A Study on the Green Cellular Network with Femtocells

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***Abstract*— In this paper, we investigate how femtocells can make conventional cellular networks *greener*. We present an energy consumption modeling framework to evaluate total energy consumption in a cellular network with femtocells. Using the proposed framework, we investigate the energy consumption and performance of the cellular network with femtocells. We consider various network environments, including indoor propagation environment, user distribution near the femtocells, and a femtocell access policy, which have effect on the performance of the cellular network. Simulation results in the various environments show that femtocell is, in general, a *greener* technology that reduces the total energy consumption in a cellular network. We obtain system performance and energy consumption for three different scenarios: different femtocell penetration rate, different open access rate, and different cell coverage. We have finally provided a guideline that helps system operators deploy and manage a cellular network with femtocells in more greener way.**

***Keywords*— Green communication, Cellular network with femtocells. Energy consumption**

I. INTRODUCTION

Recently, the development of wireless communication systems is driven by the demand for greener, i.e., more energy efficient, system design. In order to prevent dangerous climate change in future, the Kyoto Protocol was signed in 1997 and it establishes legally binding commitments for the reduction of greenhouse gases including carbon dioxide (CO_2). Information and Communications Technologies (ICT) produce 2% of total global CO_2 emission [1] and this amount is equal to that of aviation industry or one fourth of the CO_2 production of cars. Especially, 0.5% of world-wide electrical energy is consumed by cellular networks [2]. Accordingly, communication industry has already started the first step toward green communications. For example, in UK, Ofcomm announced the reduction of CO_2 emission of cellular networks to half by 2020 [3].

However, the overall energy consumption of wireless communication networks has been increasing rapidly and is expected to be accelerated. There could be many reasons contributing to the growing energy consumption, but the main cause is the increasing demand for higher users data rate (400% increase of user traffic per year). In order to achieve more system capacity, the cellular architecture has been evolved; small cell base stations, relay stations, femtocells are considered for the next generation cellular networks. As a result, now, it is much harder to design a greener cellular network with the hierarchical and dynamic cellular architectures. Especially, femtocell access points (FAPs) are randomly deployed in houses and buildings by individual users so that system operators cannot easily plan or manage the femtocells. It is undisputed that the use of femtocells would greatly affect the performance and the energy consumption of cellular networks. However, the use of femtocells is not manageable for system operators; therefore, a research on how femtocells change the performance and the energy consumption of cellular network should be studied and guidelines for system operators to efficiently design the cellular network with femtocells should be investigated.

In this paper, we present an energy consumption modeling framework to evaluate total power consumption in a cellular network, through extensive quantitative research on the power consumption of entities on typical cellular networks. We also consider different scenarios, such as different femtocell penetration rates, different open access limits, and various cell coverages, to evaluate the system from several different aspects. Using the proposed framework, we investigate the power consumption and performance of a cellular network equipped with femtocells. Simulations in various environments of the downlink cellular network with femtocells show that femtocell is, in general, a greener, i.e., energy efficient, technology. The rest of this paper is organized as follows. Section II presents some projects and paper works relating to the performance and the energy consumption of cellular networks with femtocells. In Section III, an energy consumption modeling framework evaluate power consumption in cellular networks with femtocells is proposed. In Section IV, simulation scenarios are presented and discussed. In Section V, simulation results are presented. Finally, conclusions are drawn in Section VI**.**

II. RELATED WORKS

Most of researches on the energy efficient cellular network design had focused on hardware designs, algorithms, or protocols for energy efficient battery powered mobile stations (MSs). Studies on the energy efficiency of the line-powered equipments, such as base stations (BS), relay stations, had been relatively rare. However, because of the trends of the greener cellular network design, recently, many research projects

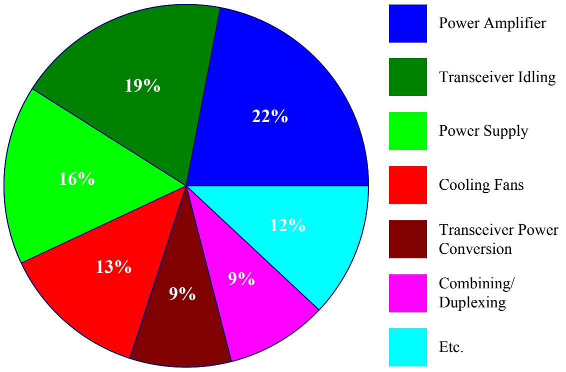

Figure 1. The power use for each component of typica base station

and paper works, which study the performance and the energy efficiency of whole radio access networks (RAN) of cellular networks, have been found.

Several research projects, such as [4], [5], [6], [7], focus on energy efficient power amplifiers in a BS. The Cool Silicon project [8] focuses on the optimization of individual aspects of the communication systems like the architecture of the system, communication algorithms and protocols as well as physical components. Mobile VCE Green Radio [9] aims at extending the efficiency studies to an energy metric for cellular and end to end communication.

In [10], the authors provide a new network planning that deactivates base stations with low traffic especially during night time. A study [11] dealt with the energy efficiency on the base station side, since base stations are dominant source of energy consumption in entire cellular networks. In a study in [12], energy consumption in cellular networks is studied in detail, based on the actual measurement from 3G networks of NTT DoCoMo in Japan. The paper concludes that the consumption ratio of mobile terminal vs. networks is about 1:150.

In [13], the authors evaluate the power consumption in a macro cellular network with micro cells, which are located on the edge of two macro cells. The study is limited to a curtain scenario that the micro cells are installed at the predetermined and optimal location. However, femtocells and micro cells are usually installed by users at random locations and the study does not reflect this practical consideration.

III. AN ENERGY CONSUMPTION MODELING FRAMEWORK TO EVALUATE ENERGY CONSUMPTION IN CELLULAR NETWORKS WITH FEMTOCELLS

A typical cellular network with femtocells consists of base stations (BSs), mobile stations (MSs), and femtocell access points (FAPs). We present an energy consumption modeling framework to evaluate the energy consumption in a cellular network with femtocells. The energy consumption modeling for each network entity is established from actual measurements of various references.

TABLE I. CONTRUBUTING COMPONENTS TO E_1, E_2, AND E_3 AND THEIR PERCENTAGES

Energy use	Contributing components	Percentage (%)
E_1	Power supply, Power supply, cooling fans, central equipment, and cabling	38
E_2	Transceiver idling combining/duplexing	28
E_3	Power amplifier, transmit power transceiver power	34

A. *Base Station (BS)*

It is well known that base stations are the main power consumer in a cellular network [2]. Within a base station, according to [14], power amplifier and transmit power consume 22% and 3% power, respectively. We assume that the power consumption from those processes have linear relationship to the utilization of radio resource. Moreover, power use of typical base station is as follows: Power supply, cooling fans, central equipment, cabling, transceiver idling, combining/duplexing, power amplifier, transmit power, and transceiver power conversion. The power use for each component is given in Fig.1

Assuming that the maximum power consumption at a BS is 3.0 kW, we model several states for BSs. A BS can be turned off when it is not in operation, and this state is called a '*turn-off state*,' and the BS in this state consumes E_1 of energy. If the BS is completely switched off, the reboot time would be too long. Thus, some parts of a BS are always on even in 'turn-off state,' and they contribute to E_1 of energy. Otherwise, when the BS is switched on, the radio part of it can be switched on or off. When the radio part is power off, the BS is called to be a 'radio-off state,' and the total consumption of the BS is $E_1 + E_2$. Finally, when even the radio part is on, the BS is in a 'radio-on state' and additional energy consumption due to the radio part is modeled as αE_3 and the total power consumption of the BS is $E_1 + E_2 + \alpha E_3$. The term α represents the utilization of radio resource allocated to the BS ($0 \leq \alpha \leq 1$) and is given as

$$\alpha = \beta + (1 - \beta)\gamma \ , \qquad (1)$$

where β denotes the portion of overhead (such as, pilot signals, preambles, control signaling, feedback signaling, and etc.) and in this paper we assume $\beta = 0.3$. The term γ represents the utilization of data portion ($0 \leq \gamma \leq 1$). Contributing components to E_1, E_2, and E_3, and their percentages to total energy consumption of a BS is given in Table I. If the BS is fully loaded (i.e., $\alpha = 1$) due to high traffic, the energy consumption of the BS is $E_1 + E_2 + E_3$. Otherwise, when the BS is empty loaded (i.e., $\alpha = \beta$), the energy consumption is $E_1 + E_2 + \beta E_3$.

B. *Mobile Station (MS)*

During talk, a typical mobile station consumes 1.0 W, and during standby, 0.017 W is consumed [15]. Since the energy consumption of MS is typically extremely lower than that of BS and FAP, we simply assume that MSs consume 1.0 W all the time during the simulation.

C. *Equations*

Energy consumption of femtocell access point has not been thoroughly investigated yet. The energy consumption is assumed to vary a lot depending on manufacturers. However, there exists a regulation on the energy consumption of a femtocell access point. EUs code of conduct on energy consumption of broadband equipment regulates the energy consumption of a femtocell access point under 9W [16]. It is natural to think that FAPs are 'always on' to be always ready for the service.

IV. SIMULATION SCENARIOS FOR ENERGY SAVINGS IN CELLULAR NETWORKS WITH FEMTOCELLS

In this section, we summarize three simulation scenarios that effectively investigate the energy consumption in a cellular network with femtocells. Quantitative investigations of the performance and the energy consumption on these scenarios are performed further in Section V.

A. *Scenario I – Femtocells Penetration Rate*

The first commercialized FAP was introduced to market in 2008 and it is expected to grow with 138 percent over the next four years and reach $1.5 billion by 2012 [17]. When femtocells are deployed in every building, they are expected to improve indoor user experience. Moreover, since downlink traffic, which was to be delivered via BSs, can be delivered through FAPs, the utilization and energy consumption of BSs are expected to decrease. Therefore, the total energy consumption in a cellular network could be reduced by increasing the use of femtocells. We further examine the performance and energy consumption of the cellular network for varying femtocell penetration rate r_p. The *femtocell penetration rate* describes the percentage of buildings with FAPs, where buildings include houses, offices, etc. The femtocell penetration rate, r_p, lies in between zero and one. When $r_p = 0$, it means no buildings are equipped with FAPs; when $r_p = 1$, it means all buildings have their own FAPs inside of them.

B. *Scenario II - Open Access Rate*

In general, FAPs are divided into closed subscriber group (CSG) closed FAPs, CSG open FAPs, and open subscriber group (OSG) FAPs [18]. CSG-closed FAP is accessible only to the MSs, which are in its CSG, while CSG-open FAP also allows additional (but limited) non-CSG MSs with low priority. OSG FAP is accessible to any MS. Because of security issues, most FAPs installed by private users are expected to be the CSG FAPs. However, CSG FAPs are known to cause severe co-channel interference to neighbor MSs. To resolve the co-channel problem, several interference cancellation techniques proposed [19] [20]. However, better and simpler solution is to allow open access to all MSs or limited MSs in the network. A paper [21] shows that open access improves total capacity of a cellular network with femtocells. Not only performance perspective, energy consumption would be reduced by allowing open access. In our simulation, we gives priority to CSG-MSs and allow open access to the other MSs, but we set the maximum allowable number of open access MSs per FAP. Further, we investigate the performance and energy consumption of the cellular network with femtocells for varying the maximum allowable number of open access MSs.

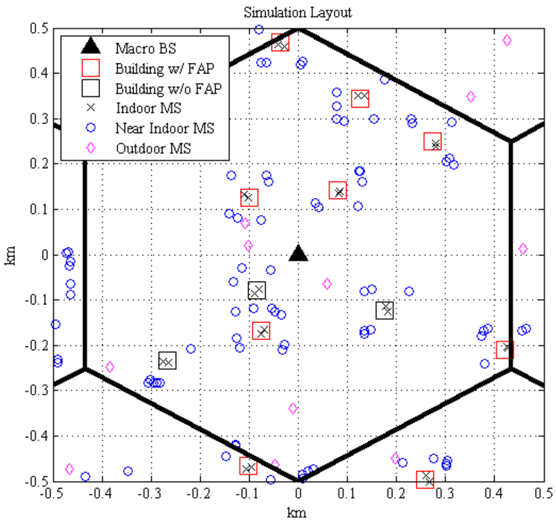

Figure 2. A snapshot of a system-level simulation of a cellular network with femtocells.

C. *Scenario III - Cell Coverage Extension*

Since base stations are the most energy consuming elements in a cellular network, if it is possible to use lesser number of base stations in a system while maintaining system performance, a lot of energy savings can be achieved. Using the concept, a research to reduce total energy consumption in a cellular network was performed by introducing optimal energy saving schemes [10]. The authors in [10] argue that any fraction of cells can be turned off and cell coverage is extended when traffic is low and this could save a lot of energy consumed in the network. Similarly, we can expect femtocells help the cell coverage be extended because the utilization of base stations decreases with femtocell deployment.

V. SIMULATION RESULTS

A. *Simulation Environments*

As shown in Fig. 2, we perform extensive system-level simulations consisting of 7 BSs with omni-directional antenna and 86 MSs per cell. BSs are placed in a regular grid, following hexagonal layout and cell radius can be varied and the default value is set to 500 m. We randomly locate ten buildings per cell to model indoor environment and each building has a square-shaped wall with a length of 10 m. The building includes typical houses, offices, or any other indoor facilities. There can be a single FAP at the center of a building or no FAP in it. It is modeled that each building has its FAP with probability of r_p.

Depending on their locations, we define three types of MSs in the simulation: indoor MSs, near indoor MSs, and outdoor MSs. *Indoor MSs* are uniformly distributed inside a building. We assume that every building has two indoor MSs inside of it.

Near indoor MSs are uniformly distributed within the distance of 5 m from the outer wall of a building. We assume that a building has six near indoor MSs around it. *Outdoor MSs* are uniformly distributed, but not too close to the buildings (at least 15 m distance from any building).

All the indoor MSs are assumed to be in the closed subscriber group (CSG) and, therefore, can access the FAP in the same building with highest priority. On the other hand, near indoor MSs and outdoor MSs are all in the open subscriber group (OSG) so that they can access OSG FAPs and CSG-open FAPs with conditions. When a CSG-open FAP can serve two additional non-CSG MSs, the CSG-open FAP orders the non-CSG MSs with their received SINRs and chooses the best two non-CSG MSs to grant the access.

Path loss between BSs and MSs is modeled as IEEE 802.16m model, $P_{out\text{-}out}$ (dB) = 130.62 + 37.6 $\log_{10}(R)$ (R in km) [22]. Path loss of a wireless link that has a wall between two end nodes is modeled as Type J model of IEEE 802.16j [23]. Path loss model in Type J is composed of a loss due to outdoor to outdoor path loss and a penetration loss, given as, $P_{out\text{-}in} = P_{out\text{-}out} + P_{pen}$. The loss $P_{out\text{-}out}$ can be modeled as in IEEE 802.16m. We assume the penetration loss P_{pen} is 15 dB. Path loss between FAP and MS when both are inside building is given as $P_{in\text{-}in} = 37 + 30 \log_{10}(d)$ (dB), where d is a distance in meters. We assume log-normal shadowing and standard deviation for outdoor-outdoor is 8 dB, indoor-indoor 3.5 dB. No shadowing is applied to outdoor-indoor link.

We assume that an idea and optimal coding scheme is used for wireless link. That is, by using a given signal-to-noise-ratio (SINR)γ, a Shannon rate $B \cdot \log_2 (1 + \gamma)$ bps is achievable, where B represents the bandwidth of the system.

We assume a *limited full-queue model* for the downlink traffic for each user in the network. With a limited full-queue model, each user has infinite number of packets arrived in the queue, but they are not allowed to send more than two packets at one frame. In a TDMA based resource management and Shannon rate achievability assumption, a transmission time duration for a packet with received SINR, γ , is given by

$$t = L / B \log_2 (1 + \gamma) \text{ seconds,} \qquad (2)$$

where L denotes the fixed size of bits transferred in a packet. We assume the same fixed size of bits. We limit the maximum length of a transmission time duration for a packet t, since with the limited full-queue model some MSs with extremely low SINR occupy most of the time resources and monopolize almost all the time resource.

The simulation parameters are provided in Table I.

B. *Analysis on Performance and Energy Consumption*

1) *Scenario I - Femtocell Penetration Rate:*

Fig. 3 shows the throughput and normalized energy consumption of the cellular network with femtocells for varying femtocell penetration rate. The total throughput of a cell, summation of throughput via a BS and throughput via FAPs in a cell, increases as r_p increases up to 20%. But it is saturated when r_p is higher than 20%. Up to r_p = 20%, throughput via the BS is increased because the BS was fully loaded when r_p = 0% and as r_p increases the BS has more chances to assign time resource to MS with high link quality. When r_p is higher than 20%, more and more MSs are served by FAPS and the BS becomes under-loaded. So throughput via BS linearly decreases whereas throughput via FAP linearly increases according to r_p. Since the BS becomes under-loaded and its utilization is below 1.0, the normalized energy consumption per cell is decreased as r_p increases. Normalized energy consumption is calculated as the total energy consumption in a cell, including BSs, FAPs, and MSs, divided by the coverage area of the cell. However, due to the high portion of standby energy at the BS, the normalized energy consumption is lower-bounded.

TABLE II. SIMULATION PARAMETERS AND VALUES

Parameters	Values
Central frequency (GHz)	2.0
Bandwidth (MHz)	20
Cell radius (Km)	Varied (default 0.5)
Maximum TX power of macro BS (dBm)	43
TX power of FAP (dBm)	23
Thermal noise density (dBm/Hz)	-174
Shadowing factor for outdoor-to-outdoor	Log-normal (0,8dB)
Shadowing factor for indoor-to-indoor	Log-normal (0,3.5dB)
Femtocell penetration rate (%)	Varied
Wall penetration loss (dB)	15
Pathloss model	130.62 + 37.6 $\log_{10}(R)$ dB
Number of FAP per a macro cell	10
Number of indoor MSs per a FAP	2
Number of near indoor MSs per a FAP	6
Number of outdoor MSs per a macro cell	6

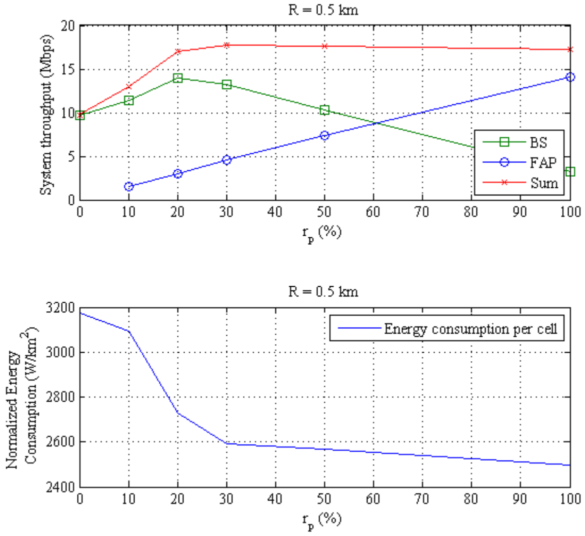

Figure 3. Throughput and normalized energy consumption of the cellular network with femtocells for varying femtocell penetration rate. Cell radius is set to 0.5 km and free open access is assumed.

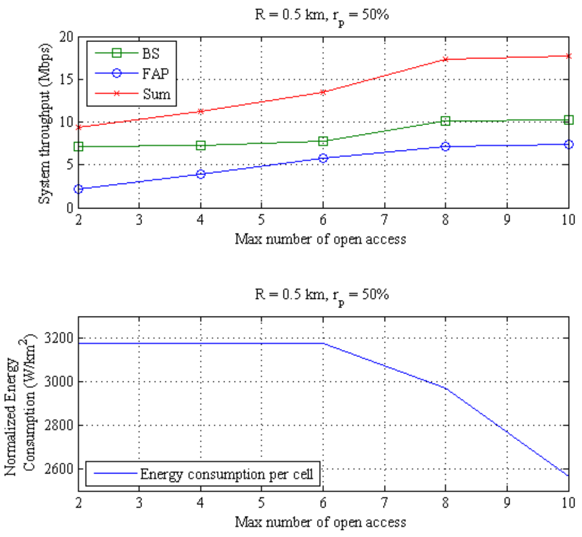

Figure 4. Throughput and normalized energy consumption for varying the maximum of open access MS. Cell radius is set to 0.5 km and 50% of femtocell penetration rate is assumed.

2) *Scenario I I – Open Access Rate:*

As shown in Fig. 4, the system throughput is increased as the maximum number of open access MS (open access limit) is increased. Obviously, throughput via FAP increases, since the FAP is under-loaded when the maximum number of open access MS is low. Interestingly, throughput via BS is also increased because as the maximum number of open access MS increases the BS has more time resource to transmit blocked packets. Accordingly, the total system throughput increases. On the other hand, the normalized energy consumption per cell is decreased and it can be explained that decreased utilization of the BS causes energy savings on the total cellular network.

3) *Scenario I I – Open Access Rate:*

Finally, in Fig. 5, the average user throughput for varying cell radius and open access limit is given. When the open access limit is 4, the average user throughput decreases from cell radius 0.5 km. However, when the open access limit is 8, the performance maintains at its best value from cell radius 0.5 km to 0.7 km and starts to decrease from 0.7 km. The average user throughput always maintains the best performance when the open access limit is infinite, i.e., all the FAPs work as OSG FAPs. When the open access limit is set to 4, BSs are fully loaded even at the cell radius 0.5 km, but it is under-loaded with the open access limit 8 or infinite. BS with FAPs of open access limit 8 becomes full-loaded at the cell radius 0.7 km. Moreover, the BSs with OSG FAPs are always under-loaded even up to cell radius 0.9 km. The normalized energy consumptions for all open access limit decrease as the cell radius increase. Among them, the energy consumption with OSG FAPs is always lowest and that with open access limit 4 is highest. The energy consumption with open access limit 8 starts to be the same as that with open access limit 4 at cell radius 0.7 km, which means that the BS becomes full-loaded from cell radius 0.7 km. The observations from Fig. 5 conclude that we can extend the cell radius and greatly reduce the energy consumption of the cellular network with femtocells if FAPs are widely used and they have higher open access limits. If all the FAPs work as OSG FAPs, the cell radius is can be further extended and substantial energy savings can be achieved.

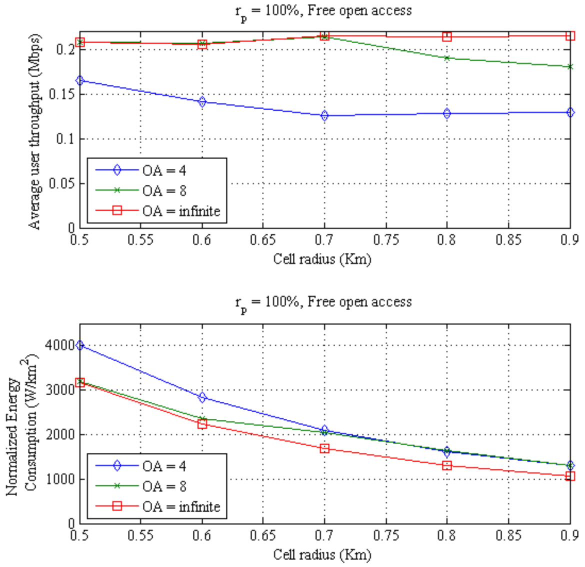

Figure 5. Throughput and normalized energy consumption for varying cell radius *R*. Free open access and 100% of femtocell penetration rate is assumed

VI. CONCLUSIONS

In this paper, we presented an energy consumption modeling framework to evaluate total power consumption in a cellular network through extensive quantitative research on the power consumption of entities on typical cellular networks. Using the proposed framework, we investigated the power consumption and performance of a cellular network equipped with femtocells, a new promising technology that provides coverage and capacity expansion to conventional cellular networks. Simulations in various environments show that femtocell is, a *greener* technology. We have finally provided a guideline that helps system operators deploy and manage a cellular network with femtocells in a greener way.

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