Coexistence of LTE Femtocells with GSM Cellular Network

Ki Won Sung, Lei Shi, and Jens Zander
Wireless@KTH, Royal Institute of Technology (KTH)
Electrum 229, 164 40 Kista, Sweden
Email: sungkw@kth.se, lshi@kth.se, and jenz@kth.se

***Abstract*—In this paper we investigate the deployment of LTE indoor femtocells on the frequency band currently used by GSM cellular network. We consider a scenario where the LTE femtocells share GSM uplink spectrum provided that the legacy GSM users are not harmed by interference from the femtocells. Difference in the characteristics of GSM and LTE technologies is exploited to enable the spectrum sharing. The performance of both systems is analyzed mathematically in terms of average SINR. Simulation is employed to support the analysis. Numerical results show that the availability of the spectrum sharing depends on the number of femtocells in each GSM cell and the locations of femtocells.**

I. INTRODUCTION

With the increasing number of multimedia applications becoming available to mobile users, the rising demand for mobile broadband data services has put a stringent challenge to mobile network operators. The industry and regulatory bodies are now investigating new strategies to better utilize spectrums allocated to voice cellular systems since the data traffic is expected to account for more than 90% of mobile communications by 2015 [1]. Refarming of GSM spectrum is regarded as one of the most cost effective solutions, especially for many incumbent operators with GSM licenses.

The GSM refarming refers to phasing out currently used GSM services and reallocating the frequency bands to more spectrum efficient and data optimized technologies such as 3GPP long term evolution (LTE). In spite of the strong need for GSM refarming, it is a time consuming process because it is difficult for mobile operators to shut down their GSM networks immediately due to the existing voice demand and global roaming capability [2].

In this paper, we study coexistence of LTE systems with existing GSM cellular network as a means of facilitating smooth transition to LTE in GSM spectrum band. We consider a scenario where LTE devices share the radio spectrum with GSM users instead of halting the current GSM services. This can be viewed as secondary access in cognitive radio regime [3, 4] where GSM network is regarded as primary system and LTE devices as secondary users. We are particularly interested in the indoor use of LTE because more than 70% of data traffic is predicted to originate indoors by 2015 [1]. Thus, LTE femtocells are considered in the investigation of the coexistence with the GSM network. Femtocell, also known as home NodeB, aims at providing improved indoor coverage and capacity via a low power indoor base station connected to core network through wired broadband infrastructure [5].

Coexistence of LTE femtocells with GSM network has several potential advantages. First, this enables rapid deployment of LTE in GSM band since the operators do not need to cease ongoing GSM services. A stepwise migration from GSM to LTE is also available because the operators can gradually increase the extent of femtocells usage as the GSM traffic decreases. Second, it has been reported that LTE femtocells may cause destructive interference to LTE macro network if the femtocells use the same frequency channel as the macro system [6, 7]. Thus, relocating some of femtocells to GSM band will be beneficial to both femto and macro users by reducing co-channel interference in the LTE macro network.

A major concern in the implementation of this coexistence is the impact of the LTE femtocells on the performance of the legacy GSM network. The authors of [8] investigated a deployment of cognitive devices in the downlink of cellular network and concluded that only a limited opportunity of spectrum sharing exists. Thus, we focus on the uplink of GSM system in this study. To the best of our knowledge, the performance of the coexistence between the LTE femtocells and the uplink of GSM cellular network has not been investigated before.

The objective of this paper is to address these questions:

- *How many LTE femtocells can be accommodated in a GSM macro cell?*
- *What is the impact of LTE femtocells locations on the performance of the GSM system?*

We propose a simple channel allocation scheme for the femtocells which is based on the different characteristics of LTE and GSM technologies. The performance of the proposed scheme is investigated through mathematical analysis. Average signal to interference and noise ratio (SINR) of both GSM network and LTE femtocell are derived depending on the number of femtocells in a GSM cell and the locations of the femtocells. Monte Carlo simulation is also employed to examine the outage probability of GSM system.

The rest of the paper is organized as follows: In section II, the system model and the basic assumptions are described. SINR of the GSM system and the LTE femtocells are derived in sections III and IV, respectively. Numerical experiments are performed and the results are provided in section V. Finally, conclusions are drawn in section VI.

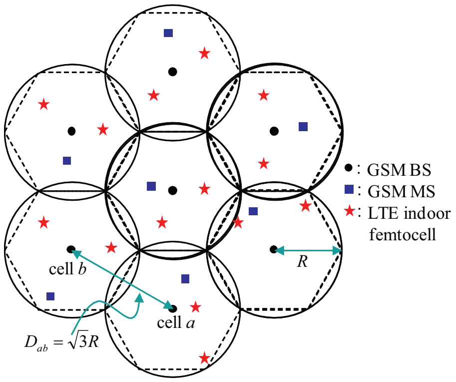

Fig. 1: Deployment of GSM cellular network and LTE indoor femtocells

II. SYSTEM MODEL

A. GSM cellular network model

GSM operates in various spectrum bands, e.g. 450MHz, 900MHz, and 1.8GHz. We consider a GSM system which operates in 1.8GHz band. Note that, however, the analysis in the paper can be readily adapted to other frequencies. GSM employs frequency reuse in order to achieve required SINR. Radio spectrum allocated to an operator is divided into K reuse clusters where K is referred to as frequency reuse factor. Let f_j denote j^{th} reuse cluster. Each reuse cluster consists of a number of frequency channels with 200kHz bandwidth each, which can be accessed by multiple mobile stations(MSs) via time division multiple access (TDMA).

Uplink of GSM is considered in this study. We assume a fully loaded system, meaning that each base station (BS) serves one MS on each of the allocated frequency channel at any time. We consider circular cell model with the cell radius R. Cells are assumed to overlap each other to reflect deployment of macro cells. The distance between the neighboring BSs is then $\sqrt{3}R$ as illustrated in Fig. 1. The inter-BS distance between cell a and cell b is denoted by D_{ab}. We consider three-tier of surrounding cells, i.e. 36 cells, in the calculation of SINR. Interference from cells beyond third-tier is neglected.

MSs are uniformly distributed in each GSM cell. Power control is employed so that the received signal power at a BS is identical regardless of the MS locations. Let $P^g(r)$ be the transmission power of a GSM MS whose distance from the serving BS is r. Also, let Q^g be the received signal power at the BS. Then,

$$Q^g = P^g(r)L(r) = P^g(R)L(R), \tag{1}$$

where $L(d)$ denotes the propagation loss for the distance d. From (1), we get

$$P^g(r) = \frac{L(R)}{L(r)}P^g(R), \tag{2}$$

where $P^g(R)$ is considered to be the maximum transmission power of the GSM MS.

By employing COST231 Hata propagation model [9, p.154] with the center frequency of 1.8GHz, BS antenna height of 30m, and MS height of 1.5m, $L(d)$ in dB scale is given as follows:

$$L(d) = 136.2 + 35.2\log_{10}(d[\mathrm{km}]). \tag{3}$$

Antenna gain of 10dB is also considered for GSM BSs.

B. LTE indoor femtocell model

We assume the LTE femtocells are used only in indoor environment. Motley-Keenan formula is employed to model the indoor propagation [10, p.80]. Let us assume a femtocell where a BS and a MS are located in the same floor of a building. Propagation loss at 1.8GHz is described as follows:

$$L(d) = 37.5 + 20\log_{10}(d[\mathrm{m}]). \tag{4}$$

Distance between MS and BS in the femtocell is assumed to be 20m. In addition to the path loss, wall penetration loss of 5 dB is considered for the propagation between indoor and outdoor entities.

We consider time division duplex (TDD) mode of LTE such that the BS and the MS of the femtocell use the same frequency band. Let P^l denote the transmission power of the femtocell BS. The MS is also assumed to have the same transmission power. Since the bandwidth of LTE is spread over a number of GSM channels, we define effective transmission power of LTE femtocell which is the portion of transmission power affecting a single GSM frequency channel, denoted by P^l_{eff}. The received signal power corresponding to P^l_{eff} is denoted by Q^l_{eff}. We assume that the BS and MS of a femtocell are not distinguished by GSM system because the separation between the femto BS and MS is negligible compared to the size of GSM cell. Hereafter, we will regard a LTE femtocell as a single entity in the calculation of interference.

C. Coexistence model

LTE femtocells need to be *cognitive* in the sense that an acceptable performance of the GSM system should be ensured while primary users (legacy GSM equipments) are unaware of the existence of secondary users (femtocells). However, this spectrum sharing is not necessarily *opportunistic* because the femtocells can have access to the information of GSM deployment such as frequency planning.

LTE is based on orthogonal frequency division multiplexing (OFDM) technology which enables the femtocells to utilize several fractions of radio spectrum without interfering with the channels between the fractions, whereas GSM employs frequency reuse with relatively narrow channel bandwidth. We propose a simple spectrum sharing scheme exploiting the OFDM characteristics of LTE to avoid detrimental inter-system interference. Let us consider a GSM cell employing reuse cluster f_3. LTE femtocells located in this GSM cell are not allowed to use f_3 in order to prevent severe interference to the GSM BS. Instead, they can utilize remaining clusters by

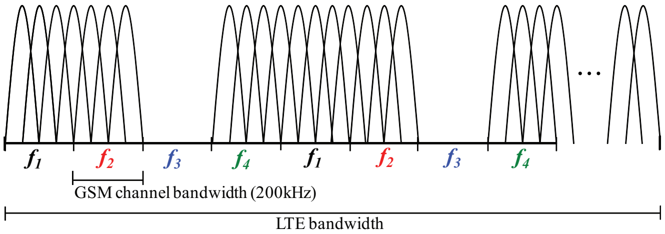

Fig. 2: Spectrum sharing scheme for LTE femtocells located in a GSM cell using reuse cluster f_3

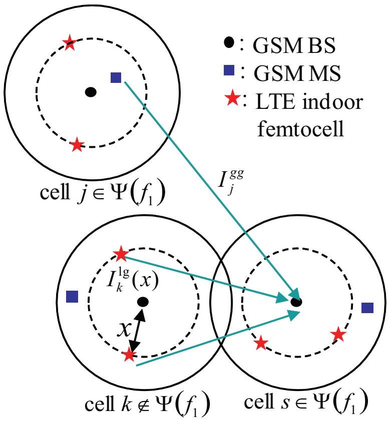

Fig. 3: Interference that the GSM BS in cell s receives

means of OFDM as depicted in Fig. 2. Then, the maximum available bandwidth of the LTE femtocell is $(K-1)/K$ of the total GSM bandwidth.

It is possible that an operator controls the number and the locations of LTE femtocells deployed in each GSM cell. The location of femtocell can be estimated by the received GSM signal level at the femtocell or by a geo-location database. Then, the operator can allow a selected group of femtocells to run in the GSM band. The effect of the number and locations of femtocells will be examined in section V.

III. SINR OF GSM UPLINK

This section investigates the impact of LTE femtocells on the performance of existing GSM system. We assume that M femtocells are operating in each GSM cell. It is also assumed that femtocells in a GSM cell have the same distance from the GSM BS in order to examine the effect of femtocell locations, i.e. distances between femtocells and GSM BSs. We further consider that M femtocells are uniformly distributed on the circle of radius x as shown in Fig. 3.

Let us consider the GSM BS in cell s in Fig. 3 to be the victim of inter-cell interference. It receives interference from GSM MSs and femtocells in other cells. We assume the interference from adjacent channels is negligible. Let $\Psi(f_j)$ denote a set of GSM cells that use the j^{th} reuse cluster f_j. Without loss of generality, we assume that cell s is a member of $\Psi(f_1)$. Then, BS s is affected by GSM MSs connected to cells $\in \Psi(f_1)$ as well as LTE femtocells located in GSM cells $\notin \Psi(f_1)$.

Let I_j^{gg} be the expected value of interference from a GSM MS in cell j to the BS in cell s. This can be obtained by employing a polar coordinate where the BS j and BS s are located at $(0,0)$ and $(D_{js},0)$, respectively. The location of the MS in cell j is denoted by (r_j,θ_j). Since the MS is uniformly distributed in the cell, I_j^{gg} is given as

$$I_j^{gg} = \int_0^R \int_0^{2\pi} P^g(r) L\left(\sqrt{r_j^2 + D_{js}^2 - 2r_j D_{js}\cos\theta_j}\right)\frac{r}{\pi R^2} d\theta_j dr_j. \tag{5}$$

Let $I_k^{lg}(x)$ denote the expected value of interference from a LTE femtocell in GSM cell k to the BS s given that the distance between the BS k and the femtocell is x. Similar to (5), a polar coordinate is employed where BS k is at $(0,0)$ and the femtocell is at (x,β_k). Then, $I_k^{lg}(x)$ is given by

$$I_k^{lg}(x) = \int_0^{2\pi} P_{eff}^l L\left(\sqrt{x^2 + D_{ks}^2 - 2xD_{ks}\cos\beta_k}\right)\frac{1}{2\pi} d\beta_k. \tag{6}$$

Background noise at the GSM BS is denoted by N_b^g and equals to $N_0 W^g N_F^g$ where N_0 is noise spectral density, W^g is the channel bandwidth of GSM, and N_F^g is the noise figure of the BS.

Let $\gamma^g(x,M)$ be the expected value of SINR of the GSM BS s given that there are M femtocells in each GSM cell with the distance of x from the nearest GSM BS. Then,

$$\gamma^g(x,M) = \frac{Q^g}{\sum\limits_{j\in\Psi(f_1)} I_j^{gg} + M \sum\limits_{k\notin\Psi(f_1)} I_k^{lg}(x) + N_b^g}. \tag{7}$$

IV. SINR OF LTE FEMTOCELL

Let us consider a LTE femtocell located in GSM cell s as shown in Fig. 4. Note that the femtocell uses all reuse clusters except f_1. Since we consider regularly located GSM cells and assume uniformly distributed GSM MSs and LTE femtocells, each reuse cluster has the same expected value of received interference. Thus, we analyze the SINR of femtocell for a frequency channel in the cluster f_2 without loss of generality. The femtocell is interfered by GSM MSs that employ f_2, femtocells in other GSM cells $\notin \Psi(f_2)$, and femtocells in the same cell s.

Let $I_j^{gl}(x)$ be the expected value of interference from a GSM MS in cell j given that the distance between BS s and the femtocell is x. As illustrated in Fig. 4, the location of the GSM MS relative to BS j is (r_j,θ_j), and that of the femtocell relative to BS s is (x,β_s). Then, by employing a polar coordinate where the BS j is at $(0,0)$ and the BS k is at $(D_{js},0)$, $I_j^{gl}(x)$ is given as (8). Similarly, the average interference from a femtocell in GSM cell k, which is denoted by $I_k^{ll}(x)$, is given by (9).

The expected value of interference from another femtocell in the same GSM cell s is denoted by $I_s^{ll}(x)$. We employ a

$$I_j^{gl}(x) = \int_0^R \int_0^{2\pi} \int_0^{2\pi} P^g(r_j) L\left(\sqrt{(r_j \cos\theta_j - D_{js} - x\cos\beta_s)^2 + (r_j \sin\theta_j - x\sin\beta_s)^2}\right) \frac{r_j}{2\pi^2 R^2} d\beta_s d\theta_j dr_j. \quad (8)$$

$$I_k^{ll}(x) = \int_0^{2\pi} \int_0^{2\pi} P_{eff}^l L\left(\sqrt{(x\cos\beta_k - D_{ks} - x\cos\beta_s)^2 + (x\sin\beta_k - x\sin\beta_s)^2}\right) \frac{1}{4\pi^2} d\beta_s d\beta_k. \quad (9)$$

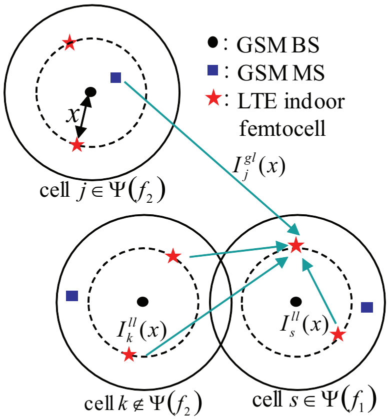

Fig. 4: Interference that a LTE femtocell in cell s receives

polar coordinate where the BS s is located at origin point. Then,

$$I_s^{ll}(x) = \int_0^{2\pi} P_{eff}^l L\left(\sqrt{2x^2(1-\cos\beta_s)}\right) \frac{1}{2\pi} d\beta_s. \quad (10)$$

Finally, background noise at the femto BS and MS, N_b^l, is given by $N_b^l = N_0 W^g N_F^l$ where N_F^l is the noise figure of the LTE BS and MS.

Similar to (7), the expected value of SINR of the femtocell given M and x is as follows:

$$\gamma^l(x, M) = \quad (11)$$
$$\frac{Q_{eff}^l}{\sum\limits_{j \in \Psi(f_2)} I_j^{gl} + M \sum\limits_{\substack{k \notin \Psi(f_2) \\ k \neq s}} I_k^{ll}(x) + (M-1) I_s^{ll}(x) + N_b^l}.$$

Note that (11) is an approximate formula because interference from different cells is not independent of each other.

V. NUMERICAL RESULTS

The performances of the GSM uplink and the LTE femtocells are examined by numerical experiments. Parameters used for the experiments are summarized in Table I. The average SINR of the GSM, $\gamma^g(x, M)$, is shown in Fig. 5 where $M = 0$ represents a reference case that no femtocell is in use. When the femtocells are located close to the center of GSM cell, e.g. $x = 0.1R$, accommodating one more LTE femtocell in each GSM cell causes about 0.53dB decline in the SINR. The impairment of the SINR increases as the femtocells approach the border of GSM cells. When $x = 0.7R$, a single femtocell in each GSM cell accounts for 0.74dB decrease in the SINR.

TABLE I: Parameters used for the numerical experiments

Parameter	Value
K	7
R	500m
$P^g(R)$	30dBm
P_{eff}^l	6dBm
N_0	-174dBm
W^g	200kHz
N_F^g	5dB
N_F^l	5dB

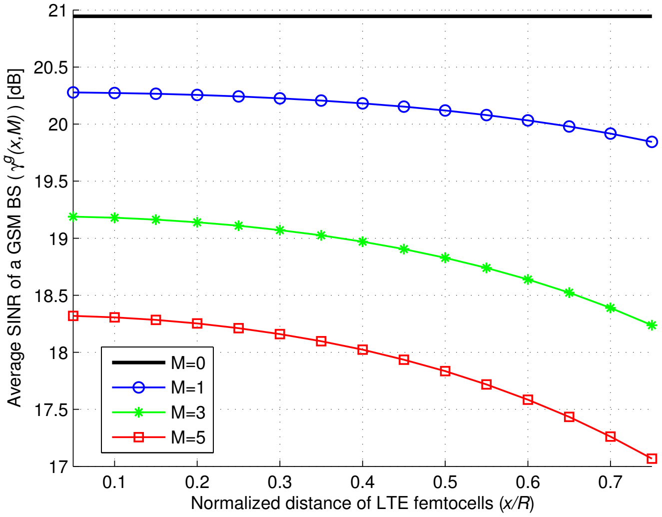

Fig. 5: SINR of the GSM BS as a function of x

The decrease in the average SINR leads to outage to the GSM MSs who cannot increase the transmission power due to the maximum power constraint. Let γ_{thr}^g be the required SINR of the GSM uplink. Then, outage probability of the GSM system, p_{out}^g, is defined as the portion of MSs whose SINR is below γ_{thr}^g. Monte Carlo simulation is employed to examine p_{out}^g considering shadow fading of 6dB standard deviation. Fig. 6 shows p_{out}^g as a function of M. Recall that the GSM network is assumed to be fully loaded. Between two and five femtocells in each GSM cell leads to about 3% increase in p_{out}^g depending on the location of the femtocells. For example, $M = 5$ results in the increase of 3.5% when $x = 0.1R$. The increase in p_{out}^g is 6.1% when $x = 0.7R$. Thus, it is preferred to deploy the femtocells near the center of GSM cell in order to protect the GSM system.

Fig. 7 shows the SINR of the LTE femtocell, $\gamma^l(x, M)$. Contrary to the GSM case, the SINR of the femtocell declines

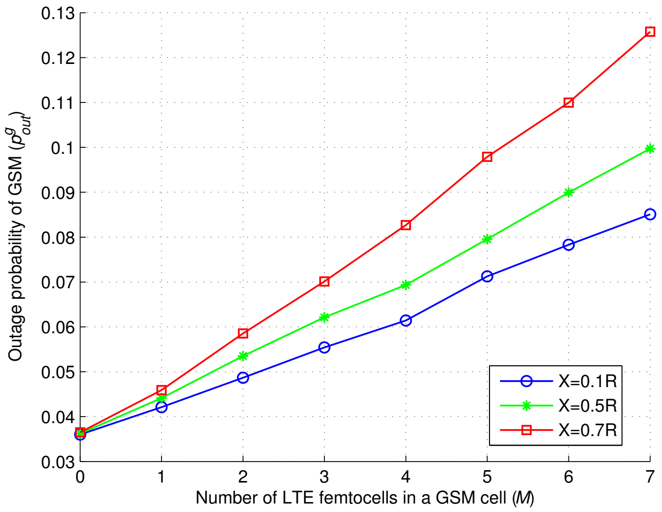

Fig. 6: Outage probability of GSM uplink ($\gamma^g_{thr} = 9$dB)

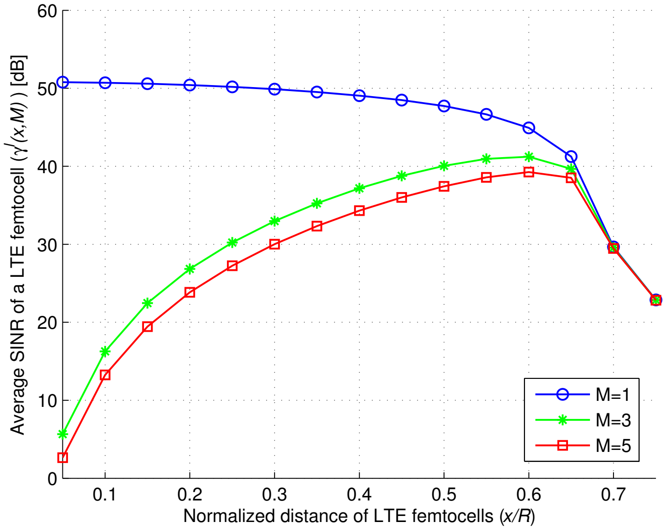

Fig. 7: SINR of the LTE femtocell as a function of x

significantly with smaller x when multiple femtocells are operating in the same GSM cell. When $M = 1$, $\gamma^l(x, M)$ is above 30dB unless the femtocell gets close to the boundary of the GSM cell. This means that the majority of interference to the femtocell comes from other femtocells rather than legacy GSM MSs.

It should be noted that this study is by no means comprehensive. The viability of the coexistence highly depends on the conditions of network deployment such as GSM cell size, traffic load, frequency reuse factor, and transmission powers of the GSM and LTE equipments. Thus, more extensive investigation is needed to identify the impact of various deployment conditions.

VI. CONCLUSION

We investigated the coexistence of LTE indoor femtocells with GSM cellular network as a means to facilitate an efficient use of radio spectrum in the era of mobile broadband services. We considered a scenario where LTE indoor femtocells share the radio spectrum with the uplink of existing GSM cellular system provided that the femtocells do not induce harmful interference to legacy GSM equipments. A simple channel allocation scheme for LTE femtocells was proposed exploiting the difference in the characteristics between GSM and LTE technologies. We obtained the average SINR of both GSM uplink and LTE femtocells through mathematical analysis. Numerical experiments were performed considering the number and the locations of the femtocells. Monte Carlo simulation was also employed to obtain outage probability of the GSM system.

Results of the experiments show that it is desirable to deploy the femtocells near the center of GSM cells for the protection of the GSM system, while this results in the decrease in the femtocell SINR due to the increasing interference coming from other femtocells. It is also observed that accommodating five femtocells in each GSM cell leads to the increase of about 4% in the outage probability if the GSM network is fully loaded. However, detailed figures highly depend on the network deployment conditions. Thus, more thorough investigation for the impact of the various conditions is required as further study. An advanced interference management scheme for the LTE femtocells also remains as interesting areas of future research.

ACKNOWLEDGEMENT

This work was supported by Vinnova project Multi-Operator Dynamic Spectrum Management (MODyS).

REFERENCES

[1] T. Norman, “The Road to LTE for GSM and UMTS Operators,” Analysys Mason Ltd., White Paper, Jan. 2009.

[2] Motorola Inc., “Spectrum Analysis for Future LTE Deployments,” White Paper, 2007.

[3] J. Mitola III and G. Q. Maguire Jr, “Cognitive Radio: Making Software Radios More Personal,” *IEEE Personal Communications*, vol. 6, no. 4, pp. 13–18, Aug. 1999.

[4] J. Zander, “Can We Find (and Use) ”Spectrum Holes”? Spectrum Sensing and Spatial Reuse Opportunities in ”Cognitive” Radio Systems,” in *Proc. of the 69th IEEE Vehicular Technology Conference (VTC)*, Barcelona, Apr. 26-29 2009.

[5] V. Chandrasekhar, J. Andrews, and A. Gatherer, “Femtocell Networks: A Survey,” *IEEE Communcations Magazine*, vol. 46, no. 9, pp. 59–67, 2008.

[6] Z. Bharucha, I. Ćosović, H. Haas, and G. Auer, “Throughput Enhancement through Femto-Cell Deployment,” in *Proc. of the 7th IEEE International Workshop on Multi-Carrier Systems & Solutions (MC-SS)*, Herrsching, Germany, May 05–06, 2009, pp. 311–319.

[7] J. Espino and J. Markendahl, “Analysis of Macro - Femtocell Interference and Implications for Spectrum Allocation,” in *proc. of the 20th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Tokyo, Sep. 13-16 2009.

[8] E. G. Larsson and M. Skoglund, “Cognitive Radio in a Frequency-Planned Environment: Some Basic Limits,” *IEEE Transactions on Wireless Communications*, vol. 7, no. 12, pp. 4800–4806, Dec. 2008.

[9] T. S. Rappaport, *Wireless Communications: Principles and Practice*, 2nd ed. New Jersey: Prentice Hall, 2001.

[10] M. J. Nawrocki, M. Dohler, and A. H. Aghvami, *Understanding UMTS Radio Network Modelling, Planning and Automated Optimisation*. Chichester: John Wiley & Sons, 2006.