

Apart from optical noise, RF noise, especially inphase/quadrature (I/Q) noise, can be an important source of performance degradation in MB-OFDM over fiber systems due to the non-ideal characteristics of the RF generator and receiver. I/Q RF noise is also introduced by the amplifiers at both the transmitting and receiving end. Due to the wideband nature of the signal, it is quite difficult to reduce its effect using other RF components. Fiber dispersion, polarization and nonlinearity will interact with RF noise and result in further performance degradation. The effect of I/Q RF noise has been studied from the wireless application view point over the last few years [5-6]. Optical engineers have recently been looking at this problem [7]. To the best of our knowledge, there has not been an extensive analysis of the system performance degradation in an MB-OFDM UWB over fiber system caused by the I/Q imbalance and phase noise. In this paper, we quantify and isolate the system impact due to I/Q imbalance, phase noise, and amplitude/phase (AM/PM) noise. Based on this study, we then define the requirements for an efficient architecture that compensates for RF noise without increasing the receiver complexity and cost.

2. Experimental Setup

The considered system setup for the performance evaluation of MB OFDM over fiber is shown in Fig. 1. An arbitrary waveform generator (AWG) is used for the UWB signal generation. First, MB-OFDM UWB signals are generated in MATLAB. The signal is loaded onto the waveform generator which provides the desired RF signal. The generated sub-band is centered at 3.96 GHz, and has an RF bandwidth of 528 MHz with 128 OFDM subcarriers at a bit rate of 480 Mb/s. Among the subcarriers, 100 carriers carry data. The rest are null, pilot and guard tones. The RF signal from the generator is amplified with a broadband RF amplifier and a variable attenuator is used to vary the RF power. A continuous wave (CW) light from a tunable laser source has a wavelength of 1550 nm, and linewidth of 800 kHz. The CW light is injected into a 10.7 GHz dual-drive Mach-Zehnder modulator (MZM), driven by the RF signal from the output of the AWG. To obtain optical single side band modulation, the RF signal is applied to both branches of the MZM through a 90^{o} hybrid coupler and bias-T. By biasing the MZM at quadrature and using a low modulation index, the MZM operates in the linear region of its characteristic. The launched optical power in the fiber is 0 dBm. The received power at the photodetector is kept constant at 4 dBm with an optical signal noise ratio (OSNR) of 22 dB.

3. Impact of RF Noise

In this section we will first show the impact on the performance due to different sources of RF noise. We analyze the penalty on the performance UWB over fiber system, and explain the need for additional compensation.

A. Impact of I/Q phase imbalance:

The impact of I/Q phase imbalance will have the most devastating effect on the performance of the system. Phase noise in any of the subcarriers will interfere with several other subcarriers in its close proximity. Figs. 2(a-b) and 3(a-b) shows the constellation after transmission through 20 km of fiber with and without phase imbalance, respectively. In MB-OFDM, pilot subcarriers are used to calculate the common phase error (CPE) and correct the phase [1]. However, the algorithm is incapable of tracking phase error in close proximity of the pilot carriers. Thus, the leakage of energy from one subcarrier into another occurs. This effect is visible in the constellation shown in Fig. 3(a-b). Error vector magnitude (EVM) is the average error vector relative to the desired constellation [Ref. 8 of 3]. EVM versus phase imbalance in Fig. 4 shows that for a phase imbalance of ~5^0, the EVM is degraded by 2.6 dB and 3.8 dB for back to back and after 20 km fiber from the intrinsic (directly from the generator) case, and if the phase error is higher than 10^0 the performance degrades rapidly.

B. Impact of I/Q amplitude imbalance and frequency offset:

The effect of I/Q amplitude imbalance is shown in Figs. 5 and 6. The degradation for back to back and 20 km of fiber was 3 and 5 dB, respectively for an amplitude imbalance of 5%. This error is of particular interest in UWB over fiber communication. Due to arbitrary polarization states in the fiber, the inphase signal might be smaller or larger than the quadrature signal in amplitude. In addition, fiber dispersion enhanced relative intensity noise will produce a similar effect. Any amplitude error at k^{th} subcarrier in OFDM signal creates an error component at $-k^{th}$ subcarrier due to amplitude to phase noise (AM/PM) conversion. Among 124 subcarriers in MB-OFDM subcarriers in position ±55, ±45, ±35, ±25, ±15 and ±5 are used as pilots [1]. The two mirror pilot subcarriers when combined with resulting amplitude errors terms will suffer an increase of amplitude. The equalizer algorithm in MB-OFDM fails to compute the amplitude fluctuations and tries to overcompensate the received signal.

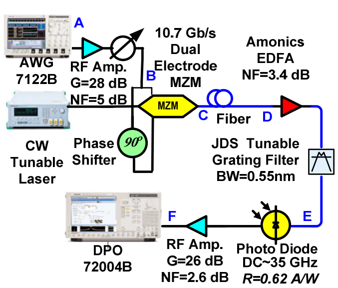

Fig. 1. Experimental setup.

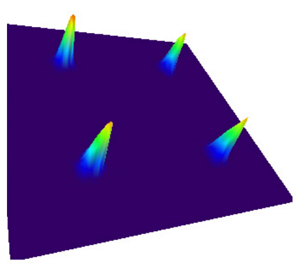

Fig. 2(a). 3-D constellation after 20 km fiber without any impairment.

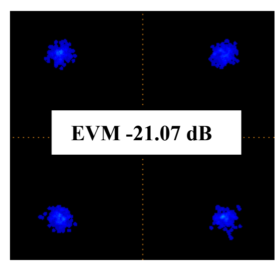

Fig. 2(b). 2-D constellation after 20 km of fiber without any impairment.

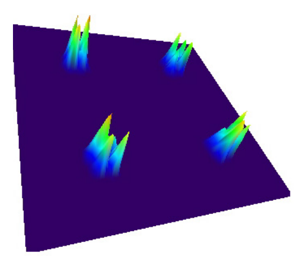

Fig. 3(a). 3-D constellation after 20 km of fiber with phase imbalance of 10^0.

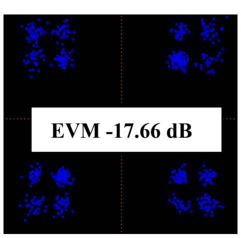

Fig. 3(b). 2-D constellation after 20 km of fiber and phase imbalance of 10^o.

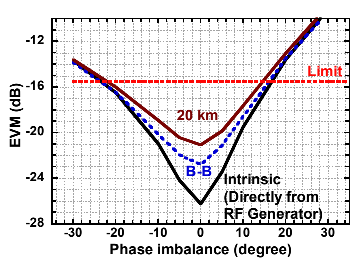

Fig. 4. EVM versus I/Q phase imbalance.

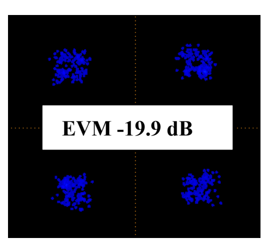

Fig. 5. Gain imbalance effect on constellation after 20 km of fiber and 10% gain imbalance.

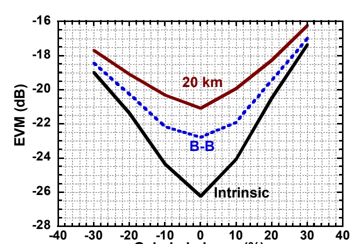

Fig. 6. EVM versus I/Q branch gain imbalance.

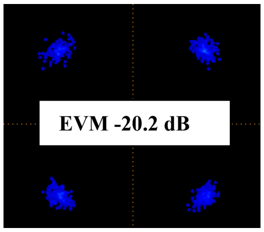

Fig. 7. I/Q frequency offset effect (250 KHz) for 20 km of fiber.

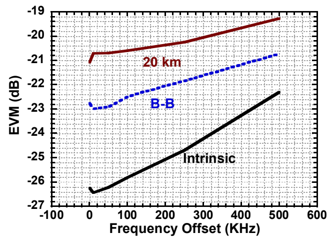

Fig. 8. EVM versus I/Q frequency offset.

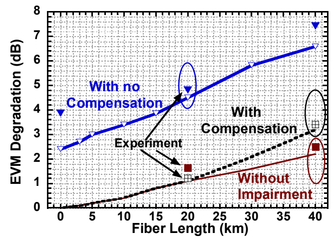

Fig. 9. EVM degradation in different cases.

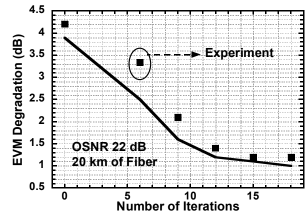

Fig. 10. EVM degradation versus number of iterations.

Under ideal conditions, each of the subcarriers in an OFDM signal is periodic within the FFT time buffer. This is critical if the subcarriers are to remain orthogonal and avoid mutual interference. A frequency error between the transmitter and the receiver will cause all of the subcarriers to have a non-integral number of cycles in the FFT time interval, causing leakage to the neighboring channels. Results from Fig. 7 shows that the constellation moves on a unit circle due to the frequency offset effect. Fiber dispersion acts as a linear effect. The penalty due to fiber shown in Fig. 8 is almost constant and is 0.1 dB/km.

4. Simultaneous Compensation of I/Q Imbalance and Phase Noise

Because of cost considerations, complex equalization schemes used in coherent optical communication [7] are not suitable for low cost access network applications. We propose the use of block-type based pilot symbols for channel estimation and equalization in UWB over fiber system [6]. The proposed scheme has several advantages- i) the scheme does not require any modification of the packet structure and ii) gives a better estimate of the channel than AWGN approximation [6]. Figure 9 shows the results of the simulations and experiment with different fiber length with an I/Q imbalance of 10%, phase noise of 10^o (worst case scenario) and 15 iterations for channel estimation with respect to the EVM for back to back transmission without any impairment. Frequency error can be described as the cumulative phase error that linearly changes with time and we will not compensate it separately. The fiber channel was modeled in VPI TransmissionMaker and the equalization was performed in MATLAB. The experiments were performed with offline processing of the captured I/Q signal. Evidently, there is no performance degradation for the fiber length of 20 km for the proposed equalization which suggests suitability of this scheme for UWB over fiber transmission. The simulated EVM degradation is also in good agreement with the measurements in Fig. 9. The number of required iterations for channel estimation is an estimate of the receiver complexity. In Fig. 10, we present the results in terms of number of iterations versus EVM degradation for 20 km of fiber transmission. The results show that we need at least 12 iterations to have an acceptable EVM performance. The complexity of the system using 12-15 iterations is currently implementable without any major modification of the MB-OFDM receiver [6]. The adjustment of only the DSP algorithm is required and there will be no change of the hardware architecture.

5. Conclusion

We have investigated the performance of multi-band OFDM UWB when transmitted over fiber under the effect of RF phase noise through experimental and simulation studies. We proposed a technique for joint estimation and equalization of RF physical layer impairments. The proposed scheme gives an EVM gain of ~3.2 dB for an I/Q imbalance of 10% and phase noise of 10^o for 20 km UWB over fiber transmission, without any major modification of the current receiver.

6. References

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