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Real-Time High-Definition (HD) Video over 10-GbE Optical Wireless Communications (OWC) Supporting Simultaneous Access to Multiple Users

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Abstract *An OWC system which automatically finds the locations of users and simultaneously serves multiple users is demonstrated. Real-time high-definition (HD) video to two users is transmitted over 10-GbE protocol, showing the feasibility for practical applications.*

Introduction

In order to meet the fast growing capacity requirements for wireless systems, wider transmission bandwidth is demanded. In the upcoming 5G systems, to reduce congestion issues extension of radio frequencies (RF) up to 100 GHz is being considered [1]. However, high-frequency devices are still expensive. Hence, it is challenging to implement high-capacity wireless systems with fully RF-based technologies. Given the maturity of fibre-optic technologies, optical wireless communications (OWC) can already support over 100 Gb/s capacity using commercial devices. Hence, OWC is catching much attention as a promising candidate for future high-capacity wireless systems [2, 3].

We apply infrared (IR) optical beams for OWC which are highly directional and narrow in spatial distribution ('pencil beams') [2]. It is a challenge to find and connect an end user to an optical antenna with such directional optical beams. In Ref. [4], an arrayed waveguide grating (AWG) -based pencil radiating antenna (PRA) is proposed and demonstrated. With this device, an optical beam can be steered in 2 dimensions into arbitrary locations by simply changing its transmission wavelength. Besides, the device is totally passive; hence the system maintenance cost can be reduced and its reliability improved.

This paper extends the work of Ref. [4], which operated in C-band and served 80 cells. We extended the coverage to 129 OWC cells at a reach of 2.5m and within an area of 1.6×1.6 m^2. Moreover, with the upgraded PRA we demonstrate a system which can automatically find the locations of users and can simultaneously serve multiple users by different wavelengths. In the demonstration, real-time high-definition (HD) video embedded in 10 Gigabit Ethernet (10-GbE) frames is successfully transmitted to two users, which shows that our system is feasible for practical applications. To the best of our knowledge, this is the first time that a real-time 10-GbE indoor OWC system simultaneously serving multiple users is demonstrated.

Principles and Experimental Setup

The principles of our system are summarized in Fig. 1 [2]. A central communication controller (CCC) inside a building is connected with the antenna hubs installed in different rooms through an optical cross-connect (OXC) and a radio cross-connect (RXC). Each antenna hub is composed of an AWG-based 2-D beam-steering PRA [4] and a set of radio units to capture the upstream 60GHz traffic from the user devices. The directions of the horn antennas at the hub are continuously swept to receive signals from different locations. The existence and the location of an end user is discovered according to the monitored radio power. Inside the PRA, the input wavelength is routed to the corresponding ports of the AWG. The output fibers of the AWG are connected to a 1D-to-2D interposer to rearrange the fibers into a 2-dimensional arrangement. The output fibers of the interposer are located close to the focal plane of the succeeding lens, so different-wavelength signals can be steered in slightly diverging beams towards different directions. Hence, the PRA is a device which spatially distributes signals according to the input wavelengths. After the locations of the end users have been determined, the CCC tunes the transmitting wavelengths of the transceiver (TRx) array, and then the signals are distributed to the corresponding end users through the PRA.

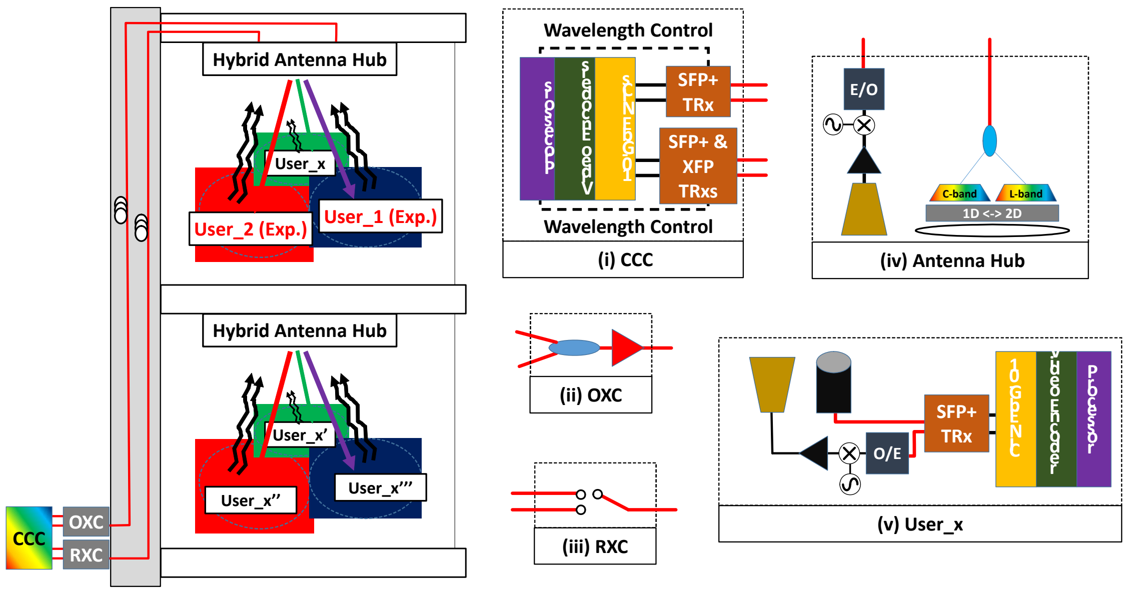

Fig. 1. AWG based 2-D PRA OWC system. Insets: the corresponding experimental unit setup. CCC: central communication controller; OXC: optical cross-connect; RXC: radio cross-connect; Exp.: used in experiment. NIC: network interface card.

As shown in Fig. 1, two end users (User_1 and User_2) are simultaneously served in our experimental testbed. Inset (v) is the setup of an end-user. The end-user transmits the 61-GHz radio signal into the antenna hub (the setup is shown in Inset (iv)). The radio horn antenna in the hub is mounted on a rotating motor, and is continuously collecting radio signals from different locations. According to the received radio power, the location of an end-user is determined. Based on the knowledge of the wavelength-to-position mapping function of the PRA, the CCC (setup shown in inset (i)) looks up the pre-calculated location-wavelength mapping table, and sets up the wavelengths of the TRx's (respectively 1536.55 nm and 1544.47 nm as shown in Fig. 2). Then, two real-time video streams (720p HD Big Buck Bunny [5]) are built. The streams are respectively encoded and transformed into 10-GbE packets through the network interface cards (NICs). The TRxs are modulated by the 10-GbE signals, and combined by an optical coupler in the OXC (inset (ii)). The combined signals are amplified to about +20 dBm and sent to the antenna hub. Eventually, the signals are distributed to the corresponding users by the PRA. The two video streams are respectively received by the corresponding users and recorded for further analyses. The total loss of the PRA is about 10 dB; hence the output power is about +10 dBm, which obeys the eye safety regulations. Compared to our previous results [4], the wavelength range supported by the PRA is extended up to 1603.59 nm (from 1569.8 nm in [4]) by adding an extra L-band AWG. The number of the PRA ports is thus upgraded to 129, and thus 129 OWC cells can be supported, covering an area of 1.6×1.6 m^2 at a reach of 2.5 m.

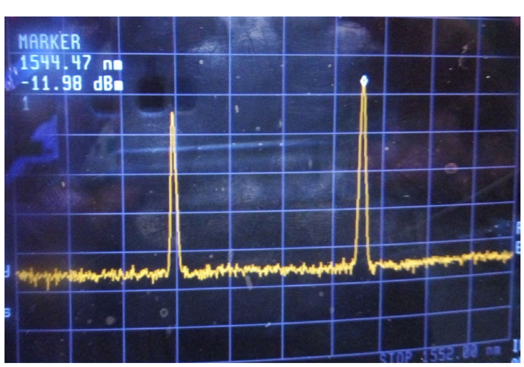

Fig. 2. Optical spectrum of the transmistted signals.

Results

The frame images of the original and the recorded videos are captured off-line. The pixel data of all frames are transformed into binary streams. The streams of the original video and of the recorded videos are compared bit-by-bit to calculate the bit-error rate (BER). The BERs of the two users at different receiving powers are shown in Fig. 3. The BER level of $3.8\text{x}10^{-3}$, 10^{-9}, and $3.16\text{x}10^{-12}$ are respectively labeled in Fig. 3. BER of $3.16\text{x}10^{-12}$ is the minimum BER observable for the video, which is limited by the length of the video. We can see that no error is observed for the whole video while the power is respectively -19 dBm for User_1 and -23 dBm for User_2. The sensitivity difference between

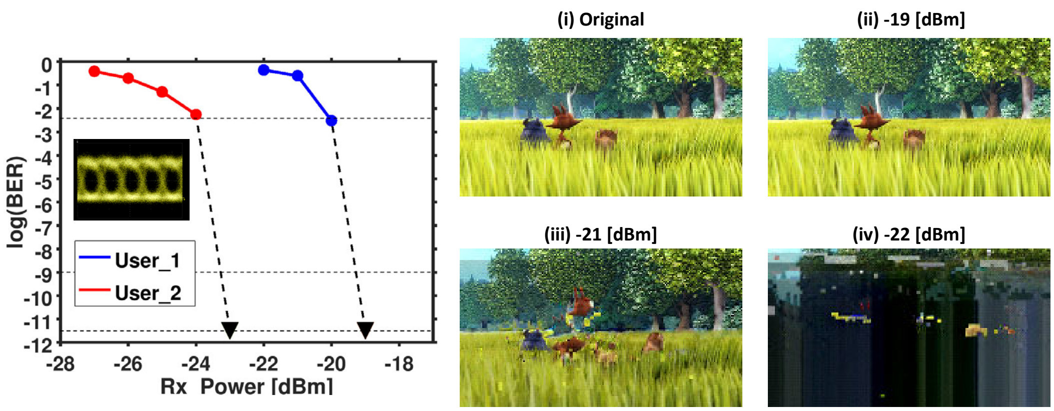

Fig. 3. BER performance of the real-time video signals. Lower triangle: minimum system BER at the corresponding Rx power.. Insets: the image quality of the corresponding receiving power.

the two users is about 4 dB. This mainly results from the different TRxs equipped in the users. Rapid BER degradation within 1-dB power range is observed in Fig. 3. We believe this phenomenon is caused by the error control modules of the NICs. In order to confirm that the 10-Gb/s signals are successfully generated from the NICs, the eye diagram is measured by

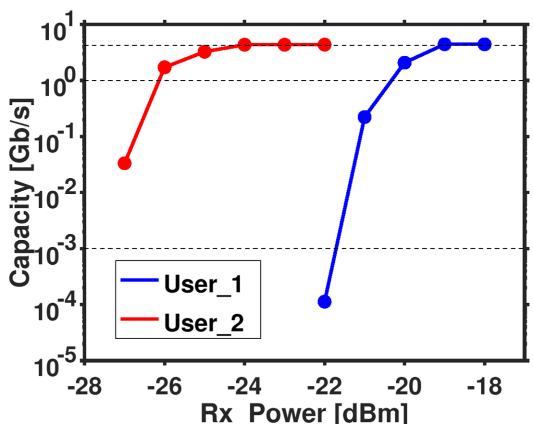

Fig. 4. Transmission capacity.

triggering the scope with the signal itself. The eye diagram is shown in inset of Fig. 3. 10-GbE pulses with open eyes are successfully observed. The image quality at different received powers is also shown in the insets of Fig. 3. While the receiving power is too low, the BER performs worse. This results in degraded image quality.

The transmission capacity of the 10-GbE connection is further analyzed by software iPerf [6]. The maximum transmission capacity versus received power is shown in Fig. 4. Compared with Fig. 3, we see that the transmission capacity decreases with the degradation of BER as expected. The measurable maximum capacity saturates at about 4.2 Gb/s. By reducing the length of the packet header, 6-Gb/s capacity can be obtained. We believe that the remaining capacity degradation comes from the latency of the computer units, as reported in [7].

Conclusions

An OWC system which can automatically find the locations of users and simultaneously serve multiple users is demonstrated. In our testbed, two real-time HD video streams over 10-GbE OWC are transmitted simultaneously, using commercially available products. With the upgraded C+L band PRA, our system is capable of simultaneously serving 129 OWC cells within area of 1.6×1.6 m² at a reach of 2.5 m.

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