Femtocell Number Influence to SINR and Throughput on Coexistence GSM and LTE Network

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ABSTRACT
Coexistence GSM network and LTE femto relies on the number of femtocell deployment position. In the earlier study, the impact of macrocell size, femtocell deployment position, and coexistence LTE femtocell network integrated with GSM macrocell had been discussed. LTE femtocell used Orthogonal Frequency Division Multiplexing (OFDM) technology for its operation. In coexistence networks, LTE femtocells operate with OFDM technology so that they can utilize several radio frequency fractions without disturbing other parts of the frequency located between them. Unfortunately, the impact of femtocell number on the coexistence network had not been discussed. SINR and femtocell throughput performance are mathematically analyzed. The result showed that femtocell number had an effect on the coexistence network performance. SINR GSM, SINR femtocell and femtocell throughput significantly degraded as the femtocell number increased. The increasing femtocell number from M =0 to M =20 on each GSM cell cause around 14 dB degradation in SINR GSM, 3 dB decline in SINR Femto, approximately 1.7% decline in throughput for K = 4. Meanwhile for K = 7, the increasing femtocell number cause 17 dB decline in SINR GSM 6.5 dB decline in SINR Femto and 3.2 % decline in throughput. Those happened since the LTE femtocell interference went up. So femtocell number greatly influences the Coexistence GSM Network and LTE femtocell

Keywords: GSM Macrocell, LTE Femtocell, Femtocell Number

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GSM, SINR femtocell dan femtocell throughput semakin menurun seiring dengan peningkatan jumlah femtocell. Peningkatan jumlah femtocell dari M = 0 ke M = 20 pada setiap sel GSM menyebabkan penurunan sekitar 14 dB SINR GSM, penurunan 3 dB SINR Femto, sekitar 1, 7% penurunan throughput untuk K = 4. Sementara itu untuk K = 7, peningkatan jumlah femtocell menyebabkan penurunan 17 dB SINR GSM, penurunan 6,5 dB SINR Femtocell dan penurunan 3, 2% dalam throughput. Hal ini disebabkan oleh peningkatan interferensi dari LTE femtocell. Maka jumlah LTE femtocell sangat mempengaruhi sistem koeksistensi LTE femtocell dengan jaringan GSM.

Kata kunci: GSM Macrocell; LTE Femtocell; Jumlah Femtocell.

1. Introduction

A refarming of the limited radio frequency spectrum is essential to be required as massive value in related to rapid growth of telecommunication technology. Nowadays mobile broadband 3G to 4G is unstoppable. Thus, one way of increasing system capacity with limited frequency resources use resources allocation by cell splitting [1].

GSM refarming refers to phasing out current GSM services and reallocating the frequency bands to more frequency efficient and data optimized technologies as you can see in 4G Long Term evolution (LTE). The coexistence of LTE systems with existing GSM cellular networks is proposed to address the challenge of growing data demand and maintain GSM service. In the coexistence system studied in [2], LTE femtocell are deployed on GSM cell. However, it operates on GSM band under certain frequency allocation scheme as a means of facilitating smooth transition to LTE on GSM frequency band. Unfortunately [2] does not provide comprehensive solution, it is needed to define and compare more metrics in many ways. It has been studied in [3] GSM macrocell size has an effect to the performance of coexistence network. Instead, the study of how impact the deployment position LTE femtocell to the network performance is stated in [4]. A problem should be questioned is how femtocell number give mutual impact between macrocell GSM and deployed LTE femtocell on each performance. This study intend to discuss the femtocell number effect to the coexistence network which is not provided in [3] and [4].

The paper is organized as follow. In section II, we discuss about coexistence model. Section III gives the detail of performance metrics used in this study, the
evaluation and result are provided in section IV. Finally, the conclusion and future work plan are outlined in section V.

2. Coexistence Model

The coexistence network is accessible for GSM and LTE systems. The deployment of LTE femtocell must be a win solution for the performance of GSM networks and proper service in a brand new deployed LTE femtocell [5].

In the coexistence network, the LTE femtocells operate on OFDM technology. Therefore, they are able to utilize several fractions of radio frequency without interfering with other parts of the frequency lying in between. The study in [2] proposed of frequency allocation between GSM and LTE femtocell. It is said that LTE femtocell uses whole channel exclude those located by GSM macrocell.

As you can see, supposing GSM cell employs reused cluster f1. LTE femtocells located on the GSM cell does not use f1 in order to prevent severe interference to the GSM BS. Each of them utilize remain clusters f2 f3 f4 by a means of OFDM as depicted in Figure 1.

![Figure 1 Channel Allocation Scheme for LTE Femtocells Located in A GSM Cell Using Reuse Cluster F1.](image)

3. Performance Metrics

3.1 SINR of GSM Uplink

This part investigates the impact of LTE femtocells on the performance of existing GSM system. Supposing that M femtocells are operating on each GSM cell. It is believed that femtocells in a GSM cell have the constant distance from the GSM
BS to examine the effect of femtocell locations, i.e. distances between femtocells and GSM BSs. We assume that M femtocells are uniformly distributed on the circle of radius x, as shown in Figure 2.

![Figure 2 Interference GSM BS](image)

We consider that the GSM BS in cells in Figure 2 to be the victim of inter-cell interference. It receives interference from GSM MSs and femtocells in other cells. Let Ψ (fj) denote a set of GSM cells that use the jth reuse cluster fj. Without loss of generality, we assume that cell s is a member of Ψ (f1). Then, BS s is affected by GSM MSs connected to cells ∈ Ψ (f1) as well as LTE femtocells located in GSM cells ∈ Ψ (f1) [2].

If P^g denotes transmission power of GSM MS and L denotes propagation Loss, I_{jgg} is 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_{jgg} is provided as:

$$I_{jgg} = \int_0^R \int_0^{2\pi} P^g(r) L \left( \sqrt{r_j^2 + D_{js}^2 - 2r_j D_{js} \cos \theta_j} \right) \frac{r}{\pi R^2} d\theta_j dr_j \quad (1)$$

If I_k^{lg}(x) denotes the expected value of interference from a LTE femtocell in GSM cell k to the BS s provided that the distance between the BS k and the femtocell is x. P^{eff} denotes effective transmission power of LTE femtocell. Similar to (1), a polar
coordinate is employed where BS $k$ is at $(0,0)$ and the femtocell is at $(x, \beta_k)$. Then, $I_{k}^{lg}(x)$ is provided by:

$$I_{k}^{lg}(x) = \int_{0}^{2\pi} P_{eff}^l L \left( \sqrt{x^2 + D_{kS}^2 - 2xD_{kS} \cos \beta_k} \right) \frac{1}{2\pi} d\beta_k$$  

(2)

Background noise at the GSM BS is denoted by $N_{bg}^g$ 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 $N_F$ is the noise figure of the BS. Let $\gamma^g(x, M)$ be the expected value of SINR of the GSM BS provided that there are $M$ femtocells in each GSM cell with the distance of $x$ from the nearest GSM BS. $Q^g$ Denotes received signal power of BS, Then,

$$\gamma^g(x, M) = \frac{Q^g}{\sum_{j \in \Psi(f_1)} I_{j}^{gg}} + M \sum_{k \notin \Psi(f_1)} I_{k}^{lg}(x) + N_{bg}^g$$  

(3)

### 3.2 SINR of LTE Femtocell

We assume that a LTE femtocell located on GSM cell $s$ shown in Figure 3. Based on OFDM concept that the femtocell uses all reuse clusters except $f_1$. As we consider regularly located on GSM cells and assume uniformly distributed GSM MSs and LTE femtocells, each reuse cluster has the constant 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 interference of the LTE femtocell comes from GSM MSs that employ $f_2$, femtocells on other GSM cells $\notin \Psi(f_2)$, and femtocells in the constant cells [2].

![Figure 3 Interference Received by LTE Femtocell][2]
If \( I_{j}^{gl}(x) \) be the expected value of interference from a GSM MS in cell \( j \) provided that the distance between BS \( s \) and the femtocell is \( x \). As illustrated in Figure 3, the location of the GSM MS relative to BS \( j \) is \((r_{j}, \theta_{j})\), and that of the femtocell relative to BS \( s \) is \((x, \beta_{s})\). 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 provided as:

\[
I_{j}^{gl}(x) = \int_{0}^{2\pi} \int_{0}^{2\pi} p_{gl}(r_{j}) L_{c} \left( (r_{j}\cos\theta_{j} - D_{js} - x\cos\beta_{s})^2 + (r_{j}\sin\theta_{j} - x\sin\beta_{s})^2 \right) \frac{r_{j}}{2\pi R_{2}} d\beta_{s} d\theta_{j} d\theta_{j} 
\]

(4)

Similarly, the average interference from a femtocell on GSM cell \( k \), which is denoted by \( I_{k}^{ll}(x) \), is provided by:

\[
I_{k}^{ll}(x) = \int_{0}^{2\pi} \int_{0}^{2\pi} P_{eff} L_{c} \left( (x\cos\beta_{k} - D_{js} - x\cos\beta_{s})^2 + (x\sin\beta_{k} - x\sin\beta_{s})^2 \right) \frac{1}{4\pi^2} d\beta_{s} d\beta_{k} 
\]

(5)

The interference value from another femtocell in the constant GSM cell \( s \) is denoted by \( I_{s}^{ll}(x) \). In the polar coordinate BS \( s \) is located at origin point, then

\[
I_{s}^{ll}(x) = \int_{0}^{2\pi} P_{eff} L_{c} \left( 2x^2 \left( 1 - \cos\beta_{s} \right) \right) \frac{1}{2\pi} d\beta_{s} 
\]

(6)

Background noise at the femto BS and MS, \( N_{b} = N_{0} W_{g} N_{F} \), where \( N_{F} \) is the noise figure of LTE BS and MS. \( Q_{eff} \) is received signal power corresponding to \( P_{eff} \). The expected value SINR of the femtocell provided \( M \) and \( x \) as follows

\[
\gamma_{l}(x, M) = \frac{Q_{eff}}{\sum_{j} \psi(f_{j}) I_{j}^{gl} + M \sum_{k} \psi(f_{j}) I_{k}^{ll}(x) + (M-1) I_{s}^{ll}(x) + N_{b}^0} 
\]

(7)

### 3.3 Femtocell Throughput

To measure throughput capacity on each channel for each LTE femtocell is calculated by using Shannon equation as follows [6].

\[
C = B \log_{2}(1 + \gamma_{l}(x, M)) 
\]

(8)

Where \( B \) is channel bandwidth of LTE femtocell, \( \gamma_{l}(x, M) \) is SINR of the LTE femtocell system.
4. Evaluation and Result

4.1 Impact of Femtocell Number on SINR of GSM

In the coexistence network, femtocell number provide a great impact on the SINR of GSM. We assume that number of femtocell operating on each GSM cell. LTE femtocell deployed on GSM cell have steady distance toward GSM BS, it is distributed on the circle of radius x.

To get clear view on the relationship between femtocell number and SINR of GSM, a study based on simulation is conducted. In table 1, configuration parameters for the simulation are listed. Parameters used for the experiments based on standard GSM and LTE parameters.

Table 1 Parameters of Femtocell Number Influence on SINR GSM

| Parameter                  | Value          |
|----------------------------|----------------|
| K                          | 4.7            |
| Macrocell Radius           | 0.6 km         |
| Femtocell Number           | (0,1,3,...,20) |
| Femtocell Position         | 0.8 R          |
| $P^f(R)$                   | 30 dB          |
| $P_{\text{eff}}$           | 6 dB           |
| $N_0$                      | -174 dB        |
| $W_f$                      | 200 kHz        |
| $N_{F,g}$                  | 5 dB           |
| $N_{F,i}$                  | 5 dB           |

Figure 4 SINR of GSM vs Change of Femtocell Number per GSM Cell
Figure 4 shows SINR of GSM tends to decrease as femtocell number increase. There is significant decline of SINR GSM from $M = 0$ to $M = 20$. Where $M = 0$ represents there is no femtocell in use, all reuse factors have SINR about 18 dB. Then increasing femtocell number from $M = 0$ to $M = 20$ on each GSM cell cause about 14 dB decline in SINR for $K = 4$ and 17 dB decline in SINR for $K = 7$. This trend can be ascribed to the increase of interference from LTE femtocell due to the increase of femtocell number. In relation to the SINR of GSM threshold about 9 dB, it can be reached by deploying 6 femtocell per GSM cell for $K = 4$ and 3 femtocell per GSM cell for $K = 7$. But to reach the SINR threshold, femtocell number are dynamic manipulated by deployment femtocell position and macrocell size. Meanwhile, we can observe that network with $K = 4$ has higher SINR of GSM than network with $K = 7$. The small reuse factor will reduce inter-femtocell interference because in small reuse factor, quantity femtocell interfering GSM BS will also be reduced. Thus, it increases SINR of GSM BS.

4.2 Impact of Femtocell Number on SINR of LTE Femtocell

To get clear view on the relationship between femtocell number and SINR of LTE femtocell, a study based on simulation is conducted. In table 2, configuration parameters for the simulation are listed.

Table 2 Parameters of Influence Femtocell Number on SINR LTE Femtocell

| Parameter                               | Value            |
|----------------------------------------|------------------|
| $K$                                     | 4, 7             |
| macrocell radius [km]                  | 0.6 km           |
| femtocell number                       | (0, 1, 2, 20)    |
| femtocell position                     | 0.8R             |
| $P^g (R)$                              | 30 dB            |
| $P_{eff}$                              | 6 dB             |
| $N_o$                                  | -174 dB          |
| $W_g$                                  | 200 kHz          |
| $N_F^P$                                | 5 dB             |
| $N_F^l$                                | 5 dB             |
The result shows in Figure 5, how the SINR of LTE femtocell changes as femtocell number increase for two different reuse factor scenarios. The SINR of LTE femtocell tends to decrease as femtocell number increase. There is significant decline of SINR LTE femtocell from $M = 0$ to $M = 20$. The increasing femtocell number from $M = 0$ to $M = 20$ per GSM cell cause about 3dB decline in SINR for $K = 4$ and 6.5 dB decline in SINR for $K = 7$. This trend can be ascribed to the increase of interference from LTE femtocell due to the increase of femtocell number. Also we can observe, When accomodating less than 6 femtocell per GSM cell, network with bigger reuse factor $K = 7$ has higher SINR of LTE femtocell than network with small reuse factor $K = 4$. It occurs because in this scenario network with bigger reuse factor receives less interference from GSM MS in co-channel cell. The bigger reuse factor will cause bigger propagation loss, thus it reduces co-channel interference strength. Nevertheless, as the increase femtocell number, SINR LTE femtocell for small reuse factor $K = 4$ will be higher than other reuse factor $K = 7$. It can be seen in this scenario accomodating 7 or more femtocell per GSM cell will make SINR in reuse factor $K = 4$ is higher than reuse factor $K = 7$. This trend occurs due to network with small reuse factor will receive less inter-femtocell interference, thus it increases SINR LTE femtocell.
4.3 Impact of Femtocell Number on Femtocell Throughput

Femtocell number provide an impact on the SINR of LTE femtocell. Yet, femtocell throughput is affected by SINR LTE femtocell. Supposing that number of femtocell operating in each GSM cell. LTE femtocell deployed in GSM cell have the constant distance toward GSM BS, it is distributed on the circle of radius \( x \).

To get clear view on the relationship between femtocell number and the femtocell throughput, a study based on simulation is conducted. In table 3, configuration parameters for the simulation are listed. Parameter used in this study based on standard GSM and LTE parameter.

| Parameter | Value          |
|-----------|----------------|
| \( B \)   | \( 2.10^6 \) Hz|
| \( K \)   | 4.7            |
| macrocell radius [km] 0.6 km |
| femtocell number (0, 1...20) |
| femtocell position 0.8 \( R \) |
| \( P^g ( R ) \) | 30 dB |
| \( P_{\text{eff}} \) | 6 dB |
| \( N_o \)   | -174 dB        |
| \( W^g \)   | 200 kHz        |
| \( N_{g}^f \) | 5 dB           |
| \( N_{f}^i \) | 5 dB           |

Figure 6 LTE Femtocell Throughput vs Change of Femtocell Number per GSM Cell
In Figure 6 shows how the LTE femtocell throughput changes as the increasing femtocell number for two different reuse factor scenarios. LTE femtocell throughput tends to decrease as femtocell number increase. There is decline of LTE femtocell throughput from $M = 0$ to $M = 20$. The increasing femtocell number from $M = 0$ to $M = 20$ in each GSM cell set off approximately 1.7% decline in throughput for $K = 4$, and 3.2% decline in throughput for $K = 7$. This trend can be ascribed the increase of interference from LTE femtocell due to the increase of femtocell number. Also we can observe, when accommodating less than 6 femtocell per GSM cell, network with bigger reuse factor $K = 7$ has higher femtocell throughput than network with small reuse factor $K = 4$. It occurs due to accommodating less than 6 femtocell on each GSM cell, network with bigger reuse factor receives less interference from GSM MS in co-channel cell. The bigger reuse factor will cause bigger path loss, thus it reduces interference strength. As the increasing number deployed femtocell i.e. accommodating 7 or more femtocell per GSM cell in this scenario, SINR LTE femtocell for small reuse factor $K = 4$ will be higher than other reuse factor $K = 7$. This trend occurs since network with small reuse factor will receive less inter-femtocell interference, so it increases SINR and femtocell throughput.

5. Conclusion

Femtocell number provides a great impact to the coexistence network performance. We find that SINR of GSM, SINR LTE femtocell and femtocell throughput tends to decrease as femtocell number increase. This trend can be ascribed to the increasing of interference from LTE femtocell because of the increasing of femtocell number. Related to SINR GSM threshold 9 dB, the number of femtocell has a great impact of it. In the scenario $R = 0.6$ km and the distance femtocell toward GSM BS, $x = 0.8R$, for reuse factor $K = 4$, to reach SINR threshold 9 dB, it is suggested to deploy 6 femtocell per GSM cell and for $K = 7$, deploying about 3 femtocell per GSM cell is suggested. However, in reach of SINR GSM threshold 9 dB, femtocell number are dynamic influenced by femtocell position and macrocell size.
It is possibly to perform Coexistence GSM and LTE femtocell properly. Yet, it relies on the network deployment conditions. Much more detail investigation about network deployment condition is required for the next research. In view of that, the advance interference management scheme for the coexistence network is essential to be further studied.

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