Femtocell Suburban Deployment in LTE Networks

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***Abstract*—In this paper, the authors present a hybrid deployment model in order to investigate the path loss behavior of a LTE-femtocell in a residential suburban scenario. The proposed model places the femtocells in a fix grid to calculate path loss for each femtocell. The path loss is used to deduce the received power. The SINR is consequently calculated from the received power which is then used to estimate the overall capacity of femtocell.**

***Index Terms*—Femtocell, LTE, CSG**

I. INTRODUCTION

The recent deployment of LTE (Long Term Evolution) networks ensures a convergence of most existing wireless mobile communication networks into a universal platform though some shortcomings of previous generation networks are still persistent. One of the prime shortcomings of LTE networks is indoor coverage. This problem is severe as 2/3 of calls and over 90% of data services occur indoors. Hence, it is extremely important for cellular operators to provide good indoor coverage for both voice, and high speed data services, which are becoming increasingly important. However, some recent surveys show that 45% of households and 30% of businesses experience poor indoor coverage problem [1]. To overcome this limitation, the development and deployment of LTE femtocell is essential. LTE-femtocells, known as ‘home evolved node base station (HeNB)’, are low-power, low-cost cellular network access points that connect standard mobile devices to a mobile operator’s network using residential DSL, cable broadband connections, optical fibers or wireless last-mile technologies. In [2], different deployment criterions have been specified for femtocell networks. For dedicated channel assignments, femtocells are assigned a separate spectrum. Therefore interference is less and capacity is more [3]. Co-Channel deployment ensures better management of frequency resources but it introduces more interference [2].

Open access allows any User equipment (UE) to access the HeNB while closed subscriber group (CSG) allows only UE with permission to access HeNB. In order to ensure the proper deployment of HeNBs’, it is essential to consider several issues such as signal propagation and other RF-related issues, system architecture and interference control [4]. Recently, HeNB deployment can be classified mainly in to two scenarios i) urban and ii) suburban deployment model [3]. The urban deployment model is comprised of two models the i) dense urban Dual Strip model and ii) 5×5 Grid model. In a dense-urban HeNB modeling, each block represents two stripes of apartments, each stripe has 2 by N apartments (N is 10 in the example illustrated in Fig.2). Each apartment is of size 10m ×10m and there is a street between the two stripes of apartments, with width of 10m. However, in the 5×5 Grid Model, it is considered a single floor building with 25 apartments. The apartments are 10m×10m and are placed next to each other on a 5×5 grid on each floor (Fig. 3)[4].The dense urban models are useful to model environments with many femtocells. This includes office blocks and Condos. Both models therefore yield accurate modeling of path loss [5].

However, in the suburban environment these models would be exaggerated as density of femtocell is less. The suburban model considers each femtocell block as a (2-dimensional, 12 m × 12 m) rectangular femtocell/house where the femtocells are dropped randomly within the macro cell [4].However, this is not a proper modelling for suburban residential neighbourhoods. This is because in these neighbourhoods there is a high probability that femtocells need to be close to each other. Consequently, it is necessary to model these neighbourhoods and calculate the capacity of femtocell within these neighbourhoods.

In this paper, we have focused on the development of a hybrid suburban deployment model in order to evaluate path loss for every HeNB and consequently calculate a HeNB capacity based on path loss.

System Model

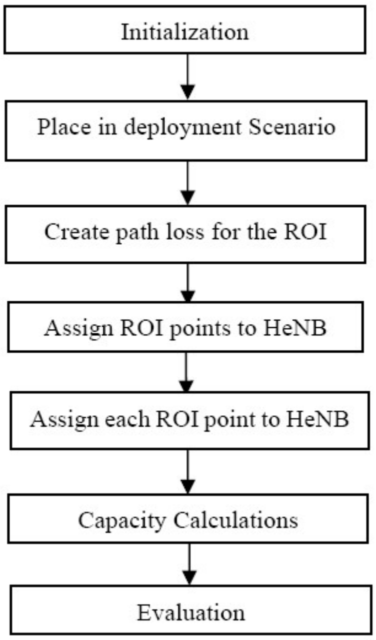

Fig. 1. System flow

A. System Flow

The system flow process is described in Fig. 1.The first phase is to initialize some system parameters. Subsequently,

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the HeNB is placed in a suburban deployment model grid and a region of interest (ROI) is defined. The path loss is defined within the ROI for each HeNB. Consequently, each point of the ROI is assigned to a HenB based on path loss. The following channel calculations for a particular HeNB is carried out. Finally an evaluation is carried out based on the calculations.

B. Proposed Hybrid Suburban Deployment Model

Our model assumes dedicated channel deployment and comprises of placing 6 femtocells in two stripes where each stripe containing 3 femtocells. The distance between each femtocell neighbor is 30m. The model consists of dual stripe of houses with roads in between the two stripes. The road is assumed to have a width of 10m and divides the stripes symmetrically. The model further describes two types of residential houses with each house assumed to have one floor. Type-I houses are of Length 10m and Width 10m (10m×10m) and type-II houses are of Length 20m and Width 10m (20m×10m). The femtocell is placed in the lower left corner of the type-I house, as viewed from above, in stripe I and placed in a symmetrically opposite position in stripe II. The femtocell is placed in the center of the left vertex, as viewed from above, in Type-II houses in stripe I and placed in a symmetrically opposite position is stripe II. For each stripe, viewed from bottom to top, the first house is depicted as type-I house followed by a road/lawn. Adjacent to this road/lawn is a type-II house. There is another road/lawn after the type-II house followed by a type-I house with a femtocell placed in the top right corner. The model also assumes stripe I and stripe II are identical. Proceeding from left to right Strip I is connected to the 10 m wide road followed by stripe II (Fig. 4.).The region of interest is defined as the block defined below. This model enables to investigate path loss in a residential neighborhood with 6 houses/femtocells in a suburban area.

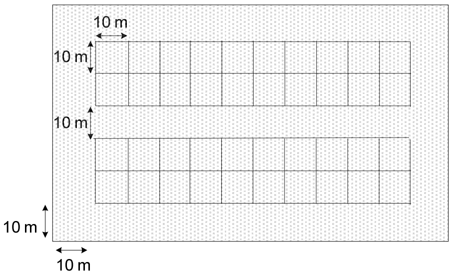

Fig. 2. Dense urban dual strip model

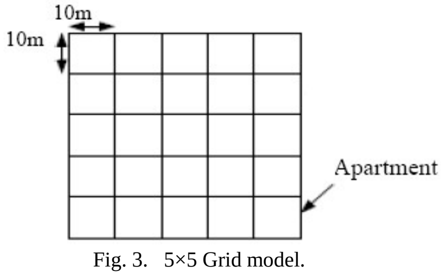

Fig. 3. 5×5 Grid model.

C. Propagation Model

LTE femtocell propagation models are vital in the calculation of path loss from HeNB to the UE. The system developed is based on the HeNB to UE path loss models. The models which are considered accurate are mentioned in [6]. The path loss between an UE located inside the building and a HeNB is calculated as:

$$L_{H,indoor} = 38.46 + 20 \cdot \log_{10}(d) + p \cdot L_w + 0.7 \cdot d_{2D,m} + L_f \cdot n^{\frac{n+2}{n+1} - 0.46} \quad (1)$$

where, p is the number of heavier walls (walls separating the apartments) between the transmitter and the receiver and Lw is the additional loss introduced by one such wall, assumed to be equal to either 10dB or 20dB. The distance between the UE and the HNB is d and is the loss due to internal walls and is modeled as a log-linear value, equal to 0.7dB/m [7]. Finally, the value for Lf is assumed to be equal to 18.3 dB. A log-normal fading value is also added, assuming a standard deviation equal to 10 dB and including some amount of correlation (0.5) between the different HNBs. Finally, a check is made that the obtained path loss is not smaller than the corresponding free space loss [8]. Furthermore, the path loss between an UE located outside the building and HeNB is the free space loss. This loss is modeled and is calculated as:

$$L_{H,outdoor} = \max\left(15.3 + 37.6 \log_{10}\left(d_{3D,m}\right), 38.46 + 20 \log_{10}\left(d_{3D,m}\right)\right) + p.L_W + 0.7.d_{2D,m} + L_f.n^{\frac{n+2}{n+1} - 0.46} \quad (2)$$

where, all the notations remain the same as (1). However, considering the particular model it is assumed that p is 1. Moreover, the path loss between the UE being in another house is calculated using (2). However, p is 2 for this scenario [7].

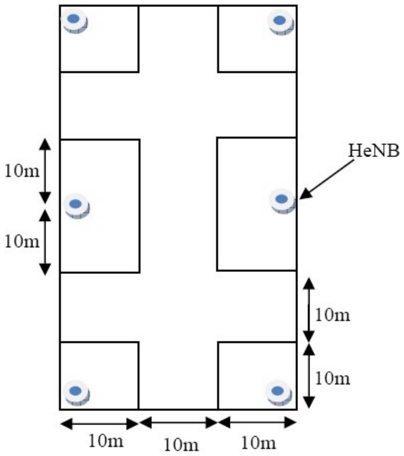

Fig. 4. Hybrid suburban deployment model

D. Path Loss

The path loss associated with each HeNB is calculated using the propagation models specified above. In accordance with the suburban deployment model it is assumed that for each HeNB, all distances less than or equal to 10m the UE is inside the house (both type-I and type-II) and therefore (1) is used to calculate path loss. Furthermore, it is assumed that for all distances greater than 10m and less than 20m from the HeNB, it is considered that the UE is in free space i.e. on the road/lawn. For this region the path loss is calculated using (2) with p=1. Finally, for all distances greater than 20m from the HenB, it is considered that the UE is in a different house.

Consequently, (2) with p=2 is used to calculate the path loss. Conclusively, the path loss for each point within the region of interest is calculated for each HeNB.

E. HeNB assignment

Every point in the region of interest is needed to be assigned to a particular HeNB, in order to estimate cell capacity. This assignment is completed on the basis of the calculated path loss. For each point the path loss due to the different HeNBs need to known. Then the path loss for that point is compared for the different HeNBs and the lowest path loss is determined. The point in the region of interest is then assigned to the HeNB with the lowest pathloss. This procedure is carried throughout the region of interest until all positions are assigned to a HeNB.

F. Capacity estimation

The received power is essential to calculate SINR which is subsequently used to calculate the overall capacity of femtocell. The received power is calculated as:

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FX} - L_M + G_{RX} - L_{RX} \quad (3)$$

P_{RX} : received power (dBm)
P_{TX}: transmitter output power (dBm)
G_{TX}: transmitter antenna gain (dBi)
L_{TX} : transmitter losses (coax, connectors...) (dB)
L_{FS} : free space loss or path loss (dB)
L_M: miscellaneous losses (fading margin, body loss, polarization mismatch, other losses...) (dB)
G_{RX} : receiver antenna gain (dBi)
L_{RX} : receiver losses (dB)

The SINR is calculated in [9]. We can express the SINR$_i$ for the symbols received in layer *i* as:

$$SINR_i = \frac{|a_{ii}|^2 \, p_i}{\sum_{j \neq i} |a_{ij}|^2 \, pj + \sigma^2 \sum_{k=1}^{v} |b_{ik}|^2 + \sum_{l=1}^{N_{\text{int}}} \sum_{m=1}^{v} |c_{l,im}|^2 \, p_{l,m}} \quad (4)$$

where, N_t specifies the number of transmit antennas and v the number of layers, P_i is the power received at layer i after macro and shadow fading losses and σ^2 the receiver noise, assumed uncorrelated. Assuming a homogeneous power distribution $p_i = p_{tx} / v$, we defined the following fading parameters: $\xi = |a_{ii}|^2$ and $\xi = \sum_{i \neq j} |a_{ii}|^2$, which model channel estimation errors ($A = I_{v \times v}$ for perfect channel knowledge), $\varphi = \sum_{k=1}^{v} |b_{ij}|^2$, which models the Zero Forcing (ZF) receiver noise enhancement, and $\theta = \sum_{m=1}^{v} |c_{1,im}|^2$, modelling the interference, We can then express $SINR_{i;u}$ for UE u as [9]:

$$SINR_{i,u} = \frac{\xi_i L_{M,O,u} L_{S,O,u} p_l}{\xi_i p_l + \varphi_i \sigma^2 + \sum_{l=1}^{N_{\text{int}}} \theta_{i,l} L_{M,l,u} L_{S,l,u} p_{l,m}} \quad (5)$$

where, $L_{M,b_i,u}$ and $L_{S,b_i,u}$ represent the macro and shadow fading path losses between the UE u and its attached heNodeB (for $b_i = 0$) and its interferers ($b_i = 1, \ldots\ldots, N_{\text{int}}$) respectively. The deduced SINR can be used to calculate the overall capacity of the femtocell. The maximum capacity for the femtocell is calculated as [10]:

$$C_{\max} = B_{fem} \times CP_r \times RS_r \times S_r \times \max\left(\log_2\left(1 + SINR\right)\right) \quad (6)$$

where, B_{fem} is the banwidth of femtocell , the cyclic prefix ratio is CP_r. Moreover the Cyclic prefix ratio is given by 1-(cyclic prefix length/symbol length). The RS_r is ratio of reference symbols/total subframe symbols. Finally, S_r is number of synchronization symbols per subframe.

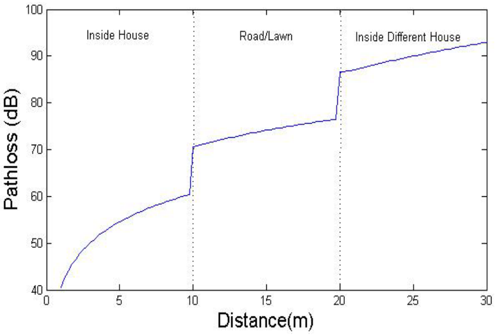

Fig. 5. Path loss profile

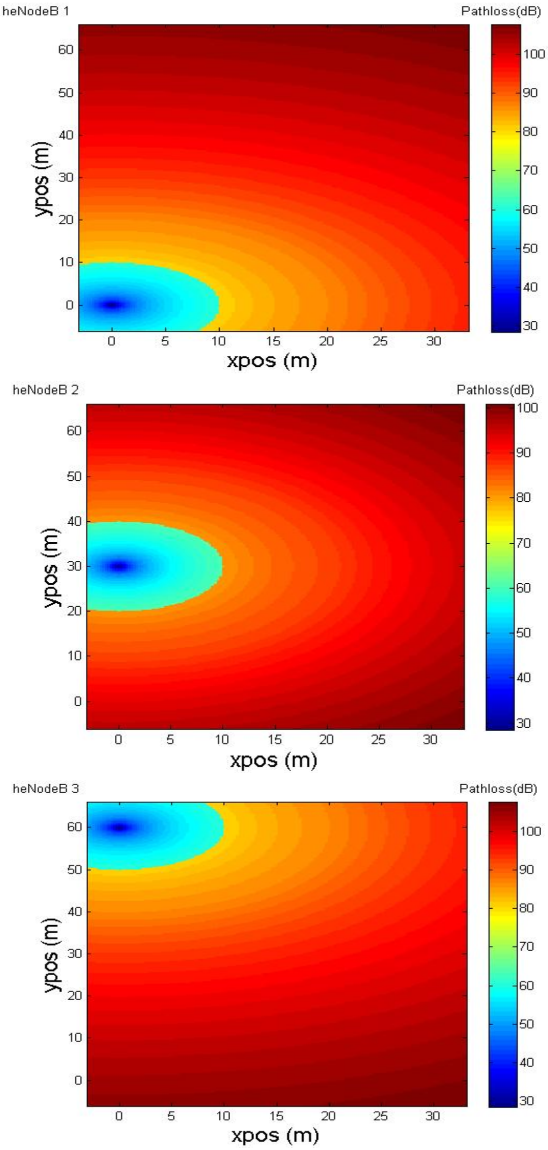

Fig. 6. Path loss image for HeNB 1-HeNB 3

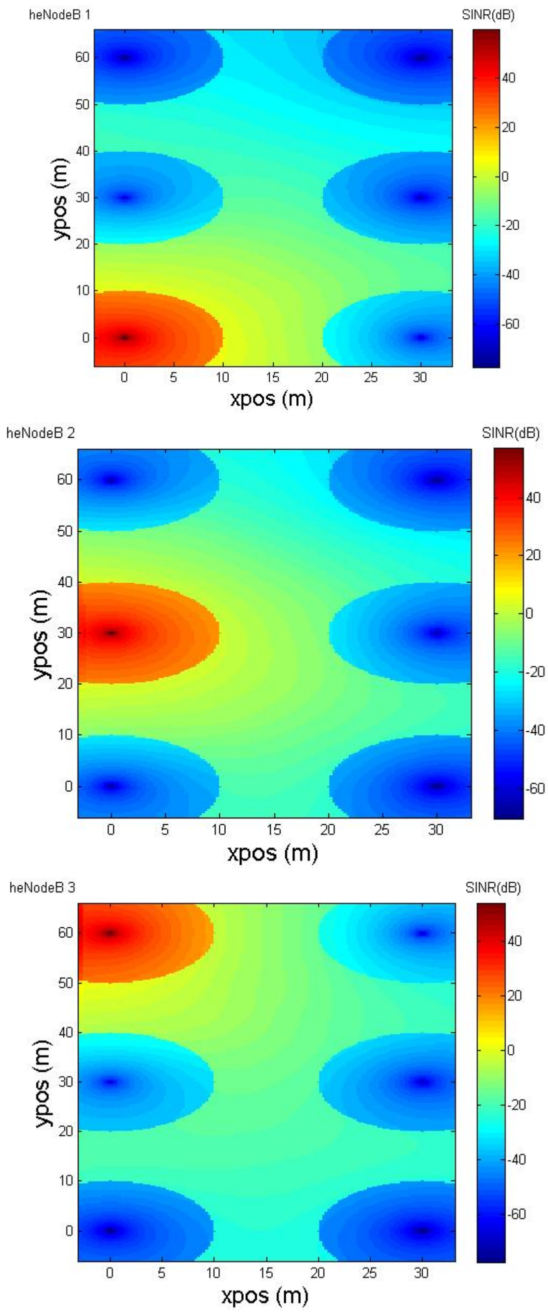

Fig. 7. SINR image for HeNB 1-HeNB 3

II. PERFORMANCE EVALUATION

The simulation parameters are given in Table I, which are in line with 3GPP LTE specifications [6] [11] In our simulation, the overlaying LTE network consists of femtocells . The network layout assumes 6 such HeNBs. The HeNBs are assumed to have a circular coverage with radius 30 meters. The HeNBs has 2 transmitting antennas and 2 receiving antennas. The HeNB antenna gain is assumed to be 0dBi.The minimum coupling loss for the HeNB is 4dB.

Fig.5. illustrates the path loss for a HeNB at various distances from the HeNB. There is a logarithmic increase in path loss within the house and reaches a maximum of 60dB at the edge of the house which is 10m from the HeNB. At 10m there is wall due to which a penetration loss of about 10dB is incurred. In free space that is between 10m and 20m from the HeNB the pathloss increases linearly. At a distance of 20m there is a penetration loss of about 10dB due to the wall of another house. At distances greater than 20m the path loss increases linearly and reaches a maximum of 92 dB at 30m. Fig. 6 specifies a detailed pathloss map for the each HenB. The pathloss within the house is relatively low and hence ensures good coverage within the house. The path loss significantly increases due to penetration loss at the wall at the edge of the house. The path loss at the edge of a different house is very high. This implies that path loss on the edge of a different house is about 80db however the path loss due a HeNB in the different house at the edge is about 20dB less. It is observed in Fig. 7 that the SINR for a HeNB within the house is high however outside the SINR very low. This ensures that it is difficult for any random UE to connect to the HeNB while the UE inside the house gets good call quality.

The overall capacity of a femtocell of the system is found to be a maximum of 162.3418Mbps and the minimum capacity is about 3.1519Mbps.

TABLE I: HENB SIMULATION PARAMETERS

Parameter	Value	
Carrier Bandwidth	10 MHz	
Frequency	2Ghz	
Cell Layout	Circular Cell	
Number of Resource Blocks	1 sector per Cell	
Subcarrier Spacing	50	
Number of Tx and Rx Antennas	15 KHz	
Tx Power	2×2	
Tx Antenna Gain	20dBm	
UE Noise Figure	0dBi	
Thermal Noise Level	9 dB	
Penetration Loss	-174dBm/Hz	
Cyclic Prefix	10dB	
Cylic Prefix Length	Normal	
Subframe	72	
	1μs	

III. CONCLUSION

This paper has proposed a suburban deployment model for femtocells and consequently investigates the path loss in suburban residential environment for HeNB to UE. Furthermore, high SINR for each HeNB proved that the problem of less coverage within a house hold is solved. The minimum overall capacity satisfies the minimum requirement of 3Mbps.

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