Energy Efficient Beamforming Transmission Scheme considering Hourly Users’ Distribution

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Abstract—A lot of telecommunication infrastructures have been built to cope with the rapid growth of smartphone users. As time goes by, natural resources start to deplete and electricity expenditure becomes expensive. This has raised the problem of power consumption in the cellular base station. Therefore, energy efficient base stations are required to overcome the difficulties. In this paper, a beamforming transmission scheme with low power consumption in the base station is proposed considering the hourly users’ distribution. The downlink directional signal transmission occurs to the places where there is a high user-density area. When users are equally distributed, the base station keeps its omni-directional transmission manner. The proposed beamforming transmission scheme is evaluated in terms of the hourly total power consumption in the base station comparing with the conventional omni-directional transmission. In addition, the uncovered user ratio to all the users in the cell is discussed to verify the effectiveness of the proposed scheme.

Keywords—energy efficient; opportunistic beamforming; user distribution; green base station; transmission scheme;

I. INTRODUCTION

Base station is the middle entity which connects wireless mobile phones with the wired cellular network system that consists of data centers and wired devices. Nowadays, many base stations have been deployed to accommodate the rise in the number of mobile phone users. According to the GSMA Technical Report [1], the total number of base stations deployed worldwide has doubled from approximately 1 million base stations in 2007 to about 2 million base stations in 2012 and it is estimated that this trend will increase year by year. However, as more base stations are deployed, the total electricity needed to operate all the base station will also increases. In Ziaul Hassan’s survey [2], each base station consumed about 25MWh on average per year which is 60% of the total cellular network consumption [3]. Besides, the rise in the number of base station also leads to deforestation. Deforestation, which is the activity of clearing a forest to build facility for other activity, can cause the greenhouse gas emission. Due to the high power consumption to operate one base station and deforestation issues, information and communication technologies (ICTs) industry has accounted for 2% of the global greenhouse gas emissions [4]. In order to provide more energy-efficient base stations, many researches have tried to reduce the overall base station’s power consumption and this work is recognized as the green base station.

Most of the green base station works focus on base station sleeping and coordinated multi-point (CoMP). Base station sleeping is a mechanism which refers to turning off the power for some or all parts of the base station. Due to the omni-directional signal transmission, it also includes the cell zooming method which makes the cell coverage expands and contracts according to certain variable. In S. Bhauumit et al. [5], they showed this approach by adjusting the network cellular’s cell size and by switching off the base station according to the traffic load; the power consumption can be reduced. Likewise, CoMP, which is the cooperation between two and more base stations to direct its transmission on specific direction, can also improve the energy efficiency. KMS Hug et al. studied the effect of different type of CoMP scheme such as Joint Transmission and Dynamic Cell Selection to the rate of base station energy efficiency [6]. The common signal transmission used inside their work is static directional transmission.

However, eventually, the users move from one place to another place. There create several vacant areas without presence of any user. It causes a significant waste of power consumption as the base station continuously transmits the signal to the vacant area. It is crucial to create a dynamic directional base station transmission according to the user distribution. In this paper, a low power consumption base station with effective usage of current technology is proposed in order to reduce the power consumption in current conventional base stations. Here, two schemes of base station transmission are used. The first scheme involves a beamforming transmission that will only be operated to the places where there is a hotspot area. In this work, the hotspot area is defined as the area where there is a high user distribution. If the users are equally distributed in the cell, the hotspot area is defined as the area where there is a high user distribution. The downlink directional signal transmission, it also includes the cell zooming method which makes the cell coverage expands and contracts according to certain variable. In S. Bhauumit et al. [5], they showed this approach by adjusting the network cellular’s cell size and by switching off the base station according to the traffic load; the power consumption can be reduced. Likewise, CoMP, which is the cooperation between two and more base stations to direct its transmission on specific direction, can also improve the energy efficiency. KMS Hug et al. studied the effect of different type of CoMP scheme such as Joint Transmission and Dynamic Cell Selection to the rate of base station energy efficiency [6]. The common signal transmission used inside their work is static directional transmission.

This paper organizations are as follows: Section II will explain the basic concepts used inside the proposed scheme of...
opportunistic beamforming. The proposed method which includes the hourly users’ distribution, the high user-density area determination process and the energy efficient transmission scheme will be explained in Section III. Next, in Section IV, the performance evaluation will be conducted by analyzing the simulation system model, the power consumption calculation process and the results obtained from the simulation. Finally, the conclusion and future work from this paper will be drawn in the Section V.

II. OPPORTUNISTIC BEAMFORMING

Opportunistic beamforming is the advanced form of beamforming, where the narrow signal transmission will only be conducted to the places where there is a possibility that the user exists inside the area. Normally, opportunistic beamforming is realized by using smart antenna system as shown in the Fig. 1. The system consists of a directive antenna hardware module and a digital signal processing (DSP) algorithm. The digital signal processing is performed based on the certain optimization goal such as maximizing the desired signal and minimizing the cellular interference signal. In the digital signal processing, there are two main algorithms involved, namely direction-of-arrival estimation algorithm and adaptive antenna algorithm. The direction-of-arrival estimation algorithm determines the user’s direction based on the angle and magnitude of receiving antenna array. Then, the adaptive antenna algorithm processes the users’ information and calculates the most optimum weight for each of the array inside the directive antenna. By appropriately controlling the multiple arrays’ weight magnitude and gain, the direction of the beamforming can be changed to the desired area. Examples of the weight algorithm for the beamforming are Maximum Signal-to-Interference Ratio (Max SIR), Minimum Mean-Square Error (MMSE) and Sample Matrix Inversion (SMI) [7].

III. PROPOSED METHOD

In this section, the proposed method which consists of hourly users’ distribution, high user-density area determination and energy efficient transmission scheme is explained. As the first step to design the user distribution, the hourly user’s activities such as working and resting are used. When the users are completely distributed according to each activity region, the base station will determine the hotspot area. Then, it will provide the most suitable energy efficient transmission scheme to the area.

A. Hourly User Distribution

The hourly users’ distribution is based on the human daily traffic pattern. According to KDDI Corporation’s report, Japan’s mobile data traffic in the residential areas tends to be at peak during night-time hour. Meanwhile, in the business district the peak hour is in the daytime [8]. The hourly users’ distribution is designed in accordance with the KDDI report. In the night-time which is between 7 pm until 8 am, all of the users will randomly distributed inside the residential areas. After 9 am until 6 pm, the 80% of the users will be distributed inside the business districts and the remaining 20% are distributed in the residential areas.

Example of hourly users’ distribution at 10 am and 10 pm are drawn in Fig. 2. Here, the users are represented with asterisk mark, the residential area is marked with shaded pattern and the business district is marked with dotted pattern. In Fig. 2(a), at 10 am, the users are distributed at both residential areas and business districts. However the number of users in residential areas is less than the number of users in the business districts. At 10 pm, all of the users gather at the residential areas and there is no single user inside the business districts as shown in Fig. 2(b).

B. Hotspot Determination

In the uplink transmission from the user to the base station, it is considered that the users’ information such as coordinate and received signal strength (RSS) are known by the base station. From the user coordinate, the user distance from the base station, d and the deflection angle, θ are derived by changing the coordinate into polar form.
After the user’s position is identified, several steps of the hotspot determination process will be conducted. In the first step, the base station separates the users’ angle into 36 small areas with deflection of 10 [deg]. Next, the users with low RSS, i.e. lower than -80 [dBm] are removed from the base station hotspot user selection. Then, the base station will group the 36 small areas into larger areas with deflection between 20 [deg] and 180 [deg]. Scanning process occurs by comparing each adjacent large grouped area. The scanning process finishes immediately when the number of users inside the large grouped area reaches 1/3 of the total active users inside half of the cell. The large grouped area is considered as the hotspot for the whole simulation mentioned later in this paper.

User distribution at 10 am

User distribution at 10 pm

Fig. 2. Hourly users’ distribution

C. Energy Efficient Transmission Scheme

When the hotspot determination process is done, the base station considers the existence of hotspot and decides which energy efficient transmission scheme is the best based on each transmission’s power consumption. In this study, three energy efficient transmission schemes shown in Fig. 3 are proposed based on the user distribution. The first transmission scheme involves beamforming from the current base station and is marked with shaded pattern. The solid grey-colored area represents the second transmission scheme which is omni-directional transmission using two directional antennas. The third transmission scheme is shown with the dotted pattern referring to the beamforming from the neighboring base station.

![Energy efficient base station transmission scheme](image)

The shaded beamforming transmission scheme will be conducted when a hotspot exists inside the macro-cell. If there is no hotspot and the users are equally distributed, the second omni-directional transmission is performed. In the case where there are still exist many users outside of the first and second transmission schemes, the nearest neighboring base station based on the user position will transmit its beamforming. Here, the beamforming radius can be dynamically changed according to the user position. In the current simulation, only the first and second transmission schemes are used and studied.

IV. PERFORMANCE EVALUATION

A. Simulation Parameters

The power consumption of the base station in the downlink beamforming transmission was evaluated through MATLAB simulation. These simulation parameters are basically follow the metric in LTE link level parameter [9]. In the macro-cell with radius of 0.5km, two directional antennas were used where one antenna was specialized for the upper part of the cell and the other antenna was specialized for the lower part of the cell, thus dividing the cell into two sectors. Each of the antennas was equipped with five linear arrays. Other simulation parameters are listed on the following Table I.

<table>
<thead>
<tr>
<th>TABLE I. SIMULATION PARAMETERS</th>
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<tbody>
<tr>
<td><strong>Constant</strong></td>
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<tr>
<td>Cell layout</td>
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<tr>
<td>Radius of the cell</td>
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<tr>
<td>Height of the base station</td>
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<tr>
<td>Uplink Carrier frequency</td>
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<tr>
<td>Base Station (BS)</td>
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<tr>
<td>Number of antennas</td>
</tr>
<tr>
<td>Number of arrays</td>
</tr>
<tr>
<td>Antenna gain</td>
</tr>
<tr>
<td>User Equipment (UE)</td>
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<tr>
<td>Number of antennas</td>
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<tr>
<td>Antenna gain</td>
</tr>
<tr>
<td>Maximum transmission power for UE</td>
</tr>
<tr>
<td>Beamforming beam width</td>
</tr>
<tr>
<td>Array spacing</td>
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<td>Cable power loss</td>
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</tbody>
</table>

The place used in the simulation was based on the real location which is in Selangor, Malaysia. Selangor was chosen because the division between residential area and business district was clear. Macro-cell was defined over the place and the base station was assumed to be positioned in the middle of the macro-cell. The users’ distribution pattern was based on the KDDI Corporation’s report [8]. It was assumed that inside
the macro-cell, 100 users were distributed according to the human daily traffic pattern, where during day time from 9 am to 6 pm, 80% of users were in business district and the remaining were left at the residential area for work and rest. During night-time from 7 pm to 8 am, all of the users were resting and positioned in the residential area. The users’ distribution pattern like Fig. 2(a) and Fig. 2(b) was created in every hour.

B. Power Consumption

In this study, the total power consumption of the base station in downlink transmission was considered. The conventional omni-directional transmission power consumption was introduced to compare the performance to the proposed energy efficient beamforming transmission scheme. Using LTE link budget parameter, the power consumption was calculated based on equivalent isotropically radiated power (EIRP) equation as shown in (4) [9].

\[
\text{EIRP} = \text{HS DSCH Power} + \text{Antenna Gain} - \text{Cable Loss} \quad (4)
\]

In the EIRP equation, HS DSCH is the abbreviation of High Speed Downlink Shared Channel and Cable Loss represents the power consumption to keep the base station active including the circuit power and site cooling. The same variable values of these two were used for calculating power consumption in the omni-directional transmission and in the beamforming transmission. The variable that differentiated the conventional transmission with the proposed beamforming transmission was the antenna gain. In the proposed transmission, five arrays antenna gain was considered. The antenna gain calculation referred to Sophocles J. O.’s Electromagnetic Waves and Antennas textbook where it is derived from the power gain of Discrete-time Fourier Transform [10].

C. Result and Discussion

In this section, the simulation result is presented in order to show the effectiveness of the proposed low power consumption base station transmission scheme. Fig. 4 presents the power consumption of the base station using the proposed beamforming in every hour. The proposed scheme was compared with the conventional omni-directional transmission.

From Fig. 4, it is proved that the proposed beamforming transmission scheme achieved lower base station power consumption than the conventional omni-directional transmission. Here, the power consumption of omni-directional transmission is equal to 1585[W] and it is constant for every hour, meanwhile, the power consumption of the proposed beamforming transmission scheme fluctuates below 284[W]. The graph also shows that during night-time from 7 pm to 8 am, the beamforming has lower power consumption than during the day time from 9 am to 6 pm.

This is mainly because during night-time, all of the users accumulate only in the residential area, thus creating some small grouped area. The number of user covered by the beamforming is small because the base station limits its beamforming transmission only on one small group, thus lowering the power consumption of the base station. On the other hand, in the day time, most of the users go to work in the business district but some of them are still in the residential area for work or rest. This causes the user distribution to disperse in the residential area and in the business district. In the proposed hotspot determination algorithm, however, all the users from grouped area are combined at the business district, thus resulting in many users in the hotspot area. Consequently, many users are covered by the beamforming and the base station’s power consumption is increased. This shows that the power consumption of base station follows the distribution of users.

Fig. 5 presents the preliminary result of the uncovered user ratio to all the users in the upper part for every hour. As shown in Fig. 5, the percentage of uncovered user in the proposed beamforming transmission scheme is above 60% which is higher than the one in the omnidirectional transmission. This shows that there are still many users that do not receive the cellular transmission. This is because of the limitation of beamforming’s shape which cannot cover the whole hotspot area. Furthermore, in the current simulation, only upper side of the cell is considered, thus all users in the lower part are considered as being uncovered by the beamforming.

In Fig. 5, it also shows that the percentage of uncovered user in the proposed scheme during the night-time fluctuates drastically compared to during the day time. This is because during night-time, the users gather only at the residential areas
and the user distribution becomes less dispersed than during the day time. As the users converge in one small area, the beamforming has a higher tendency to transmit its signal to the side of the small area, resulting in less number of user covered by the beamforming. If the beamforming is transmitted in the middle of the small high user distribution area, the number of user covered by the beamforming will increase tremendously, resulting in lower percentage of uncovered user in the proposed beamforming transmission scheme such as at 6 pm and 8 pm.

Here, there is one thing that should be discussed regarding the uncovered user ratio. As mentioned above, Fig. 5 shows the result in the upper part and the users in the lower part are counted as the uncovered users. Even though it is accepted, the uncovered user ratio is too high as a public cellular service. The result in Fig. 5 was obtained in the case where only one base station was used. If more base stations are used concurrently, the uncovered user ratio will be drastically improved. Of course, as the number of base stations increases, the total power consumption also increases linearly. However, the vertical axis in Fig. 4 indicates the power consumption in logarithmic scale. Therefore, even if five base stations are used, for example, the total power consumption at 10 am will be about 1000W which is still less than the power consumption in the conventional omni-directional transmission. This shows that the proposed beamforming transmission scheme works effectively when the hourly users’ distribution is considered as the beamforming direction.

Fig. 6 shows the graph of base station power consumption against the percentage of uncovered user in the proposed beamforming transmission scheme. As shown in the graph, the power consumption fluctuates so much when the percentage of uncovered user is in the range from 60% to 75%. However, the fluctuation becomes lower and stable when the percentage of uncovered user is more than 75%.

![Uncovered user rate against base station power consumption](image)

The linear trend line in the graph represented by the dotted line shows that as the percentage of uncovered user increases, the base station power consumption decreases. That is to say, when higher percentage of user uncovered by the beamforming which means lower number of user is covered by the beamforming, the power needed to operate the base station is also lower. This is obvious because more base stations are needed to cover all the users. As stated above, however, the total power consumption increases linearly to the number of base stations. Therefore, the power consumption per base station can be decreased in the proposed beamforming transmission scheme.

V. CONCLUSION

In this paper, a low power consumption base station transmission scheme based on hourly users’ distribution has been proposed. From the results obtained by simulation, it is proven that the proposed beamforming transmission scheme using directive antenna achieves a lower power consumption than the conventional static omni-directional antenna. The number of users uncovered by the proposed scheme is considerably high which is above 60%. However, this can be easily solved by using a multiple base station system. Therefore it is concluded that the proposed beamforming transmission scheme can work effectively in terms of low power consumption.

In future, the weight algorithm for the proposed method will be further studied and the lower part of the macro-cell will be investigated. Then, the overall two direction base station power consumption and the number of user uncovered by the beamforming will also be analyzed. Lastly, the realistic human mobility model will be included in the simulation and its energy efficient rate will also be studied.

All of the future work need to be done in order to ensure that the proposed scheme can be implemented in the real world situation. It is also hoped that this work can contribute to the eco-friendly cellular network in the long run. It is fundamental to create better environment with less pollution for the future generation goodness.

References