3GPP TSG-RAN WG2 #116e R2-21xxxxx

Electronic meeting, November 1st – 12th 2021

Agenda Item: 9.1.3

Source: Ericsson

Title: [Post115-e][302] [NBIOT/eMTC R17] carrier selection (Ericsson)

Document for: Discussion, Decision

# 1 Introduction

This document is to gather input from companies for below email discussion:

* [post115-e][302] [NBIOT/eMTC R17] carrier selection (Ericsson)

Scope: progress open issues, main aim is to converge on option 1c vs. 2a for decision in next meeting.

Intended outcome: Report to next meeting

Deadline: long

The two options are listed below

* Option 1c: Network enables UE to select a Rel-17 paging carrier by providing the coverage information (CEL/Rmax) for the carrier selection to the UE in dedicated signalling
* Option 2a: NW indicates the carrier to use explicitly via dedicated signalling based on information determined within the NW.

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# 3 Discussion

RAN2 has been discussing the two options below for paging carrier selection,

* Option 1c: Network enables UE to select a Rel-17 paging carrier by providing the coverage information (CEL/Rmax) for the carrier selection to the UE in dedicated signalling
* Option 2a: NW indicates the carrier to use explicitly via dedicated signalling based on information determined within the NW.

There are different views regarding which of these options should be specified. Let’s have a look at the commonalities and differences.

In option 1c, the eNB provides an Rmax/CEL value to the UE so that the UE can select a paging carrier based on such value when it is released to idle mode. In option 2a, the eNB maps the UE directly to a paging carrier by indicating the paging carrier explicitly. This is in principle quite similar in both options. In option 1c there has to be also additional means for the network to indicate which paging carrier should the UE select in case there are multiple paging carrier with the same Rmax/CEL value.

Another similarity between these two Options is the sort of information that needs to be signalled between the eNB and the MME as part of the paging information container. For option 1c, it would be the Rmax/CEL value and for option 2a it is the paging carrier.

Once the UE is in idle mode monitoring the paging carrier as indicated by the network explicitly (as in option 2a) or implicitly (as in option 1c), there has to be means for the UE to check whether its coverage has stayed the same since it has been released to idle mode. Otherwise, the UE would not know whether it is time for the UE to reconsider its selection for the paging carrier. RAN2 has agreed that UE metric for determining carrier suitability and selection is based on NRSRP and a hysteresis/longer averaging/timer is used such UE metric based on NRSRP. It has also been agreed that whenever this criterion is met paging carrier as indicated by the network explicitly or implicitly is used, otherwise the UE should use the fallback mechanism.

Note that upon cell change RAN2 has agreed on two alternatives for option 1c and for option 2a UE performs the fallback to the legacy mechanism.

In the rest of this document, these two options are discussed with respect to the following aspects

* Impact on paging strategy
* Load Balancing
* Exception case handling (deletion, addition or change of carrier)
* Specification and Implementation Complexity

## 3.1 Impact on paging strategy

For option 1c there are two alternatives to consider when cell change happens, as mentioned above. These alternatives are Alt 1 UE to select a paging carrier based on previously determined “coverage level” and broadcasted paging carrier configuration in the new cell, and Alt 2 fallback mechanism. It has been claimed that Alt 1 will be beneficial, especially if the UE happens to be in the same or better coverage with respect to the previous cell since there will not be any need for fallback and the UE would continue to monitor the paging carrier with the same Rmax/CEL. On the other hand, it has also been claimed that such flexibility for the UE makes it challenging for the network to predict which paging carrier the UE may be monitoring and thus have an impact on the network paging strategy. Yet another claim was that cells may have different coverage (Tx power, CE levels, quality interference) and thus it may not be suitable to use the Rmax/CEL value determined in the previous cell to determine the paging carrier in the new cell.

For option 2a and Alt2 for option 1c, fallback mechanism is performed, which is the legacy paging carrier mechanism based on UE\_ID.

Q1: Companies are requested to provide feedback regarding the impact of these two alternatives for Option 1c on the paging strategy mechanism.

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| Company name | Comments |
| Qualcomm | The main issue with Alt 1 (i.e., after reselection paging carrier selected based on previously determined coverage level) for option 1c is how can the network know that when a UE reselects to a new cell that it will monitor coverage-based paging carrier or legacy paging carrier? As we have pointed out in the past, network will have to first page on coverage-based paging carriers in the neighbour cells and if no response then page on legacy paging carriers in the neighbour cells (or alterntively page on both legacy and coverage-based paging carriers in the neighbour cells). In the end there is high probability that more paging resources will be used in the neighbour cells compared to legacy UEs. The end result is not only MT performance for UEs supporting coverage-based paging carrier will degrade but it will also impact legacy UEs due to increased paging carrier usage.  Therefore, we see far more disadvantages with Alt 1 compared to Alt 2 (i.e., fallback). Furthermore, as Alt 2 is already agreed for option 2, selecting Alt 2 for option 1c makes one more commonality between the two options.  We conclude Alt 2 is the sensible way forward for option 1c. |
| ZTE | We can understand the Alt2 is beneficial in some cases that the coverage of UE changes worse when the UE moves to another cell. With Alt2, UE and new eNB can simultaneously fallback at the first time paging that can avoid the first time paging failure. **But we should note that new eNB can only use the maximum Rmax (as legacy) to perform paging.** The benefit of R17 scheme is lost. From this perspective, it's not easy to conclude that Alt2 fallback mechanism is definitely better than Alt1 for saving paging resources.  It’s easy to understand in other cases that the coverage of UE keeps unchanged or change better when moving to another cell, Alt1 is better. Alt1 can also ensure the success of the first time paging and the benefit of less Rmax in R17 scheme still can be achieved. Moreover, based on the following further analysis, we assume the cases that the coverage of UE keeps unchanged or change better may be much more:   * If UE is assigned with large Rmax in old cell, it much probably means the UE is in bad coverage in the old cell, the UE may be likely to move to another cell later. We think it’s highly possible that the coverage would become better or at least previous large Rmax are still available in new cell. * If UE is assigned with small Rmax in old cell, it much probably means the UE is in good coverage, we assume it’s less likely to move to another cell. Even the UE moves, we assume only in a few sub-cases, the UE’s coverage may change worse.   In a summary, we assume in only a (very) few sub-cases, e.g., UE is assigned a small Rmax in old cell and the coverage changes worse after the UE moves to a new cell, to use Alt1 may likely cause first time paging failure and network needs to page on both legacy and coverage-based paging carriers. Even this is the case, the paging resources consumed in Alt1 may not be much more than Alt2. |
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| Huawei, HiSilicon | option 1c:  It is difficult to evaluate as the solution is not clear. In the following, we assume that, in a cell, two and only two carriers can be selected by a given UE: the legacy carrier and the R17 carrier. In other words, one UE cannot select different R17 carriers depending on some conditions.  Based on this assumption, we think paging escalation will work as follows:  1st paging attempt: last connected cell: R17 carrier.  further (2nd, 3rd, 4th) paging attempts:   * last connected cell: R17 carrier and legacy carrier * other cells: alt1: R17 carrier and legacy carrier , alt2: legacy carrier   Note that the reason for paging on the two carriers in every cell after the 1st attempt is that the paging area increases in size (number of cells) at each attempt and that the increase can be quite large. so it is better to find the UE as soon as possible to reduce the amount of paging.  Thus the impact on paging strategy is:  alt1: paging on two carriers in the last connected cell after the first attempt  alt2: paging on two carriers in every cell after the first attempt  option 2a:  we think paging escalation will work as follows:  1st paging attempt: last connected cell: R17 carrier.  further (2nd, 3rd, 4th) paging attempts:   * last connected cell: R17 carrier and legacy carrier * other cells: legacy carrier   Thus the impact on paging strategy is: paging in two carriers in the last connected cell after the 1st the 1st attempt  summary:  - option 1c alt 2 and option 2c are equivalent and only imply double paging in the last connected cell after the 1st attempt  - option 1c alt 1 can be very costly as it implies double paging in every cell after the 1st attempt. |
| Nokia | Motivation of this feature is to have the paging for UE in normal coverage have their own paging occasions without being impacted by UE in extended coverage because of DRX length the paging occasion limitations due to Rmax. The benefits are supposed to be extended for mobility scenarios also as the IoT UE in mobility are expected to be in normal coverage if not most, many scenarios.  When UE in normal coverage is assigned with coverage level for paging carrier selection in one cell, if it is moving to different cell in same coverage it should be able to continue to select carrier from subset of paging carriers meeting CE-level requirements. In our view this will not have much impact to paging strategy where NW need to start with paging on normal coverage carriers followed by carriers in extended coverage. If requires such ‘stepwise’ paging in non-serving cells and UE behaviour of Alt 2 can be configured by network. But support of this feature with some optional control is preferred. This is to avoid the restrict the applicability of the feature.  Even in current implementations, the network may already prefer to start paging in new cell with lesser repetition than Rmax first to avoid redundant resource usage for paging escalation. In that case also more than one paging would be required in this scenario.  Hence we propose Alt-1 is supported for cell change scenario. |
| Ericsson | Our view is that ZTE assumption’s is very bold saying neighbor cells will configure same Rmax configurations; thus UE which performs cell reselection will end up in the same coverage scenario. We do not think that would be the case. The UE movement can be in any direction and the cells may not be a perfect shape such as hexagon. A UE from a cell A from normal coverage may enter to another cell B in extended coverage.  We agree with Huawei analysis that for Option 1c Alt 1 NW will have to double the paging attempts in every cell after the 1st attempt.  We think that possibility that UE’s coverage is not changed even cell is changed cannot be assumed, there is no guarantee that the UE will have the same CEL/Rmax in another cell. If the required Rmax in the new cell is larger than the previously determined Rmax from last cell, then UE cannot be paged in the new cell using the previously determined Rmax. In such scenario, there is high risk that there will be paging latency and resource waste.  Thus, we think that for option 1c, upon cell change, Alt 1 will make things complex considering the limited benefit UE may get. So, Alt 2 is suggested to be used upon cell change. |
| ZTE2 | **Further clarifications (with feedback to HW’s comments):**  It’s unclear what the paging attempts in Huawei’s comments really means. Is it S1/NG paging attempt or air interface paging attempt? Here we assume they are referred to the (1st, 2nd, 3rd, 4th) S1/NG paging attempts for a certain UE. Firstly, we want to indicate, for each received S1/NG paging message, the cell may also trigger several air interface paging attempts based on the eNB implementation. Moreover, the cell would not distinguish between the 1st S1/NG paging attempt and subsequent S1/NG paging attempts, and will apply the same processing. Secondly, whether to triggerpaging escalation (e.g., to send 2nd and later S1/NG paging attempts to all the cells) is determined by core network, but whether to send the air interface paging attempt to more than one carriers is just eNB implementation. These two processes should not be confused.  Based on above clarifications, we think HW’s analysis would cause some confusion about process for S1/NG paging attempt and process for air interface paging attempt. We correct the HW’s analysis as following in high light text:   |  |  |  | | --- | --- | --- | |  | Option 1c with Alt1: try to keep using R17 scheme | Option 1c with Alt2: fallback mechanism  (Option 2a has similar process) | | 1st S1/NG paging attempt to last serving cell | Last serving cell:   * 1st air interface paging attempt: R17 carrier with smaller Rmax * 2nd and later air interface paging attempts: R17 carrier with smaller Rmax and legacy carrier with maximum Rmax (mainly to handle CEL change case) | Last serving cell:   * 1st air interface paging attempt: R17 carrier with smaller Rmax * 2nd and later air interface paging attempts: R17 carrier with smaller Rmax and legacy carrier with maximum Rmax (mainly to handle CEL change case) | | 2nd S1/NG paging attempts to all the cells  (same for later S1/NG paging attempts) | Last serving cell:   * 1st air interface paging attempt: R17 carrier with smaller Rmax * 2nd and later air interface paging attempts: R17 carrier with smaller Rmax and legacy carrier with maximum Rmax   Other cells:   * 1st air interface paging attempt: R17 carrier with smaller Rmax * 2nd and later air interface paging attempts: R17 carrier with smaller Rmax and legacy carrier with maximum Rmax | Last serving cell:   * 1st air interface paging attempt: R17 carrier with smaller Rmax * 2nd and later air interface paging attempts: R17 carrier with smaller Rmax and legacy carrier with maximum Rmax   Other cells:   * 1st air interface paging attempt: legacy carrier with maximum Rmax * 2nd and later air interface paging attempts: legacy carrier with maximum Rmax |   Here we summary as following:   * If UE doesn’t move, it’s highly possible that 1st S1/NG paging attempt (triggering one or more air interface paging attempts) would be successful. Then there would be no “*double paging in every cell*” issue. * If UE does move and paging escalation is triggered, it’s highly possible that the 1st air interface paging attempt would be successful in one of the other cells. We want to emphasize that in this step (1st air interface paging attempt), it’s obviously that Option 1c with Alt2 or Option 2a would consume more air interface resources in all the other cells as they use legacy scheme with maximum Rmax. Only in rare cases, the 2nd and later air interface paging attempts would be triggered. Then Option 1c with Alt1 would extend to two carriers and consume more resources. But when we consider all the steps together, it’s hard to say which option is more resource-efficient. Considering the above high light yellow text, can we even say that Option 1c with Alt1 is more resource-efficient?   **To feedback Ericsson’s concerns:**  We totally disagree that “*it is very bold saying neighbour cells will configure same Rmax configurations*”. Why it’s bold saying? The main purpose of R17 scheme is to allow the paging to UE in good coverage can use smaller NPDCCH repetitions. So at least it’s highly possible that all the cells can have a same configuration that one or more R17 carriers can be configured with Rmax = 1, right? Taking a step back, Option1c does not have any requirements that neighbour cells should provide same Rmax configurations. One of the advantage of Option 1c is just that it can handle any different SIB configuration in any cells.  Moreover, in all the previous discussion, no any company has said anything about “*to guarantee that the UE will have the same CEL/Rmax in another cell*”. We just give our analysis and based on that to assume it may be rare case that UE’s CEL/Rmax changes invalid in another cell. |
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**Summary: TBD**

## 3.2 Load Balancing

There has been no consensus on which option would provide means for the network to perform a uniform distribution of UEs to paging carriers.

In option 1c, the eNB and the UE would know which carrier to use or to monitor for paging messages based on the following formula in TS 36.304

floor(UE\_ID/(N\*Ns)) mod W < W(0) + W(1) + … + W(n)

In option 2a, the eNB would allocate a paging carrier to the UE when it is released to idle mode. In both options, it would be up to the network to make sure that UEs are uniformly distributed to the paging carriers as UEs would simply monitor the allocated paging carrier. Basically:

In Option 1c; the above formula needs to be computed by both eNB and individual UE and in option 2a it would be performed only by eNB.

One should also consider the mobile UEs moving in between cells which would make it harder for the network to maintain a uniform distribution unless UEs coming from neighbouring cells monitor legacy paging carriers based on UE\_IDs, i.e., use fallback mechanism, after cell reselection.

Q2: Companies are requested to illustrate the load balancing solution, how option 1c and option 2a can perform load balancing. Please elaborate on whether there is any difference between options when performance on uniform distribution is considered and what are pros/cons of each option with respect to load balancing.

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| Company name | Comments |
| Qualcomm | The underlying principle is that coverage-based paging carrier will provide lower coverage in a cell than legacy paging carriers because legacy paging carriers are designed to cover the entire cell. For this reason, we consider distributing UEs amongst legacy paging carriers and coverage-based paging carrriers (unlike the case of distributing UEs amongst anchor paging carrier and legacy non-anchor paging carrriers) is a lower priority. A coverage-based paging carrier can carry more paging occasions than a legacy paging carrier due to the fact that coverage-based paging carrier uses fewer repetitions (e.g., a factor of 2 more paging occasions) therefore, relatively speaking, a coverage-based paging carrier can support more UEs.  Even if all the popluation of UEs in a cell support coverage-based paging carriers, it is highly unlikely that all UEs will be in a coverage level to use the coverage-based paging carriers hence there will be a natural distribution of UEs amongts coverage-based paging carriers and legacy paging carriers. Remember, at least the anchor paging carrier has to cover the entire cell.  As with legacy paging carriers, if network finds that too many UEs are selecting coverage-based paging carrier over legacy paging carrier then network has two options:   1. Add more coverage based paging carriers. 2. Adjust coverage level of the coverage-based paging carrier to reduce the number of UEs it is suitable for in a cell.   The UE/eNB can consider all the coverage-based paging carriers that are suitable for UE’s coverage level then UE/eNB can use the legacy scheme to select one paging carrier from this list of coverage-based paging carriers (similar to the way a UE/eNB creates a sub-list of GWUS supporting paging paging carriers. If DRX is also considered then UE creates a sub-sub-list that has carrier-specific DRX no shorter than UE specific DRX. UE then selects one paging carrier from the sub-list or (the sub-sub list if DRX is of interest) according to the weights for each paging carrier in the list.  The above aproach can be used with both option 1c and option 2a hence there is no real difference in load balancing. |
| ZTE | We can agree with Qualcomm that it will be a natural distribution of UEs amongst different coverage-based paging carriers according to UEs’ different coverage levels. But even this is the case, considering huge number of UEs and limited number of paging carriers, it still needs to consider the load balancing for UEs with the same coverage level.  In above, Qualcomm mentions two ways to handle the case that “*too many UEs are selecting coverage-based paging carrier”*. They may be feasible but will related to another issue that whether the Option 1c or Option 2a can flexibly respond to changes in SIB. Here we simply conclude Option 1c can deal with SIB change more flexibly than Option 2a. The detailed analysis can be found in Q3 and Q4.  Back to the question of how to load balance the UEs with the same coverage level, we can high level summary as following:   * The load balancing concept of **Option 1c** is very similar as that in legacy, e.g., the load balancing among multiple carriers is achieved by UE-based paging carrier selection, e.g, according to number of carriers, carrier weight and UE\_ID. * For **Option 2a**, it introduces new requirement that network needs to balance the UEs when releasing them. Previously, we assume it needs network to record the load situation of idle mode UEs on each carrier that will introduce unnecessary complexity. But we understand some other companies have mentioned it may be also possible that the network can perform same carrier selection formula when it decides which carrier would be assigned to a UE when releasing it. Even we think it looks very strange for network to perform paging carrier selection during RRC release, we agree it looks feasible to guarantee load balancing among the existing coverage-based paging carriers (e.g., without need of recording the load situation of each carrier). |
| Huawei, HiSilicon | Option 1c: uniform distribution among equivalent R17 paging carriers can be achieved by using the NW configured parameters and the UE-ID, similar to legacy. However, uniform distribution cannot be achieved if external non random parameter, e.g. UE specific DRX, is used in the selection criteria.  Option 2a: Uniform distribution can be achieved is the same way as legacy, the used UE ID maybe different but the concept is the same. The eNB can also use dynamic load balancing based on paging load observation.  Summary:  No difference between the two options assuming UE specfic DRX cycle is not used in option 1c.  Use of UE specific cycle in option 1c cannot achieve uniform distribution between the carriers. |
| Nokia | We don’t think performance for load balancing differs a lot among this option. For stationary UE, network assigning different carrier within normal coverage will enable slightly more accurate load balancing than UE-ID based method which is applicable for option 2c. But this difference is not big enough to make decision against one or other. |
| Ericsson | We agree with Huawei that the benefit of Option 2a is dynamic load balancing that the NW can do. NW has other observability such as UE paging performance, paging success rate KPIs per carrier, UL RSSI, quality report of different carriers etc, which can be utilized additionally for load balancing. And for carrier selection among the Rel-17 paging carriers within same CE level, UE does not need to compute the paging formula. |
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**Summary: TBD**

In actual network deployments when the number of users grow in a certain area, additional carrier may be required. The additional carrier generally has similar characteristics as compared to the deployed carrier. Hence, it is expected that different carriers may be configured with same Rmax value, especially if the network assumes/knows that there are many UEs, which have camped in the cell, that happen to be in similar coverage. In such case how will the network ensure that UEs are distributed uniformly.

Q3: Companies are requested to illustrate the load balancing solution, how option 1c and option 2a can perform load balancing in that case; i.e., if another paging carrier is added with similar characteristics; e.g. same Rmax due to capacity concerns.

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| Company name | Load Balancing Steps |
| Qualcomm | If there are N coverage-based paging carriers that meet the UE’s coverage level then legacy scheme can be used to select one paging carrier amongst this sub-set (i.e., based on weights for each of the paging carriers in the set and UE ID). |
| ZTE | In Q2, we mainly discuss the case that there are already some coverage-based paging carriers and how to distribute all the capable UEs among these carriers. For Q3, it mainly focus on the dynamic case that a new carrier is added or an old carrier is removed (we think this is also possible). This can be seen as another issue of UE redistribution that is different from load balancing issue in Q2.  We understand Qualcomm has mentioned the same process for this case as that in the load balancing case in Q2. **We disageree.** We think Option 1c and Option 2a would perform very differently for this case. Based on the same assumption that the SIB will be updated when the network adds or removes a carrier, we further analysis the following two cases:   * For the idle mode UEs with Rmax\_1(or carrier\_A for Rmax\_1) that are released earlier than the time when adding a new paging carrier configured for Rmax\_1, e.g., carrier\_B for Rmax\_1:   + With **Option 1c**, when these UEs monitor paging later, they can use the new list with **(N+1)** paging carriers and select one according to its assigned Rmax\_1. That means some UEs can be redistributed/offloaded to the new carrier\_B as expectation.   + With **Option 2a**, when these UEs later monitor paging, they can only use the previously assigned carrier\_A. They have no way to use the new carrier\_B. Only when some other new UEs with Rmax\_1 are released later, network can assign (part of) them to the new carrier\_B. However, in the worst case, if there is no any new UE to access the network after the carrier\_B is added, the carrier\_B would be useless in a certain time period. * For the idle mode UEs with Rmax\_1(or carrier\_A for Rmax\_1) that are released earlier than the time when removing an old paging carrier configured for Rmax\_1, e.g., carrier\_A for Rmax\_1:   + With **Option 1c**, when these UEs monitor paging later, they can use the new list with **(N-1)** paging carriers and select one according to its assigned Rmax \_1.   + With **Option 2a**, if these UEs later monitor paging, as they can know there is no carrier\_A in the updated SIB, they have to fallback to legacy carrier selection scheme. From network perspective, the expection may be to redistribute all these UEs from carrier\_A to carrier\_B. But the network can only do this in the next time RRC connection/release and per UE one by one. It’s very inefficient or even highly impossible due to the UEs may re-connect to the network very infrequently.   In a summary, in the case that another paging carrier is added with same Rmax (or an old paging carrier is removed), **Option 2a** is much worse than **Option 1c**. |
| Huawei, HiSilicon | Option 1c  The new paging carrier can only be added or removed at the boundary of the eDRX acquisition period After this point, UEs will take into account the new paging carrier in the selection and uniform distribution will be achieved immediately.  Option 2c  The new paging carrier can only be added or removed at the boundary of the eDRX acquisition period. It may take a bit of time for uniform distribution to be achieved after the modification but considering that adding a new carrier will be a rare event, this is not an issue.  Summary:  The two options are equivalent |
| Nokia | For option 1c : It is UE-ID based load balancing as in existing mechanism. The modification of list of paging carriers does not affect this load balancing.  For option 2a: if specific carrier frequency is given via dedicated signalling then the UE selection is simple if this frequency is found in SIB list UE selects the same otherwise fallback. If index into SIB list is given in the frequency then it may impact the UE carrier selection if the list is modified. But this scenario is less frequent.  For specific scenarios, option 2a may have some issues to be resolved. But it can be implemented. Again the comparison based on load balancing efficiency and the implementation of the load balancing mechanism should not be main criteria for down selection. |
| Ericsson | The question was here was if 2 carriers have identical Rmax; which one UE would select based upon Option 1c and based upon Option 2a.  Our view is that there may be a risk of ambiguity with Option 1c as it is based upon UE selection and NW may not know which one of them have been selected. Further, how to perform load balance between identical carriers (carriers with same Rmax) |
| ZTE2 | **To feedback Huawei’s comments:**  We think Huawei already can agree that Option 2a cannot efficiently deal with SIB change. The saying “*to take a bit of time for uniform distribution to be achieved*” and the final conclusion “*the two options are equivalent*” are arbitrary.  Moreover, we also don’t think that configuration changes rarely happen. For example, considering energy saving of network, adjusting the number of carriers according to the traffic load at different time periods may be frequently used.  **To feedback Ericsson’s comments:**  If 2 carriers have identical Rmax, UE/network can choose one based on UE\_ID, same as legacy. |
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## 3.3 Exception case handling (deletion or change of carrier)

In this section we consider the scenario when network releases, adds or changes the configuration of a paging carrier so that the associated Rmax/CEL value changes.

For option 1c, it has been stated that the network can reconfigure the paging carriers with respect to their Rmax/CEL values so that the UEs would select accordingly once update takes place, i.e., after system information update notification. For option 2a, it has been stated that such update can be conveyed to the UEs with no need to change the carriers assigned to the UEs, but rather using pointers that are mapped to the actual carriers using a mapping table broadcast as part of system information.

Q4: Companies are requested to provide their view on exception case handling; e.g. when an assigned or selected carrier is deleted. Is there any benefit/drawback for any of the options (1c, 2a) and why?

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| Company name | Comments |
| Qualcomm | Changing paging carrier configuration is a rare event and is generally done with care due to the impact it can have on UE reachability.  Option 1c: Use legacy scheme for handling change in paging carrier configuration. If none of the coverage-based paging carriers in the new configuration are suitable then UE falls back to legacy paging carrier selection scheme.  Option 2a: If new paging carrier configuration has a carrier associated with the carrier index UE is using and it is suitable then UE continues to use the corresponding paging carrier. Otherwise UE falls back to legacy paging carrier selection scheme.  With both options, suitable means that coverage level is right and DRX cycle is right. |
| ZTE | Changing paging carrier configuration is generally infrequent, but it’s still possible and needs to be handled.  As **Option 1c** has similar mechanism as that in legacy paging carrier selection, e.g., UE and eNB perform paging carrier selection independently based on the configuration in SIB and same rule, Option 1c can naturally be easy to deal with SIB change. On the other hand, **Option 2a** is less flexible for handling SIB change. With the following example, we can see the strength of **Option 1c** and the weakness of **Option 2a** on this issue.  In the example, a UE is assigned with Rmax\_1 (in Option 1c) or carrier\_A (in Option 2a). And it’s coverage situation keeps unchanged. The carrier\_A is previously configured with Rmax\_1 and later changed to Rmax\_2. And then:   * For **Option 1c**: Based on the updated SIB, the UE will use a new carrier list corresponding to Rmax\_1 (without carrier\_A) and can select another carrier, e.g., carrier\_B for Rmax\_1 according to its assigned Rmax\_1. Specially, as mentioned by Qualcomm, if none of coverage-based paging carrier is in the new list, the UE can fallback to legacy scheme. eNB can have same understanding and perform consistently. * For **Option 2a:** there are may be two possibilities and both of them cannot avoid fallback:   + The UE is directly assigned with carrier\_A. Based on the updated SIB, the UE knows carrier\_A is no longer valid. The UE has no way to change to other coverage-based paging carriers, e.g., carrier\_B(even this carrier exists). Therefore, the UE has to fallback to legacy carrier selection. The benefit of R17 scheme is lost, again.   + The UE may not be assigned actual carrier and instead assigned with a pointer. The mapping relationship between the pointers and the carriers is included in a mapping table which needs to be broadcasted as part of system information. Previoulsy we already give an example that shows the pointer scheme infeasible: the network have assigned three carriers to all the UEs with a certain Rmax and later network removes one carrier, e.g., the third one. Even the UEs that are assigned with the first two pointers can re-match with the remaining two carriers, at least the UEs assigned with the third pointer cannot find valid carrier and still has to fallback. |
| Huawei, HiSilicon | option 1c:  Again, it is difficult to comment as the solution is unclear about what exactly is provided to the UE by the NW and what is used by the UE for the selection.  CEL/Rmax has been mentionned multiple times. It is not clear to us if CEL and Rmax are considered equal but at least we think that it should be possible for the eNB to change the relationship between them. So at least a mapping table between CEL and Rmax is needed.  option 2a:  The case where the eNB wants to change a assigned carrier or remove it completely can be handled by an indirection table, i.e. instead of assigning a pointer to a carrier, the eNB assigns a index to a table (signalled in the SIB) which entries point to a carrier. In this way, the eNB can change the assigned carrier or remove it completely by removing the mapping in which case the UE uses the legacy mechanism.  Summary: The two solutions are equal. In both cases, a mapping table is needed to allow reconfiguration of the R17 carriers. |
| Nokia | As said in above question this scenario can be handled in both options where option 2 a may need some additional implementation or spec changes. |
| Ericsson | Solution of this problem for option 2a is that it can simply be addressed by assigning an index number to each carrier so that the NW can assign the index number to a UE and when a carrier has to be replaced with another one only the mapping between the index value and the paging carrier needs to be changed. The mapping can be broadcasted in the serving cell. |
| ZTE2 | **To answer Huawei’s questions:**  In our assumption for Option 1c, what is provided to the UE is the required number of NPDCCH repetitions (call it Rmax) for receiving paging, which is same or similar as that is currently in the S1 interface, e.g., *npdcch-NumRepetitionPaging* in *UEPagingCoverageInformation-NB.* We also assume such kind of NPDCCH repetitons number need to be configured for the carriers in R17 carrier list in SIB. The carriers with same Rmax are corresponding to the same coverage level.  At its simplest, the Rmax assigned to the UEs can be a subset of the values of Rmax configured in the R17 carrier list. Certainly, the Rmax assigned to the UEs can also be different from the values configured for R17 carrier list. In this case, the UE can determine a candidate list by the way mentioned by Qualcomm in Q7 (e.g.*, if UE’s coverage level (Rmax) is X then all coverage-based paging carriers with configured coverage level (Rmax) >=X are candidates*). For this part, we don’t see any need of a mapping table between CEL and Rmax for Option 1c.  Per our understanding, for Option 2a, same NPDCCH repetitions for receiving paging are also needed for the carriers in R17 carrier list in SIB. Without such configuration, the UE would not know how many repetitions are needed for receive paging on the assigned carrier. Moreover, as mentioned in our previous comments, in order try to reduce the fallback due to SIB change, the UE may not be assigned actual carrier but instead assigned with a pointer. Then a mapping table between the pointers and the carriers would be mandatory in SIB for Option 2a. But even this is the case, the (unnecessary) fallback might be reduced but not completely avoided. |
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Summary: TBD

Another aspect to consider is when a new paging carrier with power boosting is added, an existing paging carrier is power boosted or a power boosted paging carrier is released.

Q5 Companies are requested to provide their views regarding how scenarios mentioned above are handled for option 1c and option 2a.

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| Company name | Comments |
| Qualcomm | How can UE know whether a particular paging carrier is power boosted or not? We don’t think power-boosting can be considred in either of the two options. UE can not know what is the reason for power-boosting a particular paging carrier. |
| ZTE | Generally we agree with Qualcomm that it’s no need to consider power-boosting in either of the two options. Suitable network configuration can make sure a suitable carrier is used by the UE.  In previous discussion there was a statement that with **Option 2a**, “*a UE in poor coverage could be configured to use a "better" (power boosted) car*rier”. We think it’s infeasible. Firstly, we are not sure how to configure Rmax for this "better" (power boosted) carrier? Larger Rmax or smaller Rmax? If it’s smaller, can it fulfil the needs of the UE in poor coverage? If it’s larger, will there be a waste of resources? e.g., is it reasonable of more repetitions on a power boosted carrier? So, in our thinking, the more suitable or simple way for configuring Rmax for a carrier is just according to its coverage. Secondly, to deliberately assign a sort of carrier (power boosted carrier) for some (deep coverage) UEs is easier to cause congestion on this carrier. |
| Huawei, HiSilicon | We do not see why a power boosting carrier would be used as a R17 carrier as we understand the new carriers will be used for UEs in good coverage. There are only two power boosting carriers in total, the anchor carrier and one non-anchor and they are better reserved for UEs needed coverage enhancements.  Even if they can be used, we do not think this should impact the selection criteria, up to the NW to provide an suitable configuration.  Summary: The two solutions are equivalent. Power boosting is not an issue. |
| Nokia | As selection is based on the coverage level estimation of anchor carrier there is no impact due to these options. As per quick analysis, if power boosted carrier improves the coverage of the carrier it is expected to included in the normal coverage carrier list with modified Rmax value. |
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## 3.4 Specification and Implementation complexity

Regarding the specification and implementation impacts, it is mainly the specification effort and UE/eNB implementation that needs to be considered.

Based upon the discussion so far, the paging carrier selection would be influenced by two key factors:

a) Rmax

b) DRX

Companies are requested to provide their input on the specification details such as TS 36.304 paging carrier formula update based upon their preferred option.

TS 36.304 Current Paging formula

floor(UE\_ID/(N\*Ns)) mod W < W(0) + W(1) + … + W(n)

How would the above Rmax and DRX based selection would be accommodated by the above formula. What updates are needed; if any?

Q6: Companies are requested to provide details of formula update needed to support each of their preferred option or can also provide for both options?

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| Company name | TS 36.304 Specification Impact Details |
| Qualcomm | For both options, we don’t think there is any need to change this formula. Specification needs to define how the sub-list of paging carriers is constructed from which the UE is to select a coverage-based paging carrier. This in our view is similar to the way the sub-list is constructed for GWUS. |
| ZTE | * For **Option 1c**: it’s no need to change the paging formula itself. The only change is to replace the legacy complete carrier list with a sub-set list. This sub-set list includes the coverage-based paging carrier whose Rmax is consistent with UE’s assigned Rmax. We agree with Qualcomm that it’s similar as the way of constructing the sub-list for GWUS. * For **Option 2a**: the current paging formula and some related description would no longer be used. Some new description about directly applying the assigned paging carrier would be needed. Moreover, whether and how to collaborate with other functions, e.g., WUS/GWUS may also need new description. |
| Huawei, HiSilicon | Option 1c:  We do not think that (UE specific) DRX should be taken into account in the selection criteria, i.e. we do not understand the benefit (why would the NW configure two carriers with the same Rmax and different min\_UE-specifc-DRX ?) and this would lead to non uniform distribution of the UE accross carriers  With this assumption, we think there is no need to modify the formula. What needs to be specified is how the UE builds the list of candidate paging carriers (e.g. based on its NRSRP and configured CEL/Rmax), we still do not understand how this part works.  Option 2a:  Here as well, no special need to modify the formula, just need to specify how to build the list of carriers to be used. In this case, either legacy list or the assigned R17 carrier.  Summary:  For both options no need to modify the formula, i.e. only need to specify the list of carriers to be used.  How to do this is unclear for option 1c and is straigthforward for option 2a. |
| Nokia | RAN2 has already agreed that Rel-17 paging carrier list is different from legacy paging carriers. In our view all these carriers can be used for normal coverage UE without need for further splitting them into sub-groups for simple configuration. In such case the specification impact for Option 1C is minimum as the UE have to select Rel-17 paging carrier list based on RSRP condition check.  For solution 2C this may be slightly simpler as the UE can directly use the given paging carrier after RSRP check. |
| Ericsson | Regarding the formula, option 1c need both eNB and UE to implement the formula for each sub-group of a certain Rmax/CEL Rel-17 paging carriers, while there is no need for UE to implement it for option 2a. If DRX based selection is to be considered, the 2-level carrier selection scheme will even complex UE implementation. So, from UE implementation point of view, option 2a is a bit simpler than option 1c.  Besides, for option 1c, eNB needs to signal the weight value for each Rel-17 paging carrier to the UE, while for option 2a, it is not necessary as UE should directly use the dedicated paging carrier from the eNB, so from this point, option 2a is also a slightly simpler than option 1c. |
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Q7: Companies are requested to give input on the steps that UE would need to perform for the carrier selection considering multiple factors such as Rmax and DRX and describe the UE implementation effort/complexity level for their preferred option or can also provide for both options?

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| Company name | Comments |
| Qualcomm | Option 1c:  Step 1: UE constructs a list of coverage-based paging carriers that meet the UEs coverage level (e.g., if UE’s coverage level is X then all coverage-based paging carriers with configured coverage level >=X are candidates).  Step 2: If UE is configured with UE specific DRX, then from the list constructed in step 1, UE constructs a list of all paging carriers with carrier specific DRX >= UE specific DRX. Otherwise it is the complete list from Step 1.  Step 3: If UE intends to use GWUS then UE selectes all coverage-based paging carriers that are configured with GWUS from the list of paging carrier list constructed in step 2. If UE does not intend to use GWUS or none of the paging carriers in paging carrier list constructed in step 2 is configured with GWUS then it is the complete list from step 2.  Step 4: UE uses the legacy formula to select one paging carrier, for the coverage-based paging carrier list from step 3.  Option 2a: We think same steps as for option 1c can be used by eNB for option 2.  In general, the eNB implementation is likely to be same for both option 1c (to match UE steps) and 2a.  From spec perspective, we don’t think it is too complex to implement option 1c but it is clear option 1c will need clear spec while with option 2a it is left to eNB implementation. |
| ZTE | Generally we can agree with Qualcomm that, “*it’s not too complex to implement option 1c but it's clear option 1c will need clear spec while with option 2a* (more of) *it is left to eNB implementation*”. But we think this should not be the main aspect for choosing between option 1c and option 2a. For us, with consideration on the issues mention in Q2~Q4, we think **Option 2a** has kind of fundmental disadvantage (See our comments in Q9).  We can generally agree with Qualcomm on the mentioned steps in UE side in **Option 1c**. the only difference may be that, **step 1** can also be simplified that the UE only includes the coverage-based paging carriers whose configured Rmax is just equal to the Rmax assigned to the UE. Moreover, the **step 2** would be optional, depending on whether carrier-specifc DRX is finally supported. |
| Huawei, HiSilicon | Option 1c:  As indicated in Q7 we do not think that DRX should be used in the selection criteria.  We still do not do understand how the selection works, at least the current NRSRP and the assigned NRSRP/Rmax and the UE-ID need to be used. we are not sure if it is enough to 1) prevent that the UE can choose different R17 carriers depending on the value of the current NRSRP, 2) allow reconfiguration of the relationship NRSRP/Rmax, 3) different configuration in different cells if paging carrier selection accross cells is supported.  Option 2a:  Selection is based on the current NRSRP, and the assigned NRSRP/Carrier. i.e.  if current NRSRP > assigned NRSRP  use assigned carrier  else use legacy carrier  Summary:  Option 1c is unclear and possibly quite complex. Option 2a is simple. |
| Nokia | As the DRX cycle configuration is also linked to the Rmax , paging carrier with lower Rmax can support the DRX cycles of shorter values already. Moreover, we don’t see need for multiple selection criteria for paging carrier selection. Use of DRX cycle as additional criteria is not agreed in RAN2. We prefer simple carrier selection option. |
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| Ericsson | We agree with QC about the UE implementation for option 1c, and we agree with HW about the UE implementation for option 2a. Clearly, option 2a is simpler for UE implementation. |
| ZTE2 | Firstly, we are fine to only support coverage-level DRX in R17, e.g., for all the carriers corresponding to a same Rmax, they should be configured with same DRX cycle.  Secondly, it would be totally same for Option 1c and Option 2a on how to determine whether the assigned Rmax or assigned carrier is still valid based on the NRSRP measurement. (In previous meeting, company has proposed a NRSRP range for each coverage level in the R17 carrier list. If this is the so-called assigned NRSRP in HW’s comments, we think it can be applied to both of options. We are fine to further discuss it).  As for simple UE implementation, we are still not so sure. We assume the UE needs to support two schemes for paging carrier determination in Option 2a, one is based on UE\_ID and carrier list in SIB, the other is just using the assigned paging carrier. But for Option 1c, only one scheme based on UE\_ID is used, the main change is to use different carrier list. |
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Q8: Companies are requested to give input on the steps that eNB would need to perform the carrier selection considering multiple factors such as Rmax and DRX and describe the eNB implementation effort/complexity level for their preferred option or can also provide for both options?

Note: Of-course eNB implementation is not standardized here it is more to understand some steps that would be needed to gauge some complexity involved.

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| Company name | Comments |
| Qualcomm | See response to Q7. |
| ZTE | * For **Option 1c,** eNB would perform same steps (See response to Q7) as that in UE when it intends to send paging message. * For **Option 2a,** as mentioned above, eNB needs to perform similar carrier selection as that the UE performs in idle mode when releasing the UE and assigning the paging carrier. And later when the eNB intends to send paging message to the idle mode UE, the eNB need to additionally check whether the assigned carrier is still valid (e.g., whether the assigned carrier is still in the SIB? Whether the configured parameters for it are unchanged?)   Furthermore, for eNB aspect, here we want to compare the RAN3 impacts of these two options a bit. In last RAN3 #113 e-meeting discussion (R3-214179), almost all the involved companies agree that the paged (new) eNB need to receive in the S1AP/NGAP Paging message an “indication” of whether it should use or not the received CEL (for RAN2 option 1) or the paging carrier information (for RAN2 option 2) to determine the paging carrier. Based on the discussion, we feel that the previous RAN2 assumption that S1AP/NGAP update is not needed is unsuitable. Anyway, this should be decided by RAN3. In the following, we quote the main RAN3 options about how to enhance S1AP/NGAP interface for RAN2 option 1 and option 2 respectively. RAN3 didn’t conclude and still wait for RAN2 progress.   |  |  |  | | --- | --- | --- | | RAN2 option | Option 1: last serving eNB sends to the UE the estimated Rmax-paging...... | Option 2: last serving eNB sends to the UE the paging carrier information...... | | RAN3 options on how to provide the related information in S1AP/ NGAP signaling | * Option 1: Include the “indication” in the NGAP *Cell Identifier and Coverage enhancement level* IE as proposed in 3245 and 3454. * Option 2: Include the “indication” in the existing RRC container *UERadioPagingInformation-NB* message for NB-IoT) as proposed in 3850. * Option 3: Include the “indication” in the existing RRC container *UEPagingCoverageInformation-NB* message as proposed in 3575.   (Note:*UERadioPagingInformation* isn‘t applicable as this is NB-IoT feature) | * Option 1: Include the paging carrier information in the NGAP *Cell Identifier and Coverage enhancement level* IE as proposed in 3454. * Option 2: Include the paging carrier information in the existing RRC container *UERadioPagingInformation-NB* message for NB-IoT) as proposed in 3850. * Option 3: Include the paging carrier information in the existing RRC container *UEPagingCoverageInformation-NB* message as proposed in 3575. * Option 4: Include the paging carrier information in a new RRC container as explained in 3245. | | ZTE’s views | Option 1 is the most straightforward RAN3 option for RAN2 **Option 1c**. There is already "*Coverage Enhancement Level*" IE in the "*Cell Identifier and Coverage Enhancement Level*" IE. This can be re-used as the Rmax information sent between eNB and CN in Option 1c. And then, only a simple indication needs to be introduced to distinguish between R17 usage and legacy usage for "*Coverage Enhancement Level*" IE. | As the paging carrier assigned by eNB to the UE is kind of dynamic information in each RRC connection, it’s neither UE paging capability nor the CEL related information. So it may lead confusion if this paging carrier information is included in *UE radio capability for paging* IE or *Cell Identifier and Coverage enhancement level* IE. So we think only Option 4 would be a clean and suitable way to transfer paging carrier info between eNB and CN.  Moreover, it’s still not clear what format would be used for carrying such assigned paging carrier info in RAN3 interface, an absolute value of EARFCN or a relative value of index? The former has issue of signaling overhead while the latter may cause mismatch issue. |   Based on above comparison, we think **Option 2a** would have more RAN3 impacts than **Option 1c**. |
| Huawei, HiSilicon | See answers to Q7. the same steps are performed at the eNB and the UE  For both solutions, an indication will need to be carried over the S1 interface. For option 2a, we think it will be the index in the mapping table. We do not understand how this can create mismatch issue. The index does not change, only the information pointed by the index (and signalled in SIB) can change |
| Nokia | See Q7 |
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| Ericsson | For option 1c, eNB would perform the same steps as the UE implementation.  For option 2a, eNB implementation would be more complex than UE implementation, and it is up to eNB implementation, but generally, eNB needs to perform similar steps as in option 1c.  So, there is not much difference for these two options form eNB implementation perspective. |
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Q9: Companies are requested to give an opinion based upon answer of above 3 questions regarding the complexity comparison between option 1c and option 2a. Please provide any additional comments as deemed necessary. Which option has less complexity?

* Option 1c
* Option 2a

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| Company name | Which option has less complexity | Comments |
| Qualcomm | Option 2a | From specification and UE implementation perspective option 2 is simpler. But in our view that only postpones the critical issue of how to determine the most suitable coverage-based paging carrier to eNB implementation. |
| ZTE | Option 1c | We disagree to make so-called simpler UE implementation as the main aspect for choosing between **Option 1c** and **Option 2a**. For us, with consideration on the issues mention in Q2~Q4, we think **Option 2a** has kind of fundmental disadvantage as it lets network to determine the factors that the UEs use in idle mode. Generally, the factors that the UEs use in idle mode should be determined by UE itself according to the SIB configuration. We feel Option 2a violates such principle, that is also the source reason of the aforementioned issues in Q2~Q4.  Here we reiterate the drawbacks of **Option 2a** as following:   * More fallback scenarios that may reduce the benefit of R17 paging carrier selection scheme; * Almost cannot handle UE redistribution (or very inefficiently) when adding or removing a carrier. * Less flexible for handling SIB configuration changes. * More RAN3 impact is foreseen. |
| Huawei, HiSilicon | option 2a | Option 1c is still not well defined but the proposals from the proponents involve too many levels of selection which makes it complex to specify, implement and test. |
| Nokia | Option 1C | Option 1C is simple and here the UE need to provide the similar information what it is providing to CN already for CN to select Rmax for initial paging. Decision of switching based on coverage level naturally handles the coverage change and cell change scenarios without need to define separate fallback options.  For example : If CE level is within the same CEL as provided by network sub-set of carriers selected for paging. If not other subset is selected for paging monitoring. This principle in general applies for all scenarios of coverage and cell change. |
| Ericsson | Option 2a | Option 2a is simpler for UE implementation and signaling. |
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## 3.5 Other

Please provide any other input or other pros/cons for both options, if any.

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| Company name | Comments |
| Qualcomm | Technically both option 1c and 2a are feasible but in our view the underlying issue is to ensure the coverage-based paging carrier UE ends up using is suitable for the UE and should not require UE to frequently switch between coverage-based paging carrier and legacy paging carrier. |
| Huawei, HiSilicon | 1. Low cost and low complexity UE is a key requirement of NB-IoT. Making complex solution for a flexibility which is not needed and will never be used is not a good approach. Solution 1c, is selected, will need to be simplfied. |
| Nokia | Use of 1C allows coverage of all scenarios without additional specification changes . It is also possible to achieve the same with 2B but with some changes. In our view selection of specific option should not lead to limiting the applicability of the feature to certain conditions. |
| Ericsson | We agree with Huawei that whichever solution is simple in terms of UE implementation should be preferred. |

Summary: TBD

# 4 Conclusion

This paper focused on comparion of coverage based paging carrier selection option 1c and option 2a . Corresponding proposals are listed as follows:

TBD