Minimum Interference Beam Selection for Millimeter Wave BeamSpace MIMO System

Dantao Li[1,2], Xiaohui Li[1,2](✉), Bin Zhou[3], Yanbin Zhao[4], and Danfeng Meng[1,2]

[1] State Key Laboratory of Integrated Service Networks, Xidian University Xi'an, Xi'an 710071, Shaanxi, China
xhli@mail.xidian.edu.cn

[2] Collaborative Innovation Center of Information Sensing and Understanding, Xidian University Xi'an, Xi'an 710071, Shaanxi, China

[3] AVIC Computing Technique Research Institute, Xi'an, Shaanxi, China

[4] Geographic Information Center, Yangquan, Shanxi, China

Abstract. Millimeter Wave (mmWave) combined with massive multiple-input multiple-output (MIMO) can provide wider bandwidth and higher spectrum efficiency. It has been considered as a key technique for future 5G wireless communications. However, hardware costs and power consumption make traditional MIMO processing impractical in such systems, because a large number of radio frequency (RF) chains are needed. To solve this problem, the beamspace MIMO concept is proposed in mmWave multiuser MIMO (MU-MIMO) systems, which utilizes beam selection algorithm based on the sparsity of beamspace channel to reduce the required RF chains without obvious performance loss. The existing beam selection algorithms mainly select the beam with the strongest gain, but ignore the inter-beam interference and the complexity. Thus, a novel algorithm based on the minimum interference (MI) criterion is proposed. Specifically, the performance of the beams is measured by defining the beamspace signal-to-interference ratio (SIR). When choosing beams, not only the gain of beams but also the interference to other users is considered. The simulation results demonstrate that the proposed algorithm can substantial reduce the complexity while ensuring better system performance.

Keywords: Massive MIMO · mmWave communication systems
Low RF complexity · Beamspace MIMO · Beam selection

1 Introduction

With the rise of various intelligent terminals, mobile data traffic shows explosive growth trend. Thus, there is a higher requirement for future network capacity of mobile broadband communication systems (5th generation mobile communications, 5G) [1]. Most of the current communication systems mainly work in

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low frequency band which range from 700 MHz to 2.6 GHz. The tension of spectrum resources poses an unprecedented challenge for mobile service providers. Fortunately, the mmWave has a large number of available unlicensed bands. Exploiting the rich spectrum resources of the mmWave enables to alleviate the pressure of the spectrum resources. However, the path loss of mmWave is more serious and the 60 GHz system has 22 dB additional free space loss compared with that of 5 GHz system [2]. Although the high path loss limits the mmWave communication distance, another unique advantage of the mmWave signal is that the wavelength is short and the antenna array occupies a small footprint, making it possible for the base station to install large-scale (usually tens to hundreds) antennas. Beamforming with massive MIMO and making full use of space-dimensional resources can cope with complex channel environment, enhance the quality of communication links and achieve high data rate transmission. In fact, the literature [3] shows that mmWave mobile broadband system could achieve gigabit per second data rate at distances up to 1 Km in an urban environment.

In traditional communication systems, the signal is usually processed at the baseband which can control its phase and amplitude. Full digital MIMO systems enjoy flexibility, adaptability, and performance optimality, however, with higher costs and power consumption, because that an RF unit is needed for each antenna. The large number of antennas anticipated in mmWave beamforming presents several challenges such as: high power consumption and the high cost of a large number of ADCs operating at very high sampling frequencies (possibly several GS/s to 100 GS/s) [4]. In order to take advantage of the mmWave, many researchers focus on mmWave systems designed to reduce the hardware complexity and power consumption of high-dimensional MIMO systems [5]. And beamspace MIMO system is one of the most promising approaches.

The beamspace MIMO is multiplexing data onto some fixed orthogonal spatial beams by fixed beamforming at the transmitter [6]. So the equivalent channel is low rank and sparse. With beam selection criteria, the RF chains needed is agree in the magnitude of the number of users, which will significantly reduce the hardware complexity, the digital signal processing complexity, and the power consumption [7]. Beamspace MIMO system uses spatial sparsibility to reduce RF complexity, but also requires a fast beam selection algorithm to choose optimal beams for users. The literature [6] proposed a beam selection scheme based on the criterion of magnitude maximization (MM), in which several beams with large magnitude are selected for each user. MM beam selection is simple but it only aims to maximize the power of each user without considering multiuser interferences. Another interference-aware (IA) beam selection algorithm first classifies all users into two user groups, the interference-users (IUs) and noninterference-users (NIUs). For NIUs, the beams with large power are selected, while the beams are selected based on the criterion of sum-rate maximization for IUs [8]. IA algorithm can obtain better performance, but it ignores inter-beam interference and iterative search for IUs with the large-scale matrix operation makes it more complicated.

In this paper, we propose an MI beam selection for mmWave beamspace MIMO system. Due to the criterions used in MM and IA beam selection exit the problems of users sharing beam and inter-beam interference, MI criterion not only considers the beam gain for the users, but also considers the interference to other users. At the same time, the complexity of MI is low without iteration and large matrix operation. Simulation results verify that the proposed MI selection can achieve the performance of IA and is better than conventional MM selection. With the increase of the number of users, the proposed MI algorithm is better than the IA algorithm.

Notations: Lower-case and upper-case boldface letters denote a vector and a matrix. The $(\cdot)^T, (\cdot)^H, (\cdot)^{-1}$ and $tr(\cdot)$ denote the transpose, conjugate transpose, inverse and trace of matrix respectively. The $A(:, i)$, $A(j, :)$ is the ith column and jth row of the matrix A. $|\cdot|$ represents the amplitude of vector, and $Card(\cdot)$ denotes the cardinality of set. Finally, $\mathbf{I}_N$ is an $N \times N$ identity matrix.

2 System Model and Assumption

2.1 Traditional MIMO System

Considering a single cell mmWave downlink MU-MIMO system as shown in Fig. 1, where the base station (BS) equips with an N_t dimensional uniform linear array (ULA) communicating with K single-antenna users. Then, the received signal at the i^{th} user is given by

$$y_i = \mathbf{h}_i \mathbf{w}_i x_i + \sum_{k=1, k \neq i}^{K} \mathbf{h}_i \mathbf{w}_k x_k + n_i \tag{1}$$

where $\mathbf{h}_i \in {}^{1 \times N_t}$ represents the channel vector of the ith user, $\mathbf{w}_i \in {}^{N_t \times 1}$ is a precoding vector for user i, and $n_i \sim CN(0, \delta^2)$ is additive white Gaussian noise (AWGN).

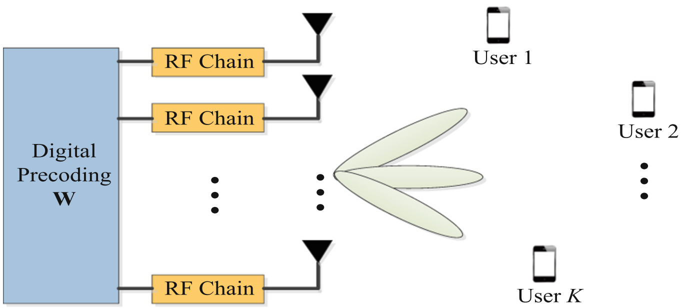

Fig. 1. Single cell millimeter wave downlink MU-MIMO system

If the received signal of K users is represented as a received vector, the $K \times 1$ received signal vector $\mathbf{y}$ for all K users in the downlink can be expressed as

$$\mathbf{y} = \mathbf{HWx} + \mathbf{n} \tag{2}$$

where $\mathbf{H} = [\mathbf{h}^T{}_1, \mathbf{h}^T{}_2, \cdots \mathbf{h}^T{}_k]^T$ is the channel matrix, $\mathbf{W} = [\mathbf{w}_1, \mathbf{w}_2, \cdots \mathbf{w}_k]$ is the precoding matrix, $\mathbf{x}$ of size $K \times 1$ is the sending signal vector for all K users with normalized power $\mathbf{E}\{\mathbf{x}\mathbf{x}^H\} = \mathbf{I}_K$. Due to the power constraint, the precoded signal $\mathbf{s} = \mathbf{W}\mathbf{x}$ satisfies $\mathbf{E}\{\mathbf{s}^H\mathbf{s}\} \le P$, where P is the transmitted power.

Obviously it can be seen from Fig. 1 that the number of required RF chains for traditional MIMO systems is $N_{RF} = N_t$, which is usually large for mmWave massive MIMO systems and definitely a dramatic increase in cost and power consumption [9].

The high free space loss of mmWave limits the spatial scattering or spatial selectivity in mmWave communications, which leads us to adopt the extended Saleh-Valenzuela geometric channel model to describe the characteristics of mmWave channel [10]. Specifically, the channel $\mathbf{h}_i$ from the BS to user-i can be modeled as

$$\mathbf{h}_i = \beta_{i,0}\mathbf{a}(\psi_{i,0}) + \sum_{l=1}^{L} \beta_{i,l}\mathbf{a}(\psi_{i,l}) \tag{3}$$

where $\beta_{i,0}\mathbf{a}(\psi_{i,0})$ is modeled for the LoS component and $\beta_{i,0}$ is the complex gain, $\beta_{i,l}\mathbf{a}(\psi_{i,l})$ for $1 \le l \le L$ is the lth non-line-of-sight (NLOS) component of the ith user, $\beta_{i,l}$ is the NLOS complex gain and L is the total number of NLOS path. The $N_t \times 1$ array response vector $\mathbf{a}(\psi_{i,l})$ for a ULA can be represented by

$$\begin{aligned}\mathbf{a}(\psi_{i,l}) &= \tfrac{1}{\sqrt{N_t}}\left[1 \; e^{-j2\pi\psi_{i,l}} \; ... \; e^{-j2\pi(N_t-1)\psi_{i,l}}\right]^T \\ &= \tfrac{1}{\sqrt{N_t}}\left[1 \; e^{-j2\pi\frac{d}{\lambda}\sin(\theta_{i,l})} \; ... \; e^{-j2\pi(N_t-1)\frac{d}{\lambda}\sin(\theta_{i,l})}\right]^T\end{aligned} \tag{4}$$

where $\psi_{i,l} = \frac{d}{\lambda}\sin(\theta_{i,l})$, λ is the signal wavelength, d is the antenna spacing satisfying $d = \lambda/2$, $\theta_{i,l} \in [-\frac{\pi}{2}, \frac{\pi}{2}]$ is the angle of departure of each cluster to the user-i, which is between the signal and the array antenna.

2.2 BeamSpace MIMO System

When the baseband RFs use fixed beamforming at the transmitter, the traditional MIMO spatial channel can be transformed into an equivalent beamspace channel. The system block diagram is shown in Fig. 2, where the fixed beamforming can be realized by discrete lens array (DLA) [11]. DLA behaves as a convex lens, directing the signals towards different points of the focal surface [12]. Specifically, such DLA plays the role of a beamforming matrix $\mathbf{U}$, which contains the array steering vectors of M orthogonal directions beam covering the entire space.

We assume that the number of generated beams is equal to the number of transmitting antenna $M = N_t$, which means the resolution of the beam is $\Delta\theta_0 = \frac{1}{N_t}$. Then, the system signal model of (2) can be expressed as

$$\mathbf{y} = \mathbf{HUWx} + \mathbf{n} \tag{5}$$

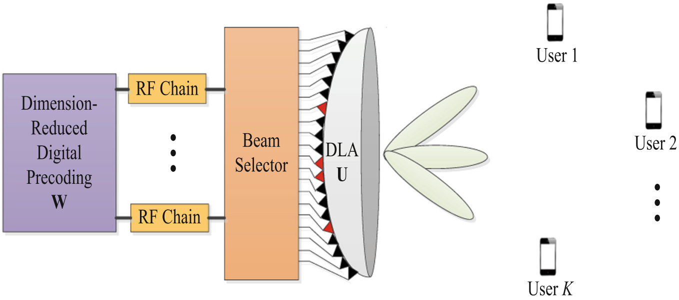

Fig. 2. Beam space MIMO system

where $\mathbf{U} \in {}^{N_t \times N_t}$ is a beamforming matrix that can be expressed as

$$\begin{aligned}\mathbf{U} &= [\mathbf{a}(0), \mathbf{a}(\varDelta\theta_0), \cdots \mathbf{a}((N_t-1)\varDelta\theta_0)] \\ &= \frac{1}{\sqrt{N_t}} \begin{Bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & e^{-j2\pi\frac{1}{N_t}} & e^{-j2\pi\frac{2}{N_t}} & \cdots & e^{-j2\pi\frac{N_t-1}{N_t}} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & e^{-j2\pi(N_t-1)\frac{1}{N_t}} & e^{-j2\pi(N_t-1)\frac{2}{N_t}} & \cdots & e^{-j2\pi(N_t-1)\frac{N_t-1}{N_t}} \end{Bmatrix}\end{aligned} \tag{6}$$

Actually, $\mathbf{U}$ is a normalized DFT (Discrete Fourier Transform, DFT) matrix from (6): $\mathbf{U}^H\mathbf{U} = \mathbf{U}\mathbf{U}^H = \mathbf{I}$. Let $\tilde{\mathbf{H}} = \mathbf{H}\mathbf{U} = [(\mathbf{h}_1\mathbf{U})^T, (\mathbf{h}_2\mathbf{U})^T, \cdots (\mathbf{h}_K\mathbf{U})^T]^T = [\tilde{\mathbf{h}}_1^T, \tilde{\mathbf{h}}_2^T, \cdots \tilde{\mathbf{h}}_K^T]^T$, the spatial domain matrix is changed to the beamspace channel matrix and the signal model of the beam domain can be expressed as

$$\mathbf{y} = \tilde{\mathbf{H}}\mathbf{W}_B\mathbf{x} + \mathbf{n} \tag{7}$$

where $\tilde{\mathbf{H}}$ is the beampace channel matrix and $\mathbf{W}_B$ is the precoding matrix of the beamspace.

The NLOS component L in (3) is much smaller due to the propagation characteristics of mmWave scattering. In addition, the high-resolution narrow beam has a strong spatial isolation, so the beamspace is sparse. Therefore $\left|\tilde{\mathbf{H}}(k,b)\right|^2$ reflects the channel energy distribution on these beams. Figure 3 gives an example of the energy distribution when the number of transmitting antenna N_t is 32 and user number K is 16. The energy distribution of conventional MIMO channel in the spatial domain is shown in the Fig. 3(a), from which we can see the energy distribution is very scattered. On the contrary, the beamspace MIMO energy distribution is relatively concentrated in Fig. 3(b).

Figure 3 obviously shows that the characteristics of the sparseness of the beamspace channel. The channel energy is mainly concentrated on some beams. So we can select only a small number of energy concentrated beams to serve users according to the sparse beamspace channel to reduce the dimension of MIMO system. After the beam selection, system model can be described as

$$\mathbf{y} \approx \tilde{\mathbf{H}}_s\mathbf{W}_s\mathbf{x} + \mathbf{n} \tag{8}$$

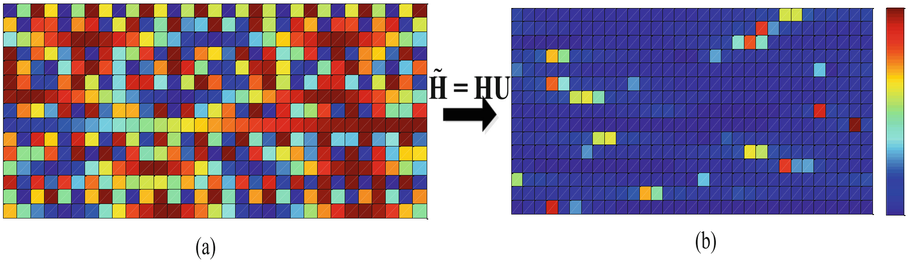

Fig. 3. Energy distribution: traditional MIMO in the spatial domain; (b) beamspace MIMO

where $\tilde{\mathbf{H}}_s = \tilde{\mathbf{H}}(:, \mathbf{B}_{select})$, $\mathbf{B}_{select}$ is the selected beam set which contains the indices of selected beams. In order to guarantee the spatial multiplexing gain of K users, each user chooses 1 beam at least, $Card(\mathbf{B}_{select}) = N_{RF} = K$, and in the scenario of each user chooses 2 beams, $Card(\mathbf{B}_{select}) = N_{RF} = 2K$.

Then, the channel matrix dimension is reduced from $K \times N_t$ to $K \times Card(\mathbf{B}_{select})$. As the dimension-reduced digital precoding matrix, $\mathbf{W}_s$ is much smaller than that of the traditional MIMO digital precoding matrix $\mathbf{W}$ in (2). As a result, the sparseness can be used to achieve spatial multiplexing and reduce the number of RF chains from $O(N_t)$ to $O(K)$, which leads to low power consumption.

3 Beam Selection

3.1 Beam Selection Challenge

The two main problems existing in beam selection are users sharing beam and inter-beam interference, which will be explained as below.

The ideal situation is that there is no interference between the beams for each user, but the ideal state does not exist. Even if the number of N_t is very large and beam resolution is very high, multiple selections of the same beam for different users are not to be ignored. Now, the case that different users have different strongest beams is equivalent to select K different beams from total N_t beams. Therefore, the probability P that there exists users sharing the same strongest beam is $P = 1 - \frac{N_t!}{N_t^K (N_t - K)!}$ [7]. For a mmWave system with $N_t = 256$ and $K = 32$, $P \approx 87\%$. As shown in Fig. 4(a), the beam b_2 is the strongest gain beam of both U_1 and U_2. It can be seen that ignores user sharing beam problem while selects the strongest beam for users, which will simultaneously select the sharing beam b_1 for U_1 and U_2 leading to the dimension-reduced beamspace channel matrix $\tilde{\mathbf{H}}_s$ rank-deficient. This means that some users cannot be served, resulting in an obvious performance loss. In order to avoid beam sharing, b_1 should be selected for U_1 and b_2 for U_2.

Figure 4(b) shows the inter-beam interference scenario. It can be seen from the figure that the strongest beam for U_3 is b_1 and U_4 is b_2. But there is serious interference between beam b_1 and beam b_2. The better option is $b_1$to provide services for U_3, b_3 for the user U_4, which will greatly reduce the interference between the beams. Figure 4(b) indicates that the strongest gain beam is not the optimal beam and should not ignore the presence of interference.

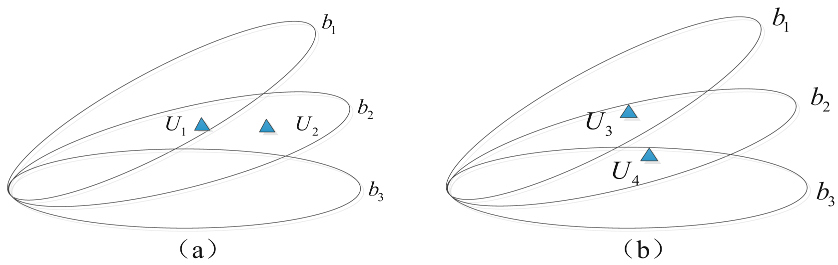

Fig. 4. User distribution scenario (a) users sharing beam; (b) inter-beam interference

3.2 Proposed MI Selection

For the above problems, this paper proposes a low complexity beam selection algorithm-MI beam selection. The two most basic criterias for beam selection are: (1) to serve the target user as much as possible; and (2) to minimize interference to other users. So the beamspace SIR B_{SIR} is defined to evaluate the beam performance selected.

$$B_{SIR}(k,b) = \frac{\left|\tilde{\mathbf{H}}(k,b)\right|^2}{\sum_{i\neq k}^{K}\left|\tilde{\mathbf{H}}(i,b)\right|^2} \tag{9}$$

where $\left|\tilde{\mathbf{H}}(k,b)\right|^2$ denotes the beam gain when the user k is served by beam b, $\left|\tilde{\mathbf{H}}(b,i)\right|^2$ is the interference of b to user i. $B_{SIR}(k,b)$ larger indicates that the beam gain is strong, on the other hand indicates that it has less interference to other users. Therefore, the first step of the beam selection is based on the channel state information and the beamforming matrix to obtain the beamspace channel matrix $\tilde{\mathbf{H}}$, and calculate the beamspace SIR B_{SIR} sorted by descending order. Choosing the maximum B_{SIR} means minimizing interference and solves the problem of inter-beam interference. Then, select the B_{SIR} first n (the number of beams per user needs) columns as an optional beam set. For the problem of shared beam between users, we classify all users into two user groups, shared beam users group (SUs) and non-shared users group (NSUs). The user k is defined as NUS if its largest $B_{SIR}(k,b)$ beam b is different from other users. For the NSUs, directly select the beam b of the largest $B_{SIR}(k,b)$ as the service beam. When a beam is the optimal beam shared by multiple users, the current beam can not be selected as the service beam. And the corresponding user needs to select the sub-optimal $B_{SIR}(k,b)$ beam b which is not selected by NSUs until all users have selected the beam. The MI beam selection algorithm is summarized in Algorithm 1.

Algorithm 1. Proposed MI beam selection algorithm

Require Beamspace channel matrix $\tilde{\mathbf{H}}$; Number of beams per user n
$\tilde{\mathbf{H}}_{abs} = \text{abs}(\tilde{\mathbf{H}})$
$\mathbf{S}_{clo}(b) = \text{sum}(\tilde{\mathbf{H}}_{abs}(:,b)), b = 1, 2, \cdots N_t$
For slot $k (1 \leq k \leq K)$
  $\mathbf{B}_{SIR}(k,:) = \tilde{\mathbf{H}}_{abs}(k,:)/(\mathbf{S}_{clo}(:) - \tilde{\mathbf{H}}_{abs}(k,:))$
  $[\,\mathbf{value\ index}(k,:)\,] = \text{sort}(\mathbf{B}_{SIR}(k,:), \text{descend})$
End for
$\mathbf{NSUs} = [], \mathbf{SUs} = [], \mathbf{B_{NSUs}} = [], \mathbf{B_{SUs}} = []$
$\{b_1^*, \cdots, b_{k-1}^*, b_k^*, b_{k+1}^*, \cdots, b_{n*K}^*\} = \text{reshape}(\mathbf{index}(:, 1:n), 1, n*K)$
If $b_k^* \notin \{b_1^*, \cdots, b_{k-1}^*, b_{k+1}^*, \cdots, b_{n*K}^*\}\ k \in [1, n*K], b_k^* \in [1, N_t]$
  $\mathbf{B_{NSUs}} = \{\mathbf{B_{NSUs}}, b_k^*\}$
Else
  $\mathbf{SUs} = \{\mathbf{SUs}, k\}$
End if
For slot $i (1 \leq i \leq Card(\mathbf{SUs}))$
  $j = 2$
  While $(\mathbf{index}(\mathbf{SUs}(i), j) \in \mathbf{B_{NSUs}})$
    $j = j + 1$
  End While
  $\mathbf{B_{SUs}} = \{\mathbf{B_{SUs}}, \mathbf{index}(\mathbf{SUs}(i), j)\}$
End For
$\mathbf{B}_{select} = \mathbf{B_{SUs}} \cup \mathbf{B_{NSUs}}$
Return: $\tilde{\mathbf{H}}_s = \tilde{\mathbf{H}}(:, \mathbf{B}_{select})$

Figure 5 shows the selected beams energy distribution by MI algorithm. It can be seen that each user selects the optimal beam as mush as possible and the users of the shared beam select the suboptimal beam.

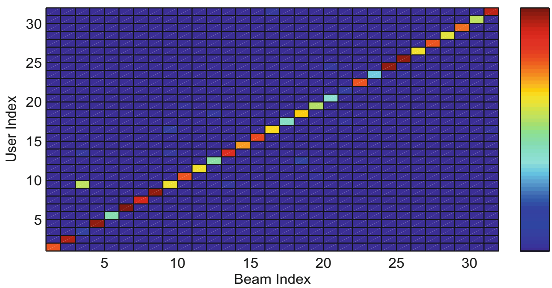

Fig. 5. The selected beams energy distribution by MI algorithm

4 Simulation Results

This section is dedicated to analyse the spectral and energy efficiency losses caused by the selection algorithm compared to the full digital system.

We use the Shannon capacity idealistic as the upper bound for the spectral efficiency [13]

$$R = \sum_{i=1}^{K} R_i = \sum_{i=1}^{K} \log_2(1 + SINR_i) \tag{10}$$

where $SINR_i$ is the signal-to-interference-and-noise ratio (SINR) for user i. With the power constraint, the classical digital zero-forcing (ZF) precoding matrix is given by

$$\mathbf{W} = \beta \mathbf{H}^H (\mathbf{H}\mathbf{H}^H)^{-1} \tag{11}$$

where $\beta = \sqrt{\frac{P}{tr(\mathbf{F}\mathbf{F}^H)}}$, $\mathbf{F} = \mathbf{H}^H(\mathbf{H}\mathbf{H}^H)^{-1}$. Then, the precoding vector $\mathbf{w}_i$ for user i is defined as the i^{th} column of $\mathbf{W}$. From (1), $SINR_i$ is calculated as

$$SINR_i = \frac{|\mathbf{h}_i \mathbf{w}_i|^2}{\delta^2 + \sum_{k=1, k \neq i}^{K} |\mathbf{h}_i \mathbf{w}_k|^2} \tag{12}$$

The simulation parameters of the system are as shown in Table 1. Then, the MM algorithm, the IA algorithm and the proposed MI algorithm are simulated and analyzed. Meanwhile the full digital ZF precoding (the number of RF links is 256) is provided as the upper bound of the comparison.

Table 1. Simulation parameters

SNR	−10 dB–30 dB	Precoding	ZF
Antennas number N_t	256	User distribution	$[-\frac{\pi}{2}\,\frac{\pi}{2}]$ uniform distribution
Users number K	2–70	NLoS components L	$\beta_{i,0} \sim CN(0,1)$ $\beta_{i,l} \sim CN(0,10^{-1})$

Figure 6 shows the spectrum efficiency comparison when user number $K = 32$. It can be seen from Fig. 6 that the performance of the proposed MI algorithm is close to the AI algorithm when the user selects 1 beam. Compared with MM algorithm, the performance of MI is about 30% higher at high SNR (SNR > 10 dB) region. Figure 6 also shows when 2 beams are selected by each user, the proposed MI algorithm is close to the full digital ZF precoding. At the same time, the performance of the MI algorithm with 1 beam per user is consistent with the performance of the MM algorithm with 2 beams per user. The main reason for the poor performance of the MM algorithm is that it ignores the problems of users sharing beam and inter-beam interference. Although IA achieves better performance, iterative searching for IUs to maximize the achievable sum-rate leads to high computational complexity because of large-scale matrix operations including inverse [8].

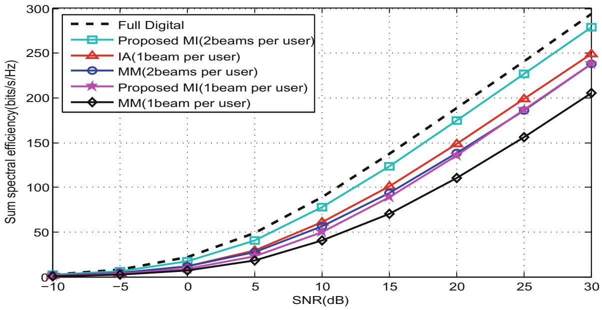

Fig. 6. Spectrum efficiency comparison when user number $K = 32$

Figure 7 further considers a $K = 64$ scenario where the MI algorithm and IA algorithm have almost the same performance when the user selects 1 beam in the low SNR environment. With the increase of SNR (SNR $>$ 15 dB), the performance of MI algorithm is obviously better than IA algorithm.

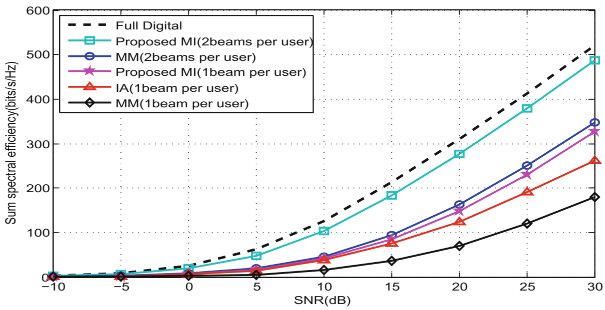

Fig. 7. Spectrum efficiency comparison when user number $K = 64$

Figure 8 illustrates the effect of the number of users K on the spectral efficiency in term of SNR = 25 dB. When the number of users is small, the performance of the MI algorithm and IA algorithm is close to that of the MM algorithm performance of 2 beams per user. As the number of users ($K > 45$) increase, the performance of IA algorithm begins to decline and the proposed MI algorithm is better than the IA algorithm. This is mainly due to MI algorithm considering the interference of the selected beam to other users, while MM and IA algorithm are based on the choice of the strongest beam.

The energy efficiency comparison is shown in Fig. 9 when SNR = 25 dB. The energy efficiency η is modeled as $\eta = \frac{R}{\rho + N_{RF}\rho_{RF}}$ (bps/Hz/W) [8], where R is spectral efficiency, ρ is the transmit power, $N_{RF}\rho_{RF}$ is the number of RF chains and energy consumed. This paper sets up the typical values $\rho = 32$ mw, $\rho_{RF} = 34.4$ mw. As expected in Fig. 9, the MI algorithm is superior to the MM algorithm for the case of 2 beams per user. For the case of 1 beam per user, with the increasing of users, MI algorithm is obviously better than the MM algorithm. When the user number satisfies $K > 42$, MI becomes the optimal algorithm.

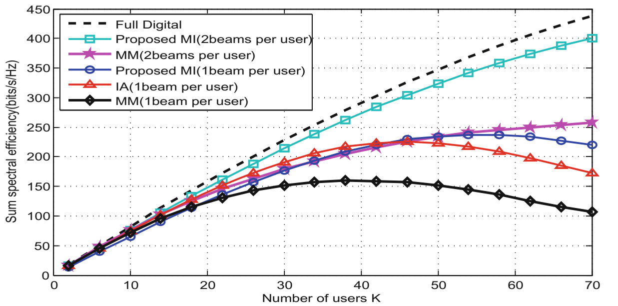

Fig. 8. Spectrum efficiency comparison when SNR = 25 dB

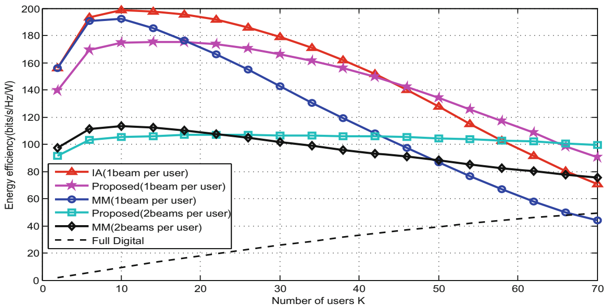

Fig. 9. Energy efficiency comparison when SNR = 25 dB

5 Conclusions

This paper introduces a low RF complexity beamspace MIMO system. Taking the potential multiuser interferences into consideration, we propose an MI beam selection algorithm. Finally, the simulation results verify that the proposed algorithm achieves the performance closing to full digital precoding when selecting 2 beams per user, and has better energy efficiency. It also has good performance when selecting one beam per user, especially in the condition of more users.

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References

1. Chen, S., et al.: Adaptive beamforming in TDD-based mobile communication systems: state of the art and 5G research directions. IEEE Wirel. Commun. **23**(6), 81–87 (2017)
2. Liu, P., Renzo, M.D., Springer, A.: Line-of-sight spatial modulation for indoor mmWave communication at 60 GHz. IEEE Trans. Wirel. Commun. **15**(11), 7373–7389 (2016)
3. Kim, Y., et al.: Feasibility of mobile cellular communications at millimeter wave frequency. In: Global Communications Conference IEEE, pp. 1–6 (2016)
4. Liu, J., Minn, H., Gatherer, A.: The death of 5G part 2: will analog be the death of massive MIMO? In: IEEE ComSoc Technology News 2015 (2015)
5. Pu, W., et al.: Low Complexity hybrid beamforming based on orthogonal constraint and phase extraction. In: IEEE Wireless Communications and Networking Conference IEEE, pp. 1–5 (2017)
6. Wang, B., et al.: Spectrum and energy efficient beamspace MIMO-NOMA for millimeter-wave communications using lens antenna array. IEEE J. Sel. Areas Commun. **35**(10), 2370–2382 (2017)
7. Xue, Q., Fang, X., Wang, C.X.: Beamspace SU-MIMO for future millimeter wave wireless communications. IEEE J. Sel. Areas Commun. **35**(7), 1564–1575 (2017)
8. Gao, X., et al.: Near-optimal beam selection for beamspace MmWave massive MIMO systems. IEEE Commun. Lett. **20**(5), 1054–1057 (2016)
9. Han, S., et al.: Large-scale antenna systems with hybrid analog and digital beamforming for millimeter wave 5G. IEEE Commun. Mag. **53**(1), 186–194 (2015)
10. Amadori, P.V., Masouros, C.: Low RF-complexity millimeter-wave beamspace-MIMO systems by beam selection. IEEE Trans. Commun. **63**(6), 2212–2223 (2015)
11. Luo, F.L., Zhang, C.: Millimeter-Wave MIMO Transceivers: Theory, Design and Implementation. Wiley-IEEE Press, Hoboken (2016)
12. Brady, J., Hogan, J., Sayeed, A.: Multi-beam MIMO prototype for real-time multiuser communication at 28 GHz. IEEE GLOBECOM Workshops IEEE, pp. 1–6 (2016)
13. Han, Y., et al.: A joint SDMA and interference suppression multiuser transmission scheme for millimeter-wave massive MIMO systems. In: Sixth International Conference on Wireless Communications and Signal Processing IEEE, pp. 1–5 (2014)