Green Network Design in Downlink MU-MIMO System Using Convex Optimization Technique

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Abstract: Wireless technology has become the primary enabler of mobility and ubiquitous network access over the past decade. Multiuser- MIMO (MU-MIMO) has emerged as one of the prime technologies for achieving spectral efficiency (SE) in 4G LTE- A system. In addition to spectral-efficiency improvement, energy efficiency (EE) is becoming increasingly important for wireless communications because of the slow progress of battery technology and the growing requirements of anytime and anywhere multimedia applications. But this two design criteria (SE and EE) conflict with each other and a careful study of their trade-off is necessary for green network planning in future wireless communication systems. By considering the SE requirement, as a constrained optimization problem where constraints redefined to maximize EE using convex optimization technique and it is done for a 2×2 antenna configuration. It is proposed to use 4×4 MIMO antenna configuration and also an optimal beam forming design for both 2×2and 4×4 configuration is considered.

Keywords: MU-MIMO, LTE-A, Beam forming, Green Network, Energy Efficiency.

I. INTRODUCTION

The next generation wireless networks are expected to provide high speed internet access anywhere and anytime. The popularity of smartphones doubtlessly accelerates the process and creates new traffic demand. Exponentially growing data traffic and the requirement of ubiquitous access have raised dramatic expansion of network infrastructures and fast escalation of energy demand. To meet the challenges raised by the high demand of wireless traffic and energy consumption, green evolution has become an urgent need for wireless networks today. Among many features in the Long term Evolution Advanced (LTE-A), which supports 1Gb/s throughput in downlink and 500Mbps in the uplink, the multi-user multiple-input-multiple-output (MU-MIMO) scheme has been identified as one of the key enablers for achieving high spectral efficiency. From both the theory and design perspectives, MU-MIMO systems have several unique features distinct from single-user MIMO (SU-MIMO) systems. In SU-MIMO where the spatial multiplexing capability of a single user’s channel is limited either due to signal-to-interference-plus-noise ratio (SINR), or fading correlations among antenna elements or by the number of receive antennas at the user side.

Once spectral efficiency was the performance metric of choice, now EE and the engineering trade-off between both metrics are also scrutinized to find an appropriate trade-off. The objective function is to design a green communication system by considering the trade-off relationship. Given the SE requirement and maximum power limit, a constrained optimization problem is formulated to maximize EE. The optimization problem where constraints are modeled as a cubic inequality and then a novel resource allocation algorithm to achieve maximum EE in a given SE. Both circuit and transmit power is considered while designing optimal EE systems. The optimization objective is to maximize EE while satisfying SE requirements. MU-MIMO networks are exposed to co-channel interference. In order to mitigate the effect of co-channel interference and improving the performances of the system Beamforming technique is also considered.

II. EXISTING SYSTEM

Green Communication design in MU-MIMO system with 2×2 antenna configuration in LTE network.

A. SYSTEM MODEL

The MU-MIMO system is illustrated in the fig.1 based on LTE technology.

Fig. 1 MU-MIMO System: Hexagonal Cell Layout

For the single cell MU-MIMO system, interference is termed as intra-cell interference i.e. multiuser interference in the case of MU-MIMO. Intra-cell interferences are originated from the UEs of the same cells. To mitigate this interference, zero-forcing (ZF) precoding is considered, which transmits the signals towards the intended user’s direction and nulls in the direction of other users, thus
reducing intra-cell interference. Adaptive power allocation (according to the 3GPP LTE adaptive modulation & coding scheme using the channel condition among PRBs) is considered and total transmit power $P = \sum_{m=1}^{M} p_u^m = \sum_{u=1}^{U} \sum_{m=1}^{M} p_u^m$ available on each HC is divided among the PRBs based on the channel condition of the UE. The main channel measurement considered is the Signal-to-Interference-plus-Noise-Ratio (SINR) of the UEs in the system. In order to determine whether a transmission has been successful, the SINR measured for a given path is employed to determine the packet error rate (PER) for the block of data sent on each PRB. The SINR of the UE, perceived by a UE $u$ on PRB $m$ can be divided into a static and a dynamic part that depend on parameters $\epsilon$ and $\sigma$, respectively. The pseudo-code for the MU-MIMO cell can be expressed as

$$\Gamma_u^m = \frac{p_u^m |H_u^m W_u^m|^2}{\sum_{u \neq u} p_u^m |H_u^m W_u^m|^2 + \sigma^2}$$

where $u \in \{1, 2, ..., U\}; H_u^m$ is the complex channel matrix whose elements combine path loss, shadowing and fast fading and which models the link between the $u^{th}$ UE and eNB of the cell; $W_u^m$ is the precoding matrix for the link between the eNB and the UE $u$; and $\sigma^2$ is the Additive White Gaussian Noise (AWGN) power as perceived by the UE. The intra-cell interference is mitigated using zero-forcing precoding design, taking the pseudo-inverse of channel matrix.

The total bandwidth $B$ is equally divided into PRB, each with a bandwidth of $W = B/M$. Then, the spectral efficiency, $SE$, obtained by Shannon theorem, of user $u$ on PRB $m$ is

$$SE_u^m = \log_2 (1 + \Gamma_u^m)$$

Then, the maximum achievable data rate, $S_u^m$, of user $u$ on PRB $m$ is

$$S_u^m = W \cdot SE_u^m$$

Let $S_u^m$, be the data rate for user $u$ on PRB $m$ at any instant. Overall system throughput $S$ and total transmit power $P = \sum_{u=1}^{U} \sum_{m=1}^{M} p_u^m$, $S = \sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m$, where $p_u^m$ is the transmitted power of eNB for user $u$ on PRB $m$. Transmit power also counts on the power amplifier efficiency, which is denoted as $\alpha$ where $\alpha \in [0, 1]$ and depends on the design and implementation of the transmitter. Apart from the transmit power we consider circuit power as well. From circuit energy consumption, $P_c$, can be divided into a static part and a dynamic part that depend on parameters of active links. $P_c = P_{st} + \delta S$, where $P_{st}$ is the static circuit power in the transmit mode and $\delta$ is a constant denoting dynamic power consumption per unit data rate.

B. PROBLEM FORMULATION

For a downlink MU-MIMO LTE network, EE optimization problem can be formulated as

$$\max SE = \frac{\sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m}{P_a + P_{st} + \delta \sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m}$$

(4)

EE is defined as transmitted bits per unit energy consumption at the transmitter side, where the energy consumption includes transmission energy consumption and circuit energy consumption of transmitter, subject to constraint:

1. $S_u^m \leq S_u^m \leq S_u^m$

2. $S_u^m > 0$

where $S_u^m$ denotes the minimum rate requirement for user $u$ on PRB $m$.

In order to ensure the convexity of the proposed optimization problem, constraint is redefined as a cubic inequality. The reformulated constraint based on non-negativity, is given as

$$1. (S_u^m). (S_u^m - S_u^m). (S_u^m - S_u^m) > 0$$

2. $S_u^m > 0$

C. CONVEX OPTIMIZATION TECHNIQUE

EE is concave in SE and the solution space defined by the constraints is convex, so it’s a convex optimization problem. Using standard optimization techniques, the Lagrangian of $L(S, \lambda)$ is (5)

$$EE + \sum_{u=1}^{U} \sum_{m=1}^{M} \lambda_u^m [(S_u^m). (S_u^m - S_u^m). (S_u^m - S_u^m)]$$

Where $\lambda$ is the Lagrange multiplier. Next differentiating $L(S, \lambda)$ with respect to $S_u^m$ and the feasible solution is given by

$$S_u^m (OPT) = D \cdot S_u^m$$

(6)

$$D = \frac{\frac{p_{st} + P_{rd}}{\frac{p}{\sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m}} + \lambda_u^m [3(S_u^m)^2 2S_u^m [S_u^m + \sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m - m]]}{\sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m}$$

(7)

Let $\Omega_u^m = \lambda_u^m$, the upper bound of the numerical search can be defined as, when $S_u^m = S_u^m$

$$\Omega_{UB} = \frac{\frac{p_{st} + P_{rd}}{\frac{p}{\sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m}} + [3(S_u^m)^2 - 2S_u^m [S_u^m + \sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m - m]]}{\sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m}$$

(8)

When $S_u^m = 0$, the lower bound of the numerical search can be defined as

$$\Omega_{LB} = \frac{\frac{p_{st} + P_{rd}}{\frac{p}{\sum_{u=1}^{U} \sum_{m=1}^{M} S_u^m}}}$$

(9)
D. OPTIMAL POWER ALLOCATION ALGORITHM

Set $S_u^m(0)$ & $\lambda_u^m(0)$ to non-negative value for all users & PRBs

Apply Optimization technique (eqn 5-6)

Calculate Upper & Lower Bounds (eqn 8-9)

Calculate $\Omega_u^m$ $\Omega_u^m = \Omega_{UB} + \Omega_{LB}$

If $S_u^m > S_u^{-m}$ $\Omega_{UB} = \Omega_u^m$

$\Omega_{LB} = \Omega_u^m$

Iterate until SE requirement achieved

III. PROPOSED SYSTEM

It is proposed to use 4x4 MIMO antenna configuration also along with Beamforming design is considered. Beamforming is a multi antenna technique that significantly reduces interference and improves system capacity. Beamforming is like a laser, which can deliver data directly to specific devices, while previous wireless is like a light bulb spreading light (data) in a set of area. A laser can focus its power, so it can reach farther. Similarly, beamforming technology provides wider coverage. Beamforming is one of several technologies, as well as smart antennas and MIMO, that is used boost the range and capacity by providing a better signal-to-noise (SNR) ratio.

A. OPTIMAL BEAM FORMING DESIGN

The complex baseband received symbol at D in the source phase is mathematically given by

$$y_{DS} = h_{DS}^T \omega_s x_s + n_{DS}$$  \hspace{1cm} (10)

where $h_{DS}^T$ denotes the channel gain vector from S to D and $n_{DS}$ is scalar additive Gaussian noise with unit variance. The signal to noise ratio (SNR) at eNB during the source phase is given by

$$\gamma_{DS} = |h_{DS}^T \omega_s|^2 p_s$$ \hspace{1cm} (11)

The baseband signal vector received at node R can be mathematically given by

$$y_{RS} = H_{RS} \omega_s x_s + n_{S,R}$$ \hspace{1cm} (12)

$H_{RS}$ denotes the channel gain matrix from source S to relay R. $n_{S,R}$ is the circular symmetry Gaussian noise vector with unit variance, i.e., Applying singular value decomposition (SVD).

It can be shown that the effective received SNR at R is given by

$$\gamma_{S,R} = |H_{S,R} \omega_s|^2 p_s$$ \hspace{1cm} (13)

The optimal solution to the optimization problem is given by considering the mapping from $\gamma_{S,R}$ to $\gamma_{DS}$. The coordinates of the point T and E is $(x_T, y_T)$ and $(x_E, y_E)$. When $y_T \geq y_E$ and $y_T < y_E$, the optimal solution of Problem is

$$\alpha_1 = 2AB \pm \sqrt{1 - 4ABp_s - 4B^2}$$

$$\alpha_2 = 1 - \alpha_1$$

$$A = \lambda_1 - \lambda_2^2 - \beta_1^2 - \beta_2^2$$

$$B = \lambda_2^4 - \beta_1^2 \beta_2^2 - \gamma_{DS}$$ \hspace{1cm} (14)

Where $\alpha_i = |w_i|^2$ and $\lambda_1, \lambda_2$ are the singular values and $\beta_i = |h_{DS}^T|v_i$. 

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By applying Gram-Schmidt orthogonalization, the orthogonal base vectors for the space spanned by the channel vectors $h_1$ and $h_2$ can be obtained as

$$e_1 = h_1$$
$$e_2 = h_2 - h_2^H h_1$$

(15)

The beamforming vector $w_i^*$ can be expressed as a linear combination of $\mu_i e_1$ and $e_1 e_2$.

$$w_i^* = \mu_1 e_1 + \mu_2 e_2$$

(16)

The optimal solution is given by

$$\mu_1^* = |\mu_1|^2$$
$$\mu_2^* = |\mu_2|^2 < h_1^* h_2$$

(17)

$$|\mu_1|^2 H_1 = (|\mu_2|^2 |e_2|^2 + r_{5,0}|\mu_1|^2 h_1^* e_1 + |\mu_1|^2 |e_2|^2 = 1$$

Where $\mu_1$ is a real number and $\mu_2$ has phase angle $h_1^* h_2$.

**IV. PERFORMANCE EVALUATION**

By using MATLAB performance characteristics of MU-MIMO system for 2×2 and 4×4 is shown from figure 4 to figure 14.

A. Results for 2×2 and 4×4 MU-MIMO configuration

Firstly the trade-off relation between EE and SE is considered. The optimal EE emphasizes the existence of a saturation point, beyond which the EE can no longer be further increased, regardless of how many additional resources are used fig. 4.

The convergence behaviour of EE and SE is analysed, which is very important for designing green communication systems and also Comparison of convergence of EE of different PRBs of 2×2 and 4×4 is get plotted fig 5 and fig. 6 from that it is clear that 4×4 MU-MIMO SE is higher than 2×2 configuration, EE is optimized as in 2×2 configuration.

EE of different PRBs, dynamic circuit power, power amplifier efficiency of 2×2 and 4×4 is compared on fromfig. 7. fig. 12 and form this plots it is clear that 4×4 MU-MIMO antenna system has better performance than 2×2 antenna system.
**Fig. 8** EE of different PRBs (4×4 Configuration)

**Fig. 9** EE vs SE various power amplifier efficiency (4×4 Configuration)

**Fig. 10** EE vs SE various power amplifier efficiency (4×4 Configuration)

**Fig. 11** Convergence of different dynamic circuit power (2×2 Configuration)

**Fig. 12** Convergence of different dynamic circuit power (4×4 Configuration)

**B. Results for Beam forming design**

Achievable transmission rate 2×2 and 4×4 is compared on fig. 13 and fig. 14. Achievable transmission rate 4×4 system is higher than 2×2.

**Fig. 13** Achievable rate vs SNR (2×2 Configuration)

**Fig. 14** Achievable rate vs SNR (4×4 Configuration)
V. CONCLUSION

The EE-SE relation in downlink 2×2 and 4×4 MU-MIMO system is considered. The convergence behaviour of EE and SE is analysed, which is very important for designing green communication systems. An analytical method to optimize energy efficiency of MU-MIMO system with respect to target SE constraints is analysed. In 4×4 MU-MIMO SE is higher than 2×2 configuration; EE is optimized as in 2×2 configuration. The behaviour of the different network parameters for 2×2 and 4×4 is compared i.e, EE of different PRBs, dynamic circuit power, power amplifier efficiency, from that it is obtained that 4×4 configuration have better performance and also achievable transmission rate 2×2 and 4×4 is compared using optimal beamforming technique and it is obtained achievable transmission rate of 4×4 is higher.

REFERENCES


BIOGRAPHY

Chithra B Das received the B.Tech degrees in Electronics and Communication Engineering from CUSAT, Kerala at College Of Engineering Adoor. And now she is pursuing her M.Tech degree in Communication Engineering under MG University, in Mount Zion College of Engineering, Kadammanitta, Pathanamthitta.