

The Maximal SINR Selection Mode for 5G Millimeter-Wave MIMO: Model Systems and Analysis

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Abstract

In mmWave massive MIMO systems, the lens antenna array and beam selection by beamspace MIMO are employed to target the number of required RF chains reduced without obvious performance loss. For cost – effective, the number of RF chain is an allowable limitation, however, to obtain the near-optimal capacity efficiently, beam selection must require the exact information of the wide size of beamspace channel. Solution to this problem, in this paper we suggest analyzing whole beamspace based on maximal SINR. More specifically, it is confirmed that the proposed beam selection algorithms achieve higher power efficiencies than a full system where all beams are employed.

Keywords: mmWave communications MIMO, Beamspace, Multiuser Interferences, Beam Selection

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1. Introduction

In the past few years, cause the number of devices growing faster, the demand for faster data rates in all of services is very importance. But at the same time, the free bandwidth and the highest radiated power are limited are the problem we must solve [1]. As a key candidate for forthcoming 5G wireless communications, advantage impact of millimeter-wave (mmWave) can be combined with massive multiple-input multiple-output (MIMO) as much interests trends [2], since it can procedure high data rates due to consuming wider bandwidth, higher spectral effectiveness and reduce radiated power, increase the data rates in service performance for distance-dependent pathloss and channel coherence time and bandwidth [3]. As a result, a high-priced hardware complexity and energy consumption can be seen in such mmWave massive MIMO systems, due to the increasing number of antennas [1] and the high energy consumption of RF chain in mmWave frequencies [4]. To required RF chains can be reduced, the novel idea of beamspace MIMO has been recently suggested as in pioneering work [5]. In mm-wave system, the lens antenna array can be applied without using the conventional electromagnetic antenna array, beamspace MIMO can convert the conventional spatial channel into beamspace channel by concentrating the signals from different directions (beams) on different antennas [3]. Besides, one can choice a trivial number of dominant beams to considerably diminish the dimension of MIMO system and remaining required RF chains without obvious performance loss [6].

Furthermore, MU-MIMO has been studied for more than a decade, the seminal work of Marzetta [7] introduced Massive MIMO, where the number of antenna elements at the BS reaches dozens or hundreds. This has the obvious advantage that the number of data streams in the cell can be increased to very large values. However, a number of additional advantages can be obtained, namely that signal processing is simplified, that “channel hardening” occurs such that small-scale fading is essentially eliminated, and that the required transmission energy becomes very small because a large beamforming gain is provided for each user. A number of papers have explored different aspects of massive MIMO; we refer to [8] for a review. We also note that massive MIMO is *beneficial* at cm-wave frequencies, but is *essential* in the millimeter-wave bands, since the high free-space pathloss in those frequency bands necessitates large array gains to “close the link”, i.e., obtain sufficient signal-to-noise ratio, even at moderate

distances of about 100 m. Motivation by these analysis, we investigate beam selection criteria for system evaluation.

In this paper, we will investigate on interference aware-maximization selection. In particular, this work will sort all user to two users group, cause to consider benefit of multiuser interference. For the first users group, it can be choose a maximum beam power, in other group the beam can be selected by low-complexity incremental algorithm. Finally, we will choose K beams to serve all K users corresponding.

2. MIMO System in the Spatial Domain

In this section, we consider $K \times 1$ received signal vector for all K users (mobile station-MS) in the downlink of mmwave system by:

$$\mathbf{z} = \mathbf{H}^H \mathbf{P} \mathbf{s} + \mathbf{n} \quad (1)$$

where $\mathbf{H} = [\mathbf{h}_1, \mathbf{h}_2, \dots, \mathbf{h}_K]$ denotes as the channel matrix, \mathbf{h}_k of size $M \times 1$ is the channel vector for the link between the base station (BS) which connected to the k th user, while \mathbf{s} stands for the original signal vector of size $K \times 1$ in all K users with normalized power $E(\mathbf{s}\mathbf{s}^H) = \mathbf{I}_K$, \mathbf{P} is the precoding matrix of size $N \times K$ adequate the total transmit power ρ as constraint $\text{tr}(\mathbf{P}\mathbf{P}^H) \leq \rho$, the noise term with distribution $\mathbf{n} \sim \text{CN}(0, \sigma^2 \mathbf{I}_K)$ denotes the $K \times 1$ additive white Gaussian noise (AWGN). It is noted that the total of essential RF chains is $M_{\text{RF}} = M$, which is usually extremely huge for mmWave massive MIMO regimes, e.g., $M_{\text{RF}} = M = 256$.

Next, we will familiarize model for mmWave communications, in which the channel vector \mathbf{h}_k stands for the k -th user. In this paper, we consider the widely used Saleh-Valenzuela channel as below [5]:

$$\mathbf{h}_k = \beta_k^{(0)} \mathbf{a}(\Psi_k^{(0)}) + \sum_{l=1}^L \beta_k^{(l)} \mathbf{a}(\Psi_k^{(l)}) \quad (2)$$

In which $\beta_k^{(0)} \mathbf{a}(\Psi_k^{(0)})$ is the line-of-sight (LoS) element of the k th user with $\beta_k^{(0)}$ presenting the complex gain and $\Psi_k^{(0)}$ meaning the spatial direction, $\beta_k^{(l)} \mathbf{a}(\Psi_k^{(l)})$ for $1 \leq l \leq L$ in the l -th non-line-of-sight (NLoS) element of the k -th user, and L is the total number of NLoS elements, $\mathbf{a}(\Psi)$ is the $M \times 1$ array steering vector.

In scenario of the typical uniform linear array (ULA) with M antennas, we obtain $\mathbf{a}(\psi) = \frac{1}{\sqrt{M}} [e^{-j2\pi\psi m}]_{m \in \Upsilon(M)}$, we denote $\Upsilon(N) = \{q - (M-1)/2, q = 0, 1, \dots, M-1\}$ as a symmetric set of indices aligned around zero. Considering other parameters such as the spatial direction is well-defined as $\Psi \sim \frac{d}{\lambda} \sin \theta$, in which θ is the physical direction, λ is the signal wavelength, and d is the antenna spacing under space distance as $d = \lambda/2$ at mmWave frequencies domain.

3. BeamSpace MIMO

Specifically, such discrete lens array (DLA) employ characterizations corresponding to an $M \times M$ spatial discrete Fourier transform matrix \mathbf{U} , which encloses the array steering vectors of M orthogonal directions in the entire space as:

$$\mathbf{U} = [\mathbf{a}(\bar{\Psi}_1), \mathbf{a}(\bar{\Psi}_2), \dots, \mathbf{a}(\bar{\Psi}_N)]^H \quad (3)$$

where $\bar{\psi}_n = \frac{m}{M} - \frac{M+1}{2M}$ for $m=1,2,\dots,M$ are the predefined spatial directions. Then, we can illustrate the system model of beamspace MIMO and it can be characterized by:

$$\tilde{\mathbf{z}} = \mathbf{H}^H \mathbf{U}^H \mathbf{P} \mathbf{s} + \mathbf{n} = \tilde{\mathbf{H}}^H \mathbf{P} \mathbf{s} + \mathbf{n}, \quad (4)$$

In which $\tilde{\mathbf{z}}$ stands for the received signal vector in the concerned beamspace, and hence, the beamspace corresponding channel $\tilde{\mathbf{H}}$ is expressed as:

$$\tilde{\mathbf{H}} = [\tilde{\mathbf{h}}_1, \tilde{\mathbf{h}}_2, \dots, \tilde{\mathbf{h}}_K] = \mathbf{U} \mathbf{H} = [\mathbf{U} \mathbf{h}_1, \mathbf{U} \mathbf{h}_2, \dots, \mathbf{U} \mathbf{h}_K], \quad (5)$$

It is noted that $\tilde{\mathbf{h}}_k$ is the beamspace channel of the k -th user. Having a look on formula (5), the M rows (elements) of $\tilde{\mathbf{H}}(\tilde{\mathbf{h}}_k)$ relate to M orthogonal beams which use spatial directions are $\tilde{\psi}_1, \tilde{\psi}_2, \dots, \tilde{\psi}_M$, respectively. Therefore, the number of NLoS components L in (2) is much smaller than M , the number of dominant components of $\tilde{\mathbf{h}}_k$ is much smaller than M . As a result, we can select only a small number of appropriate beams according to the sparse beamspace channel to reduce the dimension of MIMO system without obvious performance loss as:

$$\tilde{\mathbf{z}} \approx \tilde{\mathbf{H}}^H \mathbf{P}_r \mathbf{s} + \mathbf{n}, \quad (6)$$

Where $\tilde{\mathbf{H}}_r = \tilde{\mathbf{H}}(s,:)$, contains the indices of selected beams, \mathbf{P}_r is the dimension-reduced digital precoding matrix. As the dimension of \mathbf{P}_r is much smaller than that of the original digital precoding matrix \mathbf{P} in (1), beamspace MIMO can significantly reduce the number of required RF chains as shown in Fig. 1 (b). Note that the smallest number of required RF chains should be $M_{RF} = K$ to guarantee the spatial multiplexing gain of K users. Therefore, we consider $M_{RF} = K$ without loss of generality in this paper.

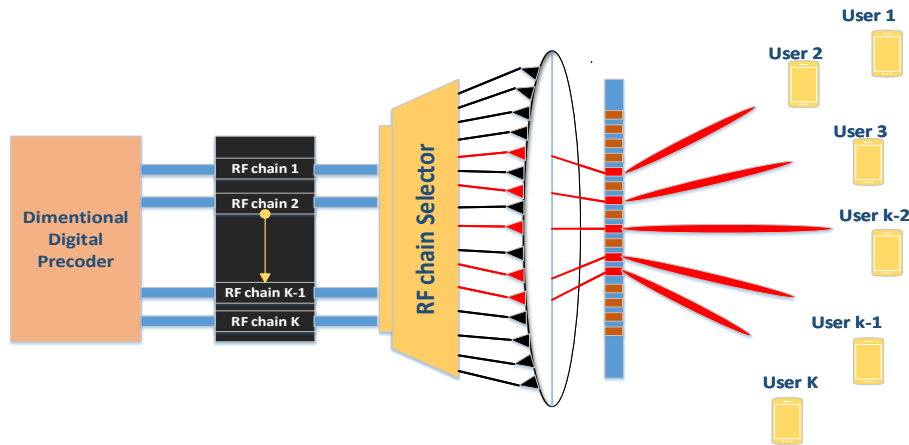


Figure 1. Selection Beams with lens antenna array

4. Maximum Magnitude Selection (MM - S)

As a reference to the proposed beam selection schemes, we define as maximum magnitude selection (MM-S) the criterion used in [4]. This criterion takes advantage of the properties of the channel model in the BS domain. The channel matrix \mathbf{H} has in fact a sparse nature, where few elements of the matrix have dominant values near the LoS direction of the MSs. This is a valid assumption for channels where the multipath component of (6) is negligible, but becomes questionable as we introduce additional paths to the model. In order to apply the

MM-S we need to define a set of beam indices called sparsity masks. Sparsity masks are used by the AP to identify the strongest beams to be selected for the transmission as:

$$\mathbf{M}_{(k)} = \left\{ i \in \mathbf{I}(n) : |h_{i,k}|^2 \geq \zeta_{(k)} \max |h_{i,k}|^2 \right\}$$

$$\mathbf{M} = \bigcup_{k=1, \dots, K} \mathbf{M}_{(k)}$$

where $h_{i,k}$ is the i -th element of the k -th column \mathbf{H} , $\mathbf{M}_{(k)}$ is the sparsity mask for the k -th MS and $\zeta_{(k)} \in [0,1]$ is the threshold used to define it. We can see that in order to obtain a minimum number of beams for each of the K MSs, the threshold $\zeta_{(k)}$ is chosen independently for each user. After the sparsity mask, we can define the channel derived from the activation of a subset of beams as:

$$\tilde{\mathbf{H}} = [\mathbf{h}_{i:}]_{i \in \mathbf{M}}$$

where the sizes $n_d \times K$ of the new channel matrix $\tilde{\mathbf{H}}$ depend on the number of strongest beams $n_d = |\mathbf{M}|$ identified in the sparsity mask. From (12) we can see that the MM-S algorithm leads to values of n_d which change according to the channel realization. In fact, the user wise selection implemented by MM-S often leads to multiple selections of the same beam for different users and therefore a varying number of required RF chains for different channel realizations and user topologies. As a consequence, a direct application of MM-S in practical systems, where the number of RF chains is fixed, is not viable. While MM-S selects the strongest channel paths, it can be seen that it is suboptimal in the receive SNR or capacity. Toward this end we investigate selection techniques, described in the following sub-sections.

5. Investigation on Interference Aware – Maximization of SINR Selection

In this section, beams are chosen to maximize the signal to interference ratio at the MS side; we represent this selection criterion as Interference Aware - Maximization of SINR selection (IA - MSS).

At first, we proposed a technique to minimize multiuser - interferences. Instead of choosing strongest beam of each user in MM - S beam selection [4], my purpose is to identify Interferences Users and Non - Interferences users from total M beams. For a mmWave massive MIMO system with $M=256$ and $K=32$, the total of finds is as large as 6×10^{40} . Finally, we need to redesign beam selection technique to achieve the Optimal - Maximization of SINR selection. We start by find maximize beam of the beamspace channel $\tilde{\mathbf{h}}_k$ and group as $m_k = \{m_1, m_2, \dots, m_K\}$ denote the strongest beam index of the k -th users from total beams. If $m_1 \neq m_2 \neq m_K$ then the power of signal is maximize and the multiuser - interferences really small, but if twos or three user user the same beam, they will be affected from serious multiuser interferences. The probability P that there users using the same strongest beam is:

$$P = 1 - \frac{M!}{M^K (M - K)!}$$

It is noted that as $P \approx 87\%$ of mmWave massive MIMO system that we can't negligible. In the end, we investigation to classify K users into two users group, is IUS and NIUs, we described in Algorithm.

In order to identify the subset of beams used during data transmission, we need to represent the SINR metric for our model. The SINR for each user depends on the precoder used at the transmitter, which can be described by the precoding matrix \mathbf{Z} .

$$\mathbf{Z} = \beta \mathbf{T} \tag{7}$$

Here, \mathbf{T} is the precoding matrix without power scaling and β the scaling factor that guarantees $E(\mathbf{ss}^H) = 1$, defined analytically as:

$$b = \sqrt{\frac{\rho}{\text{tr}(\mathbf{T}\mathbf{X}\mathbf{T}^H)}} \quad (8)$$

We denote ρ is the signal power and $\mathbf{X}_s = E[\mathbf{ss}^H]$ is the input covariance matrix, considered unitary and diagonal for our system. The received SINR of the i -th user is defined as:

$$\text{SINR}_i = (\rho, \mathbf{Z} | \mathbf{H}) = \frac{\frac{\rho|a|^2}{K} |\mathbf{h}_{:,i}^H \mathbf{t}_{:,i}|^2}{\frac{\rho|a|^2}{K} \sum_{v \neq i} |\mathbf{h}_{:,i}^H \mathbf{t}_{:,v}|^2 + \sigma^2} \quad (9)$$

in which $\mathbf{h}_{:,i}^H$ is the Hermitian transpose of the i -th column of \mathbf{H} and σ^2 is the noise power.

In this work, we focus on a practical case where the AP is equipped with a low-complexity zero forcing linear precoder, hence:

$$\mathbf{T}_{ZF} = \mathbf{H}(\mathbf{H}^H \mathbf{H})^{-1}. \quad (10)$$

The denominator term in (9) contains two different factors: the first one defines the interference while the second one identifies the noise. Applying the properties of ZF precoding we have $\sum_{m \neq i} |\mathbf{h}_{:,m}^H \mathbf{f}_{:,i}|^2 = 0$ and $|\mathbf{h}_{:,i}^H \mathbf{f}_{:,i}|^2 = 1$, leading to the definition of a simplified SINR equation.

$$\text{SINR}_{i,ZF}(\gamma, \mathbf{Z} | \mathbf{H}) = \frac{\gamma |b|^2}{K} \quad (11)$$

For simplicity, we denote $\gamma = \rho / \sigma^2$ is the signal-to-noise ratio (SNR). The maximization of the SINR can then be obtained simply, by maximizing the scaling factor b . In order to maximize the SINR, a full search algorithm would compute the SINR for all the possible combination of beam subsets and then choose the subset that leads to the highest value. Such approach leads to an optimal but computationally prohibitive selection because of its $\binom{M}{N}$

possible combinations, 1 where N is the subset size. We propose a suboptimal decremental selection of the beams that identifies the subset of beams with the minimum loss in terms of SINR, shown in Algorithm below.

Using Algorithm 1, we compute the SINR for the reduced system after the elimination of the l -th beam as:

$$\text{SINR}_{i,ZF}^{(l)}(\gamma, \mathbf{G} | \mathbf{H}_l) = \frac{\gamma |b^{(l)}|^2}{K} \quad (12)$$

With:

$$b^{(l)} = \sqrt{\frac{\rho}{\text{tr}(\mathbf{F}^{(l)} \mathbf{F}^{(l)H})}} \quad (13)$$

In this case, $\mathbf{T}^{(l)}$ is the precoding matrix obtained with the \mathbf{H}_i channel model and $b^{(l)}$ is the corresponding scaling factor. Hence, we identify the index of the beam to be disabled via the following maximization criterion.

$$v = \arg \max_i \left\{ \frac{\gamma |b^{(l)}|^2}{K} \right\} \quad (14)$$

Where v is an element of the subset of disabled beams M . Since ρ, K and σ^2 are channel independent we can reduce the maximization criterion to a simple.

$$v = \arg \max_i \left(|b^{(l)}|^2 \right) \quad (15)$$

In our studies, the selection metric for MS-S derived in (12) is obtained by exploiting the orthogonal properties of ZF precoding. However, the presented technique can be applied independently from the precoding involved at the AP. In fact, following the predefined notation and under a generic precoding assumption G , the MS-S algorithm proceeds by maximizing the SINR for the reduced system.

$$SINR_i^{(l)} = SINR_i(\rho, \mathbf{Z}^{(l)} | \mathbf{H}_i) \quad (16)$$

Here, $\mathbf{Z}^{(l)}$ represents the precoding matrix that corresponds to the reduced channel model \mathbf{H}_i .

Algorithm 1: Incremental IA – MSS

```

Input  $\mathbf{H}$ 
Output  $\tilde{\mathbf{H}}$ 
 $s\_sub = 1 \rightarrow M$ 
for  $k = 1 \rightarrow N$ 
 $m_k = \arg \max(|\mathbf{H}|)$ 
end
 $m\_sub = unique(m)$ 
 $b\_sub = m\_sub$ 
for  $i = 1 \rightarrow length(m\_sub)$ 
    if find( $m = m\_sub(i)$ )
         $b\_sub(b\_sub == m\_sub(i)) = []$ 
    end
end
 $s\_sub(b\_sub) = []$ 
 $no = N - length(b\_sub)$ 
if  $no \sim 0$ 
     $T\_sub = b\_sub$ 
    for  $j = 1 \rightarrow no$ 
         $a = []$ 
        for  $l = 1 \rightarrow length(s\_sub)$ 
             $\mathbf{T}^{(l)} = unique([T\_sub \ s\_sub(l)])$ 
             $\mathbf{F} = \mathbf{H}(\mathbf{T}^{(l)}, :) / \mathbf{H}(\mathbf{T}^{(l)}, :) * \mathbf{H}(\mathbf{T}^{(l)}, :)$ 
             $\beta^{(l)} = \sqrt{\rho / tr(\mathbf{F} * \mathbf{F}^*)}$ 
        end
    end

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         $\delta = \arg \max_l \left\{ \left| \beta^{(l)} \right|^2 \right\}$ 
         $T\_sub = \text{unique}(T\_sub \ s\_sub(\delta))$ 
         $s\_sub(\delta) = []$ 
    end
else
     $T\_sub = b\_sub$ 
end
 $\tilde{\mathbf{H}} = [\mathbf{h}_{v_i}]_{v_i \in T\_sub}$ 

```

6. Simulation Results and Analysis

This section is considered a typical mmWave massive MIMO system where the BS equips an ULA with $M = 256$ antennas and $M_{RF} = 32$ RF chains to simultaneously serve $K = 32$ users. For the spatial channel of user k , we have: 1) one LoS component with $L = 2$ NLoS components; 2) $\beta_k^{(0)} \sim \text{CN}(0,1), \beta_k^{(l)} \sim \text{CN}(0,10^{-1})$ for $l=1,2$; 3) $\psi_k^{(0)}, \psi_k^{(l)}$ follow the i.i.d. uniform distribution within $[-\frac{1}{2}, \frac{1}{2}]$.

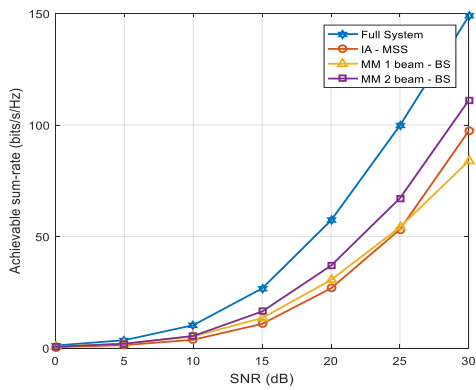


Figure 2. Achievable sum-rate

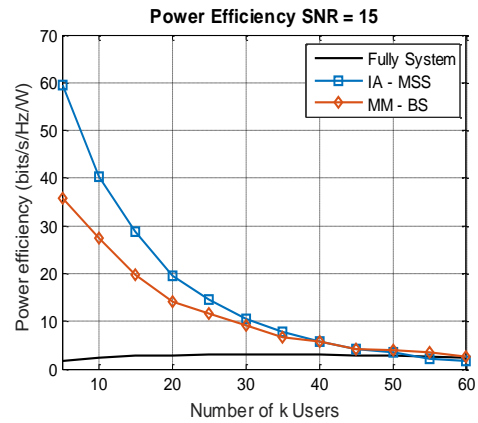


Figure 3. Power Efficiency at SNR = 15 and Number of k – user from 5 to 60

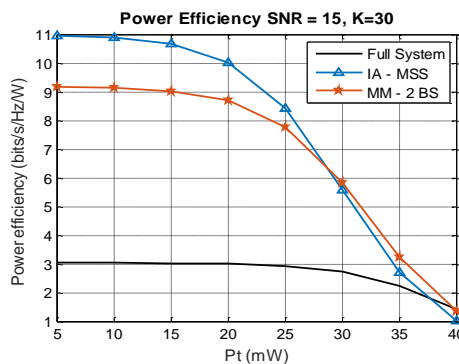


Figure 4. Power Efficiency SNR = 15, K = 30, and PRF from 0 to 40 mW

Figure 2 shows the sum-rate performance comparison between the proposed IA - MSS beam selector and the conventional MM - S beam selector. We suggest the performance of the full system digital ZF precoder all beams (256 RF chains) as the benchmark for comparison. With Figure 2, we can see that the proposed IA - MSS beam selection achieves lower than sum-rate performance than MM beam selection with 1 beams per user. But we must utilize difficult

technique for more beams of MM - S. The technique we investigate use the number of RF equal the number of users, but others technique, as same as MM – S must use 2 beams can be serve all users. The fact that for MM beam selection with 1 beam per user, the same beam will be selected for different IUs, and the dimension-reduced beamspace channel matrix cannot be apply for this technique. This means that a few users cannot be served, leading to user unfairness and an obvious performance loss in the achievable sum-rate. In contrast, IA - MSS technique can assurance that all K users can be served simultaneously with maximize the SINR.

Figure 3 give information about the power efficiency comparison against the number of users K from 5dB to 60dB, where the number of antennas is fixed as $M = 256$, at SNR = 15 dB.

The energy efficiency ζ is modeled as [8] $\zeta = \frac{R}{\rho + N_{RF} P_{RF}}$ (bps/Hz/W), ρ is the transmit power

defined in (1), P_{RF} is the energy consumed by RF chain. In this case, we using the practical values $P_{RF} = 34.4$ mW and $\rho = 32$ mW (15 dBm). In this figure, we can see IA - MSS power efficiency better than others technique. When the number of users close to minimum, power efficiency of IA – MSS is higher than MM – S . It is noted that the benchmark here is the full system which worse than the proposed system at any number of users.

Figure 4 illustrates to the dependence of the power efficiency on the transmitted power, we use the scheme where K=30 and SNR=15. We can observe that IA - MSS beam selection achieves rapid decline very similar to MM beam selection with 2 beams per user, but slightly lower than MM – 2 BS, especially when K is not very large. Our proposed system also outperforms the full system scheme. With IA – MSS technique we can change the value of transmit power can serve all users.

6. Conclusion

Low RF-complexity technology will be a necessary component for future mmWave MIMO systems since it can reduce the bottleneck of highly hardware cost and energy consumption induced by the huge number of RF chains. In this paper, we first illustrate two traditional RF-complexity technologies, including beam selection, and analog beamforming, spatial modulation. After that, we propose attractive low RF-complexity technologies for mmWave MIMO systems, i.e., maximize the signal to interference ratio for beamspace MIMO, which can achieve much higher energy efficiency than traditional schemes. Performance comparison further shows that the proposed system enjoys a better power efficient performance. Future potential opportunities in this emerging research area of low RF-complexity technology include more efficient alternatives to realize low RF-complexity, novel transceiver designs for beam-selective and time-varying mmWave MIMO channels.

References

- [1] Kehinde Odeyemi, Erastus Ogunti. Performance Analysis of a Hybrid Mimo Technique for High Data Rate Wireless Communication System. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2014; 12(7): 5458-5468.
- [2] S Han, C Li, Z Xu, C Rowell. Large-scale antenna systems with hybrid precoding analog and digital beamforming for millimeter wave 5G. *IEEE Commun. Mag.* 2015; 53(1): 186-194.
- [3] Idrissa Abubakar, Jafri Din, Manhal Alhilali, Hong Yin Lam. Interference and Electromagnetic Compatibility Challenges in 5G Wireless Network Deployments. *Indonesian Journal of Electrical Engineering and Computer Science*. 2017; 5(3): 612-621.
- [4] A Alkhateeb, J Mo, N Gonzalez-Prelcic, RW Heath. MIMO precoding and combining solutions for millimeter-wave systems. *IEEE Commun. Mag.* 2014; 52(12): 122-131.
- [5] J Brady, N Behdad, A Sayeed. Beamspace MIMO for millimeterwave communications: System architecture, modeling, analysis, and measurements. *IEEE Trans. Ant. and Propag.* 2013; 61(7): 3814-3827.
- [6] A Sayeed, J Brady. *Beamspace MIMO for high-dimensional multiuser communication at millimeter-wave frequencies*. In Proc. IEEE GLOBECOM. 2013: 3679-3684.
- [7] T Marzetta. Noncooperative cellular wireless with unlimited numbers of base station antennas. *Wireless Communications, IEEE Transactions on*. 2010; 9(11): 3590-3600.
- [8] E Larsson, O Edfors, F Tufvesson, T Marzetta. Massive MIMO for next generation wireless systems. *IEEE Commun. Mag.* 2014; 52(2): 186-195.