

Agenda item: 7.2.2.1
Source: Nokia Siemens Networks (Rapporteur)
Title: Email Discussion Report on U-Plane Alternatives [81bis#19]
Document for: Discussion and Decision

1 Introduction

During RAN2#81 bis meeting a number of contributions [1-18] have been submitted on User Plane Architecture for the study item on Small Cell Enhancements [[RP-122033](#)], but due to lack of time, they were not discussed. The purpose of this email discussion is to gather company views on the architecture alternatives in order to produce a TP for inclusion in the SCE TR [[36.842](#)]. The objective is not to already select one architecture but to agree on a qualitative comparison

2 Terminology

As latest highlighted at the beginning of the Rel-10 discussions on Carrier Aggregation, it is first important to establish a common terminology for the discussion to be fruitful on a new topic. For dual connectivity, the following is therefore proposed:

- MeNB: Macro eNB, terminates at least S1-MME and therefore acts as mobility anchor towards the CN;
- SeNB: Small Cell eNB;
- Bearer Split: refers to the ability to split a bearer over multiple eNBs;

Question 1: do companies agree with the proposed terminology?

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Company	Yes/No	Comments
MediaTek	Ok	We assume that the terminology can be updated once we have a common view what will be the functionality. However if possible, we'd prefer to not relate to cell size, e.g. use "anchor"-drift" or "anchor"-assisting" terminology instead of MeNB and SeNB.
LGE	OK	We are ok with the proposed terminology for the time being.
Nokia & NSN	Yes	One could also consider Master eNB (MeNB) and Secondary eNB (eNB) or Mobility anchor eNB (MeNB) and Secondary eNB (SeNB).
BlackBerry	OK	We are OK with the terminology as long as it is used consistently
RME		For MeNB and SeNB, we also think probably it would be good to name it as Master eNB and Slave/Secondary eNB as from RAN2 point of view, dual connectivity might apply independent from the cell size. However, we also agree that the most common case should be that macro eNB act as master eNB and small cell eNB act as slave/secondary eNB so we could still take this as assumption. For bearer split terminology, maybe we need to clarify what bearer are we referring to? E.g. radio bearer, S1 bearer?
CATT	Yes	We are fine with the terminology.
Samsung	Yes	We can introduce better terminologies during WI phase. The meaning/intention is clear and it should be fine for SI.
Panasonic	Yes	
NEC	Yes	Just for use during the email discussion. If necessary, RAN2 can discuss the terminology further in RAN2#82 meeting as proposed by email rapporteur.
InterDigital	Yes	We prefer a simple acronym, such as MeNB and SeNB terminology
Ericsson, ST-Ericsson	No	We prefer to use terminology which is not related to the eNB power class. For example, "anchor eNB" and "assisting eNB". With regards to bearer split, maybe this could be further clarified to EPS bearer split, DRB bearer split etc.
Huawei	Yes	We see these terminologies clear for current discussions. Changes can be introduced later if required by further progress in the studies (e.g., with regards to scenario 3).
ZTE		In general we are fine with the terminology for this email discussion. But we also think MeNB is not necessary always an anchor node if such anchor functionality is moved out to be an independent node e.g. one Gateway
KDDI	No	We support to remain terminologies of MeNB and SeNB and change descriptions of them as Master eNB and Secondary eNB.
ITRI	No	We tend to use "Primary"-secondary" or "anchor" - "assisting" terminology.
ASUSTeK	Yes	We are fine to use these terminologies for this discussion. If cell size relation is a concern, other terminologies, e.g. PeNB (Primary eNB) and SeNB (Secondary eNB), could be used.
Hitachi	OK	We are OK with using these terminologies in this phase. However, we are also fine to use terminologies that are not related to cell size (e.g. anchor and assisting eNB).
Alcatel-Lucent/Alcatel-Lucent Shanghai Bell	OK	For the email discussion we are ok with use of "macro eNB" and "small cell eNB". However we think "Primary eNB" and "Secondary eNB" are more appropriate terminology considering the functional and procedural aspects of eNBs involved. Bearer split: we assume this is meant for the packet level traffic split where traffic belongs to a EPS bearer could be delivered over both macro and small cell eNBs.
NTT DOCOMO	No	We prefer Master eNB and Slave/Secondary eNB as commented by Renesas. Also, we think that it will be better to define a terminology for referring the path/routing split of two different bearers (i.e., option 1 and 2 in section 2). Something in a direction of "CN service split" for option 1 and "RAN service split" for option 2.
New Postcom	OK	We prefer to apply terms "anchor eNB" and "assisting eNB" to replace "MeNB" and "SeNB".
Intel	Yes	We're OK with the proposed terminology.
Broadcom Corporation	No	We prefer not to have the terminology depend on eNB type/cell size. Instead we would prefer to use similar terminology as the CP architecture (anchor and assisting eNB).
ETRI	Yes	We are ok. However if there is consensus to change the terminologies, it can be revised through discussion.
Fujitsu	Yes	Yes, for the time being.
CMCC	No	As discussed in RAN2 email reflector, we prefer to use "anchor"-assisting" terminology instead of MeNB and SeNB would be much better, since this is decoupled with transmission power of eNB, and aligned with current C-plane discussion and future possible description of specification.

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2 Bearer Split Options

Because the user plane alternatives are tightly coupled to the bearer split options, those need to be looked at. Taking the downlink direction as an example, three options exist 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.

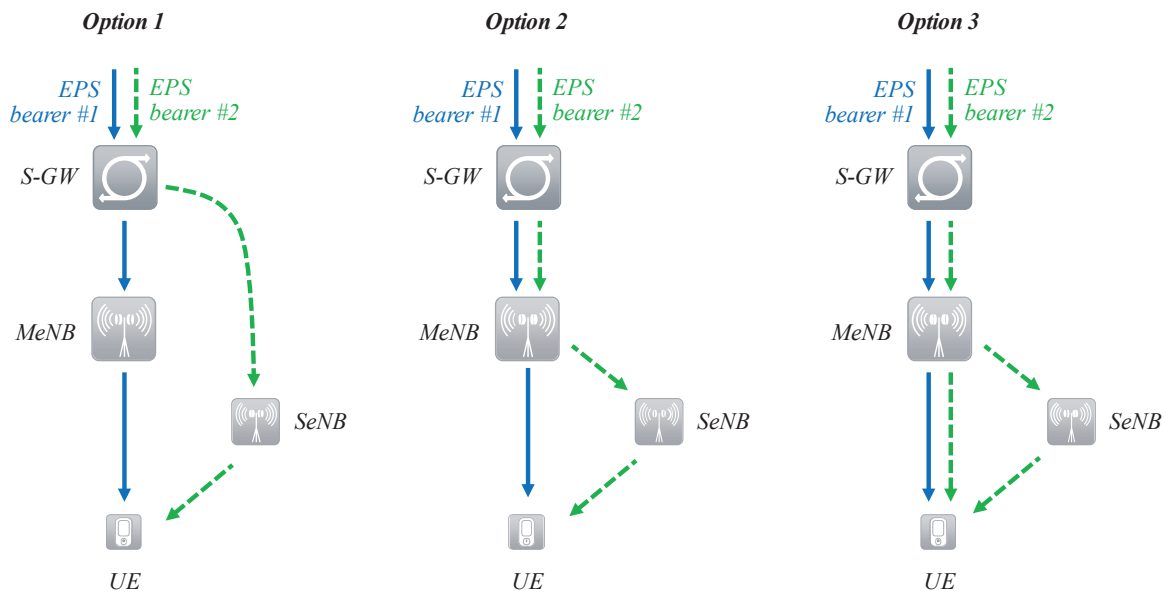


Figure 1: Bearer Split Options

Question 2: are those the three possible options?

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Company	Yes/No	Comments
MediaTek	Yes	Agree that these are the possible options. We think the study can focus on Option 1 and 3 as the main options. Most aspects of Option 2 would be subsets of options 1 and 3.
LGE	Yes	We think that Option 1 and 2 are main options. Option 3 needs radical changes considering 1-to-1 mapping rule between an EPS bearer and a radio bearer. Thus, we would like to exclude Option 3 unless significant benefits are shown.
Nokia & NSN	Yes	Offloading of MeNB is not compatible with hiding SeNB from CN i.e. hiding SeNB mobility from CN requires the MeNB to handle the SeNB bearers.
BlackBerry	Yes	It seems like option 2 is special case of option 3 (if the bearer split is set to 0% option 3 becomes option 2). We prefer to hide SeNB mobility from the core network
RME	Yes	We share the view of MediaTek and BB that option 2 could be a subset of option 3. According to the figure, our understanding is that we have the above three options in general, and according to the terminology only option 3 have bearer split feature. One point to clarify is still that when we say bearer split, do we mean radio bearer or S1 bearer?
CATT	Yes	We prefer to consider Option 1 and 2 as the main options.
Samsung	Yes	
Panasonic	Yes	
NEC	Yes	
InterDigital	Yes	Option 1 seems to be contradictive to the requirement of the study item to have minimal impact to the core network. It also seems contradictive of the objectives of the study item to identify mechanisms that minimizes inter-node UE context transfer and signalling towards the core network We agree with MediaTek that Option 2 is a flavour of Option 3, therefore we should consider Option 1 and Option 3. Additionally, multiframe should be considered as a separate issue. Furthermore, we think that multi-flow should be considered separately for the uplink direction and for the downlink direction
Ericsson, ST-Ericsson	Yes	Agree that these could be main options. Agree with MediaTek that Option 2 is not so interesting.
Huawei	Yes	Option 1 would not shield CN from impact of SeNB change of UE.
ZTE	Yes	We intend to agree with LGE that option 1 and option2 are main options. In addition for option 1 EPS bears can also split from one gateway between SGW and MeNB and SeNB
KDDI	Yes	Generally speaking, those delay-sensitive services experience much more performance degradation due to frequent interruption in the user-plane transmission. Therefore they are desired to be provided by Macro eNB. In order to encourage the non-delay-sensitive traffic offload to small cells for UEs having both delay-sensitive and non-delay-sensitive services, bearer splitting is necessary. For bearer splitting, our understanding is that options 1 and 2 are basic solutions whereas option 3 is just an extension of option 2. Moreover, if MeNB and SeNB are modified to represent master and secondary eNBs clarification on whether or not option 2 is per UE perspective may be needed.
ITRI	Yes	For option3, does the figure imply that some EPS bearer, e.g., EPS bearer 1 (drawn by blue line), can have no bearer split? If Yes, option 2 is only a subset of option3. If No, clarification on the figure of option3 is needed.
ASUSTeK	Yes	
Hitachi	Yes	
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	yes	Three options require different functions and procedures. Complexity of the support of option and the additional gain compared to the other options should be investigated.
NTT DOCOMO	Yes	
New Postcom	Yes	
Intel	Yes	We agree with LG that option 1 and 2 are main options. Option 3 has many impacts as discussed in our contribution R2-131401. The main benefit of option 3 is the increased user throughput when system load is low, however it is questionable whether such scenario is the target for optimization.
Broadcom Corporation	Yes	We believe option 1 and option 3 are the primary options. Option 2 is a subset of option 3.
ETRI	Yes	We think option 1 and option 3 are main alternatives. And option 2 seems to be a subset of option 3.
Fujitsu	Yes	Agree with Huawei.

CMCC	Yes	We think these are the possible options. From throughput enhancement point of view, option 3 is preferred.

3 User Plane Alternatives

A common proposal to all the papers submitted at RAN2#81 bis meeting [1-18] on UP Architecture is that 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.

Proposal 1: the protocol stack in the SeNB must at least support (re-)segmentation.

Question 3: can we agree that the protocol stack in the SeNB must at least support (re-)segmentation?		
Company	Yes/No	Comments
MediaTek	Yes	
LGE	Yes	
Nokia & NSN	Yes	
BlackBerry	Yes	
RME	Yes	
CATT	Yes	
Samsung	Yes	We assume there are options working properly without (re-) segmentation, but we are fine with focusing on options with resegmentation.
Panasonic	Yes	This proposal is only referring to RLC AM? If it is also supposed to be applicable for RLC UM, then further changes to the RLC protocol are required
NEC	Yes	
InterDigital	Yes	
Ericsson, ST-Ericsson	Yes	We consider this assumption valid. Naturally, also when S1-U terminates at the SeNB, SeNB must at least support (re-)segmentation.
Huawei	Yes	
ZTE	Yes	
KDDI	Yes	
ITRI	Yes	
ASUSTeK	Yes	
Hitachi	Yes	
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	yes	We are fine to focus on the protocol architectures with RLC (re) segmentation located at small cell eNB. This also implies that independent schedulers are used at the macro and small cell.
NTT DOCOMO	Yes	
New Postcom	Yes	We agree that it needs further clarification for master-slave options
Intel	Yes	
Broadcom Corporation	Yes	
ETRI	Yes	
Fujitsu	Yes	
CMCC	Yes	

Based on the assumption that the SeNB must at least support (re-)segmentation, we can distinguish four families for the UP Alternatives [1-18]:

- A. **Independent PDCCPs:** this option terminates the currently defined air-interface U-plane protocol stack completely per bearer, 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.
- 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.

Question 4: do companies agree that those are the four possible families of options?

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Company	Yes/No	Comments
MediaTek	Yes	
LGE	Yes	
Nokia & NSN	Yes	
BlackBerry	Yes	
RME	Yes	Although we agree on the options, we are not clear about the master-slave layer options because we don't know yet what function will be moved to/from where. Another comment is that if we start to re-structure the user plane layers, this might lead to larger implementation complexity to both eNB and UE sides
CATT	Yes	More details on Alt B should be provided, especially for the bearer split. We need to know exactly what function(s) the Master/Slave PDCP performs.
Samsung	Yes for A/C/D	We are not sure how Master-slave PDCP works and what is the purpose. Maybe the proponent of this option can clarify a bit.
Panasonic	Yes	
NEC	Yes	
InterDigital	Yes	Although not against the idea of split PDCP, we are slightly reluctant to agree on option B given that the functionality split is not clearly defined in the text. Additionally, it is not clear how security is applied and whether security needs to be in MeNB. If security remains in the MeNB then it is not clear how part of the PDCP functionality can reside in the SeNB as security is the last step performed in the PDCP. In particular, for security aspects and for PDCP termination, some form of alignment between UP architecture and CP architecture is desirable. There is one additional alternative that can be considered, the PDCP and the RLC reside in the MeNB and MAC in the SCell, and where (re)segmentation may be performed by the MAC layer
Ericsson, ST-Ericsson	Yes	We think that the master-slave alternatives need further clarification
Huawei	Yes	For option B, our thinking is slave-PDCP may help handling PDCP discard related operations and some inter-layer interaction. This may reduce some exchanges over backhaul between MeNB and SeNB.
ZTE	Yes	For option 1, bearer could also split in one gateway between S-GW and MeNB/SeNB
KDDI	Yes	
ITRI	Yes	
ASUSTeK	Yes	Regarding option D, if MeNB always provides built RLC PDUs to SeNB, re-segmentation is required to put those built RLC PDUs into actual available grant for both new transmission and retransmission. Then, header overhead is increased. Moreover, RLC UM needs to support re-segmentation, i.e. new UMD PDU format. Impact to RLC is significant.
Hitachi	Yes	We also think further clarification is needed for master-slave options.
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	yes	We are not clear of the functionality of option B.
NTT DOCOMO	Yes	
New Postcom	Yes	
Intel	Yes	
Broadcom Corporation	Yes	Broadcom Corporation
ETRI	Yes	
Fujitsu	Yes	Regarding Master-Slave PDCP, security may be one of the split functions. In the case when the security function is located in both MeNB and SeNB, the sequence numbering would be performed in MeNB for providing in-sequence delivery but the ciphering would be performed in SeNB,
CMCC	Yes	

Based on the options for bearer split and UP 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.

Question 5: is this a complete list of possible UP Alternatives?

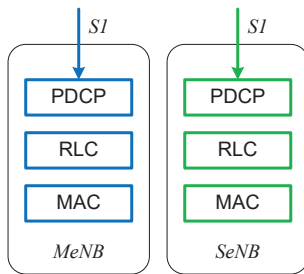
Question 5: is this a complete list of possible UP Alternatives?		
Company	Yes/No	Comments
MediaTek	Yes	
LGE	Yes	
Nokia & NSN	Yes	
BlackBerry	Yes	
RME	Yes	In general, we think the master-slave options are a bit confusing because we are not clear what function will be moved to slave and what function will be enhanced in master. So it might be a bit hard to compare with the other options. Even for the options without master-slave, same enhancement might be needed.
CATT	Yes	We should try to down-select the alternatives.
Samsung	Yes except for 2B and 3B	As indicated above, clarification would be needed.
Panasonic	Yes	
NEC	Yes	
InterDigital	Yes	As we have indicated for options B we are not sure whether it is a valid option and whether the definition is clear. The list is complete but some efforts should be made to down select the number of alternative as much as possible
Ericsson, ST-Ericsson	Yes	We think that the master-slave alternatives need further clarification
Huawei	Yes	
ZTE		If only referring to Uu interface, then yes.
KDDI	Yes	We are open for these possible UP alternatives.
ITRI	Yes	
ASUSTeK	Yes	
Hitachi	Yes	
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	yes	We are not clear of the functionality of option 2B and 3B.
NTT DOCOMO	Yes	
New Postcom	Yes	
Intel	Yes	
Broadcom Corporation	Yes	
ETRI	Yes	Function split between nodes regarding to one protocol may be less feasible in terms of specification impact.
Fujitsu	Yes	
CMCC	Yes	

4 Comparison

Having listed the different alternatives, it is now possible to compare them. Some recommended criteria for doing so include [1-18]: MeNB air interface offloading, MeNB processing offloading, throughput aspects, interruption at SeNB change, CN aspects of SeNB change, Logical Channel Prioritisation impacts, security impacts (e.g. set of keys

required), data forwarding at handover, buffering requirements and SN space, layer responsible for re-ordering, GTP impacts, possibility for local IP breakout, smart caching and traffic shaping.

Alternative 1A: S1-U terminates in SeNB + independent PDCPs (no bearer split)



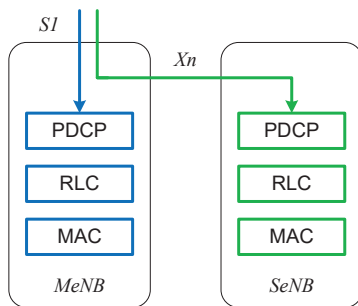
Company Views on Alternative 1A			
Company	Comments	Benefits	Drawbacks
MediaTek	Should be considered a main study alternative (for non bearer split), as it seems to be the only alternative that addresses long latency backhauls well.	No backhaul tromboning, suitable for long-latency or unknown performance backhauls. No L2 impact (almost).	Path switching when UE changes cell in the local area, i.e. CP load. Dual security need to be handled somehow, some UE impact.
LGE	Could be a possible option	No traffic routing between MeNB and SeNB No PDCP/RLC impact	CN signalling load due to SeNB change Dual security keys
Nokia & NSN	alternative that is the closest to existing specification and in light of its benefits/drawbacks would need to be carefully compared to single-connectivity.	little or no impact to PDCP/RLC and GTP-U/UDP/IP no need to route all traffic to MeNB no need for MeNB to buffer or process packets for an EPS bearer transmitted by the SeNB	logical channel prioritisation impacts for the transmission of uplink data (U-plane data from one specific EPS bearer needs to be transmitted towards a specific node using a specific uplink) multiple sets of security keys required handover like procedure between SeNB with data forwarding and path switch visible to CN CA/CoMP not possible, HO-like interruption at SeNB change
BlackBerry	MME has to select the same S-GW for the same UE served by two different eNB	No traffic routing between MeNB and SeNB and no protocol stack changes	Mobility in small cell is not isolated from core network. In addition, MME has to create the bearer split while MME may not know the load condition of the small cell
RME	We think this could be one good option if the backhaul link between MeNB and SeNB are not good enough, e.g. capacity is limited	Support local breakout Good scalability for network planning, could offload the processing of MeNB Simpler for eNB and UE implementation Lower requirement on the backhaul link between MeNB and SeNB	Hard split between bearers Change of the small cell would require signalling (path switch & data forwarding) between small cells and potentially also towards core network Security aspect need to be considered further
CATT	It seems no need to discussion if local IP breakout can be supported in RAN2. If companies have concerns on this function, we think local IP breakout can be evaluated in RAN3 or SA2.	Offloading data depending on the QoS requirements; MeNB processing offloading; no need for MeNB to buffer packets; small impact on MeNB-SeNB interface; No impact on RLC/PDCP for UE and network; No extension of SN space	Interruption reduced at SeNB-MeNB mobility event but limited reduction at other mobility events due to non-ideal backhaul; CN signalling impact at SeNB change Serving cell specific LCP (Logical Channel Priority); Multiple sets of security keys; Data forwarding needed between eNBs;
Samsung	We think small cell local-break out and small cell contents caching are important feature. Regarding the security concern, following two points need to be considered; 1) The situation is similar in home ENB. Home ENB stores security key. 2) If SeNB supports non-CA UE, SeNB anyway needs to maintain security context. Regarding peak data rate, following two points need to be considered; 1) In reality data rate increase from the macro cell wouldn't be considerable. 2) Peak data rate is still achievable by establishing two EPS bearers Regarding interruption, following points need to be considered; 1) The length of the interruption may	1. Support of useful features like small cell local break-out and small cell contents caching	1. Security. One can assume SeNB's security level is lower than MeNB. 2. Peak data rate is not achieved, when only one EPS bearer is used 3. Interruption during SCell addition/release 4. CN signalling load increase upon UE entering small cell coverage 5. Impacts to CN nodes (e.g. MME & S-GW)

	not be considerable and smaller than at handover today; 2) EPS-bearers served in the small cell would be delay-tolerant one		
Panasonic	Only alternative where no data forwarding between MeNB and SeNB occurs.	Easy from standards perspective Reuse Rel-8/9 handover mechanisms for mobility on small cell layer No additional complexity for MeNB (due to data forwarding to small cell eNB), less signalling on Xn interface	Increased CN signalling for mobility events, e.g. path switch. Security might be an issue, (e.g. forward security might be an issue). SeNB has to support full protocol stack
NEC	This would result in security to be performed in separate nodes. One option could be to transfer the KeNB to SeNB from MeNB. Currently KeNB or NH is transferred over S1. At the same time, it is worth mentioning that SeNB is secure to receive KeNB from MME for normal UEs, so any security information over non-ideal backhaul (Xn) between MeNB and SeNB should be studied further.	It is our assumption that S1-U termination information is still provided by anchor eNB (MeNB) as it was agreed to terminate S1-MME in the anchor eNB. So, no new mechanism is necessary to exchange S1-U termination points even if S1-U is terminated in the SeNB. In addition, there is no need for new protocol to transfer UP data between nodes. Additional delay due to non-ideal backhaul (Xn) could be eliminated from UP data point of view. Local breakout is possible at SeNB.	CN signalling load reduction may not be possible due to mobility across small cells.
InterDigital	Before we can settle the full set of drawbacks and benefits we need to validate whether this alternative is applicable from a security perspective. It is unclear how security is applied if there is a single security context and if not, we need to understand how security is activated in the SeNB and what the impacts to PDCP could be.	No impact on the RLC protocol Depending on the network deployment, i.e. whether there is a separate physical link going directly to the SeNB from the CN, there may be no need to dimension for data going over the MeNB No new interface needed between the MeNB and SeNB	It is unclear how security is applied and SA3 needs to be involved Increased signalling load towards the CN with the expected potential increase in the number of handovers Offloading is very static Impact to handover preparation for mobility at the small cell layer possibly involving 4 different nodes (e.g. MME, MeNB, SeNB and target SeNB) and data forwarding required Impact to admission control and interaction with the MME Multiflow cannot be supported with this option UL/DL splitting cannot be supported without significant changes to the core network
Ericsson/ ST-Ericsson		Efficient alternative as this does not consume extensively resources of backhaul or macro eNB processing. Small impact to standards. Current procedures can be reused (for handovers, path switches etc).	Does not hide all path switches towards CN when handover occurs. However, also with this alternative reduce ping-pong handovers and CN signalling to some extent.
Huawei	The feasibility assessment of this option needs involvement of WGs outside RAN (e.g. SA2 and SA3).	No impact on L2 protocols of UP.	This alternative does not work if UE has only one EPS bearer. Both RAN and CN (MME and S-GW) are impacted by SeNB change of UE to handle control and signalling operation. It suffers the longest interruption time among these alternatives for data transmission during SeNB change. Multiple security contexts are needed for UE. Control of UE-AMBR is distributed over multiple eNBs. Distribution of UE traffic between MeNB and SeNB is performed in a static way.
ZTE	If one Gateway is introduced later on, this option need involve RAN3 working group	No impact on radio protocol stack including PDCP, RLC etc. No impact on MeNB including treatment capability. Low requirement on backhaul in terms of capacity, delay	May need independent security key for SeNB In case no Gateway is introduced, changing SeNB is visible for CN

		Good network scalability In case one Gateway is introduced above SeNB, SeNB can also be hidden from CN	
ITRI	With this alternative, dual connectivity seems no gain in terms of reducing CN signalling overhead.		
ASUSTeK	It is a feasible alternative.	No data forwarding via Xn and no delay caused by non-ideal backhaul. No change to PDCP/ RLC spec.	PDCP re-establishment is required when SeNB changes. Ciphering key (KUPenc) exchange between eNBs or UE needs to maintain multiple KUPenc. CN impact, i.e. multiple S1-U for one UE.
Hitachi	Should be considered as a feasible option.	No impacts on PDCP and RLC specifications.	Traffic routing function (for SeNB traffic) is not required in MeNB. CN signalling load would not be reduced since path switch occurs in case of handover.
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	only protocol option which doesn't require data forwarding over X2 hence doesn't require high capacity backhaul link. Most straight forward option in supporting inter-vendor interoperability	Independent protocol stack is used at MeNB and SeNB, current protocol stack and functionalities can be used, No flow control is required Doesn't require high capacity backhaul link	CN signalling is required for add/remove of small cell Security handling needs investigation
NTT DOCOMO	This alt cannot achieve peak data rate comparable with Intra-eNB CA. From an operator point of view, peak data rate is one of the attractive aspect.	Does not need the additional MeNB's processing power for the data being transmitted from SeNB.	Increasing the signalling to CN The additional processing power for data routing in QoS level will be needed in CN. Cannot achieve the peak data rate aggregating CCs in MeNB and SeNB Security may not be robust.
New Postcom	It seems alternative 1A is the only option can resolve non-ideal backhaul well.	No impact on protocol stack in eNB. Offloading enhancements, improve user throughput	Impacts on CN and UE Dual security CN needs to know UE's mobility when UE changes small cell. Bearer can not be split over multiple eNBs.
Intel	This is one alternative for study	No need to route traffic between MeNB and SeNB, therefore no need to increase MeNB data processing capability Almost no impact to PDCP/RLC	Path switching signalling to CN due to SCell addition/removal is needed. When SCell is changed, data forwarding is required between MeNB and SeNB or SeNBs to avoid data loss. Security issues should be further studied since both MeNB and SeNB handle PDCP layer.
Broadcom Corporation	This architecture is independent of whether the backhaul is ideal or non-ideal. The backhaul will not impact RAN throughput. We favour the no bearer split paradigm. This architecture provides the best performance among all the no bearer split architectures considered in this document.		
ETRI	This alternative has little impact on L2 protocols at eNBs, but impacts on CN (MME & S-GW) should be considered.	No need to forward packet from MeNB to SeNB due to direct S1 interface No impacts on L2 protocols	CN signalling impact when SeNB changes Security impacts on a UE due to independent PDCP at eNBs Frequent path switching over S1 when SeNB changes
Fujitsu	Note that RAN2 has agreed that "We assume that there will be only one S1-MME Connection per UE".	All types of backhaul (X2) could be supported. No impact to L2 U-Plane operation.	RAN level dual connectivity can't be provided. E.g. for the downlink, the data distribution from S-GW to each eNB couldn't be performed based

			on the radio conditions of both MeNB and SeNB so that throughput is decreased when e.g. large amount of data is distributed to one of the eNBs with bad radio conditions.
CMCC	There is impact on CN, and from throughput of UE point of view the gain could be limited.	No impact on eNB protocol stack	Agree with MediaTek that CN load could not reduced, and there is dual security key issue (SA3 related). Furthermore, multiple streams (in one bearer) aggregation to improve throughput could not be realized.

Alternative 2A: S1-U terminates in MeNB + no bearer split in MeNB + independent PDCP at SeNB

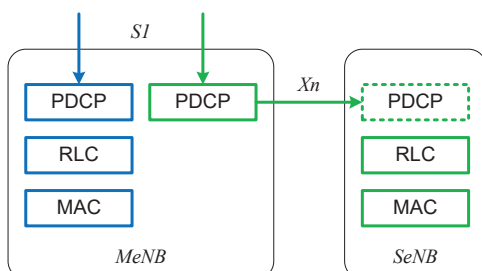


Company Views on Alternative 2A			
Company	Comments	Benefits	Drawbacks
MediaTek	Could be considered a variant of 1A, when operating towards a legacy CN.	No L2 impact (almost).	Dual security need to be handled somehow, some UE impact.
LGE	Could be a possible option	No CN signalling load due to SeNB change No PDCP/RLC impact	Traffic routing between MeNB and SeNB A new layer performing routing function is required in MeNB Dual security keys
Nokia & NSN	From a pure RAN2 viewpoint, this alternative does not seem different from 1A.	little or no impact to PDCP/RLC and GTP-U/UDP/IP no need for MeNB to buffer or process packets for an EPS bearer transmitted by the SeNB SeNB mobility hidden to CN	need to route all traffic to MeNB logical channel prioritisation impacts for the transmission of uplink data (U-plane data from one specific EPS bearer needs to be transmitted towards a specific node using a specific uplink) multiple sets of security keys required data forwarding between SeNB needed at SeNB change CA/CoMP not possible, HO-like interruption at SeNB change
BlackBerry	Agree with Nokia and NSN. No different than 1A from RAN2 point of view	Minimum protocol stack impact. MeNB can split the bearer based on feedback from SeNB	Dual security keys at two different PDCP entities. Xn has to be secured too.
RME	Alternative 2 serie could not completely offload the processing of MeNB and also has higher requirement on the backhaul link. Some of the sub-alternatives in 2 serie could be easy for UE and eNB implementation So with the same requirement, it has the drawbacks of alternative 1 but not with the benefit of alternative 3 serieses, the only benefit could be hiding the small cell from CN	Simpler for UE implementation Could hide the small cell from CN for the data transmission	Higher requirement on the backhaul link between MeNB and SeNB Will require additional layer/entity to handle the data routing Can't offload the processing of MeNB completely Hard split between bearers Security aspect need to be considered further Not good scalability, addition of SeNB will require update of the MeNB
CATT		Offloading data depending on the QoS requirements; no need for MeNB to buffer packets; No impact on RLC/PDCP for UE and network; No extension of SN space; Little impact on MeNB-SENB interface(standard effort);	Need to route all traffic to MeNB; Interruption reduced at SeNB-MeNB mobility event but limited reduction at other mobility events due to non-ideal backhaul; Multiple sets of security keys/CN possible impact at SeNB change (security); Serving cell specific LCP; Data forwarding needed between eNBs;
Samsung	Same comments as 1A; In addition, backhaul overdimensioning may not be a serious problem for certain scenarios (like ring topology or in-building deployment)	1. Support of useful features like small cell local break-out and small cell contents caching	1. Security. One can assume SENB's security level is lower than MeNB. 2. Peak data rate is not achieved, when only one EPS bearer is used 3. Interruption during SCell addition/release 4. Backhaul overdimensioning for MeNB
Panasonic		Almost no impact to CN (apart from potential security issues) Easy from (RAN2) standards perspective (same as in 1a) Mobility on small cell layer is transparent to CN (path switch in the MeNB) MeNB can map bearers based on	Data forwarding from MeNB to SeNB necessary More complexity for MeNB, e.g. new functionality for bearer mapping/data forwarding Security issue as in 1a

		information, e.g. load info, from SeNB(s)	
NEC	Security: same as option 1-A. Inter-node resource utilization primarily based on non-radio aspects.	Simple. Current X2 data forwarding scheme at inter-eNB handover could be reused. Local IP breakout is possible at SeNB.	MeNB needs a routing function based on e.g., EPS bearer id. Not sure if CN signalling reduction is still possible.
InterDigital	The security concerns are similar to Option 1A. All Option 2 and Option 3 flavours have the advantage of hiding mobility from the CN network and the disadvantage of data going through the MeNB. However, we don't think this is a big concern that should drive the design of small cell user plane architecture. The backhaul has never been an issue for achieving high rates for LTE CA and we do not see why it would become an issue now.	Handovers at the small cell layer are hidden from the core network and signalling towards CN is thereby minimized No impact on the RLC protocol Data can be forwarded without buffering directly to SeNB UL/DL traffic splitting can be supported and handled by the MeNB	It is unclear how security is applied and SA3 needs to be involved Some network impact and interaction between MeNB and SeNBs (but no need to interact with the MME) to support mobility and admission control Multiflow cannot be supported with this option
Ericsson, ST-Ericsson		Simple solution, different services (e.g. web and VoIP) can be distributed among different nodes.	Extensive increase in user plane over a limited backhaul. Some increase of user plane processing of MeNB.
Huawei	Need to consult SA3 on the feasibility of maintaining multiple security contexts for a UE.	No impact on L2 protocols of UP. Can shield SeNB change of UE from CN.	Multiple security contexts are needed for UE. It does not help UE's throughput if UE has only one EPS bearer.
ZTE	Compared to A1, from RAN2 point of view, there difference is data path between MeNB and SeNB can be reused for data forwarding	No impact on radio protocol stack including PDCP, RLC etc. Hide SeNB from CN	May need independent security key for SeNB MeNB need route IP packet for SeNB. More requirement on backhaul in terms of capacity and delay
ITRI	From CN point of view, it is simple.	This alternative can reduce the signalling overhead to CN due to SeNB change.	It may have UE impact, e.g., maintaining two sets of security keys. MeNB should forward data to SeNB.
ASUSTeK	It is a feasible alternative.	No change to PDCP/ RLC spec. Only one S1-U for a UE is required, i.e. less CN impact.	PDCP re-establishment is required when SeNB changes. Ciphering key (KUPenc) exchange between eNBs or UE needs to maintain multiple KUPenc. Data forwarding via Xn and delay caused by non-ideal backhaul.
Hitachi	This option could be used if CN does not support Alternative 1A	CN signalling load will be reduced since SeNB mobility is hidden from CN.	Traffic routing function is required in MeNB side.
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	straight forward inter-vendor interoperability	Independent protocol stack is used at MeNB and SeNB, current protocol stack and functionalities can be used, No flow control is required Add/remove of small cell is hidden from CN	Security handling needs investigation
NTT DOCOMO	This alt cannot achieve the peak data rate comparable with Intra-eNB CA. From an operator point of view, peak data rate is one of the attractive aspect. We think that in this Alt, MeNB forward the data transparently to SeNB. In that sense, we wonder much processing power is actually needed for routing. Although the X2 latency may impact on QoS, it may not be so severe for	No additional signalling to CN	Cannot achieve the peak data rate aggregating CCs in MeNB and SeNB Security may not be robust. The additional MeNB's processing power for the data being transmitted from SeNB will be needed X2 latency may impact on QoS.

	BE data.		
New Postcom	We agree that this alternative is the same as 1A from RAN2's perspective.	No impact on current protocol stack in Anchor and assisting eNBs. Offloading enhancements, improve user throughput Reduce signalling load towards CN related to SeNB mobility CN does not need to know UE's mobility in MeNB's coverage.	Dual security More processing load in eNB (e.g. data forwarding and reordering data packet before PDCP) Bearer can not be split over multiple eNBs.
Intel	This option is similar as 1A	Path switching signalling due to SCell addition/removal is not needed. Almost no impact to PDCP/RLC	Security issues should be further studied since both MeNB and SeNB handle PDCP layer. (Note that dual security keys may involve CN signalling if MME should manage security key of SeNB) Data forwarding is required between MeNB and SeNB or SeNBs to avoid data loss Need to route traffic between MeNB and SeNB.
Broadcom Corporation	May be necessary to implement no bearer if network does not support S1-U to SeNB.		
ETRI	This alt. is similar to Alt. 1A. The split point of this option seems to be GTP level.	No CN signalling impact when SeNB changes Little impact on L2 protocols at eNBs	- Need to define new functionality at MeNB for data switching/aggregation - Centralized traffic processing and data forwarding at MeNB - Security impacts on UE due to independent PDCP at eNBs
Fujitsu		All types of backhaul (X2) could be supported. No impact to L2 U-Plane operation.	This model is not supported for carrier aggregation in Rel-10/Rel-11 but Relay Node architecture may be reused for small cell bearers. There are two PDCP entities in each eNB, which may have impacts on security function of PDCP e.g. two security settings are needed. Throughput is decreased when there is packet loss over the backhaul since the retransmission is not supported in PDCP layer so that the any retransmissions have to be done at a higher layer e.g. using TCP.
CMCC	From throughput point of view the gain could be limited.	No impact on PDCP/RLC protocol	Some issues, e.g. dual security key, are still remained. Furthermore, all traffics of small cells require to be routed through MeNB (anchor eNB). So the pressure of backhaul should be evaluated. Multiple stream (in one bearer) aggregation to improve throughput could not be realized.

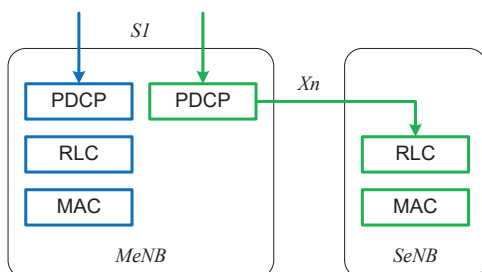
Alternative 2B: S1-U terminates in MeNB + no bearer split in MeNB + master-slave PDCPs



Company Views on Alternative 2B			
Company	Comments	Benefits	Drawbacks
LGE	Not preferred option due to PDCP impacts	No CN signalling load due to SeNB change No RLC impact	Traffic routing between MeNB and SeNB Big PDCP impacts to split PDCP functionalities between MeNB and SeNB Dual security keys
Nokia & NSN	In our opinion, because security should remain in MeNB, so should SN allocation and header compression. To cope with Xn deficiencies, it also seems more appropriate to keep reordering and duplicate detection in MeNB. This would then look like Alternative 2C.	Same as 2C	Same as 2C
BlackBerry	It is not clear the functionality of the 'slave' PDCP in SeNB. Security? Packet reordering?	'slave' PDCP function in SeNB can be done by 'master' PDCP in MeNB	'slave' PDCP function in SeNB can be done by 'master' PDCP in MeNB
RME	Alternative 2C could not completely offload the processing of MeNB and also has higher requirement on the backhaul link. Some of the sub-alternatives in 2C could be easy for UE and eNB implementation So with the same requirement, it has the drawbacks of alternative 1 but not with the benefit of alternative 3C, the only benefit could be hiding the small cell from CN	Could hide the small cell from CN for the data transmission	Higher requirement on the backhaul link between MeNB and SeNB Will require additional layer/entity to handle the data routing Can't offload the processing of MeNB completely Hard split between bearers Security aspect need to be considered further Additional specification effort to capture the master-slave PDCP related behaviour Not good scalability, addition of SeNB will require update of the MeNB
CATT	We are not sure if buffering packet is a benefit or a drawback. On the one hand, buffering packets would cause that the eNB needs more storing space and more processing capability. On the other hand, buffering packet lead to mobility anchor which reduces the CN signalling (such as signalling for path switching).	Offloading data depending on the QoS requirements; Local BreakOut in small eNB is possible; No impact on RLC/ PDCP for UE but big impact on PDCP for network; No extension of SN space	Need to route all traffic to MeNB; Big impact on MeNB-SENB interface; Interruption reduced at SeNB-MeNB mobility event but limited reduction at other mobility events due to non-ideal backhaul; Multiple sets of security keys/CN possible impact at SeNB change (security); Serving cell specific LCP; Need for MeNB to buffer packets;
Panasonic	Not clear how PDCP functionality is distributed between MeNB and SeNB. Furthermore we don't see a clear benefit of this alternative.		
NEC		No security issue as security is performed in MeNB. CN signalling reduction is possible.	Local IP breakout is not possible. New mechanism for flow control may be necessary between nodes. PDCP re-ordering is needed in master PDCP even if it is not during HO procedure.
InterDigital	We agree with NSN	Same as 2C	Same as 2C
Ericsson, ST-Ericsson	The master-slave separation of PDCP need further clarification	Moving ciphering to small cell may reduce processing load of the anchor eNB.	Extensive forwarding of user plane packets over a limited backhaul. Some increase of user plane processing in the anchor eNB.
Huawei	If 2A is feasible, this alternative is inferior to 2A, because it requires more changes on L2 protocol in UP, but doesn't provide any additional	Compared to 2A, only one security context is maintained per UE.	More specification impact than 2A. Compared to 3B, there is less potential in throughput enhancement and larger interruption time incurred

	functionality. Can be studied after 2A is ruled out.		during SeNB change.
ZTE	In general split within one protocol layer is not preferred. Since the main concern is security, it look like almost very minor functionality will be retained in SeNB considering the operation sequence in PDCP layer (referring to Figure 4.2.2.1, 36.323)	Same as 2C	Same as 2C
ASUSTeK	It is unclear which functionalities will be put in slave PDCP. Thus, the benefits are unclear.	No change to RLC spec. Only one S1-U for a UE is required, i.e. less CN impact.	Impact to PDCP spec for splitting functionalities. Data forwarding via Xn and delay caused by non-ideal backhaul.
Hitachi	Master-slave PDCP needs to be further clarified.	CN signalling load will be reduced since SeNB mobility is hidden from CN. No impacts on RLC.	Traffic routing function and processing of SeNB traffic are required in MeNB side.
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	Not see additional benefit of this approach when compared to option 2C	Add/remove of small cell is hidden from CN Single security keys	Require user data forwarding over X2 hence backhaul capacity Flow control is required Modification to PDCP is required
NTT DOCOMO	This alt cannot achieve the peak data rate comparable with Intra-eNB CA. From an operator point of view, peak data rate is one of the attractive aspect. We think that in this Alt, existing X2 HO procedure can be utilised. Although the X2 latency may impact on QoS, it may not be so severe for BE data.	No additional signalling to CN	Cannot achieve the peak data rate aggregating CCs in MeNB and SeNB Security may not be robust. The additional MeNB's processing power for the data being transmitted from SeNB will be needed X2 latency may impact on QoS.
New Postcom	Security may be only located in MeNB. The definition of "slave PDCP" is not clear, more detail solution should be further provided.	Centralized security can be performed in MeNB, which means there may be no security in SeNB. CN does not need to know UE's mobility in MeNB's coverage. Reduce the CN signalling	The Bearer can not be split over multiple eNBs. More processing load and buffer in MeNB (forwarding data to SeNB) Impact on PDCP
Intel	We agree with NSN that this option is actually Alternative 2C if we want to keep security function in MeNB.	Same as 2C	Same as 2C
ETRI		No CN signalling impact when SeNB changes	Big impact on PDCP due to function split between MeNB and SeNB PDCP traffic forwarding load at MeNB
CMCC		Only one key could be needed in MeNB	There are some PDCP impacts. And the other issues including pressure on backhaul and throughput enhancement are same with 2A.

Alternative 2C: S1-U terminates in MeNB + no bearer split in MeNB + independent RLC at SeNB

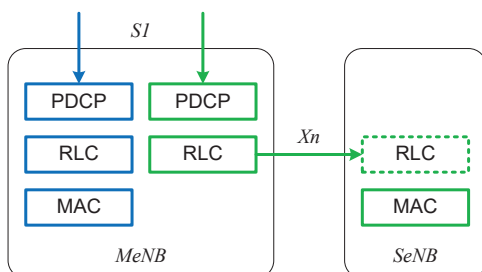


Company Views on Alternative 2C			
Company	Comments	Benefits	Drawbacks
MediaTek		Centralized security, No need to re-establish security when UE moves in the local area.	
LGE	Most preferred option because of least changes from legacy protocols	No CN signalling load due to SeNB change No dual security keys No PDCP/RLC impact	Traffic routing between MeNB and SeNB
Nokia & NSN		one set of security keys SeNB mobility hidden to CN no data forwarding required at SeNB change offloads RLC processing from MeNB to SeNB	need to route, process and buffer all UP traffic in MeNB (also for an EPS bearer transmitted only by the SeNB, MeNB required to buffer and process packets at PDCP level) logical channel prioritisation impacts for the transmission of uplink data (U-plane data from one specific RLC bearer needs to be transmitted towards a specific node using a specific uplink) PDCP to become responsible for reordering and new mechanism needed for PDCP at the UE to conclude when to ignore reception gap need to resolve packet loss between MeNB and SeNB PDCP at MeNB needs to be provided with indications of successful PDU delivery from the SeNB CA/CoMP not possible, HO-like interruption at SeNB change
BlackBerry		Can cope well with non-ideal backhaul due to no time sensitive coordination with lower layer, beside single security key	Traffic load between MeNB and SeNB
RME	Alternative 2 series could not completely offload the processing of MeNB and also has higher requirement on the backhaul link. Some of the sub-alternatives in 2 series could be easy for UE and eNB implementation So with the same requirement, it has the drawbacks of alternative 1 but not with the benefit of alternative 3 series, the only benefit could be hiding the small cell from CN	Simpler for UE implementation Could hide the small cell from CN for the data transmission	Higher requirement on the backhaul link between MeNB and SeNB Will require additional layer/entity to handle the data routing Can't offload the processing of MeNB completely Hard split between bearers Not good scalability, addition of SeNB will require update of the MeNB
CATT		Offloading data depending on the QoS requirements; No impact on RLC/ PDCP for UE but little impact on PDCP for network; No extension of SN space No CN signalling impact at SeNB change One set of security keys;	Need to route all traffic to MeNB; Big impact on MeNB-SeNB interface; Interruption reduced at SeNB-MeNB mobility event but limited reduction at other mobility events due to non-ideal backhaul; Serving cell specific LCP; Need for MeNB to buffer packets;
Samsung	Same comment as 1A for peak data rate, interruption. Same comment as 2A for backhaul		1. Peak data rate is not achieved, when only one EPS bearer is used 2. Interruption during SCell addition/release 3. Backhaul overdimensioning for MeNB
Panasonic		Single security resides in MeNB No CN signalling necessary at mobility on small cell layer	interruption time at small cell mobility will be longer due to non-ideal backhaul and protocol

			distribution among MeNB and SeNB More complexity in Macro eNB (buffer, processing) compared to 1A
NEC		No security issue as security is performed in MeNB.	Local IP breakout is not possible. PDCP reordering is necessary at MeNB. New mechanism for flow control may be necessary between nodes.
InterDigital		No security impacts – reuse of legacy security procedures Mobility is hidden from CN and therefore signalling towards CN and context transfers are minimized (e.g. no need to do PDCP data forwarding upon mobility between SeNBs and between SeNB and MeNB). No PDCP re-establishment is necessary upon a handover UL/DL traffic splitting can be supported with this option if UL/DL imbalance is an issue	PDCP has to perform reordering to resolve packet losses between nodes Flow control may be necessary to control the number of PDCP PDU transferred to the SeNB and buffering at the MeNB of PDCP data is necessary Data delivery status needs to be exchanged between MeNB and SeNB Multiflow cannot be supported in DL or UL as bearer splitting is not allowed
Ericsson, ST-Ericsson		Centralized security can reduce specifications efforts.	Extensive forwarding of user plane packets over a limited backhaul. Increase of user plane processing in the anchor eNB due to processing and ciphering of PDCP PDUs.
Huawei	If 2A is feasible, this alternative is inferior to 2A, because it requires more changes on L2 protocol in UP, but doesn't provide any additional functionality. Can be studied after 2A is ruled out.	Compared to 2A, only one security context is maintained per UE.	More specification impact than 2A. Compared to 3C, there is less potential in throughput enhancement and larger interruption time incurred during SeNB change.
ZTE	In general 2C, 2D will involve MeNB and SeNB for one radio bearer. It put even higher requirement on backhaul especially in terms of delay	no security issue for SeNB hide SeNB from CN no data forwarding during SeNB change	Non-ideal Backhaul delay become artificial packet RTT for PDCP layer Inter-layer action between PDCP and RLC layer need be specified and will be also impacted by non-idea backhaul e.g. packet loss
ITRI		This alternative can reduce the signalling overhead to CN due to SeNB change. There is no need to maintain two sets of security keys of both eNBs.	MeNB should forward data to SeNB
ASUSTeK	It is a feasible alternative.	No change to PDCP/RLC spec. Only one S1-U for a UE is required, i.e. less CN impact. PDCP re-establishment is not required when SeNB changes. No impact to security.	Data forwarding via Xn and delay caused by non-ideal backhaul. Timer based RLC SDU discard is delayed due to non-ideal backhaul. Delay of PDCP Status report caused by non-ideal backhaul.
Hitachi		CN signalling load will be reduced since SeNB mobility is hidden from CN. No impacts on PDCP and RLC.	Traffic routing function and processing of SeNB traffic are required in MeNB side. Concern on backhaul capacity in MeNB side.
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell		Add/remove of small cell is hidden from CN Single security entity (centralised) may reduce specification effort	Require user data forwarding over X2 hence backhaul capacity Flow control is required PDCP PDUs are forwarded over open interface. PDCP enhancements to handle re-ordering and duplicate detection Specification effort is high compared to 1A and 2A.
NTT DOCOMO	This alt cannot achieve the peak	No additional signalling to CN	Cannot achieve the peak data rate

	data rate comparable with Intra-eNB CA. From an operator point of view, peak data rate is one of the attractive aspect. Although the X2 latency may impact on QoS, it may not be so severe for BE data.	Security may be robust.	aggregating CCs in MeNB and SeNB The additional MeNB's processing power for the data being transmitted from SeNB will be needed X2 latency may impact on QoS. X2 impact to deliver PDCP PDU
New Postcom		Centralized security can be handled in MeNB, which is single security. CN does not need to know UE's mobility in MeNB's coverage. Reduce CN signalling when UE changes SeNB. Distribute RLC processing load in MeNB and SeNB	Bearer can not be split over multiple eNBs. More processing load and buffer in MeNB (forwarding data to SeNB) Need indication for successful PDCP PDU transmission from eNB.
Intel	For Alternatives with S1-U terminated in MeNB, we prefer this option since there is least impact to protocols	Path switching signalling due to SCell addition/removal is not needed. Almost no impact to PDCP/RLC No security issues.	Need to route traffic between MeNB and SeNB, therefore MeNB data processing capability should be increased.
ETRI		No CN signalling impact when SeNB changes No security impacts on UE	Data buffering to transfer PDCP PDUs considering available Xn resource PDCP retransmission when SeNB is attached/detached PDCP PDU forwarding load at MeNB
Fujitsu		All types of backhaul (X2) could be supported. No impact to L2 U-Plane operation.	The limited backhaul capacity gives a negative impact to e.g. for the frequency of scheduling information exchange between RLC and PDCP, and the PDCP SDU forwarding over the backhaul. The backhaul latency gives a negative impact to the ability to perform fast packet scheduling in MeNB e.g. pushing down a PDCP PDU to the RLC layer. Throughput is decreased when there is packet loss over the backhaul since the retransmission is not supported in PDCP layer so that any retransmissions have to be done at a higher layer e.g. using TCP.
CMCC		Only one key could be needed in MeNB, and there is no much impacts on PDCP.	The issues including pressure on backhaul and throughput enhancement are same with 2A.

Alternative 2D: S1-U terminates in MeNB + no bearer split in MeNB + master-slave RLCs

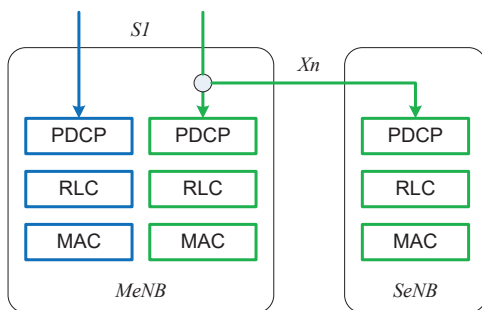


Company Views on Alternative 2D			
Company	Comments	Benefits	Drawbacks
MediaTek		Centralized security, No need to re-establish security when UE moves in the local area. AM retransmission can be used for lossless mobility when UE changes cell, also in case of re-establishment.	
LGE	Not preferred option due to RLC impacts	No CN signalling load due to SeNB change No dual security keys No PDCP impact	Traffic routing between MeNB and SeNB Big RLC impacts to split RLC functionalities between MeNB and SeNB
Nokia & NSN		one set of security keys SeNB mobility hidden to CN no data forwarding required at SeNB change maintains current functional split between PDCP and RLC (reordering, reception-gap handling) packet loss between MeNB and SeNB covered by RLC's ARQ	need to route, process and buffer all UP traffic in MeNB (also for an EPS bearer transmitted only by the SeNB, MeNB required to buffer and process packets down to RLC level) logical channel prioritisation impacts for the transmission of uplink data (U-plane data from one specific EPS bearer needs to be transmitted towards a specific node using a specific uplink) extension of RLC SN space may be needed to tackle Xn latency. application with RLC UM requires adoption of UMD PDU Segment requires deviating from the current principle of only one new RLC data PDU per RLC bearer per MAC PDU 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 CA/CoMP not possible, HO-like interruption at SeNB change
BlackBerry	It is not clear the functionality of the 'slave' RLC in SeNB. Segmentation? Retransmission for AM?	Single security key	Tight interaction between the MAC and RLC i.e. in segmentation process, might cause problem if the segmentation is taken care by the 'master' RLC in MeNB in non-ideal backhaul
RME	Alternative 2 serie could not completely offload the processing of MeNB and also has higher requirement on the backhaul link. Some of the sub-alternatives in 2 serie could be easy for UE and eNB implementation So with the same requirement, it has the drawbacks of alternative 1 but not with the benefit of alternative 3 serieses, the only benefit could be hiding the small cell from CN	Could hide the small cell from CN for the data transmission	Higher requirement on the backhaul link between MeNB and SeNB Will require additional layer/entity to handle the data routing Can't offload the processing of MeNB completely Hard split between bearers Extensive re-segmentation is expected Additional specification effort to capture the master-slave PDCP related behaviour Not good scalability, addition of SeNB will require update of the MeNB
CATT		Offloading data depending on the QoS requirements; No impact on RLC/ PDCP for UE but Big impact on RLC for network; No CN signalling impact at SeNB change No impact to logical channel prioritization; One set of security keys;	Need to route all traffic to MeNB; Big impact on MeNB-SENB interface; Interruption reduced at SeNB-MeNB mobility event but limited reduction at other mobility events due to non-ideal backhaul; Extension of RLC SN space Need for MeNB to buffer packets; Serving cell specific LCP;

Samsung	Same comment as 2A for backhaul Regarding NW implementation complexity, additional buffer in small ENB above MAC (currently RLC buffer is above re-segmentation function) is needed.		1. NW implementation complexity 2. Back haul overdimensioning
Panasonic		Single security Mobility on small cell layer is transparent to CN	More complexity in MeNB (buffering, processing packets) In case bearers configured with RLC UM are also mapped to SeNB, RLC UM needs to support (re)segmentation functionality
NEC		No security issue as security is performed in MeNB.	Local IP breakout is not possible. New mechanism for flow control may be necessary between nodes.
InterDigital		Packet losses and reordering can be performed by existing RLC reordering functionality (e.g. no impact to PDCP) No impacts to security (e.g. legacy security procedures can be applied) State of RLC buffer and interaction between RLC and PDCP at the network side remains the same UL/DL traffic splitting can be supported if two bearers can be mapped to one EPS bearer RLC/PDCP operation are anticipated to remain the same in UE	RLC header overhead may increase due to the fact that the RLC PDUs are not always optimally created according to the radio conditions and with the need to always add re-segmentation headers. RLC UM doesn't support re-segmentation Status exchange between the master – slave RLC entities necessary Multiflow cannot be supported Data routed through MeNB and data processing remains in the MeNB
Ericsson, ST-Ericsson		Centralized security can reduce specifications efforts.	Extensive forwarding of user plane packets over a limited backhaul. Increase of user plane processing in the anchor eNB due to processing and ciphering of PDCP PDUs. Possible need to extend RLC SN. Increased RLC overhead from re-segmentation
Huawei	If 2A is feasible, this alternative is inferior to 2A, because it requires more changes on L2 protocol in UP, but doesn't provide any additional functionality. Can be studied after 2A is ruled out.	Compared to 2A, only one security context is maintained per UE.	More specification impact than 2A. Compared to 3D, there is less potential in throughput enhancement and larger interruption time incurred during SeNB change.
ZTE	In general we don't prefer split within one protocol layer especially for time sensible RLC layer	Same as 2C	Non-ideal backhaul delay will become part of RLC RTT which will impact RLC layer performance quite a lot. And it seems not clean solution to split RLC protocol into two RAN nodes resulting unexpected complexity for network implementation and standardization
ITRI	Not sure how to split RLC functions in the two nodes when re-segmentation is maintained in SeNB.		
ASUSTeK	It is unclear which functionalities will be put in slave RLC. Thus, the benefits are unclear.	No change to PDCP spec. Only one S1-U for a UE is required, i.e. less CN impact. PDCP re-establishment is not required when SeNB changes. No impact to security.	Impact to RLC spec for splitting functionalities. Data forwarding via Xn and delay caused by non-ideal backhaul.
Hitachi		CN signalling load will be reduced since SeNB mobility is hidden from CN. No impact on PDCP.	Traffic routing function and processing of SeNB traffic are required in MeNB side. Concern on backhaul capacity in MeNB side. Impacts on RLC (functional split).
Alcatel-Lucent/ Alcatel-Lucent		Add/remove of small cell is hidden from CN	Require user data forwarding over X2 hence backhaul capacity

Shanghai Bell		Single security entity (centralised) may reduce specification effort	Flow control is required Modification to RLC protocol to handle RLC protocol layer split and data delivery over open interface Specification effort is high compared to 1A, 2A and 2C.
NTT DOCOMO	This alt cannot achieve the peak data rate comparable with Intra-eNB CA. From an operator point of view, peak data rate is one of the attractive aspect. Although the X2 latency may impact on QoS, it may not be so severe for BE data.	No additional signalling to CN Security may be robust.	Cannot achieve the peak data rate aggregating CCs in MeNB and SeNB The additional MeNB's processing power for the data being transmitted from SeNB will be needed X2 latency may impact on QoS. X2 impact to deliver RLC PDU
New Postcom	The definition of "slave RLC" and how it works is not clear, more detail should be further provided. Some potential operations may be considered as follows. Resegmentation and ARQ can be handled in SeNB Protocol error detection should be performed in SeNB	Centralized security can be handled in MeNB, which is single security. CN does not need to know UE's mobility in MeNB's coverage. Reduce CN signalling when UE changes SeNB. Distribute RLC processing load in MeNB and SeNB No need to extend RLC SN	Bearer can not be split over multiple eNBs. More processing load and buffer in MeNB (forwarding data to SeNB) Impact on RLC
Intel		Path switching signalling due to SCell addition/removal is not needed. Almost no impact to PDCP No security issues.	Need to route traffic between MeNB and SeNB, therefore MeNB data processing capability should be increased Significant impact to RLC layer due to the split of RLC functionalities.
Broadcom Corporation			May cause unacceptable ARQ delays for RLC-AM bearers
ETRI		No CN signalling impact when SeNB changes No security impacts on UE	Big impact on RLC due to function split between MeNB and SeNB Need to introduce a new method to cope with packets loss between MeNB and SeNB
Fujitsu	Not a preferred option due to RLC impacts.		
CMCC		Only one key could be needed in MeNB, and there are no much impacts on PDCP.	There is much impact on RLC. The issues including pressure on backhaul link and throughput enhancement are same with 2A.

Alternative 3A: S1-U terminates in MeNB + bearer split in MeNB + independent PDCPs for split bearers.

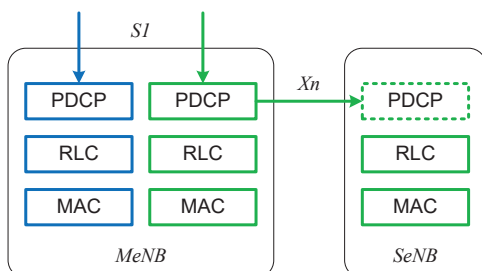


Company Views on Alternative 3A			
Company	Comments	Benefits	Drawbacks
MediaTek			A new cooperation layer, on top of the current stack, would need to implement reordering with additional layer with sequence numbers etc.
LGE	We want to exclude this option due to violation of current bearer mapping rule	No CN signalling load due to SeNB change No PDCP/RLC impact Increased throughput	Traffic routing between MeNB and SeNB A new layer performing routing function is required in MeNB Dual security keys Given that the current protocols are designed based on 1-to-1 mapping rule, violating current mapping rule would cause many potential impacts, e.g., RB configuration, status reporting, BSR, LCP,...
Nokia & NSN	Because it would require a new layer responsible for reordering, this alternative seems ill-suited for bearer split.	little or no impact to PDCP/RLC and GTP-U/UDP/IP SeNB mobility hidden to CN relaxed requirements for SeNB mobility (MeNB can be used in the meantime). CA/CoMP possible	need to route, process and buffer all UP traffic in MeNB logical channel prioritisation impacts for handling RLC retransmissions and RLC Status PDUs multiple sets of security keys required new layer above PDCP at MeNB required to take care of reordering including a new mechanism for the UE to conclude when to ignore reception gap need to resolve packet loss between MeNB and SeNB MeNB needs to be provided with indications of successful PDU delivery from the SeNB
BlackBerry	Another layer above PDCP? Perhaps just a load distributor to route part of the bearer to MeNB and the other part to SeNB	No impact to the legacy protocol stack	Require two security keys
RME	Alternative 3 series can't offload the processing of MeNB, and also these alternatives will require higher backhaul link performance Split the bearer to both MeNB and SeNB could provide more flexibility at eNB side and potentially good for per UE throughput	Flexibility for NW side for data transmission Potentially good for per UE throughput Could hide the small cell from CN for the data transmission	Higher requirement on the backhaul link between MeNB and SeNB Additional entity / specification need to be defined Difficult to perform in-order delivery or need new entity to handle the re-ordering above PDCP Security aspect need to be considered further Not good scalability, addition of SeNB will require update of the MeNB
CATT	We should try to avoid this Alternative as this causes too much unnecessary complexity (such as an extra layer above PDCP) compared with other Alternatives.	Offloading data depending on the QoS requirements; no need for MeNB to buffer packets; No impact on RLC/PDCP for network; No extension of SN space; Little impact on MeNB-SeNB interface(standard effort);	Need to route all traffic to MeNB; Interruption reduced at SeNB-MeNB mobility event but limited reduction at other mobility events due to non-ideal backhaul; Multiple sets of security keys/CN possible impact at SeNB change (security); Serving cell specific LCP; Data forwarding needed between eNBs; New Layer for reordering Dual RLC/PDCP per RB for UE
Samsung	Seems to support most benefits. Need further study on UE implementation complexity	1. Support of useful features like small cell local break-out and small cell contents caching	1. Security 2. UE implementation complexity (single EPS bearer-single DRB)

	Same comment as 2A for backhaul	2. Peak data rate is achieved 3. No interruption	principle broken) 3. Backhaul overdimensioning for MENB
Panasonic	This alternative should not be further considered since new reordering functionality above PDCP is required	No clear benefit seen over alternatives 3B-3D	New reordering layer on top of PDCP required Security concern (dual security)
NEC	Further discussion point should be whether a UE shall support the capability to receive data of EPS bearer #2 from both MeNB and SeNB in the same subframe.	Higher user throughput compared to 1x, 2x would be expected due to dynamic radio resource/cell utilization, if optimum UP data split of EPS bearer #2 can be performed.	Higher UE complexity compared to 1x, 2x. Local IP breakout is not possible. UE may need to maintain two security contexts for the same bearer; otherwise, sync the security context between two nodes. Impact on LCP.
InterDigital	This option is very similar to 2A with the difference that the bearers can be split. Since option 3 allows for multiframe, we think that support for DL vs UL multiframe should be considered separately	Similar benefits as 2A (e.g. security, mobility, etc) This option can allow the implementation of UL/DL split Multi-flow can be implemented even though reordering and packet loss detection mechanisms need to be introduced above PDCP to support this option	New layer of reordering functionality required above PDCP to ensure in order delivery to higher layer In the case where this architecture supports UL multiframe then we agree with LGE (e.g. LCP and BSR reporting would be impacted) For DL multiframe new reordering functionality needs to be added above PDCP
Ericsson, ST-Ericsson		Splitting packets inside a EPS bearer can bring some user throughput gains. However, flow control and reordering will impact the gain negatively.	Extensive forwarding of user plane packets over a limited backhaul. Increase of user plane processing in the anchor eNB. Some kind of flow control needed between MeNB and SeNB. Needs a layer for reordering above PDCP.
Huawei		SeNB change is shielded from CN. L2 protocols of UP can be largely reused. UE throughput can be improved even if UE has only one EPS bearer.	A new protocol layer is needed above PDCP to take care of distribution/aggregation of PDCP SDU.
ZTE	In general we don't prefer to do bearer split	Hide SeNB from CN One more pipe for PDCP SDU	For DL one more entity to decide packet routing policy i.e. which packet to which eNB and re-ordering is needed above PDCP layer
ITRI	Bearer split has the some benefits: 1. Bearer spit can increase UE data throughput. 2. Bearer split can have load balance between eNBs		
ASUSTek	Agree with MediaTek that a new protocol layer above PDCP needs to be introduced to handle bearer split. Thus, this alternative is not preferred.		
Hitachi	Should be avoided.	CN signalling load will be reduced since SeNB mobility is hidden from CN. No impacts on RLC and PDCP.	Traffic routing function and processing of SeNB traffic are required in MeNB side. Concern on backhaul capacity in MeNB side. New reordering function is required.
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	Similar to functions in option 2A with addition of supporting bearer split	Similar to option 2A	Similar to option 2A Additionally, requires functionality to support bearer split, hence complexity is higher than option 2A
NTT DOCOMO	This alt has more feasibility to achieve the comparable peak data rate with Intra-eNB CA. From an operator point of view, peak data rate is one of the attractive aspect. We think that in this Alt, existing X2 HO procedure can be utilised. Although the X2 latency may impact	No additional signalling to CN More feasibility to achieve the peak data rate aggregating CCs in MeNB and SeNB	Security may not be robust. The additional MeNB's processing power for the data being transmitted from SeNB will be needed X2 latency may impact on QoS. In-sequence delivery above PDCP layer may not be ensured.

	on QoS, it may not be so severe for BE data, and there will be no concern about TCP throw start because macro-cell is available.		Increasing UE/eNB complexity
New Postcom		No impact on current protocol stack in eNB. Offload enhancements, improve user throughput by bearer split Reduced signalling load towards CN related to SeNB mobility. Bearer split over multiple eNBs, which flexibility scheduling can be provided for data transmission. CN does not need to know UE's mobility in MeNB's coverage.	New function/layer may be used for allocating or splitting bearer over multiple eNB Dual security More processing load and buffer in MeNB (forwarding data to SeNB) More complexity
Intel		Path switching signalling due to SCell addition/removal is not needed. Almost no impact to PDCP/RLC Potential throughput increase when system load is low.	Security issues should be further studied since both MeNB and SeNB handle PDCP layer. (Note that dual security keys may involve CN signalling if MME should manage security key of SeNB) Need to route traffic between MeNB and SeNB. Single EPS bearer split has additional impacts like QoS handling, increased UE complexity.
ETRI		No CN signalling impact when SeNB changes No impact on L2 protocols at eNBs More flexible data transfer considering E-UTRAN condition including MeNB and SeNB	Need to define new functionality at MeNB for data switching/aggregation Centralized traffic processing and data forwarding at MeNB Security impacts on UE due to independent PDCP at eNBs
Fujitsu			This alternative would require significant protocol changes to existing architecture. This alternative would require new functionality above the PDCP layer and would require a fast and low latency backhaul.
CMCC	Acceptable	No impact on current eNB protocol stack and could realize aggregation Improvements.	A new layer is needed and there are some complexities from specification point of view.

Alternative 3B: S1-U terminates in MeNB + bearer split in MeNB ++ master-slave PDCPs for split bearers.

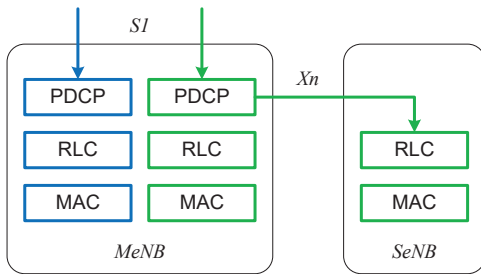


Company Views on Alternative 3B			
Company	Comments	Benefits	Drawbacks
LGE	We want to exclude this option due to violation of current bearer mapping rule	No CN signalling load due to SeNB change No RLC impact Increased throughput	Traffic routing between MeNB and SeNB Dual security keys Big PDCP impacts to split PDCP functionalities between MeNB and SeNB Given that the current protocols are designed based on 1-to-1 mapping rule, violating current mapping rule would cause many potential impacts, e.g., RB configuration, status reporting, BSR, LCP,...
Nokia & NSN	In our opinion, because security should remain in MeNB, so should SN allocation and header compression. To cope with Xn deficiencies, it also seems more appropriate to keep reordering and duplicate detection in MeNB. This would then look like Alternative 2C.	Same as 3C	Same as 3C
BlackBerry	It is not clear the functionality of the 'slave' PDCP in SeNB. Security? Packet reordering? (I think the figure need to add an arrow down from PDCP to RLC in MeNB to show the bearer split)	'slave' PDCP function in SeNB can be done by 'master' PDCP in MeNB, make this option same as option 3C	'slave' PDCP function in SeNB can be done by 'master' PDCP in MeNB make this option same as option 3C
RME	Alternative 3 series can't offload the processing of MeNB, and also these alternatives will require higher backhaul link performance Split the bearer to both MeNB and SeNB could provide more flexibility at eNB side and potentially good for per UE throughput	Flexibility for NW side for data transmission Potentially good for per UE throughput Could hide the small cell from CN for the data transmission	Higher requirement on the backhaul link between MeNB and SeNB Additional entity / specification need to be defined Not good scalability, addition of SeNB will require update of the MeNB
CATT		Offloading data depending on the QoS requirements;	Need to route all traffic to MeNB; Interruption reduced at SeNB-MeNB mobility event but limited reduction at other mobility events due to non-ideal backhaul; Multiple sets of security keys/CN possible impact at SeNB change (security); Serving cell specific LCP; Dual RLC/PDCP per RB for UE need for MeNB to buffer packets; Extension of PDCP SN space is possible; Big impact on MeNB-SENB interface; big impact on PDCP for network;
Panasonic	Not clear how PDCP functionality is distributed between MeNB and SeNB, e.g. where security is placed. Furthermore we don't see a clear benefit of this alternative.		
NEC	Same as 3A	Higher user throughput compared to 1x, 2x would be expected	Higher UE complexity compared to 1x, 2x. Local IP breakout is not possible. New mechanism for flow control may be necessary between nodes. Impact on LCP.
InterDigital	Agree with NSN		
Ericsson, ST-		Splitting packets inside a EPS	Extensive forwarding of user plane

Ericsson		bearer can bring some user throughput gains. However, flow control and reordering will impact the gain negatively.	packets over a limited backhaul. Increase of user plane processing in the anchor eNB. Some kind of flow control needed between MeNB and SeNB. Reordering in the PDCP layer (or on top) can need changes
Huawei	This may be a fine-tuning of alternative 3C, with some optimization in handling PDCP discard related operations and some inter-layer interaction. This may reduce exchanges over backhaul between MeNB and SeNB.		
ZTE	In general split within one protocol layer is not preferred. Since the main concern is security, it look like almost very minor functionality will be retained in SeNB considering the operation sequence in PDCP layer (referring to Figure 4.2.2.1, 36.323)	Same as 3C	Same as 3C
ASUSTeK	It is unclear which functionalities will be put in slave PDCP. Thus, the benefits are unclear.	No change to RLC spec. Only one S1-U for a UE is required, i.e. less CN impact. Improve throughput due to bearer split.	Impact to PDCP spec for splitting functionalities. Data forwarding via Xn and delay caused by non-ideal backhaul. PDCP reordering for RB mapping on RLC UM is required due to bearer split. PDCP needs to support flow control.
Hitachi	Gain and complexity of bearer split should be further studied.	CN signalling load will be reduced since SeNB mobility is hidden from CN. No impacts on RLC.	Traffic routing function and processing of SeNB traffic are required in MeNB side. Concern on backhaul capacity in MeNB side. Some impacts on PDCP.
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	Not see much benefit compared to option 3C	Similar to option 3C	Similar to option 3C, additionally requires specification effort is design of PDCP protocol split functionality.
NTT DOCOMO	We are interested in this Alt, because this alt has more feasibility to achieve the comparable peak data rate with Intra-eNB CA. We think that in this Alt, existing X2 HO procedure can be utilised. Although the X2 latency may impact on QoS, it may not be so severe for BE data and there will be no concern about TCP throw start because macro-cell is available.	No additional signalling to CN More feasibility to achieve the peak data rate aggregating CCs in MeNB and SeNB	Security may not be robust. The additional MeNB's processing power for the data being transmitted from SeNB will be needed X2 latency may impact on QoS.
New Postcom	Security may be only located in MeNB. The definition of "slave PDCP" is not clear, more detail solution should be further provided.	Centralized security can be handled in MeNB, which is single security. Offload enhancements, improve user throughput Reduced signalling load towards CN related to SeNB mobility. Bearer can be split over multiple eNBs, which flexibility scheduling can be provided for data transmission. CN does not need to know UE's mobility in MeNB's coverage.	Dual security More processing load and buffer in MeNB (forwarding data to SeNB) More complexity Impact on PDCP
Intel	We think that this option is actually Alternative 3C with a new reordering functionality for bearer split if we want to keep security function in MeNB.	Same as 3C	Same as 3C
ETRI		No CN signalling impact when SeNB changes Little impact on L2 protocols at eNBs	Big impact on PDCP due to function split between MeNB and SeNB PDCP traffic forwarding load at MeNB

CMCC	Security should remain in MeNB,	Could realize throughput enhancement (multiple flows in one bearer aggregation).	Impact on PDCP layer. And there is pressure on backhaul issue.

Alternative 3C: S1-U terminates in MeNB + bearer split in MeNB + independent RLCs for split bearers.

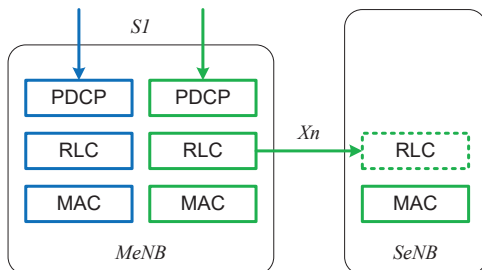


Company Views on Alternative 3C			
Company	Comments	Benefits	Drawbacks
MediaTek		PDCP SN can be used for reordering. Centralized security, No need to re-establish security when UE moves in the local area.	Probably the current PDCP reordering, which is used at handover would require some enhancements.
LGE	We want to exclude this option due to violation of current bearer mapping rule	No CN signalling load due to SeNB change No dual security keys No RLC impact Increased throughput	Traffic routing between MeNB and SeNB PDCP impacts to route PDCP PDUs to different RLC entities Given that the current protocols are designed based on 1-to-1 mapping rule, violating current mapping rule would cause many potential impacts, e.g., RB configuration, status reporting, BSR, LCP,...
Nokia & NSN		one set of security keys SeNB mobility hidden to CN no data forwarding required at SeNB change offloads RLC processing of SeNB traffic from MeNB to SeNB relaxed requirements for SeNB mobility (MeNB can be used in the meantime). CA/CoMP possible	need to route, process and buffer all UP traffic in MeNB logical channel prioritisation impacts for handling RLC retransmissions and RLC Status PDUs PDCP to become responsible for reordering and new mechanism needed for PDCP at the UE to conclude when to ignore reception gap need to resolve packet loss between MeNB and SeNB PDCP at MeNB needs to be provided with indications of successful PDU delivery from the SeNB
BlackBerry		Can cope well with non-ideal backhaul due to no time sensitive coordination with lower layer, beside single security key	Traffic load between MeNB and SeNB and need load distributor at PDCP layer to split the traffic to PDCP in MeNB and in SeNB
RME	Alternative 3 serie can't offload the processing of MeNB, and also these alternatives will require higher backhaul link performance Split the bearer to both MeNB and SeNB could provide more flexibility at eNB side and potentially good for per UE throughput	Flexibility for NW side for data transmission Potentially good for per UE throughput No additional security issue need to be considered Could hide the small cell from CN for the data transmission	Higher requirement on the backhaul link between MeNB and SeNB Not good scalability, addition of SeNB will require update of the MeNB
CATT		Offloading data depending on the QoS requirements; No impact on RLC for network; No CN impact at SeNB change One set of security keys;	Need to route all traffic to MeNB; Interruption reduced at SeNB-MeNB mobility event but limited reduction at other mobility events due to non-ideal backhaul; Serving cell specific LCP; Dual RLC per RB for UE need for MeNB to buffer packets; Extension of PDCP SN space is possible; Big impact on MeNB-SENB interface;
Samsung	Regarding peak data rate and interruption, same comment as 1A. Same comment as 2A for backhaul	1. Peak data rate is achieved 2. No interruption	1. UE implementation complexity (single DRB-single LCH principle broken) 2. Backhaul overdimensioning for MeNB
Panasonic		No security concern Data from one bearer can be scheduled in both cells	Reordering functionality in PDCP required. More complexity in Macro eNB

		Interruption time at small cell mobility can be shortened compared to 2C since bearer can be scheduled in Macro cell	(buffer, processing)
NEC	Same as 3A	Higher user throughput compared to 1x, 2x would be expected	Higher UE complexity compared to 1x, 2x. Local IP breakout is not possible. New mechanism for flow control may be necessary between nodes. Impact on LCP.
InterDigital	The main difference between 2C and 3C is the support for multiframe. UL and DL multiframe have been considered separately in the discussion.	Similar benefits to 2C (in terms of security, mobility, etc) DL multiframe is possible with introduction of reordering functionality in the PDCP can ensure that data from different nodes is properly reordered. Can support RRC diversity UL multiframe is possible UL/DL splitting is possible in the case where UL/DL imbalance is a problem	Similar drawbacks to 2C (e.g. in terms of flow control, status exchange, etc) For UL multiframe we agree with LGE, there will be issues with RB configuration, LCP and BSR For DL multiframe reordering functionality and timer needs to be introduced in the PDCP
Ericsson, ST-Ericsson		Splitting packets inside a EPS bearer can bring some user throughput gains. However, flow control and reordering will impact the gain negatively.	Extensive forwarding of user plane packets over a limited backhaul. Increase of user plane processing in the anchor eNB. Some kind of flow control needed between MeNB and SeNB. Reordering in PDCP layer might need changes.
Huawei		SeNB change is shielded from CN. L2 protocols of UP can be largely reused. UE throughput can be improved even if UE has only one EPS bearer. Can support CP option of one RRC entity per UE with RRC signalling transmission over any combination of radio resource of MeNB and SeNB. Less interruption time during SeNB change. Single PDCP at UE. Window stalling is less likely. No impact on RLC configurations.	Need to extend the use of PDCP reordering and duplicate detection function.
ZTE	MeNB and SeNB will be both involved for one pipe of one bearer	no security issue for SeNB hide SeNB from CN no data forwarding during SeNB change mobility due to SeNB change becomes smooth	More functionality is needed for PDCP layer e.g. routing policy DL and re-ordering for both UL/ DL. Non-ideal Backhaul delay become artificial packet RTT for PDCP layer Inter-layer action between PDCP and RLC layer need be specified and will be also impacted by non-idea backhaul e.g. packet loss
ITRI	Same as 3A	Same as 2C	
ASUSTeK	It is a feasible alternative.	No change to RLC spec. Only one S1-U for a UE is required, i.e. less CN impact. PDCP re-establishment is not required when SeNB changes. No impact to security. Improve throughput due to bearer split.	Data forwarding via Xn and delay caused by non-ideal backhaul. Timer based RLC SDU discard is delayed due to non-ideal backhaul. Delay of PDCP Status report caused by non-ideal backhaul. PDCP reordering for RB mapping on RLC UM is required due to bearer split. PDCP needs to support flow control.
Hitachi	Gain and complexity of bearer split should be further studied.	CN signalling load will be reduced since SeNB mobility is hidden from CN.	Traffic routing function and processing of SeNB traffic are required in MeNB side.

		No impacts on RLC.	Concern on backhaul capacity in MeNB side. Some impacts on PDCP. (Splitting and reordering)
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	Compared to option 2C, only addition is support of bearer split	similar to option 2C	similar to option 2C additionally requires the functionality support bearer split. Depending on how bearer split is enabled, channel quality of small cell, small cell load condition are required to be communicated between the cells. complexity is higher than option 2C.
NTT DOCOMO	We are interested in this Alt, because this alt has more feasibility to achieve the comparable peak data rate with Intra-eNB CA Although the X2 latency may impact on QoS, it may not be so severe for BE data.	No additional signalling to CN Security may be robust. More feasibility to achieve the peak data rate aggregating CCs in MeNB and SeNB	The additional MeNB's processing power for the data being transmitted from SeNB will be needed X2 latency may impact on QoS. X2 impact to deliver PDCP PDU
New Postcom	PDCP only in MeNB.	Centralized security can be handled in MeNB, which is single security. Offload enhancements, improve user throughput Reduced signalling load towards CN related to SeNB mobility. Bearer can be split over multiple eNBs, which flexibility scheduling can be provided for data transmission. CN does not need to know UE's mobility in MeNB's coverage.	More processing load and buffer in MeNB (forwarding data to SeNB) Need indication for successful PDCP PDU transmission from eNB. Complexity
Intel		Path switching signalling due to SCell addition/removal is not needed. No security issues. Potential throughput increase when system load is low.	Need to route traffic between MeNB and SeNB, therefore MeNB data processing capability should be increased PDCP PDUs should be split to two RLC entities. Single EPS bearer split has additional impacts like QoS handling, increased UE complexity.
ETRI		- No CN signalling impact when SeNB changes - No security impacts on UE	Data buffering to transfer PDCP PDUs considering available Xn resource PDCP PDUs retransmission when SeNB is attached/detached Out of sequence reception of PDCP PDUs
CMCC	Acceptable	There is only one key in MeNB and realise the through enhancement	There is pressure on backhaul link.

Alternative 3D: S1-U terminates in MeNB + bearer split in MeNB + master-slave RLCs for split bearers.



Company Views on Alternative 3D			
Company	Comments	Benefits	Drawbacks
MediaTek	Should be considered a main study alternative (esp for bearer split), as it reuses current functionality to large extent and can provide good mobility characteristics "for free" e.g. loss-less reestablishment.	Current RLC reordering can be reused. Centralized security, No need to re-establish security when UE moves in the local area. AM retransmission can be used for lossless mobility when UE changes cell, also in case of re-establishment.	
LGE	We want to exclude this option due to violation of current bearer mapping rule	No CN signalling load due to SeNB change No dual security keys No PDCP impact Increased throughput	Traffic routing between MeNB and SeNB RLC impacts to route RLC PDUs to different RLC entities Big RLC impacts to split RLC functionalities between MeNB and SeNB Given that the current protocols are designed based on 1-to-1 mapping rule, violating current mapping rule would cause many potential impacts, e.g., RB configuration, status reporting, BSR, LCP,...
Nokia & NSN		one set of security keys SeNB mobility hidden to CN no data forwarding required at SeNB change maintains current functional split between PDCP and RLC (reordering, reception-gap handling) no impact to logical channel prioritization in uplink (SeNB simply forwards everything to MeNB) packet loss between MeNB and SeNB covered by RLC's ARQ relaxed requirements for SeNB mobility (MeNB can be used in the meantime). CA/CoMP possible	need to route, process and buffer all UP traffic in MeNB extension of RLC SN space may be needed to tackle Xn latency. application with RLC UM requires adoption of UMD PDU Segment requires deviating from the current principle of only one new RLC data PDU per RLC bearer per MAC PDU 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
BlackBerry	It is not clear the functionality of the 'slave' RLC in SeNB. Segmentation? Retransmission for AM?	Single security key	Tight interaction between the MAC and RLC i.e. segmentation process, might cause problem if the segmentation is taken care by the 'master' RLC in MeNB
RME	Alternative 3D series can't offload the processing of MeNB, and also these alternatives will require higher backhaul link performance Split the bearer to both MeNB and SeNB could provide more flexibility at eNB side and potentially good for per UE throughput	Flexibility for NW side for data transmission Potentially good for per UE throughput No additional security issue need to be considered Could hide the small cell from CN for the data transmission	Higher requirement on the backhaul link between MeNB and SeNB Additional entity / specification need to be defined Extensive re-segmentation is expected Not good scalability, addition of SeNB will require update of the MeNB
CATT		Offloading data depending on the QoS requirements; No impact on RLC/ PDCP for UE but Big impact on RLC for network; No CN signalling impact at SeNB change No impact to logical channel prioritization; One set of security keys;	Need to route all traffic to MeNB; Big impact on MeNB-SENB interface; Interruption reduced at SeNB-MeNB mobility event but limited reduction at other mobility events due to non-ideal backhaul; Extension of RLC SN space Extension of PDCP SN space is possible; Need for MeNB to buffer packets;
Samsung	Regarding peak data rate and interruption, same comment as 1A. Same comment as 2A for backhaul	1. Peak data rate is achieved 2. No interruption	1. NW implementation complexity ; i.e. additional buffer in the SeNB, different scheduling strategy

			2. Back haul overdimensioning
Panasonic		No security concern Data from one bearer can be scheduled in both cells RLC reordering takes care of in-sequence delivery to PDCP	More complexity in Macro eNB (buffer, processing) In case RLC UM bearers are mapped to SeNB, RLC UM needs to support (re)segmentation
NEC	Same as 3A	Higher user throughput compared to 1x, 2x would be expected	Higher UE complexity compared to 1x, 2x. Local IP breakout is not possible. New mechanism for flow control may be necessary between nodes. Impact on LCP.
InterDigital	This option is similar to 2D with the difference that multiflow can be supported	Similar benefits to 2D DL multiflow and RRC diversity can be supported. No additional functional changes are required in the RLC. RLC can perform reordering using existing functionalities UL multiflow is possible UL/DL splitting can be supported	Similar drawbacks to 2D For UL multiflow, LCP, BRS may be impacted
Ericsson, ST-Ericsson		Splitting packets inside a EPS bearer can bring some user throughput gains. However, flow control will impact the gain negatively.	Extensive forwarding of user plane packets over a limited backhaul. Increase of user plane processing in the anchor eNB. Flow control needed between MeNB and SeNB. Long RLC reordering times need to be used. PDCP SN and RLC SN shortage may occur. Complex in the network side.
Huawei		SeNB change is shielded from CN. L2 protocols of UP can be largely reused. UE throughput can be improved even if UE has only one EPS bearer. Can support CP option of one RRC entity per UE with RRC signalling transmission over any combination of radio resource of MeNB and SeNB. Less interruption time during SeNB change. Single PDCP and RLC at UE.	Big impact on RLC protocol. Additional overhead and complexity due to re-segmentation. Increased network complexity in RLC configuration, e.g., of re-ordering buffer and re-ordering timer. Window stalling more frequently. Modifications to small eNB RLC for re-segmentation at initial transmission. Potential modification even to macro RLC for RLC PDU preparation timing, re-segmentation at the initial transmission to accommodate non-ideal backhaul to slave RLC on SeNB. If RLC UM or TM RB is to be supported on SeNB, new re-segmentation functionality (and header format) is needed for RLC UM or TM.
ZTE	In general we don't prefer split within one protocol layer especially for time sensible RLC layer	Same as 3C	Non-ideal backhaul delay will become part of RLC RTT which will impact RLC layer performance quite a lot. And it seems not clean solution to split RLC protocol into two RAN nodes resulting unexpected complexity for network implementation and standardization
ITRI	Same as 3A and 2D.		
ASUSTeK	It is unclear which functionalities will be put in slave RLC. Thus, the benefits are unclear.	No change to PDCP spec. Only one S1-U for a UE is required, i.e. less CN impact. PDCP re-establishment is not required when SeNB changes. No impact to security.	Impact to RLC spec for splitting functionalities. Data forwarding via Xn and delay caused by non-ideal backhaul. Delay of PDCP Status report caused by non-ideal backhaul. RLC needs to support flow control.
Hitachi	Gain and complexity of bearer split	CN signalling load will be reduced	Traffic routing function and

	should be further studied.	since SeNB mobility is hidden from CN. No impacts on PDCP.	processing of SeNB traffic are required in MeNB side. Concern on backhaul capacity in MeNB side. Some impacts on RLC.
Alcatel-Lucent/ Alcatel-Lucent Shanghai Bell	Compared to option 2D, only addition is support of bearer split	similar to option 2D	similar to option 2D additionally requires the functionality support bearer split. depending on how bearer split is enabled, channel quality of small cell, small cell load condition are required to be communicated between the cells. complexity is higher than option 2D.
NTT DOCOMO	We are interested in this Alt, because this alt has more feasibility to achieve the comparable peak data rate with Intra-eNB CA. Also, we think that for supporting bearer split, this Alt may be a compromised alternative, because there will not be much impact at least on UE. We think that in this Alt, existing X2 HO procedure can be utilised. Although the X2 latency may impact on QoS, it may not be so severe for BE data and there will be no concern about TCP throw start because macro-cell is available.	No additional signalling to CN Security may be robust. More feasibility to achieve the peak data rate aggregating CCs in MeNB and SeNB	The additional MeNB's processing power for the data being transmitted from SeNB will be needed X2 latency may impact on QoS. X2 impact to deliver RLC PDU
New Postcom	The definition of "slave RLC" and how it works is not clear, more detail should be further provided. Some potential operations are considered as follows. Resegmentation and ARQ can be handled in SeNB Protocol error detection should be performed in SeNB	Centralized security can be handled in MeNB, which is single security. Offload enhancements, improve user throughput Reduced signalling load towards CN related to SeNB mobility. Bearer can be split over multiple eNBs, which flexibility scheduling can be provided for data transmission. CN does not need to know UE's mobility in MeNB's coverage.	Extension of RLC SN space may be needed to tackle Xn latency More processing load in MeNB More Complexity Impact on RLC (e.g. extend RLC SN)
Intel		Path switching signalling due to SCell addition/removal is not needed. Almost no impact to PDCP No security issues. Potential throughput increase when system load is low.	Need to route traffic between MeNB and SeNB, therefore MeNB data processing capability should be increased Significant impact to RLC layer due to the split of RLC functionalities. Single EPS bearer split has additional impacts like QoS handling, increased UE complexity.
ETRI		No CN signalling impact when SeNB changes No security impacts on UE	Big impact on RLC due to function split between MeNB and SeNB Need to introduce a new method to cope with packet loss between MeNB and SeNB
CMCC		Same with 3C.	Much impact on RLC layer. And there is pressure on backhaul link.

5 Conclusion

A total of 28 Companies participated in this email discussion. Note that because the initial objective of the email discussion was to agree on a qualitative comparison, the proposals and related TP will only focus on facts, and exclude preferences expressed towards one alternative or the other.

Regarding the first question (on the proposed terminology), a majority of companies agreed with the proposed terminology (22 out of 28). However, concerns were also expressed on using a terminology that would refer to power classes. It is therefore suggested to refer to Master eNB and Secondary eNB.

Proposal 1: the following terminology is used:

- MeNB: Master eNB, terminates at least S1-MME and therefore acts as mobility anchor towards the CN;
- SeNB: Secondary eNB;
- Bearer Split: refers to the ability to split a bearer over multiple eNBs.

NOTE: because the level of bearer splitting is not yet agreed, the bearer split definition has to remain generic and only refer to bearer (as opposed to already use radio bearer or RLC bearer).

Regarding the 2nd question (on splitting U-Plane data), all companies agreed that we only have three options (S1-U also terminates in SeNB; S1-U terminates in MeNB, no bearer split in RAN; and S1-U terminates in MeNB, bearer split in RAN)

Proposal 2: three options exist 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.

Regarding the 3rd question (on the support of segmentation / re-segmentation) in the SeNB, all 28 companies agreed that the SeNB must at least support (re-)segmentation.

Proposal 3: the SeNB must at least support (re-)segmentation.

Regarding the 4th question (on Families of UP Alternatives), all 28 companies agreed that the four options are Independent PDCPs, Master-Slave PDCPs, Independent RLCs and Master-Slave RLCs. However, it was also highlighted that there is no clear view on the functional split for the master-slave PDCP.

Proposal 4a: capture Independent PDCPs, Independent RLCs and Master-Slave RLCs in 36.842.

Proposal 4b: discuss what split is envisioned for the master-slave PDCP approach.

Regarding the 5th question (on UP alternatives), all 28 companies agreed that the combination of bearer split options and families of UP alternatives lead to 9 different options. However, similarly as for the 4th questions, it was also highlighted that there is no clear view on the functional split for the master-slave PDCP.

Proposal 5: capture and compare the following alternatives in 36.842

- 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;
- 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;
- 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.

Proposal 5a: if a functional split can be agreed for the master-slave PDCP approach, also consider the following alternatives:

- 2B: S1-U terminates in MeNB + no bearer split in MeNB + master-slave PDCPs;
- 3B: S1-U terminates in MeNB + bearer split in MeNB + master-slave PDCPs for split bearers;

The rest of the email discussion focused on comparing the different alternatives. The text proposal for the analysis and proposals above is provided in [R2-131622](#).

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