Energy Consumption Analysis of Heterogeneous Wireless Network Using Coordinated Multipoint Transmission Technique

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Abstract—In heterogeneous network several types of base station (BSs) are deployed to satisfying user traffic demands of future communication system and improve network performance. The coordinated multi point (CoMP) transmission technique is considered a key feature in future wireless network to improve both cell edge users throughput by exploiting interference. However, to provide CoMP transmission several BSs need to be active, which eventually increases network energy consumption. Therefore, there is need to investigate the effectiveness of CoMP technique for energy efficient communication, especially in heterogeneous network scenario, where different BSs have different characteristics. In this paper, we investigate the performance of wireless system in heterogeneous environment without and with CoMP. In particular, we analysed network outage with its energy consumption efficiency with varied coverage range. Mobiles are assumed to be connected to nearest BSs. Furthermore, we have also investigated energy efficiency vs. outage probability in terms of number of coordinating BSs for joint-transmission enabling sleep mode mechanism.

Keywords—CoMP; Heterogeneous wireless network; energy efficiency; outage probability.

1. INTRODUCTION

Macro cells are collocated with micro cells, pico-cells and femto-cells in heterogeneous wireless environment. Due to low power and smaller physical size, pico/femto cells are deployed to eliminate coverage holes. These technologies are also bringing the network closer to mobile users and improve spectral efficiency (SE). However, the existence of different type of technologies increases interferences on each other. Several techniques are available in literature to overcome the interference issue [1]. Among them, coordinated multipoint (CoMP) transmission provides a good solution to increase signal level at user equipment (UE) by exploiting interference information [2]. The CoMP technique has been considered by 3GPP as a tool to improve coverage, cell-edge throughput, and/or system performance [3].

The basic principle of CoMP is to transmitting same information from several neighbouring BSs, which may provide high interference. With proper coordination, serious interference from multiple BSs can be exploited as meaningful signal [4]. There are two main schemes available for CoMP transmission; Joint Processing (JP) and coordinated scheduling/beamforming (CS/BF). In JP technique, data intended for a particular user is jointly transmitted from multiple points where as in other case the transmission points coordinates schedulers to avoid interference. In coordinated beam-forming, the beams activation at different transmission points is need to be coordinated to minimize the probability of beam collision. However, one of the main challenges in CoMP transmission is energy consumption as several BSs coordinated among each other to improve network performance and several information are needed to be exchanged amongst [4].

In [5], authors studied the energy efficiency (EE) of a two-tier heterogeneous network consists of a macro-cell and many small-cells for different spectrum deployments without coordination. The EE of the two-tier networks with orthogonal spectrum deployment is better than that with co-channel spectrum deployment. In [6], the authors studied an energy efficient hybrid CoMP-JP and CoMP-CS/CB transmission strategy in downlink heterogeneous networks. They optimized the time proportion of CoMP-JP transmission and optimize the capacity region for small cell user to minimize the total power consumed. Increasing the transmit power of the pico-BS can improve EE in the high spectral efficiency (SE) region of the macro-user. The hybrid CoMP-JP and CoMP-CB strategy has been used in time division manner in [7]. This provides a larger capacity region than the CoMP-JP only or CoMP-CB-only transmission. The authors in [8] analysed the EE performance of heterogeneous environment with lowest outage without CoMP. However, literature is lacking with many investigation on CoMP in heterogeneous environment, where different types of BSs of different characteristics are active. Especially, the transmit power of different BSs are very different, which can greater impact on network power consumption when in use.

In this paper, we investigate the energy consumption issue in heterogeneous network using CoMP. This paper particularly describes and analyses the performance of heterogeneous network with CoMP in downlink transmission with minimizing outage. Formulation of capacity, outage and energy efficiency metrics are presented and these metrics are used to compare the performance of with and without CoMP. Furthermore, we also investigated the EE of network by enabling sleep mode technique, where we switched-off the inactive BSs. Our results show that coordinated heterogeneous
network is more energy efficient than uncoordinated networks and further switching of the only macro BS increases the EE efficiency further.

Fig. 1. Coordinate multipoint transmits and receives System

The rest of the paper is organized as follows. Section II discusses the system model and path loss model. Section III presents the downlink CoMP performance metrics formulation. Section IV discusses the simulation results. Finally, Sec.V concludes our work.

II. SYSTEM MODEL

The heterogeneous network used in this paper, consists of macro-cells, micro-cells, pico-cells and femto-cells is shown in Fig. 1 and the corresponding transmission power of different types of BSs are 16, 10, 0.5 and 0.1 Watts. We assume that locations of all femto, pico, micro and macro base stations are known and all the low power BSs are located within a macro cell coverage area. Since, all the BSs are co-exist and all the small cells are located within a hexagonal macro-cell networks that are using same frequency band for communication I downlink.

In this work, the network is based on the 3GPP/LTE downlink specifications [9], where both components of the cellular wireless network, i.e. BSs and mobile terminals, implement an OFDMA air interface. OFDM symbols are organized into a number of physical resource-block (RBs) consisting of 12 contiguous sub carriers for 7 consecutive OFDM symbols. With a bandwidth of 10 MHz, 50 RBs are available for data transmission. Each user is allocated one or several RBs in two consecutive slots, i.e., the time transmission interval (TTI) is equal to two slots.

The overall channel gain is composed of a fixed distance dependent path loss. The path loss models for different low power BSs and macro BS are taken from [10]. These path loss models are expressed below by equations (1), (2) and (3) Path loss model for Macro and Micro cell:

\[
PL(dB) = 15.3 + 36.7 \log_{10}(d) + A_{ext} \quad (UE \text{ is inside})
\]

\[
= 15.3 + 36.7 \log_{10}(d) \quad (UE \text{ is outside})
\]  

(1)

Path loss model for Pico cell:

\[
PL(dB) = 37 + 30 \log_{10}(d) + A_{ext} \quad (UE \text{ is inside grid})
\]

Path loss model for femto cell is represented as:

\[
PL(dB) = 37 + 30 \log_{10}(d) + A_{ext} \quad (UE \text{ is outside})
\]  

(2)

Path loss model for Macro and Micro cell:

\[
PL(dB) = 37 + 30 \log_{10}(d) + A_{ext} \quad (UE \text{ is inside grid})
\]  

(3)

where, \(d\) is the BS-UE distance, expressed in meters and \(A_{ext}\) is the external wall loss, express in dB.

In this paper, we have considered joint processing method of CoMP to analyses the performance of heterogeneous wireless network using CoMP.

III. PERFORMANCE METRIC OF DOWNLINK COOMP TRANSMISSION

To capture the energy consumption perspective in the analysis, we employ the bit per energy measured in bit/Joules energy consumption [7] and outage probability parameters. The formulation of these parameters is discussed in details in next subsections. We have also assumed that, there are \(g\) groups of BSs and each group consists of \(b\) number of BSs within Hetnet.

A. Capacity and Outage Calculation

This paper is focused on the energy saving performance of heterogeneous network under certain outage probability constraint. Outage occurs due to two factors: when received signal strength is smaller than a threshold, i.e. outage probability; and when there is no available service channel, i.e. service blocking.

The probability of coverage in a downlink cellular network at decreasing levels of generality. Let \(x(r)\) denote the outage probability at a given node with the position \(r = (r_1, r_2)\). Then, the average outage probability is defined as:

\[
p(\tau) = \text{prob}[r < \tau].
\]  

(4)

This relation can be interpreted as the probability that a randomly chosen user can achieve a target SINR \(\tau\), and the average fraction of users who at any time achieve SINR \(\tau\), or the average fraction of the network area that is in coverage at any time. The probability of coverage gives \(\text{prob}[\text{SINR} > \tau]\). A user is in coverage when its SINR from its nearest BS is larger than some threshold and it is dropped from the network for SINR below \(\tau\). The discussion in this paper follows the notations as: \(G_{ik}^{m}\), channel gain between user \(k\) from serving BS \(i\) on RB \(m\). \(G_{ik}^{a}\) is channel gain between user \(k\) from the neighbouring BSs of same type of \(x\) on RB \(i\). \(G_{ik}^{xy}\) is channel gain between user \(k\) of serving BS \(x\) and neighbouring BS \(y\) on RB \(i\). \(P_{ik}\) is the transmit power of BS \(x\) on RB \(i\) of user \(k\).

The received SINR on RB \(i\) of \(k\)-th macro-UE of \(m\)-th macro-BS can be expressed as:

\[
m_{ik} = \frac{G_{ik}^{mm} p_{ik}^m}{\sigma^2 + I_{macro-UE}} \quad (5)
\]

\[
I_{micro-UE} = \sum_{a=1}^{m} G_{ik}^{aa} p_{ik}^m + \sum_{h=1}^{H} G_{ik}^{hh} p_{ik}^h + \sum_{l=1}^{p} G_{ik}^{al} p_{lk}^m + \sum_{p=1}^{p} G_{ik}^{pl} p_{lk}^m \quad (6)
\]
Where, $P_{ik}^m$, $P_{ik}^a$, $P_{ik}^p$ are the transmit power of serving macro-BS, neighbouring macro-BSs, femto-BS, micro-BS and pico-BSs respectively on RB $i$ of $k$-th macro-UE of $m$-th macro-BS. $G_{ik}^m$, $G_{ik}^a$, $G_{ik}^h$, $G_{ik}^h$ and $G_{ik}^m$ are the channel gain from serving macro-BS, neighbouring macro-BSs, femto-BS, micro-BS and pico-BSs respectively. $M$, $L$, $P$ and $H$ are the total number of macro-BS, micro-BS, pico-BS and femto-BSs respectively. $\sigma^2$ is the white noise power spectral density.

The received SINR on RB $i$ of $k$-th micro-UE of $\ell$-th micro-BS can be expressed as:

$$I_{\text{micro-UE}} = \frac{g_{ik}^{\text{mm}} p_{ik}^m + \sum_{h=1}^H g_{ik}^{hh} p_{ik}^h}{\sigma^2 + \sum_{l=m+1}^{M} g_{ik}^{lm} p_{ik}^l} + \sum_{l=1}^{M-1} g_{ik}^{l\ell} p_{ik}^l + \sum_{p=1}^{P} g_{ik}^{p\ell} p_{ik}^p$$

The received SINR on RB $i$ of $\ell$-th pico-UE of $p$-th pico-BS can be expressed as:

$$I_{\text{pico-UE}} = \frac{g_{ik}^{pp} p_{ik}^p}{\sigma^2 + \sum_{l=1}^{M} g_{ik}^{l\ell} p_{ik}^l} + \sum_{a=1}^{L} g_{ik}^{a\ell} p_{ik}^a$$

The received SINR on RB $i$ of $\ell$-th femto-UE of $p$-th femto-BS can be expressed as:

$$I_{\text{femto-UE}} = \frac{g_{ik}^{pp} p_{ik}^p}{\sigma^2 + \sum_{l=1}^{M} g_{ik}^{l\ell} p_{ik}^l} + \sum_{h=1}^{H} g_{ik}^{hh} p_{ik}^h$$

The above equations are derived without considering CoMP transmission. In CoMP, participating BSs perform joint transmission to transfer data to the user. The generalized received downlink SINR in joint transmission system is given by

$$I_{\text{CoMP}} = \frac{R_{\text{CoMP}}}{\sigma^2 + I_{\text{CoMP}}}$$

$$R_{\text{CoMP}} = \sum_{m=1}^{N_c_m} g_{ik}^{mm} p_{ik}^m + \sum_{l=1}^{L} g_{ik}^{l\ell} p_{ik}^l + \sum_{p=1}^{P} g_{ik}^{p\ell} p_{ik}^p + \sum_{n=1}^{N_c_h} g_{ik}^{nh} p_{ik}^h$$

$$+ \sum_{n=1}^{N_c} g_{ik}^{nh} p_{ik}^h + \sum_{a=1}^{L} g_{ik}^{a\ell} p_{ik}^a + \sum_{m=1}^{M} g_{ik}^{l\ell} p_{ik}^l + \sum_{p=1}^{P} g_{ik}^{p\ell} p_{ik}^p$$

$$I_{\text{CoMP}} = \sum_{a=1}^{N_c} g_{ik}^{a\ell} p_{ik}^a + \sum_{a=1}^{L} g_{ik}^{a\ell} p_{ik}^a + \sum_{m=1}^{M} g_{ik}^{m\ell} p_{ik}^m + \sum_{p=1}^{P} g_{ik}^{p\ell} p_{ik}^p$$

$$+ \sum_{a=1}^{N_c} g_{ik}^{a\ell} p_{ik}^a + \sum_{a=1}^{L} g_{ik}^{a\ell} p_{ik}^a + \sum_{m=1}^{M} g_{ik}^{m\ell} p_{ik}^m + \sum_{p=1}^{P} g_{ik}^{p\ell} p_{ik}^p$$

where $N_c_m$, $N_c_h$ and $N_c$ are the number of macro BSs, micro BSs, pico BSs, femto BSs respectively, which are participating in CoMP transmission. The total number of participating BSs in CoMP as

$$N_c = N_c_m + N_c_h$$

The SINR in (13) is the received SINR, where all types of BSs, i.e. macro, micro, pico, femto BSs are participating in joint transmission. However, this is not the true in all cases. Because, participating BSs are mainly depends on the predecided number $N_c$ and location of user. Since, in this work, we consider, user are connected to nearest BSs. In this case, the value of $N_c_m$, $N_c_h$ and $N_c$ will change and accordingly the channel gain in $R_{\text{CoMP}}$ and $I_{\text{CoMP}}$. In the absence of the particular BS, the corresponding terms in $R_{\text{CoMP}}$ will vanish and the channel gain in $I_{\text{CoMP}}$ will replaced by actual channel gain. In case of macro-femto combination, the $R_{\text{CoMP}}$ and $I_{\text{CoMP}}$, in equation (15) as given by

$$R_{\text{CoMP}} = \sum_{m=1}^{N_c_m} g_{ik}^{mm} p_{ik}^m + \sum_{l=1}^{L} g_{ik}^{l\ell} p_{ik}^l + \sum_{p=1}^{P} g_{ik}^{p\ell} p_{ik}^p$$

$$I_{\text{CoMP}} = \sum_{a=1}^{N_c} g_{ik}^{a\ell} p_{ik}^a + \sum_{a=1}^{L} g_{ik}^{a\ell} p_{ik}^a + \sum_{m=1}^{M} g_{ik}^{m\ell} p_{ik}^m + \sum_{p=1}^{P} g_{ik}^{p\ell} p_{ik}^p$$

Here only BSs excluded from the joint transmission act as interference. When all BS participate in joint transmission will increase the throughput and spectral efficiency but decrease energy efficiency. The transmission of user $k$ is given by,

$$C_k = \sum_{i=1}^{N_B} a_{ik} \log_2(1 + \frac{I_{\text{CoMP}}}{I_{\text{IC}}})$$

$$C_k^{\text{CoMP}} = \sum_{i=1}^{N_B} a_{ik} \log_2(1 + \frac{R_{\text{CoMP}}}{I_{\text{IC}}})$$

where $C_k$ and $C_k^{\text{CoMP}}$ are the capacity of user without and with CoMP and $a_{ik}$ is the binary assignment variable.

B. Energy Efficiency Calculation

A linear relationship between average total power consumption in BS and the average radiated RF output power per site can be modelled in the form.

$$P_{\text{NC}} = s(bP_{\text{m}} + mP_{\text{M}} + pP_{\text{P}} + fP_{\text{F}}) + P_{\text{Fixed}}$$

The coefficient $s$ represents power consumption that scales with the radiated power due to amplifier and feeder losses as well as cooling of sites. Both $s$ and $P_{\text{Fixed}}$ are number of sector and the number of antenna per sector. The linear relationship power model in the downlink [11] can be formulated as:
\[ P_{\text{CoMP}} = P_S + P_B + P_N \]
\[ P_C = P_S + P_N \]

In above equations, \( P_S \) is the signal processing power consumption and \( P_B \) backhaul power consumption due coordination between BSs. The energy-efficiency (EE) metric can be defined as:
\[ \text{EE} = \sum_{k=1}^{K} \left( \frac{c_k}{P_k^{\text{CoMP}}} \right) \]

where \( c_k \) and \( P_k^{\text{CoMP}} \) are the EE metric of network without and with CoMP.

IV. SIMULATION RESULT AND DISCUSSION

The considered heterogeneous network consists of a macro cell, micro = 5, pico = 25 and numbers of femto = 100 cell. Further, 500 users are located within the coverage area. Mobiles are connected to the nearest BSs where SINR is greater than the designed threshold and SINR at each mobile has been calculated by considering path loss only. During simulation, we have considered different coverage ranges i.e. different SINR threshold for connecting to a particular BSs. The Table II lists the simulation parameter used in this work.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Macro BS</td>
<td>1</td>
</tr>
<tr>
<td>Number of Micro BS</td>
<td>5</td>
</tr>
<tr>
<td>Number of Pico BS</td>
<td>25</td>
</tr>
<tr>
<td>Number of Femto BS</td>
<td>100</td>
</tr>
<tr>
<td>Number of mobile users</td>
<td>500</td>
</tr>
<tr>
<td>Power spectral density of noise</td>
<td>-174dBm/Hz</td>
</tr>
<tr>
<td>Maximum Transmit power of macro BS</td>
<td>16 Watts</td>
</tr>
<tr>
<td>Maximum Transmit power of micro BS</td>
<td>10 Watts</td>
</tr>
<tr>
<td>Maximum Transmit power of pico BS</td>
<td>0.5 Watts</td>
</tr>
<tr>
<td>Maximum Transmit power of femto BS</td>
<td>0.1 Watts</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>900Mhz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>5Mhz</td>
</tr>
</tbody>
</table>

Simulation is carried out for different scenarios in heterogeneous network viz. macro only, macro-femto, macro-micro and macro-micro-pico-femto. The outage probability of macro cell increases with SINR threshold and it is smallest in all the considered scenarios with different SINR threshold as shown in Fig 2. This is due to fact that with increase in distance and SINR threshold the number of active users decreases. In macro-femto scenario, the outage is higher than macro only; this is due to avoidable intra cell interference, as more heterogeneous BSs are active in a cell. The macro-micro cells scenario has higher outage than other two scenarios discussed above. As macro BS has higher power transmission capability than femto BS, which causes interference in large coverage area.

More numbers of operational BSs (macro, micro, pico and femto BSs) in a cell increase interference on environment which in turn increases outage probability. This scenario shows highest outage probability with increase in SINR threshold which is due to increase in intra-cell interference as shown in Fig 2. However, use of CoMP reduces the interference on the environment and therefore, decreases the outage probability.

![Outage vs SINR Threshold without CoMP](image1)

![Outage vs SINR Threshold](image2)

![Throughput vs degree of coordination](image3)

The main advantage of CoMP transmission in the downlink is to increase received SINR values and so the SE and data rate of the users in cellular network as is evident from Fig 3. However, the excess usage of CoMP can lead to high energy inefficiency in the system due to excess signalling between the coordinating sets. Because the increase in signal processing and backhauling power consumption is not compensated by an equal gain in downlink throughput.
The EE of heterogeneous (macro- micro- pico-femto) network against the outage probability is studied in Fig. 4. As outage probability increases the EE decreases and further increase in outage probability beyond 0.25 increases the EE.

![Fig. 4. Energy efficiency with CoMP vs Outage probability](image)

Energy efficiency(bits/Joule)

Outage probability

Nc=1

Nc=2

Nc=3

Nc=4

Nc=5

Nc=6

Fig. 4. Energy efficiency with CoMP vs Outage probability

![Fig. 5. Energy Efficiency vs Number of coordinated BSs](image)

Energy efficiency(bits/Joule)

Number of coordinated BSs

with BS switch off

BS switch off

1

1.5

2

2.5

3

3.5

4

4.5

5

5.5

6

Fig. 5. Energy Efficiency vs Number of coordinated BSs

We observe that power consumption is governed by coordination between BSs and backhaul link. As higher the degree of coordination more signals processing and backhaul power is needed. Therefore, bit per Joules efficiency increases for certain degree of coordination and decreases with higher degree of coordination as shown in Fig.4.

The unnecessary increases in cluster degree $N_c$ of the transmission set to include BSs with low received power values could decrease the energy efficiency. Because the increase in signal processing and backhauling power consumption is not compensated by an equal gain in downlink throughput. It is evident from Fig. 4 that increase in number of coordinated BS increases EE. However, increase in the number of coordinated BSs beyond four, decreases the EE. As more energy or power is required for coordination between the BSs. The results show that $N_c = 2$ to 4 system outperform the $N_c = 1$ (without CoMP) as $N_c = 2$ to 4 takes the advantage of macro- diversity. Furthermore, if we increase $N_c$ beyond 4 decrease the EE as more energy or power is required for signal processing i.e for coordination between the BSs. The excess usage of CoMP can lead to high energy inefficiency in the system due to excess signalling between the coordinating sets as in Fig 5. Coordinated turning off the BSs decrease the total power consumption and interference which in turn increases the EE as shown in Fig 5.

V. CONCLUSION

This paper addresses the energy efficient analysis of coordinated multipoint transmission in heterogeneous cellular communication system. As expected, the coverage requirement limits the energy efficiency of small cell deployment, which is due to the severe interference from small BSs around the macro-BS and the outage probability is much larger than that of small BS. The outage probability of macro cell increases as SINR threshold increases; especially it increases to be larger than that of small BS when SINR threshold is increased further. However, the coordination between the base stations reduces the interference among them and hence reduces the outage probability. We also found that the energy efficiency of coordinated heterogeneous environment decreases with outage. However, more increment in outage probability increases energy efficiency. But the increase in number of coordinated BSs beyond certain number further increase the outage probability and decreases the energy efficiency.

REFERENCE


