Multi-service, Multi-band, and MIMO Data Distribution over 60-GHz RoF System for Gigabit Wireless Local Area Networks

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Abstract: We propose and experimentally demonstrate a 60-GHz RoF system to support 3M (multi-service, multiband and MIMO) data distribution. Spectral efficiency is improved and system capacity is doubled by using 2x2 MIMO spatial multiplexing.

OCIS codes: (060.2330) Fiber optics communications; (060.4250) Networks

1. Introduction

Multiple-input and multiple output (MIMO) technique is now widely deployed in the state of the art wireless systems, such as WLAN (IEEE 802.1N), WiMAX (IEEE 802.16e) and 4G/LTE (Long Term Evolution) [1]. Generally, MIMO can be used in three ways: spatial multiplexing to improve the system capacity; spatial diversity to increase the system reliability, and beam forming for particular direction transmission. On the other hand, optical-wireless access based on 60-GHz radio-over-fiber (RoF) technology has gain increasing attentions for its huge license-free bandwidth of 7-9 GHz band [2]. The 60-GHz millimeter-wave (MMW) has been considered globally as a candidate for the next generation very high throughput (VHT) wireless personal area network (WPAN), and there are many related standardizations studied and established by industrial consortia such as ECMA, WirelessHD, WiGig etc. [3]. We demonstrated a system scheme to combine MIMO and 60-GHz RoF technologies for WLAN, where only single-band MMW signal was realized [1]. However, according to recent standardization [4], the 60-GHz license-free band is divided into four sub-bands. Thus, it is expected that future RoF systems should support multiband services at 60-GHz and other MMW bands to facilitate the integration with VHT-WPAN.

For the first time, we have conceived and implemented a 60-GHz RoF system to deliver 3M (multi-service, multiband and MIMO) data traversing over single-mode fiber (SMF) and air link. Two independent 1-Gb/s on-off keying (OOK) data are carried on 57.6-GHz and 61.2-GHz MMW bands based on optical up-conversion. At the base station (BS), the multiband MMW signals are divided and de-correlated, and two pairs of antennas are employed to realize spatial multiplexing by 2x2 MIMO subsystem, thus doubling the system capacity and spectral efficiency. Error-free performances are achieved for the multiband MMW OOK signals after 30-km SMF and 3-ft air link transmissions.

2. Operation Principle

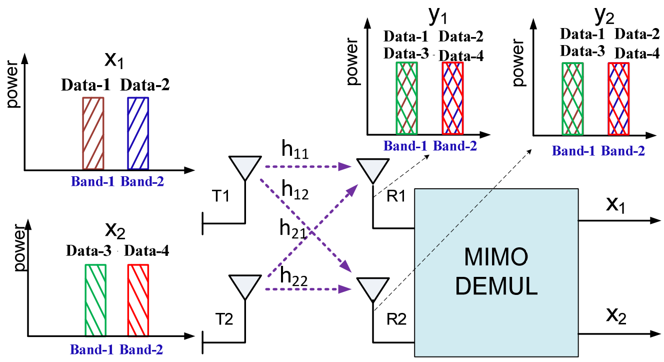


Figure 1. Schematic diagram of the proposed multi-service multiband MIMO system.

Fig. 1 shows the schematic diagram of the proposed multi-service multiband 2x2 MIMO system. Two groups of independent data (data-1, data-3 and data-2, data-4) are carried on band-1 and band-2, which are transmitted through two antennas and interference happens during the wireless transmission. At the receiver side, both bands carry mixed data (band-1 carries data-1 and data-3; band-2 carries data-2 and data-4), and MIMO de-multiplexing is required to retrieve each data. For short wireless distance and line-of-sight (LOS) transmission, the wireless channel can be represented by a well-conditioned matrix H_{MIMO}. Assuming that a flat-fading channel is satisfied for each band, the two received signals can be described as:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (1)$$

where $y_{1,2}$ and $x_{1,2}$ are received and transmitted signals, h_{ij} is the channel coefficient, and $n_{1,2}$ is the noise. In our experiment, we use zero-forcing algorithm (ZF) to eliminate channel interference and ignore the noise. The channel coefficient h_{ij} can be calculated through several training bits and the transmitted data $x_{1,2}$ can be recovered from Eq. (1). Thus, the system capacity is improved for the multi-service multiband signals based on 2x2 MIMO spatial multiplexing without occupying additional time intervals or signal bandwidth.

3. Experimental setup and results

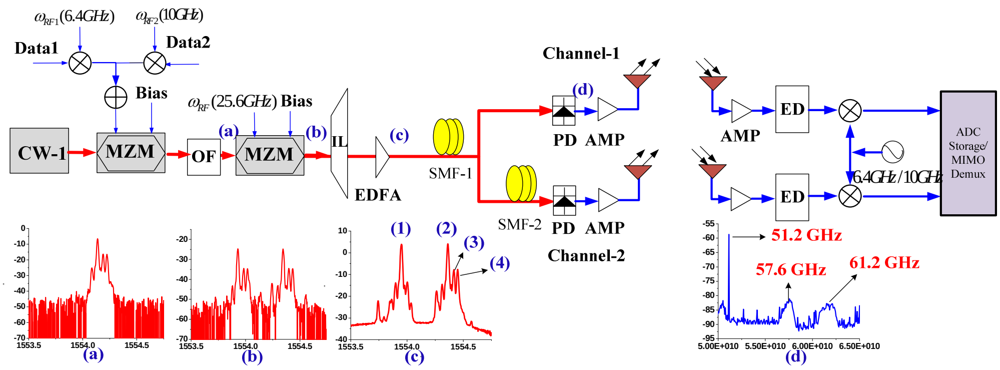
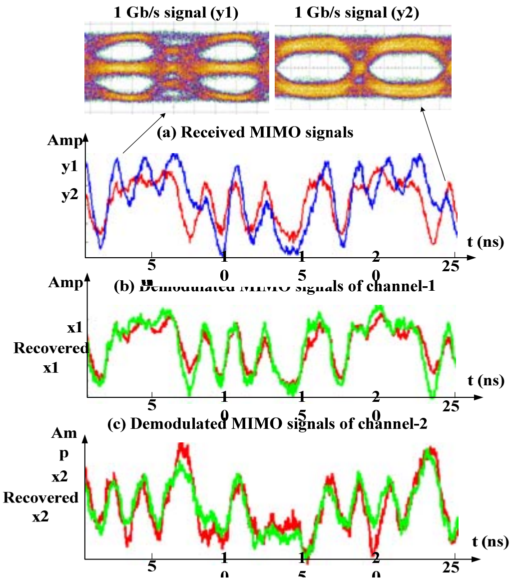


Figure 2. Experimental setup of the proposed 60-GHz RoFsystem delivering multi-service, multiband and MIMO data.

To demonstrate the multi-service, multiband and MIMO data transmission, we set up a 60-GHz RoF downlink system, as shown in Fig. 2. In the central station (CS), a continual wave (CW) light originated from a tunable laser with a wavelength of 1554.14 nm is fed into a single-drive x-cut Mach-Zenhder modulator (MZM). Two independent 1-Gbit/s pseudo-random bit sequence (PRBS) streams with a word length of 2^{31}-1 are mixed with 6.4-GHz and 10-GHz radio frequency (RF) clocks, individually. The two mixed signals are combined, amplified, and then used to drive the MZM, which is biased at the push-and-pull of the transmission curve. An optical sub-carrier modulation (SCM) signal is obtained at the output of the MZM, which is fed into an optical band-pass filter to realize single-side band (SSB) modulation, as depicted in Fig. 2(a). The optical SSB signal is up-converted by a second MZM, which is biased at the null of the transmission curve and driven by an amplified 25.6-GHz RF clock to achieve optical carrier suppression (OCS) modulation. The optical spectrum of the up-converted signal is shown in Fig. 2(b), whose unwanted bands are filtered by a 33/66 interleaver. We then achieve a four-tone signal (Fig. 3(c)), where tone-1 and tone-2 are un-modulated carriers, tone-3 and tone-4 are modulated with data-1 and data-2. The frequency spacings from tone-1 to tone-2, tone-3 and tone-4 are 51.2 GHz, 57.6 GHz and 61.2 GHz, respectively. The optical signal is amplified by an erbium-doped fiber amplifier (EDFA) to reach a power of 6 dBm and then transmitted to the BS through a 30-km single mode fiber (SMF). At the BS, a 50:50 optical coupler is used to divide the coming optical signal into two parts. The first one (channel-1) is detected by a 50-GHz photo-detector (PD u2t XPDV 2020R), where the beating of the un-modulated tone-1 and tone-2 generates a 51.6-GHz RF clock. 57.6-GHz and 61.2-GHz MMW OOK signals are obtained through the beatings of tone-1 and tone-3; tone-1 and tone-4, respectively. The electrical spectrum of the output of the PD is depicted in Fig. 2(d), which is input to a power amplifier (Narda West NW 06-0023). The second optical signal (channel-2) is transmitted a further 150-m SMF to generate another uncorrelated multiband signals. Consequently, both channel-1 and channel-2 carry independent multiband MMW signals, which are transmitted simultaneously to realize a 2x2 MIMO wireless system. In this paper, we focus on the demonstration of 60-GHz multiband MIMO data transmission. In practice, two independent RoF signals could be generated and transmitted over the same fiber by using polarization-division-multiplexing (PMD) or wavelength-division-multiplexing (WDM) schemes [1]. Two pairs of rectangular horn antennas (Ducommun ARH-1525-62) with a gain of 25 dBi at the range of 45-75 GHz are employed to broadcast and receive the MIMO signals. After transmission over 3-ft wireless link, at user terminal, the wireless signals including 51.6-

GHz RF clock, 57.6-GHz and 61.2-GHz OOK MMW signals from the two channels interfere with each other and can not be recovered directly. The interfered multiband MMW signals are input into an envelope detector (ED), where down-conversion is realized through the beating of the 51.6-GHz clock and the multiband MMW (57.6-GHz and 61.2-GHz) signals. At the output of the ED, two intermediate frequency (IF) signals at 6.4 GHz and 10 GHz are obtained, which are down-converted to baseband through a 6.4-GHz or 10-GHz clock. It is noted that the down-conversion is realized through ED, eliminating the 57.6-GHz (and 61.2-GHz) local oscillator (LO) and critical phase control, which are indispensible for the traditional 60-GHz MMW down-conversion.

In our experiment, we down-convert the 57.2- GHz MMW OOK signal to baseband data that is then recorded by a digital oscilloscope (Lecory Waverunner 6Zi) at a sample rate of 40-GSample/s. Fig. 3(a) shows an example of 25-ns recorded samples and their eye diagrams. We use two bits for the channel estimation process, and then the recorded data is demodulated and recovered to the two original sequences. Fig. 3 (b) and (c) depict the recovered signals, well matching the original transmitted data. To evaluate the transmission performances, the two antennas in the transmitter side are set to have 90^{o} phase difference and the bit error rate (BER) measurements of the multiband signals in channel-1 are implemented. As shown in Fig. 4(a), error-free performances are achieved for both 57.6-GHz and 61.2-GHz MMW OOK signals with ~1.5-dB power penalty after 30-km SMF and 3-ft air link transmission. Fig. 4(b) and (c) shows the eye diagrams of the baseband OOK signals in channe-1 carried by 57.6-GHz and 61.2-GHz MMW.



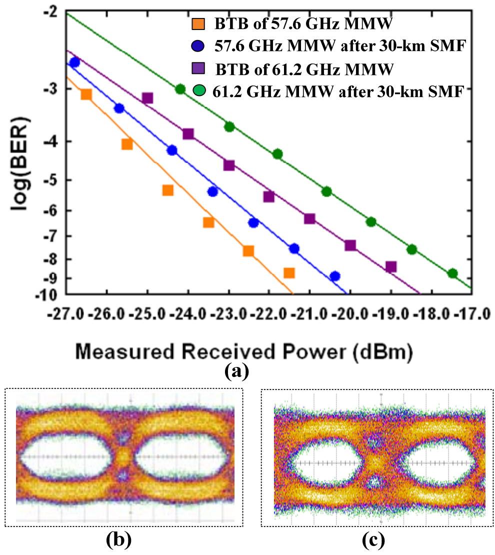


Figure 3. (a) The 57.6-GHz MIMO signals, (b) and (c) recovered data of channle-1 and channle-2 compared with the original transmitted data.
Figure 4. (a) BER measurements for 57.6-GHz and 61.2-GHz MMW signals of channel-1, (b) eye diagrams for down-converted 57.6-GHz MMW OOK signal, (c) eye diagrams for down-converted 61.2-GHz MMW OOK signals.

4. Conclusions

We have proposed and demonstrated a 60-GHz RoF system to distribute multi-service, multiband and MIMO data. Four independent MMW data have been transmitted and spatial multiplexing has been realized to increase the spectral efficiency of the 2x2 MIMO system to 2 bits/Hz. Error-free transmissions have been achieved for the 57.6-GHz and 61.2-GHz multiband MMW OOK signals employed in our system traversing over 30-km SMF and 3-ft air links. This work was supported in part by a NSF grant to Georgia Tech Center for Optical Wireless Applications (COWA). It was also supported in part by grants from NSFC (61077052/61125504), MoE (20110073110012), and Science and Technology Commission of Shanghai Municipality (11530700400).

5. References

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