Mitigating the Signaling Resources Expended in 5G Location Management Procedures at Millimeter-Wave Frequencies

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Abstract. *The signaling resources expended and the power consumed by User Equipments (UEs) in the Location Management (LM) procedures are expected to be higher in Fifth Generation (5G) than in legacy wireless communications networks. To mitigate this challenge, this work proposes a hybrid scheme that mitigates the signaling resources expended in paging and RAN-based Notification Area Update (RNAU) procedures in 5G. The approach utilizes a hybrid scheme that embeds a UE Identifier (UEID) partitioning scheme that directional pages UEs into a gNB-based UE Mobility Tracking (UEMT) scheme. The approach configures a gNB in an RRC_Inactive state to beam sweep a UEs last registered cell area before directionally paging the UE. The approach proposed in this work is implemented on a modified network architecture to reduce the signaling resources expended on both paging and RNAU of UEs at higher frequencies which is an enabling factor for mmWave systems. Simulation results of the total accumulated cost of paging showed a 65.13 % and 8.69 % reduction in signaling resources expended against the conventional approach and the existing gNB-based UEMT approach, respectively. Additionally, the total accumulated resources expended in both procedures over 24 hours showed that the modified gNB-based UEMT scheme outperformed the conventional scheme and the gNB-based UEMT scheme by 90.96 % and 38.36 %, respectively.*

Keywords

Directional paging, Fifth-Generation, Location Management, paging, RRC_Inactive.

1. Introduction

In adopting higher frequencies to meet the demand for massive connected User Equipment (UE), the signaling resources expended in wireless communications have consequently increased. As reported in [1], about two-thirds of the world's population will have access to the Internet by the year 2023. This envisaged increase would consequently signal an exponential growth in wireless network signaling resources by massive connected UEs. To address the aforesaid concern, several researchers have put much effort into optimizing the signaling resources expended by users. The Location Management (LM) procedures, which are the location update and paging process, are expected to be higher in Fifth-Generation (5G) than in legacy wireless communications technologies, as they cost about 34 % of the processing load by the Mobility Management Entity (MME) in Fourth-Generation (4G) [2]. To mitigate the processing load on the Access and Mobility Function (AMF) in executing the paging and Radio Access Network (RAN)-based Notification Area Update (RNAU) in 5G, several technologies which are introduced in 5G or adopted from legacy wireless systems are utilized to mitigate the signaling resources expended in the location management procedure.

Briefly depicted, in the following are the key factors which impact the performance of the location management procedures in 5G. Firstly, a prominent constituent recently is introduced, which is the Radio Resource Control (RRC) Inactive state [3]. This extra RRC state enables a transition to the RRC_Connected state with less signaling volume [4]. Secondly and thirdly, there are the Discontinuous Reception (DRX) and directional paging, which are considered to mitigate the power and signaling resources expended in the location management procedures in 5G [5] and [6]. But even with these interventions, most of the use cases in the literature [7], [8], and [9], that consider these performance factors to mitigate the resources expended in either the RNAU or paging procedures in 5G, do not consider the three factors earlier mentioned. And in scenarios where these factors are considered, the mobility of UEs is not considered.

To address this drawback, this work proposes a hybrid scheme that modifies the resources expended in paging and paging attempts required by the serving gNB to beam sweep the spatial area of the intended UE. The modified scheme is utilized to mitigate the overall resources expended in RNAU and paging procedures in 5G.

Concerning the rest of this paper, a review of related works is succinctly presented in Sec. 2. Section 3. delineates the methodology adopted in developing the proposed hybrid scheme for mitigating signaling resources. The results of utilizing the proposed hybrid scheme are delineated and discussed in Sec. 4. Finally, the conclusion and future research of the work are discussed in Sec. 5.

2. Review of Related Works

This section provides a review of some related works carried out and published by other researchers on minimizing signaling resources expended in paging and location update procedures in 5G. The information obtained from these reviews facilitates the decision-making on tools and approaches adopted in this research to mitigate the signaling resources expended in both LM procedures in 5G.

The work of [10] proposed an Efficient Tracking Area list Management (ETAM) framework for 5G cloud-based mobile networks to minimize the overall signaling overhead for both paging and TAU procedures. The research considered the paging and TAU signaling overhead as a linear problem to propose a solution that offered a lighter between both procedures. The proposed framework consisted of two independent parts. The first executed offline assigned TAs to TAL, whereas the second one, which was executed online, handled the distribution of TAL to UEs during their movements across TAs to minimize paging cost. The work considered several iterations on the coverage of the TAL assigned to UEs to obtain an efficient solution that offered a fair trade-off to minimize the signaling messages between both procedures.

The authors in [11] introduced a hybrid paging and location tracking scheme that considered the mobility state of UEs when configuring the UE with a paging initiator. The paging initiator been RAN initiated or CN initiated paging. In addition, the authors introduced a hierarchical location tracking and paging scheme to minimize the signaling overhead for use cases that require lower granularity (e.g., cell level). To improve the performance for these cases, the authors introduced three layers to discuss the applicability of the deployment scenario. Within these layers, some Access Points (APs) had a direct RAN/CN connection to the CN, while others accessed the CN through APs that had a direct RAN/CN connection to the CN. This configuration hid from the anchor gNB the cell level change of moving UEs, thereby proffering a lighter signaling procedure. However, the authors assumed the moving UEs trajectory to follow a straight line, which is not applicable in deployment scenarios.

The authors in [12] proposed a 4G TAL and 5G TAL scheme to reduce signaling overhead when the UE implements TAU between the 4G and the 5G layer. The developed scheme assumed smooth movements of the UE from the 5G cells to the 4G cells, and it required no inter-network update of the TAL. The simulated parameters for the 4G coverage had no gaps to accommodate UEs that moved out of the 5G cells, which had gaps and patches. The distribution of traffic and UE mobility was also considered. The Monte Carlo model was utilized to model the distribution of UEs. The proposed scheme allowed the MME to send paging messages to both networks for devices that were not stationary IoT devices. The results obtained showed that the proposed scheme achieved a reduction in UE power consumption. However, the non-consideration directional paging could have led to the wastage of data packets in directions of the TA that are excluded from the direction of the UE.

To minimize the paging latency, the work of [13] implemented a beam-aware DRX scheme for UE communication in 5G to minimize paging latency. The authors proposed an adaptive DRX scheme for the mmWave 5G system to address energy deterioration that occurs if LTE DRX is directly applied to mmWave 5G systems. The trade-off between the packet latency and sleep ratio was evaluated. The proposed scheme was compared against LTE's DRX and beam alignment as reference schemes. The beam-aware DRX scheme achieved a reduction of paging latency and improved the sleep ratio mechanism in comparison to LTE DRX and beam-alignment mechanism.

An efficient beam sweeping paging scheme composed of full paging and fast paging approaches to minimize the paging beam sweeps and the number of time slots based on user-assisted feedback was proposed by [14]. The paging mechanism developed for full paging broadcasts the paging message on each of the beams for a cell. The mobility of the UEs, which was classified as either general or delay-sensitive, received the paging broadcast through the Physical Downlink Common Control Channel (PDCCH). Also, it checked if the UE ID was incorporated in the paging message shared through the Physical Downlink Shared Channel (PDSCH). On the other hand, the fast-paging relayed paging messages mainly to delay-sensitive UEs by reducing paging beam sweeps, which utilized time slots that contained paging messages for UEs. The schemes proposed in this work attained a reduction in signaling overhead.

The work of [15] proposed a machine learning approach to automate tracking area design in 5G ultra-dense networks. The approach relied on a Self-Tuning Spectral Clustering (STSC) algorithm to group gNBs without requiring the number of clusters as input. The work utilized the STSC-based scheme to feed a similarity matrix, taking into account the measurement reports statistics of a 4G live network, inter-site distances, and Handover (HO) attempts. Since the movement of the UEs was deduced from the HO statistics of different gNBs or the HO command messages sent by the MME. The approach showed a reduction in the RNAUs and the paging signaling overhead.

The work of [7] proposed a minimal feedback-enabled paging scheme to reduce the paging overhead in highly directional systems. The scheme supported both Core Network (CN) initiated and Radio Access Network (RAN) initiated paging. The authors proposed that a subset of the active beams based on the UE (s) presence be used to directionally page the UE (s) in an RRC_Idle or RRC_Inactive state instead of using all beams in paging transmission. In addition, to minimize the resources expended during the Paging Activation Request (PAR), which was used by the UEs to identify the active set of beams, the authors introduced the concept of activation duration. When a PAR was received during this period, the gNB used the number of paging cycles defined to activate the associated beam for the activation period. This concept reduced the number of PAR requests sent on the UE side for the same beam. The proposed baseline paging solution and its enhancements were compared against the conventional directional paging scheme and the Mobile-Assisted Directional Paging (MADP) scheme. The approach achieved a reduction in paging signaling overhead for a considerable UE density in comparison to the conventional scheme and MADP. However, the mobility of UEs was not considered in this work.

The work of [8] proposed a User assisted Dynamic RAN Notification Area (UD-RNA) configuration scheme based on the delay sensitivity for 5G UEs in an RRC_Inactive state. The proposed scheme consisted of two steps, namely: offline RNA optimization and online decision making. In the former, the available RNAs for UEs were assigned to generate the new RNA list in the offline optimization step, while in the latter, the optimal RNA list generated from the offline step was assigned to UEs according to their activities.

The latency requirements considered in both steps were divided into delay-sensitive and delay-tolerant requirements. The delay-sensitive UEs had a higher priority of latency due to their real-time applications. In addition, parallel paging was adopted for delay-sensitive UEs, while sequential paging was adopted for delay-tolerant UEs. In general, a multi-objective optimization technique was used to optimize the distribution of RNAs to find a fair trade-off between paging and the RNAU overhead.

For validation, the proposed UE-RNA scheme was compared against the Cell list RNA configuration scheme (C-RNA), the RAN area ID list RNA configuration scheme (R-RNA), the parallel paging scheme, and the sequential paging scheme. Results obtained were primarily influenced by the mobility of the UE and the paging rate. The scheme mitigated the signaling resources expended in both LM procedures.

The work of [9] proposed a group-based Mobility Management (MM) mechanism to reduce the paging and location update signaling overheads due to device mobility. One of the primary highlights of the proposed scheme was its consideration of deviated devices. The proposed scheme had a deviation detection mechanism. This enabled a device whose information was not updated with its group due to its movement to another TA outside of its group to become a Group Leader (GL) of other deviated devices. This approach mitigated unnecessary location updates from deviated devices as only the GL made location updates for the group at the end of the location update timer.

In this method, two mobility models were considered, which were the random walk model and the smart logistic model. For validation, the proposed model was compared against another model, using Signaling Reduction Ratio (SSR) and Page Miss Ratio (PMR) as performance metrics. The proposed efficient group-based MM mechanism was shown to outperform the existing scheme compared with. Although the association between devices was recorded and used to map the trajectories of the devices, the storage cost in relation to maintaining a dictionary for the mobility of every M2M device was not considered.

The RRC state, the DRX cycle, the mobility of Ues, and directional paging generally influence the signaling resources expended in LM procedures. Conversely, the non-consideration of these factors influences the signaling resources expended by both paging and LU procedures [4], [5], and [16]. On this premise, this paper proposes a Modified gNB-based UE Tracking (M-UEMT) scheme that is different from the scheme in [4] to mitigate the signaling resources required to locate and track 5G inactive UEs at millimeter wave (mmwave) frequencies.

3. Methodology

This section delineates the methodology adopted in the development of the hybrid scheme. Subsection 3.1. , Subsec. 3.2. , Subsec. 3.3. , Subsec. 3.4. , Subsec. 3.5. , Subsec. 3.6. , Subsec. 3.7. , Subsec. 3.8. , Subsec. 3.9. , Subsec. 3.10. and Subsec. 3.11. expands on the framework and methodology in designing the simulation scenario to test the hybrid scheme. Subsection 3.12. gives an overview of the materials utilized in testing the hybrid scheme. Subsection 3.13. gives a summary of the schemes considered in the development of the hybrid scheme. The detailed procedures in developing the hybrid scheme in this work is referred to as the Modified gNB-based Mobility Tracking (M-UEMT) scheme and is discussed in Subsec. 3.14. A flowchart of the M-UEMT scheme is shown in Subsec. 3.15.

3.1. Partitioning the UE ID

For every UE that is paged, the paging message it receives in every PO is made up of the UE's ID, the Cyclic Redundancy Check (CRC) bits, the PDCCH bit, and the RRC bits. In this work, the preliminary steps in modifying the scheme in [4] are implemented using the UE ID partitioning technique introduced in [6] in order to mitigate the signaling resources expended in LM procedures at mmWave frequencies. In this step, the U bits of the UE ID is partitioned into two parts. The first part, denoted as U_1, is considered the Least Significant Bit (LSB), while the second part of the UE ID, denoted as U_2, is considered the Most Significant Bit (MSB). Together, U_1 and U_2 provide the total information of the UE ID as depicted in Fig. 1.

$$U = U_1 + U_2, \tag{1}$$

where:
U: is the information of the UE ID,
U_1: denotes the Significant Bit (LSB) of the UE ID,
U_2: represents the Significant Bit (MSB) of the UE ID.

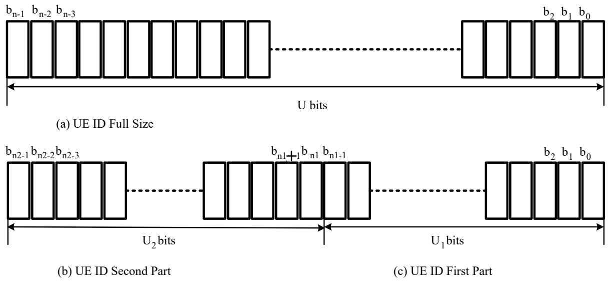

Fig. 1: Partitioning the UE ID [6].

The second part of the UE ID (U_2) in the paging message is transmitted instead in place of the entire N bits. Since several UE are configured in each PO and multiple POs are configured per DRX cycle, the reduction in the bits transmitted per UE would result in saving network resources.

3.2. Configuring Multiple POs in Each DRX Cycle Based on U_1 Bits

In legacy systems, paging all UEs in the same PO is not always possible since it is influenced by factors such as paging load, tracking area size, and user density [6]. Therefore, multiple POs are required in every DRX cycle. In directional paging, multiple POs would be needed for the same reasons. The PIDP scheme proposes that the network configures multiple POs in each DRX cycle based on bits. Let U_1 be the number of POs that can be configured per DRX cycle in PIDP, and it is evaluated as [6]:

$$U_{PIDP} = 2^{U_1} = 2^{(U-U_2)}. \tag{2}$$

The POs are subsequently mapped to all the possible bit configurations that can be attained using bits. Therefore, distinct PO in the DRX cycle has a distinct bit configuration associated with it. Furthermore, in selecting the optimal ratio of cropped UE ID size for the work of [6], the authors depicted that the crop size of $U_2 = 32$ bits has more power saving gains, in comparison to the range of bit sizes considered. This work also configures the cropped UE ID size of $U_2 = 32$ bits.

3.3. Usage of the LSBs to Distribute the UE Over Different POs

In legacy systems, multiple POs are configured by the network in the DRX cycle and the UE are distributed over these POs. Similarly, in the PIDP scheme, the UE is distributed over U_{PIDP} number of POs configured for each DRX cycle. In distributing, it was proposed that the UE with the same LSBs are configured in the same PO. Thus, in PIDP, while only U_2 of the UE ID is included in the paging message, U_1 is used to distribute the UE over different POs. This ensures that the IDs of all the UE that are paged are uniquely identified by the network, even though only partial bits are included in the paging message.

3.4. Initializing Either When the UE Begins Initial Access to the Network or When UE Ends Up in the RRC_Inactive State

In 5G, a UE not in the RRC_Connected state is in one of two states. These states, as identified in Fig. 2, are the RRC_Idle and the RRC_Inactive state. For a UE not connected to the wireless communication network, it requires an initial access procedure to register its context with the network. This procedure generally requires more signaling procedures to transit to the connected state. On the other hand, the UE is in an RRC_Inactive state, which requires fewer signaling procedures in transiting to the RRC_Connected state. This work considered the UE to be in an RRC_Inactive state.

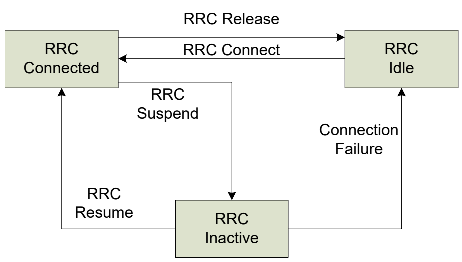

Fig. 2: RRC State Model for 5G [17].

3.5. Identifying a Group of UEs Registered as Home-UEs

Since the UE context is stored in both the gNB and the UE, the work of [4] utilized a Home Control Table, abbreviated as Home-CT, to serve as a repository whose one of three entries contain the information of registered UEs. These three entries are the Home-UE ID number, resident flag, and the visiting-gNB cell ID. The first entry, which is the Home UE ID, is a unique ID through which the 5GC can localize and deliver data packets to the UE. The second entry, which is the resident flag, is used to check if the UE is camped at its Home-gNB or not. Finally, the visiting-gNB cell ID is used to identify UEs from an external gNB. In other words, they signify UEs that are not registered to the gNB camped on.

3.6. Transmitting U_2

Regardless of its RRC state, once the signaling messages are exchanged between the 5GC and the intended UE, the transmission in the work of [4] is done omnidirectionally. As identified in the work of [6], signaling resources are wasted outside the direction of the UE when signals are transmitted omnidirectionally. To address this, the work minimizes the resources expended in paging a UE by using the procedures outlined in Subsec. 3.1. , Subsec. 3.2. and Subsec. 3.3.

3.7. Utilizing Directional Home-gNBs to Serve Home-UEs

According to [14], directional beamsweeping is an enabling factor for mmwave systems in 5G. This work adopted directional gNBs in the network model of [4] in place of omnidirectional gNBs to directional page UEs. This is to reduce the resources expended in broadcasting paging messages to the UE [6]. As discussed in [18], the high beamforming gain using directional gNBs overcomes large isotropic path loss of mmWaves, as well as improves link quality while reducing interference. In this work, both the Home-gNBs and Visiting-gNBs utilize directional gNBs in place of omnidirectional gNBs as adopted in [4].

3.8. Initiating Re-selection Based on the RSRP Measurement Report

Since the work of [4] utilized a network model that reduces TAU, the model enables UE reachability by exchanging the UE context through the Xn-Interfaces. Nonetheless, for a UE to move from one TA to another, the UE needs to monitor the Received Signal Received Power (RSRP) of its serving base station and that from its neighboring cell. Depending on the RRC state of the UE, the UE performs cell re-selection or handover whenever the RSRP drops below a set threshold. This is done by forwarding measurement reports to the UEs serving gNB.

3.9. Designing Home-CT to Enable Home-gNBs to Register their UE as Home-UE

The Home-CT is used for paging UEs in two different ways. This is based on whether the UE is registered to a Home-gNB as a Home-UE or is an unregistered UE and would be served by the gNB it is camped on as a visiting-gNB. When the gNB the UE is camped on is its Home-gNB, its resident flag is represented as h. On the other hand, when the resident flag of the UE reads v, this denotes that the UE is a Visiting-UE. In this scenario, inter-paging is used to deliver paging messages to the intended UE that is outside of its Home-gNB. In other words, the Home-gNB corresponds with the Visiting-gNB through the Xn-Interface to localize and deliver data packets to the intended UE.

3.10. Utilizing Xn-Interface for Visiting-UEs to Exchange Data-Packets with Original Home-gNBs

Independent of whether the paging procedure is 5GC-initiated or NG-RAN-initiated, it is crucial to minimize the signaling overhead of paging and RNAU. To lower this signaling overhead, a UE in an RRC_Inactive state need not always inform the AMF of an RNAU or paging procedure, as the UE context can be exchanged between the UE and its serving gNB [11]. To lighten the signaling procedure for Visiting-UEs exchanging data packets with the original Home-gNBs, the cell level change is only made aware between the involved gNBs and through the Xn-Interface. The Xn-Interface supports the exchange of data transfer and control functions between gNBs using Xn-UP. On the other hand, the Xn-CP protocol supports UE mobility in either RRC_Connected or RRC_Inactive state, while managing NG-RAN paging and Retrieve/Release UE context.

3.11. Triggering Service Switch Procedure (SSP)

Generally, the UE is responsible for triggering the location update procedure, which informs the network that the UE is switched on and connected to the network. The periodic location update procedure is usually triggered by a T3412-timer. The network provides all registered UEs a default initial value of the T3412-timer to be 54 minutes. This value counts down until it expires at $T3412 = 0$ min. When this happens, the UE triggers another location update procedure and restarts the countdown timer from a value of $T3412 = 54$ min. Generally, the time stops counting either when the UE is in a connected state or whenever the UE is switched off or deregistered from the network. In the work of [4], this procedure is simulated using a Service Switch Procedure (SSP). This procedure is used to manage the mobility of Visiting-UEs to guarantee that the cumulative time overhead is below a predefined value. Their spin on the control parameter considers an ascending timer, which is called a Service Switch Timer (SST). The conditions for triggering SSP are given as in [4]:

$$\mathrm{SST} = \begin{cases} 0\,\mathrm{sec} & \text{if} \quad \mathrm{SST} < \mathrm{t_{max}}, \\ 3600\,\mathrm{sec} & \text{if} \quad \mathrm{SST} = \mathrm{t_{max}}, \\ \text{Trigger SSP} & \text{if} \quad \mathrm{SST} > \mathrm{t_{max}}. \end{cases} \tag{3}$$

The duration of the SST is from 0 sec $\leq$ SST $\leq$ 3600 sec. In the event that SST $> t_{\max}$, it triggers SSP, which is equivalent to the Visiting-UE's context information being transferred to a new Home-gNB, and the change is updated at the AMF. At which the timer is reset to zero.

3.12. Materials and Methods

The simulations for this work were executed on a hp Intel ® Core™ i5-2520M CPU equipped with 8 GB RAM and runs on Windows 10 Pro 2019. The simulation of the proposed and existing scheme was implemented on MATLAB 2017b. The proposed algorithm in this work was adopted from two algorithms. A summary of these two algorithms, which form the basics of the proposed algorithm used in this work, are discussed hereunder.

3.13. Summary of the PIDP Scheme and the gNB-Based UEMT Scheme

The summary of both the PIDP scheme and the gNB-based UEMT schemes are crucial for the analysis executed in this paper to mitigate the signaling resources expended by the paging and RNAU procedures at mmwave frequencies.

The mmwave frequencies are among the key enabling factors of 5G. This is a result of its ability to accommodate massive traffic to massive connected UEs. The transmission of signals, which is beamformed, is done to overcome the challenge of large isotropic path loss at mmwave frequencies. Nonetheless, it was observed in [6] that as a result of the limited spatial coverage of directional beams, the transmission of paging messages which is done over multiple beams, increases the paging signaling resources expended by the network. This limitation impacts efficiency, which is a key performance goal of 5G.

On this premise, the authors in [6] propose a UE ID partitioning scheme that mitigates the signaling resources expended by the network to identify a UE in an RRC_Idle state. To achieve this, the work primarily considered the paging message, which contains the UE ID, the bits for the Cyclic Redundancy Check (CRC), the PDCCH, and the RRC state. Out of these four entities, the work considered modifications on the latter three to be inconceivable but implemented modifications on the UE ID. In this modification, the UE ID was split into Most Significant Bits (MSB) and Least Significant Bit (LSB), where the latter was included in the paging message, while the former was used to apportion the UEs over several Paging Occasions (POs). The application of this mechanism in identifying and paging the intended UE minimized the paging signaling resources expended. However, the work did not consider the mobility of UEs.

On the other hand, the work of [4] proposed a location management scheme that considered the mobility of UEs. The scheme utilizes a network model that mitigated the location management signaling resources expended. This was achieved by removing the need for location update and reducing the paging resources expended in omnidirectionally paging a 5G UE in an RRC_Inactive state. Using this scheme, Home-gNBs, which refer to BS that are assigned to UEs within their coverage area, handled the function of locating and tracking the UEs without intervention from the UEs. These UEs, known as Home-UEs, were registered in their corresponding Control Table (CT). With this procedure, the UE did not require the conventional RNAU procedure to update location changes. Rather, when the UE camps on a gNB that is outside of its Home-gNB, the foreign gNB referred to as the Visiting-gNB would interact with the Home-gNB through the Xn-interface to manage and control the mobility tracking of the Visiting-UEs. As a result, each gNB managed and controlled the mobility of UEs using the Home/Visiting CT. This was to ensure seamless mobility and lightweight signaling overhead since content fetching, and data forwarding between the gNBs was done through the Xn-interface.

Nonetheless, as aforementioned, the mmwave frequencies and beyond are key enabling factors for 5G and beyond wireless communication, respectively. As a result, it is crucial to mitigate the signaling resources expended with the adoption of directional transmission in 5G. To mitigate the exponential increase in signaling resources expended in the location management procedures for mobile UEs, this work proposes a hybrid location management scheme that embeds the partitioned UE ID-based scheme into the gNB-based UEMT scheme. The proposed hybrid scheme is discussed in the following sub-sections.

3.14. Analytical Model of the Proposed Hybrid Scheme

In consideration of the performance factors aforementioned, this work modifies the paging signaling resources expended by first localizing the intended 5G UE that would be paged. To achieve this, this work modifies Eq. (4) and Eq. (5) in the work of [4] by using the concept of partitioning a UE ID from the work of [6]. This is done to reduce the resources expended by the serving gNB in localizing a UE at mmwave frequencies.

$$AR_{pag} = \sum_{t=1}^{T} \Gamma_{pag} \cdot N_{RNAL} \cdot \sigma_t, \quad (4)$$

$$AR_{att} = \sum_{t=1}^{T} \Gamma_{pa\ g} \cdot N_{RNA\ L} \cdot \rho_t, \quad (5)$$

where AR_{pag} represents the accumulated resources expended in paging, AR_{att} depicts the accumulated resources expended in paging attempts, Γ_{pag} denotes the messages expended in Paging, N_{RNAL} corresponds to the total number of gNBs, σ_t is the rate at which the paging procedure is triggered during a time interval t, and ρ_t stands for the rate of paging attempts.

Delineated in the following is the process of partitioning the UE ID in order to mitigate the resources expended in localizing the intended UE for data packet delivery [4]. The resources expended in paging Γ_{pag}) can be mathematically expressed as:

$$\Gamma_{pag} = \frac{M_{pag}}{T}, \quad (6)$$

where the paging message, M_{pag} defined time within a time interval, T, consists of the UE ID (U) bit, alongside the context of the RRC (A_{RRC}) state, the PDCCH (A_{PDCCH}), and the CRC (A_{CRC}) bit [4] and [6]. This can be given as:

$$M_{pag} = U + A_{RRC} + A_{PDCCH} + A_{CRC}. \quad (7)$$

Building on what was surmised in the work of [6] regarding the context of the M_{pag}, the UE ID is partitioned into two. These two partitions, defined as the LSB represented as (U_1) and the MSB represented as (U_2) [6], are given in Eq. (8) as:

$$U = U_1 + U_2. \quad (8)$$

Within [6], it was observed that the ideal ratio of partitioning bit was a $20 : 80$ ratio, with 20 for (U_1) and 80 for (U_2). Adopting this ratio and substituting it into Eq. (8) yields Eq. (9):

$$M'_{pag} = U_2 + A_{RRC} + A_{PDCCH} + A_{CRC}. \quad (9)$$

The expression in Eq. (9), when substituted into Eq. (6)) yields Eq. (10), which represents the paging message with the partial UE ID.

$$\Gamma'_{pag} = \frac{U_2 + A_{RRC} + A_{PDCCH} + A_{CRC}}{T}. \quad (10)$$

Inputting Eq. (10) into Eq. (4) and Eq. (5) modifies the resources expended in paging and paging attempts, respectively. These are expressed in Eq. (11) and Eq. (12) as:

$$AR'_{pag} = \sum_{t=1}^{T} \Gamma'_{pag} \cdot N_{RNAL} \cdot \sigma_t, \quad (11)$$

$$AR'_{att} = \sum_{t=1}^{T} \Gamma'_{pag} \cdot N_{RNAL} \cdot \rho_t. \quad (12)$$

In [6], the bits transmitted per PO are transmitted over multiple beams, which eventually carry the full UE ID to establish the necessary signaling access for data packets to be transmitted to the intended UE is given as:

$$b_s = B_n \cdot \cdot (U_{PIDP} \cdot U_2 + A_{RRC} + A_{CRC} + A_{PDCCH}) \frac{2U_1}{L_{DRX}}, \quad (13)$$

where U_{PIDP} represents the UE per PO based on paging rate, B_n is the number of beams, and L_{DRX} denotes the length of the DRX cycle in seconds/milliseconds.

Therefore, to obtain the paging signaling overhead required to beam sweep the coverage area (that is, the RNA) and directionally page the intended UE, Eq. (13) is substituted into Eq. (11) to acquire the total paging cost, which is given as:

$$AR'_{pag} = \sum_{t=1}^{T} \Gamma'_{pag} \cdot (B_n \cdot N_{RNAL}) \cdot \cdot \left(U_{PIDP} \cdot \frac{2N_1}{L_{DRX}} \cdot \sigma_t \right). \quad (14)$$

In the same vein, when the DRX cycle of the UE is in an opportunity for DRX state (that is, an OFF duration), the paging message for an intended UE needs to be retransmitted to avoid a paging drop. By substituting Eq. (13) into Eq. (12), this retransmission is achieved directionally by using equation Eq. (15), which is expressed as:

$$AR'_{att} = \sum_{t=1}^{T} \Gamma'_{pag} \cdot (B_n \cdot N_{RNAL}) \cdot \cdot \left(U_{PIDP} \cdot \frac{2N_1}{L_{DRX}} \cdot \rho_t \right). \quad (15)$$

As depicted in [4], the total accumulated paging cost is the addition of the paging cost and the paging attempts. Therefore, to obtain the modified total accumulated resources expended in paging (TAR'_{pag}), the modified resources expended in paging (AR'_{pag}) of the UE are added to the modified paging attempt (AR'_{att}). Thus, the modified total accumulated resources expended in paging (TAR'_{pag}) is given as:

$$TAR'_{pag} = AR'_{pag} + AR'_{att}. \quad (16)$$

Substituting Eq. (14) and Eq. (15) into Eq. (16) yields the modified total accumulated signaling resources expended in paging (TAR'_{pag}), which is given as:

$$TAR'_{pag} = \sum_{t=1}^{T} \Gamma'_{pag} \cdot (B_n \cdot N_{RNAL}) \cdot \cdot \left(U_{PIDP} \cdot \frac{2N_1}{L_{DRX}} \cdot (\sigma_t + \rho_t) \right). \quad (17)$$

To obtain the total accumulated signaling resources expended, the resource also expended in the RNAU process, which is represented in Eq. (18), is added to Eq. (16).

$$AR_{RNAU} = \sum_{t=1}^{T} \Gamma_{RNAU} \cdot \lambda_t. \quad (18)$$

This yields the modified total accumulated load (MTC'_{tot}), which represents the resources expended in AR'_{pag}, AR'_{att}, and AR_{RNAU}. This is expressed as:

$$MTC'_{tot} = \sum_{t=1}^{T} \Big[C_{RNAU} \cdot \lambda_t + \Big(C'_{pag} \cdot B_n \cdot N_{RNAL} \cdot \cdot \Big(U_{PIDP} \cdot \frac{2N_1}{L_{DRX}} \cdot (\sigma_t + \rho_t) \Big) \Big) \Big], \quad (19)$$

where $AR_{RNAU} \cdot \lambda_t$ denotes the accumulated resources expended in RNAU in $(b \cdot h^{-1})$ and $\Gamma'_{pag} \cdot B_n \cdot N_{RNAL} \left(U_{PIDP} \cdot \frac{2N_1}{L_{DRX}} \cdot (\sigma_t + \rho_t) \right)$ represents the total accumulated paging cost in $(b \cdot h^{-1})$.

3.15. Flowchart of the Hybrid Scheme

The proposed improvement presented in [4] is shown in Fig. 3, with modifications highlighted in red. To minimize the overall signaling cost used to track and locate UEs, this research work would focus on the paging message. To localize registered UEs, the network transmits the MSB of the UE ID, which

Tab. 1: Simulation parameters.

S/No	Parameters	Values
1	Full UE ID size, (U)	40 bits
2	Partitioned UE Size, U_2	32 bits
3	Paging rate, P_R	Up to 2,400 UEs·s^{-1}
7	Number of beams, B_{TX}	8
8	CRC overhead, A_{CRC}	24 bits
9	Paging attempt, ρ_i	Average of 2 attempts·hour^{-1}
10	PDCCH overhead, A_{PC}	32 bits
11	RRC overhead, A_{RRC}	8 bits
12	TAU/RNAU overhead, Γ_{RNAU}	30
13	Paging overhead, Γ_{pag}	21
14	Power consumed per RNAU, pwr_{RNAU}	10 mW
15	Time slot	3600 sec

would be served by directional Home-gNBs and directional Visiting-gNBs to Home-UEs and Visiting-UEs, respectively. The MSB is not transmitted for UEs registered as Visiting-UEs since the direction of the UE is known by the Visiting-gNB when the Visiting-UE updates its location as a Visiting-UE on the Visiting-CT.

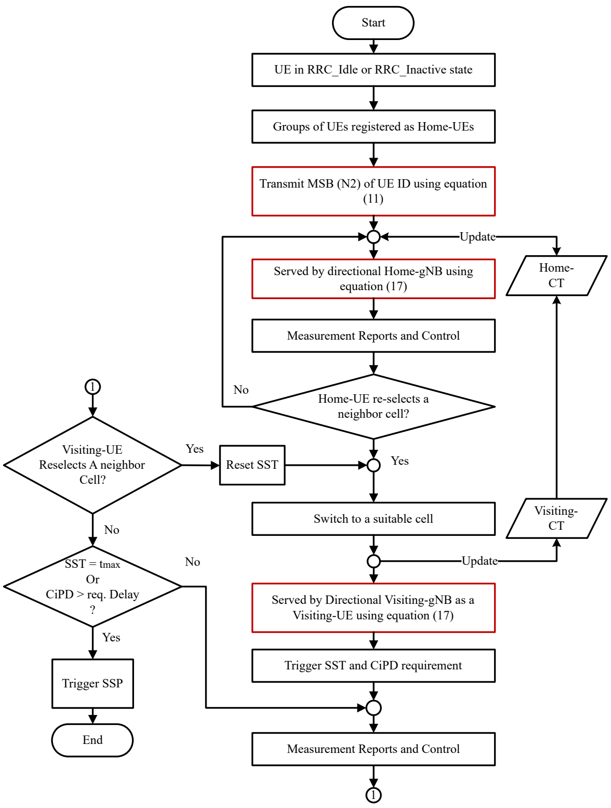

Fig. 3: Flowchart of the Improved gNB-based UEMT Process.

The simulation parameters adopted for the modified gNB-based UEMT scheme are presented in Tab. 1. These values are used to evaluate the performance of the conventional approach, the gNB-based approach, and the modified gNB-based UEMT approach adopted in this research.

4. Results and Discussion

Based on the proofs aforementioned for the proposed M-UEMT scheme, this section evaluates the performance of the M-UEMT scheme for the paging signaling cost and the accumulated signaling cost of both location management procedures. Figure 4 and Fig. 5 illustrate the performance of the proposed schemes along with the existing gNB-based UEMT scheme and the conventional TAU/RNAU.

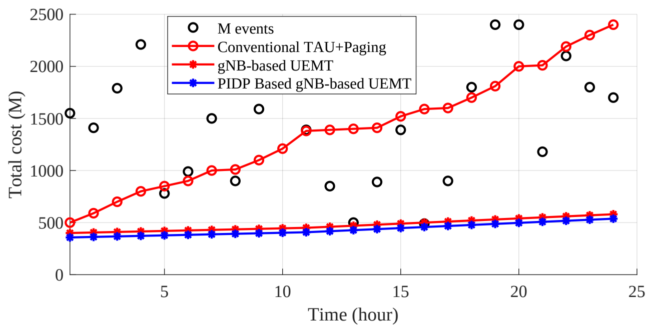

Fig. 4: Total paging resources expended by a mobile UE versus time.

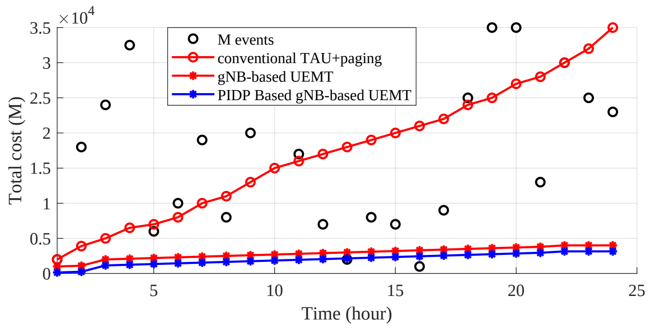

Fig. 5: Total accumulated signaling resources expended by paging and RNAU against time.

Figure 4 illustrates the performance of the conventional paging, gNB-based UEMT, and the M-UEMT scheme in terms of the modified total cost of paging. In this study, the paging cost refers to the signaling resources expended in paging a UE.

Equation (14) is used to generate the data for plotting Fig. 4. The total cost of paging represented in Fig. 4 depicts the resources expended in paging a UE in 24 hours. It is observed that as time increases, the resources expended in paging the UEs increase. This is because the paging attempt, ρ_t, has an exponential distribution with a mean of two paging attempts per hour. Although the goal of the schemes discussed is to minimize the signaling resources expended in paging UEs, the M-UEMT scheme shows a 65.13 % reduction from the conventional scheme. In addition, the M-UEMT scheme had an average percentage reduction of 8.69 % against the gNB-based UEMT scheme.

In this work, the cumulative resources expended in paging and RNAU, which also involves the paging attempts, are referred to as the total accumulated cost. This is depicted on the y-axis of Fig. 5. The total accumulated performance of the M-UEMT scheme against the gNB-based UEMT scheme and the conventional scheme is shown in Fig. 5. The data for the modified scheme is generated using Eq. (16). In the work of [4], the gNB-based UEMT depicted a 92 % reduction in the total accumulated resources expended against the conventional scheme. This percentage reduction was obtained from resources expended at the 24^{th} RNAU event. Similarly, the M-UEMT scheme showed a 93 % reduction in total accumulated resources expended against the conventional scheme.

On average, the mean reduction of the total accumulated cost of the paging and RNAU procedures which also includes the number of paging attempts, showed the proposed scheme had a 90.96 % reduction in the total accumulated cost of resources expended against the conventional scheme. In relation to the gNB-based UEMT scheme, the modified scheme showed a mean percentage reduction of 38.36 % over 24 hours.

5. Conclusion and Future Research

This research work proposed an M-UEMT scheme in order to mitigate the signaling overhead prevalent in the paging and RNAU procedures in 5G. The M-UEMT scheme was able to mitigate the signaling overhead when compared with the conventional and existing gNB-based UEMT scheme. The M-UEMT scheme, which is a hybrid scheme, embeds a PIDP scheme into a gNB-based UEMT scheme. This reduced the signal that is needlessly expended in directions outside of the location of the UE as well as the resources expended in directionally paging a UE. This was done by minimizing the UE ID bit required to beam sweep and localize the intended UE for data packet delivery.

Using the M-UEMT scheme, the performance of the scheme was observed under the influence of the resources expended in tracking and locating UEs, which also included the total paging attempts. Results of the simulation showed that, on average, the M-UEMT scheme showed 65.13 % and 8.69 % reduction in the total paging resources expended against the conventional scheme and the gNB-based UEMT scheme, respectively. In regard to the total accumulated resources expended in both procedures over 24 hours, the M-UEMT scheme outperformed the conventional scheme and the gNB-based UEMT scheme by 90.96 % and 38.36 %, respectively.

This work can be extended by considering techniques that minimize the energy consumed as the number of beams increases in order to maximize the increased paging capacity offered with the increased number of beams. This would be crucial for 5G and beyond wireless communications.

Author Contributions

A.O.A. developed the scheme, design, methodology and performed formal analysis. Both A.M.S.T. and A.S.Y. supervised the project. All authors were involved in analyzing, drafting, editing, and revision of the paper.

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