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Technical Report

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Contents

Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

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1 Scope

This document is a technical report of the work item on FDD Home eNodeB RF Requirements [1]. The goal of this technical report is to satisfy the two objectives of the work item, which are reproduced below,

Objective 1

The existing E-UTRA BS class does not fully address the RF requirements of the HeNB application. Correspondingly, Objective 1 is to specify the RF requirements for the Home eNodeB in TS 36.104, where the work done for the HNB can be taken as a basis.

Furthermore, the test specification TS 36.141 would need to be updated accordingly.

It is foreseen that the HeNB-specific additions to TS 36.104 / 36.141 can be accommodated in a manner similar to that accomplished for the UTRA HNB.

Objective 2

TR 25.820 showed that for the CSG HNB there are occasions where overall system performance may be enhanced by controlling the HNB output power dependent on the strength of signal from the macro cell layer and from other HNB. Control of CSG HNB output power mitigates interference to the macro layer and other CSG HNB. Correspondingly, it is expected that similar observations may be made for the HeNB. Objective 2 is to ensure that operators have the ability to achieve control of HeNB power; in particular, the work should cover but not be limited by the following,

- The operator has the means to obtain measurements of the strength of signals and the identity (to allow macro neighbour cell list building) from the macro cell layer and from other HeNBs. Measurements may be made by the HeNB or may make use of existing measurements defined for the UE; no new UE measurements will be defined.

- The operator has the means to set the maximum output power of the HeNB, this is expected to introduce changes to TS 36.104.

- The operator has guidance on how to control HeNB power and expected performance levels in the relevant scenarios. There are additional factors that may be controlled in E-UTRA in comparison with UTRA, such as variable bandwidth and allocation of radio sub-carriers; work will be conducted to investigate if similar mechanisms may be used for controlling HeNB resource allocation versus the macro cell layer and versus other HeNBs. Additionally, mechanisms may be applied to control HeNB coverage in the case of open access HeNB.

As objective 2 of the work item is to create a published document to provide guidance to operators it is necessary to issue a TR in the 900 series. To avoid administrative overhead this TR will also be used to document any other output from this work item.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document.*

[1] RP-081080, RAN4 work item description, "LTE FDD Home eNodeB RF Requirements".

[2] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[3] R4-093439, "Way forward on HeNB interference management," CMCC, NTT Docomo, Picochip, Motorola, Qualcomm Europe, Kyocera, Institute for Information Industry, Alcatel Lucent, CATT.

[4] R4-093349, Femtocell and Macrocell interference coordination based on SFR, Motorola.

[5] R4-092504, "LTE HeNB Interference studies: Hybrid cell deployment scenarios," Vodafone, et al.

[6] R2-092083, "Support for hybrid home base stations", Ericsson.

[7] R4-092498, "Hybrid HeNB Interference Scenarios and Techniques," Qualcomm Europe.

[8] R4-093556, "HeNB Downlink Interference Avoidance with Adaptive Frequency Selection", NEC.

[9] R4-094248, "HeNB Adaptive Frequency Selection", NEC.

[10] R4-100019, "HeNB Power Control Based on HUE Measurement", NEC.

[11] R4-092712, "HeNB to macro eNB cochannel interference simulations – uplink", picochip

[12] R4-093620, "Network Assisted Interference Coordination between Macro eNodeB and Home eNodeB in Downlink", Kyocera.

[13] R4-091907, "Frequency Reuse Results with Mixed Traffic", Qualcomm Europe.

[14] R4-091908, "Partial Bandwidth Control Channel Performance", Qualcomm Europe.

[15] 3GPP TS 22.220: "Service requirements for Home Node B (HNB) and Home eNode B (HeNB)", v9.1.1.

[16] R4-091906, "Frequency reuse results with full buffer", Qualcomm Europe, May 2009.

[17] R4-091907, "Frequency Reuse Results with Mixed Traffic", Qualcomm Europe.

[18] R4-094851, "Utility Messages for HeNB ICIC", Qualcomm Europe

[19] R4-092872, "Downlink interference coordination between HeNBs", CMCC, August 2009.

[20] 3GPP TR 25.967: "Home Node B (HNB) Radio Frequency (RF) requirements (FDD)", v900.

[21] 3GPP TS 36.331: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification", v9.0.0.

[22] R4-902712, "HeNB to macro eNB cochannel interference simulations –uplink," picoChip.

[23] R4-093617, "Home UE Uplink Interference Mitigation Schemes Based on Pathloss Difference toward LTE Release 9," Kyocera.

[24] R4-092042, "Simulation assumptions and parameters for FDD HeNB RF requirements," Alcatel-Lucent, picoChip Designs and Vodafone.

[25] R4-091796, "Power control assumptions for FDD HeNB simulation," Alcatel-Lucent, picoChip Designs and Vodafone.

[26] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures", v8.8.0.

[27] R4-093618, "Network Assisted Home UE Transmission Power Control in Uplink," Kyocera.

[28] 3GPP TR 36.922: "Evolved Universal Terrestrial Radio Access (E-UTRA); TDD Home eNode B (HeNB) Radio Frequency (RF) requirements analysis".

[29] R4-100193, picoChip Designs, Kyocera, "Victim UE Aware Downlink Interference Management".

3 Definitions, symbols and abbreviations

For the purposes of the present document, the terms and definitions given in TR 21.905 [2] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [2].

3.1 Definitions

(Void)

3.2 Symbols

(Void)

3.3 Abbreviations

HeNB	Home Enhanced Node B
HNB	Home NodeB
CSG	Closed Subscriber Group
GPS	Global Positioning System

4 General

As agreed in the work item proposal [1]:

Within the course of increasing terminal penetration and fixed-mobile convergence, an upcoming demand for LTE Home eNodeBs is observed to provide attractive services and data rates in home environments.

E-UTRAN was developed and defined under the assumption of coordinated network deployment whereas home eNodeBs are typically associated with uncoordinated and large scale deployment.

Aim of this work item is to amend the E-UTRAN eNodeB related RF specifications and base the work on the experience gathered in the RAN4 specific part of TR 25.820 to support the Home eNodeBs application. No changes to the UE RF specifications are foreseen.

The scope of this work item is limited to the E-UTRA FDD mode.

The interference analysis can be expected to be similar to that conducted for UTRA so the conclusions from that work would be expected to broadly apply to E-UTRA as well.

4.1 Task description

4.1.1 HeNB Class definition

The purpose of this work is to update the radio performance requirement specification TS 36.104, further work required to agree on new parameter values will be documented in the TR and the updates required in test specification TS 36.141 will be documented.

4.1.2 HeNB measurements and adaptation

The purpose of this work item is to ensure that operators have necessary information about how to adjust the output transmission power of HeNB as a function of the signal strength from the macro cell layer, and/or from other HeNBs, in order to enhance overall system performance.

In order to achieve this, (at least) the following areas should be addressed:

1) Guidance on how to control HeNB power

    a) The intention is to provide guidance to operators on possible strategies and expected performance in typical exemplary deployment scenarios.
    b) Is it possible to have the same mechanism to control HeNB output power with respect to the macro cell layer, other surrounding HeNBs, and in the case of HeNB coverage control for open access HeNB.
    c) It is not the intention to mandate HeNB behaviour.

2) Measurements of surrounding environment (i.e. macro and other HeNBs signal strength)
    a) Issues to address include factors that govern accuracy and timeliness of the suggested measurements, and the ability to identify the macro neighbour cell list.
    b) It is not the intention to restrict the vendor's scope about how to perform measurements.
    c) It is envisaged that measurements will be performed directly by the HeNB or by employing the UEs attached to the HeNB, using existing UE defined measurements.
3) Mechanism to set maximum power
    a) Issues to address include accuracy and timeliness of HeNB maximum power setting.
    b) It is not the intention to restrict the vendor's scope about how to process measurements.
    c) It is not the intention to restrict the vendor's scope about which network element the measurements may be processed in.
    d) It is not the intention to restrict to which network entities measurements are reported. However, it is not envisaged that new signalling will be standardised to support this.
4) Mechanism to adjust HeNB uplink.
    a) Issues to address include possibility to adjust uplink noise rise target.
    b) It is not the intention to restrict the vendor's scope about what actions may be taken regarding HeNB uplink.

5 Radio scenarios

5.1 Deployment configurations

For deployment configurations, FDD HeNB and TDD HeNB will have similar configurations. Please refer to TR 36.922 [28].

5.2 Interference scenarios

For interference scenarios, FDD HeNB and TDD HeNB will have similar scenarios. Please refer to TR 36.922 [28].

6 HeNB RF Aspects

FDD HeNB and TDD HeNB will have similar RF requirements. Please refer to TR 36.922 [28].

7 Guidance on How to Control HeNB Interference

7.1 HeNB Measurements

Several types of measurements that HeNB can perform are listed in the following subsections. The objectives of the HeNB measurements are

- to provide sufficient information to the HeNB for the purpose of interference mitigation
- to provide sufficient information to the HeNB such that the HeNB coverage can be maintained.

According to the measurement type, some of these measurements can be collected through Connected Mode UEs attached to the HeNB or via a DL Receiver function within the HeNB itself. Such DL receiver function is also called Network Listen Mode (NLM), Radio Environment Measurement (REM) or "HeNB Sniffer".

These measurements can also be used during the HeNB self-configuration process.

7.1.1 Measurements from all cells

This section identifies the potential measurements performed by HeNB during self-configuration and normal operation. Based on the measurements in Table 7.1.1-1, the HeNB can obtain useful information from its surrounding cells for purposes such as interference management.

Table 7.1.1-1: HeNB measurements from surrounding cells

Measurement Type	Purpose	Measurement Source(s)
Received Interference Power	Calculation of UL interference towards HeNB (from MUE)	HeNB UL Receiver

HeNB could use the Received Interference Power measurement to monitor the uplink interference. For example, a Received Interference Power measurement value larger than a pre-defined threshold would mean that at least an MUE which is interfered by a HeNB is close to the HeNB and that the MUE's Tx power would cause significant interference towards the HeNB. This measurement value may be used in calculating path loss between the HeNB and the MUE assuming that a single MUE dominates the interference. It is also preferable for the HeNB to distinguish between UL interference from the MUE and wanted signals from HUEs to improve the accuracy of interference measurement.

7.1.2 Measurements to identify surrounding cell layers

This section identifies the potential measurements performed by HeNB during self-configuration and normal operation. Based on the measurements in Table 7.1.2-1, the HeNB can obtain useful information to identify the layer of its surrounding cells and indirectly identifies other HeNBs nearby for purposes such as mobility handling.

Table 7.1.2-1: HeNB measurements from surrounding cells

Measurement Type	Purpose	Measurement Source(s)
Cell reselection priority information	Distinction between cell types based on frequency layer priority	HeNB DL Receiver
CSG status and ID	Distinction between cell layers based on CSG, and self-construction of neighbour list,	HeNB DL Receiver

7.1.3 Measurements from macro cell layer

This section identifies the potential measurements performed by HeNB during self-configuration and normal operation. Based on the measurements in Table 7.1.3-1, the HeNB can obtain useful information from its surrounding macro cells for purposes such as interference management.

Table 7.1.3-1: HeNB measurements from surrounding macro cells

Measurement Type	Purpose	Measurement Source(s)
Co-channel RSRP	Calculation of co-channel DL interference towards macro UEs (from HeNB) Calculation of co-channel UL interference towards macro layer (from HUEs) Calculation of co-channel UL interference towards HeNB (from MUEs) based on estimated MUE Tx power Determine coverage of macro cell (for optimization of hybrid cell configuration)	HeNB DL Receiver HUE MUE (in case of hybrid cell)
Co-channel RSRQ	Determine quality of macro cell (for optimization of hybrid cell configuration)	HeNB DL Receiver HUE MUE (in case of hybrid cell)
Reference Signal Transmission Power	Estimation of path loss from HUE to MeNB	HeNB DL Receiver
Physical + Global Cell ID	Allow HeNB to Instruct UEs to measure specific cells. Allow UE to report discovered cells to HeNB.	HeNB DL Receiver HUE
Detection of UL RS	Detection of victim UE	HeNB UL Receiver

HeNB could detect the presence of a dominant UL interferer in order to determine if there is a nearby victim UE requiring protection on the DL.

If a HeNB has receiver capability, in addition to the measurements listed in Table 7.1.3-1, HeNB is able to measure the received CRS Êc, measured in dBm, which is the Reference Signal Received Power per resource element present at the Home BS antenna connector for the Reference Signal received on the co-channel. For CRS Êc determination, the cell-specific reference signal R0 according TS 36.211 shall be used. If the HeNB can reliably detect that multiple TX antennas are used for transmission on the co-channel, it may use the average in [W] of the CRS Êc on all detected antennas. On start-up, the HeNB can measure the CRS Êc power from the most dominant co-channel deployed macro cell.

Table 7.13-2: HeNB measurements from surrounding macro cells

Measurement Type	Purpose	Measurement Source(s)
Co-channel received CRS Êc (measured in dBm)	Measurement is used to determine whether HeNB is close to dominant Macro cell, or whether it is close to macro-cell-edge border.	HeNB DL Receiver

7.1.4 Measurements of other HeNB cells

This section identifies the potential measurements performed by HeNB during self-configuration and normal operation. Based on the measurements in Table 7.1.4-1, the HeNB can obtain useful information from its adjacent HeNBs for purposes such as interference management.

Table 7.1.4-1: HeNB measurements from adjacent HeNBs

Measurement Type	Purpose	Measurement Source(s)
Co-channel RSRP	Calculation of co-channel DL interference towards neighbour HUEs (from HeNB) Calculation of co-channel UL interference towards neighbour HeNBs (from HUEs)	HeNB DL Receiver HUE
Reference Signal Transmission Power	Estimation of path loss from HUE to HeNB	HeNB DL Receiver
Physical + Global Cell ID	Allow HeNB to Instruct UEs to measure specific cells Allow UE to report discovered cells to HeNB.	HeNB DL Receiver HUE

7.2 Control of HeNB Downlink Interference

7.2.1 Control Channel Protection

Several techniques have been considered for data interference management (see [3] for a list of some of these techniques). However control channel interference management is equally important since improved data SINR is not useful if the UEs cannot receive control channels. Thus, it is vital to have techniques that address control channel interference.

Downlink control channel (PDCCH) interference can occur in two directions in co-channel HeNB deployments.

- HeNB (aggressor) to macro-UE (victim), and
- macro-eNB (aggressor) to HUE (victim) if the UE is connected to a weaker HeNB cell (e.g. to access local information at the HeNB).

This can lead to problems both in connected mode and in idle mode such as:

1) UE being unable to reliably decode paging channel resulting in missed pages and therefore a user's inability to receive UE-terminated calls,
2) UE being unable to read common control channels, and
3) throughput degradation or degraded PDSCH performance.

The following are some of the techniques that could be used for control channel protection. It should be noted that some of these aspects may require UE implementation changes and should be considered for Rel 10 and beyond. It is possible that these methods offer gains for Rel 8/9 UEs; however, this needs to be studied further.

7.2.1.1 Time shifting for overlapped carriers with frame time shifting at symbol level

7.2.1.1.1 Time shifting at symbol level

This technique is applicable when the HeNB and the eNB are time-synchronized. This approach uses time shifting of HeNB transmission by k symbols (i.e. to avoid overlap with macro-eNB control region size k) relative to macro-eNB downlink frame timing and uses HeNB/macro-eNB power reduction or muting on the portion of a symbol (or symbols) that overlap the control region of macro-eNB/HeNB (see Figure 7.2.1.1). The HeNB (macro-eNB) could also use power reduction on all the RBs (i.e. say 25 RBs) overlapping the macro-eNB (HeNB) control region to improve PDSCH performance for macro-eNB (HeNB). A single OFDM symbol HeNB control region ($n = 1$) is preferred for PDSCH efficiency which leaves 5 CCEs for HeNB control channels which should be sufficient for HeNB control signaling. However the use of all allowed symbols for control is not precluded.

Due to the time shift of HeNB transmissions, the last k symbols of the HeNB PDSCH region would see interference from the macro-eNB control region. In a similar way, some symbols in the PDSCH region of macro-eNB would see interference from a HeNB. The HeNB PDSCH overlap with macro-eNB control region could be further mitigated by either

a) using truncation so that only *14-n-k* symbols would be used for HeNB PDSCH or

b) not using truncation (i.e, using *14-n* symbols) but accounting for the overlap via link adaptation including resource allocation and MCS selection.

In Figure 7.2.1.1, a subframe shift plus two symbol shift (k = 16) is shown where the HeNB SCH/PBCH do not overlap with macro-eNB SCH/PBCH. Then HeNB (macro-eNB) would have to mute or attenuate its PDSCH symbol(s) overlapping the macro-eNB (HeNB) control region and would also attenuate or mute RBs or just the overlapping REs that overlap on the HeNB PBCH and SCH. If attenuation or muting is carried on a PRB level (by scheduling only close-by UEs or not scheduling any UEs in 6 PRBs respectively), scheduling can be conducted as normal and therefore, there are no Rel-8 backwards compatibility issues.

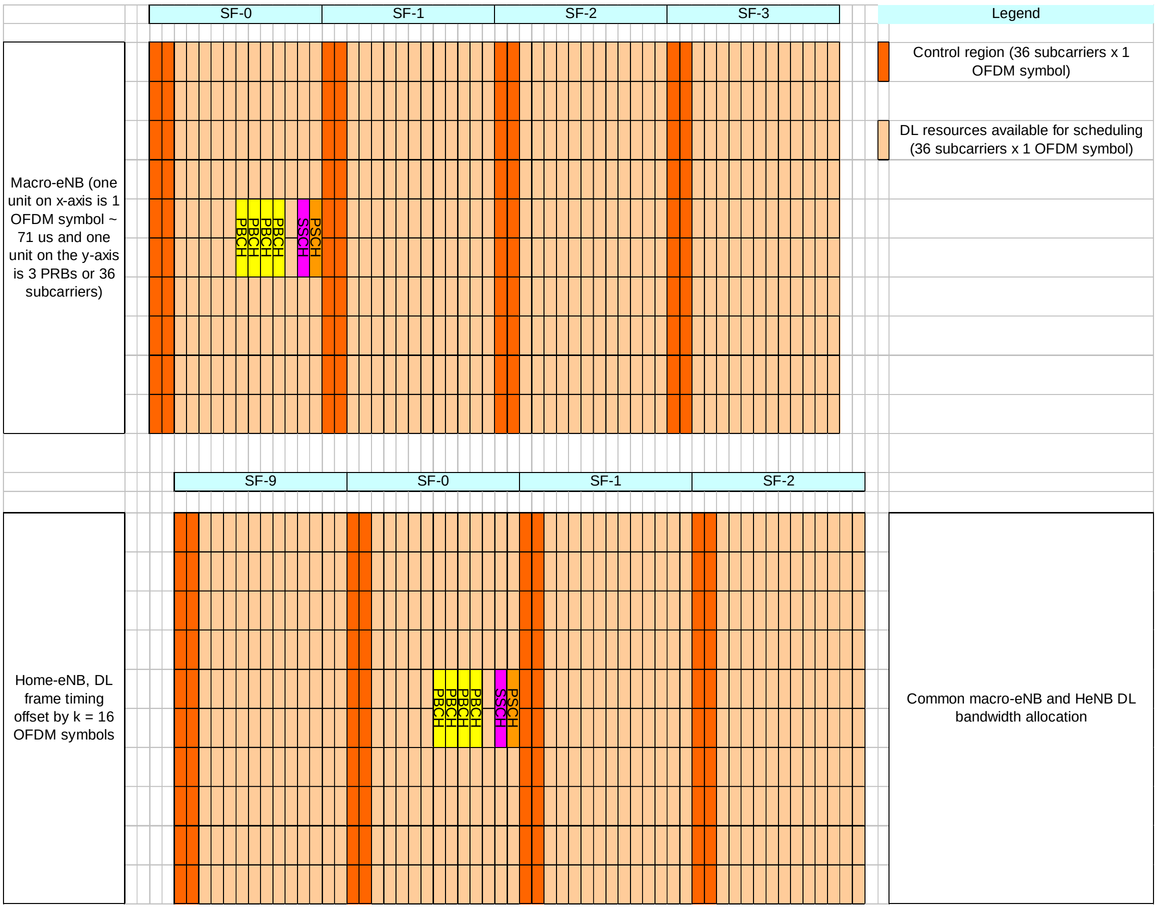


Figure 7.2.1.1 Time-shift HeNB frame timing by k = 16 OFDM symbols relative to macro-eNB timing

7.2.1.1.2 Carrier offsetting (possibly in addition to frame time shifting)

The HeNB carrier frequency can be offset from the macro-eNB carrier by 6 RBs or more in order to mitigate SCH/PBCH interference from macro-eNB. This is suitable when the HeNB downlink bandwidth is smaller than the macro-eNB downlink bandwidth (eg. 5 MHz HeNBs are deployed within a 10 or 20 MHz macro-eNB overlay). This avoids interference from HeNB (macro-eNB) to macro-eNB (HeNB) SCH/PBCH, if the HeNB (macro-eNB) were to reduce power or mute six RBs overlapping with the macro-eNB (HeNB) SCH/PBCH. Carrier offsetting could also be used in conjunction with frame time shifting, as seen in Figure 7.2.1.2.

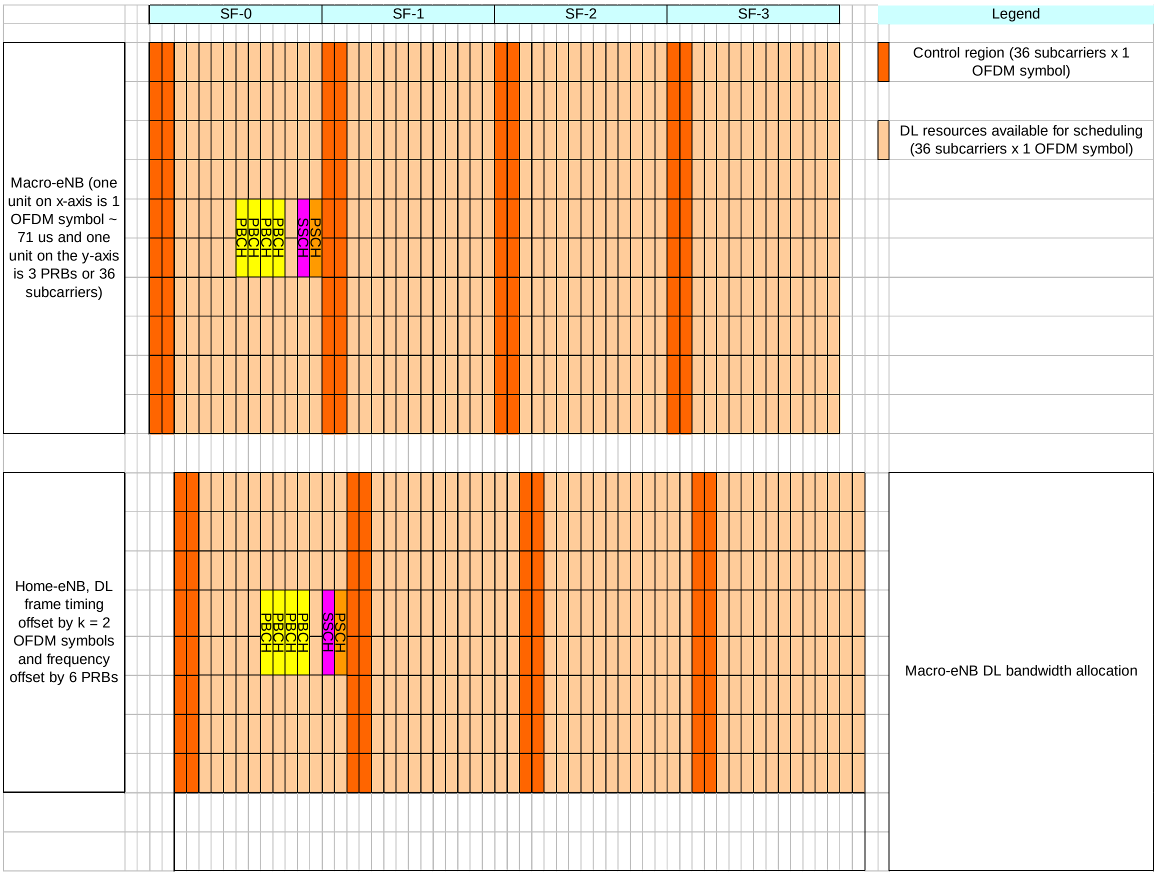


Figure 7.2.1.2 Time-shift HeNB frame timing by k = 2 OFDM symbols and offset the HeNB carrier by 6 PRBs (1.08 MHz) relative to macro-eNB timing and carrier respectively

7.2.1.2 Carrier offsetting or frequency partitioning with per-subband interference estimation

Frequency partitioning, or carrier offsetting, where HeNBs are confined to use only a part of the bandwidth can be used to mitigate interference problems. This scenario is shown in Fig. 7.2.1.2-1. By using scheduling techniques that would avoid data transmissions on those parts of the bandwidth, the levels of interference as seen at the receiver can be reduced. This could resolve the interference problem for the data transmissions, however, control channels such as PDCCH that span the entire bandwidth would still be affected.

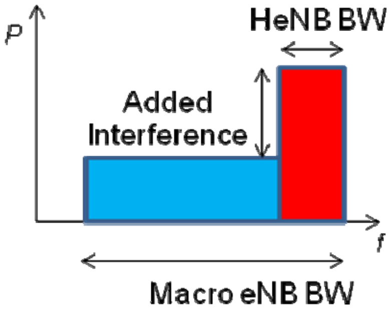


Fig. 7.2.1.2-1 Partial Bandwidth Coexistence

The effects of the high interference seen in one of the subbands can be mitigated if the interference estimation is done on a per-subband basis. This would confine the influence of the interference only to that subband and not allow it to affect the entire bandwidth. This in turn would mean that only some of the coded bits are affected. When wideband interference estimation is used, all the bits are affected and the probability of successfully decoding the message decreases. Assuming sufficient number of CCEs are used (i.e., enough code protection), the PDCCH BLER performance would be slightly degraded. But the transmission would likely be reliable enough not to significantly affect normal operation.

To illustrate the performance of this scheme, some simulation results are given. A simulation was performed to evaluate the impact on control channel performance of high interference on one of the subbands. Results for the cases of per-subband interference estimation and wideband interference estimation are presented.

The simulation considers a HeNB that uses one fourth of the bandwidth of the macro as shown in Fig. 7.2.1.2-1. A UE connected to a macro-eNB and receiving PDCCH transmission from it, sees high interference on one of the subbands. The level of interference is varied as a parameter relative to the noise level. The PDCCH error rate is compared for the cases when wideband interference estimation and per-subband interference estimation are used. The simulation parameters are given in Table 7.2.1.2. Only the results for 4 CCE PDCCH are given here but similar results were observed for other PDCCH sizes. A more extensive analysis and simulation results can be found in [14].

Table 7.2.1.2: Simulation parameters used

Parameter	Assumption
Information payload size	40 bits
Coding	1/3 rate TBCC with rate matching
Macro Bandwidth	5 MHz
HeNB bandwidth	1/4 of macro Bandwidth
Channel model	TU, 3km/h
Channel estimation	2-D MMSE channel estimation
Interference estimation	Ideal

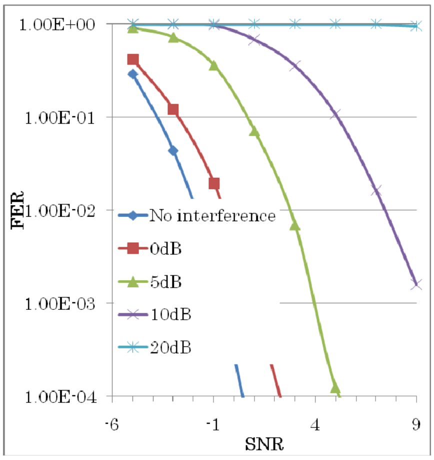


Fig. 7.2.1.4.2 4 CCE PDCCH BLER with wideband interference estimation

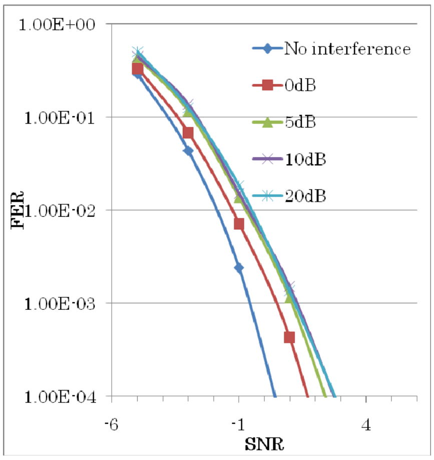


Fig.7.2.1.4.3 4 CCE PDCCH BLER with subband interference estimation

7.2.1.3 Control of HeNB downlink interference among neighboring HeNBs control channels by frequency partitioning

Unlike data (PDSCH, PUSCH), there is no HARQ for control channel transmissions which must typically target fairly low BLER of 1% or less. HeNBs that are in close proximity of each other will not have reliable downlink control channels (e.g. PDCCH, PHICH, PCFICH, PBCH, P/S-SCH). One way to solve this is to segment the LTE carrier and allow the interfering HeNBs to transmit their control signaling in separate frequency domain resources. For example, if the LTE carrier is 20MHz then it would be segmented into two 10MHz carriers on the downlink with each of the two interfering HeNBs transmitting its control signaling (PDCCH, PHICH, PCFICH, P-SCH, S-SCH, PBCH) on one of the 10 MHz carriers.

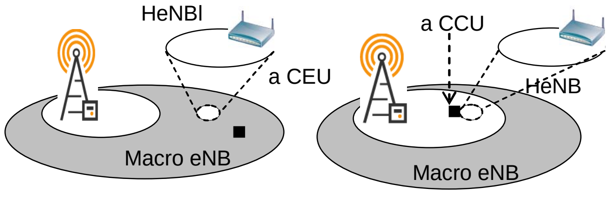
Both Release-8 UEs and Release-9 UEs would access the HeNB as a 10 MHz carrier and receive control and broadcast signaling from HeNB within 10 MHz. However, Release-10 UEs can additionally be assigned PDSCH resource on the remaining 10 MHz frequency resources using carrier aggregation. Therefore, while Release-8/9 UEs are limited to allocations of 50 RBs, Release-10 UEs could be assigned any portion of the 100 RBs.

7.2.2 Data Channel Protection

7.2.2.1 Control of HeNB Downlink Interference towards macro eNB data channels by frequency partition

Frequency partition between Macro eNB and HeNB can be utilized to mitigate the interference from HeNB to Macro eNB. HeNB can get frequency partition information of its neighbor Macro eNB through air link measurement if additional receiver is enabled on HeNB. Alternatively, a semi-static scheme can be adopted if a pre-configuration of the frequency partition can be determined by Macro eNB management server. For example, Macro eNB will schedule resource blocks to Macro UE based on its location. When HeNB gets its own location information, it will know which resource blocks will be assigned to a nearby macro UE.

With the knowledge of the frequency partition information [4], for example, HeNB knows which set of resource blocks will be used for Macro eNB cell center users (CCU), and which set of resource blocks will be used for Macrocell cell edge users (CEU), HeNB can coordinate its transmission to avoid its interference to nearby Macro UE by giving high scheduling priority to resource blocks not used by the nearby Macro UE. For example, if HeNB is located at the edge of the Macro eNB, HeNB will give higher priority to resource blocks used by macro center UEs for downlink transmission. If HeNB is located at the center of the Macro eNB, HeNB will give higher priority to resource blocks used by macro edge UEs for downlink transmission as shown in Figure 7.2.2.1-1.



(a) (b)

Figure 7.2.2.1-1 Examples of HeNB and macro UE location

In addition, to minimize the mutual interference between HeNB and surrounding cells, RSRP measurements and cell re-selection priority information in SIBs or RRC message from neighbour cells could be utilized for HeNB to adaptively select its operating carrier frequency [8, 9].

The original purpose of cell-reselection priority information is for UE to properly select its camping cell based on the frequency layer priority of each carrier. For interference avoidance, this information can be utilized by HeNB to appropriately select its operating frequency by decoding SIBs or RRC message from its neighbour cells during normal operation or in self-configuration mode. At the same time, HeNB should also measure co-channel or adjacent channel RSRP of the neighbour cells to make a proper selection. Furthermore, if the priority information of the neighbour cells is changed at a certain time after the HeNB has already started up, the HeNB should periodically update the priority information, measure the RSRP and adjust its operating frequency (if necessary).

Figure 7.2.2.1-2 below depicts a scenario where the HeNB is overlaid by both higher and lower priority frequency layers as shown for HeNB cell 1, and another scenario where the HeNB is overlaid by only one frequency layer as shown for HeNB cell 2.

For HeNB cell 1, when the measured RSRP of both higher and lower priority frequency layers exceed a predefined set of thresholds which implies that it is overlaid by more than one frequency layers, the HeNB should select its operating frequency that is being used by the cell that has the lower priority for interference mitigation. As illustrated in Figure 7.2.2.1-2, the HeNB cell 1 should select RF1 which is the lower priority carrier frequency. On the other hand, if the HeNB is overlaid by only one priority carrier frequency as shown for HeNB cell 2 in Figure 7.2.2.1-2, the HeNB should select a carrier frequency that corresponds to the smaller measured RSRP. For example, the HeNB cell 2 in Figure 7.2.2.1-2 should select RF2 which has smaller RSRP.

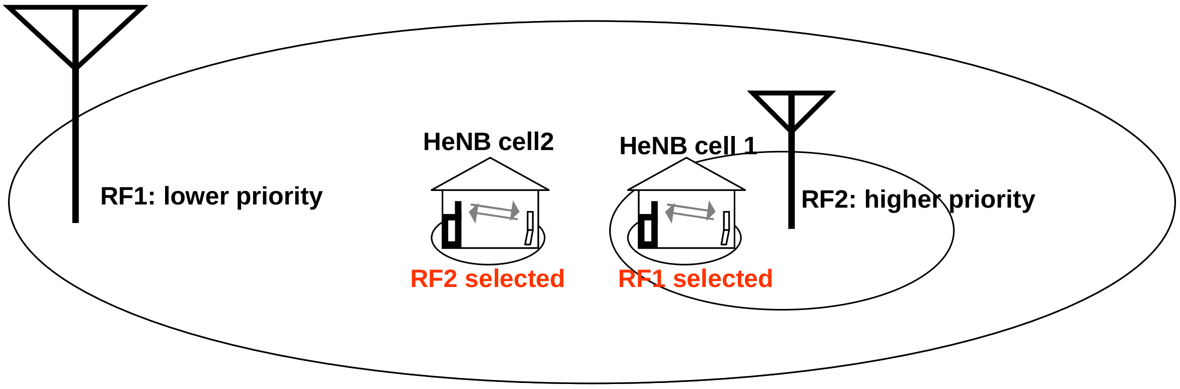


Figure 7.2.2.1-2 Examples of adaptive frequency selection scheme

The adaptive frequency selection scheme is applied most effectively to HeNBs in non-allowed CSG mode for avoiding the interference. In the case when the HeNB is operating in an open or hybrid access mode, it may also apply the scheme for interference avoidance.

7.2.2.2 Control of HeNB Downlink Interference among neighboring HeNBs

When powered on, a HeNB listens to neighboring HeNBs' control channel and reference signal transmissions, determines the cell ID of each neighboring HeNB and measures the path loss from each of them. In addition, the HeNBs could also use reports from UEs.

Based on this information, HeNBs could use fractional frequency reuse (FFR) to orthogonalize the resources used and increase the overall performance of the network.

7.2.2.2.1 Centralized Coordination

The centralized coordinator can form an adjacency graph of all HeNBs based on the reports from each HeNB.

Each HeNB estimates the fraction of time it needs to transmit according to the traffic load and channel conditions of its UEs, and reports this ratio to the centralized controller via S1 signaling.

- For mixed traffic with both delay sensitive traffic and delay tolerant traffic, two ratios which correspond to both traffic types will be reported.
- Each HeNB needs to update its report when at least one of the following event happens:
  - New traffic session initiation

- UE channel condition variation over a pre-defined threshold

Given the adjacency graph and the reported ratios from each HeNB, the centralized coordinator determines

Option 1: the subframes that each HeNB is allowed to transmit, and notifies each HeNB of its transmission pattern via S1 signalling.

A HeNB needs to properly configure DRX parameters of its UEs according to the transmission pattern notified by the centralized coordinator.

Option 2: the subbands or carrier frequency that each HeNB is allowed to transmit, and notifies each HeNB of its transmission pattern via S1 signalling.

Note that the S1 signalling load between HeNBs and the centralized coordinator could be large if the number of HeNB connections per coordinator is significant. To reduce S1 signalling, it is preferable to limit the number of HeNB reports to the centralized coordinator. For example, the centralized coordinator can assign a HeNB a lot more resources than it actually needs, and the HeNB will not send a report to the centralized controller unless it uses up all the assigned resources. As HeNBs are generally lightly loaded, a HeNB may rarely send a report if it is assigned a large fraction of resources (i.e. sub-frames).

7.2.2.2.2 Distributed Dynamic Frequency Partitioning

Based on the information collected, the HeNBs can construct a "Jamming Graph" where each node denotes an active HeNB and an edge denotes jamming condition between two HeNBs. A jamming condition is declared when the channel gain difference between the interfering and serving links exceeds a certain threshold. The distributed fractional frequency reuse planning problem is now converted into a graph coloring problem, which could be solved in a distributed manner at low complexity.

Examples of such algorithms and brief performance analysis are given in [13], [16], [19] for both the FDD and TDD case.

This algorithm could be an adaptive algorithm in which resources are negotiated and adaptively allocated for different nodes, based on a utility function that enables nodes to quantify the benefit or loss due to each resource coordination action [18]. These utility values can then be used at each node to select the right resource coordination requests to be sent to their neighbours, or to select the best requested coordination action from among multiple received requests, and hence to grant/reject the requests based on their quantified benefit to the network.

To support this adaptive algorithm, network nodes need to exchange information such as subbands reuse updates and utility information. The performance depends significantly on the latency of the messaging, especially in the case of non-full buffer traffic. This information should be taken into account while analyzing the different options for such information exchange (e.g. X2, S1, over-the-air, over-the-air via UE).

7.2.2.3 Control of HeNB Downlink Interference by dynamically changing HeNB CSG ID

To mitigate HeNB interference as well as to prevent free HeNB usage by neighbours, one option is to change the CSG ID of a closed access HeNB dynamically between

- Its default CSG ID which is assigned when it is deployed and
- A dedicated CSG ID which is configured by the operator.

This dedicated CSG ID is included in the Operator CSG list [15] (clause 5.3.2 "Closed Subscriber Group") for every UE in the operator network. When the closed access HeNB changes its CSG ID to the dedicated CSG ID, it actually becomes accessible to each passing-by UE, thus alleviating its interference towards the macro cell. Note that this scheme would only be beneficial when a large fraction of UEs support CSG.

By dynamically changing the CSG IDs of closed access HeNBs in a coordinated manner, it might be possible to ensure that the number of closed access HeNBs using default CSG IDs under each macro cell does not go beyond a pre-defined upper bound at any time instant.

- A centralized controller (e.g. HeNB Gateway or HeNB management server) can set the upper bound, and configures, for each HeNB, the time intervals it supports the default CSG ID and the dedicated CSG ID, respectively. Then each HeNB dynamically varies its CSG ID based on the configuration parameters provided by the centralized controller.

- ▪ Different macro cells may have different or common upper bounds.
- ▪ Whenever a HeNB is deployed, the centralized controller can determine its adjacent macro cell based on its location and configure the time intervals it will employ the default CSG ID and the dedicated CSG ID, respectively.
- ▪ The mechanisms of when and how to select a set of HeNBs is FFS. It may be possible to carefully arrange time intervals to employ default CSG IDs for different HeNBs to ensure that the number of closed access HeNBs using default CSG IDs under every macro cell can be upper limited at any time instant.
  - E.g. some HeNBs may use default CSG IDs the first 30 minutes of every hour, but others may not; alternatively, some HeNBs may use default CSG IDs 9AM-11PM everyday, but others may do.
- ▪ The upper bound can be determined by
  - Simulation/numerical analysis
  - HeNB subscription profile
    - > E.g. make HeNBs "less open" if the subscription rate is high and the subscribers desire to do so.
  - Macro cell load
    - > E.g. make HeNBs "more open" when macro cell is heavy loaded, and "less open" when macro cell is lightly loaded.

Further study of this proposals and comparison to alternatives (e.g. hybrid cells) may be needed. In particular, the UE and core network impact of dynamically changing the CSG ID is for further study by the relevant working groups.

7.2.2.4 Downlink interference management based on mapping between PCIs and transmission patterns

Interference Management based on mapping between PCIs and transmission patterns requires a centralized coordinator. The centralized coordinator generates a number of transmission patterns and a function which maps transmission patterns to PCIs, and then sends to all cells the information of transmission patterns and the mapping function. The essentials of this scheme are as follows:

- When powered on, a HeNB will listen to neighbouring cell transmissions, determine the Cell ID of these neighbouring HeNBs, and report them to the centralized coordinator.
- The centralized coordinator can form an adjacency graph of all HeNBs based on the reports from each HeNB as well as its UEs.
- Given the adjacency graph, the centralized coordinator determines the followings semi-statically:

  a set of transmission patterns; A pattern shows a profile of maximum Tx power for each PRB or group of PRBs

  a function which maps transmission patterns to PCIs

- The centralized coordinator notifies to HeNBs and MeNBs of the followings via S1 signaling.

  the set of transmission patterns

  the function which maps transmission patterns to PCIs

- This notification makes it possible that all cells share the information of the transmission patterns and the mapping between the patterns and PCIs.
- HeNB should use PRBs according to the transmission pattern corresponding to its PCI.

Downlink interference management can be done as follows:

If a UE connected to a serving (H)eNB is close to a neighbouring HeNB, the downlink of the UE can be severely degraded due to high interference from the neighbouring HeNB. The serving (H)eNB can be macro eNB or HeNB. The UE detects the PCI and measures the RSRP of the neighbouring HeNB, and reports these to the serving (H)eNB. Because of the sharing of the information of the transmission patterns and the mapping between these patterns and PCI, the serving (H)eNB knows the transmission pattern of the neighbouring HeNB that the UE is close to. This makes it possible for the serving (H)eNB to allocate downlink resource such that the UE is not severely interfered by the neighbouring HeNB on its downlink.

7.2.2.5 Techniques for Dynamic Frequency Partitioning

Interference in HeNB network interference can be mitigated through fractional frequency reuse (FFR) by orthogonalizing dominant interferers. Compared to a simple carrier-reuse, a frequency reuse that can be tailored to each user offers an increase in capacity and better flexibility. LTE supports subband FFR via subband CQI reporting, which allows a scheduler to schedule users based on the subband CQI reporting that reflects different interference levels on different subbands. In a 10 MHz system with 6 RBs/subband, there are 8 regular subbands and one short subband that could be used to implement fractional frequency reuse.

A distributed FFR algorithm is designed to cope with non-operator deployed networks, such as HeNBs. Each HeNB could construct an RF neighbour list through network listening and user reporting. In this method, the local RF neighbour information is called a "Jamming Graph", where each node denotes an active HeNB and an edge denotes jamming condition between two HeNBs. A jamming condition is declared when the channel gain difference between the interfering and serving links exceeds certain threshold. The distributed FFR planning problem is now converted into a graph coloring problem, which could be solved in a distributed manner at low complexity.

An example of such an algorithm and a brief performance analysis is given next [16], [17].

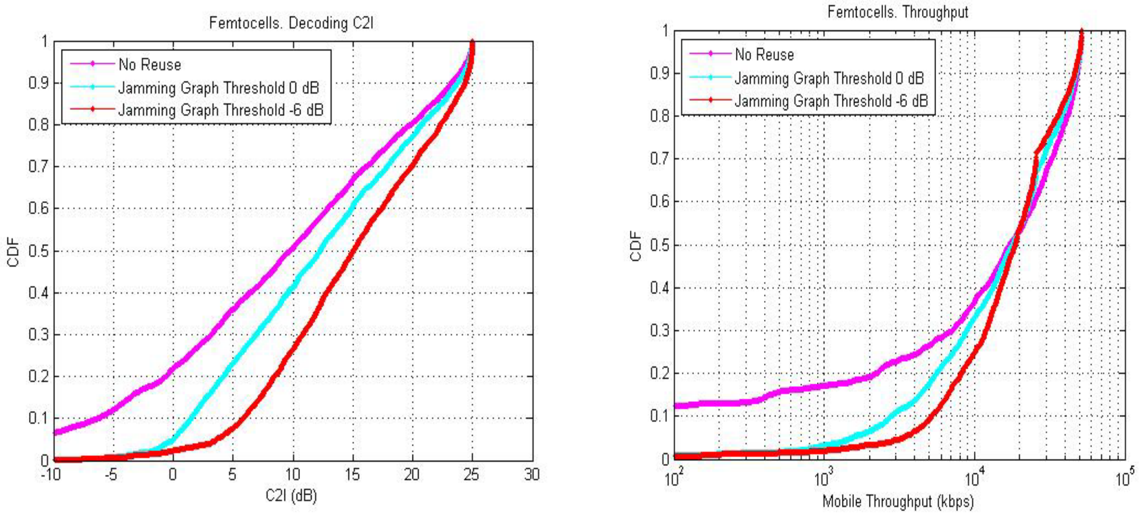
The link level performance is based on single user 2x2 MIMO with channel and interference estimation loss. Link adaptation and HARQ are modelled and the baseline performance has been calibrated with NGMN Rel. 8 performance for D1 scenario. Typical LTE system parameters are used resulting in a total system overhead close to 41%.

Other parameters are given in Table 7.2.3.1.

Table 7.2.3.1 Simulation parameters

Parameter	Value
HeNB Tx Power	10dBm
Path loss	127+30log10(R/1000)
Shadowing standard deviation	10dB
Deployment model	5x5 Grid Model

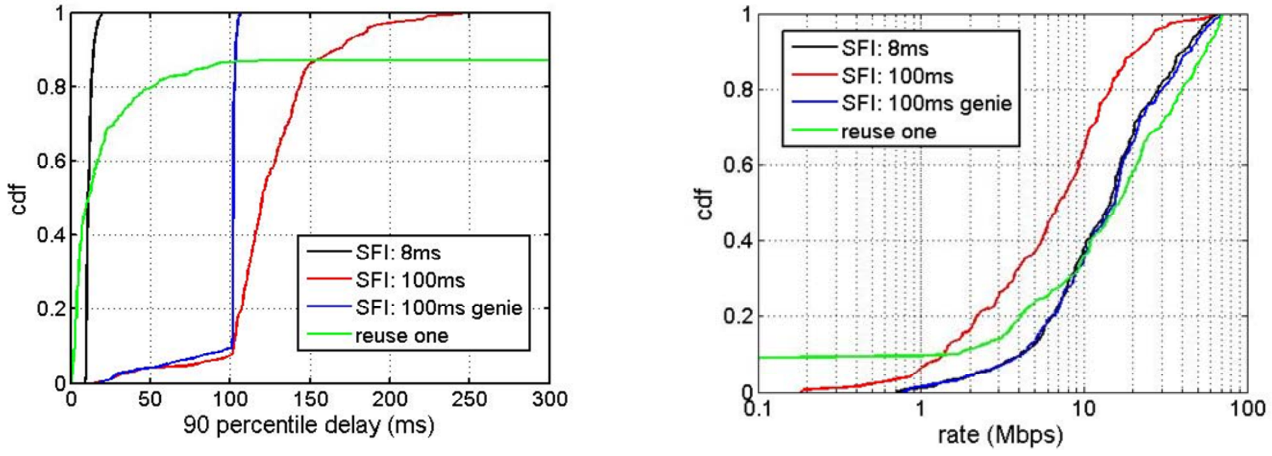
Three interference management schemes have been compared: Rel 8 with frequency reuse 1; distributed FFR with medium level of interference orthogonalizaton; distributed FFR with high level of interference orthogonalization. The level of orthogonalization is controlled by tuning the jamming graph threshold, i.e., the channel gain difference between interfering and serving link. In this simulation, 0 dB and -6 dB thresholds have been studied. The decoding C/I and mobile throughput statistics are shown in Fig. 7.2.3.1 for 20% penetration rate with full buffer traffic. It can be seen that distributed FFR schemes eliminate system outage and significantly improve the system fairness. Similar results are obtained for different penetration rates [16].



(a) Decoding C/I (b) Mobile throughput

Figure 7.2.3.1 Mobile throughput and decoding C/I for 20% penetration rate

The performance of this scheme was also analyzed for a mixed traffic model [17]. A mix of delay sensitive (QoS) flows and full-buffer flows was considered. Each UE has only one flow which is either delay-sensitive or full-buffer. For full-buffer flows, the user performance is dependent on the average rate. In particular, we assume a log utility function (corresponding to proportional fair) for full-buffer flows. The delay CDF for QoS flows and the rate CDF for full-buffer flows are plotted in Fig. 7.2.3.2. In this case reuse one is compared to a FFR scheme based on spatial feedback information (SFI) with different delays. SFI genie shows an upper bound on the performance of the large delay SFI case. These results show that FFR can significantly improve system efficiency and ensures fairness with mixed traffic also [17].



(a) Delay CDF for QoS **(b) Rate CDF for full-buffer**

Figure 7.2.3.2 Delay and data rate CDF for mixed traffic with 50% penetration

A further refinement of this algorithm is an adaptive algorithm in which resources are negotiated and adaptively allocated for different nodes, based on a utility function that enables nodes to quantify the benefit or loss due to each resource coordination action [18]. These utility values can then be used at each node to select the right resource coordination requests to be sent to their neighbours, or to select the best requested coordination action from among multiple received requests, and hence to grant/reject the requests based on their quantified benefit to the network. The utility function can be selected in accordance with the scheduler metric used at different nodes, in which case it will enable a distributed enforcement of network-wide fairness. This scheduling metric can be considered as the marginal utility function, i.e., the derivative of a utility function that the frame-by-frame scheduler attempts to iteratively maximize. One example of such utility function is $U = \sum_i U_i(R_i) = \sum_i \log(R_i)$ $U = \sum_i U_i(R_i) = \sum_i \log(R_i)$, where R_i is the long-term or average throughput of user *i*. This corresponds to the well-known proportionally fair scheduler, with the scheduling metric of $dU = \sum_i U'(R_i) dR_i \approx \sum_i r_i / R_i$ $dU = \sum_i U'(R_i) dR_i \approx \sum_i r_i / R_i$ where r_i is the instantaneous rate of user *i*. To enforce network-wide fairness, the above utility function can be extended to the entire network and defined as the sum of utilities of all individual users in the network. This utility-based resource coordination algorithm aims at adaptively determining the network-wide utility-maximizing resource allocation set for any given channel and interference conditions. Note that, with this approach, resource usage does not need to be a binary decision of either using the resource at full/nominal PSD or not using it at all, and can instead be a soft decision, or at least a selection from a set of multiple possible PSD values.

A brief performance evaluation of this scheme is shown in Fig. 7.2.3.3. The simulation parameters are the same as for the previous results. A total of four resources are defined over the entire band and the allowed PSDs on different resources are obtained by multiplying the scaling factors from the following sets; two levels: {0, 1}, three levels: {0, 0.1, 1}. These results show that substantial gains in tail and average throughput can be achieved, translating into improved network-wide fairness. Although not shown here, similar results are obtained for different penetration rates [18].

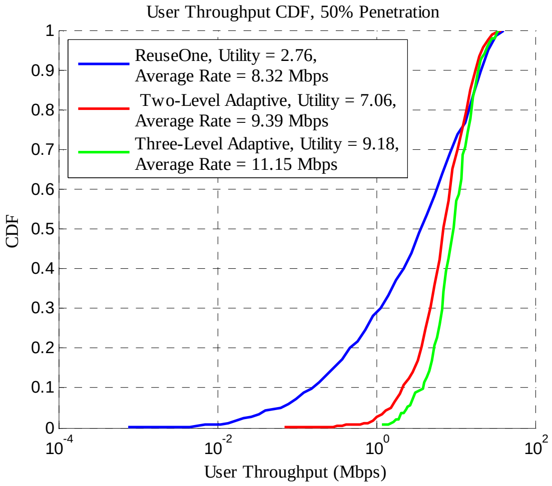


Figure 7.2.3.3: User throughput CDF for reuse one and adaptive resource coordination with 50% penetration

7.2.2.5.1 Support for dynamic FFR

The above results demonstrate the benefits of frequency reuse (and resource reuse in general) based on information exchange between eNBs. Furthermore, utility information exchange can enable network-wide fairness, which ensures that the maximum number of users can benefit from HeNB deployments. To support the adaptive algorithm introduced above, network nodes need to exchange information such as subbands reuse updates [19] and utility information [18]. It was also shown that the performance depends significantly on the latency of the messaging, especially in the case of non-full buffer traffic. This information should be taken into account while analyzing the different options for such information exchange (e.g. X2, S1, over-the-air, over-the-air via UE).

7.2.2.6 Victim UE Aware Downlink Interference Management

For closed access HeNBs, protection of the downlinks of other cells is an important consideration and can be done on the basis of managing the usage of power and/or resource blocks. This may restrict the operation of the HeNB such that the HeNB performance may be degraded. To avoid restricting the HeNBs unnecessarily, it could be useful to detect whether there are victim UEs in the vicinity of the HeNB. If so then full protection could be provided. If not then a reduced level of protection can be provided.

Two basic approaches to determining whether there are victim UEs in the vicinity of a HeNB are:

A) Determination at the macro or HeNB on the basis of reported UE measurements.

B) Determination at the HeNB on the basis of detection of uplink transmissions from victim UEs.

7.2.2.6.1 Determination based on reported UE measurements

There are multiple approaches to use UE DL measurements. In one case, the macro could share the information in a standardized interface (e.g. X2, S1 in future releases) or over a non-standardized interface in Rel 9. In another scenario, the HeNB could be a hybrid HeNB that knows it is the strongest cell and hence a dominant interferer either when the UE accesses it, or when the macro attempts to handover its UE to the HeNB. No new signaling is needed to support the latter.

7.2.2.6.2 Determination based on detected uplink transmissions

Active mode victim UEs in the vicinity of a HeNB will be transmitting data and/or control information on the uplink (using PUSCH, PUCCH, SRS and PRACH) and these uplink transmissions may be detected by the HeNB. In the case of interference management by controlling HeNB downlink power, such an approach has the potential to provide the same level of protection to the macro UEs, while improving HeNB performance when there are no victim UEs nearby.

The victim UEs will be most vulnerable when they are at or near the edge of their own cells and relatively close to the HeNB. In this case the victim UEs will likely be transmitting with a relatively high power and the pathloss to the HeNB will be relatively low. Therefore the SINR of the received reference signals at the HeNB for the most vulnerable UEs is likely to be high, and the detection at the HeNB will be reliable. In [29] it was shown that the SINR would typically be well in excess of 20dB

Two approaches for the detection of uplink transmissions can be considered. These are:

Detection based on IoT

If there are one or more victim UEs in the vicinity of the HeNB, then the IoT will be high. If the uplink transmission from the victim UE(s) only occupies a portion of the frequency or time resource, then the resulting IoT variations in time and/or frequency may be used to distinguish the case of a small number of such UEs close to the HeNB from the case of a higher number of MUEs further away.

Detection of UL RS

In order to better detect if there is a nearby UE requiring protection on the downlink, the properties of the uplink reference signals can be used. The reference signals have markedly different characteristics to the data bearing signals or to noise. The differences are exhibited in the frequency domain (and equivalently autocorrelation function), and time domain (e.g. peak to average ratio) [29]. This applies to reference signals used for PRACH, SRS and demodulation reference signals. Note however that in future releases including LTE-A, for which clustered SC-FDMA and NxSC-FDMA have been agreed, the reference signal properties may change and it is possible that a HeNB may fail to detect a LTE-A macro UE (e.g. because it has higher PAPR)

Combined Scheme

The two approaches above may be combined e.g. such a scheme could operate as follows:

- If IoT on all RBs in a subframe is below a threshold assume no protection is required
- If IoT is above a threshold (in any RB) trigger a set of RS detection attempts. If a RS detection attempt is made when the IoT is high and no MUE is detected, assume protection is not required, otherwise assume detection is required. Note that such detection would require the HeNB to not schedule its own HUEs in some subframes.

For this kind of scheme it is important to consider the false alarm and missed detection probabilities, taking into account the case where the uplink transmissions from victim MUEs are intermittent, the duration for which protection is provided in response to a detection (or false alarm), and the need to only provide protection when there are MUEs nearby to the HeNB (rather than a higher number of further away UEs). The performance of the detection schemes depends on the environment and the number of UEs nearby, their relative powers and channel fades. System-level investigation of the benefit of the combined IoT + RS/PAPR scheme in such a scenario is for further study.

7.2.2.6.3 Protection of idle mode UEs

For both approaches A and B defined above, if the HeNB is closed (CSG), an issue arises as to how to protect idle mode UEs. In the case of approach A, such UEs will not be reporting measurements to the macro eNBs. For approach B, idle mode UEs will not be transmitting in the uplink and therefore there is no opportunity to detect them at the HeNB.

The same methods used to protect macro eNB downlink control channels (PBCH, SCH, PCFICH, PDCCH, PHICH) from HeNBs can also be used to protect these channels for idle mode UEs when employing the victim aware protection schemes. These methods rely on introducing orthogonality in the time or frequency dimension between HeNB transmissions and the eNB control channel transmissions. Furthermore similar approaches could be used for the protection of paging and system information messages. For example the same (e.g. 1 or 2) DL RBs could always be used to send paging and system information mapped to PDSCH from on the macro eNB, and these could always be protected by the HeNB. The RBs to protect at the HeNB could, for example, be configured via S1 signalling or OAM. However, some of these schemes may require UE changes and hence are not applicable to Rel 8/9 UEs. Depending on the schemes employed a closed HeNB may therefore have to always reduce its power if wants to protect idle mode macro UEs.

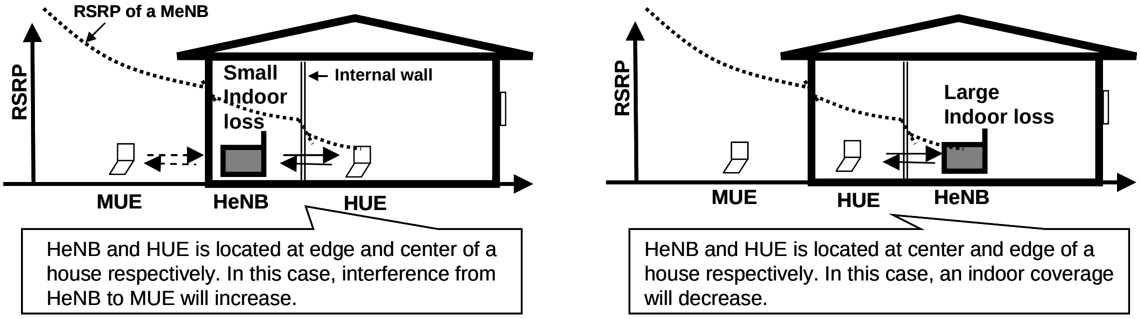
Alternatively if paging-only Hybrid cell is supported, then protection during idle mode is not an issue. In this case while a HeNB can infer the presence of a victim UE which has recently become active immediately after hand-out from the HeNB, detection of the active mode UE is still desirable in order to determine when protection on the downlink is no longer required (due to the victim UE moving away from the HeNB). This could be used as an alternative to the options in 7.2.2.6.1.

7.2.3 Power Control

7.2.3.1 HeNB power control based on HUE measurement

Home eNB (HeNB) typically sets its own transmit power by measuring surrounding RF conditions of macro cells to mitigate interference to macro UE (MUE) and maintain good HeNB indoor coverage for the Home UEs (HUE). However, there may be a significant difference between the RF conditions measured by the HeNB and those experienced by the MUEs or HUEs. Even in an indoor environment, the HeNB and the HUEs may measure significantly different RF conditions in some cases such as between different rooms, or between different floors. It is difficult to solve this difference with NLM only. The NLM during operation may be a big burden on the HeNB.

An example where there is a significant difference between the RF conditions measured by HeNB and HUEs is shown in Figure 7.2.3.1-1. In the left figure, the scenario where a HeNB and a HUE is located at edge and center of a house respectively and a MUE is located at the close proximity of the house is depicted. The edge and the center of the house assume to be isolated by an internal wall. In this case the HeNB transmit power is set to a relatively higher value because the signal level from MeNB (RSRP) is relatively high. As a result the interference to the MUE will significantly increase and the HeNB indoor coverage is unnecessarily widened. On the other hand, in the right figure, the scenario where a HeNB and a HUE is located at center and edge of a house respectively and a MUE is located at the close proximity of the house is depicted. In this case the HeNB transmit power is set to a relatively lower value because the signal level from MeNB is relatively low. As a result the HeNB indoor coverage is significantly narrowed while the interference to the MUE will decrease. In these scenarios it is necessary for the HeNB to consider measurement results of HUEs in order to set transmit power appropriately.



HeNB and HUE is located at edge and center of a house respectively. In this case, interference from HeNB to MUE will increase.

HeNB and HUE is located at center and edge of a house respectively. In this case, an indoor coverage will decrease.

Figure 7.2.3.1-1 Scenarios where HeNB transmit power are not appropriately set.

In order to improve the above described problems, it can be beneficial to utilize HUE measurements (or measurement statistics) to optimize the HeNB transmit power after the initial start up. This is particularly useful in co-channel deployments and can provide better protection for MUEs while maintaining good HeNB coverage for the HUEs. Furthermore, by utilizing HUE measurement reports, the burden on HeNB transmit power control solely based on NLM can be avoided.

HeNB should initially set transmit power of reference signal or maximum downlink transmit power based on measurements of RF conditions of macro cells such as RSRP. Then HUE should measure quality level of the reference signal from the HeNB such as RSRP or RSRQ and report this value to the HeNB via measurement reporting. Based on the measurement results, the HeNB should optimize the transmit power so that the subsequent reported measurement values are close to a predetermined or network notified target value. If multiple HUEs are connected to the HeNB, the minimum value of the reported measurement results from each HUE should become close to the target value. The measurement result may be measurement statistics such as x-percentile value.

As shown in [10], the above scheme can improve the problem shown in Figure 7.2.3.1-1. In the left figure the HeNB will decrease the transmit power and the interference to the MUE will be mitigated because the HUE measurement result shows good quality and it is preferable to decrease the transmit power. In the right figure the HeNB will increase the transmit power and the indoor coverage will be widened because the HUE measurement result shows poor quality and it is preferable to increase the transmit power.

7.2.3.2 Smart power control based on interference measurement from macro BS

In the absence of alternative techniques such as resource partitioning, a fixed maximum power setting configured by the network is not sufficient to ensure minimum HeNB coverage range while protecting macro in all cases. Hence, a sensing of the HeNB environment can be used for setting the transmit power.

The HeNB adjust its maximum DL transmit power as a function of air interface measurements to avoid interfering with macro cell UEs. Examples of such measurements are total received interference, received CRS Êc from the most dominant macro cell eNB, etc. The scheme is open loop, and does not involve the UEs and signaling between network nodes.

The HeNB shall adjust its maximum transmit power according to the following formula,

$$P_{tx} = \max(\min(\alpha \times (CRS\ \hat{E}_C + 10\log(N_{RB}^{DL} \times N_{SC}^{RB})) + \beta, P_{\max}), P_{\min})\,[dBm] \qquad (1)$$

where parameters P_{max} and P_{min} is the maximum and minimum HeNB transmit power settings, CRS Êc is measured in dBm, which is the Reference Signal Received Power per resource element present at the Home BS antenna connector received from the strongest co-channel macro cell. N_{RB}^{DL} is the number of downlink resource blocks in the HeNB channel. N_{sc}^{RB} is the number of subcarriers in a resource block ($N_{sc}^{RB} = 12$). Parameter α is a linear scalar that allows altering the slope of power control mapping curve, β is a parameter expressed in dB that can be used for altering the exact range of CRS Êc covered by dynamic range of power control.

Parameters P_{min}, α, and β are considered to be HeNB configuration parameters, and P_{max} corresponds to the HeNBs maximum transmit power capability.

For the special case where the HeNB is unable to detect any co-channel deployed macro cells. The HeNB is free to use its maximum transmit power, or apply pre-set parameterized value based on the requirement of operator.

7.2.3.3 HeNB power control based on HeNB-MUE path loss

HeNB should adjust the downlink transmit power by taking into account the path loss between the HeNB and an outdoor neighbor MUE including penetration loss in order to provide better interference mitigation for the MUE while maintaining good HeNB coverage for HUEs.

HeNB should set the transmit power of reference signal P_tx as follows:

P_tx (dBm) = MEDIAN(P_m + P_offset, P_tx_upp, P_tx_low)

Where:

- P_m (dBm) is RSRP from the nearest MeNB measured by the HeNB. P_m is dependent on path loss which includes the penetration loss between the nearest MeNB and the HeNB.

- P_offset (dB) is the power offset described below in detail.
- P_tx_upp/P_tx_low (dBm) is the upper/lower limit value for the transmit power of the reference signal. The maximum and the minimum total transmit power of HeNB should follow HNB in [20].

The HeNB can also set the maximum downlink transmit power in proportion to the transmit power of the reference signal. As the RSRP decreases, which means the HeNB is located close to the edge of the macro cell, the transmit power should be small in order to mitigate the downlink interference to the MUE.

P_offset above should be defined based on path loss between the HeNB and the MUE. The path loss may consist of indoor path loss between the HeNB and cell edge of HeNB cell and the penetration loss. Therefore, P_offset should be formulated as follows:

P_offset = MEDIAN(P_offset_o + K*LE, P_offset_max, P_offset_min)

Where:

- P_offset_o (dB) is a predetermined power offset value corresponding to the indoor path loss. Typical value range between 50 and 100dB, and can be determined by the averaged measurement value.
- K is an adjustable positive factor can be determined by the priority of HeNB operation. This value should be high to increase the total transmit power (MeNB is more acceptable to higher interference) and low to reduce the interference to MeNB operation.
- LE (dB) is estimated penetration loss as below.
- P_offset_max/P_offset_min (dB) is the maximum/minimum value of the P_offset by which the estimated and calculated P_offset can be prevented from being too large or too small. This value is dependent of the actual wall penetration loss plus P_offset_o. And the typical wall penetration loss ranges between 10 and 30dB.

If the path loss between the HeNB and the MUE can be estimated, then the transmit power of the HeNB should be set accordingly.

The path loss between the HeNB and the MUE should be estimated based on the difference between the estimated UL transmit power and the UL reception power (as the Received Interference Power) of the MUE. The estimated UL transmit power is based on the assumption that UL power control is applied for both MUE and HeNB as a UE. Then the UL transmit power can be calculated by the DL propagation loss from the surrounding MeNB to the HeNB utilizing the RSRP measurement.

7.2.3.4 GPS Based HeNB Maximum Output Adjustment

GPS is used to locate the geographical position of the user for more than a decade. Among other positioning methods, the assisted GPS (A-GPS) is considered to be one of the most viable and commonly used methods. It is tailored to work with a user terminal (UE) and thus enables UE subscribers to relatively accurately determine their location, time, and even velocity (including direction) in open area environment provided sufficient number of satellites are visible. A HeNB can incorporate a GPS or A-GPS receiver similar to the one used in the UE for location services.

7.2.3.4.1 Maximum Output Power Adjustment based on GPS Detection Performance

The GPS receiver in HeNB is used to set the maximum output power of the HeNB. Two type of information can be exploited from the GPS receiver, namely the number of detected satellites (N_S) and the reception quality (Q_R) of the detected satellites. In a normal environment, at least 4-5 satellites should be visible with sufficient quality to obtain good accuracy of the geographical location. Furthermore, the reception quality can be an aggregate value of all the detected satellites e.g. weighted average of all detected satellites or certain number of strongest satellites. Herein, we refer N_S and/or Q_R as GPS detection performance. Other examples of the reception quality can be the reception signal level, duration for determining the HeNB location, and accuracy of the detected location.

Depending upon the GPS detection performance, the maximum output power of HeNB can be set according to different mapping functions as shown below.

(1) Mapping the number of detected satellites N_S to the maximum output power of the HeNB (Pmax_HeNB):

$$F(\alpha_1 N_S) \rightarrow P_{\mathrm{max\_HeNB}}, \qquad (1)$$

(2) Mapping the reception quality Q_R to the maximum output power of the HeNB (Pmax_HeNB):

$$F(\alpha_2 Q_R) \rightarrow P_{\mathrm{max\_HeNB}}, \qquad (2)$$

(3) Mapping the number of detected satellites N_S and the reception quality Q_R to the maximum output power of the HeNB (Pmax_HeNB):

$$F(\alpha_1 N_S, \alpha_2 Q_R) \rightarrow P_{\mathrm{max\_HeNB}}, \qquad (3)$$

where α_1 and α_2 are the weighting factors. Any suitable mapping function such as weighted sum or average can be used. The above mapping functions are used to create lookup tables with multiple maximum output power levels for HeNB.

A poor GPS detection performance corresponds to a scenario where HeNB is isolated and shielded from outside base stations. This means less interference is generated by the HeNB to the outside Macro UE. Therefore higher maximum output power can be used in order to extend the HeNB coverage within the building. On the other hand, a good GPS detection performance indicates that the location of the HeNB may cause significant interference to the outside and therefore lower maximum output power should be used at HeNB in order to protect the Macro UE.

Effectively, GPS detection performance estimates to what degree the HeNB and outside base stations are isolated. The cause of the isolation in most cases is building penetration loss. Therefore one possible function of adjusting the maximum output power should be based on the estimated penetration loss, which can be obtained by the difference between an indoor measured GPS detection performance and a typical value that corresponds to an outdoor measured one.

7.2.3.4.2 GPS Detection Performance Combined with Macro eNB Measurements

The GPS based approach can also be combined with Macro eNB measurements in order to further adjust the maximum output power at HeNB. In this case, the HeNB measures the surrounding radio environment and detect the signal level of Macro eNB. This information, together with GPS detection performance, are used to adjust the maximum output power of HeNB.

7.3 Control of HeNB Uplink Interference

7.3.1 Control Channel Protection

7.3.1.1 HeNB Uplink Control Channel Protection

In the uplink, physical uplink control channel (PUCCH) interference from

- HUE (aggressor) to macro-eNB (victim),
- MUE (aggressor) to HeNB (victim), and
- HUE (aggressor) to HeNB (victim)

can be mitigated by enabling orthogonal transmissions. Uplink control signaling (PUCCH, CQI) reliability can be maintained for both HeNBs and macro-eNBs by making use of PUCCH offsets for enabling orthogonal PUCCH assignments between the HeNB and macro-eNB users. For PUCCH transmissions, over-provisioning can be made use of to ensure orthogonality of control channels between a HeNB UE and a macro-eNB UE as shown in Figure 7.3.3.1. It is possible to employ this method for Release-8 UEs without changing the physical layer design or RAN2 signaling.

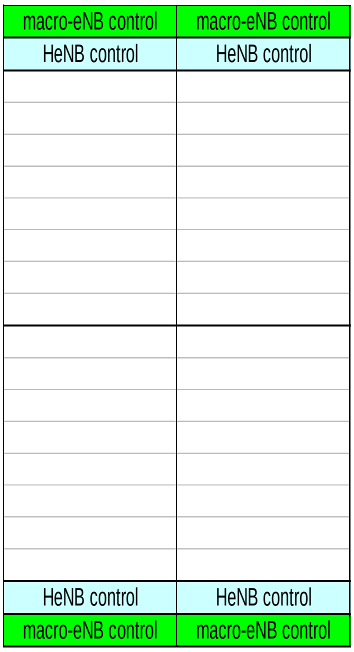


Figure 7.3.1.1 UL control interference mitigation by PUCCH orthogonalization

7.3.1.2 Signaling offset over the backhaul

It would be desirable for the macro-eNB to signal an offset to all HeNBs within its coverage area in order that transmissions from UEs connected to HeNBs do not cause interference at the macro-eNB receiver (e.g., a HeNB deployed in close range of a macro-eNB). Conversely, a macro-eNB UE that is at the cell edge and therefore transmitting close to its maximum transmit power can interfere severely with a HeNB UE and the signaled offset can be made use of to mitigate interference. Alternately, a HeNB gateway can signal over S1, the offsets that each HeNB should use, thus providing the capability of configuring orthogonal PUCCH transmissions in neighboring HeNBs thereby avoiding HeNB (aggressor) to HeNB (victim) interference on the uplink.

One option for the HeNBs is to not allocate PUCCH resources on edge RBs as shown in Fig. 7.3.3.1 using over-provisioning. A typical macro-eNB deployment is likely to have PUCCH transmission on the band-edges to maximize the number of contiguous RBs that can be allocated to PUSCH. However, unlike macro-eNBs, utilizing the full uplink bandwidth may not be critical for HeNBs as they serve only a few users at a time. Therefore, the PUCCH resources in HeNBs can be "pulled" inward. The edge RBs not used by the HeNBs can be used by the macro-eNB for PUCCH for its UEs. Also, the macro-eNB, being aware of the RBs used by HeNBs in its coverage area, can schedule some users (e.g. UEs close to the macro and not near any HeNB) on RBs that overlap with HeNB UE PUCCH region. This results in reduced interference from macro-eNB UEs to HeNB UE PUCCH.

7.3.2 Power Control

7.3.2.1 Smart Power Control based on Path Loss to Worst Victim Macro eNodeB

Interference from the Home UE (HUE) to the Macro eNodeB (MeNB) is particularly significant if the HUE is located close to the MeNB. On the other hand, an indoor HUE near its serving HeNB and far from the MeNB may be harmless. As pointed out in [20], the HUE transmission power should be controlled based on path loss (PL) from the HUE to its worst victim MeNB (i.e. nearest neighbour MeNB).

The PL from HUE to MeNB can be estimated from HUE measurements of Reference Signal Received Power (RSRP) and MeNB Reference Signal (RS) Transmission (Tx) power. HeNB might know MeNB RS Tx power by means of decoding the variable "referenceSignalPower" in System Information Block Type2 (SIB2) message broadcasted from MeNB [21]. In FDD mode, the estimated downlink PL might be used for an approximation of uplink PL.

During this work item, such smart power control methods are proposed and their performance gain is investigated [22][23]. The methods are as follows.

7.3.2.1.1 Power Cap Method

In this method, the maximum transmission power density (i.e. power cap) of HUE is restricted based on the interference rise at MeNB. The power cap is calculated as the function of PL from the HUE to its worst victim MeNB. The HUE is power-controlled based on PL to its serving HeNB, up to the level of the power cap.

Simulation results have been generated for an urban deployment model with varying HeNB density and for either full buffer or bursty traffic. The results are assume a fixed power cap of either 0.2 dB (labelled "tight") or 7 dB (labelled "loose", and it should be noted that this is a very loose cap, for which in practice the home UE power will likely be set considering coverage requirements of the HeNB alone rather than also considering interference to the macro layer).

7.3.2.1.1.1 Simulation Assumptions

The simulation parameters largely follow the assumption in [24], [25] with the following specific parameters

Table 7.3.2.1.1.1-1: Simulation Parameters

Parameter	Assumption
Deployment	Urban depolyment Macro layer has 7 sites (21 sectors) with wrap-around, 500m ISD. 0% (urban) of home UEs are outdoors and 20% of macro UEs are outdoors.
Number of macro UEs per sector	20
Exterior wall loss	20dB
Shadowing correlation (one BS to multiple UEs)	Correlated shadowing
Macrocell power uplink control	Max power based on limiting noise rise to macro neighbours
Femtocell uplink power control	Max power based on limiting noise rise to macro neighbours (a similar approach to that described in [20] section 7.3.1 for WCDMA).
Link to system mapping	Per sub-carrier capacity approach
Scheduler	Frequency selective/Proportional fair
Traffic model	Full buffer or Bursty In the case of bursty traffic being modelled, 70% of UEs use the bursty traffic model (see [22] Appendix), the remaining UEs are full-buffer.
Apartment block model	Dual stripe, 6 floors (=240 apartments), one "dual stripe" randomly dropped per macro sector. A variable probability of having active femto in each apartment.
Pathloss model	Full (rather than simplified) model [24]

7.3.2.1.1.2 Simulation Results

Figure 7.3.2.1.1.2-1 below shows the average macrocell sector throughput as a function of the probability that there is an active HeNB in an apartment. Results are shown for two values of the target maximum "noise rise" that the home UE should generate at the macro eNB ("tight" and "loose"). It can be seen that with a low density of active HeNBs the "loose" approach provides adequate protection whereas at higher densities the "tight" cap is appropriate. This goes for both the full buffer and the bursty traffic models.

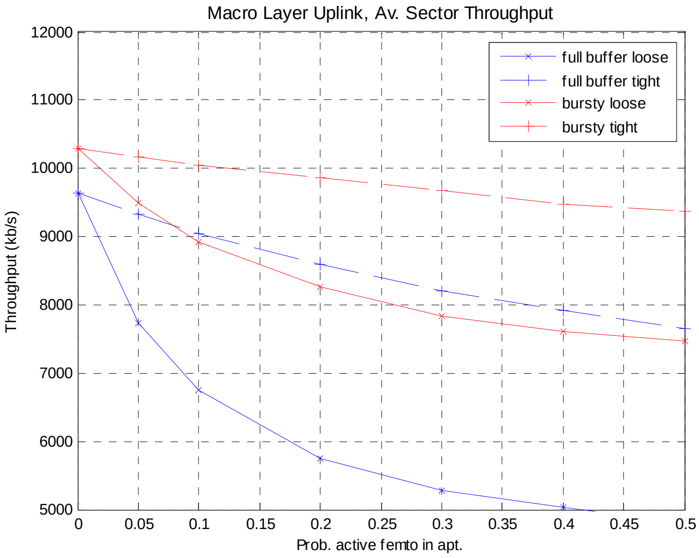


Figure 7.3.2.1.1.2-1: Macrocell uplink average sector throughput

Figure 7.3.2.1.1.2-2below shows the cell edge (5 percentile) macro user throughput as a function of the probability that there is an active HeNB in an apartment. Again it can be seen that with a low density of active HeNBs the "loose" approach provides adequate protection whereas at higher densities the "tight" cap is appropriate. This goes for both the full buffer and the bursty traffic models.

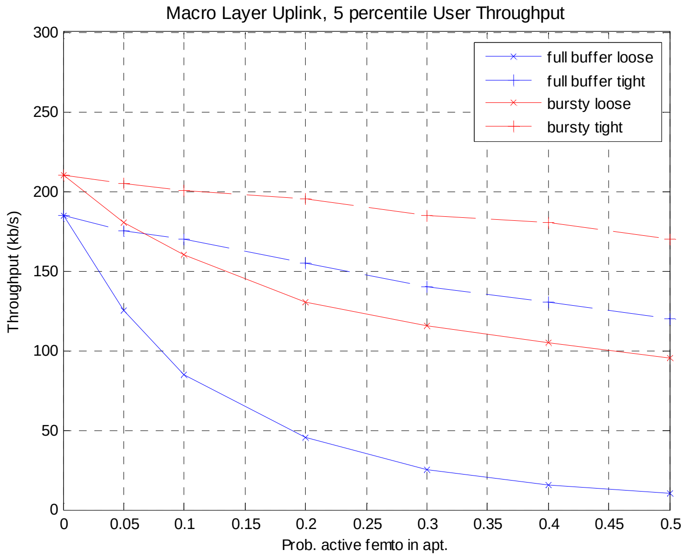


Figure 7.3.2.1.1.2-2: Macrocell uplink 5 percentile user throughput

Figure 7.3.2.1.1.2-3 below shows the mean Interference over Thermal (IoT) at the macro eNB. It can be seen that the IoT is controlled more with the "tight" cap particularly at high HeNB densities.

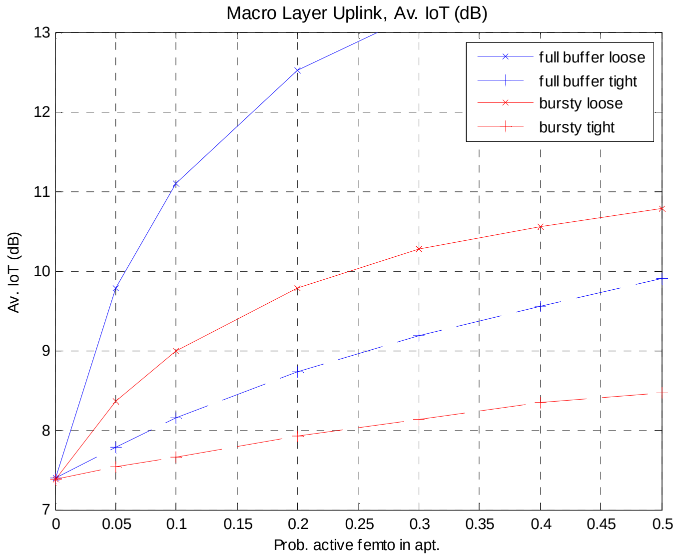


Figure7.3.2.1.1.2-3: Macrocell Interference over Thermal

Figure 7.3.2.1.1.2-4 below shows the average HeNB sector throughput as a function of the probability that there is an active HeNB in an apartment. It can be seen that the "loose" cap results in a higher throughput. This goes for both the full buffer and the bursty traffic models.

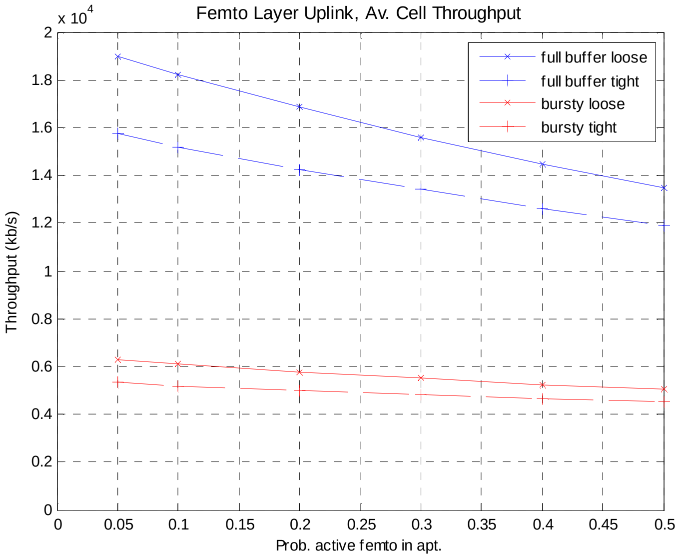


Figure7.3.2.1.1.2-4: Femtocell uplink average sector throughput

Figure 7.3.2.1.1.2-5 below shows the cell edge (5 percentile) home user throughput as a function of the probability that there is an active HeNB in an apartment. Again it can be seen that the "loose" cap results in a higher throughput.

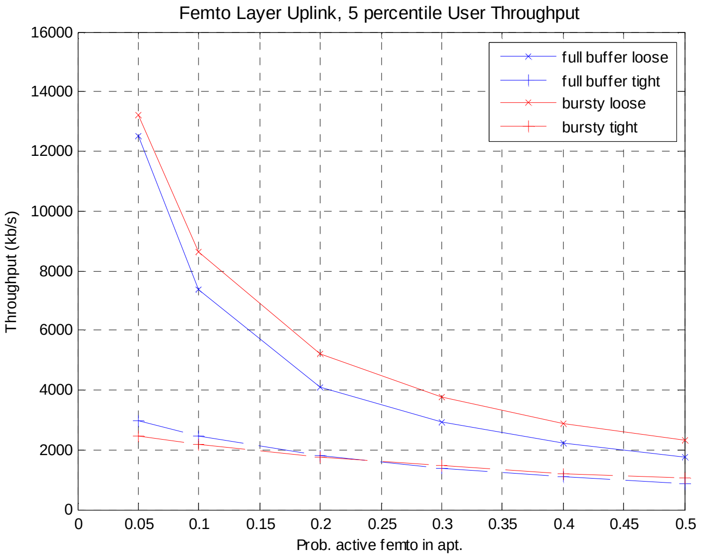


Figure7.3.2.1.1.2-5: Femtocell uplink 5 percentile user throughput

Figure 7.3.2.1.1.2-6 shows the mean Interference over Thermal (IoT) at the HeNB.

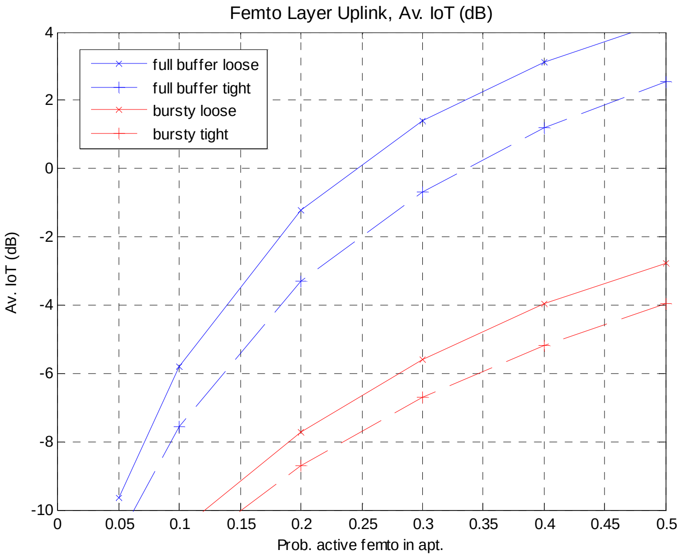


Figure7.3.3.1.1.2-6: Femtocell Interference over Thermal

7.3.2.1.1.3 Discussion of Results

For low densities of HeNB a "loose" power cap is sufficient which allows higher HeNB throughputs than the "tight" power cap which is required for higher HeNB densities.

7.3.2.1.2 Power Control based on PL from HUE to its serving HeNB and PL from HUE to its worst victim MeNB

The UE specific term of the transmission power density $P_{\text{O\_PUSCH}}$ should be defined as the function of PL from HUE to its serving HeNB ($PL_{\text{HUE-HeNB}}$) and PL from HUE to its worst victim MeNB ($PL_{\text{HUE-MeNB}}$) because the uplink transmission power is explicitly defined as the form using PL from UE to its serving eNodeB in the current specification [26]. For example, the power control where the UE specific term of $P_{\text{O\_PUSCH}}$ is set to $PL_{\text{HUE-MeNB}} - \alpha \times PL_{\text{HUE-HeNB}} + \text{interference\_rise\_at\_MeNB}$ (in dB) corresponds to the power cap method (The term $-\alpha \times PL_{\text{HUE-HeNB}}$ is cancelled by path loss compensation term and the parameter α is path loss compensation coefficient [9]). In general, the UE specific term of $P_{\text{O\_PUSCH}}$ might be non-decreasing function of $PL_{\text{HUE-MeNB}}$ and the dependency of $PL_{\text{HUE-HeNB}}$ is implementation issue.

One realization of such power control is proposed during this work item; PL difference based power control. In this method, the UE specific term of $P_{\text{O\_PUSCH}}$ is defined as the non-decreasing function of PL difference $\Delta PL = PL_{\text{HUE-MeNB}} - PL_{\text{HUE-HeNB}}$ (in dB). The explicit form of the UE specific term of $P_{\text{O\_PUSCH}}$ is shown in [23].

7.3.2.1.2.1 Simulation Assumptions

The simulation parameters largely follow the suburban model defined in [24] with the following specific parameters,

Table 7.3.2.1.2.1-1: Simulation Parameters

Parameter	Assumption
Deployment	Suburban model Macro layer has 7 sites (21 sectors) with wrap-around, 500m ISD. 10% of home UEs are outdoors and all macro UEs are indoors.
Number of macro UEs per sector	10
Exterior wall Loss	20dB
Shadowing correlation (one BS to multiple UEs)	Correlated shadowing
Macrocell power uplink control	Closed loop ICIC based on overload indicator, targeting the IoT value to 10 dB
Femtocell uplink power control	PL difference based TPC and FPC (for comparison)
Link to system mapping	EESM, same β value for all MCS
Scheduler	Frequency selective / Proportional fair
Traffic model	Full buffer
Pathloss model	Full model [24]

7.3.2.1.2.2 Simulation Results

Figures 7.3.2.1.2.2-1 and 7.3.2.1.2.2-2 show the MUE and HUE throughputs for various HeNB densities, which is the number of HeNB per macro sector. The power control based on PL difference (PL-diff.) and conventional fractional power control (FPC) (set 2 of [25]) are compared. These results are appeared in [23].

Figure 7.3.2.1.2.2-1 indicates that the PL difference based power control mitigates the degradation of MUE throughput than FPC. Figure 7.3.2.1.2.2-2 (right) shows the PL difference based power control can keep the HUE average throughput at the same level of FPC. Its cost is the degradation of HUE 5 percentile throughput as shown in Fig. 7.3.2.1.2.2-2 (left). In the suburban model with 10 % outdoor HUE, the HUE that is correspond to HUE 5 percentile throughput is mainly located outdoors.

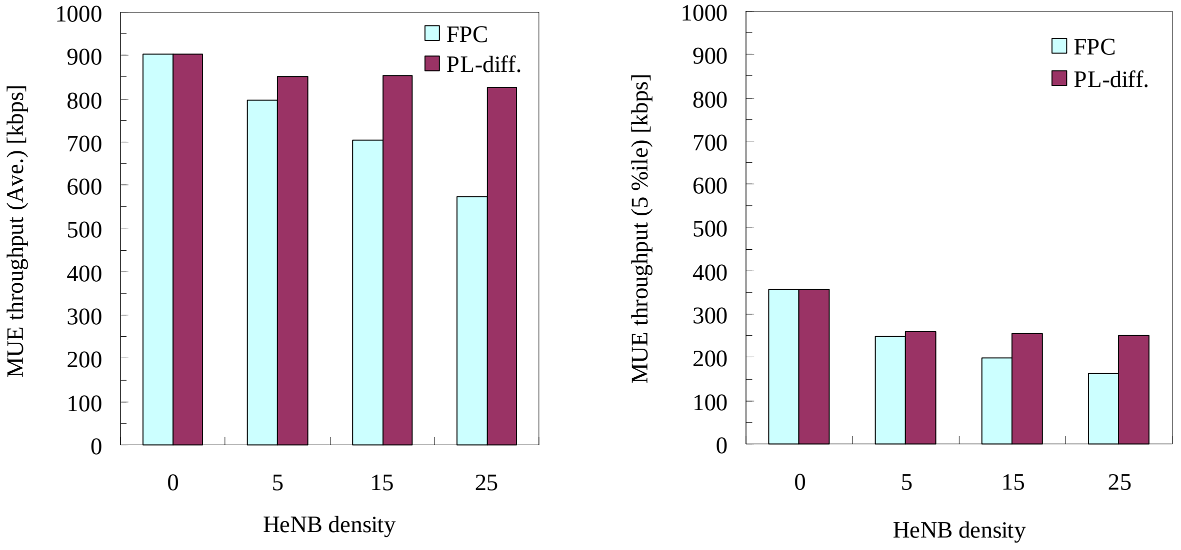


Figure 7.3.2.1.2.2-1: MUE throughput (Left: Average, Right: 5 percentile)

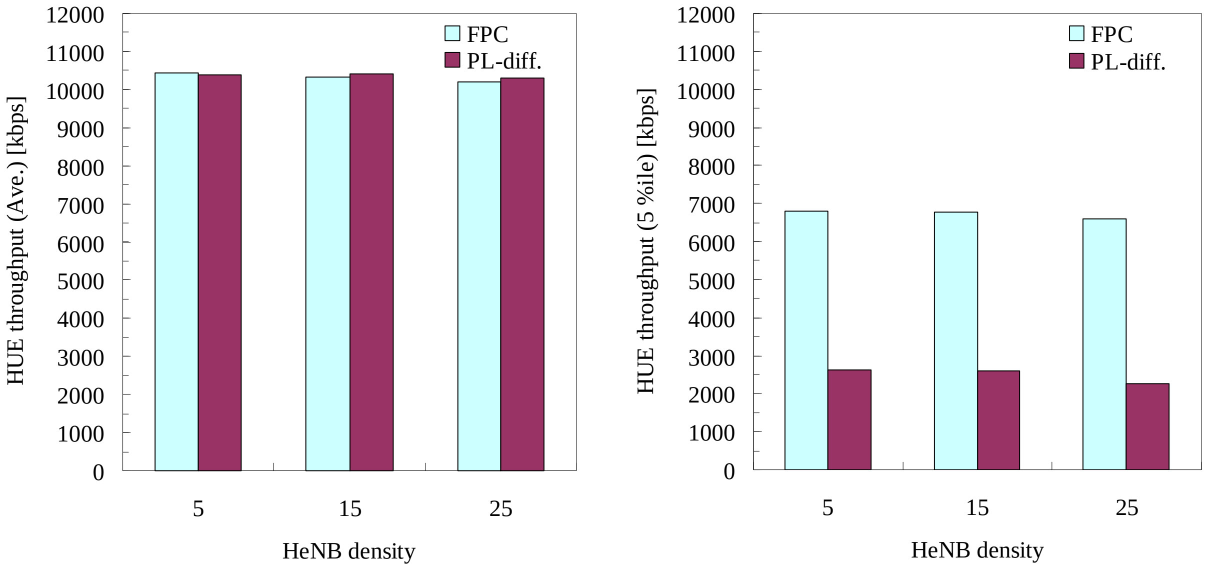


Figure 7.3.2.1.2.2-2: HUE throughput (Left: Average, Right: 5 percentile)

7.3.2.1.2.3 Discussion of Results

The power control based on PL difference can mitigate the degradation of MUE throughput. Its cost is the degradation of HUE 5 percentile throughput which is mainly correspond to outdoor HUE.

7.3.2.1.3 For Future Releases

The above smart power controls require no interference coordination between eNodeBs. As the result, it might be difficult to manage the interference from HUE as HeNB density increases. For future releases (LTE Release 10 or LTE-Advanced), the adaptive power control by means of X2 or S1 signaling between MeNB and HeNB or between HeNBs should be investigated (e.g. to take account of the density of active femtocells within a macrocell coverage area). Notice that during this work item, the adaptive power controls are proposed and their performance gain is investigated [22][27].

7.4 HeNB Self-configuration

7.4.1 Information Exchange between eNBs and HeNBs

The provision of information exchange between eNBs ↔ HeNBs and HeNBs ↔ HeNBs has potential benefits in allowing HeNBs to take account of uplink and downlink conditions at nearby eNBs and HeNBs when configuring power and/or resource blocks to use in uplink and downlink.

We consider several relevant metrics to compare these approaches:

(1) Latency: It was recognized in several contributions that a reliable low latency scheme is desirable for interference management. In [11] it was discussed that the adaptation of HeNB parameters could be relatively slow, such that changes in interference/loading at eNB are not tracked on a sub-frame by sub-frame, or frame by frame, basis, but rather more slowly as the traffic load varies on the eNB. Simulation results in [4] showed that with 50ms latency such relatively slow adaptation still offers significant performance benefits. Similarly simulation results in [12] also showed significant performance benefits at comparable latencies. Further benefits can be obtained by faster interference coordination [13], especially in the case of bursty traffic.

(2) Scalability and Complexity: It is desirable to have the network complexity scale in a manageable manner with increasing number of HeNBs, UEs etc. Furthermore, different approaches are expected to have different implementation impacts at different network entities (eNB, MME etc.).

(3) Overhead: The signaling overhead for exchanging interference management messages (for both the backhaul and Over-the-Air methods discussed subsequently) should be small.

Possible approaches for performing the information exchange are illustrated in Figure 7.4.X-1 and their potential benefits and drawbacks are described in the following. Flexible operations should be allowed to choose one or combination of information exchange approaches in HeNB deployment.

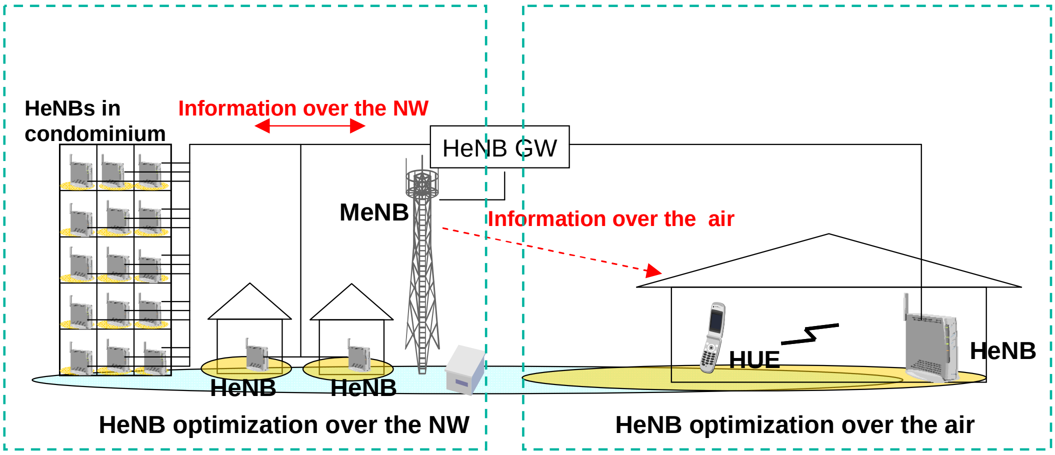


Figure 7.4.X-1: Illustration of information exchange for Over-the-Air and Network based approaches

Option1. Over-the-air information, direct eNB to HeNB

Potential benefits of this approach include:

- No impact to network load.
- Low latency for information signalled from eNB to HeNBs.
- Predictable timeline (independent of backhaul conditions), can be used for coordinated scheduling/transmission.

While this approach may offer low latency, there are several drawbacks:

- The eNB may not always be visible from the HeNB, even though there are victims requiring protection.

- For some advanced approaches for managing interference, it may be desirable to send different information to different groups of eNBs or HeNBs. An over the air broadcast would preclude such operation.
- The downlink would need to be interrupted whenever information is read over the air.
- Requires changes to eNB implementation

Option2. Over-the-air information, (H)eNB to HeNB via UE

For the DL: a victim UE forwards interference coordination related information to the aggressor HeNB.

For the UL: An aggressor UE forwards interference coordination related information from the victim (H)eNB to its serving (H)eNB.

Potential benefits of this approach:

- The downlink would not need to be interrupted to receive information over the air.
- Lower latency compared to backhaul solutions (i.e. Option3 and 4) (higher latency relative to Option 1).
- Predictable timeline (independent of backhaul conditions), can be used for coordinated scheduling/transmission.
- Different information can be sent to different HeNBs

Potential drawbacks to this approach:

- Rel8 UEs can't be used to relay the messages.
- Requires changes to (H)eNB implementation
- Can increase the number of UEs that need to be handled by the HeNB.

Option3. X2 based interface between eNB and HeNB, and between HeNBs

The potential benefits of this approach:

- Higher accuracy of information received at destination than the Over-the-Air approach
- Different information can be sent to different groups of eNBs or HeNBs

The potential drawbacks of this approach:

- The eNB may have large numbers of HeNBs within its coverage area which potentially means the macro would need to deal with many messages to/from HeNBs. Ways in which this could be mitigated could be considered by the relevant working groups for further study e.g. X2 could be between macro eNBs and HeNBs via HeNB gateways only, with the HeNB gateways performing a distribution/aggregation function towards the HeNBs. To reduce the complexity further the set of supported X2AP procedures could be limited, e.g. no handover over X2, and only sending Load Indication (OI, HII, RNTP) in the direction macro eNB to HeNB.
- Potentially large latency.

Option4. S1 based interface between eNB and HeNB, and between HeNBs

In some cases it is likely that direct physical links would not exist between (H)eNBs and HeNBs, and as such X2 would be a logical interface sharing a similar physical path to S1. With this in mind it could be argued that the information exchange could be made over S1 instead of X2. If compared to the X2 based approach there are some potential benefits to this approach:

- Higher accuracy of information received at destination than the Over-the-Air approach
- Different information can be sent to different groups of eNBs or HeNBs
- S1 signalling interface already exist in the current specifications

Potential drawbacks of this approach:

- Increased functionality and processing load at the MME.

- Increased latency
- Lack of alignment between eNB↔eNB, eNB↔HeNB and HeNB↔HeNB SON/interference management.
- Potential lack of alignment with likely future evolutions of interference management in Release 10 and beyond (assuming that these are less likely to be based on S1)

7.5 Hybrid Cells

Hybrid cells are being included in the 3GPP release 9 specifications. Hybrid HeNBs may provide different service levels to UEs that are members of the HeNB and non-member UEs. In [5], extensive deployment scenarios of hybrid cells have been discussed. The interference scenarios apply to most of the deployments listed in [5].

For the scenario where HeNBs are on a shared carrier with eNBs, the interference management considerations are different between closed and hybrid access modes. For the closed access mode the used HeNB resources (e.g. power, RBs) are selected as a trade-off between performance at the HeNB/HUEs and interference caused to the macro eNB/MUEs. For the hybrid access mode the trade-off is between overall system performance (including both macro eNB and HeNB layers), and resources consumed at the HeNB by "visiting" (i.e. non-CSG member) UEs. These aspects are considered in more detail in the following sub-sections.

7.5.1 Hybrid Access Level of Service

Hybrid HeNB may provide different service levels to UEs that are members of the HeNB and non-member UEs. The lowest level of services is paging service, where a hybrid cell allows a non-member UE to access the cell to receive pages. A paging only hybrid cell is an interesting alternative to pure CSG cells. Since CSG cells have separate PCID space, switching between CSG and hybrid mode would have impact on both idle state and connected state home UEs. On the contrary, a hybrid cell could with paging-only service provides similar functionality as a CSG cell without incurring CSG-hybrid switching penalty.

If a hybrid cell only provides paging services to non-member UEs, data channel interference is similar to CSG HeNBs. The difference is that the hybrid cell has more information about the victim UE than a CSG cell. When the hybrid cell decides to handover (HO) the UE to a macro cell, interference coordination could be negotiated with the macro as part of the HO procedure. Some examples, are:

1. DL interference: The hybrid cell could reduce transmit power such that the UE handed over to the target cell has sufficient DL C/I to receive DL control channels from the target cell. The hybrid cell could also engage in fractional frequency reuse (FFR) with the target cell to enhance DL data rate of the victim UE.
2. UL interference: A hybrid cell and HO target cell could choose the power setting of this UE such that UL interference could be coordinated. UL control channels of the HO sUE could also be orthogonalized with the PUCCH of the source hybrid cell. UL data channel coordination through UL FFR could be configured on a semi-static basis.

Note that hybrid cells also have additional information on the channel quality of active UEs. Hence the adjustment made at the hybrid cell could fully take into account on the impact to ongoing traffic. In some extreme scenarios, hybrid cell could handover both the member UEs and non-member UEs to the macro cell.

If a hybrid cell provides data services to non-member UEs, the hybrid HeNB is similar to a pico cell with lower Tx power and different service level for members and non-members. In addition, a hybrid HeNB is different from a operator deployed pico cell in the following areas

1. A release 9 hybrid HeNB does not support X2 interface.
2. A hybrid HeNB could be customer deployed without proper RF planning
3. The density of hybrid HeNB could have much high density than operator deployed pico cells.

Given the challenges mentioned above, non-Rel-8 interference coordination schemes should be investigated for hybrid cells.

7.5.2 DL Performance Evaluation

Full buffer performance analysis is performed for CSG and hybrid HeNB deployments. The dense-urban model corresponds to to densely-populated areas where there are multi-floor apartment buildings with smaller size apartment units as described in [7].

The set of simulation parameters are shown below:

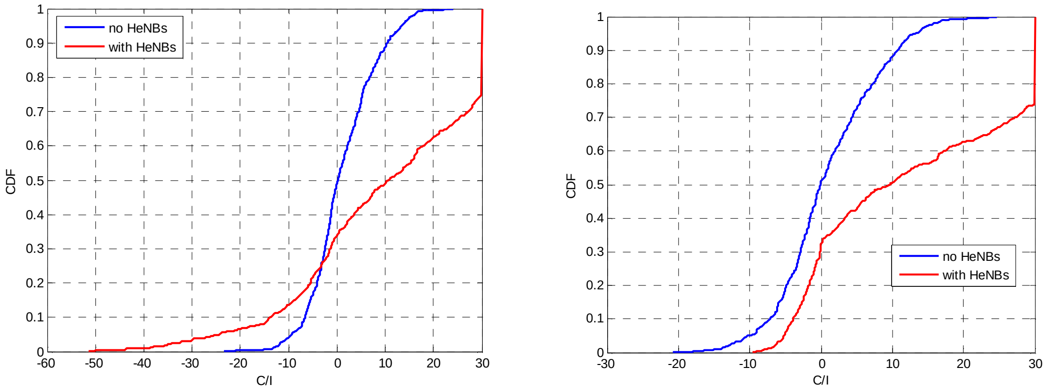
- System bandwidth 5 MHz
- Macro Power = 43dBm
- HeNB power between [-10 dBm, 10 dBm].
  - Case 1, the HeNB power is fixed to 8 dBm
  - Case 2, the adaptive HeNB power setting is used to reduce the MUE outage
- ISD of 1km
- Noise power = -99dBm
- 57 cell wrap around model with 3 center cells simulated for traffic
- 10 macro UEs per cell
- HeNB penetration rate of 5%, and activity factor of 13%, this leads to 12 active home UEs per cell

The association algorithm in all cases is based on the best RSRQ among allowed cells. In the case of CSG cells, UEs are only allowed to associate with the macro cell or the HeNB in the same CSG group. In the case of hybrid cells, all cells are open.

The C/I and throughput distribution for CSG and hybrid cells are shown in Figures 7.5.2.1 to 7.5.2.4. As shown in [6], adaptive power control could reduce outage for CSG cells. In the case of hybrid cells, there is no outage even without adaptive power control due to open association. Note that if different service levels are enforced for group member and non-group members, the fairness could be different from those shown in the figures.

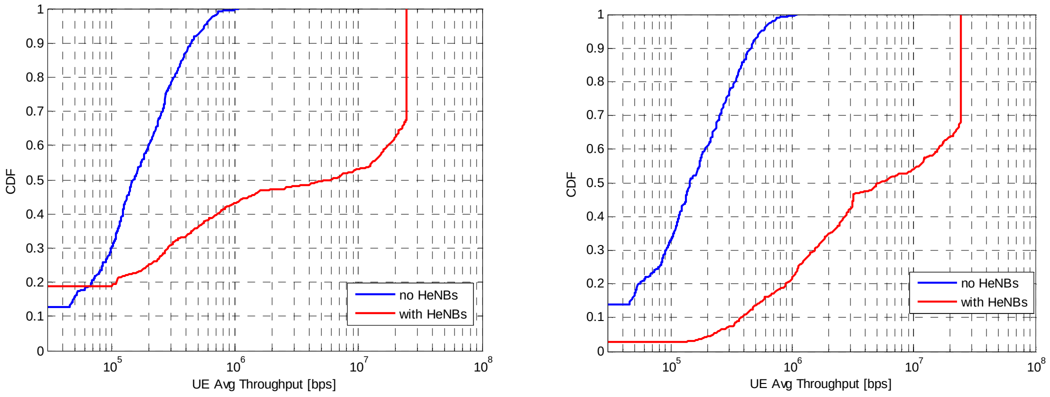
Key mobile statistics (outage, 20% throughput and median throughput) are shown in Table 7.5.2.1. It is noted that hybrid cells improve the outage and edge user performance, while making little difference in high throughput region. This is consistent with the expectation that with hybrid cells, the network would be able to offload macro UEs in poor channel conditions to close by hybrid cells. It is also interesting to note that the improvements due to hybrid cell is much higher when adaptive HeNB power control is not available (800% gain versus 60% gain).

Note that backhaul limitation of CSG and hybrid cells are not modeled in the simulations. For practical deployments, users close by a hybrid cell is likely to be backhaul limited rather than air-interface limited.



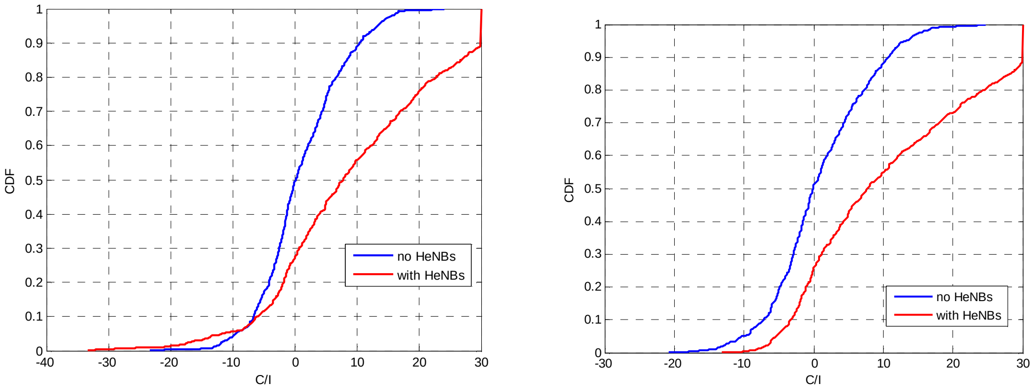
(a) CSG cells (b) Hybrid cells

Figure 7.5.2.1 C/I for CSG cells and hybrid cells deployments with 8 dBm HeNB Tx power



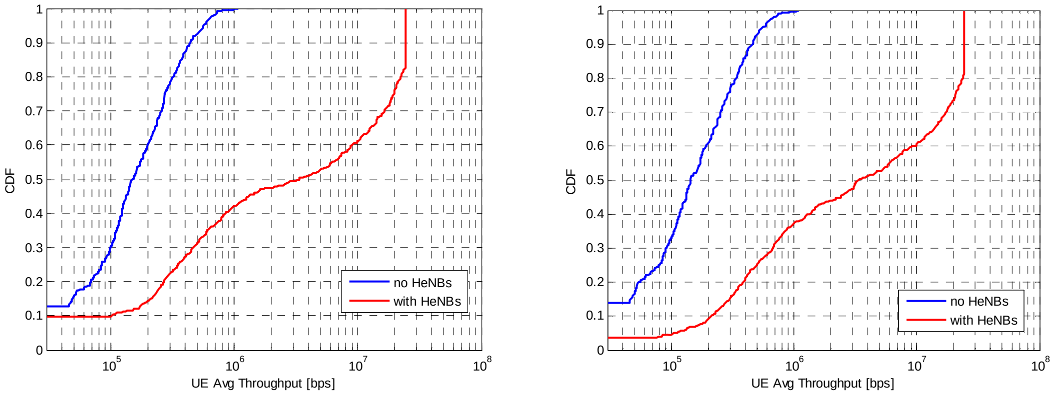
(a) CSG cells (b) Hybrid cells

Figure 7.5.2.2 Throughput for CSG cells and hybrid cells deployments with 8 dBm HeNB Tx power



(a) CSG cells (b) Hybrid cells

Figure 7.5.2.3 C/I for CSG cells and hybrid cells deployments with adaptive HeNB Tx power



(a) CSG cells (b) Hybrid cells

Figure 7.5.2.4 Throughput for CSG cells and hybrid cells deployments with adaptive HeNB Tx power

Table 7.5.2.1 Summary of results

	Outage Probability (SNR < -6 dB)	**Worst 20% mobile throughput (kbps)**	**Median throughput (kbps)**
No HeNB	12.7%	35	150
CSG HeNB with fixed Tx power of 8 dBm	18.9%	100	5600
CSG HeNB with adaptive Tx power	9.8 %	250	3300
Hybrid HeNB with fixed Tx power of 8 dBm	2%	900	5100
Hybrid HeNB with adaptive Tx power	3%	400	3400

7.5.3 Hybrid Cell RB Resource Management

For hybrid cells, non-CSG members consume RB resources at the HeNB, the amount of which will depend on the number of non-CSG UEs and the service level provided to the non-CSG UEs. One possible method of managing the RB resources used at a HeNB for non-CSG UEs is to reserve some RB resources for use by non-CSG UEs.

In hybrid access mode, if a HeNB accepts non-CSG members as temporary users, it would degrade CSG members' capacity similar to the open access HeNB. Moreover, when HeNB is under heavily loading, non-CSG UEs may be blocked first and diverted to macro eNBs. These diverted non-CSG UEs that are still within the coverage of the hybrid access HeNB may experience strong interferences from the HeNB.

In order to manage RB resource and mitigate the DL interference of the hybrid cells, a method called "Resource Priority Region (RPR)" may be used which guarantees a small percentage of HeNB resources for non-CSG members.

The RPR for the hybrid access HeNB divides radio resources of a HeNB into two regions for non-CSG members and CSG members respectively. The detailed definitions for each resource region are:

1. Non-CSG member priority region - non-CSG members have higher priority than CSG members.
2. CSG member priority region - CSG members have higher priority than non-CSG members.

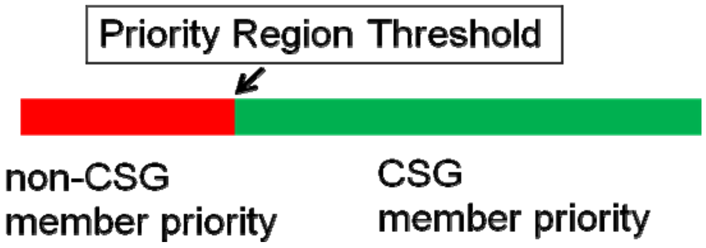


Fig. 7.5.3.1 Resource Priority Region

A threshold – *Priority Region Threshold* (PRT) is set to separate resources between two priority regions. The PRT could be a time or physical resource block (PRB) in radio frames, and PRT could be statically or dynamically adjusted by exchanging ICIC messages between HeNB and macro eNB. The HeNB could autonomously define the threshold for release 9, and further enhancements allowing the threshold to be adapted e.g. based on S1 signaling could be considered for release 10.

The hybrid access HeNB with RPR efficiently decreases the blocking probability to non-CSG members when HeNB is exhausting its resource. Also, this method guarantees the CSG members throughput that HeNB are not affected by sharing the resource with non-CSG members.

7.5.4 Hybrid Cell Power Management

The optimum power setting for hybrid cells is likely to be different than for closed cells, in that for closed cells the power is set as a compromise between HeNB coverage and interference caused to neighbour "victim" cells, whereas for hybrid HeNB it is set as a compromise between overall system performance versus resources used at the HeNB by non-CSG UEs.

Measurements made by the HeNB of neighbour cells ("sniffing") can be used to set an appropriate downlink power. However the propagation conditions between a neighbouring (H)eNB and its associated UEs may differ significantly from the propagation conditions between a neighbouring (H)eNB and the HeNB as measured during "sniffing". Furthermore the propagation conditions between the HeNB and nearby non-served UEs will not be known. These differences will result in uncertainty when estimating the coverage of HeNB and neighbouring (H)eNBs to non-served UEs.

One potential way to allow a hybrid access mode HeNB to get a more accurate picture of its local environment is for the HeNB to request a UE to measure RSRP and/or RSRQ of both source and target cells immediately after a UE hands-in (active state) or registers with (idle state) the HeNB. This would apply particularly to non-CSG UEs but could also apply to CSG UEs. In this way the HeNB could, for example, determine if the hand-in or re-selection is a) due to poor signal level from the source (e.g. macro) cell or b) due to high interference from the HeNB. This would then allow the HeNB to determine its output power appropriately. For example if the signal is particularly poor on the source (e.g. macro) cell, the HeNB could use a relatively high power and/or provide relatively high access priorities for non CSG UEs, compared to the case where the signal level on the source cell is not so poor.

This basic approach would require no standards changes. Future standards releases could consider more sophisticated approaches aimed at improved performance e.g. based on UE storing measurement reports and/or events prior to a hand-in or reselection of a HeNB, with subsequent reporting to the HeNB.

Annex A (informative): Change history

Change history

Date	TSG #	TSG Doc.	CR	Rev	Subject/Comment	Old	New
2009-03	RAN4#50 bis	R4-091338			TR Skeleton		0.0.1
2009-11	RAN4#53	R4-095019			Agreed TPs in RAN4#53: R4-094948, Text Proposal for Downlink Control Channel Interference Mitigation: FDD R4-094949, Text Proposal for Uplink Control Channel Interference Mitigation: FDD R4-094831, Text Proposal for TR36.9xx: Hybrid Cells R4-094961, Text Proposal for TR 36.9xx Reducing HeNB interference towards micro eNB data channels R4-094963, Text Proposal for TR 36.9xx: Downlink interference mitigation among neighbouring HeNBs	0.0.1	0.2.0
2010-02	RAN4#54	R4-101073			Agreed TPs in RAN4#53: R4-094997 Techniques for dynamic frequency partioning R4-094981 Text Proposal for 36.9xx HeNB Self-configuration R4-095020 Text Proposal for TR36.9xx: Smart Power Control Agreed TPs in RAN4#54: R4-100235 Text Proposal for TR 36.921: Interference control for LTE Rel-9 HeNB cells Nokia Siemens Networks, Nokia R4-100232 TP Correction to Resource Partitioning R4-100034 Simulation results of interference mitigation schemes and text proposal for TR 36.921 R4-100018 Text Proposal for 36.9xx: HeNB Adaptive Frequency Selection R4-100019 HeNB Power Control Based on HUE Measurement R4-100017 Text Proposal for 36.9xx: HeNB Measurements R4-100020 Revision on Information Exchange Option 2 of TR36.921 R4-100197 Text proposal for TR 36.9xx: Reducing interference from CSG cells by dynamically changing their CSG IDs R4-100936 Text Proposal for 36.9XX: Power Control R4-100703 Text proposal on interference control among neighboring HeNBs R4-100426 Text Proposal for TR36.921: Victim UE Aware Interference Management	1.0.0	1.1.0
2010-03	RAN4#54	R4-101077			Editorial modifications	1.1.0	1.1.1
2010-03	RAN#47	RP-100277			Presented to RAN for approval	1.1.1	2.0.0
2010-03	RAN#47	RP-100277			Approved by RAN	2.0.0	9.0.0

History

Document history		
V9.0.0	April 2010	Publication