4G Femtocell Solutions for the Dense Metropolitan Environment

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4G Femtocell for the Dense Metropolitan Environment

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Abstract

Femtocells can be deployed in various environments, such as residential, public or enterprise. Each type of environment involves a different set of interference scenarios. This paper provides an overview of the potential interference issues and solutions for dense metropolitan deployment. Some Fujitsu-specific interference mitigation techniques and plug-and-play features are also discussed.

Introduction

Small cells have been used for many years to enhance indoor coverage and capacity for 2G and 3G networks. For 2G networks, indoor cells are often deployed using indoor DAS; 3G indoor cells can be deployed using either DAS or 3G femtocells. Indoor cells in 2G/3G systems face similar inter-layer interference[1] issues to 4G femtocells. However, 2G/3G small cells do not have advanced features such as ICIC, so it is only possible to rely on "classic" RF engineering deployment techniques to mitigate interference. 4G systems incorporate advanced features like ICIC and eICIC; nevertheless, classic engineering deployment techniques still can and should be used; together they allow 4G femtocells to provide much better indoor performance than 2G/3G indoor systems.

General In-Building Deployment Considerations

Traditional cellular networks are two-dimensional, but buildings are three-dimensional objects and most office buildings are three-dimensional hotspots; thus unique engineering considerations apply to in-building deployment.

One factor that needs to be considered is Building-Penetration Loss (BPL). The effect of BPL is that buildings act as "natural shields" that attenuate signal power from outdoor macrocells into the buildings. BPL also reduces interference from the indoor system to outdoor networks.

- At one extreme with BPL=∞, the indoor and outdoor systems are isolated from each other. There is no inter-layer interference between the two, and the indoor capacity is the highest. This is the best-case scenario. Examples with almost infinite BPL are subway stations, basements, and underground parking garages (Figure 1).

Figure 1: Indoor systems deployed for subway stations do not need to account for inter-layer interference.

- At the other extreme with BPL=0, there is no isolation between the indoor and outdoor systems. In this case, the two systems are strongly coupled and the inter-layer interference is at its highest, especially if the buildings are located close to the center of the macrocell. In this case adding small cells to the building (with the same frequency) is like adding cells to the center of another cell (Figure 2). This is the worst-case scenario.

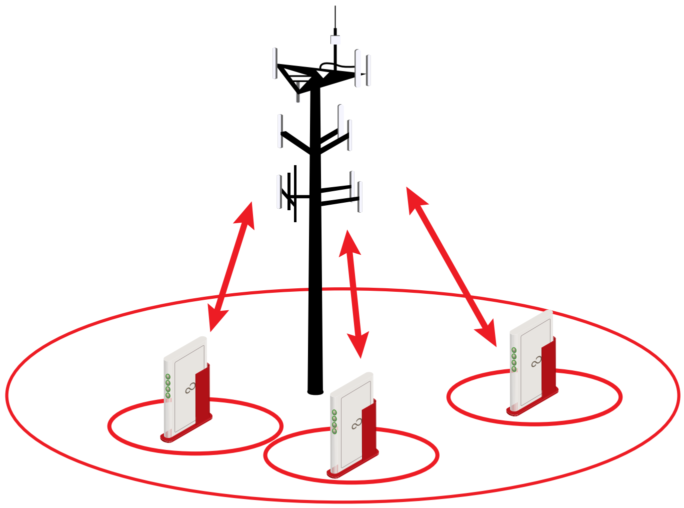

Figure 2: If BPL=0, deploying an indoor system is equivalent to adding small cells to the center of a large cell.

[1] Inter-layer interference is the interference between the indoor small-cell-layer and outdoor macrocell-layer.

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In most real-life situations, the BPL is neither zero nor infinity, so the situation lies somewhere between the two extremes. The higher the BPL, the less the inter-layer interference will be, and vice versa.

BPL values vary at different locations within a building. For example, a location behind the first wall will experience much lower penetration loss compared to a location behind a second wall. Figure 3 shows a comparison between penetration loss values in locations behind the first wall and in locations behind the second wall, from 25 typical (North America) metropolitan buildings [1].

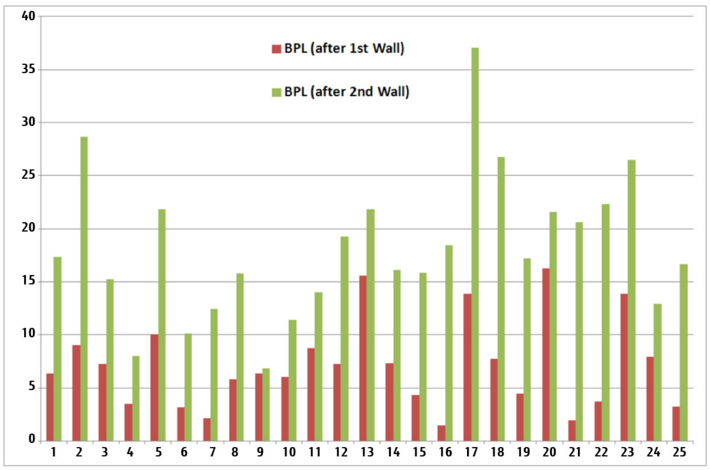

Figure 3: Measured penetration losses behind the first wall and behind the second wall

Note that, even for buildings with few interior walls, it is generally true that the deeper the location is inside the building, the higher the penetration loss. One example is a large shopping mall. Malls typically do not have many interior walls, but there are usually dead zones near the center of the mall, especially on the first floor (Figure 4).

In the case of tall buildings, the upper floors will likely have lower BPL (and thus higher received power levels from outdoor macrocells) than the lower floors, due to the fact that surrounding buildings and other "clutter" produce higher shadowing effects, which increases the effective BPL on lower floors.

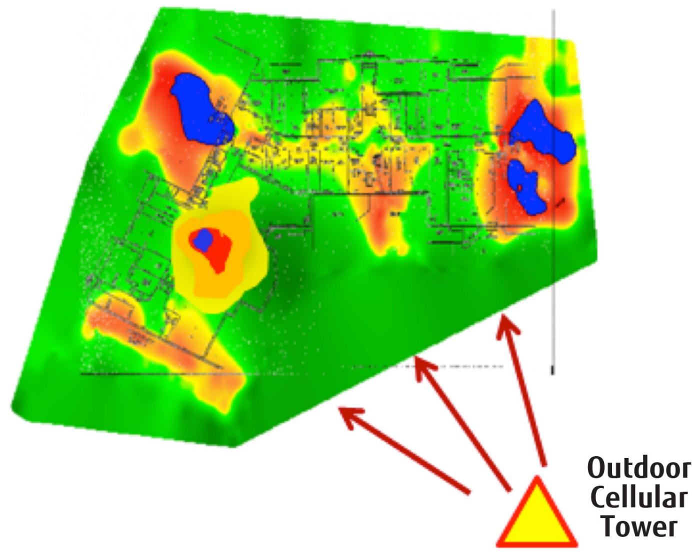

Figure 4: Dead spots measured deep inside a large building with few inner walls

These observed facts are generally important for indoor deployment (regardless of whether it is 4G or 3G or 2G), because RF engineers can take advantage of unequal interference levels at different locations in a building. For 4G indoor systems, RF resource allocation can take the following factors into consideration:

- For areas with high BPL, few or no restrictions are needed on femtocell-allocated RF resources (bandwidth and time), which means higher indoor capacity.
- Interference mitigation techniques[2] are only needed for locations with low BPL, such as areas near the windows.

The Fujitsu femtocell product manages these factors using a cognitive and learning mechanism, which can either directly measure interference levels or derive information about the interference situation via UE feedback, and make intelligent decisions on RF resource allocation. Further details are discussed in the next few sections.

[2] Interference mitigation techniques generally require some type of restrictions on RF resources so they almost always result slightly lower capacity.

HetNet Interference Scenarios

Femtocells can be deployed in homes, public areas or office buildings. The potential interference scenarios vary among the different types of deployment (Fig.5).

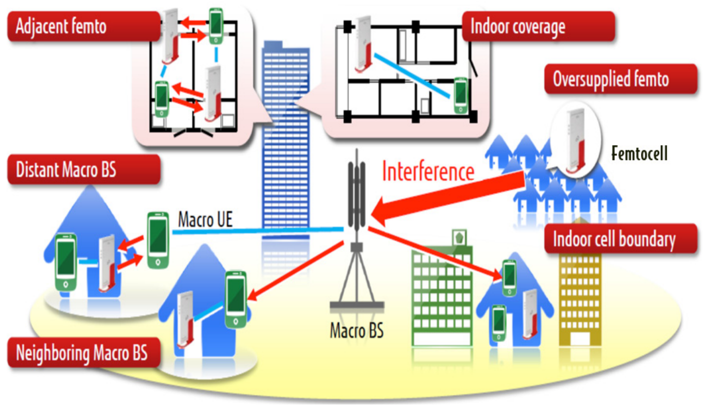

Figure 5: Different types of femtocell deployment scenarios have different interference concerns

For dense metropolitan residential femtocell deployments, there are two main interference scenarios:

(1) **Inter-layer interference:** Interference between indoor femtocell-layer and outdoor macrocell/microcell layer. If BPL is too small, this type of interference is the main interference of concern. If BPL is very large, then it is less of a concern.

(2) **Interference within the femtocell layer:** Interference among neighboring femtocells within the building can also be a major concern. For enterprise deployment, femtocell locations are carefully planned rather than randomly placed. Hence, the randomness of femtocell locations in residential environments causes major interference concern among neighboring cells because some femtocells may be located too close to each other, as shown in Figure 6. The SINR distribution for a network with random eNB placement will likely have a "long tail" with the worst-case SINR < −10 dB. UE located in areas with poor SINR will need extra help from interference mitigation techniques like ICIC or eICIC.

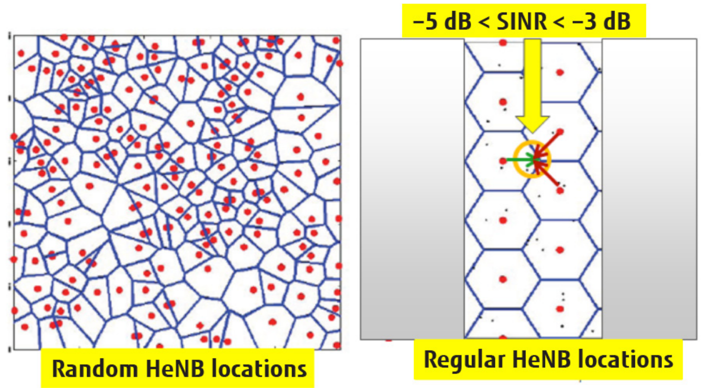

Figure 6: Residential femtocell locations are likely to be random but femtocell locations in an enterprise environment should be planned.

There are a total of six interference scenarios for HetNet with femtocell layer and macrocell layer. These scenarios are summarized in Table 1.

Table 1: Interference Scenarios

Scenario #	Aggressor	Victim
1	Macro eNB	HeNB downlink
2	Macro UEs (located near the building)	HeNB uplink
3	HeNB	Macro eNB downlink
4	HUE (UE attached to HeNB)	Macro eNB uplink
5	HeNB	Neighboring HeNB downlink
6	HUEs (UEs attached to HeNB)	Neighboring HeNB uplink

Interference Scenario 1

Under the worse-case scenario, this type of interference can be severe because macrocells typically use much higher PA power (46~49 dBm) than femtocells (10~20 dBm). In an urban environment, if a macrocell is installed on the rooftop of one building, neighboring buildings with line-of-sight (LOS) condition at the macrocell antennas will have very strong DL macrocell power, especially in areas near the windows (Figure 7). If the femtocell and macrocell layers both use the same carrier frequency, the received DL power on HUE from the macrocell is interference.

Classic engineering deployment techniques will always help. For example, it is good practice to avoid installing femtocells with the same carrier frequency in locations where the DL power from outdoor macrocells is too strong. ICIC and the Fujitsu proprietary interference mitigation algorithms will also improve the performance, as discussed in the following sections.

Figure 7: DL interference from macrocell to femtocells near windows can be severe.

Interference Scenarios 2 and 3

A unique challenge is caused by the fact that most residential femtocells use the CSG feature that disallows "strangers" (users that are not on the access "white list") to use their HeNB. This causes an interference issue that is not encountered in other types of environments.

- Normally, UE will handoff to a cell with the highest receive signal level (i.e., the best server), to ensure the highest signal and the lowest interference.
- However, if a UE sees a "best server" but is not allowed to handoff to this server, then the power from the "best server" becomes interference. This can result very poor SINR for the UE. In order to survive the call, the UE will "fight the interference" by requesting higher DL power from its current server (which is not the best server), this causes higher DL interference to users in other cells. Also it will have to increase its UL Tx power which increases UL interference to users in other cells. Figure 8 shows the DL transmitted power from residential femtocells leaking to the streets, causing interference to users not in the CSG. Figure 9 [2] shows the impact to the received SINR from a UE that is not in the White List but moves near the houses with HeNBs, assuming no interference mitigation techniques applied.

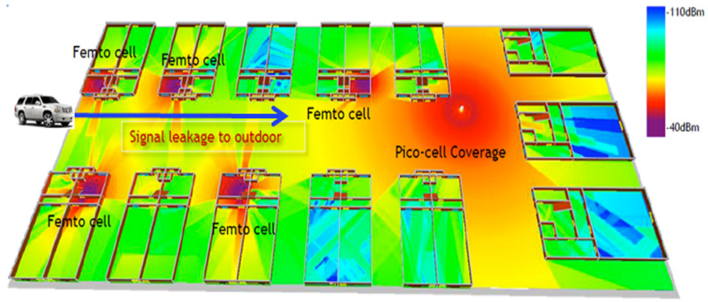

Figure 8: Power from the residential femtocells leaking to the streets and causing interference to UE not on the white list

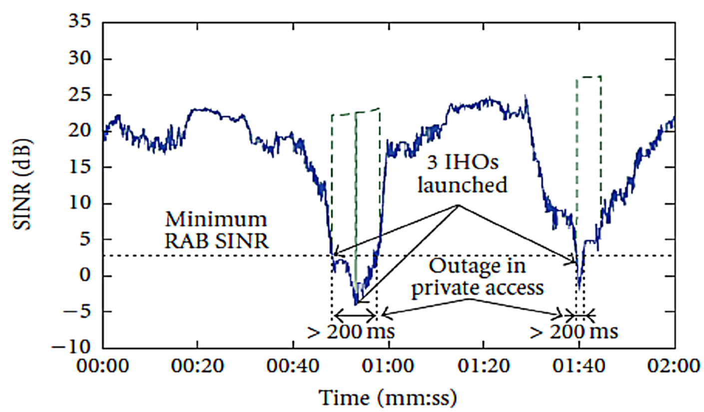

Figure 9: SINR drops experienced by an UE not in the white list passing two houses with HeNBs

Although Figure 9 only shows the effect of DL interference from HeNB to UE, in a real-life situation all interference scenarios will become worse when UE needs to handoff to the best server but is not allowed to do so.

The Fujitsu femtocell uses a proprietary (power domain) solution to address this type of interference issue. The femtocell eNB will reduce its Tx power level if it detects a non-CSG UE trying to handover to the femtocell. As a result of the power reduction, the interference to the non-CSG user is reduced. The effect of interference reduction is shown in Figure 17.

Interference Scenario 4

The main issue is that there can be a large number of femtocells deployed within the coverage footprint of one macrocell; thus, the total number of HUE can be large. The aggregate UL interference, i.e., the sum of the UL interference contributions from all HUE, can be significant.

Interference scenarios 2 and 4 are UL interference which can be addressed by frequency domain ICIC techniques. Additionally, the Fujitsu femtocell has a cognitive and learning capability based on multiple measurements. The femtocells "learn" the interference situation and dynamically change the RF resource allocation to avoid interference. If little or no interference is measured, full bandwidth will be allocated to maximize the indoor capacity.

Interference Scenarios 5 and 6

Interference scenarios 5 and 6 are interference within the femtocell layer. In a public or enterprise environment with carefully optimized femtocell locations, interference within the femtocell layer can be kept low.

However, for a residential deployment with random femtocell locations, interference within the femtocell layer can be very high if some femtocells are located too close to each other.

In scenarios 5 and 6, the cognitive and learning capabilities of the Fujitsu femtocell become particularly attractive. In addition to the interference control capability, the Fujitsu femtocell product has a Cell Boundary Control feature that can further dynamically optimize the coverage footprint of each femtocell to best serve indoor users, based on these users' measured locations. This feature also effectively reduces interference within the femtocell layer. The Cell Boundary Control feature is discussed in later sections of this paper.

ICIC Techniques for Different LTE Physical Channels

LTE uses OFDM on the DL and SC-OFDM on the UL. To mitigate interference, there are three domains to work with: the time domain, frequency domain, and power domain. ICIC techniques generally work on one or two of these three domains.

- A "collision" happens if more than one eNB or UE transmits on the same frequency at the same time, so they directly interfere with each other.
- In spread-spectrum systems like CDMA or UMTS, because power is spread uniformly across the entire channel bandwidth (1.25 MHz or 3.84 MHz), and the channels are continuously transmitting, the neighbor cells and UE always interfere with each other; a spread-spectrum system is also called a "self-jamming" system. For the same carrier deployment, one can only work in the power domain, i.e., using power control.
- LTE OFDMA systems allow multiple techniques to be used to avoid collisions, i.e., they try to avoid conflict either in the frequency domain, or in the time domain (Figure 10). The power domain can be used in combination with either the frequency or time domain.

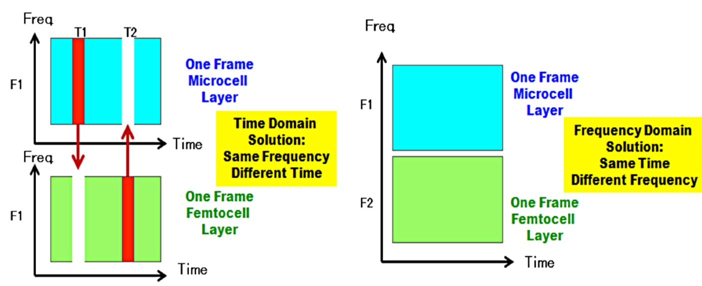

Figure 10: For OFDM/SC-OFDM systems, ICIC can work either on the time domain or the frequency domain

LTE Physical Channels

A summary of the LTE physical channel structure is given here to illustrate how ICIC techniques can be applied to these channels.

UL Physical Channels

The LTE UL uses SC-OFDM. Because of the single-carrier property, frequency domain ICIC techniques are the most appropriate solution. For this reason, most UL ICIC algorithms work on the frequency domain, sometimes in combination with power domain remedies.

In LTE, there are three types of UL physical channels: PUSCH (UL traffic channel), PUCCH (UL control channel) and PRACH (access channel).

PUSCH

The minimum RF resource that can be allocated by the scheduler is one scheduling Resource Block (RB), which is 180 kHz by 1 ms. The maximum number of RBs per channel scales with the channel bandwidth. For example, a 5 MHz channel contains a maximum of 25 RBs; a 10 MHz channel contains a maximum of 50 RBs.

The UL scheduler determines how many RBs each active UE will have, depending on several factors. These factors include how much data this UE has to send; whether the UE's UL link budget allows it to use wider bandwidth; and whether strong UL interference is measured in part of the UL channel.

PUSCH has power control. The UE located near the cell edge will likely cause the highest out-of-cell interference because they transmit the highest power and they are physically located closest to the neighbor cells. However, because of the UL link budget limitations, the cell-edge UEs often cannot use the full amount of bandwidth, so they typically only cause high interference on part of the UL RB frequencies. In UL ICIC, neighbor eNBs are coordinated in such a manner that cell-edge UEs from each cell only use a certain part of the non-overlapping bandwidth. As a result, the cell-edge UEs from direct neighbors do not cause interference to each other.

PUCCH

Except in the case of 1.4 MHz channel bandwidth, in most cases each PUCCH occupies a pair of RBs located on two edges of the channel.

The number of RBs needed for PUCCH is based on a number of factors, such as the UL signaling capacity requirements and the interference situation.

- For UL signaling capacity: Obviously a 20 MHz channel can accommodate a higher number of UE in the channel and thus will generate higher UL signaling traffic on PUCCH, so a 20 MHz channel will need more RBs for PUCCH than a 5 MHz channel.
- For UL interference considerations: if PUCCH interference on some RBs used by a macrocell is too strong, it is possible for the femtocell PUCCH to use different sets of RB frequencies. The macrocell should not use the same RBs and thus would cause no interference on these RBs (Figure 11) [3].

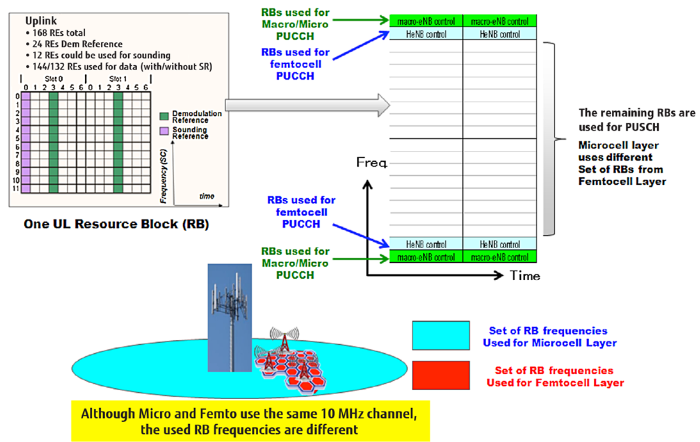

Figure 11: PUCCH interference avoidance

PRACH

In the frequency domain, PRACH occupies 6 RBs (1.08 MHz). For FDD, there is at most one random-access region per sub-frame in the time domain.

Because an access probe can be sent out multiple times (thus offering time diversity gain), PRACH itself is a very robust channel. The error impact from PRACH is connection setup delay and/or handover delay. This is not a big issue for metropolitan femtocell deployments due to low mobility. Therefore, generally ICIC on the PRACH is not necessary except in special situations.

Note that, if the femtocell layer and macrocell layer use different channel bandwidths, then the channel centers of two layers will be offset from each other (in the frequency domain), so there will be no collisions of PRACH between the two layers.

DL Physical Channels

There are many DL physical channels. These can be divided into four groups:

- PDSCH (DL traffic channel)
- PDCCH (DL control channel). There are multiple channels inside the PDCCH region, such as PCFICH, PHICH and RS
- PBCH/P-Synch/S-Synch (broadcast, primary- secondary synch channel)
- RS (DL reference signal)

For the DL traffic channel, frequency domain ICIC solutions can be used in a manner similar to the UL traffic channel; but for DL control channels, frequency domain solutions are not always possible.

PDSCH

The DL ICIC on traffic channel can work in a very similar manner to the UL ICIC, i.e., if high interference is detected on some RB frequencies, the DL scheduler will restrict the allocated bandwidth and only allocate RBs to frequencies with less interference (so-called bandwidth control), as shown in Figure 12.

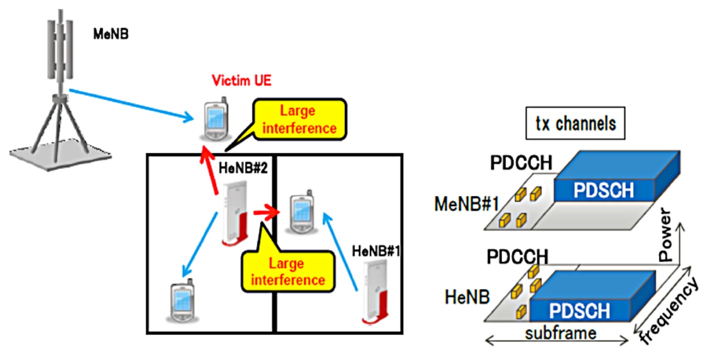

Figure 12: DL ICIC working on the frequency domain

PBCH, P-Synch and S-Synch Channels

Both broadcast channel and primary/secondary synch channels use the center 6 RBs. They are also transmitted in fixed time slots. If the macrocell layer and femtocell layer use the same channel bandwidth and also have time synchronization, then there will always be collisions between the two layers on these overhead channels (Figure 13).

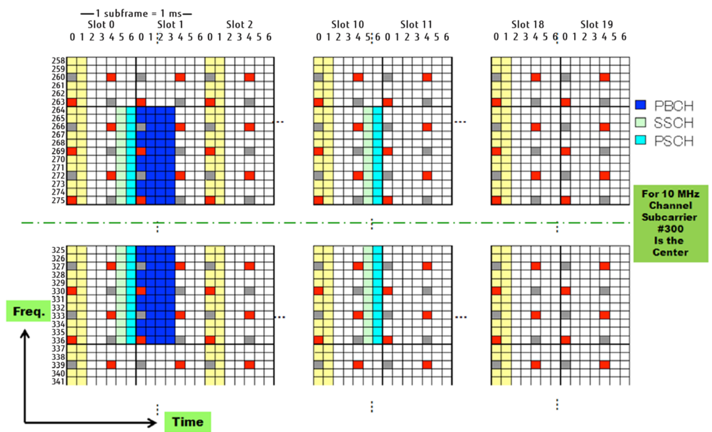

Figure 13: Locations of DL overhead channels (PBCH, P-/S-Synch)

Fortunately, these channels are quite robust and can work at very low SINR. Also, the impacts of interference on these channels are not disastrous.

- Weak sync channels result in longer sync time, but have no impact on connected mode performance.
- Four receptions of PBCH transmission will be executed in 40 ms to ensure the UE's correction reception. In a bouncing RF environment, the interference level will never be a constant. The performance is acceptable even if UEs can only receive part of PBCH transmissions correctly.

For these reasons, ICIC is generally not necessary on these channels unless under extreme situations.

Under extremely strong interference, it is possible to provide time offset between the macrocell layer and femtocell layer so these overhead channels will not collide in the time domain, as described in [3]. Also note that if the femtocell layer and macrocell layer use different channel bandwidths, then the channel centers of the two layers will be offset from each other (in the frequency domain), so there will be no collisions on these channels between the two layers (Figure 14).

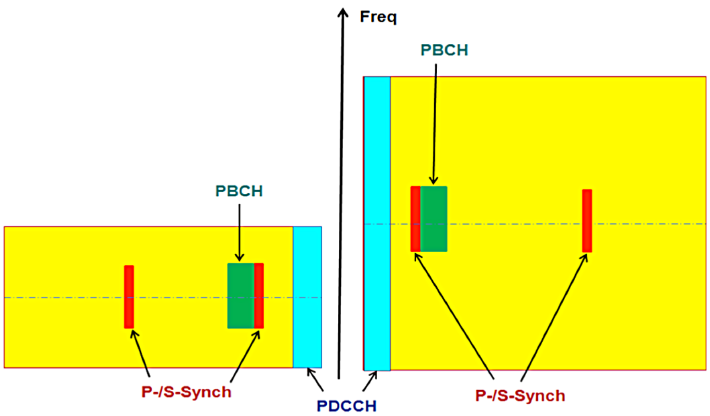

Figure 14: Effect of using different channel bandwidth

PDCCH

Unlike traffic channels or PUCCH, PDCCH must occupy the entire channel bandwidth, which makes "bandwidth restriction" techniques such as FFR difficult. PDCCH is not as robust as some other channels. Because it contains time-sensitive scheduling information, techniques like H-ARQ re-transmissions cannot be applied on PDCCH. Failure of PDCCH has a direct impact on throughput because the UE will not be able to find scheduling information. Radio Link Failure (RLF) is a direct result of poor PDCCH reception (block-error-rate > 10%).

Multiple techniques can be used to enhance PDCCH performance. They are only briefly listed here because detailed discussions are very lengthy.

For Release 8/Release 9:

- **CCE-based Power Boosting:** Boost the Tx power level on CCEs serving femtocell layer cell-edge users (aggregation level 8).
- **Control the loading level on PDCCH:** PDCCH uses a scrambling mechanism to minimize the probability of collision with neighbor cells on the CCE level [4], as long as the load level is sufficiently low. The DL scheduler can purposely restrict the load level on PDCCH to minimize interference.
- If possible, femtocells use wider channel bandwidth than macrocells (Figure 14). Since CCEs are scrambled across the entire channel bandwidth, if the femtocell layer uses a wider channel, part of the channel will not be subject to interference by the macrocell layer, and the UE will still be able to retrieve the information from an unaffected part of the CCEs.

Release 10 added additional features to mitigate interference on the PDCCH:

- **Cross-Carrier Scheduling (CCS):** The macrocell layer and femtocell layers each use different carriers to send PDCCH; the scheduling information can cover all carriers. This is a beneficial frequency-domain solution, but only Release 10 UEs can benefit from this feature.
- **Almost-Blank-Subframes (ABS):** The "aggressor" purposely minimizes the transmission (with almost no scheduling and lower Tx power) on some selected sub-frames, so the "victim" can schedule cell-edge UE on these "almost-blank" sub-frames (Figure 15) [5]. Cell-center UE can be scheduled at non-blank subframes.

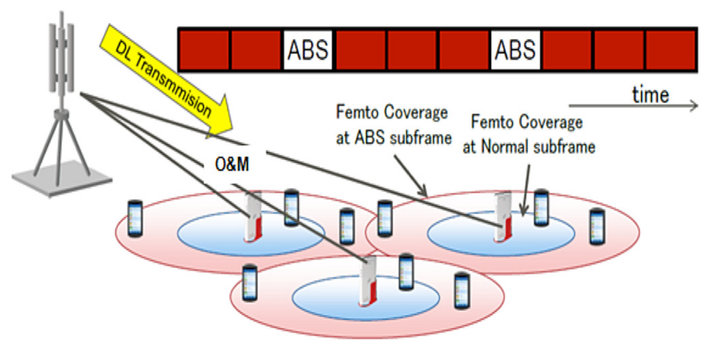

Figure 15: Illustration of ABS

[3] According to the Release 10 standard, the X2 interface is supported between the macrocell layer and picocell layer, but is not supported between the femtocell layer and macrocell layer, so O&M is used for ABS deployment in femtocells.

The ABS pattern must be communicated between the macrocell and small-cell layers. For HetNet with macrocells and picocells, a bitmap pattern is communicated between the two layers via the X2 interface. For HetNet with macrocells and femtocells, the ABS pattern is configured semi-statically and controlled via an Operation and Maintenance (O&M) center, as shown in Figure 16.

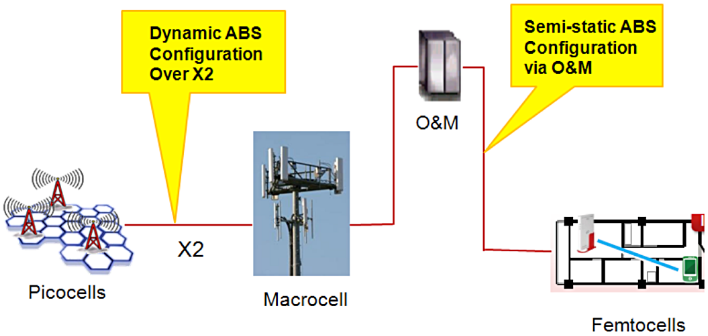

Figure 16: Communication of ABS among different layers

Table 2 gives a summary of LTE channels and possible ICIC techniques [6], [7], [8], [9].

Table 2: Solution(s) for different LTE channels

Channel Type	ICIC Method
DL/UL Traffic	Frequency Domain ICIC (e.g., FFR)
PBCH, PRACH, P-/S-Synch	Most time they are robust enough. In rare cases, if interference is too strong, it is possible to apply different time or frequency offsets to avoid collisions
PUCCH	The macrocell layer and femtocell layer use different RB frequencies for their PUCCH
PDCCH	CCE-based power boosting; PDCCH load control; use different channel bandwidths for femtocell and macrocell; Cross-Carrier Scheduling; Almost-Blank-Subframes

Figure 17 shows the result of reduction of femtocell power spillage to outside of the house due to interference control; Figure 18 [2] shows the simulation results of SINR improvements of non-CSG users moving near the femtocell. These two figures can be compared with Figure 8 and Figure 9 (no IC techniques were applied).

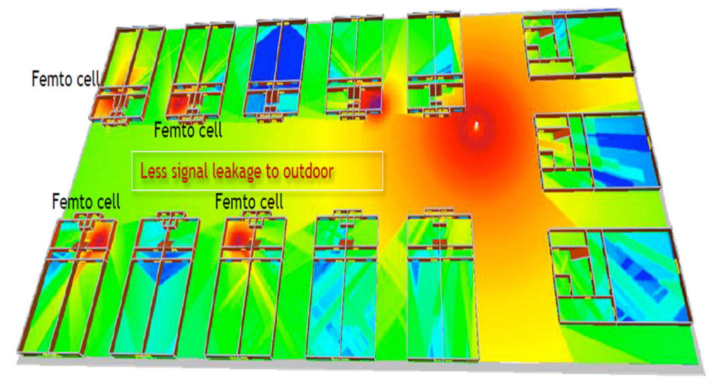

Figure 17: Reduced power spillage to outdoor areas as a result of interference control.

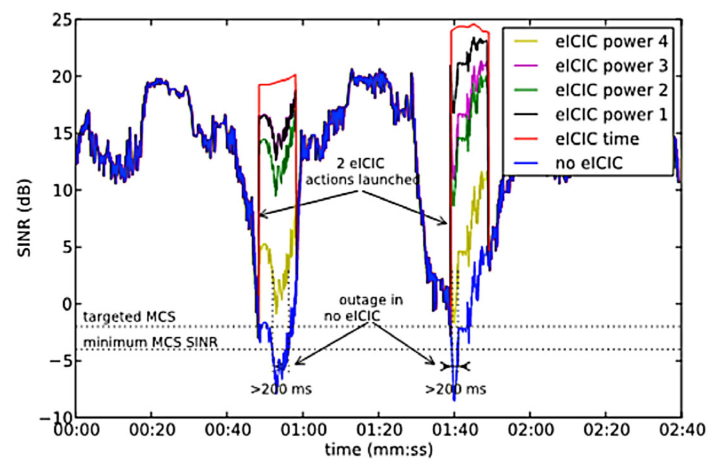

Fig. 18: Improved SINR as a result of interference control.

Fujitsu Proprietary Interference Control Solutions

Both cross-carrier scheduling and ABS are Release 10 features that will not be available before LTE-Advanced. However, Release 9 femtocells do face the same inter-layer interference issues and so proprietary solutions must be used to mitigate interference. These proprietary solutions can be combined with the Release 10 solutions once they become available.

The proprietary Fujitsu solutions take a cognitive and learning approach to interference control (IC) algorithms that requires minimum assistance from macrocells [10]. The femtocell itself makes multiple measurements and, by getting information via UE feedback, the femtocell can learn the current interference situation on both the DL and UL, as well as the current locations of UE. From this information, RF resources are optimally allocated to maximize capacity and minimize interference (Figure 19).

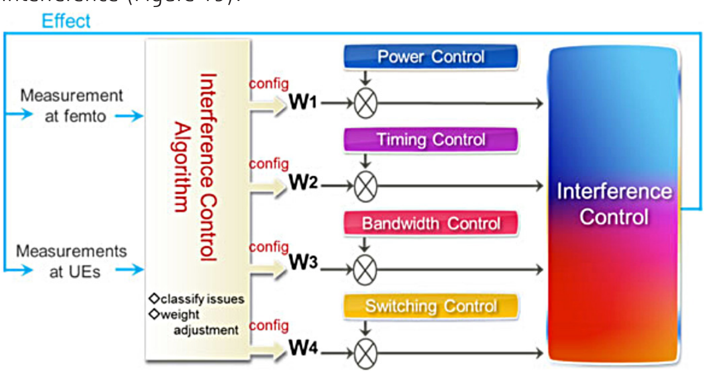

Figure 19: Cognitive and Learning interference control

As shown in Figure 19, there are four main features in the IC mechanism:

(1) Power domain: RS power boosting, traffic channel power boost/ power backup, and CCE-based power boost. The effect on traffic and RS power boost is coverage expansion, as shown in Figure 20.

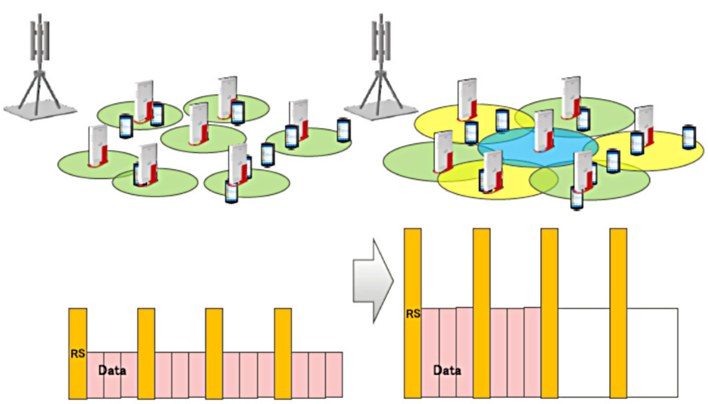

Figure 20: Power boosting to expand coverage footprints

(2) Frequency domain: also called bandwidth control, which is a dynamic FFR algorithm [11] with additional intelligence; it can optimally allocate RF resources based on the current UE locations. This will reduce interference to areas with high user density at the expense of increasing interference to locations with no users, as shown in Figure 21. Because the frequency allocation can change to best serve the users based on their locations, the overall performance is improved compared to a fix FFR scheme.

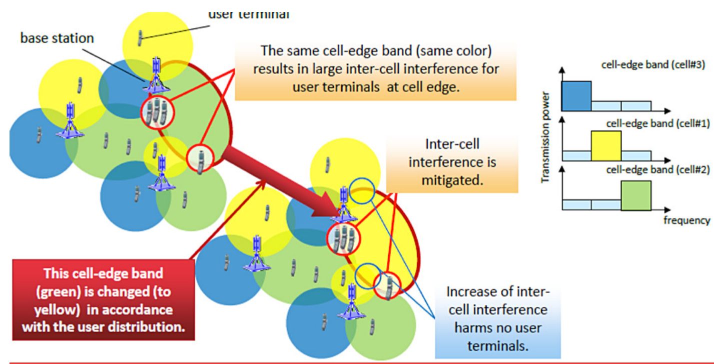

Figure 21: Intelligent dynamic FFR allocates RF resources based on user locations

(3) Cell boundary control: A centrally controlled intelligent algorithm that can adjust the Tx power levels on different femtocells to produce an overall optimum coverage footprint based on current user locations. As shown in Figure 22, when the algorithm is applied, some previous cell-edge users will no longer be on the cell edge.

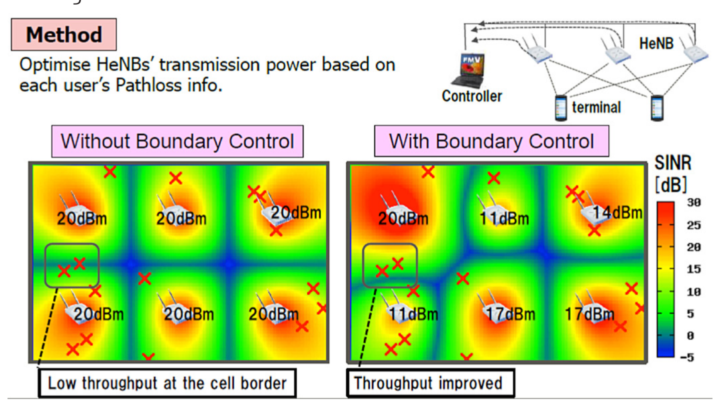

Figure 22: Footprints of femtocells are changed to provide optimum services based on current user locations

[4] The newly added femtocell's transmitter is not "on" during the sniffing phase, so a DL receiver can be used to measure the DL signals from surrounding neighbor cells.

(4) LTE/WiFi Switching Control: If interference from the macrocell layer is so large that the femtocell coverage footprint shrinks too much, the femtocell will direct UE to switch to Wi-Fi, as shown in Figure 23. Additionally, Fujitsu's product offers a Link Aggregation (LA) feature that can combine the throughput of LTE and WiFi (Figure 24). The LA feature allows a significant increase of aggregate UE throughput (LTE + WiFi); this greatly improves user experience even if one of the networks (LTE or WiFi) is experiencing link degradation. The measurement results are shown in Figure 25.

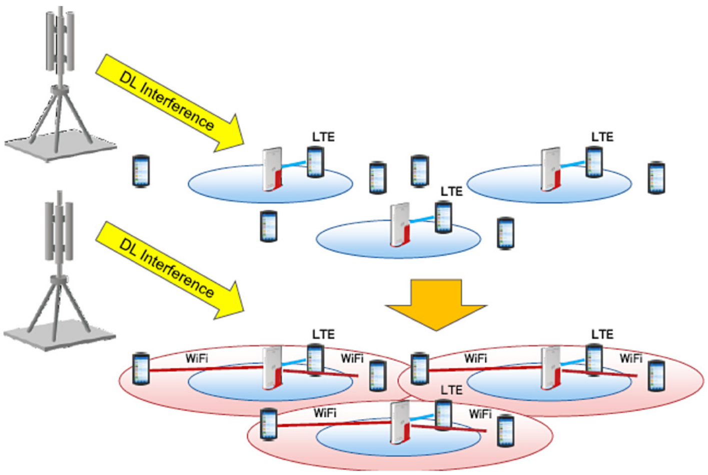

Figure 23: LTE/WiFi switching feature

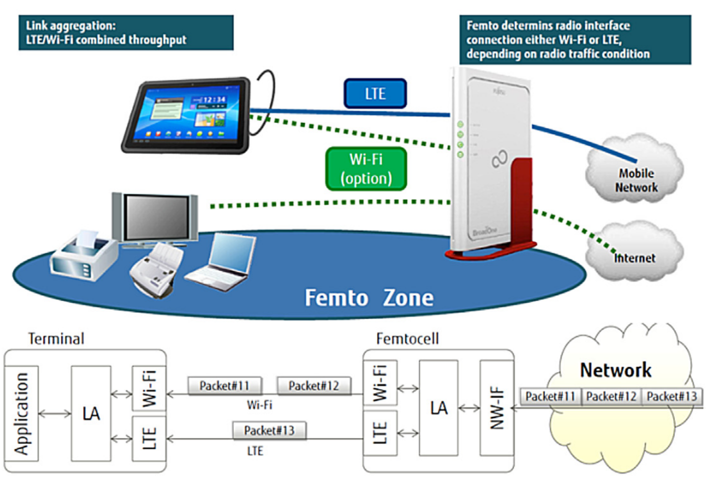

Figure 24: Link Aggregation (LTE + WiFi) feature

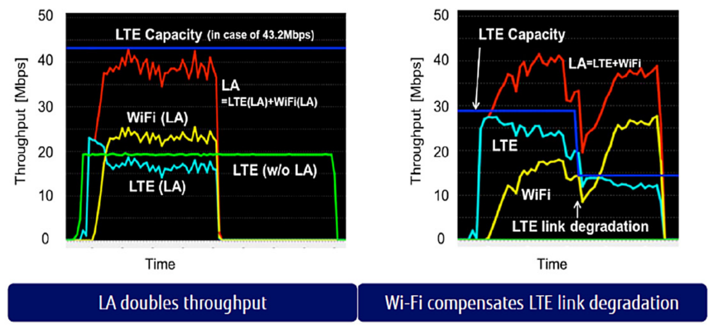

Figure 25: Measured throughput enhancement from LA.

The combined frequency domain, time domain, and power domain solutions can effectively combat different types of interference.

Plug-and-Play

The Fujitsu LTE femtocell provides plug-and-play capability, including sniffing and auto-configuration.

- The sniffing feature allows a newly added femtocell eNB to "learn" the surrounding environment by making various measurements.
- The information learned allows the femtocell eNB to perform all necessary auto-configuration for a new cell to be added to the existing network.

This plug-and-play feature enables service providers to put the unit into service on the network and configure the necessary parameters automatically without any action from a technician. The installation steps are shown in Figure 26.

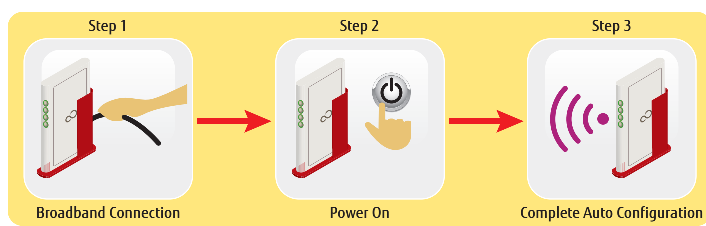

Figure 26: A simple three-step process to install femtocells

The sniffing feature includes the following functions:

- In the case of multiband operation, the femtocell eNB selects the operating frequency from one of the frequency bands based on a set of criteria.
- The femtocell eNB learns its neighbor cells and their Physical Cell IDs (PCIs) by hearing the PCIs over the air via a DL receiver[4].
- The femtocell eNB knows if it has been moved to a new location based on whether the neighbor cells' PCIs measured RSRP from neighbors are changed.
- The femtocell eNB can perform open-loop interference control by determining its own optimum Tx power level based on measured signal strength from neighbor cells.

The auto-configuration capability consists of following features (Figure 27):

- Femtocell Authentication: The femtocell user ID is registered at the AAA Server. The UICC is created with the femtocell ID and PPPoE ID/PW.
- The IPsec security tunnel is established.
- SW/CM is downloaded from HeMS.

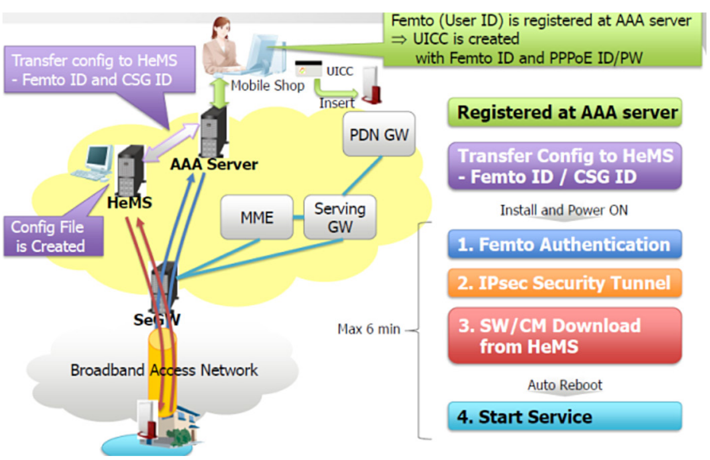

Figure 27: Fujitsu one-step plug-and-play flow diagram

Several Self-Organizing-Network (SON) features are used to configure parameters such as the Physical Cell ID (P-CID) [11] and the neighbor list [12].

- Automatic P-CID allocation: The femtocell's PCID is autonomously allocated depending on the PCID detected from neighbors. The algorithm will also avoid PCI collision, as shown in Figure 28

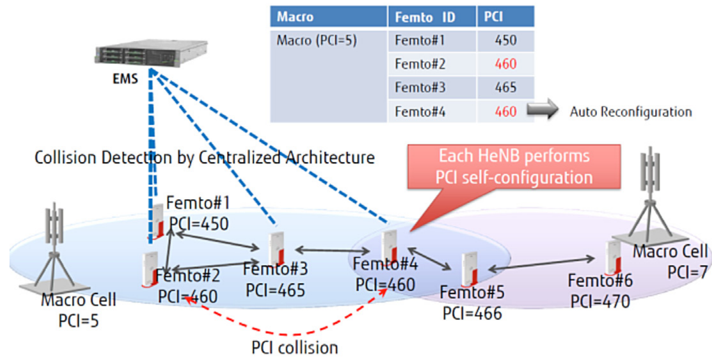

Figure 28: Illustration of Auto PCI Allocation and PCI Collision Detection.

- Automatic Neighbor Relation (ANR): The neighbor list is automatically configured by the femtocell using ANR (Figure 29).

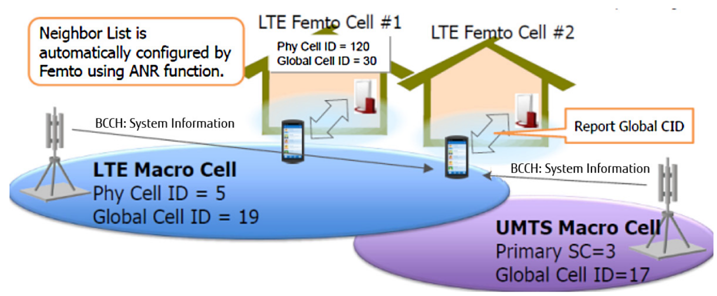

Figure 29: Illustration of automatic neighbor relation

The serving EMS is discovered in the initial access inside the operator's private secure network domain. The femtocell automatically upgrades itself with the latest software and configurations by the serving EMS, as shown in Figure 30.

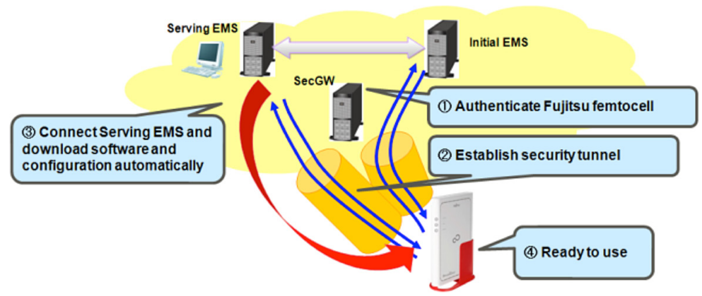

Figure 30: Serving EMS discovery

With these automatic features, installing the Fujitsu femtocell is as easy as installing a Wi-Fi AP.

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Conclusion

Because buildings can be located very close to macrocell base stations, if BPL is too small, adding small cells into the buildings is equivalent to adding small cells in the middle of large cells. This "overlaid /underlaid" network structure can face severe interference issues if the same-carrier frequency is used. The inter-layer interference, i.e., the interference between the outdoor-cell layer and indoor-cell layer, can be a major concern regardless of whether the network is 2G, 3G or 4G. Additionally, residential femtocells face two unique interference issues due the randomness of HeNB locations, and CSG.

For early cellular systems, the only way to minimize the inter-layer interference is the classic RF deployment techniques that take advantage of the building penetration loss and antenna patterns; since the early cellular systems do not have the sophisticated features like ICIC or eICIC.

4G systems added ICIC and eICIC. The 4G Fujitsu femtocell product added proprietary algorithms to further mitigate interference and optimize overall performance. Fujitsu is in a unique position to create the optimum HetNet solutions in any types of complicated RF environment allowing it to be installed as easy as a Wi-Fi AP by untrained end customers.

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Acronyms

AAA	Authentication, Authorization and Accounting
ABS	Almost Blank Subframes
ANR	Automatic Neighbor Relation
BPL	Building Penetration Loss
CCE	Control Channel Elements
CCS	Cross-Carrier Scheduling
CDMA	Code Division Multiple Access
CSG	Closed Subscriber Group
DL	Downlink
eICIC	Evolved ICIC
EMS	Element Management System
eNB	Evolved Node B (LTE base station)
FFR	Fractional Frequency Reuse
HeNB	Home eNB (LTE femtocell)
HetNet	Heterogeneous Network
HUE	UE connected to an HeNB
IC	Interference Control
ICIC	Inter-Cell Interference Coordination
LA	Link Aggregation
LOS	Line-of-Sight

OFDM	Orthogonal Frequency-Division Multiplexing
PBCH	Physical Broadcast Channel
PCFICH	Physical Control Format Indicator Channel
PCID	Physical Cell ID
PDCCH	Physical DL Control Channel
PDSCH	Physical DL Shared Channel
PHICH	Physical H-ARQ Indicator Channel
PRACH	Physical Random Access Channel
PUCCH	Physical UL Control Channel
PUSCH	Physical UL Shared Channel
PCI	Physical Cell ID
RB	Resource Block
RLF	Radio Link Failure
RS	Reference Signal
SON	Self Organizing Network
Tx	Transmit
UE	User Equipment (LTE terminal)
UICC	Universal Integrated Circuit Card
UL	Uplink
UMTS	Universal Mobile Telecommunications System

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