THE TRADEOFF BETWEEN POWER CONSUMPTION AND AVERAGE THROUGHPUT FOR ENERGY EFFICIENT MACROCELL STRATEGY

Nur Ellina Binti Ishak, Eiji Kamioka
Graduate School of Engineering and Science, Shibaura Institute of Technology
ma14084@shibaura-it.ac.jp, kamioka@shibaura-it.ac.jp

ABSTRACT
Recently, the growing demand for high quality cellular transmissions due to the increase number of smartphone users has triggered an issue in power consumption of the base station. The conventional cellular transmission in a macro cell base station is commonly conducted in omnidirectional manner to provide a wide range of cellular transmission. However, as the smartphone users move from one place to another, there are some areas inside the macro cell where no user exists. Despite this, the base station keeps transmitting the cellular signal towards those areas and consequently this causes an energy waste. In this paper, a new implementation strategy of energy efficient LTE macro cell base station based on hourly user location distribution is proposed to reduce the energy waste inside the base station. Here, the hourly user location distribution follows the data traffic trend of smartphone users at the residential area and commercial area during weekdays. An opportunistic beamforming technology is introduced into the macro cell base station to provide a cellular transmission only to the high user-density area. The active calling users who cannot receive the cellular transmission from the opportunistic beamforming will be covered by the small cell technology namely the femtocell. Concretely, the low power consumption femtocell access point is designed to be turned on only when the active calling users are inside the range of the femtocell. If the users are equally distributed inside the macro cell, the omnidirectional transmission from two directive antennas will be performed. Consequently, the proposed strategy can reduce the total power consumption of the base station inside the macro cell and at the same time provide high quality cellular transmission to almost all the active calling users.

1. INTRODUCTION

In recent years, the tremendous growth of Information and Communication Technology (ICT) has significantly increased the energy demand and agitate the carbon dioxide (CO_2) gas emissions level [1] [2], consequently worsen the energy crisis and global warming problems. Green Cellular Network, a research direction for the evolution of future wireless architectures and techniques towards high energy efficiency, has been introduced as one of the solutions for this problems [3].

Green Cellular Networks aims to reduce the power consumption of the mobile communication equipment by designing new energy-efficient architectures, protocols and algorithms, targeting various types of mobile networks. Basically, it involves all stages of cellular network which are backhaul network, base station and user equipment. It also includes the improvement of the base station hardware design, power saving protocol, self-organizing network algorithm and use of renewable energy resources [4].

In order to confirm the validity of the Green Cellular Network method, which can reduce the energy consumption whilst simultaneously maintain the quality of service (QoS), the tradeoff relationship between energy efficiency and system performance needs to be highly considered. W. Guo et al. had studied the tradeoff between operational power consumption and throughput QoS for their proposed base station sleep mode operation and vertical sectorized antenna layout, in order to demonstrate their work was better than the baseline [5]. F. Cao et al. also studied the tradeoff relationship between energy efficiency and system performance for the femtocell deployment condition [6].

This paper is structured into 4 sections. In section 2, our previous work and current work on energy efficient opportunistic beamforming with additional femtocell deployment based on calling user location distribution will be explained. Section 3 will clarify the evaluation metric used to create the tradeoff relationship. This paper’s novelty point, which is the tradeoff relationship between power consumption and network performance will be further discussed in section 4. Finally, this paper will be concluded in the conclusion section.

2. OPPORTUNISTIC BEAMFORMING WITH FEMTOCELLS DEPLOYMENT BASED ON USER LOCATION DISTRIBUTION

Opportunistic beamforming is the advanced form of a signal processing technique which directs the radio transmission in a specific angular direction where there is an opportunity that the users exists. Generally, the opportunistic beamforming is realized through a smart antenna system inside the directional base station. The beamforming direction can be changed by controlling the multiple arrays' gain and phase according to the obtained weight.

In the previous work, Maximum Signal-to-Interference Ratio (Max SIR) weight algorithm is used to direct the beamforming only to the highest density area inside the macro cell [7]. The highest density area, known as hotspot area, exists depending on the hourly user location distribution, which during daytime most smartphone users randomly gather inside the business area and during night-time all the users are located inside the residential area. From the weight algorithm used in the previous work, the call dropping percentage was still high at above 60% of the overall users. In this work, the call dropping percentage is defined as the percentage of beamforming uncovered users.

Currently, the previous work is improved by adding some noise, σ_n inside the weight equation and this weight algorithm is similar to Godara Signal-to-Interference Ratio (Godara SIR) weight algorithm [8]. The following equation (1) shows the final Godara SIR weight, $\boldsymbol{w}$ equation.

$$\boldsymbol{w}^H = \boldsymbol{u}_1{}^T \cdot \boldsymbol{A}^H (\boldsymbol{A} \cdot \boldsymbol{A}^H + \sigma_n{}^2 \boldsymbol{I})^{-1} \qquad (1)$$

Where, $\boldsymbol{A}$ is a matrix of steering vectors [$\boldsymbol{a}_0$ $\boldsymbol{a}_1$ $\boldsymbol{a}_2$] and $\boldsymbol{u}_1$ is a Cartesian basis vector of $[1\ 0 \ldots 0]^T$. By adding the noise, the opportunistic beamforming beam width becomes wider towards the center of the hotspot area, resulting in decreasing number of call dropping percentage to 40% of the overall users as shown in Fig. 1. However, the call dropping percentage is still considerably higher and many active users outside of the beamforming area cannot establish the cellular connection. In order to solve this problem, the beamforming uncovered active users need to be covered with small low power consumption cellular areas called femtocells.

Femtocell has the smallest range of cellular coverage at maximum radius of 50 meter and is usually installed inside small buildings. The femtocell access point connects directly to the core cellular network through the Internet via the building's broadband line. It also consumes less power among other types of base stations due to its small size and easy set up to the cellular connection.

In the proposed work, the femtocell access points are in the sleeping mode as the default setting. It will be woken up only when the calling users are within the range of femtocell. The calling user is defined as the user who will initiate a call to other user and its probability of making call is based on the 2013 hourly number of phone call data from Japan Ministry of Internal Affairs and Communications [9].

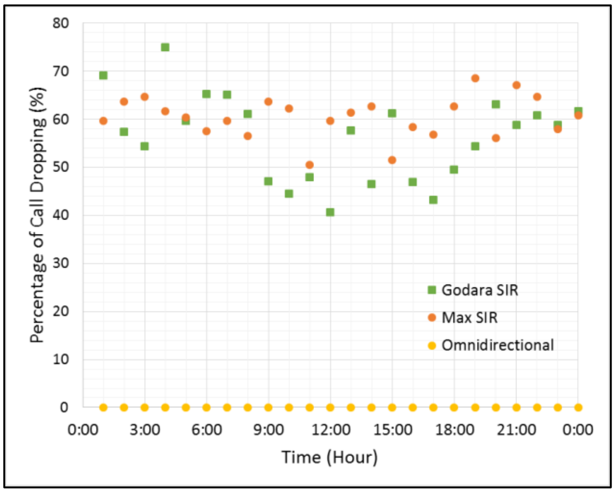

Fig.1 Percentage of uncovered user in every hour

3. EVALUATION METRIC

In this work, the significant evaluation metrics that will be used in the tradeoff graph are average throughput in downlink transmission and total power consumption of the cellular sources involved. The tradeoff relationship is based on the result obtained in every hour. Both of the metric values depend on the user location distribution, thus, the values change in every hour according to the user activity.

The average throughput value acts as a metric to value the quality of service for the proposed work. It was derived by finding the average of all calling users maximum downlink throughput covered by the cellular transmission. The maximum downlink throughput is calculated by equation (2).

$$\text{Max. Downlink Throughput [bps]} = B \log_2\left(1 + \frac{S}{N}\right) \qquad (2)$$

Where, B is the general bandwidth of 10 [MHz] for the LTE Band 7 in Malaysia and S/N represents the signal to noise ratio. S/N is estimated from the Received Signal Strength Indicator (RSSI) in each mobile phone through dividing Reference Signal Received Power (RSRP) with the noise power for one LTE subcarrier [10]. RSSI provides information about total received entire band power including noise information. Meanwhile, RSRP only provides the raw power of LTE Reference Signals that spread over the entire bandwidth. RSRP is calculated by equation (3).

$$\text{S/N : RSRP [dBm]} = \text{RSSI[dBm]} - 10\log(12 \times \text{N}) \qquad (3)$$

Here, N represents the number of resource block in the LTE bandwidth.

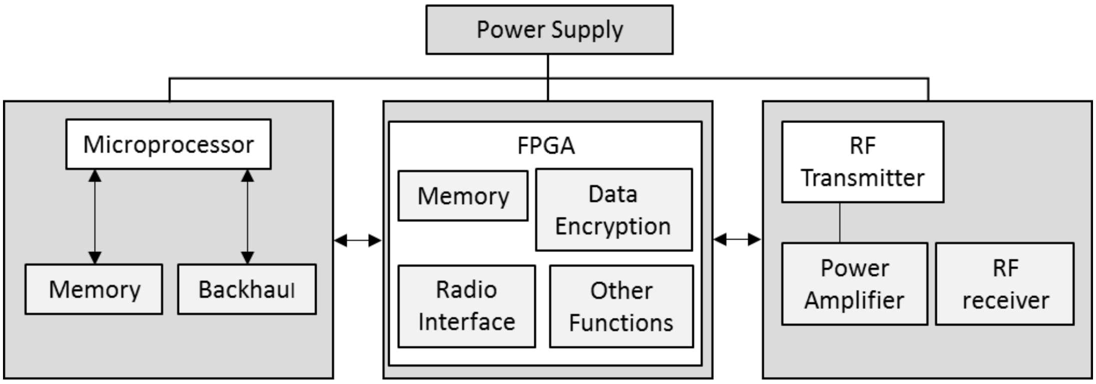

Fig. 2 Hardware inside femtocell access point

The second evaluation metric involved is hourly total power consumption. It was simply obtained as the summation of the power consumptions in the macro cell base station and in the additional femtocell access points. The macro cell base station power consumption is calculated by equation (4).

$$P_{\mathrm{macrocell}}[\mathrm{W}] = 10^{((P_{\mathrm{HS\ DSCH}} + \mathrm{AntennaGain} - \mathrm{CableLoss} - 30)/10)} \qquad (4)$$

In the equation (4), 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 the power consumption in the omnidirectional transmission and in the beamforming transmission. The variable difference between the conventional transmission and the proposed beamforming transmission was the antenna gain which is derived from the power gain of Discrete-time Fourier Transform.

The power consumption calculation process in a femtocell access point is quite different from the one in the macro cell base station since the hardware involved in the system was different as shown in Fig. 2.

In fig. 2, FPGA is the abbreviation of Field Programmable Gate Array and functions as the interface between the microprocessor and radio frequency (RF) transmitter. The power consumption for femtocell access point in its default sleeping mode is calculated by equation (5).

$$P_{\mathrm{femtocell/sleep}}[\mathrm{W}] = P_{\mathrm{microprocessor}} + P_{\mathrm{FPG}} \qquad (5)$$

When there exist uncovered calling users in the range of femtocell access point, the access point will be woken up. During the wake up mode, the RF transmitter hardware will be turned on to facilitate the cellular transmission towards the users. The power consumption for this wake up mode is calculated by equation (6).

$$P_{\mathrm{femtocell/wakeup}}[\mathrm{W}] = P_{\mathrm{microprocessor}} + P_{\mathrm{FPGA}} + P_{\mathrm{Transmitter}} \qquad (6)$$

Finally, the total power consumption of all femtocells was calculated by equation (7).

$$P_{\mathrm{femtocell}}[\mathrm{W}] = N_{\mathrm{femtocell/wakeup}} \times P_{\mathrm{femtocell/wakeup}} + (N_{\mathrm{femtocell}} - N_{\mathrm{femtocell/wakeup}}) \times P_{\mathrm{femtocell/sleep}} \qquad (7)$$

Here, $N_{\mathrm{femtocell/wakeup}}$ is the number of woken up femtocells and $N_{\mathrm{femtocell}}$ is the total amount of femtocells existing inside the macrocell.

4. RESULT AND DISCUSSION

In this section, the tradeoff relationship between the hourly average throughput and the hourly total power consumption are discussed. The user location distribution is fixed for every strategy but changed in every hour. The proposed opportunistic beamforming is compared with the previously proposed opportunistic beamforming and conventional omnidirectional transmission as shown in Fig. 3.

From Fig. 3, the currently proposed opportunistic beamforming with additional femtocells (see "Beamforming + Femtocell" in Fig. 3) and previously proposed opportunistic beamforming (see "Beamforming" in Fig. 3) can achieve higher throughput than the conventional omnidirectional (see "Omnidirectional" in Fig. 3). In terms of power consumption, both of our proposed macro cell strategies have lower power consumption than the conventional omnidirectional.

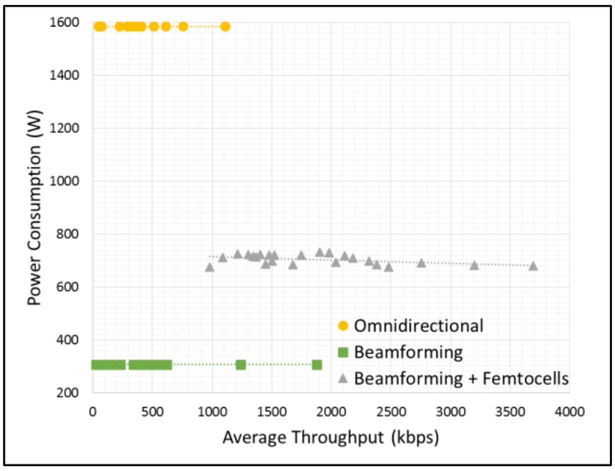

Fig. 3 Tradeoff relationship between average throughput vs power consumption for all macro cell strategies

As shown in Fig. 3, the tradeoff relationship trend line for previously proposed beamforming and conventional omnidirectional are constant at power consumption of 300[W] and 1580[W] even though the average throughput increases. On the other hand, the currently proposed beamforming with femtocells has trend line where the power consumption slightly decreases when the average throughput increases. This is because when the average throughput increases, the users are close to the base station. The nearer the users are with the base station, the less number of femtocell access point is needed to be woken up. Thus, resulting in lower power consumption. As a result, it can be said that the additional number of femtocells largely affects the average throughput and the total power consumption of the whole macro cell.

CONCLUSION

In this paper the tradeoff between power consumption and average throughput of the proposed opportunistic beamforming with femtocell deployment based on user location distribution has been studied. From the tradeoff result obtained, the proposed work has a characteristic where when the average throughput is higher, the power consumption is slightly reduced. This shows the effectiveness of the additional low power consumption femtocells deployment. It can be concluded that the proposed opportunistic beamforming with femtocell deployment can majorly contribute to lower power consumption and simultaneously provide a higher quality of cellular services. In the future, the overall cost for realizing the proposed macrocell strategy in the short and long terms needs to be investigated in order to provide more reliable energy efficient macrocell strategy.

REFERENCES

[1] "Gartner Estimates ICT Industry Accounts for 2 Percent of Global CO2 Emissions," Stamford Conn., April 26, 2007.

[2] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014-2019, Cisco White Paper, pp.1-42, February 2015.

[3] Z. Hasan, S. Member, and H. Boostanimehr, "Green cellular networks : a survey, some research issues and challenges," Proc. IEEE Comm. Surveys & Tutorials, vol.13, no.4, pp.524–540, 2012.

[4] CR. Murthy and C. Kavitha, "A survey of green base stations in cellular networks," Int' Journal of Computer Networks and Wireless Communications, vol.2, no.2, pp.232-236, Apr 2012.

[5] W. Guo, and T. O'Farrell, "Green cellular network: deployment solutions, sensitivity and tradeoffs," Proc. Wireless Advanced, pp.42-47, June 2011.

[6] F. Cao and Z. Fan, "The tradeoff between energy efficiency and system performance of femtocell deployment," Proc. International Symposium on Wireless Communication System, pp. 315-319, Sept. 2010.

[7] NEB. Ishak and E. Kamioka, "Environmental friendly opportunistic beamforming based on hourly users' distribution," Proc. SEATUC Symposium '15, Aug. 2015.

[8] F. Gross, "Smart antenna," in Smart Antennas for Wireless Communication with MATLAB, McGraw-Hill, 2005.

[9] Telecommunication Bureau, "Voice calling usage of our country as seen from the data transfer usage [2013 fiscal year] (in Japanese)," Japan Ministry of Internal Affairs and Communications, Nov. 2014.

[10] ML. Rocca, "RSRP and RSRQ Measurement in LTE", Larocca Solution Article, May 2015.

BIBLIOGRAPHY

Nur Ellina Binti Ishak obtained her Diploma Degree in Electrical Engineering from Industrial University of Selangor, Malaysia and B. Eng. in Electrical Engineering from Tokyo University of Science, Japan. Currently she is pursuing her M. Eng. at Shibaura Institute of Technology, Japan. Her research interest includes wireless mobile communication, green technology and antenna theory.

Eiji Kamioka is a Professor at Shibaura Institute of Technology. He received his B.S., M.S. and D.S degrees in Physics from Aoyama Gakuin University, Japan. Before joining SIT, he was working for SHARP Communications Laboratory, Institute of Space and Astronautical Science (ISAS) as a JSPS Research Fellow and National Institute of Informatics (NII) as an Assistant Professor. His current research interests encompass mobile multimedia communications and ubiquitous computing.