INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

OPEN ACCESS
Received: 14-01-2022
Accepted: 11-04-2022
Published: 06-06-2022

Citation: Abose TA, Olwal TO, Hassen MR (2022) Hybrid Beamforming for Millimeter Wave Massive MIMO under Multicell Multiuser Environment. Indian Journal of Science and Technology 15(20): 1001-1011. https://doi.org/10.17485/IJST/v15i20.114

* **Corresponding author**.

tadenegn@gmail.com

Funding: Article processing charge is deferred partially by Indian Society for Education and Environment

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Hybrid Beamforming for Millimeter Wave Massive MIMO under Multicell Multiuser Environment

Tadele A Abose[1]*, Thomas O Olwal[2], Murad R Hassen[1]

1 Lecturer, School of Electrical and Computer Engineering, Addis Ababa University, Addis Ababa, Ethiopia
2 Professor, Department of Electrical Engineering, Tshwane University of Technology (TUT), Pretoria, South Africa

Abstract

Objectives: Due to the high cost and power consumption of fully digital beamforming, the goal of this research is to thoroughly investigate Kalman-based beamformers in conjunction with existing beamformers for multicell multiuser scenarios. **Methods:** In this research work, Kalman based hybrid beamforming for millimeter wave massive MIMO along with existing linear beamformers has been investigated. Mathematical model for spectral efficiency has been developed for each linear beamformer under multicell multiuser scenario and the performance has been shown using MATLAB software. **Findings:** Simulation results show that all the beamformers perform better for multi-cell systems compared to single cell systems i.e. better spectral efficiency for a given signal to noise ratio has been achieved for multicell system. Simulation results also depict precoders spectral efficiency improved as the number of transmitting antennas increase and the number of users decrease for multicell multiuser scenario. **Novelty:** Expanding the kalman based beamformer that contains digital combiner for multicell multiuser scenario is the novelty of this research.

Keywords: Hybrid Beamforming; Massive MIMO; Millimeter Wave; Multicell; Multiuser

1 Introduction

5G is being used all around the world due to its fast data throughput, low latency, low jitter, and great mobility. Various enabling technologies, including as massive MIMO and millimeter wave, are being used to meet the 5G needs. Massive Multiple-Input Multiple-Output (MIMO) is one of the most important technologies for 5G and beyond wireless communication networks since it has the potential to offer very high improvements in Spectral Efficiency (SE) and Energy Efficiency (EE)[1,2]. Millimeter wave, another enabling technology, is likely to play a significant part in the 5G ecosystem due to its large channel spacing, which allows for better throughput and acceptable coverage. Beamforming is being used in conjunction with those major enabling technologies to increase the received signal to noise ratio. Fully digital beamforming architecture which requires separate Radio Frequency (RF) chain for each antenna at both transmitter and receiver is challenging to apply since it increases the cost and power consumption associated with dedicated RF chain [3]. Hence, to alleviate aforementioned challenge, hybrid beamforming is being utilized intensively for 5G communication [4]. As far as hybrid beamforming is concerned, there are two important components: precoders and combiners. Hybrid beamforming has been introduced in massive MIMO to provide reasonable performance with optimum cost by dividing signal processing into two domains: analog and digital domains within precoder and combiners. Various works have been done on performance of precoder/combiners in millimeter wave massive MIMO. For example, the authors in [1] have considered Kalman based beamforming approach to provide better spectral efficiency with affordable complexity but, digital combiner and multicell environment were not considered in their work. The authors in [4] considered the extended simultaneous orthogonal matching pursuit (ESOMP) algorithm to improve spectral efficiency when compared to existing algorithms but did not consider Kalman based algorithm for performance comparison since Kalman based beamformers provide better spectral efficiency with affordable complexity. Hence, including Kalman based beamformer in their performance comparison will make their work more compact. The authors in [5] proposed hybrid precoding by decomposing the maximum achievable rate optimization problem in to series of sub rate optimization problems so as to maximize overall beamforming gain but did not consider Kalman based algorithm which provides better spectral efficiency with affordable complexity. The authors in [6,7] considered multiuser performance analysis but did not consider multicell environment as we do in this research. The authors in [8] considered hybrid precoding for non-orthogonal multiple access transmission scheme and achieved better spectral efficiency compared to state of art algorithms but did not consider Kalman algorithm for performance comparison. The authors in [9] considered multicell multiuser environment and analyzed energy efficiency of hybrid precoding but did not consider Kalman based algorithm for performance comparison as we do in this research. The authors in [10,11] considered multicell millimeter wave systems using phase shifter based analog beamforming and regularized zero forcing digital beamforming for performance analysis but did not consider Kalman based beamforming as we do in this research. In [12], the authors suggested unique signal processing method that combines precoding and equalization to improve spectrum efficiency under multiuser environment but did not consider multicell environment. The authors of [13] considered at multi-user signal transmission using zero-forcing (ZF) beamforming and user grouping to exploit transmission performance loss, however they didn't take into account the multicell environment. The authors of [2] presented a novel unequal sub-connected architecture for hybrid combining at the receiver of a massive MIMO system in order to improve the overall achievable rate and reduce computational complexity, however they did not take into account the multicell environment. In [14], the authors examined impairment and incorporated a kalman based beamformer for a single cell multiuser scenario, however they did not address multicell environment for kalman based beamformer performance study.

As mentioned above, on single cell single user/multiuser environments, several research works on hybrid precoders/combiners have been done [1,5–8]. Some works have also been done on multicell multiuser scenario [9–12]. However, hybrid beamforming that contains digital combiners along with analog combiners under multi cell multi user environment has now not been adequately investigated. After reviewing different literatures, this research work intends to investigate the performance of Kalman based beamformer that includes digital combiner along with existing analog combiner for multicell multiuser environment and compare its performance with single cell scenario. Besides, the work compares kalman based beamformers with other linear beamformers including hybrid minimum mean square error, fully digital mean square error, and zero forcing beamformers. To the best of our knowledge kalman based hybrid beamformer that incorporates digital combiner for multicell multiuser environment has not been done yet.

Table 1. Related works summary table on hybrid beamforming schemes

References	Approach	Gaps
[1]	A Kalman-based beamforming technique has been considered.	Did not consider digital combiner and multicell environment.
[4]	The extended simultaneous orthogonal matching pursuit (ESOMP) algorithm was considered.	For performance comparison, they didn't use a Kalman-based approach even though Kalman-based beamformers offer reasonable spectral efficiency at a lower cost of complexity.
[5]	To increase total beamforming gain, proposed hybrid precoding by dividing the highest feasible rate optimization problem into a series of sub rate optimization problems.	For performance comparison, a Kalman-based approach was not considered.
[6,7]	Multiuser performance analysis was taken into consideration.	Did not take into account the multicell, multiuser situation as we do in our research.
[8]	In comparison to state-of-the-art methods, hybrid precoding was considered for non-orthogonal multiple access transmission schemes and resulted in higher spectral efficiency.	For performance comparison, the Kalman precoding was not used.

Continued on next page

Table 1 continued

[9]	The energy efficiency of hybrid precoding was examined in a multicell multiuser scenario.	For performance comparison, a Kalman-based approach was not considered.
[10,11]	For performance analysis, they looked at multicell millimeter wave systems that used phase shifter-based analog beamforming and regularized zero forcing digital beamforming.	As we do in this research, Kalman-based beamforming was not considered.

The rest of the paper is organized as follows. Section-2 presents precoding schemes, Section-3 presents proposed method. Section- 4 presents the results and discussion, and section- 5 concludes the paper.

2 Precoding schemes

In this section, precoding schemes: Zero Forcing (ZF) hybrid precoder, Minimum Mean Square Error (MMSE) fully digital precoder, kalman based hybrid precoder, and hybrid MMSE precoder have been described and used for performance comparison later in the simulation part.

2.1 Zero-Forcing precoding

Multiple antenna transmitters can be used in this approach to eliminate multiuser interference in a millimeter wave massive MIMO scenario. High noise reduction can be achieved since it nulls interference from the layer of other symbols. Authors in[15,16] demonstrated how to compute the precoder's closed form: $F_{BBZF} = H^H (HH^H)^{-1}$

2.2 Minimum Mean Square Error (MMSE precoding

The MMSE scheme is used to minimize error between Base Station (BS) transmitted symbols and user terminal received signals. This technique provides the best out of the Maximum Ratio Combining (MRT) and Zero Forcing (ZF) hence reasonable performance having moderate interference and noise can be achieved[11],[17].

2.3 Hybrid Kalman Based precoder

In this precoder, Base Station (BS) sends a message signal s, after which the mobile station (MS) estimated signal is $s_e = [s_{e1}, ..., s_{eA}]^T$ with the training vector s(n) at the iteration, n. The mean squared error of the training vector between the transmitted signal, s and estimated signal, s_e, $E||s - se||^2$ is minimized by kalman filter algorithm[1].

$$\begin{aligned} &\min\ \text{imize}\ \mathrm{E}\left\{\|s - se\|^2\right\} \\ &F_{RF}, F_{BB} \\ &\text{subject to}\ \|F_{RF}F_{BB}\|_F^2 = N_s \end{aligned} \tag{1}$$

By considering $s_e = [s_{e1}, ..., s_{eA}]^T$ at the MS the vector observed at the n iteration can be expressed: as $s_{eA}(n) = (w_a^H H_a F_{RF} F_{BB})\, s(n) + n_a(n)$ then the minimization problem can be written as:

$$\begin{aligned} &\min\ \text{imize}\ \mathrm{E}\,\|I - H_e F_{BB}(n/n-1)\|_F^2 \\ &F_{RF}, F_{BB} \\ &\text{subject to}\ \|F_{RF}F_{BB}\|^2 = N_s \end{aligned} \tag{2}$$

where He is the effective channel.

The Kalman filter state expression by considering FBB can be written as:

$$F_{BB}(n/n) = F_{BB}(n/n-1)\| + K(n)E\{\text{diag}[e(n)] \tag{3}$$

where the e(n) is nth Kalman iteration error, K(n) represents the gains of Kalman filter and E{diag[e(n)]} is the error s(n)−se(n). Then the expanded equations can be written as:

$$F_{BB}(n/n) = F_{BB}(n/n-1) + K(n)\frac{I - H_e F_{BB}(n/n-1)}{\|I - H_e F_{BB}(n/n-1)\|_F^2} \tag{4a}$$

$$K(n) = R(n/n-1)H_e^H\left[H_eR(n/n-1)H_e^H + Q_n\right]^{-1} \tag{4b}$$

$$R(n/n) = [I - K(n)H_e]R(n/n-1) \tag{4c}$$

where Qn is noise n(n) covariance matrix which can be written as: $Q_n = \left(\frac{1}{SNR}\right) * I$

In this section, precoding schemes that exist in the literature have been discussed. We found that, precoding schemes can achieve Spectral Efficiency of Massive MIMO but with the complexity higher than kalman based precoding. We hence, proposed kalman based precoding under multicell multiuser environment which achieves spectral efficiency with affordable complexity. In the next section, we developed a system model in order to formulate the problem, defines the solution criteria and apply deep insights towards the solution.

3 Proposed method

In this section, mathematical model for kalman based beamformer that incorporates the digital combiner, hybrid zero forcing, hybrid minimum mean square error, and fully digital mean square error under multicell multiuser scenario has been developed.

3.1 System model

Symbols: F_{RF}, F_{BB}, W_{RF} and W_{BB} denotes analog precoder, digital precoder, analog combiner, and digital combiner respectively. $[.]^H$, $[.]^T$, $[.]^{-1}$ denotes Hermitian, transpose, and inverse of matrix respectively. E [.] represents expectation operator, $||.||_F$ denotes frobenius norm. N_s, N_T, N_R and N_{RF} denotes number of data streams, number of transmitting antennas, number of receiving antennas, and the number of radio frequency chains respectively. H represents channel matrix.

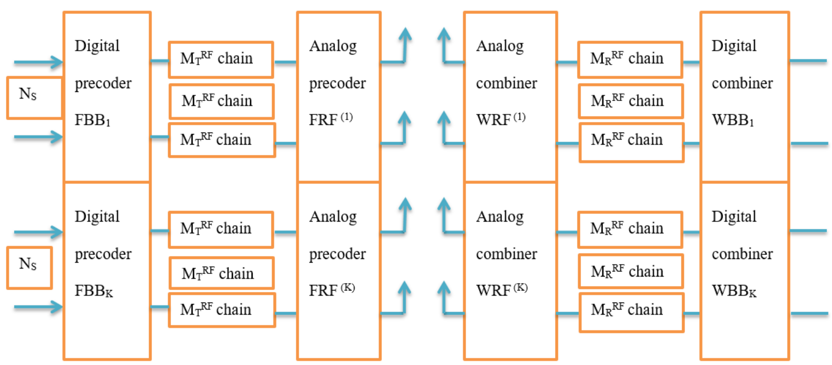

Fig 1. Millimeter wave multicell multiuser hybrid system

From the Figure 1, it can be seen that the hybrid beamformer contains: analog precoder, analog combiner, digital precoder, digital combiner, analog to digital converter, digital to analog convertor and arrays of antennas. From the Figure 1, NS denotes the number of data streams per user in each cell, K is the number of users in each cell, N_T^{RF} represents the total number of RF chains at each TP, M_T^{RF} is the number of RF chains connected to the baseband precoder for one user, and N_T denotes the number of TP antenna elements in each cell.

The estimated signal at the receiver once combining vectors WRF for all MSs and analog precoder $FRF_{k,\,l}$at the BS are determined can be:

$$S_m = (W_{RF}W_{BB})H_mF_{RF}F_{BB}S_m + nW_{RF}W_{BB} \tag{5}$$

For transmission point (TP) 'i' and user 'k' in cell 'l' the terms can be noted as follow:

$N_T \times N_T^{RF} = F_{RFk,l}$ denotes RF precoding matrix, $M_T^{RF} \times N_S = F_{BBk,l}$denotes baseband precoding matrix, $N_T^{RF} \times N_S = F_{BBk,l}$ denotes base band combining matrix, $N_R \times N_R^{RF} = W_{RFk,l}$denotes RF combining matrix, $N_R \times N_T = H_{i,k,l}$ denotes Downlink channel. N_T^{RF} Total number of RF chains at each TP, M_T^{RF} the number of RF chain connected to baseband precoder for one user, $N_R$number of antennas with N_R^{RF} chains, N_R^{RF} number of RF chain at each user, N_T denotes the numbers of TP antenna elements, N_{S-} numbers of data stream per user. The total interference on the signal for user 'K' in the cell 'L' can be:

$$I_{K,L} = \sum_{(m,i)\neq k,l} W_{BBK,L}^H W_{RFk,l}^H H_{k,l,i} F_{RFk,i} S_{k,i} \tag{6}$$

Having (6) received signal by user 'K' in the cell 'L' can be expressed as:

$$\bar{S}_{k,l} = W_{BBk,l}^H W_{RFk,l}^H H_{k,l,l} F_{RFk,l} F_{BBk,l} S_{k,l} + I_{k,l} + W_{BBk,l}^H W_{RFk,l}^H n_{k,l} \tag{7}$$

By substituting (6) into (7)

$$S_{k,l} = W_{BBk,l}^H W_{RFk,l}^H H_{k,l,i} F_{RFk,l} F_{BBk,l} S_{k,l} + \sum_{(m,i)\neq k,l} W_{BBK,L}^H W_{RFk,l}^H H_{k,l,l} F_{RFk,i} S_{k,i} + W_{BBk,l}^H W_{RFk,l}^H n_{k,l} \tag{8}$$

The symbol based filter algorithm that minimizes the sum MSE for multi-cell multi-user scenario can be:

$MSE_{k,l} E_{k,l}\left\{\left\|S_{k,l} - \bar{S}_{k,l}\right\|^2\right\}$ as squared difference between estimated signal at the transmitter and receiver.

Error e (n) at the nth Kalman iteration is for multi-cell multi-user scenario can be formulated as:

$$e(n) = \frac{s(n)_{k,l} - \bar{s}(n)_{k,l}}{\left\|s(n)_{k,l} - \bar{s}(n)_{k,l}\right\|_F^2} \tag{9}$$

Having the baseband combining matrix $\mathrm{W}_{BB,}$ Kalman hybrid multi-cell multi-user state equation becomes:

$$W_{BBk,l}(n/n) = W_{BBk,l}(n/n-1)k(n)_{k,l} E_{k,l}\{\operatorname{diag}[e(n)]\} \tag{10}$$

The diagonal matrix error representation of multi-cell multi-user can be expressed as:

$$E_{k,l}\left\{\operatorname{diag}\left[e(n)_{k,l}\right]\right\} = \frac{I - H_{e,k,l} W_{BBk,l}(n/n-1)}{\left\|I - H_{e,k,l} W_{BB}(n/n-1)\right\|_F^2} \tag{11}$$

By substituting (11) in to (10):

$$W_{BBk,l}(n/n) = W_{BBk,l}(n/n-1)K(n)k,l\frac{I - H_{e,k,l} W_{BBk,l}(n/n-1)}{\left\|I - H_{e,k,l} W_{BBk,l}(n/n-1)\right\|_F^2} \tag{12}$$

Formulization of hybrid millimeter wave combining matrix through the Kalman hybrid multi cell-based approach that minimize error e(n) can be:

$$minimize\mathrm{E}\left\{\left\|S_{k,l} - W_{BBk,l}^H W_{RFkl}^H \bar{S}_{k,l}\right\|^2\right\} subjectto\mathrm{W}_{RFk,l} \in \mathrm{W}_{RFk,l} and\ \mathrm{W}_{BBk,l} \tag{13}$$

Taking the assumption WRF then (13) can be written as:

$$minimize\mathrm{E}\left\{\left\|S_{k,l} - W_{RFk,l}^H W_{BBk,l}^H \bar{S}_{k,l}\right\|^2\right\} subjectto\mathrm{W}_{BBk,l} \tag{14}$$

With the given error calculation (9) the minimization problem can be expressed as:

$$\begin{aligned}&\left\|S_{k,l} - H_{e,k,l} W_{BBk,l}(n/n-1)\right\|_F^2\\ &W_{RFk,l}, W_{BBk,l}\\ &\text{subject to } W_{RFk,l,} \in W_{RFk,l}\end{aligned} \tag{15}$$

The spectral efficiency of Kalman hybrid precoding under multi cell multi user scenario can be:

$$SE_{K,L} = \log_2\left(\frac{\left[1 + \frac{P_{k,l}}{M_{k,l}} W_{BBk,l} W_{RFk,l} H_{mk,l} F_{RFkll} F_{BBk,l}\right]^2}{\frac{P_{k,l}}{M_{k,l}} \sum_{(m,i)\neq k,l} W_{BBk,l} W_{RFk,l} H_{mk,l} F_{RFk,l} F_{BBk,l} + \sigma^2 + \sum_{(i,l)\neq k,l}^{L} \beta_{k,l}}\right) \tag{16}$$

The value $\sum_{(i,l)\neq k,l}^{L}\beta_{k,l}$ has been added on the spectral efficiency to show the decrement of spectral efficiency by $\sum_{(i,l)\neq k,l}^{L}\beta_{k,l}$ due to inter cell interference.

The channel matrix for linear precoders under multi-cell multi-user scenario can be:

$$H_{k,l,i} = \left(\sqrt{\frac{N_{BSk,l}N_{MSk,l}}{L_{k,l,i}}}\right)\sum_{l=1}^{lk} a_{k,l}L_{a,k,l}M_{sk,l}\left(\theta_{k,l},L_{k,l}\right)^{H}B_{sk,l} \tag{17}$$

The signal to noise ratio of MMSE precoding under multi cell multi user can be expressed as:

$$\mathrm{SINR}^{MMSE} = \frac{N_T p_{m,l}\left(K_{k,l}+S_{k,l}\right)^2\beta_{i,k,l}}{N_T S_{k,l}^2\left(K_{k,l}+1\right)\psi_{k,l}+p_{k,l}\left(K_{k,l}+S_{k,l}\right)\left(K_{k,l}+1\right)\beta_{k,l}v_{k,l}+p_{k,l}g_{k,l}\left(K_{k,l}+1\right)\beta_{k,l}S_{k,l}} \tag{18}$$

The spectral efficiency of MMSE precoding can then be SE=$log_2(1+SINR)$

The spectral efficiency of fully digital MSE precoding under multicell multiuser scenario can be:

$$SE_{MSEk,l}^{FD} = \sum_{n=1}^{k}\log_2\left(I_{NSk,l}+\frac{p}{K_{NS}}R'W_{BBk,l}^{H}H'F_{BBk,l}F_{BBk,l}^{H}H^{H}W_{BBk,l}\right) \tag{19}$$

The signal to noise ratio of zero forcing precoding under multi cell multi user scenario can be expressed as:

$$\mathrm{SINR}_{k,l}^{\nexists f,dl} = \frac{(M-K)pdl\bar{r}_{l,k}\eta_{k,l}}{1+pdl\in\left(\beta_{l,k}^{l}-r_{k,l}^{l}\right)\left(\sum_{k=1}^{k}\eta_{k,l}\right)+pdl\sum_{l}\beta_{k,l}^{k}-\left(\sum_{k=1}^{k}\eta_{k,l}\right)+(M-K)\Big)pdl} \tag{20}$$

The spectral efficiency of Zero Forcing precoding can then be SE=$log_2(1+SINR)$, where, the estimated signal at the receiver end is $y_{k,l}$

$$y_{k,l} = \sqrt{p_{dl}}\sum_{LEPL}g_{l,k}AlD\eta lv_{ql}-\sqrt{p_{dl}}\sum_{l\in px}\bar{g}_{l,k}\sqrt{x}+\sqrt{pdxg_{l,k}^{lT}}x_k+w_{l,k} \tag{21}$$

where ρ_{dl} is vector of power control coefficients, and A_l is precoding matrix

In this section we have developed mathematical formulations for precoding schemes including kalman based, fully digital MSE, hybrid MMSE and zero forcing under multicell multiuser environment. In the next section, we have presented simulation results for performance comparison.

4 Results and Discussion

The entire performance of beamforming for massive MIMO networks at millimeter wave frequency is evaluated and examined in this section using MATLAB simulation results. A hybrid beamforming for massive MIMO at mm Wave frequency with a Base station (BS) implemented with 16 × 16 Uniform phased array (UPA) and associated with 4 mobile stations (MSs) is considered, each mobile station is implemented with 4 × 4 Uniform phased array (UPA). Angle of departure (AoDs) and angle of arrival (AoAs) are uniformly distributed over $[-\pi/2, \pi/2]$. The azimuth AoAs/AoDs are expected to be uniformly distributed in $[0, 2\pi]$, the elevation AoAs/AoDs are uniformly distributed in $[-\pi/2, \pi/2]$, and perfect channel knowledge is considered for performance analysis. The simulation parameters are mentioned in the form of table in Table 2.

Table 2. Simulation parameters

Parameters	Value
Elevation AoA/AoD	$[-\pi/2, \pi/2]$
Azimuth AoA/AoD	$[0, 2\pi]$
Number of transmitting antennas	128, 64, 256, 512
Number of users	4, 8
SNR	[-10, 20]

The multicell multiuser based kalman beamformer algorithm for performance evaluation is shown in algorithm 1.

Algorithm 1: Multicell multiuser based Kalman beamforming algorithm

1. Input: $\mathcal{F}$ is BS RF codebook , $\mathcal{W}$ is MS RF codebook
2. Output: $F_{BB\,k,l}$, $F_{RFk,l}$, $W_{BB\,k,l}$, $W_{RF\,k,l}$ $\forall_l = 1,\ldots k$ & $\forall_l = 1,\ldots k$
3. Step1: Analog design for each user k in cell L single user $F_{RF\,k,l}$ and $W_{RF\,k,l}$ $\forall_l, \forall_k$
4. BS and MS_k selects $v_k g_k \forall_k$ so that
5. $g_k, v_k \underset{\forall g_m \in \mathcal{W}, \forall v_m \epsilon \mathcal{F}}{\operatorname{argmax}} ||g_k^H H_k v_k||$
6. BS sets $F_{RFk,l}$= [v_1………. V_k] and MS_k sets $W_{RF\,k,l} = g_k \forall_k$
7. Step2: Digital design: multi-cell multi-user precoding and combining
8. MS_K channel $h_{k,l,i}^H = W_{RFk,l} W_{BBk,l} H_{k,l,i} F_{RFk,l}$ and quantizes H_k using codebook $\mathcal{H} \forall_k$
9. MS_K_k calculates $\hbar_{k,l,i} \forall_k$ where $\hbar_k = \underset{h_m \epsilon \mathcal{H}}{\operatorname{argmax}} \left|\left|h_{k,l,i}^H h_{k,l,i}\right|\right|$
10. BS sets $H_D H_{ek,l} = [\hbar_1 l, i \ldots \ldots \hbar_{k,l,i}]^2$
11. MS_K_k receives $H_D = h_{k,l,i}^H$
12. At MS for $n \leq N$ do:
13. $e_{k,l}(n) = \frac{I - \mathcal{H}_D F_{BBk,l}(n|n-1)}{||I - \mathcal{H}_D F_{BBk,l}(n|n-1)||_F^2}$
14. $\boldsymbol{F}_{BBk,l}\,(n|n) = F_{BB}(n|n-1) + k(n\,) \in (n)$
15. $e_{k,l}(n) = \frac{I - \mathcal{H}_D W_{BBk,l}(n|n-1)}{||I - \mathcal{H}_D W_{BBk,l}(n|n-1)||_F^2}$
16. $\boldsymbol{W}_{BBk,l}\,(n|n) = W_{BB}(n|n-1) + k(n\,) \in (n)$
17. $k(n) = R(n|n-1) H_D^H\, [H_D R(n|n-1) H_D^H + Q_n]^{-1}$
18. $R(n|n) = [I - k(n) H_D] R(n|n-1)$
19. End
20. Normalize $F_{BBk,l} = \sqrt[2]{P_{k,l}} \frac{F_{BBk,l}}{\|F_{RFk,l} F_{BBk,l}\|_F}$ and $W_{BBk,l} = \sqrt[2]{\bar{P}_{k,l}} \frac{W_{BBk,l}}{\|W_{RFk,l} W_{BBk,l}\|_F}$
21. Return $W_{BBk,l}$, $F_{BBk,l}$

Three important points can be raised from computed results. I) SE of all beamformers improved by increasing transmitting antennas under multicell multiuser scenario as can be seen in Figure 2 and Figure 3II) SE of all beamformers under multicell multiuser scenario decrease by increasing the number of users as can be seen in figure4, and figure5. III) SE of beamformers under multicell multiuser scenario is better than that of single cell multiuser scenario. The simulation results show that kalman based beamformer with digital combiner under multicell multiuser scenario gives better performance as compared to Minimum Mean Square Error (MMSE) beamformer and Zero forcing beamformers with affordable complexity and better performance than Zero Forcing (ZF) beamformer as the number of base station antennas increases. In Figure 3 Kalman based hybrid precoder/combiner with 64 base station antennas performance is very close to fully digital MSE precoder and better than zero forcing hybrid precoding and combining and MMSE hybrid beamformers. The results depicts that the spectral efficiency of fully digital MSE, kalman, hybrid MMSE, and zero forcing at SNR of 20 dB can be 9.8 bps/Hz, 9.7 bps/Hz, 8 bps/Hz, and 5.1 bps/Hz respectively.

In Figure 2 kalman based hybrid precoder/combiner under multicell multiuser scenario with 128 base station antennas performance is better than MMSE hybrid precoder and combiner and zero forcing hybrid precoding and combining and close to MSE fully digital precoding. The results depicts that the spectral efficiency of fully digital MSE, kalman, hybrid MMSE, and zero forcing at SNR of 20 dB can be 11.5 bps/Hz, 10 bps/Hz, 9.5 bps/Hz, and 7.2 bps/Hz respectively.

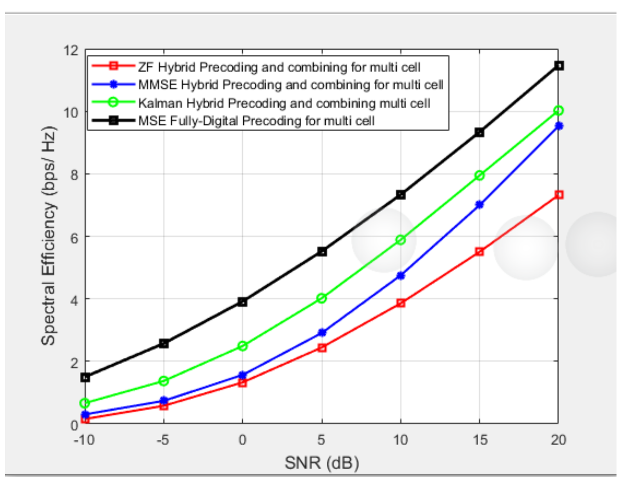

Fig 2. Spectral efficiency vs SNR curve for multicell basedbeamforming schemes (Nt = 128)

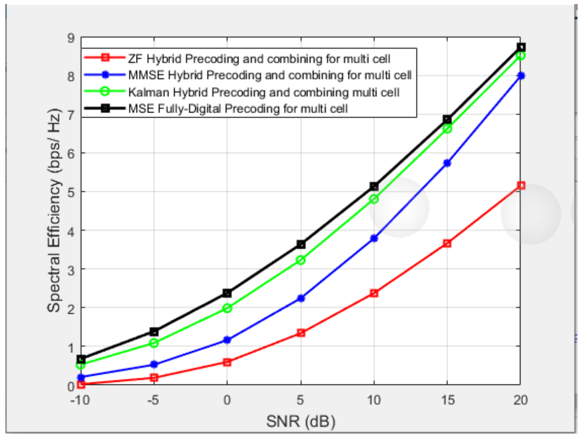

Fig 3. Spectral efficiency vs SNR curve for multicell based beamforming schemes (Nt = 64)

The simulation results in Figure 4 and Figure 5 depict performance of all beamformers decreases as the number of user's increases under multicell multi user scenario. It is obvious that when the number of users increase, the interference also increases. Which in turn results in decrement of spectral efficiency. In Figure 4 kalman based hybrid precoder/combiner with 4 user's performance is very close to MSE fully digital precoder and better than zero forcing hybrid precoding and combining and MMSE hybrid beamformers. The results depicts that the spectral efficiency of fully digital MSE, kalman, hybrid MMSE, and zero forcing at SNR of 20 dB can be 8.8 bps/Hz, 8.7 bps/Hz, 8 bps/Hz, and 5.1 bps/Hz respectively. In Figure 5 kalman based hybrid precoder/combiner with 8 user's performance shows the significant reduction as compared to MSE fully digital precoder and better than zero forcing hybrid precoding and combining and MMSE hybrid beamformers. The results depicts that the spectral efficiency of fully digital MSE, kalman, hybrid MMSE, and zero forcing at SNR of 20 dB can be 7 bps/Hz, 6.5 bps/Hz, 4.9 bps/Hz, and 3.3 bps/Hz respectively.

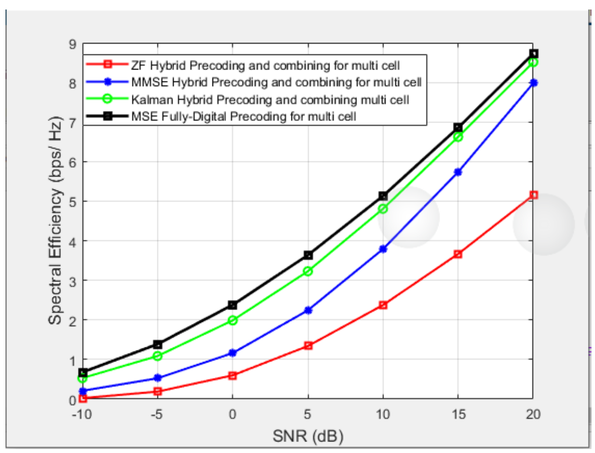

Fig 4. Spectral efficiencyvs SNR curve for multicell based beamforming schemes (Users =4)

The beamformers with multi cell systems exhibit better spectral efficiency as compared to beamformers with single cell systems by considering transmission points (TPs) antennas varying from 64 (8X8) to 128(16X8) for single cell and from 256 (16X16) to 512 (16X32) for multicell. Figure 6 and Figure 7 show the performance improvement of multicell systems as compared to single cell systems.

The beamformers with multi cell systems exhibit better spectral efficiency as compared to beamformers with single cell systems even the number of users increases. Figure 8 and Figure 9 show the performance improvement of multicell systems as compared to single cell systems for four (4) users in each cell for both single-cell and multi-cell and eight (8) users in each cell respectively. In this case, thirty-two (32) users for multi cell we mean eight (8) users in each of the four (4) cells.

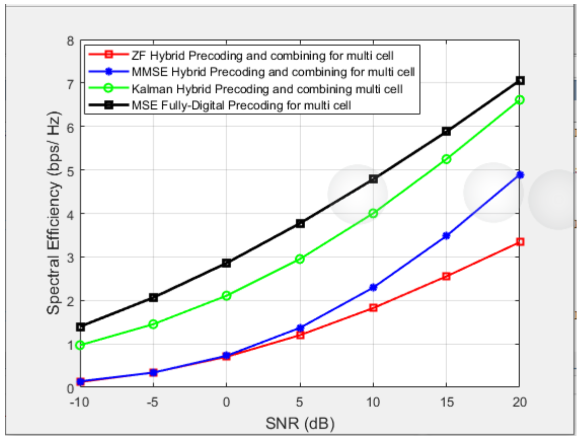

Fig 5. Spectral efficiency vs SNR curve for multicell based beamforming schemes (Users =8)

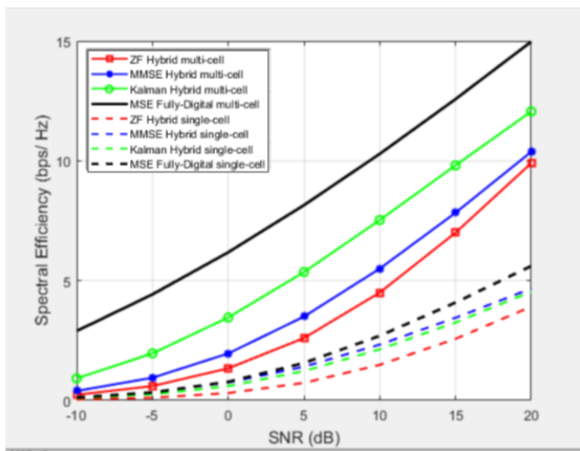

Fig 6. Spectral efficiency vs SNR curve for multicell based beamforming schemes (withtransmission points (TPs) antennas of 64 (8X8) for single cell and 256 (16X16) for multicell)

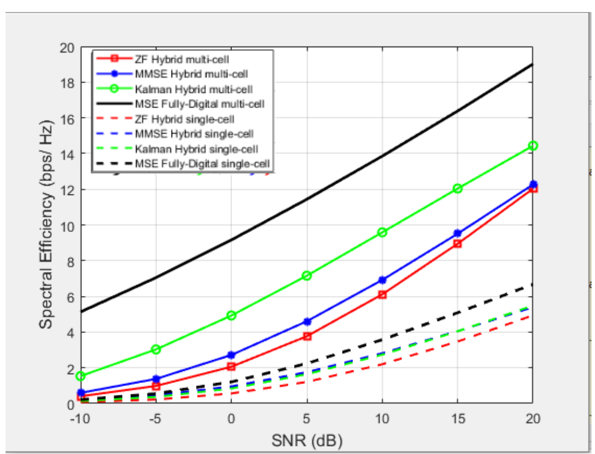

Fig 7. Spectral efficiency vs SNR curve for multicell based beamforming schemes (withtransmission points (TPs) antennas of 128(16X8) for single cell and 512 (16X32) for multicell)

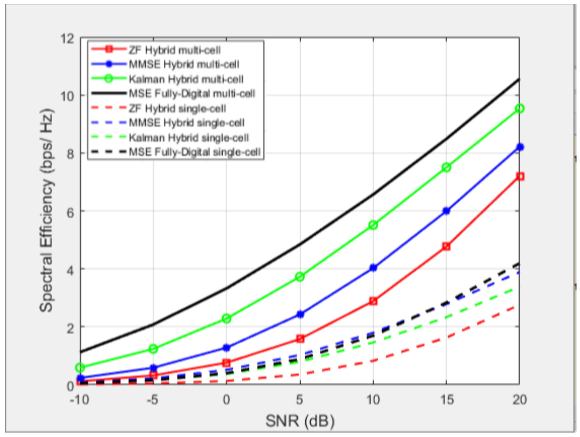

Fig 8. Spectral efficiency vs SNR comparison of single and multicell based beamforming schemes (Users = 8)

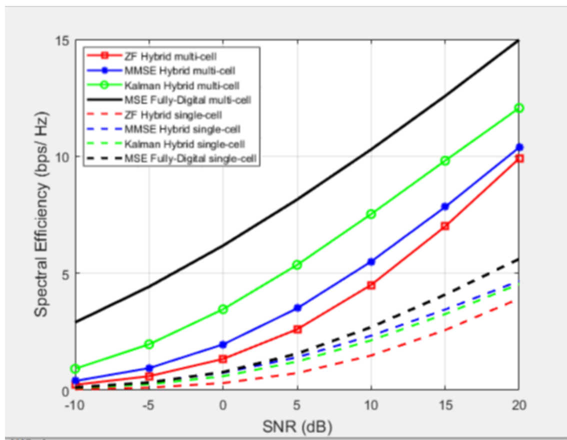

Fig 9. Spectral efficiency vs SNR comparison of single and multicell based beamforming schemes (Users =4)

5 Conclusion

This research considered hybrid beamforming for multicell multiuser environment. It extended single cell multiuser scenario for Kalman based beamformer to multicell multiuser scenario in which intercell and intracell interferences are counted. In addition, extended work performance has been compared with other linear beamformers including zero forcing, hybrid minimum mean square error and fully digital mean square error beamformers. The simulation results show that SE of all beamformers improved by increasing transmitting antennas and decrease by increasing the number of users under multicell multiuser scenario. The spectral efficiency of Kalman based beamformer, hybrid minimum mean square error beamformer, fully digital beamformer, and zero forcing beamformer at signal to noise ratio of 20 dB for multicell containing 512 transmitting antennas is around 14.1 bps/Hz, 12.1 bps/Hz, 18.8bps/Hz, 12 bps/Hz respectively while the spectral efficiency of aforementioned beamformers for multicell containing 256 transmitting antennas is around 12 bps/Hz, 10.2 bps/Hz, 15 bps/Hz , and 10 bps/Hz respectively for the same signal to noise ratio. Similarly, the spectral efficiency of Kalman based beamformer, hybrid minimum mean square error beamformer, fully digital beamformer, and zero forcing beamformer at signal to noise ratio of 20 dB for multicell containing 4 users is around 12 bps/Hz, 10.2 bps/Hz, 15 bps/Hz, 10 bps/Hz respectively while the spectral efficiency of aforementioned beamformers for multicell containing 8 users is around 9.8 bps/Hz, 8.1 bps/Hz, 10.3 bps/Hz, and 7 bps/Hz respectively for the same signal to noise ratio. Simulation result also shows SE of beamformers under multicell multiuser scenario is better than that of single cell multiuser scenario.

References

1) Vizziello A, Savazzi P, Chowdhury KR. A Kalman Based Hybrid Precoding for Multi-User Millimeter Wave MIMO Systems. *IEEE Access*. 2018;6:55712–55722. Available from: https://dx.doi.org/10.1109/access.2018.2872738.
2) Nguyen NT, Lee K. Unequally Sub-Connected Architecture for Hybrid Beamforming in Massive MIMO Systems. *IEEE Transactions on Wireless Communications*. 2020;19(2):1127–1140. Available from: https://dx.doi.org/10.1109/twc.2019.2951174.
3) Yang B, Yu Z, Lan J, Zhang R, Zhou J, Hong W. Digital Beamforming-Based Massive MIMO Transceiver for 5G Millimeter-Wave Communications. *IEEE Transactions on Microwave Theory and Techniques*. 2018;66(7):3403–3418. Available from: https://dx.doi.org/10.1109/tmtt.2018.2829702.
4) Nalband AH, Sarvagya M, Ahmed MR. Optimization of Precoder and Combiner in mm Wave Hybrid Beamforming Systems for Multi-user Downlink Scenario. *Journal of Applied Science and Engineering*;2021(2):257–265. Available from: http://dx.doi.org/10.6180/jase.202204_25(2).0002.
5) Du J, Wang Z, Zhang Y, Guan Y, Jin L. Multi-user hybrid precoding for mmWave massive MIMO systems with sub-connected structure. *EURASIP Journal on Wireless Communications and Networking*. 2021;2021(1):1–21. Available from: https://dx.doi.org/10.1186/s13638-021-02031-0.
6) Haqiqatnejad A, Kayhan F, Ottersten B. Robust SINR-Constrained Symbol-Level Multiuser Precoding With Imperfect Channel Knowledge. *IEEE Transactions on Signal Processing*. 2020;68:1837–1852. Available from: https://dx.doi.org/10.1109/tsp.2020.2978591.
7) Dilli R. Performance analysis of multi user massive MIMO hybrid beamforming systems at millimeter wave frequency bands. *Wireless Networks*. 2021;27(3):1925–1939. Available from: https://dx.doi.org/10.1007/s11276-021-02546-w.
8) Alraddady F, Ahmed I, Habtemicail F. Robust Hybrid Beam-Forming for Non-Orthogonal Multiple Access in Massive MIMO Downlink. *Electronics*. 2021;11(1):75–75. Available from: https://dx.doi.org/10.3390/electronics11010075.
9) Akhtar I, Li L, Yang F, Li X, Gao A, Chen W, et al. Energy Efficient Hybrid Precoding for Cooperative Multicell Multiuser Massive MIMO Systems with Multiple Base Station Association. *2018 14th International Wireless Communications & Mobile Computing Conference (IWCMC)*. 2018;p. 418–423. Available from: https://doi.org/10.1109/IWCMC.2018.8450379.
10) Sun S, Rappaport TS, Shafi M, Tataria H. Analytical Framework of Hybrid Beamforming in Multi-Cell Millimeter-Wave Systems. *IEEE Transactions on Wireless Communications*. 2018;17(11):7528–7543. Available from: https://dx.doi.org/10.1109/twc.2018.2868096.
11) Mai R, Le-Ngoc T. Hybrid Precoder Design with MMSE-VP for Multi-Cell Massive MIMO Systems. *2018 IEEE International Conference on Communications (ICC)*. 2018;2018:1–6. Available from: https://doi.org/10.1109/ICC.2018.8422135.
12) Phuong NT, Van Son V, Hiep PT. Combining precoding and equalization for interference cancellation in MU-MIMO systems with high density users. *EURASIP Journal on Wireless Communications and Networking*. 2022;2022(1):34–34. Available from: https://dx.doi.org/10.1186/s13638-022-02118-2.
13) Jung GW, Kim HK, Lee YH. Zero-Forcing Beamforming with User Grouping in Spatially Correlated Channel Environments. In: 2020 International Conference on Computing, Networking and Communications (ICNC). IEEE. 2020;p. 1–5. doi:10.1109/ICNC47757.2020.9049758.
14) Abose TA, Olwal TO, Hassen MR. Hybrid Beamforming for Millimeter Wave Massive MIMO under Hardware Impairments and Imperfect Channel State Information. *2021 IEEE International Conference on Mobile Networks and Wireless Communications (ICMNWC)*. 2021;p. 1–6. doi:10.1109/ICMNWC52512.2021.9688468.
15) Zheng Z, Zhang J, Wu X, Liu D, Tian L. Zero-Forcing Precoding in the Measured Massive MIMO Downlink: How Many Antennas Are Needed? *International Journal of Antennas and Propagation*. 2019;2019(3):1–10. Available from: https://dx.doi.org/10.1155/2019/3518691.
16) Mostafa M, Newagy F, Hafez I. Complex Regularized Zero Forcing Precoding for Massive MIMO Systems. *Wireless Personal Communications*. 2021;120(1):633–647. Available from: https://dx.doi.org/10.1007/s11277-021-08482-4.
17) Huang Y, Liu C, Song Y, Yu X. DFT codebook-based hybrid precoding for multiuser mmWave massive MIMO systems. *EURASIP Journal on Advances in Signal Processing*. 2020;2020(1):11–11. Available from: https://dx.doi.org/10.1186/s13634-020-00669-4.