Power Consumption Modelling in massive-MIMO Systems to Increase Energy Efficiency

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ABSTRACT

This work provides a simple, realistic and practically implementable model of energy efficiency in massive MIMO systems. The linear processing schemes are used for precoding and detection. A power consumption model is proposed that pondered the total power consumption including uplink and downlink communication in a massive MIMO system. The optimal values of a number of the served user terminal and the total transmit power are computed at which the optimal energy efficiency values are achieved for each processing scheme. The provided results support the precision of the projected power consumption model as considerable enhancements.

Ⅰ. INTRODUCTION

In massive MIMO architecture, the base station is prepared by using a large number of transmission antennas to provide considerable success in exploiting spatial resources [1]. A two-cell scenario in which, UEs are randomly spread in the cell. It also shows the desired UEs and interference scenario of UEs in neighboring cells. We are aimed at providing deep understandings regarding the influence of total antennas at the station, users served and the power ingestion on the computation of energy efficiency in a massive MIMO system.

Ⅱ. SYSTEM MODEL

We have considered a single-cell scenario for massive MIMO systems where the BS (base station) with M antennas are used to attend N single-antenna user equipment (UEs). The B is bandwidth, T_{coh} and B_{coh} are coherence time and bandwidth, respectively. In further, ɣ (UL), ɣ (DL) symbols are used as constant transmission ratio symbols for bidirectional transmissions, correspondingly. Fig.1 provides the demonstration of Time Division Duplex (TDD) Coherence block frame for bi-directional transmissions. The received vector (at l^{th} BS) is signified by Y_l where $Y_l \in \mathbb{C}^{M}$ is

$$Y_l = \sum_{l=1}^{N} G \sqrt{\rho_l^{Tx}}\, x_l + n_l \quad (1)$$

In (1), the M×N channel matrix amongst UE and station is denoted by G. Fig. 1. Bi-directional Time Division Coherence block frame.

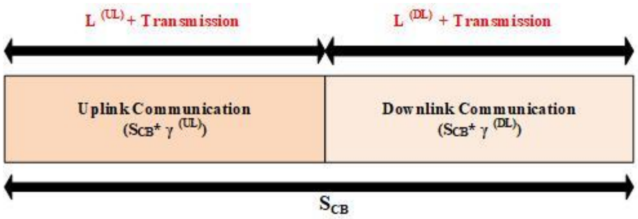

Fig. 1: Bi-directional Time Division Coherence block frame

The $x_l\sqrt{\rho^{TX}}$ represents the N×1 symbol vectors and average dispersed power is denoted with ρ^{TX}. Moreover, the noise vector is represented by n_l that is AWGN for which the variance is 1 and mean is zero. The g_{il} is written as $g_{il} = h_{il}\sqrt{\beta_{il}}$, where l = {1, 2⋯ N}, h_{il} is flat-fading coefficient (from l^{th} UE to i^{th} antenna of station). The Q = $[q_1, q_2, ..., q_i]$ $\in \mathbb{C}^{M\times N}$ denotes the uplink received matrix where the q_i column is assigned to the i^{th} UE. The linear pre-coding matrix for three processing techniques is given as (2).

$$Q = \begin{cases} H\,(H^H H)^{-1} & Zero\ Forcing \\ H(H^H H\, P^{UL} + \sigma^2 I)^{-1} & MMSE \\ H & MRT \end{cases} \quad (2)$$

In (2), $(.)^H$and $(.)^{-1}$ denotes Hermitian matrix and inverse transpose, correspondingly. H includes the values of channels for all UEs. The symbol r represents the concentrated distance of a UE for communication and d m is the least distance of a UE. The UEs are carefully chosen from $f(x)$[2].

$$f(x) = \begin{cases} \left(\pi(r^2 - d_m^2)\right)^{-1} & d_m \le \|x\| \le r \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

The fading is large scale fading symbolized by ζ given as ζ = $(\omega/\|x\|^{\varphi})$, where φ represents the path loss exponent and its value is greater than 2, ‖.‖=Euclidean norm and the value of constant ω is greater than 0 that is channel attenuation at least distance d_m. The inverse channel attenuation is calculated as (4) [3].

$$\mathrm{E} = \mathbb{E}((\zeta)^{-1}) = \left\{ \frac{(r^{\varphi+2} - d_m^{\varphi+2})}{((1+(\varphi/2))(r^2 - d_m^2)\omega)} \right\} \quad (4)$$

Ⅲ. Methodology and Calculations

The average data rate can be calculated as: $R_i^{tot} = R_i^{UL} + R_i^{DL}$. The achievable rate for single-cell uplink communication is $\left\{ R_i^{UL} = \overline{R}_{UL}\left(\gamma^{UL}\left(1 - \frac{L^{UL}N}{S_{CB}\,\gamma^{UL}}\right)\right)\right\}$ where, γ^{UL} gives uplink fraction. $\overline{R}_{UL}$ is the gross rate as:

$$\overline{R}_{UL} = B\log\,(1+\Phi_1), \Phi_1 = \frac{\left(p_i^{UL}|q_i^H h_i|^2\right)}{\sum_{l=1,l\neq i}^{i} p_l^{UL}|q_i^H h_l|^2 + \sigma^2\|q_i\|^2} \tag{5a}$$

where σ^2 is noise power. The uplink power is equal to $P^{UL} = [p_1^{UL}, p_2^{UL}, \ldots, p_i^{UL}]^T$. According to [2] if zero-forcing pre-coder is applied where M≥ $N+1$, where ρ is proportional to received SINR. R_i^{tot} in (5b) as [3].

$$R_i^{tot} = \left(N - \left(\frac{N(L^{UL}+L^{DL})}{S_{CB}}\right)\overline{R}\right) \tag{5b}$$

The total power dissipation can be modelled as $\{P_{total} = P_{PA} + P_{Cir}^{total}\}$. where, P_{PA} is the power absorption by amplifier and P_{Cir}^{total} represents the circuit power consumed by different components of UE and BS, correspondingly [4], $P_{PA} = \frac{B\gamma}{\eta}\sum_{N=1}^{N}\mathbb{E}\{p_N^{UL}\}$. The overall power ingestion by the amplifier is the sum of power given as

$$P_{PA}^{ZF} = \left\{\frac{(\rho NB\sigma^2)}{\eta_{PA}}\left(\frac{r^{\varphi+2} - d_m^{\varphi+2}}{\omega\,(1+(\varphi/2))(r^2-d_m^2)}\right)\right\} \tag{6}$$

The following mathematical expression defines the calculation of power consumption by the circuit components.

$$P_{Cir}^{total} = P_{\mathrm{t}} + P_{\mathrm{C/d}} + P_{\mathrm{b}} + P_{\mathrm{e}} + P_l + P_{\mathrm{s}} \tag{7}$$

In (7), P_t represents the power consumed by transmitter and receiver chains. In further, the power disbursed in coding and decoding is written off as $P_{C/d}$ and modelled as

$$P_b = \left(\sum_{i=1}^{N}\left(\mathbb{E}\left(R_i^{UL} + R_i^{DL}\right) * (P_{cod} + P_{dec})\right)\right) \tag{8}$$

linear pre-coding power for MRT/MRC is calculated as (9).

$$P_l^{MRC/MRT} = \left\{\frac{2MNB}{\Psi_{BS}}\left(1 - \left(\frac{L^{UL}+L^{DL}}{3S_{CB}}\right)\right) + \left(\frac{3BMN}{S_{CB}\Psi_{BS}}\right)\right\} \tag{9}$$

Furthermore, for ZF processing, the power ingestion is approximately intended as (12)

$$P_l^{ZF} = \left\{\left(\frac{BN^3}{3S_{CB}\Psi_{UE}}\right) + \left(\frac{BM(3N^2+N)}{\Psi_{BS}}\right)\right\} \tag{10}$$

The energy efficiency gain can be calculated as in (13).

$$\max_{\substack{M,K\in\mathbb{Z}\\ \overline{R}\geq 0}}(\eta_{EE}) = \left\{\frac{\sum_{i=1}^{M}(R_i^{tot})}{\left(P_{Tx}^{UL} + P_{Tx}^{DL} + P_{Cir}^{total}(M,N,\overline{R})\right)}\right\} \tag{11}$$

IV. Simulation Results:

In Fig. 3, the graphical results of energy efficiency gain vs M for different precoders are presented. As compare to [2], our projected power consumption modelling displays improved performance. Fig. 2 reveals the difference of results in which the maximum value opposing to the M at the base station in single-cell set-up stretches 15 % enhanced results by a fewer number of transmission antennas. Fig.3 shows the power ingestion by an amplifier that exploits the efficiency gain for diverse values of (M) with optimal number of UEs (N). The power ingestion for MMSE technique is upto 50 Watt, ZF with perfect-CSI and imperfect-CSI is 55 and 70 watt, correspondingly while for MRT/MRC numerical assessment is 5 Watt and it is fairly lesser as compared with other two schemes.

V. CONCLUSION

We can realize maximum efficiency gain by using ZF and MMSE processing schemes however, the letter one is more complex as compared to ZF. The MRT is simple as compared to ZF and MMSE but numerical values of efficiency gain are low.

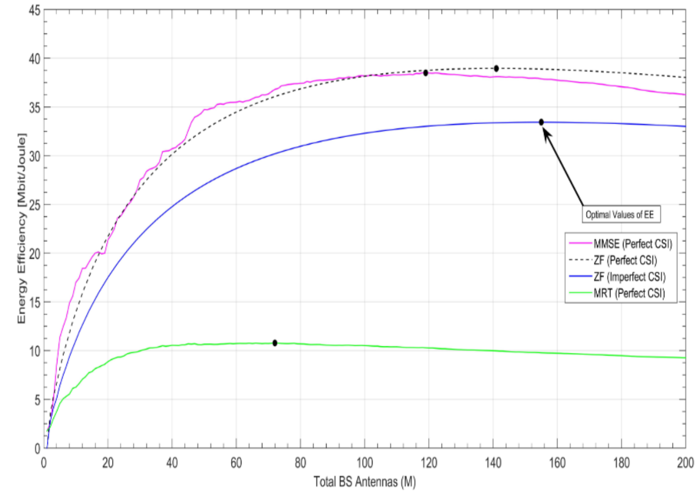

Fig. 2. EE Performance Comparison

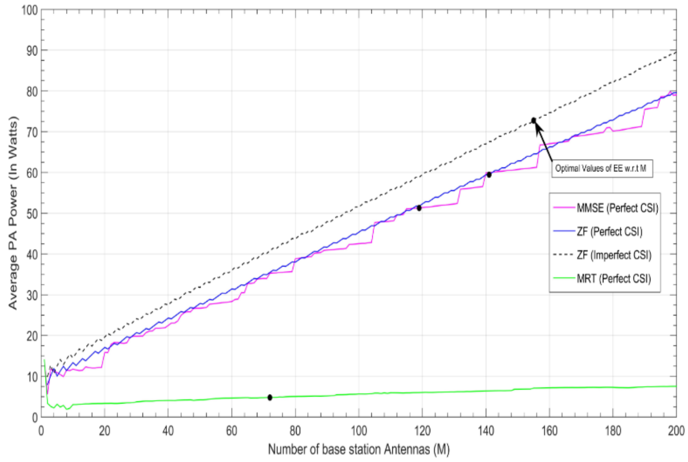

Fig. 3. Comparison of PA's power consumption

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government. (MSIT) (No. 2022R1A2B5B01001994)

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