Dual Connectivity in LTE

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Outline

- Background
- Scenario
- Architecture
- User Plane feature
- Control Plane feature

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Background (1/2)

- Small cells are:
  - Becoming a promising technology to meet ever increasing traffic capacity and data rate demand.
  - Typically deployed as hotspots within macro cell coverage.

- 3GPP progress of:
  - Study item (SI): LTE small cell enhancement (SCE) – higher layer aspects [1]

Background (2/2)

- SCE SI is completed in December 2013, and the corresponding WI was created.
  - LTE release 12 SCE SI concerns inter-eNB CA and CoMP operations with non-ideal backhaul.
  - Then, Work item (WI): dual connectivity (DC) [2].
    - Multiple Rx/Tx capable UE in inter-frequency scenario is prioritized in the WI.

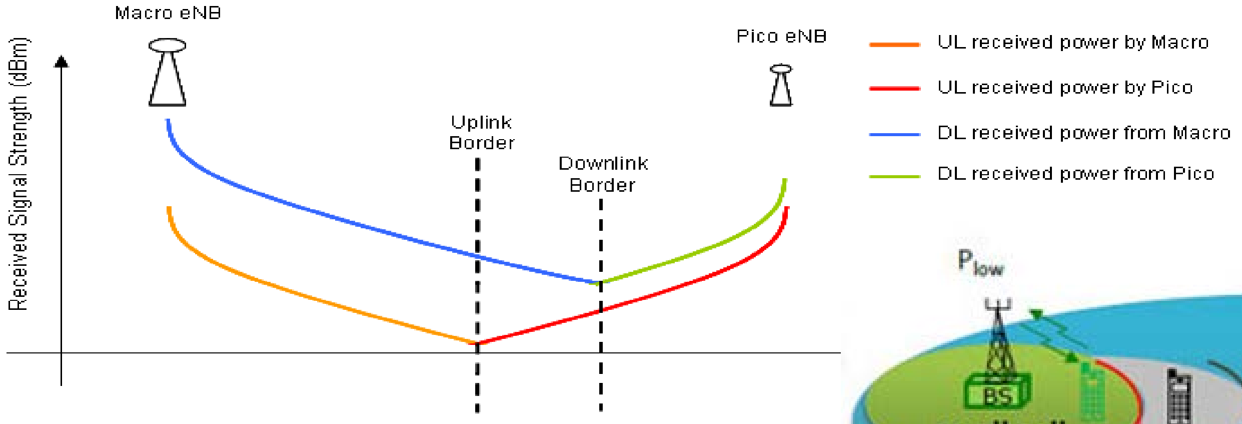
- Existing intra-eNB CA and CoMP architectures assume ideal backhaul in which centralized scheduling can be implemented for efficient radio resource utilization.

Challenges

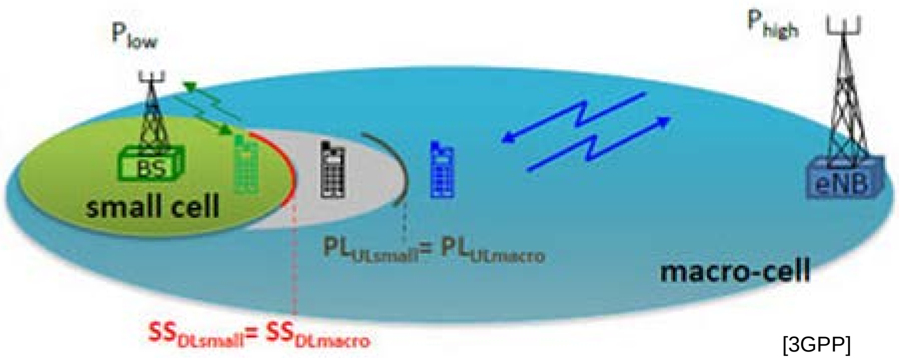
For inter-eNB CA and CoMP with non-ideal backhaul, distributed resource allocation and coordination have to be relied upon and new challenges emerge:

- Efficient radio resource utilization across eNBs
- Mobility robustness
- Increased signalling load
- UL/DL imbalance between macro and small cells

UL/DL Imbalance



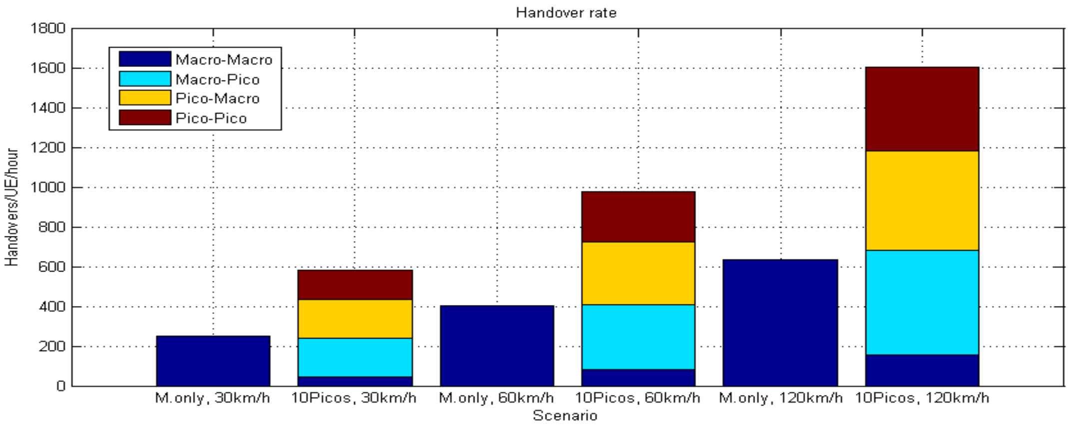
UL/DL imbalance issue in HetNet deployments



[3GPP]

- UE’s best uplink cell and best downlink cell are different
- RSRP-based cell selection is often used
- pico cell size < macro cell size

Increased Signalling Load



Increase in number of handovers where 10 small cells are deployed per macro cell

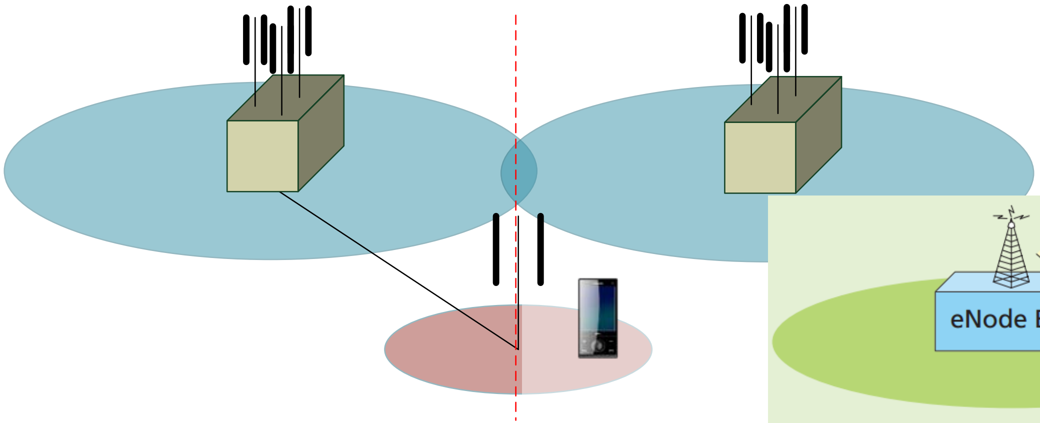
Scheme	Number of connection setups (per UE per hour)	Number of handovers (per UE per hour)				
		Mobility Rate (cell changes per minute per UE)				
		0.1	0.3	1	3	10
Full use of RRC_CONNECTED	0	6	18	60	180	600
RRC Release timer = 5s	64	0.6	1.8	6.1	18.5	62
RRC Release timer = 10s	53	1.0	3.3	10.9	32.3	109

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

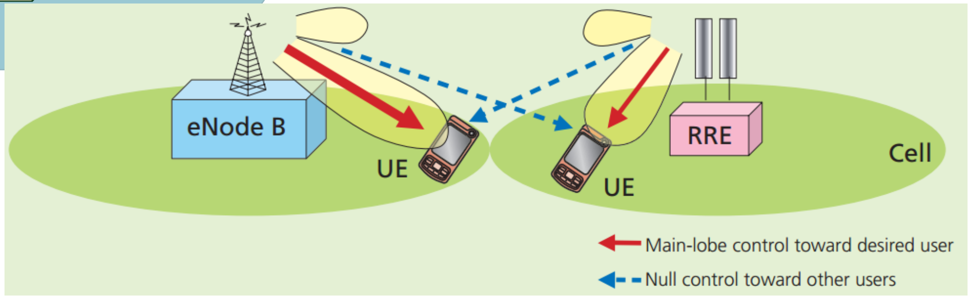
[TR 36.822]

- 10 small cells per macro cell, randomly deployed with 50 m of the minimum ISD

Inefficient radio resource utilization across eNBs



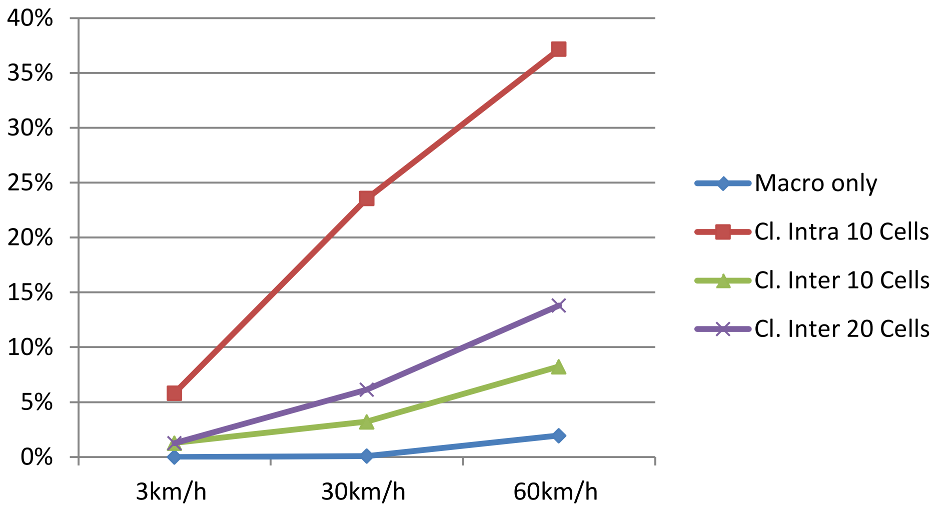
CoMP/CA deployment at the macro cell edge



[NTT DOCOMO Technical Journal Vol. 12 No. 2]

- Different services and bearers typically have different QoS characteristics.
- CoMP can be considered as a way of utilising multiple cell resources
- Rel-11 CoMP assumed that small cells are low power RRHs using ideal backhaul.

Mobility robustness



Handover failure rate without DRX

- Handover from a small cell to a macro cell / between small cells occurs.
  - Interference in the small cell carrier

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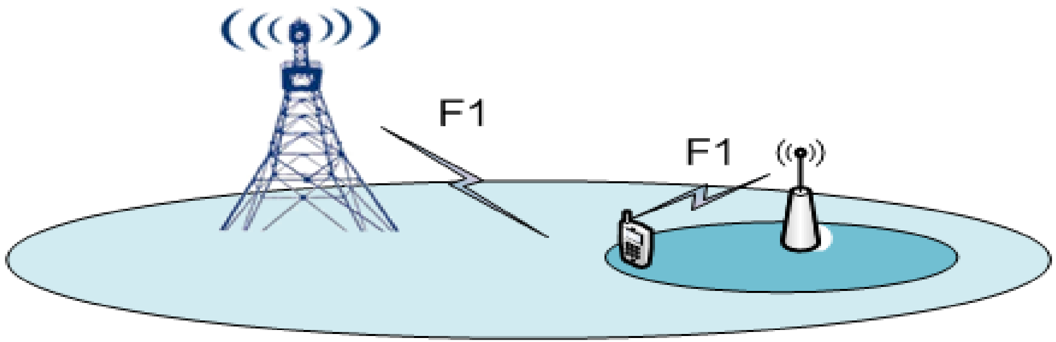
Scenario 1: co-channel

- Macro and small cells on the same carrier frequency (intra-frequency) are connected via non-ideal backhaul.

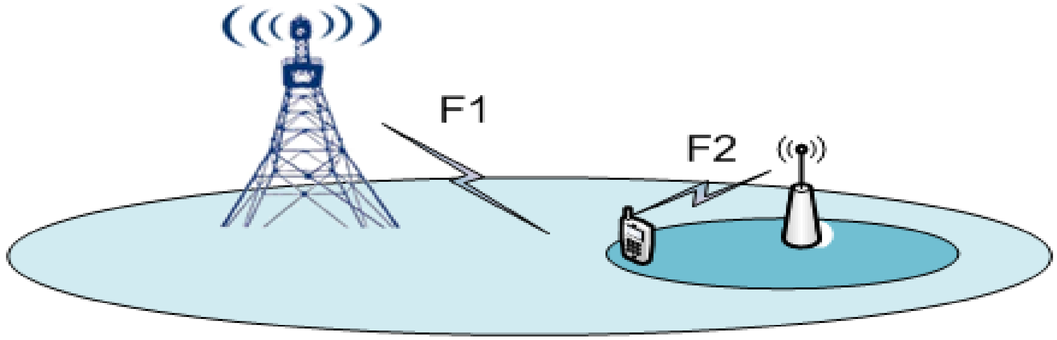


Challenges of Scenario #1

1. Mobility robustness: In particular increased HOF/RLF upon mobility from pico to macro cells
2. UL/DL imbalance between macro and small cells;
3. Increased signalling load (e.g., to CN) due to frequent handover
4. Difficult to improve per-user throughput by utilizing radio resources in more than one eNB
5. Network planning and configuration effort

Scenario 2: inter-frequency scenario

- Macro and small cells on different carrier frequencies (inter-frequency) are connected via non-ideal backhaul.

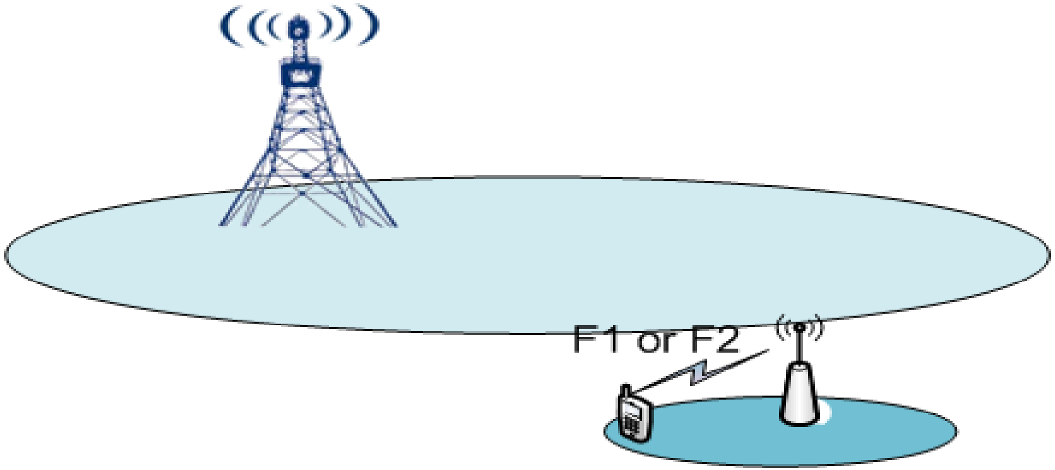


Challenges of Scenario #2

1. Mobility robustness
2. UL/DL imbalance between macro and small cells
3. Increased signalling load (e.g., to CN) due to frequent handover
4. Difficult to improve per-user throughput by utilizing radio resources in more than one eNB
5. Network planning and configuration effort

Scenario 3: out of coverage

- Macro and small cells on the same/diiferent carrier frequency are connected via non-ideal backhaul.
- Small cell out of coverage of macro cell



Challenges of Scenario #3

1. Mobility robustness
2. Increased signalling load (e.g., to CN) due to frequent handover
3. Network planning and configuration effort

Potential Solution

Dual connectivity

Dual Connectivity

- Dual Connectivity (DC) operation:
  - Multiple RX/TX UE in RRC_CONNECTED
  - Utilise radio resources provided by two distinct schedulers
  - Schedulers located in two eNBs
  - Two eNBs connected via a non-ideal backhaul over the X2 interface.

- Enhancing small cells by dual connectivity:
  - Increased UE throughput especially for cell edge UEs
  - Mobility robustness enhancement
  - Reducing signaling overhead towards the core due to frequent handover.

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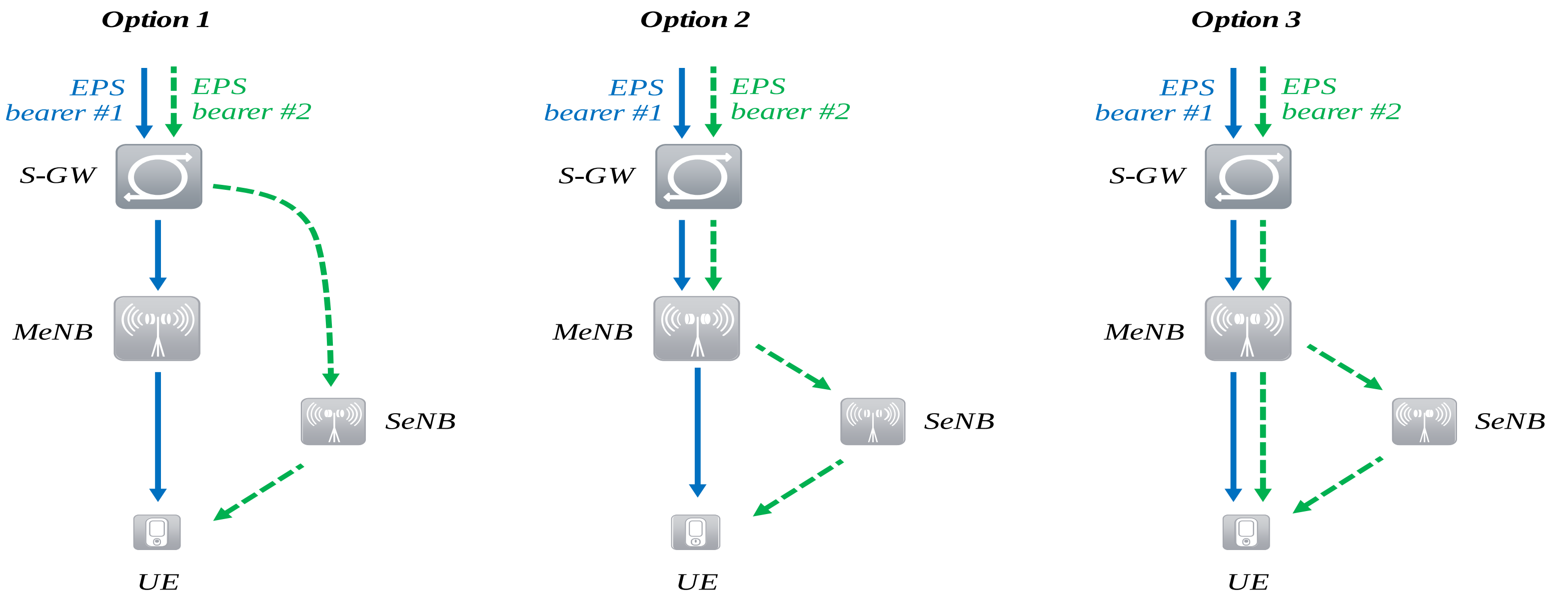
Architecture

- User plane architecture
  - 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

Architecture (cont.)

- Bearer Split Options



U-plane protocol stack

Four families of U-plane alternatives emerge:

A. Independent PDCPs

B. Master-Slave PDCPs

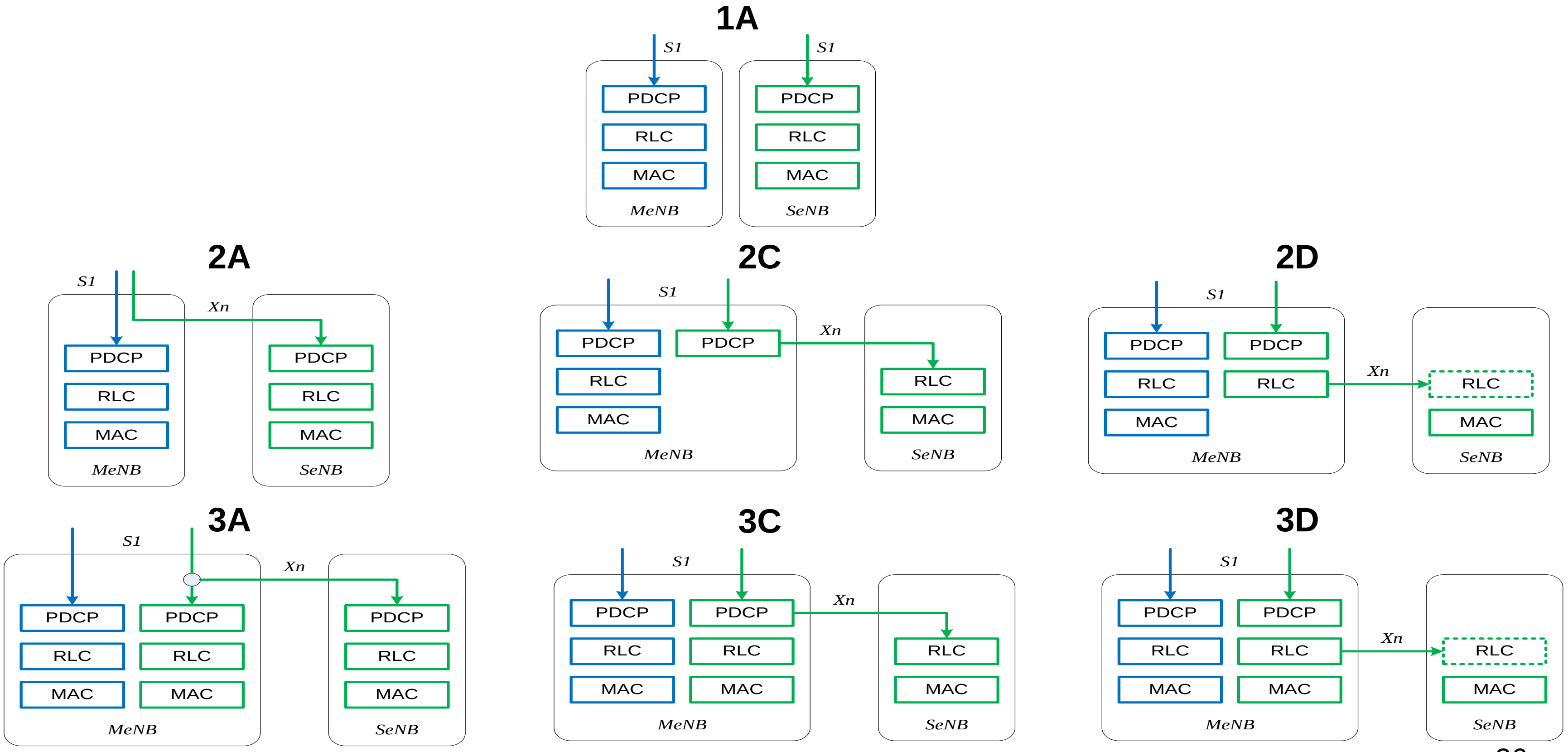
C. Independent RLCs

D. Master-Slave RLCs

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.

Alternatives



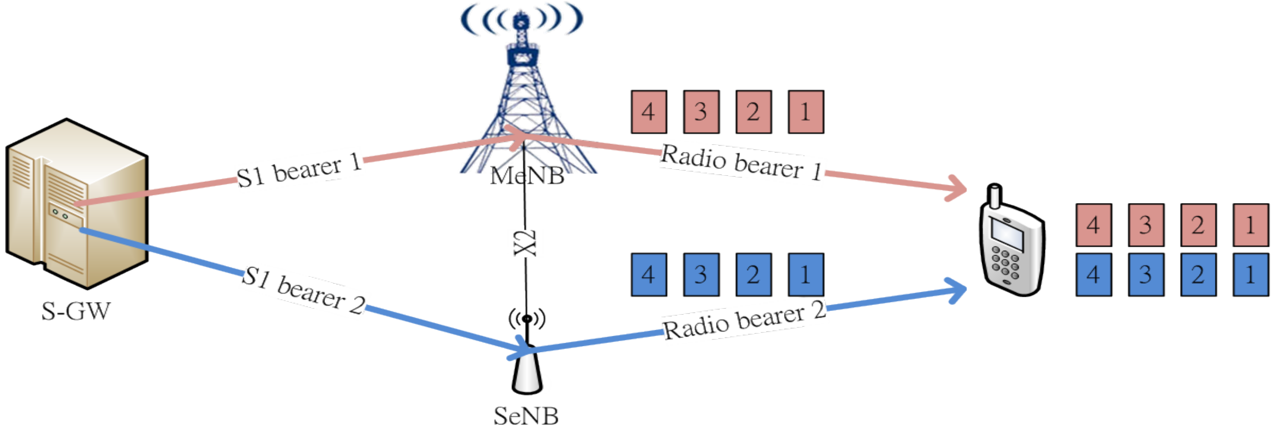
Comparison of U-plane data split options

	Option 1	Option 2	Option 3
Per-user throughput enhancements	Lower gain is expected.		Higher gain is expected.
Mobility robustness	Can be achieved.		
Signalling load to CN	Both SeNB and MeNB mobility is visible to CN.	Comparable to the macro only network.	
Backhaul requirements	No additional throughput requirement on backhaul of MeNB	Not analysed	The Xn interface has to offer the latency of 5-30 ms and sufficient capacity.

- Alternative 1A and 3C are to be progressed to support U-plane data split options of Option 1and 3 in this study

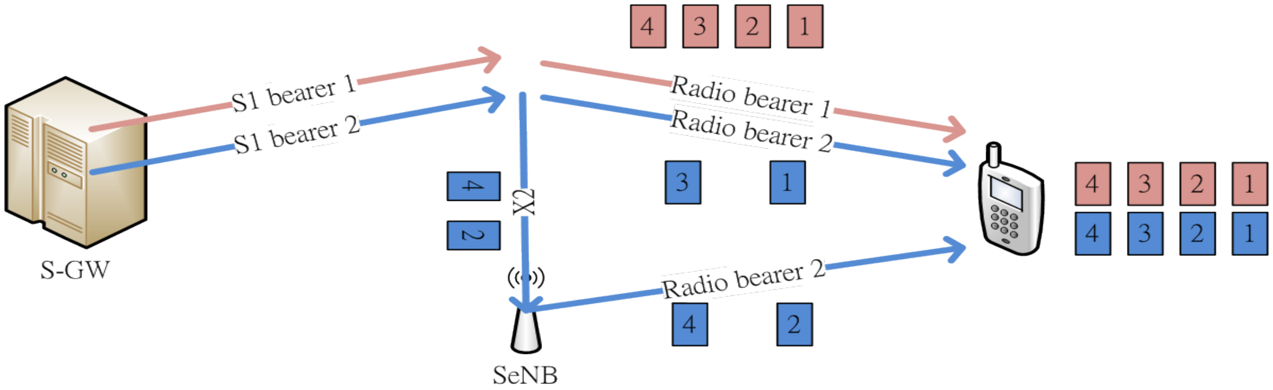
Architecture (1/2)

- Option 1A - Bearer level split at S-GW



Architecture (2/2)

- Option 3C - Packet level split as PDCP PDUs at MeNB



Comparison of user plane architectures

- Pros and cons for 1A/3C user plane architectures

	Alt 1A	Alt 3C
Pros	• MeNB don’t need buffer traffic of SeNB • Low impact on PDCP RLC	• SeNB mobility not visible to CN • Security only required in MeNB
Cons	• SeNB mobility affect CN • Security required in both eNBs	• Need routing, buffering. • PDCP reordering • Flow control

How about UL bearer split?

- Benefits of UL DRB Splitting
  - Uplink TP
  - Downlink TP (effect of TCP RTT)
  - UL Load Balancing
  - Increased re-transmissions after SeNB change

- Expected complexities of UL DRB Splitting
  - Physical Layer Procedure (e.g. Power splitting)
  - L2 procedures BSR, LCP

Uplink Throughput

- Some TCP ACKs will reach UE via SeNB and others via MeNB
  - Incur the re-ordering delay in UE PDCP and will thus affect the TCP RTT

- Therefore, from this perspective the TCP throughput can only be lower compared with when all the DL packets were received via MeNB only.

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User Plane Features

- Buffer Status Reporting (BSR)
- LCP procedure
- Discontinuous Reception (DRX)
- Mac entity

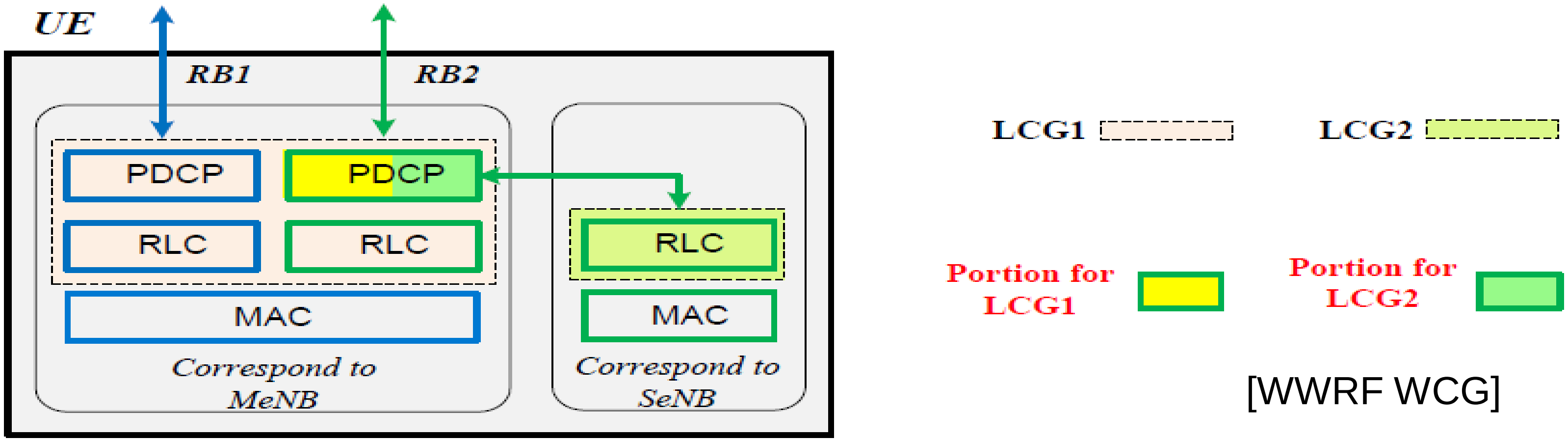
Legacy BSR

- TS 36.321
  - Provide the serving eNB with information about the amount of data available for transmission in the UL buffers of the UE.
  - UL data, for a logical channel which belongs to a LCG, becomes available for transmission in the RLC entity or in the PDCP entity

- Legacy-buffer status of eNB specific bearers is only reported to the corresponding eNB.

BSR in DC

- RLC entities are logical channel specific
  - Buffer status in RLC is reported to the corresponding eNB for both logical channels of the split bearer
- UE calculates PDCP buffer size in the BSR for the MeNB and the SeNB according to the configured ratio



[WWRF WCG]

Legacy LCP procedure

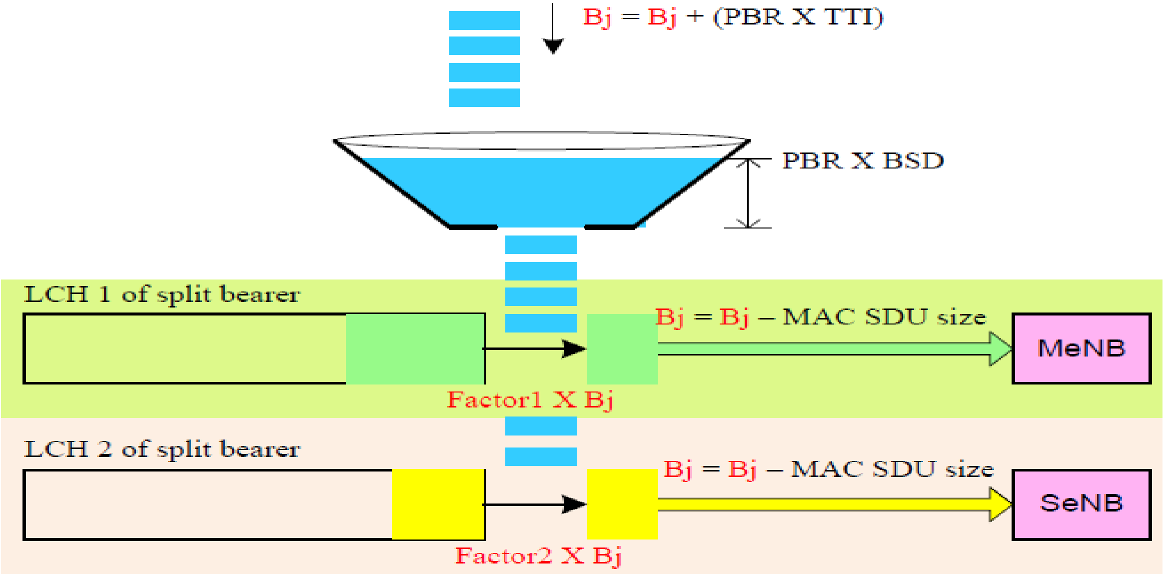
- TS 36.321
  - UE shall maintain a variable *Bj* for each logical channel *j*. *Bj* shall be initialized to zero when the related logical channel is established, and incremented by the product *PBR* × *TTI* duration for each *TTI.*
    - PBR-Prioritized Bit Rate of logical channel j
  - Bj can never exceed the bucket size.
    - Bucket size of a logical channel is equal to PBR × BSD.
    - PBR and BSD are configured by upper layers

LCP procedure in DC

- Common/separate token bucket modeling.
- PBR of the original split bearer needs to be divided by a configured ratio between the corresponding logical channels.
- Common token bucket
  - Two logical channels of the split bearer share the same token bucket
  - Bucket size reuses that for the original bearer.

LCP procedure in DC

- Common token bucket modeling



[WWRF WCG]

Starvation of RLC status report may occur.

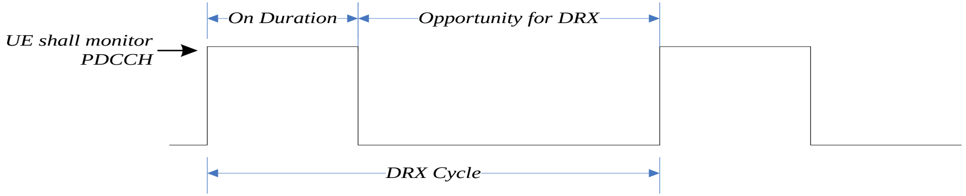
LCP procedure in DC

- Separate token bucket
  - Each logical channel maintains its own token bucket independently.
  - Increasing rate of tokens for each bucket is according to its split rate of PBR.

- In release 12 LTE DC, separate token bucket modeling is adopted.

Legacy DRX

- The UE may be configured by RRC with a DRX functionality that controls the UE's PDCCH monitoring activity.



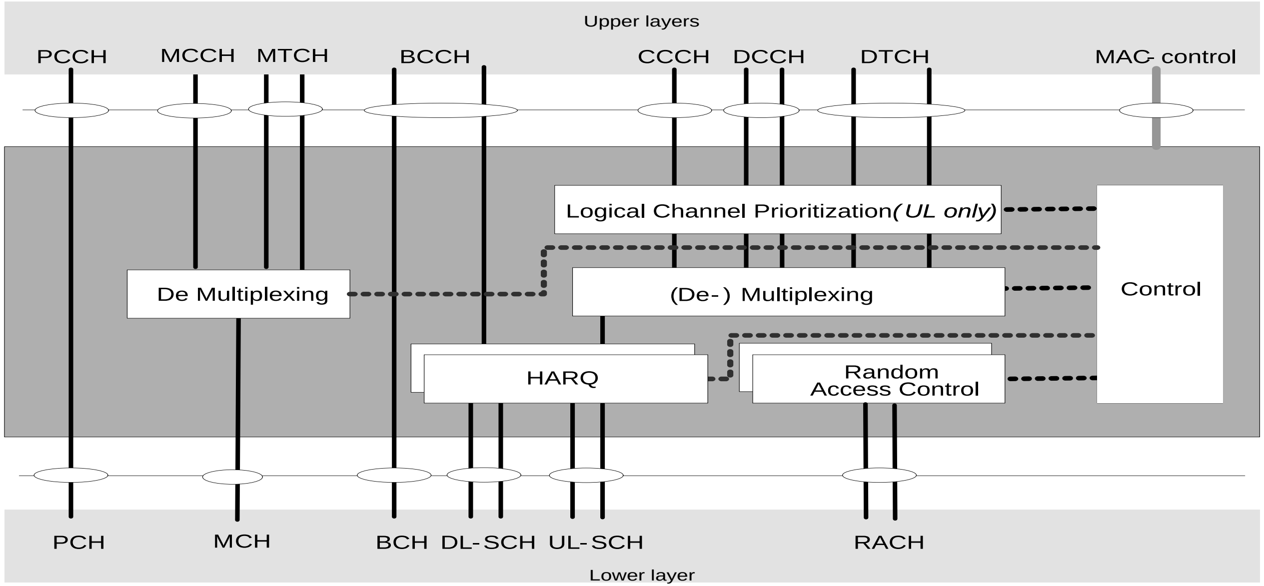
- RRC controls DRX operation by configuring
  - *onDurationTimer*
  - *drx-InactivityTimer*
  - *drx-RetransmissionTimer*
  - *longDRX-Cycle*
  - *drxStartOffset*
  - *drxShortCycleTimer*
  - *shortDRX-Cycle*

DRX in DC

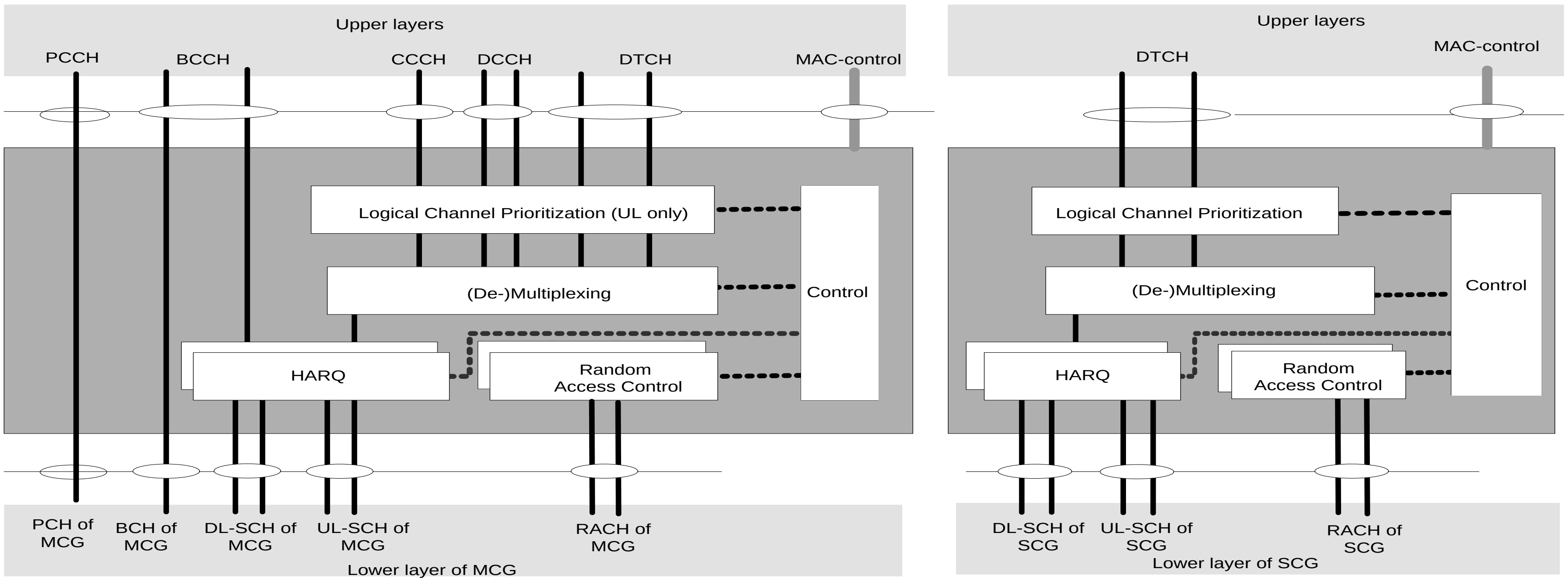
- MeNB and the SeNB cannot obtain each other's cell status in time.
- Exchange of the DRX parameters configuration between the MeNB and the SeNB.

- Whether to align DRX operation between two eNBs is up to implementation.

Legacy MAC entity



MAC entity in DC



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Control Plane Feature

- For a UE configured with DC, all RRC messages on SRB1 and SRB2 (both in downlink and uplink) are transferred via the MCG.
  - eNB Sychronization
  - System information acquisition
  - SeNB radio resource management
  - Selection of connection at the UE

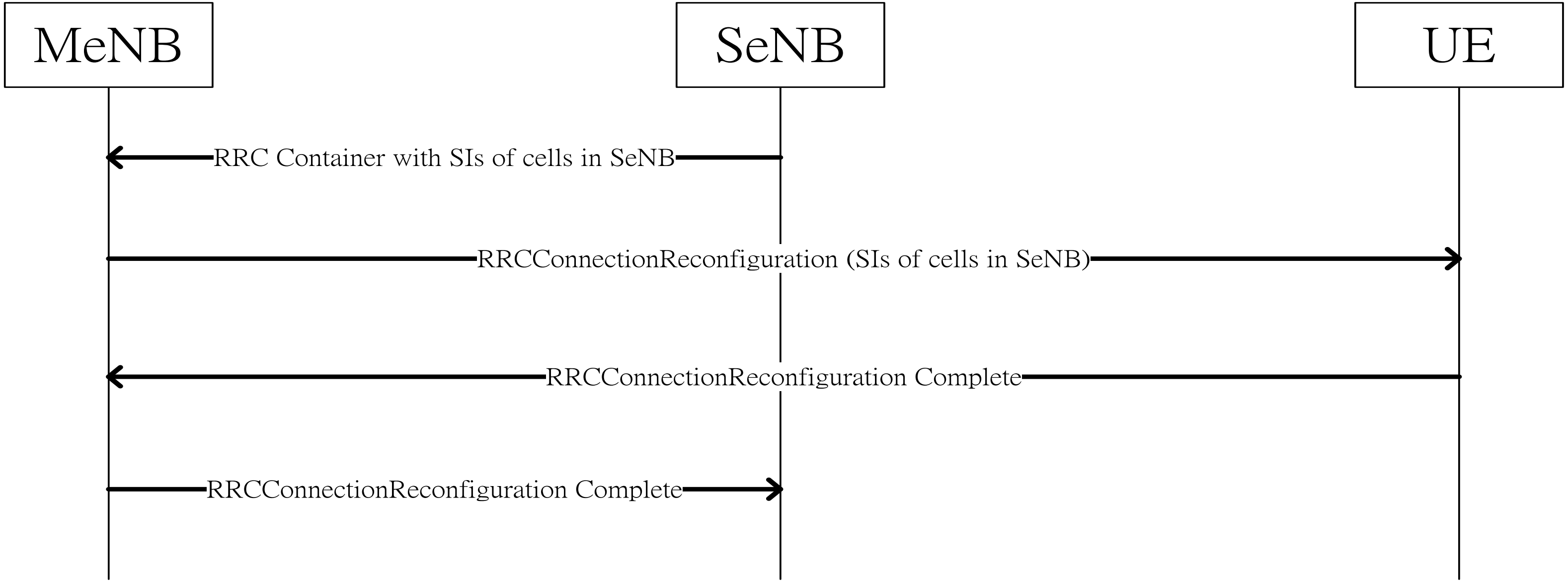
eNBs Synchronization

- Not required for the MeNB and SeNB to be SFN synchronized
  - (not like the carrier aggregation (CA) case in which the aggregated serving cells from the same eNB are strictly SFN synchronized).

- The UE may only need to obtain SFN of one special cell in the SeNB, i.e. the always activated cell with configured PUCCH.

System information acquisition

- In Rel-10 and Rel-11 CA technology, system information of all SCells is configured to the UE by dedicated RRC signaling.

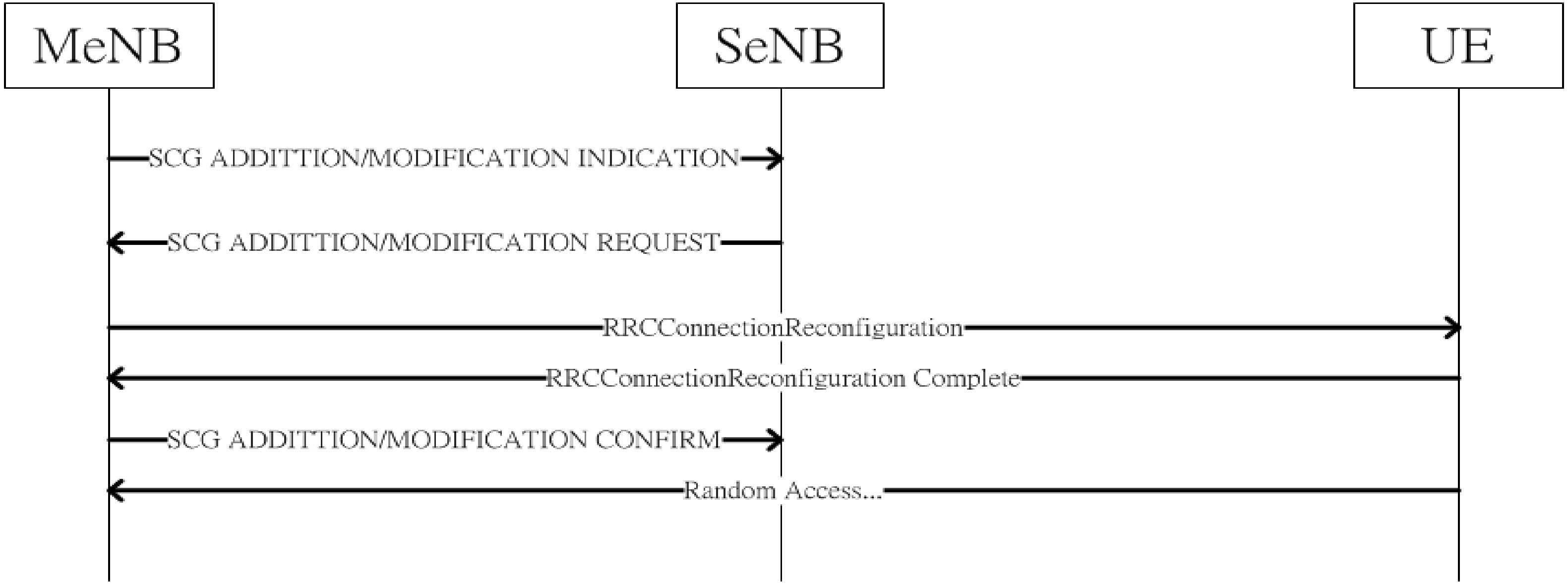


SeNB radio resource management

- SeNB is primarily responsible for allocating radio resources of its own cells.
- Inter-eNB coordination is needed for
  - UE capabilities
  - Cell/bearer management
  - QoS requirements
- Information is exchanged through RRC containers carried in X2 messages and both eNBs can understand each other's radio resource configurations.

Addition Procedure

- **SeNB (SCG) addition/modification procedure**



Selection of connection at the UE

- MeNB decide which SeNB as additional connection for the UE based on UE's measurement report.

- In future releases, it is a potential candidate or migration path to have the UE to decide which SeNB to connect with
  - Quality of wireless signal, can be best measured at the UE, battery usage, running application.

References

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6. 3GPP TS 36.321Medium Access Control (MAC) protocol specification.

Thank you for your kind attention

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