A System-level Power Saving Approach for Cellular Networks with Microcells/Picocells

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***Abstract*—Network power consumption reduction has recently become an active research topic. In this paper, we propose a novel approach to save power consumption of a three-cell microcellular network. When the traffic load in the middle cell is low, it can be switched-off and its users are covered. This is enabled by increasing the transmission power of one sector antenna in the two neighboring cells. Numerical results show that by increasing antenna transmission power of the two sectors, the overall network power consumption can be reduced.**

I. Introduction

Nowadays, power consumption of Information and Communication Technology (ICT) has become a major issue from both economic and environmental point of view. In general, between 2% - 10% of the world power consumption is carried out only by ICT. Telecommunication networks, in particular, are a big contributor in this picture. Alongside, the number of mobile phone subscribers has surpassed four billions worldwide [1]. Thereby, a larger quantity of infrastructure equipment is also required consuming mammoth amount of total energy. As the ratio between power demand and power resources is also increasing, and thus an increase in energy cost, the result is huge energy bills for network operators. However, the impact ultimately transfers to end customers.

In cellular networks, urban cell sizes are usually limited by capacity constraints while rural cell sizes will strongly affect the power budget in the uplink of the Mobile Station (MS). Due to this reason, power efficient small cells such as microcells are becoming increasingly popular. However, at the microcellular network level, the infrastructure power consumption reduction needs to be investigated thoroughly, especially for the interest of the network operator.

As the power consumption of networks has become a major concern for the telecommunication network operators worldwide, they view the reduction in power consumption of their network as a direct approach towards cost reduction. Some investigations have been recently carried out on how to reduce the power consumption of the entire infrastructure instead of single component only. For example, in [2], the overall reduction of power consumption in a UMTS network is evaluated considering only the minimum number of active devices while guaranteeing service continuity. In [3], it is shown that dynamic adjustment of cell size, given that traffic varies significantly during a day, can help reduce network energy consumption. According to their solution, the *whole* cell size is shrunk or enlarged. However, this approach may create blind spots in the geographical coverage of the network. How to cater for these blind spots is not considered in their work. Moreover, the authors of [4] evaluate energy saving that can be achieved using energy-aware cooperative management of two cellular access networks from two operators offering service over the same geographical area. During the periods of low traffic intensity such that just one network has enough resources to provide desired Quality-of-Service (QoS) for the users of both networks, the other network can be switched off. However, their approach requires complex inter-network cooperation as well as potential modifications in the hardware of the involved stations.

In this paper, we propose a simple approach to save power consumption of the network at the microcell or picocell level. The main idea behind our approach is to decrease the network power consumption by shutting down a cell, with population below a threshold level, and covering its users by increasing transmission power of a sector antenna of each of the two neighboring cells. A network of only three adjacent microcells is studied to keep the analysis simple and to have an initial insight on power savings. Six-sectored hexagonal cell shape is assumed, however, the analysis is extendible to other cell shapes with minor modifications. The middle cell can be switched off by increasing transmission power of only one antenna of each of the two neighboring cells. The power consumption is calculated for individual cells as well as the whole network. Moreover, the effects of the scheme on the power consumption of the involved MSs are also described. It is observed that some tradeoff in the form of increased transmission power for the MS and the BSs reduces overall network power consumption without creation of potential blind spots.

In the rest of the paper, Sec. II describes the network scenario with assumptions and Sec. III gives the power consumption analysis of the scheme. Numerical results are are presented and discussed in Sec. IV. Conclusions are given in Sec. V.

II. Network Scenario and Assumptions

The pictorial scenario of the studied cellular network is illustrated in Fig. 1. The overall network comprises of three same size adjacent hexagonal cells, i.e., $cell_1$, $cell_2$, and $cell_3$, with corresponding Base Stations (BSs), i.e., BS_1, BS_2, and

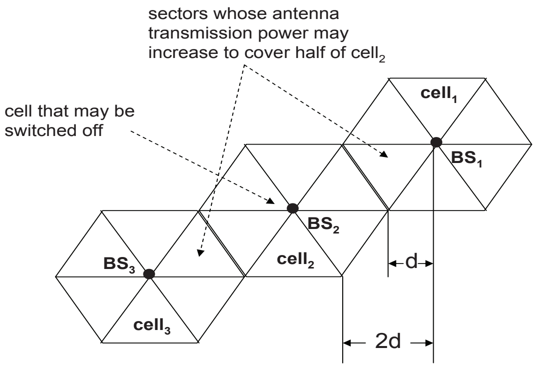

Fig. 1. Network architecture.

BS_3, respectively. [In the remainder of this paper, the terms BS_i and $cell_i$ would be interchangeably used; $i = 1, 2, 3$.]

Each cell is divided into six sectors and hence each BS comprises of six sectored antennas each covering a sector in the geographical region of its corresponding BS. Based on the number of active users in a cell and the radius of the cell, the total transmission power of the corresponding BS's antenna array including all six sectors is calculated. This transmission power is related to the minimum received power of an MS in the cell in order to maintain the Signal-to-Noise Ratio (SNR) for a service. Hence, the smaller the cell size the lower should be the total transmission power of a cell for a constant number of active users in the cell.

In our scheme, based on the population of active users in the middle cell ($cell_2$), the neighboring cell, BS_1, can increase the transmission power of only one of its sectors (i.e., from d to $2d$) to cover half of the geographical region of $cell_2$. Similarly, BS_3 can also cover the remaining half of $cell_2$. Hence, BS_2 can be switched off and its users can be covered by BS_1 and BS_3. The total transmission power of a cell before and after the increase in transmission power of the sector antenna is calculated. Similarly, the total transmission power of the network, before and after $cell_2$ is switched off, is calculated. Correspondingly, the tradeoff in the total consumed transmission power is obtained. The effects of transmission power increase of the BS antenna are also considered for the MSs residing in the enhanced sector.

The analysis is based on the assumption that the transmission power increase for the BSs (and for the corresponding MSs) remains under the transmission regulation limits and that there are free channels available for BS_1 and BS_3 to handle the users handed over to them from the switched-off cell (i.e., $cell_2$). Code Division Multiple Access (CDMA) connectivity is assumed between the MSs and the BSs. Protocols among the BSs are ignored. For the power increase and BS switch-off decision, a Base Station Controller (BSC) is assumed to be responsible on the back end.

Furthermore, MSs are considered to be at the cell boundaries for the maximum power consumption calculations to cater to the worst-case scenario. The same density of MSs is assumed in all cells. Both uplink and downlink power control schemes are assumed to be active for the BS [5] and the MS. Base stations are passively cooled. Only Speech service is considered for calculation convenience.

It is also worth mentioning here that the approach studied in this paper cannot be utilized for the macrocell case because the transmission power may easily increase beyond limits, and the size of the macrocell cannot be further extended.

III. Power Consumption Analysis

This section presents the basic power consumption analysis of the studied scheme. Firstly, we calculate the minimum received power by an MS in a cell for a given SNR. From this received power, we can find the minimum transmission power required by the BS to reach the MS. Hence, we can find the total transmission power by the BS to reach all MSs in a cell. The total actual power consumption by the BS is the sum of the total transmission power component and a fixed power consumption component. During all the analysis, relevant loss components are also taken into consideration to make the analysis more realistic. Furthermore, the power consumption of the MS to transmit to the BS is also analyzed. Hence, the energy consumption of the MS battery can be calculated which can in turn give the lifetime of the MS battery.

In order to maintain certain QoS for any specific type of traffic flow, a minimum SNR level needs to be maintained at the target MS receiver. Thus, there should be a minimum level of power received at the MS for maintenance of the minimum SNR. Suppose γ is the required minimum SNR level requirement at the user end (i.e., MS). Assuming a maximum value I of the interference level, we can calculate the minimum received power, P_{rx}, at the MS as

$$P_{rx} = \gamma \cdot (W \cdot T_0 + I) \tag{1}$$

where W is the channel bandwidth in Hertz and T_0 is the thermal noise level in Watts/Hertz. Hence, $W \cdot T_0$ is the total thermal noise.

The BS is required to transmit with a power necessary to ensure reception of P_{rx} at the MS. Using Eq. (1), we can find this minimum transmission power, P_{tx}, required by the BS for an MS as

$$P_{tx} = L_A \cdot P_{rx} \cdot d^{\alpha} \tag{2}$$

where d is the distance between the MS and the BS, and α is the path-loss coefficient. The loss factor, L_A, collectively represents the losses due to fading and building penetration etc.

Suppose A_N is the total area of the network with K_N number of total active users. The total number of cells in the network, N_C, can be written as $N_C = A_N/A_C$ where A_C is the area of a hexagonal cell given as $A_C = (3\sqrt{3}/2) \cdot d^2$. The number of total active users per cell is thus determined as

$$K_U = K_N/N_C. \tag{3}$$

Now using Eq. (2) and (3), we can find the total transmission power by the BS as

$$\begin{aligned} P_{Total\_tx} &= K_U \cdot P_{tx} \\ &= (3\sqrt{3}K_N \cdot L_A \cdot P_{rx} \cdot d^{\alpha+2})/2A_N \\ &= \frac{3\sqrt{3}K_N \cdot L_A \cdot \gamma \cdot (W \cdot T_0 + I)}{2A_N} \cdot d^{\alpha+2}. \end{aligned} \quad (4)$$

A. Total BS Power Consumption

There are two major parts of the total BS power consumption: the component associated with the transmission power of the antennas and the fixed power consumption component. Thus, we can represent the total BS power consumption, P_{BS}, as

$$P_{BS} = L_B \cdot P_{Total\_tx} + P_{fixed}. \quad (5)$$

Here, L_B collectively denotes the losses associated with several components of the BS like power amplifier efficiency, antenna feeder cable loss, directional antenna gain, etc. P_{fixed} represents the fixed power consumption (BS gains power through AC power lines, consumes power for electronic processing of the received and transmitted signals, and heating effects, etc.).

The power consumption of the network can thus simply be obtained as

$$P_{Network} = P_{BS} \cdot N_C. \quad (6)$$

From Eq. (5) we can fix representative values of the parameters like path-loss exponent, number of active users, BS fixed power consumption etc. and observe the variation in the total power consumption of the BS[1].

B. MS Power Consumption

The power consumed per bit by the MS battery, P_{MS}, has two main components, i.e., the power needed in order to generate P_t amount of radiated power, and the power used for electronic processing of the radiated signal. Thus we can write

$$P_{MS} = P_t + P_{et} \quad (7)$$

where P_{et} denotes the power used for electronic processing of the signal. For analysis simplicity, we ignore the power consumption of the MS for the reception of signals. The reason for this is twofold: our main purpose is to investigate the effects of alteration in the distance between the MS and the BS on the MS battery lifetime when it is *transmitting* to the BS; and secondly, the contribution of the component of the MS power consumption for transmission is much higher than that of the one for reception[2].

A simplified path-loss model, $P_{rec} = GP_t/d^{\alpha}$, can be used to find the transmission power needed by the MS in order to reach the BS with power P_{rec}. G is a unitless constant that depends on the corresponding antenna characteristics. The electronic processing power [8] is assumed to be constant.

Correspondingly, the energy consumption per bit of the MS can now be calculated using the relation

$$E_{MS} = P_{MS}/R \quad (8)$$

where R is the supported data rate.

IV. Numerical Results and Discussions

The scheme studied in this paper is evaluated using Matlab as the tool. The initial value of the MS battery energy is taken as 10 Joules. The other parameters used in the evaluation of the scheme are summarized in Table I [8] - [11].

TABLE I
ANALYSIS PARAMETERS.

Parameter	**Value**
channel bandwidth	5 MHz
SNR value for a service	-18 dB
total noise + interference density	-166 dBm/Hz
receiver sensitivity	-117 dBm
loss component (Rayleigh fading)	$2 \sim 5$ dB
loss component (building penetration)	$12 \sim 15$ dB
loss component (shadowing)	$6 \sim 7$ dB
α	4
d	$300, 600$ meters
BS directional antenna gain	10 dB
MS antenna gain	0 dB
P_{et}	-141 dBm
P_{fixed}	48 dBm
BS antenna feeder cable loss	-2 dB
power amplifier efficiency	50%
R	2 Mbps

A. Base Station Power Consumption

As mentioned earlier, BS power consumption has two major parts, i.e., the power consumed for the transmission of signals and the fixed power consumption. Below we discuss them one by one.

1) BS Transmission Power Consumption: Figure 2 illustrates the total power transmitted by the BS antennas for two different values of d, i.e., 300 and 600 meters, as the number of MSs varies. In this figure, for the same value of K_U, the difference between the total transmission power for these

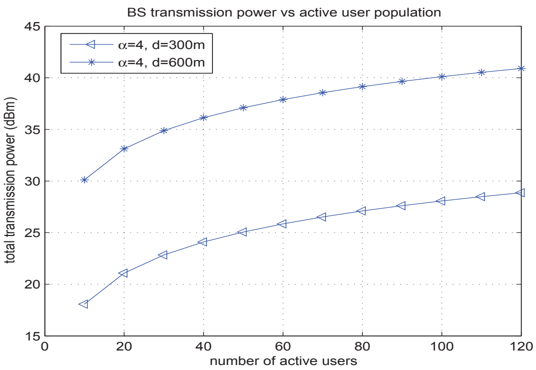

Fig. 2. Total BS transmission power for different user populations.

[1]It is worth mentioning that in the first term of Eq. (5) the influence on the power can be much higher if better power amplifiers are used, e.g., futuristic amplifiers with 65% - 70% efficiency. We have, however, considered power amplifiers which are commercially available [6].

[2]A thorough analysis in this regard can be found in our earlier paper, [7].

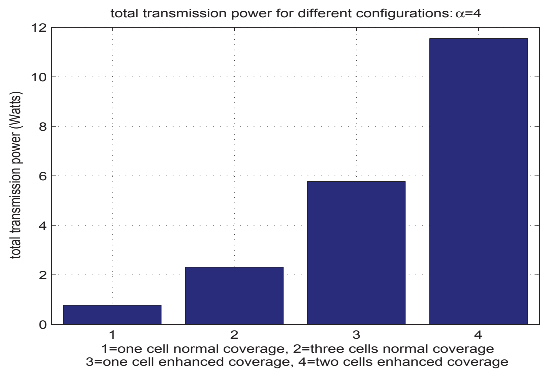

Fig. 3. Total BS transmission power for different network configurations.

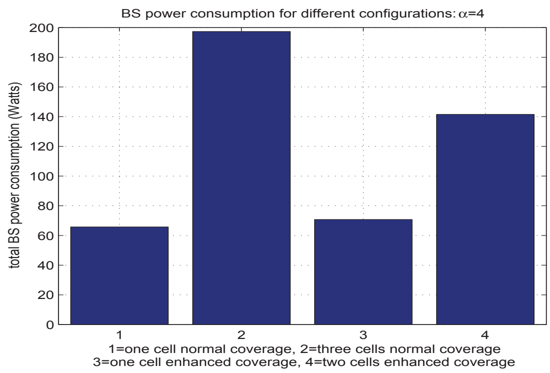

Fig. 4. Total BS power consumption for different network configurations.

two values of d is about 40 dBm ($\approx$ 11 Watts). Though not explicitly shown in the figure, the curves projected to 150 users indicate that the same total transmission power is required for only 10 users at $d=$600 meters as that for 120 users at $d=$300 meters. Hence, for the same total transmission power, more users can be handled at shorter distances.

The figure also indicates that we need huge increase in the total transmission power if we double the radius of the cell. This would also be true even if the transmission power of just one sector antenna is increased to cover three more sectors of the neighboring cell, albeit with more number of active users in the total enhanced sector, as per our scheme mentioned in Sec. II. The threshold level for the BSC to decide to increase the transmission power of the sector antenna is set at 50%, i.e., BS_1 and BS_3 would increase the transmission power of their corresponding sector antennas if the active user population in $cell_2$ reduces to 50% of the maximum allowed population in a cell (while keeping some channels unoccupied). Furthermore, the upper limit on the active user population in a cell also needs to be imposed by keeping some channels free (hence, only quasi-orthogonal codes) while satisfying the desired SNR threshold value even if those free channels are later occupied by the users handed over by the switched-off neighboring cell. Nevertheless, the number of active users in a cell cannot be increased arbitratily. This is due to the reason that the total BS antenna transmission power also needs to be kept below a limit imposed by transmission regulation limits.

The following section addresses on how the network can benefit from this increase in the transmission power at the cell level.

2) Total BS Power Consumption and Network Power Saving: This section describes the power saving achieved at the network level by our scheme. Fig. 3 shows the total BS transmission power for different configurations. For normal coverage, the radius of each cell is taken as 300 meters while K_U is 120. Enhanced coverage of a cell means that only one sector antenna of the corresponding cell increases its transmission range to 600 meters in order to cover half of the neighboring cell and hence extra 30 users of the neighboring cell. (Here, 30 users of the neighboring cell means a total number of 60 users in this cell, i.e., the population of this cell is at 50% of the allowed maximum population, i,e., at the threshold value.) As indicated in the figure, one cell with enhanced coverage consumes more total transmission power than three cells with normal coverage. Similarly, two cells with enhanced coverage consume about 9 Watts more than three cells with normal coverage, but cover the extra middle cell. This is because that the increase in the sector size to cover half of the neighboring cell requires much more total transmission power due to extra distance to be reached by the sector antenna for more number of users. This is also clear from Eq. (4).

Figure 4 shows the total power consumed for different configurations of the network. For example, by comparing bar 1 and bar 3, we observe that one cell with an enhanced sector power consumes about 4 Watts more than one cell with normal coverage. Similarly, a comparison of bar 2 and bar 4 indicates that network can save about 45 Watts in total consumed power. This is because of the reason that in bar 4 the contribution is from the total transmission power of two BSs with one enhance sector each while one BS is switched off, saving considerable amount of network power. That is, we can save a relatively larger amount of network power by switching BS_2 off, and covering its users through BS_1 and BS_3. Hence, *a cost of about 9 Watts extra in terms of total transmission power of all network antennas, we can save about 45 Watts of network power.*

It is worth mentioning here that the neighboring cells' sector enhancement triggers the middle cell's switch-off only when its population is at or below 50% threshold level of the total allowed user population. However, when the population of the middle cell is above the threshold level, our scheme achieves no power saving.

B. Effects on the MS Lifetime

This section briefly presents the effects of the scheme studied in this paper on the corresponding power consumption and the battery lifetime of the MS.

Figure 5 presents the MS power consumption for different distances from the BS. Both the MS transmission power and the actual consumed power are given in the figure for two different values of α. As illustrated in the figure, for higher

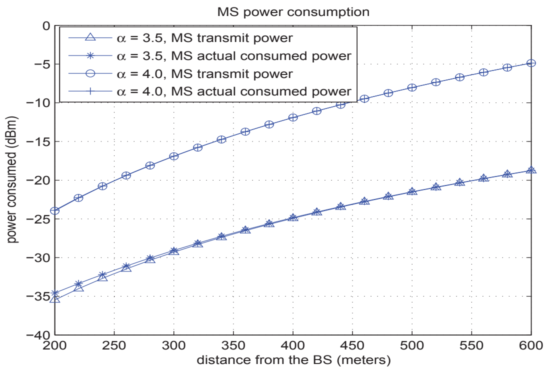

Fig. 5. MS power consumption at different distances from the BS.

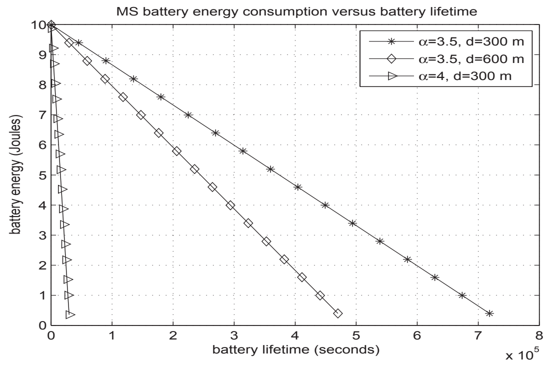

Fig. 6. MS battery lifetime for two sector boundaries.

values of α, the transmission power and the actual consumed power are almost identical. However, for relatively smaller value of α ($\alpha = 3.5$), this difference is more visible for shorter distances between the MS and the BS. The reason for this effect is that for higher values of α and d, the P_t component in Eq. (7) overwhelms the P_{et} component. Moreover, for the same value of α (e.g., $\alpha = 4$), the MS's power consumption (inclusive of both the transmission power and the actual consumed power) at $d = 300$ meters is about -17 dBm while at $d = 600$ meters is about -4.8 dBm. Hence, when an MS in the switched-off cell is handed over to the neighboring cell's sector, it needs to consume more power to reach the new BS.

Furthermore, increased power consumption also translates into shorter lifetime for the MSs in the increased sector. Fig. 6 illustrates the lifetime of MS for only transmission of signal to BS, and not reception, for the normal and increased sector boundaries. As expected, the MS battery lasts longer when it resides at the boundary of a normal-sized cell (i.e., $d = 300$ meters) than when it resides at the boundary of the enhanced sector (i.e., $d = 600$ meters). This is because of the fact that at higher values of d, the MS needs to transmit with larger P_t, which negatively affects its battery lifetime. Hence, *for considerable power saving at the network level, the users also need to sacrifice in terms of shorter battery lifetime (for the MSs of the switched-off cell).*

V. Conclusions and Future Work

In this paper, we have proposed an approach to reduce the overall network power consumption by switching off the BS of the middle cell in a simple three-cell network configuration, when the number of active users in this cell is lower enough. The users of the switched-off cell are covered by the neighboring cells by increasing the transmission power of only one of the sector antennas for each cell. The effects of the proposed scheme on the residing MS's power consumption (and corresponding battery lifetime) are also presented. Overall network power saving is achieved by trading off some power in terms of increased antenna transmission power of the neighboring cells as well as some loss in the MS battery lifetime. Hence, the network operator saves power by possibly sacrificing the battery lifetime of the affected users.

Some improvements, e.g., selection of population threshold for switch-off decision, optimum number of channels to be kept free, optimum radius of a cell, optimum number of candidate antennas for the transmission power increase, etc. need to be addressed for our proposed scheme. In this regard, as our future work, an optimum number of cells to be switched off for the minimization of network power would be studied for a larger multi-tier microcellular network.

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