An Artificial Neural Network MIMO Demultiplexer for Small-Cell MM-Wave RoF Coordinated Multi-Point Transmission System

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Abstract *We propose and experimentally demonstrate an artificial neural network (ANN) MIMO demultiplexer for small-cell millimeter-wave RoF system. The new scheme has improved the system capacity and synchronization tolerance between two adjacent RRUs in 5G mobile fronthaul.*

Introduction

The deployment of millimeter-wave (mm-wave) wireless communications can greatly extend the system capacity for wireless services and make it a promising candidate for indoor-mobility, high-proximity and outdoor small-cell applications in the upcoming 5th generation (5G) mobile data communications. The high propagation loss and frequency bandwidth make the network coverage design very challenging [1-3]. A reasonable coverage planning is significant to provide users robust wireless links, satisfying the Enhance Mobile Broad (eMBB) requirements in 5G. The density of remote radio units (RRUs) increases as the cell sizes decrease, so the utilization of each cell goes down and the chance of inter-cell interferences (ICI) goes up [4]. In order to overcome the interferences in the cell edge areas, fractional frequency reuse (FFR) in which adjacent cells use different and non-overlapped frequency channels is introduced. However, the small coverage sizes and line-of-sight (LoS) wireless links raise the probability of sharp handoff and aggravate the negotiation load between different small cells.

To support good mobility and connectivity in high-traffic outdoor environments, the concept of macro-assisted small cells, called Phantom Cell, is proposed, consisting of Control/User (C/U)-planes, as shown in Fig. 1(a) [5]. The user equipment (UEs) in C-plane only is provided by a macrocell in a lower frequency band. For the UEs in both C-plane and U-plane, higher frequency band is employed to provide services in U-plane while the control signalling such as frequency handover and synchronization are completed in C-plane. In order to take full advantages of small cells, generalized distributed antenna system (GDAS) is proposed recently with multiple antennas clusters located at different RRUs to make beam forming and coordinated multi-point transmissions to

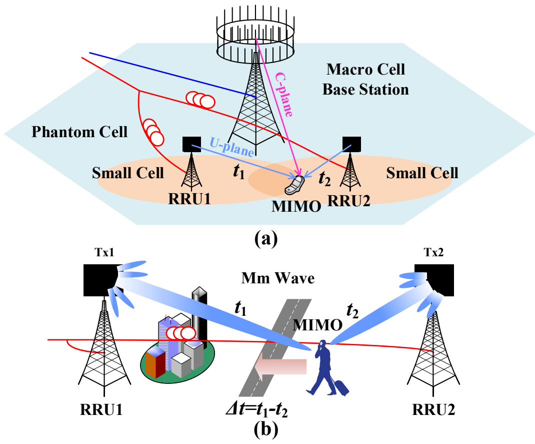

Fig. 1: (a) Phantom-cell structure in 5G mobile fronthaul. (b) Transmission time discrepancy between the two RRUs.

increase the signal capacity and robustness [6]. However, in outdoor scenarios, small-cell nodes may be deployed to cover certain busy streets where a relatively higher terminal speed can be expected, making the precise synchronizations between different RRUs very challenging and the signalling between different small cells heavy, as shown in Fig. 1(b). The time discrepancy between the two RRUs leads to very large deviations when using the traditional matrix inversed-based multi-input multi-output (MIMO) demultiplexer (DeMUX) because it only considers the current received signals with the assumption that the two channels are well synchronized.

In this paper, we, for the first time, propose a complex-valued artificial neural network (ANN) 2×2 MIMO DeMUX for mm-wave analog radio-over-fiber (A-RoF)-based 5G mobile fronthaul system. The ANN MIMO DeMUX has a much better time tolerance to the time discrepancy between the two channels compared to the traditional matrix inversed-based method. 2.344-Gbps 16QAM OFDM signals are successfully transmitted through the mm-wave 2×2 MIMO A-RoF channel with help of the ANN MIMO

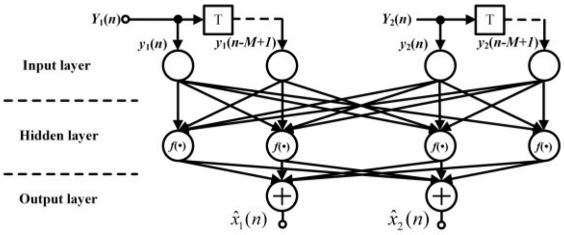

Fig. 2: Structure of the proposed ANN 2×2 MIMO DeMUX

DeMUX under the required EVM of 12.5%, with a time discrepancy tolerance of 4 ns.

Operation principles

Suppose we have two different radio signals over fiber from a central unit (CU) and they are transmitted by two antennas TX1 and TX2. The signals are then received by two receiver antennas, RX1 and RX2. The received signals are the summation productions of the two transmitters through different channel paths, h_{11}, h_{12}, h_{21} and h_{22}. These coefficients are measured with training symbols and the zero-forcing algorithm can be utilized to demultiplex the transmitted signals [7]:

$$\begin{bmatrix} \hat{x}_1(n) \\ \hat{x}_2(n) \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}^{-1} \begin{bmatrix} y_1(n) \\ y_2(n) \end{bmatrix} \qquad (1)$$

$y_1(n)$ and $y_2(n)$ are the received signals from RX1 and RX2. $\hat{x}_1(n)$ and $\hat{x}_2(n)$ are the estimated transmitted symbols. This MIMO demultiplexing scheme is based on the assumption that the two channels are completely synchronized, and only considers the relationship between the present received symbols.

Fig. 2 shows the structure of the proposed ANN 2×2 MIMO DeMUX. The input of ANN consists of two series of the received signals, $Y_1(n)=[y_1(n), y_1(n\text{-}1),\dots, y_1(n\text{-}M+1)]$ and $Y_2(n)=[y_2(n), y_2(n\text{-}1),\dots, y_2(n\text{-}M+1)]$. The ANN is a multi-layer structure that consists of many signal processing units, termed neurons. The output of each neuron is defined as follow

$$f(x) = \frac{2c_2}{1+\exp(c_1 real(x))} - c_2 + j\left(\frac{2c_2}{1+\exp(c_1 imag(x))} - c_2\right) \qquad (2)$$

where $c_1=c_2=2$ in this experiment. The ANN DeMUX considers the inter-channel interferences within a certain period defined by the bitrate and tap number at the input layer. Therefore, the ANN MIMO DeMUX has a better tolerance to the non-ideal synchronization between the two channels.

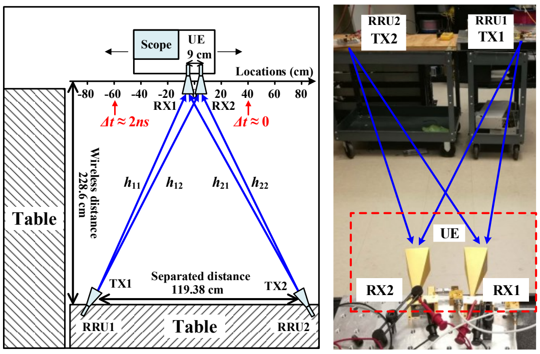

Fig. 4: Spatial arrangements for the proposed 2×2 MIMO mm-wave A-RoF system.

Experimental setup and results

Fig. 3 shows the experimental setup of the small-cell 2×2 MIMO mm-wave RoF system with the proposed ANN MIMO DeMUX. The arrangement of the test field with two RRUs for two small cells and one UE is demonstrated in Fig. 4. At the distributed unit (DU), a continuous-wave optical source from a distributed feedback laser (DFB) is firstly injected into a Mach-Zehnder modulator (MZM) to generate microwave signals at 56 GHz with optical carrier suppression. The optical signal is split into two branches and modulated by two streams of baseband signals produced by the two arbitrary waveform generator (AWG) ports. Each channel is modulated by a 16QAM-OFDM signal with a bandwidth of 293 MHz. The total bitrate of the MIMO system is 2.344 Gbps. After transmitted through the standard single mode fiber (SSMF) in the two channels, the signals are radiated by two horn antennas separated 119.38 cm away from each other. At the receiver, another pair of antennas with an interval of 9 cm are used to capture the received mm-wave signals. Envelope detectors (EDs) are employed to

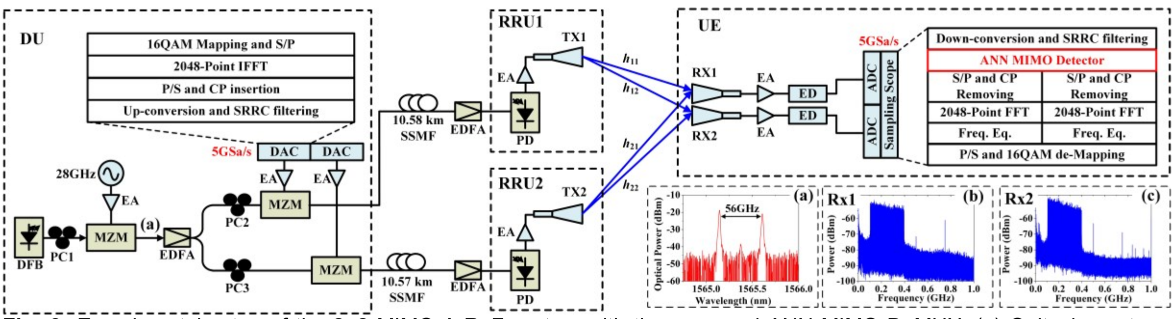

Fig. 3: Experimental setup of the 2×2 MIMO A-RoF system with the proposed ANN MIMO DeMUX. (a) Opitcal spectrum after mm-wave modulations with carrier suppression. (b) and (c) are the electrical spectrum of the signals at RX1 and RX2 after mm-wave down-conversions.

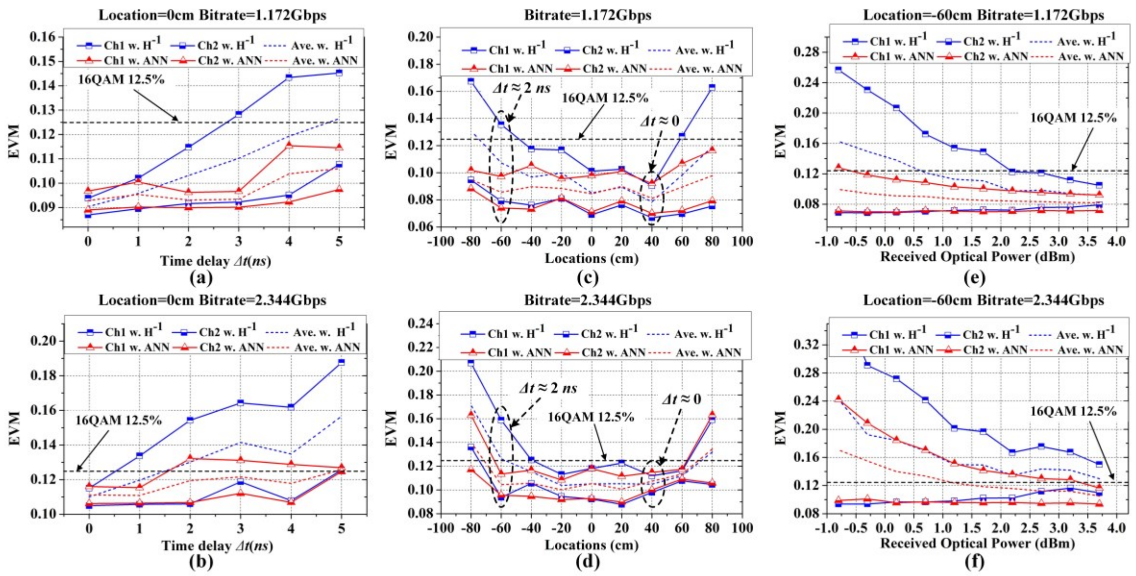

Fig. 5: EVM performances of the 2×2 MIMO mm-wave A-RoF system at bitrates of 1.172 Gbps and 2.344 Gbps with varying (a)-(b) time delay between the two channels, (c)-(d) UE locations and (e)-(f) optical received power at RRU1.

make mm-wave down-conversions. Finally, the signals are captured by a sampling scope with 5 GSa/s and demodulated offline in Matlab. The numbers of neurons in the input, hidden and output layers of ANN DeMUX are 10, 30 and 2.

We first test the error vector magnitude (EVM) performances of the system when the receiver is located at the centre of the receiver side (location=0 cm, as illustrated in Fig. 4) with varying time delay Δt between the two channels, as shown in Fig. 5(a) and (b). The optical received power at the two RRUs are fixed at 4 dBm. The time delay is adjusted by shifting the transmitted sequences at the two ports of the AWG. With increasing Δt, the traditional MIMO DeMUX with an estimated inversed matrix H^{-1} can only recover one channel while the other channel is in worse situations. The signals with higher bitrate is more sensitive to the time discrepancy. The inversed matrix scheme suffers seriously from the time delay when Δt is larger than 1 ns. While the ANN DeMUX performs much better than its counterpart and the average EVM maintains under OFDM 16QAM threshold of 12.5% within time delay of 4 ns when the bitrate is 2.344 Gbps. Fig. 5(c) and (d) are the EVMs with varying receiver locations. We manually adjust the time delay between the two AWG ports to make the arrival time of the two channels equal at location 40 cm. As the receiver moving from 40 cm to -80 cm, the time discrepancy Δt increases as the distances change and the gain of the ANN MIMO DeMUX stands out. With the receiver located at the edge of the test field, the signals are distorted by the increasing air distance, obstacles on the table and absorptions from the wall. Fig. 5(e) and (f) show the optical sensitivity performances of the system with varying optical received power at RRU1 located at -60 cm.

Conclusions

We have proposed an ANN-based 2×2 MIMO DeMUX for mm-wave RoF system to increase coordinated multi-point transmission capacity and synchronization tolerance between the two adjacent RRUs in small-cell 5G mobile fronthaul. We experimentally demonstrated that the ANN-based MIMO DeMUX has tolerated a time discrepancy of 4 ns under the required EVM of 12.5% when the bitrate is 2.344 Gbps which is much more improved than the traditional method with an inversed matrix.

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