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Uplink millimeter-wave multi-cell multi-user massive multi-input multi-output systems

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ABSTRACT

In this paper, we delve into the maximized spectral efficiency (SE) of millimeter-wave (mmWave) multicell multiuser massive MIMO Systems for uplink transmission with low-resolution phase shifters (LRPSs). Millimeter-wave massive multiple-input multiple-output (mMIMO) is an important technology for upcoming cellular networks which will provide higher bandwidth and throughput than current wireless systems and networks. LRPSs are commonly used to minimize power consumption, maximize spectral efficiency and diminish the complexity of hybrid precoder and combiner. In this paper, we consider a hybrid analog-digital precoder and combiner design with LRPSs for mmWave multi-cell multiuser mMIMO systems for uplink transmission to spectral efficiency in terms of iterations. The proposed technique outperforms when compared to traditional optimization approaches concerning spectral efficiency and bit error rate (BER). We show through simulation results that our designs with LRPSs outperform standard iteration procedures.

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1. INTRODUCTION

The next generation of new air interface communication will use a mmWave system due to its ultra-wide bandwidth [1], [2]. smaller wavelengths (in terms of a millimeter) support huge-scale antenna arrays into a small size, appropriate for massive multiple-input multiple-output (mMIMO) systems, which increases system capacity, improve throughput, better data throughput, and enhances spectrum efficiency [3]. In massive MIMO, the base station (BS) can be outfitted with large-scale antennas (many hundreds) at the transmitter and receiver ends, which can achieve a considerably greater array gain [4]. However, in traditional MIMO, Digital beamforming (Fully) demands that a single antenna element be powered by a distinct RF chain, which is no longer appropriate for mMIMO system. The increasing number of radiofrequency (RF) links significantly raises implement costs, power consumption (PC), and computational complexity, posing problems to realize the system. To address this issue, hybrid beamforming designs have been suggested, in which RF chains are reused by requiring many antennas to share fewer RF chains [5]-[7]. The combination of an analog beamformer and a digital beamformer produces hybrid beamforming. Analog precoding with phase shifters (PSs) is an alternate approach for sinking the number of radiofrequency chains needed by the complete digital precoding structure while preserving superior performance [8]. However, most known analog precoding techniques presuppose the use of high-resolution PSs, which use a substantial amount of energy and have a high level of system complexity at millimeter-wave frequencies [9]. In mMIMO systems, low-resolution phase shifters

(LRPSs) are preferred to implement analog beamforming. Nonetheless, the utilization of LRPSs creates precise beam steering difficulty, resulting in loss of performance. As a result, one significant research area is the investigation of methods for analog beamforming architectures that might maximize the performance of beamforming precision caused by LRPSs. Many types of research [10]-[14] have demonstrated the benefits of spectrum efficiency by utilizing a subgroup of antennas both on the transmitting side and on the receiving side in recent years. These are the results that encourage us to use a selection of antennas in analog beamforming architecture and to use enhanced diversity of antenna to reduce the loss caused by LRPSs. To get acceptable performance that is comparable to that of the full-digital technique, the above mentioned contemporary hybrid precoder and combiner designs often necessitate the use of high-resolution phase shifters (HR-PSs) to produce the analog beamformers. Implementing HR-PSs at millimeter-wave frequencies, on the other hand, would dramatically increase PC and the computational complexity of the hardware circuits required [15]. It is obvious that using HR-PSs for mMIMO systems is impracticable, therefore, LRPSs will be used to build better analog beamformers. As a result, one significant research area is the investigation of signal processing algorithms for hybrid (analog/digital) systems that might maximize the performance of beamforming caused by LRPSs. To produce a limited-resolution beamformer, first, build an infinite-resolution analog beamformer and then directly quantize with phase into a countable set [16]. However, when the PSs have poor resolution, this method becomes inefficient. The authors studied the hybrid precoder and combiner architecture with LRPSs (with 1-bit and 2-bit) presented a new analog precoder and combiner codebook technique according to the Hadamard transform [17]. However, as the simulation results prove, there is still a substantial variation in performance between the technique of [17] and the optimum solution. The authors proposed to iteratively construct low-resolution hybrid beamforming to enhance spectral efficiency (SE) [18], [19]. However, when 1-bit quantized phase shifters are used, the performance of this technique frequently decreases. The authors showed a hybrid MMSE precoder at the transmitter side and designed an orthogonal matching pursuit (OMP) based method [20]. According to the MMSE criterion, the author explored the precoding architecture for improving the SE of the system. The authors examined the difficulty of designing hybrid beamforming for mMIMO systems with quantized LRPSs and presented an efficient iterative technique that generates low-resolution analog beamforming for each data stream [21], [22]. The digital beamforming was then computed according to the provided effective baseband channel to increase SE even further. The development of low-resolution hybrid beamformers for multiuser mMIMO systems was studied. N. Akbar and Nan Yang developed a generalized welch-bound-equality pilot sequence architecture for multicell multiuser massive MIMO networks [23]. In this paper, we examine the challenge of implementing hybrid beamforming with LRPSs for multicell multiuser massive MIMO systems. When compared to current hybrid beamforming algorithms, simulation results shows that the methodology may offer a performance enhancement with LRPSs methods, and also analyzed power consumption [24] of each component in multicell multiuser massive MIMO systems.

2. MILLIMETER-WAVE CHANNEL MODEL

In this paper, A geometric channel model [25] is used to describe the mmWave propagation channel. The mmWave channel $H_j = \mathbb{C}^{M_t \times M_r}$ matrix for the uplink transmission can be expressed as:

$$H_j = \sqrt{\frac{M_t \times M_r}{M_C \times M_R}} \sum_{j=1}^{M_C} \sum_{l=1}^{M_R} \alpha_{j,l} b_r \left(\phi_{j,l}^r, \theta_{j,l}^r\right) b_t^H \left(\phi_{j,l}^t, \theta_{j,l}^t\right) \tag{1}$$

where $\alpha_{j,l}$ is the gain of the ℓth and jth path, denotes the number of propagation paths, $\left(\phi_{j,l}^r, \theta_{j,l}^r\right)$ and $\left(\phi_{j,l}^t, \theta_{j,l}^t\right)$ are its angles of arrival and departure, respectively. Then, the vectors $b_r \left(\phi_{j,l}^r, \theta_{j,l}^r\right)$ and $b_t \left(\phi_{j,l}^t, \theta_{j,l}^t\right)$ denotes with equally spaced uniform linear array (ULA) the normalized response array vectors at both the transmitter and the receiver, where $\left(\phi_{j,l}^r, \theta_{j,l}^r\right)$ and $\left(\phi_{j,l}^t, \theta_{j,l}^t\right)$ represent AoD/AoD respectively. The array response of the receive antenna array response vector can be written as:

$$b_t \left(\phi_{j,l}^t, \theta_{j,l}^t\right) = \sqrt{M_t^{-1}}[1, e^{j\Theta^t}, ..., e^{j(M_t-1)\Theta^t}]^T \tag{2}$$

the array response vector of the receive antenna array response vector can be written:

$$b_r \left(\phi_{j,l}^r, \theta_{j,l}^r\right) = \sqrt{M_r^{-1}}[1, e^{j\Theta^r}, ..., e^{j(M_r-1)\Theta^r}]^T \tag{3}$$

where $\Theta^t = \frac{2\pi d}{\lambda} sin(\theta^t_{k,l})$, $\Theta^r = \frac{2\pi d}{\lambda} sin(\theta^r_{k,l})$, d is the distance between antenna elements.

3. UPLINK (UL) SYSTEM MODEL AND PROBLEM FORMATION

In this section, we explore a mmWave multicell multiuser mMIMO uplink system, as well as hybrid beamforming architecture with LRPSs for the multicell multiuser system shown in Figure 1. The transmitter uses an analog precoder which is built with M_t LRPSs, signal transmits through M_t transmit antennas. A jth-BS is located in rth cell is integrated with M_r antennas and M_{RF} RF chains and supports K UEs at the same time. Mainly, the quantized phases of LRPSs are controlled by B bits and have a constant modulus $1/\sqrt{M_t}$. The various possible phases of each PS are for rth cell and jth BS:

$$V_{RF,rj}(k) = W_{RF,rj}(k) \triangleq \left\{ \sqrt{M_t^{-1}} e^{\frac{2\pi b}{2^B}} \mid b = 0, 1, 2, ...2^B - 1 \right\} \forall r, j \tag{4}$$

in the hybrid precoding, the transmitted signal of the $r - th$ cell at $j - th$ user can be represented as x_{rj}:

$$x_{rj} = \sum_{j=1}^{J} \sqrt{\rho}_{rj} V_{RF,rj} V_{BB,rj} \upsilon_{rj} \tag{5}$$

where $\upsilon_{rj} = \mathbb{C}^{M_s \times 1}, j = 1, \ldots, J$ is the $j - th$ user's transmit symbol. Within a user stream and between users in a cell, all information symbols are independent $\mathbb{E}\left\{\upsilon_j \times \upsilon_j^H\right\} = I_{M_s}$, and ρ_{rj} are the transmit power of the $j - th$ user's in $r - th$ cell. Consider a narrow-band fading with additive white complex Gaussian noise with variance σ^2.

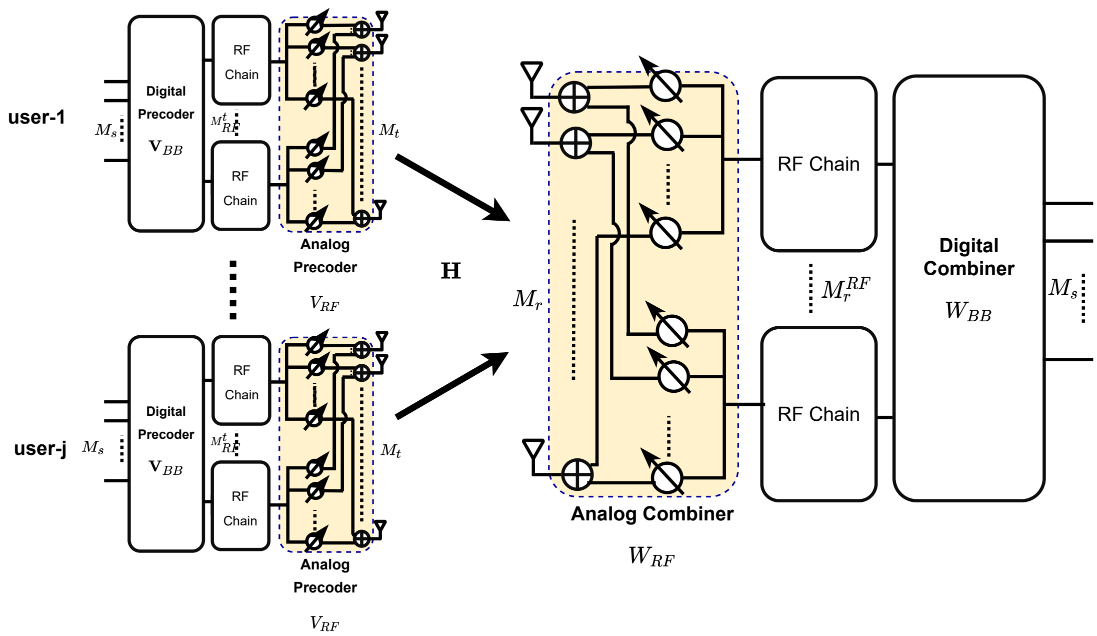

Figure 1. Design of the uplink multiuser massive MIMO transmission

Mathematically, the received signal can be written as:

$$y_{rj} = \sum_{j=1}^{J} \sqrt{\rho}_{rj} H^r_{rj} V_{RF,rj} V_{BB,rj} \upsilon_{rj} + \sum_{l=1}^{L} \sum_{j=1}^{J} \sqrt{\rho}_{lj} H^r_{lj} V_{RF,lj} V_{BB,lj} \upsilon_{rj} + z_r, \forall r, l, j \tag{6}$$

$W_{RF,rj}$ is a $M_{RF} \times M_s$ combination matrix at $j - th$ user in $r - th$ cell. Focusing on a flat-fading wireless channel, then after spatial processing at the receiver side, the signal may be written as:

$$\hat{\upsilon}_{rj} = W_r^H \sqrt{\rho}_{rj} H_{rj}^r V_{RF,rj} V_{BB,rj} \upsilon_{rj} + \sum_{j=1}^{J} W_r^H \sqrt{\rho}_{rj} H_{rj}^r V_{RF,rj} V_{BB,rj} \upsilon_{rj} \tag{7}$$

$$+ \sum_{l=1}^{L} \sum_{j=1}^{J} W_r^H \sqrt{\rho}_{lj} H_{lj}^r V_{RF,lj} V_{BB,lj} \upsilon_{rj} + W_r^H Z_r \tag{8}$$

let $W_r \triangleq W_{RF,rj} W_{BB,rj}$ represent the hybrid combiner corresponding to the $r-th$ cell and the $j-th$ user, $H \in \mathbb{C}^{M_t \times M_r}$is the channel matrix and should be normalized to satisfy $E[\|H_{rj}\|_F^2] = M_r \times M_t$. P is the average received power. The total transmission power meets $E[\upsilon_{RF,rj} \upsilon_{RF,rj}^H] = \frac{1}{M_s} \times I_{M_s}$.

The BS has estimate channel $H_k, \forall k$, for uplink transmission, we use a low-resolution phase shifter to reduce system complexity. Under such constraints, we aim to collaborate design of hybrid precoding and hybrid combined precoding in mmWave multicell MU mMIMO systems. When the Gaussian signal is in mmWave multicell MU massive MIMO, the achievable rate can be expressed as follows:

$$R = \sum_{j=1}^{J} log_2 \mid \tag{9}$$

$$1 + \frac{\mid W_r^H \sqrt{\rho}_{rj} H_{rj}^r V_{RF,rj} V_{BB,rj} \upsilon_{rj} \mid^2}{\mid \sum_{j=1}^{J} W_r^H \sqrt{\rho}_{rj} H_{rj}^r V_{RF,rj} V_{BB,rj} \upsilon_{rj} \mid^2 + \mid \sum_{l=1}^{L} \sum_{j=1}^{J} W_r^H \sqrt{\rho}_{lj} H_{lj}^r V_{RF,lj} V_{BB,lj} \upsilon_{rj} \mid^2 + \mid W_r^H \mid^2 \sigma^2} \mid \tag{10}$$

our objective is to determine the analog precoder that optimizes sum-rate, s.t to phase, and constant modulus of the LRPSs. The selection of antennas and the architecture of analog precoders are intimately connected and must be examined concurrently. To maximize the sum rate of the uplink multiuser system, We intend to collaborate on the design of the analog beamformer used by LRPSs, as well as the digital combiners.

$$\{V_{RF,rj}, W_{RF,rj}\} = arg\ Max(R), \tag{11}$$

$$\text{s.t. } V_{RF,rj}(i), W_{RF,rj}(i), \forall i, j.r$$

4. DESIGNING A LOW-RESOLUTION HYBRID BEAMFORMING

Analog beamforming is used to change the phases of signals with a single data stream to achieve maximum antenna array gain and signal to noise ratio. The analog beamformer uses M_t antennas at the user with an RF chain to transmit a single data stream to BS with M_r antennas.

Step-1: The analog precoder and combiner are intended to improve the related channel gain for the initial user. Find $W_{RF_r1}^*$ and $V_{RF_r1}^*$ for user-1 by (12).

$$\left\{V_{RF,r1}^{opt}, W_{RF,r1}^{opt}\right\} = arg\ Max \mid W_{RF,r1}^H H_1 V_{RF,r1} \mid, \tag{12}$$

$$\text{s.t. } V_{RF,r1}(i) \in \left\{\sqrt{M_r^{-1}} e^{\frac{2\pi b}{2^B}} \mid b = 0, 1, 2, ...2^B - 1\right\} \forall r, i$$

$$W_{RF,r1}(k) \in \left\{\sqrt{M_t^{-1}} e^{\frac{2\pi b}{2^B}} \mid b = 0, 1, 2, ...2^B - 1\right\} \forall r, j$$

Step-2: Aims to improve the effective spectral efficiency by constructing the analog beamformer vector $V_{RF,r1}^*$ and $W_{RF,r1}^*$ the analog combiner. An iterative approach is used to design and the remaining users in r-th cell analog combiner vectors $W_{RF,r1}^*, W_{RF,r2}^* W_{RF,r3}^* .... W_{RF,rj}^*$.

Let ,$\Phi_{r1} = W_{RF,r1}$ we try to obtain the analog beamformer vectors that minimize interference from users and also in between cells whose analog beamformers have already been computed in each iteration.
Step-3: To develop an orthonormal basis $\Phi_{ri} = \Phi_{r1}, \Phi_{r2}...\Phi_{ri}$of the formerly calculated analog combiners, $W^{*}_{RF,ri}, i = 1, ..., j–1$ using the Gram-Schmidt orthogonalization procedure for the j-th user's analog beamformer vectors in r-th cell:

$$\Psi_{r2} = W^{*}_{RF,r2} - \Phi^{H}_{r1} W^{*}_{RF,r2} \Phi_{r1}, for\ i = 2, \tilde{\Phi}_{r2} = \frac{\Psi_{r2}}{\|\Psi_{r2}\|} \tag{13}$$

$$\Psi_{r3} = W^{*}_{RF,r3} - (\Phi^{H}_{r1} W^{*}_{RF,r3} \Phi_{r1} + \Phi^{H}_{r2} W^{*}_{RF,r3} \Phi_{r2}), i = 3, \tilde{\Phi}_{r3} = \frac{\Psi_{r3}}{\|\Psi_{r3}\|} \tag{14}$$

$$\Psi_{ri} = W^{*}_{RF,ri} - \sum_{j=1}^{J} \Phi^{H}_{rj} W^{*}_{RF,ri} \Phi_{rj}, \forall i, j, \qquad \tilde{\Phi}_{r3} = \frac{\Psi_{r3}}{\|\Psi_{r3}\|} \tag{15}$$

removing component along $\Psi_{r1}, \Psi_{r2}, \ldots \Psi_{ri}$.

Step-4: Note that $\Phi_{r1} = W^{*}_{RF,r1}$ and $W^{*}_{RF,r1}$ is the analog combiner vector intended for the initial user. Then, the removing combiner component along $\Psi_{r1}, \Psi_{r2}, \ldots \Psi_{ri}$ from the j-th user's channel to find the adjusted channel $\hat{H}_k$ as:

$$\hat{H}_k = \left(I_{M_r} - \sum_{i=1}^{k-1} \Psi_{ri} \Psi^{H}_{ri} \right) H_k \tag{16}$$

then, in an OMP way, the remainder of the users' channels are updated.
Step-5: After determining all users' analog beamformers, the effective baseband channel for each user may be calculated as follows: Find $W^{*}_{RF_r k}$ and $V^{*}_{RF_r k}$ for user-k, by calculating the below:

$$\left\{ V^{opt}_{RF,rk}, W^{opt}_{RF,rk} \right\} = arg\ Max \mid W^{H}_{RF,rk} H_k V_{RF,rk} \mid, \tag{17}$$

$$\text{s.t. } V_{RF,rk}(i) \in \left\{ \sqrt{M_t^{-1}} e^{\frac{2\pi b}{2^B}} \mid b = 0, 1, 2, ...2^B - 1 \right\} \forall r, i$$

$$W_{RF,rk}(j) \in \left\{ \sqrt{M_t^{-1}} e^{\frac{2\pi b}{2^B}} \mid b = 0, 1, 2, ...2^B - 1 \right\} \forall r, j$$

Step-6: Obtain digital combiners $W_{BB,rk}$, i = 1, . . . , J, Then, for the j-th user, a multi-cell minimum mean squared error (M-MMSE) baseband digital combiner is used to further decrease the interference and j-th user in cell $r$is maximized by the M-MMSE combining vector:

$$W_{BB,rj} = \left(\sum_{l=1}^{L} \hat{H}^{r}_{l} P_l \left(\hat{H}^{r}_{l} \right)^{H} + \sum_{l=1}^{L} \sum_{i=1}^{I} P_{li} C^{r}_{li} + \sigma^2 I_{M_r} \right)^{-1} \hat{H}^{r}_{j} P_r \tag{18}$$

where Correlation matrix $C_{li} = \left\{ \tilde{h}^{r}_{li} \left(\tilde{h}^{r}_{li} \right)^{H} \right\} P_{li}$ implies that j-th user, l-th cell uses the same pilot as user-j in cell r. Table 1 shows the power consumption of individual elements such as LRPSs $(B = 1, 2)$, a switch, each RF chain, and a baseband processor [24].

Table 1. The power consumption of each component

Component	Power consumption (mW)	Reference
Low resolution phase shifter (LRPS)	PRF=8 (B=1)	[24]
Low-resolution phase shifter (LRPS)	PRF=15 (B=2)	[24]
Switch	PSW=4	[24]
RF chain	PRF=290	[24]
Baseband processor	PBB=198	[24]

5. SIMULATION RESULTS

In a multi-cell multiuser uplink transmission system, we proposed the performance analysis of a low-resolution hybrid analog and digital beamformer iterative algorithm. In simulation results, the proposed algorithm concerning spectral efficiency (SE) and bit error rate (BER) were compared to existing Hybrid beamforming methods. The simulation settings are as follows: the transmitter is integrated with $M_t = 64$ antennas, and the BS is integrated with $M_r = 64$ antennas through RF chains $M_{RF} = 4$ and streams M_s respectively, and $M_s = M_{RF} = 4$ and $SNR = -15dB\ to\ 40dB$. We can show that our proposed approach with LRPSs consistently beats existing codebook-based techniques. Furthermore, even with LRPSs, the suggested method may reach comparable performance when (j= 8) compared to the iterative-HB and MMSE-HB approaches. In Figure 2, the proposed low-resolution hybrid beamformer algorithm with j=8 multiuser uplink system bit error rate performance in BPSK transmission is an advantage over existing schemes.

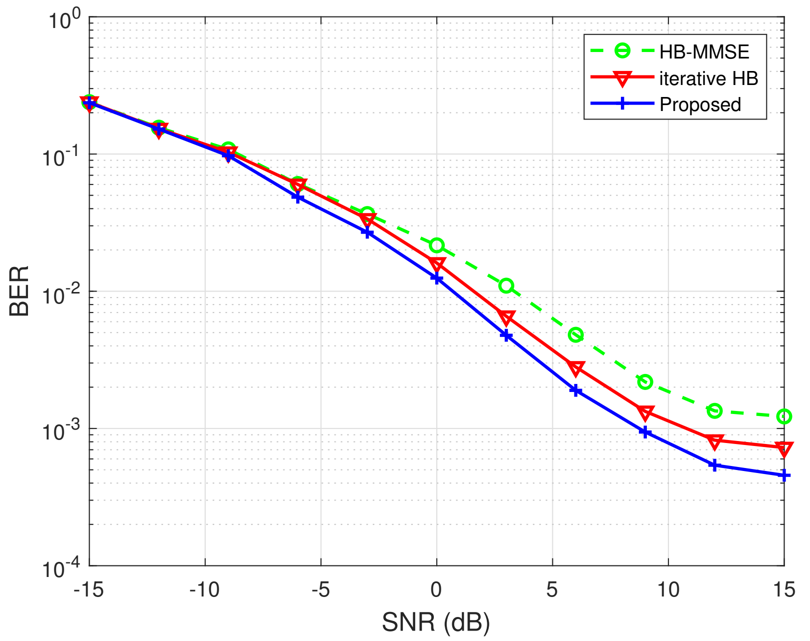

Figure 2. BER versus signal to noise ratio $(M_t = 16; M_r = 64; J = 8)$

Next, the proposed low-resolution hybrid beamformer design technique is then evaluated in a multicell multiuser uplink system. Figure 3 shows the sum rate vs signal to noise ratio for various low-resolution hybrid beamformer designs. In particular, for comparison with MMSE-based hybrid beamforming (MMSE-HB) in [21] and Iterative hybrid beamforming (I-HB) in [20], we include three state-of-the-art multiuser hybrid beamforming methods. The proposed low-resolution hybrid beamformer algorithm was then tested in a multicell multiuser uplink transmission. The sum-rate vs signal to noise ratio for several hybrid beamformer configurations is depicted in Figure 3. We present three cutting-edge multiuser hybrid beamforming methods for comparison with MMSE-HB in [20] and I-HB in [21].

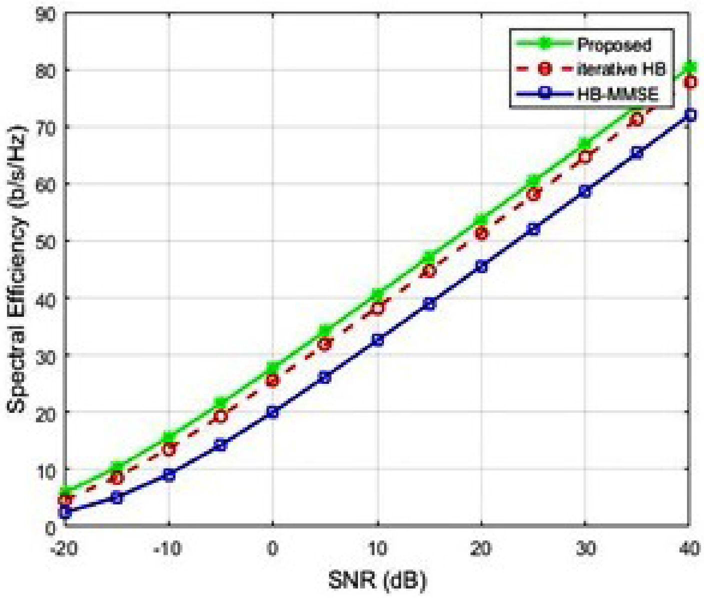

Figure 3. Spectral efficiency of the proposed algorithm compared with existing HBF algorithm when $M_s = 4$ and $M_{RF} = 4$

6. CONCLUSION

In this paper, we presented hybrid beamformer architecture with LR-PSs of the multi-cell MU massive MIMO for uplink transmission. To optimize the sum-rate performance of the investigated system, we presented an iterative hybrid beamformer (HB) design algorithm. The suggested algorithm's spectral efficiency and bit error rate are validated using various simulation conditions. The low-resolution hybrid beamformer architecture for the multi-cell MU massive MIMO for the uplink transmission was also examined.

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