

Enterprise Multi-Femtocell Deployment Guidelines



Qualcomm Incorporated
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2 Executive Summary

Femtocells are low-power cellular base stations typically deployed indoors in residential, enterprise or hotspot settings. Femtocell deployments provide excellent user experience through better coverage for voice and very high data throughputs. Enterprise femtocell deployment is commonly used to refer to a commercial multi-femto deployment. It covers a wide range of deployments such as enterprise buildings, small offices, and shopping malls.

While enterprise femtocells offer great benefits in terms of coverage extension and capacity offload, they also pose certain challenges in terms of interference management and mobility management. Because of the unique characteristics of enterprise femtocells (e.g., larger RF variations inside the building, inter-femto interference and large number of users), special care needs to be taken in their deployment.

This document provides recommendations for deployment, configuration and downlink and uplink operation of enterprise femtocells. These recommendations are meant to ensure that excellent coverage and data rates are provided to the enterprise users by the femtocells in the entire enterprise building while limiting the interference to macro network. The recommendations are supported by detailed analysis, simulations and over-the-air tests. The document focuses on ULTRAN. Co-channel deployment with closed access is assumed since this is the most typical and most challenging deployment scenario for UMTS/HSPA enterprise femtocells. However, many of the recommendations in this document apply to other deployment scenarios as well.

Below is a summary of the deployment guidelines and recommendations for enterprise femtocell deployments. More details can be found in the rest of the document.

- Femtocell downlink power calibration is crucial to providing excellent coverage for the femto users while limiting the RF leakage to outside the boundary of enterprise.
 - Technician/IT person assistance is required for coverage planning, placement and self calibration of enterprise femtocells since the technician/IT person is able to define the desired coverage boundary for the enterprise femtocells.
 - Uplink interference management is critical in enterprise femtocell deployments. Without proper uplink interference management mechanisms, femto users can cause significant interference to macro uplink especially when the enterprise is near the macro cell site. Uplink interference to macro uplink can be controlled by limiting the UL resources (e.g., Tx power) of femto UEs.
 - For proper femtocell DL power calibration and uplink interference management, coverage region of each femtocell needs to be kept to a small area (e.g., similar to a WiFi access point).
 - Soft handover is recommended to achieve excellent voice quality and coverage in enterprise femtocell deployments. If soft handover is not supported, transmit diversity can significantly
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improve the voice quality. With transmit diversity and fast hard handover, acceptable voice quality can be achieved.

3 Introduction

Femtocells are low-power cellular base stations typically deployed indoors in residential, enterprise or hotspot settings. Femtocell deployments provide excellent user experience through better coverage for voice and very high data throughputs. In addition, cellular operators benefit from reduced infrastructure deployment costs that are otherwise needed for network evolution, including capacity upgrades and coverage improvements. In addition to coverage extension, femtocells provide capacity offload benefits by transferring users from macro to femtocells, which in turn helps macro users to achieve higher throughputs, since fewer users share the macro network resources. A femtocell is sometimes referred to as a Home Node B (HNB) or Home Access Point (HAP).

Enterprise femtocells, as opposed to residential femtocells, serve the capacity and coverage needs of businesses. The deployment models for enterprise femtocells vary based on size of the enterprise, co-existence with macro network and access mode of the femtocells.

3.1 Enterprise Femtocell Deployment Models

Enterprise femtocell deployment is commonly used to refer to a commercial multi-femto deployment. It covers a wide range of deployments such as enterprise buildings, small offices, big-box stores and shopping malls. Enterprise categories for femto deployment can be roughly identified as (1) small - with 1-5 subscribers, typical of SoHo enterprises, (2) medium - with 6-100 subscribers, typical of small and medium businesses (SMB/SME), and (3) large – with number of subscribers exceeding 100.

Enterprise femtocells may be deployed on a dedicated carrier or on a shared carrier with macro network. Furthermore, they may be deployed as closed cells, open cells or hybrid cells. In a closed-access enterprise deployment, only the enterprise users can be served by the femtocells and other non-enterprise users are not allowed to access or get service from the femtocells. In hybrid mode, all users can access the femtocells but the enterprise users have priority over non-enterprise users for getting service from the femtocell.

3.2 Enterprise Femtocell Deployment Considerations

While enterprise femtocells offer great benefits in terms of coverage extension and capacity offload, they also pose certain challenges in terms of interference management and mobility management. Some of the challenges overlap with those for residential femtocells (discussed in [1]). On the other hand, enterprise femtocells have certain characteristics that make them significantly different from residential femtocells. More specifically inter-femto interactions play an important role in enterprise femtocell deployment and pose new challenges compared to the residential case. The coverage area of an enterprise femtocell is typically larger than that of a residential deployment. Moreover, in a large enterprise, RF variations can be much greater than those observed in a residential scenario. These large RF variations need to be taken into account in the deployment of enterprise femtocells to ensure that the femtocell provide sufficient coverage in

the entire enterprise while limiting the interference to non-enterprise users. Further, the larger area per femtocell coverage leads to lower path-loss *differentials* relative to the surrounding macrocells. This results in higher uplink interference to macrocell from an enterprise femto UE compared to that from a typical residential femto UE. In addition, the number of users served by an enterprise femtocell can be large. As a consequence of these issues, femto-macro interference needs to be well managed for enterprise deployment, both on the downlink (DL) and on the uplink (UL).

Due to the unique characteristics of enterprise femtocell deployments, special care needs to be taken in deployment of enterprise femtocell particularly in the co-channel deployment where femtocells share the same carrier as the macro network.

In this report, we focus on the co-channel, closed access deployment scenario since this is the most typical deployment model for enterprise femtocells in UMTS. Moreover, this deployment model is the most challenging one particularly in terms of interference management. Additionally we restrict our attention to medium to large enterprise deployment. The findings readily extend to other deployment models as well. Also, in this report, we provide recommendations for deployment, configuration and downlink and uplink operation of enterprise femtocells. These recommendations are meant to ensure that excellent coverage and data rates are provided to the enterprise users by the femtocells in the entire enterprise building while limiting the interference to macro network. Most of the guidelines and recommendations presented in this document apply to other deployment scenarios as well (*e.g.*, dedicated channel, open access). For example, in case of open access, it is still desirable to contain the femtocell coverage to within the building and limit the leakage outside to avoid excessive signalling due to unnecessary registrations and active handovers by passing-by users (or potential call drops due to lack of active hand-in support). Furthermore, even with open access, if active hand-in is not supported, nearby macro users can cause significant interference on the uplink of femtocells.

4 RF and System Simulation Modelling

This section describes the tools and models used for the results discussed in this document. It covers enterprise building model, path loss modeling, macro signal strength modelling, fading modelling and user mobility models.

4.1 Path Loss and RF Modelling

The modelling platform used in the document is based on the WinProp® software tool [2]. This tool is used to generate path loss (PL) data for a variety of building settings in which enterprise femtocells may be deployed. The data encompasses path loss between macro cells and all locations for UEs, between femtocells and UEs, and between macro cells and femtocells. It incorporates all of the shadowing effects of the local environment. Architectural drawings of floor plans of the modelled building are imported into the WinProp® software and materials such as drywall, glass, concrete and metal are selected from the material database. Additionally outer walls of surrounding structures are modelled to capture shadowing. The path loss data generated via WinProp® is combined with fading model and user mobility models to provide detailed propagation environment

4.2 Large Enterprise Commercial Building Model

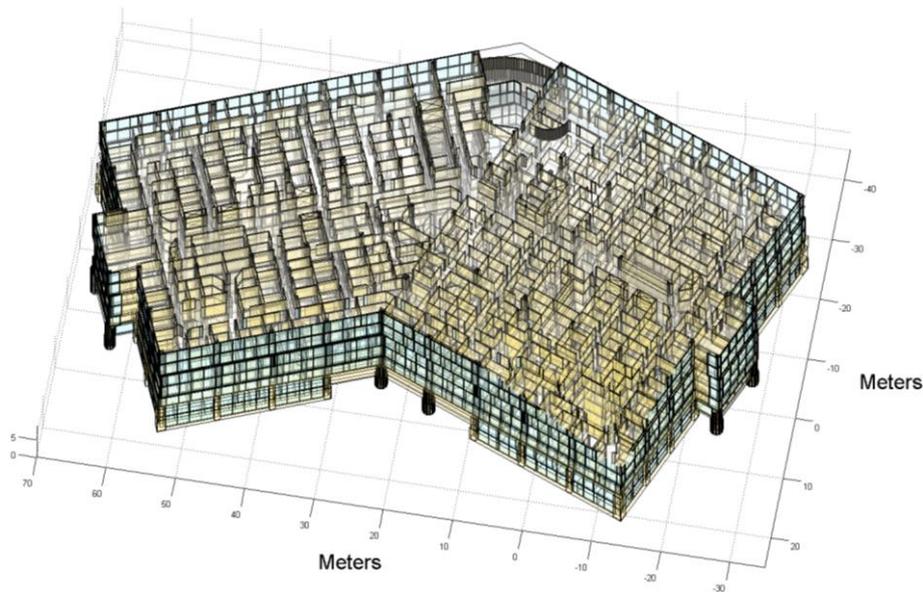


Figure 4-1 Model of seven-floor Large Enterprise Commercial Building (LEC)

The model of Large Enterprise Commercial (LEC) building shown in Figure 4-1 is obtained from a real building that consists of seven floors, each approximately 42,000 sq. ft. Each floor has a distinct floor plan (following the layout of the actual building) although most floors have similar layouts. Each floor consists of several hallways and corridors, conference rooms, labs and a large number of office rooms. The average number of

office rooms is about 100. Candidate femtocell locations are identified on one or more floors of the building. Path loss to points on the floor, other floors and outside is evaluated for selected candidate femto locations on each floor. Most floors have similar floor plans and hence similar femto locations. The various buildings surrounding the LEC building are also modelled to help create a realistic diffraction and reflection pattern for macro cell signal propagation. A sample PL profile for a femto located on the 1st floor is given in Figure 4-2.

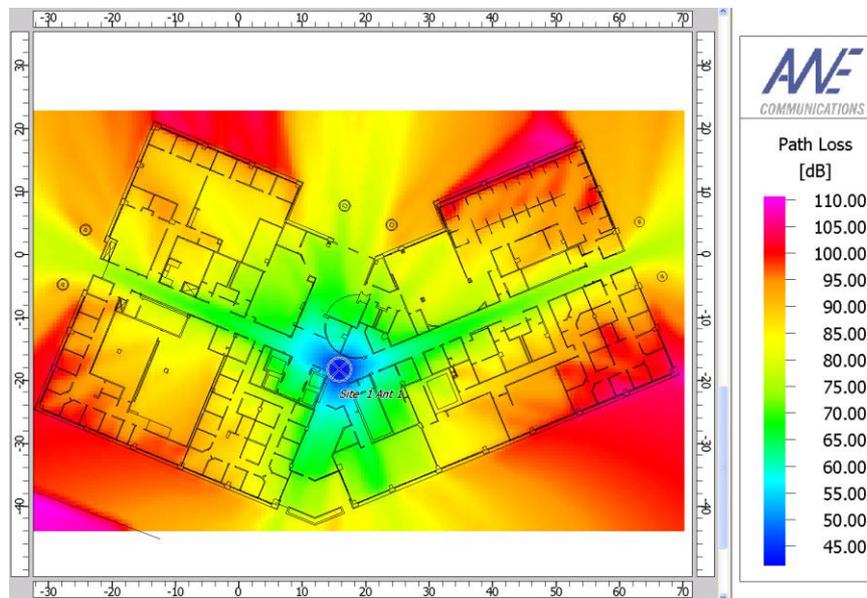


Figure 4-2 Sample Path Loss Profile in LEC Building

4.3 Macro Cell Propagation Modelling

To capture Macro signal strength variation within a macro cell, Macro signal strength is modelled by placing the enterprise campus (LEC building and surrounding clutter) within the macro cell at two locations. The two locations depicted in Figure 4-3, correspond to Macro cell-site and Macro cell-edge scenarios.

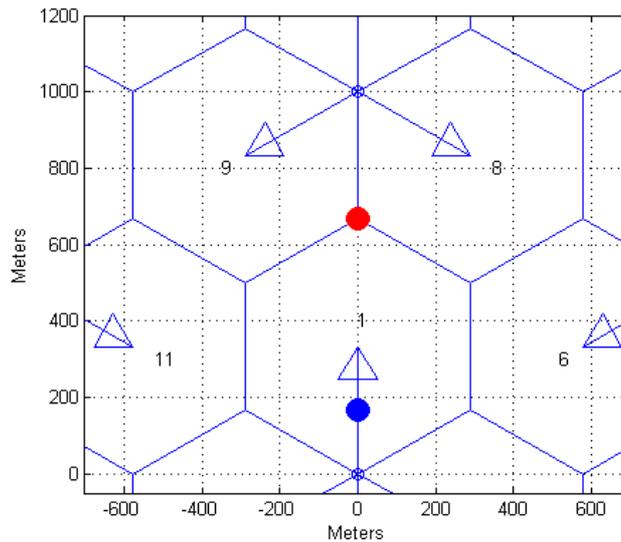


Figure 4-3 Illustration of cell-site (blue) and cell-edge (red) locations in macro cell at which enterprise model is typically placed in simulations

4.4 Fading and User Mobility

For some analysis, fast fading is added to the femto PL values generated. We use a Jakes fading simulator with a static Rician component with a K factor of 1.5 (linear units). This fading distribution has been verified to match closely with measurements made along various stationary and walk routes. The velocity used in the simulator is 0.86 km/h, corresponding to a stationary user. For macro fading a similar model is used with a K factor of 5.0.

The modelling of various user and technician walks in Sections 4.2 and 4.3 include the path loss variation along the walk routes combined with fast fading reflecting Doppler corresponding to the appropriate user speed. Typical user speeds are taken to be 3km/h, which reflects walking speeds and 0.86 km/h, which reflects a stationary user experiencing Doppler due to movement of the surrounding objects.

5 Coverage Planning Considerations

Enterprise femtocell deployment needs to account for two main factors that are absent in traditional macro cell network planning, namely co-channel operation with a surrounding macro network, and closed access mode operation.

Co-channel operation with a macro network requires the femtocells to overcome the macro interference in the desired femtocell coverage areas. On the other hand, under closed access model, femtocell signals act as interference to mobiles not allowed on the femtocell.

Coverage planning process for femtocell deployment, therefore, needs to address coverage as well as interference considerations. These and additional considerations for downlink and uplink are listed in the following sections. They govern the number of femtocells to be deployed within the enterprise, their placement and their transmit power calibration. In Section 5.1, an overview is provided of all the considerations required for coverage planning for enterprise femtocell deployment. In Section 5.2, the macro cell signal-strength variation in an enterprise is examined. In Section 5.3, 5.4 and 5.5, the factors deciding the number of femtocells to be deployed per enterprise and their placement are discussed.

Note that femtocell power calibration related aspects for enterprise deployments are covered in details under interference management in Chapter 6.

5.1 Overview of Coverage Planning Considerations on Downlink and Uplink

5.1.1.1.1 Following are the principal aspects affecting coverage planning for enterprise femtocell deployment.

5.1.1.1.2 Location of the enterprise within the macro network

The location of the enterprise within the macro network determines the level of co-channel interference (captured by RSSI) that a femtocell must overpower to provide coverage. At a given transmit power the size of the region served by the femtocell will be smaller at a macro cell site (location characterized by a strong dominant macro with large RSSI) than at a macro cell edge location with low level of RSSI. Conversely, the transmit power required to serve a given area will be higher at macro cell site than at macro cell edge.

5.1.1.1.3 Variation of macro RSSI within the enterprise

In medium to large enterprises, with floor space in 10000 sq feet or more, there may be significant variation in the macro RSSI within the enterprise. This variation is common and is typically due to presence of large shadowing obstacles such as surrounding buildings, windows, and internal walls. This RSSI variation also results in potential mismatch between Network Listen Module (NLM) measurements and actual RF conditions seen by UEs.

5.1.1.1.4 Coverage Performance

The goal of the planning process is to have good radio conditions everywhere within the enterprise for UEs to acquire, initiate and sustain voice calls on the serving femtocell. Additionally, the requirements call for excellent radio conditions with high data rates in the desired coverage area. Good coverage performance is

addressed by limiting the maximum path loss that needs to be covered by each femtocell in addition to proper femtocell power calibration.

5.1.1.1.5 Downlink Interference considerations

The crucial implication of co-channel closed operation for network planning is the need for managing interference to non-allowed users on the downlink.

We refer to all non-allowed users as macro UEs (MUEs). This interference appears in the following forms: (1) Interference to MUEs outside the desired coverage area: this includes interference to adjacent – upper and lower – floors when applicable, (2) Interference to macro UEs present within the desired coverage area, and (3) Adjacent channel interference.

Interference of type (1) and (3) is managed by proper power calibration and guidelines for femto placements, while that of type (2) is handled by optimization of handover and reselection parameters.

Consideration of interference to non-allowed users also dictates the recommended number of femtocells that need to be deployed.

5.1.1.1.6 Uplink interference considerations

There are constraints imposed by UL considerations arising out of maximum path loss served by UE, impact to macrocell uplink, potential DL-UL imbalance due to different DL transmit powers, and UL noise rise levels at adjacent femtocells.

5.1.1.1.7 PSC planning considerations

Primary Scrambling Codes (PSCs) allocated to femtocells are typically restricted to a set much smaller (of size 4-10) than total available (512) of PSCs. This can potentially cause PSC collisions. Self-configuration of PSCs based on NLM measurements of surrounding PSCs alleviates this problem to a certain extent. Yet self-configuration may suffer from the hidden node problem (a UE sees colliding PSCs but NLM at the femtocells do not). In enterprise deployments, due to presence of potentially many femtocells in the same enterprise, careful PSC assignment is needed to ensure that PSCs of neighbouring femtocells do not collide with each other. Throughout this document we assume that PSCs of neighbouring femtocells do not collide with each other.

5.1.1.1.8 Other considerations

Placement of the femtocells in the enterprise may also be constrained by availability of GPS drop, ports for backhaul, electrical power outlets and concerns for physical safety and security of the device. We assume that these requirements are met.

5.2 Macro Signal Variations in the Enterprise

The location of the enterprise within the macro network determines the level of co-channel interference (captured by RSSI) that a femtocell must overpower to provide coverage. Figure 5-1 depicts the variation of

macro cell RSSI in the LEC building when the enterprise is located at Macro cell site and Macro cell edge locations respectively.

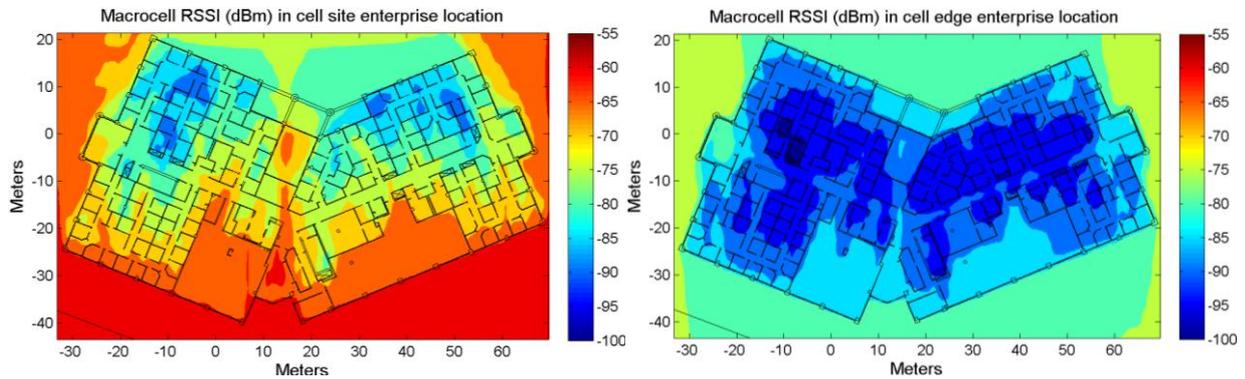


Figure 5-1 Variation of macro cell RSSI in the enterprise building at Macro cell site and Macro cell edge locations

As expected, across locations the average macro DL RSSI in the enterprise may vary from -60 dBm to -100 dBm or lower. The most significant observation is that for enterprises of the size of the LEC building, the variation of RSSI inside the enterprise floor itself can be up to 30 dB. For femtocells, this implies that femtos located at different places within the enterprise may have different coverage for the same transmit power or may require different transmit powers to provide similar coverage.

On the uplink, within an enterprise a UE may face path loss to nearest Macro cell that varies from 80 to 110 dB as depicted in Figure 5-2. At these low values of path losses, a femto user transmitting at high power may contribute significant UL interference to the nearest macro cell. This interference is exacerbated if outdoor UEs are served by femtocells. Figure 5-3 depicts the differential between path loss from a femto UE to serving femtocell and from the UE to nearest macrocell. The figure assumes a 10dB higher noise figure for the femtocell compared to macrocell. It is observed that the path loss differential (including the NF difference) can be as low as 10 dB for indoor users and even lower for outdoor users.

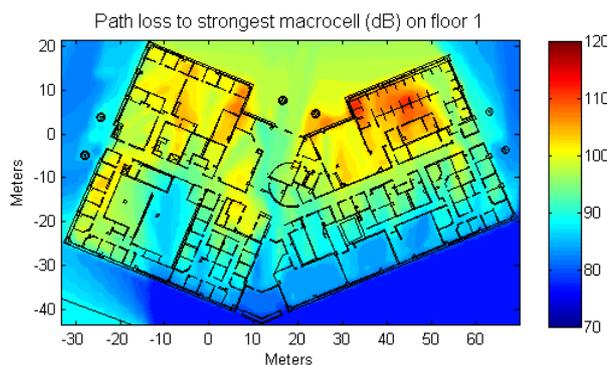


Figure 5-2 Path loss to strongest Macro cell in LEC building at Cell Site location

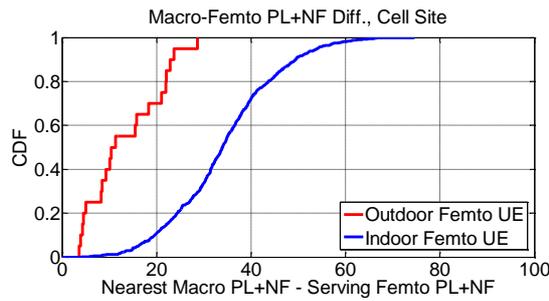


Figure 5-3 Distribution of Path loss differential between closest Macro cell and closest femtocell, within LEC building at cell site location

5.3 Impact of Number of Femtocells on Coverage and Interference

To determine the number of femtocells needed to cover an enterprise, first we consider the simplest cases of femtocells transmitting at maximum allowed transmit power of 20 dBm.

Figure 5-4 depicts the femtocell coverage (downlink CPICH E_c/I_0) with 1 and 2 femtocells deployed in the LEC building at cell site. CPICH E_c/I_0 of -16 dB or greater is an indication of good coverage. It is clear that due to strong macro RSSI, femtocells transmitting at 20 dBm may not provide adequate coverage. A higher number of femtocells transmitting at 20 dBm may yield adequate coverage.

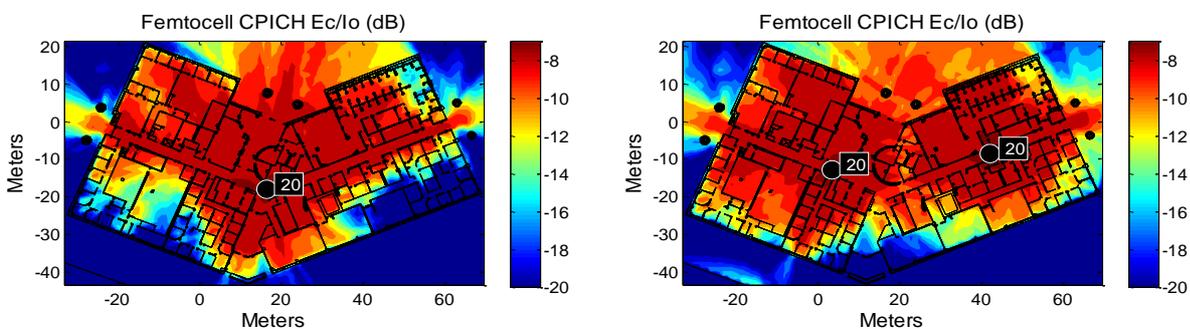


Figure 5-4 CPICH E_c/I_0 of the serving cell for a floor in LEC building. One or two femtocells are inadequate to provide sufficient coverage to the floor due to strong macro RSSI. Cell Site location. The black circles indicate location of femtocells. The figures in squares represent maximum transmit powers in dBm. CPICH E_c/I_0 of -16dB or greater is an indication of good coverage.

Although using femtocells transmitting at maximum power may yield the smallest number of femtocells required to cover the floor, this strategy has several drawbacks. Structures and walls in the building result in highly irregular coverage zones for femtos. Femtos transmitting at maximum power may result in significant leakage outside the enterprise, leading to significant interference to users on the macro network. Avoiding the

leakage by placing the femtos differently may be possible, e.g., as depicted in Figure 5-5, but determining the right locations for these femtocells requires very careful RF planning.

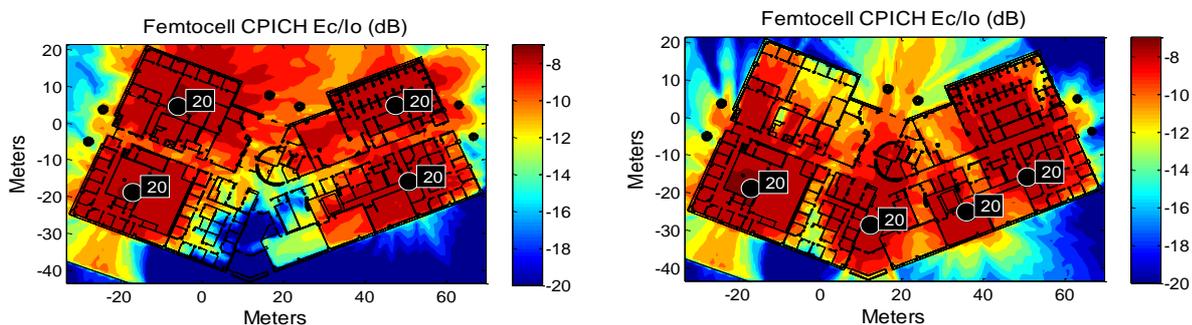


Figure 5-5 With a few high power femtos, controlling coverage/leakage tradeoff becomes very challenging. Figure on the left results in significant interference outside while still not achieving adequate coverage with 4 femtocells. Figure on the right achieves adequate coverage but determining such efficient set of femto locations it is very difficult. CPICH E_c/I_o of -16dB or greater is an indication of good coverage.

Also the smallest number of femtocells needed to cover an enterprise cannot be determined a priori as it is dependent on its relative location in the macro cell as shown in Figure 5-6.

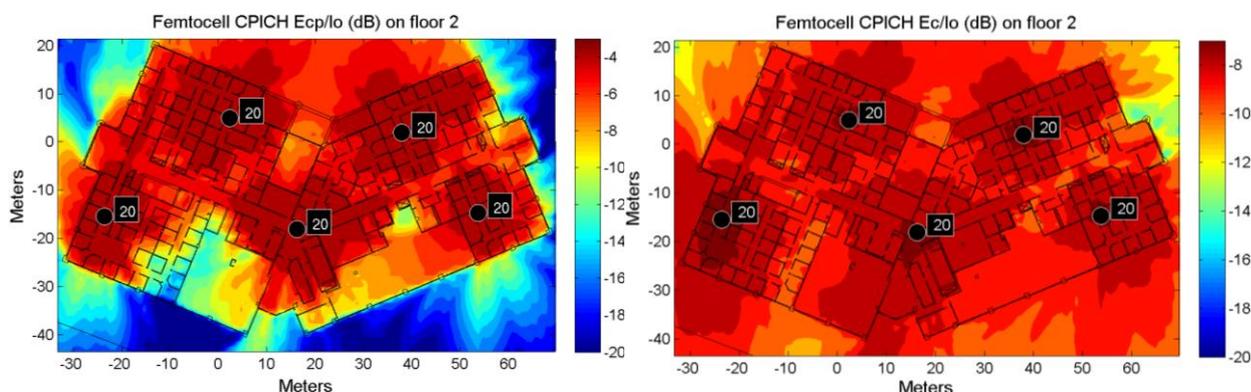


Figure 5-6 Illustration of fixed femtocell transmit power of 20 dBm . Linear average of faded CPICH E_c/I_o (dB) is shown. The total transmit power, in dBm, is shown in the box next to the femtocell location. Results are provided for enterprise location in cell site (left) and cell edge (right). Same set of femtocells cause significant leakage outside on cell edge compared to cell site.

In addition, deploying few femtos to cover an enterprise results in a large coverage radius or equivalently large path loss edge for the femtocell. Figure 5-7 shows the path loss to the serving femtocell for different location inside the femtocells when four femtos are located in the enterprise such that they cover the entire floor (see Figure 5-5). Although the enterprise floor is well covered by this particular placement of four femtos, the path loss to the serving femto can be as large as 100dB . As a result, the femto users would need to

transmit at high power to close the uplink with their own serving cell. This can result in significant interference to the macrocell uplink. This impact is demonstrated by the example depicted in Table 5-1 and Figure 5-8.

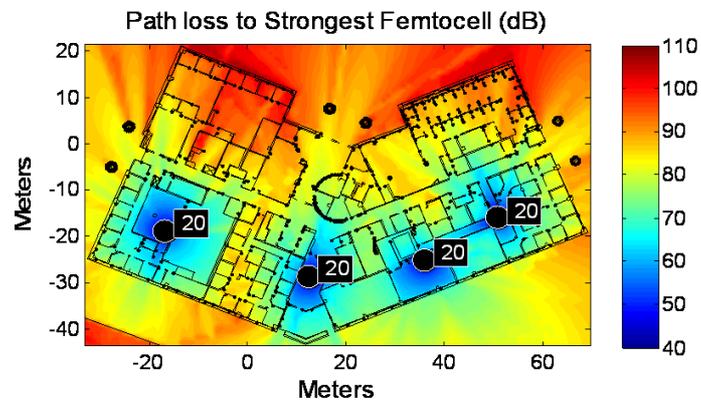


Figure 5-7 Path loss to strongest femtocell. The path loss to serving femtocell in this case can be as large as 100 dB.

Table 5-1 Parameters for Figure 5-7

Quantity	Value	Description
PL_femto	96 dB	Path loss to serving femto
PL_macro	100 dB	Path loss to nearest macro cell (see Fig. 5.2)
Femto_NF	15 dB	Femto Noise Figure on UL
Femto_NR	3 dB	Noise Rise at Femto
Femto UE Ec/Nt Target	-5 dB	UL SIR Target at Femto
Femto UE Tx Pwr	+ 1 dBm	From PL_Femto, Femto_NF, Femto_NR and Femto Ec/Nt Target
Ioc at macro cell	-99 dBm	From UE Tx Pwr and PL_macro. Is 4 dB above macro noise floor

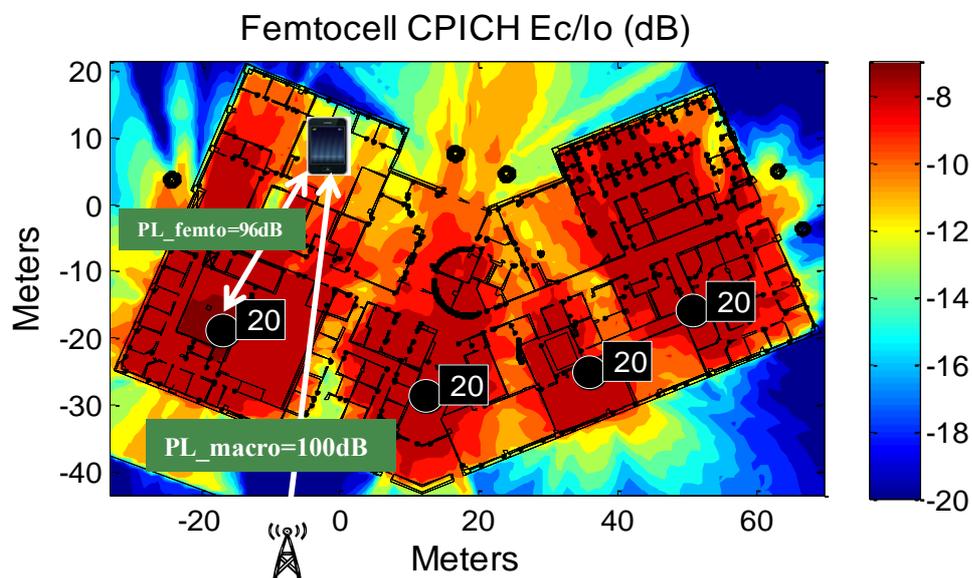


Figure 5-8 Example of Significant interference to macro cell by the femto UE with large PL to serving femtocell

These observations lead to the conclusion that obtaining the smallest number of femtocells required to cover a floor is not a robust solution. It has following drawbacks:

- **Interference to macro cell on the downlink (non-allowed users):** With few large power femtos, controlling the coverage/leakage becomes challenging. To cover the enterprise, the femtocell coverage may extend significantly beyond the desired region in some areas.
- **Interference to macro cell on the uplink:** With few large power femtos, the femto users at the edge of the femtocell coverage have large PL to serving femtocell. Consequently, these UEs need to transmit at higher Tx power on the uplink, which causes higher interference to the macro cell UL.

The solution to these issues is a deployment with larger number of femtocells than the minimum required, with careful transmit power calibration. With larger number of femtos, three critical objectives are achieved:

1. Tighter control of coverage interference trade-off: By transmit power calibration – discussed in more detail in Chapter 6 - the boundary of coverage and leakage to outdoors and other floors can be controlled more finely,
2. The impact of RSSI variation within the enterprise is diminished, and
3. The maximum path loss to a serving femto is reduced on the uplink. Therefore, the UEs served by femtocells transmit at lower power, thereby reducing the interference to the macro uplink.

5.4 Determination of Number of Femtocells

As illustrated in the previous section, the number of femtocells that are required for enterprise coverage is decided by maximum tolerable path loss to the serving cell. The maximum tolerable path loss may either be governed by uplink or by downlink transmit power limitation of the femtocell. In the worst case of macro RSSI, e.g., near the macro cell site, because of the 20 dBm maximum Tx power limit of femtocell [3], each femtocell can cover at most a region of up to 83 dB path loss (assuming 50% loading on the femtocell). Furthermore, a PL edge of less than 85 dB is desirable based on uplink interference considerations to limit the uplink interference to macrocell.

Depending on the type of the enterprise (e.g., corporate building with walled offices, warehouses, big-box stores), the coverage area corresponding to 83 dB path loss can be different.

For the LEC building with walled office spaces shown in Figure 3-2, 83 dB path loss corresponds to approximately 6000 to 8000 square feet area. It should be noted that the 6000 to 8000 square feet number is an approximate estimate as PL vs. distance may vary depending on antenna pattern, structure and materials used in the enterprise. For example, the LEC building is about 42000 square feet. It requires 6 femtocells to cover the entire floor. This corresponds to one femtocell per 7000 square feet.

Given the area of the enterprise, the number of femtocells required based on coverage and interference considerations is given by:

$$\text{Num_femtos} = \lceil \text{Area(sq.ft.)} / \text{Femto_Coverage_Area} \rceil$$

For a large enterprise building with walled offices such as the LEC building, Femto_Coverage_Area of 6000-8000 sq. ft. is found to be sufficient. For other types of enterprises, depending on the layout of the building and the building materials, the femto coverage area may be different. Note that number of femtocell is independent of whether the enterprise is at the macro cell edge or cell site.

5.5 Femtocell Placement

The second part of femtocell coverage planning involves identifying locations for installing the femtocells. Femtocell locations play a vital role in achieving a good trade-off between coverage and interference. Poor choices of femtocell locations may result in coverage holes. Coverage hole occur if femtocells are placed distant apart and the maximum transmit power-level is not sufficient to cover certain regions in the enterprise. Moreover, incorrect locations such as placing femtocells too close to each other may result in excessive interference to non-allowed users on adjacent floors; placing a femtocell closer to enterprise periphery will result in interference to outdoor macro cell users; femtocells covering large path loss may cause excessive interference by femtocell UEs to the macro cell uplink.

Given the number of femtocells and the floor plan, the guidelines discussed below should be followed for placement of femtocells to ensure good coverage-interference trade-off:

- First, femtocells should be placed symmetrically across the enterprise floor. This ensures that the coverage of each femtocell is approximately equal and symmetrical. Issues such as UL/DL imbalance due to femtocell power differentials can be reduced.
- Second, femtocells that lie at the periphery should not be too close or too far from the enterprise boundary. Femtocell coverage and macro cell interference must be taken into account while identifying femtocell locations. This ensures that the boundary is well covered while preventing too much interference outside the enterprise.
- Third, femtocells must not be placed in close proximity of each other. Ideally, femtocells must be placed at least 8-10 meters away from each other. Placing femtocells too close may result in excessive interference to non-allowed users on adjacent floors; excessive inter-femto interference, under utilization of femtocell resources; and sharp handover boundary.

In general, the approach for femtocell placement is similar to a Wi-Fi deployment rather than that of a picocell deployment (i.e., large number of lower power femtos instead of few high power femtos). Although macro RSSI plays an important role in actual coverage achieved by a femtocell, the impact of macro RSSI should be countered by femtocell transmit power calibration.

5.6 Need for Technician/IT Assistance

For multi-femto enterprise deployment, the need of a technician/IT person assistance is evident for determining the number and placement of femtocells. In addition, limited assistance of technician/IT person is also needed for transmit power calibration of the femtocells. Transmit power calibration of femtocells determines the femto coverage vs. macro cell interference trade-off of the deployment. Ideally the transmit power of the femtocells provides good coverage throughout the enterprise and the interference to macro network is also confined to the boundaries of the enterprise. Solely relying on auto calibration based on Network Listen Module (NLM) measurements or on femtocell user-reports may yield suboptimal performance. The network listen module is not aware of the boundaries of the premises, especially in a multi-femto deployment. Additionally, enterprise users are large in number and may move in and out of the enterprise premises frequently. Hence, user-reports do not represent the boundaries of the enterprise premises either.

Because of these reasons, a technician/IT person assistance is needed in the power calibration process. The technician/IT person helps define the desired coverage area of the enterprise femtocells. This is covered in more details in the next section.

6 Interference Management

This chapter covers interference management aspects and guidelines for both downlink and uplink for enterprise deployments.

6.1 Need for Femtocell Power Calibration

As shown in Figure 5-6, a fixed femto transmit power of 20 dBm may yield wildly different coverage depending on the surrounding macro RSSI (i.e., cell site vs. cell edge). This is evidently true for any value of fixed power. Figure 6-1 shows analogous coverage plots for transmit power of 0 dBm.

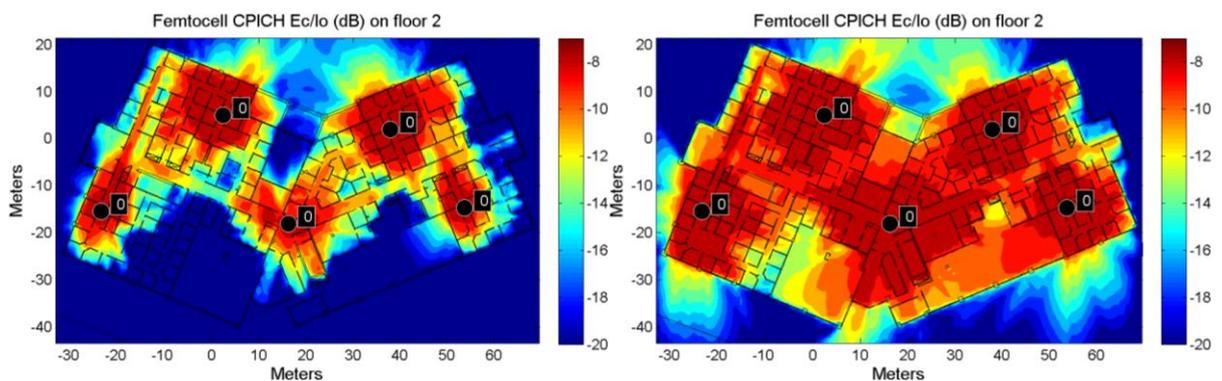


Figure 6-1 Illustration of fixed femtocell transmit power of 0 dBm. CPICH Ec/Io (dB) is shown. The total transmit power, in dBm, is shown in the box next to the femtocell location. Results are provided for enterprise location in cell site (left) and cell edge (right). CPICH Ec/Io of -16dB or greater is an indication of good coverage.

Clearly, the coverage of a co-channel femtocell transmitting at a given power depends on the surrounding RF environment. No single value of femtocell Tx power can guarantee the right femtocell coverage/macro interference trade-off in all deployment scenarios. Hence, Tx power calibration of femtocells is critical.

6.2 Femtocell Downlink Tx Power Calibration

A simple method of power calibration can be based on Network Listen Module (NLM) measurements at the femtocell. NLM allows measurement of surrounding macro cell signal (e.g., RSSI and CPICH RSCP). These measurements of the surrounding are used to calibrate femtocell transmit power to cover a certain radius. In NLM-based power calibration (called NLPC) each femtocell uses a desired coverage range (as an input) and RF measurements by the NLM to calculate the femto Tx power. The underlying assumption for NLPC is that the RF conditions measured at the femtocell are identical to those observed by users at the edge of the desired coverage range. Example algorithm for NLPC is provided in [4].

However NLPC method suffers from two main drawbacks:

RF mismatch: There could be significant mismatch in the RF conditions measured by the femtocell and those observed by the femtocell UE at various locations in the enterprise premises. Figure 6-2 shows that macro RSSI may vary significantly within an enterprise. This variation may result in RF mismatch. Furthermore, field tests were carried out in an enterprise to estimate RF mismatch. A femtocell was placed at a location in the enterprise and a UE was placed at different locations on the same floor. Macro CPICH RSCP was collected at the femtocell location and also at various UE locations inside the enterprise. A CDF of the difference of macro RSCP at UE location and macro RSCP at the femtocell location is provided in Figure 6-3. The figure shows that the RF mismatch can be as much as 25 dB (from -10dB to +15dB).

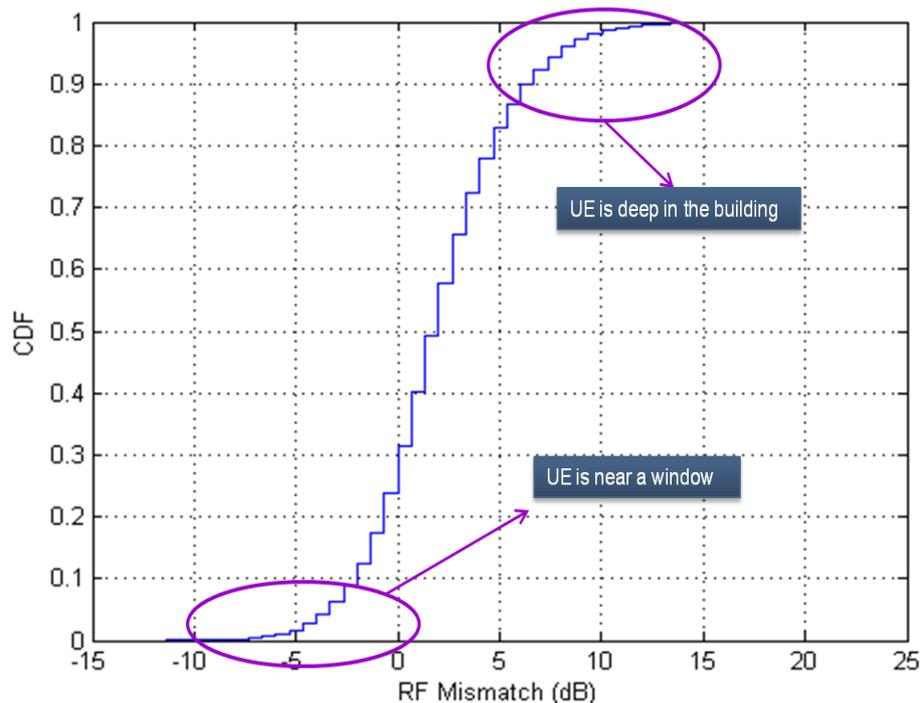


Figure 6-2 Field measurements of RF mismatch inside an enterprise. The x-axis shows the difference of CPICH RSCP of the strongest macro cell measured at the femtocell and that of the strongest macro cell measured at the UE that is placed at various locations within the enterprise.

Unknown desired coverage boundary: The desired coverage range is not known a priori. Setting the coverage range too high or too low will result in suboptimal performances. This is illustrated with the following two examples:

We consider six femtocells in the locations shown in Figure 6-3. Let $PL_{(edge,NL)}$ denote the coverage range path loss used as an input for NLPC algorithm. The coverage plots for the enterprise located in macro cell site and cell edge for $PL_{(edge,NL)} = 80$ and 100 dB are shown in Figure 6-3 and Figure 6-4 respectively.

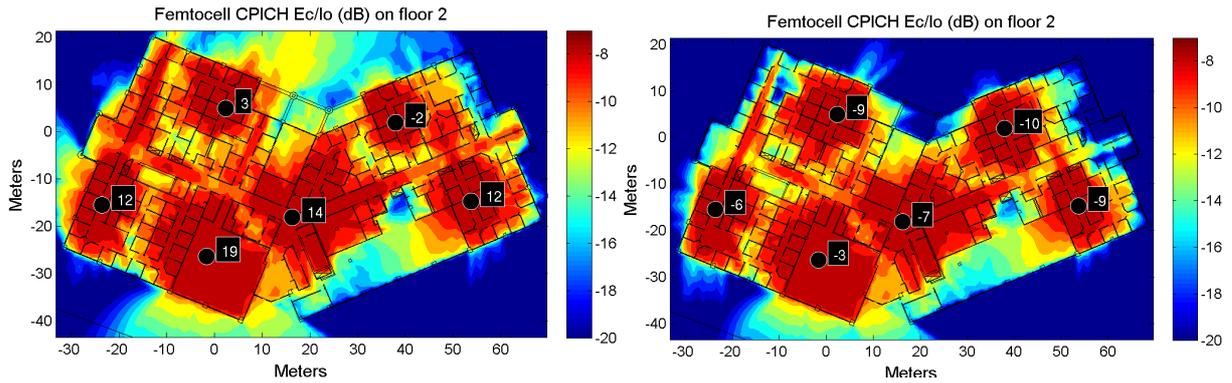


Figure 6-3 Illustration of NLPC with $PL_{(edge,NL)} = 80\text{dB}$. Linear average of faded CPICH Ec/Io (dB) is shown. The total transmit power, in dBm, is shown in the box next to the femtocell location. Results are provided for enterprise location in Cell Site (left) and Cell Edge(right). CPICH Ec/Io of -16dB or greater is an indication of good coverage.

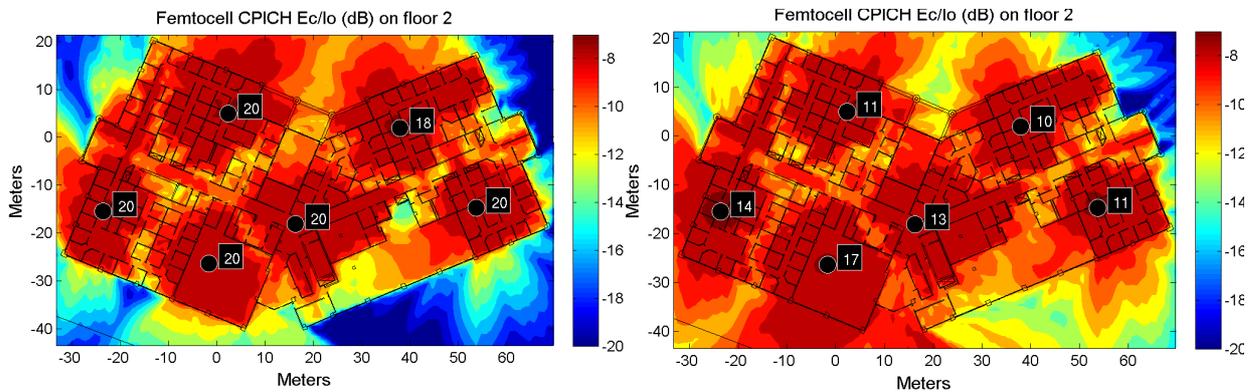


Figure 6-4 Illustration of NLPC with $PL_{(edge,NL)} = 100\text{dB}$. Linear average of faded CPICH Ec/Io (dB) is shown. The total transmit power, in dBm, is shown in the box next to the femtocell location. Results are provided for enterprise location in Cell Site(left) and Cell Edge(right). CPICH Ec/Io of -16dB or greater is an indication of good coverage.

Results show that both in cell site and cell edge locations, NLPC with $PL_{(edge,NL)} = 80\text{ dB}$ input is insufficient to ensure coverage within the enterprise.

On the other hand, NLPC with $PL_{(edge,NL)} = 100\text{ dB}$ results in excellent coverage both in cell site and cell edge locations. In cell edge location, however, coverage extends significantly beyond the desired region. This results in excessive interference to macro cell network.

Above examples illustrate that NLPC has limitations and cannot guarantee good coverage-interference trade-off. The femtocell Tx power calibration method must take into account femtocell location in a macro cell; correct for RF mismatch; and estimate desired coverage region (or enterprise boundaries).

To overcome the limitations of NLPC, technician/IT person assistance is needed. Technician assistance is used to obtain the desired coverage boundary of the femtocells deployed, via a walk-around with a UE in active call in the enterprise, and to correct for RF mismatch based on UE measurement reports. A sample technician walk is shown in Figure 6-5



Figure 6-5 Sample technician walk route in the enterprise covering hallways, conference rooms and common areas

Technician assistance based power calibration results in excellent femtocell coverage that is confined essentially to the desired coverage area while limiting the leakage to outside the enterprise. The resulting transmit power levels and femtocell coverage plots for cell site and cell edge enterprise locations are shown in Figure 6-6. The coverage plots depict CPICH E_c/I_o with 50% loading on the femtocells.

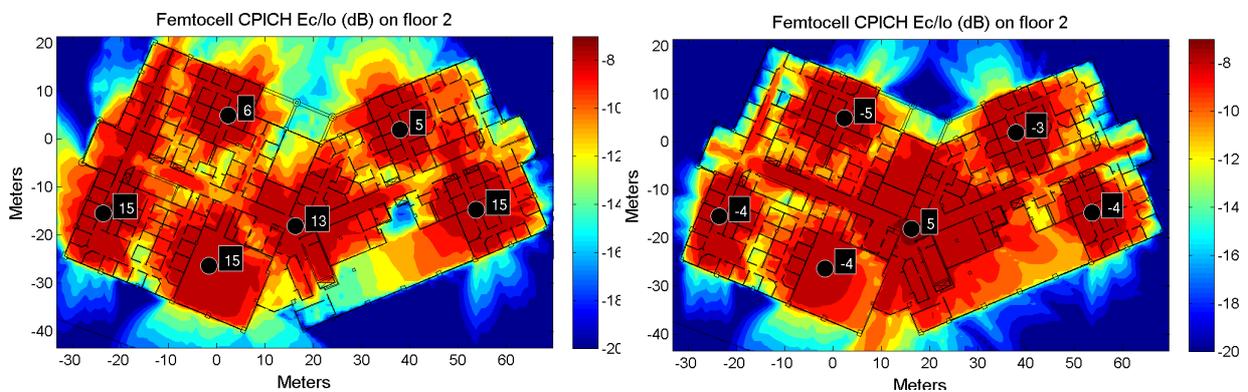


Figure 6-6 Femtocell CPICH E_c/I_o in dB (linear average of faded samples) after the technician assisted power calibration procedure. Each point corresponds to the CPICH E_c/I_o of the best femtocell. The total transmit power in dBm is shown in box next to the femtocell. Results are for Cell Site (left) and Cell Edge (right). CPICH E_c/I_o of -16dB or greater is an indication of good coverage.

As desired, with technician-assisted femtocell power calibration, femtocell coverage/leakage trade-off is much better controlled.

6.3 Uplink Interference Issues and Mitigation Methods

By keeping the maximum path-loss served by a femtocell small, the interference to the macro cell due to femto UEs can be limited to certain extent. However, femto UEs in some locations can still cause interference to macro UE. Interference to macro cell from femto UEs is more significant when a nearby macro UE jams the uplink of the femtocell (due to closed access or lack of active hand in). An example of this is illustrated in Figure 6-7. It shows the contribution to the interference at the macro cell uplink due to a femto UE placed at different locations in the enterprise floor. The noise-rise at the femtocells is assumed to be 13 dB due to the presence of nearby active macro UEs. The femto UE needs to transmit at higher power in order to overcome this increased noise-rise to maintain its data rate. Similar to the example from Figure 5-7, when the femto UE is located at some trouble spots (where the PL differential to femto and macro is small), the interference level to the macro can be high (e.g., a few dB above the noise floor of the macro cell). This interference can therefore significantly affect the UL performance of the macro UEs in the entire macro cell.

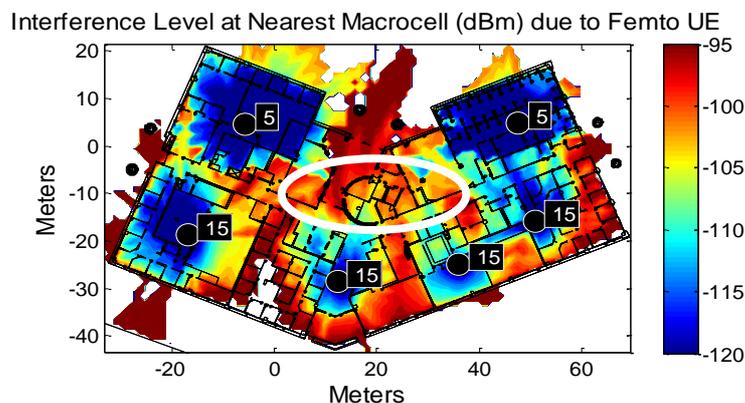


Figure 6-7 Illustration of interference to the macro cell on the UL. The figure shows interference level at the nearest Macro cell in dBm due to a Femto UE at any point in the enterprise. The noise rise at the femtocells is 13 dB due to presence of nearby Macro UEs (not shown) which act as jammers. A UE in the circled region creates UL interference several dB above noise floor at macro cell.

The impact on the macro cell uplink can be controlled by limiting the resources (e.g., Tx power and scheduling grant) allocated to the femto UEs (FUE). The benefit of such UL interference management (IM) techniques is illustrated in Figure 6-8 through Figure 6-10. They represent system level HSUPA simulations where multiple femtocells are deployed in the LEC building and multiple UEs are placed inside and outside the building. The UEs that are in coverage of femtocells are served by corresponding femtocells. The UEs not served by femtocells are served by the surrounding Macro cells. Table 6.1 describes the assumptions and parameters used for the simulations. In separate sets of simulations, the LEC building is placed at the macro cell site and macro cell edge as shown in Figure 6-8. Figures 6-10 and 6-11 show throughput distributions over multiple drops with fixed number of FUEs and MUEs in each drop. Figure 6-9 shows that in absence of UL IM, macro UE throughputs suffer significantly. This impact could be severe if the interference is coming

from an enterprise located near the macro cell site (Figure 6-9(a)). Notice that, when enterprise is near a macro cell site, the MUE performance of that macrocell suffers considerably while the throughputs seen by MUEs in other macrocells remain roughly unaffected. On the other hand, when the enterprise is at cell edge (Figure 6-9(b)), the MUE throughputs suffer uniformly as all the three macrocells are impacted by the UL interference from the enterprise. Figure 6-9 also demonstrates that UL IM restores the Macro UE throughputs. Figure 6-10 illustrates that the impact of UL IM on femto UE performance remains small.

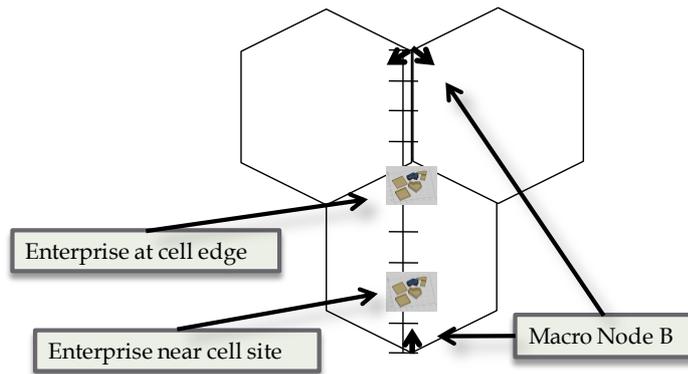


Figure 6-8 Locations for Enterprise (LEC Building) in Macro Cell Site and Macro Cell Edge

Aspect	Value and Description
Number of active Macro UEs	30 MUEs in 3 Macro cells
MUEs near the enterprise	Total of 3 MUEs (1 outdoor MUE and 2 indoor MUEs)
Number of Femtocells in the enterprise	42 Femtos (6 on each floor of 7 floor LEC building)
Femto DL	Power Calibrated
Active FUEs	65 with (9 FUEs on each floor and 2 outdoor FUEs)
Number of drops	10
Traffic Type	HSUPA
TTI	2ms
Max Retransmissions	4 for both FUEs and MUEs

Table 6-1 Simulation Parameter for Uplink simulations in Section 6.4

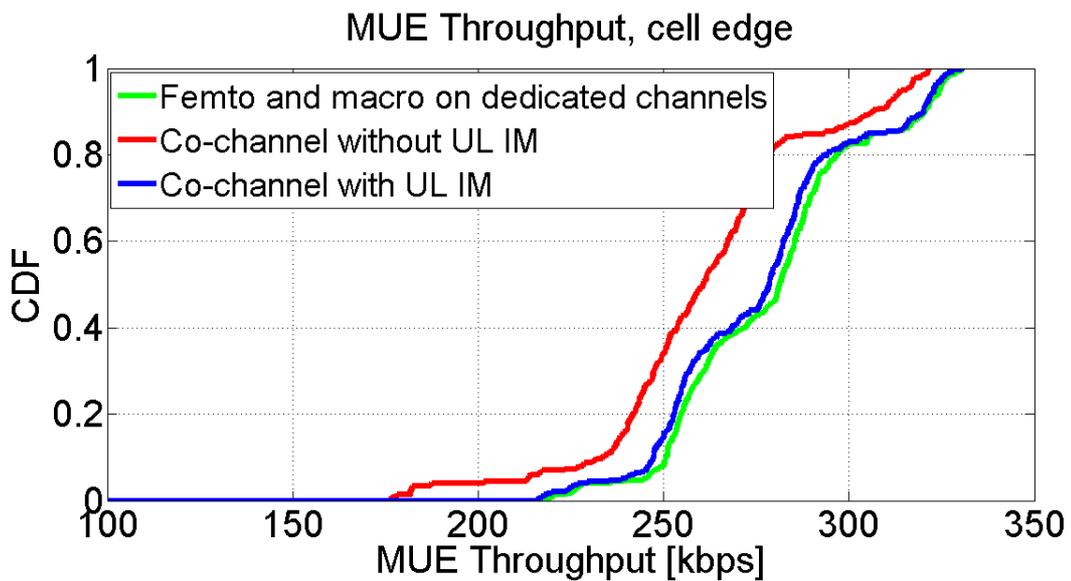
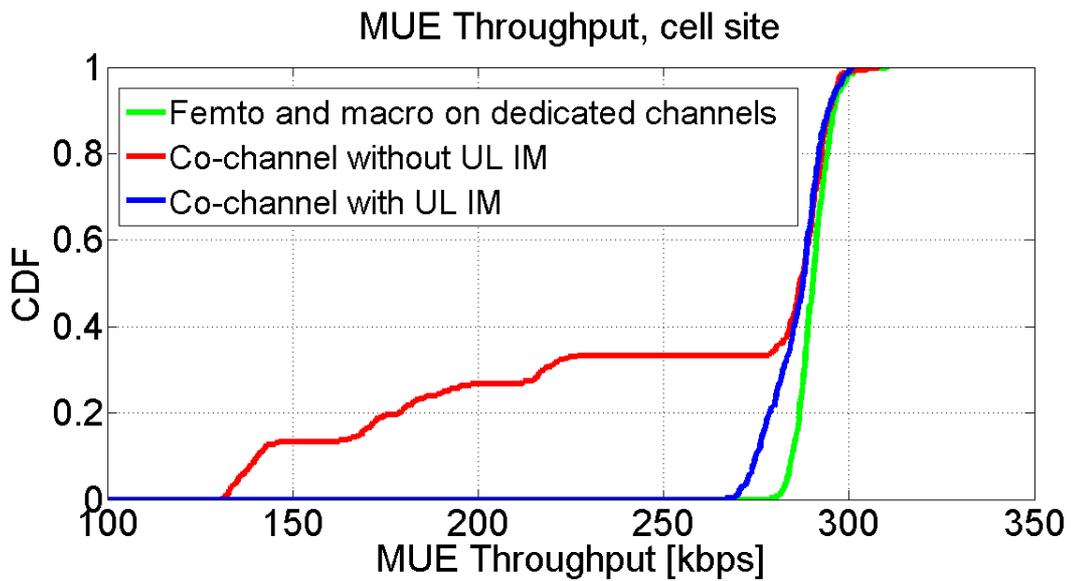


Figure 6-9 (a) and (b) UL Performance of Macro UEs with and without femtocell UL Interference Management (IM). The figures represent enterprise at macro cell site (a) and cell edge (b). In absence of UL IM, femtocell UEs may affect macro UE throughputs in the entire macro cell significantly. With UL IM the loss in MUE UL throughput is seen to be small.

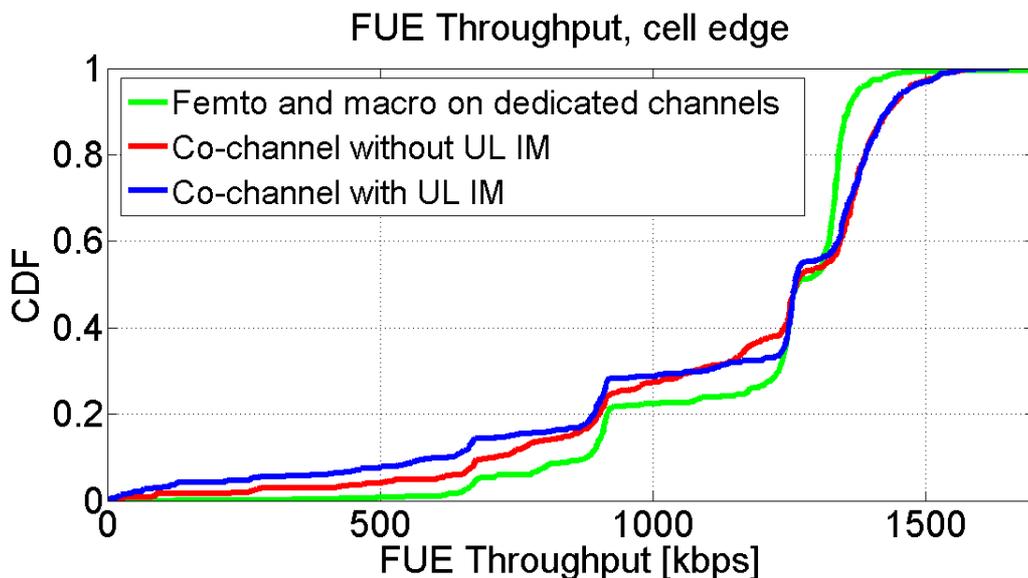
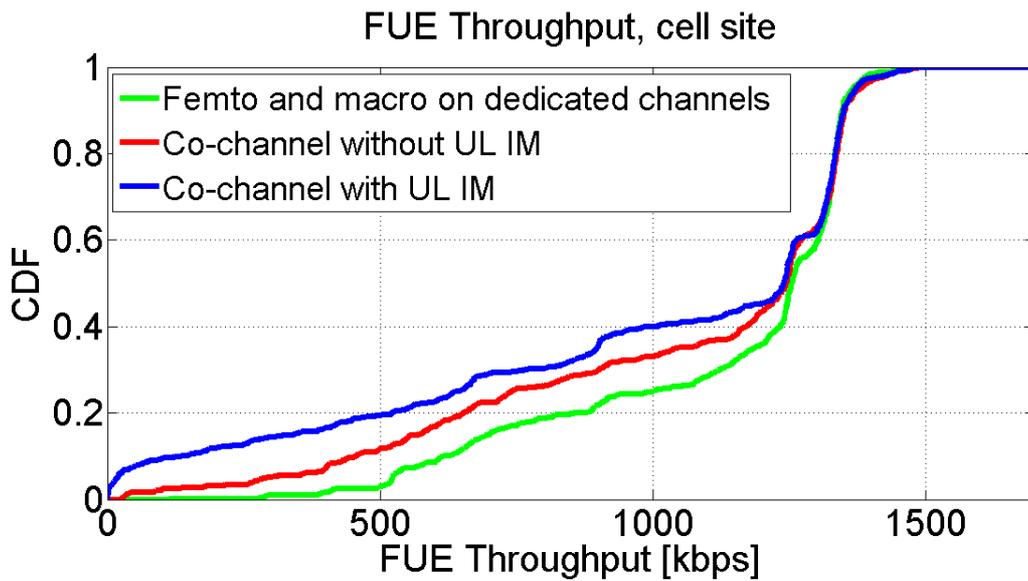


Figure 6-10 (a) and (b) UL Performance of femtocell UEs with and without UL Interference Management (IM). The figures represent enterprise at macro cell site (a) and cell edge (b). The loss in femtocell UE performance due to IM is seen to be small.

In summary, interference management on both downlink and uplink is critical for shared channel deployment of enterprise femtocells. Incorrect DL power settings may lead to coverage holes and/or interference to Macro UEs on the downlink. DL power settings also determine the maximum path loss served and hence the UL impact on the macrocell to some extent. Further, the uplink interference to macrocell from an enterprise can be severe particularly when the enterprise femtocells also encounter active MUEs in the vicinity as jammers. UL IM techniques can effectively control the UL interference to the macro network without any noticeable impact on FUE performance.

7 Performance Analysis under Mobility Conditions

This chapter covers mobility management aspects and guidelines for enterprise deployments.

7.1 Fading Environment and Mobility

Femtocell signals experience largely single path fading due to small delay spread. Additionally, UEs served by femtocells are either stationary or slow speed users, resulting in low Doppler speeds (0-3km/h) and slow fading. Single path fading with some Rician component has been verified in field measurements to be a good model for indoor propagation.

Single path slow fading creates a harsh environment for circuit switched voice calls, in particular on the downlink, as a large fraction of UEs have a single Rx antenna.

The frequency and depth of deep fades affect not only the resources consumed by a voice call at the Node B, but also the serving cell. This affects mobility management and handover decisions significantly. As typically a hard handover (HHO) is associated with a loss of a few voice frames, having a large number of hard handovers is undesirable.

In this chapter, the performance of voice calls in absence of diversity on the downlink is examined in a multi-femto environment. In particular, the number of Hard Handovers is analysed. Further, the benefits of different options available for obtaining diversity and improving the voice quality—namely soft handover and transmit diversity - are evaluated.

7.2 Voice Call Performance in Absence of Diversity

Over the Air (OTA) tests with multiple femtocells were conducted on one of the floors of a large commercial enterprise building (source of the LEC building simulation model in Chapter 4). In this test, two femtocells were deployed as shown in Figure 7-1. A Test UE is placed at a location between the two femtos as illustrated by the green circle. This location is chosen such that the Test UE has almost equal pathloss (about 70dB) from both the femtocells. The Test UE makes a 12.2kbps voice call through one of the femtocells.

Two types of mobility are considered for the tests:

- Conversational movement, *e.g.*, the tester holds the phone in talking position with some regular body and head movement.
 - Walking movement, *e.g.*, where the tester walks back and forth for 1 minute in a 4 meter range at a speed of approximately 1km/hr.
-

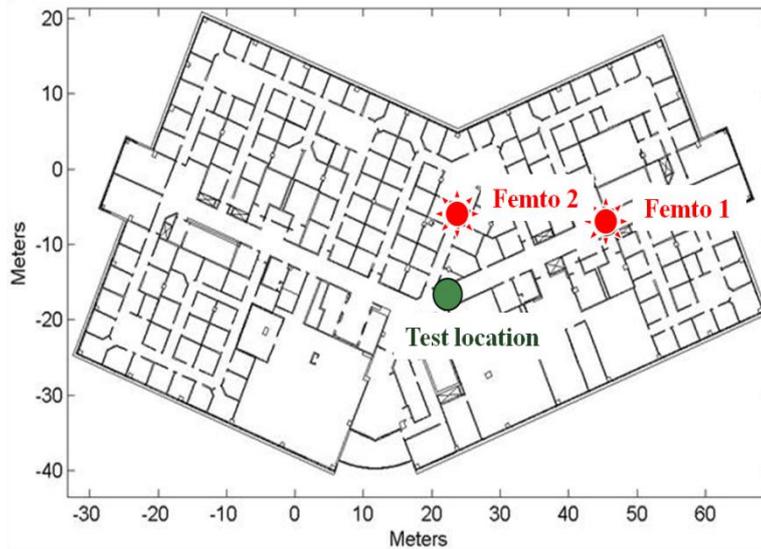


Figure 7-1 Layout of the voice call/ mobility OTA tests

The voice frames in a Release 99 voice call are transmitted over the DPCH channel. The voice frame error rate (FER) is typically maintained to 1% via inner-loop and outer-loop power control of the DPCH channel. Channel conditions such as deep fades may result in periods where the FER is not maintained at 1%. A burst of frame errors may become a noticeable voice artefact and is undesirable. The FER burst may occur due to any of the following: DL DPCH hitting the upper limit on allocated power, UE going out of synchronization because of bad DPCCH quality, or due to service interruption during a hard handover between two cells. In the absence of diversity options such as SHO and transmit diversity, significant signal fluctuations are observed due to fading in the serving femtocell as well as the interfering femtocell. Figure 7-2 shows the filtered CPICH E_c/I_0 traces of the two femtocells at the UE in one of the test logs. We refer to the case without any diversity options as '1 Tx'.

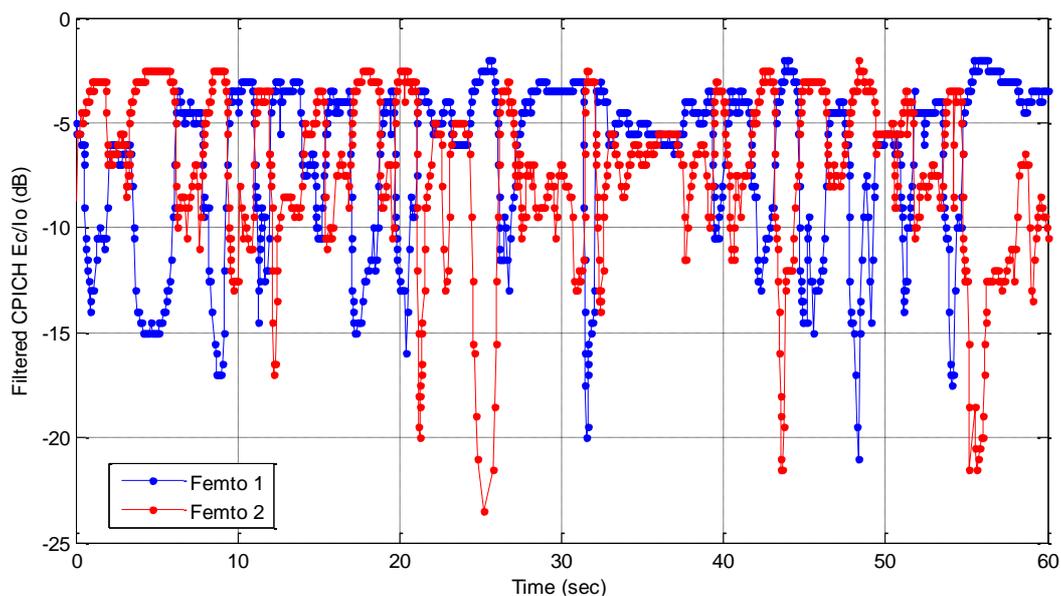


Figure 7-2 Sample logs in OTA tests for 1 Tx antenna: The blue and red lines are the CPICH E_c/I_0 traces of the two femtocells.

Table 7-1 shows the number of HHOs occurred in one minute. We see that a large number of HHOs could occur in this location as the two femtocells have comparable CPICH Ec/Io. Each HHO results in consecutive voice frame interruptions and hence causes noticeable voice artefacts. The frequent HHOs can cause significant voice quality degradation. It is worthwhile to note that the voice artefacts caused by the HHO would not diminish even if the femto CPICH Ec/Io is high.

	Hysteresis =6dB
Conversational Movement	11
Walking Movement(1km/hr)	19

Table 7-1 Number of HHOs per minute, 1 Tx antenna.

The principal conclusion from these tests is that, in absence of diversity mechanisms, the voice call quality may suffer significantly at the boundary regions of neighbouring femtocells due to frequent HHOs.

7.3 Voice Call Quality with Soft Handover

Soft handover (SHO) addresses many of the issues arising in a single path fading environment for receivers without Rx Diversity. The benefits of soft handover are well known. It helps a voice call in multiple ways, namely - (1) providing diversity due to independent fades on the SHO legs (2) providing higher DPCH power (each of the SHO legs can transmit the maximum allocated DPCH power), and (3) eliminating service interruption artefacts due to make-before-break architecture. Soft handover is, therefore, a desirable feature that ensures smooth voice call quality in a multi-femto deployment (provided the deployment permits the added complexity of its implementation). Figure 7-3 illustrates the coverage benefits of soft handover available due to soft combining via simulations. Note that the figure does not capture the gains due to added diversity. Comparing the two figures with and without SHO, we can see that SHO can significantly improve the femto coverage especially in areas between two femtocells. Note that while SHO improves the femtocell coverage, the interference caused to macro network is the same for the SHO and no-SHO cases since the femtocell Tx powers are the same.

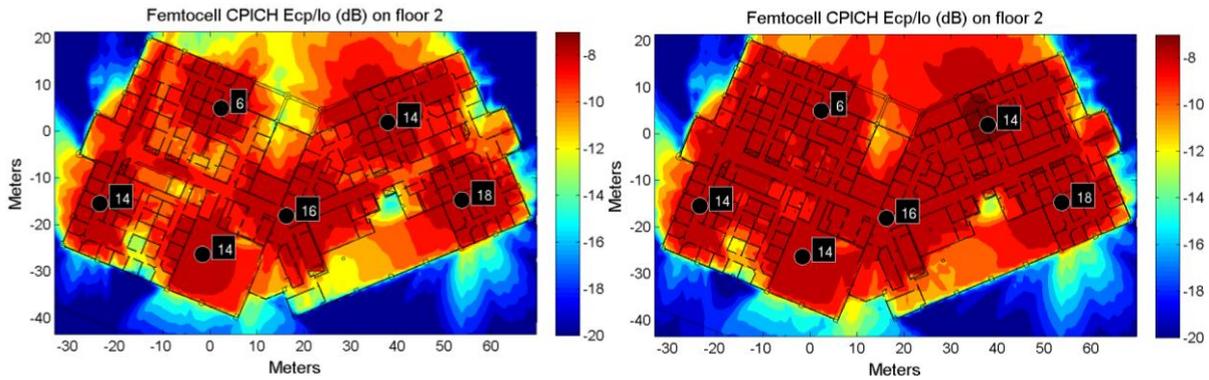


Figure 7-3 Illustration of femto coverage with and without soft handover. The figure on the left shows CPICH Ec/Io of the strongest femto. The figure on the right represents combined CPICH Ec/Io under soft handover. Macro Cell Site scenario. Soft handover reporting range: 3 dB. Note that femto transmit powers and consequently interference to Macro is the same in both figures.

If soft handover is not available, transmit diversity can provide robustness against single path fading environment. In the following section transmit diversity is compared against no-transmit diversity via lab tests.

7.4 Voice Call Quality with Transmit Diversity

UMTS allows two ways of providing transmit diversity, namely, the Space Time Transmit Diversity (STTD), which is a two antenna, “open loop” technique, and the Closed Loop Transmit Diversity (CLTD), which relies on feedback from the UE. These Tx diversity options provide the diversity needed to reduce the signal fluctuations due to single path slow fading in indoor environment.

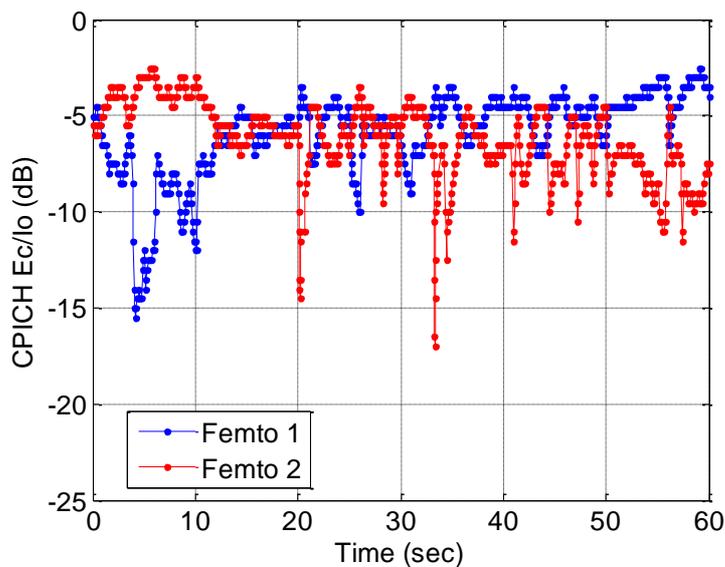


Figure 7-4 Sample logs in OTA tests under transmit diversity: Combined CPICH Ec/Io shows significantly lower fluctuations compared to that in Figure 7-2

Figure 7-4 shows the combined filtered CPICH Ec/Io traces of the two femtocells at the UE in one of the test logs using CLTD. Comparison of Figure 7-4 with Figure 7-2 illustrates that the deep fades are reduced due to transmit diversity. Note that in CLTD, the CPICH transmission on both antennas is open-loop, that is, independent of the feedback from the UE. Therefore the Figure 7-4 is expected to be also applicable when STTD is the mode of transmit diversity. Diversity gains are further evident when we compare the number of observed hard handovers. Figure 7-5 compares the HHOs per minute when transmit diversity is present, with the case when 1 Tx antenna is employed.

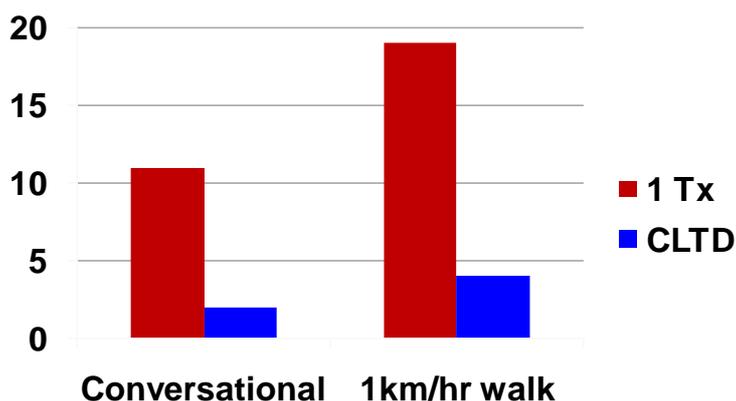


Figure 7-5 Number of hard handovers per minute in OTA tests. Hysteresis is 6 dB.

It is seen that transmit diversity reduces the number of hard handovers considerably thereby reducing the voice artefacts in the handover region. Additionally, the closed loop option, namely CLTD provides voice coverage extension at the edge of femtocell coverage as well. As shown in Figure 7-6, given the same CPICH Ec/Io, CLTD achieves better FER than 1Tx antenna. The coverage extension gain of CLTD can be attributed to both diversity gain and beam-forming gain.

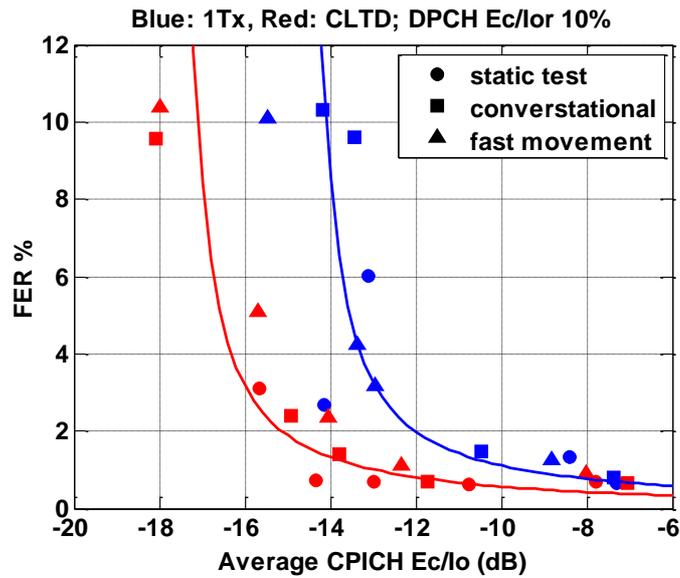


Figure 7-6 Coverage extension obtained by CLTD. CLTD can operate at lower frame error rate at given CPICH Ec/lo. The circles, triangles and squares represent lab test results. The solid lines are trend lines. Max DPCH allocation is 20%.

In summary, SHO is desirable in enterprise deployments to achieve excellent voice quality. However, in absence of SHO, transmit diversity is needed to combat the single path fading environment and avoid frequent HHOs. Furthermore, if the hard handover is optimized to reduce service interruption duration (e.g. below 100 ms), the combination of transmit diversity and fast HHO can provide acceptable voice quality. Also, CLTD provides additional benefit in the form of coverage extension to voice calls at the boundary of femto coverage.

8 Summary and Conclusions

Enterprise femtocell deployments can provide large capacity and coverage benefits, but require special care due to their unique characteristics, especially in a closed access, shared channel deployment model. The new challenges (compared to residential femtocells) arise due to larger indoor RF variations, larger number of users per femtocell, lower path loss differentials relative to neighbor macro cells and neighbor femtocells. The number of femtocells needed in an enterprise is decided by DL coverage requirement and UL interference consideration. To control better the femto coverage vs. macro interference trade-off on the downlink, and to keep femto UEs from creating large UL interference on the macro, larger number of femtocells with smaller coverage area per femtocell are desirable. This deployment model is closer to a Wi-Fi deployment model. It is unlike a picocell deployment model where typically active hand-in and soft-handover with macrocell are available. The number of femtocells needed depends on the shape, size and structure of the building as well as the building material.

It has been shown that unlike residential femtocells, enterprise femtocell deployment needs assistance from a technician/IT person. Technician assistance is needed in a multi-femto deployment, primarily because multi-femto coverage boundaries need to roughly coincide with the enterprise premises. This needs to be achieved via proper femto placement, and proper transmit power calibration.

DL power calibration in a multi-femto deployment in a large enterprise needs to consider macro RSSI variation inside the enterprise, interference to the macro users outside the enterprise premises, and potential uplink interference to surrounding macrocell. It is demonstrated that technician assisted femtocell power calibration performs significantly better than a network listen based power calibration towards controlling the femto coverage and leakage trade-off.

Interference impact of femto deployment on the downlink is localized to the macro users in the vicinity of the enterprise. On the other hand, the uplink impact of unmanaged interference on the macrocell uplink is experienced by all the users in the macrocell. Especially for enterprise deployment near a macro cell site, the uplink interference from femtocell UEs can be significant and can hurt the throughputs seen by macro users considerably. Uplink interference for enterprise needs to be addressed by interference management techniques that limit the uplink resources (e.g., Tx power and scheduling grant) allocated to the femtocell UEs. Indoor radio environment seen by femtocell signals is typically a slow speed single path fading environment. In the absence of receive diversity at the UE, the single path fading creates harsh conditions for Release 99 voice calls. Without diversity, voice calls may suffer bursts of frame errors and resulting noticeable voice artefacts due to fading and due to service interruptions arising from hard handovers. Soft handover, if available provides the requisite diversity and seamless user experience during handovers. If soft handover is not available, Tx diversity options such as Space Time Transmit Diversity and Closed Loop Transmit Diversity are needed for reducing the number of hard handovers and improving voice quality in enterprise femtocell deployments. Further, if hard handovers are optimized to minimize the service interruptions, transmit diversity plus fast hand handover can provide acceptable voice performance in enterprise femtocell deployments.

9 References

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