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Enhancing Idle Mode Mobile Termination Calls in 5G & LTE Cellular Networks through Optimized Paging Procedures

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1. Introduction

With the introduction of the 5G standards and recent significant utilization of the LTE technology, the mobile communication system has witnessed notable changes whereby the new voice over New Radio (VoNR) has been introduced and the existing voice over LTE (VoLTE) standards maintained (Kapoor et al., 2019) . The progress made in the area of voice communication has not only taken the quality of voice communication to a new level but also the technicalities associated with transitioning from different Radio Access Technologies (RATs) have been addressed. Implanted at the core of these technologies is the mobile terminated call paging process which is a vital mechanism needed to ensure uninterrupted and efficient communication (Alsaeedy & Chong, 2018) . This machine learning - based procedure informs a mobile device about its ringing whenever there is an incoming call, thereby promoting the initial stage connection process to be completed very fast. Even though there are many technological modifications human errors such as radio link failure and coverage issues are inevitable, causing the unreliability of the paging operation, particularly when devices are in idle mode. This research paper explores in detail the paging process in 5TH and 4TH generation communication networks; however, the research will concentrate on the ways of improving the idle mode mobile termination call performance using innovative network solutions (Alsaeedy & Chong, 2018) .

VoNR, EPSFB, and VoLTE are the concepts that are vital in the context of understanding the mobile communication sector that we have in 5G and LTE networks. The technology is developed in a way that speech services can be delivered over historically dominant data network infrastructures (Alsaeedy & Chong, 2018) . The preservation of the paging process, one of the substantial features of these technologies, will guarantee the proper and efficient routing of incoming calls to mobile devices even when in idle mode. Although various real - life issues, including spoilage of radio links and slow network connections, can disrupt the performance of the procedure, some calls may not be successfully connected, and the quality of the service may deteriorate. This paper therefore outlines a multi - RAT (Radio Access Technology) paging solution in which a mobile termination call timer is introduced to improve the probability of call establishment under different system circumstances. Employing a fully comprehensive approach, this solution is being explored from all possible aspects with the hope of advancing the current endeavors for the improvement of mobile network quality and reliability.

2. Literature Review

The newest technologies driving the fourth industrial revolution—big data, AI, and the Internet of Things (IoT) — are anticipated to be key components of fifth - generation (5G) networks. The projected 26 billion individuals will have 5G subscriptions by 2025. To provide a variety of services via the network, 5G specifically needs ultra - high speed, hyper - connectivity, and ultra - low latency (Gupta & Jha, 2015) . Therefore, supporting a large number of IoT devices and offering ultra - low latency connections to user equipment (UE) is crucial for 5G mobile communication in both the radio access networks and core networks. The AMF conducts a paging procedure to signal its transmission to the UE via the gNodeB when an access and mobility management function (AMF) is necessary for communication between the UE and IoT devices. The UE registers with the matching gNodeB when it travels to a nearby gNodeB (Egilmez et al., 2019) . However, the mobility registration process of the AMF between the gNodeB and UE wastes a large amount of superfluous radio resources, assuming that the UE travels between gNodeBs regularly (Coronado et al., 2020) . The AMF is anticipated to page numerous gNodeBs for the actual connection with its managed UE as not all UE mobility registration operations are relayed to it. This strategy leads to poor network performance, higher communication delays, and other signal - processing burden (Subramanya et al., 2020) . Various methods are available in research related to the 4G network paging process that reduces the overall performance degradation of the Mobile Management Entity (MME) in the overall paging process (MME) (Behrad et al., 2020) . The implementation of enhancements like load reduction and delay reduction, which were hypothesized in similar research, to real - world commercial 5G networks has not shown their effectiveness (Jeong et al., 2021) . As a result, the enhancement in 5G networks was unfounded.

To notify the UE of subscribers about the arrival of voice or data to be supplied to the UE in the connection management (CM) - idle state, paging is the process of locating the UE (Alsaeedy & Chong, 2018) . In the 5G AMF - initiated paging method, the gNodeB in the tracking area (TA) gets the next - generation application protocol (NGAP) paging signal from the AMF after it receives the N1N2 message transfer signal from the SMF (Weng et al., 2018) . The AMF then retransmits the NGAP paging signal to the gNodeBs in each TA if it does not hear back from the gNodeB on the completion of the radio resource's connection with the UE within a certain amount of time (Agiwal & Jin, 2018) . The AMF's paging profile

configuration set a maximum number of paging attempts, and the percentage of these paging signals made up around 30% of all signals processed in the AMF (Singla et al., 2020) . This constituted a significant load on the linked gNodeB and was a key area for performance improvement for the AMF. Based on the analysis of MME signal data gathered from many LTE commercial systems, they were applied to the AMF; the paging signal part ranged from 20% to 40%. More specifically, paging averaged 25%, UE - triggered service averaged 38%, MME - triggered service averaged 25%, and attach or tracking area update averaged 28% among the other signals (Alsaeedy & Chong, 2018) . The reduced paging signal burden on the AMF and gNodeB is thus necessary to optimize paging in a 5G wireless communication environment that demands hyper - connectivity with the UE (Alsaeedy & Chong, 2018) . We think that the suggested approach should result in successful 5G system creation and commercialization, as well as improved paging performance.

In the literature review, the modern 5G network's main paging procedures shortcomings are identified. The existing radio resource utilization is poorly planned and the high computing power might be wasted during the UE mobility handling and UE paging process (AMF). These inefficiencies cause delays and decrease the performance of the network which is in total disagreement with the 5G goals of ultra - high speed, hyper - connectivity, and ultra - low latency. The proposed system of having a Mobile Termination Call timer well considered the pitfalls identified and the solution revolves around optimizing the paging process. This is inspired by an innovative approach that favors a timer setup in the network and paging the idle - mode UE upon receiving a mobile - originated call to a mobile - terminated UE. If there is no response from the timer expiry time, it tries paging through other RATs with which it can communicate. Utilizing this technique helps to significantly reduce avoidable paging attempts as well as to conserve the radio resources and reinforce the probabilities of call setup success that in turn improves network efficiency and reduces the latency which gives an effective solution that targets the gaps identified in the literature review.

3. Mobile Termination Call Improvement Model Architecture (Proposed Solution)

Here is a comprehensive explanation of the proposed model architecture:

Overview of the Architecture

The innovative path presented here concentrates on the task of paging improvement in the area of cellular networks, specifically addressing the MT call setup issue in the case of IDLE UE. There's where at the heart of this solution is a proposal of a Mobile Termination Call timer which can work to somewhat increase the efficiency and reliability of paging procedures. Such a design is ingeniously engineered to operate autonomously of the range of current Radio Access Technologies (RATs) like 5G, LTE, and UMTS. This naturally designed objective is to downplay the risk of inconclusive attempts at paging as these cases are not uncommon in situations characterized by unresponsive UEs due to various factors including link failures between the UE and radio or UEs being on other RATs when being paged. With a timer setup upon every paging request to the non - interacting UE, the network activates a self - updating protocol that keeps the search going for the target device to connect.

At the expiration date of the said timers without any response from the UE, the system tactically initiates its page attempts at an alternative RAT, starting with LTE and then back to UMTS if the need arises. It is a tiered paging mechanism employing the RAT capabilities which will deliver a high likelihood of call connection success. This is realized by making the best of the diverse spatio - temporal availability and technical characteristics which are the characteristics of each of the network types. The fundamental feature of this solution is that it dynamically maneuvers through the intricacies of the network protocol, ensuring and improving the listening attempts to avoid failures that have been caused by different network issues.

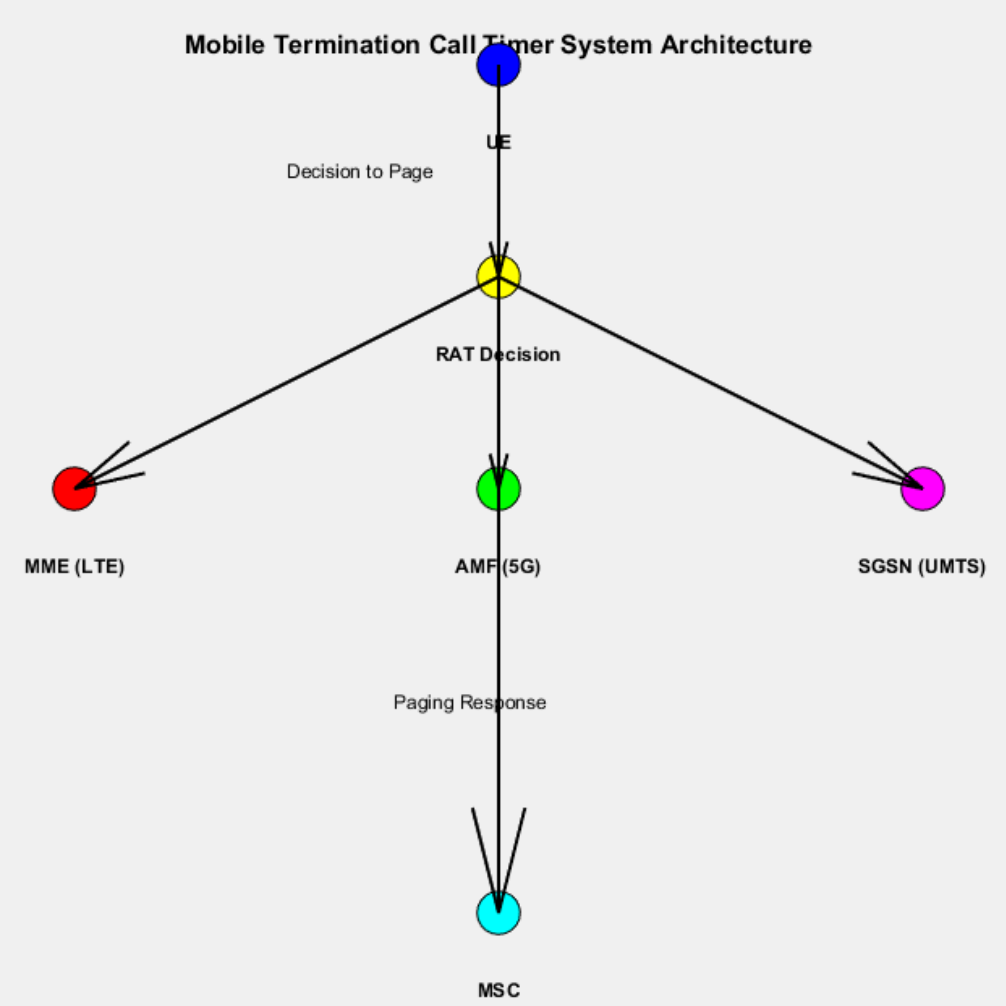

Chart 1: System Architecture Overview

An illustration of the key components used in the proposed solution fitted up by the Mobile Switching Center (MSC), Mobility Management Entity (MME) for LTE, Access and Mobility Management Function (AMF) for 5G as well as Serving GPRS Support Node (SGSN) for UMTS. The diagram reveals the paging requests flow as well as the request forwarding process among several RATs.

Detailed Description of Components

The architecture devised to improve the paging function of cellular networks gets its functionality from several key elements each of which stands out as having a discrete but essential function in handling and managing communication, particularly the Mobile Terminated (MT) calls. The role of the identifiers and how they influence the efficient provision of the service across multiple Radio Access Technologies is an important issue that must be understood.

First of all, the User Equipment (UE) plays the most critical role which, for this paging architecture, is the person whom the service is meant for. The UEs get broad coverage of mobile devices per user class that act as the communication media inside the network area. A critical element of the work of the UE is its capability to be switched between different RAT channels including 5G, LTE, and UMTS. This capability is crucial to supporting end users with different mobility patterns and to keep connectivity even with challenging network conditions. For example, a UE would be normally connected to the 5G network, but moving out of the 5G coverage area, it would have to switch to an LTE orUMTS network to maintain service continuity.

For mobility, paging, and session management handling intricacies, the system is built using specified entities of its own. For LTE networks, the MME implements this function, while the AMF performs its role in 5G networks. The MME and AMF function into the rerouting mechanism, as both devices remain connected to the network while subscribed, and therefore it is possible for MT calls a user receives to be routed to them through appropriate paging procedures.

In the context of a UMTS network the Serving GPRS Support Node (SGSN) performs similar functions to the MME and AMF. At the SGSN, the mobility management and session state of UEs within the domain are dealt with and voice and data services are provided for continuous connections needed. The SGSN is just as important in the SGSN as are the LTE and 5G counterparts, where it is expected to meet this requirement that the paging messages be directed accurately to the UE even as it moves across different areas of coverage.

The MSC (Mobile Switching Center) stands as the vital element for interworking all call setups (even MT calls). The MSC is a marshaling point where calls are connected to the cellular network so that call connections can be established

between callers and receivers. Its task goes beyond only call routing where the MSC interworks with MME, AMF, SGSN, and idle or roaming users during handovers and changing from one RAT to another. This coordination is the cornerstone of the proposed scheme on account of its objective of improving the efficiency of the paging process by enabling the network to change dynamically to the current state of the UE and the state of the network, hence boosting the delivery rate of the MT call.

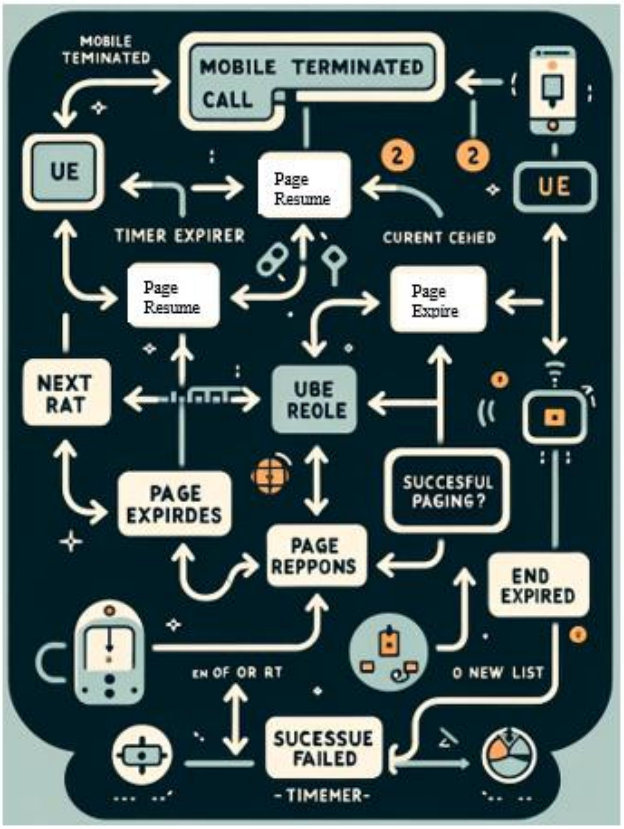

Chart 2: Component Interaction Flowchart

The flowchart shows the overall scheme of initiation of Mobile Terminated call requests based on different RATs and their associated decision - making processes.

Paging Procedure with Mobile Termination Call Timer

The procedure of paging a User Equipment (UE), primarily in the course of transmitting a Mobile Terminated (MT) call, is a crucial operation executed in cellular networks. This process guarantees that target recipients receive a call even if they left their devices in idle mode thus improving the network resilience to maintain its connectivity. This process has a critical element which is the Mobile Termination Call (paging) timer that helps define the paging strategy, as the initial paging does not always generate a reply from the UE. Again, in this paragraph, we explain, step by step, how to open the timer, the protocol to follow if it ends, and the mechanism for moving the paging work to other RATs.

The treatment kicks off when the network receives a call, targeting a UE to be MT. The network then invokes a location request that aims at identifying and informing the UE of incoming calls. While activating the network, the MTC also activates the Mobile termination Call timer, which is a critical monitoring tool. Here the timer is to be configured to utilize the duration (s) in which the network can receive a response from the UE which is being paged. It initiates the message that serves as a critically important phase in the paging process – a precursor of further activities based on the UE's reaction or deficiency.

If the timer expires with no specific acknowledgment or response from the UE which would signify that the initial paging was unsuccessful, then the network will go into a vital phase of decision - making. This phase constitutes to assessmentof the need to shift the paging effort to an alternative random - access technique. Broadly the criteria for this transition depend on the consideration that the UE could probably not be reached at the first time by the selected RAT because of various factors like the network's limited coverage, the UE moving out of the coverage area, or the technical constraints within the network.

When the network has selected an alternative RAT for paging, the network makes the required focused paging try on the chosen alternative technology. Such a change can include the movement from 5G to LTE or the transition from LTE to UMTS conditionally on the network's configuration and the available RATs. Such a strategic move is aimed at taking advantage of the widearea and extensive functional coverage provided by alternative RATs, hence increasing the likelihood that communication with the user equipment (UE) will be successfully set up.

The flow of this paging procedure above is an indication of the network’s agile strategy in guaranteeing that MT calls are effectively delivered to the UEs even under adverse conditions. The Mobile Termination Call Timer is thus employed as the pivotal tool, and the alternative Radios Access Technologies are the leverages through which the network remains robust in maintaining ceaseless communication. This exercise demonstrates the network's strength and its goal of delivering uninterrupted services to the users; such that in the event of a devise malfunction or a user moving outside the coverage area, the user's connection and accessibility will remain unchanged.

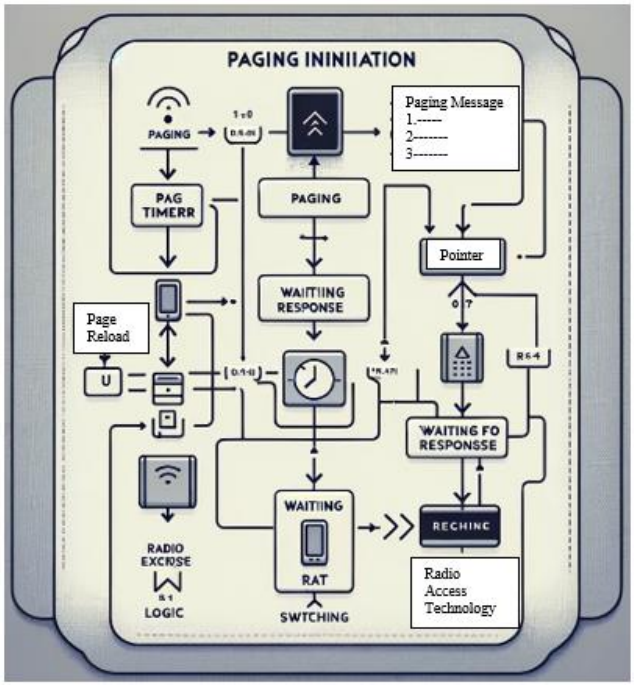

Chart 3: Paging Procedure Flowchart

Multi - RAT Paging Strategy

The Multi - RAT Paging Strategy is a complex method chosen to achieve maximum MT call connection probability considering various conditions (network and UE availability) and diverse UE types. This strategy relies on RATs as multi - purpose communication channels — with 5G being first to be leveraged, then LTE, followed by UMTS. Thus, this strategy ensures access to UEs even in complicated environments. The idea behind this sequence of selection is the use of the technology that has already reached its peak of development, 5G, to enjoy the benefits of higher speed and lesser latency that 5G offers. If the UE is out of the coverage of 5G, the network seamlessly falls back to LTE and, when required, to UMTS, and hence the whole framework utilizes the wider coverage and compatibility of the older technologies.

This hierarchical paging method significantly increases the step of completing the MT call by intelligently adapting to the UE's chosen RAT connectivity and prevailing network conditions. Likewise, as a UE leaves the 5G coverage area and is in a zone where LTE or UMTS is the only network available, the multi - RAT strategy assures its continuity, as the paging process remains uninterrupted guaranteeing the network reliability. Adopting this feature, the architecture serves the purpose of compensating the inconsistencies at which the UE has available, thus users are still connected and reachable through any location and the actual RAT of the device.

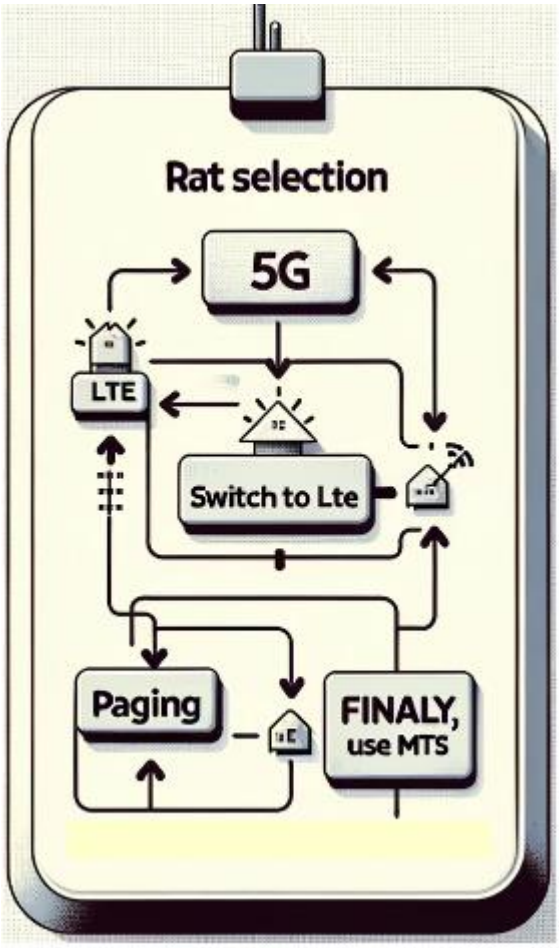

Chart 4: RAT Selection Logic Diagram

Implementation Considerations and Challenges

The suggested multi - RAT paging solution deployment should be taken with great caution and particular aspects and potential difficulties must be considered to maintain its efficiency and suitability to existing network infrastructure. The critical factor would be the network configuration that needs to implement the steps precisely without disrupting the already working system. This may be setting up network elements to support smooth handovers of RATs and operating the paging efficiently and reliably.

An important challenge that the interoperability between different Radio Access Technologies (RATs) introduces, is another one. The network has to coexist in a harmonious interaction of 5G, LTE, and UMTS technologies, where the paging (mobile call) is smooth and continuous. This requires optimization and harmonization of specifications and rules throughout different types of RATs to avoid any interruption during the paging process.

On the other hand, it is important to implement the solution with the least effect possible on network performance. Using an additional paging construct may tend to cause network resource overload. Hence, the system here must be optimized to eliminate unnecessary overhead, to avoid a worse user experience that lowers network efficiency. Finally, the solution we offer has to adapt to the existing network standards and protocols. Such interaction guarantees that the layering of multiple RAT paging strategies will be integrated into the ongoing operations with

the use of the existing network infrastructure and at the same time, improve the quality of calls that are expected to be established under different conditions.

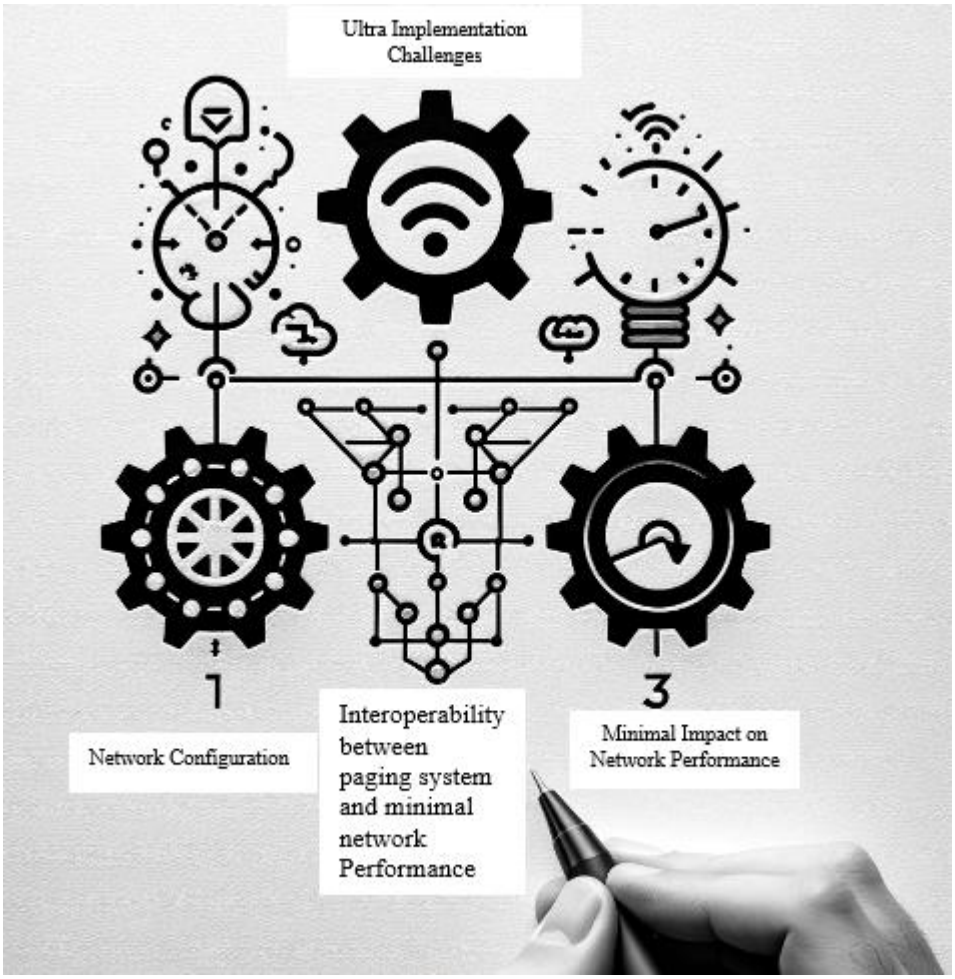

Chart 5: Implementation Challenges and Solutions

4. Conclusion

The investigation into improving the Paging in 5G, LTE, and LTE into 5G procedure using an innovative paging method can be an appealing line of research on the way to affordable and reliable mobile communications. The implementation of mobile termination call timers (MTCT), as part of a multi - tech paging solution, has demonstrated the eagerness of cell network technology to address the adverse conditions that affect the basic network functions of connectivity and service continuity. Adopt this approach and you will be acknowledging the fluctuations of user equipment (UE) mobility and dealing with the network coverage limitation as well as Radio Access Technologies (RATs) that are inherently coupled. The implementation of a smooth migration from 5G to LTE and UMTS is based on the idea of creating a cohesive system that allows calls to reach their designated recipients without any unwanted delay, thus making the user experience more pleasant and contributing to the overall improvement of the network's performance in terms of high - quality voice communication services.

The deployment of such a solution would nevertheless need a holistic review of the practicalities involved, spanning from network configuration reconfiguration to maintaining compatibility across different RATs and yet not compromising the ultimate quality of the entire network. Future recommendations will face the task of carrying out rigorous testing, and adjustments to the paging mechanism which are supposed to be following the new network standards and user demands. Furthermore, the application of machine learning and artificial intelligence technologies will be another promising approach for better optimization of the paging process that anticipates user behaviors and network conditions for adjusting the paging strategies dynamically. The realization of these innovations can offer a new trajectory in the arena of idle mode reliability of mobile terminated calls and also substantially enrich the gamut of network management and service delivery leading to the realization of the ambitions of the next generation of cellular networks.

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