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Contents

Foreword

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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

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

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1 Scope

The present document is related to the technical report for the study item "Study on Small Cell Enhancements for E-UTRA and E-UTRAN – Higher layer aspects" [2]

This activity involves the Radio Access work area of the 3GPP studies and has impacts both on the Mobile Equipment and Access Network of the 3GPP systems.

This document is intended to gather all technical outcome of the study item, and draw a conclusion on way forward.

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] Contribution to 3GPP TSG-RAN meeting #58 RP-122033: "New Study Item Description: Small Cell enhancements for E-UTRA and E-UTRAN – Higher layer aspects".

[3] 3GPP TR 36.932: "Scenarios and Requirements for Small Cell Enhancements for E-UTRA and E-UTRAN".

[4] 3GPP TR 36.839: "Mobility enhancements in heterogeneous networks".

[5] 3GPP TS 36.300: "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access (E-UTRAN); Overall description; Stage 2".

[6] 3GPP TR 36.822: "LTE Radio Access Network (RAN) enhancements for diverse data applications".

[7] 3GPP TR 36.819: "Coordinated Multi-Point Operation for LTE Physical Layer Aspects".

[8] 3GPP TS 36.133: " Evolved Universal Terrestrial Radio Access (E-UTRA); "Requirements for support of radio resource management".

[9] Contribution to 3GPP TSG-RAN WG2 meeting #81bis R2-131233: "Frequent handovers and signaling load aspects in heterogeneous networks".

[10] Contribution to 3GPP TSG-RAN WG2 meeting #81bis R2-131056: "Mobility Statistics for Macro and Small Cell Dual-Connectivity Cases".

[11] Contribution to 3GPP TSG-RAN WG2 meeting #82 R2-131712: "Mobility Performance for Rel-12 Small Cell Scenario 3".

[12] Contribution to 3GPP TSG-RAN WG2 meeting #82 R2-132038: "Contributions to S1 Signaling for Small Cells".

[13] Contribution to 3GPP TSG-RAN WG2 meeting #82 R2-131666: "Performance evaluation of Inter-Node User Plane Aggregation".

[14] Contribution to 3GPP TSG-RAN WG2 meeting #81 R2-130124: "User data rate enhancements with inter-site CA".

[15] 3GPP TR 36.872: "Small cell enhancements for E-UTRA and E-UTRAN - physical aspects".

[16] Contribution to 3GPP TSG-RAN WG1 meeting #67 R1-114311: "Further-eICIC Performance with Finite Buffer Traffic".

[17] Contribution to 3GPP TSG-RAN WG1 meeting #67 R1-114312: "Typical RE values and UE Rx signal statistics for FeICIC".

[18] Contribution to 3GPP TSG-RAN WG1 meeting #66 R1-112381: "Uplink co-channel HetNet performance and PC optimization".

[19] Contribution to 3GPP TSG-RAN WG3 meeting #75bis R3-120715: "Performance of uplink power control in co-channel macro+pico deployment".

3 Definitions, symbols 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].

Bearer Split: in dual connectivity, refers to the ability to split a bearer over multiple eNBs.

Dual Connectivity: Operation where a given UE consumes radio resources provided by at least two different network points (Master and Secondary eNBs) connected with non-ideal backhaul while in RRC_CONNECTED.

Master eNB: in dual connectivity, the eNB which terminates at least S1-MME and therefore act as mobility anchor towards the CN.

Secondary eNB: in dual connectivity, an eNB providing additional radio resources for the UE, which is not the Master eNB.

Xn: interface between MeNB and SeNB.

Editor's note: the terminology and definition could be discussed for further and may be changed. The Xn interface will be verified with RAN3.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

<symbol> <Explanation>

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].

CRE Cell Range Extension
HOF HandOver Failure
MeNB Master eNB
RLF Radio Link Failure
RSRP Reference Signal Received Power
RSRQ Reference Signal Received Quality
SeNB Secondary eNB
ToS Time of Stay

4 Introduction

At the 3GPP TSG RAN #58 meeting, the Study Item description on "Study on Small Cell Enhancements for E-UTRA and E-UTRAN – Higher layer aspects" was approved [2]. This study item covers potential higher layer technologies to be considered for enhanced support of small cell deployments in E-UTRA and E-UTRAN to fulfil the deployment scenarios and the requirements specified in TR 36.932 [3].

5 Deployment scenarios and challenges

This section describes the deployment scenarios assumed in this study and the challenging issues in each scenario. In the following scenarios, the backhaul technologies categorised as non-ideal backhaul in TR 36.932 [3] are assumed. Fibre access which can be used to deploy Remote Radio Heads (RRHs) is not assumed in this study. HeNBs are not precluded, but not distinguished from Pico eNBs in terms of deployment scenarios and challenges even though the transmission power of HeNBs is lower than that of Pico eNBs.

5.1 Scenario #1

Scenario #1 is the deployment scenario where macro and small cells on the same carrier frequency (intra-frequency) are connected via non-ideal backhaul. In Scenario #1, the following challenges are expected:

a) Mobility robustness: In particular increased HOF/RLF upon mobility from pico to macro cells [4];

b) UL/DL imbalance between macro and small cells;

c) Increased signalling load (e.g., to CN) due to frequent handover;

d) Difficult to improve per-user throughput by utilizing radio resources in more than one eNB;

e) Network planning and configuration effort;

5.1.1 Mobility robustness

Mobility performance in this scenario was analysed in TR 36.839 [4]. The conclusions in TR 36.839 are a baseline for this study. Potential solutions to address this challenge are investigated and compared to the ones developed in the heterogeneous network mobility work item in terms of complexity and gain under this study. The denser small cell deployment described in [3] may also be taken into account.

5.1.2 UL/DL imbalance between macro and small cells

A UE is said to be in UL/DL imbalance situation if the UE’s best uplink cell and best downlink cell are different. In heterogeneous networks, the eNBs have different downlink output power, e.g., macro eNBs with high output power and pico eNBs with low output power, and the cells may have different UL PC settings. Due to this, an UL/DL imbalance situation may occur for some UEs.

UL/DL imbalance is illustrated in Figure 5.1.2-1. In Figure 5.1.2-1, the location of the UE and macro/pico eNBs is depicted on the X axis whereas the received signal strength is depicted on the Y axis. The curves are plotted with the assumption that UE transmission power is fixed and the UE location relative to the eNBs is varied. The received DL power from the macro eNB at the UE is depicted in blue. The received DL power from the pico eNB at the UE is depicted in green. The received UL power from the UE at the macro eNB is depicted in orange. The received UL power from the UE at the pico eNB is depicted in red. Uplink cell border in Figure 5.1.2-1 means that the received uplink signal strength from the UE is equal at the two eNBs. Downlink cell border in Figure 5.1.2-1 means that the received downlink signal strength from the two eNBs is equal at the UE.

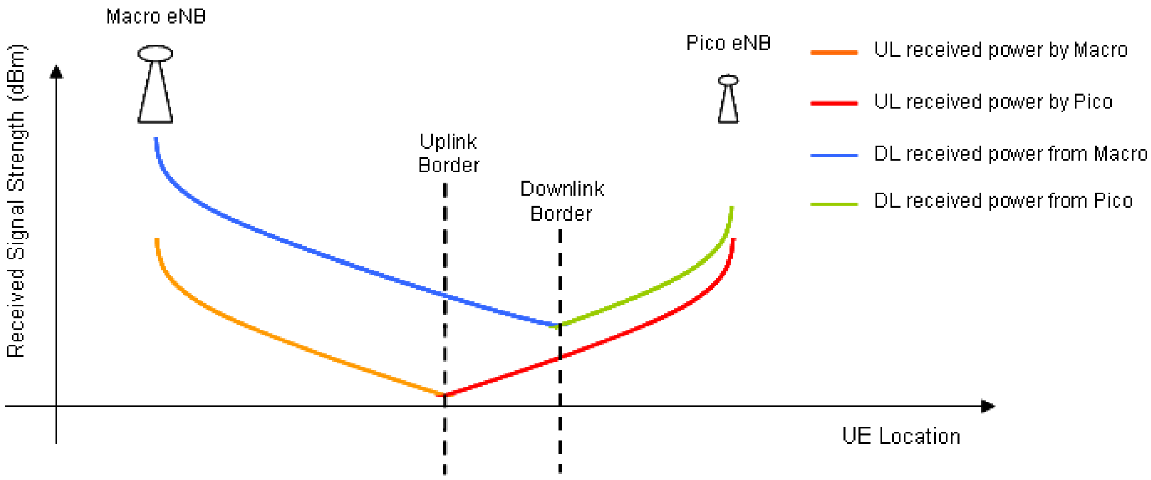

Figure 5.1.2-1: UL/DL imbalance issue in HetNet deployments

In LTE, Reference Signal Received Power-based (RSRP-based) cell selection is often used. In this scheme, UEs may connect to the macro cell even though the path loss to the pico is lower due to the power imbalance. As a result, the pico cell size becomes relatively small compared to the macro cell size which can result in low UE uptake and small traffic offloading to the pico cells. To increase traffic offloading to the pico cells and to improve uplink performance, there is a need to increase the size of the pico cells. This can be done with the concept of Cell Range Extension (CRE) [5]. With CRE, a terminal is associated to a pico eNB even if the pico cell RSRP biased by a cell specific offset (CSO) is below the macro cell RSRP. In a heterogeneous deployment when the macro and pico cells are operated on the same frequency, a UE connected to a pico cell with CRE may experience strong interference from the macro cell. Adopting the RAN1 Rel-12 Small Cell simulation assumptions [15], where the macro and small cell Tx power equals 46 dBm and 30 dBm, respectively, there is 16 dB shift in optimal single-user UL and DL cell border. However, when using further enhanced inter-cell interference coordination (feICIC) in addition to CRE, it is generally found that the best downlink co-channel HetNet performance with Rel-11 feICIC for medium to high offered traffic is obtained by using approximately 9-14 dB CRE for the pico-cells, and configuring 3 to 4 out of every 8 subframes as ABS at the macro-layer [16, 17]. Likewise in the uplink, the optimal CRE that maximizes the UL performance depends on the cell load, but also on the configuration of the UE power control (PC). Given that optimized open-loop PC parameters are used, the CRE value resulting in the best UL system performance is found to be on the order of 8-16 dB for multi-user co-channel HetNet scenario with medium to high offered traffic [18, 19].

In summary, for a multi-user scenario with medium to high offered traffic (using DL feICIC and optimized UL power control parameterization), the UL/DL imbalance "challenge" seems to be smaller issue, and therefore there are potentially less gains expected from having different UL and DL serving cells for a UE as compared to low load scenario. Potential solutions with different UL and DL serving cells shall only be considered if possible with minor additional complexity, as gains from such techniques are mainly relevant for low load scenarios. Consequently, there is no conclusion that the effects of UL/DL imbalance are significant and this study is is deprioritised.

5.1.3 Increased signalling load (e.g., to CN) due to frequent handover

TR 36.932 defines a requirement to minimise signalling load to the CN as well as increase of backhaul traffic due to small cell deployments [4]. This section provides an insight into quantified signalling load with respects to increasing number of small cells in Scenario #1 [9].

Figure 5.1.3-1 shows the number of handovers for different UE speeds in a more dense heterogeneous deployment with 10 small cells per macro cell, randomly deployed with 50 m of the minimum ISD. Otherwise, simulation parameters are the same as in [4]. The increase in the number of handovers compared to a macro only network is 120 % - 140 %, depending on the UE speed. This could imply the increased amount of signalling messages over the radio interface between the source eNB and the UE, signalling over X2 interface as well as signalling towards the MME and the S-GW.

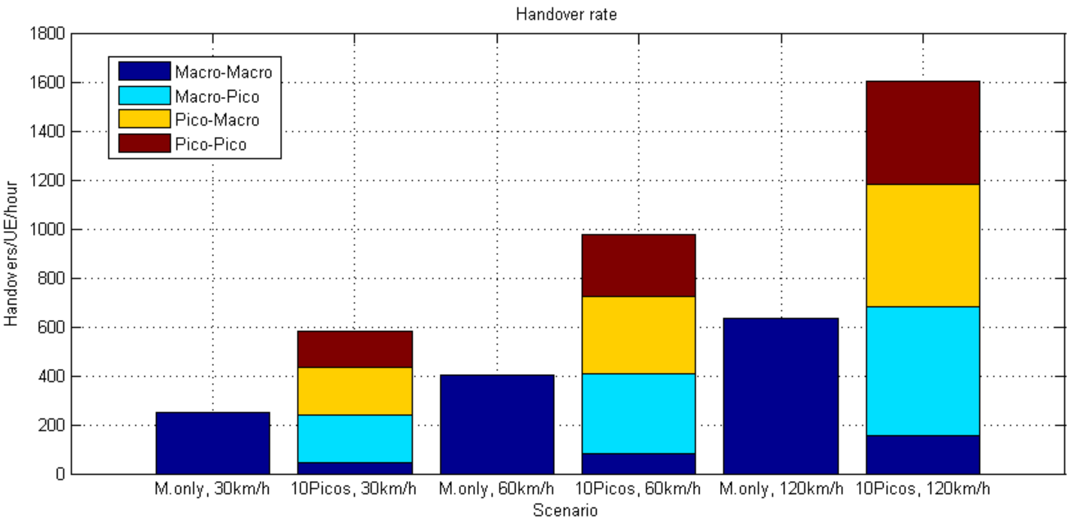

Figure 5.1.3-1: Increase in number of handovers where 10 small cells are deployed per macro cell

On the other hand, how much the signalling load due to handover is dominant to the total signalling load of different network nodes such as MME and eNB depends on amount of other signalling messages for e.g. connection maintenance as well different network configurations such as RRC inactivity timer. Furthermore, with the RRC inactivity timer, the eNB can release the RRC connection when there is no data activity for a given period to control the amount of connected mode UEs. By releasing the RRC connection, the amount of handover signalling can be reduced whereas that of connection setup signalling is increased. Alternatively, the amount of handover signalling can be reduced by releasing the inactive UE when the handover would occur. Table 5.1.3-1 shows a comparison of the number of RRC connection setups and handovers for background traffic (Trace ID: 1) analysed in TR 36.822 [6]. Table 5.1.3-2 shows the amount of signalling messages over the S1 interface for both connection setup and X2 handover. For connection setup, the following S1-AP messages are assumed:

1. Initial UE message (including Service Request)
2. Initial Context Setup Request
3. Initial Context Setup Response
4. UE Context Release Request
5. UE Context Release Command
6. UE Context Release Complete

For X2 handover, the following S1-AP messages are assumed:

1. Path Switch Request
2. Path Switch Request ACK

These results could imply that the amount of signalling due to handover is clearly smaller than that of state transition messages when shorter RRC inactivity timer is applied. Furthermore, it should be noted that there are also other messages sent over S1-MME such as tracking area updates, paging etc. In summary, the followings are observed:

- The amount of signalling due to handover is increased over the radio interface and E-UTRAN including toward the CN as the number of small cells is increased.
- How much dominant the handover signalling load to the CN is to the total signalling load in the E-UTRAN depends on the RRC inactivity timer. If the network releases RRC connection by setting the RRC inactivity timer to be shorter, the share of handover signalling to the CN can be reduced to be small as compared to connection setup up signalling. The longer timer results in the opposite way. The optimum RRC inactivity timer depends on the mobility rate and the traffic characteristics.

Table 5.1.3-1: Comparison of the number of RRC connection setups and handovers [6]

Scheme	Number of connection setups (per UE per hour)	Number of handovers (per UE per hour)				
		Mobility Rate (cell changes per minute per UE)				
		0.1	0.3	1	3	10
Full use of RRC_CONNECTED	0	6	18	60	180	600
RRC Release timer = 5s	64	0.6	1.8	6.1	18.5	62
RRC Release timer = 10s	53	1.0	3.3	10.9	32.3	109

Table 5.1.3-2: Comparison of S1 messages between idle-connected state transition and handovers

Scheme	Number of S1 messages due to connection setup (per UE per hour)	Number of S1 messages due to handover (per UE per hour)				
		Mobility Rate (cell changes per minute per UE)				
		0.1	0.3	1	3	10
Full use of RRC_CONNECTED	0	12	36	120	360	1200
RRC Release timer = 5s	384	1.2	3.6	12.2	37.0	124.0
RRC Release timer = 10s	318	2.0	6.6	21.8	64.6	218.0

5.1.4 Difficult to improve per-user throughput by utilizing radio resources in more than one eNB

Different services and bearers typically have different QoS characteristics. For example, VoIP traffic has tight delay requirements but does not require high bit rates and can tolerate rather high packet losses. In contrast, best effort traffic benefits from higher bitrates but is less delay sensitive as compared to VoIP traffic. It is desirable to take such QoS requirements into account when multiple cell resources are available. However, if non-ideal backhaul as in [3] is utilised between macro and small cells, increasing user throughput by utilising radio resources across those of cells while taking QoS requirements into account is a challenge.

For Scenario #1, CoMP can be considered as a way of utilising multiple cell resources as specified in TR 36.819 [7]. Nevertheless, Rel-11 CoMP assumed that small cells are low power RRHs using ideal backhaul. With non-ideal backhaul between macro and small cells, Rel-11 CoMP may not work well due to larger backhaul latency.

Furthermore, if the macro cell edge is also the area boundary served by the different eNBs, and a small cell is deployed as such that it covers the area boundary of different eNBs as shown in Figure 5.1.4-1, there would be a region that CoMP cannot be configured for the UE (Right half of a small cell in Figure 5.1.4-1). This is because Rel-11 CoMP can only support the case where all serving transmission points are served by the same eNB.

Since technology potential compared to the existing interference coordination functionalities has not been justified, the per-user throughput enhancement for Scenario #1 is deprioritised in this study. Whether the protocol architecture developed for Scenario #2 can support Scenario #1 can be considered later.

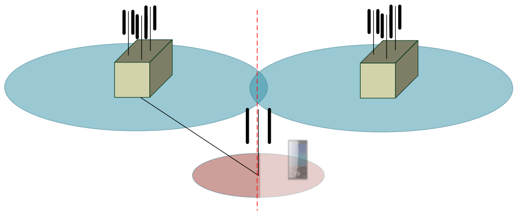

Figure 5.1.4-1: Issue on the CoMP/CA deployment at the macro cell edge

5.1.5 Network planning and configuration effort

Operator should be able to utilize small cells as a mean to flexibly and promptly provide coverage and/or additional capacity whenever such a condition prevails. Although some of self-configuration SON function may help for the initial setting of e.g. handover parameters, tailoring the setting of handover parameters to provide the same performance as in macro area may be difficult e.g. if there are many small cells deployed.

Specific solutions for network planning and configuration effort will not be discussed in this study item and will be handled by the other study item or work item later.

5.2 Scenario #2

Scenario #2 is the deployment scenario where macro and small cells on different carrier frequencies (inter-frequency) are connected via non-ideal backhaul. In Scenario #2, the following challenges are expected:

a) Mobility robustness (not investigated in [4] and the problem of strong interference from macro on same carrier is not present);

b) UL/DL imbalance between macro and small cells;

c) Increased signalling load (e.g., to CN) due to frequent handover;

d) Difficult to improve per-user throughput by utilizing radio resources in more than one eNB;

e) Network planning and configuration effort;

For e), the same issue as in Scenario #1 is foreseen as described in subclause 5.1.5.

5.2.1 Mobility robustness

Challenges of mobility robustness in Scenario #2 are FFS.

5.2.2 UL/DL imbalance between macro and small cells

UL/DL imbalance as described in subclause 5.1.2 may exist between macro and small cells in Scenario #2. Unlike Scenario #1, there is no interference between macro and small cells.

For Scenario #1, technology potential allowing difference serving cell in UL and DL is not justified as described in subclause 5.1.2. Likewise, there is no conclusion that the effects of UL/DL imbalance are significant and this study is is deprioritised.

5.2.3 Increased signalling load (e.g., to CN) due to frequent handover

The observation on the signalling load in Scenario #1 as described in subclause 5.1.3 can also be applied for Scenario #2. In addition, this section looks into mobility statistics for Scenario #2 [10]. The following performance metrics are evaluated:

1) Statistics for number of mobility events per UE per hour

2) Number of inter-eNB PCell handover events per UE per hour

These performance metrics are evaluated for the following methods:

- Method A: For UEs served by a single cell only, i.e., either by a macro or a small cell

- Method B: For UEs configured to deliver data via macro and small cells simultaneously

For Method B, mobility is always served by the macro cell layer while a small cell is added/ released depending on its vicinity. Detailed mobility and simulation assumptions are described in Annex B.

Figure 5.2.3-1 and 5.2.3-2 summarise the statistics for number of mobility events per UE per hour for both the methods, respectively. Results are presented for the cases with either 2 or 10 small cells per macro cell area, and different UE speeds. For Method A, the relative fraction of macro-to-macro handovers (MM HO) is modest, as the mobility events are dominated by macro-to-pico handovers (MP HO) and pico-to-macro handovers (PM HO). For the case with 10 small cells per macro-cell area, the fraction of pico-to-pico handovers (PP HOs) starts to become visible.

The results of Method B in Figure 5.2.3-2 show a constant number of PCell handovers (MM HO) independent on whether there are 2 or 10 small cells per macro-cell area. This is due to the fact that mobility is always served on the macro-layer. Comparing the results in Figure 5.2.3-1 and Figure 5.2.3-2 shows that the cost of Method B is a 20% increase in the number of RRC reconfigurations.

The increased number of RRC reconfigurations originates from managing both macro and small cells simultaneously, as opposed to only managing either macro or small cell for Method A. The number of events in Fig. 5.2.3-2 is clearly dominated by events related to small cell configuration (roughly 60-80%). This is because a UE will naturally cross higher number of small cells (as compared to macro cells), and therefore experience more small cell reconfigurations than macro cell changes.

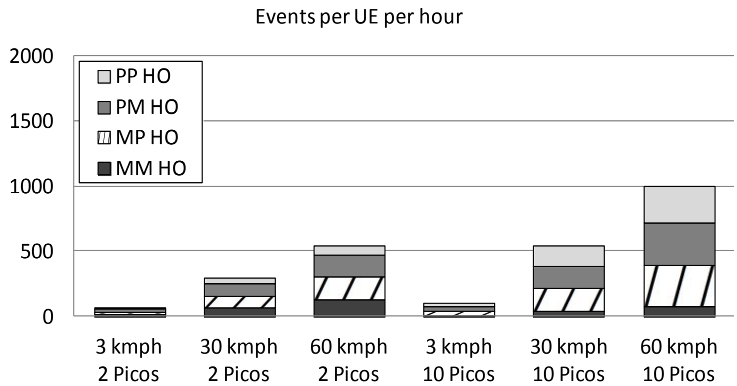

Figure 5.2.3-1: Statistics for number of mobility events per UE per hour for Method A

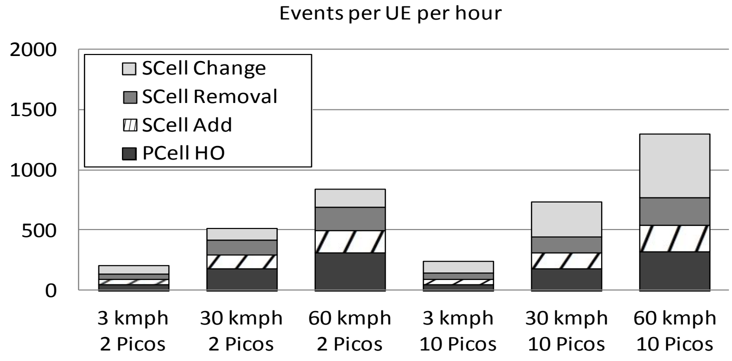

Figure 5.2.3-2: Statistics for number of mobility events per UE per hour for Method B

Figure 5.2.3-3 shows the cumulative distribution function for the number of small cell configuration operations (i.e., add, remove, change) without performing inter-eNB handover between macro cells. Hence, it basically shows the statistics for number of small cell mobility events while having the PCell on the same macro eNB. At the medium level, it is observed that 1-3 Small cell operations typically happen while the UE has the PCell on the same macro eNB. However, with 10% probability (i.e. 90th percentile), UEs can be subject to 8 small cell mobility events while having the PCell on the same macro eNB. The statistics in Fig. 5.2.3-3 are useful to get a first estimate of the core network signalling impact, if the data flow for UEs with Method B is from S-GW to the macro cell and from the macro cell to the small cell together. Given the assumptions for the data flow, it basically means that small cell mobility events, while still having the same macro-eNB as PCell, will not trigger any core network signalling (i.e. no path-switching). On the other hand, U-plane overhead on Transport Network as well as inter-eNB signalling will be increased due to routing all traffic via the macro cell.

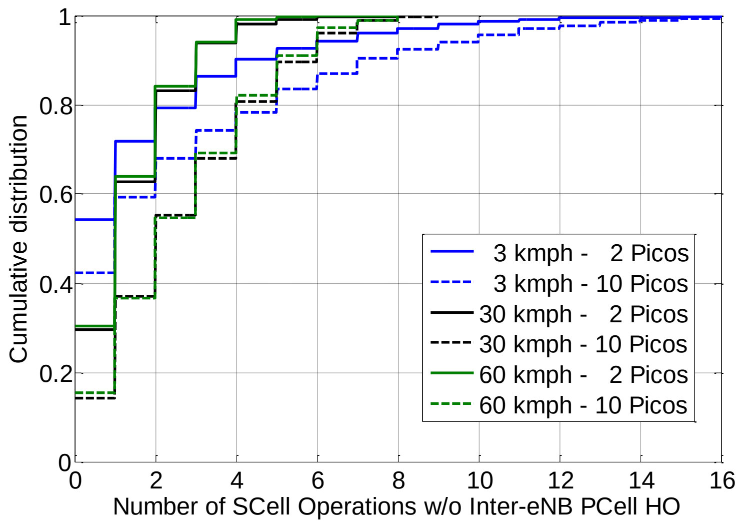

Figure 5.2.3-3: CDF for the number of small cell configuration operations

Fig. 5.2.3-4 shows statistics for the number of inter-eNB PCell handovers per UE per hour for both the methods. For Method A, a higher number of inter-eNB PCell changes is clearly observed as this happens for every inter-frequency handover between macro and small layer, as well as for intra-frequency handovers between different small cells (or different macro eNBs). In contrast, for Method B, inter-eNB PCell handovers are only triggered for the macro layer (intra-frequency). The results in Fig. 5.2.3-4 therefore shows on the order of a factor 3-4 higher number of inter-eNB PCell handovers for Method A, as compared to Method B.

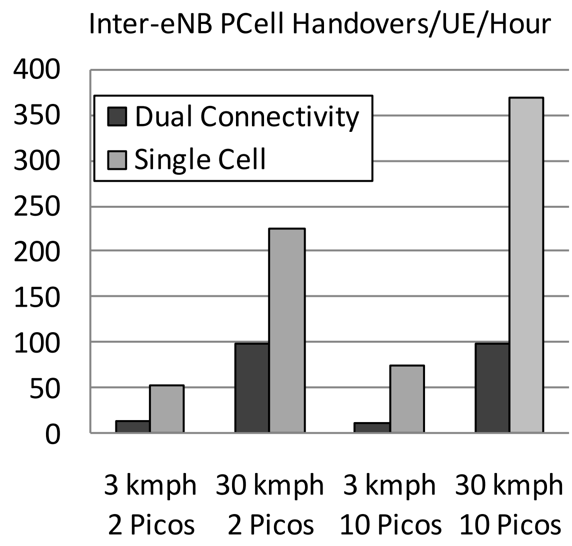

Figure 5.2.3-4: Number of inter-eNB PCell handover events per UE per hour

In summary, the followings are observed:

- For dual Rx/Tx UEs, keeping the mobility anchor (S1-U and S1-MME) in the macro cell can save signalling overhead towards the CN (S1 path switch).
- There is a trade-off between saving C-plane signalling towards the CN and U-plane overhead on Transport Network due to routing all traffic via the macro as well as inter-eNB C-plane signalling.
- RRC reconfiguration overhead of managing both macro and small cells simultaneously is higher than that of managing either macro or small cell only.

5.2.4 Difficult to improve per-user throughput by utilizing radio resources in more than one eNB

Increasing user throughput by utilising radio resources across cells, while taking into account QoS requirements, is a challenge also in Scenario #2.

For Scenario #2, CA could be considered as a way of utilising multiple cell resources as specified in TS 36.300 [5]. Nevertheless, Rel-10/11 CA assumes that small cells are low power RRHs using ideal backhaul. With non-ideal backhaul between macro and small cells, Rel-10/11 CA may not work well due to larger backhaul latency.

The same issue as in Scenario #1 can be considered when a small cell is deployed as such that it covers the area boundary of difference eNBs as described in subclause 5.1.4.

5.3 Scenario #3

Scenario #3 is the deployment scenario where only small cells on one or more carrier frequencies are connected via non-ideal backhaul. In Scenario #3, the following challenges are expected:

a) Mobility robustness (not investigated in [4] and the problem of strong interference from macro on same carrier is not present);

b) Increased signalling load (e.g., to CN) due to frequent handover;

c) Network planning and configuration effort;

For c), the same issue as for Scenario #1 is foreseen as described in subclause 5.1.5.

5.3.1 Mobility robustness

This section looks into mobility performance in Scenario #3 [11]. Detailed simulation assumptions are described in Annex C.

Figure 5.3.1-1 shows statistics of RLF and HOF for different UE speeds where the fractional traffic load is assumed as in Annex C. For the UE speed of 3 and 10 km/h, the probability of RLF and HOF is quite low. For the 30 km/h case, an increase in RLFs and HOFs can be observed for both cases with and without time synchronisation. Nevertheless, the HOF rate in the case without time synchronisation is still below 3 % at the 30 km/h speed and the 30 % load (i.e., 6 UEs per cell. see Annex C). For the 60 km/h case, the number of RLFs and HOFs becomes rather high for all the cases except for the case without time synchronisation and the 10 % load (i.e., 2 UEs per cell).

Figure 5.3.1-2 shows statistics of RLF and HOF for different UE speeds where the full traffic load is assumed. The statistics are compared with ideal and non-ideal cell detection for synchronous cells. With ideal cell detection, the HOF rate is close to 0 % at the 3km/h of UE speed. However, the HOF rate rises to rather high for the faster UE speeds.

From these statistics, the following is observed:

- Up to the 3km/h of UE speed, there is no mobility robustness problem in Scenario #3.

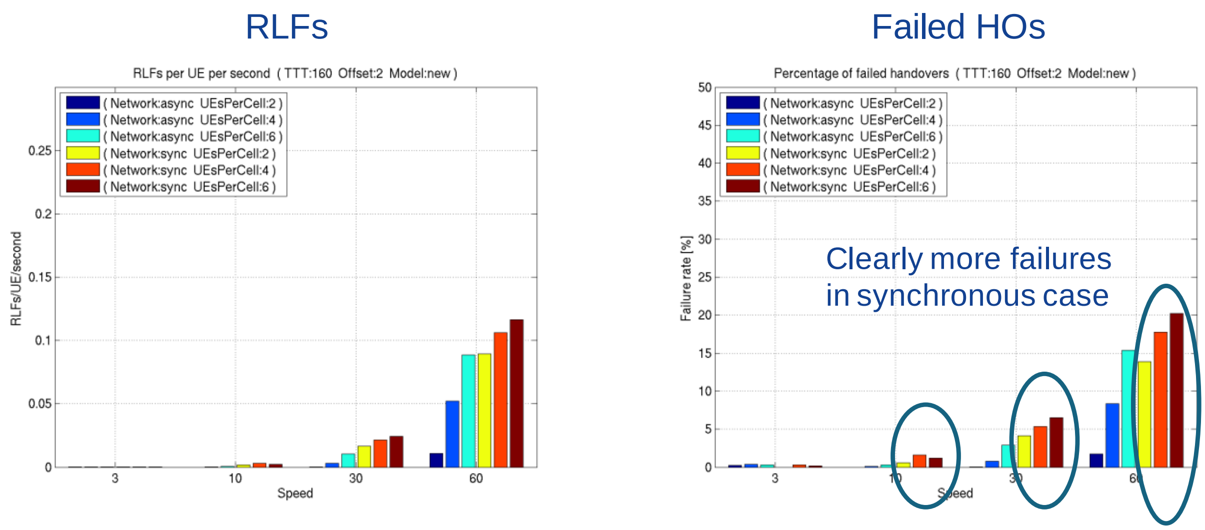

Figure 5.3.1-1: Statistics for RLF and HOF (fractional load)

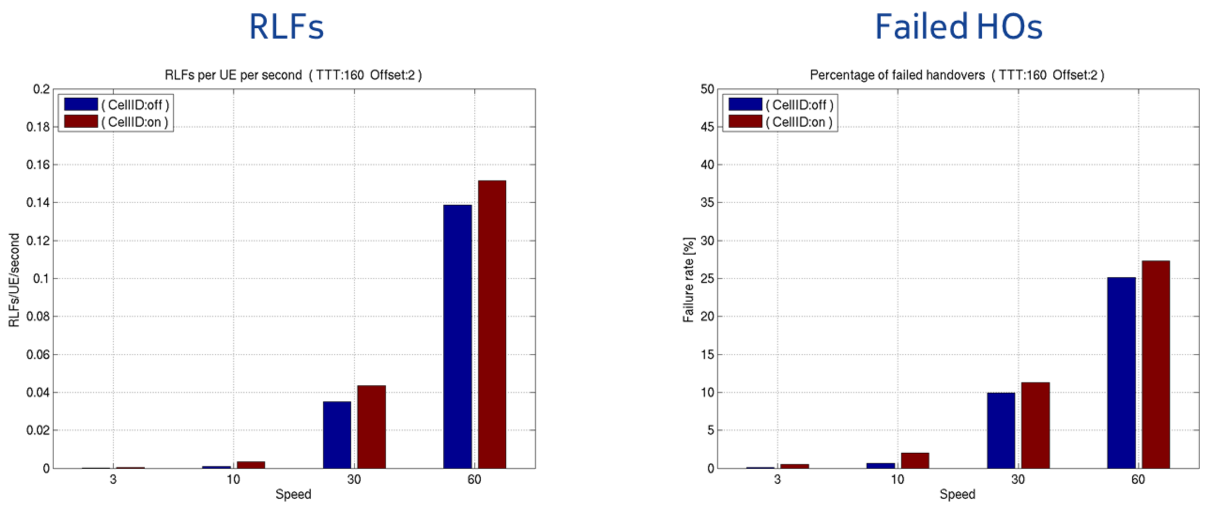

Figure 5.3.1-1: Statistics for RLF and HOF (full load)

5.3.2 Increased signalling load (e.g., to CN) due to frequent handover

This section analyses the increased signalling load due to small cell deployments without the macro cell coverage [12]. Table 5.3.2-1 shows the statistics of number of mobility events per UE per minute. The simulation is conducted according to the mobility parameter of Set 1 and others in [4]. For Scenario #3, the number of mobility events is about 4 times higher than that of a macro only network. From this result, the following is observed:

- A mechanism to cope with the increase of signalling due to cell change traffic should be considered for Scenario #3 as well as Scenario #1 and #2.

Table 5.3.2-1: Statistics for number of Mobility events per UE per minutes in Scenario #3

Deployment	**HOs / min**, 30 km/h	**HOs / min**, 3 km/h
Macro-Only	3.5	1.0
Scenario #3: 10 small cells/Macro site (single channel)	14.5	4.3

6 Design goals

In order to resolve the challenges described in section 5, the following design goals are taken into account for this study in addition to the requirements specified in TR 36.932 [3].

In terms of mobility robustness:

- For UEs in RRC_CONNECTED, Mobility performance achieved by small cell deployments should be comparable with that of a macro only network.

In terms of increased signalling load due to frequent handover:

- Any new solutions should not result in excessive increase of signalling load towards the CN. However, additional signalling and user plane traffic load caused by small cell enhancements should also be taken into account.

In terms of improving per-user throughput and system capacity:

- Utilising radio resources across macro and small cells in order to achieve per-user throughput and system capacity similar to ideal backhaul deployments while taking into account QoS requirements should be targeted.

7 Potential Solutions

This section describes the potential solutions to realise the design goal described in section 6. The quantified technology potential compared with the existing technologies up to Rel-11 is also shown.

7.1 Dual connectivity

A term “dual connectivity” is used to refer to operation where a given UE consumes radio resources provided by at least two different network points connected with non-ideal backhaul. Furthermore, each eNB involved in dual connectivity for a UE may assume different roles. Those roles do not necessarily depend on the eNB’s power class and can vary among UEs. In the form of dual connectivity, the following potential solutions can be considered.

7.1.1 Inter-node radio resource aggregation (for Scenario #2)

Inter-node radio resource aggregation is a potential solution for improving per-user throughput. This can be done by aggregating radio resources in more than one eNB for user plane data transmission as illustrated in Figure 7.1.1-1. Depending on realization of this solution, signalling overhead towards the CN can potentially be saved by keeping the mobility anchor in the macro cell as described in subclause 5.2.3.

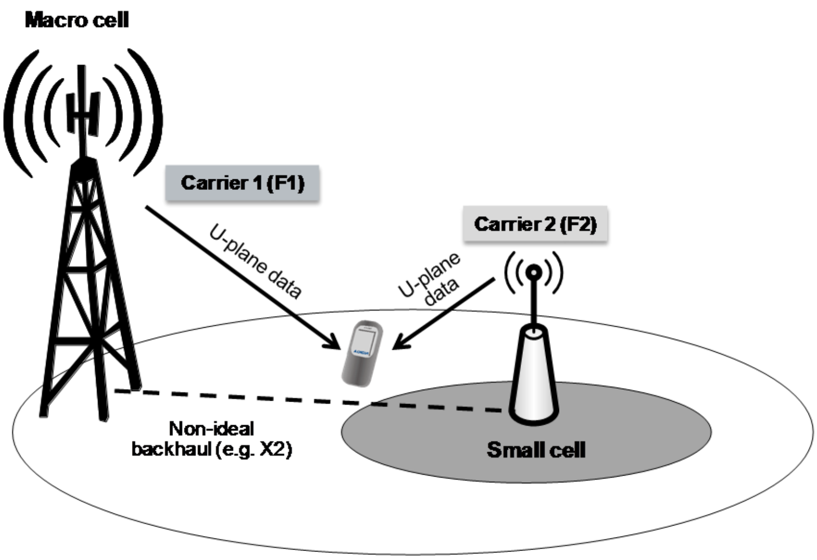

Figure 7.1.1-1: Inter-node radio resource aggregation

7.1.1.1 Analysis of technology potential

7.1.1.1.1 Potential gain from the existing features

This section analyses technology potential on the throughput improvement compared with the existing features up to Rel-11 [13]. The user throughput performance in the following scenarios as illustrated in Figure 7.1.1.1.1-1 is evaluated:

- Scenario #A: Both macro and pico eNBs are equipped with the same two carriers. The macro and pico eNBs apply Rel-10 CA to aggregate both carriers.
- Scenario #B: Both macro and pico eNBs are equipped with one carrier which differs from one another. The macro and pico eNBs apply inter-node radio resource aggregation.

In both scenarios, remote radio heads with ideal backhaul are deployed at the place of pico eNBs with non-ideal backhaul. The simulation assumptions are listed in Table D-1 of Annex D.

Figure 7.1.1.1.1-1: Simulation scenarios for inter-node radio resource aggregation

Figure 7.1.1.1.1-2 shows user throughput CDF at high traffic load for macro and pico users separately. Figure 7.1.1.1.1-3 shows PDSCH SINR on the secondary carrier, f2 in Figure 7.1.1.1.1-1. In both figures, Scenario #A is denoted as “co-channel, CA”, while Scenario #B is “sepdep, INUPA”. For pico UEs, Scenario #B results in better user throughput than Scenario #A while for macro UEs, the similar CDFs of user throughput are observed. This can be explained by the lack of strong interference from macro cells on the pico carrier as shown in Figure 7.1.1.1.1-3. Lack of interference significantly increases the throughput of pico UEs and the effective coverage area of the pico cells.

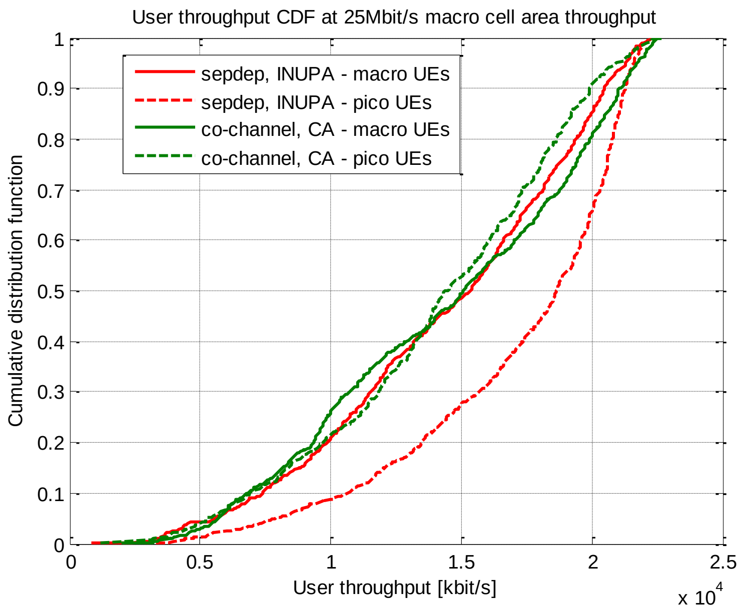

Figure 7.1.1.1.1-2: User throughput CDF at high traffic load for macro and pico users separately

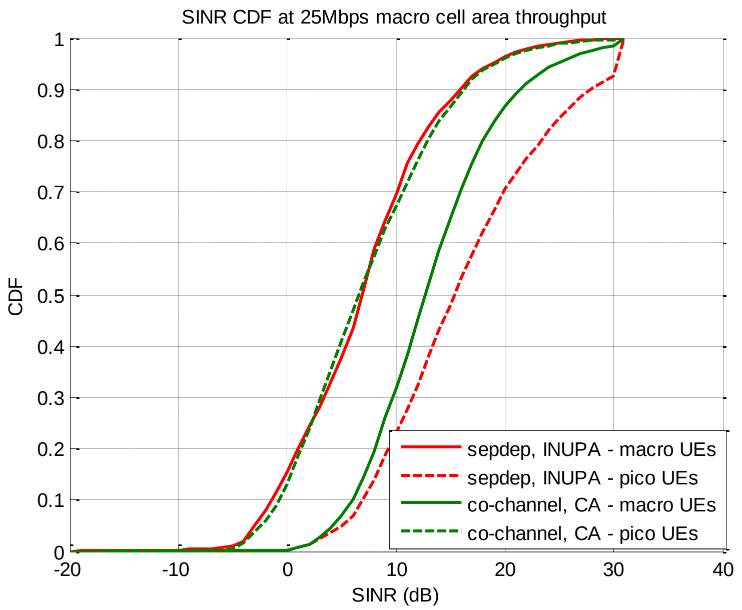

Figure 7.1.1.1.1-3: PDSCH SINR on carrier f2 (in Figure 7.1.1.1.1-1)

7.1.1.1.2 Potential gain with non-ideal backhaul deployments

The potential gain from the existing features described in subclause 7.1.1.1.1 is evaluated according to the proportional fair in time and frequency principles, preferably on the cell/carrier where the highest RSRP is measured. If the buffer of a user is large enough, it may be scheduled on the remaining available resources of the second carrier. However, such the coordination between carriers is not feasible if non-ideal backhaul is assumed between macro and pico eNBs. Scheduling has to be done independently at each carrier. This independent scheduling method may not be optimal compared with the coordinated scheduling. This section analyses technology potential with the assumption of non-ideal backhaul, i.e., independent scheduling at macro and pico eNBs [14].

Figure 7.1.1.1.2-1 shows 5 and 50 percentile user throughput performance as a function of the offered load per macro cell. In Figure 7.1.1.1.2-1, Scenario #B in subclause 7.1.1.1.1 is denoted as “with inter-site CA”. The term “w/o inter-site CA” denotes the scenario where inter-node radio resource aggregation is not applied in Scenario #B. Both the 5 and 50 percentile user throughput performance with inter-node radio resource aggregation are significantly higher than without inter-node radio resource aggregation. Users experience gains up to 90 % in low load conditions. On the other hand, the gain decreases as the load increases. At very high load the user data rate performance with and without inter-node radio resource aggregation is almost the same. This behaviour can be explained as follows; at low-to-medium load UEs can benefit from larger transmission bandwidth and increased multi-user diversity available with this method. When the offered load is high, it does not really matter whether the UE can receive data from one or both frequency layers since the system is saturated and the schedulers try to allocate the available resources among all UEs in a fair manner. The simulation assumptions are listed in Table D-2 of Annex D.

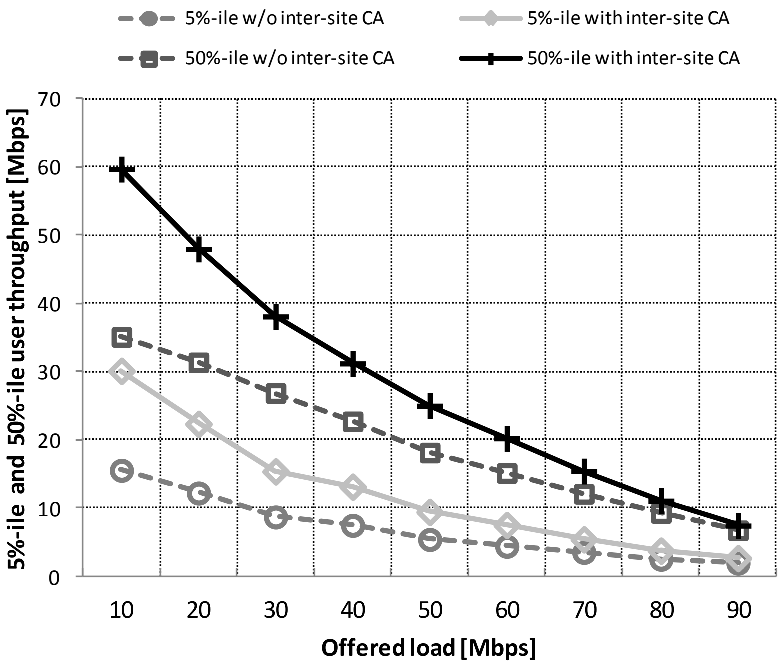

Figure 7.1.1.1.2-1: User throughput as a function of the offered load per macro cell

From these results, the following is observed assuming ideal backhaul and no protocol impact:

- For Scenario #2, inter-node radio resource aggregation shows technology potential in terms of per-user throughput.

- This observed technology potential justifies investigating protocol architectures.

- The gains achievable with a realistic realisation of inter-node radio resource aggregation, considering e.g., backhaul delay, backhaul capacity and protocol impact, will be evaluated and compared with existing functionalities (e.g., with/without CA, eICIC, etc.) later.

7.1.2 RRC diversity (for Scenario #1)

RRC diversity is a potential solution for improving mobility robustness. With RRC diversity, the handover related RRC signalling could additionally be transmitted from or to a potential target cell as illustrated in Figure 7.1.2-1. RLF could in this case be prevented as long as the UE is able to maintain a connection to at least one of the cells. This will eventually lead to a more successful handover performance (i.e. avoiding UE RRC re-establishment procedure). The RRC diversity scheme could also be applied for handovers from the macro to pico cells, between macro or between pico cells.

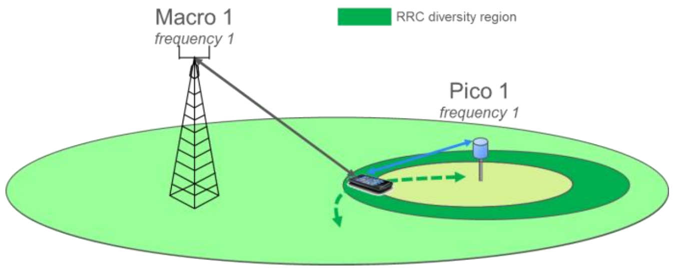

Figure 7.1.2-1: Handover region where RRC diversity can be applied

7.1.2.1 Analysis of technology potential

In terms of complexity and gain, technology potential of RRC diversity compared with the solutions developed in the Hetnet mobility work item is to be studied.

8 Architecture and protocol enhancements

This section describes possible architecture and protocol enhancements to realise the potential solutions described in section 7.

8.1 Architecture and protocol enhancements for Dual connectivity

8.1.1 User plane architecture for dual connectivity

Dual Connectivity consists in configuring a UE with one MeNB and at least one SeNB. When doing so, we can distinguish 3 options for splitting the U-Plane data:

- Option 1: S1-U also terminates in SeNB;
- Option 2: S1-U terminates in MeNB, no bearer split in RAN;
- Option 3: S1-U terminates in MeNB, bearer split in RAN.

Figure 7.1.1-1 below depicts those three options taking the downlink direction as an example.

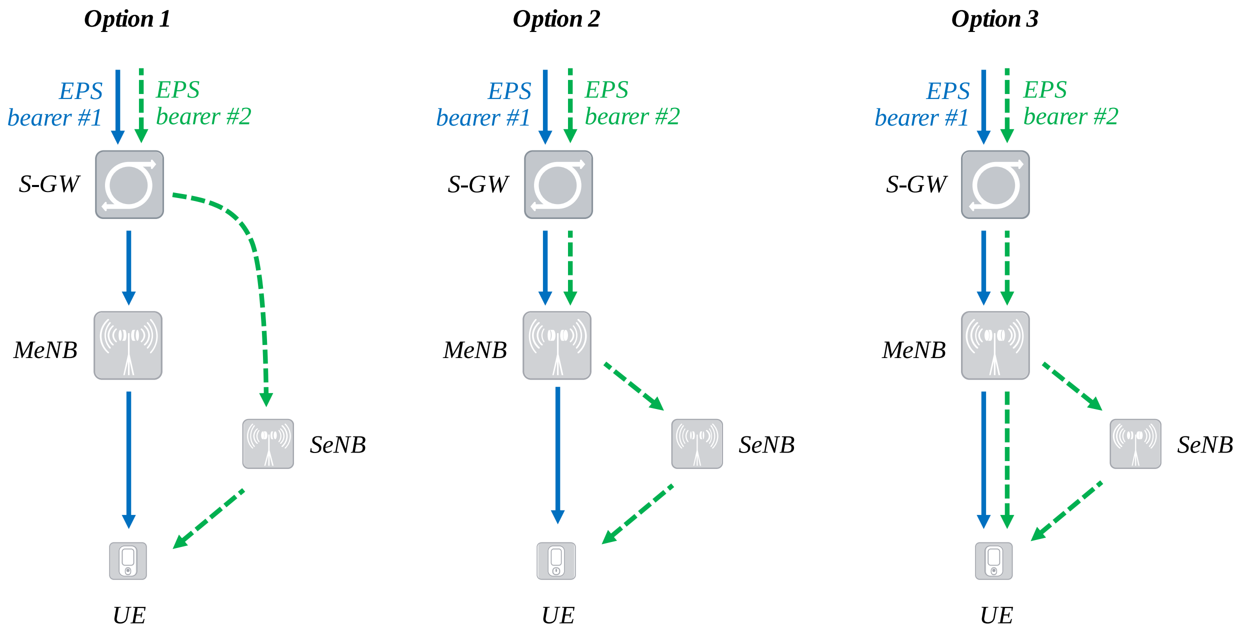

Figure 8.1.1-1: Bearer Split Options

In terms of protocol architecture, when S1-U terminates at the MeNB, the protocol stack in the SeNB must at least support (re-)segmentation. This is due to the fact that (re-)segmentation is an operation that is tightly coupled to the physical interface, and when non-ideal backhaul is used, (re-)segmentation must take place in the same node as the one transmitting the RLC PDUs. Based on this assumption, four families of U-plane alternatives emerge:

A. **Independent PDCPs**: this option terminates the currently defined air-interface U-plane protocol stack completely per bearer at a given eNB, and is tailored to realize transmission of one EPS bearer by one node, but could also support splitting of a single EPS bearer for transmission by MeNB and SeNB with the help of an additional layer. The transmission of different bearers may still happen simultaneously from the MeNB and a SeNB.

B. **Master-Slave PDCPs**: this option assumes that S1-U terminates in MeNB with at least part of the PDCP layer residing in the MeNB. In case of bearer split, there is a separate and independent RLC bearer, also at UE side, per eNB configured to deliver PDCP PDUs of the PDCP bearer, terminated at the MeNB.

NOTE: the functional split of Master-Slave PDCP is FFS.

C. **Independent RLCs**: this option assumes that S1-U terminates in MeNB with the PDCP layer residing in the MeNB. In case of bearer split, there is a separate and independent RLC bearer, also at UE side, per eNB configured to deliver PDCP PDUs of the PDCP bearer, terminated at the MeNB.

D. **Master-Slave RLCs**: this option assumes that S1-U terminates in MeNB with the PDCP layer and part of the RLC layer residing in the MeNB. While requiring only one RLC entity in the UE for the EPS bearer, on the network side the RLC functionality is distributed between the nodes involved, with a “slave RLC” operating in the SeNB. In downlink, the slave RLC takes care of the delay-critical RLC operation needed at the SeNB: it receives from the master RLC at the MeNB readily built RLC PDUs (with Sequence Number already assigned by the master) that the master has assigned for transmission by the slave, and transmits them to the UE. The custom-fitting of these PDUs into the grants from the MAC scheduler is achieved by re-using the currently defined re-segmentation mechanism.

Based on the options for bearer split and U-plane protocol stack above, we obtain the following alternatives:

- 1A: S1-U terminates in SeNB + independent PDCPs (no bearer split);
- 2A: S1-U terminates in MeNB + no bearer split in MeNB + independent PDCP at SeNB;
- 2B: S1-U terminates in MeNB + no bearer split in MeNB + master-slave PDCPs;
- 2C: S1-U terminates in MeNB + no bearer split in MeNB + independent RLC at SeNB;

- 2D: S1-U terminates in MeNB + no bearer split in MeNB + master-slave RLCs;
- 3A: S1-U terminates in MeNB + bearer split in MeNB + independent PDCPs for split bearers;
- 3B: S1-U terminates in MeNB + bearer split in MeNB + master-slave PDCPs for split bearers;
- 3C: S1-U terminates in MeNB + bearer split in MeNB + independent RLCs for split bearers;
- 3D: S1-U terminates in MeNB + bearer split in MeNB + master-slave RLCs for split bearers.

NOTE: because the functional split of Master-Slave PDCP is FFS, 2B and 3B are also FFS.

In the following subclauses, the expected benefits and the expected drawbacks of each alternative are analyzed. It is to be noted that those alternatives only represent how dual connectivity can be realised for one UE. They do not restrict the handling of bearers of other UEs, e.g. it is not because Alternative 2C is used for one UE that legacy UEs cannot connect directly to SeNB.

8.1.1.1 Alternative 1A

Alternative 1A is the combination of S1-U that terminates in SeNB + independent PDCPs (no bearer split). It is depicted on Figure 7.1.1.1-1 below, taking the downlink direction as an example.

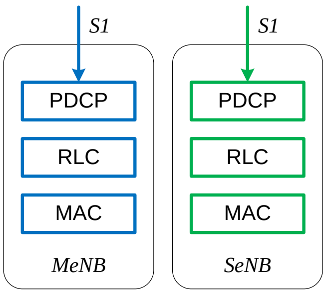

Figure 8.1.1.1-1: Alternative 1A

The expected benefits of this alternative are:

- no need for MeNB to buffer or process packets for an EPS bearer transmitted by the SeNB;
- little or no impact to PDCP/RLC and GTP-U/UDP/IP;
- no need to route all traffic to MeNB, low requirements on the backhaul link between MeNB and SeNB and no flow control needed between the two;
- support of local break-out and content caching at SeNB straightforward for dual connectivity UEs.

The expected drawbacks of this alternative are:

- SeNB mobility visible to CN;
- offloading needs to be performed by MME and cannot be very dynamic;
- security impacts due to ciphering being required in both MeNB and SeNB;
- utilisation of radio resources across MeNB and SeNB for the same bearer not possible;
- for the bearers handled by SeNB, handover-like interruption at SeNB change with forwarding between SeNBs;
- in the uplink, logical channel prioritisation impacts for the transmission of uplink data (radio resource allocation is restricted to the eNB where the Radio Bearer terminates).

8.1.1.2 Alternative 2A

Alternative 2A is the combination of S1-U that terminates in MeNB + no bearer split in MeNB + independent PDCP at SeNB. It is depicted on Figure 7.1.1.2-1 below, taking the downlink direction as an example.

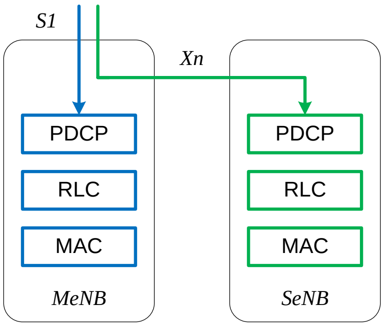

Figure 8.1.1.2-1: Alternative 2A

The expected benefits of this alternative are:

- SeNB mobility hidden to CN;
- little or no impact to PDCP/RLC and GTP-U/UDP/IP;
- processing of packets for an EPS bearer transmitted by the SeNB limited to routing, without buffering;

The expected drawbacks of this alternative are:

- need to route all traffic to MeNB;
- security impacts due to ciphering being required in both MeNB and SeNB;
- utilisation of radio resources across MeNB and SeNB for the same bearer not possible;
- for the bearers handled by SeNB, handover-like interruption at SeNB change with forwarding between SeNBs and PDCP re-establishment;
- in the uplink, logical channel prioritisation impacts for the transmission of uplink data (radio resource allocation is restricted to the eNB where the Radio Bearer terminates).

8.1.1.3 Alternative 2B

This alternative is FFS pending clarifications on the functional split between Master and Slave PDCP.

8.1.1.4 Alternative 2C

Alternative 2C is the combination of S1-U that terminates in MeNB + no bearer split in MeNB + independent RLC at SeNB. It is depicted on Figure 7.1.1.4-1 below, taking the downlink direction as an example.

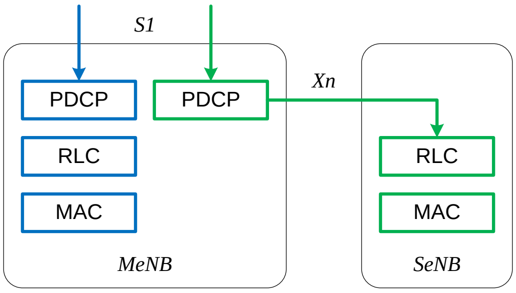

Figure 8.1.1.4-1: Alternative 2C

The expected benefits of this alternative are:

- SeNB mobility hidden to CN;
- no security impacts with ciphering being required in MeNB only;
- no data forwarding between SeNBs required at SeNB change;
- offloads RLC processing from MeNB to SeNB;
- little or no impacts to RLC.

The expected drawbacks of this alternative are:

- need to route, process and buffer all dual connectivity traffic in MeNB (also for an EPS bearer transmitted only by the SeNB, MeNB required to buffer and process packets at PDCP level);
- utilisation of radio resources across MeNB and SeNB for the same bearer not possible;
- for the bearers handled by SeNB, handover-like interruption at SeNB change;
- in the uplink, logical channel prioritisation impacts for the transmission of uplink data (radio resource allocation is restricted to the eNB where the Radio Bearer terminates);
- no support of local break-out and content caching at SeNB for dual connectivity UEs.

8.1.1.5 Alternative 2D

Alternative 2D is the combination of S1-U that terminates in MeNB + no bearer split in MeNB + master-slave RLCs. It is depicted on Figure 7.1.1.5-1 below, taking the downlink direction as an example.

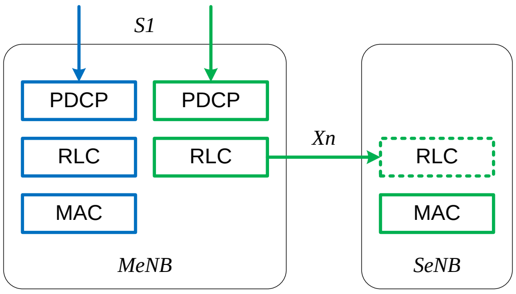

Figure 8.1.1.5-1: Alternative 2D

The expected benefits of this alternative are:

- SeNB mobility hidden to CN;
- no security impacts with ciphering being required in MeNB only;
- no data forwarding between SeNBs required at SeNB change;
- FFS: packet loss between MeNB and SeNB covered by RLC's ARQ;
- little or no impacts to PDCP.

The expected drawbacks of this alternative are:

- need to route, process and buffer all dual connectivity traffic in MeNB (also for an EPS bearer transmitted only by the SeNB, MeNB required to buffer and process packets down to RLC level)
- extension of RLC SN space may be needed to tackle Xn latency (backhaul delay becomes part of RLC RTT);
- application with RLC UM requires adoption of UMD PDU Segment;
- Re-segmentation header (SO - 2bytes) always added to SeNB RLC PDUs during segmentation;

- need to define RLC PDU as a possible T-PDU in GTP-U;
- for RLC status reports to reach MeNB, relaying over Xn may be needed;
- utilisation of radio resources across MeNB and SeNB for the same bearer not possible;
- for the bearers handled by SeNB, handover-like interruption at SeNB change;
- in the uplink, logical channel prioritisation impacts for the transmission of uplink data (radio resource allocation is restricted to the eNB where the Radio Bearer terminates);
- no support of local break-out and content caching at SeNB for dual connectivity UEs.

8.1.1.6 Alternative 3A

Alternative 3A is the combination of S1-U that terminates in MeNB + independent PDCPs for split bearers. It is depicted on Figure 7.1.1.6-1 below, taking the downlink direction as an example.

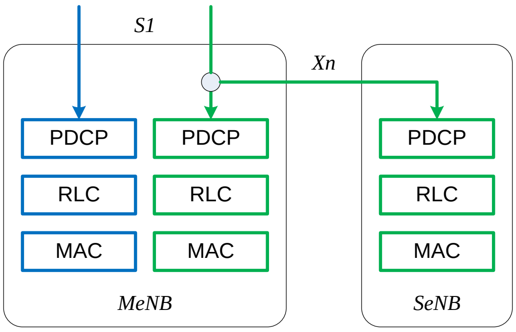

Figure 8.1.1.6-1: Alternative 3A

The expected benefits of this alternative are:

- SeNB mobility hidden to CN;
- utilisation of radio resources across MeNB and SeNB for the same bearer possible;
- little or no impact to PDCP/RLC and GTP-U/UDP/IP;
- relaxed requirements for SeNB mobility (MeNB can be used in the meantime).

The expected drawbacks of this alternative are:

- need to route, process and buffer all dual connectivity traffic in MeNB;
- security impacts due to ciphering being required in both MeNB and SeNB;
- new layer above PDCP required to take care of reordering;
- for the bearers handled by SeNB, forwarding between SeNBs at SeNB change;
- in the uplink, logical channel prioritisation impacts for handling RLC retransmissions and RLC Status PDUs (restricted to the eNB where the corresponding RLC entity resides);
- no support of local break-out and content caching at SeNB for dual connectivity UEs.

8.1.1.7 Alternative 3B

This alternative is FFS pending clarifications on the functional split between Master and Slave PDCP.

8.1.1.8 Alternative 3C

Alternative 3C is the combination of S1-U that terminates in MeNB + bearer split in MeNB + independent RLCs for split bearers. It is depicted on Figure 7.1.1.8-1 below, taking the downlink direction as an example.

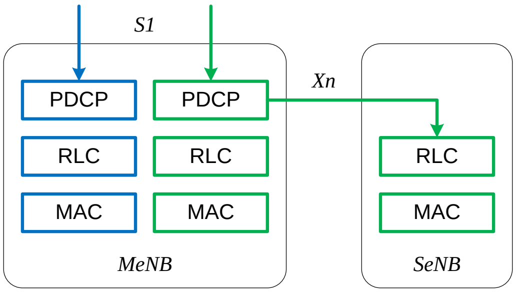

Figure 8.1.1.8-1: Alternative 3C

The expected benefits of this alternative are:

- SeNB mobility hidden to CN;
- no security impacts with ciphering being required in MeNB only;
- no data forwarding between SeNBs required at SeNB change;
- offloads RLC processing of SeNB traffic from MeNB to SeNB;
- little or no impacts to RLC;
- utilisation of radio resources across MeNB and SeNB for the same bearer possible;
- relaxed requirements for SeNB mobility (MeNB can be used in the meantime).

The expected drawbacks of this alternative are:

- need to route, process and buffer all dual connectivity traffic in MeNB;
- PDCP to become responsible for routing PDCP PDUs towards eNBs for transmission and reordering them for reception;
- flow control required between MeNB and SeNB;
- in the uplink, logical channel prioritisation impacts for handling RLC retransmissions and RLC Status PDUs (restricted to the eNB where the corresponding RLC entity resides);
- no support of local break-out and content caching at SeNB for dual connectivity UEs.

8.1.1.9 Alternative 3D

Alternative 3D is the combination of S1-U that terminates in MeNB + bearer split in MeNB + master-slave RLCs for split bearers. It is depicted on Figure 7.1.19-1 below, taking the downlink direction as an example.

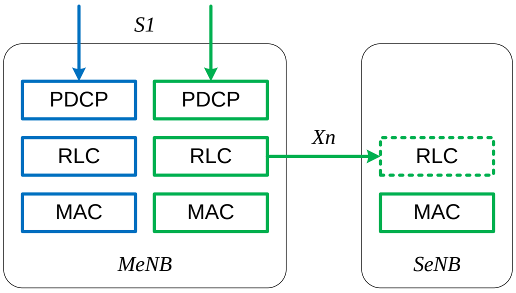

Figure 8.1.1.9-1: Alternative 3D

The expected benefits of this alternative are:

- SeNB mobility hidden to CN;
- no security impacts with ciphering being required in MeNB only;
- no data forwarding between SeNBs required at SeNB change;
- little or no impacts to PDCP;
- utilisation of radio resources across MeNB and SeNB for the same bearer possible;
- relaxed requirements for SeNB mobility (MeNB can be used in the meantime, and no data forwarding required at SeNB change;
- FFS: packet loss between MeNB and SeNB covered by RLC's ARQ;

The expected drawbacks of this alternative are:

- need to route, process and buffer all dual connectivity traffic in MeNB;
- RLC to become responsible for routing the RLC PDUs towards the eNBs;
- flow control required between MeNB and SeNB;
- extension of RLC SN space may be needed to tackle Xn latency (backhaul delay becomes part of RLC RTT);
- application with RLC UM requires adoption of UMD PDU Segment;
- for RLC status reports to reach MeNB, relaying over Xn is needed;
- re-segmentation header (SO - 2bytes) always added to SeNB RLC PDUs during segmentation;
- need to define RLC PDU as a possible T-PDU in GTP-U;
- no support of local break-out and content caching at SeNB for dual connectivity UEs.

8.1.2 Control plane architecture for dual connectivity

In this section, C-plane protocols and architectures for dual connectivity are evaluated.

From a standards point of view, each eNB should be able to handle UEs autonomously, i.e., provide the PCell to some UEs while acting as assisting eNB for other.

It is assumed that there will be only one S1-MME Connection per UE (FFS: requires confirmation by RAN3).

8.1.2.1 RRC Protocol architecture

At least the following RRC functions are relevant when considering adding small cell layer to the UE for dual connectivity operation:

- Small cell layer's common radio resource configurations
- Small cell layer's dedicated radio resource configurations
- Measurement and mobility control for small cell layer

In dual connectivity operation, a UE always stays in a single RRC state, i.e., either RRC_CONNECTED or RRC_IDLE. With this principle, the main two architecture alternatives for RRC are the following:

- Option C1: Only the MeNB generates the final RRC messages to be sent towards the UE after the coordination of RRM functions between MeNB and SeNB. The UE RRC entity sees all messages coming only from one entity (in the MeNB) and the UE only replies back to that entity. L2 transport of these messages is FFS (e.g. transfer via SeNB).

- Option C2: MeNB and SeNB can generate final RRC messages to be sent towards the UE after the coordination of RRM functions between MeNB and SeNB and may send those directly to the UE (depending on L2 architecture) and the UE replies accordingly. How and whether to distinguish source and destination RRC entity are FFS. How to route UL messages is FFS. L2 transport of these messages is FFS (e.g. transfer via SeNB).

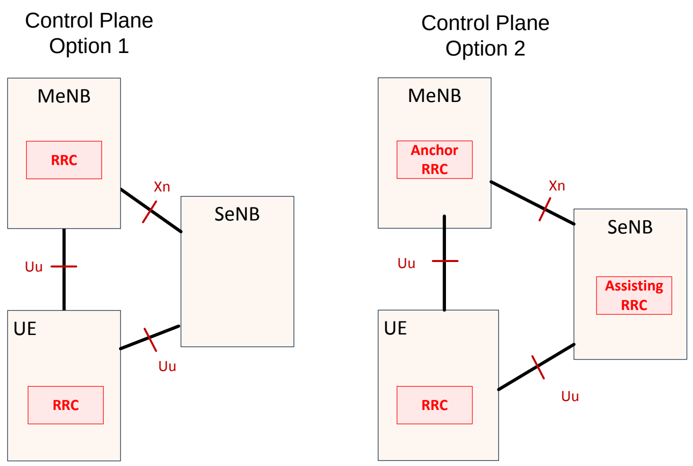

Figure 8.1.2.1-1: Radio Interface C-plane architecture alternatives for dual connectivity

9 Conclusions

Annex A (informative): Performance evaluation

Simulation models (i.e., simulation parameters or detailed scenarios) are not specified for this study. Calibration exercise is not performed. However, the following evaluation metrics can be considered as examples when companies provide simulation results:

- System throughput (capacity);
- Per-user throughput;
- Packet delay spikes (e.g., due to mobility);
- Mobility performance metrics (HOF/RLF, ToS);
- UE power consumption;
- Implementation complexity;
- Transport network load;

Annex B: Mobility and simulation assumptions for mobility evaluation in Scenario #2 (subclause 5.2.3)

B.1 Mobility assumptions

Intra-frequency macro-to-macro cell handover is based on UE RSRP A3 event (neighbour cell becomes offset better than PCell). In order to optimize the UE power consumption and avoid unnecessary UE measurement gaps, periodic inter-frequency measurements every 40 ms are only enabled for non-CA UEs having reported the A2 event (cell becomes worse than threshold).

The A2 threshold is set such that approximately 80% of the UEs on macro-layer perform inter-frequency measurements, i.e. meaning that the 20% macro-UEs with strongest macro cell signal level are not offloaded to the small cell layer i.e. UEs close to the macro will likely not utilize small cell layer in this simulation setup. When the inter-frequency measurements are enabled for a macro-UE, the same UE is configured with RSRQ A4 event (neighbour cell becomes better than threshold) for performing handover to the small cell. Thus, when the quality of the small cell becomes sufficiently good, the UE is offloaded to the small cell layer.

As illustrated in Figure B.1-1, the handover to the small cell may happen for example at locations 1 or 2 depending on the settings of the A4 event. Note that if the handover is made too early to the small cell (say at location 1), the UE may experience a throughput loss as compared to being at the macro-layer, depending on the channel quality and number of active users at the two layers. Inter-frequency handover from the small cell and back to the macro-layer is initiated based on RSRQ A2. Also here it is important that the A2 event is optimized to maximize the end-user experienced throughput. If the UE trajectory is crossing two small cells with overlapping coverage area, intra-frequency small-to-small handover is based on RSRP A3 events from the UE.

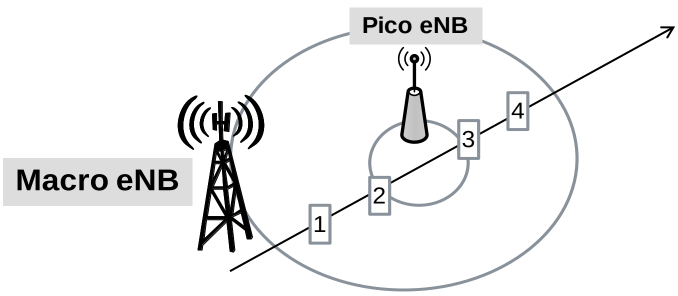

Figure B.1-1: Mobility events for a UE with Method A

For UEs with Method B, inter-frequency measurements on a second carrier are performed without measurement gaps i.e. while being served at macro layer carrier without the need for measurement gaps to perform inter-frequency measurements (although this may not be the case for all UEs as performing inter-frequency measurement without gaps is a UE capability). Thus, a UE on the macro layer is assumed to make transparent inter-frequency RRM measurements on the small cell layer without any measurement gaps. Having frequent inter-frequency measurements activated has a cost in terms of UE power consumption independently whether these are performed with or without gaps. Also in this case intra-frequency PCell handover at the macro-layer is assumed to be based on RSRP A3, while small cell addition (configuration) and removal (de-configuration) are based on RSRQ based A4 and A2, respectively. Intra-frequency Small cell change on the same carrier is triggered by RSRP A6 (signal level from another small cell candidate becomes a threshold better than the current small cell). An example of the various RRC reconfiguration events that may happen to a UE with Method B, when following a certain trajectory, is illustrated in Figure B.1-2. Whenever a handover, or small cell addition/release, takes place, it also involves sending a RRC reconfiguration command to the UE.

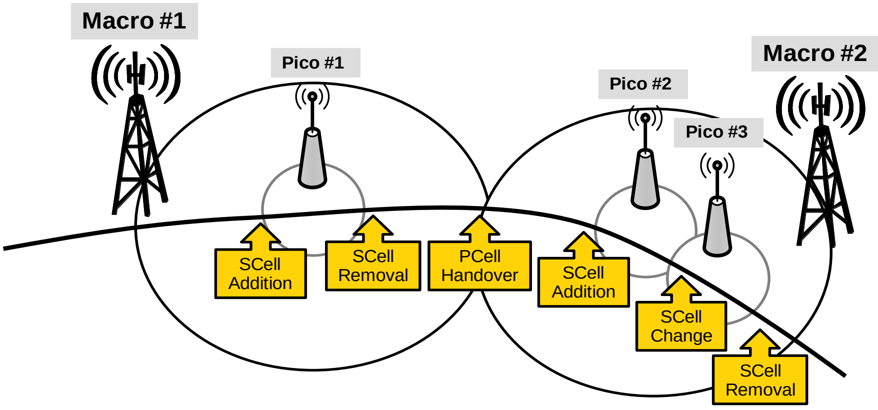

Figure B.1-2: Mobility events for a UE with Method B

B.2 Simulation assumptions

Dynamic system level simulations are conducted in coherence with 3GPP HetNet simulation guidelines outlined in [4]. The network topology consists of a regular 3-sector hexagonal macro layout, supplemented by either 2 or 10 small cells placed randomly in each macro cell area. Placement of small cells is, however, subject to constraints. The major downlink RRM algorithms are modelled, including detailed representation of the mobility mechanisms. The former includes UE physical-layer RRM measurement errors, Layer-3 filtering of those measurements, UE A{2,3,4,6} reporting events, and signalling delays for preparing a new target cell as well as execution delays. For the sake of simplicity, only RRC connected UEs are simulated (assuming full buffer traffic). Uniform spatial UE distribution is assumed, with users moving at constant speed in a fixed direction chosen random for each terminal at the start of the simulation. The default simulation parameters are summarized in Table B.2-1.

Table B.2-1: Simulation parameters

Parameter	Value
Bandwidth	10 MHz
Macro and Pico Frequency	1.8 GHz and 2.6 GHz
Simulation Time	200 s
Shadowing Standard Deviation Macro	8 dB
Shadowing Standard Deviation Pico	10 dB
Shadowing Correlation Distance Macro	50 m
Shadowing Correlation Distance Pico	13 m
BS Tx Power Macro	46 dBm
BS Tx Power Pico	30 dBm
Distance Dependent Path-Loss Macro	128.1 + 37.6 log10 (R)
Distance Dependent Path-Loss Pico	140.7 + 36.7 log10 (R)
RSRP error – zero mean Gaussian	1 dB std dev
Filtering Factor K	4 or 1
RLF: Qout Threshold	- 8 dB
RLF: Qin Threshold	- 6 dB
Inter-frequency Measurements	6 ms measurement gaps CA: 40 ms, NO CA: A2-based
A3 Time To Trigger (TTT)	256 ms or 160 ms
A3 Prep + Exec	100 ms
A3 Offset	3 dB
A2, A4 and A6 Time To Trigger (TTT)	256 ms or 160 ms
A2, A4 and A6 Prep + Exec	100 ms
A2 Threshold	-16 dB or -17 dB RSRQ
A4 Threshold	-12 dB or -17 dB RSRQ
A6 Offset	1 dB

Annex C: Simulation assumptions for mobility evaluation in Scenario #3 (subclause 5.3.1)

C.1 Scenarios and main assumptions

A dense small cell deployment scenario on a dedicated carrier is simulated with network layout as illustrated in Figure C.1-1. Wrap around is used, and UEs move in straight lines with constant speed – each UE moving in a random direction that is chosen at the start of each simulation. DRX is not used in these simulations. Major simulation assumptions are according to the HetNet mobility study in [4] including the definition of mobility key performance indicators such as RLF, HOF. Mobility events are based on A3 RSRP based event report from UEs and the following two cases of cell detection have been simulated:

- Ideal cell detection: UEs are assumed to be able to measure the RSRP from all cells independent of the signal strength and SINR and in this case the cell is regarded as detected when SINR is above given threshold.
- Realistic cell detection: The cell detection is based on PSS and SSS and is modelled in the system level simulator by using link level results for PSS and SSS detection – see more detailed description in Annex C.2. UEs measure the RSRP from cells which it has detected. Also the effect of losing the synchronization to a cell (and therefore the ability to measure RSRP) is explicitly modelled.

Cases with and without time-synchronization are simulated. For the case with time-synchronization, the PSS and SSS transmission from all the small cells are colliding (i.e. no shifting applied), resulting in more challenging SINRs and cell detection conditions as compared to the case without time-synchronization.

A fractional load scenario is simulated with 2, 4, and 6 UEs per cell, corresponding to roughly 10%, 20%, and 30% PRB utilization per cell for the considered traffic model. Additionally full load scenario with time-synchronization is simulated for reference. More detailed parameters are presented in Annex C.3.

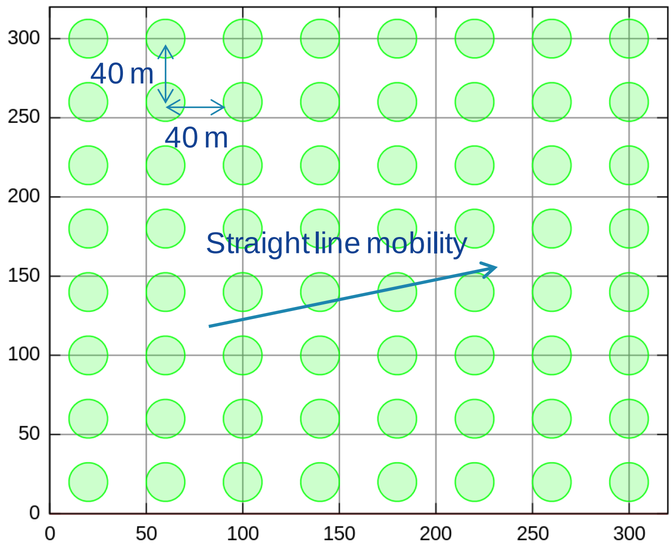

Figure C.1-1: Simulated network layout

C.2 Modelling of realistic cell detection

The realistic cell detection modelling is based on PSS and SSS detection in system level simulation studies. Link level simulation studies have been performed to obtain PSS and SSS detection hit probability mapped on average subframe SNR level assuming AWGN interference. These link level results have been used in the fully dynamic system simulations.

Figure C.2-1 shows the general process of the cell detection modelling. PSS is present in subframe 0 and SSS in subframe 5. The UE monitors the signal continuously, thus no power saving aspect is considered in the initial simulations. The UE has to detect PSS successfully before it starts to monitor SSS in the modelling. After both signals have been successfully detected, the UE can start to perform measurements from CRS, A cell is considered detected and measurable as long as a 200 ms filtered RSRP and Es/Iot measurement quantity from CRS are above certain thresholds. The following thresholds adapted from measurement conditions in [8] have been used in the initial simulations: RSRP -127 dBm and Es/Iot -6 dB. If either of the measurements is below threshold cell is considered lost and in order to perform measurements from that cell again PSS/SSS must be detected again. UE measures CRS in 40 ms intervals.

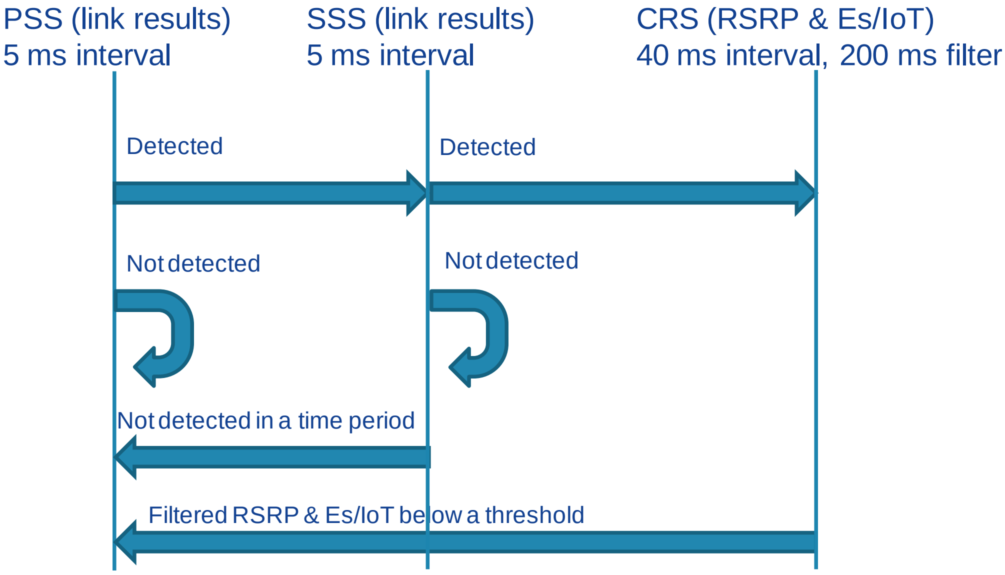

Figure C.2-1: Modelling of realistic cell detection

C.3 Simulation assumptions

Feature/Parameter		Value/Description
DRX		Not configured
Handover parameters	Handover criteria A3 baseline offset A3 baseline time-to-trigger	Event A3 RSRP 2 dB 160 ms
Traffic parameters	Full load network (100%) Fractional load network (10, 20, 30%)	Full buffer 2, 4, 6 UEs/cell with 512 kbps CBR traffic in both DL and UL
Bandwidth		10 MHz
IFFT/FFT length		1024
Duplexing		FDD
Number of sub-carriers		600
Sub-carrier spacing		15 kHz
Resource block bandwidth		180 kHz
Sub-frame length		1 ms
Reuse factor		1
Number of symbols per TTI		14
Number of data symbols per TTI		11
Number of control symbols per TTI		3
Pico cell layout [6]	Distance between Picos	40 m
	Location	Uniform grid
	Number of pico cells	64
Macro-pico deployment type		Pico in dedicated frequency layer No macro cells deployed
Distance-dependent path loss	Pico cell model (TS 36.814, Model 1)	140.7 + 36.7log10(r)
BS Tx power	Pico	30 dBm
Shadowing standard deviation	Pico	10 dB
Shadowing correlation distance	Pico	13 m
Multipath delay profile		Typical Urban
UE speed		3, 10, 30, 60 km/h
RSRP Measurement	L1 measurement cycle Measurement bandwidth Measurement error standard deviation L1 sliding window size L3 filtering	40 ms 6 RBs 2 dB 5 Disabled
Handover preparation time		50 ms
Handover execution time		40 ms
Radio link failure monitoring	Qout threshold Qin threshold T310	-8 dB -6 dB 1000 ms
Cell detection	Ideal Non-ideal	All cells measurable constantly PSS/SSS based cell detection

Annex D: Simulation assumptions for performance evaluation of inter-node radio resource aggregation (subclause 7.1.1.1)

This annexsection list the simulation parameters used for the throughput performance simulation described in subclause 7.1.1.1.1 and 7.1.1.1.2.

Table D-1: Simulation parameters for potential gain evaluation from the existing features (subclause 7.1.1.1.1)

Parameter	Values used for evaluation
Scenario	3GPP model 1, as specified in TS 36.814
Deployment	7 3-sector macro sites with inter site distance 500 m (21 sectors), 4 picos per macro cell area, deployed in center of hotspots of 40 m radii, each pico forms a cell
System and carrier bandwidth	Each carrier is 10 MHz wide
Carrier frequency	Carrier 1 at 2 GHz and carrier 2 at 2.6 GHz
eNB Antenna model	Macro: 3D antenna, as specified in 36.814 Pico: Omnidirectional antenna, as specified in 36.814
Network synchronization	Synchronized
PCI planning	Same CRS shift in all points, colliding CRS ("non-shifted CRS")
UE distribution	2/3 in hotspots (4 hotspots per macro cell) No mobility modeled, user fast fading speed 3 km/h, UE antenna height 1.5 m
Traffic model	File download traffic over TCP, 2MB file size Each UE downloads a single file of 2MB and disappears from the system.
Antenna configurations	Macro sector: 2 ±45°cross-polarized antennas Pico: 2 Omni-directional ±45°cross-polarized antennas UE: 2 Omni-directional ±45°cross-polarized antennas
Transmit powers	Macro: 46 dBm Pico: 30 dBm
Noise figure	9 dB in UE, 5 dB in eNB
DL EVM	None
Cell selection	Co-channel deployment: RSRP based cell selection + 6dB cell selection offset Inter-frequency deployment: RSRQ cell selection
Transmission schemes	DL: Spatial multiplexing, 2 layers, QPSK/16QAM/64QAM
Receiver	DL: Linear MMSE
Scheduling	PFTF (Proportional Fair in Time and Frequency)
Channel estimation	Ideal for both demodulation and CSI

Table D-2: Simulation parameters for potential gain evaluation with non-ideal backhaul deployments (subclause 7.1.1.1.2)

Parameters	Settings/Assumptions
Network layout	7 macro sites (21 macro cells), wrap-around 4 small cells randomly placed per macro cell

Channel profile	SCM channel model with 3D antenna
UE location	Indoor UEs with 20dB penetration loss
Inter-site distance / cell radius	Macro cell: 500 m (ISD); Small cell: 40 m (Cell radius)
Transmit power	Macro eNB: 46 dBm Small cell: 30 dBm
Bandwidth	2 x 10 MHz @ 2GHz and 3.5 GHz
Antenna configuration	2 x 2 MIMO with rank adaptation and interference rejection combining
Antenna gain	Macro: 14 dBi Small cell: 5 dBi
Bursty traffic model	Poisson arrival with fixed payload size of 10 Mbits per UE Hotspot UE distribution - 1/3 of UEs dropped within the macro cell coverage area, - 2/3 of UEs dropped within the small cell coverage area (without RE)
Packet scheduling	Almost independent scheduling (proportional fair) at macro and small cell. Only information exchanged between macro and small cell is the past scheduled throughput per UE.
Cell selection metric (only with no dual-connectivity)	RSRQ
Available MCSs	QPSK (1/5 to 3/4), 16QAM (2/5 to 5/6), 64QAM (3/5 to 9/10)
BLER target	10%
HARQ modeling	Ideal chase combining with max 4 transmissions
Path loss	Macro cell: 140.7+36.7log10(R[km]) Small cell: 128.1+37.6log10(R[km])
Shadow fading	Lognormal, std.=8 dB for macro cell Lognormal, std.=10 dB for small cell

Annex E: Agreements

This annex section captures the part of agreements for this study that may not fit in the main section so far. These agreements are supposed to be captured somewhere in this TR appropriately later.

- We assume that the performance that can be achieved with Rel-10/11 solutions available with ideal backhaul (e.g. CA, CoMP, …) sets the technology potential of potential solutions developed in this SI for non-idea backhaul.
- Overall observations from heterogeneous network SI should be used as input when analysing mobility robustness in SCE scenario #2.
- Solution proposals addressing mobility robustness should be evaluated also in terms of scenario #2.
- Further study SCE Scenario #2 regarding robust inter-frequency mobility. If we identify mobility robustness issues for scenario 2, we should also consider solutions for single RX/TX capable UEs.
- Inter-frequency mobility robustness in scenario 2 is less of a problem than intra-frequency mobility if no DRX is used.
- RAN2 thinks that there are mobility robustness issues in scenario 2 that may justify studying solutions in this SI (which seem to be similar as the solution considered for enhancing throughput in scenario 2).
- Packet loss on the interface between MeNB and SeNB is rare if the Xn is not the bottleneck.
- The load increase due to routing via the MeNB is not negligible.
- The results in this document (Figure 6 in R2-132103) show that the fixed RTT has a significant impact on the performance for files of a few MByte assuming that U-plane data is routed via MeNB before sent from SeNB: The download delay for a 1 MByte file increases from 2.6 to 3.6 seconds when the latency increases from 50 to 110 ms (one way)

Annex F:
Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2013-01	RAN2 #81	R2-130443			Skeleton TR	-	0.0.1
2013-02	RAN2 #81	R2-130845			TR 36.842 v0.1.0 as agreed by RAN2 in email discussion [81#05] after RAN2 #81	0.0.1	0.1.0
2013-05	RAN2 #82	R2-132226			Rapporteur's proposal for RAN2 #82	0.1.0	0.1.1
2013-05	RAN2 #82	R2-132250			TR 36.842 v0.2.0 as agreed by RAN2 in email discussion [82#06] after RAN2 #82	0.1.1	0.2.0