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Alignment Simplified Free Space Optical Communication for Radio Spectrum Coexistence

Taichu Shi, Yang Qi, James Garofolo and Ben Wu*
Department of Electrical and Computer Engineering, Rowan University, Glassboro, NJ 08028, USA
wub@rowan.edu

Abstract: We proposed and demonstrated an alignment simplified FSO system that enable the coexistence of radio spectrum. The FSO channel functions as a reference to cancel the interference without pre-known motion pattern of mobile receiver. © 2022 The Author(s)
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1. Introduction

Free space optics (FSO) has been proven as a highly effective method for high-speed wireless communication where free space acts as a medium between transmitters and receivers. As it uses a free space laser to transmit data, we can achieve wider bandwidth and low error rates. Thus, FSO communication is commonly introduced for solving the workload issue of the Sub-6 GHz radio frequency (RF) band. In the meanwhile, FSO is a line-of-sight technology in which the transmitter and the receiver are at both networking locations that must see each other. If the receiver is a moving mobile device, the FSO light beam must dynamically follow and align with its motion pattern [1].

By combining FSO and traditional RF communications, systems can leverage the strengths of both. Compared with simply substituting RF wireless communication with FSO, it can enable the RF band so that we can not only achieve a better workload, but it’s not necessary to have strict alignment in the FSO channel as well. Blind source separation (BSS) method in Multiple-input and multiple-output (MIMO) system is an effective way to cancel the interference between different channels. Recently photonic BSS can separate signal of interest (SOI) from mixed signal at GHz bandwidth in real-time by converting the mixed signals to optical frequencies [2,3]. Through establishing a FSO channel to send a reference signal together with MIMO system for interference cancellation, it can solve the ill-condition problem which occurs when two receivers are close to each other making it difficult to do BSS [4]. In the hybrid system, since the FSO channel is merely functioned as interference, the FSO light beam only needs to cover the areas with strongest interference and doesn’t require the motion pattern of moving mobile receivers, which greatly simplifies the beam alignment between the transmitter and the receiver. The interference generator only needs to control the radiation of optical carrier (beam steering) based on the radiation of RF interference.

In this paper, we demonstrated the relationship between the number of antennas at the massive MIMO transmitter and the performance of the interference cancellation system with FSO reference signal and obtain preliminary results. As the numbers of antennas used at the MIMO transmitter increase, the RF and optical radiation patterns get more directional. Therefore, the FSO receiver gets more optical power with higher signal to noise ratio (SNR). In our experiment, when the coverage areas with radiation angle decreases from 21 to 5.2 degrees, the received power increases from -31 dBm to -14 dBm while the quality of signal remains in a similar range.

2. Principles and System Setup

A show case of beam steering of hybrid massive MIMO and FSO system is shown in Fig. 1 (a). the interference signal from massive MIMO transmitter is limited within a narrow angle. The blue curves in Fig. 1 (a) show the transmission pattern of a massive MIMO transmitter (Tx2) which is sending signals to the corresponding receiver Rx2. Since the position of Rx1 is located on the path of Tx2 and Rx2, such signals will become interference for Rx1, while they will have a very small impact on other receivers which are not in between, such as Rx3 or Rx4. Thus, the FSO channel for interference cancellation (Red area) only needs to cover the direction with strongest RF interference signal (in the direction of Rx1).

The schematic setup is shown in Fig. 1 (b). Two boxed areas are representing Tx2 and Rx1 in Fig. 1 (a) respectively. The interference signal is transmitted both from MIMO antenna (grey arrow) and FSO channel (green arrow). On the receiver side, once the antenna received the interference, it can be modulated as optical signal. Since the FSO channel also received the reference signal, the interference can be cancelled by controlling the tunable delays and tunable attenuators.

In the experiment, we first test the radiation pattern of massive MIMO transmitter with 4, 8, 16 antennas at 2.4GHz and record their angles when they reach full widths as soon as the power drop to -10 dB of their peak values.

The radiation pattern of FSO channel can be manipulated by controlling the lens of the FSO transmitter. A QPSK signal with 5M bandwidth at 2.4 GHz is used in the experiment.

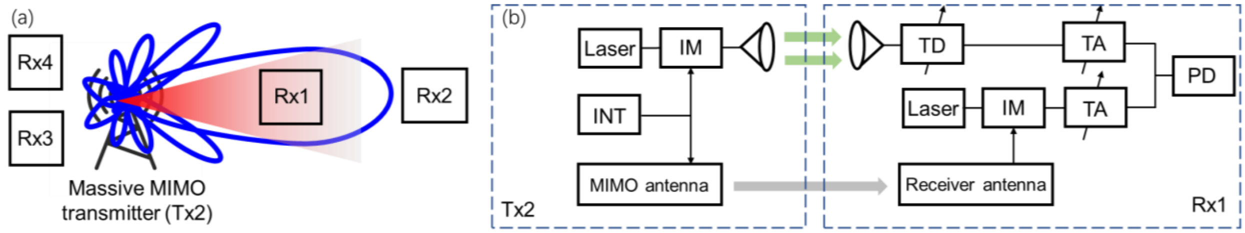

Fig. 1. (a) Show case of FSO and massive MIMO transmitter for beam steering. (b) Schematic system setup. IM: Intensity modulator; INT: Interference signal; TD: Tunable delay; TA: Tunable attenuator; PD: Photodiode.

3. Results and Analysis

The results are shown in the Fig. 2. Fig. 2 (a) - (c) are the calculated radiation pattern of massive MIMO transmitter with 4, 8, 16 antennas. The carrier frequencies are all at 2.4 GHz. When the power drop to -10dB of their peak values, the full widths of the angles are 21°, 10.8°, and 5.2°, respectively. Such angle ranges are covered with FSO channel (red areas in Fig. 2 (a) – (c)). The radiation pattern can be controlled by turning the lens of the FSO transmitter. Fig. 2 (e) shows the constellation diagram of recovered SOI. It's clear to observe the correct pattern. The black curve in Fig. 2 (d) shows the relationship between angles and received power. As the angle becomes more and more narrow, the power becomes stronger. When the received power is increasing from -31 dBm to -14 dBm, we can still get a relatively clear constellation diagram. This is a strong proof to the reliability of our system.

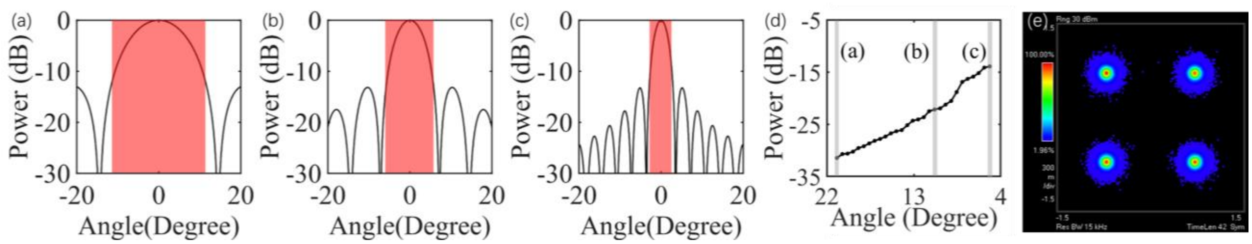

Fig. 2. (a) - (c) The black curves show the radiation patterns of massive MIMO transmitters with 4, 8, 16 antennas respectively; the red areas cover the peak of the black curves and show the radiation patterns for FSO channels. (d) Experimental results of FSO and massive MIMO system. The grey lines represent the angles of (a) – (c) respectively. (e) Constellation diagram of recovered SOI.

4. Conclusion

We proposed and experimentally demonstrated an alignment simplified method for FSO and Massive MIMO hybrid system and demonstrated its feasibility. By controlling the radiation pattern of the interference transmitter, we can get a highly directional reference signal for interference cancellation without pre-known information of moving pattern of mobile receiver or aligning FSO channel based on the movement of it. When the numbers of antennas increase and the received power is increasing from -31dBm to -14 dBm, the constellation diagram is still clear to observe. This work was supported by the National Science Foundation (NSF) under Grant ECCS-2128608.

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