High Speed MIMO-OFDM Wireless Data Transport in 60-GHz Radio-over-Fiber System Multiplexed by Optical TDM

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Abstract: A spectrum-efficient MIMO-enhanced 60-GHz RoF system based on optical TDM has been demonstrated. It consists of two QPSK-OFDM MIMO channels with a simple TDM network design as a practical solution for mm-wave MIMO-based wireless communications.

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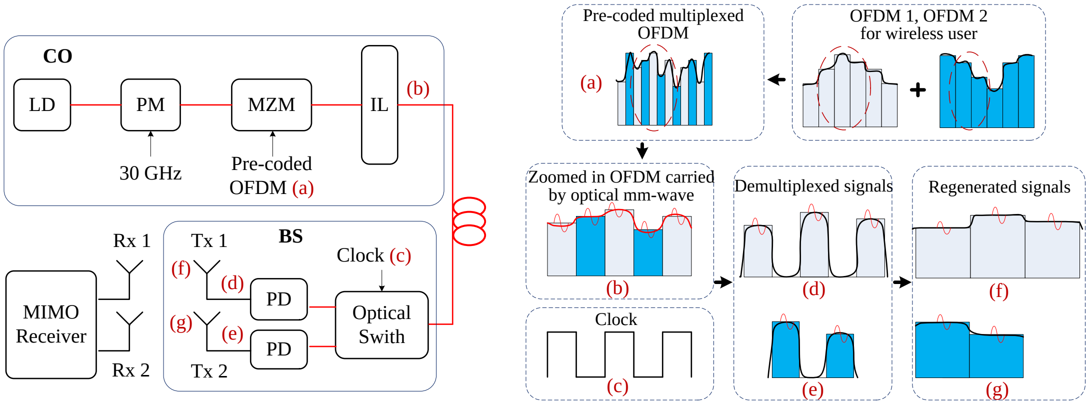
1. Introduction

Transmission of multi-gigabit wireless channels in local area network (LAN) environment is becoming a reality as the rush to develop license-free 60-GHz networking technology garnering strong grassroots support by the next generation wireless communications industry. Task groups in worldwide standard body, such as ECMA TC-48 and IEEE 802.15.3 Task Group 3c, developed physical layer (PHY) and media access control layer (MAC) in this new band [1, 2]. Radio-over-Fiber (RoF) technologies have been developed to deliver wireless services as a cost-efficient solution to deliver multi-gigabit/s 60-GHz wireless access services with high performance and long distance transmission [3].

The MIMO technology is suitable for gigabit wireless data delivery in wireless over fiber access systems to improve transmission distances by mitigating channel noise and increase system capacity. In the past, several methods for generating MIMO signals multiplexed by wavelength-division multiplexing (WDM) [4] and frequency-division multiplexing (FDM) [5] have been reported. For comparison, time-division multiplexing (TDM) system is spectral-efficient and widely deployed in today's passive optical networks (PONs). A TDM-based, multiband RoF system for transporting several RF signals, achieved by a complex central station design, has also been proposed [6]. However their method is quite straight forward since the actual wireless MIMO signals are obtained from multiplexing on two wavelengths, i.e., WDM. In this paper, to the best of our knowledge, a flexible and scalable RoF system has been demonstrated for the first time using 2x2 MIMO millimeter-wave (mm-wave) signals based on optical TDM technique. Two independent quadrature phase shift keying orthogonal frequency-division multiplexing (QPSK-OFDM) signals at 60 GHz are multiplexed in time domain and demultiplexed by an optical switch.



(i) (ii)

Fig. 1. (i) System diagram of the proposed 2x2 MIMO-OFDM MMW RoF system. (ii) Signals at different locations in RoF testbed as indicated in (i).

2. Operating Principle

The system diagram of the optical TDM based MIMO-OFDM RoF system is illustrated in Fig. 1(i). At the central office (CO), a continuous-wave (CW) lightwave from the laser diode (LD) is launched into a phase modulator (PM), driven by a 30-GHz RF signal, to generate optical subcarriers. Then the light is modulated with a pre-coded OFDM signal by a Mach-Zehnder modulator (MZM). Using an optical interleaver (IL), the real valued baseband OFDM signal is up-converted to 60-GHz mm-wave by the 30-GHz optical carrier suppression (OCS) [7]. The pre-coded OFDM signal is generated by inser-ting two different OFDM signals at each point alternately as shown in Fig. 1(ii, a). In this way, the MIMO RF signal is multiplexed in time domain. Fig. 1(ii, b) illustrates the zoomed in lightwave modulated by mm-wave signal after the IL.

At the base station (BS) the downlink (DL) signal is demultiplexed with an optical switch driven by an electrical clock signal, shown in Fig. 1(ii, c), with the frequency half of the sample rate for the pre-coded OFDM signal. The demultiplexed optical signals are converted at two photodiode (PD) to electrical RF signals (Fig. 1(ii, d) and (ii, e)). Each signal can be viewed as a sampled train with a repetition frequency sufficiently higher than the bandwidth of the OFDM signals. The antennae with limited bandwidth, Tx1 and Tx2, serve as band pass filters (BPFs) to regenerate original RF signals (Fig. 1(ii, f) and (ii, g)), and transmit them wirelessly. The MIMO-OFDM signals received at the mobile user are processed by conventional digital signal processing (DSP) [8].

Compared to WDM and FDM, only one wavelength and one RF are used for a BS in our TDM based scheme, which simplifies the configuration of the system and reduces operation and maintenance costs. It’s compatible with existing PON architectures. Moreover it’s easy to scale up to NxN MIMO system since pre-coded MIMO-OFDM signal is generated digitally without alterations of the network structure. An optical switch is deployed to ensure an adequately high switching speed for future broadband wireless communication.

3. Experimental Setup and Results

To demonstrate MIMO RF signal generation and transmission based on time multiplexing in the RoF system, we set up a 60-GHz RoF DL with TDM and 2x1 MIMO array for preliminary study, as shown in Fig. 2. An Agilent 83433A distributed feedback laser (DFB) is followed by a polarization controller (PC) before the light is modulated by a PM for optical sidebands generation. Two independent real-valued 128-subcarrier QPSK OFDM baseband signals with 278 Mb/s net data rate and 400-MHz baseband bandwidth are first generated by a Matlab® program. The OFDM symbols are arranged in a frame of 10 blocks. The first 2 blocks implement the training sequence, and 12.5% cyclic prefix is added. Then two sets of points are converged alternately to one signal with a 0.5-GHz clock sequence added in the beginning for synchronization purpose. This multiplexed OFDM signal is generated by a Tektronix AWG610 arbitrary waveform generator (AWG) which is sampled at 1 GSample/s. The Fig. 3(i, a) shows the zoomed in pre-coded OFDM signal received at the wireless receiver without demultiplexing. The spectrum after the MZM in the CO is shown as inset (i) in Fig. 2. The optical mm-wave at 60 GHz is generated after a 33/66 GHz IL for carrier suppression as inset (ii) in Fig. 2 indicates. Two OFDM mm-wave signals are multiplexed in time domain and sent to the BS by a piece of standard single-mode fiber (SSMF).

At the BS the lightwave is equally split by a power splitter. Two MZMs are used to substitute for an optical switch. A clock signal at 0.5 GHz and its inverse $\overline{\text{clock}}$ are synchronized to drive the MZMs biased at $V_{\pi/2}$ for intensity modulation. The clock is also adjusted to be synchronized with the MIMO-OFDM signal by referring to the inserted clock sequence. The optical spectrum of the MZM output is shown as inset (iii) in Fig. 2. Fig. 2(iv) shows the optical eye diagram after the switch. The on state clock signal carries 60-GHz OFDM imformations. Each lightwave is pre-amplified by an erbium-doped fiber amplifier (EDFA) and detected by a PD. Two OFDM RF signals are boosted by electrical amplifiers (EA) before transmitted by two broadband horn antennae. In this experiment we measure the two channels individually when one is switched on and the other is off. Therefore, the demultiplexed OFDM RF signals are received by one antenna at the wireless user, and then down-converted to

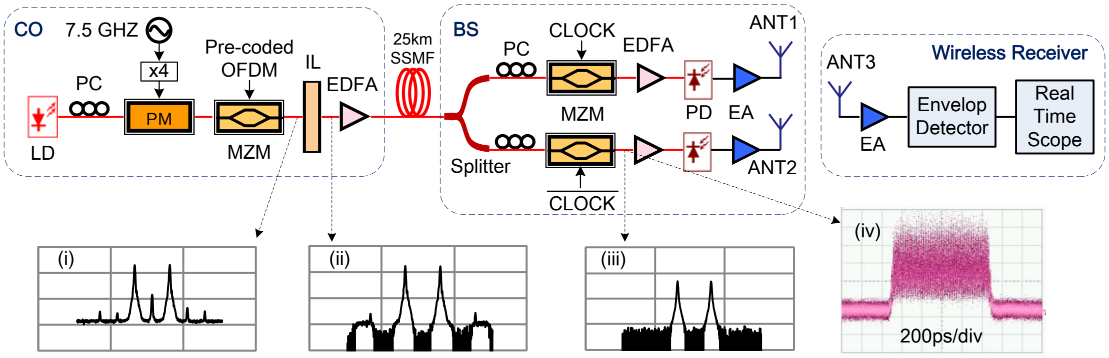
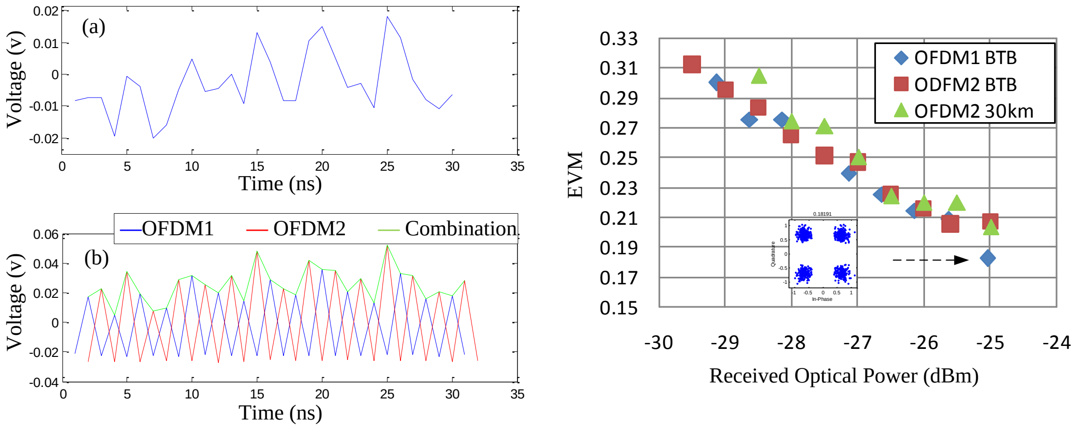


Fig. 2. Experimental setup of the TDM based MIMO-OFDM 60-GHz RoF system. (i) Optical spectrum before the IL. (ii) Optical spectrum after the IL in the CO. (iii) Optical spectrum after the MZM in BS. (iv) Optical eye diagram after the MZM in the BS for the demultiplexed mm-wave OFDM signal.



(i) (ii)

Fig. 3. (i) The received multiplexed and demultiplexed MIMO-OFDM signals. (ii) EVM curves of OFDM signals for optical BTB and after 30-km SSMF.

baseband OFDM signals through an envelop detector. The signals are recorded by 10-GSa/s LeCroy WM818Zi oscilloscope for the offline DSP.

The two demultiplexed OFDM signals received individually by the oscilloscope are shown in Fig. 3(i, b). Since the passband of the antennae is much larger than the bandwidth of OFDM signal, the transmitted signal is not converted to original OFDM signals. The blue line (the first line) depicts the OFDM1 signal transmitted from ANT1, and the red line (the second line) depicts the OFDM2 signal sent by ANT2. It's clear to observe the precise switching function from the well aligned curves. We connect the peaks of two signals, which are the samples of the two original OFDM signals, to retrieve the pre-coded OFDM signal as the green line (upper line) in Fig. 3(i, b) indicates.

Fig. 3(ii) presents variation of error vector magnitude (EVM) with optical power measured before the PDs, for OFDM1 signal in back-to-back (BTB) transmission (diamond) and OFDM2 signal propagates in BTB (square) and 30-km SSMF (triangle). Equal and good performances of the two OFDM signals are demonstrated. A clear constellation of QPSK-OFDM1 at EVM 0.18 is also shown in Fig. 3(ii). After the 30-km fiber transmission the power penalty is less than 0.5 dB. The polarization rotation in the fiber will impair the switching performance. However, polarization-insensitive MZMs or optical switch can be used in the BS for stable transmission.

4. Conclusions

It is important to support the MIMO for wireless applications using RoF technologies, especially for bandwidth-efficient wireless services. By multiplexing multiple OFDM RF signals in time domain, the RoF system can increases data rate without requiring additional laser wavelength. The same MIMO RoF system can also be used to achieve better system reliability through spatial diversity. The 2x2 MIMO-OFDM signals can be easily carried by a lightwave in the proposed RoF design, and demultiplexed by an optical switch, which is desirable for high data rate mm-wave signals. In the RoF experiment, we evaluate the optical transmission characteristics of the MIMO-type OFDM mm-wave signals in an indoor environment. System performance has been validated through the measurements of the two recovered OFDM signals. We believe that our method is simple and practical for delivering spectral-efficient gigabit wireless services in the future RoF-TDM PON networks.

5. References

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