Potential of Energy Conservation of Femtocells in WCDMA Networks

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Abstract- In the strive for lessening of the environmental impact of the information and communication industry, energy consumption of communication networks has recently received increased attention in this regard, the deployment of small, low power base stations called femtocells, alongside conventional sites is often believed to greatly lower the energy consumption of mobile access networks. In this paper we focus on the impact of femtocell deployment on WCDMA network energy consumption. We introduce the model of area power consumption as a system performance metric based on WCDMA downlink load equations. The model is used to investigate the impact of load sharing between femtocells and macrocells on the overall energy consumption of the network. Based on the model we present two examples where two different deployment scenarios have been compared.

Keywords – WCDMA network, femtocell, energy efficiency, WCDMA downlink load equations, comparisons.

I. INTRODUCTION

Deployment of increasingly powerful mobile network technologies has taken place within the last decade. In roll-outs of new networks, focus has been shifting from the second generation mobile network technology to 30, and currently first commercial Long Term Evolution (LTE) networks are rolled out. Each new generation has brought increased data rates and more services. Although network efficiency has been growing, the higher access rates inevitably have led to increased energy consumption in base stations (BSs) and network densities have been constantly growing [1].

One of the main energy saving approaches is to switch base stations off whenever traffic load is small. This approach was used in [5] where focus was in WCDMA energy savings through cell breathing. Similar approach was used in [6] while in [4] daily variation in traffic load was also modeled. In this paper we consider the impact of uncoordinated femtocell deployment to the power consumption in WCDMA network. Similar problem was previously investigated in [4] from well-planned microcell deployment perspective. While most of the recent papers rely on simulations, we use WCDMA downlink load equations so that all parameters can be easily tracked from deduced formulae. In particular, when Femtocells are introduced to the network, they will offload traffic from macrocells. In WCDMA the decreased macrocell load can be utilized through cell breathing so that inter-site-distance (ISD) between active macrocells is increasing and energy consumption by macrocells is decreasing. However, the increasing energy consumption by femtocells will be the expense for the decay in macrocell energy usage.

The rest of the paper is organized as follows. In Section 2, we first recall the WCDMA downlink load equations and their relation to the network dimensioning. Then we introduce general energy usage model and comparison scenarios. In Section 3 we show some numerical examples that throw light on the energy saving opportunities in WCDMA networks and in Section 4 we conclude the paper.

II. MODELING AND COMPARISON SCENARIOS

2.1 Load equations and dimensioning –

The cell range and ISD are defined using the layout of figure 1. Thus, the area covered by a three-sector site is given by $A_{Site} = 9/4*R^2 = ISD^2$. In the following we simplify the load equations by assuming that dimensioning is done based on a certain service. Then we can start from a simplified form of the well-known WCDMA downlink mean load equation [9], [10].

$$\lambda = \lambda + N_{users} \cdot \frac{(E_b/N_0).R_d.\nu}{BW} \cdot \left(1 - \overline{\alpha} + \overline{i}\right) \tag{1}$$
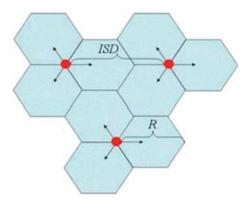
Figure 1.   Macrocell layout: Cell range and ISD.

In formula (1) parameter λ_o refers to the minimum load due to control signaling, N_{user} is the number of users in the cell, E_b/N_o is the energy per user bit divided by the noise spectral density, R_d is the user bit rate, v is the connection activity factor, BW is the system chip rate, α is the spreading code orthogonality factor and i is the other to own cell interference factor. We note that we have considered the mean load that is depending on the expected (α and i over the whole cell.

Moreover, for the mean output power in BS transmission we have:

$$P_{Tx,out} = \frac{n_{RF}.\overline{L}.N_{users}.\left(E_b/N_0\right).R_d.v}{1-\lambda} \tag{2}$$

Where n_{RF} is the noise spectral density of the receiver front end. We note that part of the transmission power is used for control overhead.

After combining (1) and (2) we can express the mean signal loss as follows:

$$\overline{L} = P_{Tx,out}.\frac{1-\lambda_0 - N_{users}.\dfrac{\left(E_b/N_0\right)}{BW}.R_d.v.\left(1-\overline{\alpha}+\overline{i}\right)}{n_{RF}.N_{users}.\left(E_b/N_0\right).R_d.v} \tag{3}$$

$$R = \left\{ \frac{P_{Tx,out}(1-\lambda_0 - N_{users}.\dfrac{\left(E_b/N_0\right)}{BW}.R_d.v.(1-\overline{\alpha}+\overline{i}))}{a \cdot dL \cdot n_{RF} \cdot N_{users} \cdot (E_b/N_0) \cdot R_d \cdot v} \right\}^{\frac{1}{b}} \tag{4}$$

We note that mean signal loss is usually 6dB less than maximum signal loss in the cell edge [9], so that in dimensioning we need to take into account the corresponding value in (3). Furthermore, the mean signal loss should include impact of distance dependent path loss, shadow fading loss and interference margin. If single slope model $a*R^b$ for distance dependent path loss is used, then we can express the macrocell range as:

Here dL contains the impact of signal loss averaging as well as shadow fading and indoor penetration margins.

In simplest form of network dimensioning a target load for a certain service is first selected. Then number of supported users can be calculated from (1) and corresponding macrocell range from (4). Other information besides service rate and load in (1) and (4) can be obtained from link budget. We will show concrete example in next section.

2.2. General energy usage model –

We start from a simple model that was previously applied in [5], [8] to describe the macrocell base station power sharing between load independent and load dependent operations:

$$P_{cell} = P_{Oper} + \lambda \cdot P_{Tx} \tag{5}$$

Here term P_{Tx} is the power that is needed to create required transmission power in the antenna output and λ is the cell load that may vary between 0.1 and 0.9 depending on the load and radio interface configuration. Term P_{Oper} contains all load independent power that is needed to operate the BS.

The equation (5) defines the cell power while sites are usually composed by three or more sectors that each forms a logical cell. Therefore, the power consumed in site is of the form

$$P_{Site} = N_{Cell} + \left(P_{Oper} + \lambda \cdot P_{Tx} \right) \tag{6}$$

Where N_{Cell} refer to the number of cells in the site. Then the site energy consumption over a certain time period T is of the form

$$E_{Site} = N_{Cell} + \left(P_{Oper} + \lambda \cdot P_{Tx} \right) \cdot T \tag{7}$$

Although network adaptation to temporal variations of the load is an important topic we ignore it in this paper since our focus is in the impact of femtocells. Impact of temporal load variations has been investigated in e.g. [4].

The energy usage over time T in a macrocell network is given by

$$E_{Ntw} = N_{Site} \cdot E_{Site} + N_{UE} \cdot E_{UE} + E_{Other} \tag{8}$$

In (8) the first term in the right defines the energy consumption in all macrocell BSs (N_{site} and E_{site} refer to number of BS sites and energy consumed by single BS site respectively), second term defines the energy usage in all UEs (N_{UE} and E_{UE} refer to number of user equipment and energy consumed by single UE respectively) and last term contains energy consumed by other mobile network elements such as core network elements and radio network controllers in WCDMA.

We ignore the second term on the right since terminal power and energy efficiency has been under extensive investigations for a long time due to strict battery constraints. Therefore, recent energy efficiency studies have been focusing on the network side where more room for notable improvements exists. Furthermore, since we concentrate on the energy efficiency of the radio access the last term in (8) is out of our scope. We also recall that BS energy efficiency is of great importance for operators since BSs form a vast majority of mobile network nodes and thus, they also have largest contribution to the energy consumption of a modem mobile network creating a significant operational cost factor [11], [12], [13].

When femtocells are employed in the network, the energy utilized by the network is given by

$$E_{Ntw} = N_{Site} \cdot N_{Cell} \cdot \left(E_{Cell} \cdot N_F \cdot P_F \cdot T \right) \tag{9}$$

Where N_F is the number of femtocells in each macrocell and P_F is the femto BS mean power usage over time T. In order to simplify the analysis we do not share femto BS power between load dependent and independent parts since it is assumed that impact of load to the femto BS power usage is relatively small.

In order to make calculations more concrete we adopt from [5] the UMTS macrocell base station specific values

$$P_{Oper} = 137 \text{ W}, P_{Tx} = 57 \text{ W}$$

This will be then used in comparisons. Within three sector site the maximum energy consumption over 24 hours is round 14kWh. For femto BS input power we use two values, 2W and 5W. The former value is optimistic but reachable in future while latter value is already reality in products [14].

2.3. Comparison scenarios

We consider two comparison scenarios to estimate how the change in network configurations will effect to the energy consumption in the network. In the first scenario we fix the macrocell ISD and estimate the change in the network energy consumption when femtocell penetration rate is increasing. In the second scenario we scale the ISD

which reflects to the number of macrocell sites. Thus, when number of femtocells is increasing the load in macrocell sites is decreasing and required number of macrocell BSs is decreasing due to cell breathing. As a performance measure we will use the daily energy consumption per square kilometer in the network:

Thus, dimension for the performance is the kWh/km^2. In the above equation, number of sites in new deployment and corresponding load λ^{New} refer to the new parametric values of the modified network with respect to the old parametric

$$
\begin{aligned}
\left(E/A\right)_{Ntw} = &\frac{N_{Site}^{New} \cdot N_{Cell} \cdot \left(P_{Oper} + \lambda^{New} \cdot P_{Tx}\right)}{N_{Site} \cdot A_{Site}} \cdot 24h \\
&+ \frac{N_{Cell} \cdot N_F \cdot P_F}{A_{Site}} \cdot 24h
\end{aligned}
\tag{10}
$$

values of the reference network. We also note that the number of femto BSs is given per macrocell in reference deployment. Either of these changes is expected to take place in one of the two compared networks depending upon the scenario.

First scenario: Assume that macrocell ISD is fixed. Then number of macrocells is the same for both networks but load is decreasing with additional femtocells and we have

$$
\left(E/A\right)_{Ntw} = \frac{N_{Cell} \cdot \left(P_{Oper} + \lambda^{New} \cdot P_{Tx} + N_F \cdot P_F\right)}{A_{Site}} \cdot 24h
\tag{11}
$$

Second scenario: Assume that the macrocell ISD is not fixed but instead, we fix the target load in macrocells.

$$
\begin{aligned}
\left(E/A\right)_{Ntw} = &\frac{N_{Site}^{New} \cdot N_{Cell} \cdot \left(P_{Oper} + \lambda \cdot P_{Tx}\right)}{N_{Site} \cdot A_{Site}} \cdot 24h \\
&+ \frac{N_{Cell} \cdot N_F \cdot P_F}{A_{Site}} \cdot 24h
\end{aligned}
\tag{12}
$$

Since femtocells offload part of the traffic, the required number of macrocell BSs is decreasing and we have
Here, the number of macrocells is decreasing due to cell breathing that is caused by data offload to femtocells.

For comparisons we first carry out dimensioning of the network without femtocells using (1) and (4). When cell range **R** is known we can calculate site area and daily energy consumption per square kilometer from the formula

$$
\left(E/A\right)_{Ntw} = \frac{N_{Cell} \cdot \left(P_{Oper} + \lambda \cdot P_{Tx}\right)}{A_{Site}} \cdot 24h
\tag{13}
$$

When N_F femtocells are added to the system they take a certain portion of the users, say ($\boldsymbol{R_{femto}}$*100) % of users ($\boldsymbol{R_{femto}}$ is the ratio between femtocell and macrocell connections). Then either load in macrocells (first scenario) or ISD (second scenario) is decreasing. The latter phenomena reflect directly to the number of macrocell sites.

III. NUMERICAL EXAMPLES

We consider a WCDMA related example where parameters are given in Table 1.

Table -1 Network Parameters

Reference Parameters	
Parameter	Value
Operating frequency	2000MHz
BS Antenna height	30m
MS antenna height	1.5m
Propagation model	Okumura-Hata (Urban Model)
Indoor penetration loss	10dB

BS antenna gain (incl. losses)	16dBi
User data rate	64kbps, 128kbps, 256kbps
E_b/N_0	5dB
Macro BS transmission power	20W
Femto BS input power	5W, 2W
Control overhead	15%
System chip rate	3.84Mcps
Shadow fading margin	7dB
Mean α	0.80

Mean i	0.65
Activity factor v	1.00
Minimum load	0.10

In Figure 2 we have cell ranges as a function of number of users when user data rates are 256kbps, 128kbps and 64kbps. If dimensioning is done e.g. based on 64kbps user rate and assuming load 0.8, then cell range is round 600m.

Figure 2.   Cell range as a function of number of users when user data rates are 256kbps (dotted curve), 128kbps (dashed curve) and 64kbps(solid curve).

3.1 Numerical comparisons

Consider 64kbps service and assume that initial system load is 0.9. We can then solve number of users from (1) and cell range from (4). Furthermore, if femtocells offload data of $R_{femto} . N_{users} = N_F$ macrocell users, then we can calculate new load λ^{new} from (1) and daily energy consumption per square kilometer from (11). Resulting numerical values are given in Table 2.

Table -1 Daily Energy Consumption in the Network First Scenario.

100%*Rfemto	0%	25%	50%	75%
(E/A)M [KWh/Km^2]	24.35	22.88	21.40	19.93
(E/A)$_{Total}$ [KWh/Km^2], PF=5W	24.35	25.77	27.18	28.59

(E/A)$_{Total}$ [KWh/Km^2], PF=2W	24.35	24.03	23.72	23.39

From second row of Table 2 we find that energy consumption per square kilometer is clearly decreasing in macrocells when ratio of femto connections is increasing. If femto BS input power is 5W, then the total energy consumption in the network is growing since the load decay in macrocell load cannot compensate the additional consumption due to femtocells. On the other hand, if femto BS input power is only 2W, then the total energy consumption is slightly decreasing with additional femtocells. Finally, we note that:

- In above calculations it was assumed that femto BSs are turned on only when there is traffic. If a number of femtocells are also active when traffic is nonexistent, then network energy consumption Increases accordingly.
- From network operating costs perspective the values on the second row of Table 2 are important since they contribute directly to the energy bill paid by the operator.

Results regarding to the second scenario has been plotted in Figure 3.

It is found that energy consumption by macro cells is rapidly decreasing since lower load allows less dense macrocell grid. The decrease in macro BS density is limited by the non-femtocell users and in practice it is not possible to shut down all the existing macrocell sites due to coverage reasons. Yet, if network is to be built from scratch then second scenario would be beneficial from energy efficiency perspective. From figure 3 we see that in case of 50% femtocell (2W) penetration, around 63% of energy would be saved and it keeps on increasing as the femtocell penetration increases. Whereas in case of 50% femtocell penetration (5W), the maximum energy saving would be around 49% and it will not further increase with the increase in femtocell penetration. In order to fully exploit this gain, a green field network should be built. However, part of the energy

savings can be achieved also in existing networks if macrocell BSs can be switched off during low load periods.
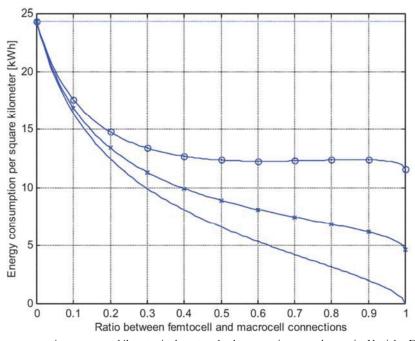

Figure 3. Daily energy consumption per square kilometer in the network when assuming second scenario. No ticks: Energy consumption by macro cells only. Total energy consumption when 5W femto BS power (O), and 2W femto BS power (x).

IV. CONCLUSION

In this paper we investigated the potential energy savings when deploying femtocells along with macro base stations in WCDMA network. To find the energy consumption per unit area we used WCDMA downlink load equations. We determined how the load sharing between femtocells and macrocells will contribute to the overall energy consumption of the network.

We introduced two comparison scenarios to make visible the impact of femtocells on the energy consumption per unit area. To elaborate these scenarios, two simple examples were presented. In first scenario we fixed the macrocell inter site distance and assumed different femto base station penetration ratios. Results show that total energy consumption in network per unit area was increasing when employing femto base stations that apply 5W input power. On the other hand, energy consumption was found to decrease slightly when employing femto base stations that apply 2W input power.

In second considered scenario the macrocell inter site distance was not fixed and the addition of femtocells to the macro cellular system decreased the macrocell base station density. In this case there was a significant amount of energy savings. Achieved gain can be fully exploited only in green field deployments but part of the energy saving potential can be utilized also in existing networks through macrocell breathing: decreased macrocell load due to femtocells results in larger macrocell coverage and in dense macrocell deployments part of the base stations can be switched off.

Finally, we note that number of active femto base stations strongly affect to the network energy efficiency. If femto BSs are on all the time then femto base station energy consumption easily overtake the achieved savings on the macrocell side. Therefore it is an important task to design efficient sleep mode procedures for femto base stations. Another topic for future work is to take into account the impact of daily traffic variations. For that purpose a new performance metrics will be needed.

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