Hybrid Beamforming with Fixed Phase Shifters for Uplink Cell-Free Millimetre-Wave Massive MIMO Systems

Abdulrahman Al Ayidh*†, Yusuf Sambo*, Shuja Ansari* and Muhammad Ali Imran*
*School of Engineering, University of Glasgow, Glasgow, United Kingdom
†Collage of Engineering, King Khalid University, Abha, Kingdom of Saudi Arabia

***Abstract*—Several innovative ideas are being proposed by researchers to lay a foundation for future generations of wireless communications due to anticipated explosive demand for throughput, ultra-low latency, ultra-high reliability and ubiquitous coverage. However, these demands will consume huge amount of resources, especially for cell-free (CF) millimetre-wave (mm-Wave) massive multiple input multiple output systems (MIMO), which is the promising direction for the coming wireless generations. In this paper, we present hybrid beamforming scheme based on alternating minimization and a few number of fixed phase shifters to maximize energy efficiency in the uplink CF mm-Wave massive MIMO systems. Simulation results illustrate that our proposed scheme with much fewer fixed phase shifters, e.g., 10 phase shifters, achieves up to approximately 20% and 50% energy efficiency improvement compared to adaptive radio frequency (RF) chains activation/deactivation and antenna selection schemes.**

***Index Terms*—mm-Wave communications, hybrid beamforming, cell-free massive MIMO, fixed phase shifters.**

I. Introduction

In recent years, much research has focused on achieving very high data rates through utilizing the mm-Wave range of frequencies due to the availability of very high bandwidth. However, mmWave frequencies have poor propagation characteristics, which leads to the degradation of system performance and poor cell coverage. [1], [2]. This challenge has been overcome by compensating the effect of path loss via large beamforming gain which can be obtained by utilizing massive MIMO systems [2], [3]. Furthermore, CF massive MIMO has been proposed to provide high QoS, whereby a large number of access points (APs) are connected to a single central processing unit (CPU) and normally distributed for serving fewer users with the same resources [2].

Zero forcing precoding technique was proposed with a low complexity power control scheme for CF massive MIMO systems to maximize energy efficiency [4]. Additionally, the double total maximum energy efficiency was achieved by utilizing an optimal power allocation algorithm compared to the equal power control scheme [5]. The performance of CF mm-Wave massive MIMO systems was investigated by introducing hybrid beamforming technique with limited fronthaul capacity, in which precoders and combiners were generated via eigen beamforming scheme [2]. Specifically, quantization of the dominant eigenvectors of the known channel covariance matrix at the APs are used to obtain the phases of analog beamformers. A large number of antennas at each AP in the service area with fewer APs is proposed in [6] instead of large number of APs with smaller number of antennas to overcome the issue of the propagation loss in mm-Wave channels. However, this approach results in significant increase in power consumption due to an increase in the number of RF chains and analog-to-digital converter (ADC) for the digital part connected to each antenna. To reduce the power consumption in CF mm-Wave massive MIMO systems, the authors in [7] introduced an antenna selection (AS) scheme with limited RF chains. However, degradation of system performance may occur due to highly correlated channels of mm-Wave systems, especially with the hybrid beamforming technique. The authors in [1] proposed an adaptive RF chain activation (ARFA) with tabu search and fast search algorithms, in which the fully connected hybrid beamforming scheme is separately generated at each AP with perfect channel state information (CSI). The proposed scheme also dynamically switches on/off the RF chains to reduce the power consumption and obtain better total achievable rates. However, the phase shifters in this proposed method are very large especially with the huge number of antennas at each AP, which leads to high cost of hardware implementation and power consumption. Thus, energy-efficient low complexity hybrid beamforming schemes for CF mm-Wave massive MIMO systems are required, but the works focusing on the hybrid beamforming for CF mm-Wave massive MIMO systems are limited.

In this paper, we extend the work in [8], which has been proposed for small cell mm-Wave massive MIMO to CF mm-Wave massive MIMO system to maximize energy efficiency. Additionally, the authors in [8] proposed installing a cascade dynamic switch after the fixed phase shifters N_{ph} in order to overcome the drawback of the performance loss caused by inaccurate variation of the adaptive fixed number of phase shifters with the channel state, in which these fixed phase shifters are restricted to $N_{ph} << N_t N$, where N_t and N denote the transmit antennas and RF chains, respectively. In contrast to [8], we consider the uplink transmission process, that means the fixed phase shifters with the dynamic switches are applied at the receivers which are the APs to achieve significant spectral efficiency and lower power consumption. We used an alternating minimization algorithm to obtain the optimal analog combiner for each AP. Simulation results show that our proposed scheme with much fewer fixed phase shifters for each AP can achieve low power consumption as well as high total achievable rate, especially if there exists a large number of APs are available in the service area compared to the existing schemes.

The remainder of this paper is organized as follows. Section II presents the system model, while the problem formulation is presented in Section III. Section IV provides the proposed algorithm based on alternating minimization method with fixed phase shifters to solve the formulated problem. Power consumption analysis is explained in Section V. Simulation results and discussion of these are provided in Section VI. We conclude our paper in Section VII.

II. System Model

We consider the uplink transmission of the CF mm-Wave massive MIMO system, in which *M* APs and *K* user equipments (UEs) are normally distributed in a large service area. We assume that each AP is equipped with receive antennas N_r, and N RF chains which are restricted as $N < N_r$. On the other side, each UE is equipped with N_t transmit antennas. In this work, we focus on the hybrid analog combiner at each AP and propose a smaller number of N_t for each UE; hence, a fully digital precoder is utilized at each UE [1]. We assume that Error-free fronthaul links are used to connect *M* APs to the CPU. Additionally, it is assumed that the analog combining signals are passed through sphere decoding [9], or tabu search [10] which are defined as techniques of a capacity achieving advanced digital receiver at the CPU [1]. Baseband processing

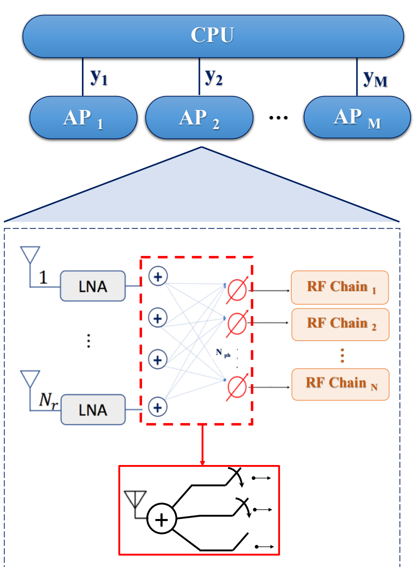

Fig. 1. Hybrid Beamforming structure for each AP with fixed phase shifter as well as a dynamic switches, in which $N_{ph} << N_r N$.

of the received signal is carried out at the CPU, whereas analog operations, such as RF chains and phase shifters, are separately performed at each AP, as shown in Fig. 1. In this paper, we adopt a narrowband block-fading channel model. Therefore, the received signal at m_{th} AP is expressed as

$$y_m = \sqrt{P} \sum_{k=1}^{K} W_{RF}{}_m^H H_{km} x_k + W_{RF}{}_m^H z_m, \qquad (1)$$

where $x_k \in \mathbb{C}^{N_t \times 1}$ is the transmitted vector symbols by k_{th}, such that $E[x_k{}^H x_k] = 1 \ \forall m$. z_m is a complex vector with a size $N_r \times 1$ and its elements describe an independent identically distributed (i.i.d.) of additive white Gaussian noise (AWGN) with a distribution of $\mathcal{CN}(0, N_o)$. $H_{km} \in \mathbb{C}^{N_r \times N_t}$ is known as a channel matrix between k_{th} UE and m_{th} AP, whereas P denotes the average transmission power. The analog combining matrix for m_{th} AP is symbolized by $W_{RFm} \in \mathbb{C}^{N_r \times N}$. Therefore, the composite received signal at the CPU is expressed as

$$\begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ y_M \end{bmatrix} = \sqrt{P} \sum_{k=1}^{K} \begin{bmatrix} W_{RF}{}_1^H H_{k1} \\ W_{RF}{}_2^H H_{k2} \\ . \\ . \\ W_{RF}{}_M^H H_{kM} \end{bmatrix} x_k + \begin{bmatrix} W_{RF}{}_1^H z_1 \\ W_{RF}{}_2^H z_2 \\ . \\ . \\ W_{RF}{}_M^H z_M \end{bmatrix}. \qquad (2)$$

We define $H_m = [H_{1m}, H_{2m}, ..., H_{Km}] \in \mathbb{C}^{N_r \times K N_t}$ as the channel between K UEs and m_{th} AP. As a consequence, the total channel between M APs and K UEs is given as $H = [H_1, H_2, ..., H_M]^T \in \mathbb{C}^{M N_r \times K N_t}$ [1]. Additionally, $y = [y_1, y_2, ..., y_M]^T \in \mathbb{C}^{M N_r \times 1}$, $z \in \mathbb{C}^{M N_r \times 1}$, whereas *W* = blkdiag $\{W_{RF1}, W_{RF2}, ..., W_{RFM}\} \in \mathbb{C}^{M N_r \times M N}$. In this work, we focus on the analog combiners which are individually generated at APs, and it is assumed that for simplicity the CSI is perfect.

A. Channel model

Due to the limited scattering that can be shown by mm-Wave channels, we use a geometric channel model [3] which can be expressed as

$$H_{km} = \sqrt{\frac{G_a}{\imath_{km}} \frac{N_r N_t}{L_{km}}} \sum_{l=1}^{L_{km}} \alpha_{km}^{(l)} \mathbf{a}_r(\phi_{km}^{(l)}) \mathbf{a}_t^H(\varphi_{km}^{(l)}), \qquad (3)$$

where G_a denotes the sum of the antenna gains for transmitter G_{TX} and receiver G_{RX} as well. L_{km} denotes the scatters between k_{th} UE and $m_{th} AP$. The parameter$\alpha_{km}^{(l)}$ symbolizes the complex l_{th} path gain while $\phi_{km}^{(l)}$ and $\varphi_{km}^{(l)}$ denote the angles of arrivals (AoAs) and departures (AoDs), respectively. Furthermore, $\mathbf{a}_r$ and $\mathbf{a}_t$ are the receiver and transmitter response array vectors, respectively. In addition, uniform linear array (ULA) is used at both the transmitter and receiver. Hence, the array response can be written as $\mathbf{a}_r(\theta) = \sqrt{\frac{1}{N_r}}[1, e^{\frac{j\ 2\pi\ d_s \sin(\theta)}{\lambda}}, ..., e^{\frac{j(N_r-1)\ 2\pi\ d_s \sin(\theta)}{\lambda}}]^T$, where the wavelength is denoted by λ, and d_s is the antenna spacing in the antenna array, which is assumed to be half of the wavelength. Also, $\mathbf{a}_t(\varphi)$ can be straightforwardly written in the same fashion. Moreover, there exist three probability conditions which describe the propagation loss between m_{th} AP and k_{th} UE. These probabilities are outage, line of sight (LOS), and non line of sight (NLOS) which can be expressed as $P(d_{km}) = max(0, 1 - e^{-a_{out} d_{km} + b_{out}})$, $P_{LOS}(d_{km}) = (1 -$

$P_{out}(d_{km}))e^{-a_{LOS}d_{km}}$, and $P_{NLOS}(d_{km}) = 1 - P_{out}(d_{km}) - P_{LOS}(d_{km})$, respectively. The path loss between k_{th} UE and m_{th} AP is assumed as a large scale-fading and symbolized by $\imath_{km}$ which can be expressed as

$$\imath_{km}[dB] = 10\log_{10}(\frac{4\pi d_o}{\lambda})^2 + 10\varsigma\log_{10}(\frac{d_{km}}{d_o}) + A_\epsilon, \quad (4)$$

where d_o is 1 meter, ς denotes the average path loss exponent over distance, and A_ϵ represents the effect of shadowing fading with zero mean and ϵ standard deviation in dB.

B. Fixed phase shifters network with switches in each AP

In this work, we focus on the the signal flow from the antenna to the RF chains, and the main task of N_{ph} is to generate multiple signals with different phases of the input signal. In addition, we adopt the method from [8] to compose the analog combining from the antenna to the RF chains by using an adaptive switch for each AP, as illustrated in Fig.1. Therefore, the total required switches are equal $N_r N N_{ph}$, and without loss of generality, these adaptive switches are with binary states [8]. Thus, the analog combining for m_{th} AP is expressed as

$$W_{RFm} = \delta_m G_m, \quad (5)$$

where δ_m denotes a switch matrix with binary states $\delta_m \in \left\{0\ ,1\right\}^{N_r\times N_{ph}N}$ and G_m is a block diagonal matrix $\in \mathbb{C}^{N_{ph}N\times N}$ and represents the normalized phase shifters with fixed phases $\{\theta_u\}_{u=1}^{N_{ph}}$ which can be written as

$$G_m = \text{blkdiag}\left\{G_{1m}\ , G_{1m}\ , ..., G_{Nm}\right\}, \quad (6)$$

where $G_{nm} = \frac{1}{\sqrt{N_{ph}}}\left[e^{j\theta_1}, e^{j\theta_2}, ..., e^{j\theta_{N_{ph}}}\right]^T$ denotes the normalized fixed phase shifter vector.

III. Problem Formulation

In order to obtain the maximum of the total achievable rate for all APs, it is necessary to minimize the Euclidean distance between the fully digital combiner and the hybrid combiner in mm-Wave systems [11]. To overcome the interference between K UEs, the optimal combiner at each AP, W_{mOpt}, is mutually orthogonal and the baseband combiner, which is carried out at the CPU and denoted as $W_{BBm} = \alpha I_K$ where α is a scaling factor, such that $W_{BB}{}_m^H W_{BBm} = \alpha^2 I_K$ in order to simplify the analog combiner W_{RFm} [12]. Thus, the optimization problem can be expressed as

$$\begin{aligned} \underset{\delta_m,\alpha}{\text{minimize}} \quad & \|W_{mOpt} - \alpha\delta_m G_m\|_F^2 \\ \text{subject to} \quad & \delta_m, \in \left\{0\ ,1\right\}^{N_r\times N_{ph}N}, \end{aligned} \quad (7)$$

where W_{mOpt} denotes the optimal analog combiner for each AP, such that $W_{mOpt} \in \mathbb{C}^{N_r\times N}$. The objective function in (7) can be expressed as

$$\|W_{mOpt}\|_F^2 - 2\alpha\Re tr(W_{mOpt}^H\delta_m G_m) + \alpha^2\|\delta_m G_m\|_F^2. \quad (8)$$

The upper bound for the last term in (8) can be simplified due to the phase shifter matrix being a semi-unitary matrix, such that $G_m^H G_m = I_N$ [8]. Thus, the last term in (8) can be given by

$$\|\delta_m G_m\|_F^2 = tr(G_m^H\delta_m^H\delta_m G_m) = \|\delta_m\|_F^2 \quad (9)$$

Thus, the main objective function can be written as

$$\|W_{mOpt}\|_F^2 - 2\alpha\Re tr(W_{mOpt}^H\delta_m G_m) + \alpha^2\|\delta_m\|_F^2 \quad (10)$$

Our main optimization problem of a hybrid analog combiner after dropping the constant term W_{mOpt} because the equation (10) is considered as the surrogate objective function. Therefore, the hybrid combiner for each AP is reformulated as

$$\begin{aligned} \underset{\delta_m,\alpha}{\text{minimize}} \quad & \alpha^2\|\delta_m\|_F^2 - 2\alpha\Re tr(W_{mOpt}^H\delta_m G_m) \\ \text{subject to} \quad & \delta_m, \in \left\{0\ ,1\right\}^{N_r\times N_{ph}N}. \end{aligned} \quad (11)$$

IV. Proposed Solution

In this section, we present our proposed hybrid beamformer by decomposing the optimization problem in (11) into two parts. The first is to obtain W_{mOpt} for each AP, and the second is to find the optimal value of α and the optimal matrix of δ_m based on the alternating minimization algorithm which is widely applied in the hybrid beamforming design due to due to the fact that it can successfully obtain satisfactory results results especially with fixed phase shifters, as mentioned in [8], [13]. To solve (11) based on the alternating minimization algorithm, we divide (11) into two main subproblems based on two main variables, which are α and δ_m in order to save the number of subproblems in the proposed algorithm to obtain lower computational complexity. Then, it is necessary to add the constant term $\left\|\Re(W_{mOpt}G_m^H)\right\|_F^2$ to the objective function in (11) in order to obtain updating α and δ_m. Thus,

$$\begin{aligned} \underset{\delta_m,\alpha}{\text{minimize}} \quad & \left\|\Re(W_{mOpt}G_m^H) - \alpha\delta_m\right\|_F^2 \\ \text{subject to} \quad & \delta_m, \in \left\{0\ ,1\right\}^{N_r\times N_{ph}N}. \end{aligned} \quad (12)$$

The proposed solution of (12) is to find $\alpha^\star$ and $\delta_m^\star$. Therefore, we adopt the method from to find these values [8] in order to solve (12). The optimal switch matrix can be obtained as expressed below

$$\delta_m^\star = \begin{cases} \mathbb{1}\Big\{\Re(W_{mOpt}G_m^H) > \frac{\alpha}{2}\mathbb{1}N_r \times N_{ph}N, \\ \mathbb{1}\Big\{\Re(W_{mOpt}G_m^H) < \frac{\alpha}{2}\mathbb{1}N_r \times N_{ph}N, \end{cases} \quad (13)$$

where $\mathbb{1}$ denotes the indicator function and $\mathbb{1}N_r \times N_{ph}N$ represents that all elements in the complete matrix $N_r \times N_{ph}N$ equal one. On the other hand, the optimal $\alpha^\star$ is expressed as

$$\alpha^\star = \underset{\{\tilde{x_i},\bar{x_i}\}_{i=1}^n}{\text{argmin}}\ \left\{f(\tilde{x_i}), f(\bar{x_i})\right\}, \quad (14)$$

where $\mathbf{x} = vec\big\{\Re(W_{mOpt}G_m^H)\big\}$, x_i is the i_{th} smallest value in $\mathbf{x}$, and

$$\bar{x_i} = \begin{cases} \frac{\sum_{j=1}^{i}\tilde{x_j}}{i},\ \alpha < 0, \\ \frac{\sum_{j=i+1}^{n}\tilde{x_j}}{n-i}, \alpha > 0, \\ +\infty, \text{otherwise}. \end{cases} \quad (15)$$

The first two conditions in (15) should belong to $[2\tilde{x}_i, 2\tilde{x}_{i+1}]_{i=1}^n$, where $n = N_r N_{ph} N$.

Lemma 1: Due to the large value of n, the computational complexity is very high, especially when the number of N_r is very large [8]. Thus, it is necessary to obtain $f(\bar{x}_i)$ that can satisfy the first two conditions in (15) which are denoted as $\mathcal{X}$. Therefore, the optimal solution of α is expressed as [8]

$$\alpha^{\star} = \underset{\bar{x_i} \in \mathcal{X}}{\operatorname{argmin}} f(\bar{x_i}). \tag{16}$$

As a consequence, the complexity of the proposed method will decrease.

On the other hand, in order to obtain the achievable rate for m_{th} AP, it is assumed that $W_{RF}{}_m^H W_{RFm} \approx I_N$ for simplicity [3], and for all APs $W_{RF}^H W_{RF} \approx I_{MN}$. Then, the noise covariance matrix can be expressed after the analog combining as $\mathbf{C} = N_o W_{RF}^H W_{RF} \approx N_o I_{MN}$. This can represent the white Gaussian noise. The achievable rate (*R*) [1] can be expressed as

$$R = \log_2 det(I_{MN} + \frac{P}{N_o} W_{RF}^H H H^H W_{RF}). \tag{17}$$

Lemma 2: In CF mm-Wave massive MIMO system, the total achievable rate *R* is equal to the sum of the achievable rate for each AP [1] as demonstrated below

$$R = \sum_{m=1}^{M} R_m, \tag{18}$$

where $R_m = \log_2 det(I_N + \frac{P}{N_o} W_{RFm}{}_m^H H_m \mu_{m-1}^{-1} H_m^H W_{RFm})$ with $\mu_o = I_{KN_t}$, and

$$\mu_{m-1} = \mu_{m-2} + \frac{P}{N_o} H_{m-1}^H W_{RFm-1} W_{RF}{}_{m-1}^H H_{m-1}. \tag{19}$$

It is noted that $\alpha^{\star}$ and $\delta_m^{\star}$ can yield the optimal matrix of W_{RFm} for m_{th} AP according to (5). This will also yield the maximum R_m which in turn yields the maximum *R* based on (18) and (19), respectively. Finally, the proposed algorithm to obtain the maximum *R* for uplink hybrid beamforming with fixed phase shifters as well as dynamic cascade switches based on alternating minimization method for CF mm-Wave massive MIMO system is described in detail in Algorithm 1. This algorithm seeks to obtain the analog combiner for each AP as well as total achievable rate. The first three steps are used to find the optimal analog combiner for each AP. Next, the normalized phase shifter with fixed phases which are within [0, 2π] by N_{ph}. Then, the parameters of the proposed method as mentioned previously are obtained by alternating minimization algorithm according to (13) and (16), respectively. Finally, Q_m and μ_m are computed to obtain the sub-rate corresponding to each AP and the total achievable rate *R* is computed according to (18).

Algorithm 1: The proposed algorithm based on alternating minimization method with fixed phase shifters to obtain the maximum *R*.

Output: W_{RF} and *R*.
for $m = 1 \rightarrow M$ **do**
  for $n = 1 \rightarrow N$ **do**
    Compute the Singular value decomposition (SVD) for $H_m \mu_{m-1}^{-1} H_m^H$;
    The singular vector $W_{mOptm} = \{u_{m1}^{\star}, u_{m2}^{\star}, ..., u_{mN}^{\star}\}$.
  end
  Compute G_m **according to (6)**.
  Then, compute the vector of real values of $(W_{mOptm} * G_m^H)$ **according to (14)** ;
  Repeat
    Obtain $\alpha^{\star}$ *and* $\delta_m^{\star}$ *according to (13) and (16), respectively.*
  Until convergence
  $Q_m = H_m^H W_{RFm} W_{RF}{}_m^H H_m$
  $\mu_m = \mu_{m-1} + \frac{P}{N_o} Q_m$
  Compute R_m.
end
Compute *R* **according to (18).**

V. Energy Efficiency analysis

In this section, we analyse the power consumption for the proposed method. Moreover, the power consumption model in this work is designed based on [7], and [14], in which each antenna in the AP requires a low noise amplifier (LNO), a 90^o hybrid and local oscillator (LO) buffer, and two mixers. Each RF chain requires an analog-to-digital converter (ADC) as well as a fixed phase shifter N_{ph} fixed phase shifters. LO is operated inside the AP and let P_{sw} be the power consumed by the cascade dynamic switches which are connected to the N_{ph} at each AP. Thus, the power consumption P_C of the proposed method for CF mm-Wave massive MIMO system is expressed as

$$\begin{aligned} P_C = M P_{LO} + M N_{ph}(N_r + P_{ph} + P_{sw} + N P_{RF} \\ + P_{ADC}) + (N_r M)(P_{LNA} + 2P_m + P_H). \end{aligned} \tag{20}$$

Hence, the energy efficiency (EE) in [bps/Hz/W] can be calculated as expressed in the equation below

$$EE = \frac{\sum_{m=1}^{M} R_m}{P_C}. \tag{21}$$

VI. Simulation Results

This section provides the simulation results and discussion. Table 1 shows the general simulation parameters for CF mm-Wave massive MIMO system. In addition, the AoA and AoD are uniformly distributed $\in [0, 2\pi]$, and the phases in the analog combiner based on 4-bit quantization of the phase shifters are chosen from $\theta = \{0, \frac{2\pi}{2^b}, \frac{4\pi}{2^b}, ..., \frac{2(2^b-1)\pi}{2^b}\}$, where b = 4 [1]. In addition, the noise power is demonstrated as N_o = -174 dBm/Hz + $10\log_{10}$ (B) + NF.

Fig. 2 shows that the total achievable rate versus the average transmission power. The proposed scheme in this paper outperforms the existing schemes by approximately 65% improvement total achievable rate at low average transmission power. For our proposed scheme, we set *N* = 8 and use three values of fixed phase shifters, i.e., N_{ph} = 10, 15 and 20. It can be seen that our scheme outperforms the fixed activation method when all RF chains are activated and some of the RF chains are activated as mentioned in the proposed schemes [1], which are TS-ARFA and FS-ARFA when n_a activated RF chains, and antenna selection (AS) [7]. Our proposed scheme with ten fixed phase shifters can approximately attain 12%, 14%, 16% and 33% compared to fixed activation with fully digital analog phase shifting network, TS-ARFA, FS-ARFA and AS schemes, respectively. This is due to the analog phase shifting network in the previous methods being very high which results in loss of performance caused by large consumed power, whereas in the our proposed method, with fewer fixed phase shifters which connected to dynamic switches can achieve better total of achievable rate than the existing methods and overcome the loss of the system performance.

Fig. 3 shows the energy efficiency performance versus the average transmission power. To compute the P_C as expressed in (20), we assume $P_{LO} =$ 22.5 mW, $P_{ph} =$ 30 mW, $P_{sw} =$ 5 mW, $P_{RF} =$ 40 mW, $P_{ADC} =$ 200 mW, $P_{LNA} =$ 20 mW, $P_m =$ 0.3 mW, and $P_H =$ 3 mW [1], [14], and [15]. It is noted that the energy efficiency for all schemes increases as average transmission power increases. Specifically, the energy efficiency performance improved by using the proposed scheme with N = 8 and fixed phase shifters, and provided better performance than the activation method with fewer RF chains. Also, it can be seen that a smaller number of RF chains with high analog phase shifter network consumed high power whereas minimizing the phase shifters with the dynamic switches without considering any activation/deactivation of RF chains can significantly improve the energy efficiency. Specifically, our proposed method has the ability to attain approximately 77% EE improvement compared to ARFA schemes [1] and 163.76% compared to AS [7] at $P = 30$ dBm and $N_{ph} = 10$. This is also due to a large analog phase shifter network requiring a large amount of power to obtain satisfactory level of total achievable rate.

Fig. 4 shows that the energy efficiency performance versus different numbers of APs. We can observe that energy efficiency for all schemes decreases as the number of APs increases. Also, it can be observed that as M increases, the power consumption in each AP including large analog phase shifter network increases, which results in the degradation in the energy efficiency performance. While the proposed scheme with different fixed number of phase shifters outperform the existing schemes with also fixed number of RF chains. It is noticeable that the activation/deactivation of RF chains scheme outperforms AS scheme, and fixed activation schemes either with N = 8, or N = $N = n_a = 4$. However, the analog phase shifter networks in this scheme is still very high, which leads to huge amount of power consumption, especially, when there exists a large number of APs are normally distributed in the service area with different locations as well as path losses. Additionally, the proposed scheme in this paper outperforms this issue and achieves a satisfactory performance with respect to total achievable rates and energy efficiency. For example, our proposed scheme can attain approximately 22.6% and 69.4% EE improvement compared to ARFA and AS schemes at 60 APs, respectively.

VII. Conclusions

In this paper, we proposed a hybrid beamforming scheme with fixed phase shifters for uplink CF mm-Wave massive MIMO systems. We used fixed phase shifters at each AP with dynamic cascade switches in order to overcome the drawback of the performance loss caused by inaccurate variation of the adaptive fixed number of phase shifters with the channel state. Also, we utilized alternating minimization to obtain the optimal parameters of our proposed method in order to achieve the optimal analog combiner for each AP to maximize the total achievable rates. We also analysed the power consumption model based on the proposed method and compared the achieved results with existing methods, such as TS-ARFA, FS-ARFA, and AS. Our proposed method achieves better results with respect to both spectral and energy efficiencies.

TABLE I
Simulation Parameters

Parameters	Values
Service area $D \times Dm^2$	D = 200 m [2]
Channel paths	$L_{km} = 3$ [16]
Frequency (f_c)	28 GHz [1], [2]
Bandwidth (B)	100 MHz
Noise Figure (NF)	9 dB [1]
Path loss exponent (ς)	$\varsigma_{LOS} = 1.9,\ \varsigma_{NLOS} = 4.1$ [17]
Shadowing factor standard deviation (ϵ)	$\epsilon_{LOS} = 1.1,\ \epsilon_{LOS} = 7.6$ [17]
Antenna gains	$G_{TX} = 15\ dBi, G_{RX} = 24.5\ dBi$
Outage parameters	$1/a_{out} = 30\ m,\ b_{out} = 5.2$ [2]
LOS parameter	$1/a_{LOS} = 67.1\ m$ [2]

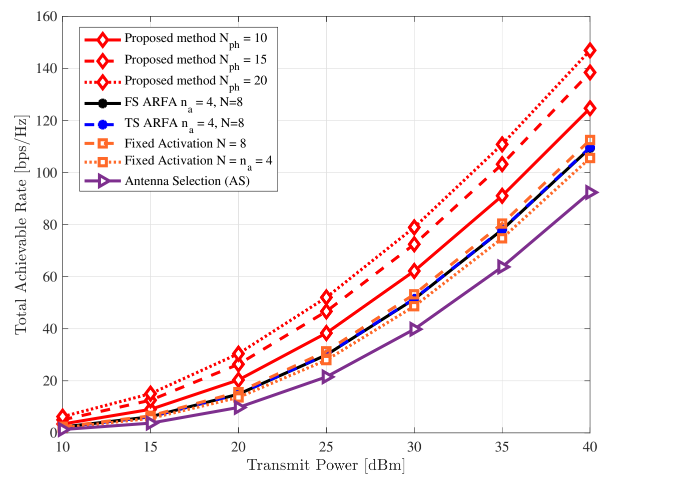

Fig. 2. The total achievable rate in bps/Hz versus the average transmission power in dBm, in which the proposed method is assumed with different values of fixed phase shifters N_{ph} compared to ARFA schemes in [1], AS in [7], and fixed RF chain activation for all M APs. Simulation parameters are M = 40, K = 8, N_r = 64, and N_t = 4.

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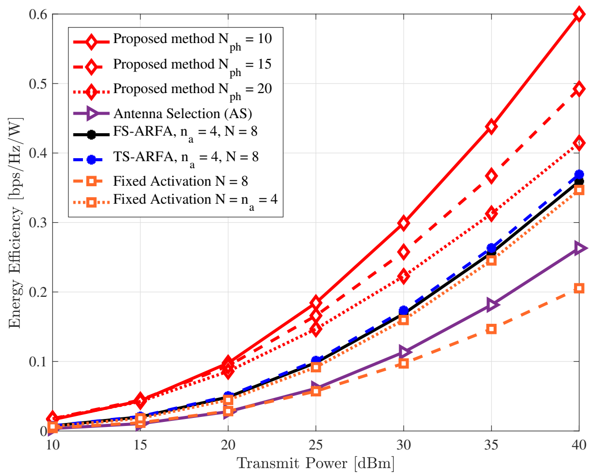

Fig. 3. The energy efficiency in bps/Hz/W versus the average transmit power in dBm with same simulation parameters as well as same comparable works as mentioned in Fig. 2.

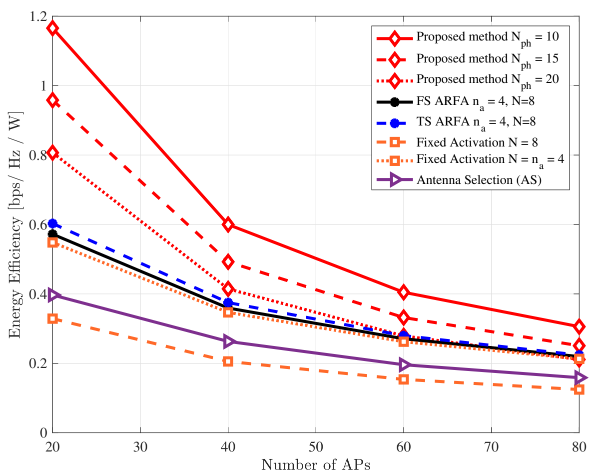

Fig. 4. The energy efficiency for the proposed method compared to those works mentioned in Fig. 2 versus M APs. Simulation parameters are N_r = 64, N_t = 4, and the average transmission power P = 40 dBm.

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