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Coordinated Multi-Source (CoMS) transmission for Optical Wireless Communications (OWC)

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Abstract *Multiple optical sources are coordinated in order to create extra power budget, and increase transmission distance and capacity. Wireless transmission over 1.7 meters of 20 Gb/s PAM-4 data synthesized from two sources is experimentally demonstrated.*

Introduction

The demand for wireless capacity for communication application is continuously increasing. New spectrum is widely planned for high capacity transmission. Beam-steered infrared (IR) optical wireless communications (OWC) recently gets much attention as it can already support over 10 Gb/s capacity building on mature fibre-optic technologies [1-3]. However, compared to the widely deployed radio-frequency (RF) systems, OWC is still facing challenges to serve mobile users with its highly directional and narrow optical beams.

Currently, OWC mainly uses beam steering technologies to direct optical beams to different locations of the mobile users. Refs [4,5] have proposed the pencil radiating antenna (PRA) architectures, with which the optical beams can be steered towards arbitrary locations according to their wavelengths. Multiple users can be simultaneously served with the PRA system by equipping a transmitter (Tx) array or a multi-wavelength source in the central station. Besides, a PRA can be operated fully in passive mode; hence it can potentially reduce the system operational expenses (OPEX).

As mentioned above, multiple Tx-s may be included in the central station, so as to simultaneously serve different users. Some Tx-s are idle if the number of users is less than the number of Tx-s, or if users with low capacity can be served by just a few Tx-s. In order to use the Tx's more efficiently, coordinated multi-source

(CoMS) transmission is proposed in this paper. In the central station, the Tx's are synchronously controlled. While a Tx is idle, it coordinately transmits signals with other busy Tx's, so as to improve the signal performance by offering extra power. The CoMS technique can extend the transmission distance, and may enable the transmission of advanced modulation formats (that may need higher sensitivity), which increases the transmission capacity.

In this paper, we double the transmission capacity by operating two coordinated optical Tx-s to synthesize a 20 Gb/s 4-ary pulse amplitude modulation (PAM-4) signal from two 10-Gb/s on-off keying (OOK) signals. To the best of our knowledge, this is the first time CoMS transmission is proposed and demonstrated for OWC systems.

Principles

Our OWC system is a hierarchical structure as shown in Fig. 1. A central communication controller (CCC) is the principal node of the system. The CCC is connected to different branches of the fibre indoor backbone through an optical cross-connect (OXC). One or multiple PRAs are installed in each room. (In Fig. 1, an AWG-based PRA [5] is used as an example.) According to the input wavelengths, the PRA distributes signals towards users at different locations. Hence, the users are successfully connected into the OWC system.

Fig. 1. Conceptual diagram of the CoMS OWC system. Insets: the conceptual principles of the corresponding operation modes. CCC: central communication controller; OXC: optical cross-connect; Tx: transmitter.

In our CoMS scheme, three transmission modes are defined for the CCC as shown in Fig. 2. The common mode is used for general transmission. In the common mode, the CCC allocates only one Tx to transmit signals for one end user. In the common mode, the signals are transmitted in OOK. OOK is chosen for the general case because it is the most cost-effective and robust modulation choice. In the amplification and the synthesis modes, the CCC allocates two (or more) coordinately operated Tx-s for one user. In the amplification mode, the coordinately operated Tx-s are simultaneously modulated by the same signal. After the signals of the two Tx-s are combined, the optical power is doubled, hence higher capacity or longer distance is possible. For example, as shown in insert (ii) of Fig. 1, higher-power PAM4 can be

used to double the capacity (compared to the common mode). In the synthesis mode, the electrical drivers of the CCC are kept intact in the common mode. The OOK sequences modulating the two coordinately operated Tx-s are pre-coded in the central processor. The optical powers are adjusted by the succeeding attenuators, so that higher-level modulation formats can be synthesized. As shown in inset (iii) of Fig. 1, one PAM4 signal is synthesized from two OOK signals with 1.5 times power enhancement. Compared to the common mode signal, the signals generated from the amplification and synthesis modes will both have higher power. The synthesis mode may result in lower power than the amplification mode since some power is lost in the synthesis process. Though the amplification mode may result in the highest optical power, it requires pre-installation of electrical circuits to generate advanced-modulation signals, which may result in higher cost.

Experiment

A demonstration experiment is performed in order to verify our proposed CoMS system. Figure 3 shows the experimental setup. The user location is pre-localized by a 61-GHz RF system. The center wavelength required to steer the optical beam to the user through our PRA is 1536.54 nm. Two commercial XFP transceivers (TRx's) set at the corresponding wavelength are used as the coordinated sources. 10 Gb/s OOK PRBS7 signals are generated by a pulse pattern generator (PPG), and modulate the XFPs. The

Fig. 2. Conceptual architecture of the CCC.

Fig. 3. Experimental Setup. PPG: pattern generator; CCC: central communication controller; OXC: optical cross-connect; TRx: transceiver; PRA: pencil radiating antenna.

lower XFP is connected with a polarization controller (PC) and an optical delay line. The tunable channel grid of our XFPs is limited, so this PC is used as a temporary replacement for reducing the beating noise between the two XFPs. The optical delay line is used to align the patterns of the optical signals at different paths. This is not necessary in a practical system, since the patterns can be well aligned by the central controller. The upper XFP is connected with an optical tunable attenuator, and its output power is set to -7 dBm (3 dB higher than the lower path). The two optical paths are combined by an optical coupler to synthesize the PAM-4 signal. After the coupler, the signal is amplified to about +22 dBm, and is sent to the remote PRA through the fiber. An AWG-based PRA is used in the experiment [5]. The PRA is implemented by combining a C-band AWG and an L-band AWG in order to extend the supported wavelength range. The total loss of the PRA is about 10 dB. Together with other connection losses, the output power is about +10 dBm, which obeys the eye-safety power regulation. The output optical signal is then transmitted through 1.7-meter in free-space. In the receiving plane, the $1/e^2$ beam diameter is about 11.4 cm. The beam is collected by a collimator and received by the oscilloscope.

Fig. 4. Performance of the signals. Insets: eyes diagrams of the corresponding curves.

Results

Since we do not have a bit error rate tester (BERT) for PAM-4, the bit error rate (BER) is calculated according to the amplitude histogram of the signal displayed in the scope [6]. Fig. 4 shows the calculated BER of the synthesized PAM-4 at different powers. The BER of the OOK signal is also included as a reference. The OOK signal is generated by directly turning off one XFP transmitter. At the forward error correction (FEC) level ($BER=3.8 \times 10^{-3}$, the dash line of Fig. 4), the power penalty between the OOK and the PAM-4 signals is about 5 dB, for which can be roughly compensated by four coordinated Tx-s. The required power for both signals is high and this is limited by the scope module. Since the typical sensitivity of 10 Gb/s receiver is about -19 dBm, we can expect that about 12 dB sensitivity improvement can be obtained with practical receivers. The eye diagrams of the corresponding signals are shown in insets of Fig. 4. For both signals, open eyes are observed.

Conclusions

In this paper, CoMS transmission is proposed to more efficiently use the idle laser resources. Three transmission modes are introduced in our CoMS system. In the amplification and synthesis modes, additional power can be obtained from multiple coordinated optical sources. Hence, the transmission distance can be extended and advanced modulation formats may be used to increase the capacity. Transmission of a PAM-4 signal synthesized from two coordinated Tx-s is successfully demonstrated by an experiment.

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References

- [1] T. Koonen, "Indoor Optical Wireless Systems: Technology, Trends, and Applications," J Lightwave Technol., Vol. 36, pp. 1459 (2018).
- [2] A. Gomez et al., "A 50 Gbs Transparent indoor optical

wireless communications link with an integrated localization and tracking System," J Lightwave Technol., Vol. 34, pp. 2510 (2016).

- [3] K. Wang et al., "Experimental demonstration of a novel indoor optical wireless localization system for high-speed personal area networks," Opt. Lett., Vol. 40, pp. 1246 (2015).
- [4] T. Koonen et al., "Ultra-high capacity indoor optical wireless communication using 2D-steered pencil beams," J Lightwave Technol., Vol. 34, pp. 4802 (2016).
- [5] A.M.Khalid et al., "Real time 10Gb-Ethernet transmission over 2D indoor passive beam steered optical wireless system based on high port arrayed waveguide gratings," Proc. ECOC, Germany, pp. 1–3 (2016).
- [6] J. G. Proakis, *Digital Communications*, 4th Edition, New York: McGraw-Hill, 2001.