A 60-GHz RoF System Providing 5-Gbps BPSK Signal Employing LMS Equalizer

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Abstract: A 60-GHz RoF system transmitting 5-Gbps BPSK signal employing LMS equalizer is experimentally demonstrated. The results prove that the LMS equalizer with appropriate parameters can substantially improve the BER performance of the system.
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1. Introduction

Wireless communications networks inside rooms are playing an important role in today's society. Rapidly increasing demand for high bit-rate wireless communication is fueling renewed interest in the license free spectrum at 60GHz (57-64GHz in the US) [1]. 60-GHz millimeter-wave (mm-wave) RoF system has been widely researched because of its worldwide available unlicensed bandwidth 7-9GHz and huge separation in frequency domain from current low-frequency wireless services [2]. However, 60-GHz wireless network is facing many technical challenges owing to higher carrier frequency and the wide channel bandwidth used. 60-GHz mm-wave signal suffers from much higher air-link loss than 2.4-GHz wireless signal (about 30dB higher than 2.4GHz). The electrical and optical devices with such a working bandwidth higher than 60GHz are severely subjected to nonlinear effect introduced by RoF link and power amplifier (PA) connected in series and such higher bandwidths also indicate larger noise power and reduced SNR. All these defects make the 60-GHz wireless transmission distance limited within 10m.

The performances of simple optically up-converted IM-DD RoF links for single-carrier 60-GHz are severely distorted by the non-flat channel responses which will lead to serious inter-symbol interference (ISI). Even when we use simple OOK modulation, the ISI can't be neglected when the bit rate reach a high level. So, estimation and subsequent equalization of the concatenated fiber-wireless channel needs to be done, especially when at the high bit rates [3]. Considering the best tradeoff between complexity and performance, we choose algorithm of least mean squares (LMS). One of the main problems of the RLS solution is its high complexity. In the RLS, matrix operations increase considerably the number of the multiplications and divisions. Therefore it is not suitable for our high-speed 60-GHz wireless transmission.

In this paper, we proposed and experimentally demonstrated a 60-GHz RoF system employing LMS equalizer. LMS equalizers with different number of taps are considered. With the help of equalizer, the system can successfully transmit BPSK signal at bitrate 5Gbps under FEC (Forward Error Correction) limit 10^{-3}.

2. Principle

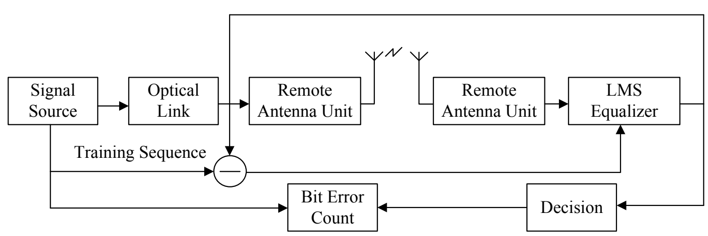


Fig. 1. Block diagram of the proposed 60-GHz RoF system exploiting LMS equalizer

The simplified block diagram of the system model is depicted in Fig. 1. An input signal is fed to optical link and will also be transmitted through antennas. The LMS algorithm is widely used thanks to its low compute complexity. At the LMS equalizer block, the nonlinear distortions of the optical/wireless link will be compensated. The conventional LMS algorithm can be given by the following form [4]:

$$\boldsymbol{w}(\boldsymbol{n}+\boldsymbol{1}) = \boldsymbol{w}(\boldsymbol{n}) + \mu_{LMS} e(n) \boldsymbol{y}(\boldsymbol{n}) \quad (1)$$

$$e(n) = z(n) - \boldsymbol{w}(\boldsymbol{n}) \boldsymbol{y}(\boldsymbol{n})$$

where $\boldsymbol{w(n)}=[w_0(n),w_1(n),\ldots w_N(n)]^T$ is the filter weight vector. N is tap number of the filter. $\boldsymbol{y(n)}=[y(n), y(n\text{-}1),\ldots y(n\text{-}N)]^T$ is the feedback signal vector for adaption. μ_{LMS} denotes the step size, and $z(n)$ represents the desired signal. The tradeoff between the convergence speed and steady-state misadjustment is the main limitation of the LMS algorithm. They are both controlled by the parameters step size and tap number. The step size is conventionally inversely proportional to the received signal power. The larger step size means a faster convergence speed but a weaker steady state.

A string of training sequences will be sent and received in advance to optimizing the coefficients of the LMS filter. In order to reach the optimized the coefficients of the LMS filter, signal block with training sequence with length of 80000 is exploited to complete channel estimation before transmitting real signal.

3. Experimental Setup and Results

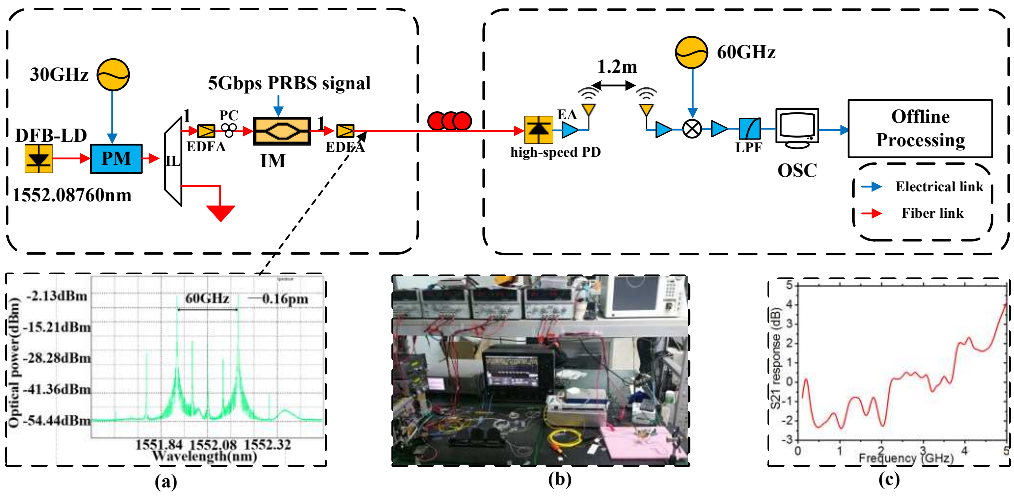


Fig. 2. Experimental setup of the proposed 60-GHz RoF system employing LMS equalizer. Inset (a) is the optical spectrum of the signal after intensity modulator. (b) Picture of the real experimental setup (c) Frequency response S21 (down-converted) of the 60-GHz Radio-over-fiber links without equalization.

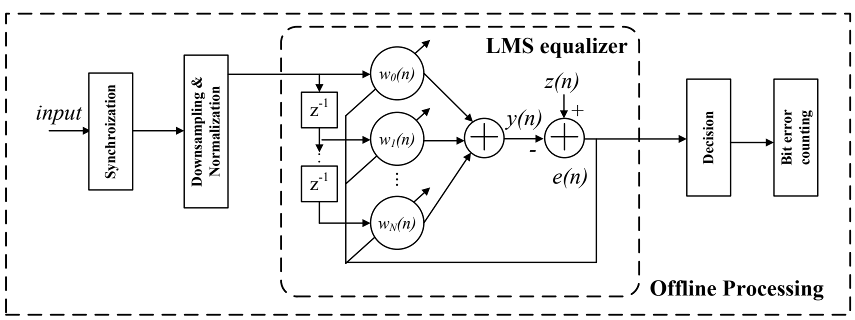
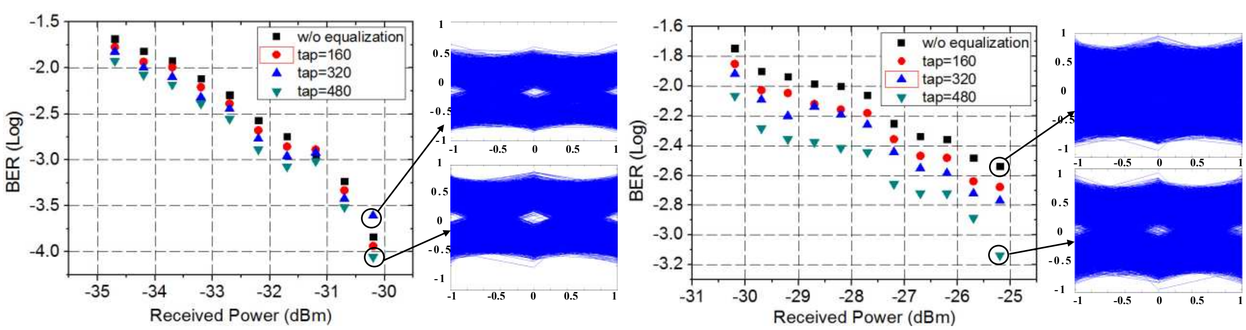


Fig. 3. Offline processing diagram of the signal after the signal is captured by oscilloscope.

The experimental setup is illustrated in Fig. 2. The IM-DD based RoF system consists of a DFB laser with the center wavelength and power at 1552.08nm and 10.02dBm followed by a high-speed phase modulator (PM) with bandwidth larger than 40GHz. The PM is driven by a microwave source working at frequency 30GHz to produce two sidebands. An interleaver is utilized to suppress the central wavelength of the optical signal. The intensity modulator (IM) is driven by a 5-Gbps electrical rectangular NRZ PRBS (Pseudo-Random Binary Sequence) signal, which is generated from a signal quality analyzer. The amplitude of the electrical signal is adjusted to accommodate the linear zone of the intensity modulator. The optical spectrum of the two modulated sidebands is given in Fig. 2(a). At the received point, after the two sidebands detected by a high-speed PD (Photodiode), we use two rectangular horn antennas with a gain of 20dBi, frequency range of 50-70GHz to broadcast the mm-wave component of the electrical signal. The two antennas can also act as two band-pass filters to remove the baseband unused components. Two amplifiers are utilized before transmitting antenna and after received antenna respectively to compensate the great loss of the 60-GHz wireless signal in air. Limited by the gain of 60-GHz radio amplifiers, the transmission distance of 60-GHz wireless signal is only 1.2m. If high-efficiency amplifier is available, the distance can be greatly extended. The S21 response of the optical and 60-GHz mm-wave wireless link without equalization is shown in Fig. 2(c). It can be seen that the response of the optical-wireless link is not uniform over the 5-GHz channel bandwidth. The signal will be inevitably distorted when bitrate up to 5Gbps. The received baseband data is then captured with a 20-GS/s real-time scope (ADC) and passed on to a computer for further analysis in Matlab.

The block diagram of offline processing is also given in Fig. 3. After synchronization, down-sampling and normalization, the captured signal will be sent into a LMS equalizer. The equalization algorithm is based on least-mean-square adaption to maximum the eye-opening at the decision points. In this paper, the step size is set to 0.0005 to optimize performance of the system. The number of taps for different bitrate is investigated.

The BER performances of the system at bitrate 1Gbps and 5Gbps are demonstrated in Fig. 4(a) and (b). It is clear from the Fig. 4 that the LMS equalization substantially improves the sensitivity of the system both at bitrate 1Gbps and 5Gbps, making it possible to have error free transmission. The 5-Gbps transmission improves further than 1-Gbps transmission. When the system is at bitrate 5Gbps, an error floor at BER beyond FEC limit 10^{-3} is observed in the system without LMS equalizer. So equalization is indispensable when the system is working at bitrate as high as 5Gbps. Also, the effect of the number of taps is shown in the diagram. When number of tap is at 480, the equalizer greatly improves the performance of the system in both cases. When we decrease the number of taps to 320 and 160, the system also gets improvement, but not as good as 480. However, larger number of taps means a higher computation complexity and will increase the cost the system. In conclusion, the system requires tap number of 480 to achieve the best performance.



(a) (b)

Fig. 4. BER performances of the 60-GHz RoF system with 1.2-m wireless transmission. The LMS equalizers with different number of taps are investigated in the system at different bitrate (a) 1Gbps and (b) 5Gbps.

4. Conclusion

This work proposed a RoF link with 1.2-m mm-wave wireless transmission and the performance of the optical/wireless link can be substantially improved by LMS equalizer when the step size and tap number are set at appropriate values. Employing LMS equalizer, the system can successfully transmit 5-Gbps NRZ BPSK signal at BER under FEC limit 10^{-3}. The experiment results verify the feasibility of the LMS equalizer using in 60-GHz RoF system.

5. Acknowledgements

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