4G Femtocell for the Enterprise 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 gives an overview of potential interference issues and solutions for enterprise 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 added 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 hot spots; thus unique engineering considerations must be given to in-building deployment.

One factor that needs to be considered is 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 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.

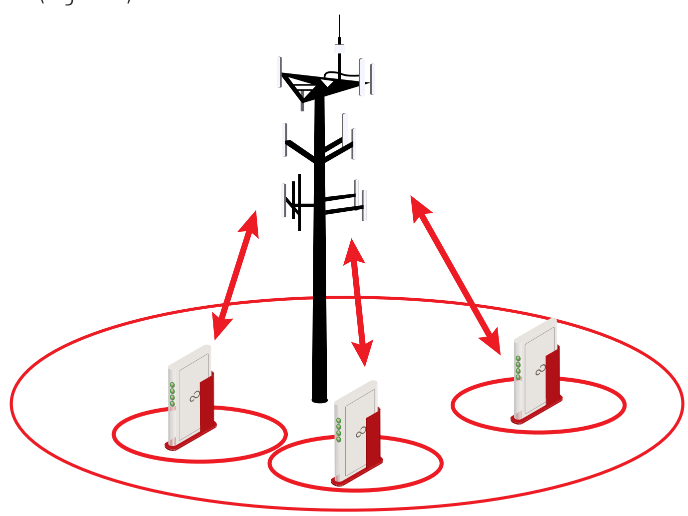

Figure 2: If BPL=0, deploying an indoor system is equivalent to adding small cells to the center of a large cell.

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

- 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, 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) office buildings [1].

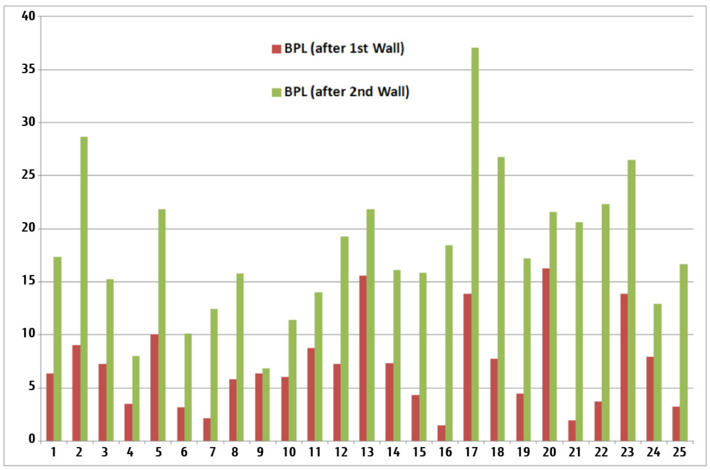

Figure 3: Measured penetration losses behind the first wall and behind the second wall

Note that, even for buildings without many inner 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 inner walls, but there are usually dead zones near the center of the mall, especially in the first floor (Figure 4).

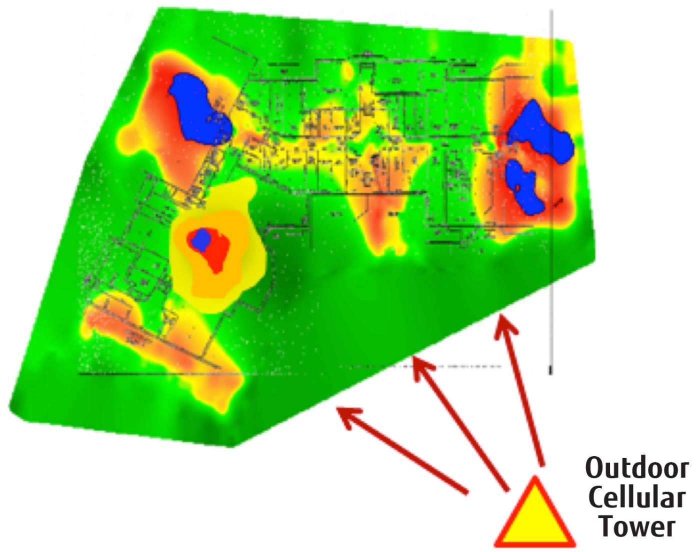

Figure 4: Dead spots measured deep inside a large building with few inner walls

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.

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 uses 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 restrictions on RF resources, so they almost always result in slightly lower capacity.

HetNet Interference Scenarios

Femtocells can be deployed in homes, public areas or office buildings. The potential interference scenarios vary with the type of deployment (Figure 5).

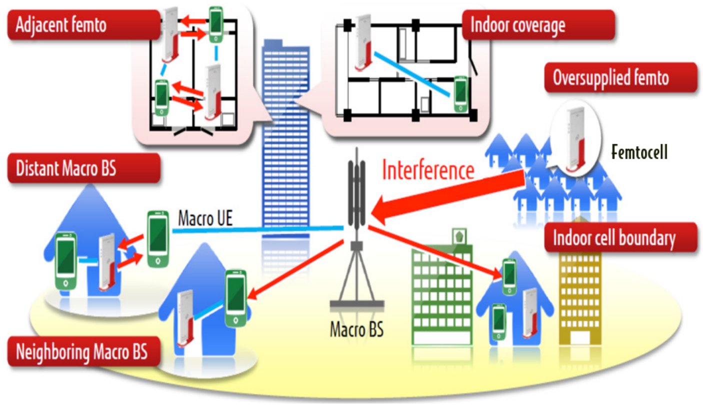

Figure 5: Different types of femtocell deployment scenarios have different interference concerns

For enterprise femtocell deployments, there are two main interference scenarios:

(1) **Inter-layer interference:** This is interference between the indoor femtocell layer and outdoor macrocell/microcell layer. This type of interference is the main interference of concern, especially in the DL, although UL interference can be significant as well.

(2) **Interference within the femtocell layer:** Interference among neighboring femtocells within the building is not a major concern; for enterprise deployment, femtocell locations are carefully planned rather than randomly placed, unlike the situation in residential areas. If femtocells are deployed as a "regular lattice," interference among neighboring femtocells will be well-controlled (with SINR >= –5 dB for most locations). There is no such luxury for residential deployments, which are unplanned. 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.

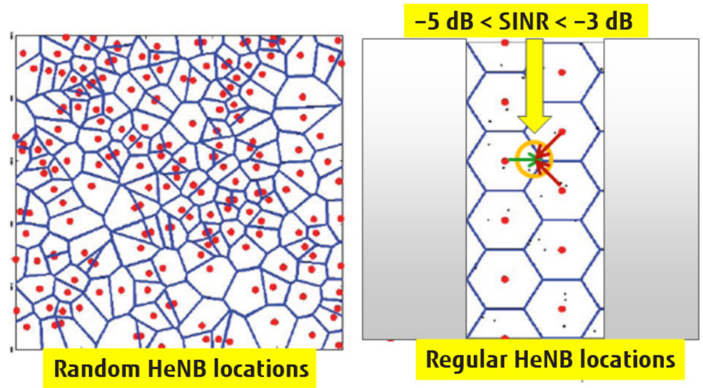

Figure 6: Residential femtocell locations are likely to be random but femtocell locations in an enterprise environment should be planned.

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. Additionally, ICIC and other interference mitigation techniques can be used, as discussed in the following sections.

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

Interference Scenarios 2 and 4

Interference scenarios 2 and 4 are UL interference, which can easily be mitigated via frequency domain solutions such as FFR. Because the worst interferers are from UE located near the cell edge (which must transmit higher power), but due to the UL link budget limitations, this cell-edge UE cannot use the full bandwidth. As a result, it is easy for the FFR algorithm to restrict the allocated cell-edge UE UL bandwidth and arrange the neighbors' cell-edge UE Tx frequencies to avoid UL interference; that is, macrocell cell-edge UE and femtocell cell-edge UE each use different parts of the channel frequencies.

For large office buildings, only those femtocells and femtocell UEs located near the windows or outer walls (i.e., with low penetration losses) will face strong inter-layer interference. Those located deep inside the building will have very high BPL or high "isolation," so their Tx power will not cause much interference to the outdoor system. Additionally, the Tx power from outdoor systems cannot reach them. These femtocells and femtocell UEs with high BPL do not need to restrict the resource allocations and can therefore have higher capacity.

As mentioned previously, 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 Scenario 3

Generally speaking, this is not a serious concern for enterprise deployment for two reasons:

- The Tx power level from the femtocell is much lower compared to that of a macrocell.
- BPL adds isolation between the femtocell layer and the macrocell layer. Although quite a large number of indoor femtocells may be deployed, only those femtocells installed near the windows or outer walls (with low BPL) will cause noticeable interference to outdoor systems.

For office building deployments, classic RF engineering design techniques can minimize the femtocell signal power "spilled" to the exterior of the building, thus minimizing interference to the outdoor network, while simultaneously maximizing the femtocell signal power inside the intended indoor coverage areas. These design techniques have been successfully used for 2G and 3G indoor systems; the same techniques should also be used for 4G femtocells.

In addition to these classic RF design techniques, the cognitive and learning capabilities of Fujitsu femtocell products adds another dimension to the interference control capabilities. The Fujitsu femtocell reduces the transmitted power toward the outside of the building if it measures strong interference from that direction.

Interference Scenarios 5 and 6

Interference scenarios 5 and 6 are interference within the femtocell layer. As discussed previously, for a carefully planned indoor network with optimum femtocell locations, interference within the femtocell layer can be kept low, so that even without ICIC, interference scenarios 5 and 6 should not be a concern.

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 further 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.
- On the other hand, for OFDMA systems, multiple techniques can be used to avoid collision, i.e., try to avoid conflict either in the frequency dimension, or in the time dimension (Figure 8). Use of the power domain can be combined with either the frequency or time domain.

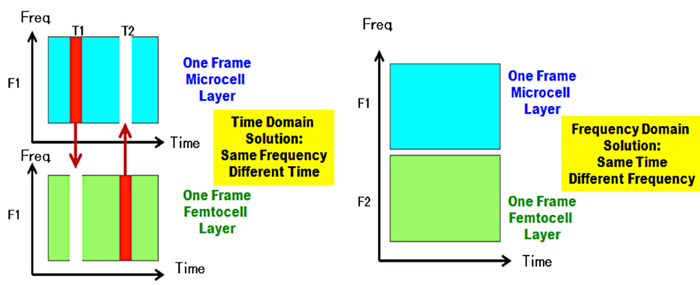

Figure 8: For OFDM/SC-OFDM systems, ICIC can work either on the time domain or the frequency domain

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 channel: 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, 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 interference situation.

- For UL signaling capacity: Obviously a 20 MHz channel can accommodate a higher number of UEs 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 9) [2].

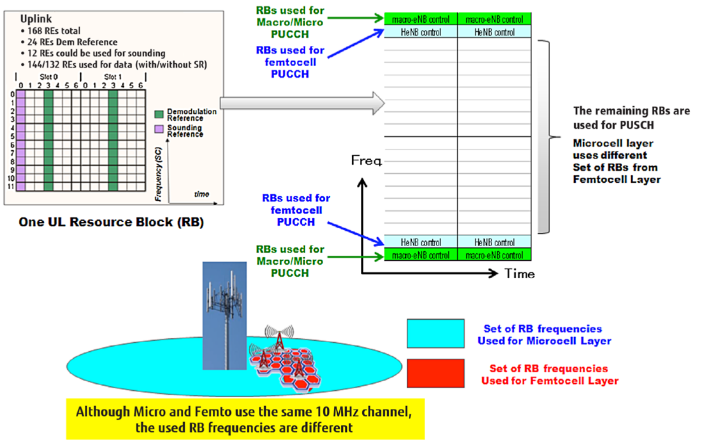

Figure 9: PUCCH interference avoidance

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 enterprise 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 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 10.

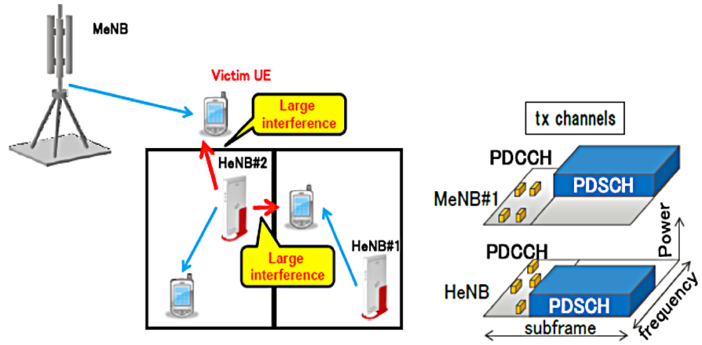

Figure 10: DL ICIC working on the frequency domain

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 11).

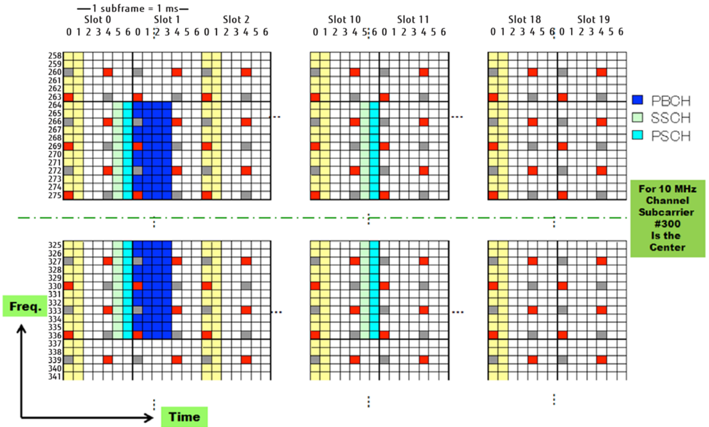

Figure 11: Locations of DL overhead channels (PBCH, P-/S-Synch)

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 except in 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 [2]. 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 12).

Reference Signals

For homogeneous networks, the RSs from direct neighbors are offset from each other in the frequency domain (via different V-Shifts) so the probability of RS collision among direct neighbors is minimized.

This is not always possible for HetNet, since one macrocell can cover a large number of femtocells and there are not enough different V-Shifts to avoid collisions for all of them. In this case, good engineering practice can be used to minimize the interference on RS. For example, try to use different V-Shifts (from macro) on those femtocells located near the windows; femtocells located deep inside the building can use the same V-Shift as the macrocell since they will not face strong interference with the macrocell layer thanks to the large BPL.

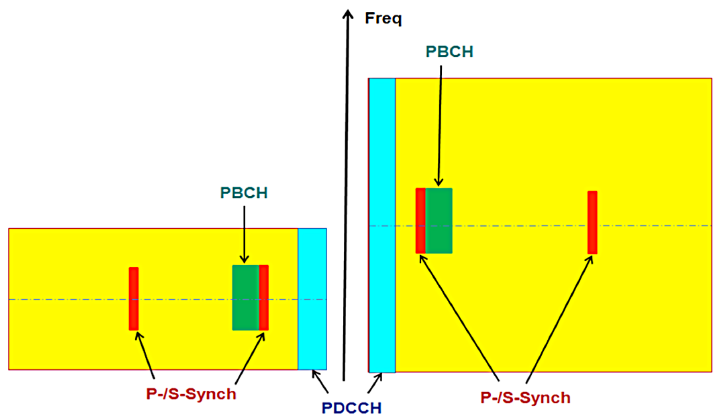

Figure 12: Effect of using different channel bandwidth

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 up 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 [3], 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 12). 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):** Macrocell layer and femtocell layer 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 13) [4]. Cell-center UE can be scheduled at non-blank subframes.

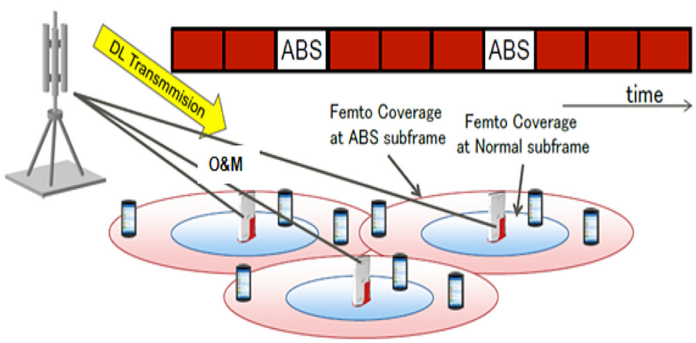

Figure 13: Illustration of ABS

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 Center (O&M)[3], as shown in Figure 14.

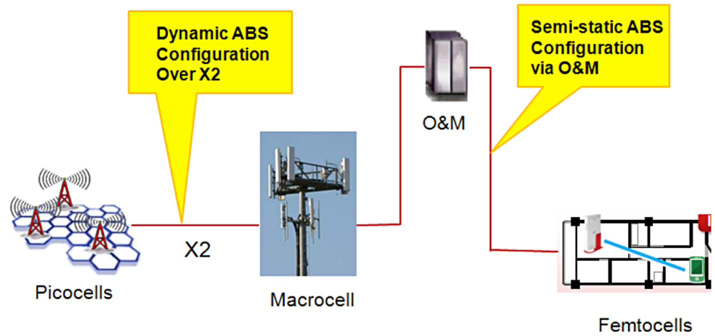

Figure 14: Communication of ABS among different layers

Table 2 provides a summary of LTE channels and possible ICIC techniques [5], [6], [7], [8].

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

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.

[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 proprietary Fujitsu solutions take a cognitive and learning approach to interference control (IC) algorithms that requires minimum assistance from macrocells [9]. The femtocell itself makes multiple measurements and, by getting information via UE feedback, the femtocell can learn the current interference situation on both 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 15).

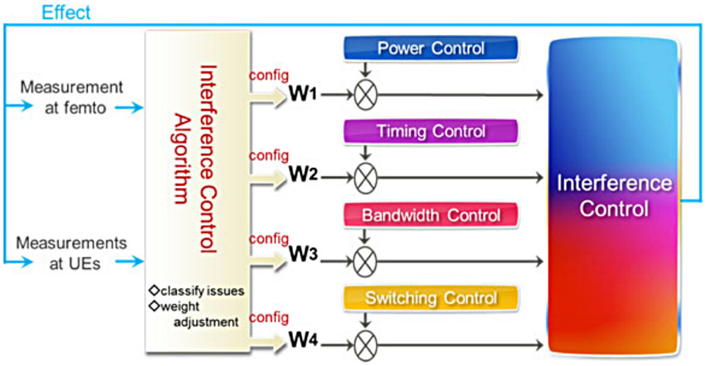

Figure 15: Cognitive and Learning interference control

As shown in Figure 15, 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 shown in Figure 16.

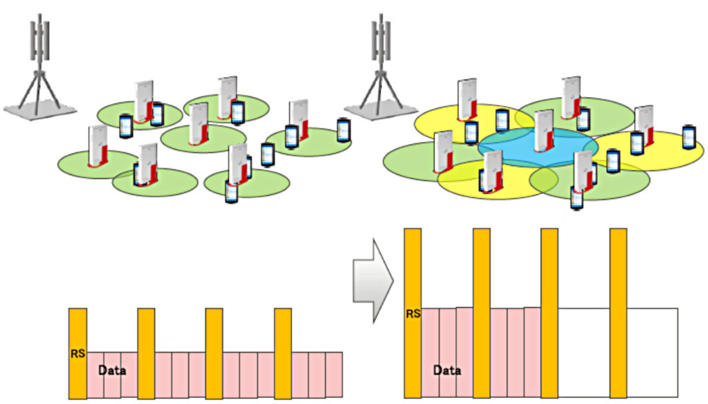

Figure 16: Power boosting to expand coverage footprints

(2) Frequency domain: also called bandwidth control, which is a dynamic FFR algorithm [10] 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 17.

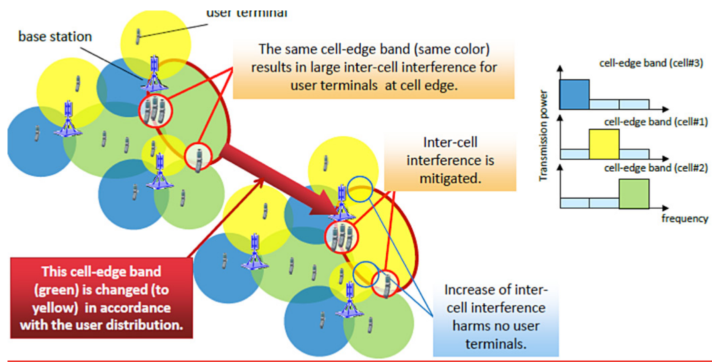

Figure 17: Intelligent dynamic FFR allocates RF resources based on user locations

(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 18, when the algorithm is applied, some previous cell-edge users will no longer be on the cell edge.

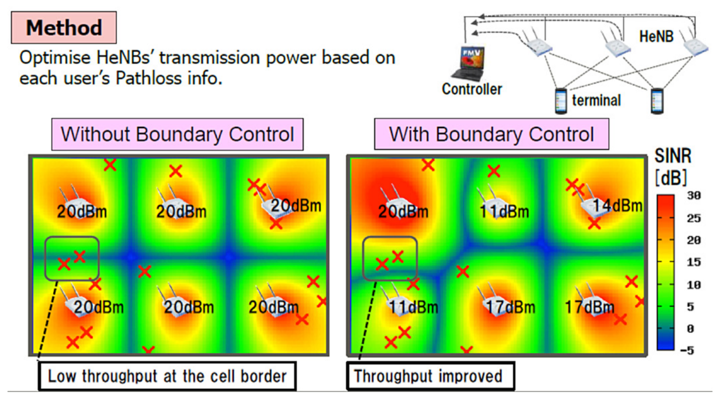

Figure 18: Footprints of femtocells are changed to provide optimum services based on current user locations

(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 19.

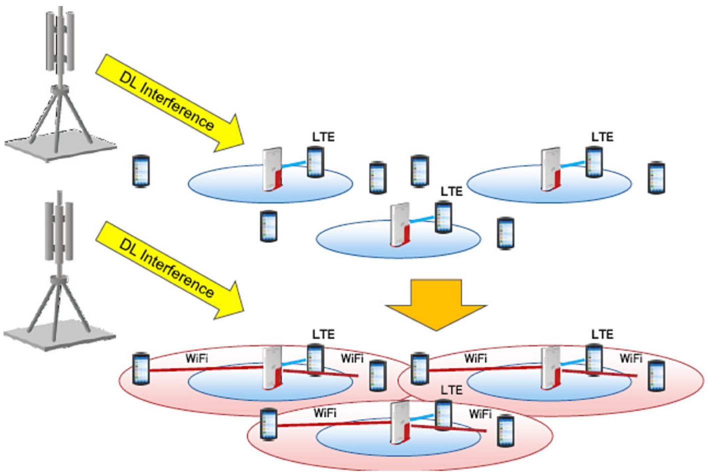

Figure 19: LTE/WiFi switching feature

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 20.

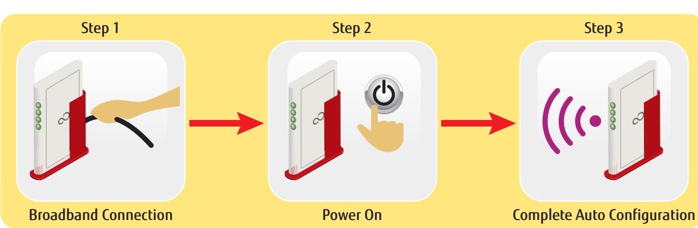

Figure 20: A simple three-step process to install femtocells

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 21):

- 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.

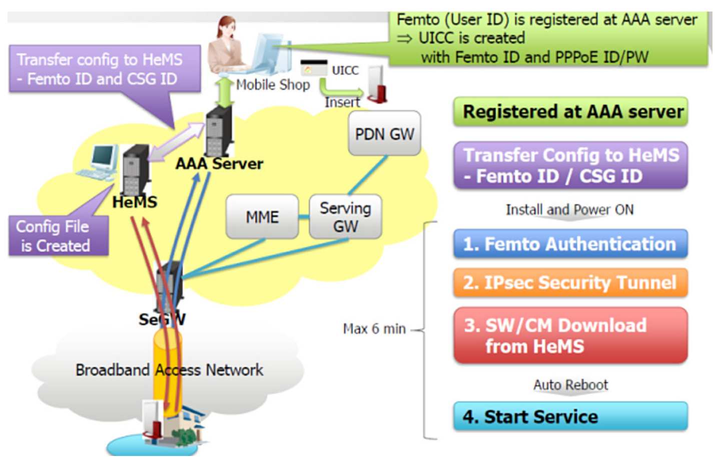

Figure 21: Fujitsu one-step plug-and-play flow diagram

[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.

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 automatically allocated depending on the PCID detected from neighbor cells (Figure 22).

PCI/PSC	Global CID	RAT	HO	CSFB	RSRP
5	19	LTE			xxdBm
120	30	LTE			xxdBm
3	17	UMTS			xxdBm

Figure 22: Illustration of automatic PCI allocation

- Automatic Neighbor Relation (ANR): The neighbor list is automatically configured by the femtocell using ANR (Figure 23).

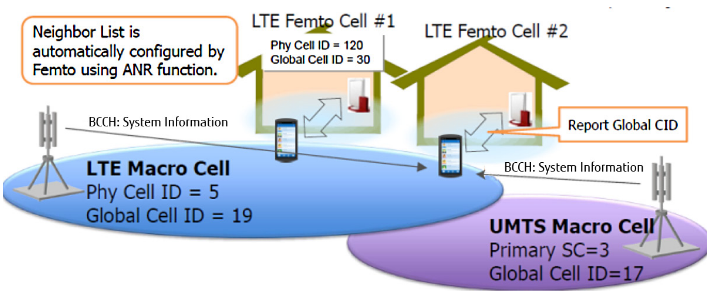

Figure 23: Illustration of automatic neighbor relation

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 24.

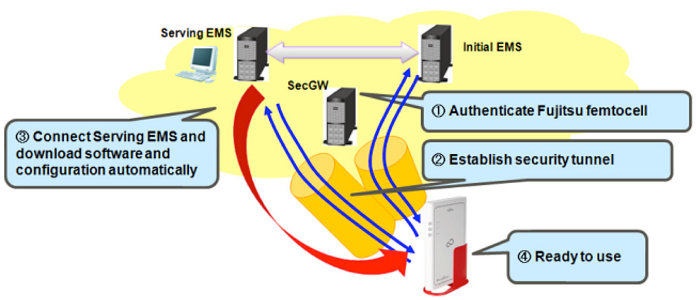

Figure 24: Serving EMS discovery

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

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.

For early cellular systems, the only way to minimize this type of 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. Additionally, The Fujitsu femtocell product added proprietary algorithms to further mitigate interference and optimize overall performance. The combined rich product features and the extensive indoor deployment experience from the engineering team put Fujitsu in a unique position to design and deploy the optimum HetNet solutions in any types of complicated RF environment.

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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
DL	Downlink
eICIC	Evolved ICIC
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
LOS	Line-of-Sight
OFDM	Orthogonal Frequency-Division Multiplexing
PBCH	Physical Broadcast Channel
PCFICH	Physical Control Format Indicator Channel
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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