Ultra Reliable Advanced Framework for Emergency and Mission Critical Data for 5G Services

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Abstract: The paper provides a novel approach of using heterogeneous devices and future networks, with impact on ultra-reliable services for the next generation 5G networks and emergency mission critical data. The user-centric framework used here, together with the network interoperability, as well as the symbiosis with emergency communications systems, complements the IoT systems and the heterogeneous networks, enabling reliable transfer of time critical data communication. A new approach is establishing reliable communication of time-critical data, where the user is at the center and is able to use multiple available data networks to deliver the service. The architecture of the EMCD system model is based on the fundamental principals of 5G architecture, allowing IoT devices to communicate with IoT applications, hosted in a cloud datacentre. The simulation results and analysis show superior performance with a high level of ultra-reliable and low latency communications in a variety of network conditions and different network coverage. The packet duplication, the proposed emergency and mission-critical data algorithm, and multi-connectivity architectures are the basic principles that provide solution for high reliability and low latency.

1 INTRODUCTION

Digital transformation is present everywhere in our society, changing our way of communication and transforming into the digital age, where ubiquitous and reliable data connectivity is the foundation for such a transformation. Internet of Things (IoT) will connect all of objects and devices to the Internet and will exploit the full potential benefits of devices equipped with enough sensing, acting and processing capabilities. Domination of data communications between devices in the following years will many times overcome today's data transfers initiated by humans. Wireless networks are the main enabler of connected IoT, working within an environment of heterogeneous devices and networks with a variety of data types, used in various applications, such as health, networked vehicles, industrial IoT and media. Wireless sensors network are not anymore short-range small ad-hoc networks, but part of a wider ecosystem called IoT. IoT is a system that includes various types of sensing devices that communicate with smart devices, which continue to confidently and securely transfer data to the appropriate cloud platforms, where data for the respective applications are stored, archived and subsequently processed.

On the other hand, the emergency and mission critical data networks cover services, important for the security of society and citizens, and also encounter challenges for acceptance of smart phone applications based on their capability and interoperability between heterogeneous networks.

Despite the enormous development advances of technology and the standardization of new technologies, commercial use of digital applications that require highly reliable communications in case of emergencies and mission-critical events is still in the early stages. Moreover, according to International Telecommunication Union (ITU) the 5G is classified into ultra-reliable low latency communications (URLLC), enhanced mobile broadband (eMBB), and massive machine-type communications (mMTC).

Motivated by such a situation, this paper presents analysis and simulations of how highly trusted services can be used in everyday life, by defining the paradigm Emergency and Mission-Critical Data (EMCD) communication and presen-ting a system model for communication in case of critical events. EMCD requires ultra-reliable data communication in case of serious life threatening events, as well as possible high property damage if the critical data is not delivered in due time.

At present, the telecommunication networks are completely IP based, where applications are using higher TCP/IP layers. Emergency services, natively using data packets, can use the EMCD system model horizontally integrated between different network providers through isolated IP peering, dedicated to EMCD packet communication. End user devices should support EMCD packet communication, integrating an EMCD agent in the firmware, creating a possibility for standardization and wider usage of the EMCD system model and supporting devices within a global international EMCD data network, enabled by all telecom providers.

Next-generation data networks and 5G, in addition to availability and reliability, should provide consistent service with certain network parameters (delays, jitter, and packet loss) [1-2] that will secure new services. In comparison, existing wireless data networks are not satisfying the parameters for ultra-reliable communication. Within 5G frameworks, solutions are being investigated that could enable the required parameters for Ultra-Reliable Low Latency Communication - URLLC as in [3]. Moreover, with current 3GPP standardization, in new versions of Release 15 and 16, new mechanisms are required to address the challenges of ultra-reliable communication [4].

The paper is organized as follows. Section II gives an overview of the most relevant research work in this field. Section III presents our system model, architecture and EMCD framework. Section IV provides simulation results. Finally, Section V concludes this paper.

2 RELATED WORKS

The major goal in current and future mobile and wireless networks and services is providing a high level of QoS support for any given service and minimal latency for real-time services. One heterogeneous network environment, where 5G takes central place, requires collaboration and interoperability of all entities for greater availability and reliability [5]. 5G networks will support the massive spread of intelligent IoT nodes to support wider acceptance of mission critical communication services [6]. The proposed approach does not refer to the unification of currently most widely used WLAN and mobile networks, but to all wireless networks used for communication in the IoT systems and platforms. Also, the proposed approach considers many challenges of 5G URLLC with IoT devices [7].

On the other hand, when we focus on the architecture of the EMCD framework presented here, many similar schemes for dual-mode mobile equipment are being proposed. For example an UMTS/WLAN interworking network has been proposed in [8] and [9], but without emphasizing QoS issues and without ultra-reliable low latency issues. Similarly, a dual-mode mobile node for UMTS/WLAN is presented in [10], including implemented handover logic modules. The dual-mode user equipment design includes a monito-ring and reporting unit to determine the status of the interfaces and an interface selection unit to activate or deactivate the interfaces (UMTS and WLAN) for mobile handoff. The results indicate a smoother and seamless handoff process. The shortcoming of this model is in focusing only on mobile HO processes and not implementing any adaptive QoS framework for improving the results of other QoS parameters (including URLLC). Furthermore, [11] presents adaptive QoS framework implemented in dual-mode UMTS/WLAN mobile terminals. According to the presented results, the proposed dual-stack UMTS/WLAN mobile equipment with an adaptive QoS module, performs fairly well in different network conditions, achieving better performance but only in comparison to the cases when only WLAN or only UMTS mobile equipment has been used. Moreover, URLLC or any emergency and mission critical data are not considered.

Despite all related works, one of the advantages for our proposed EMCD system model is that it relies on the basic 5G postulates for integration of different Radio Access Technology (RAT) networks and ultra-reliability [12-14] with reliability >99,999% [15] based on the packed duplication methodology and dual RAT interfaces (or multi-connectivity [14]) on IoT devices.

Moreover, accompanying mission critical with emergency data will lead to more efficient use of resources that for the most part of the time are unused. Use of public communication infrastructures to enable emergency services for citizens, but also for IoT devices, is necessary to provide next generation emergency service. Having in mind that separate networks for emergency data transfer, commonly owned by the government, usually exist, the symbiosis with these networks, in the event of a failure of commercial networks, can lead to greater reliability and interoperability, as proposed in [16].

The theoretical background for reliability of the proposed EMCD system is based on the packet duplication concept and corresponds to the basic principles of communication theory within system engineering [17].

3 SYSTEM MODEL AND ALGORITHM

As mentioned before, the proposed ECMD system architecture is based on the URLLC and should support a variety of services that request challenging reliability (99.999%) and latency (1 ms).

In the new 5G RAN networks, comple-mentary to improving existing Physical (PHY) layer techniques, a packet duplication protocol is intro-duced. The EMCD architecture is primarily being focused on higher layer solutions based on Packet Duplication (PD) as a practical and low complexity technique for URLLC. The theoretic framework behind PD is investigated, and the recent enhan-cements in the 5G Dual Connectivity (DC) architec-ture for supporting PD are discussed, without excessively increasing the complexity in the RAN.

The fundamental principle underlying PD, involves generating multiple instances of a packet at higher layers and transmitting the packets simultaneously over different uncorrelated channels or transmission links [18]. At the receiver, the redundancy and diversity in the channel conditions is exploited, such that higher transmission reliability is achieved. While the reliability with PD is achieved using multiple redundant links, low latency is realized by eliminating the need for packet retransmission. With PD, duplicate packets are proactively transmitted simultaneously, thus eliminating the need to use time-diversity schemes such as HARQ to satisfy the URLLC requirements.

The user plane comprises Packet Data Convergence Protocol (PDCP), RLC, MAC, and physical (PHY) layers, all of which are collectively responsible for ensuring reliable over-the-air transmission of packets in both uplink (UL) and downlink (DL) directions [19]. The radio resource control (RRC) entity, the primary control plane (CP) function in the RAN, is responsible for configuring all protocol layers in the network and the IoT device.

The architecture of Dual Connectivity with packet duplication PD in 5G is intended to provide high throughput and high reliability by enabling the use of radio resources from two access nodes with distinct schedulers of the same or different RATs [20]. So, both the master node (MN) and secondary node (SN) are connected over the Xn interface, which supports data forwarding, flow control functions, and should provide interconnectivity with guaranteed bandwidth and latency for EMCD packets. As such, only semi-static coordination at the RRC level is supported in DC, taking in consideration small packet size for IoT data communication related to EMCD. On the other hand, both MN and SN have greater flexibility in independently scheduling resources for the IoT devices, as shown in Figure 1.

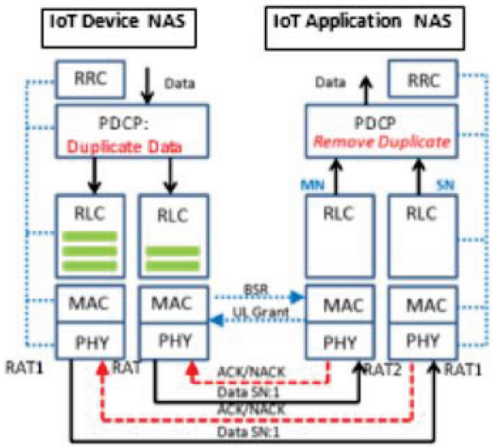

Figure 1: EMCD architecture and PD between IoT MN and SN.

In the case of 5G, both access nodes host the NR RAN protocol stack and are connected to the 5G Core Network (5GC) in a standalone NR-NR DC architecture [20] as shown in Fig. 2. In this case, the IoT MN and IoT SN are referred to as Master Next-Gen Node B (MgNB) and Secondary Next-Gen Node B (SgNB), respectively. The architecture of the referent EMCD system model (Figure 2) is based on the fundamental principals of 5G, C-RAN architecture and the architecture of the 5G Core Network, allowing IoT devices to communicate with an IoT application, hosted in a cloud datacenter. IoT devices communicate with the IoT application trough dual connectivity RAT establishing not only higher reliability, but also better handover in a case of mobility of wireless nodes with intention to reach lowest mobile interruption time.

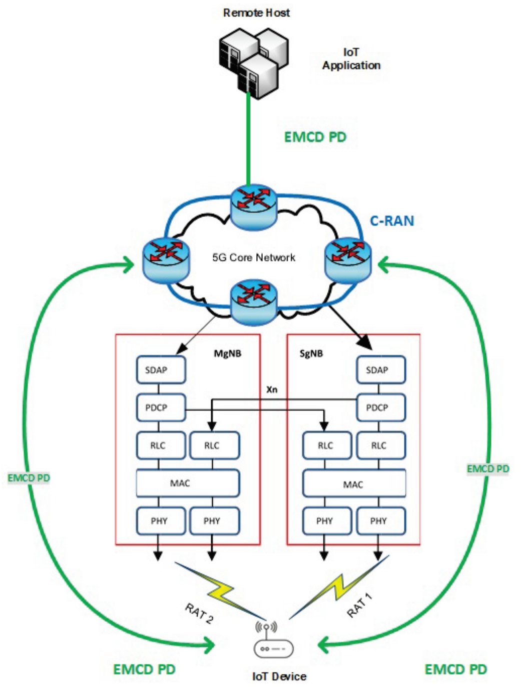

Figure 2: 5G IoT EMCD architecture.

Namely, a handover with 0 ms interruption is mandated, and extreme reliability will not tolerate any mobility failures. Consequently, softer handover concepts where the IoT device is multi-connected to a source, based on the dual connectivity principle is shown in [21].

The EMCD Algorithm for communication of the IoT device (MN) with the IoT application hosted in the edge of the RAT in a cloud (SN), is securing the reliable communication using redundant connectivity within the predefined WAN EMCD network.

The EMCD algorithm uses an EMCD user agent in the IoT device to send multiple copies of the same packet through independent RAN routes. The EMCD algorithm will be applied for the EMCD labelled IP packets in the IoT device and are related to emergency and mission critical situations that require fast and reliable communication. All other IP packets will not be replicated and will use a predefined network interface. Taking in consideration the fact that only a selected part of IP packets are replicated, the algorithm should secure a reliable mechanism, transparent in the application layer, for detection and management of duplicated IP packets.

Within the EMCD algorithm, the EMCD agent cannot control IP packets' route, accept the destination IP address and the choice of network interface to send IP packets through. The EMCD algorithm will transparently replicate IP packets, using different network interfaces connected to the EMCD WAN network segment, and will transmit them to the IP destination.

On the receiving side, the EMCD algorithm will receive the first IP packet and forward it to the upper layers, while the replicated packets will be silently discarded. The EMCD algorithm will be used in a secure and isolated EMCD WAN network environment that complies with the existing network protocols, and will not introduce additional security concerns. The EMCD WAN environment includes separate 5G network slices, separate PVC and VLAN's within the operator transport layers, and separated hidden SSID Wi-Fi segment on the end user CPE, where IoT devices will be connected. Since the EMCD algorithm will be used in heterogeneous public networks, it's obvious that the transparency of the network is one of the basic requirement, and the EMCD algorithm should be placed in the upper application layers. Additionally, part of the functionality can be moved on the transport layer, as in 5G, where the functions of replication are supported from the networks from same type.

Furthermore, since the EMCD algorithm is introduced on the application layer, all IoT devices should have an EMCD user agent incorporated, in order to support this algorithm, as well as an IoT application hosted in the cloud.

Once the EMCD session is established, the EMCD user agent is ready to transmit duplicated EMCD packets to the corresponding EMCD host. All packets related to EMCD are inspected, duplicated on the both network interfaces, and added an EMCD header containing a 32-bit sequence identification (SNID), representing a unique identifi-cation of an EMCD session.

4 SIMULATION RESULTS

Before presenting the simulation results and analysis, it is important to emphasize that the theoretical background for reliability of the EMCD system is based on packet duplication concept and corresponds to basic principles of communication theory within system engineering [17]. Reliability of the systems will increase with simultaneous use of multiple heterogenic uncorrelated RATs, where reliability of entire system can be presented as:

$$R = 1 - \prod_{i=1}^{N}(1 - R_i) \quad (1)$$

where R_i presents the subsystems' reliability and where N is the number of simultaneous fully uncorrelated RATs at a location. In the heterogeneous wireless and mobile system with multiple sub-networks, ultra-high reliability can be achieved with sending duplicated packets trough all available networks.

For URLLC, the reliability achievable over link *i* is determined as:

$$R_i = P(l_i \leq LT)P(SNR_i > SNR_i^T)P(b_i > BT) \quad (2)$$

where:

- $P(l_i \leq LT)$ is the probability that the overall latency li (processing and propagation) over link *i* is less than the URLLC latency requirement *LT*.
- $P(SNR_i > SNR_i^T)$ is the probability that the signal-to-noise ratio (SNR) achievable on link *i* is greater than SNR_i^T, the *SNR* threshold for achieving a target block error ratio (BLER) value on link *i*.
- $P(b_i > BT)$ is the probability that b_i, the bandwidth allocation on link *i*, is greater than *BT*, the bandwidth required to transport an URLLC packet.

We will present simulations for end-to-end reliability depending on the link delays and reliability for different network coverage, based on the EMCD system model using multiple communication links. As described previously, in the EMCD model, usage of multiple links is in the same time connected with duplication of packets, while copies of packets are delivered at the same time through multiple links, according to the EMCD algorithm. Since mobile and IoT devices today have multiple wireless radio interfaces (4G, WLAN, NFC, Bluetooth etc.), the next generation of devices based on 5G are expected to support all backward radio technologies. Existence of multiple links connectivity, used with PD will improve our system towards the ultra-reliable EMCD services.

Packet Duplication with the EMCD algorithm and Multi-Connectivity architectures in the EMCD system model are the basic principles that provide solutions for high reliability and low latency. Based on these principles, losses within the radio networks due to fading and interference on individual links or possible network outage will be compensated with the copies of the packet travelling through the diverse infrastructure. Having in mind that packet duplication is used, for the EMCD data transfer the handover time is equal to zero.

Since, each geographical area has its own specificity in terms of terrain and RAT coverage, in order to create a simulation model that can realistically include these parameters, the geographic areas will be divided into three generic parts related to population: urban, suburban and rural areas. Since, the raw data we use, incorporate the information about availability per cell, we decided to divide the geographical areas according to population, thus forming groups of base stations and calculating the reliability of each of these areas for different technologies.

Usually, the areas that are densely populated, have a high number of wireless and mobile networks that cover all varieties of mobile and IoT devices (with incorporated EMCD). The mobile networks of all operators usually have full coverage of urban areas, using a large number of overlapping mobile cells and providing high-quality spatial and traffic signal coverage.

For further analysis of the regional impact by the EMCD framework, we will take advantage of the fact that the coverage of LTE networks is uneven across regions and network reliability in certain regions is lower. In addition to simulating our EMCD framework, the system uses historical real data as a reference value when comparing single current technologies. Furthermore, we will consider that the reliability of the second LTE network has different reliability in the aforementioned regions and we will see its impact over the overall reliability.

Table 1: Regional reliability of 2G, 3G, 4G and WLAN.

	2G (EDGE)	3G (HSPA)	4G (LTE)	WLAN
Urban	0.998	0.988	0.998	0.965
Sub-urban	0.988	0.986	0.983	0.931
Rural	0.92	0.91	0.912	0.882

Furthermore, Table 1 and 2 present regional reliability for urban, sub-urban and rural areas for different mobile and wireless technologies for the three simulation scenarios. As shown in Table 2, the confidentiality ratio of the two LTE networks, for the three scenarios, is given separately.

In the first scenario we will consider simulating the EMCD framework compared to single 2G, 3G and LTE reference models. The assumption is that the second mobile network has lower reliability than the first one, and it is different for each of the areas: 90%, 80% and 60% respectively. In the first scenario, we will consider simulating the EMCD framework compared to single 2G, 3G and LTE reference models. The assumption is that the second mobile network has lower reliability than the first one, and it is different for each of the areas: 90%, 80% and 60% respectively.

Figure 3 depicts the simulation results for the average reliability of different networks and of our proposed EMCD framework in the urban, sub-urban and rural regions, when simulation scenario 1 is used.

Table 2: Regional reliability for proposed scenarios.

	LTE2/LTE1 Scenario1	LTE2/LTE1 Scenario2	LTE2/LTE1 Scenario3
Urban	0.9	0.9	0.95
Sub-urban	0.8	0.9	0.95
Rural	0.6	0.8	0.95

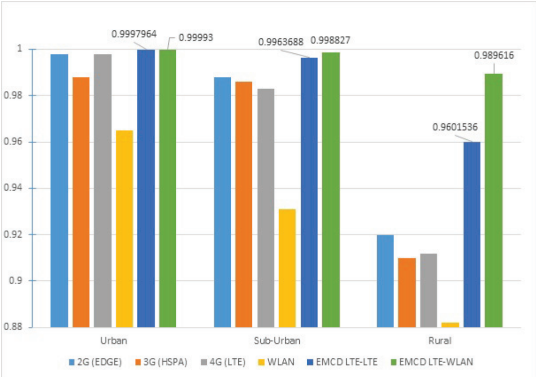

Figure 3: Regional reliability of different networks and EMCD framework for Scenario 1.

In Scenario 1, each technology has different values for the respective areas. As expected, the reliability for each of the technologies is particularly high in urban areas. Consequently, the simulation values for the EMCD framework in this area are very close to ultra-reliable requirements, because the reliability in urban areas is higher than in other regions. Next, comes the suburban area, and the lowest reliability is presented in the rural area.

Even though single systems (in each technology), don't have redundant links, they present comparable results to the EMCD framework, but for urban areas only. This is because the mobile system is redundant itself, i.e. within a single mobile system if the device is in the zone of coverage of two or more base stations and if one of them gets interrupted, the others within range of the device have predefined algorithms to seamlessly connect the device to the next available one. At the same time, to meet the high demand for data, in urban areas a significant number of base stations from several mobile operators and independent WLAN networks exist. The EMCD framework offers greater advantages in sub-urban and especially in rural areas compared to urban areas, with the greatest improvement over a single link being presented for the EMCD framework in rural areas.

Comparing the reliability of the EMCD model simulated with two LTE networks to the EMCD model using LTE and WLAN we can see that if we have one of the LTE networks with significantly lower reliability in certain regions, the $EMCD_{LTE-LTE}$ implicit reliability shows lower reliability than $EMCD_{LTE-WLAN}$.

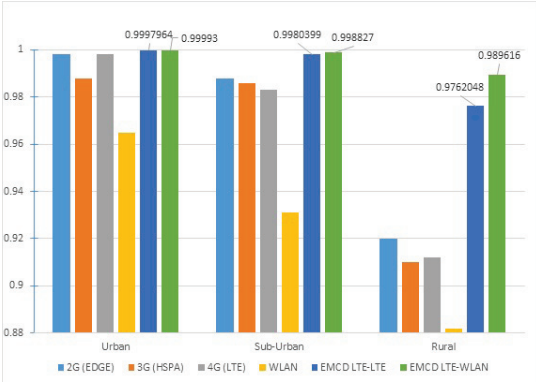

Figure 4: Regional reliability of different networks and EMCD framework for Scenario 2.

In addition, Figure 4 shows simulation results for the average reliability of different networks and of our proposed EMCD framework, for Scenario 2.

The scenario 2 presents the simulation of both types of EMCD frameworks compared to single 2G, 3G and LTE reference models. The assumption is that the second mobile network has lower reliability than the first one, and it is different for each of the areas: 90%, 90% and 80% respectively. Although the second LTE network in the second scenario has significantly better reliability in the rural areas, still the effective reliability of $EMCD_{LTE-LTE}$ is lower than that of $EMCD_{LTE-WLAN}$.

Scenario 3 presents simulation of the two types of EMCD models, compared to each other and with respect to single technologies. Again the assumption is that the second mobile network has lower reliability than the first one and is 95% for all regions. Again, Figure 5 presents the simulation results for the average reliability of the different networks and our proposed EMCD framework for this third scenario. In this Scenario 3, we consider that the second LTE network has reliability that is 5% lower than the reliability of the first LTE network. However, despite relatively minor difference in reliability of both mobile networks, we see that this has an impact on the $EMCD_{LTE-LTE}$ model.

Figure 5 shows that for these reliability values regarding the cellular networks, the reliability values for both EMCD models are almost identical in each of the regions, with insignificant differences.

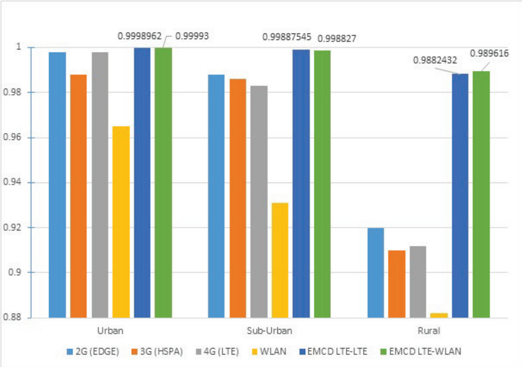

Figure 5: Regional reliability of different networks and EMCD framework for Scenario 3.

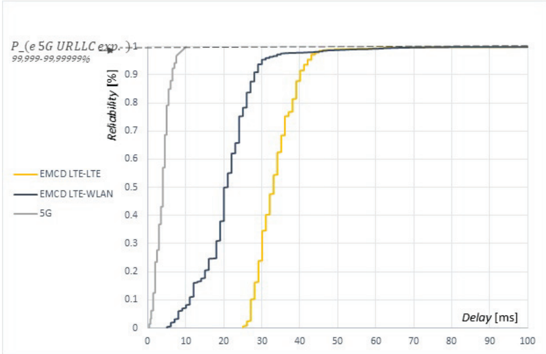

Figure 6: Average reliability of different EMCD models and 5G for URLLC vs delay.

Figure 6 shows a comparison of the EMCD model to the expected/desired theoretical values of 5G technology for URLLC. As it can be seen, simulated reliability values for the EMCD model are quite comparable to 5G technology, but with a significant difference in delays. Based on the results from the three scenarios, we conclude that differences in reliability between the networks of two different operators, plays a great influence on the resultant reliability for the EMCD system. Taking into consideration the regional reliability of each of the networks, the reliability of proposed EMCD framework may vary from one region to another, depending on the reliability of single networking radio technologies. The simulations of the EMCD model in the previous sections were generally aimed at simulated system reliability with respect to ultra-reliable applications. On the other hand, one of the interesting feature reuirement introduced by 5G technology is the URLLC support, which requires high reliability of the system and small latency at the same time.

Thus, taking this into account, Fig. 6 presents the simulation of the two EMCD models: $EMCD_{LTE-LTE}$ and $EMCD_{LTE-WLAN}$ compared to each other and with respect to the parameters that are expected to be supported by the 5G network, through their cumulative distribution functions for URLLC.

Based on the records for system measurements of the networks for average delay per technology within the same period, we can present reliability in correlation with the delay with cumulative distribution function (CDF) [22].

Comparing the two EMCD models, $EMCD_{LTE-LTE}$ and $EMCD_{LTE-WLAN}$ in terms of delay we can see that the simulation of the $EMCD_{LTE-WLAN}$ model presents better delay features.

Namely, this can be accounted to the use of a heterogeneous combination of networks, mobile LTE and WLAN networks. Moreover, as the model defines, the IoT devices send duplicate packets over the LTE and WLAN networks to the IoT application server. We can assume that WLAN's link delay is shorter (going through fixed broadband network). Thus it can be shown that packets will first arrive at the IoT application server via this link, and will use the link with better characteristics, amounting to a combined increased performance, with the resultant graph shown in Figure 6.

Ultimately, Figure 6 clearly presents the final conclusion that the EMCD model brings comparable reliability performance to 5G and can be proposed as a transitional model applicable for the presented network architectures and algorithms. Consequently the EMCD model enables utilizing current heterogeneous LTE and WLAN technologies, while presenting comparable performance to 5G envisioned URLLC standards.

3 CONCLUSIONS

This paper proposes a novel Emergency and Mission-Critical Data framework for mobile and wireless IoT devices in heterogeneous wireless environments, using ultra-reliable applications. The proposed EMCD model has been tested using several simulation scenarios, with the aim to obtain its statistical characteristics and to compare it with existing cases, when a single radio access technology is used by a single mobile terminal. According to the presented results, the proposed dual-stack EMCD framework performs fairly well in different network conditions and coverage, achieving better performance in comparison to the cases when only one RAT is used and is comparable to 5G reliability performance. One of the major innovations, on which we focused in this paper, introduced by 5G technology as well, is the URLLC support, where despite the high reliability of the system it is required to support a short delay at the same time.

The results have shown performance gain by the EMCD module in the dual network scenario that can easily be generalized to a multi wireless and mobile networks scenario, including any 5G and Next Generation Radio Access Network, as well as IoT network access technologies. The EMCD framework brings comparable 5G reliability performance and can be recommended as a transitional model applicable to the proposed architecture and algorithms, especially for ultra-reliable low latency applications and multimedia services that require high reliability.

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