Achievable Rate and Power Efficiency of Massive MIMO in Cooperative Network with ZF Receivers

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***Abstract*—In this paper, we consider a cooperative network, where base station (BS) and relay station (RS) are enabled with a large number of antenna. For such network, the achievable rate and power efficiency is investigated. In uplink scenario, received signals across the RS and BS are detected with zero forcing (ZF) detector. We have also chosen ZF technique for precoder design, which is utilized across the RS in end-to-end signal transmission. When statistics of channel matrix and precoding matrix are known then SNR and achievable rate can be eaisly found by using random matrix theory. In such network, performance is also measured under different cooperation protocol. We have derived the tractable lower bound for the achievable rate which has also been numerically verified. Numerical results analyze the impact of a large number of RS and BS antenna for determining the achievable rate, where total transmit power remains constant. On the other side, the impact of a total number of RS and BS antenna on power efficiency has also been investigated where variation with total power to RS antennas is observed keeping BS antenna constant and vice versa.**

Index Terms: **Direct decoding; Non-cooperative decoding; Cooperative decoding; ZF**

I. INTRODUCTION

Massive multiple-input-multiple-output (MIMO) is one of the key 5G technology that has potential to support increased data rate and power efficiency compared to conventional MIMO systems [1]. In multiuser scenario, large number of antennas introduce additional degree of freedom and can effectively serve many users in one time-frequency slot [2]. Prominently, in massive multiuser MIMO systems simple linear processing schemes, such as maximum ratio combining (MRC), zero forcing (ZF) and linear minimum mean-square error (MMSE) have been extensively used [3]. In this, SNR improvement is achieved through spatial multiplexing and better diversity. ZF and MMSE detection technique provide similar performance for large number of antenna. Hence, ZF detector is also applied in multi-cell uplink scenario, for improvising the total system throughput [4]. Under Known CSI, ZF detector offer lower computational complexity compared to MMSE and superior spectral efficiency compared to the MRC detector.

Spatial densification [2] and network densification [5] have become an integral part of modern wireless communication. Base station (BS) assisted by relay station (RS) is one of the practical example of a denser network that has also attracted a lot of attention due to its improved spectral efficiency and extended communication range. Cooperative network framed by BS and RS where both terminals are enabled with single antenna can be considered as the simplest example of a denser network. Rajiv Devrajan $et.al$ have analyzed the impact of imperfect CSI over achievable rate and power allocation for SISO cooperative network [6, 7].

Spatial and network densification have also extensively research under cooperative MIMO [8]. ZF is also used as a precoder which has also been discussed in cellular cooperative MIMO network for measuring QoS-aware power allocation [9]. In another form, two hop relay network where each hop is enabled with few antenna terminal, ZF detection can be applied across each receiving hop for getting total system capacity [10]. In [11], the achievable rate for a cooperative network consisting of a large number of RS antenna and end-to-end terminals are enabled with single antenna device has been addressed. But cooperative network consisting BS and RS where both terminals are enabled with a large number of antenna has not been addressed. This paper addresses such scenario with ZF based signal detection and precoding.

The major contribution of this paper can be summarized as follows

1) An analytical expression for total achievable rate along with power efficiency by formulating the end-to-end SNR in massive MIMO based cooperative network has been derived.
2) The achievable rate and power efficiency for different cooperation protocol [12] for a large number of antenna across BS and RS using ZF detector has been investigated.

The remainder of this paper is organized as follows. Different cooperation protocol and cooperative massive MIMO system are introduced in Section II while the channel model for such a complex network is presented in Section III. Based on channel model, end-to-end (E2E) SNR, total achievable rate under different cooperation protocol and power efficiency are also formulated in Section IV. The proposed models are numerically verified with simulation in Section V. The possible extension with certain limitation has been suggested in the conclusion presented in Section VI.

Notation: Superscript ($\dagger$) stands for the conjugate transpose and I_N is $N \times N$ identity matrix. The expectation operation and the trace operator are denoted by $\mathbb{E}(.)$ and Tr (.) respectively. Finally, we use $H_1 \sim \mathcal{CN}_{M,N}(0_{M\times N},\ I_M \otimes I_N)$ to denote the $M \times N$ circularly symmetric complex Gaussian matrix where each entries has zero mean and unit variance. Covariance matrix $\frac{1}{M}\mathbb{E}(H_1^{\dagger}H_1) \to I_N$ and $\frac{1}{N}\mathbb{E}(H_1 H_1^{\dagger}) \to I_M$

II. SYSTEM MODEL

Consider a cooperative network presented in Fig.1, where relay and BS are enabled with large number of antennas. For such a wireless network, BS and RS have M_r and M_s number of antennas, whereas K number of mobile users (MU) are enabled with single antenna and situated at the cell edge boundary, where $M_s > M_r > K$. In such network, E2E signal transmission occurs in two time slots. For uplink system, signal is received across RS and BS in 1^{st} time slot whereas received signal of RS is amplified and forwarded (AF) in 2^{nd} time slot. Based on such type of signal transmission we have considered three wireless link which has been given below and also presented in Fig.1.

1) 1^{st} link: MU → BS, (Multiuser MIMO)
2) 2^{nd} link: MU → RS, (Multiuser MIMO)
3) 3^{rd} link: RS → BS, (Point-to-point (p2p) MIMO)

When direct path between MU to BS does not provide enough gain, relay assisted cooperative network is used for enhancing the E2E SNR and total achievable rate. Following system models under different cooperation protocol [12] in massive MIMO based cooperative network is presented.

1) Direct Decoding

When channel gain between MU to BS is sufficiently large then there is no need of relay or no cooperation required. Therefore signal reception and detection occur in single time slot.

2) Non-cooperative Decoding

In this decoding scheme, it is assumed that direct path or 1^{st} link is either in deep fade or separation between MU to BS is enough large. Hence for improvising the E2E SNR, signal transmission occur in two time slots. RS receive the signal in 1^{st} time slot and transmit the received signal in 2^{nd} time slot.

3) Cooperative Decoding

Due to large separation between MU to BS we get less amount of power in 1^{st} time slot but due to presence of relay we receive good SNR in 2^{nd} time slot. Under this decoding scheme we are capable to linearly and coherently combined the 1^{st} time slot power to the next time slot for improvising the E2E SNR.

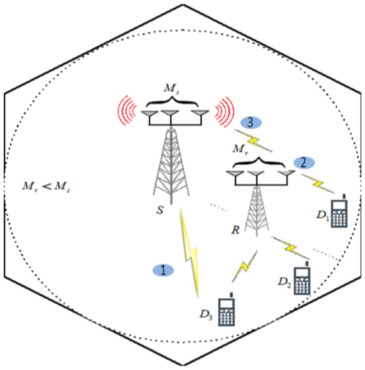

Fig. 1: Co-operative Network in Single cell system where relay and base station carry large number of antennas

III. CHANNEL MODEL

From Fig.1, the received signal across the BS when K number of MU transmitting, can be expressed as

$$Y_{b_1} = \sqrt{p_u} H_1 D_1^{1/2} X + n_{ub} \tag{1}$$

where p_u and X are the transmitted power by each user and $K \times 1$ transmit symbol vector respectively. Y_{b_1}, $n_{ub} \sim \mathcal{CN}(0, I_{M_s})$ are the $M_s \times 1$ received signal vector and noise vector respectively. $H_1 \sim \mathcal{CN}_{M_s,K}(0_{M_s\times K},\ I_{M_s} \otimes I_K)$ and D_1 are the circularly symmetric complex Gaussian CSCG random channel matrix from the MU to BS and $K \times K$ diagonal matrix (where each diagonal element carry large scale fading coefficient of each user for 1^{st} link). This received signal is further detected by applying ZF detection technique, when CSI is known. To derive the detected output, we will use of following Theorem [13], where $G_1 = H_1 D_1^{1/2}$.

Theorem 1 For a central Wishart matrix $G \sim \mathcal{G}_{\mathcal{N}}(M, I)$ with $M > N$

$$\mathrm{Tr}\big(\mathbb{E}[\{(G^{\dagger}G)^{-1}\}]\big) = \frac{N}{(M-N)} \tag{2}$$

From (2), if covariance matrix of central Whishart matrix is a diagonal matrix in stead of identity matrix then

$$\mathrm{Tr}\big(\mathbb{E}[\{(G_1^{\dagger}G_1)^{-1}\}]\big) = \sum_{k=1}^{K} \frac{1}{(M_s - K)\beta_{1k}} \tag{3}$$

where β_{1k} is the large scale fading coefficient between k^{th} user to BS for 1^{st} link. Using ZF detector, $A_{ub} = (G_1^{\dagger}G_1)^{-1}G_1^{\dagger}$, the detected signal vector can be expressed as

$$\begin{aligned} Y_{bd_1} &= A_{ub} Y_{b_1} \\ Y_{bd_1} &= \sqrt{p_u} X + D_{1_d} n_{ubd} \end{aligned} \tag{4}$$

where Y_{bd_1} and n_{ubd} are the $K \times 1$ detected signal vector and noise vector. D_{1_d} is the $K \times K$ diagonal matrix with diagonal entries are $\frac{1}{\sqrt{(M_s-K)\beta_{11}}}, \frac{1}{\sqrt{(M_s-K)\beta_{12}}}, \ldots\ldots\ldots, \frac{1}{\sqrt{(M_s-K)\beta_{1K}}}$ and $K \times 1$ noise vector respectively, where $\mathbb{E}[n_{ubd} n_{ubd}^{*}] = I_K$.

Similarly in same time slot, the received signal across RS for 2^{nd} link can also be expressed as

$$Y_{ur} = \sqrt{p_u} H_2 D_2^{1/2} X + n_{ur} \tag{5}$$

where Y_{ur} and $n_{ur} \sim \mathcal{CN}(0, I_{M_r})$ are the $M_r \times 1$ received signal vector and $M_r \times 1$ CSCG random vector respectively. $H_2 \sim \mathcal{CN}_{M_r,K}(0_{M_r \times K},\ I_{M_r} \otimes I_K)$, D_2 are the channel matrix from the MU to RS and $K \times K$ diagonal matrix carry large scale fading coefficient for each user in 2^{nd} link respectively. Likewise (2), we also detect this received signal through ZF detection technique across the RS, which can be expressed as

$$\begin{aligned} Y_{ur_d} &= A_{ur} Y_{ur} \\ Y_{ur_d} &= \sqrt{p_u} X + D_{2_d} n_{urd} \end{aligned} \tag{6}$$

The ZF detector at relay, $A_{ur} = (G_2^{\dagger} G_2)^{-1} G_2^{\dagger}$, where $G_2 = H_2 D_2^{1/2}$. Here Y_{ur_d} and n_{urd} are $K \times 1$ detected signal vector and $K \times 1$ detected noise vector, where $\mathbb{E}[n_{urd} n_{urd}^H] = I_K$ across the RS respectively. D_{2_d} is the $K \times K$ diagonal matrix with diagonal entries are $\frac{1}{\sqrt{(M_r-K)\beta_{21}}}$, $\frac{1}{\sqrt{(M_r-K)\beta_{22}}}$,........,$\frac{1}{\sqrt{(M_r-K)\beta_{2K}}}$ and. For (E2E) signal transmission this detected signal vector is further transmitted by applying AF relaying technique.

In 2^{nd} time slot the received signal for p2p MIMO network across the BS can be expressed as

$$\begin{aligned} Y_{b_2} &= \frac{1}{\sqrt{M_r}} \chi_{rb} H_3 D_3^{1/2} W Y_{ur_d} + n_{rd} \\ &\Rightarrow \frac{1}{\sqrt{M_r}} \chi_{rb} H_3 D_3^{1/2} W (\sqrt{p_u} X + D_{2_d} n_{urd}) + n_{rb} \end{aligned} \tag{7}$$

where Y_{b_2}, $H_3 \sim \mathcal{CN}_{M_s,M_r}(0_{M_s \times M_r},\ I_{M_s} \otimes I_{M_r})$, D_3, W, n_{rb} are the $M_s \times 1$ received signal vector, $M_s \times M_r$ channel matrix from RS to BS, $M_r \times M_r$ diagonal matrix carry large scale fading coefficient for 3^{rd} link from each relay antenna terminal, $M_r \times K$ random unitary matrix, where $WW^H = I_{M_r}$ and $M_s \times 1$ noise vector for 3^{rd} link. Amplification factor χ_{rb} can be expressed as

$$\chi_{rb} = \sqrt{\frac{p_r}{\frac{K \times p_u}{\text{Tr}\left(\mathbb{E}\left\{\left(D_{2_d}^{\dagger} D_{2_d}\right)^{-1}\right\}\right)} + \frac{1}{K}\mathbb{E}[\text{Tr}\ (n_{urd} n_{urd}^{\dagger})]}} \tag{8}$$

In such a p2p MIMO network, let $G_3 = H_3 D_3^{1/2}$ and $G_d = G_3 W$. Under known CSI and precoding matrix (W) the joint expectation of trace of $(G_d^{\dagger} G_d)^{-1}$ matrix can be understood by **Theorem 2** which is as follows

Theorem 2 If $U \sim \mathcal{CN}(0,1)^{M \times N}$ and $V \sim \mathcal{CN}(0,1)^{N \times P}$ are two random matrices and Z is the another random matrix such that $Z = UV$, where $M > N > P$. In such a scenario trace of the inverse of covariance matrix ie $(Z^{\dagger} Z)^{-1}$ converges like (9), which has been presented below

$$Tr\big(\mathbb{E}\big[(Z^{\dagger} Z)^{-1}\big]\big) \approx \frac{K}{(M_s - K)(Mr - K)} \tag{9}$$

Referring the above relation we can detect the transmitted signal across RS by ZF detector under known CSI and precoding matrix. Hence

$$Tr\big(\mathbb{E}[(G_d^H G_d)^{-1}]\big) = \frac{K}{(M_r - K)(M_s - K)\ \beta_r} \tag{10}$$

where $\beta_r = \beta_{31} = \beta_{32}..... = \beta_{3M_r}$ be the large scale fading coefficient. Since large scale fading mainly depends on the separation between transmitter and receiver. The detected signal vector considering G_d as an overall channel matrix by ZF detector can be expressed as

$$\begin{aligned} Y_{bd_2} &= A_{rs} Y_{ur_d} \\ Y_{bd_2} &= \underbrace{\frac{1}{\sqrt{M_r}} \chi_{rb} \sqrt{p_u} X}_{Signal\ Component} + \underbrace{\chi_{rb} \left\{G_d^{\dagger} G_d\right\}^{-1} G_d^{\dagger} D_{2_d} n_{urd}}_{Interference} + \\ &\underbrace{\left\{G_d^{\dagger} G_d\right\}^{-1} G_d n_{rb}}_{Noise} \end{aligned} \tag{11}$$

where ZF detector, $A_{rs} = (G_d^{\dagger} G_d)^{-1} G_d^{\dagger}$. Under cooperative diversity scenario the observed received signal in two time slots can be expressed as

$$Y_d = [Y_{bd_1} Y_{bd_2}] \tag{12}$$

where Y_d is the $K \times 2$ received signal matrix. First column carry the detected signal of 1^{st} time slot whereas second column carry the detected signal of 2^{nd} time slot. Observed power after linearly and coherently combining the received signal can be expressed as

$$P_{obs} = Tr\big(\mathbb{E}\{Y_d^{\dagger} Y_d\}\big) \tag{13}$$

IV. ACHIEVABLE RATE ANALYSIS

Signal power and noise power in 1^{st} time slot remains independent from signal power and noise power of the 2^{nd} time slot. Similarly observed SNR in 1^{st} time slot remains independent from the SNR of 2^{nd} time slot in e2e signal transmission.

A. Observed SNR γ_1 in 1^{st} time slot :

In 1^{st} time slot the observed power P_{d1} is a $K \times K$ covariance matrix. Mathematically it can be expressed as

$$P_{d1} = \underbrace{p_u I_K \mathbb{E}(X^{\dagger} X)}_{Signal\ Power\ matrix} + \underbrace{D_{1_d}^{\dagger} D_{1_d} E(n_{ub}^{\dagger} n_{ub})}_{Noise\ Power\ Matrix} \tag{14}$$

This covariance matrix consist sum of signal power and noise power which has been presented in (14). In perfect channel condition covariance matrix of signal power is a diagonal matrix after applying ZF detection technique. Observed covariance matrix of SNR can be expresses as

$$\gamma = p_u I_K \mathbb{E}(X^{\dagger} X)\{D_{1_d}^{\dagger} D_{1_d} E(n_{ub}^{\dagger} n_{ub})\}^{-1} \tag{15}$$

where γ is a $K \times K$ matrix. Simplified form of (15) can be expressed as

$$\gamma = \left\{ \begin{matrix} p_u(M_s-K)\beta_{11} & \epsilon_{12} & \cdots & \epsilon_{1K} \\ \epsilon_{21} & p_u(M_s-K)\beta_{12} & \cdots & \epsilon_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ \epsilon_{K1} & \cdots & \cdots & p_u(M_s-K)\beta_{1K} \end{matrix} \right\} \tag{16}$$

where γ is the $K \times K$ matrix and $\epsilon_{ij} \to 0 \ \forall\, i, j \ \&\ i \neq j$

From Jensen's inequality

$$\mathbb{E}\{C(\gamma)\} \leq \log_2(1+\bar{\gamma}) \tag{17}$$

where average SNR in 1^{st} time slot or under direct decoding scheme can be expressed as

$$\bar{\gamma_1} = \frac{\gamma_{11}+\gamma_{12}+......+\gamma_{1K}}{K} \ \forall\ \gamma_{1j} = p_u(M_s-K)\beta_{1j} \tag{18}$$

B. Observed SINR γ_2 in 2^{nd} time slot

In 2^{nd} time slot the received signal of each user is precoded and transmit in amplify and forward manner. In such a relaying scheme, during detection and amplification, noise is also amplified. From (11), observed signal power, interference power and noise power in 2^{nd} time slot have been given below.

$$Signal\ Power\ (S) = p_u \frac{\chi_{rb}^2}{M_r} I_K$$

Similarly interference power after mathematical simplification can be expressed as

$$Interference\ (I) = \frac{\chi_{rb}^2}{M_r(M_r-K)} D_{2_d}^{\dagger} D_{2_d} \mathbb{E}(n_{urd} n_{urd}^*)$$

Whereas expected noise power is formulated using **Theorem 2** that can be expressed as

$$Noise\ (N) = \frac{1}{(M_s-k)(M_r-k)\beta_r} \mathbb{E}(n_{rb} n_{rb}^*)$$

So observed SINR in 2^{nd} time slot across the BS can be expressed as

$$\gamma_2 = \frac{S}{I+N} \tag{19}$$

where γ_2 is also a $K \times K$ matrix. Hence simplified covariance matrix of SNR can be expressed as

$$\begin{aligned} \gamma_2 =& p_u \frac{\chi_{rb}^2}{M_r} I_K \Big\{ \frac{\chi_{rb}^2}{M_r(M_r-K)} D_{2_d}^{\dagger} D_{2_d} \mathbb{E}(n_{urd} n_{urd}^*) + \\ & \frac{1}{(M_s-k)(M_r-k)\beta_r} \mathbb{E}(n_{rb} n_{rb}^*) \Big\}^{-1} \end{aligned} \tag{20}$$

From this analytical observation, the SNR experienced at the BS by k^{th} user can be expressed as

$$\gamma_{2k} = \frac{p_u \frac{\chi_{rb}^2}{M_r}}{\frac{\chi_{rb}^2}{M_r(M_r-K)\beta_{2k}} + \frac{1}{(M_s-K)(M_r-K)\beta_r}} \tag{21}$$

So average SNR can be expressed as

$$\bar{\gamma_2} = \frac{\gamma_{21}+\gamma_{22}+......+\gamma_{2K}}{K} \tag{22}$$

Hence under non-cooperative decoding scheme the observed capacity, due to E2E signal transmission can be expressed as

C. Achievable Rate Analysis

Using derived SNR and SINR, we can eaisly formulate the achievable rate under different cooperation protocol. Lower bound capacity for direct decoding scheme can be expressed as

$$C_{Direct} = \sum_{i=1}^{K} \log_2(1 + p_s(M_s-K)\beta_{1K}) \tag{23}$$

Similarly lower bound for non-cooperative decoding can be expressed as

$$C_{non-coop} = \sum_{k=1}^{K} \frac{1}{2} \log_2(1+\gamma_{2k}) \tag{24}$$

Here degree of freedom in such scheme is 0.5 because e2e signal transmission occurs in two time slot. Meanwhile utilizing the optimum link performance (1^{st}, 2^{nd}, 3^{rd}) the observed achievable rate under cooperative decoding scheme with ZF detector can be expressed as

$$C_{coop} = \sum_{k=1}^{K} \frac{1}{2} \log_2(1+\gamma_{1k}+\gamma_{2k}) \tag{25}$$

Putting average SNR from (18) and (22), we can also express the upper bound achievable rate in cooperative decoding scheme

$$C_{upper} = \frac{K}{2} \log(1+\bar{\gamma_1}+\bar{\gamma_2}) \tag{26}$$

From above formulation it is clear that total achievable rate depends on RS and BS antenna both under different cooperation protocol.

D. Power Efficiency Analysis

In case of uniform power assignment to each user the power efficiency for such system can be expressed as

$$\eta_{ee} = \frac{CB}{Kp_u + p_r} \tag{27}$$

where C is the observed total achievable rate in (bps/Hz) and B is bandwidth consumption during uplink signal transmission. For p2p network relay power can be minimized by increasing the number of relay antennas for getting constant amplification factor χ_{rb}. Similarly transmit power p_u can also be scaled by increasing the number of M_r and M_s [14] keeping total achievable rate constraints remain fixed.

V. RESULT AND DISCUSSIONS

In this section, investigated achievable rate and power efficiency have been numerically verified. Large number of antenna across BS and RS plays a vital role for evaluating the system performance of proposed wireless network. Relay is placed in between the cell edge user and BS. In above section, it has already been mentioned that there exist three wireless links for such network. Large scale fading coefficient is considered to be 0.001 for 1^{st} wireless link or in another sense $\beta_{1k} = 0.001$ for $k = 1, 2, ...K$. For the 2^{nd} link (between MU to RS), $\beta_{2k} = 0.01$ where $k = 1, 2..., K$. In same network, large scale fading coefficients for p2p MIMO network (3^{rd} link) due to each relay antenna terminal is 0.01 or $\beta_{3m} = 0.01$ for $m = 1, 2, ...M_r$. Total number of mobile users ie $K = 3$ remain fix whereas parameter like M_r and M_s are considered to be variable. Total transmit power by all users ie $\sum_{i=1}^{K} p_{u_i} = 15\ dB$ and transmit power by RS $p_r = 15\ dB$ also remain fix for numerical validation. The achievable rate for different cooperation protocol using ZF detector has been shown in Fig.2 and Fig.3. For three wireless link, channel condition are supposed to be perfect ie BS knows the CSI for 1^{st} and 3^{rd} link. Similarly for 3^{rd} link BS also knows the precoding matrix along with channel condition for p2p MIMO network whereas RS knows the CSI for 2^{nd} wireless link. When transmit power (p_r, p_u) and a total number of BS antenna $M_s = 50$ are constant and CSI across each node along with precoding matrix are known then the impact of a total number of RS antenna M_r on achievable rate has been shown in Fig.2. In this plot, the achievable rate remains flat due to the variation of M_r for two curve. The highest flat response is observed through direct decoding when reception and detection of transmitted signal occur in single time slot whereas lower flat response is nothing but the observed capacity in 1^{st} time slot under cooperative decoding scheme. For these two responses, the achievable rate remains independent form the M_r and another parameter like power remains constant. Observed analytical results are also compared with the simulated result where all simulation results were averaged over 10000 independent channel realization. When received power in 1^{st} time slot is ignored the achievable rate under the non-cooperative scheme and has been shown in Fig.2. End-to-end SNR and total achievable rate highly depend on M_r which can be easily observed through Fig.2. When received signal of two-time slot across BS are linearly and coherently combined, the overall SNR increases which result high achievable rate can also be observed in Fig.2 under cooperative decoding scheme. Since signal transmission occurs in two-time slot hence achievable rate performance is lower for less number of relay antenna in comparison to direct decoding. But if number of relay antenna increases we observe better performance. Under this scheme, system complexity mainly decoding complexity increases but our SNR also increases significantly.

Similarly in Fig.3 achievable rate also increases by increasing M_s. When non-cooperative decoding protocol is executed during end-to-end signal transmission, we observe the flat response due to the variation of M_s. Although end-to-end SNR in 2^{nd} time slot depends on M_r and M_s but impact of SNR improvement due to M_s become nullified. Because in AF relaying, carry forwarded noise power amplify in 2^{nd} time slot with same proportion as a signal power using ZF detection. Hence end-to-end SINR remains constant even if for very large M_s is taken.

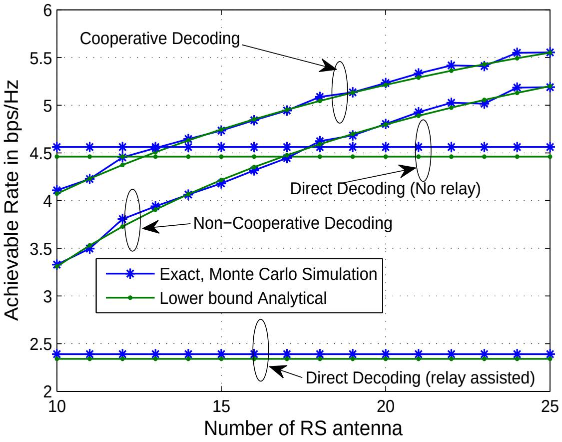

Fig. 2: Achievable rate vs total number of RS antenna where $K = 3$, $M_s = 50$, $p_r = 15\ dB$ and $\sum_{i=1}^{K} p_{u_i} = 15\ dB$

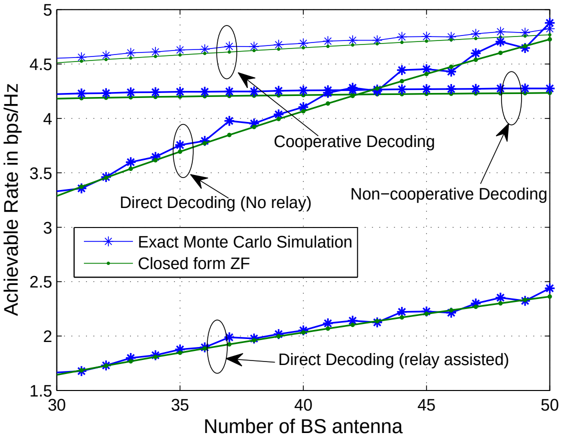

Fig. 3: Achievable rate vs total number of BS antenna where $K = 3$, $M_r = 15$, $p_r = 15\ dB$ and $\sum_{i=1}^{K} p_{u_i} = 15\ dB$

For justifying the power efficiency we make our transmitted power as a variable parameter. At constant M_s, such network is less energy efficient for the fewer number of M_r at low transmit power constraints. At same power, such network will be more energy efficient if M_r increases. From Fig.4 we can observe that small increment of M_r makes more energy efficient to this wireless network. In the same network if the number of BS antenna M_s is increased with larger number keeping M_r to be constant, such network becomes less energy efficient which can be observed from Fig.5.

VI. CONCLUSION

In this paper, we have considered the application of massive MIMO in cooperative networks. We first derived the tight lower bound of the achievable rate which is also verified with Monte Carlo simulation result. In such simulation, a large number of channel realization is averaged. We then presented the different types of cooperation protocol and compared their performance in massive MIMO scenario using ZF detector across the receiver. We have also discussed the impact of

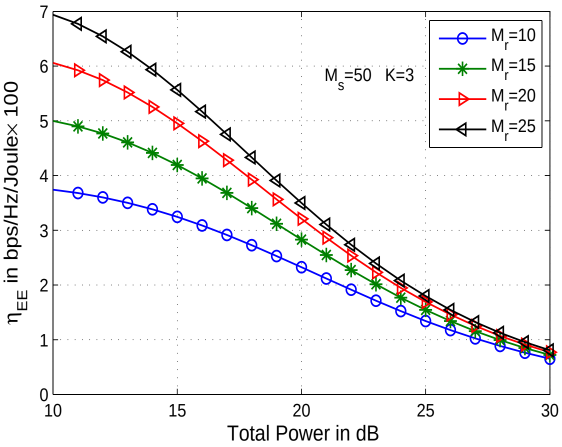

Fig. 4: EE vs total transmit power $\left(P_T = p_r + \sum_{i=1}^{K}\right)$ in dB where $K = 3$, $M_s = 50$

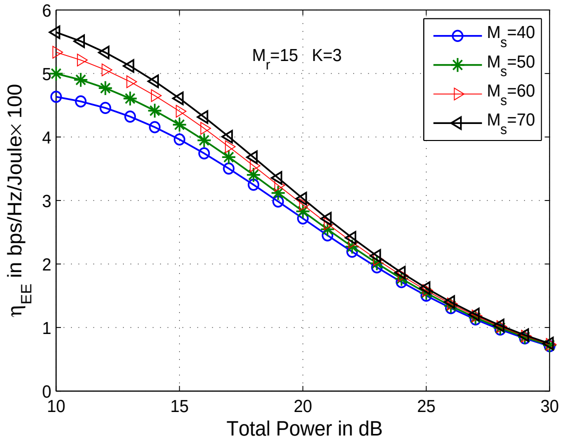

Fig. 5: EE vs total transmit power $\left(P_T = p_r + \sum_{i=1}^{K}\right)$ in dB where $K = 3$, $M_r = 15$

large number of antenna over power efficiency. The analytical results thus can facilitate the basic understanding towards application area of massive MIMO in cooperative network.

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