Hybrid paging and location tracking scheme for inactive 5G UEs

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Abstract— User Equipment (UE) paging and location tracking are influenced by the underling state handling model. There are recent proposals to introduce a new RRC state called RRC Inactive as a main state for inactive UEs in 5th Generation (5G) cellular systems. One of the characteristics of the new state is that the interface between the Radio Access Network (RAN) and Core Network (CN) is kept. Considering this characteristic, there are proposals for a RAN controlled paging and location tracking schemes for RRC Inactive UEs. In this paper, we show that this approach is not always beneficial, especially for high mobility UEs. Instead, we propose a hybrid paging and location tracking scheme where both RAN and CN are involved in the paging and location tracking of RRC Inactive UEs. This is done transparently to the UE. We further propose a hierarchical paging and location tracking scheme to reduce the signaling overhead from paging and location tracking updates. The scheme is applicable to both RAN based and CN based paging and location tracking schemes.

Keywords—5G Mobility; RRC State Transitions; Connection Management ; Mobility Management

I. INTRODUCTION

Paging is a system access functionality that is triggered by the network to locate a User Equipment (UE). The paging is initiated, e.g., when there is a downlink packet for the UE. One of the architectural questions for paging design is which network entity initiates the paging procedure and how the paging messages are distributed. In current cellular systems, the paging is initiated from either the Radio Access Network (RAN) or the Core Network (CN) depending on the Radio Resource Control (RRC) state of the UE [1][2][3].

In Universal Mobile Telecommunication System (UMTS), the paging is initiated from the CN if a UE is in idle mode [1]. If the UE is in one of the connected mode states, e.g., CELL_FACH, CELL_PCH and URA_PCH, the RAN, i.e. the Radio Network Controller (RNC), controls the paging and location tracking of the UE [1]. In CELL_FACH and CELL_PCH, the location of the UE is tracked on a cell level. Thus, the paging is also done on a single cell level. In URA_PCH, the paging is done on a group of cells level called UTRAN Registration Area (URA) where the UE may move without updating its location. It should be noted that different UE identifiers, i.e. U-RNTI, C-RNTI, H-RNTI, E-RNTI, are included in the paging message depending on the state of the UE.

In Long Term Evolution (LTE) cellular systems, the paging and location tracking of a UE in RRC_IDLE state is controlled by the CN, i.e. Mobility Management Entity (MME) [2]. The MME tracks the location of RRC Idle UEs on a tracking area code list level. When a Mobile Terminating (MT) data is received by the Signaling Gateway (S-GW), it notifies the MME. The MME initiates the paging procedure. The identifier S-Temporary Mobile Subscriber Identity (S-TMSI) is typically used as UE identifier in the paging message.

Another aspect regarding paging and location area update design is the minimization of the signaling load that arises from the procedures. If the tracking area consists of a large number of cells, the signaling load from tracking area updates is relatively low. However, the signaling load from paging is significantly high if the UE is paged through all the cells in the tracking area of the UE. If the tracking area consists of a small number of cells, the opposite holds. Thus, there is a trade-off between the paging load and the location updates load as the size of tracking area varies. In existing cellular systems, such as LTE, the tracking area list typically consists cells in hundreds of eNodeBs (eNBs). This leads to a significant paging load over the air interface and RAN/CN interface. The signaling load from tracking area updates is relatively low. For example, paging represents 29% of the total processing load at the MME, while tracking area updates account for 5% of the total load [4].

Several schemes have been proposed in the literature for minimizing the paging and tracking area updates load in LTE, see e.g. [4][5][6]. In blanket paging approach, a large number of cells are paged in order to minimize the signaling overhead due to frequent tracking area updates. However, this approach leads to a waste of resources due to paging as UEs are paged via many cells. In sequential paging, cells are paged sequentially; while in adaptive paging, cells are paged sequentially but in a smarter manner, such as paging the last known position of the UE first or paging randomly in a parallel manner, etc [4][5][6]. However, the sequential and adaptive paging schemes may increase the delay to reach UEs. Other schemes try to minimize the signaling overhead due to paging and location tracking updates taking the trade-off into account, see e.g. [7].

In 5G, paging and location updates load is expected to be even more severe that in LTE networks due to massive Machine-Type Communication (mMTC) devices and dense small cell deployments. In addition, the latency requirement for the Mobile Terminated (MT) 1st packet transmission is tighter than the previous wireless generations [8][9][10]. Therefore, the paging and location tracking schemes for 5G need to be designed such that the paging load is minimized and at the same time the latency for reaching UEs and transmitting the 1st MT packet is reduced. In addition, due to large number of 5G use cases, how the paging is initiated needs to be flexible unlike in existing systems, where the paging always initiated from either the RAN or the CN in each RRC state.

In this paper, we consider paging and location tracking for UEs in RRC Inactive state, which is recently proposed and discussed as a potential state for inactive UEs in 5G [11][12]. The contribution of the paper is two-fold. On the one hand, it tries to address the architectural question regarding the role of the RAN and the CN in paging and location tracking of UEs in RRC Inactive. In particular, it proposes a hybrid scheme where either RAN initiated or CN initiated paging can be used, e.g. depending on the mobility status of the UE. Similar approach is also used for location tracking. On the other hand, the paper proposes a hierarchical paging and location tracking scheme to minimize the signaling load from paging and location tracking updates irrespective of the entity involved in the procedures. This is shown to hide intra-5G-NB mobility from the entity that is serving as a mobility anchor, which effectively reduces significant load from location tracking updates and paging.

The paper is organized as follows. Section II presents a brief overview RRC Inactive state. Section III discusses RAN initiated paging procedure in RRC Inactive and Section IV discusses CN initiated paging. In Section V, a hybrid paging and location tracking scheme is proposed. A hierarchical location tracking and paging is presented in Section VI. Section VII concludes the discussion in the paper.

II. Overview of RRC Inactive state

Discussions on RRC state machine design for 5G systems have recently kicked-off in 3GPP and literature [11][12]. One of the objectives is to reduce the control plane latency to lower the latency of 1st packet transmission and achieve a seamless RRC state transition [9]. Most of the solutions propose a state model with three states: the conventional RRC idle and RRC connected states and a new RAN controlled state called RRC Inactive as shown in Figure 1. It is proposed that the behavior of a UE in RRC Inactive state can be configured based on the service requirements of UEs with divergent requirements.

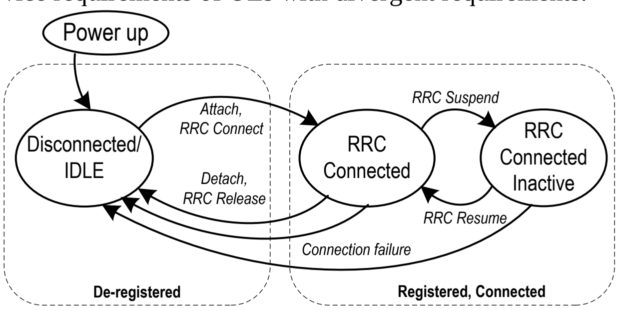

Figure 1: Potential state model for 5G radio access network

The characteristic feature of RRC Inactive state is that UE is always connected from the CN network perspective. This is achieved by keeping the RAN/CN connection to anchor NextGen NodeB (gNB). Therefore, the UE is also in connected state in Connection Management function of CN. The UE Access Stratum (AS) context, e.g. AS security context, is stored in the UE and the RAN. Location tracking during the RRC Inactive is based on cell reselection where the UE may move within the configured area in RAN without notifying the network about location. Paging initiation during the RRC Inactive state to reach the UE can be done from RAN and CN. Hybrid paging scheme is proposed to control the paging initiator role and achieve the benefits of both paging schemes in one approach.

The RRC Inactive state is shown to have several advantages for location tracking and paging. Finally, the RRC Inactive to RRC Connected state transition is achieved using a significantly lighter signaling procedure than LTE's RRC IDLE to RRC Connected state transition. This leads to a significant signaling overhead reduction, especially for UEs with application that frequently transmits small packets.

III. RAN initiated paging

As the RAN/CN interface is kept, one natural option regarding UE reachability in RRC Inactive is for the RAN to control the UE location tracking and paging functionalities. In this option, the RAN is partitioned into small areas that consists of a group of cells that belong to a single gNB or multiple gNBs, where a gNB is a base station that provides a 5G radio interface. This area may be referred as RAN Tracking Area (RTA) and has a unique identifier, e.g. RTA ID. When a UE transitions from RRC Connected to RRC Inactive, the anchor gNB (i.e. the gNB that terminated the RAN/CN interface for the UE) provides the UE with RTA list that the UE may move without updating its location.

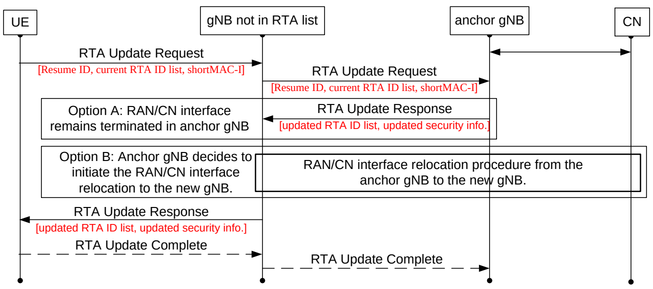

Figure 2: RTA update

If the UE reselects a cell that is not in its RTA list, it initiates a RTA update procedure, e.g. as shown in Figure 2. After a RACH procedure, the UE sends a RTA Update Request message that is integrity protected using the AS security context that is stored in the UE and the anchor gNB. The message includes shortMAC-I for UE authentication, the current UE's RTA list and Resume ID that contains the address of the anchor gNB. If a gNB other than the anchor gNB received the RTA Update Request message, it forwards the message to the anchor gNB. After authenticating the UE, the anchor gNB may either initiate a RAN/CN interface relocation to the gNB that received the RTA Update Request message or keeps the RAN/CN interface and responds with an RTA Update Response message. The RTA Update Response message includes a new RTA list. After receiving the RTA Update Response message, the UE may send RTA Update Complete message as an acknowledgement.

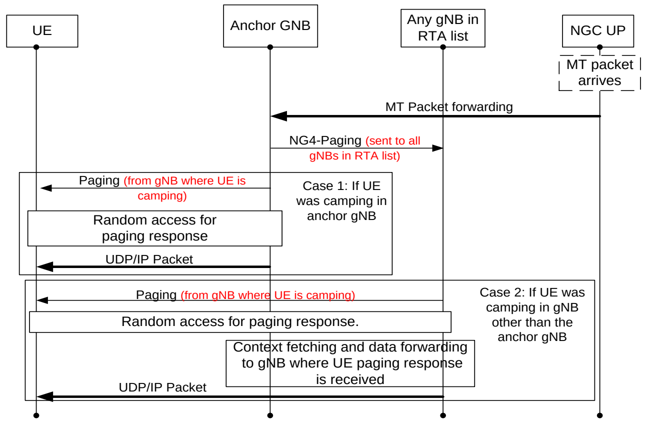

Figure 3: Potential RAN initiated paging procedure in RRC Inactive.

When an MT data arrives at the Next Generation Core User Plane (NGC-UP), i.e. a 5G equivalent of LTE's S-GW, it forwards the data to the anchor gNB of the UE. The anchor gNB buffers the received MT data and initiates paging procedure to reach the UE, see Figure 3. The anchor gNB pages the UE through its cells that are part of the UE's RTA list. It also sends the paging message to all gNBs in RTA list of the UE. The gNBs then page the UE through their cells that are in the RTA list. Here, the anchor gNB needs to keep an gNB-gNB interface (which will be referred as NG 4) relationships with all the gNBs in the RTA list of the UE.

Up on the reception of the paging message, the UE proceeds to resume its RRC connection. The RRC resumption procedure may include context fetching procedure if the UE was camping in a gNB other than the anchor gNB.

IV. CN INITIATED PAGING

CN initiated paging and location tracking is used for UEs in RRC Idle state. In 5G, CN initiated paging can be used also for UEs in RRC Inactive but the CN needs to be aware that the UE is in RRC Inactive state. Therefore, when the UE is transitioning from RRC Connected to RRC Inactive, the anchor gNB informs the NGC Control Plane (NGC-CP), i.e. a 5G equivalent of LTE's MME, that the UE is in RRC Inactive. In the response message to the notification, the NGC-CP may include the list of RTA that the UE may move without updating its location. As the NGC-CP has a wider area knowledge of the gNBs in the RAN, the list of RTA ID may potentially include cells in several gNBs. The NGC-CP needs to inform the NGC-UP that the UE in RRC Inactive so that the NGC-UP buffers any MT data until the UE is reached through CN initiated paging.

When an MT data arrives at the NGC-UP, it sends a data arrival notification message to the NGC-CP, see Figure 4. The NGC-CP initiates the paging procedure by sending a paging message to all the gNBs in the RTA list of the UE. The gNBs then page the UE through the cells which are included in the RTA list. Upon the reception of the paging message, the UE initiates a RACH procedure to reactivate its RRC connection. If the paging is received from a gNB other than the anchor gNB, a RAN/CN interface relocation is initiated. Alternatively, the gNB may request the NGC-UP to proactively forward the UE data.

If the UE reselects a cell that is not in its RTA list, it initiated a location update procedure. The location update procedure is like the one discussed in Section III. However, the CN may assist the RAN in providing a list of updated RTA IDs.

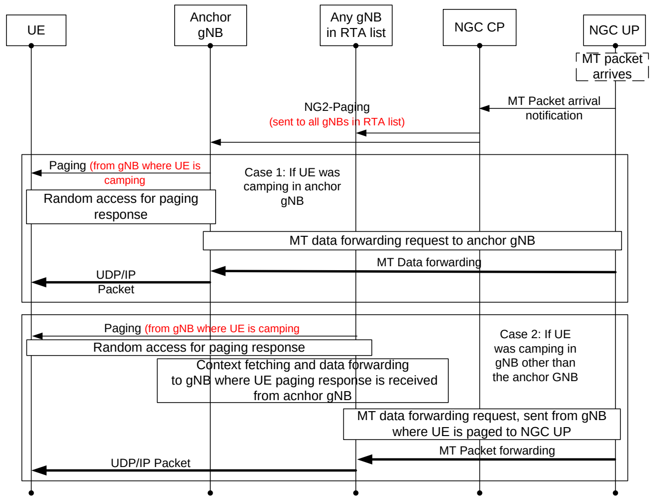

Figure 4: Potential CN initiated paging procedure in RRC Inactive. NG 2 interface refers to the interface between the NGC-CP and a gNB.

V. HYBRID RAN/CN CONTROLLED UE REACHABILITY

A. Performance comparison of RAN-initiated and CN-initiate paging schemes

Based on the discussion on Sections III and IV, the RAN initiated and the CN initiated paging have different pros and cons. Among the advantages of the RAN initiated paging include a reduced latency to reach the UE as the MT data is immediately forwarded to the anchor gNB. This is especially more beneficial if the UE were camping in the anchor gNB during paging. There is also no need to inform the NGC-CP that the UE is in RRC Inactive, avoiding the relevant signaling messages. However, the RAN initiated paging required data buffering in anchor gNB which affect the memory capacity of the anchor gNB. It also requires an inter-gNB paging and data forwarding, which adds an overhead to the NG 4 interface. If there is no direct NG 4 interface between the anchor gNB and a gNB in the RTA list of the UE, the anchor gNB needs to forward the paging message to the new gNB through the CN. Similarly, data forwarding to the new gNB through the CN may also be required. Paging message and data forwarding through the CN has significant impact on the RAN/CN interface.

In the CN initiated paging, there is no need for data buffering at the anchor gNB and inter-gNB paging. However, the latency to reach UE might be longer than in the RAN initiated paging. The additional latency might not have significant contribution to the overall latency if long DRX cycles are used for paging monitoring. In CN initiated paging, additional signaling messages are also required to make the CN aware that the UE is in RRC Inactive.

The RAN-initiated and the CN-initiated paging schemes affect the radio, RAN/CN and gNB/gNB interfaces with different level of severity. For performance comparison, let M and N denote the number of cells and gNBs per UE's RTA list, respectively. The paging load in the RAN initiated paging is M messages (over radio) + (N-1) messages (over NG4). It is M messages (over radio) + (N+3) messages (over NG2) + 3 message (over NG6) in the CN initiated paging. Note that the extra two NG2 (NGC-CP-gNB interface) and two NG6 (interface between NGC-CP and NGC-UP) messages in the CN-initiated paging are included to take into account the signaling messages required to make the NGC CP and NGC UP be aware that the UE is in RRC Inactive. If M = 1 and N = 1, i.e. the paging area is restricted to a single cell, the paging load in the RAN initiated paging is 87.5% less than the paging load in the CN initiated paging (1 message vs 8 messages). However, if M = 3*19 and N = 19, the percentage of paging signaling load reduction is only 8.5 % (75 vs 82 messages).

Thus, it can be concluded that neither the RAN initiated paging nor the CN initiated paging has always a significantly better performance than the other in terms of, e.g. signaling overhead, buffering requirement, etc, for all use cases. For example, the paging load reduction in the RAN initiated paging compared to the CN initiated paging is significant only when the paging area is small. Based on this and similar observations, we propose a hybrid RAN and CN initiated paging scheme.

B. *Hybrid paging scheme*

In hybrid paging, a RAN initiated or CN initiated paging can be used to reach a UE in RRC Inactive in a transparent manner to the UE. The choice is made by the anchor gNB based on, e.g. the mobility state of the UE, latency requirement, etc. For example, if the UE has low mobility, the anchor gNB configures the UE for a RAN initiated paging with an RTA list that includes cells that belong to the anchor gNB. This choice can be justified by the significant signaling reduction when the paging area is small as discussed above and a lower MT packet latency. There is no need for inter-gNB paging message transfer as well as data forwarding. However, if the UE is moving fast, limiting the RTA list to include a small number of cells increases the signaling overhead from location updates. Therefore, in such cases, it is important to provide the UE with an RTA list that consists of a large number of cells. Therefore, it is beneficial to configure fast moving UE with CN initiated paging over an RTA list that consists of a large number of cells. As discussed above, the signaling reduction achieved from using a RAN initiated paging is small in such use cases, i.e. a large RTA list. There is also no need for buffering MT data in the anchor gNB, inter-gNB paging and data forwarding in CN-initiate paging.

The UE should not be aware whether the paging is initiated from the RAN or the CN to avoid implementation complexity on the UE side. Such a transparent implementation can be achieved, for example, by using the same UE identity in both RAN initiate paging and CN initiated paging. At least, the same UE ID needs to be used for paging occation calculation in both cases. For example, the CN based identity S-TMSI can be provided to the RAN during attach procedure and registration updates, and the S-TMSI is used as UE identity in both RAN initiate paging and CN initiated paging. As the Paging Frame (PF) and Paging Occasion (PO) is calculated based the same UE identity, the UE will not have to monitor different PF/PO for RAN initiated paging and CN initiated paging during its DRX cycle. This saves the UE battery consumption when compared to using to monitoring two paging occasions, i.e. independent paging occasion used for RAN initiated and CN initiated paging, during a DRX cycle.

C. *Performance analysis of hybrid paging scheme*

We consider a macro-cellular deployment scenario with hexagonal cells to analyze the performance of hybrid paging [13]. Each gNB consists of three cells. Two traffic model are considered: a) an mMTC traffic characterized by Poisson distributed with average arrival rate of 1 packet per 7716 second (averaged over average arrival rate values for three types of mMTC traffic in [14]), and b) an FTP traffic with the same characteristic but an arrival rate of 1 packet per 60 seconds [13]. UE mobility is assumed to follow a trajectory over a straight line. The considered UE speed values are {3, 30, 60, 90, 120} km per hour (kmph). We assume the UE provides its mobility state estimation to the network, e.g. during location update or while in RRC Connected state. RAN initiated paging and CN initiated paging are taken as a baseline for comparison.

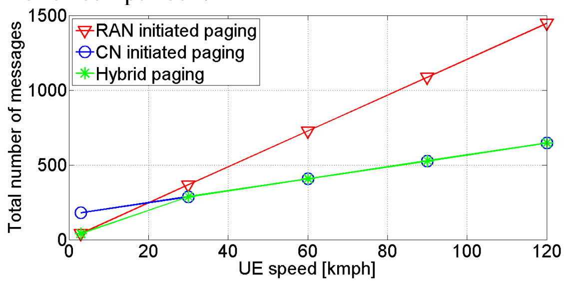

Figure 5: Total number of paging and location update signaling messages per hour of a UE with mMTC traffic (with average packet arrival rate of 2.1433 packets per hour).

Figure 5 shows the overall signaling overhead of a UE with mMTC traffic from paging and location tracking in an hour. For RAN initiated paging, the RTA consists of one gNB. The tracking area list in the CN initiated paging consists of 19 gNBs. In the hybrid paging, the UE is configured either for RAN initiated paging with an RTA of one gNB or for CN initiated paging with a tracking area list that consists of 19 gNBs. The simulation result shows that RAN initiated paging has better performance than the CN initiated paging for low speed UEs. This is due to the reason that signaling overhead from paging constitutes significant proportion of the overall signaling overhead at lower UE speed, and RAN initiated paging has lower paging signaling overhead than CN initiated paging. On the other hand, the hybrid paging is able to configure the UE with the optimal paging scheme based on its speed.

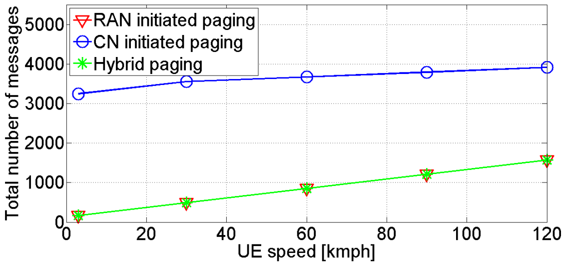

Figure 6: Total number of paging and location update signaling messages per hour of a UE with FTP traffic (with average packet arrival rate of 60 packets per hour).

Figure 6 illustrates the total paging and location tracking signaling messages of a UE with FTP traffic per hour. We assume an inactivity timer of 10 s. The FTP traffic leads to a relatively higher number of paging events such that the paging signaling overhead is significantly dominant over the signaling overhead from location updates. Thus, the RAN initiated paging has significantly lower overall signaling overhead than the CN initiated paging due to its smaller paging area. In such scenario, the hybrid paging effectively remains as RAN initiated paging, where the RAN does not need to transfer the paging initiator role to the CN.

It is worthwhile to note that Figures 5 and 6 does not show how the signaling overhead affects different interfaces. It is for further study to optimize the hybrid paging scheme with the objective of reducing the signaling overhead over a specific interface, e.g. for load balancing purpose, and considering dynamic RTA or tracking area size.

VI. SIGNALLING REDUCTION THROUGH HIERARCHICAL LOCATION TRACKING AND PAGING

Independent of whether the paging is initiated from the RAN or the CN, it is important to minimize the signaling overhead from paging and location tracking updates. The 5G cellular system is expected to be heterogeneous network composed of several air interface variants and access points working on a different frequency layers. In such environment, UE location tracking with lower granularity, e.g. cell level, may create a significant signaling overhead although the paging load will be minimized. Tracking lower granularity of UE location is generally required for use cases with strict control plane latency requirement for MT data.

We propose a hierarchical location tracking and paging to minimize location update and paging load, especially for use cases that require lower granularity, i.e. cell level, location tracking. A heterogeneous deployment network scenario is considered, such as the one shown in Figure 7. The conventional approach to track a cell level location of a UE would be to define a RTA list that consists of only a single cell. However, this leads to significant signaling overhead from location update if the UE is moving. Instead, an RTA list with large number of cells can be defined for the UE. The UE is then configured to indicate its cell change to the network, e.g. using a lighter signaling procedure than an RTA update procedure. Cell level change within a gNB is hidden from the anchor gNB. Only gNB a cell change involving a gNB change is informed to the anchor gNB. In other words, the anchor gNB know under which gNB the UE is located but not the precise cell level location. This way, the cell level location of the UE is known with the minimum signaling overhead. Upon MT data, the anchor gNB sends the paging message only to the gNB where the UE is located. The gNB pages the UE only through the cell where the UE is located. The MT data can also be proactively forwarded to the gNB where the UE is located to minimize the control place latency.

For example, consider Figure 7. An Access Point (AP) may refer to a cell of a gNB or a small cell that does not have a direct RAN/CN interface connection to the CN but accesses the CN through a gNB that has a RAN/CN connection to the CN. Note that also the number of APs per gNB can be arbitrary although only 3 APs per gNB are considered in the figure. Let us assume that gNB 1 is serving as an anchor gNB for UE 1. The list of RTA ID of UE 1 includes the APs under gNBs 1, 2 and 3. For the sake of simplicity, consider the case where the RAN tracks the cell level location of the UE so that the paging can be done on a single cell. Referring to Figure 7, if UE 1 moves from AP 2 to AP 3, it indicates its cell level location to gNB 1 (the anchor gNB). If UE 1 moves from AP 3 to AP 4, it indicates its cell level location to gNB 2, which in turn informs gNB 1 that UE 1 is camping in one of its APs without the need to inform the actual cell level location of the UE. If UE 1 moves from AP 4 to AP 5, it indicates its cell level location to gNB 2. However, gNB 2 does not inform gNB 1 about the AP change. This way the intra-gNB mobility is hidden from the anchor gNB enabling the tracking of the cell level location of the UE with minimum signaling overhead.

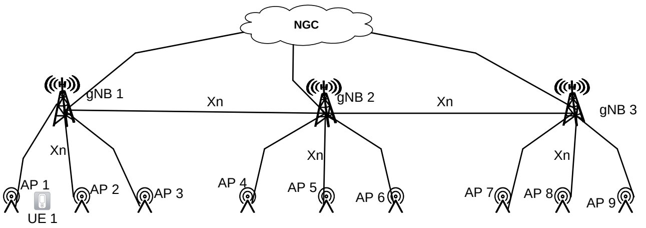

Figure 7: Hierarchical location tracking and paging.

Similarly, the paging can be done in a hierarchical manner. Consider a RAN initiated paging is used and the UE is camping in AP 5. When an MT packet arrives at the anchor gNB, it initiates the paging procedure. The anchor gNB sends the paging message only to gNB 2. As gNB 2 has the cell level location information of the UE, it pages the UE only through AP 5. In the CN initiated paging, similar approach can be applied. However, the anchor gNB may have to inform the CN about inter gNB mobility to the CN so that the CN can send the paging message to the gNB where the UE is located. Alternatively, the CN sends the paging message only to the anchor gNB. The anchor gNB then forwards the paging message to the gNB where the UE is located. The gNB where the UE located in then pages the UE through the AP where the

UE is camping. This way, the signaling overhead from paging is also minimized.

The hierarchical location tracking and paging that is explained with respect to cell level of tracking of the UE can be generalized to a group of cell level tracking. The UE can be configured to report its location when it moves from one group of APs to another group under the same gNB, or from an AP in a given gNB to an AP in another gNB. Similar to the cell level tracking, the intra-gNB mobility between two groups of APs is hidden from the anchor gNB. It should be noted that the hierarchical location update and paging discussed in the paper for arbitrary number of layers, although we have more at most three layers in practical deployment scenarios.

VII. Conclusion

In this paper, we discussed paging and location tracking design for 5G radio access networks. Both RAN initiated paging and CN initiated paging schemes are explored. We showed that the signalling load depends on the UE speed and by selecting the paging initiator it is possible to decrease the signalling load. Thus, we proposed a hybrid UE transparent paging scheme. The RRC state of a UE is decoupled from the entity that initiates the paging procedure for the UE, unlike in existing cellular systems, e.g. the paging to an RRC Idle LTE UE is always initiated from the CN. It is shown that the hybrid paging approach provides flexibility to the network to select either the RAN initiated paging or CN initiated paging scheme, e.g. based on UE mobility, latency requirement, etc. Furthermore, hierarchical location tracking and paging was discussed as a means to minimize the signaling overhead, especially when tracking a lower granularity UE location is required.

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