DNN-based CSI-RS Port Virtualization Matrix Design in Massive MIMO System

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***Abstract*—In massive multiple-input multiple-output (MIMO) systems, the channel state information (CSI) is needed to achieve high data rate. However, getting the CSI of the full antennas is hard since channel state information reference signal (CSI-RS) overhead is large. Therefore the CSI-RS port virtualization matrix which groups the antennas in a single CSI-RS port at the base station is used. In this paper, we propose a deep neural network (DNN) based CSI-RS port virtualization matrix design scheme for a time division duplex (TDD) massive MIMO system. The proposed scheme utilizes both the CSI-RS and sounding reference signal to get the CSI and estimates the CSI-RS port virtualization matrix in terms of codebook index. Simulation result shows that the proposed DNN based scheme can achieve up to 25.8% performance gain, particularly in high uplink signal-to-noise ratio regions where more accurate uplink channel information can be obtained.**

***Index Terms*—MIMO, CSI-RS port virtualization matrix, DNN.**

I. Introduction

In a downlink massive multiple-input multiple-output (MIMO) system, the channel state information (CSI) is essential to achieve a high performance gain in terms of the data rate. However, to get the CSI between the base station (BS) and UE, the amount of time resource to transmit the channel state information reference signal (CSI-RS) is needed proportional to the number of antennas. Time resource used for transmitting the reference signal to get the CSI makes network inefficient since the time resource can not used for transmitting the data signal.

Therefore, the CSI-RS port virtualization matrix is used to transmit one CSI-RS to the multiple physical antennas only with the change of the phase [1], [2]. With the CSI-RS port virtualization matrix, the system can save the time resources by using fewer CSI-RS to get the channel information although the system performance can be degraded [3], [4]. Therefore, the researches for reducing the feedback overhead of CSI by designing a feedback scheme or designing dual-stage precoding shceme in CSI-RS port virtualizaiton aided system [5], [6]. designing the CSI-RS port virtualization matrix based on the precise CSI is important to achieve high data rate performance. The BS can get the CSI from the CSI-RS through the feedback of the precoding matrix indicator (PMI) and from the sounding reference signal (SRS) by exploiting channel reciprocity of time-division duplex (TDD) system [7], [8].

In this paper, we use both the CSI-RS and SRS to get the CSI at the BS and use both CSIs to design the CSI-RS port virtualization matrix. The CSI from the CSI-RS is a quantized CSI and the CSI from the SRS is a partial CSI. Detailed information obtained from the reference signals are discussed in Section II. We use the imperfect CSI from the CSI-RS and SRS to estimate the CSI-RS port virtualization matrix by applying supervised learning. Since getting the optimal solution of the CSI-RS port virtualization matrix in the system under consideration is an NP-hard problem, we generate the sub-optimal solution to design the target of the supervised learning.

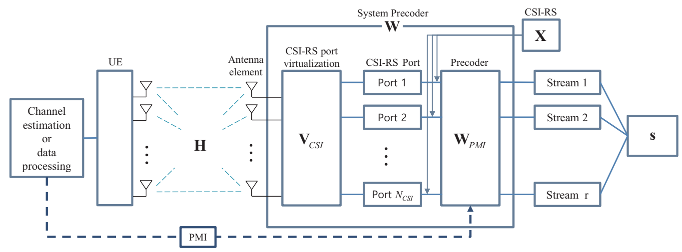


Fig. 1. Block diagram of the system model.

II. System Model

We consider a TDD massive MIMO system, especially a single user MIMO with spatial multiplexing. The BS has N_t antennas and the user equipment (UE) has N_r antennas. The number of CSI-RS ports is N_{CSI}. Fig.1 shows the block diagram of the considered system model. The precoder and the CSI-RS port virtualization matrix designing process are explained as follows. At first, BS transmits CSI-RS to UE and the UE estimates the effective channel using that. Then, the UE quantizes the effective channel using the given codebook and feedbacks the obtained PMI to the BS. We consider the Type-1 codebook which is defined on 3GPP standard for the PMI [9]. The UE transmits the SRS to the BS and the UE estimates the downlink channel between the BS antenna and the UE using the received SRS and the property of the channel reciprocity. The BS designs the CSI-RS port virtualization matrix using both the channel from CSI-RS and SRS channel. The BS transmits CSI-RS through the newly designed CSI-RS port virtualization matrix and designs the precoder using PMI received from UE. Then the UE conduct the downlink data transmission.

The received signal at the UE when the BS transmits CSI-RS from the n^{th} CSI-RS is expressed as below.

$$\mathbf{y}_n = \mathbf{H}\mathbf{v}_n x_n + \mathbf{n}_n,$$

where $\mathbf{X} = \mathrm{diag}\left(x_1, \cdots, x_{N_{CSI}}\right)$ is CSI-RS and CSI-RS is transmitted from one port at one time step, therefore CSI-RS is transmitted totally N_{CSI} times. We consider $x_n = 1,\ n \in \{1, ..., N_{CSI}\}$. $\mathbf{n}_n \sim \mathcal{CN}\left(0, \sigma^2_{down}\mathbf{I}\right)$ denotes downlink noise and $\mathbf{H}_{N_r \times N_t} = [\mathbf{h}_1, \cdots, \mathbf{h}_{N_r}]^T$ denotes a downlink channel. $\mathbf{V}_{N_t \times N_{CSI}} = [\mathbf{v}_1, \cdots, \mathbf{v}_{N_{CSI}}]$ denotes the CSI-RS port virtualization matrix. We consider partially connected structure where each CSI-RS port is connected to same number of different antennas. Therefore, $\mathbf{v}^n_{CSI} = [\mathbf{0}_{(n-1)}, \mathbf{f}_n, \mathbf{0}_{N_t - nJ}]^T$, where $\mathbf{f}_n$ is the $J \times 1$ weight vector for the n-th antenna port and $J = N_t / N_{CSI}$. After the UE receives CSI-RS N_{CSI} times, the UE can reconstruct the effective channel which consists of channel and CSI-RS port virtualization matrix. The reconstructed channel can be expressed as below.

$$\begin{aligned}\mathbf{Y} &= [\mathbf{y}_1,\ \cdots,\ \mathbf{y}_{N_{CSI}}] \\ &= \mathbf{HVX} + \mathbf{N} \\ &= \mathbf{HV} + \mathbf{N},\end{aligned}$$

The codebook index which can achieve the highest spectral efficiency performance among the codebook $\mathbf{C}$ at the UE is selected as a PMI. The selected codebook which can achieve the highest spectral efficiency performance can be deemed as a quantized effective channel. Therefore, the obtained channel at the BS from CSI-RS can be expressed as below.

$$\begin{aligned}&\mathbf{H}_{CSI} \\ &= \arg\max_{\mathbf{W}_i \in C} \log_2\left(\det\left(\mathbf{I}_{r_i} + \tfrac{1}{\sigma^2 r^*}\mathbf{HV}\mathbf{W}_i\mathbf{W}_i^H\mathbf{V}^H\mathbf{H}^H\right)\right),\end{aligned}$$

where $\mathbf{W}_i$ denotes an i^{th} codeword in a codebook $\mathbf{C}$ and r denotes the number of columns of $\mathbf{W}_i$. The UE can transmit the SRS using the specific number of transmit antennas. The uplink channel information which can be obtained from the SRS can be expressed as below.

$$\mathbf{H}_{SRS} = [\mathbf{h}_m]^T_{m \in \mathcal{S}(N)},$$

where $\mathcal{S}(N)$ denotes a set of N SRS transmit antenna index combinations and $\mathbf{n}_{up} \sim \mathcal{CN}\left(0, \sigma^2_{up}\mathbf{I}\right)$ denotes the uplink noise. The finalized spectral efficiency of the system can be expressed as below.

$$\log_2\left(\det\left(\mathbf{I}_{r^*} + \frac{1}{\sigma^2 r^*}\mathbf{H}\mathbf{V}^*\mathbf{W}^*\mathbf{W}^{*H}\mathbf{V}^{*H}\mathbf{H}^H\right)\right), \quad (1)$$

where $\mathbf{V}^*$ and $\mathbf{W}^*$ denote updated CSI-RS port virtualization matrix using the proposed scheme and precoder obtained using PMI , respectively.

III. DNN based Port CSI-RS Virtualization Matrix Design

In this section, we describe the proposed DNN structure. Fig. 2 shows the DNN structure corresponding to the weight vector of the nth CSI-RS port. The input of the DNN is the channel obtained from CSI-RS $(\mathbf{H}_{CSI})$ and the channel obtained from SRS $(\mathbf{H}_{SRS})$. The target of the DNN is the codeword index in the beam codebook for the weight vector of the n-th CSI-RS port. We consider the DFT codebook as the weight matrix for the CSI-RS port virtualization matrix. The codebook consists of J orthogonal weight vectors for J antennas. We design the CSI-RS port virtualization matrix using J codeword indices obtained by running all N_{CSI} DNNs in parallel.

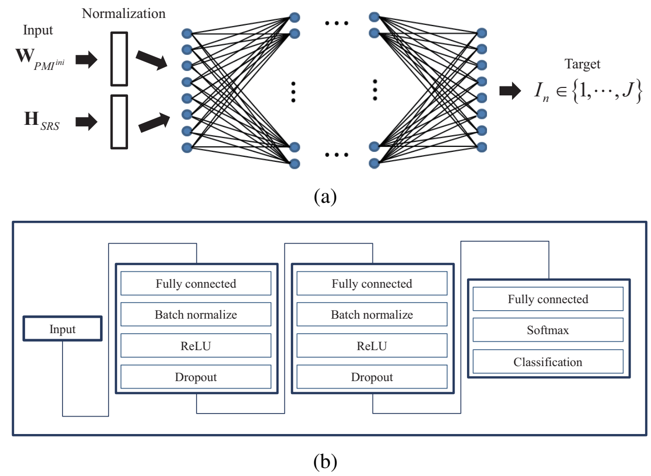
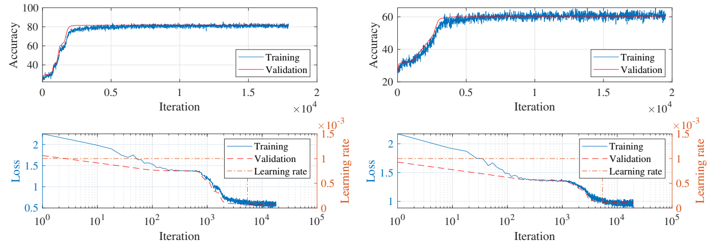


Fig. 2. (a) Proposed DNN structure. (b) Detailed network architecture of the proposed model.

TABLE I
DNN parameters

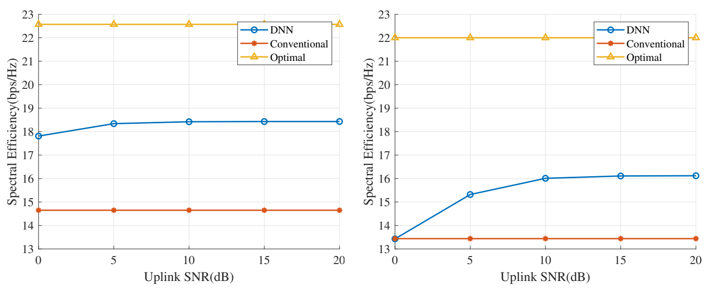
Optimizer	Adam
Number of training / validation set	90000/15000
Batch size	1000
Number of hidden layer	2
Number of nodes for input layer	128
Number of nodes for hidden layer	384
Number of nodes for output layer	4
Dropout probability	0.4
Activation function	Hidden : ReLU, Output : Softmax

The total number of candidate CSI-RS port virtualization matrices that can be designed from the DFT codebook is $N_{CSI} \times J$. Also, as shown in equation (1), since the spectral efficiency is calculated from the combination of the CSI-RS port virtualization matrix and the precoder, the number of all cases that need to be considered is $N_{CSI} \times J \times 384$, where 384 is the size of the Type-1 codebook. If the size of N_{CSI} or J is large, it is difficult to perform an exhaustive search, so the process of fixing the precoder and finding the CSI-RS port virtualization matrix that maximizes the spectral efficiency, fixing the found CSI-RS port virtualization matrix and finding the precoder is repeated until there is no change, and the target value is obtained.



(a) (b)

Fig. 3. (a) Accuracy and loss according to the iteration in channel A. (b) Accuracy and loss according to the iteration in channel B.



(a) (b)

Fig. 4. (a) Spectral efficiency according to the uplink SNR in channel A. (b) Spectral efficiency according to the uplink SNR in channel B.

IV. Simulation Results

In this section, we evaluate the performance of the proposed CSI-RS port virtualization matrix design scheme. The BS has $N_t = 32$ and the UE has $N_r = 4$ uniform linear array (ULA) dual-polarized antennas. The number of the CSI-RS ports is $N_t = 8$. The number of the transmit antennas at the UE used to transmit SRS is $|\mathcal{S}(N)| = 1$. We adopt the widely used Saleh-Valenzuela channel model [10], [11]. We evaluate the proposed scheme for two types of channels called channel A and channel B. Channel A consists of four paths with the same gain. Channel B consists of three paths with the same gain and one main path with a gain 100 times greater than the others. For the comparison, we use the SRS channel to design the CSI-RS port virtualization matrix by applying the matched filter method as a conventional scheme. The CSI-RS port virtualization matrix for the conventional scheme is $\mathbf{V}_{conv} = [\mathbf{v}_{conv}^1, \cdots, \mathbf{v}_{conv}^{N_{CSI}}]$, where $\mathbf{v}_{conv}^n = [\mathbf{0}_{(n-1)J}, \mathbf{H}_{SRS[(n-1)J+1:nJ]}, \mathbf{0}_{N_t-nJ}]^T$. Optimal scheme in Fig. 4 shows the capacity of the channel.

Fig. 3 shows the accuracy and loss performance of the proposed DNN-based scheme as a function of iteration in Channel A and Channel B. It can be seen that both the accuracy and loss converge, and the accuracy and loss performance are higher in channel A than channel B, where the power of the main path is higher. Fig. 4 shows the spectral efficiency performance of the proposed DNN-based scheme, the conventional scheme, and the channel capacity according to the uplink SNR in Channel A and Channel B. In Channel A, the proposed DNN-based scheme can achieve a 25.8% performance gain compared to the conventional scheme. In Channel B, the proposed DNN-based scheme can achieve a 19.9% performance gain compared to the conventional scheme. Higher performance gain is achieved in high uplink SNR region, where more accurate uplink channel information can be obtained.

V. Conclusions

In this paper, we propose the DNN based CSI-RS port virtualization matrix design scheme in massive MIMO system. The proposed scheme utilizes the channel information from both the CSI-RS and SRS. Channel information from the CSI-RS has quantized CSI-RS ports by UE antennas channel while channel information from the SRS has original certain number of UE antenna by BS antennas channel. We apply DNN to estimate the CSI-RS port virtualization matrix in terms of the codebook index. The simulation result shows that the proposed scheme can achieve up to 25.8% performance gain.

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