Power-efficient Radio-over-Fiber aided Spatial Modulation

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***Abstract*—Spatial modulation (SM) is a multiple-input multiple-output technique, that is capable of providing energy-efficiency and spectral-efficiency trade-off. Here, we propose an optically-controlled SM by invoking the radio over fiber based processing, for demonstrating enhanced power-efficiency and flexibility, on the expense of insignificant performance loss.**

***Index Terms*—Spatial modulation, radio over fiber, power-efficient, MIMO, flexibility.**

I. Introduction

Multiple-input multiple-output (MIMO) communication has been deployed in mobile networks, to improve the channel capacity by a factor of over 100 [1], [2], while spatial modulation (SM) is a typical MIMO technique that can provide energy-efficiency and spectral-efficiency trade-off [2]. Traditionally, SM is performed using digital signal processing, where fast electronic switches are used for selecting the active antenna for data transmission [1]. This is power hungry implementation [1], [3], especially when massive MIMO is implemented, since it requires large-scale MIMO digital signal processing (DSP) and ultra-fast switches.

In order to address the above-mentioned challenges, in [3] we proposed and experimentally demonstrated the feasibility of using radio over fiber (RoF) techniques for SM generation, where a twin-antenna SM scheme can be achieved by dispensing with the electronic SM switches. However, the proposed work in [3] can only support dual-antenna-based SM system.

There is a paucity of research on multiple-antenna-based RoF-aided SM, when considering more power-consuming massive MIMO [4]. In this article, we present a power-efficient RoF-aided architecture, exploiting the microwave-photonic-based signal processing for generating the SM signal without using the power-consuming switches and MIMO DSP for arbitrary number of transmitter antennas. Our contributions are summarised as follows:

1) Power-efficient SM design: dispensing with the DSP-based SM scheme, we propose a power-efficient RoF-aided SM, where arbitrary number of SM transmit antennas can be supported.
2) Centralised SM signal processing: using RoF aided signal processing, the antenna selection mechanism is operated in the optical domain without the need to use ultra-fast electronic switches.
3) Supporting multiple-antenna system: exploiting the MZM and passive optical filters, our design is capable of performing massive-MIMO communications.

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II. System Architecture and Simulation Results

We consider the centralised radio access network (C-RAN), which has been widely deployed in the 5G network [5] as shown in Fig. 1. Conventionally, the SM transceiver relies on MIMO DSP placed on the remote radio head (RRH), requiring power-consuming ultra-fast electronic switches and complex massive-MIMO scheme [5]. SM splits the data bits into two parts, namely antenna selection bit and data bit, with one controlling the antenna transmitting the data and the other being modulated by radio frequency carriers. In the receiver side, these two parts are simultaneously detected to attain a multiplexing gain.

Our proposed technique invokes the microwave-photonic-based RoF scheme to optically centralise the SM scheme in a central office (CO) for reducing the MIMO-induced high power-consumption. Fig. 1 shows the RoF-aided SM design, where the CO performs the power-efficient optical processing, while the remote radio head (RRH) accommodates the power-efficient SM transceiver and MIMO transmission. In the CO, the SM selection block splits the transmitted bits into data bits (DB), carrier selection bits (CSB) and side-band selection bits (SBSB), where the SBSB controls the phase shifter shifting the phase of the RF signal for generating the optical single side-band signal, while the CSB determines the center frequency of the modulated RF signal. DB is the classic-modulated signal to be carried by the RF carrier. To be more specific, the CSB tunes the selected RF spectrum of each time slot, which will be modulated by the DB. Then, the dual-arm MZM of Fig. 1 performs as the optical modulator, which is driven by the two streams of RF signal fed into each arm, where the bottom-arm-fed RF signal is of a 90° phase-shift difference from the upper-arm. This 90° or -90° phase-shifts will result in left or right optical single side-band signal [6], where the SBSB phase-shifts the RF signal using a RF phase shifter. In a nut shell, with the aid of the DB, CSB and SBSB, the MZM can optically generate the SM signal, where at each time slot, different optical single side-band signal is transmitted in the fiber as shown in Spectrum of Stage ① of Fig. 1.

In the remote radio head (RRH), in order to remove the electronic switches of conventional SM scheme, as shown in the RRH of Fig. 1, a power-efficient SM transceiver based on a set of passive optical components is introduced. The optical power splitter separates the optical signal into two parts, with

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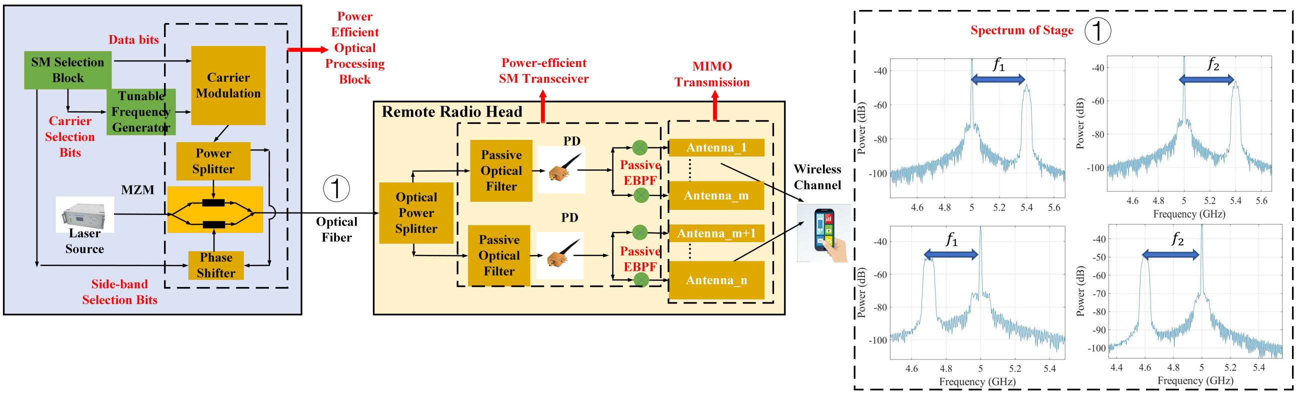

Fig. 1. Proposed System Architecture

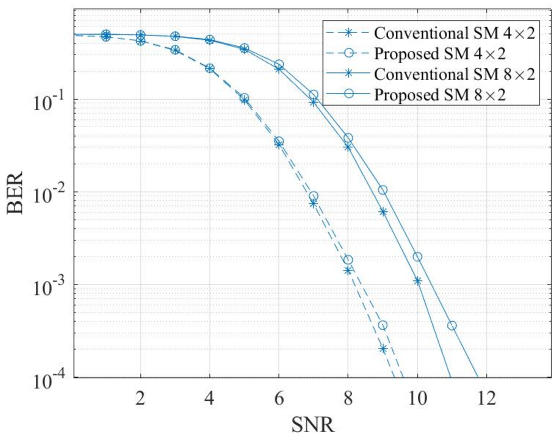

Fig. 2. System BER performance

each being fed into two passive optical filters of Fig. 1 with different center frequencies, removing the left side or right side of the optical carrier (i.e. remaining one side-band and the optical carrier), after which the corresponding photo-detector and electronic band-pass filter (EBPF) recover the RF signal of each side. Then the optical-RF-processed analogue signal will be sent to the antennas for wireless transmission without exploiting extra DSP.

For example, if we consider a 4×2 MIMO system, Spectrum of Stage ① of Fig.1 gives the optical spectrum in the fiber carrying the data into the four different antennas. Since each optical spectrum can be mapped to a corresponding antenna, the SM antenna selection process has been pre-performed in the CO, where the CBS and SBSB can determine the specific side-band location which corresponds to each antenna thanks to our power-efficient passive filters.

The proposed system was simulated using MATLAB. In our simulation, the fiber-link channel was modelled by the split-step fourier method, and the wireless channel adopted the Rayleigh fading channel model. Both 4×2 and 8×2 schemes are considered, where RF frequencies of 300 MHz, 400MHz, 500MHz and 600MHz were externally modulated by the optical carrier of 1550 nm (Relative to 5GHz in our simulation). A convolutional code of a code rate of 1/3, a constraint length of 7 and generator polynomials of (171,133) was used, where the bit sequence is then modulated using binary phase shift keying (BPSK).

To further verify our system performance for multiple-antenna-based spatial modulation, we compare the bit error ratio (BER) performance of the proposed system to that of conventional SM system without optical processing. Fig. 2 presents the simulated BER performance, showing that BER degradation would be less than 1 dB for both 4×2 and 8×2 schemes. Note that our system is capable of supporting arbitrary number of transmit antenna relying on the selection of carriers, which can be employed for massive-MIMO communications.

III. Conclusions

In this paper, we proposed a multiple-antenna-based RoF-aided SM RAN design, where the power-efficient microwave-photonics-assisted SM-MIMO signal generation is performed. Our system applies the MZM's optical single side-band generation principle to optically control the SM antenna selection. Furthermore, our proposed system can achieve similar performance to the conventional SM systems using all electronic processing requiring high-speed switches.

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