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Energy-Efficient Planning Tool for WCDMA Heterogeneous Network Deployment

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ABSTRACT

The population of powerful mobile network technologies has increased in recent years also focus has been shifting from second generation mobile to third generation technology. This higher access rates have led to increased energy consumption in base stations (BTS) and network densities have been constantly growing. This paper developed an energy efficient planning tool for analytical modeling of heterogeneous networks and observed the potential energy savings statistics when deploying heterogeneous networks. A model developed from wcdma downlink equation was used in determining the energy consumption per unit area of the network. The model was also used to observe how heterogeneous network deployment contributes to the total energy consumption of the network. The result was presented in three scenarios. The first scenario presented the daily energy consumption per square kilometer and it was observed that the energy consumption by the macrocell decreases when increasing the ratio of femtocells in the network. However, the introduction of femtocells to the network ordinarily does not gauranty decrease in energy consumption the scenario depends on the power budget of the femtocells as presented in second and third scenarios where power budget of 2 W and 5 W were used respectively. By introducing femtocell of low power budget into the network, the density of the network reduces therefore, bringing about reasonable reduction in the total power consumption of the network. To that end, this research developed software that helps to observe the total energy that could be saved when deploying heterogeneous networks.

Keywords

Energy Efficiency, Femtocell, Load Sharing, Macrocell, Power Consumption

1. INTRODUCTION

Energy efficiency in mobile communication is becoming an important topic across the globe for the fact that information and communication technology is responsible for about 2-4% of the global carbon emission [1, 2]. The trend in mobile communication today has approached new technologies like Wideband Code Division Multiple Access (WCDMA); Enhanced Date Rates for GSM Evolution (EDGE); Long Term Evolution (LTE) etc and all these technologies are known to provide users with high bit rates and they demand a high data transmission rate to provide these bit rates. In recent times, multimedia users or third generation network mobile network are tremendously growing and are responsible for the huge part of traffic on mobile access networks [3]. As the number of subscribers increase, the capacity need to increase and this require additional network resources like BTS in order to avoid traffic congestion in the network, solutions to reduce the energy consumption due to additional base stations needs to be considered because around 80% of the total network energy is consumed by the base stations [4][5]. Recently, most energy saving researches has been focused on the base stations because of the statistics mentioned earlier. Many strategies like improvement in base station energy efficiency through better performance of base station hardware, usage of system level and software features, usage of base station site solutions, heterogeneous network deployment etc has been proposed [4][6] but only heterogeneous network deployment was considered in this report. This paper focused on wcdma technology because from the report of the standardization forums, wcdma technology has emerged as the most widely adopted third generation air interface [7]. Also, it is easy to take advantage of the downlink load equations of wcdma, the link budget equations and energy consumption equations can all be easily tracked from available literatures. To that end, we developed a stand-alone energy efficient planner that performs network dimensioning automatically and gives out graphic results based on the results obtained. The work in [8] is an advanced radio planner integrated with features such as Google earth, mesh and point to multi point design, RF prediction etc. The work in [9] is a java based network planner that has the ability to accommodate infrastructure sharing of network. The works in [8, 9] can only analysis where the base stations could be sited for better performance where aspect of energy efficiency was not covered. This paper gives a clear insight on how load sharing between macrocell and femtocell (heterogeneous network deployment) contributes to the networks energy consumption. The rest of this paper is organized as follows: section 2 covers heterogeneous network deployment in BTS, section 3 discussed the system model while the power constraints was discussed in section 4, section 5 and section 6 gives the numerical example and numerical results. The conclusion was stated in section 7.

2. HETEROGENEOUS NETWORK DEPLOYMENT

Heterogeneous networks is an organized mixture of networks where high power budget macrocells are combined with many nodes usually low power nodes like picocell, distributed antennas, femtocells and relays. The low power nodes are mostly deployed to compensate for poor coverage experienced by some selected indoor and outdoor environments. The low power nodes are may also be deployed to relief the high power cells during off peak period in order to minimize the energy consumed by the network

2.1 Macrocells

Microcells provide radio coverage for cell in a mobile phone network. The radio coverage is transmitted with high power budget than other radio coverage cells like microcells. The antenna for macrocells could be installed on (ground mast, rooftop etc) at a height that can accommodate clear reception over the building surrounding it and also the geographic terrain should also be considered. The macrocells are known for about 1-10km coverage capacity and height of 30m or above is favorable for clear reception.

2.2 Femtocells

Compared with macrocells, femtocells are low power budget nodes that are mounted to enhance coverage in indoor and residential environments. Femtocells are deployed by customers with poor coverage or no coverage. They provide the user terminals with services like voice and data by connecting to the core network through a broadband internet connection like cable or digital subscriber line.

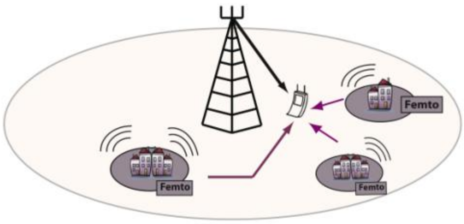

Fig 1: Heterogeneous Deployment [10]

2.3 WIDEBAND CODE DIVISION MULTIPLE ACCESS (WCDMA)

WCDMA is a 3G technology air interface that operates using code division multiplexing to provide customers with high bandwidth, multimedia support among others. WCDMA compared with the GSM system that operates using time division multiplexing spreads its transmission over a wide carrier (5 MHz) and it can accommodate both voice and data service simultaneously. WCDMA can offer up to 2 Mbps of downlink speed at peak network, it has a high throughput of between 220-320 Kbps for file downloads and data rate of 384 Kbps at peak network. All these features serve as a boast over other air interface like EDGE.

3. SYSTEM MODEL

The problem to be addressed is the deployment of low power nodes alongside with macrocell this is often believed to reduce the energy consumption of cellular networks [4]. The idea is based on WCDMA downlink load equation. The introduction of femtocells would reduce the macrocells density which will in turn reduce the energy consumed by the macrocell of the network. More specifically we assumed:

- No interference among users.
- Femtocells are turned on only when there is traffic.
- We also assumed that Macrocell Inter Site Distance (ISD) is fixed, but load is decreasing with additional femtocells.
- Femtocells are turned on only when there is traffic

For comparisons the software carries out dimensioning of the network with femtocells penetration at different percentage, also with femtocells of different power budgets (2 W and 5 W). The dimensioning was carried out with software developed with Microsoft Visual Studio 10 [11], a database was also created for the software using Microsoft Access 2010 [12] and the data obtained was displayed in graphic form. The software automatically calculates the total number of users in the cell area, the area site, range of the cell base on okumura- hata (urban area) and daily energy consumption per square kilometer.

3.1 SOFTWARE ANALYSIS

The software is classified into six modules. The six modules available are compute, refresh, femtocell power graph, 5 W femtocell power graph, 2 W femtocell power graph and plot combined graph.

- **Compute module:** This is the command that works out all the required operations based on the equations supplied by the program. The services provided by this module are as follows;
  - ✓ Computes the Equivalent Isotropic Radiated Power (EIRP)
  - ✓ Computes the Reciever Noise density
  - ✓ Computes the Receiver Noise power
  - ✓ Computes the Interference Margin
  - ✓ Computes the Reciever Interference power
  - ✓ Computes the Noise and Interference
  - ✓ Computes the Processing Gain
  - ✓ Computes the Receiver Sensitivity
  - ✓ Computes the Maximum and Average path losses
  - ✓ Computes the Cell Range base on Hata- Model
  - ✓ Computes the Total number of users in the cell
  - ✓ Computes the Daily energy consumption kWh
  - ✓ Computes the Amount of energy saved based on the femtocell power budget and ratio.
- **Refresh module:** This module that clears the screen of the application.
- **Femtocell power graph module:** This is the command that plots the graph based on the data obtained from the first module.
- **5 W Femtocell power graph module:** This is the command that plots the graph based on the data obtained with a femtocell power budget of 5 W.
- **2 W Femtocell power graph module:** This is the command that plots the graph based on the data obtained with a femtocell power budget of 2 W.
- **Plot combined graph module:** This is the command that plots it graph based on data obtained from the third, fourth and fifth.

3.2 SOFTWARE DESIGN ANALYSIS

This section outline the design of the most common objects, their basic identity and actions performed in the system.

- **Computes the Equivalent Isotropic Radiated Power (EIRP)**

This is the total amount of power that a functional isotopic antenna needs to radiate in order to achieve the required value. The EIRP can be calculated from the equation below.

$$EIRP(dBm) = P_t(dBm) + h_f(dBi) - L_t(dB) \quad (1)$$

Where $EIRP$ and P_T (output power of transmitter) are measured in dBm, antenna gain h_f is expressed in dBi. and losses L_t is in dB.

- **Computes the Reciever Noise density**

It is the power spectral density of the noise [13]. The thermal noise density is given by N0 = kT, where k is Boltzmann's constant measured in joules per Kelvin, and T denotes the receiver system noise temperature in Kelvin is given in dBm/Hz

- **Computes the Reciever Noise power**

This total noise per bandwidth unit at the input or output of a device when the signal is not present and can be calculated by the formular below:

$$Np = Nd + 10 * \log(CR) \quad (2)$$

Where Np is the noise power, CR is the value for the chip rate and Nd represents the noise density

- **Computes the Interference Margin**

This is the increase noise level caused by greater load in a cell.

$$IM(dB) = -10\log10(1-\lambda) \quad (3)$$

Where IM is the interference margin and λ is the load factor

- **Compute the Processing gain**

In a spread spectrum system, the process gain (or 'processing gain') is the ratio of the spread (or RF) bandwidth to the unspread (or baseband) bandwidth. It is usually expressed in decibels (dB).

$$PG = 10\log10\frac{SF}{\eta} \quad (4)$$

Where PG the processing gain, SF is the spreading factor and η is the bit rate

- **Computes the Receiver sensitivity**

The receiver sensitivity can be calculated from the formula below

$$RxS = N_i - PG + Eb/No - h_f + \vartheta \quad (5)$$

Where RxS is the receiver sensitivity, Ni is the noise interference, PG is the processing gain, Eb/No the ratio of energy per bit to the spectral noise density, h_f is the antenna gain and ϑ is the antenna loss.

- **Computes the Maximum and Average path losses**

This is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. The path loss could be Maximum path loss or Average path loss which is usually about 6dB less than maximum path loss.

$$Mpl = EIRP - R.S \quad (6)$$

Where Mpl is the maximum path loss, $EIRP$ is equivalent isotropically radiated power and $R.S$ is the receiver sensitivity.

$$Apl = Mpl - \kappa - \delta + \mu \quad (7)$$

Where Apl is the average path loss, Mpl is the maximum path loss, κ is the log normal fading, δ is the indoor penetration loss and μ is the soft handover gain.

- **Computes the Cell range base on Hata- model**

In this work we adopted Okumura–Hata propagation model as it predits and provides a realiable path loss in Nigeria based on the analysis given in [14] [15] [16]. For an urban macrocell with base station receiver height of 30 m, mobile equipment antenna height of 1.5 m and carrier frequency of 2000 MHz [5].

$$L(db) = 137.4 + 35.2\log10(R) \quad (8)$$

Where L (db) is the path loss and R is the range in km.

4. POWER CONSTRAINT

From the WCDMA downlink load equations [7]. This research work introduces modeling for performance comparisons and show how load equations can be utilized in this context. In the following we simplify the load equations by assuming that dimensioning is done based on a certain service. The load factor [7] can be calculate from Equation 9

$$\lambda = \lambda o + Nuser * \frac{(Eb/No) * Rd * V}{BW} * (1 - \alpha + \iota) \quad (9)$$

In equation (9) parameter λo refers to the minimum load, N is the number of users in the cell, Eb/No is the energy per users bit divided by the spectral density. V is the connection activity factor, BW is the system chip rate, α is the spreading code orthogonality factor and ι is the other-to-own cell interference factor. To calculate the total numbers of users can be obtained from equation (9). From the work in [4] the total power consumption of the mobile network over certain period of time can be expressed in the form

$$Pcell = Nbs * Pbs + Nue * Pue + Pother \quad (10)$$

Where Nbs, Pbs refers to number of base stations and power consumed by single base station respectively. Nue, Pue defines the number of user equipment's and power consumed by single user equipment respectively and the last term contains power spent by other mobile network equipment's such as core network elements etc. The power spent by other mobile equipment's was not considered in this research.

$$Pcell = P.O + \lambda * P.T \quad (11)$$

From equation (11) power to transmit (P.T) is needed to create required transmission power in antenna output and λ is the cell load that may vary between 0.1 and 0.9 depending on the users load and radio interface configuration. Power to operate (P.O) contains all load independent power that is needed to operate the base station.

$$Psite = Ncell * (P.O + \lambda * P.T) * T \quad (12)$$

Equation 12 defines the cell power while sites are usually composed by three or more sectors that each forms a logical cell. Where $Ncell$ is the number of cells in the site. The site energy consumption over a time period T is could be obtained from equation below

$$Esite = Ncell * (P.O + \lambda * P.T) * T \quad (13)$$

When heterogeneous networks are deployed, the daily energy utilized by the network is given by

$$(E/A)ntw = Ncell * \frac{(P.O + \lambda new * P.T)}{Asite} * 24h \quad (14)$$

In order to make our calculation more accurate this research considered [4] the UTMS macro base station specification value $P.O$ = 137 W and $P.T$ = 57 W which will be then used in calculation and P.F is the power of femtocell.

$$(E/A)ntw = Ncell * \frac{(P.O + \lambda new * P.T + Nf * P.F)}{Asite} * 24h \quad (15)$$

The model for calculating the energy consumed can be more easily understood through the flow chart in Fig. 1

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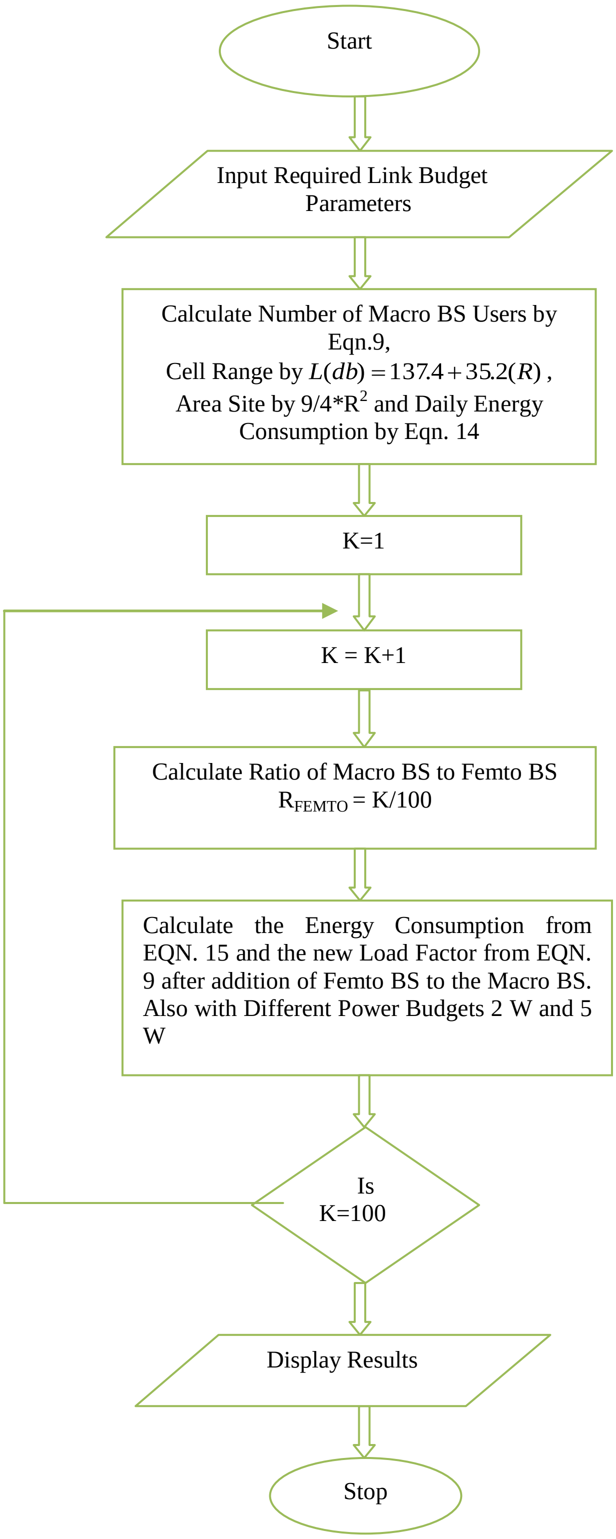

Fig 2: Flow chart for the energy consumption model

5. NUMERICAL EXAMPLE

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

Table 1. UTMS Link Budget

PARAMETER	VALUE
Operating frequency	2000 MHz
BS antenna height	30 m
MS antenna height	1.5 m
Propagation model	Okumura-Hata (urban area)
BS transmission power (dBm)	43 dBm (20w)
Femtocell input power	2 W, 5 W
Bit rate	64 kbps
BS antenna gain including losses	16 dBi
System chip rate W	3.84 Mcps
Shadow fading margin	7 dB
Orthogonality factor α	0.50
Other to own cell I	0.65
Activity factor	1.0
Minimum load	1.0
Indoor penetration loss	10 dB
Load factor	0.75
Cable and connector losses (dB)	3
Soft handover gain	2 dB
Antenna gain Rx	2 dBi
Noise figure	7
Eb/No	5 dB

Fig 3: Interface of the energy efficient software

6. NUMERICAL RESULTS

Base on the value obtained from the second row in table 2 it was observed in figure 4 that energy consumption per square kilometer is clearly reducing in macrocell when ratio of femtocells connection is increasing.

Table 2. Increment in femtocells in the network

100%R femto	10%	20%	30%	40%	50%	60%	70%	80%	90%
(E/A)m Kwm/Km^2	23.24	22.75	22.26	21.77	21.28	20.79	20.30	19.81	19.32

Fig. 4 shows the daily energy consumption per squre kilometer. It can be observed that the energy consumption by the microcell decrease with increase in the ration of femtocell cells in the network.

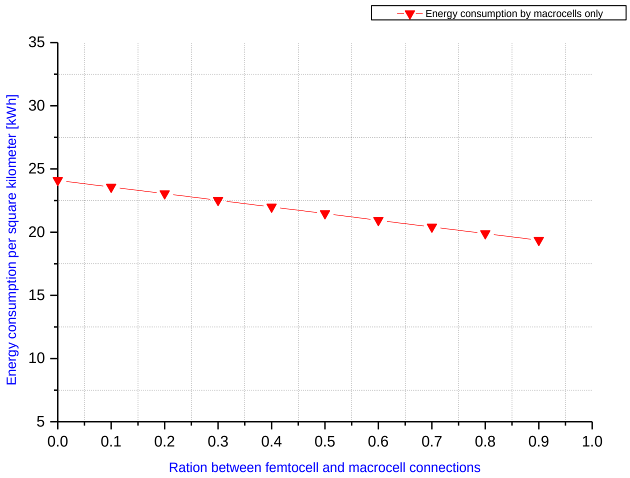

Fig 4: Daily energy consumption per square kilometer in the network when introducing femtocell into the network.

From fig. 4, when no femtocell is introduced on the network, the energy consumption is about 24.0 kwm/km^2, this decreases to about 21.28 kwm/km^2 and 19.32 kwm/km^2 when 50% and 90% of femtocells are deployed respectively. However, the introduction of femtocells to the network ordinarily does not gauratiy decerease in power consumption. The scenario depends on the power budget of the femtocell as shown in figure 5 and 6

Table 3. Show the result of increment in femtocells with power budget of 5 W in the network

100%R femto	10%	20%	30%	40%	50%	60%	70%	80%	90%
(E/A)m kwm/km^2	24.38	24.65	24.93	25.21	25.49	25.79	26.04	26.32	26.59

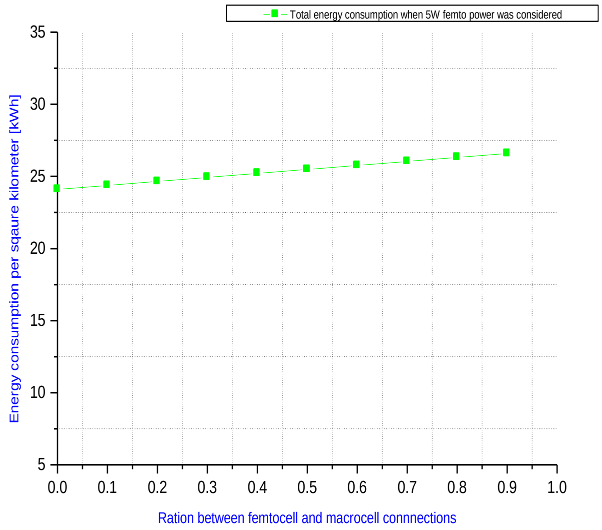

Fig 5: Total energy consumption with 5W femtocell

In table 3 and figure 5 if femtocells with power budget 5W, is introduced to the network then the total energy consumption in the network increases since load decay in macrocell load cannot compensate the increase consumption due to femtocells.

Table 4. Show the result of increment in femtocells with power budget of 2 W in the network.

100%R femto	10%	20%	30%	40%	50%	60%	70%	80%	90%
(E/A)m kwm/km^2	23.90	23.69	23.49	23.28	23.08	22.87	22.66	22.46	22.25

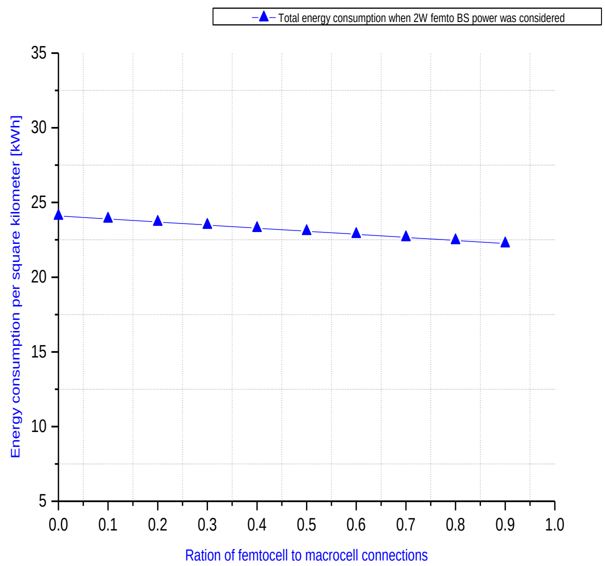

Fig 6: Total energy consumption with 2 W femtocell

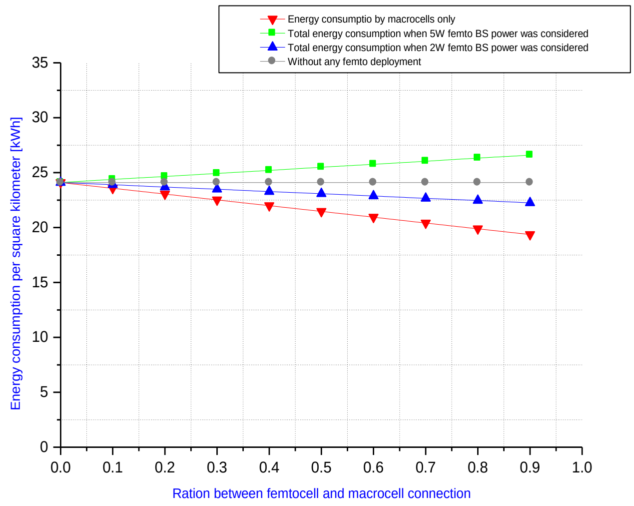

Fig 7: Daily energy consumption per square kilometer in the network when assuming energy consumption by macrocell only, total energy consumption with 5 W femtocells power and total energy consumption with 2 W femtocells power

From fig. 7 we observed that in case of 40% femtocells with 2 W power budget deployment in macrocell, around 4% of the energy would be save and it keeps on increasing as femtocells deployment increases. Where as in case of 10% femtocells with 5 W power budget, then the total energy consumption in the network is growing since the load decay in macrocell cannot compensate the additional consumption due to femtocells.

7. CONCLUSION

This paper focused on the WCDMA energy saving through femtocells deployment. A simple model for the energy consumption per unit area has been derived based on WCDMA downlink load equations. Based on the model, three different deployment scenarios have been compared to make the conclusion from energy consumption perspective. In conclusion, the significance of femtocells to the energy efficiency of the WCDMA network has been studied under the consideration of a valuable power save feature of femtocell.

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