Enhanced Multicast Performance for a 60-GHz Gigabit Wireless Service over Optical Access Network Based on 16-QAM-OFDM Hierarchical Modulation

Liang Zhang[1,2], Pan Cao[1], Xiaofeng Hu[1], Cheng Liu[2], Ming Zhu[2], Anlin Yi[2], Chenhui Ye[2], Yikai Su[1], and Gee-Kung Chang[2]

[1]*State Key Laboratory of Advanced Optical Communication System and Network, Shanghai Jiao Tong University, Shanghai, 200240, China*
[2]*School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332 USA*

Abstract: We propose and experimentally demonstrate a 60-GHz ultra-high throughput (VHT) wireless over fiber multicast system. A novel 16-QAM-OFDM hierarchical modulation is implemented and 2.5-dB performance improvement is achieved comparing with conventional I-Q modulation.

OCIS codes: (060.4510) Optical communications; (060.5625) Radio frequency photonics

1. Introduction

The ever-increasing video-based interactive and multimedia services by smart phones or terminals are demanding large bandwidths and high data rates in wireless access networks. The abundance of bandwidth in the unlicensed 60-GHz millimeter-wave (MMW) band enables multi-Gigabit throughput for Wireless Local Area Networks (WLANs) and Personal Area Networks (WPANs). Applications of such high-speed wireless transmission include high-definition (HD) video, interactive multimedia game and next-generation wireless sensor network (WSN). Among them, distribution of HD video is a practical and promising application. When there are two or more users subscribing different videos, multicast scheme should be employed to transmit videos to the corresponding users. In real scenario, the link condition for each user could be varied due to different wireless transmission distances or other reasons. In order to serve all users, the system should be adapted according to the worst-performance channel [1]. On the other hand, although there are many advantages and applications for 60-GHz millimeter wave (MMW), the effective wireless-access coverage is limited to tens of meters due to its high atmospheric absorption and large free-space propagation loss [2]. Owning to the huge bandwidth and low transmission loss of optical fibers, radio-over-fiber (RoF) technology is considered to be an attractive solution to increase capacity and mobility as well as to reduce overall cost in wireless access networks [3].

In the paper, for the first time to the best of our knowledge, we propose and experimentally demonstrate a 60-GHz and gigabit/s wireless-over-fiber multicast system implemented with different channel performances, where a novel 16-quadrature amplitude modulation-orthogonal frequency division multiplexing (16QAM-OFDM) hierarchical modulation is used. Compared with the conventional I-Q 16-QAM modulation, the proposed hierarchical modulation has the ability to shift the power margin of the better-performance channel to the inferior-performance channel, thus improving the overall performance of the multicast system. At central station (CS), two video data streams as illustrated in Fig. 1 are combined to form one data stream, which is then up-converted to a 60-GHz optical signal and transmitted to base station (BS). At the BS, optical/electrical (O/E) convention is realized and the 60-GHz MMW signal is sent to the two users via free space. Subsequently, the two users will receive the 60-GHz MMW signal and demodulate their own subscribed video data. The experimental results show that the proposed hierarchical 16-QAM modulation has 2.5-dB better performance than the conventional I-Q 16-QAM modulation.

2. Concepts of hierarchical modulation and I-Q modulation for 16-QAM

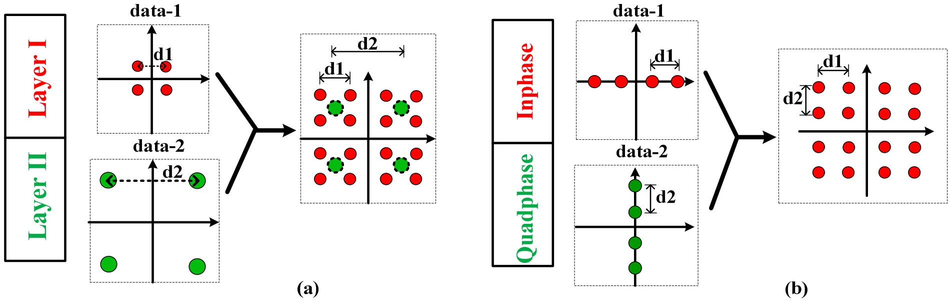

Fig. 1. Conceptual diagrams of (a) hierarchical 16-QAM modulation and (b) conventional I-Q 16-QAM modulation.

Hierarchical modulation is implemented to multiplex and modulate multiple data streams into one single data stream. The principle of the proposed QPSK/16QAM hierarchical modulation is shown in Fig. 1(a), where two independent data streams, data-1 and data-2, are mapped onto Layer-I and Layer-II with QPSK constellations. The two QPSK symbols are then superimposed together to generate a 16-QAM symbol. The minimum distances between adjacent points of the two QPSK constellations are denoted by d_1 and d_2, respectively. Since d_2 is larger than d_1, data-2 exhibits better bit error rate (BER) performance than that of data-1[4]. Here, we define a hierarchical parameter α as the ratio of d_2 to d_1 ($\alpha = d_2/d_1$), which can be flexibly adjusted according to link conditions. In contrast, Fig. 1(b) shows the principle of conventional I-Q 16-QAM modulation, where data-1 and data-2 are mapped onto in-phase (I) and quad-phase (Q) components, respectively. The I and Q components are superimposed to constitute a uniform 16-QAM symbol. Since d_1 is equal to d_2, data-1 shows the same BER performance with data-2.

3. Experimental setup

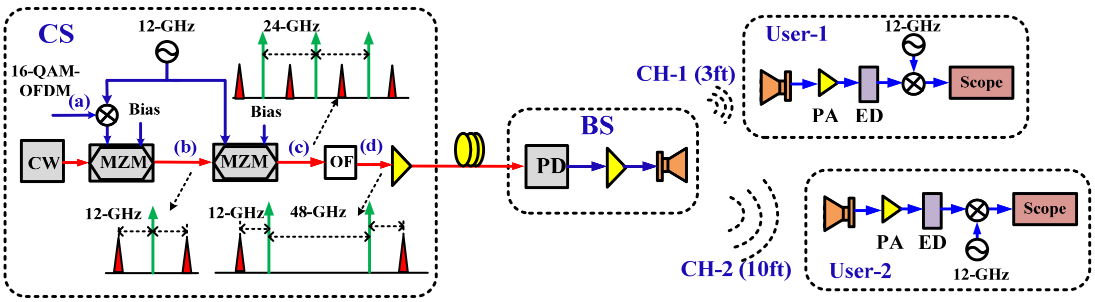

Fig. 2. Experimental setup of the proposed 60-GHz wireless-over-fiber multicast system.

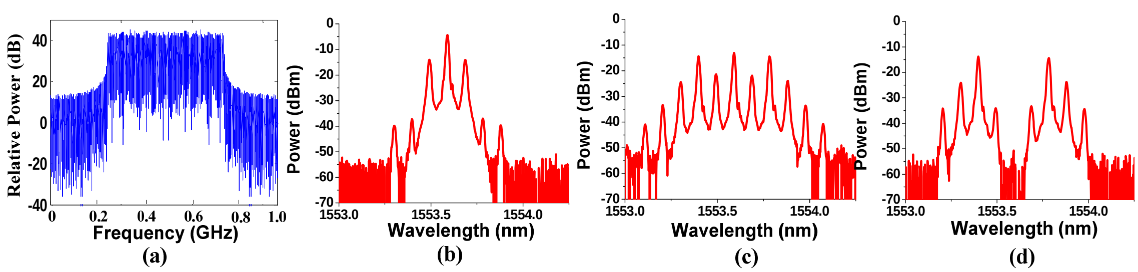

Fig. 3. Electrical and optical spectra measured at different positions depicted in Fig. 2.

We experimentally demonstrated the proposed 60-GHz wireless-over-fiber multicast system with a test-bed setup as shown in Fig. 2. In the two-users structure illustrated here, the wireless links for user-1 and user-2 are 3-ft and 10-ft, respectively, while the other conditions are kept the same. Therefore, channel-1 (CH-1) exhibits better performance than that of channel-2 (CH-2) with the same received optical power at the BS. At the CS, a continual wave (CW) light originated from a tunable laser with a wavelength of 1553.60 nm is coupled into a single-drive Mach-Zehnder modulator (MZM). The OFDM signal is generated offline by Matlab. The total subcarrier number is 256, in which 128 subcarriers are used for the two users and the others are set to zero as guard band. Each data subcarrier of the OFDM signal is modulated with 16-QAM format. After mapping, a 256-point IFFT with Hermitian symmetry is conducted to provide real numerical output data and a cyclic prefix of 20 samples is added to alleviate the inter-symbol interference (ISI). The OFDM data is generated by an arbitrary waveform generator (AWG) with 2.5-GSa/s sampling rate and 1-GHz bandwidth. Therefore, the data rate of the OFDM signal (Fig 3.(a)) is 1-Gb/s, which is mixed with a 12-GHz intermediate frequency (IF) clock. The output of the mixer is amplified and used to drive a single-drive MZM biased at the push-and-pull of the transmission curve. An optical subcarrier modulation (SCM) signal (Fig. 3(b)) is obtained at the output of the MZM, which is fed into a second single-drive MZM. The optical SCM signal is up-converted by the second MZM, which is biased at the peak of the transmission curve and driven by an amplified 12-GHz IF clock. The spectrum of the up-converted signal is shown in Fig. 3(c), whose unwanted bands are filtered by an optical filter (a 33/66 GHz interlevel). After the filter, the optical signal (Fig. 3(d)) is amplified by an erbium-doped fiber amplifier (EDFA) to reach a power of 6 dBm and then transmitted to the BS through 30-km standard single mode fiber (SSMF).

At the BS, a high-speed photo-detector (u2t XPDV 2020R) is used to detect the incoming optical signal and a following power amplifier (Narda West NW 06-0023) is employed to amplify the electrical signal. A rectangular horn antenna (Ducommun ARH-1525-62) with a gain of 25 dBi at the range of 45-75 GHz is utilized to send the 60-

GHz MMW signal to the two user terminals. After transmission over 3-ft wireless link, at the user-1 terminal, the wireless signal is received by another 60-GHz antenna and is down-converted to baseband by a two-stage down-converter [5]. A real-time oscilloscope is used to sample the baseband 16-QAM-OFDM signal at a sampling rate of 25 GSa/s. Offline processing is then implemented to recovery the 16-QAM constellations and estimate BER performances. The same receiving system structure is employed by the user-2. Since the user-2 has longer wireless link (10ft) than that of the user-1 (3ft), channel-2 will show inferior link performance than channel-1.

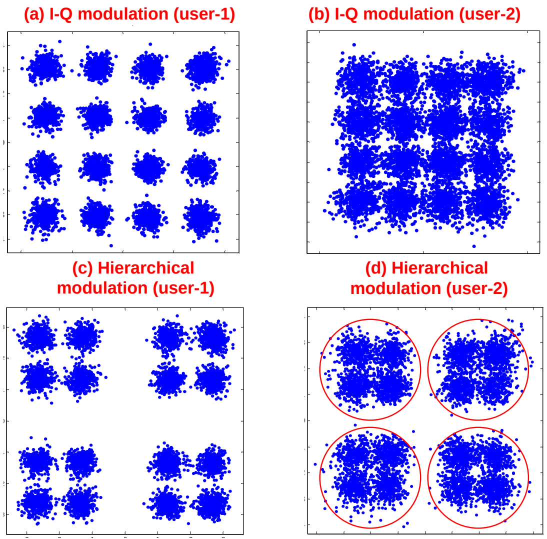

Fig. 4. (a), (b) Constellations of I-Q modulation for user-1 and user-2, (c),(d) constellations of hierarchical modulation for use-1 and user-2

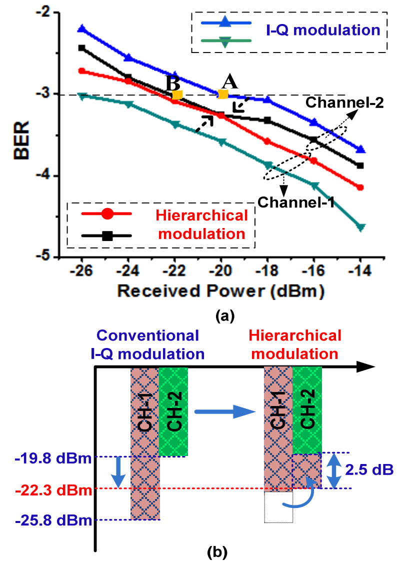

Fig. 5. (a) BER Performances for I-Q modulation and hierarchical modulation, (b) histogram illustration for performance improvement

In the experiment, both conventional I-Q and hierarchical modulation are used for the 16-QAM-OFDM signal. When the received optical power is -21 dBm, the constellations of recovered 16-QAM are shown in Fig. 4. For the conventional I-Q modulation, the user-1 can extract its subscribed data (I-component) with BER$<10^{-3}$, while user-2 is unable to extract the subscribed data (Q-component) with BER$<10^{-3}$ due to its inferior channel performance. For the proposed hierarchical modulation, both users can extract their own components (layer-I for user-1 and layer-II for user-2) with BER$<10^{-3}$. The BER performance is shown in Fig. 5(a), the system sensitivity is improved from -19.8 dBm (point A) to -22.3 dBm (point B), therefore, 2.5-dB performance improvement is achieved for hierarchical modulation comparing with the conventional I-Q modulation. The improved system performance of hierarchical modulation is depicted in Fig. 5(b). The proposed hierarchical modulation has the ability to shift the power margin of the better-performance channel (CH-1) to the inferior-performance channel (CH-2). As a result, both channels will have roughly the same performance and the overall performance of the multicast system is improved by 2.5 dB. It is believed that higher performance improvement can be achieved if the two channels have higher performance difference, which could be the topic of our next-step investigation.

4. Conclusion

We have proposed and experimentally demonstrated a 60-GHz and 16-QAM-OFDM gigabit/s wireless-over-fiber multicast system, where both the novel hierarchical modulation and conventional I-Q modulation are implemented and the BER performances are analyzed for the two channels with 3-ft and 10-ft wireless links. The hierarchical modulation has improved the system performance by 2.5 dB than the conventional I-Q modulation. We believe that our novel scheme can dynamically mitigate the system impairments.

5. References

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