3GPP TR 25.800 V2.0.0 (2013-08)

Technical Report

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Study on UMTS heterogeneous networks
(Release 12)

Logos: *Use <u>exactly one of the above lines</u>. Delete the other two.*
Use the top line for documents which are specific to GERAN technology only.
Use the second line for documents which are specific to UTRAN technology only or to GERAN and UNTRAN technologies only.
Use the third line for documents which relate to LTE technology (regardless of their applicability to GERAN or to UTRAN technologies) in Releases ***prior to*** *Release 10.*

Keywords

UMTS, heterogeneous networks

Use the fourth line for documents which relate to LTE technology (regardless of their applicability to GERAN or to UTRAN technologies) in Release 10 onwards.

MCC selects keywords from stock list.

3GPP

Postal address

3GPP support office address

650 Route des Lucioles - Sophia Antipolis
Valbonne - FRANCE
Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Internet

http://www.3gpp.org

Contents

Foreword

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

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

- x the first digit:
  - 1 presented to TSG for information;
  - 2 presented to TSG for approval;
  - 3 or greater indicates TSG approved document under change control.
- y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.
- z the third digit is incremented when editorial only changes have been incorporated in the document.

1 Scope

The present document captures evaluation results and analysis from the study item on "UMTS Heterogeneous Networks" described in [2].

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

[2] RP-121436: Work item description for "Study on UMTS Heterogeneous Networks".

[3] 3GPP TR 36.819: "Coordinated multi-point operation for LTE physical layer aspects".)

[4] R2-131106: "Mobility simulations and discussions in Heterogeneous Networks", Ericsson, ST-Ericsson

[5] R2-131449: "Mobility performance in Hetnet - Simulation Results", Qualcomm Incorporated

[6] R2-131458: "Simulation results for HetNet mobility", Huawei, HiSilicon

[7] R2-130926: "Thoughts on UMTS HetNet Mobility Enhancement", ZTE

[8] R2-131104: "Mobility Aspects in Heterogeneous Networks", Ericsson, ST-Ericsson

[9] R2-131129: "HetNet mobility considerations", Renesas Mobile Europe Ltd

[10] R2-131214: "LPN Cell Discovery in Inter-Frequency HetNet Scenarios", Nokia Siemens Networks

[11] R2-131299: "Discussion on Inter-frequency small cell discovery", Huawei, HiSilicon

[12] R2-131301: "Mobility performance issue based on UE speed", Huawei, HiSilicon

[13] R2-131303: "Mobility issues for massive small cell deployment", Huawei, HiSilicon

[14] R2-131215: Dynamic Neighbour Cell List Allocation in Cell_DCH", Nokia Siemens Networks

[15] R2-131981: "Non DCH states optimization for HetNet", Nokia Siemens Networks

[16] R2-131876: "Further discussions on mobility performance issue based on UE speed", Huawei, HiSilicon

[17] R2-131930: "HetNet speed based mobility", Renesas Mobile Europe Ltd

[18] R2-131978: "Dynamic Neighbour Cell List Allocation in Cell_DCH", Nokia Siemens Networks

[19] R2-131927: "Neighbour list extension to support HetNet", Renesas Mobile Europe Ltd

[20] R2-131957: "Further discussions on mobility issues for massive small cell deployment", Huawei, HiSilicon

[21] R2-131910: "Mobility Aspects for Co-Channel deployment in Heterogeneous Networks", Ericsson, ST-Ericsson

[22] R2-132082: "Mobility enhancements for multi-carrier Hetnet and multiflow", Qualcomm Inc.

[23] R2-131859: "Mobility for Multiflow deployments in HetNet", Huawei, HiSilicon

[24] R2-131911: "Mobility Aspects for Combined Cell deployment in Heterogeneous Networks" Ericsson, ST-Ericsson

[25] 3GPP TR 36.839: "Evolved Universal Terrestrial Radio Access (E-UTRA); Mobility enhancements in heterogeneous networks"

[26] R2-131972: "LPN Cell Discovery in Inter-Frequency HetNet Scenarios", Nokia Siemens Networks

[27] 3GPP TS 25.321: "Medium Access Control (MAC) protocol specification"

[28] 3GPP TS 36.101: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception".

[29] 3GPP TR 25.814: "Physical layer aspect for evolved Universal Terrestrial Radio Access (UTRA)".

[30] R2-132620: "Mobility and Node Selection in Combined Cell Deployment for Heterogeneous Networks", Ericsson, ST-Ericsson

[31] R2-132625: "Mobility Performance Evaluation in Combined Cell Deployment in Heterogeneous Networks", Ericsson, ST-Ericsson

[32] R2-132707: "Measurements for small cells in UMTS", Ericsson, ST-Ericsson

[33] R2-132374: "Mobility for range expansion with Multiflow deployments", Huawei, HiSilicon

[34] R2-132664: "Mobility enhancements for multi-carrier Hetnet and multiflow", Qualcomm Inc.

[35] R2-132641: "Neighbour Cell List Enhancements for HetNet", NSN

[36] R1-133848: "System simulation results of HetNet in co-channel scenarios", Huawei, HiSilicon

[37] R1-130929: "Bias optimisation in heterogeneous networks", Alcatel-Lucent, Alcatel-Lucent Shanghai Bell

[38] R1-130612: "Downlink Interference Analysis for Heterogeneous Networks", Ericsson, ST-Ericsson

[39] R1-133605: "DL Control Channel Evaluation", Huawei, HiSilicon

[40] R1-133636: "Analysis of Downlink Control Channel Performance in Heterogeneous Networks", Ericsson, ST-Ericsson

[41] R1-133792: "Link Analysis of F-DPCH performance in Hetnets for different CIOs", Qualcomm Inc.

[42] R1-133673: "Link Analysis of E-HICH performance in Hetnets for different CIOs", Qualcomm Inc.

[43] R1-133793: "Link Analysis of HS-SCCH performance in Hetnets for different CIOs", Qualcomm Inc.

[44] R1-133647: "Impact of Shadow Fading in Combined Cell Deployment", Ericsson, ST-Ericsson

[45] R1-133646: "Link Level Simulation Results for Combined Cell Deployment", Ericsson, ST-Ericsson

[46] R1-132431: "Performance of Rel-12 UEs in Spatial Reuse Mode", Qualcomm Inc.

[47] R1-133644: "Link Level Analysis of Legacy UE Performance in Combined Cell Deployment", Ericsson, ST-Ericsson

[48] R1-132430: "Impact of Combined Cell Operation on Legacy Users in SFN mode", Ericsson, ST-Ericsson

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] 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 [1].

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply.
An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

CIO	Cell Individual Offset
DF-DC	Dual Frequency Dual Cell
DL	Downlink
DPCCH	Dedicated Physical Control Channel
E-DPCCH	E-DCH Dedicated Physical Control Channel
E-DPDCH	E-DCH Dedicated Physical Data Channel
E-DPCH	Fractional Dedicated Physical Channel
E-HICH	E-DCH HARQ Acknowledgement Indicator Channel
E-RGCH	E-DCH Relative Grant Channel
HetNet	Heterogeneous Networks
HS-DPCCH	Dedicated Physical Control Channel (uplink) for HS-DSCH
HS-SCCH	High Speed Physical Downlink Shared Control Channel
LPN	Low Power Node
NAIC	Network Assisted Interference Cancellation
NCL	Neighbour Cell List
RoT	Rise over Thermal
SF-DC	Single Frequency Dual Cell
SHO	Soft HandOver
SI	Scheduling Information
SIR	Signal-to-Interference Ratio
SINR	Signal to Interference plus Noise Ratio
UL	Uplink

4 Design objective of UMTS heterogeneous networks

The detailed objectives of this study are:

- Define deployment scenarios and simulation assumptions for heterogeneous networks
- Investigate uplink and downlink interference issues and solutions for co-channel deployment of Macro and small cells
    - identify small cell coverage issues and potential solutions
    - identify the uplink interference issues between Macro cell and small cell and potential mitigation techniques
    - identify the downlink interference issues between Macro cell and small cell and potential mitigation techniques
    - investigate uplink and downlink imbalance issues and solutions for co-channel deployment of Macro and small cells
- Investigate range expansion techniques with multi-flow
    - evaluate system performance benefits of range expansion in different multi-flow configurations (including multi-carrier multi-flow configurations) over solutions possible with Rel-11 and earlier techniques
    - investigate uplink and downlink imbalance effects to uplink and downlink performance due to range expansion and identify potential mitigation techniques
- Investigate mobility issues, performance impacts and possible optimizations for both co-channel and dedicated frequency deployments of Macro and small cells
    - investigate improvements to UE discovery and identification of small cells
    - investigate UE speed based mobility solutions
    - investigate the mobility issues of mass small cell deployment(e.g. UE measurement requirements, limited NCL size, PSC confusion) and possible solutions
    - identify the requirements and potential solutions of mobility enhancement for multi-flow deployments, including multi-carrier multi-flow
- Investigate issues and solutions in shared cells scenarios, where shared cell refers to one cell over several transmission points, e.g. spatially separated antennas
- Consider to minimize the impact on physical layer and legacy terminals.

5 Deployment scenarios

Heterogeneous network deployments aim at improving capacity and/or coverage. For capacity, solutions are targeted to increase the network capacity in some portions within the original Macro cell area. For coverage, solutions need to mitigate the poor coverage in certain areas. The major scope of the investigations in this study item is finalized to capacity improvements.

There are different deployment scenarios for heterogeneous networks, and depending on the combination of UE serving cells, the interference environment is different and presents different challenges.

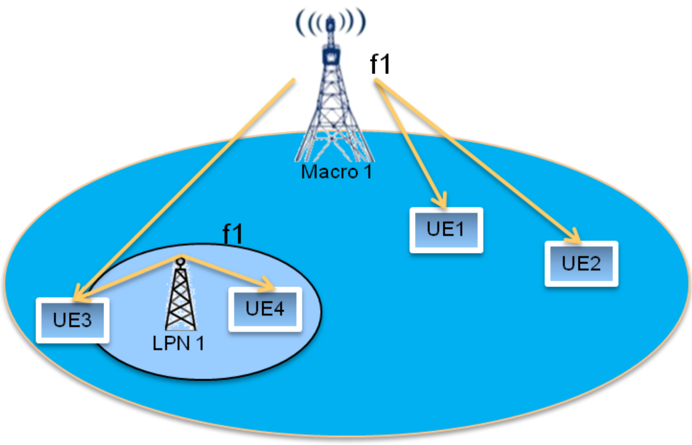

Figure 1: Co-channel deployment scenarios

Figure 1 illustrates the co-channel deployment scenario for heterogeneous networks.
LPN1 is deployed within the Macro cell1 coverage and uses the same frequency f1.
UE1 and UE2 are served by Macro cell1.
UE3 is positioned on the cell edge of LPN1 and can be served by both Macro cell1 and LPN1 when both are in the SHO active set. UE4 is only served by LPN1.

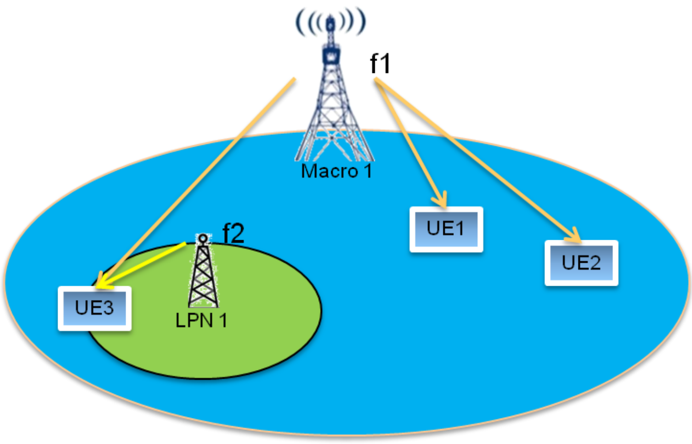

Figure 2: Dedicated frequency deployment scenario

Figure 2 illustrates the dedicated frequency deployment scenario.
Macro cell1 uses frequency f1 and LPN2 uses frequency f2.
UE1 and UE2 are served by Macro cell1.
UE3 is served by Macro cell with frequency f1 and by LPN1 with frequency f2.

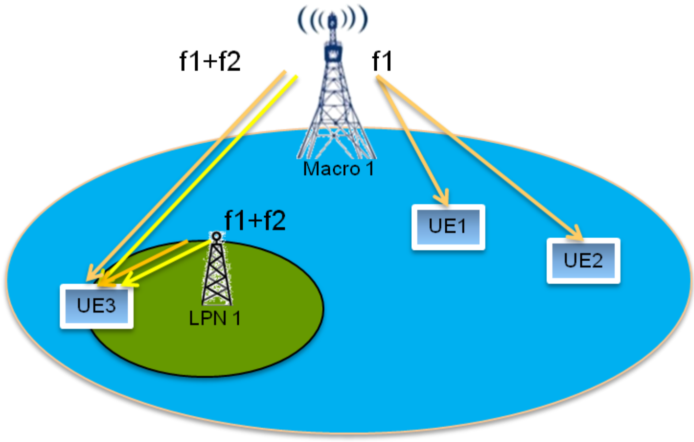

Figure 3: Multi-carrier deployment scenario

Figure 3 illustrates the multi-carrier scenario.
Macro cell1 and LPN1 use two frequencies, f1 and f2.
UE1 and UE2 use a single frequency and are served by Macro cell1.
UE3 is served by Macro cell1 with f1 and f2, and by LPN1 with f1 and f2.
In this example the transmit power on both frequencies is the same.

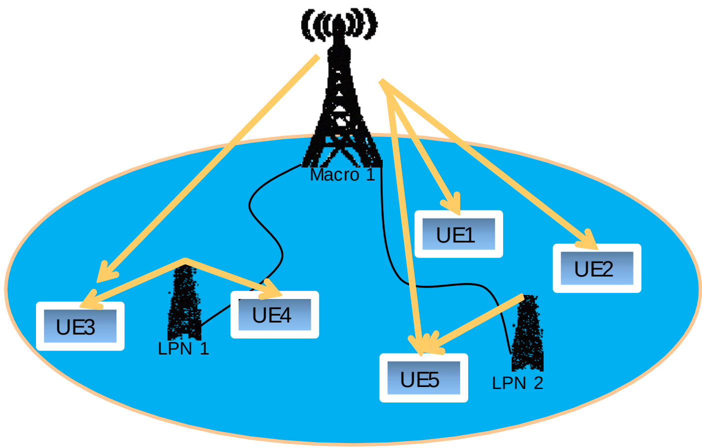

Figure 4: Combined cell deployment scenario

Figure 4 illustrates the combined cell (also called shared cell) deployment scenario.
The LPNs deployed within the Macro cell area have the same primary scrambling code.
All the LPNs' time reference is closely coupled to the macro clock.

6 Aspects of heterogeneous networks

6.1 Interference in co-channel scenario

In co-channel scenarios the transmit power difference between the high power Macro cells and the LPNs creates an interference environment different from the interference in networks with all Macro cells.
Considering that the typical transmit power for Macro cells is 43 dBm, and for LPN can be 37dBm, 30dBm or 24dBm, a UE that receives both signals from a Macro cell and a LPN with the same strength, generates an UL signal which is received at the LPN and at the Macro cell with a substantially different strength.
This has an impact on coverage, cell load and the overall interference environment.

Generally speaking, coverage is determined by a number of factors, including the transmit power and the path loss (further coverage analysis can be found in clause 7.1.1).
As the serving cell selection as well as the active set management are mainly based on the downlink received signal strength, the transmit power of each cell largely determines the coverage area of the cell. Typically, high transmit power nodes cover larger areas than low transmit power nodes. However, from the uplink perspective, the strength of the signal being received at each node does not rely on the downlink transmit power of each node. Consequently, introduction of LPNs in the network could potentially cause a large DL-UL imbalance in the sense that, in the uplink, cells other than the serving cell could receive a much stronger signal from the UE than the serving cell.

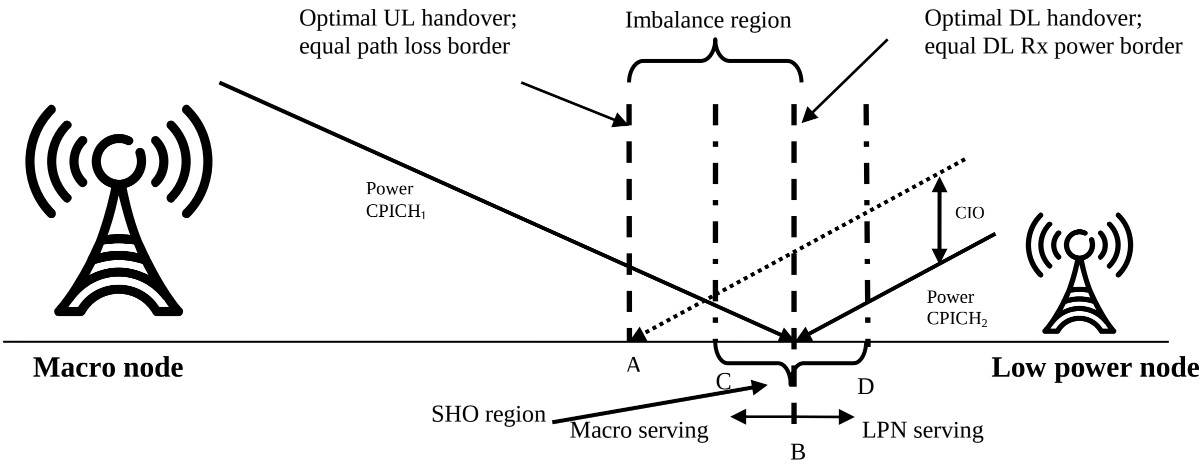

Figure 5: Heterogeneous network deployment

Given a certain deployment of macro nodes and LPNs, depending on the UE position relative to the Macro cell and the LPN, the interference scenario can be very different. Figure 5 illustrates a heterogeneous network deployment and the distance points between a macro node and a LPN where the interference scenario is substantially different.
The interference characteristics at different distance points between macro and LPN are discussed.

A is the UL boundary. The UL boundary represents the point where UE path loss to the Macro cell and to the LPN is the same. The received downlink power difference depends on the transmit power difference between the macro node and the LPN. If for example the transmit power of macro node and LPN is 43dBm and 37dBm, respectively, the received downlink power difference is 6 dB because the path loss to the macro node and the LPN is the same.
This means that at this point the DL signal from the Macro cell is much stronger than the signal from the LPN, while the UE signal received at the macro and LPN is the same.

B is the DL boundary. The DL boundary represents the point where the UE measures the same CPICH receive power of the pilot signals transmitted by the macro node and the LPN. The path loss difference is equal to the transmit power difference because the received downlink power from the Macro cell and the LPN is the same and the transmit powers are different. If the Cell Individual Offset (CIO) of the serving cell change is configured at 0 dB, event 1D for cell change is reported when the UE is positioned at the DL boundary.

This means that when the cell change occurs, the UE signal received at the Macro cell is much weaker than the signal received at the LPN.

Thus, in heterogeneous networks the difference in transmit power between the macro node and the LPN causes different coverage areas for the UL and the DL, and this is generally referred to as *UL-DL imbalance*. The UL boundary (equal path loss) and the DL boundary (equal downlink received power) are different and the region between such boundaries is referred to as the *imbalance region* or *imbalance zone*.

6.1.1 Coverage issues

As a consequence of the downlink interference from the Macro cell to the downlink of the LPN, the LPN coverage reduces when the LPN is deployed closer to the Macro cell center. When deploying LPNs within the Macro cell coverage, the LPN coverage is defined as the area where the received signal from the LPN is stronger than the signal from the Macro cell,

CPICH Ec/N0 (LPN) > *CPICH Ec/N0* (macro).

Since the DL received signal from the macro is stronger at the Macro cell center with respect to the Macro cell edge, the LPN can have larger coverage if deployed at the Macro cell edge, and the LPN coverage will shrink if deployed closer to the Macro cell.

6.1.2 Uplink interference issues

With the DL-UL imbalance caused by the transmit power difference as well as the loading imbalance between macro and LPNs, co-channel deployment could potentially cause issues in the UL as described below.

1. UL interference from macro UEs to LPN

This type of interference occurs when the macro UE is located in the imbalance region, closer to the UL boundary and outside the SHO region (UE located closer to point A in Figure 5). The excessive interference to the LPN is caused by the UEs being served by the Macro cell, who do not have the victim LPN in the active set. The UE is not in SHO however the UL to the LPN could be stronger than the UL to the serving macro node (the path loss to the LPN is smaller than that the path loss to the macro node). The LPN will not be able to power control the UE or limit the UE grant by sending RGCH because the UE is not in SHO. Consequently, the UE will transmit at high power and the LPN could be a victim of large interference from the neighbour macro UEs. This might impact the performance of receiver algorithms and reduce the RoT budget, and therefore reduce the cell throughput in the LPN. This imbalance region is referred to as the *strong mismatch zone*.

2. UL interference from LPN UEs to macro node

This problem mainly arises from the uneven loading from the heterogeneous network. When the LPN serves only a small number of UEs as compared to the Macro cell, each UE served by the LPN receives generous grants and hence transmits at a higher power. These high power LPN UEs are likely to be not in SHO and can generate considerable uplink interference to the macro node while the Macro cell cannot control this interference. When there are many LPNs deployed within the Macro cell, the number of UEs served by the LPNs could be very large, and this type of interference would be significant and will degrade the UL throughput of the UEs served by the macro node.

3 UE in SHO

Whenever the UE is in SHO (both macro and LPN are included in the active set) and power controlled towards the LPN, it might be problematic to reliably receive essential control channel information in the serving cell (macro NodeB) due to the weak link between the serving NodeB and the UE. For example, the HS-DPCCH (which carries HARQ-ACK and CQI information to support DL data transmission) and in-band/out-band SI need to be received in the serving cell with sufficient good quality. Consequences such as poor HSPA cell throughput in the serving cell, state-oscillations and dropped calls may otherwise be present.

6.1.3 Downlink interference issues

Co-channel deployment for heterogeneous networks could potentially cause two types of issues in the DL as described below.

1. DL interference from macro node to LPN UEs

This type of interference occurs when the LPN UE is located near the DL boundary (point B in Figure 5). The macro node downlink transmission generates interference to the LPN UE downlink reception. The UE will change its serving cell at point B if the CIO of event 1D is 0 dB. In this case, the macro downlink interference to the LPN UE is not very strong and decreases as the UE moves away from point B towards the LPN location because the received signal from the macro node is weaker than the signal received from the LPN. Since it is desired to offload more UEs to the LPN, the CIO for serving cell change could be modified so that the serving cell change point is moved towards the macro node location, as illustrated by the dashed arrow in Figure 5. The technique of setting the CIO to a value larger than zero (as usually used in homogeneous networks) is called *range expansion*. In this way, the coverage of the LPN is enlarged so that UEs in the imbalance region can be served by the LPN. However, the DL interference from the Macro cell to the LPN UEs will be stronger.

2. DL interference from LPN to macro node UEs

This type of interference occurs when the UE is in the SHO area and the Macro cell is the serving cell. The LPN downlink signal generates interference to the macro UEs.

6.1.4 Strong mismatch zone

The size of the strong mismatch zone could be significant, especially without UL-DL mismatch compensation. Figure 6 shows these areas without LPN desensitization and with LPN desensitization of 6dB for LPN 30dBm.

The legend for these figures is as follows:

- CYAN depicts the strong mismatch zone (UE is seen by LPN but the LPN has not yet been added to the active set of the UE);
- BROWN where the UE is in DL SHO area (LPN is stronger radio link);
- YELLOW is the area where UE is in DL SHO area (macro is stronger radio link).

It is noted that the results shown below do not include multipath fading in the propagation modeling. Therefore the results must be considered to be optimistic compared to a practical network deployment.

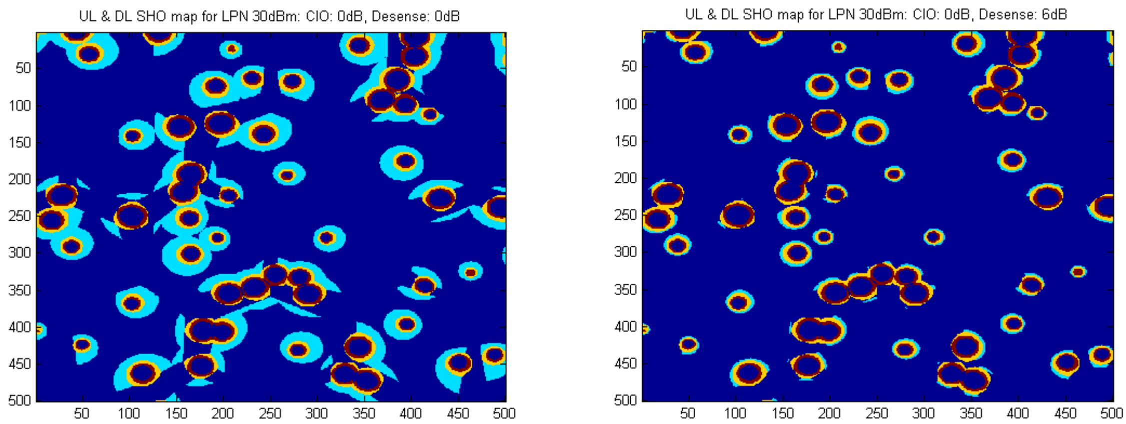

Figure 6: DL SHO areas and strong mismatch zone for LPN 30dBm, CIO=0dB (desensitization = 0dB on the left and desensitization = 6dB on the right, shadowing OFF)

The histograms in Figure 7 show the percentage of DL SHO area and the strong mismatch zone area related to the total network area for different values of desensitization.

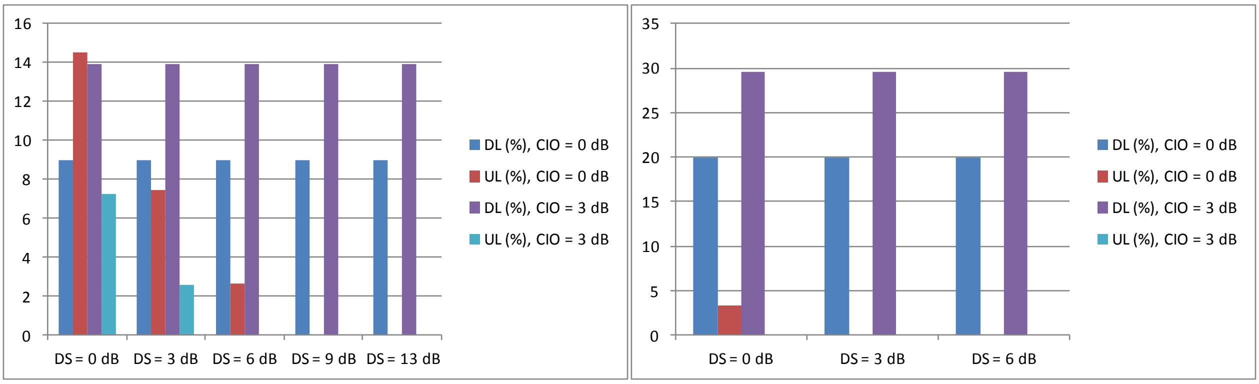

Figure 7: Histogram of the DL SHO areas (DL) and strong mismatch zones (UL) for LPN=30dBm (left) and LPN=37dBm (right) for different values of CIO and padding/desensitization

The cumulative area of the strong mismatch zone compared to the cumulative area of DL SHO is significant especially for an LPN with a power level of 30dBm. For an LPN of 30dBm and without any desensitization or CIO, strong mismatch zone is about 14% of total network area and is larger than DL SHO area which equals 9%.

When CIO is applied, the strong mismatch zone decreases because the DL SHO area boundary shifts closer to the edge contour of the zone. The usage of 9dB desensitization in LPN causes the contour of the zone to be included in the DL SHO area where UE can add LPN to Active Set.

When CIO is not applied, complete balancing is achieved only when desensitization level equals UL-DL mismatch which is 13dB for LPN with power 30dBm. However, a desensitization level of 13dB cannot be recommended due to excessive amount of UL interference to the macro. When lower levels of desensitization are applied, strong mismatch zone regions still exist. The macro UEs located in this area generates the highest interferences to the LPN in comparison to other areas in the network. With a LPN 37dBm the situation is less problematic. With a desensitization level of 0dB (a recommended value), the strong mismatch zone is approximately a few meters around the DL SHO area. If LPNs with power levels of 24dBm were to also be considered, then the strong mismatch zones would be quite large. The impact of noise desensitization on UL throughput is described in clause 7.1.5.

The strong mismatch zone is located outside of LPN DL boundaries. In order to identify those UEs located in the strong mismatch zone, the following steps could be performed:

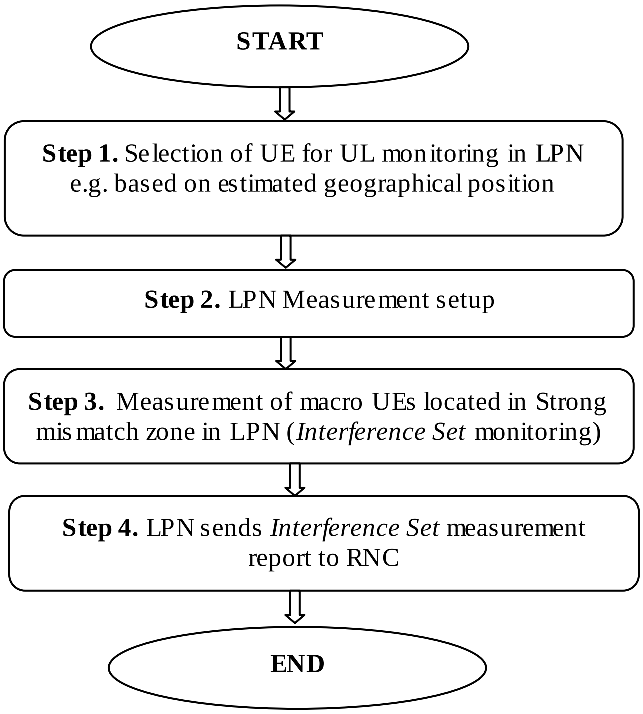

Figure 8: Steps to identify UEs located in strong mismatch zones

In the first step a UE position is estimated by checking how it relates to a particular LPN position. Some ways to do that are:

- Monitor UE measurement reports messages for a particular LPN. It is possible to set a trigger using legacy measurement control which would allow the UE to report LPNs at low detection threshold. An early report would indicate that UE is getting close to a reported LPN.
- Network driven localization methods could be used for that purpose to compare the measured UE location with an LPN position. The UE could be localized using GPS or Round-Trip-Time measurements.

Once identified, the RNC may provide to the LPNs the UEs UL transmission details (Step 2) enabling the LPN to:

1. Synch to UE transmission and,
2. Measure the UE UL transmission,
3. Report the measurement result to the RNC,

It is possible for an LPN to tune its UL receiver to a given UE UL scrambling code with a given timing reference from the serving macro cell. Then the LPN can measure the UE transmission (Step 3) and provide the measurement report to the RNC (Step 4). In co-channel deployment the most useful measurement would be the UL SINR. A comparison of the SINR reports from the Macro and LPN would enable the RNC to detect the UE in the strong mismatch zone.

6.1.5 Uplink/Downlink imbalance issues

To address some of the UL-DL imbalance problems described above, available network parameters such as the CIO and handover thresholds can be adjusted to achieve *range expansion* and *soft handover extension*. This will allow the SHO region to cover parts of or in case of a limited imbalance level the entire imbalance region. One positive effect from this is that the problem of UEs creating excessive interference towards the LPNs is reduced.

Another aspect of a heterogeneous network deployment where LPNs have less transmit power than macros is that the traffic uptake by the LPNs and therefore the effect of macro traffic offloading may be very limited. From network management perspectives, it is useful to be able to control the level of Macro-cell offloading according to traffic load and distribution. Techniques that can be used to expand the service area of a small cell, such as range expansion, are desirable as they can be used to achieve load balancing between Macro and small cells. Unfortunately range expansion introduces new DL interference problems that need to be mitigated by other techniques.

6.1.5.1 Essential UL control information in the serving cell

Next we focus on reliable reception of UL control channel information in the serving cell when a UE in SHO (both macro and LPN are included in the active set) has a weak link towards the serving Macro cell due to UL/DL imbalance. The following UL channels are considered:

- **HS-DPCCH** – The HS-DPCCH carries UL control information, such as HARQ ACK and PCI/CQI, related to DL transmissions. Poor reception quality of the HS-DPCCH in the serving cell will cause degraded HSDPA cell and end-user throughput. Clause 6.1.4.2 further discusses this issue.
- **E-DPCCH** – The E-DPCCH carries information about E-TFCI, re-submission number (RSN), and happy bit. The E-TFCI indicates which TBS the UE has employed and is used for demodulating and decoding data carried on E-DPDCH. The RSN is used for HARQ combining purposes. It should be noted that during SHO it is in general enough that one node (typically the LPN in this case) receives control information related to payload data demodulation reliably. Furthermore, the E-TFCI provides information about the gain factors used for E-DPDCH which can be useful for scheduling purposes. The happy bit is used by the UE to inform the network that it would benefit from a higher grant. Hence, the happy bit provides the network with important SI. Poor reception of the happy bit in the serving cell can cause worse end-user throughput and in worst case no UL granted rate at all.
- **E-DPDCH** – The E-DPDCH carries payload data and also occasionally in-band SI, e.g. buffer and power statuses. Reliable reception of payload data in the serving cell is not crucial since it is enough that one node (in this case the LPN) receives it reliably. Also, it is worth noticing that for moderate to high data rates, the E-DPDCH is, in general, more costly in terms of power than other UL channels. Furthermore, it should be noted that if the UE has no grant it only reacts on DL HARQ feedback from the serving cell, i.e. HARQ feedback from non-serving cells is ignored. The reason is that it is the serving cell that needs to receive the grant request. Poor reception of the in-band SI in the serving cell can consequently cause degraded end-user throughput and in worst case no UL granted rate at all.

- **DPCCH** – The DPCCH carries pilot bits and is used for channel estimation, path searching, synchronization, etc. Hence, a sufficiently good DPCCH reception quality is required to ensure reliable detection of any other UE channel.

From above it is clear that reliable reception of DPCCH, HS-DPCCH and E-DPCCH are crucial for good system performance, whereas the E-DPDCH quality might be less important, at least if in-band SI is not considered.

The power levels of UL channels are set relative to the DPCCH power via channel dependent beta-values. The DPCCH power is adjusted by means of fast power control to meet the SIR target, and the SIR target is controlled by the OLPC to make sure that E-DPDCH satisfies a certain QoS target (number of transmissions for successful decoding). Hence, the DPCCH SIR operating point can be adjusted by choosing smaller or larger beta-ed values. Clearly, depending on how one chooses to operate the system will affect the severity of the imbalance problems discussed above. For example, operating at a low DPCCH SIR means that the channel estimate becomes more sensitive to a reduction in received signal quality. Furthermore, it should be noted that the impact of the problems discussed above in practice will depend on several factors, such as margins being used in the system and the size of the UL-DL imbalance region.

It is obvious that heterogeneous network deployments need to work for legacy users. This means that the problems described above need to be addressed taking legacy into account. Nevertheless, this does not preclude that performance enhancing features requiring standardization are considered for Rel-12. One can envision that heterogeneous networks at a first stage are deployed using simple and robust means to reduce the impact of the problems discussed above, and at a later stage the performance is improved by introducing Rel-12 standardized features.

6.1.5.2 Impact on HS-DPCCH

Consider the soft handover region between the macro and the LPN. The Macro cell (being the more dominant cell) is more likely to be the serving cell. However, the uplink to the LPN is much better when the received pilot SNR on the UL is considered. Since both the macro and the LPN power control the UE, the transmit power of the UE would largely be driven by the LPN. As a consequence, the HS-DPCCH channel which carries the HARQ-ACK and CQI information may not be reliably decoded at the serving (Macro) cell. In this scenario, unreliable HARQ-ACK decoding, especially high ACK to DTX error, could cause unnecessary retransmissions and degrade the DL throughput performance.

This impact on the HS-DPCCH is demonstrated by a simulation. In the simulation conducted, the LPNs have a transmit power of 30dBm and have the same UL noise figure (sensitivity) as the Macro cell. The cell that has the strongest received CPICH RSCP at the UE receiver is assigned to be the serving cell.

Four LPNs are uniformly dropped per geographic area of each Macro sector. 16 UEs are uniformly dropped per geographic area of each Macro sector. For each UE in SHO between Macro and LPN, the HS-DPCCH power off set (Δ_{ACK}, Δ_{NACK}) to be 10dB.

Since the pilot consumes 10% of the total power at each node, the largest UL imbalance is effectively the power difference between the LPN and the Macro cell which is around 13dB in this example.

UL/DL imbalance is computed for each UE in the system as follows:

$$\text{Imbalance [dB]} = SIR_{\text{Target}}[\text{dB}] - SIR_{\text{Serving}}[\text{dB}]$$

Figure 6 shows the imbalance distribution for the UEs in soft handover in the entire system.

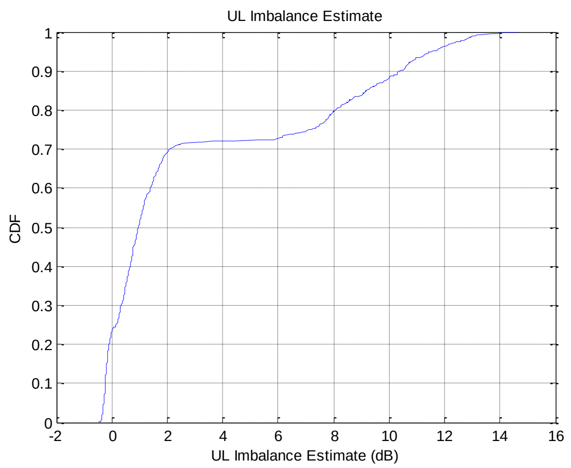

Figure 9: UL Imbalance CDF for SHO UEs

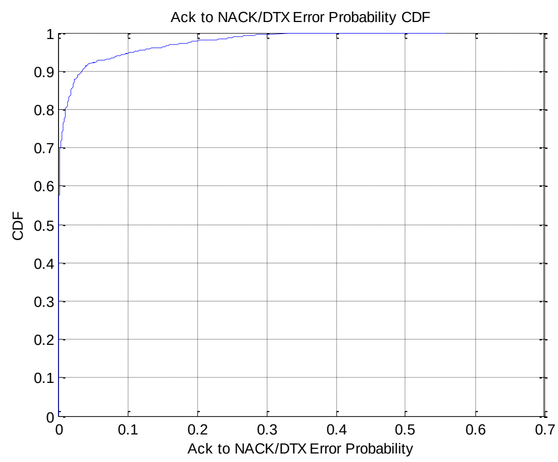

Figure 10: HS-DPCCH ACK->DTX Error Prob CDF

From Figure 9, it can be seen that 20% of the UEs that are in SHO observe UL imbalance higher than 8dB. This corresponds to around 8% of the total UE population. Those UEs would be received with quite low pilot SINR values (~ -30dB) at the serving cell. Finger tracking loops in practical receivers would be challenged at such low pilot power levels. This would in turn affect the decoding performance of the HS-DPCCH channel.

Figure 10 shows the ACK -> NACK/DTX error probability CDF for the whole UE population. This is caused by UL/DL imbalance which in turn is a consequence of the different transmit power levels of the macro and the LPNs. High ACK -> NACK/DTX probabilities lead to additional DL retransmissions which affect DL throughputs.

6.1.5.3 Impact on uplink SI

A similar issue as described in clause 6.1.4.2 for HS-DPCCH exists for transmission of SI for enhanced uplink. In problematic case, the UE has smaller path loss to LPN but serving cell is the Macro cell due to node B transmission power imbalance. The imbalance in pathloss can be relatively high since it depends on node B transmission power and pilot Ec/Ior.

In case where SI problem occurs the Macro cell acts as a serving cell and uplink is in macro diversity.
The uplink power control is thus dominated by the small cell reception performance. SI is transmitted on E-DPDCH and received only by E-DPDCH serving cell instead of macro diversity which is generally used for E-DPDCH data. This may cause a situation where uplink transmission power can get too low for successful reception of SI in the serving node B. SI is needed only by scheduler function of serving node B.
There are two different cases for transmission of SI depending on whether it is transmitted together with data or not (see 3GPP TS 25.321 [4]):

1. When the SI is sent alone:
    - The power offset is configured by RRC and the maximum number of re-transmissions is defined in 3GPP TS 25.321
    - HARQ (re)transmissions are performed until an ACK from the RLS containing the serving cell is received or until the maximum number of transmissions is reached
2. When the SI is sent with data
    - HARQ power offset for the highest priority data is used and the maximum number of transmissions among all the considered HARQ profiles associated to the MAC-d flows for the MAC-e / MAC-i PDU to be transmitted
    - HARQ (re)transmissions are performed until an ACK is received, or until the maximum number of transmissions is reached
        - if the UE receives an ACK from an RLS not containing the serving cell for a packet that includes SI, it flushes the packet and includes the SI with new data payload in the following packet

As can be seen there are fewer problems in case SI is transmitted alone since UE keeps doing HARQ re-transmissions as long as it gets acknowledgement from serving cell and also power offset is configurable, however case where SI is transmitted together with data is more complicated. In such case data reception is done in macro diversity mode and if cell other than serving cell acknowledges data first then SI is retransmitted with new data payload as a new data packet with less HARQ gain compared to the standalone SI case. Such a mechanism could cause severe delay or even permanent failure in SI transmission if reception performance of serving cell is much worse than some other cell in macro diversity.

Obviously increasing E-DPDCH beta factor can be used as a solution in transmission case 1 but in case 2 it would cause increased transmission power also for data payload which has been determined by E-TFC selection procedure with the constraint of maximum allowed E-DPDCH transmission power. Hence there is a high possibility that maximum transmission power determined by serving grant would be exceeded. Also E-DCH data other than SI is received in macro diversity mode, which would further affect the outer loop power control action. Hence a different solution is needed for case 2.

More insight into the problem can be gained by comparing uplink packet error rates of macro diversity UEs in each cell before selection combining. Related simulation results can be seen in figures 11 and 12, where "primary PER" and "secondary PER" refer to UL packet error rates of the serving cell link and the best non-serving cell link in the radio link sets respectively. The serving cell chosen in the simulations is the best cell in the downlink perspective i.e. transmission power of node B affects the selection as usual. The "Total PER" refers to packet error rate obtained by applying the selection diversity combining. The HetNet scenario results are further divided into several groups e.g.:

- "Macro-LPN HO UEs": Primary (best) cell for UE is Macro cell and secondary (second best) cell is LPN cell.
- "LPN-Macro HO UEs": Primary (best) cell for UE is LPN cell and secondary (second best) cell is Macro cell.
- "Macro HO UEs": All UEs where primary cell is Macro cell

- "LPN HO UEs": All UEs where primary cell is LPN cell
- "HO UEs": All handover UEs in HetNet scenario

In this clause it was assumed that UEs in soft handover between macro and LPN cell could have a problem in SI reception and indeed "Macro-LPN HO UEs" has much higher Packet Error Rate than the rest of the cases.
The PER degrades when transmission power difference between node Bs in hand over gets higher. The problem can be somewhat mitigated by applying CIO but there is an upper limit to CIO value that can be used.

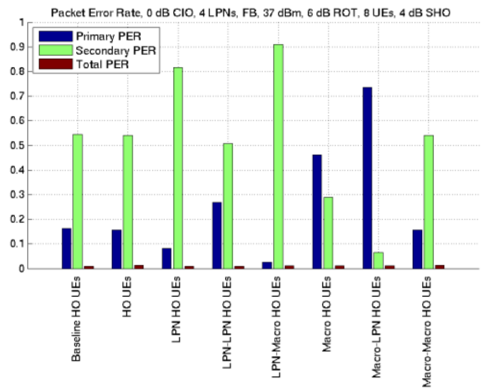

Figure 11: Uplink packet error rate for two best cells with 37dBm node B Tx power, 0dB CIO

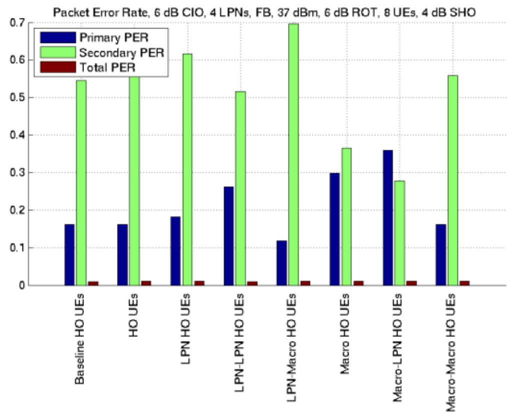

Figure 12: Uplink packet error rate for two best cells with 37dBm node B Tx power, 6dB CIO

6.2 Mobility aspects

6.2.1 Discovery and identification of small cells

The typical deployment scenarios for small cell are:

- One macro frequency layer provides full coverage and small cells are deployed in the same frequency layer, i.e., co-channel deployment. This scenario applies to single or multi frequency deployments, where Macro and small cells can be deployed on one or multiple carriers.

- Small cells are deployed on another frequency layer, i.e., dedicated channel or dedicated frequency deployment, for the purpose of traffic offloading. Thus it is required that the UE under the coverage of the small cell should be able to select/reselect/handover to the small cell frequency in order to offload the UE to the small cell.

- Mixed co-channel and dedicated carrier deployments.

- One or more low power nodes are deployed within the combined-cell coverage area, where a LPN is one of the spatially separated transmit-receive points in the combined cell and the transmission/reception points created by the LPNs have the same L3 cell identity (same primary scrambling code) as compared to the Macro cell.

Since small cells are typically scattered within macro layer providing non-continuous coverage, it is the common understanding that continuously performing inter-frequency measurements may be unnecessary, and will cause significant UE battery consumption and potential data transmission interruption (e.g. if compressed mode is needed). The unnecessary intra-frequency measurements should also be minimized (especially in Idle mode), although these issues are expected to be less significant (e.g. on UE battery consumption) than the inter-frequency measurements.

This study focused on the discovery and identification of small cells on a different frequency, aiming the purpose of reducing UE battery consumption and data transmission interruption.

6.2.2 Mobility performance issues based on UE speed

For co-channel deployment, the coverage of small cell is much smaller than the Macro cell, and typically the radio channel around the small cell will change faster than the Macro cell channel. When UE moves between the Macro cell and the small cell, more challenges on the performance of serving cell change and active set update, especially when UE speed increases, could be expected, i.e. more active set update failure and more serving cell change failures may happen.

Another issue is more handover procedures and signalling messages due to the deployment of small cells.
After deploying the small cell, the UE has to perform more handover procedures (between Macro and small cell, and vice versa) compared with the legacy Macro cell deployment.

Some observations for simulation results have been described in the Annex A.8.

6.2.3 Mobility issues of massive deployment of small cells

Depending on the requirements of system throughput gain and the transmission power of small cell, many small cells may be deployed within one Macro cell coverage.

There might be an issue of PSC confusion or not, pending on different mechanism of PSC allocation for small cells. There are two kinds of PSC allocation method for the small cells:

1. Non-sharing allocation: In this method, each small cell is assigned with a unique PSC in one Macro cell coverage.

2. Sharing allocation: In this method, one PSC can be assigned to several small cells within one Macro cell coverage if those small cells are not adjacent to each other, which enables the possibility that all of the neighbouring Macro cells and small cells can be put into the NCL without extending the NCL size.

PSC confusion might happen for the sharing allocation case, which technically is similar as what had been discussed for the HNB in Rel-11. For Non-share allocation, it should be noted that if the small cells deployed in a coordinated way with careful network planning, it is reasonable to assume that there should be no PSC confusion issue.

While for non-sharing allocation case, even if each small cell is assigned with a unique PSC, if all the small cells could not be included in the Neighbour Cell List (NCL), the detection of small cells may need to rely on the intra/ inter-frequency detect set operation which may cause a significant delay in the handover procedure. However, the current size of NCL is limited to 32 cells per frequency which might be insufficient if small cells are to be deployed.

6.2.4 Mobility issues of Multiflow and multi-carrier operation

Currently DF-DC is not a valid configuration in Multiflow operation, while it might be useful in HetNet deployment scenario, thus there might be some mobility related issues, including sub-optimal inter-frequency measurements/events and the changing of serving frequency/cell (see [26]).

In case of power range expansion on one carrier, the coverage of Macro cell on that frequency is shrunk, so if the UE moves from Macro cell to small cell on that frequency in case of DC-HSDPA operation, there may be an issue of inefficient secondary serving cell change (see [25]).

7 Solutions and techniques

7.1 Solutions for co-channel scenarios

7.1.1 Analysis of UL/DL mismatch

In co-channel scenarios for heterogeneous networks, there is a UL/DL mismatch region between the Macro cell and LPN since the LPN has smaller power than the Macro cell. Besides the DL and UL interference issues, illustrated in Figure 13, the UL/DL mismatch can also introduce problems for the serving cell in order to receive essential control information.

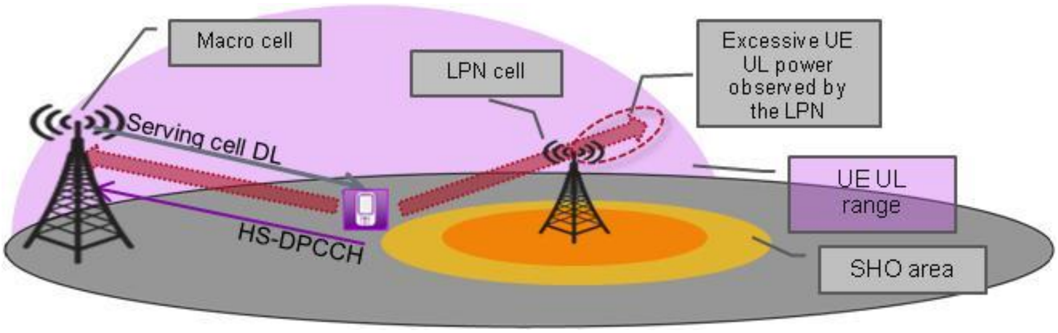

Figure 13: The issue of macro UE uplink reception quality in non SHO area

As illustrated in Figure 14, when the UE is in the SHO region, its uplink transmit power is controlled by both the macro NodeB and LPN. Considering the SHO area is usually on the right side of the UL boundary, the UE will have larger received power on the LPN compared with that on the Macro cell. Therefore the dominating power control loop would be on the LPN side, which causes the SIR on the macro side be likely below the expected SIR target on the macro.
If the UE serving cell is still Macro cell, the reception of essential control information will have bad performance on the macro side due to the low signal quality. This will surely impact the HSDPA performance on the downlink.
This situation is depicted in Figure 11 where the issue with HS-DPCCH reception is shown.

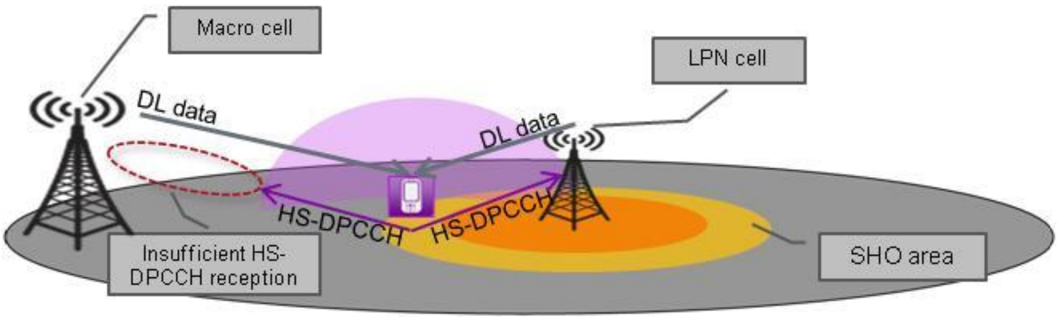

Figure 14: Scenario with a UE in SHO area between a Macro cell and an LPN cell

In the next subclauses is provided a link budget analysis to derive the condition for balancing or matching the UL and DL coverage defined as a situation where the UL and DL coverage boundaries coincide. Following the analysis, in clause 7.1.2, a number of solutions are described that are applicable to all UEs, including legacy UEs not implementing Rel-12 functionality.

7.1.1.1 DL coverage boundary

Assuming that:

- The RRM decisions are based on primary CPICH RSCP or E_c/N_0.
- The $E_{c,CPICH}/I_{or}$ setting is the same at each node.
- The same UE receiver functionality is employed for reception from each Node B.

The DL coverage boundary is defined as the locus where received CPICH RSCP from both types of node, seen at the UE antenna port, is equal. This can be written as:

$$I_{or,MN} + G_{DL,MN} - L_{DL,MN} + G_{DL,UE} = I_{or,LN} + G_{DL,LN} - L_{DL,LN} + G_{DL,UE} \qquad (1)$$

where $I_{or,i}$ is the maximum transmit power; $G_{DL,MN}$, $G_{DL,LN}$ are the network node TX antenna gains towards the UE, $G_{DL,UE}$ is UE antenna gain (same towards both nodes), and $L_{DL,i}$ is the pathloss. The values are taken in the logarithmic domain i.e. in dB and dBm.

NOTE: Reference is made to the physical DL coverage boundary, rather than the boundary biased by offset terms such as the CIO.

7.1.1.2 UL coverage boundary

Compared to the DL, the UL coverage boundary is affected by additional factors specific to each network node, namely:

- Receiver factors, including the number of RX antennas, receiver sensitivity or equalizer implementation.
- The cell load.

The UL coverage boundary is the locus that leads to the desired signal SNR, taken at the channel decoder input, is the same. This can be written as:

$$\begin{aligned} &E_{c,UE} + G_{UL,UE} - L_{UL,MN} + G_{UL,MN} + G_{Div,MN} - N_t - N_{RX,MN} - RoT_{MN} + G_{eq,MN} = \\ &E_{c,UE} + G_{UL,UE} - L_{UL,LN} + G_{UL,LN} + G_{Div,LN} - N_t - N_{RX,LN} - RoT_{LN} + G_{eq,LN} \end{aligned} \qquad (2)$$

where $E_{c,UE}$ corresponds to UE TX power, $G_{UL,UE}$ is UE antenna gain (same towards both nodes), $L_{UL,i}$ is the pathloss, $G_{UL,MN}$, $G_{UL,LN}$ are the network node RX antenna gains towards the UE, $G_{Div,MN}$, $G_{Div,LN}$ are gains relating to RX antenna diversity (if present), N_t is the thermal noise power (same assumed in either node), $N_{RX,i}$ is the receiver noise figure, RoT_i is the rise-over-thermal value dependent on UL cell load and scheduler implementation, $G_{eq.i}$ captures the potentially different equalizer implementation for each node.

7.1.1.3 Matching the UL and DL coverage

Assuming that:

- the UE antenna gain is identical in UL and DL;
- the network node antenna gains are identical in UL and DL and denoted G_{MN} and G_{LN};
- the pathloss between the UE and network node is identical in UL and DL and is denoted L_{MN} and L_{LN}, respectively;

equations (1) and (2) can be simplified and combined, leading to the following condition for UL/DL coverage match i.e. the UL and DL coverage boundaries coinciding:

$$I_{or,MN} - I_{or,LN} = \left(G_{Div,MN} - G_{Div,LN}\right) - \left(N_{RX,MN} - N_{RX,LN}\right) - \left(RoT_{MN} - RoT_{LN}\right) + \left(G_{eq,MN} - G_{eq,LN}\right) \qquad (3)$$

Given the assumptions, the following observations can be made:

- The condition is not dependent on UE-specific parameters.

- The condition is not dependent on the pathloss elements or network node antenna gain towards the mobile station.
- The condition is dependent solely on network node characteristics: transmit power, antenna subsystem, noise figure, cell load and receiver implementation.

The UL/DL mismatch or imbalance M_{UD} can be defined as the difference between the left and right hand side of (3):

$$M_{UD} = \left(I_{or,MN} - I_{or,LN}\right) - \left(G_{Div,MN} - G_{Div,LN}\right) + \left(N_{RX,MN} - N_{RX,LN}\right) + \left(RoT_{MN} - RoT_{LN}\right) - \left(G_{eq,MN} - G_{eq,LN}\right) \quad (4)$$

A positive mismatch value results in the situation illustrated by Figure 15 where a UE served by the Macro cell causes excess interference of M_{UD} dB into a neighbouring LPN cell.

The Node B parameters such as I_{or}, N_{RX} and RoT may be set to achieve the desired mismatch. It needs to be studied what mismatch value leads to maximum system capacity.

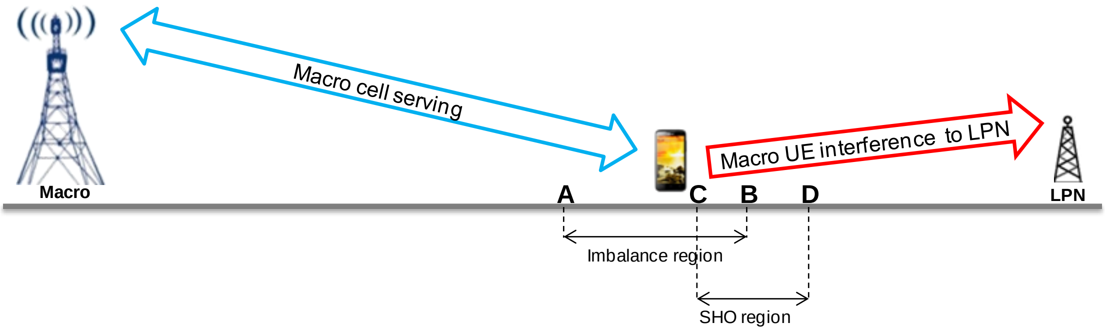

Figure 15: Macro UE interference to LPN

7.1.2 Solutions for legacy terminals

Several solutions to handle the UL/DL imbalance that are applicable to all users, including legacy users, can be envisioned, such as:

- LPN Noise Padding/Desensitization
- Macro Node B TX power reduction
- RoT target adjustment
- SIR target manipulation
- Semi-static or dynamic parameter tuning – adjust available parameters, such as beta-values (delta values) if the serving cell is the Macro cell, employ repetition, or adjust cell individual offsets and SHO parameters.

All these methods provide solutions that aim at reducing or limiting the UL/DL imbalance. However, at the same time some of these methods reduce some of the benefits offered by a heterogeneous network deployment. For example, desensitization and SIR target manipulation imply that the interference level increases towards the macro nodes. Macro node TX power reduction may negatively affect coverage and excessively increasing the RoT or SIR target may affect UL stability.

HS-DPCCH power offset boosting

In Rel-11, additional power offset values were added to the HS-DPCCH channel. The additional power offsets could be used in heterogeneous networks as well. Based on the received SIR measurements from the macro and LPNs, the RNC estimates the amount of mismatch between the two cells and boosts the HS-DPCCH power offset accordingly to overcome the mismatch.

Power control enhancements

In this scheme, the power control procedure is modified by the RNC in order to allow better reception at the Macro cell. The RNC estimates the power mismatch based on the received SNRs at the macro and LPNs and disables the power control from the LPN. This can be done in two ways:

- Remove the LPN from the UE active set. This would essentially put in the UE in a single cell mode where the macro power controls the UE.
- The TPC commands from the LPN are always +1. This would effectively switch the power control to the Macro cell exclusively. The benefit of this scheme would be to maintain the benefits of soft handover while improving performance of the HS-DPCCH.

SIR manipulation

In this scheme the DPCCH SIR target is increased to provide a better phase reference to the HS-DPCCH at the Macro cell. The RNC estimates the mismatch between the macro and the LPN and adjusts the DPCCH set point to ensure adequate HS-DPCCH decoding performance at the Macro cell.

The E-DPDCH power offsets are also correspondingly lowered to ensure that there is no excess Ec/No seen at the LPN cell. While the link to the LPN may be operating at a link in-efficient point, the control channel performance is preserved. The new T/Ps would have to be signalled to the UE for the adjustment to take effect.

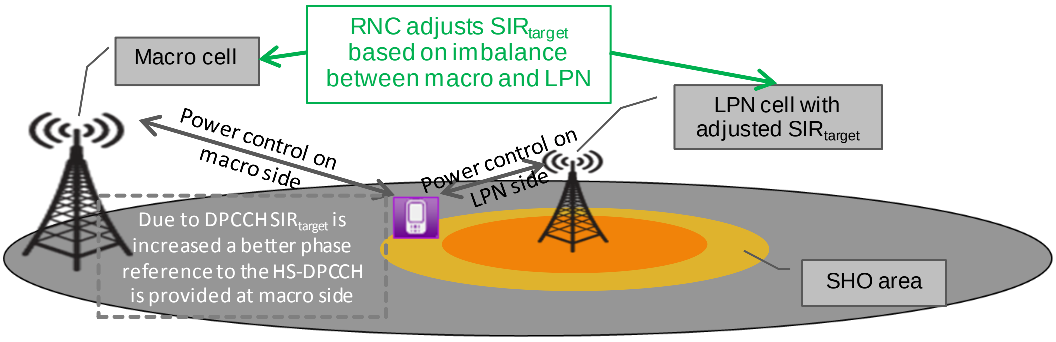

Figure 16: SIR adjustment for the reception of essential control information on the serving cell side

E-DCH decoupling

E-DCH decoupling is possible for legacy terminals. E-DCH decoupling is described in clause 7.1.3.

LPN noise padding/desensitization

This is a way of reducing/removing the imbalance that can be implemented on the network side and can therefore be used to address all users. By applying desensitization, the received SINR in the LPN becomes worse and the UE needs to increase the transmit power to reach the SINR target. For a UE in SHO between a Macro cell and an LPN cell, this implies that the reception quality in the Macro improves in some cases. Desensitization is described in clause 7.1. 5.

Range expansion

Range expansion, realized by CIO or Macro cell transmit power reduction, is described clause 7.2.

RoT target adjustment

The LPN RoT target could be increased to accommodate the increased dynamic range of interference. However, increasing the RoT target may affect UL stability.

Inner Loop Power Control (ILPC) restriction

The UE would follow power control commands only from the serving cell (hence ignoring the LPN commands or LPN commands if always +1). Additionally, a safety mechanism can be introduced to control the level of interference towards the LPN. This can be done in several ways, e.g. beta-ed is scaled to ensure that the average E-DPDCH power in the LPN is kept roughly constant. This information can be conveyed via RRC signalling.

7.1.3 Rel-12 enhancements

Different solutions to handle the UL control channel reception problem that require standardization support can be considered. The objective is to solve the problem while retaining as much as possible of the benefits offered by heterogeneous network deployments. Furthermore, these solutions should preferably be applied independently to different users, meaning that a user in a good position should not suffer much if a user in a bad position employs a particular method. Examples of such solutions include:

- **Active set manipulation** - Power control towards the weakest link or ignoring power control commands from strong non-serving cells are examples of possible solutions. These solutions have a severe drawback, namely that the interference towards the LPN increases, and therefore causing worse LPN performance (e.g. reduced coverage and off-loading capacity).
- **Dynamic parameter tuning** – In heterogeneous network deployments it might be beneficial to have more dynamic ways of handling parameter settings.
    - Moving the control of gain values (delta values) from the RNC to relevant nodes. This allows more dynamic signalling of parameter settings via e.g. HS-SCCH orders instead of relying on slow RLC signalling. Furthermore, it makes it possible for a node that experiences poor reception of a channel to quickly react and order the UE to increase corresponding gain value(s).
    - One issue is that for some physical channels all involved nodes (NodeBs and UEs) need to have a consistent view on what gain values are used. In this case it might be difficult to let the nodes operate independently of each other since that might lead to miss-matches between them. However, for other channels a unified view might be less important, making independent and dynamic gain value signalling an attractive approach. Whether a unified view on gain values is important depends on a number of factors, such as the receiver structure.
- **Dynamic power boosting** – Dynamic power boosting of individual uplink channels is one interesting approach to ensure reliable reception of control information. This is closely related to the previous bullet and a central question is how dynamic the boosting needs to be. One alternative is to boost via HS-SCCH orders, and another is to introduce a separate power control loop for channels that need to be boosted.
- **Power backoff** – Power imbalance causes performance issue in case where uplink SI is transmitted with data payload in E-DPDCH. In such case it would be better to avoid boosting E-DPDCH power due to relatively high data rate causing high cost in power. One way to avoid that would be using power backoff in E-TFC selection so that TB size used would be lower and hence obtained coding gain higher. Another benefit of this method is that it causes less RoT variation than boosting E-DPDCH power.
- **Additional pilots** – It is important to receive pilots with sufficiently good quality. One way to ensure this would be to boost the DPCCH, but this might be tricky since powers of other channels are set relative the DPCCH. Another alternative could be to introduce new and boosted pilots for UEs experiencing problems with the DPCCH quality.
- **DPCCH operating point manipulation** – The quality of the E-DPDCH is essentially determined by the total power on E-DPDCH. Consequently, if the DPCCH SIR is increased while the gain factors (beta-eds) are decreased correspondingly, the quality of E-DPDCH will be maintained. Hence, by reducing the beta-eds, the DPCCH SIR is forced to increase, and the quality of DPCCH (and all other channels except E-DPDCH) is increased. This is one way of increasing the power of all channels except the E-DPDCH. This is beneficial since the quality of control channels increases and it avoids boosting the E-DPDCH.

7.1.3.2 Introduction of secondary pilot

A secondary pilot is introduced on the uplink to act as the phase reference for the HS-DPCCH channel and is power controlled only by the weaker Macro cell. The E-DPCCH and the data channels would still be based on primary pilot and UL data decoding performance is not affected. Due to the change in the physical layer, this scheme would be applicable only to Rel-12 UEs.

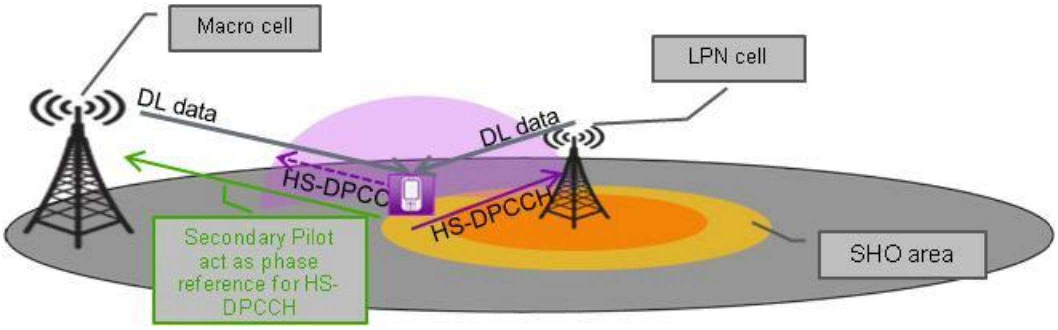

Figure 17: Secondary pilot based solution for reception of essential control information issue on the serving cell side

7.1.3.4 Dynamic power boosting

Dynamic power boosting of individual uplink channels is one interesting approach to ensure reliable reception of control information. A central question is how dynamic the boosting needs to be.
One alternative is to boost via HS-SCCH orders, and another is to introduce a separate power control loop for channels that need to be boosted. Another alternative would be to allow the UE to autonomously change its gain values.

In general it can be favourable to let the UE constrain/control its gain values since the UE has most up-to-date information about the power situation (i.e. when extreme or excessive power is used). For example, whenever the total (or data) power becomes too high relative the average power, the UE limits the serving grant. This means that the UE will not cause excessive interference towards the LPN (or best node) in situations where it most likely is anyway unfavourable for the system to transmit with such high power. The network does not have this up-to-date information and cannot respond as quickly as the UE. Merits, drawbacks and exact mechanisms might need further discussion.

One scenario where dynamic power boosting, or rather UE initiated power boosting, could be very beneficial is for an initial UE grant request using the happy bit conveyed on the E-DPCCH. Poor reception of an initial grant request in the serving cell causes degraded end-user throughput or in worst case no UL granted rate at all.

7.1.3.5 E-TFC selection backoff for uplink SI

Transmit power imbalance between macro node and LPN causes performance issue in case where uplink SI is transmitted with data payload in E-DPDCH. In such case it would be better to avoid boosting E-DPDCH power due to relatively high data rate which would result in high overall transmit power. One way to avoid that would be using power backoff in E-TFC selection so that the resulting TB size would be lower and hence higher coding gain would be obtained. Another benefit of this method is that it causes less RoT variation than boosting E-DPDCH power. This procedure can be either UE or network controlled. The relative grant signalling is one such network controlled mechanism that already exists. A UE controlled procedure could be to reduce the serving grant by a factor proportional to the difference in instantaneous and average DPCCH power. To further improve performance the application of backoff can be combined with serving cell only HARQ acknowledgement where subframe is assumed to be correctly received after acknowledgement is received from the serving cell.

Applying E-TFC selection backoff improves code rate of SI but at the same time reduces payload data rate. If applied backoff is too small then packet error rate of SI in the serving cell remains too high and scheduling algorithm can not reliably track the buffer status of the UE. If too high backoff value is applied then the achieved payload data rate can get lower than in the baseline homogeneous network case. However in such case the SI PER is below the baseline level. Actual value of backoff used in each case needs to be optimized taking into account e.g. transmission power of LPN, used CIO value and the HARQ acknowledgement mode used.

Despite the method used for maintaining backoff, applying it would change the uplink BLER. Hence usage of backoff should be somehow taken into account in the uplink power control operation. The easiest way to do that would be ignoring subframes where SI is transmitted when uplink SIR target is updated for outer loop power control.

Due to the change in E-TFC selection behaviour and the possible additional signalling required this scheme is limited to Rel-12 UEs only.

7.1.3.6 E-DCH decoupling

In order to minimize negative effect of DL/UL mismatch it is proposed that the LPN should be giving the UL grants/UL Tx power allocation to the UE. Two approaches are possible:

- LPN is providing grants directly to the UE (Rel-12 enhancement)
- Grants are provided to the UE through macro (applicable to legacy terminals)

Figure 18 shows the first approach, the RNC adds LPN to the UE AS. In the RL reconfiguration and RL setup procedures, the decoupling configuration parameters are provided if the E-DCH decoupling operation is allowed for the UE.. The same is transacted to the UE. Once the UE acknowledges the LPN addition, the LPN starts providing the UL budget to the UE. The LPN directly communicates this grant to the UE and the scheduling operation is initialized. The Serving Grant update keeps happening as long as the LPN is in the AS of the UE.

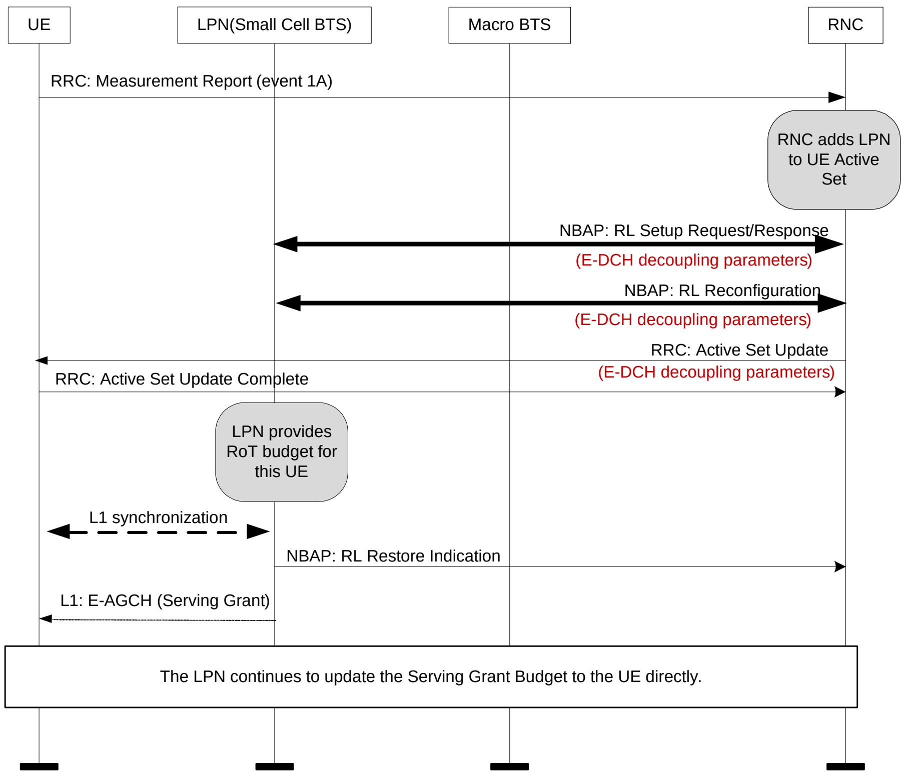

Figure 18: Approach 1 (E-DCH decoupling for new terminals)

Figure 19 shows the second approach, the RNC adds LPN to the UE AS. In the RL reconfiguration and RL setup procedures, the decoupling configuration parameters are provided if the E-DCH decoupling operation is allowed for the UE. Once the UE acknowledges the LPN addition, the LPN starts providing the UL budget to the UE. The message is shown to be routed via the RNC (although in principle a direct message could also be sent between the Node-Bs). Beyond this point, the macro communicates this grant to the UE and the scheduling operation is initialized. The Serving Grant update keeps happening as long as the LPN is in the AS of the UE.

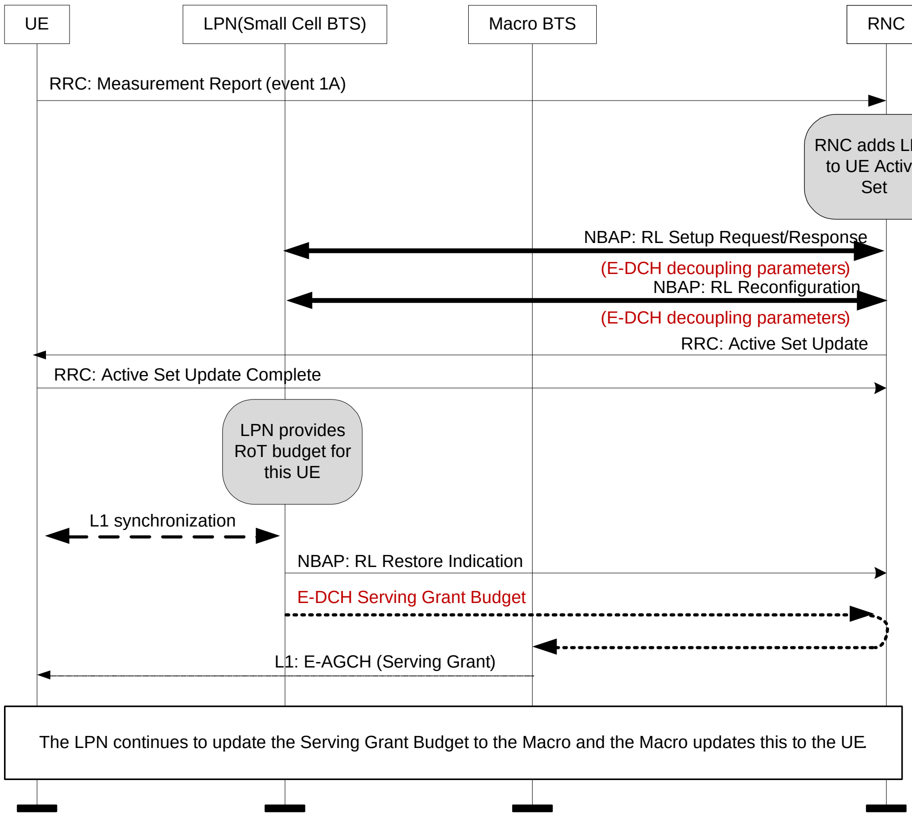

Figure 19: Approach 2 (E-DCH decoupling for legacy terminals)

Decoupling the UL transmission to the smaller cell enables the UL transmission to be power adjusted in such a way that it is received by the LPN only. This, in contrast to the other approach in which the macro sets the UL transmission range, is not causing high interference at the LPN, while still ensuring that the small cell is receiving the UL transmission with sufficient quality. Due to this UL transmission decoupling it is possible to utilize also macro UL resources in a more efficient way: The macro does not need to allocate an UL budget to the UE so it can be available for other UEs in macro area.

For this operation to succeed it is assumed that the UE can receive DL channels from the LPN that pertain to E-DCH reception, such as E-HICH, E-AGCH and E-RGCH in case LPN directly controls the UL grant.

When the LPN is controlling directly or indirectly the UL grant, it must be ensured however that the UL feedback channels for the macro DL are still being received by the macro. That is, it must be ensured that the macro can receive the HS-DPCCH. However in this case we have more power headroom for HS-DPCCH boosting when E-DCH decoupling is used because E-DCH channels power is now controlled by the LPN and due to much lower path loss towards LPN those power levels are reduced. This situation is depicted on Figure 20 below. When the LPN is providing grants directly to the UE the E-AGCH is transmitted not by the macro, but by the LPN. The macro instead may transmit the E-RGCH.

When the LPN is providing grants indirectly to the UE through the macro, it will inform the macro via the RNC about the grants that the macro can then relay to the UE via the E-AGCH or E-RGCH. There is a delay associated with the relaying of the grant. The delay can be assumed to be in the range of 50 to 200 msec. The longer the UE performs UL transmission the less relevant the delay will be. This operation can be transparent to the UE.

Main advantage of this solution is that UE UL power is utilized in optimal way.

The proposed decoupling method solves also an important problem with reliable reception of UL control information (E-TFCI, RSN, happy bit, in-band SI) for E-DCH transmission sent via E-DPCCH and E-DPDCH channels. In a legacy system in HetNet environment and inside the SHO area (when UL serving cell is Macro and power control is dominated by LPN), important UL control information may not be reliably decoded at the serving Macro cell. With E-DCH decoupling method, the LPN is the UL serving cell and dominates UL power control for SHO UEs so the reliable detection of E-DCH control channels designated to serving cell is guaranteed.

NOTE: The solution has some commonalities with the "common E-RGCH" described in clause 7.1.6.2.

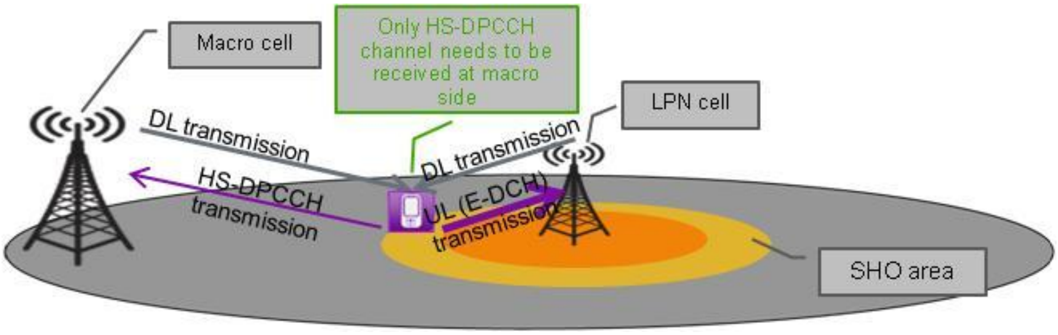

Figure 20: Power of E-DCH channels is controlled by LPN and in the effect there is more power headroom for HS-DPCCH boosting in order to ensure proper reception on macro side

7.1.3.7 Enhanced inner-loop power control restriction

One way of ensuring a reliable uplink towards the serving cell would be to restrict the existing power control procedure by enforcing the UE to only follow power control commands from the serving cell (the UE would ignore LPN issued commands or one would ensure that LPN commands are always UP). For this to work properly, additional constraints to ensure that the interference towards the LPNs (and other cells) is controlled need to be added:

1) *UE constrained* - One alternative is to let the UE control that the effective data transmit power does not become too high. For example, the UE could compare its instantaneous transmit power with its average transmit power and autonomously adjust the serving grant to keep a reasonable data power. This alternative would require standard change.
2) *Network constrained* – Another alternative is to let the network adapt the serving grant via the E-RGCH, and possibly also adjust the UEs gain reference values in order to control the LPN received power. This alternative can be achieved without any standard impact as described in Section 7.1.2 (ILPC restriction). It is, however, an open question whether new standardized signalling could improve the performance.

7.1.4 Evaluation of solutions for HS-DPCCH

7.1.4.1 Evaluation 1

Solutions to ensure HS-DPCCH reliability are evaluated. The different solutions considered are HS-DPCCH boosting, power control modification, SIR manipulation and secondary pilot. Such solutions are described in clauses 7.1.2 and 7.1.3.

False alarm and misdetection probabilities are the metrics used for evaluating the performance of the HS-DPCCH channel, and are defined below.

False alarm

This event occurs when the NodeB falsely detects an ACK on the HS-DPCCH channel. This can occur in two ways:

- When the UE does not transmit (DTX) and the NodeB falsely receives an ACK.
  - This event occurs when the HS-SCCH is not received on the downlink at the UE. The UE therefore does not transmit an acknowledgement on the HS-DPCCH channel. The NodeB then falsely decodes the DTX as an ACK.
  - It is assumed that the HS-SCCH misdetection probability at the UE is 1%
- When the UE transmits a NACK which is falsely received as an ACK.
  - This error is unlikely to happen very often as the transition probabilities $P(N \rightarrow A) << P(D \rightarrow A)$
  - It is assumed that a NACK would be transmitted 9.9% of the time. This assumes 10% BLER after the first transmission on the downlink.

Therefore, the false alarm probability can be expressed as:

$$P(\text{FA}) = P(N \rightarrow A \mid N) \cdot P(N) + P(D \rightarrow A \mid D) \cdot P(D)$$

In the simulation we target the total false alarm probability to be 0.1%.

Since $P(N) = 0.099$ and $P(D) = 0.01$, the $P(N \rightarrow A \mid N) \cdot P(N)$ component is rather small and can potentially be considered to be negligible.

Therefore, the effective false alarm target can be considered to be:

$$P(D \rightarrow A \mid D) \cong 0.1$$

NOTE: Such simplifying assumptions are not made in the following results. It is expected though that such an assumption would not change the nature of the results in a significant way.

Misdetection or decoding error

This event occurs when the NodeB does not detect the ACK transmitted by the UE. This error event occurs in two ways:

- When the UE transmits an ACK but the NodeB does not detect the transmission and instead assumes DTX.
  This event is the more common of the two.
- When the UE transmits an ACK and the NodeB detects that there is a transmission on the HS-DPCCH channel (not DTX) but erroneously decodes it as a NACK.

It is assumed that an ACK is transmitted 89.1% of the time which results from the assumption of 10% BLER after the first transmission.

Therefore, the misdetection or decoding error probability can be expressed as:

$$P(MD\ \ or\ \ Dec\,Err) = P(A \to D|A) \cdot P(A) + P(A \to N \mid \overline{D}, A)$$

For purposes of comparison, the target probability for the misdetection or decoding error considered in the simulations is 1%. Note that since the CQI decoding error rate is typically an order of magnitude lower than that of the A/N decoding error rate, we focus on the HARQ-ACK decoding in this document. Any solutions for the impact on HARQ-ACK decoding due to mismatches can also be applied to CQI decoding.

The different solutions are compared by assessing the increase in the amount of interference introduced at the LPN. The amount of interference is measured by the increase in the Rx Ec/No.

The Rx Ec/No for the HS-DPCCH boosting, Power Control Modification, SIR Manipulation solutions is computed as:

$$Total\ Rx\,\frac{E_c}{N_o} = \frac{E_{cp}}{N_o}\left[1 + \frac{T}{P} + \left(\frac{C}{P}\right)_{E-DPCCH} + \left(\frac{C}{P}\right)_{HS-DPCCH}\right]$$

The Rx Ec/No for the Secondary Pilot solution is given by:

$$Total\ Rx\,\frac{E_c}{N_o} = \left(\frac{E_{cp}}{N_o}\right)_{pri}\left[1 + \frac{T}{P} + \left(\frac{C}{P_{pri}}\right)_{E-DPCCH}\right] + \left(\frac{E_{cp}}{N_o}\right)_{sec}\left[1 + \left(\frac{C}{P_{sec}}\right)_{HS-DPCCH}\right]$$

The baseline value is the Rx Ec/No at the LPN for 0dB mismatch. Results are shown in tables 1 and 2. The simulation assumptions are listed in Table 20 in Annex A.5.

Table 1: Required HS-DPCCH C/P and the Rx Ec/No impact when UL data IS transmitted

Imbalance [dB]	Required HS-DPCCH C/P [dB]				Excess LPN Rx Ec/No [dB]			
	HS-DPCCH Boosting	Power Control Modified	SIR Modified	Secondary Pilot	HS-DPCCH Boosting	Power Control Modified	SIR Modified	Secondary Pilot
0	3.62	-2.62	3.62	-2.69	N/A	2.25	N/A	0.10
3	8.61	-1.91	6.05	-2.62	1.59	5.22	1.46	1.38
6	21.3	-0.82	4.26	-2.34	9.29	7.1	2.92	2.48
9	N/A	2.74	7.72	-1.75	N/A	8.54	5.16	3.74
12	N/A	14.09	5.78	-1.87	N/A	11.79	7.4	5.63
18	N/A	N/A	N/A	-1.68	N/A	N/A	N/A	10.46

Table 2: Required HS-DPCCH C/P and the Rx Ec/No impact when UL data IS NOT transmitted

Imbalance [dB]	Required HS-DPCCH C/P [dB]				Excess LPN Rx Ec/No [dB]			
	HS-DPCCH Boosting	Power Control Modified	SIR Modified	Secondary Pilot	HS-DPCCH Boosting	Power Control Modified	SIR Modified	Secondary Pilot
0	4.84	-2.72	4.84	-1.43	N/A	1.48	N/A	0.99
3	12.07	-2.53	6.28	-1.44	5.9	4.24	3.91	3.17
6	21.56	-2.69	7.9	-1.41	15.26	7.25	7.6	5.65
9	N/A	-2.56	5.89	-1.5	N/A	10.6	10.67	8.07
12	N/A	-2.65	3.65	-1.36	N/A	13.48	13.74	11.03
18	N/A	-2.52	N/A	-1.5	N/A	19.56	N/A	16.82

7.1.4.2 Evaluation 2

Results for the methods described below can be found in Table 3. The simulation assumptions are listed in Table 20 in Annex A.5. It is noted that an overview of the methods is given in subclauses 7.1.2 and 7.1.3. Here further details are specified in order to describe the simulation settings.

- *Desensitization (LPN padding)* – For the results in Table 3 the desensitization corresponding to the imbalance is applied in the LPN.

- *New pilot channel* – A new pilot channel is introduced in the UL that is only power controlled by the serving cell. Power offsets of essential control channels (HS-DPCCH and possibly E-DPCCH) are set relative to this new channel. The SINR target for the new pilot channel equals the DPCCH SINR target, i.e. -21dB.
- *SINR target manipulation* – The SINR target is increased to ensure that the quality of essential received signals in the serving macro is sufficient, e.g. DPCCH, HS-DPCCH and E-DPCCH. At the same time the reference gain values are reduced correspondingly to ensure that the effective E-DPDCH quality (as seen by the LPN) remains the same. In the results presented below, the increase in SINR target and reduction of E-DPDCH gain factors corresponds to the imbalance plus a fixed offset by 2dB which gives a margin for Macro diversity effects.
- *Inner loop power control (ILPC) restriction* – In this scheme the UE follows power control commands only from the serving cell (hence ignoring the LPN or LPN is always sending +1). Furthermore, a safety mechanism is introduced to control the level of interference towards the LPN. This can be done in several ways, but in the results the β_{ed} is scaled to ensure that the average E-DPDCH power in the LPN is kept roughly constant. In practice the safety mechanism can be UE or network controlled.

Table 3: Required HS-DPCCH C/P and the excess receive Ec/N0 that achieve a ~1% miss detection probability for different imbalances. The excess Rx Ec/N0 is computed with respect to the baseline case (i.e., no solution applied or desensitization at 0 dB imbalance) at imbalance = 0 dB.

Imbalance [dB]	Required HS-DPCCH C/P [dB]				Excess Rx E_c/N_0 [dB]			
	Desens.	ILPC & β_{ed} restriction	SINR target	Secondary pilot	Desens.	ILPC & β_{ed} restriction	SINR target	Secondary pilot
0	4.0	-3.1	0	-2.63	0	-0.25	-0.25	0.15
3	4.0	-3.1	0	-2.63	3	0.7	-0.1	1.65
6	4.0	-3.1	0	-2.63	6	2.0	1.3	2.9
9	4.0	-3.1	0	-2.63	9	3.7	3.25	4.15
12	4.0	-3.1	0	-2.63	12	5.85	5.6	5.7
18	4.0	-3.1	0	-2.63	18	11.05	11.1	9.9

The results indicate that the ILPC restriction with E-DPDCH power constraint, the new pilot channel, and the SINR target manipulation schemes have very similar performance in terms of required transmit power and HS-DPCCH reception quality in the serving cell.

There are, however, some differences between the schemes that should be considered:

- The ILPC restriction and the SIR target manipulation schemes can be applied to legacy users and ensure reliable reception of all control channels (HS-DPCCH, E-DPCCH, and in-band E-DPDCH control information) in the serving cell. One question is how frequently the constraints (SIR target, reference values or serving grant) need to be updated for satisfactory operation. For legacy users, some of this information is conveyed via quite slow and expensive higher layer signalling, possibly making the schemes less robust.
    - o Several Rel-12 enhancements can be envisioned, for example, the E-DPDCH power restriction can be handled autonomously by the UE, which makes it easier to respond faster to link imbalance changes, and thereby provides more robustness. One question is whether the UE should be allowed to change reference values, and not only the serving grant, autonomously as well.
- The new pilot approach requires standardization changes and is therefore not applicable to legacy users. Also, the baseline solution addresses only the HS-DPCCH quality. The scheme can, however, be updated to take also E-DPCCH information into consideration. There will be an impact on both network nodes and UEs since the physical layer needs to be updated with the new pilot channel, and extra receiver processing is needed to estimate the additional channel and handle the HS-DPCCH power control. A benefit of this approach is that it is very dynamic, robust and can respond quickly to changes in the link quality.

7.1.5 Evaluation of noise padding/desensitization

For legacy terminals one method to reduce the UL-DL imbalance is noise padding/desensitization at the LPN, which moves the UL balance point towards the DL balance point. The use of noise padding forces LPN UEs to transmit at higher power, potentially causing unnecessary interference to the neighbouring cells. This could have significant impact to the overall performance in heterogeneous networks, especially when most of the UEs are served by the Macro. From an UL throughput point of view, LPN UL padding should be applied at the minimum value, i.e. just enough to overcome the UL interference from the neighbouring Macro UEs.

One of the main purposes for LPN UL padding is to overcome the excessive out-of-cell UL interference that LPNs could observe. The levels of interference each LPN observes is different and depend on the location of the LPN, the type of UE, traffic distribution in the system, etc. To maximize the UL system performance, adaptive algorithms to determine the best UL padding for each LPN can be considered.

The UL capacity analysis presented in this clause does not take UL control channel reliability into account (e.g. ideal E-DPCCH and HS-DPCCH decoding is assumed). Modelling practical control channel reliability and overhead is expected to affect UL throughput results: as the amount of LPN padding reduces, the relative gains over the macro-only baseline reduce as well. Quantifying the impact of UL control channel overhead is FFS.

Uplink system simulation results

The simulation assumptions are listed in Annex A.1. Some additional salient assumptions are as follows: the LPN noise figure is assumed to be the same as the noise figure of Macro nodes; 4 LPNs are uniformly dropped per geographic area of each Macro sector; 8 UEs are dropped per geographic area of each Macro sector with 50% Hotspot distribution; UL Full Buffer traffic is considered. The Macro transmit power is 43dBm and the LPN transmit power is 30dBm, therefore there is a maximum imbalance of 13 dB. To get insights about the impact of Noise Padding on UL throughput, the configurations listed in Table 4 have been simulated. It is noted that the parameter values used in the different configurations should be considered as examples to investigate the UL performance trend.

Table 4: Configurations

Configuration	1	2	3	4	5	6	7	8
CIO (dB)	0	0	0	3	3	3	6	6
NP (dB)	0	6	13	0	6	10	0	7

Figure 21 shows the average, median and edge (5%) throughput gains in the uplink for Macro + LPN UE. Gains are relative to the baseline case in which no LPNs are deployed within the Macro cell area. It can be seen that a NP of 6dB can improve UE average throughput, but median and edge throughputs are reduced. A large NP of 13dB cannot further increase UE average throughput. Instead, it reduces the median and edge throughputs significantly. Even negative gain can be observed for edge UE throughput. Further analysis of this fact will be given with separate Macro/LPN edge throughput performance results as well as Macro/LPN RoT results.

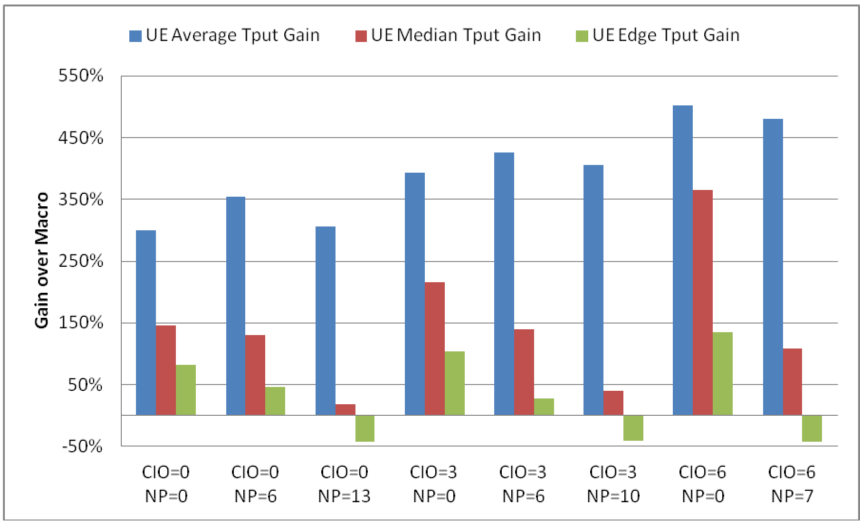

Figure 21: Uplink performance with different configurations for Macro + LPN UE

Figure 22 shows separately the edge performance of Macro + LPN UE, Macro UE and LPN UE. It can be seen that with NP, LPN UE performance improves significantly, however Macro UE performance reduces significantly, especially when NP is large. As there are more Macro UEs than LPN UEs, and LPN UE performance becomes much higher than Macro UE performance when increasing the amount of NP, the overall Macro + LPN edge UE performance is dominated by Macro edge UE performance. This explains why Macro + LPN edge UE performance is very close to the Macro edge UE performance, especially when LPN edge UE performance is very high. Enlarging the CIO without NP, however, improves both Macro edge UE and LPN edge UE performance.

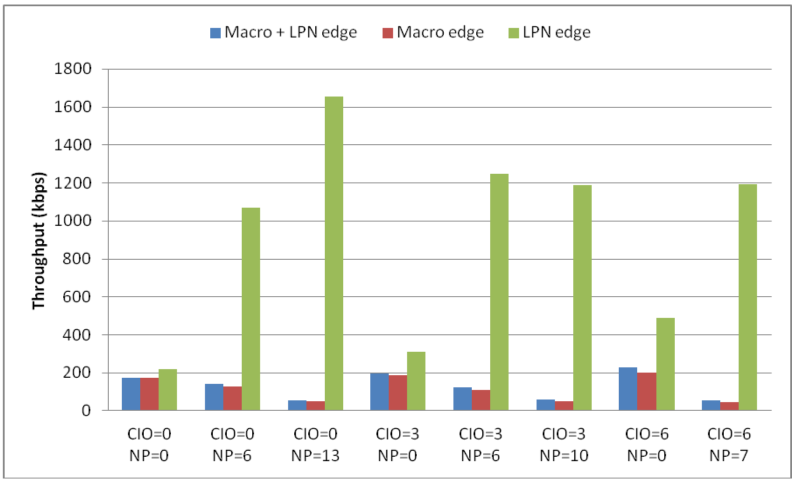

Figure 22: Edge (5%) UE performance with different configurations

Table 5 shows the 90% Macro/LPN RoT of each configuration. It can be seen that increasing NP increases the RoT of the Macro since the transmit power of all LPN UEs increases and the interference level to the Macro node increases. On the LPN side, for CIO=0dB, increasing NP reduces RoT at the LPN with more than 1dB because when CIO=0dB, there is strong uncontrolled uplink interference to the LPN. For CIO larger than 0 dB, increasing NP only reduces RoT at the LPN within 1dB because the CIO already reduces the amount of Macro UE interference to the LPN.

Table 5: Macro/LPN 90% RoT with different configurations

Configuration	1	2	3	4	5	6	7	8
CIO (dB)	0	0	0	3	3	3	6	6
NP (dB)	0	6	13	0	6	10	0	7
Macro 90% RoT (dB)	6	6.1	7.6	6	6.5	7.7	6	7.9
LPN 90% RoT (dB)	6.3	5.2	4.7	5.9	5.1	5	5.5	5.1

Adaptive noise padding at the LPN

The design goal of an adaptive algorithm to determine the best UL padding for each LPN would be to apply minimum amount of padding necessary to control the out-cell interference to the desirable level.

The following quantities are defined.

- UL RoT (Nose Rise) is defined as $RoT = (Ior + No)/No$, where Ior is the total received signal power from all UEs in the system, No is the NodeB receiver thermal noise.
- Ior can be divided into $Ior = Ior_{serving} + Ior_{nsAS} + Ior_{outcell}$, where $Ior_{serving}$ is the total received signal power from all UEs served by the cell. Ior_{nsAS} is the total received signal power from all UEs not served by the cell but having the cell in the active set. $Ior_{outcell}$ is total received signal power from all UEs not having the cell in the active set.
- Out-cell RoT can be defined as $RoT_{outcell} = (Ior_{outcell} + No)/No$. Measurement of out-cell RoT can be obtained from the measurement of No and measurement of out-cell total received power $Ior_{outcell}$. To get estimate of $Ior_{outcell}$, NodeB can estimate the total received power Ior, and the total received power from the UEs that have the cell in the active set, i.e. $Ior_{serving} + Ior_{nsAS}$. Then, the remaining is the out-cell interference $Ior_{outcell}$.

The purpose of adaptive LPN UL padding is to control the $RoT_{outcell}$ since this is the interference that LPN cannot control via power control loop or relative grant channel (E-RGCH). When LPN operates at the fixed RoT target and observes excessive out-cell interference, to protect the UEs served by the LPN, LPN needs to increase its noise figure via UL padding and ask UEs (served by the LPN) to transmit at higher power in order to overcome the excessive out-cell interference.

One possible adaptive LPN UL padding procedure is as follows:

- The LPN periodically measures the out-cell RoT, $RoT_{outcell}$.
- If the $RoT_{outcell}$ is greater than the upper limit, $RoT_{outcel}^{measure} > RoT_{outcel}^{up}$, increase the LPN UL padding by Δ.
- If the $RoT_{outcell}$ is smaller than the lower limit, $RoT_{outcel}^{measure} < RoT_{outcel}^{down}$, decrease the LPN UL padding by Δ.
- The LPN padding is limited within the range $[p_{\min} \quad p_{\max}]$.

There could be modifications to the procedure including the employing of hysteresis margins, usage of out-cell load (the ratio between the out-cell interference over the Ior) instead of the out-cell RoT, etc. However, the underlying idea is simply to improve the UL performance by applying the UL padding to the LPN when needed, i.e. when the LPN observes high out-cell interference that it cannot control.

The system performance of the above mentioned adaptive noise padding technique is shown below. The simulation assumptions are given in the Annex A. Some additional salient assumptions are as follows:

- The LPN noise figure is assumed to be the same as the noise figure of Macro nodes.
- The Macro transmit power is 43dBm and the LPN transmit power is 30dBm.
- 4 LPNs are uniformly dropped per geographic area of each Macro sector. 16 UEs are dropped per geographic area of each Macro sector with 50% Hotspot distribution.
- CIO is 3dB biased toward the LPN
- UL Full Buffer traffic is considered
- 3dB is used as the out-cell RoT upper limit RoT_{outcel}^{up} and 2dB as the lower limit RoT_{outcel}^{down}. The padding adjustment step size $\Delta = 1dB$. The padding is limited to be within [0dB 10dB].

Adaptive LPN UL padding is compared with 2dB and 6dB fixed padding values. Figure 23 shows the UL throughput performance comparing adaptive LPN UL padding with 2dB and 6dB fixed padding. It is clear to see that with adaptive padding, the fairness has been improved over 6dB fixed padding.

In Table 5, the following types of system performance metrics are compared:

- Average UE throughput: it is calculated as the average throughput of all UEs in the system
- 50% UE throughput: it is computed as the median throughput of all UEs in the systems
- 5% UE throughput: it is computed as the throughput of the UEs at 5% tail across all UEs in the system
- RoT statistics: RoT is only considered for non-empty cells. A non-empty cell is defined as a cell that serves at least one UE. The statistics of both average RoT and 90% point at the RoT CDF (Cumulative Distribution Function) for Macro nodes and LPNs are shown. The 90% RoT indicates those cells in the system that are experiencing very high out-cell interference.

The gains are presented as percentage throughput increase over the baseline system. The baseline is a system where LPNs are not present in the Macro cell. It is observed that adaptive padding provide gains over the 6dB padding, especially at the median and tail. Compared to fixed 2dB padding which is close to the optimum fixed padding setting, the adaptive padding offers a slight performance improvement.

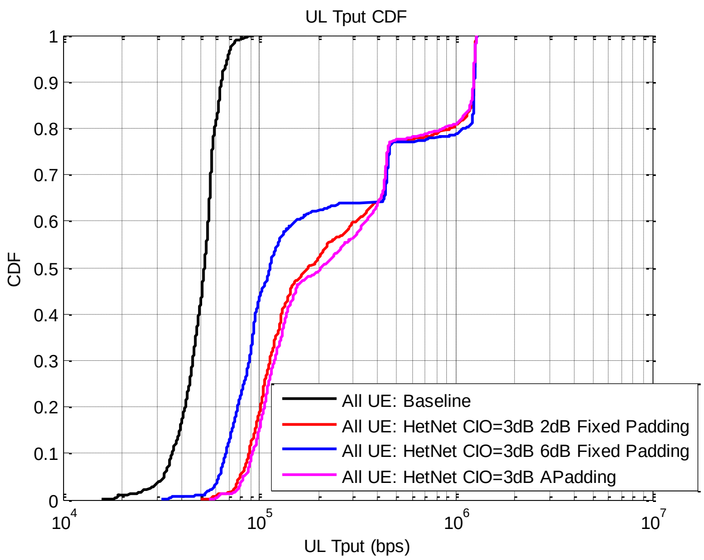

Figure 23: UL Performance in HetNet co-channel deployment with noise padding

Figure 24 shows the CDF of the padding being applied at LPNs. Most LPNs do not observe high out-cell interference, hence require no or minimum padding (~2dB). Only a small percentage of LPNs needs padding greater than 4dB. The application of small LPN UL padding actually provides better UL performance compared to the application of large LPN padding in some cases. This is explained by noting that the LPN serves a smaller number of UEs compared to Macro and hence each UE served by LPN enjoys a larger share of the available RoT.

If large LPN UL padding is applied to fully remove the DL-UL imbalance, system fairness would degrade since the UEs served by LPNs would have much better UL performance as compared to the UEs served by Macro cells.

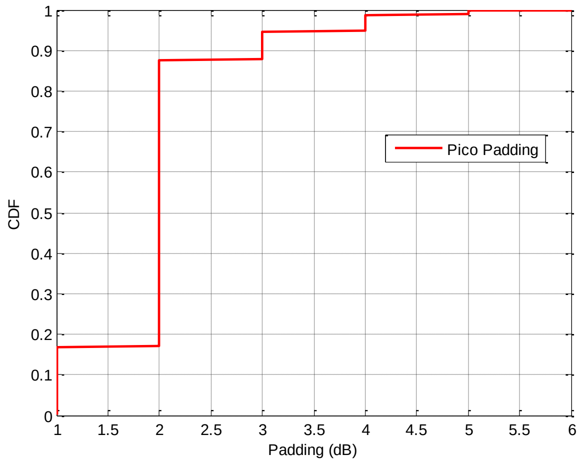

Figure 24: CDF of UL padding being applied at each LPN with adaptive padding mechanism

Table 6 summarizes the UL throughput gains respect to Macro only deployment. Compared to results with no LPN padding, a small gain in mean user throughput is seen with moderate LPN padding, while losses are experienced for the cell-edge throughput with moderate LPN padding and for both mean and cell-edge throughputs with more aggressive LPN padding. As expected, the Macro RoT increases while the LPN RoT decreases as the noise padding increases.

Table 6: UL Performance in HetNet co-channel deployment with noise padding

LPN padding [dB]	UL Throughput Gain [%]			Macro RoT [dB]		LPN RoT [dB]	
	Mean	Median	5%	Mean	90%	Mean	90%
0dB	699%	353%	160%				
Fixed 2dB	708%	237%	142%	5.5	5.6	4.4	5.8
Fixed 6dB	673%	116%	91%	5.7	6.0	3.2	5.1
Adaptive	716%	294%	154%	5.5	5.7	4.5	5.8

7.1.6 Solutions for the strong mismatch zone

One possible solution for the Strong Mismatch Zone is desensitization; however care should be taken to avoid UL capacity loss. Another solution is the use of a CIO larger than 0dB. However, other solutions can also address the problem in perhaps a more efficient way. The solutions are as follows:

- Introduction of an extended active set
- Common E-RGCH
- Inter-Cell Interference-Cancellation

7.1.6.1 Introduction of an extended active set

For the UEs in the strong mismatch zone, the respective LPNs are added to the UE's active set (see Figure 25). If the network has the ability to identify the UEs outside the DL SHO area but inside the strong mismatch zone, adding those cells to those UE's active sets would have the benefit of reducing the RoT contribution of the UE to the macro UL.

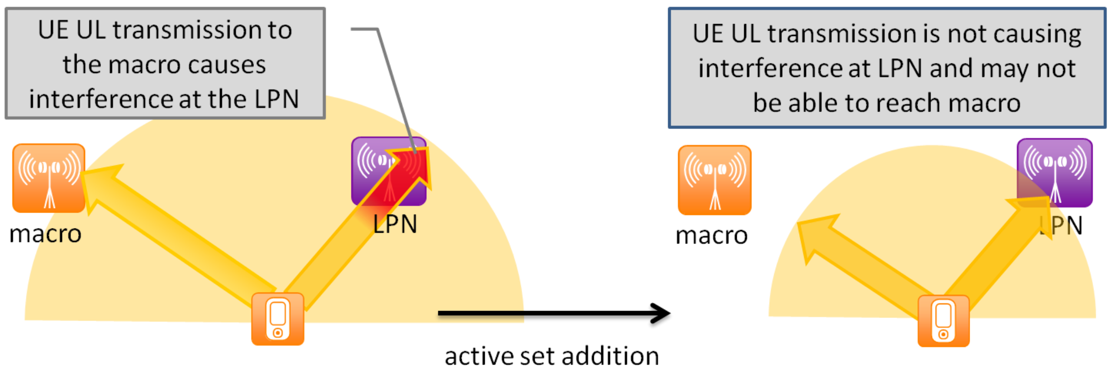

Figure 25: Left: UE is required to transmit at high power levels, while being a strong interferer to the LPN. Right: Less power is required after LPN addition to the active set, leading to less UL interference.

The UEs in the strong mismatch zone which need the LPNs outside their current DL SHO area to be added to the AS need to be identified. The network may identify these UEs by a variety of means including those mentioned in clause 6.1.4. It should be noted that there would be some impact to the UE complexity since there would be a need to monitor and demodulate the common channels from an LPN at low geometries.

7.1.6.2 Common E-RGCH

For UEs in the strong mismatch zone, it could be beneficial to expand the E-RGCH operation outside the active set, i.e. allow the UEs to listen to the E-RGCH from the cells not in the active set. One reason is that active set is decided based on the DL received signal quality. For the homogenous deployment, it is mostly true that if a cell has a better DL received signal, it should also have a better UL received signal. However, for HetNet deployment, due to the transmit power difference between different types of nodes, it is quite likely that a cell may not be in the active set due to relative weak DL signal, but still have a quite a strong UL to the UE. The other consideration is that with LPN deployment, there could be more load discrepancy in the system, i.e. the number of UEs served by Macro and LPNs can be quite different. UEs that are served by the lightly loaded cells can transmit at very high data rate/power, which may cause large interference to the neighbouring cells not in the active set.

Based on the above discussion, for HetNet deployment, more robust UL interference management can be achieved by allowing UEs to listen to the common E-RGCH from cells not in the active set. The notion of common E-RGCH has already been specified for the CELL_FACH state in Rel-11 and can easily be extended to the CELL_DCH state for robust UL interference management. The salient aspects of common E-RGCH based interference control are as follows:

- Spreading code for the common E-RGCH is either hardcoded or broadcasted in a SIB. The structure of the physical channel is the same as legacy E-RGCH.
- A 1 bit flag per cellID in the neighbour list that is part of SIB11 is added to indicate identities of the cells that support common E-RGCH. Alternatively, this information can be conveyed through an existing dedicated message.
- Specify the conditions under which the UEs would listen to common E-RGCH from the neighbour cells. The Event 1a could, for example, be used for this purpose. Since common E-RGCH is for UL interference management, a metric that better represents the UL quality such as path loss could be used. Therefore, a UE would only listen to a common E-RGCH from a neighbour cell if the path loss to the cell passes criteria similar to Event 1a.

If a cell observes high uncontrollable out-cell interference and, consequently, UEs within its cell coverage suffering from poor UL performance, the cell could transmit an common E-RGCH grant “DOWN” command in order to instruct the UEs who listen to the common E-RGCH channel to transmit at lower rate/power.

Simulation results to demonstrate the effectiveness of common E-RGCH for UL interference management are given below. In addition to the simulation assumptions in the Annex, the following are assumed:

- The LPN noise figure is the same as the noise figure of Macro nodes.
- The Macro transmit power is 43dBm and the LPN transmit power is 30dBm.

- 4 LPNs are uniformly dropped per geographic area of each Macro sector. 8 UEs are dropped per geographic area of each Macro sector with 50% Hotspot distribution.
- The CIO is set to 3dB biased toward the LPN
- UL Full Buffer traffic is considered to be the traffic model
- No LPN padding/desensitization is considered.

Figure 26 illustrates the performance benefit from enabling the E-RGCH from the LPNs not in the active set. Compared with a baseline Hetnet deployment, 11% gain in the average throughput, 16% gain in the media throughput and 9% in the 5% tail throughput is observed.

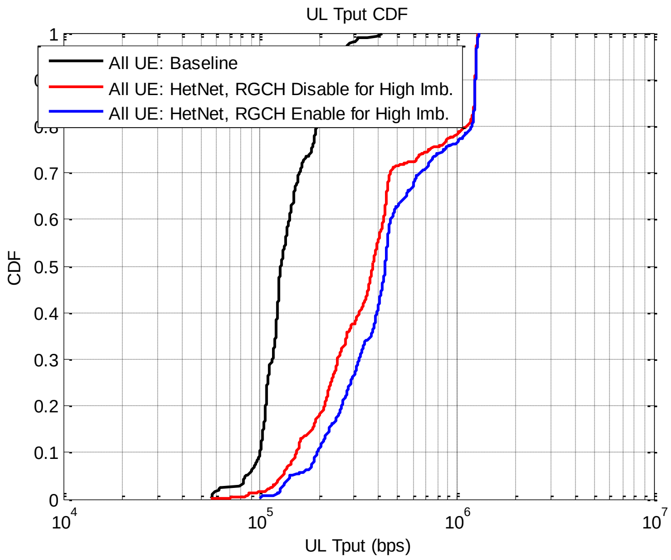

Figure 26: UL throughput CDF, 30dBm LPN

The cells transmitting the common E-RGCH channel would have to account for the additional control channel overhead. There would also be requirements defined for the UE to monitor the E-RGCH from neighbouring cells that are not in the active set. However, it is considered that UEs that are capable of common E-RGCH operation in CELL_FACH state would be also capable of this feature in CELL_DCH state.

In summary, common E-RGCH allows the UE to be rate controlled by the cells not in the active cell. This gives each cell more opportunities to control the out-cell interference, thereby improving UL interference management.

7.1.6.3 Inter-Cell Interference Cancellation (ICIC)

System performance can also be improved by ICIC. Inter-Cell Interference at an LPN is due to the sum of the waveforms of all the users in the strong mismatch zone, i.e. the LPN is not in the active set of the users. In these scenarios, the LPN is not aware of these users and hence does not power control or rate control these users.

Allowing the LPNs to cancel the UL interference from the UE not communicating with it could significantly improve UL performance, especially in a HetNet deployment. In order to perform ICIC, the LPN would require the UL DPCH and E-DPCH Information sent by the RNC during Radio Link Setup/Addition procedure. In particular, the following pieces of information are considered to be required for the LPN to attempt cancellation:

- UL Scrambling Code
- UL DPCCH Slot Format
- Frame Offset
- Chip Offset
- Max Number of UL DPDCHs
- Maximum Set of E-DPDCHs
- Puncture Limit

- E-TFCS Information
- E-TTI
- E-DPCCH Power Offset

Similar to common E-RGCH, the UE identifies the LPNs that are not in the active set, but there could be quite strong interferers on the UL. One way to identify those LPNs would be to rely on the path loss measurement. Once a UE measures low path loss to some NodeB cells not in the active set, the UE could report the LPN cell identity to the RNC. Then, the RNC could inform the respective LPN and provide the necessary information to conduct ICIC.

7.1.6.4 UL throughput limitation for identified UEs

Similar to common E-RGCH, the UL interference could potentially be limited by applying bearer specific rate control e.g. by E-TFCI restriction. This can be achieved by reducing the system resources allocated to such UEs. This is shown in Figure 27.

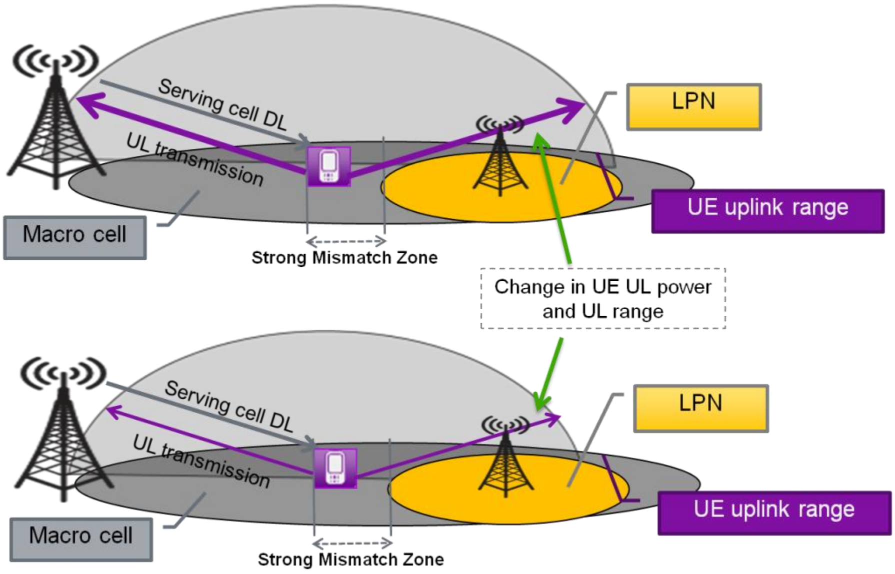

Figure 27: Change in grants allocated to the UE to limit UL interference

This solution improves the average UL throughput of the UEs served by the LPNs. The exact parameters to be applied are specific to UEs.

7.1.6.5 Carrier frequency switch for identified UEs

One way to address extensive UL interference originating from macro UEs in the strong mismatch zone is an inter-frequency handover for the UEs causing highest interference. The identified interfering UEs could be handed-over to a different macro frequency carrier. This is shown in Figure 28.

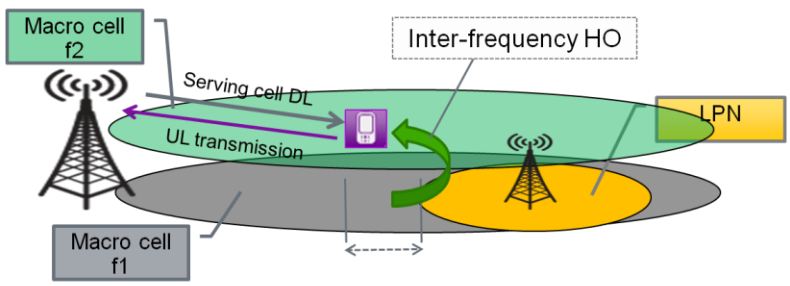

Figure 28: Inter-frequency HO for a UE in the strong mismatch zone

This solution assumes that:

- There is a second (other) frequency carrier available at the serving macro cell,

- The second (other) frequency carrier is not loaded and can accept new UEs without causing any degradation (due to e.g. increased interference level) to current cell throughput.

The RNC controlling the macro and the LPN is aware of the load situation in both cells and on all carriers and can decide whether the proposed hand-over for UEs is possible and beneficial from a system level perspective. It may not be necessary to switch all interfering UEs to other macro carrier, but potentially only a certain number, since the LPN interference levels reduce with each handover.

7.1.7 Performance evaluation of HetNet in co-channel scenarios

For the evaluation of downlink and uplink system performance for HetNet in Single Carrier (SC) co-channel scenarios, full buffer and bursty traffic models are considered. System simulation assumptions are summarized in Annex A.1 and system performance evaluation metrics in Annex A.2. The gains are presented as the percentage increase over the baseline throughput. The baseline throughput is obtained when LPNs are not present in the Macro cell.

7.1.7.1 Downlink system performance

Below are further clarifications of the simulation assumptions for the downlink system evaluation.

- Outdoor path loss model is assumed. Since the ISD is assumed to be 500m, without lowering the Macro transmit-power, the geometry distribution will not differ noticeably for the mixed scenario (60% indoor and 40% outdoor).

- Channel model is assumed to be PA3. Since HetNet deployment benefits the system performance mostly through offloading, the gain is expected not to be very sensitive to the channel model.

- Only SIMO case is assumed.

- As perfect control channel (HS-DPCCH) performance is assumed in the simulation, DL performance is not impacted by the availability of SHO between Macro and LPN.

- For the UE positions, two dropping criteria are considered: uniform UE dropping and 50% clustering UE dropping, as described in Annex A.1.

For the full buffer traffic model, the following system performance metrics are considered:

- Average UE throughput: it is calculated as the average throughput of all UEs in the system.

- 50% UE throughput: it is calculated as the median throughput of all UEs in the system.

- 5% UE throughput (edge throughput): it is calculated as the throughput of the UEs at 5% tail across all UEs in the system.

- Offloading percentage: it is calculated as the percentage of UEs among all UEs that are served by LPNs in the system.

The simulation results obtained by different companies are collected in [36]. Most of the results are reasonably aligned and show similar performance trends. However, it is important to note that when averaging all results there are some variations in the resulting performance that may suggest slightly different conclusions from the obvious conclusions that can be drawn independently from the results of most companies. Here we show the resulting performance which gives an indication of the achievable gains of HetNet deployment in co-channel scenarios. For further details it is suggested to refer to the extensive simulation results available in [36], and in several other contributions in RAN1#71 and up to RAN1#73.

Table 7 shows the UE throughput gains for a HetNet scenario with full buffer traffic and uniform UE dropping (random scenario), with 37dBm, 30dBm and 24dBm LPNs.

Table 7: Downlink full buffer performance with uniform UE dropping

LPN Power	LPN Num	CIO [dB]	Downlink Throughput Gain [%]			Offloading [%]
			Mean	Median	5%	
37dBm	1	0	57%	15%	1%	10%
		3	57%	24%	8%	13%
	2	0	100%	30%	20%	16%
		3	110%	50%	27%	23%
	4	0	195%	79%	25%	31%
		3	201%	103%	56%	39%
30dBm	1	0	33%	7%	3%	4%
		3	39%	13%	2%	6%
	2	0	52%	11%	10%	6%
		3	61%	23%	12%	11%
	4	0	113%	28%	8%	14%
		3	109%	46%	23%	19%
24dBm	1	0	16%	2%	-1%	2%
		3	19%	5%	-1%	3%
	2	0	23%	4%	3%	5%
		3	26%	8%	6%	4%
	4	0	39%	7%	2%	8%
		3	46%	14%	6%	8%

From the simulation results, it is observed that when placing LPNs within the Macro area, the average, median and edge throughputs increase significantly, and throughput increases when increasing the number of LPNs per Macro area and/or increasing the transmit power of the LPNs. The cell edge throughput gains are significantly less than the average throughput gains. This is because adding LPNs in the Macro coverage areas introduces more interference in the system and the interference has a more significant impact on cell edge UEs. To increase throughput gains, more UEs can be offloaded from Macro nodes to LPNs by applying the cell individual offset (CIO) to bias towards the LPNs during serving cell selection. As shown, with a CIO of 3 dB the offloading percentages increases and consequently the throughput. Using a larger CIO setting can degrade the geometry of those UEs that are offloaded from Macro nodes to LPNs, which may result in performance loss for those UEs. From simulation results, not shown here, it has been observed performance loss for cell edge UEs while CIO values above 6 dB are applied. Advanced receivers which are capable of performing interference cancellation can be used to improve HetNet deployment performance when applying a large CIO.

Table 8 shows the UE throughput improvements for a HetNet scenario with full buffer traffic and 50% clustering UE dropping (hotspot scenario), with 37dBm, 30dBm and 24dBm LPNs.

Table 8: Downlink full buffer performance with 50% clustering UE dropping

LPN Power	LPN Num	CIO [dB]	Downlink Throughput Gain [%]			Offloading [%]
			Mean	Median	5%	
37dBm	1	0	100%	56%	32%	26%
		3	93%	67%	43%	32%
	2	0	175%	77%	41%	30%
		3	164%	104%	61%	40%
	4	0	296%	137%	65%	41%
		3	284%	177%	104%	51%
30dBm	1	0	95%	56%	42%	25%
		3	92%	67%	45%	30%
	2	0	157%	65%	44%	26%
		3	160%	90%	53%	32%
	4	0	258%	84%	43%	31%
		3	271%	127%	67%	38%
24dBm	1	0	98%	59%	47%	26%
		3	96%	73%	58%	32%
	2	0	155%	61%	30%	25%
		3	156%	85%	50%	32%
	4	0	247%	80%	29%	28%
		3	266%	114%	52%	34%

As shown, the percentage of UEs served by LPNs is higher in the hotspot scenario than in the random scenario. The percentage of offloaded UEs increases if more LPNs are deployed within a Macro cell coverage area, and if the transmit power of the LPN is higher. The higher offloading percentage benefits the average, median and edge throughputs which are all significantly higher than the throughputs in random scenario. Thus, comparing with random scenario, higher gains can be achieved in the hotspot scenario.

For the bursty traffic model, the following system performance metrics are considered:

- Average UE burst rate: it is calculated as the average burst rate of all UEs in the system
- 5% UE burst rate: it is calculated as the burst rate of the UEs at 5% tail across all UEs in the system
- Offloading Percentage: it is calculated as the percentage of UEs among all UEs that are served by LPNs in the system.
- Average TTI utilization: For each cell, the TTI utilization is defined as the percentage of TTIs during which each cell schedules a packet to at least one UE. The TTI utilization is averaged over all non-empty cells (Macro cells and LPNs). A non-empty cell is defined as a cell that serves at least one UE.
- Percentage of UEs that are in outage: It is defined as the percentage of UEs whose average burst rate is lower than the offered load (the offered load is assumed 400kbps per UE).

Table 9 shows the UE throughput improvements for a HetNet scenario with bursty traffic and uniform UE dropping, with 37dBm, 30dBm and 24dBm LPNs.

Table 9: Downlink bursty traffic performance with uniform UE dropping, 16 UEs

LPN Power	LPN Num	CIO [dB]	16 UE/Macro		Offloading [%]
			Average Burst Rate Gain	5% Burst Rate Gain	
37dBm	1	0	37%	31%	8%
		3	50%	52%	13%
	2	0	67%	144%	17%
		3	91%	175%	24%
	4	0	166%	223%	32%
		3	152%	378%	40%
30dBm	1	0	16%	11%	3%
		3	25%	18%	5%
	2	0	25%	29%	7%
		3	44%	55%	11%
	4	0	87%	76%	17%
		3	90%	144%	21%
24dBm	1	0	9%	11%	1%
		3	11%	14%	2%
	2	0	11%	9%	3%
		3	15%	18%	4%
	4	0	19%	19%	5%
		3	30%	55%	8%

From the simulation results, it can be clearly seen that there is significant performance benefit from HetNet deployment in terms of both the system capacity (average burst rate) and the system coverage (5% burst rate), especially at high load. By increasing the LPN transmit power and the number of LPNs, higher burst rate gains can be achieved as more UEs are offloaded from the Macro cells to the LPNs. For example, by placing 4 37dBm LPNs per Macro area, around 40% of the UEs are offloaded to LPNs and then more than 150% average gain in burst rate can be achieved.

It is also important to note that, the system performance improvement from a HetNet deployment mostly comes from offloading. Given the current simulation assumption, 500m ISD, the system is interference limited. LPN deployment does not have significant improvement on the UE geometry distribution as the system is still interference limited. For the burst traffic simulation, there are two extremes.

- One extreme is that the system is sparsely loaded. In this case, the UE burst rate is close to the UE peak rate, since, statistically speaking, the UE does not need to compete with other UEs when burst arrives. As a result, the gain from LPN deployment is very limited.
- The other extreme is that the system is heavily loaded. In this case, the UE burst rate gain not only relies on the UE geometry, but also highly relies on the loading of the cell. LPN deployment helps reduce the loading for each cell, and therefore, significantly improves the UE burst rate.

Table 10 shows the UE throughput improvements for a HetNet scenario with bursty traffic and 50% clustering UE dropping, with 37dBm, 30dBm and 24dBm LPNs.

Table 10: Downlink bursty traffic performance with 50% clustering UE dropping, 16 UEs

LPN Power	LPN Num	CIO [dB]	16 UE/Macro		Offloading [%]
			Average Burst Rate Gain	5% Burst Rate Gain	
37dBm	1	0	145%	180%	26%
		3	150%	228%	32%
	2	0	181%	270%	30%
		3	200%	392%	38%
	4	0	236%	368%	41%
		3	258%	627%	50%
30dBm	1	0	149%	148%	24%
		3	159%	240%	30%
	2	0	172%	262%	26%
		3	180%	341%	32%
	4	0	193%	243%	31%
		3	217%	435%	40%
24dBm	1	0	124%	302%	25%
		3	142%	488%	31%
	2	0	124%	316%	27%
		3	149%	532%	34%
	4	0	122%	357%	25%
		3	147%	575%	33%

Compared to uniform UE dropping, for 50% clustering UE dropping higher percentages of UEs are offloaded to LPNs and larger system performance improvements are achievable. However even with the 50% clustering of users around LPNs, LPNs are still much less loaded compared to Macro nodes. For the 50% clustering UE dropping simulations, the UE distribution is adjusted according to the LPN transmit power. The clustering radius in 50% clustering UE dropping reduces as the LPN transmit power reduces. The clustering radius is chosen to be 20m, 35m, and 60m when the LPN power is 24dBm, 30dBm, and 37dBm, respectively. As a consequence, the additional systems gains due to the deployment of LPNs with larger transmit power is less significant in 50% clustering UE dropping than in uniform UE dropping where deploying LPNs with larger transmit power provides more UE offloading compared to LPNs with low transmit power.

Regarding the TTI utilization, from simulation results captured in [36], it is observed that even if placing 4 LPNs with 37dBm transmit power, the TTI utilization of non-empty LPNs is significantly less than the TTI utilization for Macro cells.

It is important to emphasize that the deployment of HetNet is targeted for performance improvements when the system is capacity limited (highly loaded) in the pure Macro only system. As observed from the simulation results, the performance improvements from HetNet deployment dramatically increase as the load in the system increases. At extremely low load scenario (around 10-20% average Macro TTI utilization in the baseline), there may be a small to medium loss from HetNet as it introduces additional interference into the system.

The consideration of the outage metric is important because for UEs characterized as in outage, their burst rate eventually approaches zero as the simulation time increases. The bursty traffic model used in the HetNet simulations and described in Annexes A.1 and A.2, is an “open loop” model. The arrival of the burst follows the pre-defined statistic model, irrespective of the current queue status (length), as well as the UE physical layer supportable data rate. The computation of burst rate considers both the over the air transmission delay and the queuing delay. Given such a bursty traffic model, as the number of UEs increases, each UE has less chance of being scheduled by the NodeB, hence its physical layer supportable data rate reduces. When the UE physical layer supportable data rate becomes lower than the offered load from the bursty traffic source, the UE starts to have an unstable queue, i.e. the queue starts to build up and the queue length keeps increasing as the simulation time increases. Under such an unstable queue, the later burst that arrives at the queue observes increasingly larger queuing delay and, consequently, smaller and smaller burst rate. As a result, for the UEs whose physical layer supportable data rate (average burst rate) are lower than the offered load, their burst rate eventually approaches zero. The fact that the outage percentage increases with the simulation time in the baseline case makes it difficult to quantify accurately the HetNet gain over the Macro-only baseline. It is desirable to further study the effect of a reduced file size to ensure a reliable baseline.

As an example, Figure 29 shows the CDF of the average burst rate for the HetNet deployment with 4 LPNs and the baseline deployment with only Macro cells. The UEs suffering from outage are visualized by the part of CDF lying on the left of the offered load line. In the Macro only scenario about 30% of the UEs experience burst rate inferior to the average offered rate. In the HetNet scenario only less than 1% of the users fails to transmit at or above the average offered data rate. It can be then be concluded that adding 4 LPNs practically eliminates the outage problem given the assumed burst traffic parameters.

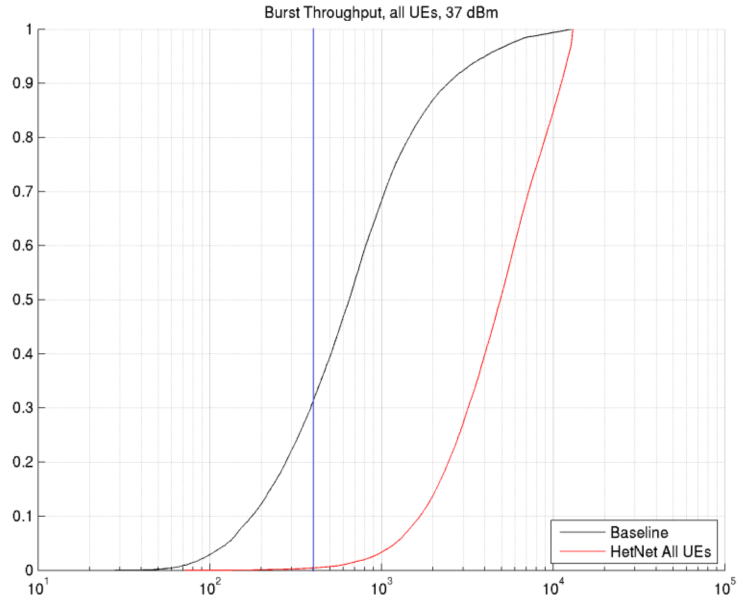

Figure 29: Average burst rate CDF for baseline and HetNet deployment, with offered load of 400 kbps

In conclusion, from the evaluation of the downlink system performance for HetNet in co-channel scenarios it is observed:

- LPN deployment significantly improves both the average user experience and worst case user experience.
- Compared to full buffer, bursty traffic shows significantly higher tail user experience gain, especially for highly loaded system.
- LPN deployment significantly reduces the percentage of UEs that are in outage.
- Given the same UE location, the performance gain from LPN deployment improves with the number of LPNs, the larger transmit power of the LPNs, LPN being deployed in hotspot where more UEs are present, and LPN being deployed in highly loaded system.
- Compared to a CIO of 0dB, applying a moderate CIO of 3dB allows more UEs to be offloaded to LPNs, which in turn improves the HetNet deployment performance gain, especially at high load. Applying larger CIO values increases the number of offloaded UEs, however the reliability of the downlink control channel needs to be taken into consideration. The evaluation of the downlink control channel is done in clause 7.2.1.1.

7.1.7.2 Uplink system performance

Below are further clarifications of the simulation assumptions for the uplink system evaluation.

- Outdoor path loss model is assumed.
- Channel model is assumed to be PA3.
- UE targets 1% BLER after four transmissions.
- LPN noise figure is assumed to be the same as the noise figure of Macro nodes.
- For the UE positions, two dropping criteria are considered: uniform UE dropping and 50% clustering UE dropping, as described in Annex A.1

For the full buffer traffic model, the following system performance metrics are considered:

- Average UE throughput: it is calculated as the average throughput of all UEs in the system
- 50% UE throughput: it is calculated as the median throughput of all UEs in the system
- 5% UE throughput (edge throughput): it is calculated as the throughput of the UEs at 5% tail across all UEs in the system
- Offloading Percentage: it is calculated as the percentage of UEs among all UEs that are served by LPNs in the system
- RoT statistics. It is considered only the RoT for non-empty cells. A non-empty cell is defined as a cell that serves at least one UE. The statistics of both average RoT and 90% point at the RoT CDF (cumulative distribution function) for Macro nodes and LPNs, are shown separately. The 90% RoT indicates those cells in the system that are experiencing very high out-cell interference. The 90% RoT gives an understanding of the interference problem caused by a HetNet deployment.

As discussed in clause 6.1, the UL/DL imbalance that occurs with the deployment of LPNs creates interference issues in the uplink between Macro and LPN, and this affects the reliability of the uplink control channels, including HS-DPCCH reception at the serving cell. The impact of UL/DL imbalance on HS-DPCCH is discussed in clause 6.1.4.2 and the evaluation of potential solutions in clause 7.1.4. The system simulations shown here assume ideal HS-DPCCH decoding, and the power consumption for transmitting control information in the uplink is unchanged respect to the baseline deployment where LPNs are not present in the Macro cell. It is noted that if additional power is needed for the transmission of control information in the uplink in HetNet deployments, the impact on UL system performance needs to be considered.

The simulation results from different companies are collected in [36]. It is observed that there are differences between the simulation results and averaging all results is not possible. However some results are quite aligned and give a good indication of the range of expected uplink gains when deploying LPNs in Macro cells.

From the simulation results with uniform UE dropping, it is observed that when placing LPNs within the Macro area, the average, median and edge throughputs increase significantly, and throughput increases when increasing the number of LPNs per Macro area and/or increasing the transmit power of the LPNs. For example, by placing 1 37dBm LPN per Macro area, around 15% of the UEs are offloaded to LPNs and then around 100% average throughput is achieved. When placing 4 37dBm LPNs per Macro area, around 40% of the UEs are offloaded to LPNs and then above 250% average throughput can be achieved. Compared to a CIO of 0dB, applying a moderate CIO of 3dB allows more UEs to be offloaded to LPNs, which in turn improves the performance gains.

From the simulation results with 50% clustering UE dropping, it is observed that a larger percentage of UEs is offloaded compared with uniform UE dropping. As a result, the UE throughput gains are larger. For example, by placing 4 37dBm LPNs per Macro area, around 50% of the UEs are offloaded to LPNs and then average throughputs on the order of 300-350% can be achieved.

With the deployment of LPNs with 30dBm or 24dBm power, the power difference between the Macro and LPN is large and the interference issue becomes more relevant as the interference generated by the Macro UE to LPN becomes large. The RoT of the LPN then can be higher than the target RoT and consequently the LPN UEs will receive a smaller grant. It has been observed in the simulations that, as the loading on LPN is much lower than the loading on Macro, 5% tail throughput gains can be achieved even though LPN RoT can be higher than the target of 6dB. Even with the 50% clustering of users around LPNs used in these simulations, LPNs are generally less loaded compared to Macro nodes.

The case when SHO is not allowed between Macro and LPN has been investigated. It is observed that significant interference issues in terms of performance loss at the 5% UE throughput exist. For low LPN density (1, 2 LPN/Macro), the problem is even worse when CIO is 3dB. With the increase of CIO from 0dB to 3dB, more UEs are offloaded to LPNs. Since LPN is typically less loaded compared to Macro, LPN UE tends to receive large grants and hence transmit at higher power which may cause large interference to the neighbouring Macro. Considering the example of 1 LPN/Macro, 90% Macro RoT is at 5.9dB for CIO 0dB, and increases to 6.3dB for CIO 3dB. The 5% tail performance loss increases from -9% to -34%. This suggests that without appropriate interference management, offloading too many UEs to LPN could negatively impact the UL performance.

For the bursty traffic model, the following system performance metrics are considered:

- Average UE burst rate: it is calculated as the average burst rate of all UEs in the system
- 5% UE burst rate: it is computed as the burst rate of the UEs at 5% tail across all UEs in the system
- Offloading percentage
- RoT statistics

Similar to the performance for the full buffer traffic model, it is observed that when placing LPNs within the Macro area, the average and edge UE burst rates increase significantly, and the gains increase when increasing the number of LPNs per Macro area and/or increasing the transmit power of the LPNs. Larger gains are found for the 50% clustering UE dropping as a larger percentage of UEs are offloaded to the LPNs.

In conclusion, from the evaluation of the uplink system performance for HetNet in co-channel scenarios it is observed:

- LPN deployment significantly improves the system capacity and system coverage
- Given the same UE location, the performance gain from LPN deployment improves with the number of LPNs being deployed, LPN being deployed with larger transmit power, and LPN being deployed in hotspot where more UEs are present.
- Allowing SHO between Macro and LPN is very important to improve the UL performance as well as manage UL interference between Macro and LPN.
- UL interference issues becomes more severe as the transmit power difference between LPN and Macro increases. Combined with allowing SHO between Macro and LPN, applying fixed LPN UL padding can help mitigate the UL interference issues.

7.1.7.3 MIMO performance

In system level simulations 4 LPNs per cell is assumed. In the simulations, a full buffer traffic model is assumed. The baseline case is taken without any deployment of LPN. The statistics are collected for 16 UEs per cell. Figure 30 shows the average sector throughput comparison for the cases with and without LPN when all the UEs are in SIMO and MIMO modes. It can be seen that with the addition of LPNs the average sector throughput can be significantly increased for both SIMO and MIMO modes. Table 11 shows the percentage of gains achieved in both cases. Similar to SIMO case, the gains achieved in due to load balancing even though there are more number of users are with rank 1 transmission.

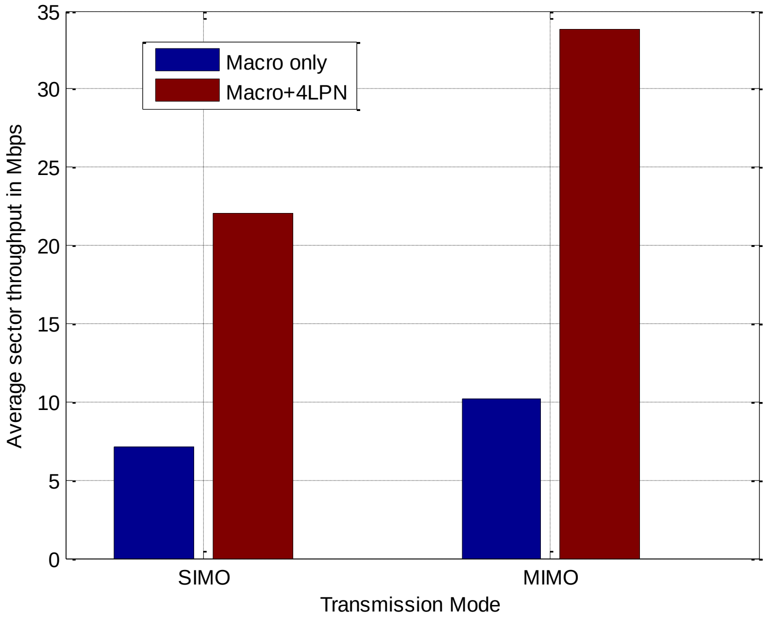

Figure 30: Average sector throughput for SIMO and MIMO modes (LPN power = 37 dBm)

Table 11: Percentage of gain with respect to homogeneous network with LPN power = 37 dBm

Number of users per Macro node	SIMO	MIMO
16	213	232

System level simulation results indicate that significant gains can be achieved in average user throughput and average sector throughput when LPNs and multiple antennas are deployed.

7.1.8 Network Assisted Interference Cancellation

In heterogeneous deployments due to the transmit power difference between the Macro node and LPN, there is a high probability that the performance of a UE connected to the LPN is impacted by the strong Macro interference. One method to mitigate this performance loss is to adopt an interference cancellation receiver. The network (Macro, LPN, or both) can assist the victim UE to mitigate the interference by sending some scheduling information of the interferer. The victim UE with an interference cancellation receiver can remove the interference once some scheduling information of the interferer is received.

7.1.8.1 Interference Cancellation

Assuming that there are Np interfering nodes (macro or LPN), the received signal during a slot can be written as follows:

$$\mathbf{r} = \sqrt{L_0}\mathbf{H}_0\sqrt{P_{p0}}\mathbf{x}_p + \sqrt{L_0}\mathbf{H}_0\sqrt{P_{c0}}\mathbf{x}_{c0} + \sqrt{L_0}\mathbf{H}_0\sqrt{P_{do}}\mathbf{x}_{d0} + \sum_{j=1}^{Np}\left(\sqrt{L_j}\mathbf{H}_j\sqrt{P_{pj}}\mathbf{x}_{pj} + \sqrt{L_j}\mathbf{H}_j\sqrt{P_{cj}}\mathbf{x}_{cj} + \sqrt{L_j}\mathbf{H}_j\sqrt{P_{dj}}\mathbf{x}_{dj}\right) + \mathbf{n}$$

where $\mathbf{H}_0$ is the channel between the connected node and the UE, and $\mathbf{H}_j$ is the channel between the j^{th} node and the UE. Note that the channel is represented by a Toeplitz matrix. The vector $\mathbf{x}_p$ denotes the common pilot chip sequence,

$\mathbf{x}_{c0}$ denotes the control channel chip sequence from the macro node, and $\mathbf{x}_{d0}$ denotes the data chip sequence from the macro node. The pilot symbols, control channel symbols and the data symbols are different from each node. Hence $\mathbf{x}_{pj}$ denotes the pilot channel chip sequence from node j, $\mathbf{x}_{cj}$ denotes the control channel chip sequence from node j, and $\mathbf{x}_{d}$ denotes the data chip sequence from node j. The variables P_{p0}, P_{c0}, and P_{d0}, respectively, are the transmitted power levels for the common pilot, control channels (overhead channels), data channel (HS-PDSCH) from the desired node, and P_{pj}, P_{cj}, and P_{dj}, respectively, are the transmitted power levels for the common pilot, control channels (overhead channels), and data channel (HS-PDSCH) from the j^{th} node. The variable L_0 is the path gain from the desired node to the UE and L_j is the path gain from the j^{th} node to the UE, and **n** is the additive white Gaussian noise which includes both the thermal noise and other-cell interference.

It can be observed that the desired signal's pilot, control channel and data channel are impacted by the interference. Hence three types of interference can be cancelled:

a. Pilot cancellation

b. Control channel (overhead channel) cancellation

c. Data traffic channel cancellation

Hence it could be beneficial if the UE can process first pilots, other overhead channels and HS-PDSCH from one or more interfering cell(s), and then reconstruct and cancel those channels from the received signal. Once the dominant interference is removed the UE can decode the desired HS-PDSCH from its serving HS-DSCH cell. However, it should be noted that the feasibility of control channel cancellation due to strict timeline constraints in a practical UE receiver has not been evaluated.

7.1.8.2 Aspects of Network Assisted Interference Cancellation

7.1.8.2.1 Post-decoding and pre-decoding IC

There are essentially two types of interference cancellation. One is post-decoding IC, in which the UE demodulates and decodes the interfering signal and then reconstructs and cancels it from the total received signal. In this case in order to decode the interfering HS-PDSCHs, the UE needs to know the transport block size and HARQ RV information besides the modulation and code set of the interfering signal. The other type of IC is pre-decoding IC, in which the UE does not decode the interfering signal but reconstruct it from the demodulated values. In this case the UE needs to know modulation and code set of interfering signal.

7.1.8.2.2 Signalling of information for IC

One method for the network to convey the scheduling information about the interferer is by sending an additional HS-SCCH with a common H-RNTI so that the network assisted interference cancellation UE can decode the HS-SCCH from interfering cell(s).

The network can send the scheduling information about the interferer either explicitly or implicitly. In explicit signalling, the network will convey the scheduling information about the modulation, number of channelization codes and the transport block information to the victim UE. In implicit signalling, the network will convey the dedicated H-RNTI of the UE which is scheduled. Note that with implicit signalling, the UE needs to decode the HS-SCCH of the other cell for obtaining the scheduling information. Implicit signalling is beneficial as the victim UE can use this information for cancelling the control channel interference thereby improving the performance of downlink control channel.

Another method is to send higher layer signalling to configure a transmission pattern for the Macro NodeB and LPN and to signal such pattern to the UE is also beneficial to improve the performance of the victim IC UEs in LPN.

It is noted that the type of information needed at the UE depends on the IC architecture. The signalling will impact the transmit power of the data channel in the interfering cell and it needs to be taken into account in the evaluation of the IC gains.

7.1.8.2.3 Coordinated scheduling and Restricted Resources Subframe

Depending on the receiver structure and scheduling strategy the victim UE with NAIC may experience a more or less hostile interference environment. Especially considering co-channel deployment for HetNet, the use of coordinated scheduling between Macro and LPNs can help realize the full potential IC gains.

Therefore, if the LPN schedules the victim IC UE in a better interference environment, the victim IC UE can achieve higher IC gain and the performance of LPN edge IC UE could be further improved. Some kind of coordinated scheduling is beneficial to be considered as a network assisting method for interference cancellation receivers.

Restricted Resources Subframe on Transport Format (RRS on TF) is a method of NAIC to improve the performance of the LPN UEs with advanced IC capability. RRS is a form of coordinated scheduling between the Macro and LPNs where the Macro NodeB restricts the scheduled resources. The restriction on modulation type is one way to implement the RRS method. The restricted resources could also be scheduled codes. The details of which resources are restricted can be signalled to the LPN UEs, along with the pattern information. The information about the pattern and restricted resources can be conveyed through higher layer signaling to minimize the impact of signaling on the system capacity.

The steady and known interference environment when using RRS helps reduce CQI mismatch. If the scheduling at the Macro NodeB and LPN is done independently, as in legacy operation, the Macro NodeB can schedule any modulation type and number of codes, and this can change from TTI to TTI. The LPN UE experiences a changing interfering environment and this will cause a CQI mismatch. With RRS pattern, there is no CQI mismatch because the modulation type of interfering signal does not change over a certain time period and it is known at the LPN UE side.

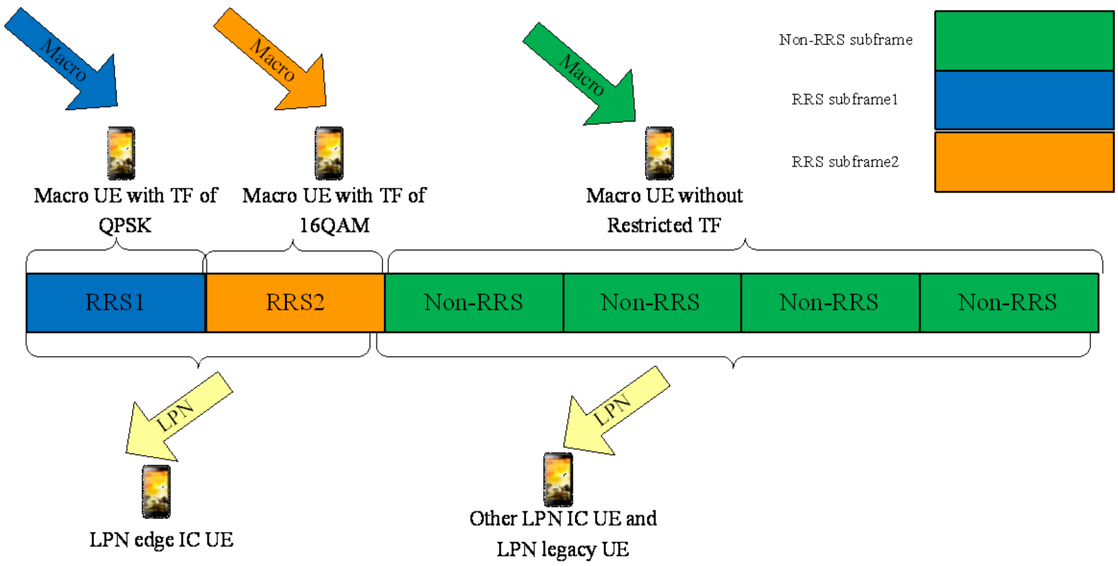

Figure 31: Example of Tx pattern for Restricted Resource Subframe on Transport Format

One example of RRS pattern is illustrated in Figure 31. The RNC will negotiate a pre-configured TTI pattern between the Macro and the related LPNs. On Macro NodeB, some specific TTIs, which are called RRS subframes, are indicated to only transmit some pre-defined transport format, for example, QPSK+15codes or 16QAM+15codes. On the LPN side, since the victim IC UE can have higher IC gain on RRS, the LPN should schedule LPN IC UE on the restricted resource subframes with higher priority. Depending on the network load, different RRS patterns can be considered to optimize performance.

7.1.8.3 Network assistance for signalling for type 3i receiver

Signalling from the interfering cell can be considered to improve the performance of type 3i receivers. One example is to send to the victim UE information related to the instantaneous transmit power of a neighbour interfering cell. This can help the victim UE to suppress interference. It is expected that higher gains can be achieved in bursty traffic.

Depending on the receiver structure and scheduling strategy the victim UE with NAIC may experience a more or less hostile interference environment. Especially considering co-channel deployment for HetNet, the use of coordinated scheduling between Macro and LPNs can help realize the full potential IC gains.

7.1.8.4 Simulation scenario

The simulation scenario for analyzing the network assisted interference cancellation receiver performance is shown in Figure 32. We assume a network model with 57 Macros. In one of the macro cell regions, one LPN has been dropped. This is a simplified HetNet model between one LPN and one dominant macro with outer cell interference (from other 56 macros). Twelve possible UE locations are created and shown in Figure 32 (marked from L_1 to L_{12}). In the following we elaborate the network layout and UE locations.

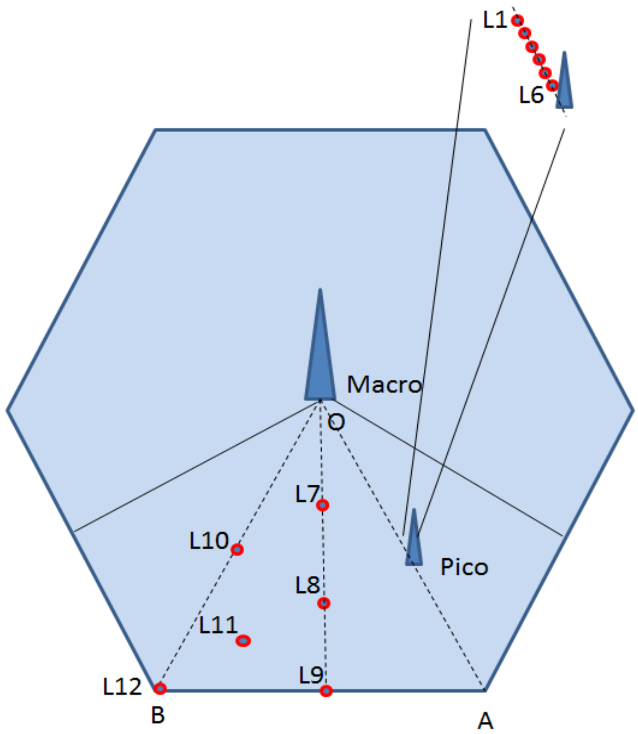

Figure 32: Simulation scenario for analyzing the network assisted interference cancellation receiver

A hexagonal cell structure is assumed with ISD = 500 meters, and one Macro is located at the origin *O*. Assume point *A* lies at the vertex of the hexagon, with the distance *OA* 288 meters. Further, consider that the LPN is located at the mid-point of *OA*, with the distance to the Macro 144 meters.

The selection of UE locations is based on the following two criteria. First, some locations can only be served by the Macro, and others can be served by both the Macro and the LPN. Second, for the UE locations that can be served by both the Macro and the LPN, the value (Ior/Ioc)LPN - (Ior/Ioc)macro should vary in a wide range, from smaller than -10dB to larger than 10dB.

Based on the above two criteria, we assume 12 UE locations, where 6 locations L_1, L_2, …, L_6 lie on the line connecting the Macro (*O*) and LPN, and other 6 locations L_7, L_8, …, L_{12} are scattered in the lower part of the hexagon. Assume that the distances between locations L_1, L_2, …, L_6 and the Macro are 30m, 25m, …, 5m, and respectively; and the other 6 locations L_7, L_8, …, L_{12} are scattered in the triangle *OAB* where *B* is another vertex of the hexagon. The locations of L_7, L_8, …, L_{12} are shown below.

Table 12: UE locations

UE Location	Coordinates
L7	[0, -250/3]
L8	[0, -500/3]
L9	[0, -750/3]
L10	[-125/sqrt(3), -125]
L11	[-125/sqrt(3), -625/3]
L12	[-250/sqrt(3), -250],

Note that location L_1, L_2, …, L_6 can be served by both the Macro and the LPN depending on the CIO, but locations L_7, L_8, …, L_{12} can only be served by the Macro.

We assume the Macro (*O*) and the LPN that transmits with its full power, and all other Macros transmit with only 20% of the total power (unloaded). We pick out one additional interfering Macro cell with the maximum interference to each location among other 56 Macro cells. This additional Macro cell is modelled in the link-level simulator as an interfering cell; and all other 55 Macro cells are considered to be as the part of additive white Gaussian noise. Intable xx,, the Ior/Ioc for all the three cells under consideration is listed for different UE locations, where the Macro denotes the Macro cell at the origin (O) and the Macro2 denotes the additional Macro interferer.

Note that for the location L_7, L_8, …, L_{12}, the Ior/Ioc for LPN is smaller than -10dB, we constrain that the UE at those locations can only be served by the Macro. We consider different LPN CIOs, corresponding to different LPN serving area S_{LPN} and the Macro serving area S_M.

Two UEs are simulated, one dropped into one of the locations in the LPN serving area S_{LPN} and the other dropped into one of the locations in the Macro serving area $S_{M.}$ Each UE will be scheduled from each cell based on the reported CQI.

Table 13: Received signal powers at each UE location

UE Location	LPN Ior / Ioc [dB]	Macro Ior / Ioc [dB]	Macro2 Ior/Ioc [dB]
L1	5.2774	18.555	0.92192
L2	8.3307	18.003	0.66949
L3	12.144	17.59	1.1988
L4	16.951	17.167	1.6937
L5	23.603	16.737	2.1588
L6	34.812	16.302	2.5979
L7	-12.658	24.273	4.2725
L8	-10.256	15.356	1.9603
L9	-20.806	6.9397	4.8632
L10	-18.964	15.547	2.6975
L11	-20.781	10.415	7.7891
L12	-28.111	3.8369	10.577

7.1.8.5 Link level simulation results with Network Assisted Interference Cancellation

Although initial evaluations were performed in the study, a more thorough analysis is required to be able to evaluate the benefits of NAIC.

Some of the aspects that need further study are:

- CQI feedback and outer loop efficiency
- Impact of signaling overhead on legacy users
- Impact of the additional overhead due to the DL control channels on capacity

7.2 Range expansion

In heterogeneous networks, most of the gains stems from the offloading of the Macro users to the LPNs. On the other hand, in an interference limited system, it is desirable for the UE to be served by the cell from which it receives the strongest signals. Therefore, offloading from the Macro to the LPNs through range expansion needs to be carefully considered.

In a heterogeneous network, Macro cells with larger transmit powers than the LPNs cause more interference and have larger coverage areas. In some deployment scenarios, the LPN could be over-shadowed by the Macro cell; consequently, there would be limited offloading capability.

From the system performance perspective, it is desirable to evenly distribute the UEs among all cells in the system. This can be achieved by extending the range of the LPNs to cover a larger part of the cell and is referred to as "range expansion".

7.2.1 Range expansion for co-channel deployments

The cell individual offset (CIO) is an existing mechanism that can be used to increase UE offload from the Macro to the LPN layer in the co-channel HetNet deployment.

As the LPN cell CIO is increased (while Macro cell CIO is 0 dB), it is important to ensure the detectability of the LPN cell by the UEs located in the CIO region between the LPN cells and Macro cells.

7.2.1.1 Downlink control channel evaluation

7.2.1.1.1 Evaluation methodology

A simplified HetNet model with one serving LPN and one dominant interfering Macro is considered. The network comprises 19 Macro nodes, and each of them has 3 sectors. The 19 times 3 Macro cells form a hexagonal grid. One of the Macro cells becomes the dominant interferer of the LPN, whereas the rest of the Macro cells are regarded as additional interference radiators, whose transmission power ratio can be scaled according to the traffic loads. Figure 32 in subclause 7.1.8.3 illustrates the HetNet model used for the evaluation.

Table 14 shows the parameters used in the simulations.

Table 14: System simulation assumptions

Parameter	Value
CIO	0dB, 3dB, 6dB, 9dB, 12dB
Number of antennas at the UE	1 and 2
Path Loss	Macro Node: L=128.1 + 37.6log10(R), R in kilometres LPN: L=140.7 + 36.7log10(R), R in kilometres
Penetration loss	20dB
Shadow Fading	Not applied
NodeB Antenna Gain	14dBi for Macro and 5dBi for LPN
NodeB Transmit Powers	Macro: 43 dBm LPN: 30 dBm
UE Antenna Gain	0dB
Effective Path Loss (EPL)	Path loss + Penetration Loss – NodeB Antenna Gain– UE antenna gain
Transmit Powers for Physical Channels NOT considered for Power Control	P-CPICH Ec/Ior = -10dB P-CCPCH Ec/Ior = -12dB PICH Ec/Ior = -15dB SCH Ec/Ior = -12dB HS-PDSCH Ec/Ior = -3.5 dB OCNS: OVSF indices and relative powers of the 6 codes are as in 3GPP TS 25.101 (Table C6). Total power of all OCNS codes is fixed in each slot = Ior- $\sum_c P_c$, where P_c = average power of channel c in that slot.
Max F-DPCH Ec/Ior	-10 dB
Max HS-SCCH Ec/Ior	-8 dB
Min HS-SCCH Ec/Ior	-18 dB
Channel Estimation	Realistic
Propagation Channel	PA3

Due to the lower transmit power of the LPN, the UL boundary is not aligned with the DL boundary. The smaller coverage area of LPN usually leads to a lower loading factor. Therefore, it is desirable to expand the DL coverage of LPN, and this can be achieved by cell biasing. Basically, the DL boundary of LPN can be pushed towards the direction of macro by the use of cell individual offset (CIO). CIO can be defined as the dB difference in received signal power from the macro and the LPN.

The serving LPN and the macro allocate the transmit power proportionally according to the Ec/Ior assigned to a particular control channel. At UE side, the power received from LPN and macros are calculated using the pathloss formula in Table 14. For the topology in Figure 32, Table 15 shows Ior and Ioc of LPN and its dominant macro interferer for given CIO values, where Ior represents the received power and Ioc includes the thermal noise as well as the interference from 56 outer macro cells as shown in Figure 32. As a result, the received power at UE consists of three parts, that is: the desired signal from LPN ($I_{or,\ LPN}$), the interference from dominant macro interference ($I_{or,macro}$) and the interference from outer cells plus noise (Ioc). Then the receiver of UE tries to decode the DL control channel of its serving LPN in the presence of interferences $I_{or,macro}$ and Ioc. Table 16 gives the Ior/Ioc values of LPN and the dominant macro interferer for fully loaded and unloaded situations.

Table 15: Ior and Ioc of LPN and its dominant interferer for CIO = 0, 3, 6, 9, 12 dB

CIO [dB]	Ior, LPN [dBm]	Ior, macro [dBm]	*Ioc* (outer inference is fully loaded) [dBm]	*Ioc* (outer interference is unloaded) [dBm]
0	-59.74	-59.74	-70.19	-77.15
3	-62.37	-59.37	-70.07	-77.04
6	-64.94	-58.94	-69.92	-76.88
9	-67.43	-58.43	-69.72	-76.69
12	-69.84	-57.84	-69.47	-76.44

Table 16: Ior/Ioc of LPN and its dominant Macro interferer for CIO = 0, 3, 6, 9, 12, 15 dB

CIO [dB]	Ior/Ioc, LPN (fully loaded) [dB]	Ior/Ioc, macro (fully loaded) [dB]	Geometry with LPN serving (fully loaded) [dB]	Ior/Ioc, LPN (unloaded) [dB]	Ior/Ioc, macro (unloaded) [dB]
0	10.45	10.45	-0.37	17.41	17.41
3	7.70	10.70	-3.35	14.67	17.67
6	4.98	10.98	-6.33	11.94	17.94
9	2.29	11.29	-9.31	9.26	18.26
12	-0.37	11.63	-12.29	6.60	18.60
15	-3.01	11.99	-15.27		

7.2.1.1.2 Evaluation of F-DPCH performance and impact on the uplink

Evaluation from [39]

Simulation results for two sets of UE locations are shown.

Set 1. UE is located at the point where the difference in the geometry equals the CIO value in Figure Y.

Set 2. UE can be located at any of the L1,…,L6 locations and the UE association is determined based on the Ior difference between Macro and LPN, and the CIO. All Macro cells are fully loaded. The interference environment for UE placed at any of the L1,…,L6 locations is listed in Table 17, where LPN_Ior is the received signal power from the LPN, Macro_Ior is the received signal power from the major interfering Macro cell, and Ioc is the sum of received signal from all other 56 Macro cells.

Table 17: Ior and Ioc of LPN and its dominant interferer (outer cells are fully loaded)

UE Location	LPN_Ior [dBm]	Macro_Ior [dBm]	LPN_Ior – Macro_Ior	*Ioc* [dBm]
L1	-69.8104	-57.892	-11.9184	-69.4917
L2	-66.9044	-58.5909	-8.3135	-69.785
L3	-63.3478	-59.2611	-4.0867	-70.0322
L4	-58.7626	-59.9049	1.1423	-70.238
L5	-52.3001	-60.5243	8.2242	-70.4069
L6	-41.2521	-61.1211	19.869	-70.5431

When LPN_Ior - Macro_Ior >= CIO (RSCP based), then LPN is selected as the serving cell of the UE. Otherwise, Macro is the serving cell. Table 18 lists the UE locations that can be served by LPN with different CIOs.

Table 18: UE locations that can be served by LPN with different CIOs

CIO (dB)	12	9	6	3	0
UE locations	L1,…,L6	L2,…,L6	L3,…,L6	L4,…,L6	L4,…,L6

As L4,...,L6 can already be served by LPN with CIO=0dB, the downlink control channel performance is evaluated in locations L1, L2 and L3. The geometry for an LPN UE is defined as

Geometry = (LPN_Ior / (Macro_Ior + Ioc)).

The UE geometry at L1,L2 and L3 locations when LPN is the serving cell is given in Table 19.

Table 19: LPN UE geometry when served by LPN (other cells fully loaded)

UE Location	Geometry with LPN serving (dB)
L1	-12.2089
L2	-8.63146
L3	-4.43592

The performance of F-DPCH with 1 Rx and 2 Rx UE, Rake receiver, is evaluated. Realistic path search is used at the receiver. TPC BER is considered in the F-DPCH performance evaluation without the consideration of the erasure threshold. The TPC BER target is set to 4%. Tables 20 and 21 show the F-DPCH evaluation results. Erasure behaviour is not modelled in the calculation of BER.

Table 20: TPC BER and averaged F-DPCH Ec/Ior (set 2)

UE Location	1 Rx UE		2 Rx UE	
	Averaged F-DPCH Ec/Ior (dB)	BER	Averaged F-DPCH Ec/Ior (dB)	BER
L1	-10.56	14%	-10.49	4.1%
L2	-10.41	7.9%	-14.72	4.6%
L3	-11.76	4.1%	-18.59	4.2%

Table 21: TPC BER and averaged F-DPCH Ec/Ior (set 1)

CIO (dB)	1 Rx UE		2 Rx UE	
	Averaged F-DPCH Ec/Ior (dB)	BER	Averaged F-DPCH Ec/Ior (dB)	BER
0	-17.4	3.7%	-22.5	4.1%
3	-15.1	4.2%	-19.6	4.2%
6	-11	5.6%	-16.8	4.6%
9	-10.3	8.8%	-13.1	3.8%
12	-10.1	14.1%	-10.3	4%
15	-10	21.7%	-10	8.7%

From the simulation results, it can be seen that for 1 Rx UE, the TPC BER cannot converge to 4% with CIO larger 6dB, even with the maximum F-DPCH power. For 2 Rx UE, the TPC BER can converge to 4% even with a 12dB CIO.

When the CIO is large, the required F-DPCH Ec/Ior to reach 4% BER is also large. From the simulation results, one can see that relaxing the TPC BER target to a higher value can reduce the required F-DPCH Ec/Ior. According to 25.331, the highest TPC BER target set by the network is 10%. It is then of interest to look at the uplink performance when F-DPCH TPC BER is higher than 4%.

Impact of F-DPCH performance on the uplink

FRC3 traffic is assumed for the uplink simulations. UE changes the transmit DPCCH power in accordance with the detected TPC bit, i.e. either down or up. PA3 channel is simulated.

Table 22: FRC3

Fixed Ref Channel	TTI [ms]	N_inf	SF1	SF2	SF3	SF4	N_bin	Coding rate	Max inf bit rate [kbps]
FRC3	2	8100	2	2	4	4	11520	0.703	4050

The following figure shows the throughput performance of FRC3 with 4%, 10%, 15% and 20% TPC BER. It can be seen that when close to the peak throughput, the difference in UE transmit power is very small even when TPC BER is 15%. When TPC BER is 20%, excessive transmit power is needed.

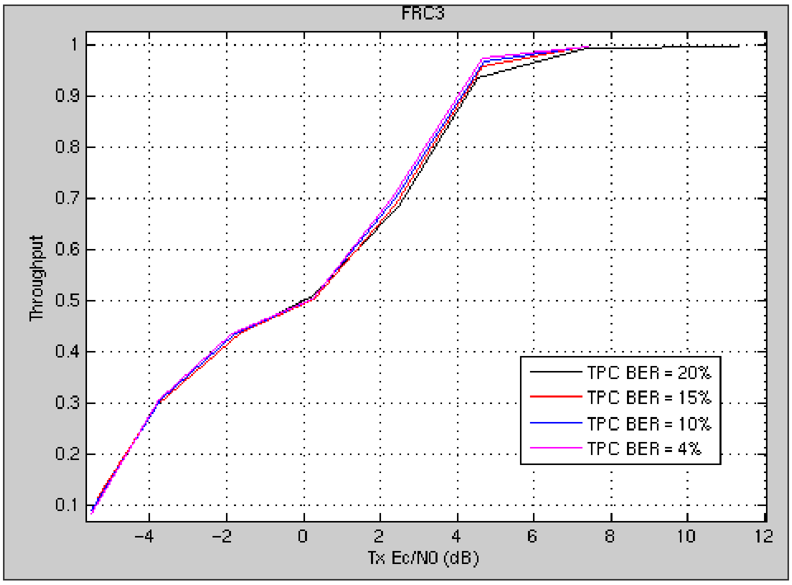

Figure 33: UL throughput with TPC BER of 4%, 10%, 15% and 20%

The results in Figure 33 show that with TPC BER of 10-15% the impact on UL performance is small. This seems to suggest that a higher TPC BER target (higher than 4%) for the LPN UE in range expansion region can be use. This could effectively save the transmit power on F-DPCH.

From the evaluation of F-DPCH, it is observed that for single antenna UE, F-DPCH has sufficient reception quality for CIO up to 6dB for single antenna UE and CIO up to 9dB for dual antenna UE.

Evaluation from [41]

In order to guarantee the reliability of control signalling in an interference-limited environment without wasting the transmit power in DL, the F-PDCH channel is operated under power control mode, and the TPC bits for F-DPCH is sent on the UL DPCCH. In this study, we impose an upper bound on the Ec/Ior of power controlled F-DPCH as shown in Table 14.

The F-DPCH is power controlled to meet the BER target of 4%. Ideal uplink for DL TPC is assumed in this study. The dynamic range of F-DPCH Ec/Ior is set to [-30 dB, -10 dB]. Tables 23-25 show the average Ec/Ior, BER and erasure rate of F-DPCH channel.

It can be observed from Table 25 that when UE is equipped with single receive antenna, the F-DPCH channel alone can consume a significant amount of transmit power in order to meet the BER target of 4% and to accommodate CIO >0 dB in fading channels. From Table 23, we can see that when CIO ≥ 9 dB, the 4% target cannot be met for UE with single receive antenna, no matter the outer cell interference is fully loaded or unloaded. Using dual receive antennas can ameliorate the situation to some extent, but the BER target still cannot be met when CIO ≥ 12 dB even though the Ec/Ior level of F-DPCH reaches the upper bound of -10 dB.

Table 23: Average BER for power controlled F-DPCH

BER Target of F-DPCH	Propagation Condition	CIO [dB]	Average BER of TPC Bits of F-DPCH			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
4%	PA3	0	0.01	0.00	0.01	0.01
		3	0.03	0.01	0.03	0.01
		6	0.07	0.01	0.07	0.01
		9	0.14	0.03	0.13	0.03
		12	0.24	0.07	0.23	0.07
	PB3	0	0.00	0.00	0.00	0.00
		3	0.01	0.00	0.01	0.00
		6	0.03	0.00	0.02	0.00
		9	0.10	0.02	0.09	0.01
		12	0.27	0.08	0.24	0.07
	VA30	0	0.00	0.00	0.00	0.00
		3	0.01	0.00	0.01	0.00
		6	0.03	0.00	0.02	0.00
		9	0.08	0.02	0.07	0.01
		12	0.20	0.07	0.19	0.06
	VA120	0	0.00	0.00	0.00	0.00
		3	0.01	0.00	0.01	0.00
		6	0.03	0.01	0.03	0.01
		9	0.07	0.02	0.06	0.02
		12	0.16	0.07	0.15	0.06

Table 24: Average erasure rate for power controlled F-DPCH

BER Target of F-DPCH	Propagation Condition	CIO [dB]	Average Erasure Rate of TPC Bits of F-DPCH			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
4%	PA3	0	0.01	0.00	0.01	0.00
		3	0.02	0.00	0.02	0.00
		6	0.04	0.00	0.04	0.00
		9	0.10	0.01	0.09	0.01
		12	0.18	0.04	0.17	0.04
	PB3	0	0.00	0.00	0.00	0.00
		3	0.00	0.00	0.00	0.00
		6	0.01	0.00	0.01	0.00
		9	0.06	0.00	0.05	0.00
		12	0.20	0.04	0.18	0.03
	VA30	0	0.00	0.00	0.00	0.00
		3	0.00	0.00	0.00	0.00
		6	0.00	0.00	0.00	0.00
		9	0.02	0.00	0.02	0.00
		12	0.10	0.01	0.09	0.01
	VA120	0	0.00	0.00	0.00	0.00
		3	0.00	0.00	0.00	0.00
		6	0.00	0.00	0.00	0.00
		9	0.01	0.00	0.01	0.00
		12	0.03	0.01	0.03	0.01

Table 25: Average Ec/Ior for power controlled F-DPCH

BER Target of F-DPCH	Propagation Condition	CIO [dB]	Average Ec/Ior [dB]of F-DPCH			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
4%	PA3	0	-14.92	-18.48	-15.39	-19.04
		3	-12.39	-16.07	-12.96	-16.68
		6	-10.13	-13.54	-10.20	-14.15
		9	-10.04	-10.42	-10.05	-11.26
		12	-10.00	-10.04	-10.02	-10.07
	PB3	0	-13.62	-16.78	-13.86	-17.02
		3	-11.62	-14.61	-11.87	-14.93
		6	-10.04	-12.17	-10.05	-12.48
		9	-10.01	-10.04	-10.02	-10.05
		12	-10.00	-10.01	-10.01	-10.01
	VA30	0	-12.87	-16.41	-13.13	-16.68
		3	-10.24	-14.12	-10.48	-14.44
		6	-10.04	-11.50	-10.04	-11.81
		9	-10.01	-10.04	-10.02	-10.04
		12	-10.00	-10.01	-10.01	-10.01
	VA120	0	-11.84	-15.72	-12.06	-16.01
		3	-10.07	-13.33	-10.07	-13.60
		6	-10.03	-10.64	-10.03	-10.95
		9	-10.01	-10.03	-10.01	-10.04
		12	-10.00	-10.01	-10.00	-10.01

The impact of the F-DPCH error and erasure on the uplink is shown in Table 26. For each of the CIO values, the erasure and errors were modelled on the F-DPCH channel on the downlink. When an erasure occurs, the UE does not apply the decoded TPC command but instead maintains the transmit power level unchanged. The Tx and Rx Ec/No losses corresponding to the error and erasures for the different CIO values are shown.

Table 26: Impact of F-DPCH erasure and error on the uplink

Channel	CIO	Single RX		Dual Rx	
		Tx Ec/No Loss [dB]	Rx Ec/No Loss [dB]	Tx Ec/No Loss [dB]	Rx Ec/No Loss [dB]
PA3	0	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.02
	6	0.12	0.09	0.00	0.03
	9	0.26	0.25	0.00	0.03
	12	0.61	0.61	0.12	0.04
VA30	0	0.00	0.00	0.00	0.00
	3	0.03	0.05	0.03	0.05
	6	0.09	0.13	0.09	0.13
	9	0.20	0.30	0.19	0.26
	12	0.62	0.86	0.32	0.48

As seen in Table 26, the uplink impact becomes pronounced when CIO values exceed 9dB for both the single and dual Rx antenna cases.

7.2.1.1.3 Evaluation of E-HICH performance

Evaluation from [39]

In this evaluation the transmit power of E-HICH is fixed and the relative BLER for different E-HICH Ec/Ior values is given. Single antenna UE and PA3 channel are assumed in the link level simulations. Rake receiver with realistic path searcher is used. The 3-slot E-HICH format is simulated.

E-HICH performance test depends on UE association. When LPN is the serving cell, false alarm rate (FAR) is P(DTX or NACK -> ACK). Miss detection rate (MDR) is P(ACK -> DTX or NACK). When LPN is the non-serving cell, FAR is P(DTX->ACK), and MDR is P(ACK->DTX). In the evaluation, a detection threshold is determined according to a FAR, with the transmitter sending an “all-DTX” pattern. Then, MDR is evaluated using that threshold, with the transmitter sending an “all-ACK” pattern. The following table shows the test cases according to the UE association. It can be seen that when LPN is the serving cell, the FAR is much higher when compared with the case when LPN is the non-serving cell. This is because the serving cell MDR for a UE uplink transmission is very low (MDR=0.1%).

Table 27: Test cases according to UE association

Scenario	Parameter	Value
Case 1: UE is not in soft handover and LPN is the serving cell	Target Misdetection	5%
	Target False Alarm	10%
Case 2: UE is in soft handover and LPN is the serving cell	Target Misdetection	5%
	Target False Alarm	10%
Case 3: UE is in soft handover and LPN is the non-serving cell	Target Misdetection	5%
	Target False Alarm	0.2%

The offset for event 1A/1B is 4.5dB. Test cases for the UE in different locations with various CIOs are listed in Table 28, where an empty space means that the UE is only served by the Macro, and the LPN does not transmit E-HICH.

Table 28: Test cases for UE in different locations with various CIOs

CIO (dB)	L1	L2	L3
0			Case 3
3			Case 3
6		Case 3	Case 2
9	Case 3	Case 2	Case 1
12	Case 2	Case 2	Case 1

E-HICH performance for the above test cases is shown in Table 29.

Table 29: E-HICH performance (set 2)

UE Location	L1		L2		L3	
Test Case	Case 2 LPN Serving CIO=12dB	Case 3 Macro Serving CIO=9dB	Case 2 LPN Serving CIO=9,12dB	Case3 Macro Serving CIO=6dB	Case1/2 LPN Serving CIO=6,9,12dB	Case3 Macro Serving CIO=0,3dB
E-HICH Ec/Ior	-10dB	-10dB	-14dB	-10dB	-20dB	-14dB
E-HICH MDR	5%	17%	3.6%	5.9%	4%	4%

Table 30: E-HICH performance (set 1)

CIO (dB)	1 Rx UE				2 Rx UE			
	LPN serving		LPN non-serving		LPN serving		LPN non-serving	
	Ec/Ior (dB)	MDR	Ec/Ior (dB)	MDR	Ec/Ior (dB)	MDR	Ec/Ior (dB)	MDR
0	-26	6%	-20	5.9%	-32	5.4%	-27	5.9%
3	-22	4.9%	-16	4.9%	-29	5%	-24	5.7%
6	-18	4.4%	-12	4.5%	-26	5.1%	-20	4.1%
9	-14	4.5%	-10	7.4%	-22	4.2%	-17	5%
12	-10	5.2%	-10	17.1%	-19	5.1%	-13	5.1%
15	-10	25.9%	-10	31.5%	-14	4.4%	-10	7.7%

Simulation results show that when the LPN is the serving cell, detection performance is much better than when LPN is the non-serving cell. To evaluate whether a UE can support a certain CIO, both cases when LPN is the serving cell and when LPN is the non-serving cell need to be considered. For CIO=6dB, the UE location at CIO=6dB for serving LPN, and the location at CIO=10.5dB (considering that the offset for event 1A/1B is 4.5dB) for non-serving LPN.

For single antenna UE, the 5% MDR can be reached for CIO=0dB and 3dB. For CIO=6dB, E-HICH MDR would be slightly higher than 5% when LPN is the non-serving cell. CIO=6dB would be the largest value that can be used, otherwise the MDR would be too high when LPN is the non-serving cell, even with -10dB E-HICH Ec/Ior. For dual antenna UE, the reception quality substantially improves, and a CIO of 9dB can be used. The required E-HICH power is also reduced. In order to save E-HICH power and achieve better LPN E-HICH reception quality for UE, 10ms E-DCH can be used for larger CIOs.

Evaluation from [42]

Assuming the target for the false alarm rate (FAR) is 10% and the target for the missed detection rate (MDR) is 5%, Table 31-33 show the FAR, MDR along with the average Ec/Ior for the non-SHO situation, wherein the E-DCH TTI is 2ms and the E-HICH power offset is chosen as -6 dB (relative to F-DPCH) to satisfy the target FAR/MDR in large CIO scenarios. Table 6-8 show the FAR, MDR along with the average Ec/Ior for the SHO situation, wherein 10ms E-DCH TTI is assumed and the E-HICH power offset is chosen as -8 dB (relative to F-DPCH) to meet the target FAR/MDR in large CIO.

It can be seen from Table 31-36 that the performance targets of FAR and MDR can be satisfied by UE with dual receive antennas in both SHO and non-SHO scenarios. Thanks to the use of power control, the required Ec/Ior is under -16 dB for 2ms TTI and under -18 dB for 10ms TTI. For UE with single receive antenna, the performance targets can be met for most of the CIOs at a higher level of average Ec/Ior.

Table 31: FAR of power controlled E-HICH (non-SHO, 2ms E-DCH TTI)

FAR Target of E-HICH	Propagation Condition	CIO [dB]	Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
FAR≤10%	PA3	0	0.05	0.05	0.01	0.01
		3	0.06	0.06	0.03	0.02
		6	0.09	0.06	0.07	0.03
		9	0.13	0.07	0.11	0.04
		12	0.20	0.10	0.18	0.07
	PB3	0	0.07	0.07	0.07	0.07
		3	0.07	0.07	0.07	0.07
		6	0.08	0.08	0.08	0.08
		9	0.15	0.08	0.10	0.08
		12	0.21	0.09	0.17	0.09
	VA30	0	0.05	0.06	0.05	0.05
		3	0.06	0.06	0.06	0.05
		6	0.07	0.06	0.07	0.06
		9	0.09	0.07	0.08	0.07
		12	0.11	0.08	0.09	0.08
	VA120	0	0.05	0.05	0.05	0.05
		3	0.06	0.06	0.06	0.06
		6	0.08	0.07	0.06	0.07
		9	0.09	0.08	0.07	0.07
		12	0.10	0.08	0.08	0.08

Table 32: MDR of power controlled E-HICH (non-SHO, 2ms E-DCH TTI, E2F=-6 dB)

MDR Target of E-HICH	Propagation Condition	CIO [dB]	Average Ec/Ior [dB] (MDR)			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
MDR≤5%	PA3	0	0.01	0.00	0.00	0.00
		3	0.01	0.00	0.01	0.00
		6	0.02	0.00	0.02	0.00
		9	0.03	0.01	0.03	0.01
		12	0.05	0.02	0.05	0.02
	PB3	0	0.00	0.00	0.00	0.00
		3	0.00	0.00	0.00	0.00
		6	0.01	0.00	0.01	0.00
		9	0.03	0.00	0.03	0.00
		12	0.08	0.03	0.07	0.02
	VA30	0	0.00	0.00	0.00	0.00
		3	0.00	0.00	0.00	0.00
		6	0.01	0.00	0.01	0.00
		9	0.04	0.00	0.04	0.00
		12	0.13	0.03	0.09	0.03
	VA120	0	0.00	0.00	0.00	0.00
		3	0.00	0.00	0.00	0.00
		6	0.00	0.00	0.00	0.00
		9	0.01	0.00	0.01	0.00
		12	0.10	0.01	0.08	0.01

Table 33: Average Ec/Ior of power controlled E-HICH (non-SHO, 2ms E-DCH TTI, E2F=-6 dB)

Target of E-HICH	Propagation Condition	CIO [dB]	Average Ec/Ior [dB] (MDR)			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
MDR≤ 5% FAR ≤ 10%	PA3	0	-20.94	-24.51	-21.74	-25.05
		3	-18.37	-22.09	-18.79	-22.70
		6	-16.13	-19.53	-16.19	-20.17
		9	-16.04	-16.39	-16.05	-17.28
		12	-16.02	-16.04	-16.03	-16.07
	PB3	0	-19.62	-22.83	-19.84	-23.00
		3	-17.57	-20.59	-17.85	-20.91
		6	-16.04	-18.15	-16.05	-18.47
		9	-16.01	-16.04	-16.02	-16.05
		12	-16.00	-16.01	-16.00	-16.01
	VA30	0	-18.88	-22.41	-19.12	-22.66
		3	-16.23	-20.12	-16.51	-20.48
		6	-16.04	-17.51	-16.04	-17.85
		9	-16.02	-16.03	-16.02	-16.04
		12	-16.01	-16.01	-16.01	-16.01
	VA120	0	-17.86	-21.74	-18.06	-22.01
		3	-16.07	-19.35	-16.07	-19.60
		6	-16.03	-16.65	-16.03	-16.96
		9	-16.01	-16.03	-16.01	-16.04
		12	-16.01	-16.01	-16.01	-16.01

Table 34: FAR of power controlled E-HICH (SHO, 10ms E-DCH TTI)

FAR Target of E-HICH	Propagation Condition	CIO [dB]	Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
FAR≤10%	PA3	0	0.07	0.07	0.07	0.07
		3	0.07	0.06	0.07	0.07
		6	0.08	0.06	0.08	0.06
		9	0.11	0.06	0.11	0.07
		12	0.17	0.07	0.16	0.07
	PB3	0	0.06	0.06	0.06	0.06
		3	0.07	0.07	0.06	0.06
		6	0.08	0.07	0.07	0.06
		9	0.09	0.07	0.08	0.07
		12	0.15	0.07	0.14	0.09
	VA30	0	0.05	0.05	0.05	0.05
		3	0.06	0.05	0.06	0.05
		6	0.07	0.05	0.07	0.05
		9	0.08	0.07	0.08	0.06
		12	0.10	0.08	0.09	0.07
	VA120	0	0.05	0.05	0.05	0.05
		3	0.05	0.05	0.05	0.05
		6	0.06	0.06	0.05	0.06
		9	0.07	0.06	0.06	0.06
		12	0.08	0.06	0.07	0.06

Table 35: MDR of power controlled E-HICH (SHO, 10ms E-DCH TTI, E2F=-8 dB)

MDR Target of E-HICH	Propagation Condition	CIO [dB]	Average Ec/Ior [dB] (MDR)			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
MDR≤5%	PA3	0	0.00	0.00	0.00	0.00
		3	0.01	0.00	0.01	0.00
		6	0.02	0.00	0.02	0.00
		9	0.03	0.00	0.03	0.00
		12	0.05	0.02	0.05	0.01
	PB3	0	0.00	0.00	0.00	0.00
		3	0.00	0.00	0.00	0.00
		6	0.00	0.00	0.00	0.00
		9	0.02	0.00	0.02	0.00
		12	0.06	0.02	0.06	0.01
	VA30	0	0.00	0.00	0.00	0.00
		3	0.00	0.00	0.00	0.00
		6	0.00	0.00	0.00	0.00
		9	0.01	0.00	0.00	0.00
		12	0.04	0.00	0.04	0.00
	VA120	0	0.00	0.00	0.00	0.00
		3	0.00	0.00	0.00	0.00
		6	0.00	0.00	0.00	0.00
		9	0.00	0.00	0.00	0.00
		12	0.01	0.00	0.01	0.00

Table 36: Average Ec/Ior of power controlled E-HICH (SHO, 10ms E-DCH TTI, E2F=-8 dB)

MDR Target of E-HICH	Propagation Condition	CIO [dB]	Average Ec/Ior [dB] (MDR)			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
MDR≤5% FAR≤ 10%	PA3	0	-22.93	-26.49	-23.38	-27.03
		3	-20.38	-24.05	-20.94	-24.68
		6	-18.13	-21.53	-18.20	-22.15
		9	-18.04	-18.43	-18.05	-19.31
		12	-18.02	-18.04	-18.02	-18.07
	PB3	0	-21.61	-24.80	-21.87	-25.03
		3	-19.63	-22.62	-19.89	-22.95
		6	-18.04	-20.16	-18.05	-20.49
		9	-18.01	-18.04	-18.02	-18.04
		12	-18.00	-18.01	-18.01	-18.01
	VA30	0	-20.87	-24.43	-21.13	-24.68
		3	-18.25	-22.13	-18.47	-22.43
		6	-18.04	-19.50	-18.04	-19.81
		9	-18.01	-18.04	-18.02	-18.04
		12	-18.01	-18.01	-18.01	-18.01
	VA120	0	-19.82	-23.74	-20.05	-24.00
		3	-18.06	-21.33	-18.07	-21.60
		6	-18.03	-18.65	-18.03	-18.96
		9	-18.01	-18.03	-18.01	-18.04
		12	-18.00	-18.01	-18.00	-18.01

7.2.1.1.4 Evaluation of HS-SCCH performance and impact on the downlink

Evaluation from [39]

HS-SCCH type 1 is assumed. The HS-SCCH has a fixed power. Tables 37 and 38 show the BLER of HS-SCCH, the HS-PDSCH throughput when HS-SCCH is ideally decoded, and the real throughput when the corresponding decoding error of HS-SCCH is considered. The HS-PDSCH Ec/Ior is always -3.5dB.

Table 37: HS-SCCH performance and DL impact (set 2)

UE Location	1 Rx UE				2 Rx UE			
	Ec/Ior (dB)	BLER	Throughput, 0% HS-SCCH BLER (kbps)	Throughput, real HS-SCCH BLER (kbps)	Ec/Ior (dB)	BLER	Throughput, 0% HS-SCCH BLER (kbps)	Throughput, real HS-SCCH BLER (kbps)
L1	-8	45.7%	36	33.7	-8	13.7%	72	70
L2	-8	24.4%	80	77.7	-8	3%	226	219
L3	-8	8.3%	249.2	243.6	-10	1%	665	664

Table 38: HS-SCCH performance and DL throughput (set 1)

CIO (dB)	1 Rx UE				2 Rx UE			
	Ec/Ior (dB)	BLER	Throughput, 0% HS-SCCH BLER (kbps)	Throughput, real HS-SCCH BLER (kbps)	Ec/Ior	BLER	Tput w/ ideal HS-SCCH BLER (kbps)	Tput w/ real HS-SCCH BLER (kbps)
0	-8	2.2%	624	619	-15	1.3%	1491	1465
3	-8	5.7%	341	332	-12	1.3%	840	835
6	-8	13.9%	133.3	131.5	-10	2%	427.9	423.2
9	-8	28%	68.9	66.8	-8	4.3%	187.5	185.5
12	-8	46.2%	35	33	-8	14.2%	70.4	68.7
15	-8	68.6%	16.2	14.1	-8	39.3%	33.4	30.4

From the simulation results, it can be seen that for single antenna UE, even for CIO=0dB the HS-SCCH BLER with maximum HS-SCCH Ec/Ior of -8dB cannot converge to 1%. However, the performance loss caused by HS-SCCH BLER is rather small even for large BLERs. For dual antenna UE, HS-SCCH BLER can reach 1% when UE is at CIO=0dB and 3dB. For CIO=9dB, the BLER is 4.3% with -8dB HS-SCCH Ec/Ior, and the performance loss is only 1%.

As a result, an increased HS-SCCH BLER has only marginal impact on throughput at low geometry. However the power consumption is not marginal even for a single antenna UE at CIO=0dB. It can be observed then that for 1 Rx UE, about 1% throughput loss is caused by HS-SCCH BLER when UE is at CIO=6dB location. For 2 Rx UE, about 1% throughput loss is caused by HS-SCCH BLER when UE is at CIO=9dB location.

Evaluation from [43]

In order to guarantee the reliability of control signalling in an interference-limited environment without wasting the power in DL, power control is activated for HS-SCCH in our simulations. The power control of HS-SCCH can be implemented by the serving LPN based on the channel quality information (CQI) obtained from HS-DPCCH. In this study, we impose an upper bound on the Ec/Ior of power controlled HS control channels as shown in Table 14. Targeting 1% BLER with power control, the actual BLER and the corresponding power requirements of HS-SCCH are given by Table 3 and 4, respectively. The dynamic range of Ec/Ior for HS-SCCH is set as [-18, -8] dB and a realistic outer loop adjustment was used in HS-SCCH power control. It can be observed from Table 39-40 that using single receive antenna, the 1% BLER target of HS-SCCH cannot be met when CIO ≥ 3dB for most of the cases studied, even though the transmit Ec/Ior operates at the upper bound -8 dB. Using dual receive antennas can effectively improve the BLER performance and reduce the power consumption, which makes the 1% target to be met for CIO up to 9 dB in most of the cases. If CIO were to be increased further to allow for more advanced receivers such as network assisted interference canceller (NA-IC), we would need to study further enhancement strategies for the HS-SCCH performance. This is because HS-PDSCH can benefit from NA-IC but the strict latency requirement on HS-SCCH decoding may prevent it from benefiting from advanced interference cancellation techniques.

To illustrate the impacts of power-controlled HS-SCCH channel, we also show the average throughput of HS-PDSCH with and without genie-aided ideal HS-SCCH decoding in Table 41 and 42, respectively, assuming the HARQ operates at 10% BLER target after the first transmission. Moreover, the actual BLERs of HS-PDSCH after 1st transmission with and without ideal HS-SCCH decoding are shown in Table 43 and 44, respectively. It can be observed from Table 41-44 that compared with ideal HS-SCCH decoding, there is additional throughput loss due to higher BLER of realistic HS-SCCH decoding. Nevertheless, the performance loss of HS-PDSCH due to realistic HS-SCCH decoding is not significant. This is obvious for cases that CIO < 6 dB, since the BLER of HS-SCCH is lower than 0.05, and the difference between using ideal or realistic decoding for HS-SCCH is small. For cases that CIO ≥ 6 dB and the BLER of HS-SCCH ≥ 0.05, the performance loss is not significant either since when HS-SCCH decoding fails, HS-PDSCH is also likely to decode unsuccessfully. Therefore, whether or not we have an ideal HS-SCCH decoder will not have much impact on the throughput of HS-PDSCH.

Table 39: BLER of power controlled HS-SCCH (BLER target = 1%)

BLER Target of HS-SCCH	Propagation Condition	CIO [dB]	Average Ec/Ior of HS-SCCH [dB]			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
1%	PA3	0	0.02	0.01	0.02	0.00
		3	0.04	0.01	0.04	0.01
		6	0.10	0.01	0.09	0.01
		9	0.21	0.01	0.18	0.01
		12	0.34	0.02	0.32	0.02
	PB3	0	0.01	0.00	0.01	0.00
		3	0.01	0.00	0.01	0.00
		6	0.01	0.01	0.01	0.00
		9	0.03	0.01	0.03	0.01
		12	0.13	0.01	0.11	0.01
	VA30	0	0.02	0.00	0.02	0.00
		3	0.03	0.00	0.03	0.00
		6	0.05	0.01	0.05	0.01
		9	0.12	0.02	0.11	0.02
		12	0.32	0.04	0.28	0.04
	VA120	0	0.02	0.00	0.02	0.00
		3	0.03	0.01	0.03	0.00
		6	0.07	0.01	0.07	0.01
		9	0.27	0.03	0.24	0.03
		12	0.38	0.06	0.35	0.05

Table 40: Average Ec/Ior of power controlled HS-SCCH (BLER target = 1%)

BLER Target of HS-SCCH	Propagation Condition	CIO [dB]	Average Ec/Ior of HS-SCCH [dB]			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
1%	PA3	0	-13.76	-18.00	-13.87	-18.00
		3	-11.52	-17.71	-12.01	-17.89
		6	-9.93	-16.87	-10.30	-17.38
		9	-8.89	-14.91	-9.15	-16.17
		12	-8.34	-12.21	-8.58	-14.49
	PB3	0	-17.11	-18.00	-17.34	-18.00
		3	-15.27	-18.00	-15.80	-18.00
		6	-12.49	-18.00	-13.19	-18.00
		9	-8.79	-17.36	-9.44	-17.99
		12	-8.08	-15.21	-8.19	-17.04
	VA30	0	-12.90	-18.00	-13.27	-18.00
		3	-10.76	-18.00	-11.19	-18.00
		6	-9.12	-14.90	-9.50	-16.87
		9	-8.30	-11.60	-8.47	-13.19
		12	-8.04	-9.05	-8.09	-10.10
	VA120	0	-12.96	-18.00	-13.40	-18.00
		3	-10.73	-18.00	-11.20	-18.00
		6	-8.88	-14.17	-9.23	-15.59
		9	-8.09	-9.96	-8.16	-10.93
		12	-8.01	-8.76	-8.02	-9.47

Table 41: Throughput of HS-PDSCH with realistic HS-SCCH decoding

HS-PDSCH Mode	Propagation Condition	CIO [dB]	Average Throughput of HS-PDSCH [kbps]			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
VRC, Target 1st Transmission BLER 10%	PA3	0	1128.97	3503.50	1217.90	4357.53
		3	617.32	2526.06	725.22	3496.92
		6	303.91	1699.67	380.15	2709.07
		9	144.62	1046.25	165.33	1876.81
		12	69.45	545.54	84.29	1215.35
	PB3	0	951.96	3000.04	1057.04	3518.26
		3	548.79	2144.32	646.70	2782.10
		6	304.21	1397.58	357.81	2039.95
		9	142.67	843.18	180.83	1374.73
		12	68.46	473.31	73.89	824.58
	VA30	0	387.91	1763.97	442.70	2181.42
		3	213.42	1116.95	240.64	1485.59
		6	109.85	610.74	126.81	869.38
		9	60.19	277.80	67.26	430.99
		12	32.91	112.96	38.01	169.34
	VA120	0	449.10	1917.70	503.00	2321.18
		3	223.05	1188.05	263.12	1556.89
		6	107.37	583.94	123.26	813.49
		9	42.44	194.48	48.01	269.13
		12	21.62	100.06	25.23	137.59

Table 42: Throughput of HS-PDSCH with ideal HS-SCCH decoding

HS-PDSCH Mode	Propagation Condition	CIO [dB]	Average Throughput of HS-PDSCH [kbps]			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
VRC, Target 1st Transmission BLER 10%	PA3	0	1133.90	3511.53	1224.40	4366.15
		3	623.96	2540.91	744.75	3559.33
		6	313.81	1705.04	398.31	2715.41
		9	160.81	979.32	180.73	1900.84
		12	76.18	557.69	100.51	1227.56
	PB3	0	968.09	3005.84	1070.47	3518.65
		3	557.55	2151.94	660.75	2787.97
		6	315.34	1412.16	364.19	2068.80
		9	147.21	874.08	191.08	1378.67
		12	70.37	475.25	84.75	831.33
	VA30	0	396.81	1783.21	445.61	2184.98
		3	215.26	1124.09	241.99	1482.96
		6	111.75	616.08	131.61	879.05
		9	66.47	285.90	74.26	433.40
		12	42.21	115.02	46.41	168.93
	VA120	0	452.58	1927.34	498.30	2319.33
		3	231.53	1193.64	265.40	1549.24
		6	111.63	588.82	127.51	821.45
		9	58.07	198.37	63.11	268.44
		12	40.48	111.66	43.98	144.41

Table 43: BLER of HS-PDSCH after 1st transmission with realistic HS-SCCH decoding

HS-PDSCH Mode	Propagation Condition	CIO [dB]	BLER of HS-PDSCH after 1st Transmission			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
VRC, Target 1st Transmission BLER 10%	PA3	0	0.11	0.10	0.11	0.10
		3	0.12	0.11	0.12	0.11
		6	0.15	0.11	0.14	0.11
		9	0.20	0.11	0.18	0.11
		12	0.30	0.11	0.27	0.11
	PB3	0	0.11	0.10	0.11	0.10
		3	0.11	0.10	0.11	0.10
		6	0.11	0.10	0.11	0.10
		9	0.14	0.11	0.11	0.11
		12	0.26	0.11	0.19	0.11
	VA30	0	0.12	0.10	0.13	0.10
		3	0.13	0.10	0.14	0.10
		6	0.16	0.11	0.16	0.11
		9	0.24	0.12	0.23	0.12
		12	0.46	0.14	0.43	0.14
	VA120	0	0.12	0.10	0.12	0.10
		3	0.13	0.11	0.13	0.10
		6	0.17	0.11	0.16	0.11
		9	0.35	0.13	0.32	0.13
		12	0.60	0.15	0.55	0.15

Table 44: BLER of HS-PDSCH after 1st transmission with ideal HS-SCCH decoding

HS-PDSCH Mode	Propagation Condition	CIO [dB]	BLER of HS-PDSCH after 1st Transmission			
			Fully Loaded		Unloaded	
			Single RX	Dual RX	Single RX	Dual RX
VRC, Target 1st Transmission BLER 10%	PA3	0	0.10	0.10	0.10	0.10
		3	0.11	0.10	0.11	0.10
		6	0.14	0.10	0.13	0.10
		9	0.19	0.10	0.18	0.10
		12	0.28	0.11	0.27	0.11
	PB3	0	0.10	0.10	0.10	0.10
		3	0.10	0.10	0.10	0.10
		6	0.10	0.10	0.10	0.10
		9	0.12	0.10	0.11	0.10
		12	0.20	0.10	0.18	0.10
	VA30	0	0.11	0.10	0.11	0.10
		3	0.12	0.10	0.12	0.10
		6	0.14	0.10	0.14	0.10
		9	0.22	0.10	0.21	0.11
		12	0.45	0.12	0.40	0.12
	VA120	0	0.10	0.10	0.10	0.10
		3	0.10	0.10	0.10	0.10
		6	0.11	0.10	0.11	0.10
		9	0.23	0.10	0.20	0.10
		12	0.52	0.11	0.45	0.11

The results show that for single Rx UEs, the loss in HS-PDSCH throughput is around 5% due to HS-SCCH decoding until a CIO of 6dB and increases to up to 46% for a CIO of 12dB. Therefore, CIO values beyond 6dB are not recommended for single Rx users.

For dual Rx UEs, the performance degradation is not significant up to a CIO of 9dB. The loss in throughput increases to up to 10% for CIO 12dB. Therefore, for dual Rx UEs, a CIO of less than 9dB is recommended.

Evaluation from [40]

Performance of downlink control channel (HS-SCCH) by link level simulations for PedA channel is evaluated. No power control is assumed. Simulation model as described in [38] is used. RAKE receiver is used for our analysis. Figure 34 shows the message error probability as a function of transmit Ec/Ior in dB when Ioc = 0 dB and receive Ior/No = 0 dB. (The noise power spectral density, No, is assumed 0 dB for the below discussion.) This is the typical case at cell boundaries. We also plotted the performance with Ioc = -100 dB, that is without any interference. It can be observed that 3 dB of additional power is needed to maintain the same message error probability of 1% with Ioc = 0 dB as compared to that of no interference.

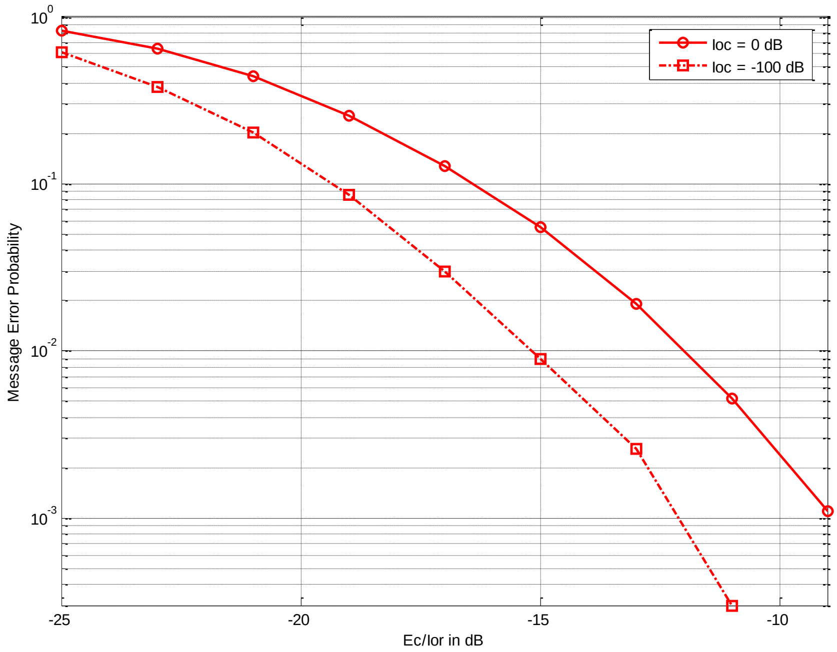

Figure 34: Impact of HS-SCCH performance with the interference power at receive Ior/No = 0dB

Figure 35 shows the message error probability as a function of transmit Ec/Ior in dB when Ioc = 0 dB and receive Ior/No = 5 dB. We also plotted the performance with Ioc = -100 dB, that is without any interference. In this case 6 dB of additional power is needed to maintain the same message error probability of 1% with Ioc = 0 dB as compared to that of no interference. That is the impact of downlink control channel is severe as we increase the geometry.

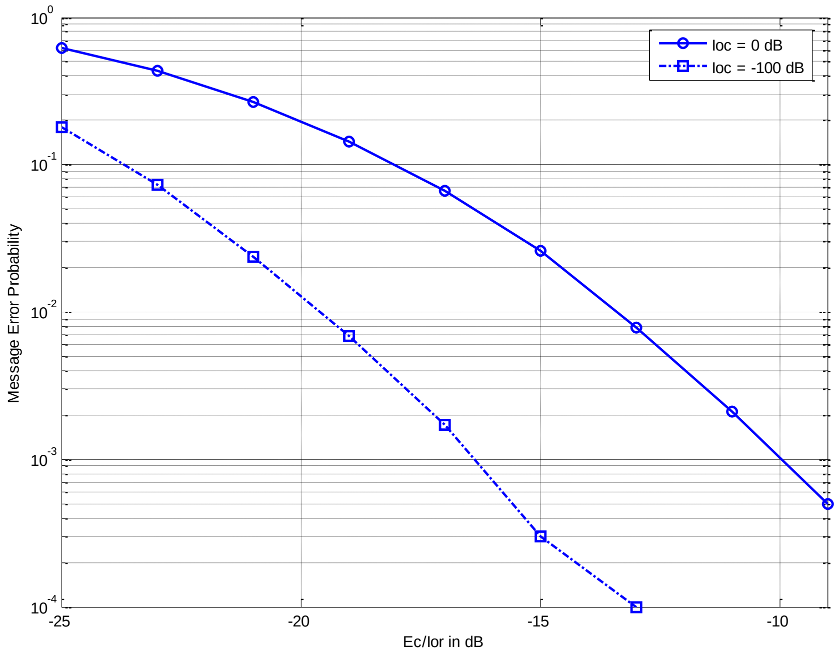

Figure 35: Impact of HS-SCCH performance with the interference power at receive Ior/No = 5 dB

Figures 36 and 37 shows the Ec/Ior in dB with Ioc = -5 dB when Ior/No = 0 dB and 5 dB respectively. In this case the impact is minimal as the interference power is less.

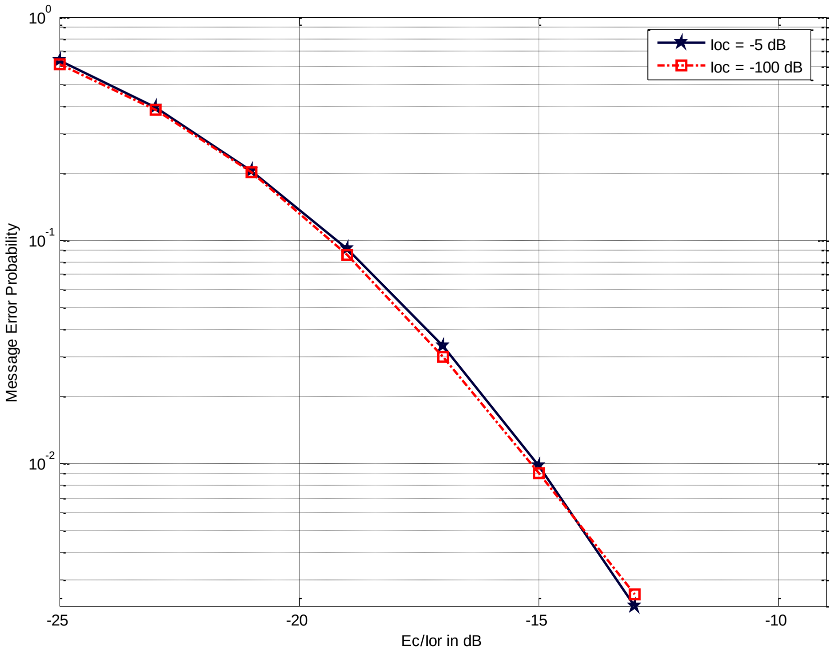

Figure 36: Impact of HS-SCCH performance with the interference power at receive Ior/No = 0 dB

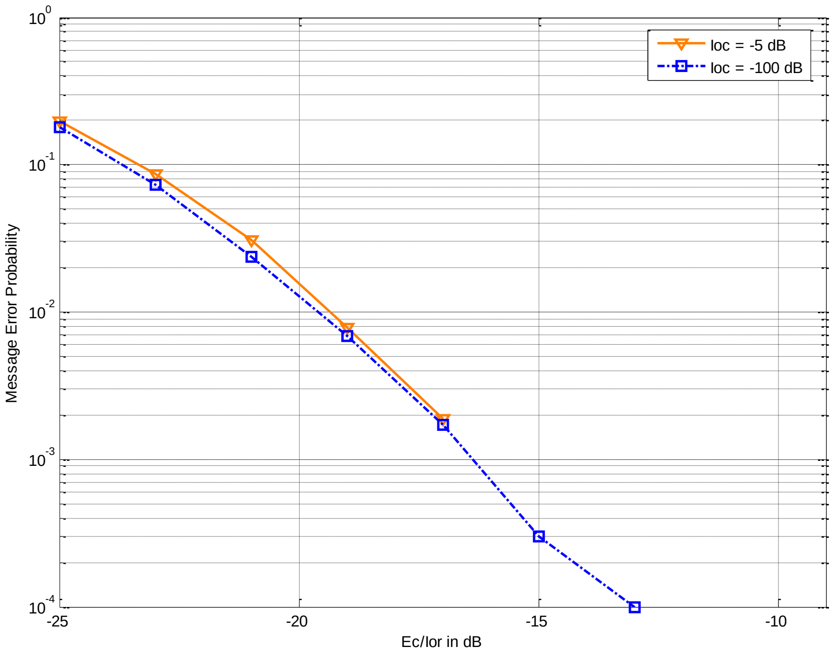

Figure 37: Impact of HS-SCCH performance with the interference power at receive Ior/No = 5 dB

The impact on HS-SCCH link performance is tabulated in Table 45 for PedA channel. It can be observed that performance is worse and there might be instances for example when the user geometry (receive Ior/No) is high and there is an interferer with Ioc = 0 dB. In these cases, it might be needed to increase Ec/Ior by 10 dB to maintain the message error probability of 1%.

Table 45: HS-SCCH performance for PedA channel

User geometry (Ior/No) [dB]	Ec/Ior required for achieving 1% message error probability		
	Ioc = -100 dB (Macro only)	Co-channel deployment	
		Ioc = 0 dB	Ioc = -5 dB
0	-15.1 dB	-12 dB	-15 dB
5	-19.6 dB	-13.4 dB	-19.4 dB
10	-22.9 dB	-13.7 dB	-22.3 dB
15	-24.3 dB	-13.9 dB	-23.6 dB
20	-24.9 dB	-13.95 dB	-24.1 dB

It is observed that Node B needs to allocate additional power to maintain the HS-SCCH message error probability of 1%. Due to this power allocated for downlink control channel the power allocated for HS-PDSCH decreases. Hence the gains in HetNet will decrease. The impact due to additional power overhead is evaluated via system simulations. The system simulation assumptions are the same as in Annex A.1, except the power for HS-PDSCH set to 70%. Table 46 shows the reduction in co-channel deployment gains due to additional pilot overhead. It can be observed that gains are reducing by approximately 20% due to this additional power.

Table 46: System level gain in co-channel deployment

Throughput Metric	% of gain with Ideal HS-SCCH reception	% of gain with additional power overhead for HS-SCCH reception
Average Sector Throughput	213	191
Average User Throughput	212	190.5

7.2.1.1.5 Total power overhead for F-DPCH, E-HICH and HS-SCCH

Table 47 shows the power overhead for F-DPCH, E-HICH and HS-SCCH. The control channels are power controlled.

Table 47: System level gain in co-channel deployment

CIO	F-DPCH [dB]		HS-SCCH [dB]		E-HICH [dB]		Total power [dB]		Total power [%]	
	1 Rx	2 Rx	1 Rx	2 Rx	1 Rx	2 Rx	1 Rx	2 Rx	1 Rx	2 Rx
0	-14.92	-18.48	-14.09	-18	-20.94	-24.51	-11.0095	-14.7393	7.93%	3.36%
3	-12.39	-16.07	-11.81	-17.78	-18.37	-22.09	-8.59653	-13.2267	13.81%	4.76%
6	-10.13	-13.54	-9.99	-16.83	-16.13	-19.53	-6.54313	-11.1832	22.17%	7.62%
9	-10.04	-10.42	-8.97	-14.96	-16.04	-16.39	-6.00782	-8.36663	25.07%	14.57%

From the results above it is observed that F-DPCH has the major contribution to the total power overhead of these control channels. The F-DPCH power can be reduced by relaxing the operating TPC BER target above 4%. For dual antenna UE, the power overhead is below 15% for CIO up to 9dB.

7.2.1.1.6 Conclusion

Based on this study, it is possible to operate at a CIO of 9dB for dual antenna UE. Some problems may be caused by CIOs exceeding 6dB (1 Rx) and 9 dB (2RX), respectively.

7.2.2 Range expansion for multi-carrier deployments

The scenarios for multi-carrier deployment and the associated Multiflow configurations are listed in Table 48.

Table 48: Multi-carrier Scenarios and the associated Multiflow configurations

Scenario	Macro cell	LPN (Low-Power Node)	Multiflow configuration
1	F1+F2	F2	SF-DC DF-DC (note) DF-3C
2	F1+F2	F1+F2	SF-DC DF-DC DF-3C DF-4C
NOTE: DF-DC is described in clause 7.2.2.3			

7.2.2.1 Scenario 1: Macro cells and LPNs have only one shared carrier

Figure 38 illustrates the coverage of Macro cells and LPN for scenario 1, when Macro cells and LPNs have only one shared carrier. On the shared carrier – F2, there are range expansion techniques similar to those that are applicable in the co-channel scenario that could be used so that more UEs can be offloaded from the Macro cells to the LPNs.

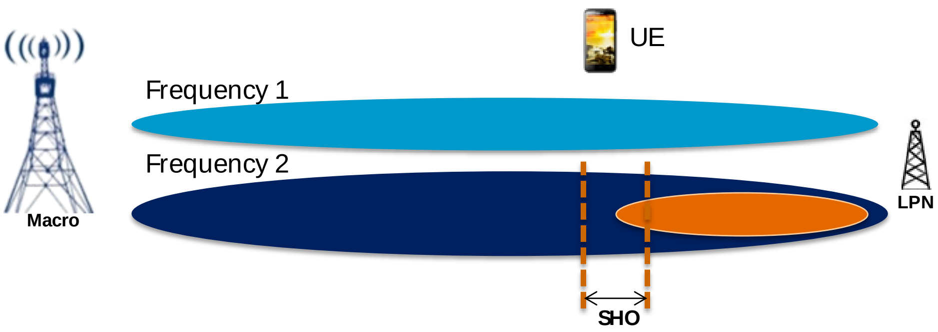

Figure 38: Scenario 1 - Macro cells and LPNs have one shared carrier

When the UE is within the coverage region of the LPN on F2 (through offloading or otherwise), it is also within the coverage area of the Macro cell on F1, since there is no interference between the Macro cell and the LPN on F1.
In this scenario, the Multiflow configuration DF-DC can be used to obtain significant performance benefits.
The UE in a DF-DC configuration would be served by the Macro cell on F1 and by the LPN on F2 simultaneously.
More details about DF-DC are given in clause 7.2.2.3.

When the UE is within the SHO region between the Macro cell and the LPN on F2, then the UE would also be in the coverage region of the Macro cell on F1. In this case, the Multiflow configuration DF-3C can be considered to further improve user throughput, where the UE is served by all 3 cells simultaneously.

7.2.2.2 Scenario 2: Macro cells and LPNs have two shared carriers

Figure 39 illustrates the scenario where the Macro cells and the LPNs have two shared carriers.

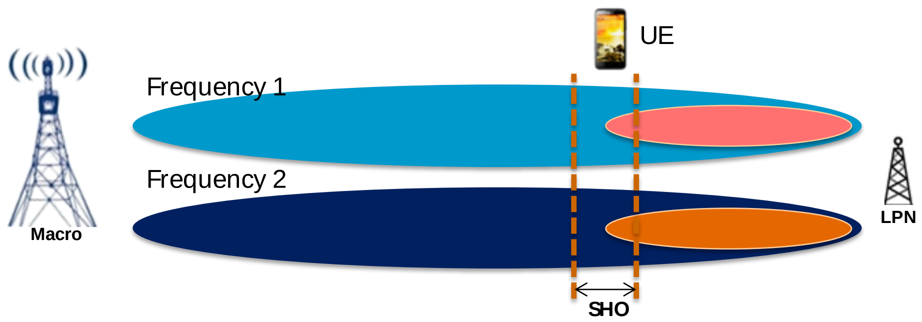

Figure 39: Scenario 2 - Macro cells and LPNs have two shared carriers

In this scenario, Macro power reduction could be used as a range expansion technique to extend the coverage of the LPNs. This scheme effectively partitions resources between LPNs and Macro cells in the frequency domain.
As the Macro cell transmit power is lowered on one carrier, the DL coverage of the LPNs on that carrier automatically expands while coverage decreases for the Macro cell. The power of all common channels and dedicated channels for the Macro on that carrier is also reduced proportionally.

Impact on Downlink coverage

- Macro UEs at the cell centre would not see much of a reduction in their geometries, while cell edge UEs may see some reduction. Indoor UEs that are predominantly noise limited may experience some reduction in the geometry on the range expansion carrier. However, these UEs would typically change their serving cells to the carrier for which the power is not reduced.
- All Macro UEs will enjoy more frequent scheduling on the range expansion carrier due to offloading of UEs to LPNs.
- Reducing Macro cell power also reduces interference to neighbouring UEs served by other Macro or LPNs, which can improve overall system throughput.

In general, it should be noted that the reduction of the transmit power of a Macro cell that has an LPN should be performed carefully while taking into account the long term loading conditions in the system. If a neighbouring Macro cell that does not have any LPNs, is typically highly loaded, then reduction of Macro transmit power may cause some load discrepancies in the neighbour Macro. However, this is pertinent only to boundary Macro cells and does not diminish the usefulness of the range expansion technique as a whole.

As seen in Figure 40, there are two different SHO regions for each frequency: SHO1 on F1 and SHO2 on F2. DF-DC or DF-3C can be used for UEs in these regions to further improve cell-edge performance. In addition, DF-DC can be used for UEs located between the two SHO regions.

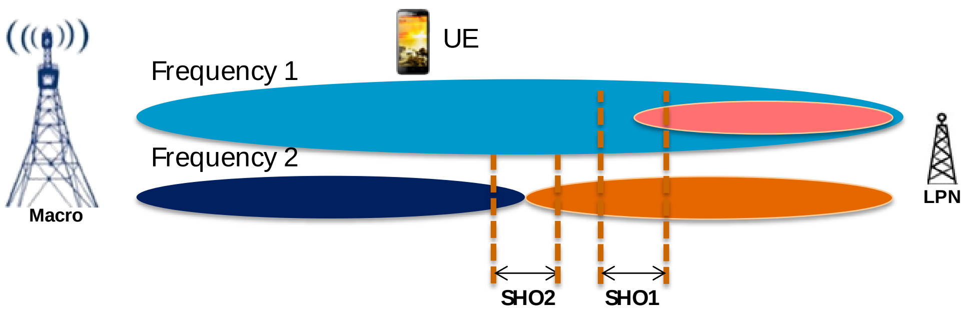

Figure 40: Macro power reduction as a range expansion technique

7.2.2.3 Dual-Frequency Dual-Cell (DF-DC) operation

In the DF-DC Multiflow configuration, the UE receives data from two nodes (Macro or LPNs) simultaneously on two difference frequencies. This is illustrated in Figure 41.

Figure 41: Dual-Frequency Dual-Cell

Figure 41 shows that the UE receives data on frequencies F1 and F2 from different cells. The cells could be Macro cells or LPNs. Both cells receive HARQ-ACK and CQI information on the HS-DPCCH channel from the UE transmitted on a single UL carrier that corresponds to the serving HS-DSCH cell.

If the serving cell corresponds to F1, then it is essential that the UE is in soft handover between the two cells on that carrier. The uplink would therefore be power controlled by both the nodes by transmitting F-DPCH on F1 as in legacy operation. Data transmission for the non-serving cell would occur on F2, similar to Rel-8 DC operation.

It is important to note that when compared to Single-Frequency Dual-Cell (SF-DC) operation, there is no requirement for UE interference rejection as DF-DC operates on two different frequencies, therefore, DF-DC operations are feasible for single receive antenna UEs as well.

7.2.2.4 Performance of Single Frequency Dual Cell scenario

The benefit of the Multiflow (SF-DC) operation mostly comes from the load balancing. In a medium to lightly loaded system, each cell does not always have UEs to serve due to the bursty nature of the traffic. For the cell that has available resources (code and power), Multiflow operation allows the cell to serve nearby UEs that do not have this cell as the serving cell. The cell that schedules the UE in addition to its own serving cell is called assisting serving cell. It is important to note that, for each cell, compared to the UEs who have the cell as the serving cell, the UEs that have the cell as the assisting serving cell typically experience a lower geometry. Hence, Multiflow operation cannot help a highly loaded system. On the contrary, when the system load is not very high, Multiflow operation takes advantage of the statistical multiplexing and offers enhanced user experience (user burst rate).

The evaluation shown here considers the bursty traffic model and the system simulation assumptions as specified in Annex A.1. The user dropping criterion is 50% clustering UE dropping, and for SF-DC downlink scheduling, in each cell, UEs that have this cell as serving have the highest priority. Type 3i receiver is assumed. The gains are presented as the percentage increase over of the baseline throughput. The baseline is the result for the case where LPNs are not present in the Macro cell and the Multiflow (SF-DC) operation is not allowed. The simulation results are collected in [36].

From simulation results, with 8 UEs/Macro, the average TTI utilization is at 56% for baseline Macro only deployment without Multiflow, and when 4 LPNs per Macro are deployed, the average TTI utilization is reduced to lower than 35% at Macro cell. As a result, higher improvement from the Multiflow operation, especially at the 5% burst rate, is observed for the 4 LPN case than for the Macro only scenario. For the 5% burst rate in the scenario that 4 LPNs with 37dBm power are deployed with a 3dB CIO, it is observed a relative gain in the range of 50% to 70% respect to the case that Multiflow operation is not used. For the average burst rate, the gain is smaller. For the case of CIO of 6dB, the 5% burst rate gain is larger. For the case of CIO of 0 dB, the Multiflow gains are smaller.

For uniform UE dropping, the performance trend is similar to 50% clustering UE dropping case, as the LPN deployment helps to lower the loading per Macro cell, and consequently improves the system performance gain from the Multiflow operation.

In conclusion, Multiflow operation improves the system performance at medium to low loading, especially for the cell edge users. LPN deployment reduces the loading per Macro cell as UEs are offloaded to LPNs from Macro cells. As the load reduces, more gains can be observed from Multiflow operation. As the CIO increases and the cell edge burst rate becomes smaller, Multiflow can improve the performance of the cell edge users that are affected by the non-optimum downlink cell selection. Hence Multiflow can be used as a complementary method to improve the cell edge user performance when applying CIO.

7.2.2.5 Performance of Macro power reduction as an LPN range expansion technique

To evaluate the performance of Macro power reduction as an LPN range expansion technique, the following two scenarios are considered:

1. Interference limited system: The outdoor path loss model and Inter-Site-Distance of 500m is considered (refer to the Annex for additional simulation assumptions). Reducing the Macro transmit power in the Macro only system does not result in geometry degradation since the UE is interference limited.

2. Thermal noise limited system: This scenario corresponds to the case when the indoor path loss model is considered. In such systems, indoor UEs may have large path loss values even to the strongest cell. The geometries of these UEs are thermal noise limited.

Additionally, the following UEs are considered based on the serving cell selection criterion:

1. DC only: The UE is served by the same NodeB on both carriers. Serving cell selection is based on the Max-Rate criterion. For each sector, among the Ec/Io's on both carriers, the best Ec/Io is used to denote the quality of that sector. The UE selects the sector that has the best quality as the serving sector. 3dB CIO is applied to bias serving cell selection toward the LPN.

2. DF-DC capable: The UE could be served by different sectors on each carrier. The serving cell selection is performed independently on each carrier, i.e., for each carrier the UE selects the cell that has the best Ec/Io as the serving cell. 3dB CIO is applied to bias serving cell selection toward the LPN.

7.2.2.5.1 Interference limited system with full buffer traffic

Four types of system performance metrics are considered:

- Average UE throughput: it is calculated as the average throughput of all UEs in the system
- 50% UE throughput: it is calculated as the median throughput of all UEs in the systems
- 5% UE throughput: it is calculated as the throughput of the UEs at the 5% tail across all UEs in the system
- Offloading Percentage: The LPN offloading percentage is calculated as follows:

$$\frac{L_{F1}+L_{F2}}{M_{F1}+M_{F2}+L_{F1}+L_{F2}}$$

where,

L_{F1} is the number of radio links associated with LPNs in frequency F1

L_{F2} is the number of radio links associated with LPNs in frequency F2

M_{F1} is the number of radio links associated with macro cells in frequency F1

M_{F2} is the number of radio links associated with macro cells in frequency F2

For purposes of this evaluation, in the figures shown below, the definitions of range expansion on and off are as follows unless otherwise stated:

- Range Expansion Off refers to the case where the Macro power on the secondary carrier is not altered. However, a CIO of 3dB is applied to bias the serving cell selection towards the LPN.
- Range Expansion On refers to the case where the Macro power on the secondary carrier is not reduced. A CIO of 3dB is applied to bias the serving cell selection towards the LPN.

The gains are given in percentage throughput increase over the baseline. The baseline is the result for the case where LPNs are not present.

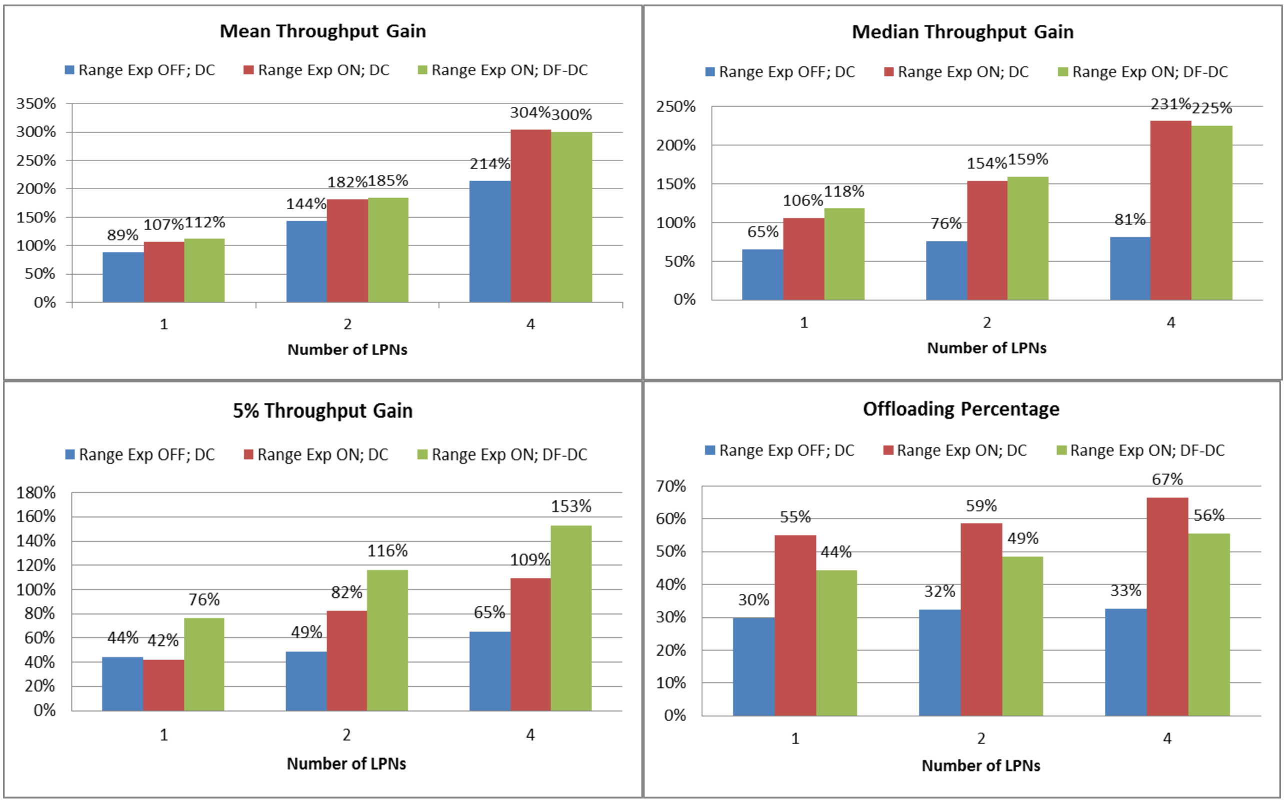

Figure 42: DL full buffer performance with 30dBm LPNs and 50% clustering dropping, no-indoor UEs

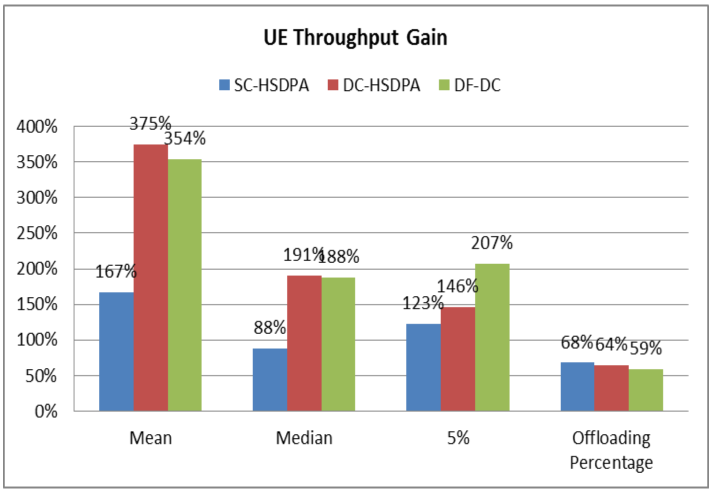

Figure 43: DL full buffer performance with 30dBm LPNs and 50% clustering dropping

Figures 42 and 43 show the UE throughput improvement from the Dual Carrier HetNet deployment with 30dBm LPNs and 50% clustering UE dropping, with no-indoor UEs.

Range expansion allows more UEs to be offloaded to LPNs, hence improves the HetNet deployment gain. From Figure 42, with DC only operation, at 4 LPNs/Macro, comparing range expansion off with on, an increase in offloading is seen from 33% to 67%.

From figures 42 and 43, the average UE throughput gain improves from around 191% to 340% and the 5% UE throughput gain improves from around 94% to 128%. Note that the numbers quoted have been averaged across Figures 33 and 34.

DF-DC operation improves the range expansion gain. The benefit from DF-DC operation is more evident at the 5% UE throughput, which implies that DF-DC operation improves the fairness in the system. Using 4 LPNs/Macro as an example, compared to DC only operation with range expansion, DF-DC operation increase the 5% UE throughput gain from around 128% to 180%, while keeping the mean and media UE throughput almost the same.

Figure 44: DL full buffer performance with 30dBm LPNs and uniform UE dropping, no-indoor UEs

Figure 44 shows the UE throughput improvement from the Dual Carrier HetNet deployment with 30dBm LPNs and uniform UE drops throughout the system.

When compared to 50% clustering UE dropping, uniform dropping results in fewer UEs being offloaded to LPNs and, hence, less performance improvement from HetNet deployments. The same trends are observed for DC only operation compared to HetNet deployment without range expansion i.e. HetNet deployment with range expansion provides further improvement, especially the mean and media performance points. Furthermore, when we enable DF-DC operation under range expansion, improvement to the system fairness is seen. Specifically, increased 5% UE throughput gains can be observed.

7.2.2.5.2 Thermal noise limited system with full buffer traffic

The impact on coverage-limited indoor UEs needs to be considered when reducing Macro power. Even though, LPNs are typically deployed in dense urban areas with small ISD, there still could be coverage limitations for indoor UEs. To model indoor UEs, additional Building Penetration Loss (BPL) is added. The salient simulation assumptions for indoor UEs are listed in Table 49.

Table 49: Salient system simulation assumptions for indoor UEs

Parameter	Value
Building Penetration Loss (BPL) Mean	11 dB
Building Penetration Loss (BPL) Standard Deviation	6.5 dB
Indoor UE Modelling	Each UE is assigned as indoors with a probability of x% (x = 0, 60). For indoor UEs, BPL is randomly generated and added to the path loss.
UL Link Budget	140 dB

Figure 45 illustrates the geometry impact on indoor UEs given power reduction for the baseline Macro-only system. In cases with no indoor UEs, reducing the Macro transmit power from 43dBm to 30dBm has very minimum impact on the

UE geometry since the system is interference limited. As indoor UEs with additional BPL are added, the system becomes more noise limited and there is more of an impact on the geometry distribution especially at the tail.

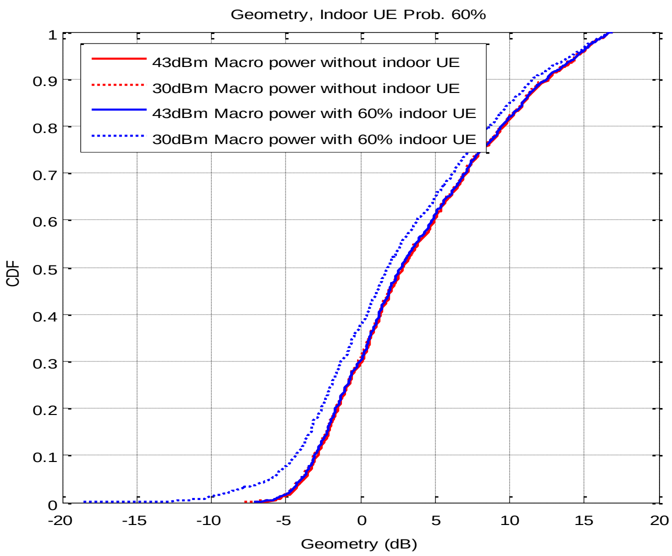

Figure 45: Geometry CDF for Macro-only system under different power settings

Figure 46: DL full buffer performance with 30dBm LPNs and 50% clustering dropping, 60% indoor UEs

Figure 46 shows the UE throughput improvement from the Dual Carrier HetNet deployment with 30dBm LPNs and 50% clustering UE dropping and 60% indoor UEs. Compared to the case when indoor UEs are not modelled, the gain from range expansion with DC or DF-DC operation is slightly decreased.

When considering DC only operation, comparing range expansion off with on, an improvement in system performance is provided by range expansion. For example, at 4 LPNs/Macro, range expansion increases the offloading from 36% to 66%. Further the average UE throughput gain improves from 226% to 301% and the 5% UE throughput gain improves from 67% to 99%. Enabling DF-DC operation with range expansion significantly improves the system fairness, or the

5% UE throughput. Using 4 LPNs/Macro as an example, compared to DC only operation with range expansion, DF-DC operation increase the 5% UE throughput gain from 99% to 141%.

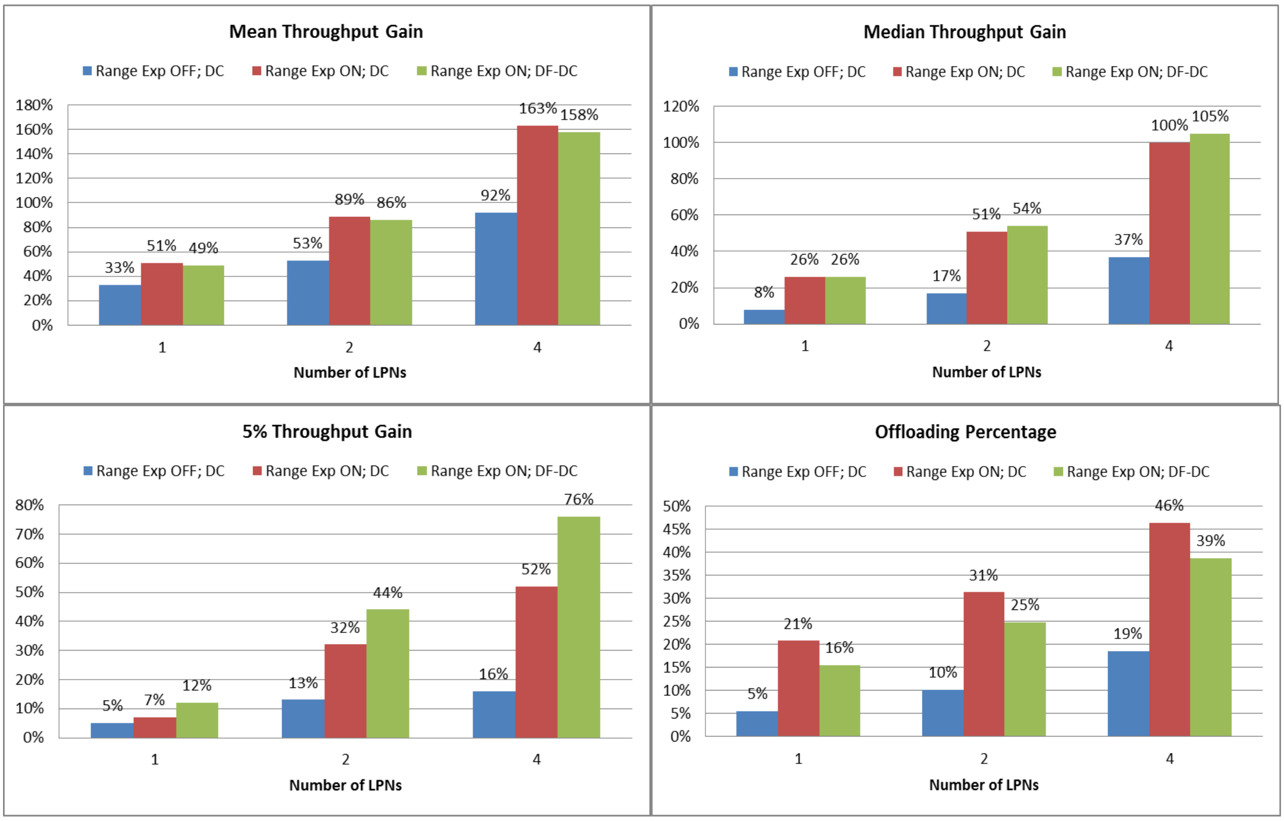

Figure 47: DL full buffer performance with 30dBm LPNs and uniform UE dropping, 60% indoor UEs

Figure 47 shows the UE throughput improvement from the Dual Carrier HetNet deployment with 30dBm LPNs and Uniform UE dropping, 60% indoor UEs. The results also confirm the gain from range expansion with DC only and DF-DC operation.

7.2.2.5.3 Interference limited system with bursty traffic

The following system performance metrics are considered:

- Average UE burst rate: Calculated as the average burst rate of all UEs in the system
- 5% UE burst rate: Calculated as the burst rate of the UEs at 5% tail across all UEs in the system.
- Offloading Percentage: The LPN offloading percentage is calculated as follows:

$$\frac{L_{F1}+L_{F2}}{M_{F1}+M_{F2}+L_{F1}+L_{F2}}$$

where,

L_{F1} is the number of radio links associated with LPNs in frequency F1

L_{F2} is the number of radio links associated with LPNs in frequency F2

M_{F1} is the number of radio links associated with macro cells in frequency F1

M_{F2} is the number of radio links associated with macro cells in frequency F2

- Average TTI utilization: For each cell, the TTI utilization is defined as the percentage of TTIs during which each cell schedules a packet to at least one UE. Then, for each Macro/LPN, TTI utilization is averaged over both carriers. TTI utilization is only considered for non-empty cells and is a direct metric to quantify the load in the whole system.

The gains are presented as the percentage increase over the baseline throughput. The baseline is the result for the case where LPNs are not present in the Macro cell.

Figure 48 shows the UE burst rate improvement from the Dual Carrier HetNet deployment with 30dBm LPNs and 50% clustering UE dropping, with no-indoor UE. It is important to note that range expansion for HetNet dual-carrier deployment benefits the system performance by allowing more UEs to be offloaded from the Macro to LPNs. However, if the system has a low load to begin with, i.e. low UE density or low TTI utilization in the baseline Macro only system, the gains from range expansion are limited.

Additionally, if the range expansion is performed with DC only operation, it may lead to a small performance loss at very low load situations, especially at the 5% tail. When UEs are limited to be in DC only operations, the UEs in the range expansion region have to be served by the same sector on both carriers with a weaker cell on one carrier. This may negatively impact the UE peak rate. For a lightly loaded system with bursty traffic, the UE burst rate is mostly determined by the peak rate, hence, any scheme that limits the UE peak rate may result in a performance loss. On the other hand, allowing DF-DC operation with range expansion removes this limitation, therefore, does not face the same limitations.

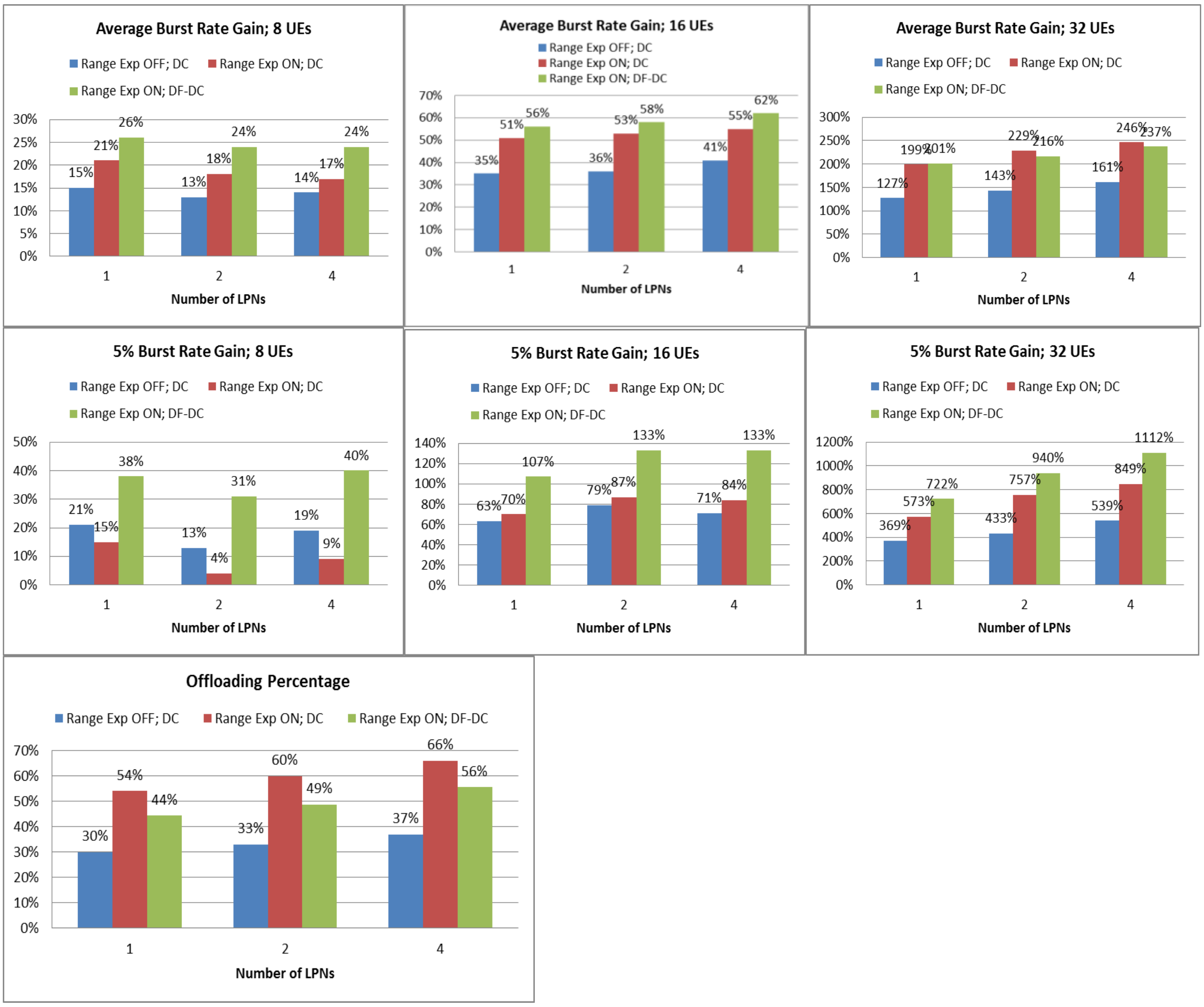

Figure 48: DL bursty traffic performance, 30dBm LPN and 50% clustering UE dropping, no-indoor UE

Table 50 shows additional simulation results using range expansion with different CIO values. It is observed that the burst rate performance, especially for the cell edge, of DC is sensitive to the CIO values used whilst DFDC is insensitive to changes in CIO values at low to mid loading. Using a suitable CIO value (e.g. 0 dB), a gain in burst rate performance of DC can be achieved at low load with range expansion instead of a loss (e.g. when using CIO = 3 dB). At high load, it is observed that using SC UEs can achieve greater cell edge burst rate gain than that of DC UEs if the appropriate CIO values are selected. In this scenario the SC CIO is set such that it is 1 dB towards secondary carrier (F2) of macro cell, 2 dB towards primary carrier (F1) of LPN and 3 dB towards secondary carrier (F2) of LPN.

Table 50: Burst rate performance using different CIO values

Config	CIO (dB)	Number of users per macro sector							
		8		16		32		64	
		Average	5%	Average	5%	Average	5%	Average	5%
DC (Range Exp Off)	3	10%	25%	53%	168%	629%	709%	789%	57%
DC (Range Exp On)	0	11%	31%	66%	200%	750%	1099%	1255%	91%
	3	8%	-9%	69%	178%	790%	1098%	1397%	558%
DF-DC (Range Exp On)	0	17%	46%	70%	281%	807%	1510%	1325%	488%
	3	16%	43%	70%	278%	817%	1557%	1379%	721%
SC (Range Exp On)	1-2-3	-35%	-18%	-3%	114%	439%	897%	937%	358%

Table 51 shows the average TTI utilization with deployment of 30dBm LPNs and 50% clustering UE dropping, no-indoor UE.

Table 51: Average TTI utilization, 30dBm LPNs and 50% clustering UE dropping, no-indoor UE

LPN Density	Scenario	8 UE/Macro		16 UE/Macro		32 UE/Macro	
		Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.	Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.	Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.
1	Baseline	24%	0%	58%	0%	97%	0%
	Range Expansion Off	15%	8%	36%	17%	80%	44%
	Range Expansion On DC Only	12%	9%	27%	18%	63%	43%
	Range Expansion On DF-DC Only	10%	14%	21%	30%	49%	65%
2	Baseline	24%	0%	58%	0%	98%	0%
	Range Expansion Off	15%	5%	33%	10%	75%	26%
	Range Expansion On DC Only	11%	5%	24%	11%	53%	26%
	Range Expansion On DF-DC Only	8%	8%	18%	17%	40%	38%
4	Baseline	24%	0%	59%	0%	98%	0%
	Range Expansion Off	13%	4%	30%	7%	68%	15%
	Range Expansion On DC Only	7%	5%	14%	10%	31%	22%
	Range Expansion On DF-DC Only	10%	4%	20%	7%	42%	15%

Figure 48 and Table 51 show that the gains increase with the increase in load and LPN density. DF-DC operation under range expansion offers higher and more robust gains over DC only operation. For example, for the case of 4 LPNs/Macro and16 UEs/Macro, without range expansion, the system offers an average burst rate gain of 41% and a 5%

burst rate gain of 71% over the no LPN baseline. Range expansion with DC-only operation increases the average burst rate gain to 55%, and increases 5% burst rate gain to 84%.

Range expansion with DF-DC operation increases both the average burst rate gain and the 5% burst rate gain to 62% and 133%, respectively. When the load is increased to 98% (32 UEs/Macro), deploying 4 LPNs without range expansion offers an average burst rate gain of 161% and a 5% burst rate gain of 539% over the baseline. Range expansion with DC-only operation increases the average burst rate gain to 246% and increases the 5% burst rate gain to 849%. Range expansion with DF-DC operation increases both the average burst rate gain and the 5% burst rate gain to 237% and 1112%, respectively.

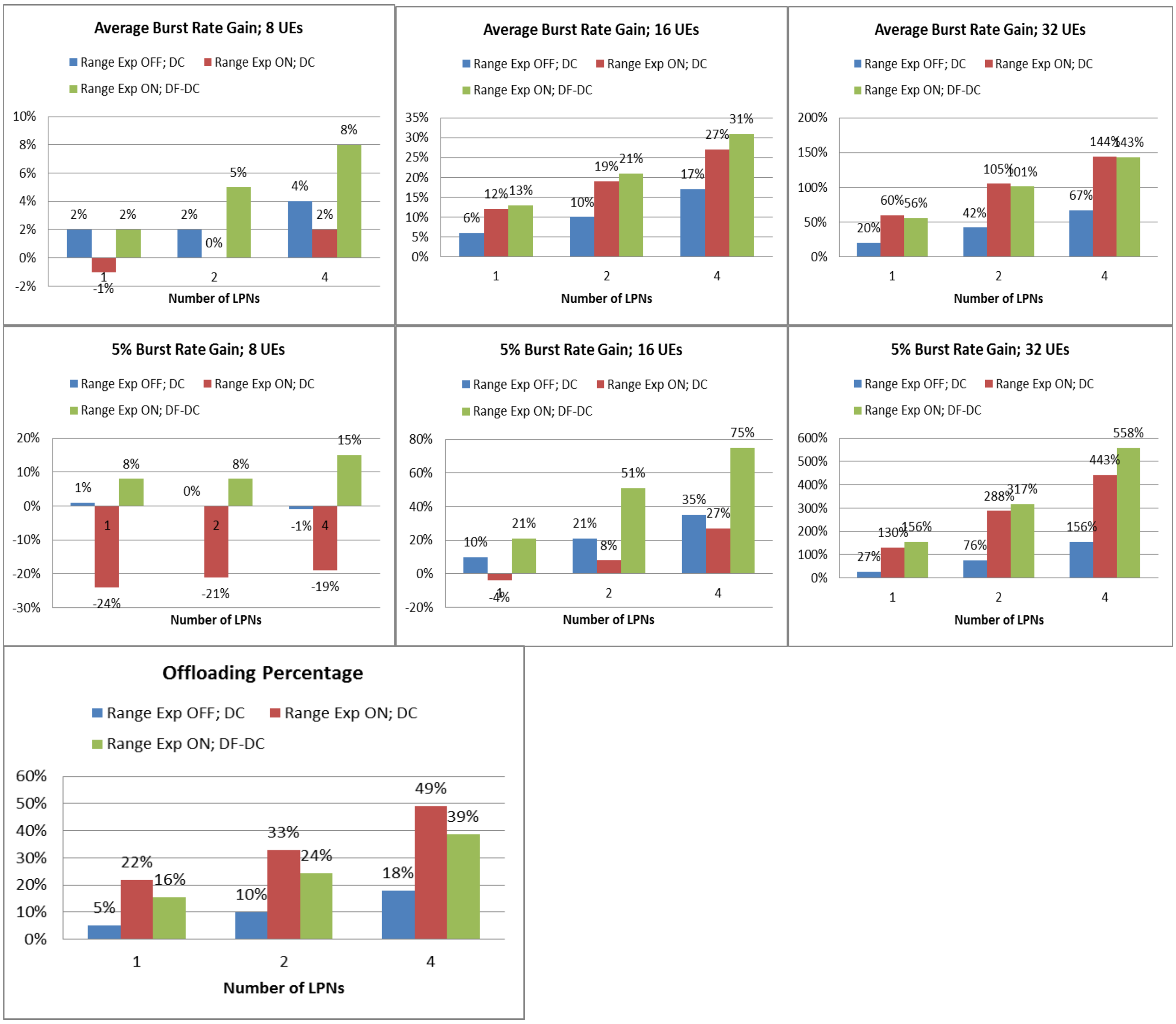

Figure 49: DL bursty traffic performance, 30dBm LPNs and uniform UE dropping, no-indoor UEs

Figure 49 and Table 52 show the UE burst rate improvement and average TTI utilization, respectively, from the HetNet deployment with 30dBm LPNs and Uniform UE dropping and no-indoor UEs. Similar observations can be obtained as those from the 50% clustering UE dropping. In general, range expansion with DF-DC operation provides more robust and higher gains compared to range expansion with DC only operation. The HetNet gain, as well as the range expansion improvement, increases as the loading in the system increases. For range expansion with DC only operation may cause some performance loss at low to medium loading (due to UE peak rate impact). However, this could be overcome by allowing DF-DC operation.

Range expansion with DC only operation performs worse than the HetNet deployment without range expansion at 5% burst rate, under 16 UE/Macro which corresponds to a baseline loading of 57%. On the other side, when DF-DC operation is allowed for range expansion, UEs can be served by different sectors on each carrier. As a result, the negative impact on the UE peak rate is greatly mitigated.

Table 52: Average TTI utilization, 30dBm LPNs and uniform dropping, no-indoor UEs

LPN Density	Scenario	8 UE/Macro		16 UE/Macro		32 UE/Macro	
		Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.	Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.	Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.
1	Baseline	24%	0%	58%	0%	98%	0%
	Range Expansion Off	22%	5%	53%	9%	97%	15%
	Range Expansion On DC Only	20%	8%	46%	16%	92%	39%
	Range Expansion On DF-DC Only	17%	13%	42%	24%	88%	53%
2	Baseline	24%	0%	57%	0%	98%	0%
	Range Expansion Off	21%	5%	48%	9%	95%	18%
	Range Expansion On DC Only	14%	9%	32%	17%	72%	39%
	Range Expansion On DF-DC Only	17%	6%	38%	12%	80%	29%
4	Baseline	24%	0%	57%	0%	98%	0%
	Range Expansion Off	19%	5%	42%	8%	91%	14%
	Range Expansion On DC Only	10%	7%	25%	11%	54%	25%
	Range Expansion On DF-DC Only	14%	5%	30%	9%	63%	19%

7.2.2.5.4 Thermal noise limited system with bursty traffic

Similar to the full buffer traffic scenario, the performance in a thermal limited system with indoor UEs is considered. Indoor UEs are modelled with an additional building penetration loss as before. The details of the simulation and the distribution of the geometries can be found in clause 7.2.2.5.2.

Figure 50 and Table 53 show the UE burst rate improvement and average TTI utilization, respectively, from the HetNet deployment with 30dBm LPNs and 50% clustering UE dropping, 60% indoor UEs.

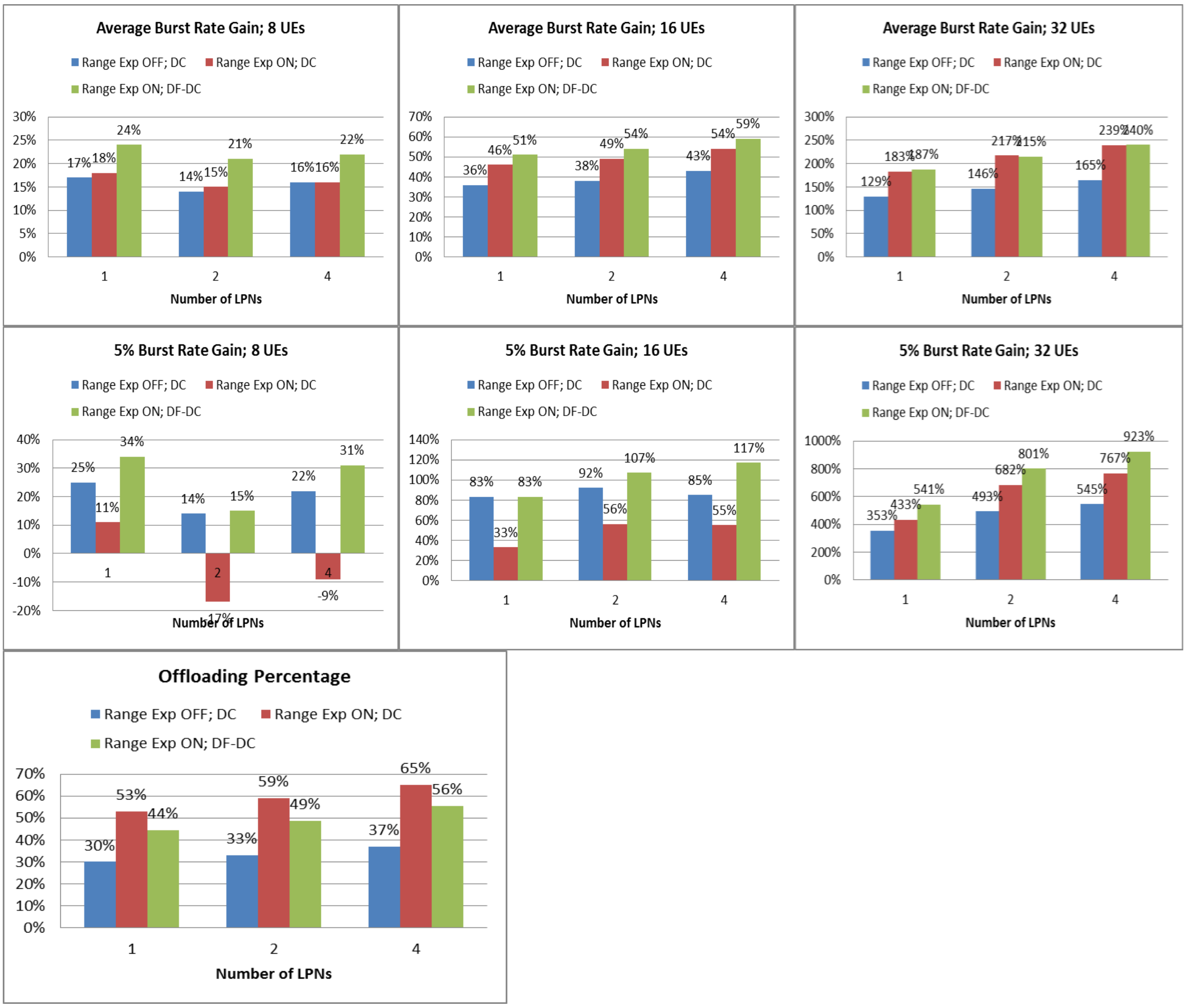

Figure 50: DL bursty traffic performance, 30dBm LPNs and 50% clustering dropping, 60% indoor UE

Table 53: Average TTI utilization, 30dBm LPNs and 50% clustering UE dropping, 60% indoor UEs

LPN Density	Scenario	8 UE/Macro		16 UE/Macro		32 UE/Macro	
		Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.	Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.	Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.
1	Baseline	28%	0%	62%	0%	98%	0%
	Range Expansion Off	17%	9%	39%	18%	82%	45%
	Range Expansion On DC Only	12%	15%	26%	34%	60%	70%
	Range Expansion On DF-DC Only	15%	10%	33%	21%	71%	49%
2	Baseline	26%	0%	61%	0%	98%	0%
	Range Expansion Off	15%	6%	35%	11%	78%	28%
	Range Expansion On DC Only	9%	9%	22%	18%	49%	42%
	Range Expansion On DF-DC Only	12%	6%	27%	12%	60%	30%
4	Baseline	26%	0%	62%	0%	99%	0%
	Range Expansion Off	14%	4%	33%	7%	71%	16%
	Range Expansion On DC Only	8%	6%	17%	11%	38%	24%
	Range Expansion On DF-DC Only	11%	4%	23%	8%	47%	17%

In general, we have the same observations as in the case of the interference limited system. Consistent and significant performance benefit can be achieved from HetNet deployment under range expansion with DF-DC operation, in terms of both the average user experience (average UE burst rate) and worst case user experience (5% UE burst rate).

Figure 51 and Table 54 show the UE burst rate improvement and average TTI utilization, respectively, from the HetNet deployment with 30dBm LPNs and 50% clustering UE dropping, 60% indoor UEs. In general, the gain is smaller compared to clustering UE dropping.

Figure 51: DL bursty traffic performance, 30dBm LPNs and uniform dropping, 60% indoor UEs

Table 54: Average TTI utilization, 30dBm LPNs and uniform UE dropping, 60% indoor UEs

LPN Density	Scenario	8 UE/Macro		16 UE/Macro		32 UE/Macro	
		Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.	Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.	Mean Macro TTI Utiliz.	Mean LPN TTI Utiliz.
1	Baseline	28%	0%	62%	0%	98%	0%
	Range Expansion Off	25%	8%	57%	10%	97%	15%
	Range Expansion On DC Only	22%	15%	50%	27%	94%	55%
	Range Expansion On DF-DC Only	24%	10%	54%	19%	96%	44%
2	Baseline	26%	0%	60%	0%	99%	0%
	Range Expansion Off	22%	6%	50%	10%	96%	19%
	Range Expansion On DC Only	18%	10%	38%	19%	81%	42%
	Range Expansion On DF-DC Only	20%	7%	43%	14%	87%	34%
4	Baseline	26%	0%	60%	0%	98%	0%
	Range Expansion Off	20%	6%	44%	9%	92%	14%
	Range Expansion On DC Only	13%	8%	29%	13%	63%	28%
	Range Expansion On DF-DC Only	16%	6%	34%	10%	69%	22%

7.2.2.5.5 Performance in a mixed deployment scenario

A mixed HetNet deployment, in which only a subset of Macro cells have LPNs being deployed is considered.

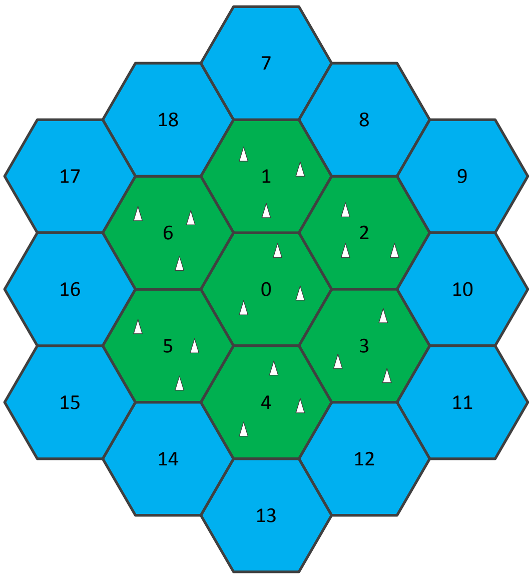

Figure 52: Mixed HetNet deployment, only green NodeBs (21 sectors) have LPNs deployed, while light blue NodeBs (36 sectors) do not have LPNs

Figure 52 illustrates an example of a mixed HetNet deployment. The 57 cells layout consists of three tiers of Macro NodeBs. Each Macro NodeB is sectorized into three sectors. The first tier has 1 Macro NodeB (3 sector), the second tier has 6 Macro NodeBs (18 sectors) and the third tier has 12 Macro NodeBs (36 sectors). We only deploy LPNs in the geographic area of the centre 7 green Macro NodeBs (21 sectors). The outer 12 light blue Macro NodeBs (36 sectors) do not have any LPNs deployed. When range expansion is applied on carrier F2, only the centre 21 green Macro sectors reduce their transmit power, the outer 36 light blue Macro sectors keep the same transmit power.

The general system simulation assumptions are summarized in the annex. Some salient aspects are:

- 4 LPNs are uniformly dropped in the geographic area of each green Macro sector.
- 16 UEs are dropped in the geographic area of each Macro sector. For the 21 green Macro sectors with LPNs, 50% Hotspot drops are used. For the 36 light blue Macro sectors without LPN, uniform dropping is applied.
- Outdoor path loss model is considered.
- LPNs transmit power is 30dBm per carrier. Without power reduction, Macro transmit power is 43dBm, with power reduction, green Macro sectors reduce their transmit power on F2 to 30dBm.

The same amounts of UEs are dropped per Macro sector irrespective of whether the Macro sector has an LPN or not. As a result, the Macro sector without an LPN is loaded more heavily as compared to the Macro sector with LPNs. Once the transmit power on F2 from the Macro sectors with LPN is reduced, some of the UEs could be switched to the Macro sectors without LPNs, which could further increase the load discrepancy. In a practical deployment, LPNs are more likely to be deployed in the Macro sectors that experience heavier traffic load compared to the neighbouring Macro sectors. From this perspective, the simulation results shown represent the worst case scenario.

Figure 53 shows the UE throughput improvement across the entire UE population with and without range expansion. Without range expansion, performance gain from the mixed HetNet deployment is much lower than the universal LPN deployment as shown in previous subclauses. This is expected since in a mixed HetNet deployment scenario, only 37% (21 out of 57) Macro sectors have LPNs deployed. It is also interesting to see that the median and tail UE performance improvement is small. This is because the majority of the UEs are served by Macro cells without LPNs, therefore do not benefit from the HetNet deployment under full buffer traffic.

Comparing range expansion on with range expansion off, we still observe improvement in every system performance metric. The improvement is not as significant as in the case of universal LPN deployment. The main benefit from the range expansion technique is to equalize the load between the Macro sector and LPNs, allowing more UEs to be served by LPNs. As LPNs are only deployed in a subset of Macro sectors, the benefit from range expansion still exists, but is somewhat reduced. With range expansion, DF-DC operation helps to improve the system fairness. When compared to DC only operation, the DF-DC operation improves the 5% UE tail throughput.

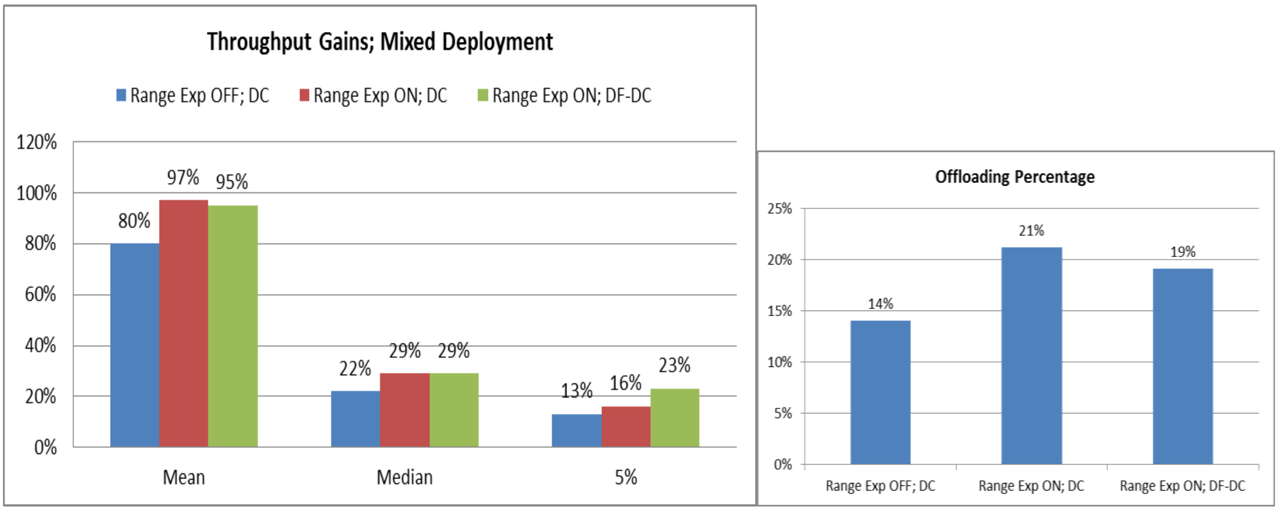

Figure 53: DL full buffer performance with 30dBm LPNs and mixed HetNet deployment, entire UE population

Under the mixed HetNet deployment scenario, once the Macro sectors with LPNs reduce their transmit power some UEs could be offloaded to the neighbouring Macro sectors without LPNs. This could potentially cause some performance degradation since the same amount of UEs per Macro sector are present regardless of whether LPNs are deployed or not. In this setup, the Macro sectors without LPNs serve more UEs than the Macro sectors with LPNs.

However, by reducing the Macro transmit power on F2; the interference to the neighbouring Macro cells on F2 is also reduced. As a result, the UEs that are served by the neighbouring Macro cells experience a geometry improvement on F2. Consider the UEs that are served by the outer 36 Macro cells that have no LPNs when range expansion is off. Their geometries on frequency F2 is shown in Figure 54. Around 0.5- 1dB geometry improvement can be observed for the most part.

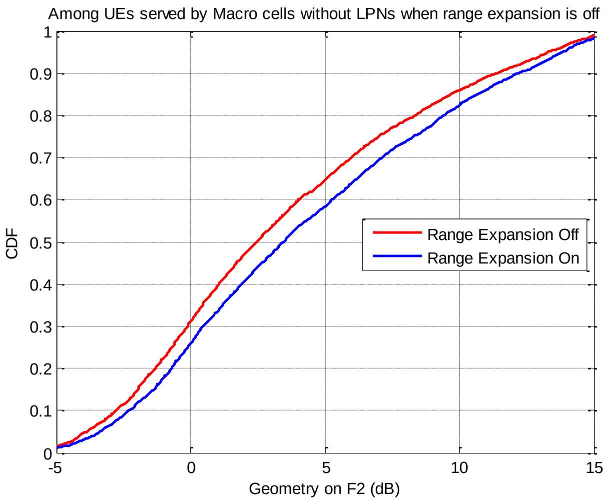

Figure 54: CDF of geometry on F2 for UEs served by Macro cells without LPNs

Next, consider the UEs that are located in the second tier Macro NodeB (NodeB 1-6). As a whole population, after the range expansion, some UEs may experience better performance since they are offloaded to LPNs, some may experience worse performance since they are offloaded to the neighbouring Macro cells without LPN. The rest of them stay with Macro cell and may observe some geometry losses but also benefit from the reduction in Macro load as more UEs are offloaded to the LPNs.

Figure 55 shows the throughput CDF among UEs that are dropped in the second tier NodeB (NodeB 1-6). The gains are given in percentage throughput increase over the baseline no LPN case. With range expansion on, some tail performance loss is observed for DC only operation compared to the range expansion off. As the Macro transmit power on F2 is reduced, we have different coverages on F1 and F2. Dual carrier operation forces the UE to be served by the same sector on both F1 and F2 which explains the tail performance loss. However, after enabling DF-DC, it is seen that consistent better performance is obtained compared to range expansion off scenario.

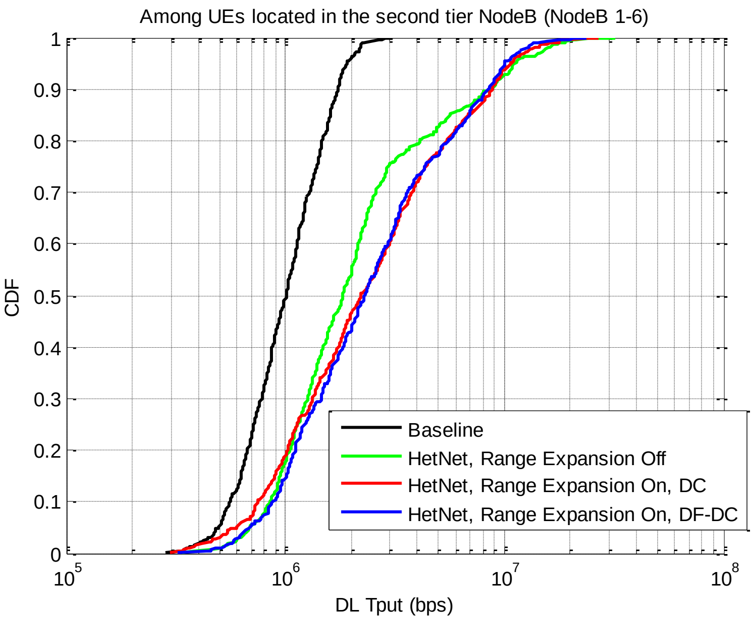

Figure 55: Throughput CDF among UEs located in the second tier Macro NodeB (NodeB 1-6)

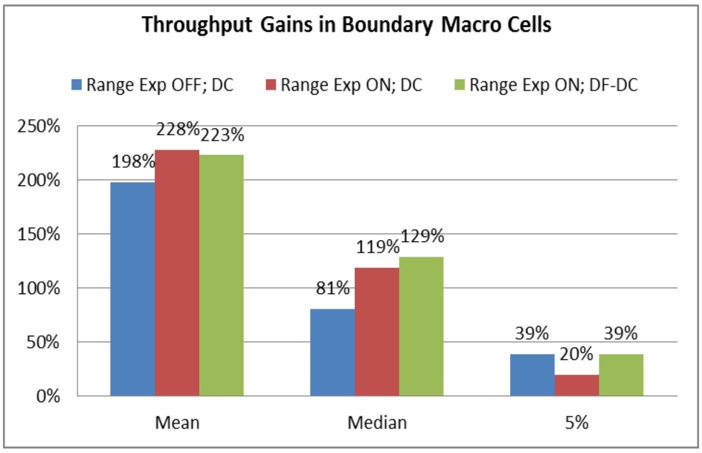

Figure 56: DL full buffer performance among UEs located in the second tier Macro NodeB

In summary, simulation results show that, even for the mixed HetNet multi-carrier deployments, range expansion by transmit power reduction on one carrier still provided performance improvement. However, it should be emphasized that the decision to lower the Macro transmit power should be made while also considering the long term loading in the system. If a macro cell that has LPNs deployed has neighbouring macro cells that are highly loaded any without any LPNs, it may be better to avoid reduction of the transmit power since it may add to the load discrepancy in the system. All range expansion techniques need to be applied while taking into account the long-term loading conditions in the system.

The levels to which the Macro transmit power is reduced are determined by the network. For example, when the LPN power level is 24dBm, most of the benefits can be obtained by reducing the Macro transmit power level to 30dBm on the secondary carrier. In this case, an UL/DL imbalance of 6dB is observed. This imbalance is the same as the UL/DL imbalance seen on the primary carrier as described in clause 6 and the solutions identified in clause 7.1 can also be applied on the secondary carrier.

7.2.2.5.6 Summary

- The following conclusions can be drawn from the performance results shown in subclauses 7.2.2.5.1 to 7.2.2.5.5
- Compared to a dual carrier HetNet co-channel deployment, range expansion significantly improves the system performance, especially the average UE throughput.
- Further system performance benefit was observed by allowing DF-DC operation in addition to DC-only operation with range expansion. Compared to DC only operation, DF-DC operation improves the system fairness by significantly increasing the 5% UE throughput.
- The impact of loss of DL coverage in a thermal noise limited system was also evaluated. The evaluation used a large percentile of indoor UEs with added Building Penetration Loss (BPL). Even with the indoor UE model, significant system performance gain was observed due to range expansion.

7.2.3 Decentralised biasing

In HetNet, the capacity gain is increased by offloading traffic from a Macro to an LPN, utilising the scheduling resources of the LPN. This offloading can be increased by biasing the UEs to hand over to the LPN at an earlier stage by increasing the Cell Individual Offset (CIO) parameter, which effectively expands the cell range of the LPN. Although this would increase the number of UEs served by the LPN, the UEs being offloaded may suffer from poor geometry especially when the biasing (i.e. CIO) value is large. Furthermore, capacity gain may not be available to the offloaded UEs if the LPN does not have spare capacity. Therefore, the gain of cell range expansion via biasing depends upon the loading condition of the macro and LPN. A fixed uniform biasing where the CIO for all LPNs is set to a fixed value would not be able to offer the capacity gain that it is intended to do. It is therefore beneficial that the biasing values (i.e. CIO values of the LPN) can be optimised according to the condition of each cell. Moreover, the biasing value may be further optimized accounting for UE receiver capacity or/and capability in addressing interference.

In [37], centrally optimised biasing values based on loading conditions of each cell are shown to improve the mean and 5% UE throughputs by 119% and 103% respectively compared to a fixed uniform biasing value. A centralised controller that can manage network wide biasing for all cells may not be available, and therefore a decentralised biasing method is considered.

In the decentralised biasing method, measurement parameters such as SINR or throughput are collected for all UEs in each cell by the network, and an adaptation metric for each cell is computed based on these measurements. Examples of suitable adaptation metrics are the 5% percentile UE SINR and 5% percentile UE throughput. Using the adaptation metric, the network computes the biasing value (CIO) for each cell. The updated CIO values are signalled to the UEs. The rate of change of the biasing values is expected to be slow, e.g. a few seconds. The details of a possible scheme can be found in Appendix B of [37]. It is found in [37] that the decentralised biasing method is able to give 112% to 119% average UE throughput gain and 77% to 88% 5% UE throughput gain compared to using a fixed uniform biasing value.

The adaptation metrics from the cells need to be signalled to the RNC where the biasing values can be updated, which would have some RAN3 impact. In computing the adaptation metric, existing UE measurements can be used. However, there may be some RAN1 and RAN2 impact if other UE measurements are found to be beneficial in computing the adaptation metric. This feature would be applicable for both single carrier and dual carrier deployments.

7.3 Combined cell

The main principle of combined cell is that a UE can move seamless within the combined cell coverage without any RNC interaction. Figure 57 shows the system architecture for the combined cell deployment, where all the nodes within a combined cell are tightly coupled by high speed and low latency backhaul to a central unit in the combined cell. For example, this central unit may be a macro scheduling unit similar to a current main unit in main/remote base station implementations. Coupling between various nodes is not a requirement in the combined cell deployment. Note that in the combined cell deployment, RNC connects to the central unit and is not aware of these different nodes. For example, these nodes can be Remote Radio Units (RRUs). In the co-channel deployment, scheduling is done per each cell while in a combined cell scheduling is performed per combined cell. Hence, the scheduler decides which nodes should transmit to a particular UE. Some of the mobility and resource management operations performed in the RNC in the co-channel deployment will be performed by the central scheduler in the combined cell deployment. For example, the central scheduler tracks the UE between multiple nodes. Hence, this configuration avoids the loading of RNC, while at the same time the decisions and execution can be performed very fast (on TTI level). This improves the overall performance of the network as well as the UE performance (qualitatively and quantitatively).

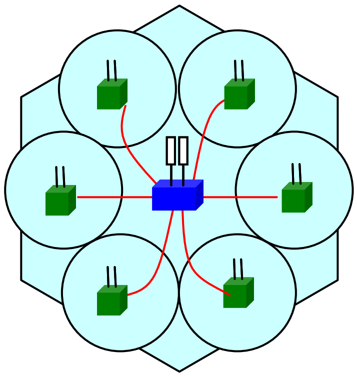

Figure 57: System architecture of the combined cell deployment, where all the nodes within a combined cell are tightly coupled and connected to the central scheduler

7.3.1 Motivation of combined cell deployments

Since the introduction of LPNs does not create individual cells as in the co-channel deployment, the following benefits can be achieved with the combined cell deployment.

1. **Handovers and Impact on End User Performance:** Since the LPNs are part of combined cell, from a RNC perspective, the UE can move seamlessly within the macro and LPN coverage areas that belong to the same combined cell, without any handover. Hence, the number of handovers will be the same as that of a homogenous network deployment (e.g., a macro-only deployment). Since there are less handovers in this deployment, the probabilities as well as the number of handover signalling failure are both reduced. Furthermore, this results in less frequent RRC signalling. As a result, the end user performance can be enhanced. For example, less dropped calls due to RRC signalling delay or handover signalling failure.

2. **Neighbour Cell List (NCL) Size:** Since in a combined cell deployment the LPNs deployed within the Macro cell coverage area have the same L3 cell Identity, i.e. for RNC the combined cell is considered as one L3 cell Identity, so all LPNs that are deployed within the combined cell coverage area including the Macro cell will have the same L3 cell Identity in the combined cell deployment. Consequently, the current NCL size for a homogenous network would be enough and there is no need to extend the NCL with the combined cell deployment in heterogeneous networks. Moreover, because LPNs and Macro cell share the same L3 cell identity in the combined cell deployment, the PSC confusion problem could be avoided, especially when the number of LPNs increases and consequently the network cell planning complexity will decrease.

3. **Downlink/Uplink Imbalance:** The introduction of LPNs in a macro coverage area can cause a downlink/uplink imbalance problem in a heterogeneous network, when a UE is served by a strong macro downlink and has a stronger uplink to the LPN. This might cause problems, for both uplink and downlink control channels. Since in a combined cell deployment, both macro and LPN are part of one combined cell, this problem can be avoided in the combined cell deployment.

4. **Interference Avoidance:** With the introduction of low power nodes, the interference structure becomes more complex than in a homogenous network. Since in a combined cell all the nodes are connected to a central node, the interference can be avoided using co-ordinated scheduling.

5. **Network Management:** With the introduction of low power nodes, the network management, for example keep tracking of KPI, parameter tuning, deployment strategies, become more complex. With combined cell, we can avoid this problem as the network views these LPNs as part of one combined cell. This is particularly appealing for network operators as they can reduce the cost of deployment without compromising on the performance.

6. **Shadow fading effects** can be reduced in combined cell deployments for a large number of small cells [44].

7.3.2 Typical deployment scenarios and use cases

This subclause outlines a few typical deployment scenarios where combined cell is attractive for heterogeneous deployments. Note that combined cell is not only limited to these scenarios; it can be deployed in other scenarios as well.

A. High mobility between nodes:

These types of scenarios arise when a UE is moving at high speed between different nodes. For example as shown in Figure 58, the UE is moving between 3 nodes in a high mobility scenario (e.g. a high speed train). Hence, instead of treating these nodes as separate cells, if these 3 nodes are treated as one cell (e.g., combined cell), one can avoid the handovers between LPNs and the frequent signalling from RNC.

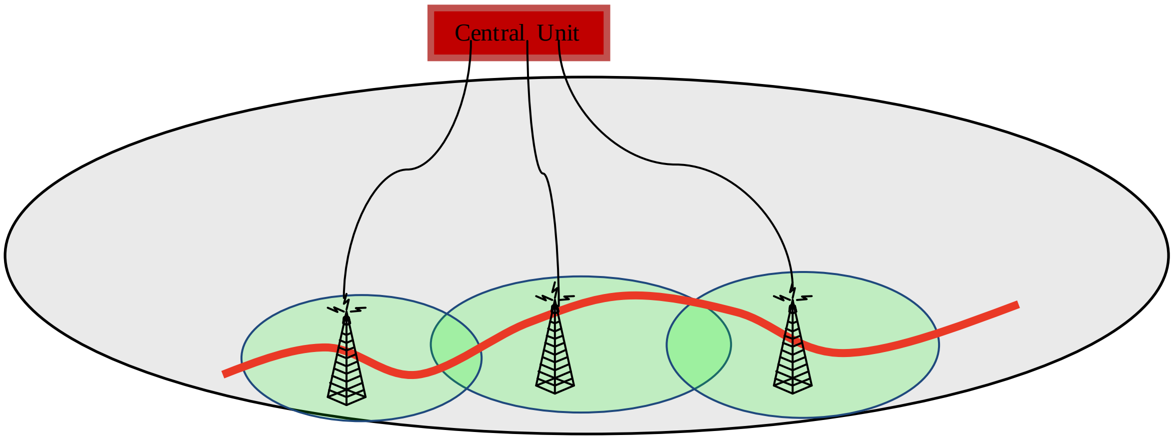

Figure 58: Combined cell deployment when a UE is moving between different nodes with high speed

B. In-Building deployments:

In certain existing deployments, in-building systems are deployed using distributed antennas which typically form one logical cell per floor. By deploying LPNs using the combined cell deployment one can reduce the neighbour list in the RNC.

C. UE is in the vicinity of severe interference:

It is well known that the introduction of LPNs causes interference to legacy UEs. If the UE is connected to a LPN the performance may be impacted by the dominant interference from the macro node, hence the performance may be impacted severely. As shown in Figure 59, using the combined cell deployment avoids this problem by transmitting the same signal to the UE when the UE is in the vicinity of strong interfering node.

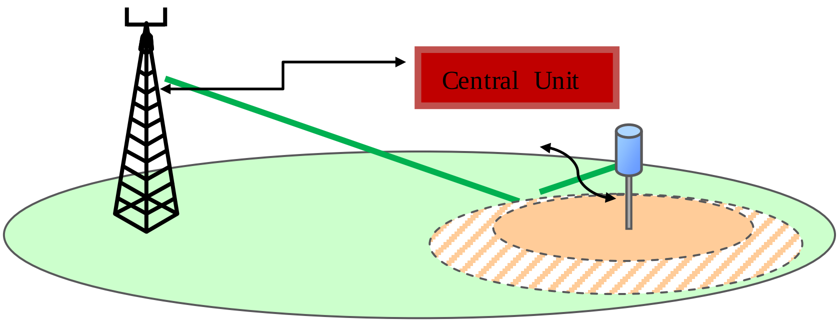

Figure 59: Combined cell deployment when the UE is in the vicinity of strong interference

D. Deployments where the number of LPNs is very large:

Another application of combined cell is when the number of LPNs is very large, for example, in public places such as shopping malls, train/subway stations, airports, stadiums, etc. By deploying LPNs in these places as a combined cell one can avoid the frequent handovers and a very large neighbour list.

7.3.3 Transmission modes

The downlink transmission modes can be divided into three types.

A. Single Frequency Network (SFN) mode: This mode combines signals over the air from all nodes by means of transmitting exactly the same pilot channel, downlink control channels and downlink data channels using the same carrier frequency, spreading and scrambling codes. Figure 60 shows the conceptual diagram of this transmission mode, where we assumed one macro node and 3 LPNs are deployed in combined cell. Here only downlink physical channels which are relevant for the study are shown. The other downlink physical channels such as common control physical channel, synchronization channel, Acquisition Indicator Channel are not shown. They are transmitted either from all nodes or from a subset of nodes. Note that same colour code is used to indicate that same data is transmitted from all the nodes. Since in this mode, signal to noise ratio is improved by the addition of LPNs, this mode can be used for coverage improvements.

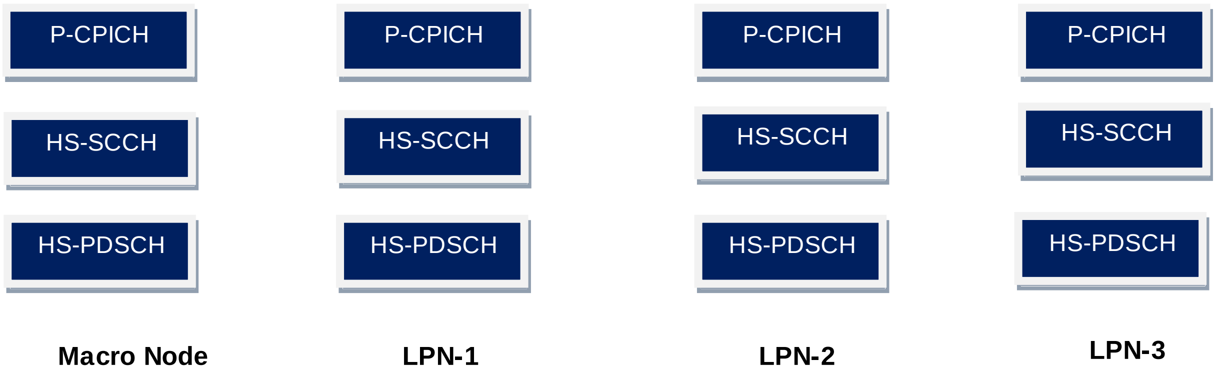

Figure 60: Downlink physical channel configuration in combined cell deployment with SFN mode

B. Node Selection with Spatial Reuse: Figure 61 shows the conceptual diagram of this mode, where it is assumed that one macro node and 3 LPN are deployed in a combined cell. Similar to the SFN mode, the same pilot signal P-CPICH is transmitted from all the nodes, thereby allowing this mode to serve the legacy users using this mode. The downlink control channels and the data traffic channels are scheduled to different UEs from different nodes, and are shown with different colour codes. Note that additional demodulation pilot channels are needed for data demodulation. Since the scheduling is done per combined cell, the central scheduler decides which nodes should transmit to the various UEs. Since each node can serve different UEs at the same time using same channelization codes, this mode can be used for capacity improvements.

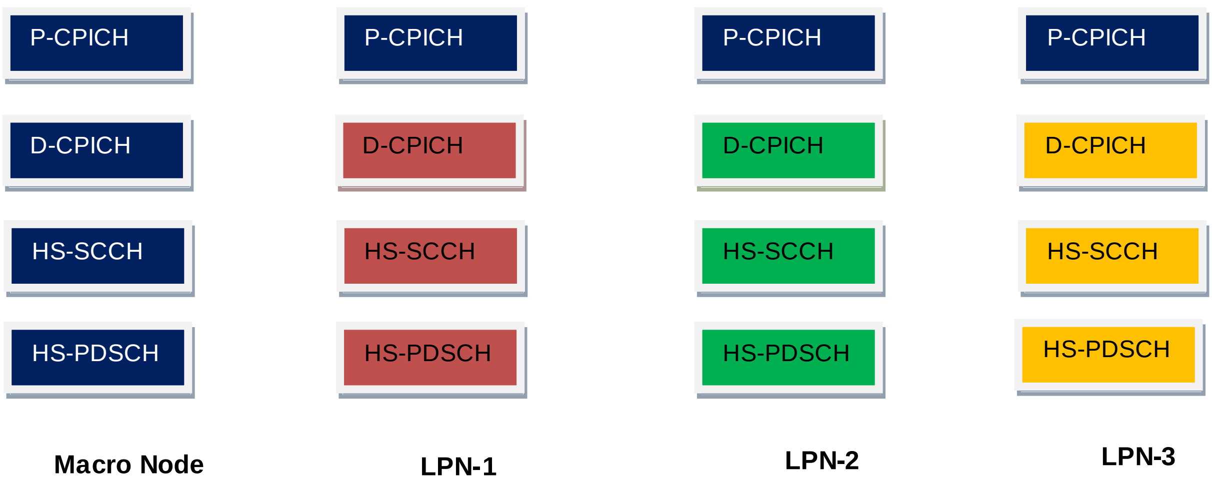

Figure 61: Downlink physical channel configuration in combined cell deployment with SR mode

C. MIMO mode with spatially separated nodes: Figure 62 shows the downlink channel configuration for this mode. The combination of the nodes acts like distributed MIMO, i.e. MIMO transmission with spatially separated nodes. For simplicity we have shown only MIMO transmission from macro node and LPN-1 and spatial reuse from LPN-2 and LPN-3. In this mode, it is expected that in addition to the spatial re-use gains, MIMO gains (both diversity and multiplexing gains) are possible. Hence this mode can be used for capacity improvement when there are many MIMO capable UEs in the combined cell.

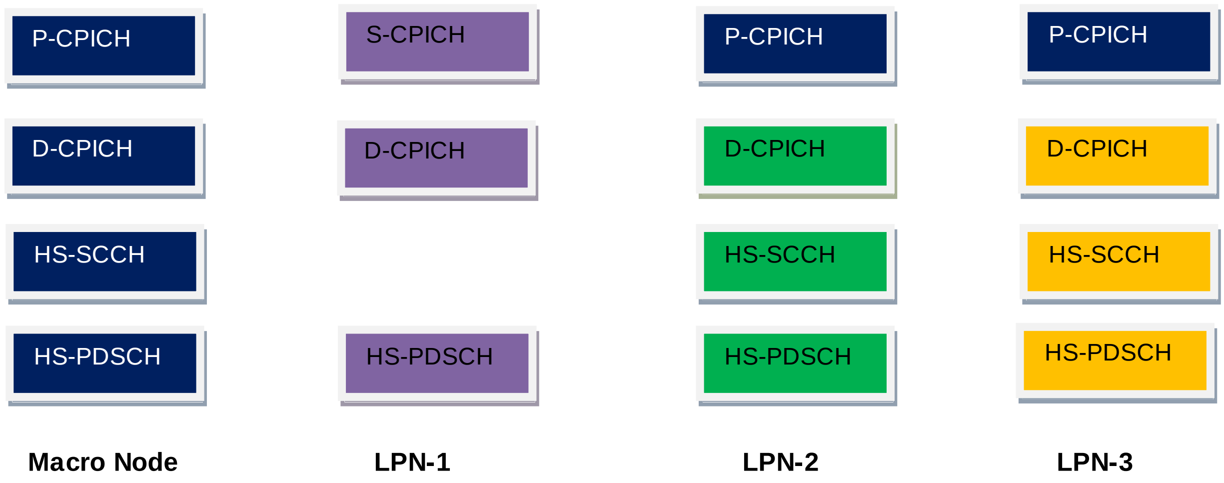

Figure 62: Downlink physical channel configuration in combined cell deployment in MIMO mode with spatially separated nodes

7.3.4 System performance

The performance of combined cell deployment was evaluated via system and link simulations. For system simulations full buffer traffic is assumed. System simulation assumptions are summarized in Annex A.1 and system performance evaluation metrics in Annex A.2. Link simulation assumptions are summarized in Annex A.3. The gains are presented as the percentage increase over the baseline throughput, where the baseline throughput is obtained when LPNs are not present in the Macro cell.

7.3.4.1 Single Frequency Network Mode

Figure 63 shows the average sector throughput vs. number of users per macro node. The number of LPNs per Macro cell is 4. It can be observed that the performance is improved at all loads. This is due to the increase in signal to noise ratio with the addition of LPNs.

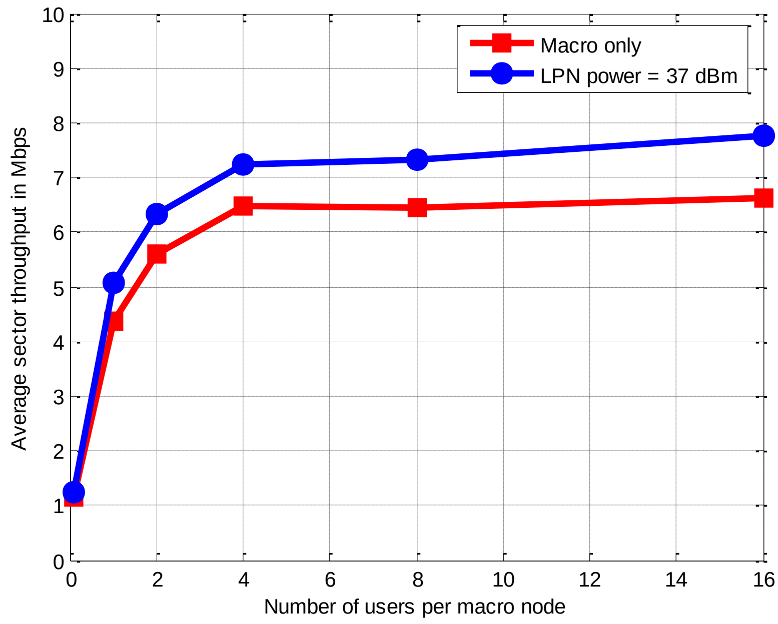

Figure 63: Average sector throughput vs. number of users per macro node

Figure 64 shows the percentage of gain with respect to the case when no LPN is deployed when we change the power of each LPN. The number of LPNs per Macro cell is 4 with 16 UEs per Macro. Note that the gains decrease as we decrease the power of each LPN as the SINR of the SFN channel is reduced when we reduce the power of each LPN.

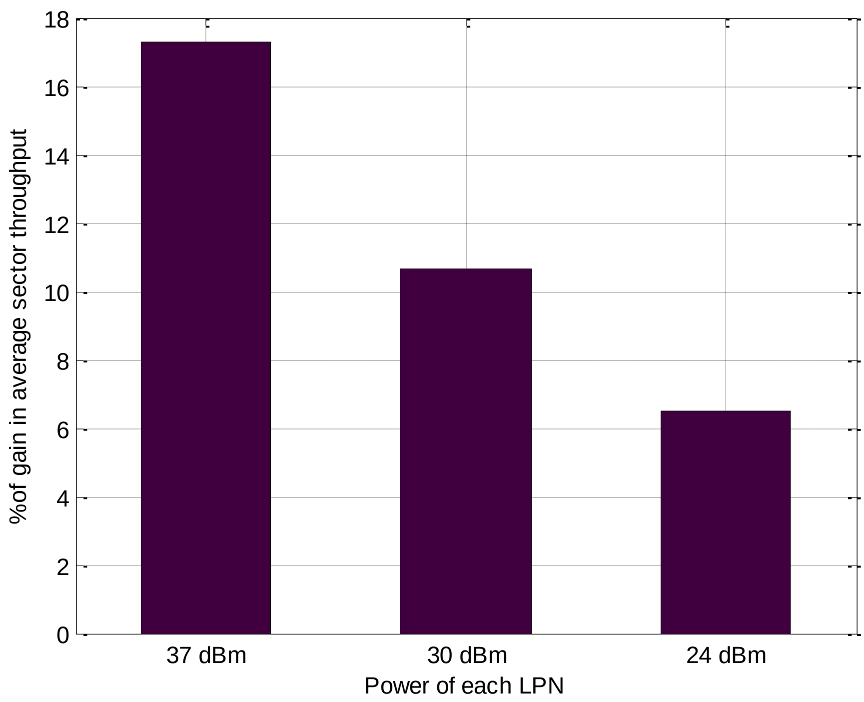

Figure 64: Percentage of gain in average sector throughput as a function of LPN power

It should be noted that figures 63 and 64 show the gains when the propagation offsets have not been taken into account. The gains when propagation offsets have been accounted for are shown in Table 55.

Further, when a continuous dedicated pilot is configured for the spatial re-use mode (referred to as Solution II discussed later in section 7.3.4.2), the available HS-PDSCH power is reduced. This would impact the gains as seen in Table 55.

Table 55: HSDPA throughput comparison between Macro-only and Single Frequency Network (SFN) modes of operation

Channel	User location	Macro only [Mbps]	Solution I (idealistic probing pilots)	
			w/o prop. offsets (K=0)	w/ prop. offsets
PA3	L1	15.15	15.16(0)	14.82(-2)
	L2	14.46	15.03(4)	13.51(-7)
	L3	13.73	15.73(15)	13.13(-4)
	L4	13.73	17.84(30)	14.43(5)
	L5	17.56	17.52(0)	17.52(0)
	L6	12.10	12.15(0)	12.13(0)
	L7	12.98	12.90(-1)	12.90(-1)
	L8	4.62	4.55(-2)	4.55(-2)
PB3	L1	10.77	10.94(2)	10.93(1)
	L2	10.58	10.85(3)	10.57(0)
	L3	10.21	11.10(9)	10.52(3)
	L4	10.28	11.79(15)	11.19(9)
	L5	11.65	11.74(1)	11.74(1)
	L6	9.65	9.68(0)	9.68(0)
	L7	10.00	10.05(1)	10.05(1)
	L8	4.04	4.11(2)	4.11(2)
VA30	L1	8.90	9.01(1)	8.96(1)
	L2	8.68	8.94(3)	8.75(1)
	L3	8.41	9.10(8)	8.89(6)
	L4	8.42	9.65(15)	9.40(12)
	L5	9.62	9.67(1)	9.64(0)
	L6	7.79	7.83(1)	7.87(1)
	L7	8.12	8.16(0)	8.16(0)
	L8	3.00	3.04(1)	3.04(1)

7.3.4.2 Node selection with Spatial Reuse Mode

In a combined cell deployment, all the nodes transmit the same common pilot (P-CPICH) and the UE computes the channel quality indicator (CQI) based on the combined pilots. Hence the central node does not know where the UE is located or which nodes should transmit data to this particular UE. This is similar to cell selection in co-channel deployment, where the UE compares the pilot strengths of each node and decide which cell is most suitable. Since in a combined cell all the nodes have the same primary scrambling code, the UE cannot distinguish between individual pilots. For identifying the best suitable node for data transmission, two solutions are considered. The first one is introducing new probing pilots which can be transmitted continuously at a low power level, the other one is using demodulation pilots as probing pilots with higher power.

7.3.4.2.1 Solution I (using low power level probing pilots and demodulation pilots)

Figure 65 shows the message sequence chart of this method. Assume that a combined cell deployment consists of 4 Nodes serving multiple UEs (the same procedure applies if the number of nodes is more than 4 or less than 4). A reference signal which is unique to each node in a combined cell called fractional CPICH (F-CPICH) is transmitted from each node simultaneously and continuously. The F-CPICH is characterized by a spreading code (typically SF= 256) and a scrambling code which is either the primary scrambling code or a secondary scrambling code of the combined cell. The F-CPICH channel power levels may be indicated to the UE during the initial cell set up. In addition to F-CPICH, the primary common pilot (P-CPICH) which is common to all the nodes is continuously transmitted. From these two different pilot signals, the UE estimates the channel and feeds back the channel quality information (CQI) associated with these two pilots at two time intervals. Note that the CQI estimated with F-CPICH indicates the channel quality corresponding to a specific node, referred to hereafter as CQI_F, and the CQI computed using P-CPICH is the channel quality using the combined nodes, referred to hereafter as CQI_P. These two CQIs are time multiplexed and sent on the uplink feedback channel HS-DPCCH. The same HS-DPCCH signal is received by all the nodes. The central processing unit processes the received signal (HS-DPCCH) from all the nodes. From CQI_F the central scheduler identifies which node the UE is close to. Hence the scheduler informs the respective node to transmit to the UE. The assigned node transmits the demodulation pilot channel (D-CPICH), downlink control channel (HS-SCCH) and the downlink traffic channel (HS-PDSCH) to the respective UE. Similarly, the central scheduler informs the other nodes to transmit to the other UEs. Note that D-CPICH and F-CPICH use different spreading codes and may have different power levels. For example, the power level of F-CPICH may be relatively low and D-CPICH may be relatively high.

The effectiveness of F-CPICH and the corresponding CQI_F for cell association has not been evaluated. The accuracy of the CQI reports would depend on the measurement interval, the filtering length, and Ec/Ior for probing pilots. The impacts due to the delays associated with cell selection that can result in loss of opportunity to schedule the user from the right node and the additional power allocated to probing pilots have also not been evaluated. Therefore, the simulation gains presented in this section should be considered as an upper bound.

When the scheduler relies on CQI_P to schedule HS-PDSCHs to the UE, some inefficiencies may arise due to the distortion of the channel quality information. The scheduler may employ CQI correction mechanisms to mitigate this impact although some impact is expected due to estimation errors in the SNR and can vary depending on the receiver implementation and the channel profile. It should be noted however, that in the results presented, ideal knowledge of the channel conditions from each cell to the UE have been assumed.

There is additional complexity introduced in the UE when compared to co-channel deployments. The UE would additionally have to:

- Monitor F-CPICH channels and report the corresponding CQI_F in addition to the CQI reports on the P-CPICH channel
- Implement an equalizer for F-CPICH in addition to P-CPICH for demodulation purposes. Depending on specific implementations, this could be significant increase in UE complexity.
- Implement a mechanism for determining the cell from which the D-CPICH is transmitted. Depending on how this mechanism is specified the impact on complexity could be minimal.

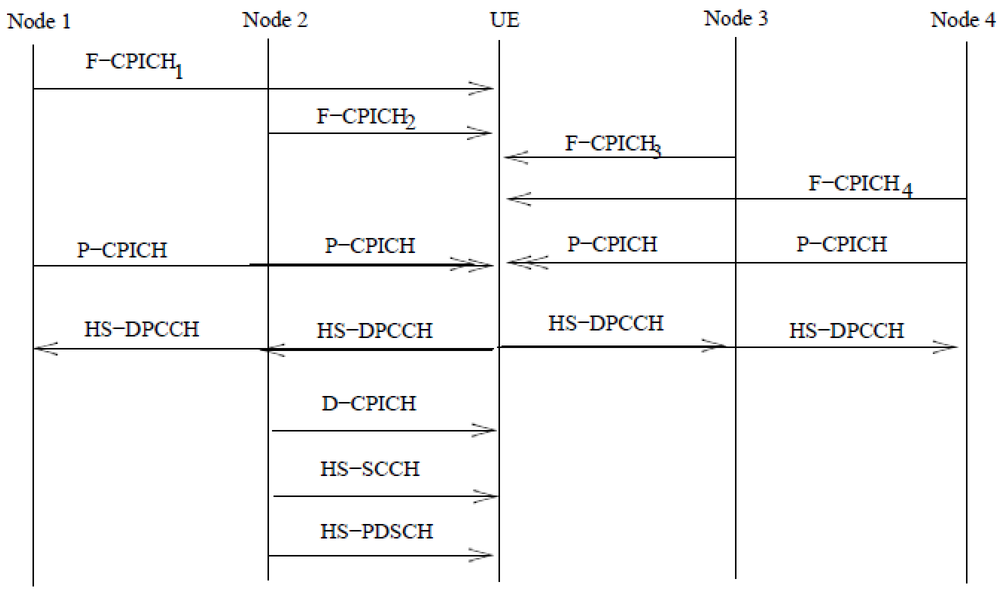

Figure 65: Message sequence chart between the Nodes and the UE using Solution I

7.3.4.2.2 Solution II (using high power level demodulation pilots)

Figure 66 shows the message sequence chart of this solution. Assume that a combined cell deployment consists of 4 Nodes serving multiple UEs (the same procedure applies if the number of node is more than 4 or less than 4). Instead of probing pilots, demodulation pilots are used from each node. In addition all the nodes transmit the same pilot signal P-CPICH. Note that channel sounding for CQI estimation is done on D-CPICH. From the D-CPICH signal the UE estimates the channel and fed back the channel quality information (CQI). The CQI information is sent in HS-DPCCH. The same HS-DPCCH signal is received by all the nodes.

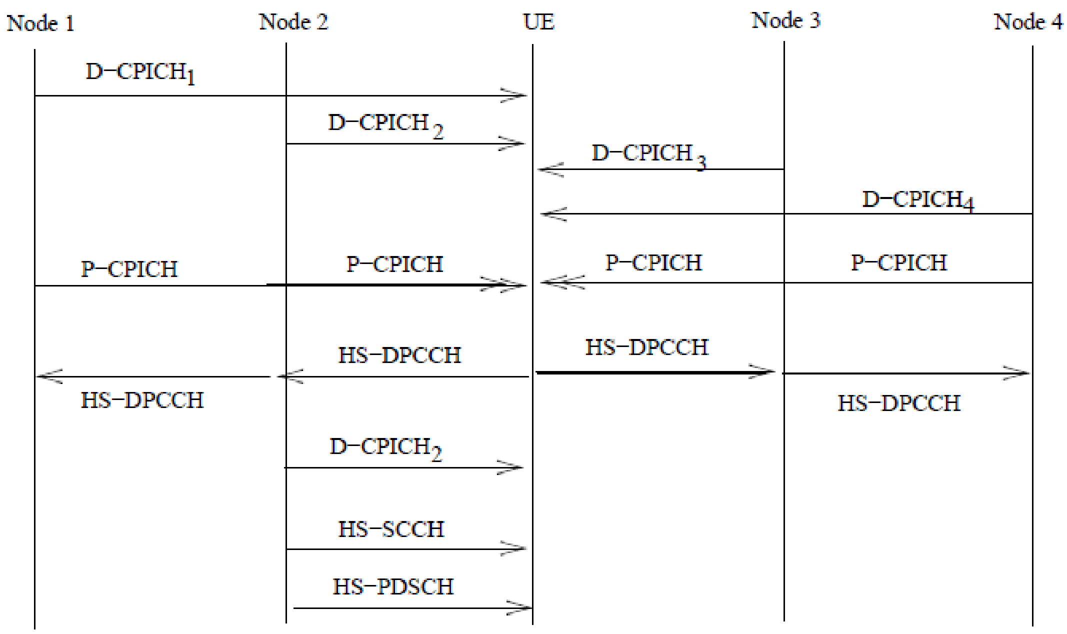

Figure 66: Message sequence chart between the Nodes and the UE using Solution II

The central processing unit processes the CQIs and identifies which node(s) a UE is closest to. Hence the scheduler informs the respective node to transmit to the UE. The assigned node transmits the downlink control channel (HS-SCCH) and the downlink traffic channel (HS-PDSCH) to the respective UE. Note that in this solution, D-CPICH needs to be continuously transmitted from each node with a higher power as it is used for data demodulation.

The transmit power levels of the D-CPICH channels are the same as P-CPICH. This ensures that the quality of the channel estimation is the same that observed in legacy networks and consequently also ensures the quality of the CQI report. The use of D-CPICH to report the CQI enables the network to avoid additional CQI adjustments that are required in Solution 1.

Similar to Solution I, there is additional complexity introduced in the UE when compared to co-channel deployments. In the case of Solution II, the UE would additionally have to:

- Monitor the D-CPICH channels and report the corresponding CQIs. This is in addition to the monitoring of the P-CPICH for mobility measurements and event reporting.
- Implement an equalizer for D-CPICH in addition to P-CPICH.
- Implement a mechanism for determining the cell that is transmitting data.

7.3.4.2.3 System simulation results for Solution I

Figure 67 shows the percentages of gain with respect to homogeneous network vs. number of users per macro node with uniform UE dropping. The number of LPNs per Macro cell is 4. It can be observed that the performance is improved at all loads except at 0.1 users per macro node. Similar to co-channel deployment, the gains are mainly due to offloading and also the improved geometry for those UE which are getting downlink transmission from LPN. The performance with co-channel deployment is also shown. Without taking into account the demodulation pilot (D-CPICH) overhead, the performance of spatial reuse mode is slightly better compared to that of co-channel deployment. With the addition of demodulation pilot overhead (-13 dB) i.e. 25% overhead in total, the gains due to combined cell reduce as the power allocated for HS-PDSCH is less. Hence a slight degradation is observed in Figure 67.

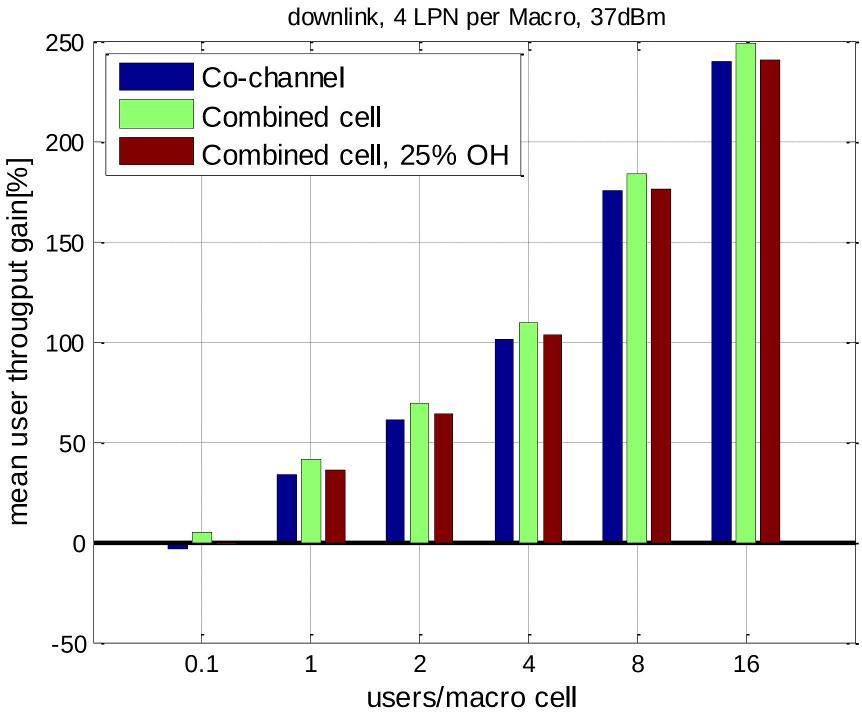

Figure 67: Percentage gains with respect to homogeneous network

7.3.4.2.4 System simulation results for Solution II

Table 56 shows the percentage of gains achieved with Solution II. Note that in this scheme the gains are smaller compared to solution I. This is due to the additional pilot overhead of D-CPICH (-10 dB).

Table 56 Percentage of gains with Solution II (16 UEs per macro cell)

Throughput Metric	Homogeneous Network [Mbps]	Spatial Reuse Mode	
		Value[Mbps]	% Gain
Average Sector Throughput	6.6	20	203.1
Average User Throughput	0.41	1.25	204.87
Average cell edge user Throughput	0.069	0.11	59.42
Median user Throughput	0.37	0.72	94.6

7.3.4.2.5 Link simulation results for Solution I and Solution II

Figure 68 shows the user placement assumed when analyzing the gains achieved with spatial reuse mode via link simulations. The macro node is placed at the center of the hexagon and the LPN is placed on the line joining the macro to a hexagon's corner. We consider 8 user locations indexed from 1-8 in Fig. 68. Locations 1-4 are close to the LPN while locations 5-8 are distributed in the hexagon's sector. A 57-cell network simulator to calculate the received Ior (Macro), Ior (LPN) and the Ioc values (includes contribution from other macro-cells with 20% loading) is considered. In these simulations, we assume a 30 dBm transmit power for the LPN-cell and use 3GPP path loss models.

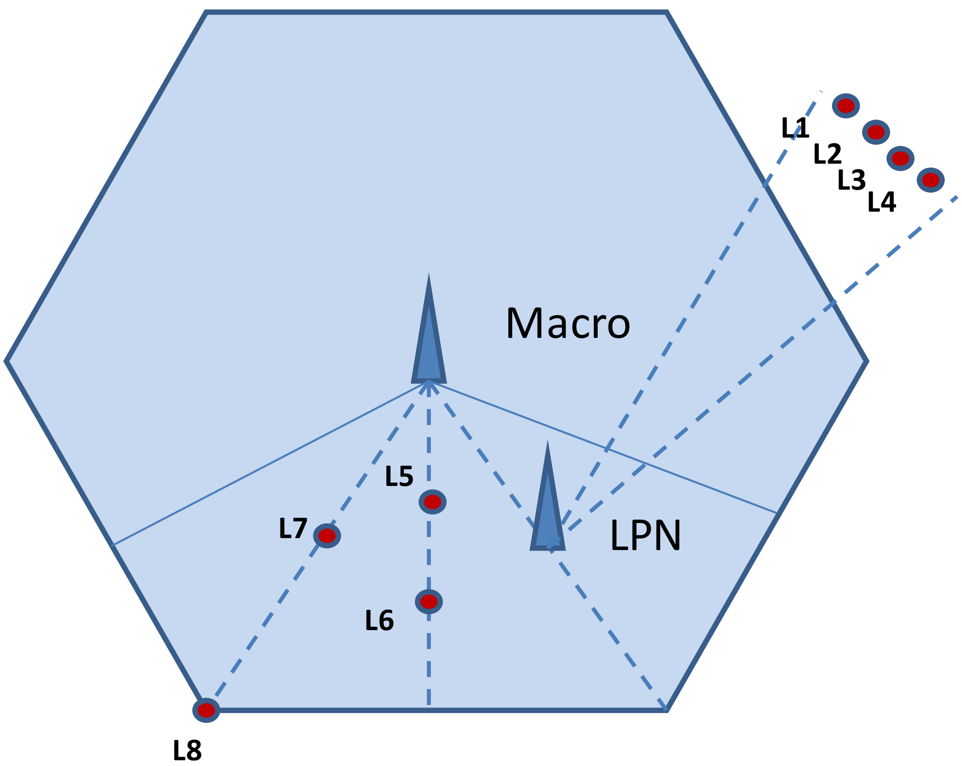

Figure 68: User placement configuration

The geometry (macro/LPN) is defined as the ratio of the Ior (macro/LPN) to the Ioc, where Ioc does not include the contribution for the other cell (LPN/macro). This quantity is tabulated in Table 57. Different path delays between the macro and LPN result in an offset of the LPN-signal relative to the macro-signal at the user. Assuming the speed of light *c*, this offset Δt is given by,

$$\Delta t = (d_P - d_M)/c,$$

where d_P, d_M denote the distances to the LPN and the macro-cell from the user. The offsets are tabulated in Table 57 both in nano-seconds and UMTS chips (260ns/chip).

Table 57: User geometries and propagation offsets for different placements; co-ordinates are given with reference to macro (as origin), LPN at (72 m,-125 m).

Location Index	Co-ordinates (x,y) in meters	Macro Ior/Ioc (in dB)	LPN Ior/Ioc (in dB)	LPN propagation offset relative to Macro (in ns)	LPN propagation offset relative to Macro (in UMTS chips)
L1	(57,-99)	19	5	281	1.1
L2	(62,-107)	18	12	343	1.3
L3	(65,-112)	17	17	381	1.5
L4	(67,-116)	17	24	412	1.6
L5	(0,-83)	24	-13	0	0
L6	(0,-167)	15	-10	278	1.1
L7	(-72,-125)	16	-19	0	0
L8	(-144,-250)	4	-28	129	0.5

For the settings of spatial reuse mode and co-channel heterogeneous network modes, two users are simulated in the network. The first user is always allocated to the macro-cell and the second user is allocated to the LPN. The link simulation results from [45] and [46] are shown in tables 58-60.

Table 58 and 59 shows the percentage of gain/loss compared to the Macro only case for solutions I and II.

In Table 58, up to 50% gains and losses up to 95% over a Macro deployment can be seen.

Table 58: Percentage of gains/losses with Solution I from [45]

	L1	L2	L3	L4	L5	L6	L7	L8
L1	-	-35.50	-21.86	1.08	-47.19	-33.65	-36.54	-14.13
L2	-65.21	-	-46.82	-22.71	-68.26	-59.95	-61.69	-47.68
L3	-81.56	-75.91	-	-38.60	-83.97	-79.51	-80.53	-73.04
L4	-94.10	-88.76	-76.19	-	-95.47	-94.13	-94.49	-92.38
L5	8.11	14.91	28.98	50.01	-	22.4	17.73	54.57
L6	-16.74	-8.82	8.14	34.88	-25.21	-	-7.48	33.44
L7	-11.29	-3.57	12.82	38.37	-19.9	3.17	-	38.72
L8	-50.04	-40.86	-20.11	15.27	-56.93	-38.97	-43.19	-

Due to additional power of D-CPICH which is set to -10 dB, the gains are somewhat less compared to solution I where the power overhead due to F-CPICH is -16 dB and D-CPICH is -13 dB.

In Table 59, up to 55% gains and losses up to 95% over a macro deployment can be seen.

Table 59: Percentage of gains/losses with Solution II from [45]

	L1	L2	L3	L4	L5	L6	L7	L8
L1	-	-36.55	-22.94	-0.002	-48.14	-34.83	-37.67	-15.66
L2	-65.31	-	-50.82	-27.32	-67.58	-59.96	-61.61	-47.69
L3	-81.56	-75.91	-	-38.66	-83.96	-79.51	-80.53	-73.04
L4	-94.34	-88.99	-76.44	-	-95.68	-94.41	-94.76	-92.74
L5	7.98	14.78	28.84	49.88	-	22.38	17.58	54.38
L6	-20.75	-12.94	3.86	30.61	-28.85	-	-11.99	26.94
L7	-11.51	-3.80	12.59	38.13	-20.10	2.91	-	38.36
L8	-50.79	-41.64	-20.92	14.45	-57.6	-39.91	-44.07	-

Table 60 shows the link throughout comparison with solution I and solution II from [46] In these results, gains as high as 66% are obtained over macro-only network when solution II is considered. This corresponding highest gain for solution I is 59%. For both these solution, the highest gain was observed when Users 1 and 2 are placed at locations **L**5 and L4 and associated to macro and low power node respectively. Compared with solution I, we observe 4-10% additional gains for solution II at most of the highlighted locations. It is worthwhile to note that these gains are obtained in spite of the fact that extra power is allocated to D-PICH, reducing the available HS power. This extra power allocation to the control channels might be the reason the performance of the enhanced proposal is still lower than the co-channel heterogeneous network deployment by 8-11% at most locations.

Table 60: Link throughput comparison between solutions I and II in spatial reuse mode from [46]

Channel	User locations (User1, User2)	Macro-Only Mbps	Solution I Mbps (%gain)	Solution II Mbps (%gain)	Co-channel deployment Mbps (% gain)
PA3	(L1,L3)	14.44	18.29(27)	17.70(23)	18.91(31)
	(L1,L4)	14.44	20.21(40)	20.41(41)	22.00(52)
	(L2,L4)	14.09	17.62(25)	17.57(25)	18.89(34)
	(L5,L1)	16.35	15.62(-4)	18.40(13)	19.15(17)
	(L5,L2)	16.01	19.11(19)	20.99(31)	21.96(37)
	(L5,L3)	15.64	21.99(41)	23.34(49)	24.81(59)
	(L5,L4)	15.64	24.80(59)	26.03(66)	27.59(76)
	(L6,L2)	13.63	14.64(7)	15.40(13)	16.70(23)
	(L6,L3)	13.26	17.84(35)	17.77(34)	18.95(43)
	(L6,L4)	13.26	19.96(51)	20.63(56)	22.09(67)
	(L7,L1)	14.06	11.99(-15)	13.79(-2)	14.57(4)
	(L7,L2)	13.72	15.84(15)	16.54(21)	17.69(29)
	(L7,L3)	13.35	19.15(43)	18.70(40)	19.93(49)
	(L7,L4)	13.35	21.00(57)	21.43(61)	23.08(73)

PB3	(L1,L3)	10.49	13.21(26)	13.59(30)	14.58(39)
	(L1,L4)	10.53	15.37(46)	15.86(51)	16.87(60)
	(L2,L4)	10.43	13.31(28)	13.61(30)	14.63(40)
	(L5,L1)	11.21	10.50(-6)	12.14(8)	12.90(15)
	(L5,L2)	11.12	12.60(13)	14.24(28)	15.16(36)
	(L5,L3)	10.93	15.30(40)	15.95(46)	16.96(55)
	(L5,L4)	10.97	17.40(59)	18.14(65)	19.31(76)
	(L6,L2)	10.12	10.88(8)	12.08(19)	12.92(28)
	(L6,L3)	9.93	13.61(37)	13.78(39)	14.74(48)
	(L6,L4)	9.97	15.67(57)	16.10(61)	17.24(73)
	(L7,L1)	10.38	9.28(-11)	10.41(0)	11.09(7)
	(L7,L2)	10.29	11.40(11)	12.48(21)	13.44(31)
	(L7,L3)	10.10	14.05(39)	14.31(42)	15.27(51)
	(L7,L4)	10.14	15.95(57)	16.57(63)	17.61(74)
VA30	(L1,L3)	8.66	9.82(13)	10.46(21)	11.19(29)
	(L1,L4)	8.66	11.86(37)	12.49(44)	13.39(55)
	(L2,L4)	8.55	9.79(15)	10.36(21)	11.13(30)
	(L5,L1)	9.26	8.71(-6)	9.57(3)	10.14(10)
	(L5,L2)	9.15	9.96(9)	10.95(20)	11.63(27)
	(L5,L3)	9.02	11.76(30)	12.65(40)	13.43(49)
	(L5,L4)	9.02	13.79(53)	14.69(63)	15.53(72)
	(L6,L2)	8.24	8.33(1)	9.10(10)	9.66(17)
	(L6,L3)	8.10	10.07(24)	10.79(33)	11.52(42)
	(L6,L4)	8.10	12.16(50)	12.83(58)	13.71(69)
	(L7,L1)	8.51	7.49(-12)	8.15(-4)	8.66(2)
	(L7,L2)	8.40	8.73(4)	9.53(13)	10.17(21)
	(L7,L3)	8.27	10.53(27)	11.22(36)	11.96(45)
	(L7,L4)	8.27	12.57(52)	13.27(60)	14.11(71)

7.3.4.2.6 Conclusions on performance of Spatial Reuse Mode

Both system level simulations and link level simulations have shown significant throughput gains with spatial reuse mode as compared to the macro only network. Compared to the co-channel deployment, there is an 8 – 11%loss due to the additional pilot overhead in spatial reuse mode.

7.3.5 Legacy UE performance in combined cell

The SFN mode is used for data transmission to a legacy UE. One potential issue with the SFN mode is the increased delay spread due to the propagation delay difference between transmitting nodes. Due to propagation delay the combined channel impulse response (CIR) becomes longer due to different propagation delays between two nodes. Note that when the LPNs are co-located with macro node the propagation delay mismatch does not occur.

Another issue with SFN mode is that there might be some performance loss due to the additional pilot overhead when some Release 12 UEs are in the network. To understand the performance of the legacy UE in combined cell, system level simulations and link level simulations were carried out.

7.3.5.1 System level analysis

In system level simulations 4 LPNs per macro cell is assumed. The statistics are collected for 16 UEs per cell. Table 61 shows the percentage of loss compared to the macro only case with ISD of 500 m. It can be observed that the legacy UEs which are served in the SFN mode may not get benefit with LPN deployment. One could expect a loss in user throughput due to the additional pilot overhead propagation delay mismatch, but from Table 61 it is seen that the percentage of loss is small. A loss of 5.7% is observed at the cell edge, while a loss of 2.4% is observed in mean user throughput. The percentage of loss might be increased if the ISD is increased to 1.73 km.

Table 61: Percentage of loss with additional pilot overhead of -10 dB and propagation delay mismatch

Throughput Metric	Homogeneous Network in Mbps	SFN mode with ISD = 500 m	
		Value in Mbps	%loss
Average sector throughput	6.6	6.55	0.76
Average user throughput	0.42	0.41	2.38
Average cell edge user throughput	0.07	0.066	5.71
Median user throughput	0.38	0.37	2.63

7.3.5.2 Link level analysis

The simulation setup is the same as described in subclause 7.3.4.2 E (see Figure 68 and Table 57).

The achievable gains when the UE operates in SFN mode are shown in [47] and [48]. Table 62 summarizes the results from [47] The gains were shown for two cases. The first case is when the propagation offset is set to zero, and the second case is when the propagation offset is set according to Table 57. Note that in both cases the pilot overhead is set to -16 dB (i.e. solution I of spatial reuse mode in Section 7.3.5.1). As can be observed from Table 62 the impact due to propagation delay and pilot overhead is very small. There are some cases where the SFN mode will give gains, while in some cases there might be some losses due to propagation mismatch.

Table 62: Achievable gains with SFN mode from [47]

Channel	User Location	% of gain over macro only case without propagation delay modeled	% of gain over macro only case with propagation delay modeled
PA3	L1	-1	0.5
	L2	2	2
	L3	8.8	7.7
	L4	15.7	15.5
	L5	0	0
	L6	-3	-1
	L7	-2.6	-2.6
	L8	-6	-6

The achievable gains from [48] are shown in Table 63

Table 63: Achievable gains with SFN mode from [48]

Channel	User location	Macro-Only Mbps	SFN throughput in Mbps (% gain over macro-only)			
			Solution I (idealistic probing pilots)		Solution II (continuous D-PICH)	
			w/o prop. offsets (K=0)	w/ prop. offsets	w/o prop. offsets (K=0)	w/ prop. offsets
PA3	L1	15.15	15.16(0)	14.82(-2)	14.28(-6)	13.04(-14)
	L2	14.46	15.03(4)	13.51(-7)	13.73(-5)	10.93(-24)
	L3	13.73	15.73(15)	13.13(-4)	14.03(2)	10.36(-25)
	L4	13.73	17.84(30)	14.43(5)	16.23(18)	11.91(-13)
	L5	17.56	17.52(0)	17.52(0)	17.01(-3)	17.01(-3)
	L6	12.10	12.15(0)	12.13(0)	11.57(-4)	11.51(-5)
	L7	12.98	12.90(-1)	12.90(-1)	12.29(-5)	12.29(-9)
	L8	4.62	4.55(-2)	4.55(-2)	4.19(-9)	4.19(-9)
PB3	L1	10.77	10.94(2)	10.93(1)	10.02(-7)	9.85(-9)
	L2	10.58	10.85(3)	10.57(0)	n/a	8.72(-18)
	L3	10.21	11.10(9)	10.52(3)	8.98(-12)	8.33(-18)
	L4	10.28	11.79(15)	11.19(9)	9.72(-5)	9.23(-10)
	L5	11.65	11.74(1)	11.74(1)	11.17(-4)	11.17(-4)
	L6	9.65	9.68(0)	9.68(0)	9.14(-5)	9.15(-5)
	L7	10.00	10.05(1)	10.05(1)	9.51(-5)	9.51(-5)
	L8	4.04	4.11(2)	4.11(2)	3.79(-6)	3.79(-6)
VA30	L1	8.90	9.01(1)	8.96(1)	8.15(-8)	8.08(-9)
	L2	8.68	8.94(3)	8.75(1)	7.35(-15)	7.17(-17)
	L3	8.41	9.10(8)	8.89(6)	7.11(-15)	6.89(-18)
	L4	8.42	9.65(15)	9.40(12)	7.91(-6)	7.66(-9)
	L5	9.62	9.67(1)	9.64(0)	9.13(-5)	9.13(-5)
	L6	7.79	7.83(1)	7.87(1)	7.36(-6)	7.32(-6)
	L7	8.12	8.16(0)	8.16(0)	7.70(-5)	7.70(-5)
	L8	3.00	3.04(1)	3.04(1)	2.76(-8)	2.76(-8)

7.3.5.3 Conclusions on legacy UE performance

SFN mode is primarily used for legacy users. When the propagation delay offsets between different transmitting nodes are not accounted for, there is a gain of up to 30% seen for legacy users in link simulations and gains of around 6-17% in system simulations.

However, when practical propagation offsets are considered, the gains are reduced. System level simulation results have shown a loss of around 5.7%, while link level simulation results show that the loss is around 6% for solution I and around 25% for solution II. This loss is observed in the Pedestrian A channel and is smaller for other multipath channels.

7.4 Mobility aspects

7.4.1 Solutions to small cell discovery and identification

This subclause describes some solutions identified so far. Some solutions including the proximity detection have been investigated in LTE; see 3GPP TR 36.839 [25].

1. UE based proximity detection

Proximity based mechanism was introduced for CSG cell detection and measurement, in which autonomous search function is used to determine when and where to search for the member CSG cells, similar mechanism could also be extended to small cell discovery, and could be divided to several options [11].

Based on UE implementation (e.g. the fingerprint info), UE is able to determine that it is near a small cell and may provide to the network a proximity indication, the network could configure the compressed mode gaps for the UE to measure the inter-frequency small cells. The difference from CSG case is that there is no "CSG whitelist" for small cells, and the small cells are open and deployed in the public place, so how to maintain feasible fingerprint info might be a challenge.

2. Network based proximity detection

As described in [8], [10], [11] and [26], proximity detection for inter-frequency small cells for UEs in the vicinity areas of Macro or small cells is performed by the macro network or small cell through detecting the uplink signal of UEs which are near the small cells in CELL DCH, upon being detected by macro network or small cell, the UEs are further commanded to initiate inter-frequency measurements towards small cells. Here the main challenge is how to determine those nearby candidate UEs, Round Trip Time (as used in location based service, for example) measurements, information on Active Set or pre-configured information, e.g., fingerprint info, are possible ways.
The network can perform the proximity detection based on the existing measurement report on the serving carrier. Based on the detected proximity information, the network will make decision about when to activate the inter-frequencies measurements.

3. UE detects small cell with network assistance

The basic approach here is for the network to indicate the information of the presence of small cells to the UEs, such info could help the UE to detect the small cells nearby, in other words, network provides, the fingerprint info for example, for the UE to use, which could improve the discovery efficiency and save the power consumption. Such info could include (precise or approximate) location info of the small cell(s) overlaid with the Macro cell, or distance info of small cells towards Macro cells either in RSCP or in pathloss, or even the frequency info of the small cell with which UE could use DRX to perform background search. In general, the intention is to try to reduce the impact on power consumption and data transmission introduced by proximity detection.

4. Relaxed and limited measurements for UE in Non DCH state

The basic approach of this method is that the measurements towards interfrequency cells are changed:

   a. The network could request the UE to perform Inter-frequency measurements for a limited period of time when entering non DCH states to save battery power [15].

   b. Also some relaxed inter-frequency measurements for cell reselection can be used as described in [15][32].

5. Configurable NCL in CELL_PCH and CELL_FACH

When the UE is in CELL_FACH or CELL_PCH, the Network can change the NCL of the UE using dedicated signalling, cells can be added or removed from the list broadcasted in the SIB on a per UE basis [15]

Table 64 compares different solutions above in terms of power consumption, performance, complexity and specification impact.

Table 64: Comparison of possible solutions to small cell discover and identification

Solution	Power Consumption	Performance	Specification impact	Complexity	Impact node
1)	Additional power consumption is expected from UE.	Depending on UE implementation, but it may bring data interruption.	Should be RAN2.	High complexity in UE side.	UE & RNC
2)	Should be no additional power consumption in UE.	Depending on detailed network implementation, better performance could be expected.	Should be RAN3 if needed.	Additional complexity introduced in the network side.	RNC
3)	Should be of no additional power consumption.	Depending on accuracy of the info provided by network, performance could be better than 1.	Should be RAN2	Additional complexity introduced in both network and UE side.	UE & RNC
4)	Additional power consumption should be low.	Performance remains arguable.	RAN2 & RAN4	The complexity is how to find the correct trade-off between latency and power consumption	UE & RNC
5)	Should be no additional power consumption.	Performance remains arguable.	RAN2	The complexity is foreseen in both UE and network side.	UE & RNC

7.4.2 Solutions to the mobility performance degradation caused by high UE speed

This subclause describes some solutions identified so far ([7][8][9][12][14][16][17][18][35]). Possible solutions achievable by proper NW configuration and/or implementation are not covered.

1. Solution to more signalling messages

To keep the Macro cell always in the active set will reduced the handover procedures for the UE travelling across the Macro cell, i.e., when UE enters the coverage of small cell, the UE will not report 1b, and the active set update procedure for removing Macro cell from active set will not be triggered. When UE moves out of the small cell coverage, the UE will not need to report 1a for adding Macro cell into the active set.

2. Solution based on UE speed knowledge

This approach firstly requires the knowledge of UE speed information. UE speed information could be estimated through the statistics of the frequency of cell reselection or active set changes, some additional info, e.g., cell size or cell type (Macro cell or small cell), could help the estimation to be more accurate.

Assuming an accurate knowledge of the UE speed, in CELL DCH, NCL could be allocated dynamically based on UE speed in order to make the best use of existing NCL size. Dynamically allocating NCL for medium and high speed UE could decrease number of measurement reports and improve HO performance.

3. Solutions to avoid handover or reselection to small cells without using speed estimation.

In CELL_DCH state it is possible to configure measurements in order that some measurement events are applicable to small cells and others to Macro cells – this can be done using the existing "cells for measurement" IE, or in case NCL needs to be extended it is possible to allocate extended values to small cells while using the existing NCL for Macro cells. By configuring those applicable to small cells to use, e.g. longer TTT, different CIO, or hysteresis/threshold values it is possible to trigger small cells measurement events when UE is at a relatively low speed or in good conditions without affecting the Macro cell measurements. This approach can be studied, for example, to cover cases of active set update, multiflow.

In Idle, PCH, FACH is also possible to use separate thresholds or CIO, longer Treselection for small cells, or use uplink coverage as well as downlink coverage when performing cell reselection calculation.

4. Additional cell information per cell in NCL in CELL_DCH

Some information elements can be added in the NCL. The UE may use all or a subset of the proposed parameters and report measurements back to the network. The network may use these measurements to enable better decision making in HetNet environments. Some possible information are: LPN power class for the UE to know that the cell is low power node; LPN timing offset, to help the UE cell search; LPN UL desensitization, for the UE to estimate UL/DL imbalance; compensation factor for UE to calculate boosting factor for UL channels e.g. HS-DPCCH; cell specific Time to Trigger.

Table 65: Comparison of possible solutions to mobility issues for high speed UE

Solution	Power Consumption	Performance	Specification impact	Complexity	Impact node
1)	Should be no additional power consumption.	Potential benefits could be expected, but if the benefits apply to low speed or high speed UEs depends on the detailed mechanism.	May or may not have spec impact pending on the detailed mechanism, e.g., if a cell type indication is needed in the radio interface.	Low .	UE and RNC.
2)	Should be no additional power consumption.	Performance depends on the implementation.	No spec impact.	Complexity depends on the implementation.	UE and RNC.
3)	Should be no additional power consumption.	It is believed that the number of HO could be reduced.	RAN2	In general, low .	UE and RNC
4)	Should be no additional power consumption.	Could bring better mobility performance.	RAN2	In general higher complexity is introduced.	UE and RNC.

7.4.3 Solutions to the issues of massive deployment of small cells

There are some solution alternatives or suggestions to PSC confusion which have been discussed and suggested in [7][8][9][13][18][20][21].

1. Extend the Neighbour Cell List (NCL) size

Actually this method is not for addressing PSC confusion but for NCL size limitation. The main motivation of extending the size of NCL is to allow the network to include all the small cells in the NCL so that UE could report each detected small cell to the network side. More issues, however, might be expected in this solution, e.g., how many additional entries could be extended on top of existing size of NCL, should the measurement requirement be updated or not, etc.

2. Measurement event specific cell lists

The basic approach would be that a list of cells apply to some measurement events (e.g. the current NCL in CELL_INFO_LIST containing Macro cells), and another list of cells apply for other measurement events (e.g. an extension to CELL_INFO_LIST containing PLN cells).

Table 66: Comparison of possible solutions to massive deployment of small cells

Solution	Power Consumption	Performance	Specification impact	Complexity	Impact node
1)	It depends on the number of added cells.	In general, with a reasonable size extension of the current NCL, it is a reasonable solution with good performance if RAN4 requirements could be maintained.	RAN2 and RAN4 would be impacted	Low complexity for network, the main updates inside the UE is measurement behaviour and requirement.	UE and RNC
2)	Should not be significant.	Some mobility performance improvements could be expected, pending on the detailed solution.	Mainly RAN2, e.g., a new CELL_INFO_LIST for small cell and some other new IEs need to be introduced pending on the detailed solution.	Medium.	UE & RNC

7.4.4 Mobility aspects related with combined cell

As described in [24], in a combined cell deployment the Macro cell and LPNs that are deployed within the combined cell coverage area will have the same L3 cell identity, and consequently the UE only needs to discover and identify the combined cell (which includes LPNs deployed within the combined cell coverage area). There is no need to discover and identify each LPN individually. Hence, as far as cell discovery and identification are concerned, the UE will behave as it is in a macro-only network and combined cell deployment can complement co-channel deployment to improve the mobility performance of a heterogeneous network.

7.4.4.1 Hand Over aspects in combined cell deployment

For combined cell deployment, in any transmission mode, see 7.3.4, no HO occurs between LPNs or between a LPN and the macro cell within the coverage of combined cell. Since there is no HO between Macro cell and LPN neither between the LPNs within the combined cell, the robustness of the serving cell change is improved in combined cell deployment compared to co-channel deployment [30].

In SFN transmission mode, see 7.3.4, a subset of or all the LPNs in a combined cell are selected to transmit the same signalling in parallel which improves the transmission robustness for the HO signalling messages, which improves the HO performance especially for UEs with a limited coverage area.

In the SR transmission mode, see 7.3.4, the central scheduler select the node which has the best link to transmit HO signalling which will increase the robustness of the HO performance and improve the resource utilization of the Macro cell.

It is important to select the most suitable transmission modes to transmit HO signalling in combined cell. The selection of the transmission nodes can be switched on a TTI basis. Hence, the transmission node or transmission mode could be different for different RLC (re)transmission attempts for the same HO signalling message. In addition, adding LPNs in combined cell nullifies the impact of shadow fading due to the combined reception of the P-CPICH signals from all nodes and reduce the number of HOs compared to macro cell only case and also compared the co-channel deployment case [31].

Hence, the introduction of LPNs does not affect the number of HOs in combined cell compared to Macro only networks. In addition fewer HOs are triggered compared to the co-channel deployment, see [31]. The HO performance improvement in combined cell is especially important for a high speed UE.

7.4.4.2 Primary Scrambling Code in combined cell deployment

Since in a combined cell deployment the LPNs deployed within the combined cell coverage area have the same primary scrambling code, then only one PSC is needed to identify the combined cell including the macro cell and all LPNs that are deployed within the combined cell coverage area and sharing the same cell identity. Hence, there is a clear benefit with combined cell deployment to avoid the PSC confusion problem.

7.4.4.3 Neighbour Cell List in combined cell deployment

In a combined cell deployment the LPNs deployed within the combined cell coverage area have the same L3 cell identity as the macro cell, from RNC perspectives, hence the entire combined cell is considered as one L3 cell identity. Consequently there is no need to increase the NCL size due to the deployment of LPNs, this helps to avoid the potential extension of NCL size in heterogeneous networks.

7.4.5 Solutions to the issues of Multiflow and multi-carrier operation

Since there may be an issue of inefficient secondary serving cell change during multi-carrier operation in HetNet deployment, some enhancements could be considered. Here we provide examples of issues and possible solutions.

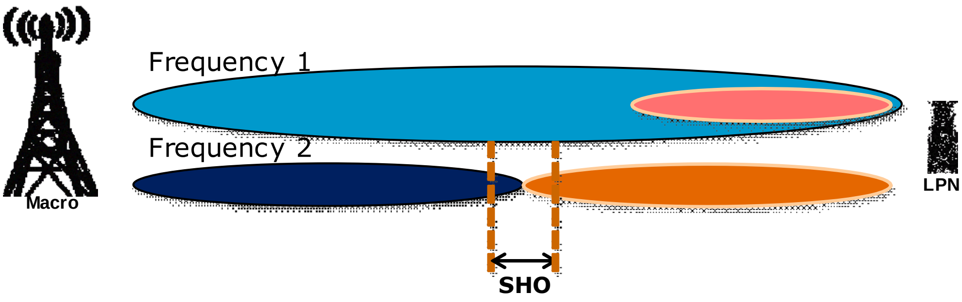

Figure 69: Range expansion scenario by reducing Macro power

In the first example in [33], as illustrated in Figure 69, the UE is working in DC-HSDPA operation and the macro cell on frequency 2 is the serving cell and the macro cell on frequency 1 is the secondary serving cell. If the UE moves toward the small cell on frequency 2, the UE may trigger event 1D on this carrier and then the serving cell is changed to that cell.

In order to optimize the handover performance for the above use case, for the UE supporting inter-frequency measurements without compressed mode and independent event reporting on the secondary carrier, it is suggested to use inter-frequency measurement events in order for changing of the best cell to the secondary carrier. For this procedure, the serving cell will be changed from the macro cell on frequency 2 to the macro cell on frequency 1 instead of the small cell on frequency 2.

In addition, the time for inter-frequency handover procedure will be shorter as the network does not have to configure event 2d in order to know how bad the used frequency is.

In the second example in [34], also illustrated in figure 69, it would be efficient to transition from DC to DF-DC as soon as the quality of the secondary carrier cell from the neighbor Node B becomes good enough, for example when it becomes better than current secondary cell. In this regard it would be desirable that the UE could notify the RNC when certain measurement events (e.g. change of best cell, pilot entering/leaving an ASET reporting range) happen on the secondary carrier, similarly to what is defined for DC-HSUPA (specifically, events 1a, 1b and 1c on the secondary carrier can be reported when DC-HSUPA is configured).As illustrated above, let us assume a UE moves from the macro cell to the small cell on frequency 2, starting in DC mode, with F1 as the anchor carrier.

If we rely on the existing mobility mechanism applied to the anchor carrier, DF-DC could be triggered by event 1a. The triggering process is not efficient though: in the specific case above, an event 1a will not be triggered until UE enters the SHO region near the DL boundary of F1. At that point, the UE can be switched to DF-DC by RNC blindly, or after an MCM instructing the UE to perform an inter-frequency measurement (e.g. using compressed mode).

By adding new event triggering functionalities, e.g. event 1d reporting (best cell change) on the secondary carrier, the RNC could reconfigure the UE from DC to DF-DC much earlier than waiting for an event 1a on the primary carrier (as with legacy mobility). As such, it will increase the performance gains of DF-DC because DF-DC region is extended. Note that when receiving an event 1d on F2, the RNC would perform both anchor carrier switch (from F1 to F2) and DF-DC reconfiguration, so that both cells on the anchor carrier (F2) can be in SHO (it would not be possible on F1).

To efficiently exploit the described benefits of independent event reporting on the secondary carrier (i.e. not triggered by events on the anchor carrier), it is important to minimize or avoid performance issues due to periodic or long inter-frequency compressed mode gaps.

8 Impact on specifications

For co-channel deployments, for the support of enhanced quality of pilots in the uplink, the solution of boosting the existing channels requires setting the rules when to apply boosting, while the solution of adding of a new pilot channel requires the specification of such channel. The impact is on RAN1/2/3 specifications.

For the support of E-TFC selection backoff for uplink SI, rules for applying the backoff need to be specified. The impact is on RAN2 specifications.

For the support of decentralized debiasing, the signalling of the biasing values has impact on RAN3 specifications. UE receiver capability may be signalled.

For the support of E-DCH decoupling, RAN2/3 signalling needs to be specified.

For the support of DF-DC, it is expected that the impact is on RAN1/2 specifications to add the new configuration.

For the support of NAIC, new signalling is expected to be specified: physical layer signalling and/or higher layer signalling (impact on RAN1/2/3 specifications). UE receiver capability may be signalled. New RAN4 requirements may be specified for the IC capable UE receiver.

For the support of combined cell, the physical channel structure for pilots needs to be added in RAN1 specifications, along with the control/feedback channels, and the associated higher layer signalling in RAN2/3 specifications.

9 Conclusion

Heterogeneous networks offer substantial throughput gains for HSPA. The gains increase as the percentage of UE offloaded from Macro cell to LPN increases.

For co-channel deployment, when placing LPNs within the Macro area, the average, median and edge throughputs increase significantly, and throughput increases when increasing the number of LPNs per Macro area and/or increasing the transmit power of the LPNs. UL/DL imbalance in HetNet create issues such as HS-DPCCH reliability and uplink interference, limiting the downlink and uplink throughputs. To increase throughput gains, more UEs can be offloaded from Macro nodes to LPNs by applying the cell individual offset (CIO) to bias towards the LPNs during serving cell selection.

On the downlink, with 4 37dBm LPNs and CIO=3dB, the gains are in the order of 250% and 100% for the average and 5% UE throughput, respectively, with offloading percentage of about 50%. As an example for the uplink, when placing 4 37dBm LPNs per Macro area, around 40% of the UEs are offloaded to LPNs and then above 250% average throughput can be achieved. Compared to a CIO of 0dB, applying a moderate CIO of 3dB allows less UL/DL imbalance and more UEs can be offloaded to LPNs, which in turn improves the performance gains. For further details on the results, see Section 7.1.7.

Further gains can be achieved when the CIO values are adapted based on the cells' loading. An example of adapting the CIO values is to use the decentralised biasing method as described in Section 7.2.3. Other way to achieve further gains is to implement methods which will allow minimizing interferences from UEs not in Soft HO towards macro and LPN base stations originating from the UL/DL imbalance situation. Those can be based on limiting macro UL UE throughput, applying different values of CIO or receiver sensitivity level in LPN, ICIC or changing the carrier frequency for terminals located in Strong Mismatch Zone (SMZ). Further details can be found in Section 7.1.6.

The reliability of the control information in the downlink and uplink has been investigated. Based on this study, it was found that some problems may arise when applying CIOs exceeding 6dB for single Rx antenna UEs and exceeding 9dB for dual Rx antenna UEs. To ensure HS-DPCCH reliability in the uplink, boosting of HS-DPCCH or changes in power control/SIR can be done in current networks, or a new uplink pilot channel can be added.

SF-DC operation improves the system performance at medium to low loading, especially for the cell edge users. As the CIO increases and the cell edge burst rate becomes smaller, SF-DC can improve the performance in the range of 50% to 70% for the cell edge.

DF-DC operation improves the range expansion gain. Using 4 LPNs/Macro as an example, compared to DC only operation with range expansion, for interference limited scenario DF-DC operation increase the 5% UE throughput gain from around 128% to 180% while keeping the mean and media UE throughput almost the same. For noise limited scenario, the average UE throughput gain improves from 226% to 301% and the 5% UE throughput gain improves from 67% to 99%.

E-DCH decoupling solution was considered in order to minimize negative effect of DL/UL mismatch. It assumes that the uplink scheduling grants are controlled by the LPN while the HSDPA data is transmitted by the macro cell. The LPN could either signal the grants directly over the air or by routing the grants via RNC to the macro cell.

For combined cell:

- SFN mode is primarily used for legacy users. When the propagation delay offsets between different transmitting nodes are not accounted for, there is a gain of up to 30% seen for legacy users in link simulations and gains of around 6-17% in system simulations. However, when practical propagation offsets are considered, the gains are reduced. System level simulation results have shown a loss of around 5.7%, while link level simulation results show that the loss is around 6% for solution I and around 25% for solution II. This loss is observed in the Pedestrian A channel and is smaller for other multipath channels.

- Both system level simulations and link level simulations have shown significant throughput gains with spatial reuse mode as compared to the macro only network. Compared to the co-channel deployment, there is an 8 – 11% loss due to the additional pilot overhead in spatial reuse mode.

Network Assisted Interference Cancellation (NAIC) was studied and potential benefits and techniques have been identified. Further investigations are needed.

Some of the solutions discussed in the Technical Report do not need standard support.

For the mobility study, RAN2 concludes as follows:

- For mass small cell deployment, any further focus should be on NCL extension
- For speed based mobility, further enhancements can be considered
- For small cell discovery and identification, any further focus should be on proximity detection (UE based, NW based, UE based NW assisted) and the relaxed inter-frequency measurements for UE in Non DCH state.
- For combined cell, mobility benefits could be expected, and no RAN2 mobility impact has been identified.
- For range expansion, further mobility enhancements (e.g., intra-frequency event triggered reporting on the secondary carrier) can be considered.

Annex A: Performance evaluation methodology

A.1 System simulation assumptions

The system simulation assumptions for UMTS heterogeneous networks are shown in Table 67.

Table 67: System simulation parameters for UMTS HetNet performance evaluation

Parameters	Values and comments
Carrier Frequency	2000 MHz
Carrier Spacing	5MHz
Cell Layout	57 cell hexagonal (19 NodeB, 3 sectors per Node B with wrap-around) 21 cell hexagonal (optional)
Inter-site distance	500 m 1000 m (optional)
Number of LPNs	1, 2, 4; 8 (optional); 16 (optional)
Deployment of LPNs	Minimum distance between LPN and Macro cell: 75m Minimum distance between LPNs: 40m
Dropping criteria for LPNs	LPNs are randomly and uniformly distributed within a Macro cell. (Optional) LPNs are deployed according to the received CPICH RSCP of the Macro cell: CPICH RSCP = TxPow_CPICH + AntGain - PL – PenLoss TxPow_CPICH is the CPICH tx power of Macro cell (33dBm) AntGain is the antenna gain PL is large scale fading calculated according to path loss model PenLoss is the penetration loss The deployment of LPNs will be labelled as *centre*, *near*, *middle*, *far*, *edge*, from the Macro cell depending on the CPICH RSCP value, P(dBm). P=-46dBm, *centre* (the min distance between UE and Macro cell, and UE is in main beam of antenna); P=-66dBm, *near* (1/3 of distance centre-edge of the Macro cell) P=-74dBm, *middle* (1/2) P=-80dBm, *far* (2/3) P=-88dBm, *edge*
Number of UEs	For full buffer (DL) 16, optional 32 for the case of 16 LPNs For full buffer (UL) 8 For bursty traffic model variable up to system stability level
Deployment of UEs	The minimum distance between UE and Macro cell is 35m The minimum distance between UE and LPN is 10m
Dropping criteria for UEs	Random: UE randomly and uniformly distributed within a Macro cell Hotspot: Randomly and uniformly dropping with $P^{hotspot}$ of the total users within a radius, *r*, of LPN base station, and randomly and uniformly dropping of the remaining users in the entire macro geographical area of the given Macro cell (including LPN area). Type 1: $P^{hotspot}$ = ½ Type 2: $P^{hotspot}$ = ¾ (optional) The radius *r* of the LPN is equal to 20m, 35m, and 60m when the LPN power is 24dBm, 30dBm, and 37dBm, respectively.

RoT	Macro cell: 6dB LPN: 6dB
Scenarios	Outdoor Mixed scenario with 60% indoor and 40% outdoor users Indoor users modelled with path loss with a lognormal distribution, mean = 11dB, and std dev = 6.5dB.
Path Loss	Macro Node: L=128.1 + 37.6log10(R), R in kilometres LPN: L=140.7 + 36.7log10(R), R in kilometres
Log Normal Fading (outdoor)	Standard Deviation: 8dB (Macro cell); 10 dB (LPN) Inter-Node B Correlation: 0.5 Intra-Node B Correlation :1.0 Correlation Distance: 50m
Antenna pattern	3GPP ant (2D ant): $A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$ θ_{3dB} = 70 degrees, Am = 20 dB LPN: 2D Antenna, omni-directional
LoS channel model	Optional, channel model from TR36.819 0 with fast fading with Rician K factor
Channel Model	PA3, VA3
Penetration loss	20dB
Maximum UE EIRP	24dBm
Maximum Tx Power of NodeB	Macro Node: 43dBm LPN: 37 dBm, 30 dBm, 24 dBm
Max BS Antenna Gain	Macro cell: 14dBi LP cell: 5 dBi
Max UE Antenna Gain	0dBi
NodeB Noise Figure	Macro Node: 5 dB LPN: 5 dB; 11 dB (optional)
UE Noise Figure	9 dB
Thermal noise density	-174dBm/Hz (reception bandwidth 3.84MHz)
HS-DSCH	Up to 15 SF 16 codes per carrier for HS-PDSCH Total available power for HS-PDSCH is 80% (SIMO) / 75% (MIMO) of Node B Tx power, with HS-SCCH transmit power being driven by 1% HS-SCCH BLER. HS-PDSCH HARQ: Both chase combining and IR based can be used. Maximum of 4 transmissions with 10% target BLER after the first transmission. Retransmissions are of highest priority. UL HARQ operating point: 1% residual BLER after 4th transmission
Number of HARQ processes	6
HS-SCCH code number	4
Total overhead power	20% (SIMO) / 25% (MIMO)
UE Receiver	Type 3i (LMMSE 2-rx with IC); Type 3 (LMMSE 2-rx); 1-rx
Soft Handover	Consideration Scenarios with and without SHO
Soft Handover Parameters	SHO available R1a (reporting range constant) = 4.5dB R1b (reporting range constant) = 4.5dB Consideration of scenarios without SHO
CIO	3 dB
Max active set size	3
HARQ Operating Points	UL: 1% Residual BLER after 4^{th} transmission DL: 10% BLER after 1^{st} transmission
Network Configuration	SIMO MIMO (optional)

.

Parameters for downlink and uplink bursty traffic model are given in Tables 68 and 69, respectively

Table 68: Downlink bursty traffic model

Component	Distribution	Parameters	PDF
File size (S)	Truncated Lognormal	Mean = 0.25 Mbytes Std. Dev. = 0.0902 Mbytes Maximum = 1.25 Mbytes	$f_X = \frac{1}{\sqrt{2\pi}\sigma x} \exp\left[\frac{-(\ln x - \mu)^2}{2\sigma^2}\right], x \geq 0$ $\sigma = 0.35, \mu = 12.368$
Inter-burst time	Exponential	Mean = 5 sec	$f_X = \lambda e^{-\lambda x}, x \geq 0$ $\lambda = 0.2$

Table 69: Uplink bursty traffic model

Component	Distribution	Parameters	PDF
File size (S)	Truncated Lognormal	Mean = 0.0625 Mbytes Std. Dev. = 0.0225 Mbytes Maximum = 0.3125 Mbytes	$f_X = \frac{1}{\sqrt{2\pi}\sigma x} \exp\left[\frac{-(\ln x - \mu)^2}{2\sigma^2}\right], x \geq 0$ $\sigma = 0.35, \mu = 10.982$
Inter-burst time	Exponential	Mean = 5 sec	$f_X = \lambda e^{-\lambda x}, x \geq 0$ $\lambda = 0.2$

A.2 System performance evaluation metrics

For bursty traffic, the following performance measures are used for evaluation:

- Average burst rate:
  - The burst rate is defined as the ratio between the data burst size in bits and the total time the burst spent in the system.
  - The total time the burst spent in the system is the time difference measured between the instant the data burst arrives at the Node B and the instant when the transfer of the burst over the air interface is completed.
  - The total time the burst spent in the system is equal to the sum of the transmission time over the air and the queuing delay.
- Total system throughput
- UE throughput: average, 50%, and 5%
- Percentage of UEs served by LPNs
- PDF of RLC packet delay: the delay is calculated as the time between when the RLC packet is constructed at the RNC until it is delivered by UE RLC receiver to upper layers; RLC packets discarded after maximum number of retransmissions should be counted separately. This metric is only applicable for scenarios as MultiFlow, where the RLC may be modelled.
- Average and CDF of RoT for UL

For full buffer traffic, the following performance measures are used for evaluation:

- Sector throughput
- UE throughput: average, 50%, and 5%
- Percentage of UEs served by LPNs
- Average and CDF of RoT for UL

A.3 Link simulation assumptions

The link simulation assumptions for UMTS heterogeneous networks are shown in Table 70.

Table 70: Link simulation parameters for UMTS HetNet performance evaluation

Parameter	Value	Comments
P-CPICH_Ec/Ior	-10dB	
S-CPICH1 Ec/Ior	-13dB	If other values are simulated, the assumed values are to be indicated. Pilot configuration with S-CPICHs is for MIMO case only.
S-CPICH2 Ec/Ior	-19dB	
S-CPICH3 Ec/Ior	-19dB	
Demodulation-CPICH Ec/Ior	As needed (-13 dB)	
Spreading factor for HS-PDSCH	16	
Modulation	QPSK, 16QAM, 64QAM	
TBS	Variable	CQI based scheduling
Number of Transport Blocks	1,2, or 4	Other values can be simulated and should in that case be described
HSDPA Scheduling Algorithm	CQI based	The assumed mapping of CQI to TBS needs be provided.
Geometry	[0 5 10 15 20 25]dB	
CQI Feedback Cycle	1 TTI	
CQI feedback error	0 %	Other values can be simulated and should be provided
HS-DPCCH ACK/NACK feedback error	0 %	
Maximum number of HS-DSCH codes	15	
Number of HARQ Processes	6	
Maximum Number of H-ARQ Transmissions	4	
HARQ Combining	Chase Combining, Incremental Redundancy	If other combining methods are used, they should be indicated
Redundancy and constellation version coding sequence	{0,3,2,1} for QPSK and 16QAM {6,2,1,5} for 64QAM	
Target Number of H-ARQ Transmissions	1	
Residual BLER	10% after 1 transmission	
Number of Rx Antennas	2, 4	
Channel Encoder	3GPP Turbo Encoder	
Turbo Decoder	Max- Log MAP	
Number of iterations for turbo decoder	8	
Precoding weight vector determination	SNR maximizing	Details of the PCI determination need to be provided
Quantization of Precoding vector	Quantized	Details of the PCI codebook need to be provided
PCI/CQI Feedback delay	12 slots	See clause 2.2.7
Precoding Feedback error rate	0%	
Precoder update rate	3 slots	
Propagation Channel Type	PA3	See clause 4
Channel Estimation	Realistic	
Noise Estimation	Realistic	
UE Receiver Type	Type3 or Type3i	
Tx Antenna Correlation	0	Other values may be simulated (e.g. according to 3GPP TS 36.101 [30] Annex B.2.3 or 3GPP TR 25.814 [31] SCMA-D)
Rx Antenna Correlation	0	
Interference Modelling	Realistic	Details of Interference modelling need to be provided

A.4 Link performance evaluation metrics

The following performance measures are used for evaluation:

- Throughput in Mbps, averaged over the duration of the simulation for specific geometries at the UE.
- Rank distribution
- CQI distribution per layer
- BLER statistics per transport block.

A.5 Link simulation assumptions and metrics for modelling HS-DPCCH performance

Table 71: Simulation assumptions for HS-DPCCH modelling

Parameter	Value
Scenario	UE is in soft handover between a Macro and an LPN.
Imbalance between the cells [dB]	[0 3 6 9 12 18]
Physical Channels	E-DPDCH, E-DPCCH, DPCCH, HS-DPCCH
E-DCH TTI [ms]	2
TBS	120
T/P [dB]	0
HS-DPCCH C/P [dB]	-9.54 … 14.09
CQI Feedback Cycle	1TTI
SIR Target [dB]	-21 dB
False Alarm Target	1%
Target Misdetection or Decoding Error	TBD
Number of Rx Antennas	2
Channel Estimation	Realistic
Inner Loop Power Control	ON
Outer Loop Power Control	OFF
Propagation Channel	PA3
NodeB Receiver Type	Rake Receiver
Number of Rx Antennas	2

The metrics used to evaluate the HS-DPCCH are described as follows:

- False alarm
  - This event occurs when the NodeB falsely detects data when the UE transmits only DTX.
- Misdetection or decoding error
  - This event occurs when one of the following events occur
    - The NodeB does not detect data when the UE transmits data, OR
    - The NodeB correctly detects data but decodes it incorrectly.

The misdetection or decoding error metric is computed as follows:

$$P(\text{MD or DecErr}) = \frac{C_{MD} \cdot P(MD) + C_{DE} \cdot P(DE \mid \overline{MD})}{C_{MD}}$$

where

C_{MD} = number of active carriers

C_{DE} = total number of streams that are in error.

A.6 Mobility simulation assumptions

Simulation assumptions for mobility are given in Table 72.

Table 72: Mobility simulation assumptions

Parameter	Value
Macro-pico deployment type	Co-channel
Cell loading [%]	100, 50 (optional)
Number of sites/sectors	19/57, 7/21(optional)
LPN deployment method	Random placement: LPN randomly and uniformly placed within a Macro cell satisfying the distance requirement
UE speed [km/h]	3, 30, 60, 90,120
UE movement	Random (After initially being dropped at a random location, the UE will randomly select a direction and move in a straight line at a constant speed)
Event 1A, 1B Reporting Range [dB]	1A 4.5, 1B 4.5
Event 1A, 1B, 1C TimeToTrigger [ms]	1A 320, 1B:640, 1C:320
Event 1A, 1B, 1C Hysteresis [dB]	1A:0dB, 1B:0dB, 1C:1dB
Event 1A, 1B Maximum Network Delay [ms]	200 for SRB over DCH and 100 for SRB over HSPA (the interval between the time UE sends a mobility event report (E1a, E1b) on the UL till the time it receives a L3 confirmation on the DL (ASU))
Event 1D TimeToTrigger [ms]	160, 320, 640
Event 1D Hysteresis [dB]	0, 1, 2, 3
Event 1D Maximum Network Delay [ms]	200 for SRB over DCH and 100 for SRB over HSPA (the interval between the time UE sends a mobility event report (E1d) on the UL till the time it receives a L3 confirmation on the DL (RBR or PCR))
$T_{measurement\ period\ intra}$ [ms]	200
Layer3 Filter Parameter K (corresponding to 458ms filter time constant with $T_{measurement\ period\ intra}$ =200 ms)	3
CIO [dB]	0, 3 (value 0 for Macro/LPN to Macro , 0 & 3 for macro/LPN to LPN)
Max active set size	3, 4
Threshold for receiving RBR/ASU, Ec/Io [dB]	*-20dB for single rx, -23dB for dual rx*
UL UE category	2ms TTI and 10ms TTI (optional)
Active set size to trigger 1C	Equal to Max active set size
Active set size to trigger 1A	Equal to or lower than (Max active set size-1)
Event 1A, 1B W	0
HS-SCCH Order Decoding Threshold in Ec/Io	*-28dB for single rx, -31dB for dual rx*
Period to evaluate the Ping-pong handover [s]	1

A.7 Mobility simulation performance metrics

- For UEs, a handover failure is declared if
  - after event 1D is triggered for the target cell, UE fails to receive the RBR from the source cell, or
  - after the event 1A or event 1C was triggered for the same target cell, UE failed to receive the ASU that added the target cell in the active set.
- RRC message reception failure can be modelled by either one of the two methods:
  - actual decoding failure;
  - comparing the CPICH EcIo with the respective threshold for the RRC message.
- Ping-pong handover:
  - Period during UE hand-in a cell and hand-out this cell less than define threshold (i.e. 1 second).
- Ping-pong handover ratio :
  - defined by (number of Ping-Pong HOs) / (Total number of HO attempts- number of HO failures).

A.8 Mobility simulation results

Based on the mobility simulation assumption and performance metrics defined above, simulation has been conducted focusing on the following cases: active set update failure, serving cell change failure and ping-pong handover, detailed simulation results could be seen in [6][7][8].

A.9 Observations from the mobility simulation results

From the simulation results, the following observations could be achieved:

- With the deployment of small cells, especially with the number of deployed small cells within one Macro cell increasing, both active set update and serving cell change increase.
- With the increase of LPN density and UE's moving speed, both active set update failure ratio and serving cell change failure ratio increase.
- In general, higher failure ratio for active set update and serving cell change is observed for mobility between Macro cells and smalls than between Macro cells, especially for mobility from small cell to Macro cell.
- When SRB over HSPA is configured with pre-Rel8 serving cell change, the handover failure ratio is observed to be higher than using SRB over DCH or Rel8 enhanced serving cell change (using SRB over HS).
- eSCC (SRBoH) can also achieve much better HO (serving cell change) performance than SCC with SRBoH

SCC with SRBoD and eSCC (SRBoH) could achieve similar HO (serving cell change) performance

Annex B: Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2012-10	RAN1#70-bis	R1-124624			Initial Draft, Skeleton TR		
2013-01	RAN1#72	R1-130512			Added text in Sec.4, Sec.5, Sec.6.1 and Annex A		0.1.0
2013-04	RAN1#72-bis	R1-131489			Revised Clauses 5 and 6. Added text in Clauses 7.1.1, 7.1.2, 7.2.2, 7.3.		0.1.1
2013-04	RAN1#72-bis	R1-131710			Updated Clauses 7.1 and 7.3.		0.2.0
2013-06	RAN1#73	R1-132837			Added Clauses 6.2 and 7.4 on mobility Added Clauses 7.1.3.1, 7.1.3.2, 7.1.3.3, 7.1.3.4 Updated Clause 7.1.2 and added subclauses Updated Clauses 7.3, added 7.3.1, 7.3.2, 7.3.3 Added Annex A.6—9 New TR template used	0.2.0	0.3.0
2013-06	RAN1#73	R1-132845			Approved version to be presented to RAN	0.3.0	1.0.0
2013-06	RAN#60	RP-130679			Presentation for information to RAN#60		1.0.0
2013-06	RAN#60	RP-130797			Minor editorial changes	1.0.0	1.0.1
2013-08	RAN1#74	R1-133611			MCC editorial changes Added Clauses 6.1.4, 7.1.6, 7.1.7, 7.2.2.4, 7.2.2.2.5, 7.2.3	1.0.1	1.0.2
2013-08	RAN1#74	R1-133854			Some agreements from RAN1#74	1.0.2	1.0.3
2013-08	RAN1#74	R1-134011			Approved version	1.0.3	1.1.0
2013-08	RAN1#74	R1-134012			Added Clauses 7.1.3.7, 7.1.4.2, 7.1.7.3, 7.1.8, 7.2.1.1, 7.3.4,7.3.5, 7.4.5, 8, 9	1.1.0	2.0.0
2013-08	RAN#61	RP-131186			Presentation to TSG RAN		2.0.0