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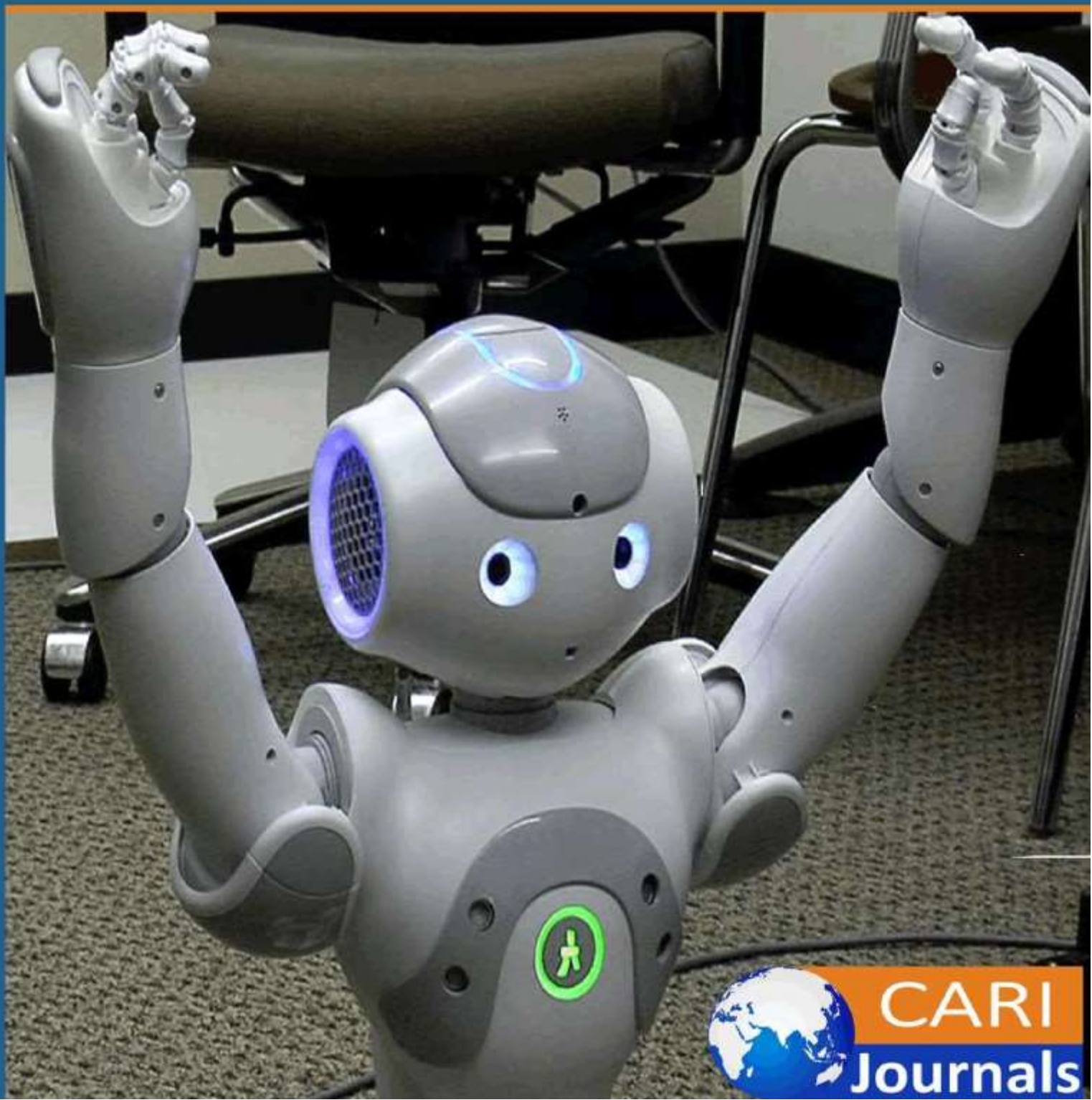

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Enhanced Network Reliability Following Emergency (E911) Calls

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Abstract

Purpose: In this research, the purpose is to explore E911 call reliability requirements, study real-world issues related to telecommunication networks transitioning from LTE to 5G (NR) and WCDMA, and present network optimization solutions. The primary objective is to ensure the continuous supply of emergency services and improve the dependability of Enhanced 911 (E911) calls.

Methodology: The research methodology involves an examination of the transition from LTE to 5G (NR) and WCDMA in telecommunication networks. The study delves into government-mandated E911 call reliability requirements and conducts a detailed analysis of two real-world issues affecting tight connectivity for E911 calls. Additionally, the research proposes network optimization solutions to address these challenges and enhance the overall reliability of emergency services.

Findings: The findings of this research reveal insights into government-mandated E911 call reliability requirements and identify two practical issues affecting the continuity of emergency services during the transition from LTE to 5G (NR) and WCDMA.

Unique contributor to theory, policy and practice: The study presents network optimization solutions aimed at overcoming these challenges, with the ultimate goal of improving the dependability of E911 calls and enhancing public safety.

Keywords: *Post-E911, Call, Network, Optimization, 5G Connectivity*

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Introduction

The expansion of its range has performed well for the LTE network, which is represented in broad coverage and common existence in most service providers. Just like LTE, the 5G (NR) Network is anticipated to offer a wide range of base stations to different service providers. Most people know that they can rely on it mainly because of its widespread presence, and it serves as a default option for many emergency calls. However, "mobile connectivity and its role for emergency services is a broader topic than merely in urban centers." Currently, this remains a crucial option in populated areas when other communication methods are limited. In emergencies, the availability of open communications within this dual-network landscape is essential for ensuring the safety of all members of the population.

Emergency E911 Call Requirement from Government

Governments set up Enhanced 911 (E911) call reliability requirements, pivotal to modern emergency response infrastructure, in order for mobile devices and landlines to act as lifelines in times of crisis. These requirements are important in facilitating timely emergency services, enhancing public safety, and reducing turnaround times. E911 requirements have as one of their main objectives the completion of emergency calls [14]. This involves strong callback and call completion plans. In case of a break, the emergency search units should be able to reconnect with the caller immediately.

On the other hand, call completion emphasizes the significance of ensuring a flawless first emergency call. Another dimension of the E911 requirements is the need for interoperability. It requires all the service providers to be in a position to move calls from one Network and technology to another within treatment interchangeably [5]. This interworking is particularly crucial in a given situation whereby, during an emergency call, the mobile user's device may need to switch networks on several occasions, ending this conversation so that it is directed ultimately to the intended emergency response unit.

Fig 1. Requirements for Emergency E911 Calling System

Requirement	Description
Call Back and Call Completion	Ability to call back the caller if a call is disconnected. Ensuring successful call completion.
Interoperability	Seamless transfer of calls between different service providers and technologies.
Reliability and Availability	High reliability and availability with uptime, redundancy, and failover mechanisms.

The underlying necessity for reliability and availability is one of the most important tenets stated in E911 mandates. Fundamentally, the provision of E911 services should always be available as

well as reliable throughout. To attain such reliability requires a range of technical and infrastructural features that span across redundancy to failover mechanisms for ensuring emergency services' presence in the network-connected life. Service providers, network operators, and equipment manufacturers must strictly meet these requirements, given that the reliability of E911 directly affects people's safety and well-being. The following parts of this paper discuss two current issues in the real world that hinder compliance with these needs and recommend network optimization solutions for mitigating them.

Emergency E911 Call Flow with Normal Registration

The 3rd Generation Partnership Project specifications also define the process that includes a well-documented procedure such as the E911, a normal registration process in telecommunication networks. This call flow was very important in dealing with emergency calls because, without emergency calls, people would not be able to save lives and assist in desperate situations. This kind of E911 call initiated by a UE normally registered in the home PLMN is processed through carefully thought out and specified steps [15]. Such calls are made towards the intended destination, which can be PSAP or the emergency service center. The process commences with the transmission of the type SIB1 message from NW to the UE. Also, SIB1 is crucial because it sends a message to the UE to confirm whether the Network supports IMS (IP Multimedia Subsystem) emergency call service.

This involves the provision of support to IMS Emergency Calls, which is integral to the proper management of emergency calls. Then, the NW sends an attached accept message to the UE. The UE requires this message for confirmation that the Network supports IMS Emergency Calls [1]. The bearer supports critical data such as Emergency Bearer Supportability and also contains the Emergency Number List that the UE should know about the capabilities of the Network's emergency. Then, the user proceeds to make an emergency call after these first two preliminary checks. Therefore, the UE responds by sending an emergency-type PDN connectivity request to the NW.

Fig 2. Steps in the Emergency E911 Call Flow with Normal Registration Information

Step	Description
1	Network to UE: SIB1 - UE determines if the Network supports IMS Emergency calls
2	Network to UE: Attach Accept - UE determines if the Network supports IMS Emergency calls (Emergency Bearer Supportability, Emergency Number List, etc.)
3	UE dials Emergency Call
4	UE to Network: UE sends PDN connectivity requests (emergency type PDN request)
5	Network to UE: Activate default EPS bearer context request (Assigns EPS Bearer and Emergency APN)
6	UE to Network: SIP Invite
7	Network to UE: SIP 183 Session Progress
8	The emergency call connects

Emergency call request implies that this communication is urgent, which triggers a process of establishing a dedicated bearer for emergencies. The NW receives the demand and creates an EPS-bearer of this emergency call, which the emergency APN will be assigned later [3]. Bearer allocation also guarantees that the emergency call traffic has a good quality of service and call success probability. The UE, therefore, sends a SIP invite because this defines the signaling path for the emergency call. NW answers by sending a SIP 183 Session Progress message saying that the call is already in progress. The establishment of a connection is one of the crucial steps while setting the emergency call. A well-defined call flow of E911 ensures that each emergency call is treated with utmost care, promptness, and priority. However, real-world problems, including interferences, can still affect the effectiveness of E911 services [2]. This paper is divided into two parts, where each part deals with a particular aspect of reliability. It offers recommendations on ways in which the Network can be optimized in order to handle all emergency 911 phone calls effectively.

Real-world Issue 1: Enhancing Reliability for Emergency E911 Calls in LTE Networks with ENDC Dual Connectivity

E911 calls are not reliable on a normal LTE registration basis. The UE has been enhanced with Enhanced Data Rates for GSM Evolution, which has increased its coverage and features, but these are limited within the LTE network. Needs to be addressed with post-emergency call

behavior in networks can make E911 services unreliable. For instance, network operators choose to add an ENDC NR cell to the LTE system after a successful E911 call in the traditional LTE registration context [4]. Furthermore, this is because of the aim to achieve maximum efficiency through the simultaneous utilization of dual connectivity to 5G NR and LTE. This is one of the numerous merits of this approach in strategic management. However, this operation results in a deplorable situation in which the Network can send an RRC connection release command with deflection instructions to a different LTE EARFCN and cell even if the UE is still under normal LTE registration mode. This way of redirection, however, could be associated with a sub-optimal situation when the UE switches to another LTE cell for no apparent reason.

Fig 3. Notwork Optimization for Real Issue 1

Optimization Strategy	Description
Configurable Time Window	Introduce a configurable time window after an E911 call to ensure network stability.
Restriction on ENDC NR Measurements	Avoid sending or adding 5G NR cell measurement requests during the time window.
Restriction on RRC Reconfigurations	Prevent the Network from sending RRC connection reconfiguration messages during the time window.
CQI Monitoring	Continuously monitor the UE's Channel Quality Indicator (CQI) reports to efficiently allocate resources.
Location and Mobility Considerations	Account for UE location and mobility patterns during the emergency call timer to make informed redirection decisions.

Nevertheless, suspicions increase concerning reliability in relation to E911 service. Consequently, this means that emergency services should be in a position to call back to the initial device in case it becomes necessary after an E911 call. Diversion of the UE to another LTE cell in the early could disturb the important communication connection for time-critical emergency calls that may delay or disrupt the call [5]. This problem continues within the LTE, though it can be significant in the future when a five-G NR call becomes the common E911 call registration within the five-G NR networks. This calls for reliable emergency services when the 5G NR networks are expanding their areas of operation and coverage.

Real-world Issue 2: Ensuring Emergency E911 Call Reliability in UMTS Circuit Switch Networks with Limited LTE Coverage

However, in real-life scenarios like these, a UE can be automatically registered in the normal UMTS circuit switch network. Still, it will be operating in a region with very limited LTE network coverage. In such instances, network operators are faced with numerous challenges when handling E911 calls. The subsequent network operations may compromise the reliability of emergency services. Upon fulfillment of a successful E911 call, the Network sends a handover request to the UE to shift to any other UMTS cell or may lead the UE to the available LTE cell [7]. The Network's motivation for these actions can be twofold: better quality of the signal, optimization of resources, and enhanced connectivity of UE, among others. However, handover requests and redirects are meant to disrupt the connection between the UE and the Network, thus rendering the emergency services unable to reconnect to the caller. The above disturbances can be caused by degraded signaling, co-channel interference, and the complex UMTS/LTE handovers between these two networks.

Fig 4. Notwork Optimization for Real Issue 2

Optimization Strategy	Description
Configurable Time Window	Introduce a configurable time window at network after an E911 call to ensure network stability.
Avoidance of Handover Requests	Restrict the Network from sending handover requests to other UMTS cells during the time window.
Restriction on WCDMA Cell Measurements	Avoid sending measurement requests for WCDMA/UMTS cells during the time window.
Restriction on RRC Reconfigurations	Prevent the Network from sending RRC connection reconfiguration messages during the time window.
CQI Monitoring	Continuously monitor the UE's Channel Quality Indicator (CQI) reports to efficiently allocate resources.
Location and Mobility Considerations	Account for UE location and mobility patterns during the emergency call timer at Network to make informed redirection decisions.

This issue emphasizes the vulnerability of e911 calls whenever UMTS circuit switch systems dominate LTE networks are present and offer limited coverage. Unfortunately, network optimization efforts are aimed at improving connectivity and call quality. However, these efforts can be problematic for the emergency services. The reliability of E911 services depends on their ability to ensure that a call back is possible immediately after a dropped call or any other

unidentified problem. This link could be hindered by handovers or redirections, particularly in regions where LTE networks are not available, thus affecting the effectiveness of E911. Emerging networks and the deployment of LTE or 5G technologies make this matter important [6]. Specifically, these issues have to be addressed as we strive to ensure that the E911 calls remain safe under any network conditions or technology adopted by a network operator.

Network Optimization of Real Issue 1

Enhancing the reliability of E911 calls for an LTE network having an emphasis on ENDC dual connection mode. If E911 call reliability must persist as a genuine problem following a successful call, network optimization strategies should be considered. One of the possible ways of optimization after a successful emergency call is a configurable time window at network. In this period, the Network never adds and sends any measurement requests for 5G NR NARFCN. Therefore, this decision will play a significant role in keeping the high reliability of the emergency service call back. With reference to this, the Network will not put up 5G NR measurements because the UE would be focusing on LTE as a way of avoiding any unnecessary network handovers that could interfere with an impending E911 call [8]. Finally, the Network should not send RRC connection reconfigure messages in the ENDC NR cell addition or a UE relocation to another LTE EARFCN. Callbacks are not prematurely redirected, thereby preserving their reliability in significant stages of this approach.

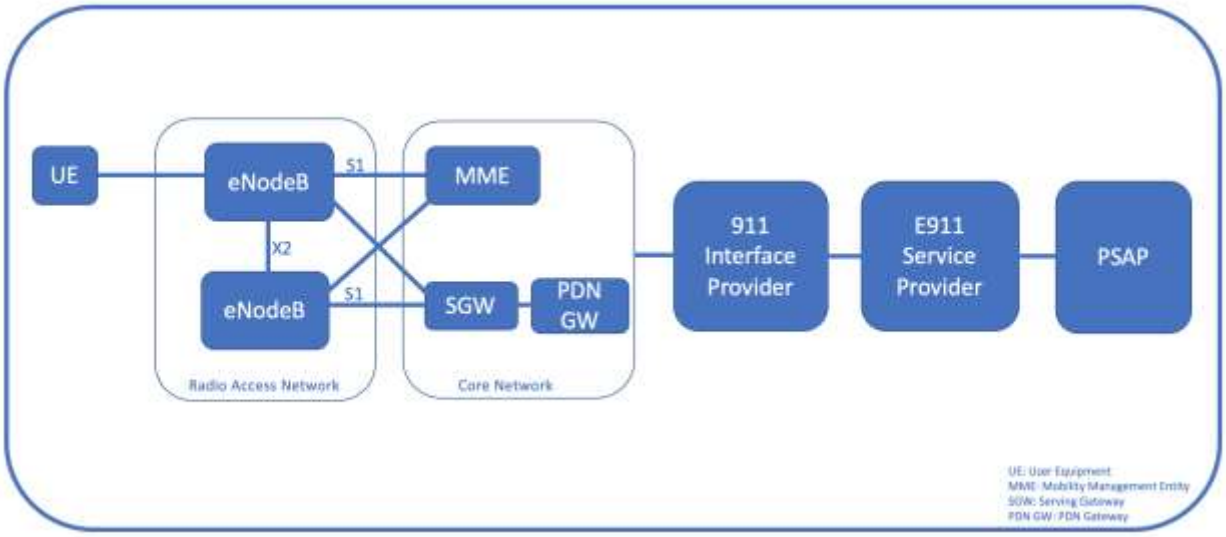

Fig 5: Network Topology for E911 Calls

The Network must also periodically collect CQI reports from the UE, which is the final stage. CQI is one of the key parameters used to determine the quality of the channel, primarily based on signal-to-noise ratio. This way, the resources are distributed efficiently, and the quality of emergency service becomes effective by means of a high-quality and reliable E911 call [10]. Furthermore, the location and mobility pattern of the UE have to be considered by the Network during the use of the emergency call timer after completion of the call. With UEs moving away

from the cell center, there might be long distances to factor in, as well as environmental factors that could lead to the degradation of signal quality. For instance, the Network is able to predict the extent of signal deterioration at a long distance and other environmental attributes via path loss models. These models hold the link steady, preventing it from deteriorating as the UE heads towards a part of neighboring cells or close to the cell edge [10]. Nevertheless, these network optimization strategies are just as relevant as 5G NR networks continue to expand their coverage and accessibility.

Network Optimization of Real Issue 2

During the operation of the LTE network in areas with relatively reduced coverage, it is hard to make sure that E911 messages will be reliable when a UMTS circuit switch network registers the UE. However, targeted network optimization yields tremendous gains in the number of users that will experience a callback after a successful E911 call release/drop [2]. Another basic optimization solution is a configurable time window placed after a successful emergency call. Furthermore, this also includes that the Network will issue no handover request in any other UMTS cells, and no measurement request will be added for WCDMA/UMTS cells [12]. This time interval is fundamental in ensuring the reliability of the emergency service callback. The Network ensures that the UE is on the UMTS circuit switch network throughout the handover period without any handovers or secondary measurements. The Network should also not send any RRC connection reconfiguration message during the timer operation and should not add other WCDMA cells or allow the carrier aggregation to begin. Such an approach ensures that there are no premature network reconfigurations and helps ensure that callback services are continuously reliable during the critical phase.

Another component of network optimization is periodically assessing the UE by means of CQI reports. In fact, the CQI, or the signal-interference ratio, has been used as a measure of radio channel quality. This means that the Network has to monitor the CQI reports continuously in order to ensure that the E911 call is of the highest quality and reliability and the resources are allocated effectively. In addition, the Network will also consider the location and mobility behavior of UE when still running an emergency call timer after the completion of a call [11]. UEs may encounter weak signals due to being farther away from the cell tower coupled with other environmental factors that would have been experienced moving away from the cell center. In terms of path loss models, the Network can apply empirical data to predict signal reduction based on distance or surrounding elements. The models ensure that the UE remains connected at any point, even when moving to the edge of the cell or neighboring cells. E911 calls must provide a high level of reliability [11]. Consequently, this is especially important in areas where the LTE network services operate poorly. Therefore, the development of network optimization strategies must be addressed for E911 calls.

Conclusion

E-911 call reliability continues to be crucial in modern telecommunications as a foundation for the present-day public safety and emergency response system. The safety of a community, however, depends upon prompt response to distress calls emanating from mobile devices or landlines. However, two problems exist in the practical provision of E911 services against the background of changing networking technologies and scenarios. ENDC dual connectivity has been considered to solve some of the problems faced by the LEN network, particularly where enhanced user equipment data are being implemented for the evolved GSM New Radio (ENDC). Hence, various network improvement schemes were studied so that user callback was effective for successful E911 call completion or a dropped call. Following an emergency call, there was a time window where the networks would not perform some actions like ENDC NR cell measurements and RRC connection reconfiguration that would be optimized.

Additionally, CQIs are constantly monitored towards increasing reliability depending on the positioning and mobility of the UE. Nonetheless, this means to the future since it refers to 5G-NR e911 calls. The primary goal was to ensure the reliability of the E911 call when CSN is unavailable or in the event of poor network coverage in an LTE-limited environment. Network optimization strategies like configurable time windows, skipping handover requests, and CQI periodically helped with this problem. The Network keeps vigilant to avoid doing any unnecessary network actions that would reduce the reliability of a 911 call in areas with scanty LTE coverage. In essence, handling these real-life issues and the optimization methods for the Network will be crucial, as the robustness of E911 calls in telecommunications. This is because E911 services are a lifeline in case of emergency. The Network's capability to overcome some of these challenges reminds the telecommunication sector of its commitment to national security. These strategies will form the basis of ensuring the dependability of E911 calls in light of the dynamic environment of network technologies such as 5G, LTE & WCDMA.

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