Performance Evaluation of Limited Feedback Schemes for 3D Beamforming in LTE-Advanced System

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Abstract: - The three-dimension (3D) multiple input and multiple output (MIMO) system is one of the key technologies studied for some advanced wireless communication systems such as Long Term Evolution-Advanced (LTE-A) In the 3D MIMO systems, uniform planar array (UPA) is equipped at BS. It enable elevation beamforming as well as azimuth beamforming. This paper investigates two limited feedback schemes for 3D beamforming. The spectral efficiency is evaluated for two limited feedback schemes in various antenna configurations.

Key-Words: - 3D beamforming, 3D MIMO, Limited feedback scheme, LTE-A, Spectral efficiency, UPA

1 Introduction

Massive multiple input and multiple output (MIMO) employs a large number of antennas at base stations (BS) and can simultaneously serve multiple user equipment (UE) [1]. It is being considered to improve the system throughput and the spectrum efficiency in some advanced wireless communication systems such as Long Term Evolution-Advanced (LTE-A) [2-3]. In legacy MIMO systems, a uniform linear array (ULA) is usually considered at BS. However, since it is difficult to apply ULA due to the limited room in massive MIMO, Two-dimensional (2D) antenna arrays such as a uniform planar array (UPA) are considered. Antenna elements in UPA are placed vertically and horizontally at the BS. They enable 3D beamforming, elevation beamforming as well as azimuth beamforming. Recently, the 3rd Generation Partnership Project (3GPP) has released a 3D MIMO system and a 3D spatial channel model (SCM) [4-5], and many studies for 3D MIMO systems are investigations [6-8].

To perform 3D beamforming, a BS requires channel state information (CSI) for horizontal and vertical dimensions. However, the feedback overhead increases as the number of antennas and more computational complexity is required for the best code word selection. For massive MIMO, effective limited feedback scheme needs to minimize the feedback overhead and to achieve the high spectral efficiency. In this paper, we investigate two limited feedback schemes for 3D beamforming in in downlink 3D MIMO system. And, the performance by their two schemes is analyzed in 3GPP 3D SCM scenario.

This paper is organized as follows. In section 2, we describe the system model. Section 3 describes two limited feedback schemes. Simulation results are presented in Section 4. Section 5 concludes the paper.

2 System Model

We consider a downlink 3D-MIMO system where a BS is equipped with a UPA having $N_t = N_v \times N_h$ antennas based on LTE-A. K UEs are equipped with a single antenna, as shown in Figure 1. Antenna elements at BS are placed in the vertical and horizontal direction. N_t is the number of total transmit antenna elements. N_h and N_v are the number of horizontal and vertical antenna elements, respectively.

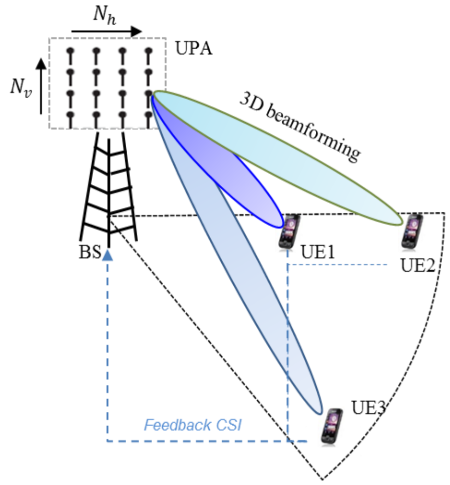

Figure 1. 3D MIMO beamforming with UPA.

To evaluate the performance of 3D MIMO system, a 3D channel model is considered. The 3GPP has developed a 3D SCM based on 2D SCM [9-10]. It is considered two different scenarios of channel environments, Urban Macro (3D-UMa) and Urban Micro (3D-UMi), for 3D MIMO systems. This paper considers 3D-UMa scenario. It is assumed that the BS (height: 25m) is well above the height of UEs of the surrounding buildings, and outdoor line-of-sight (LOS), outdoor non-line-of-sight (NLOS), indoor LOS, and indoor NLOS are considered.

2.1 Received signal model

In 3D MIMO systems, the signal y_k received by k-th UE can be expressed as follows:

$$y_k = \sqrt{\rho} H_k W_k s_k + \sum_{i=1, i\neq k}^{K} \sqrt{\rho} H_i W_i s_i + N_k \quad (1)$$

Where s_k is the transmit signal. ρ is the average transmit power. $H_k \in C^{(N_v \times N_h)\times 1}$ is the channel matrix from BS to k-th UE. For 3D MIMO, the channel coefficient matrix is three-dimensional by antennas of vertical dimension. $W_k \in C^{1\times(N_v \times N_h)}$ is the precoding matrix for k-th UE, corresponding to 3D channel. $\sum_{i=1,i\neq k}^{K} H_i W_i s_i$ denotes the undesired signal. N_k denotes Gaussian noise.

2.2 Codebook for 3D beamforming

Since frequency-division duplexing (FDD) is used in advanced wireless communication systems such as LTE-A, to minimize the feedback overhead need. To reduce feedback overhead, LTE-A use discrete Fourier transform (DFT) based LTE codebooks [11]. In FDD massive MIMO systems with a ULA, the DFT based codebook is usually used for the beamforming since it can provide a good performance in highly correlated channels [12].

In 3D MIMO, elevation beamforming should be supported as well as horizontal beamforming. Thus, 3D codebook, Kronecker product codebook (KPC), is proposed for 3D beamforming, in which the DFT-based 2D codebook has been expanded [13]. It is generated by Kronecker product of two DFT code words for vertical and horizontal domains as follows.

$$C_v = [w_0^v \;\; w_1^v, \dots, w_{M_v-1}^v] \quad (2)$$

C_v is the a DFT based codebook for the vertical domain. Where k-th codeword w_k^v is

$$w_k^v = \frac{1}{\sqrt{N_v}} \left[1,\ e^{-j2\pi \frac{k}{M_v}},\ \dots, e^{-j2\pi \frac{(N_v-1)k}{M_v}}\right]^T,$$

$$k = 0,1,\dots, M_v - 1 \quad (3)$$

N_v is the number of vertical antennas, and M_v is a codebook length, $2^{B_v} = M_v$, where B_v is the codebook bit for the vertical domain. Where a DFT based codebook for the horizontal domain, C_h, and k-th codeword w_k^h is

$$C_h = [w_0^h \;\; w_1^h, \dots, w_{M_h-1}^h] \quad (4)$$

$$w_k^h = \frac{1}{\sqrt{N_h}} \left[1,\ e^{-j2\pi \frac{k}{M_h}},\ \dots, e^{-j2\pi \frac{(N_h-1)k}{M_h}}\right]^T,$$

$$k = 0,1,\dots, M_h - 1 \quad (5)$$

N_h is the number of horizontal antennas, and M_h is a codebook length, $2^{B_h} = M_h$, where B_h is the codebook bit for the horizontal domain.

$$\begin{aligned} C_{3D} &= C_v \otimes C_h \\ &= \left[w_0^v \otimes w_0^h \;\; w_0^v \otimes w_1^h \;\; \cdots \;\; w_{M_v-1}^v \otimes w_{M_h-1}^h\right] \\ &= \left[w_0^{3D} \;\; w_1^{3D} \;\; w_2^{3D} \;\; \cdots \;\; w_{M_v \cdot M_h - 1}^{3D}\right] \quad (6) \end{aligned}$$

C_{3D} is the Kronecker product-based 3D codebook. The length of a 3D codebook is $M_v \cdot M_h$.

For example, if both B_v and B_h are 5 bits, 32 code words are generated for vertical and horizontal domains, respectively. For a 3D codebook, 1024 code words are generated.

3 Limited feedback schemes

Each UE selects its own best code word, and an index of selected code word, called precoding matrix index (PMI), is reported to BS. An PMI for horizontal domain is reported in legacy LTE-A. However, it need to fed back the precoding information for the horizontal and vertical domains for 3D beamforming. In this paper, we introduce two different limited feedback schemes, one PMI feedback scheme and two PMI feedback scheme.

First, in one PMI feedback scheme, 3D codebook $C_{3D} = [w_0^{3D}, w_1^{3D}, \dots, w_{M_v \cdot M_h - 1}^{3D}]$ in (6) is required in both BS and UEs. And, assume the channel matrix $H_k \in C^{(N_v \times N_h) \times 1}$ from k-th UE to BS. In k-th UE, the best code word can be selected using

$$w_p^{3D} = \arg \max_{l=0,\dots M_v \cdot M_h - 1} \left| H_k w_l^{3D} \right|^2 \tag{7}$$

where p denotes PMI, and k UE feeds back it to BS. In this scheme, $M_v \cdot M_h$ computation is required to select the best code word in each UE. The transmit signal is beamformed by the code word corresponding to feedback PMI.

Next, in two PMI feedback scheme, two DFT based codebooks for vertical and horizontal domains are required in (2) and (4). The best code word is selected for two domains, respectively, and UE feeds back two PMI. Assume the channel matrix H_k is

$$\begin{array}{l} \quad\quad \text{Vertical channel} \\ H_k = \begin{bmatrix} h_{11} & \cdots & h_{1n} & \cdots & h_{1N_h} \\ \vdots & & & & \vdots \\ h_{m1} & & \ddots & & h_{mN_h} \\ \vdots & & & & \vdots \\ h_{N_v1} & \cdots & h_{N_vn} & \cdots & h_{N_vN_h} \end{bmatrix} \\ \hfill \text{Horizontal channel} \end{array} \tag{8}$$

The channel $H_{v,k}$ for first column antenna elements is called the vertical channel and the channel $H_{h,k}$ for first row antenna elements is called the horizontal channel in this paper. The best code word for the vertical domain is selected using

$$w_i^v = \arg \max_{l=0,\dots M_v - 1} \left| H_{v,k} w_l^v \right|^2 \tag{9}$$

The best code word for the horizontal domain is selected using

$$w_j^h = \arg \max_{l=0,\dots M_h - 1} \left| H_{h,k} w_l^h \right|^2 \tag{10}$$

i and j are selected PMIs for two domains, respectively. In this scheme, $M_v + M_h$ computation is required to select the best code words in each UE. Kronecker product is computed for the two code words corresponding to feedback PMIs in BS as follows

$$w_{3D} = w_i^v \otimes w_j^h \tag{11}$$

4 Simulation results

Table 1. Simulation parameters.

Parameters	Value
Carrier frequency	2.1 GHz
System bandwidth	10 MHz
TTI length	100 ms
Noise power density	−174 dBm/Hz
Scenarios	3D-UMa
Inter-site distance	500 m
Network layout	1 sector in a site
Number of UEs per cell	2, 4, 6, 8, 10
UE distribution	Uniformly distributed
BS height	25 m
BS transmit power	46 dBm
BS Antenna configuration (N_t, N_v, N_h)	UPA (8,2,4), (16,2,8), (16,4,4), (32,4,8)
Vertical antenna element spacing	$\lambda / 2$
Horizontal antenna element spacing	$\lambda / 2$
Codebook	5bits DFT based codebook
Scheduler	Max C/I
UE height	3*(UE_floor-1)+1.5 m
UE max floor	8
UE Antenna elements	1
Receiver type	MMSE
UE speed	3 km/h
Channel estimation	Ideal
Feedback CSI	PMI, CQI, RI
	PMI and CQI reporting per 5ms

In this section, the average spectral efficiency of two limited feedback schemes is evaluated and compared. To simulations, 3GPP 3D SCM scenario is considered, and 3D-UMa is adopted [4]. A 120° sector in a single cell is considered where UEs are uniformly distributed. We consider various transmit antenna configurations, 2×4, 2×8, 4×4, and 4×8. Two 5 bits DFT codebooks are used for vertical and horizontal domain. We assume the perfect channel knowledge. Detailed simulation parameters are listed in Table 1.

Figure 2 shows the spectral efficiency as the antenna configuration equipped at BS (K = 10). The spectral efficiency of one PMI feedback scheme were higher than two PMI feedback scheme in most cases.

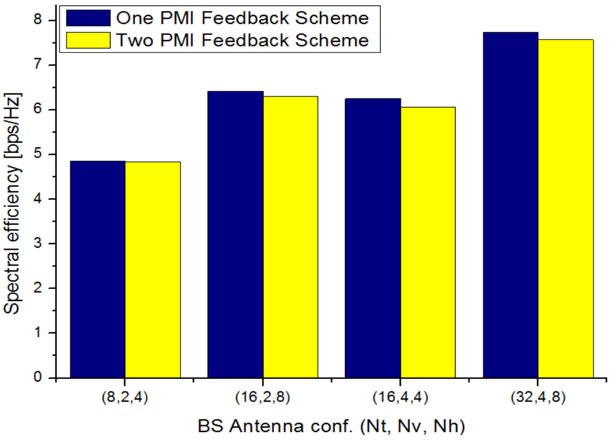

Figure 2. Spectral efficiency as transmit antenna configurations; K=10.

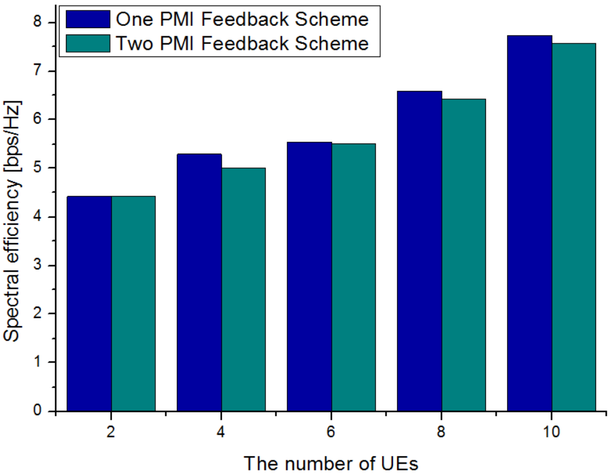

Figure 3. Spectral efficiency for an increasing number of UEs; $N_t = 32, N_v = 4, N_h = 8$.

In the case (16,2,8), the spectral efficiency difference is approximately 0.1 bps/Hz, and it is approximately 0.2 bps/Hz in the cases (16,4,4) and (32,4,8). In the case (32,4,8), the spectral efficiency is highest, and it is 7.73501 bps/Hz for one PMI feedback scheme. Compared with the case (16,2,8), it shows the performance improvement of 1.3 bps/Hz.

Figure 3 shows the results of the spectral efficiency analysis for an increasing number of UEs when the antenna configuration equipped at BS is the case (32,4,8). The spectral efficiency of one PMI feedback scheme were higher than two PMI feedback scheme in Figure 3 in common with Figure 2. The spectral efficiencies of one and two PMI feedback schemes were same for 2 UEs and 6 UEs, and 5.29309 bps/Hz and 5.00845 bps/Hz for 4 UEs, and 6.59408 bps/Hz and 6.42691 bps/Hz for 8 UEs, respectively.

5 Conclusion

In this paper, we investigate two limited feedback schemes for 3D beamforming in LTE-A. One PMI feedback scheme required high computation complexity to select the best code word than two PMI feedback scheme. The performance of two schemes were compared through average spectral efficiency analysis. The simulation results show that one PMI feedback scheme has the highest spectral efficiency. In our future work, we will perform further optimization of 3D MIMO system, and the limited feedback scheme to attain the higher spectral efficiency will be developed.

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