Improving Energy Efficiency of Massive MIMO Using Small Cell Network

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Abstract— **Nowadays, the compaction of the cellular network resulted in increased demand in wireless data services. However, the cellular energy efficiency (EE) can be improved by densification the network topology, without bothering quality-of-service (QoS) constraint at the users. In this paper, small cell network (SCN) is applied in massive MIMO (MM) and analyze the power consumption of these two densification approaches for different QoS constraints. For this paper, three beamforming (BF) algorithms are compared which are optimal BF is using only the base station (BS), multiflow regularized zero forcing (RZF) BF and optimal spatial soft-cell coordination BF. Numerical result compared with BF algorithm proposed in different simulation parameters and show that by increasing the number of small-cell access points (SCAs), the antennas per SCAs could enhance the total system energy efficiency**

Keywords— beamforming, massive MIMO, energy efficiency, power consumption

INTRODUCTION

The demand for data service is increasing dramatically and wireless systems with high throughput and the capability to serve a large number of user equipment are desired[1].

This problem can be overcome by providing an effective and simple solution for improving EE of MM in current cellular network [2]. One of the methods is by applying SCN in MM. The combined approaches that provides the highest energy efficiency; small cells contributes to reduce the propagation losses while MM enables multiplexing of users with controlled interference[3]. SCN is a cellular network where the sizes of the cells employed are very small.

Small cells can extend network coverage and reduce the cell size leads to higher spatial frequency reuse and increased network capacity [4]. It is developed with low-cost, self-organizing and low-power BS in each cell. In addition, the system capacity can be increased through the simplest and most effective way according to their benefits that explored in the green system design[5]. With reduction of the cell-size, the area spectral efficiency is increased in any cellular networks [6].

MM technique is one of the approaches that can be used to increase the system capacity. A large number of antennas were provided at each BS of multi-cell MM networks. High multiplexing and diversity gains were provided for uplink and downlink directions[7]. Therefore, MM technique could reduce the transmission power while increasing the capacity of the network [6]. Large antenna arrays potentially reduce uplink and downlink transmit powers through coherent combining and an increasing antenna aperture [8]

This project investigates how EE can be improved using SCN and MM; and to investigate if the size of small cell can effect on the performance of MM systems. Two main approaches will be investigated in this project which are MM and SCN. Besides, the investigation will be done on the BF techniques.

In the first approach, existing macro BSs are equipped with large scale antenna arrays. This will result in higher EE when emitted energy of the users is enabled with precise focusing. The block diagram of MM systems as shown in Figure 1 where each BS is equipped with more than one antenna for receive and transmit signals. The second approach is applying SCN to offload traffic from BSs with an overlaid layer of SCAs. By reducing distance between user and transmitters, lower propagation losses and also higher EE are achieved.

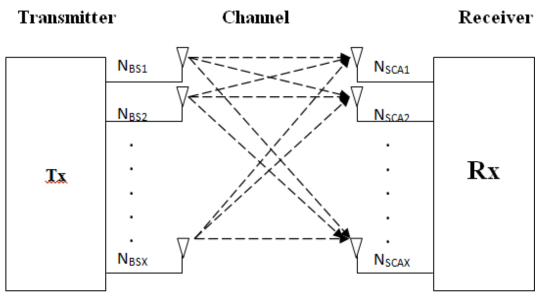


Figure 1: The structure of MM system.

The increasing number of antennas per SCA will obtain higher energy efficiency for SCAs, thus higher overall network energy efficiency[9].

The system is more power efficient when the data rate increases without increasing the power used. So the MM is the hottest issue which can greatly improve the spectrum efficiency and energy efficiency to meet the demand. Since the distance between SCAs and users are short, small cells will require less radiated transmit energy and its will decrease the circuit power consumption[10]. Modeling and analysis in MM and SCN has been studied in [11]. Some investigations about BF techniques have been studied recently in [9] and[10].

METHODOLOGY

For this study, the concept of small cell networks will be employed in MM. At the same time, the size of the cell will be investigated and the frequency of carrier will be varied. This is to compare the effect of EE for each size and frequency due to EE and power consumption through the BF techniques.

One circular macro cell is overlaid by number of SCAs antennas, N_{SCA} and number of single antenna, K in each SCA. Numbers of antenna at BS, N_{BS} is more than ten, which is $N_{BS} >> K$. Every SCA has one user uniformly distributed within 50 meters. The average performance of user locations and also realizations of the channel will be evaluated.

The propagation loss is different for each BSs and SCAs. The radius of the macro cell is 0.5 km. The carrier frequency, f = 2GHz and number of subcarriers, C = 600. The simulation of the model will be analyzed using MATLAB software.

Figure 2 shows the flowchart of methodology employed in designing and simulating wireless communication between a BS and SCA. Literature review about scheduling algorithm was studied and determined. The algorithm was scripted and simulated by using MATLAB R2012a software.

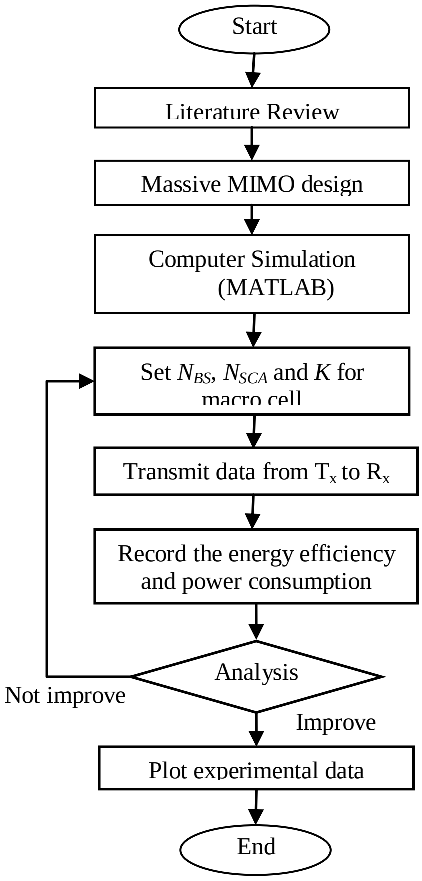


Figure 2: Flow chart for the project development.

SYSTEM MODELS

This paper utilizes optimal BF using only the BS, multiflow-RZF BF and optimal spatial soft-cell coordination BF to optimize the transmit power for energy efficiency maximization in the cellular network. There has only one BS overlaid with several SCAs. An iterative algorithm is proposed with provable convergence.

Consider a macro cellular network consisting of one BS equipped with N_{BS} antennas and arbitrarily deployed N_{CSA} SCAs antenna nested within the macro cell range which is characterized by power constraints that limit the coverage. BSs are the main source of energy consumption in cellular networks. The system model area is illustrated in figure 3.

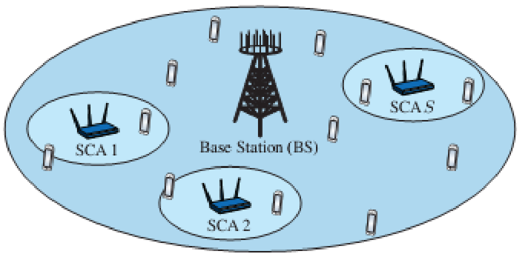


Figure 3: Illustration of system model of one macro cell that overlaid by N_{SCA} SCAs antennas, where N_{SCA} are number of SCAs antennas.

For the massive MIMO, the number of antennas, N_{BS}, is anything from eight to several hundreds. It means that $N_{BS} >> K$. The channels to user h_k are modeled as block fading. The receive signal at user k is given by

$$y_k = h_{k,0}^H x_0 + \sum_{j=1}^{s} h_{k,j}^H x_j + n_k \qquad (1)$$

where x_0 and x_j are the transmitted signals sent to the BS and jth SCA, respectively.

Each user can be presented with a variety of transmitters but the information symbol will be encrypted and transmitted independently. It enables users barely covered by a SCA to receive additional signals from the BS or other SCAs, which is called *spatial multiflow transmission*.

This paper considers minimization of the total power consumption while satisfying QoS constraints for each user. The QoS constraints specify the information rate [bits/s/Hz] that each user should achieve in parallel. These are defined as is the aggregate signal-to-interference-and-noise ratio (SINR) of the kth user. The information rate $\log_2(1 + \mathrm{SINR}_k)$ is achieved by applying successive interference cancellation on the own information symbols and treating co-user symbols as noise.

The power consumption for each subcarrier can be modeled as $P_{dynamic} + P_{static}$ with the dynamic and static terms:

$$p_{dynamic} = p_0 + \sum_{k=1}^{K} \|w_{k,0}\|^2 + \sum_{j=1}^{s} p_j \sum_{k=1}^{K} \|w_{k,j}\|^2 \qquad (2)$$

$$p_{static} = \frac{\eta_0}{C} N_{BS} + \sum_{j=1}^{s} \frac{\eta_j}{C} N_{SCA} \qquad (3)$$

The dynamic term is the summation of the emitted powers [12], $\sum_{k=1}^{K} \|w_{k,j}\|^2$ each multiplied with a constant $p_j \geq 1$ contribute inefficiency on the transmitter's power amplifier. The static term, P_{static}, is proportional to the number of antennas and $\eta_j \geq 0$ models the power dissipation in the circuits of each antenna. P_{static} is normalized with the total number of subcarriers, $C \geq 1$. Representative numbers of these parameters are given in Table I.

The formula is being formulated for the optimization problem. This is to reduce the total power consumption while meeting the QoS constraints and the power constraints, thus minimize $P_{dynamic} + P_{static}$ subject to

$$\begin{aligned} &\log_2(1 + SNRk) \geq \gamma k \\ &\sum_{k=1}^{K} w_{k,j}^H Q_{j,l} w_{k,j} \leq q_{j,l} \end{aligned} \qquad (4)$$

In addition, the optimal power-minimizing solution is self-organizing in the sense that only one or a few transmitters will serve each user. In this paper, we focus on comparing the performance of optimal BF using only the BS, RZF BF and optimal spatial soft-cell coordination BF.

Algorithm Design

For each iteration step, geometric programming CVX packet is used to solved this optimization problem until the algorithm converges to the optimal solution.

This complexity is rather simple, but the algorithm becomes more infeasible for the implementation of real-time when N_{BS} and N_{SCA} grow large. Centralized algorithm requires all channel knowledge to be gathered at the BS. To demonstrate the usefulness, the low-complexity non-iterative Multiflow-RZF BF is proposed.

Issues of power allocation have low complexity alike regardless of the number of antenna. The algorithm is non-iterative, but some scalar parameters are exchanged between the BS and SCAs to allow coordination. In practice, only users in the SCA environment are affected by it, with the only a few parameters are exchanged per SCA while all other parameters are set to zero.

Simulation Results

Simulation shows that the proposed power allocation algorithm will enhance the overall energy efficiency with the increasing number of small-cells, antennas per SCA and the served users. Macro BS is equipped with N_{BS} antennas and each SCA is equipped with N_{SCA} antennas. Cell radius is set to be 500 m and each SCA radius is 40 m where the distance from SCA to BS is set to be 350 m. The minimum distance between served user and BS/SCA is 35 m and 3 m respectively. It compares the average overall energy efficiency in the scenarios where different NBS and NSCA deployed in the whole cell which serves $Kr = 10$ users.

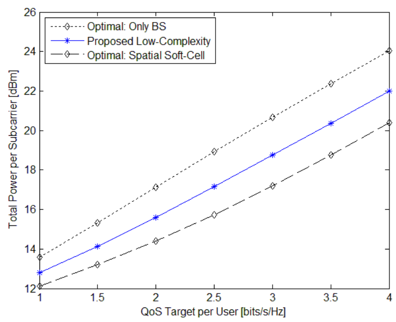
Table 1: Channel Parameters in the Numerical Evaluation.

parameters	Values
Macro cell radius	05.km
Carrier frequency	F = 2 GHz
Number of subcarriers	C = 600
Subcarrier bandwidth	15kHz
Standard deviation of log normal shadowing	7 dB
Path and penetration loss within 40m from SCA	127 + 37.6log10(d) dB

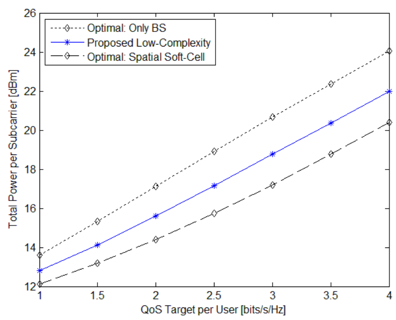
Matlab software is used for theoretical simulation. The number of mobile users is fixed at ten. This section describes the results of the analysis and the algorithm in a scene depicted in the figures shown in Figure 2.

First, the effect of having different numbers of antennas in BS, N_{BS} while the N_{SCA} fixed at two is analyzed. Ten users are randomly distributed, where K = 10, γ_k = 2bits/s/Hz. The simulation shown in Figure 4:

Subplot 4a) $N_{Bs} = 40$



Subplot 4b) $N_{BS} = 50$



Subplot 4c) $N_{BS} = 60$

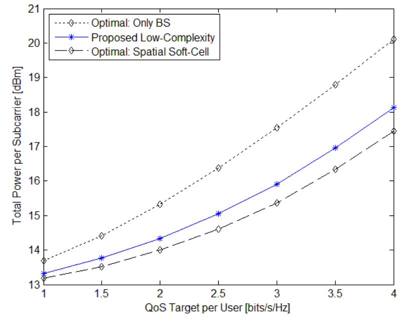


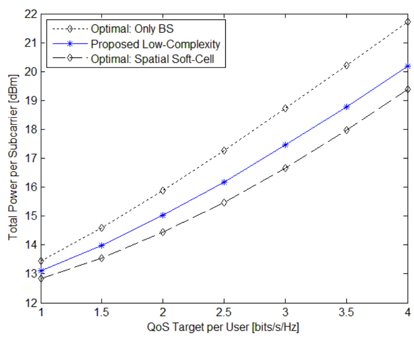
Figure 4: The total power per subcarrier with different N_{BS} while N_{SCA} fixed at 2.

In Figure 3, the graph shows plot of the total power per subcarrier with different number of antenna at BS, N_{BS} while number of antenna at SCA, N_{SCA} fixed at two for different values of the QoS.

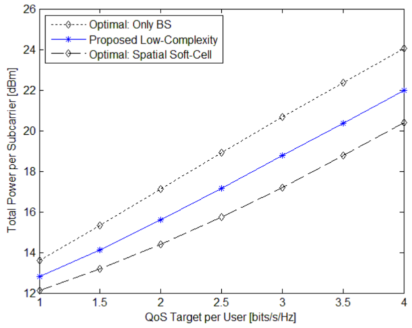
When the QoS target per user is low, the total power per subscriber is small for these three methods of BF. The total power per subscriber for each method increases while the QoS target increased. In addition, it can be seen that the total power is lower when the number of antenna at BS, N_{BS} is higher. For example, from the simulation result, for optimal spatial soft-cell coordination BF, at N_{BS} = 40, the QoS = 4 bits/s/Hz, the total power is 11.96dBm. This value increases to 12.11dBm when N_{BS} = 50 and 13.18dBm at N_{BS} = 60.

Then the same model is used, but is simulated using different number of N_{SCA} and N_{BS} fixed at 50. The results are shown in Figure 5:

Subplot 5a) $N_{SCA} = 1$



Subplot 5b) N_{SCA} = 2



Subplot 5c) N_{SCA} = 3

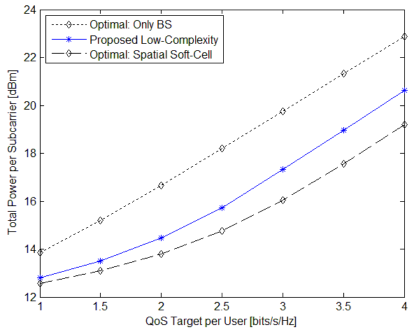


Fig. 5. The total power per subcarrier with different N_{SCA}, while N_{BS} fixed at 50.

In Figure 5, the total power per subcarrier versus QoS target per user is also shown. This simulation is for NSCA = 2and the number of antenna at BS, N_{BS} is fixed at 50. The graphs also show the total power per subscriber increases while the QoS constraint increased even though the N_{SCA} is different.

However it can be seen that the total power higher when the smaller number of antenna used at SCA. For example, for the optimal spatial soft-cell, the power consumed for NSCA = 2 at QoS = 4 bits/s/Hz is equal to 20.41 dBm. The value decrease to 19.21 dBm when NSCA = 3.

Discussion And Conclusion

In this paper, the throughput and energy efficiency of MM were investigated by using the SCN and the power consumption for different QoS constraints has been analyzed. Three BF algorithms are compared which optimal BF is using only the base station (BS), Multiflow regularized zero forcing (RZF) BF and optimal spatial soft-cell coordination BF.

It is observed that increasing the number of QoS constraint will increase the total power consumption per subcarrier. It depends on the number of antenna used in BS and SCAs. The more antenna used in BS, the higher power will be consumed. On the other hand, the higher number antenna used in SCA will reduce the power consumption in each case. Improvements in the throughput can be realized.

It can be concluded that the power increases as the QoS constraints increased. The increasing number of antennas per SCA will give higher energy efficiency for SCAs, thus higher overall network energy efficiency. The increases in power as the number of antennas, the total transmit power along with the data rate of change varies.

The proposed optimal spatial soft-cell coordination BF gives promising results for practical applications, as part of improving energy efficiency can be achieved by this BF method.

Acknowledgment

I would like to express my sincere gratitude to my supervisor, Dr. Nur Idora Abd. Razak, for her constant support, guidance and motivation. It would never have been possible for me to take this work to completion without her incredible support and encouragement.

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