Two-Stage Multiuser Access in 5G Cellular Using Massive MIMO and Beamforming

Hussein Seleem(✉), Abdullhameed Alsanie, and Ahmed Iyanda Sulyman

King Saud University, Riyadh, Saudi Arabia
{hseleem,sanie,asulyman}@ksu.edg.sa

Abstract. This paper explores the possibility of using multiuser massive MIMO and beamforming together as two-stage multiuser access methods in 5G cellular. Multi-carrier OFDM transmission as currently used in the 4G-LTE may be difficult to implement in 5G cellular because of the peculiarities of mmWave channels. Therefore, there is the need to analyze and propose suitable physical layer techniques suitable for 5G systems that are amenable to beamforming and/or massive MIMO. It turns out that both of these schemes are inherently multiuser access methods and can be used together in 5G cellular. Our results show that simple transmitter and receiver processing can be achieved when using the combined system. Moreover, the proposed approach will allow the system to accommodate more users at minor error rate degradation.

Keywords: Millimeter waves · 5G cellular networks · Massive MIMO · MU-MIMO · Beamforming

1 Introduction

Mobile communication has evolved significantly over the last four decades, from the early voice systems to today's highly sophisticated integrated platforms that provide numerous services, and support countless applications used by billions of people around the world [1]. The bandwidth-intensive media services that were earlier confined to wired transmission are now being used on mobile devices. The exponential growth of cellular data traffic and also the continued advances in computing and communications coupled with the emergence of new customer devices such as smart-phones are driving technology evolutions and moving the world toward a fully connected networked society where access to information and data sharing are possible anywhere, anytime, by anyone or anything [1,2].

This has created unprecedented challenges for wireless service providers. They need to overcome a global bandwidth shortage and support ever-growing data rate demands. Subsequently, an efficient radio access technology (RAT) combined with more spectrum availability is essential to meet this overwhelming challenges faced by wireless carrier [1–4]. Consequently, wireless carriers will

---

H. Seleem—Student Member IEEE.
A.I. Sulyman—Senior Member IEEE.

M. Weichold et al. (Eds.): CROWNCOM 2015, LNICST 156, pp. 54–65, 2015.
DOI: 10.1007/978-3-319-24540-9_5

be able to provide peak and cell edge rates higher than tens of Gb/s and 100 Mb/s respectively [2–4]. Also it will offer a minimum of 1 Gb/s data rate anywhere to provide a Gb/s experience to all end users and up to 5 and 50 Gb/s data rates for high mobility and pedestrian users, respectively [3]. In addition, they will be able to provide latency less than 1 -ms for local area networks (LANs) [4], ultra-low energy consumption, massive numbers of connected devices, very high volumes of data transfer, low cost devices, ultra-reliable connectivity with guaranteed availability for mission-critical machine type applications [1].

Recently the large amount of underutilized spectrum in the millimeter wave (mmWave) frequency bands has attracted researchers attentions as a potentially viable solution for achieving tens to hundreds of times more capacity compared to current fourth generation (4G) cellular networks [5–8]. Historically, mmWave bands were kept out for cellular usage mainly due to the high propagation loss and lack of cost-effective components. Accordingly, mmWave have mostly been utilized for outdoor point-to-point back-haul links or for carrying high-resolution multimedia streams in indoor applications, but not for cellular access links. In addition, mmWave frequencies can be severely vulnerable to shadowing, resulting in outages and irregular channel quality. Power consumption in mmWave to support large numbers of antennas with very wide bandwidths is also a key challenge. In order to reform these underutilized spectra for future outdoor cellular applications, two key hurdles must be overcome: sufficiently large geographical coverage and support for mobility even in non-line of sight (NLOS) environments where the direct communications path between the transmitter (TX) and the receiver (RX) is blocked by obstacles. Today, the cell sizes in urban environments are about 200 m, so it becomes clear that mmWave cellular can overcome these issues [7].

The next step is to develop an efficient RAT and core network technologies to efficiently utilize the abundant spectrum in the mmWave bands and achieve commercial viability. Due to the much smaller wavelength combined with advances in cost-effective CMOS-based low-power radio frequency (RF) circuits, enabling large numbers of miniaturized antennas (such as 64 elements), we may exploit polarization and new spatial processing techniques, such as multiuser multiple input multiple output (MU- MIMO) [9–11] and adaptive beamforming [12,13] using Massive MIMO [9,14–17], and highly directional antennas at both the user equipment (UE) and base station (BS). Consequently, the increase in omnidirectional path loss (PL) when using the higher frequencies can be completely compensated [18].

Using Adaptive Beamforming, one can focus the radio transmission from multiple antenna elements using very narrow beams, which results in reduced interference and improves overall system performance. In spatial multiplexing, we exploit the propagation properties to provide multiple data streams to one or more terminals simultaneously. These techniques are already integral parts of the long-term evolution (LTE) cellular system but their full potential remains to be released. They are now set to play an even bigger role in future cellular systems. MIMO is an advanced antenna solutions that include a substantial number of antenna elements that can be used to reduce the impact of RF imperfections and control the way interference is distributed in a network.

Therefore, the base station to device links, as well as back-haul links between base stations, will be able to handle much greater capacity than today's 4G networks in highly populated areas when deploying massive MIMO system. Also, as operators continue to reduce cell coverage areas to exploit spatial reuse, and implement new cooperative architectures such as cooperative MIMO, relays, and interference mitigation between BSs, the cost per BS will drop as they become more plentiful and more densely distributed in urban areas, making wireless back-haul essential for flexibility, quick deployment, and reduced ongoing operating costs.

This paper introduces a two-stage multiuser access in fifth generation (5G) cellular using baseband precoding and RF beamforming. The baseband (BB) precoding is done in digital domain to optimize capacity using various MIMO techniques. On the other hand, RF beamforming is executed in analog domain to overcome higher path loss with beamforming gain in mmWave bands. By implementing both schemes together, we could be able to reach high performance with low complexity for mmWave 5G cellular systems.

The rest of the paper is organized as follows. Section 2 describes the mmWave channel model. Section 3 introduces the system model for the two-stage multiuser access for 5G cellular system using massive MIMO and beamforming. The main contribution of the paper appear in this section. Section 4 and section 5 describe the multiuser massive MIMO downlink model and beamforming downlink model, respectively. Numerical results and discussions are presented in section 6, while the computational complexity analysis is given in section 7. Finally, the conclusions are presented in section 8.

2 Millimeter wave Channel Model

Over 90 percent of the allocated radio spectrum falls in the mmWave band (30 - 300 GHz). Industry has considered mmWave to be any frequency above 10 GHz. The most common misunderstanding of the propagation characteristics at higher frequencies is that they always suffer a much higher propagation loss even in free space compared to lower frequencies, and thus are not adequate for long-range communications. To clarify this misunderstanding, let us start with the Friis transmission equation, given by [19].

$$P_r = P_t G_t G_r \underbrace{(\frac{\lambda}{4\pi d})^2}_{PL} = P_t G_t G_r \quad \underbrace{(\frac{c^2}{4\pi f^2})}_{Aperture\ Size} \quad \underbrace{(\frac{1}{4\pi d^2)})}_{Shperical\ Area} \tag{1}$$

The received power can be seen as inversely proportional to the frequency squared when an ideal isotropic radiator $G_t = 1$ and an ideal isotropic RX $G_r = 1$ are used at each end. By employing array of antennas at TX or/and RX with antenna gains of $G_t = A_{e,tx}(\frac{4\pi f^2}{c^2})$ or/and $G_r = A_{e,rx}(\frac{4\pi f^2}{c^2})$ respectively, which is greater than unity, the received power will be given as:

$$P_r = P_t . A_{e,tx} . A_{e,rx} (\frac{4\pi f^2}{c^2}) . (\frac{1}{4\pi d^2)}) \tag{2}$$

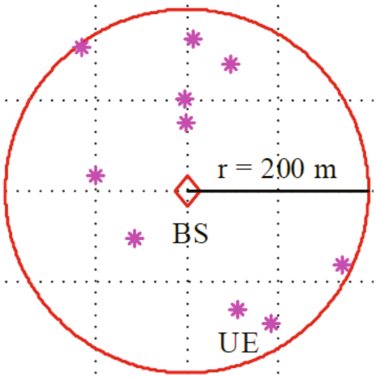

Fig. 1. Single cell scenario in mmWave massive MIMO, the BS is fixed and it is deployed with ULA antennas. The K UE are randomly uniform distributed and the BS communicates with all UE simultaneously.

Using antenna arrays at both TX and RX transmitting at higher frequencies, given the same physical aperture size, can allow us to send and receive more energy though narrower directed beams [3].

Consider a single cell massive MIMO transmission system working at mmWave frequencies and adopting time division duplex (TDD) transmission mode. BS is located at the cell center and deployed with N_t uniform linear array (ULA) antennas. A total number of K single antenna users are randomly distributed in the cell as shown in Fig. 1.

Using the spatial multi-path channel model (SCM) [12], the physical downlink (DL) channel Matrix for k^{th} user can be written as:

$$\bar{\mathbf{H}}_{d,k}(t) = \sum_{i=1}^{N_p} \sqrt{\frac{P_i}{N_t N_r}} \sum_{j=1}^{N_{sp}} \mathbf{\Lambda}_{ij}.[\mathbf{a}_r(\theta_{ij}^{AoA})\mathbf{a}_t^T(\theta_{ij}^{AoD})].e^{j2\pi f_{ij}^{d} t}\delta(t-t_i) \qquad (3)$$

Where N_p is the total number of paths per channel link, N_{sp} is the total number of subpaths per path, P_i is the power of the i^{th} path. N_r is the total number of antennas at receiver, $\mathbf{\Lambda}_{ij}$ is $N_r \times N_t$ initial phase matrix for the j^{th} sub-path of the i^{th} path. θ_{ij}^{AoA} and θ_{ij}^{AoD} is the angle of arrival (AoA) and angle of departure (AoD), respectively for the j^{th} sub-path of the i^{th} path. $\mathbf{a}_r(\theta_{ij}^{AoA})$ and $\mathbf{a}_t(\theta_{ij}^{AoD})$ is the array response vector of length $N_r \times 1$ and $N_t \times 1$ for the given AoA and AoD, respectively. f_{ij}^{d} is the Doppler frequency. Symbols (.) , $()^T$ and $()^H$ stands for element wise product, transpose, and Conjugate transpose operations, respectively.

For the ULA, the array response vector is given by:

$$\mathbf{a}(\theta) = \frac{1}{\sqrt{N}}[1 \quad e^{jkdsin(\theta)} \cdots e^{jkd(N-1)sin(\theta)}]^T \qquad (4)$$

Where N is the number of antennas and $\frac{1}{\sqrt{N}}$ is the normalization factor such that $\|\mathbf{a}(\theta)\|_2^2 = 1$, where θ is the path angle from antenna boresight and $\lambda = c/f_c$ is the wavelength corresponding to the operating carrier frequency f_c and $k = 2\pi/\lambda$ is the wave number. Assume $d = \lambda/2$ where d is the antenna spacing then $kd = \pi$.

In mmWave massive MIMO systems, the main propagation path is LOS, so $P_1 >> P_i$ for $i \geq 2$, also assume there are only one sub-path for simplicity. In our model we assume that UE is equipped with a single antenna element where $N_{r,k} = 1$ is the number of receive antennas at k^{th} user. Consequently, the physical channel becomes,

$$\bar{\mathbf{H}}_{d,k}(t) = \mathbf{H}_{d,k}(t)\mathbf{A}_{d,k}. \tag{5}$$

where $\bar{\mathbf{H}}_{d,k} \in \mathbb{C}^{1\times N_t}$, $\mathbf{H}_{d,k}(t) = \sqrt{\frac{P_i}{N_t N_r}}\mathbf{\Lambda} e^{j2\pi f^d t}\delta(t - t_1)$ and $\mathbf{A}_{d,k} = \mathbf{a}_t^T(\theta^{AOD})$

3 Two-Stage Multiuser Access Using Multiuser Massive MIMO and Beamforming

Consider the mmWave massive MIMO system shown in Fig. 2 in which a BS transmits to all users simultaneously. The received signal at k^{th} user is given by:

$$\bar{\mathbf{y}}_{d,k} = \bar{\mathbf{H}}_{d,k}\bar{\mathbf{W}}\bar{\mathbf{P}}\bar{\mathbf{s}} + \bar{\mathbf{n}}_{d,k} \tag{6}$$

Where $\bar{\mathbf{s}}$ is the $K \times 1$ vector of user symbols, $\bar{\mathbf{P}}$ is the $N_t^c \times K$ BB precoding matrix and it will used as the first stage multiuser access scheme. $\bar{\mathbf{W}}$ is the $N_t^c \times N_t$ RF beamformer weight matrix and it will be considered as the second stage

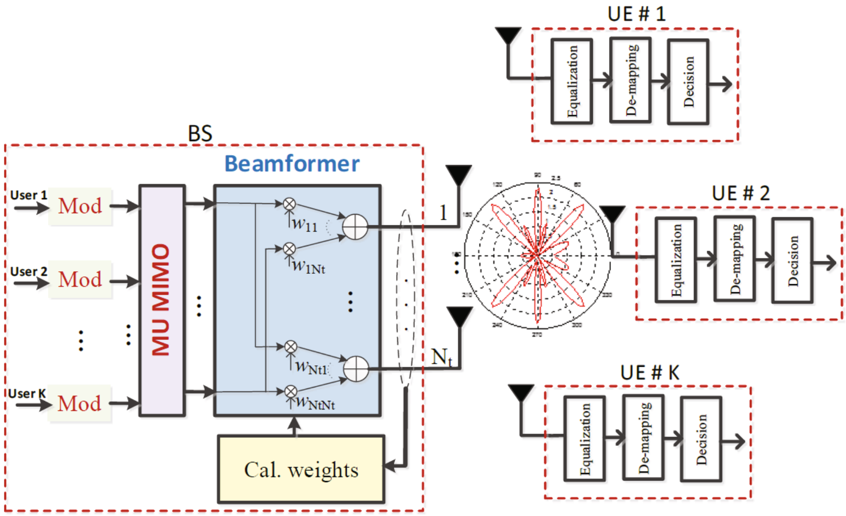

Fig. 2. System model for the mmWave multiuser massive MIMO system.

multiuser access scheme. N_t^c is the number of RF chains and this number we need to decrease it as much as possible to decrease the complexity. On the other hand by decreasing number of RF chains the performance will be worse. So that by using the RF beamforming in analog domain we can decrease complexity and increase the performance at the same time. The RF beamformer weights could be implemented using variable gain attenuators (VGAs) and phase shifters that are connected with the antennas, while BB precoder weights are processed in the digital domain as for the conventional MU-MIMO implementation. We consider a MIMO fading channel which yields a received signal $\bar{\mathbf{y}}_{d,k}$. $\bar{\mathbf{H}}_{d,k}$ is the channel matrix that can be analytically represented according to the SCM-based multipath channel model as described before in section 3. $\bar{\mathbf{n}}_{d,k} \in \mathbb{C}^{N_{r,k} \times 1}$ is the additive zero mean circular symmetric complex Gaussian noise at the k^{th} user with the variance of σ^2.

4 Multiuser Massive MIMO Downlink System Model

MU-MIMO deal with multiple users who are sharing the same radio (time-frequency) resources. It has brought a great improvement in the system capacity by serving multiple users simultaneously. Multiple antennas allow the independent users to transmit their own data stream in the uplink (many-to-one) at the same time or the base station to transmit the multiple user data stream to be decoded by each user in the downlink (one-to-many). In the multiuser MIMO system, downlink and uplink channels are referred to as broadcast channel (BC) and multiple access channel (MAC), respectively. We are interested in the system where $N_t >> KN_r, k$, hence this system refers to a massive MU-MIMO.

We further assume that the channels will stay constant during a coherence interval of T symbols. The downlink transmission will occur in two phases: training phase and downlink data transmission phase, where τ is the coherence duration used for the training phase. In the training phase, the base station estimates the channel state information (CSI) from K users based on the received pilot sequences in the uplink. The base station uses this CSI and a precoding scheme to process the signals before transmitting them to K users. We assume that perfect CSI is available at the BS which can be achieved by simple TDD training method [20]. Also, this assumption is reasonable under the scenarios that the training power is large or the coherent interval is large (and hence, we can spend large τ for training).

In the case of downlink channel, Let $\mathbf{x} \in \mathbb{C}^{N_t \times N_r}$ is the transmit signal from the BS and can be written as $\bar{\mathbf{x}} = \bar{\mathbf{P}}\bar{\mathbf{s}}$. The average transmission power is constrained by $E_s = \mathbf{E}[\|\mathbf{x}_k\|_2^2] = tr(\mathbf{P}\mathbf{P}^H)$. the received vector $\mathbf{y}_k \in \mathbb{C}^{N_{r,k} \times N_t}$ at the k^{th} user, is expressed as: $\bar{\mathbf{y}}_{d,k} = \bar{\mathbf{H}}_{d,k}\bar{\mathbf{x}} + \bar{\mathbf{n}}_{k,d}$. Representing all user signals by a single vector, the overall system can be represented as: $\mathbf{y} = \mathbf{H}_d\mathbf{x} + \mathbf{n}$.

The linear precoding will be considered in this paper which include zero forcing (ZF), linear minimum mean squared error (LMMSE) and maximum ratio transmission (MRT) [21]. A simple way to deal with the inter user interference (IUI) is to set the constraint so to force all interference terms to zero, the method is known as the ZF. Since the transmitted power is limited by E_s, the precoding matrix has to be designed to satisfy the transmit power constraint, that is: $E_s = \mathbf{E}[\|(1/\beta)\bar{\mathbf{P}}\bar{\mathbf{s}}\|_2^2]$, where β is a factor to make sure that the transmitted signal power after precoding will not be changed. So that the estimation of the transmitted signal at the receiver side is given by: $\hat{\mathbf{s}} = \mathbf{s} + \beta_{CI}\mathbf{n}$.

Then, the ZF precoding design problem can be described as follows:

$$\begin{aligned} \underset{\mathbf{P},\beta}{\operatorname{argmin}} \quad & \mathbf{E}[\|\hat{\mathbf{s}} - \mathbf{s}\|_2^2] \\ \text{s. t.} \quad & \mathbf{E}[\|(1/\beta_{ZF})\mathbf{P}_{ZF}\mathbf{s}\|_2^2] = E_s \\ & \hat{s}|_{n=0} = \mathbf{s} \end{aligned} \tag{7}$$

The solution of the above optimization problem is: $\mathbf{P}_{ZF} = \mathbf{H}_d^H(\mathbf{H}_d\mathbf{H}_d^H)^{-1}$. So, this precoding is assumed to implement a pseudo-inverse of the channel matrix. If the channel matrix is ill conditioned β_{ZF} will become larger and the performance of ZF precoding will be poor due to noise enhancement.

In order to reduce the noise enhancement and to maximize the signal to interference plus noise ratio (SINR), the second constraint in the optimization problem needs to be dropped. the resultant problem is the well known LMMSE constraint optimization problem that is average power at each transmitted antenna is constrained. Thus, LMMSE precoding technique is the optimal in MU-MIMO downlink system and its solution is given by:

$$\mathbf{P}_{LMMSE} = \mathbf{H}_d^H(\mathbf{H}_d\mathbf{H}_d^H + \sigma^2\mathbf{I})^{-1},$$

for MRT precoding, it is on of the common methods due to its simplicity, which maximizes the SNR. MRT works well in the MU-MIMO system where the base station radiates low signal power to the users. Hence precoder matrix can be expressed as:

$$\mathbf{P}_{MRT} = \mathbf{H}_d^H.$$

The normalization constants can be given by:

$$\beta = \sqrt{\frac{tr(\mathbf{P}\mathbf{P}^H)}{E_s}}$$

for all linear precoding techniques.

5 Beamforming for Downlink System Model

In this section, the proposed RF beamforming and equalization scheme is presented. This scheme consists of two stages. In the first stage, the beamforming at the base station is used to reduce the effect of the IUI. The second stage uses the equalization at the mobile unit to reduce the effect of the ISI and to provide a better estimate of the desired data. The uplink beamforming weights are calculated via the minimum variance distortion-less response (MVDR) algorithm [22]. This algorithm minimizes the total received power while maintaining a unity power gain towards the desired user with his N_p paths. Assuming reciprocity between the uplink and the downlink and thereby the calculated uplink beamforming weights are used in the downlink to mitigate the IUI. In our work, we assume for simplicity that all users send their signals at the same time in the uplink.

The uplink weights of all users with their N_p paths are calculated as follows; in uplink, all users send their signals synchronously after spreading and modulation:

$$\bar{\mathbf{y}}_{BS} = \mathbf{A}_u \mathbf{H}_u \bar{\mathbf{P}}_u \bar{\mathbf{s}}.$$

Where $\bar{\mathbf{y}}_{BS}$ is the received data matrix at the output of the antenna array at BS. $\mathbf{A}_u$ is the array response matrix of the antenna array for all active users with their paths. $\mathbf{H}_u$ is the uplink channel response matrix. $\bar{\mathbf{P}}_u$ is the precoding matrix that used as access scheme between users for uplink. The multi-path MVDR algorithm is applied for calculating the weights as follows:

$$\mathbf{w}_k = \frac{Cov^{-1}(\mathbf{R}_{yy})\ \mathbf{a}_k}{[\mathbf{a}_k^H]^{-1} Cov^{-1}(\mathbf{R}_{yy})\ \mathbf{a}_k} \tag{8}$$

Where $\mathbf{R}_{yy}$ is $N_t \times N_t$ covariance matrix of the received signal at antenna array and $\mathbf{w}_k$ are the weight vector of the k^{th} user. These weights enable the antenna array to receive/transmit from/to a certain user in a multipath environment and to optimize the signal quality. The previous step is repeated K times to calculate all weights of the active users. Next, After calculating the weights of the active users at the uplink, we use these weights for downlink beamforming as: $\bar{\mathbf{y}}_{d,k} = \mathbf{H}_{d,k}\mathbf{A}_{d,k}\bar{\mathbf{W}}\bar{\mathbf{s}} + \bar{\mathbf{n}}_{d,k}$. Where $\bar{\mathbf{y}}_{d,k}$ is the received data vector at the desired UE. After that, the received signal is equalized to suppress the ISI as follows:

$$\hat{\mathbf{s}} = (\mathbf{H}_{d,k}^H \mathbf{H}_{d,k} + \alpha \mathbf{I})^{-1} \mathbf{H}_{d,k}^H \bar{\mathbf{y}}_{d,k}, \tag{9}$$

Finally, the decision process is performed to produce the estimate of the desired data. The optimum regularization factor α that minimizes the equalization error is 1/SNR, which is the MMSE weight.

6 Numerical Results and Discussion

Several simulations are carried out to test the performance of the proposed two-stage multiuser access scheme using MU-MIMO and beamforming. The simulation environment is based on the downlink MU-MIMO and beamforming system, in which each user transmits binary phase shift keying (BPSK) information symbols. The wireless channel model used in the simulation is the SCM model. It has N_p Raleigh fading taps. The fading is modeled as quasi-static (unchanged during the duration of a block).

In the first part of the simulations, a comparison study between the BB precoding, RF beamforming and both BB precoding combined with RF beamforming in single user (SU) case is conducted and the results, in terms of bit error rate (BER), are shown in Fig. 3. In BB precoding, the precoding is done

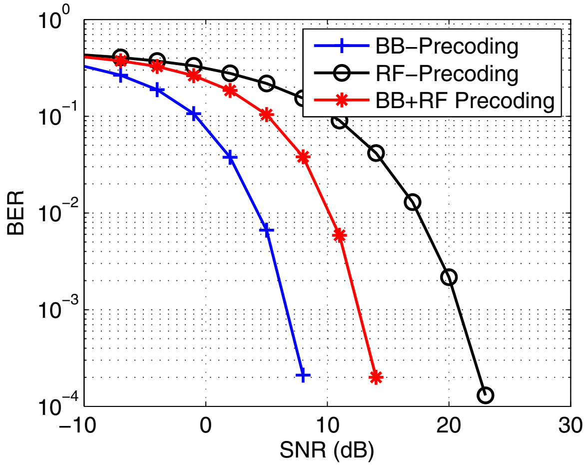

Fig. 3. Performance comparison for SU case between BB precoding with LMMSE precoder, RF beamforming with LMMSE equalization at the receiver side and BB with RF precoding using LMMSE precoder at $K = 1$, $N_t = 4$, $N_r = 1$, and BPSK

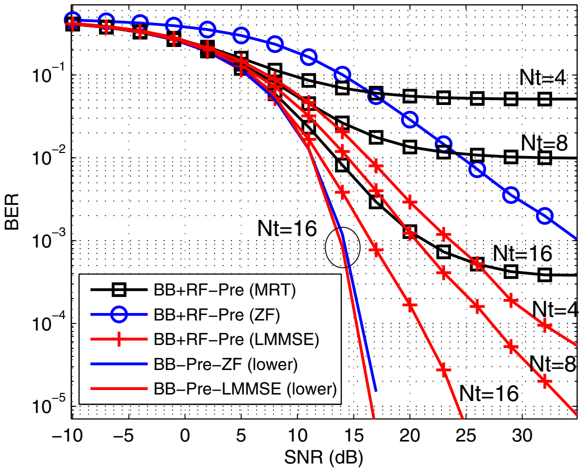

Fig. 4. Performance comparison for MU case between BB precoding and BB with RF precoding at $K = 4$, $N_t^c = 4$, $N_r = 1$, and BPSK

in the form of digital pre-processing that multiplies a particular coefficients with the modulated baseband signal per RF chain. For RF beamforming, the precoding is done in analog form where complex coefficients are applied to manipulate the RF beams by means of controlling the phase shifters and/or variable gain amplifiers (VGAs). As can be observed from Fig. 3, the BB precoding provides

Table 1. Computational complexity Comparison

Scheme	**Complexity (flops)**	for case: $N_t = 16$, $N_t^c = 4$, $K = 4$
BB Precoding (LMMSE)	$16{N_t}^3 + 3{N_t}^2$	66304
BB+RF precoding (LMMSE)	$16N_t^{c3} + 3N_t^{c2}$	1072

a higher degree of freedom as it has better performance, but at the expense of increased complexity. On the other hand, RF beamforming is a simple and effective method of generating high beamforming gains to user from a large number of antennas, but it has a degraded BER performance than BB precoding. Therefore, there is a tradeoff between performance and simplicity. Using a two-stage scheme as proposed, we can achieve good performance in between at reasonable complexity. This case is depicted by the middle curve in Fig. 3.

In the second part of the simulations, same comparison above is conducted for the case of multiuser system using ZF, LMMSE and MRT precoding for MU-MIMO as an access scheme. Fig. 4 shows the BER performance versus the SNR for that case. Note that in digital BB processing, the TX processing is complex while the RX processing is simple. In RF beamforming, the TX processing is simple while the RX processing is complex. The proposed two-stage approach will combine the benefits of both schemes achieving simple TX and RX processing. In addition, the results shows that the proposed two-stage scheme gives BER performance that is comparable to the digital BB processing only.

Moreover, the proposed two-stage scheme allows more users to be served since the BB MU-MIMO part will give access service to some users, while the RF BF part will also give access service to additional users.

7 Computational Complexity Analysis

In this section we assess the computational complexity of different multiuser access schemes. The computational load is primarily a function of the number of users K, the number of transmit antennas at BS Nt, the number of RF chains N_t^c and the number of receive antenna at each user $N_{r,k}$. The computational complexity considered here is expressed in terms of the total number of flops[1]. In real arithmetic, a multiplication followed by an addition needs 2 flops. With complex-valued quantities, a multiplication followed by an addition needs 8 flops. Thus, the complexity of a complex matrix multiplication is nearly 4 times its real counterpart. For a complex $m \times n$ matrix $\mathbf{A}$, we summarize the total FLOPs needed for the matrix operations as shown below:

1. Multiplication of $m \times n$ and $n \times p$ complex matrices $= 8mnp - 2mp$.
2. Pseudo-inversion of an $m \times n \quad (m \leq n)$ complex matrix$= \frac{4}{3}m^3 + 7m^2n - m^2 - 2mn$.

---

[1] A flop stands for floating point operation. Operations such as addition, multiplication, subtraction, division and compare are considered as one flop.

The required number of flops for the BB precoding and BB with RF precoding are given in Table 1. The case given in the table with $N_t = 16$, $N_t^c = 4$, $K = 4$, it is worth noting that with the decrease in the number of RF chains, there is a considerable reduction in complexity. Therefore, the proposed BB with RF beamforming scheme has low complexity compared with the BB precoding only.

8 Conclusion

We have proposed a novel two-stage multiuser access scheme for 5G cellular using massive MIMO and Beamforming. The results show that the proposed two-stage scheme will combine the benefits of both BB and RF precoding, achieving simple TX and RX processing. For the multiuser case, the proposed approach will also allow the system to accommodate more users since BB MU-MIMO part will give access service to some users, while the RF beamforming part will also give access service to additional users at minor error rate degradation.

Acknowledgments. This work was supported by NSTIP strategic technologies programs (no 11-ELE1854-02) in the Kingdom of Saudi Arabia.

References

1. Dahilman, E., Mildh, G., Parkvall, S., Peisa, J., Sachs, J., Selen, Y.: 5G radio access. Ericsson Review (2014)
2. Rappaport, T.S., Shu, S., Mayzus, R., Hang, Z., Azar, Y., Wang, K., Wong, G.N., Schulz, J.K., Samimi, M., Gutierrez, F.: Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!. IEEE Access **1**, 335–349 (2013b)
3. Roh, W., Seol, J.-Y., Park, J., Lee, B., Lee, J., Kim, Y., Cho, J., Cheun, K., Aryanfar, F.: Millimeter-Wave Beamforming as an Enabling Technology for 5G Cellular Communications: Theoretical Feasibility and Prototype Results. IEEE Communications Magazine **52**(2), 106–113 (2014)
4. Rangan, S., Rappaport, T.S., Erkip, E.: Millimeter wave cellular wireless networks: Potentials and challenges (2014). arXiv preprint arXiv:1401.2560
5. Rappaport, T.S., Gutierrez, F., Ben-Dor, E., Murdock, J.N., Qiao, Y., Tamir, J.I.: Broadband millimeter-wave propagation measurements and models using adaptive-beam antennas for outdoor urban cellular communications. IEEE Transactions on Antennas and Propagation **61**(4), 1850–1859 (2013a)
6. Rappaport, T.S., Roh, W., Cheun, K.: Mobile's millimeter-wave makeover. IEEE Spectrum **51**(9), 34–58 (2014)
7. Sulyman, A.I., Nassar, A.T., Samimi, M.K., Maccartney, G.R., Rappaport, T.S., Alsanie, A.: Radio propagation path loss models for 5G cellular networks in the 28 GHZ and 38 GHZ millimeter-wave bands. IEEE Communications Magazine **52**(9), 78–86 (2014)
8. Rappaport, T.S., Heath Jr., R.W., Daniels, R.C., Murdock, J.N.: Millimeter Wave Wireless Communications. Pearson Education (2015)
9. Hu, Y., Ji, B., Huang, Y., Yu, F., Yang, L.: Energy-Efficient Resource Allocation in Uplink Multiuser Massive MIMO Systems. International Journal of Antennas and Propagation (2014)

10. Yang, Y.-H., Lin, S.-C., Su, H.-J.: Multiuser MIMO downlink beamforming design based on group maximum SINR filtering. IEEE Transactions on Signal Processing **59**(4), 1746–1758 (2011)
11. Xiang, G., Edfors, O., Rusek, F., Tufvesson, F.: Linear pre-coding performance in measured very-large MIMO channels. In: 2011 IEEE Presented at Vehicular Technology Conference (VTC Fall) (2011)
12. Han, Y., Jin, S., Li, X., Huang, Y.: A joint SDMA and interference suppression multiuser transmission scheme for millimeter-wave massive MIMO systems. In: 2014 Sixth International Conference on Presented at Wireless Communications and Signal Processing (WCSP) (2014)
13. Sulyman, A.I., Hefnawi, M.: Adaptive MIMO Beamforming Algorithm Based on Gradient Search of the Channel Capacity in OFDM-SDMA Systems. IEEE Communications Letters **12**(9), 642–644 (2008)
14. Swindlehurst, A.L., Ayanoglu, E., Heydari, P., Capolino, F.: Millimeter-wave massive MIMO: the next wireless revolution? IEEE Communications Magazine **52**(9), 56–62 (2014)
15. Larsson, E., Edfors, O., Tufvesson, F., Marzetta, T.: Massive MIMO for next generation wireless systems. IEEE Communications Magazine **52**(2), 186–195 (2014)
16. Hoydis, J., ten Brink, S., Debbah, M.: Massive MIMO in the UL/DL of Cellular Networks: How Many Antennas Do We Need? IEEE Journal on Selected Areas in Communications **31**(2), 160–171 (2013)
17. Hoydis, J., ten Brink, S., Debbah, M.: Massive MIMO: How many antennas do we need? In: 2011 49th Annual Allerton Conference on Presented at Communication, Control, and Computing (Allerton) (2011)
18. Sun, S., Rappaport, T.S., Heath, R., Nix, A., Rangan, S.: MIMO for millimeter-wave wireless communications: beamforming, spatial multiplexing, or both? IEEE Communications Magazine **52**(12), 110–121 (2014)
19. Friis, H.T.: A note on a simple transmission formula. Proc. IRE **34**(5), 254–256 (1946)
20. Bogale, T.E., Le, L.B.: Pilot optimization and channel estimation for multiuser massive MIMO systems. In: 48th Annual Conference on Information Sciences and Systems (CISS), pp. 1–6 (2014)
21. Peel, C.B., Hochwald, B.M., Swindlehurst, A.L.: A vector-perturbation technique for near-capacity multiantenna multiuser communication-part I: channel inversion and regularization. IEEE Transactions on Communications **53**(1), 195–202 (2005)
22. Trees, H.V., Harry, L.: Optimum array processing, Part IV of detection, Estimation, and Modulation Theory. Wiley-Interscience, New York (2002)