Demonstration of W-band 2×2 MIMO Millimeter Delivery Employing CMA and MRC Technology with over 7dB Gain

Qiutong Zhang(1), Jianjun Yu (1,2)*, Weiping Li(1), Min Zhu(2,4), Jiao Zhang(2,4), Junjie Ding(2,4), Xianming Zhao(3), Jiaxuan Liu(1), Yi Wei(1), Kaihui Wang(1), Wen Zhou(1), Bo Liu(1), Feng Zhao(5) and Jianguo Yu(6)

*1) Fudan University, Shanghai, 200433, China * jianjun@fudan.edu.cn*
2) Purple Mountain Laboratories, Nanjing, China 3)HIT, Harbin, China, 150001 4)Southeast University, Nanjing, China
5) XUPT, Xi'an, 710121, China 6) BUPT, Beijing, 100876, China

Abstract: We demonstrate 32 GBaud QPSK signal transmission over a 2 m wireless range at 93.5 GHz using CMA and MRC techniques with over 7 dB gain in a photon-assisted millimeter wave 2×2 MIMO communication system. © 2024 The Author(s)

1. Introduction

Millimeter wave (MMW) and terahertz (THz) communications have the advantage of larger available bandwidth compared with traditional wireless communications. Photonics-assisted generation of MMW and THz signals can support larger modulation bandwidths compared with electronic algorithms so that it is considered as a key technology for future RoF communications [1-6]. W-band (75 GHz~110 GHz), as the transition band between MMW and THz bands, has received widespread attention [7]. However, W-band signals are susceptible to loss and rain attenuation, which will seriously affect the transmission distance. In multi-input multi-output (MIMO) system, the signal energy can be concentrated in an extremely narrow beam in space and precisely directed to the downlink users, thereby maximizing the propagation distance in that direction [8]. Meanwhile, since the antenna size is proportional to the signal wavelength, MIMO antenna arrays can be easily arranged in millimeter wave systems without taking up too much space. Therefore, the millimeter wave communication based on MIMO system has great advantages in the future development. Recently, we experimentally demonstrated combined 1×2 MIMO CMA and MRC reception technology in a photon-assisted long-distance SIMO millimeter wave transmission system, which can achieve up to 80 Gbps 16 QAM 87.5 GHz millimeter wave signals with a 1.5 dB improvement in optical power budget [9]. In order to obtain more gain, we can use 2×2 MIMO and MRC receiving technology to further improve receiving sensitivity.In this paper, we demonstrate a W-band photonics-assisted MMW 2×2 MIMO communication system. We employ a photo-generated millimeter wave approach to generate a 93.7 GHz W-band signal, which is received according to the maximum ratio combining (MRC) technique after 2×2 MIMO wireless transmission and carrier recovery using advanced digital signal processing (DSP) algorithms. According to the experimental results, the maximum signal-to-noise ratio (SNR) gain between 1×1 and 2×2 MIMO can up to 7.1 dB. To the best of our knowledge, this is the first experimental demonstration of high gain in a W-band mmWave 2×2 MIMO system by using these technologies.

2. Principles and Experimental Setup

The experimental setup is illustrated in Fig.1. At the TX side, an external cavity laser-1 (ECL1) is utilized as the optical carrier source at a wavelength of 1549.31 nm. The baseband electric signal, which is generated by the 65 GSa/s arbitrary waveform generator (AWG) and amplified by the electric amplifier (EA) beforehand, undergoes modulation through the I/Q modulator. After the amplification of the modulated signal by a polarization-maintaining Erbium-doped optical fiber amplifier (PM-EDFA), it is then coupled with the optical oscillator signal generated by the ECL2. The frequency space between two signals is designated as 93.7 GHz. The polarization and power of the coupled signal are precisely regulated using the EDFA and variable optical attenuation (VOA). The wireless 93.7 GHz signal is being heterodyne beaten by the 100GHz photodiode (PD) and amplified by the 30 dB gain low-noise amplifier (LNA) before delivered by the 25 dB gain horn antenna.

At the transmitter, the baseband signal for transmission utilizes the 16 and 32 GBaud QPSK signal. We constructed 1×2 and 2×2 MIMO systems in order to investigate the SNR improvements achieved by 1×2, 2×1, and 2×2 configurations in comparison to the 1×1 system. In the 1×2 system, a horn antenna is utilized at the transmitter to facilitate the transmission of the terahertz signal. In the 2×2 system, a pair of horn antennas is utilized for transmission. After the terahertz signal has been wirelessly transmitted over a distance of 2 m, it is subsequently transmitted using two horn antennas. Among them, two of the transmitting antennas are distributed in parallel on the same plane, with a distance of 15 cm between the antennas. The two receiving antennas are also placed in the same way. Meanwhile, the wireless transmission of MMW technology necessitates precise beam alignment. One tripod head is utilized to facilitate the adjustment of the elevation, azimuth, and height of the TX and RX in order to enhance overall performance.

At the RX side, the process of down-converting the signal is achieved by utilizing two integrated mixer/amplifier/multiplier chains (IMAMC). Each chain consists of a 12.65 GHz radio frequency (RF) source, a ×6 frequency multiplier and a mixer. The employment of the EA is implemented in order to enhance the sensitivity of the receiver. The intermediate-frequency (IF) signal, which operates at a frequency of 17.8 GHz (93.7-12.65×6=17.8), is acquired using a 256 GSa/s oscilloscope (OSC) with a bandwidth of 59 GHz. This signal is then utilized for subsequent offline digital signal processing.

The DSP in the receiver includes two parts: MRC technology and equalization for QPSK. MRC combines N signals of diversity by multiplying them with different coefficients $w_i\left(i=1,2,...,N\right)$, and the determination of the coefficients is related to the fading coefficients $h_i\left(i=1,2,...,N\right)$ of the n-way branches, i.e. $\frac{w_m}{w_n}=\frac{h_m}{h_n}$. Therefore, among diversity combining techniques, MRC is the optimal choice as it achieves the best performance compared to selective combining and equal gain combining. The performance improvement is attributed to the higher signal-to-noise ratio achieved through array gain, resulting in improved BER characteristics. According to this principle, the theoretical maximum SNR gain that can be obtained from MRC based 1×2, 2×1 and 2×2 MIMO systems are 3dB, 6dB and 9dB compared to 1×1 system, while the actual gain will not be able to reach the theoretical value due to wireless channel fading in specific applications. The sampled signals are initially down-converted to the baseband in preparation for subsequent DSP operations. In this experiment, an 89-tap MIMO-constant modulus algorithm (MIMO-CMA) equalizer is adopted to compensate for the linear distortions during the transmission. Subsequently, the carrier recovery operation, which involves the frequency offset estimation (FOE) and carrier phase estimation (CPE) is performed. Additionally, in order to enhance the BER performance, a decision-directed least-mean-square (DD-LMS) equalizer with 199-tap is implemented.

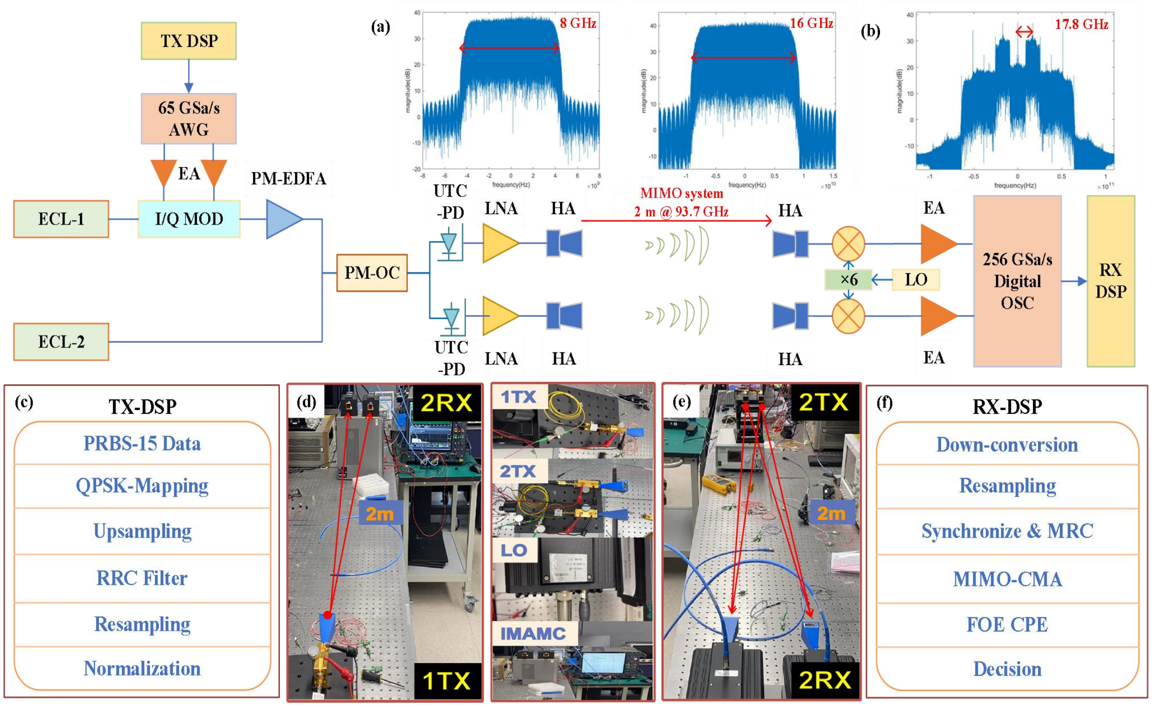

Fig. 1. The experimental setup of MIMO mmwave-over-fiber transmission system: (a) electrical spectrum of 16GBaud and 32GBaud QPSK signal after DSP; (b) spectrum of the received IF signal; (c) TX-side offline DSP procedure; (d) photos of 1×2 system experimental setup; (e) photos of 2×2 system experimental setup; (f) RX-side offline DSP procedure.

3. Experimental results and discussions

Fig.2 (a) illustrates the variations in SNR and BER performance for 16 GBaud QPSK signals with different transmit powers after 2 m 1×1, 1×2, 2×1, and 2×2 MIMO wireless transmission. It can be seen that compared to 1×1 wireless transmission, the other three forms of antenna multiplexing achieve SNR gains. The BER performance has also been improved. Moreover, after the transmit power increases to 2 dBm, the SNR gradually stabilizes, and the gains of the three MIMO structures can reach 2.9, 5.6, and 7.1 dB compared to the 1×1 wireless transmission. Under the same conditions, the SNR and BER performance of the 32 GBaud QPSK signal are shown in Fig.2 (b). Different from 16 GBaud, the high data rate 32 GBaud results in a small symbol width and wide bandwidth. Therefore, the multi-path signal generated by small-scale fading in wireless transmission causes significant interference with the symbol. Moreover, the use of multiple transmit antennas will further amplify the impact of the multi-path effect. As a result, the gains achieved by the three MIMO structures are only 2.2, 2.8, and 4 dB once the performance stabilizes. In addition, the BER 16 and 32 GBaud QPSK signals under all conditions in the experiment satisfies the FEC threshold of $3.8\times10^{-3}/4.0\times10^{-2}$.

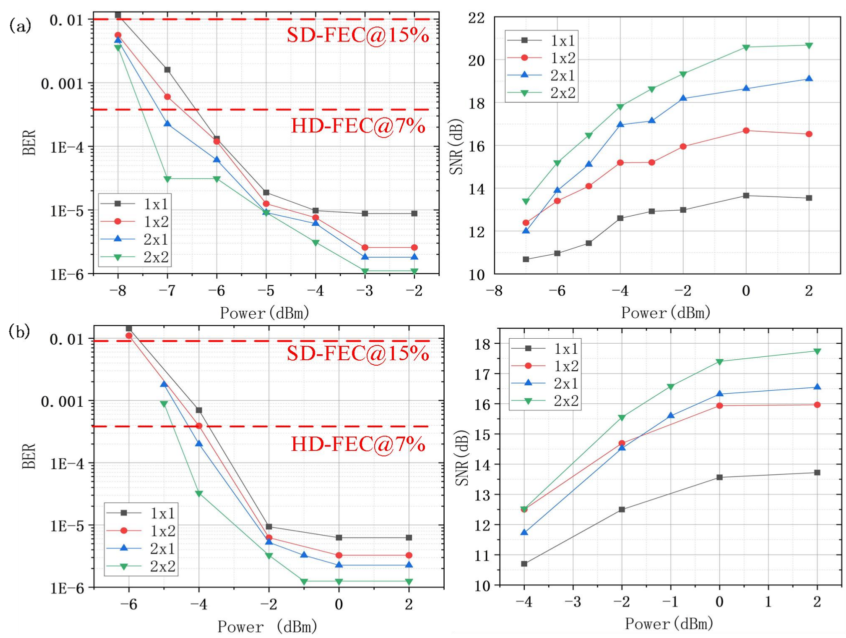

Fig. 2. SNR and BER of the received (a) 16 GBaud and (b) 32 GBaud QPSK signals with different MIMO systems versus input power into PD after wireless transmission.

4. Conclusions

We have experimentally demonstrated 16 and 32 GBaud QPSK signal transmission over 2 m wireless distance at 93.5 GHz in a photonics-aided mmwave multi-input multi-output communication system. Thanks to the MRC technology and advanced DSPs, the maximum SNR gain between 1×1 and 1×2, 2×1, 2×2 MIMO can up to 2.9, 5.6 and 7.1 dB, and the BER of transmission can satisfy the FEC threshold of $3.8\times10^{-3}/4.0\times10^{-2}$. This work was partially supported by the National Nature Science Foundation of China (NSFC) under grant No 62305067, 61935005, 61835002, 62375219 and 62331004.

5. References

[1] C. W. Chow et al. Journal on Selected Areas in Communications. 28, pp. 800-807 (2010).
[2] S. Pan and J. Yao, J. Lightwave Technol. 35, 3498-3513 (2017).
[3] C. Ho et al. J. Lightwave Technol. 32, 3901-3909 (2014).
[4] B. Schrenk and F. Karinou, Proc. OFC (2022).
[5] W. Li, et. al. in Proc. Asia Communications and Photonics Conference (ACP 2021), 2021, pp.T4D.8.
[6] J. Ding, et. al. Optics Letters, 2022, doi: 10.1364/OL.465696.
[7] K. Wang, et. al. J. Lightw. Technol., 2021, 39(10): 3137-3144.
[8] J. Shi, et. al. Optics Letters, 2023, doi: 10.1364/OL.486349.
[9] W. Li, et. al. ECOC 2023, Tu.B.4.2.