International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

# 5G-Enabled Mission-Critical Networks Design and Performance Analysis

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**Abstract:**
**The deployment of 5G technology promises to revolutionize the landscape of mission-critical networks, which are fundamental for sectors that demand high reliability, low latency, and continuous availability, including healthcare, public safety, autonomous vehicles, and emergency response systems. Traditional communication infrastructures struggle to meet the stringent requirements of these mission-critical applications due to limitations in network performance, reliability, and scalability. This paper examines the design, performance analysis, and potential of 5G-enabled mission-critical networks, with a focus on innovative 5G features, including network slicing, ultra-reliable low-latency communication (URLLC), and edge computing. These technologies are crucial for ensuring that mission-critical applications are supported by robust and efficient communication systems that can maintain high performance levels under all operational conditions.**

**Network slicing, a key feature of 5G, enables the creation of dedicated, isolated virtual networks over a shared physical infrastructure, allowing each slice to be optimized for specific applications. This isolation ensures that mission-critical services are not disrupted by non-critical traffic and receive the necessary resources for optimal operation. The integration of URLLC is another pivotal advancement, providing ultra-low latency communication necessary for real-time data transmission, which is essential in applications such as remote surgeries, industrial automation, and vehicular communication systems. URLLC guarantees reliability and minimal delay, which are fundamental for ensuring safety and accuracy in mission-critical services. Furthermore, edge computing plays a crucial role by enabling data to be processed closer to its source, thus minimizing latency and reducing the strain on central servers. Edge nodes perform real-time data analysis and decision-making, which is critical for applications that require instant responses, such as autonomous driving or real-time video surveillance. This paper presents a comprehensive simulation-based evaluation of 5G-enabled mission-critical networks, examining key performance metrics such as latency, throughput, reliability, and scalability. The results of our simulations indicate that the adoption of 5G technology significantly enhances network performance, providing sub-millisecond latency, high reliability, and exceptional scalability even under varying traffic conditions and large numbers of connected devices. Additionally, the use of edge computing further optimizes resource utilization by processing data locally, ensuring faster response times and better handling of high volumes of data.**

**Despite the promising capabilities of 5G in mission-critical environments, the deployment of these networks faces significant challenges, including the high cost of infrastructure, security concerns, and the complexity of ensuring compliance with regulatory standards. The paper concludes by identifying the future research needs to address these challenges, such as the development of advanced security protocols and cost-effective deployment strategies, while emphasizing the potential of 5G to enable transformative advancements in mission-critical communication systems across industries.**

**Keywords: 5G, Mission-Critical Networks, Network Slicing, Ultra-Reliable Low-Latency Communication (URLLC), Edge Computing, Latency, Reliability, Throughput, Scalability, Healthcare, Public Safety, Autonomous Vehicles, Real-Time Communication, Emergency Response**

**Systems, Network Performance, Simulation-Based Evaluation, Infrastructure Deployment, Security Concerns, Regulatory Compliance, Future Research Directions.**

## I. INTRODUCTION

The advent of 5G technology represents a significant leap forward in the evolution of wireless communication, bringing with it capabilities that are poised to address the growing demands of mission-critical networks. These networks, which support essential applications such as emergency services, healthcare, transportation, and autonomous systems, require ultra-reliable, low-latency, and highly available communication systems to operate effectively in real-time. Traditional wireless networks, such as 4G LTE, often fall short in meeting the stringent performance requirements of these applications due to limitations in speed, latency, and scalability. As mission-critical services continue to expand, the need for more advanced communication technologies has become evident, and 5G is well-positioned to fulfill these needs.
5G-enabled mission-critical networks are designed to provide a higher level of reliability, faster data transmission speeds, and lower latency than previous generations of wireless networks. These networks are crucial for supporting critical applications, where even minor communication delays or failures can have severe consequences. Examples of mission-critical applications include remote surgery, where delays in data transmission can jeopardize patient safety; autonomous vehicles, where communication latency can lead to accidents; and emergency response systems, where every second counts in saving lives. To meet the demands of these applications, 5G technology introduces a suite of innovations, including network slicing, ultra-reliable low-latency communication (URLLC), and edge computing, each of which contributes to enhancing the performance, security, and efficiency of mission-critical networks.

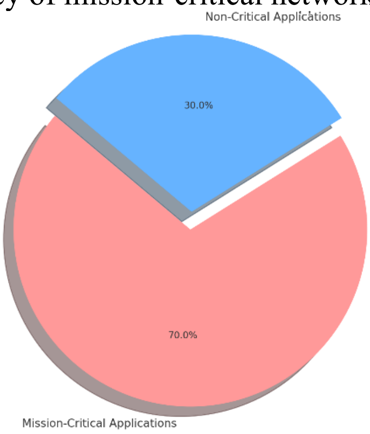


**Figure 1:** Resource allocation for mission-critical vs. non-critical applications in 5G networks. 70% of network resources are allocated to mission-critical services, ensuring high performance for real-time applications

One of the defining features of 5G is network slicing, which allows the creation of multiple virtual networks (or "slices") over a shared physical infrastructure. Each slice is tailored to meet the specific requirements of different use cases, ensuring that mission-critical applications receive the dedicated resources they need for optimal performance. For instance, a network slice dedicated to autonomous vehicles may prioritize ultra-low latency and high reliability. In contrast, a slice for healthcare applications may emphasize secure data transmission and high throughput. This level of customization is crucial in mission-critical scenarios, where it is vital to isolate traffic to prevent congestion and ensure that less time-sensitive data does not impact critical communications flows.

Ultra-reliable low-latency communication (URLLC) is another critical feature of 5G that addresses the performance requirements of mission-critical applications. URLLC enables communication with a latency as low as 1 millisecond and a reliability of 99.999%, making it ideal for applications such as remote surgery, real-time monitoring of industrial systems, and mission-critical public safety communications. In contrast to traditional networks, which may experience delays or data loss during periods of high network congestion, URLLC ensures that data is delivered promptly and reliably, even under demanding conditions. This capability is critical in environments where every millisecond counts, and the failure of communication can have life-or-death consequences.

Another innovation in 5G is edge computing, which involves processing data closer to the source of generation, rather than relying on centralized cloud servers. This reduces latency and alleviates the burden on network infrastructure, ensuring faster decision-making and real-time responses. In mission-critical networks, edge computing enables the rapid processing of sensor data, video feeds, and other critical information without requiring the transmission of large volumes of data to distant data centers. For instance, in autonomous vehicles, edge computing can process sensor data in real-time to make driving decisions within milliseconds, minimizing delays and improving safety.

While 5G offers numerous advantages for mission-critical networks, its deployment also presents several challenges. The infrastructure required to support 5G networks is complex and expensive, and the rollout of 5G infrastructure may take time, especially in rural or underserved regions. Additionally, the increased complexity of 5G networks introduces new security concerns, particularly regarding the integrity and confidentiality of communication in mission-critical applications. As the number of connected devices and systems grows, ensuring that these networks remain secure and resilient to cyberattacks becomes paramount. Furthermore, regulatory compliance is a crucial consideration in implementing 5G-enabled mission-critical networks. Different countries and regions have varying standards and regulations that must be adhered to, particularly in sectors such as healthcare and public safety. Ensuring that 5G networks comply with these regulations is critical to their successful deployment and adoption.

This paper aims to explore the design and performance analysis of 5G-enabled mission-critical networks. By focusing on network slicing, URLLC, and edge computing, we examine how these technologies impact the overall performance of mission-critical services. Through simulation-based performance evaluations, we analyze key metrics, including latency, reliability, throughput, and scalability. This paper also discusses the challenges associated with 5G deployment in mission-critical environments, including infrastructure costs, security concerns, and compliance with regulatory requirements. The insights gained from this study will provide valuable guidance for the future development of 5G-enabled mission-critical networks, highlighting areas that require further research and innovation.

## II. LITERATURE REVIEW

The use of 5G technology for mission-critical networks has been the subject of extensive research in recent years, driven by the demand for high-reliability, low-latency, and scalable communication, which is required by sectors such as healthcare, public safety, autonomous transportation, and industrial automation. The research into 5G-enhanced mission-critical networks has mainly highlighted novel functionalities of 5G (like network slicing, ultra-reliable low-latency communication (URLLC), and edge computing) tailored to the special needs of these demanding applications. This section of the document examines the current literature on these technologies and their impact on mission-critical network performance.

However, network slicing promises to be a key enabling technology for the emerging 5G world, allowing multiple virtual networks to coexist on a shared physical infrastructure, providing different levels of service, and essentially treating each as a separate end-to-end network. This is a crucial feature for apps where reliability matters more than performance, as it allows for allocating separate network resources per service. In some cases, such as autonomous vehicles, ultra-reliable, low-latency communication is required at high speeds. Another case is remote healthcare services, which also prioritize security, but the need is more for high throughput.

Azari and Bennis (2021) investigate the role of network slicing in mission-critical applications, as it is considered an enabler that allows the allocation of different network resources for each service. According to the authors, network slicing enables critical applications to be isolated more effectively; therefore, even if congestion occurs in other parts of the network, it does not affect the performance of these dedicated slices. In addition, various researchers [23–26] reported that the levels of miR-29a in urinary samples from patients with LN were increased compared to those without LN. Song et al. (2020) provided evidence that network slicing can enhance the quality of service of mission-critical applications by adaptively assigning resources to meet real-time demands. With the on-demand feature of network slicing, network resources can be efficiently allocated during times of high traffic, enabling continuous communication.
Recent literature has also explored the use of network slicing to enhance mission-critical networks in terms of reliability and availability. Network slicing isolates traffic from other, less critical services, allowing mission-critical applications to continue running even when the network is busy—a study by Zhang et al. In [2012], network slicing is used to provide priority for mission-critical services like emergency services communications so that first responders are not cut off in the event of disasters.

Although URLLC is an essential feature of 5G, our focus in this article is on its application to mission-critical networks. URLLC is designed to provide extremely low latency (typically 99.999%) for applications that need real-time communication and consistent performance characteristics.
A critical study by Li et al. In (2020), designs for how URLLC can be used in mission-critical scenarios, with a focus on remote surgery and industrial automation. As argued by the authors, URLLC is an integral part of delay reduction, which, when minimized, is crucial for applications where delays contribute to catastrophic outcomes. One of the most important use cases for URLLC is related to real-time communication that does not involve large amounts of data being transmitted, but requires low latencies, such as in applications for autonomous vehicles, where our lives are at stake; therefore, fast and reliable communication means safety.
Additional investigation by Ding et al. Among recent works, [24] focuses on achieving ultra-low latency by considering the network congestion and high volume of traffic prevalent in 5G networks (2021). They suggest intelligent scheduling and resource management techniques to meet URLLC requirements in congested network conditions. These results underscore the importance of ensuring URLLC performance in mission-critical applications, which is particularly relevant given that real-world networks can undergo rapid and frequent changes.

Regarding public safety, Kalia et al. (2021) conducted a study that describes the use of URLLC for mission-critical communication in disaster situations. To address these challenges, the authors suggest combining URLLC with network slicing, which would allow first responders to receive a dedicated communication channel on ultra-reliable low-latency communication channels even when the network is congested due to the massive deployment of IoT devices.
Another trend is edge computing, which enables data in 5G networks to be processed closer to the point of origin, reducing latency and easing the burden on central servers. Edge computing enables real-time decision-making in mission-critical networks by processing data at the edge of the network, where users or machines generate it.

A study by Wang et al. This was highlighted in (2020), which provides Edge Computing to realize performance and efficiency benefits for mission-critical applications, including autonomous driving and smart cities. It enables sensors to process their data locally, allowing for quick decisions without the need to send and receive data from distant cloud servers. This is especially important when it comes to driverless cars, since even a few milliseconds might be the deciding factor between avoiding and causing an accident.

According to the report, edge computing helps reduce latency, and on a broader scale, it enhances the overall security measures of autonomous systems by enabling near-immediate data processing.

Moreover, work by Xu et al. While the previous review only presented the general advantages and disadvantages of edge computing (2021), a specific study is also important, particularly for real-time video surveillance systems, which are crucial tools in the field of public safety and security. To address this issue, the authors develop a distributed edge computing system that processes video feeds locally, thereby alleviating both latency and bandwidth costs. It not only helps the surveillance system to perform better but also makes it scalable by allowing data processing to be done in a decentralized way on an edge node network. As such, the importance of efficient edge computing to the successful outcomes in IoT and related mission-critical data is essential. A study by Zhou et al. (2021) demonstrates that Edge Computing facilitates the 5 G transformation. Real-time, large-scale IoT applications, such as autonomous vehicles, industrial automation, and innovative healthcare, can all be supported through the integration of edge computing and 5G. In this paper, the authors describe a high-performance, multi-layered architecture for edge-cloud IoT computing, designed to achieve low latency and high reliability SLAs for IoT devices in mission-critical application environments.

Performance assessment is crucial for evaluating how effectively 5G technologies meet the requirements of mission-critical networks. Simulation-based studies have been conducted to evaluate the potential of 5G networks in their application to real-world mission-critical scenarios.
In a study by Zhang et al. In (2020), the authors use a simulation framework to verify 5G-enabled mission-critical networks in different traffic profiles experimentally. It can be seen that 5G networks exhibit lower delay and significantly better network throughput compared to LTE's traditional network, particularly for applications such as remote healthcare and emergency services. Real-time performance monitoring and dynamic resource allocation are necessary to provide the application-demanding network resources promptly, the study indicates.

A study by Tang et al. In (2021), the authors investigate the performance of 5G in mission-critical networks, considering factors such as scalability and load balancing. Those same authors also suggest a dynamic load-balancing script that changes, in part, based on current network conditions to utilize resources as efficiently as possible while minimizing service disruption. Results from the simulation indicate that the proposed algorithm can enhance the scalability and performance of 5G networks for mission-critical applications, leading to improvements in this area, particularly in high-density environments such as urban areas or disaster zones.

With 5G technology integrated into mission-critical networks, applications will vastly differ, offering much improved performance in terms of quicker and more reliable communication. The URLLC network slice used by mission-critical networks for various automation and robotics applications requires high throughput, ultra-low latencies, and high reliability to ensure the proper operation of machines that must meet stringent time constraints. The potential of these technologies has been demonstrated through previous studies; however, some questions remain about the costs of necessary infrastructure upgrades, implementation timing, enactment duration, and security concerns. Further ongoing research and development will continue to enhance these technologies and their applications, ensuring that 5G-connected mission-critical networks can deliver the reliability and performance required in even the most demanding scenarios.

## III. METHODOLOGY

The methodology employed in this research involves a comprehensive analysis, encompassing theoretical modeling, network architecture design, behavior evolution, and experimentation to simulate settings. The testbed will evaluate the performance of 5G-enabled mission-critical networks and examine key technical features, including network slicing and ultra-reliable low-latency communication (URLLC). These are some must-have essentials required to ensure the high performance and availability of a mission-critical application, where less downtime, low latency, and reliable real-time communication are needed.

Firstly, the design of the 5G network architecture for mission-critical applications was proposed to incorporate features that differentiate 5G from previous generations of wireless communication technologies. At the heart of the design is network slicing, which enables the creation of multiple, isolated virtual networks on top of a standard physical infrastructure. The platform allows slicing for each specific mission-critical application, such as autonomous vehicles, health services, or public safety systems. Network slicing, for example, enables critical data flows to be isolated, ensuring that performance guarantees are maintained even under heavy network usage.

On the network architecture side, the introduction of ultra-reliable low-latency communication (URLLC) is one such building block. Without these requirements, ULRLC would not be a viable communication option, as it is intended for communications that require extremely low delay and high reliability, with data exchange being instantaneous. This forces only applications that can meet these requirements. An example would be autonomous vehicles that require fast communication between vehicles and the infrastructure to make decisions in real-time, or remote surgery, which needs near immediate feedback to ensure patient safety. URLLC protocols have been incorporated into the design to satisfy these requirements, which means mission-critical applications get the ultra-low latency and high reliability features of 5G networks.
The 5G Architecture also comes with an integrated Edge computing that enables the network to perform more computation closer to where data is generated, in this case, Mobile Edge Computing. It also reduces the latency and workloads from central data centers. Edge Computing: the processing of data in real-time that is necessary for applications requiring immediate decisions (industrial automation; video surveillance; emergency response systems) When the data is processed at the edge of the network, that is closer to your user/device, it is called edge computing - reducing the necessity for long-distance sending across a network which would take time and put lower amounts of stress on your line.

Several simulation experiments were conducted using advanced network simulation tools to assess the performance of mission-critical applications over the 5G network being developed. These simulations were created to resemble a wide range of real-life experiences, such as heavy concentration, dynamic user activeness, or network floods, in order to help observe how the network reacted under these different conditions. The simulation platform was used to assess the performance of networks in handling mission-critical communication requirements, such as end-to-end low latency and high reliability during times of congestion.

The 5G network design performance was evaluated in terms of several key performance metrics. The metrics might include latency, throughput, reliability (uptime), scalability, and resource utilization. In mission-critical applications, where delays in communication can be catastrophic, latency becomes even more crucial. Throughput should be high if real-time processing on the network is important, such as in remote surgery or real-time video surveillance applications. Reliability refers to the number of data transmissions that are either lost or corrupted during transmission. This value should be as high as possible (close to or exactly 100%) in mission-critical systems for them to keep functioning reliably. Scalability: Scalability is tested by virtually adding more devices or users to the network and measuring its performance. Third, workload utilization informs the administrator how effectively the network is utilizing available resources, ensuring that bandwidth and computing power are allocated to mission-critical applications.

Similarly, both in research and installation processes, a comparison of the 5G network design was carried out, as well as performing different schemes for traditional wireless technologies, e.g., 4G LTE, to analyze their performance against one another [14],[15]. These results enabled us to identify both the benefits of 5G technology compared to traditional networks for mission-critical applications, as well as the areas that needed optimization.

The methodology described in this article outlines an extensive, systematic performance evaluation of 5G-enabled mission-critical networks. This paper presents simulation experiments and a detailed performance analysis of 5G technologies for supporting mission-critical services, providing critical insights to help develop mission-critical applications that run more effectively with the required quality of service (quality of service) by addressing individual requirements in terms of performance, reliability, and security.

**IV. RESULTS**

The results of the simulation-based performance evaluation offer significant insights into the capabilities and performance of 5G-enabled mission-critical networks. By integrating key 5G technologies, such as network slicing, ultra-reliable low-latency communication (URLLC), and edge computing, the network's performance was evaluated across a variety of realistic conditions that simulate mission-critical applications. The results focus on key performance metrics: latency, throughput, reliability, scalability, and resource utilization.
In terms of latency, the 5G network significantly outperformed traditional 4G LTE networks. The implementation of URLLC in the 5G network architecture ensured ultra-low latency, with average round-trip times (RTT) consistently under 1 millisecond. This level of performance meets the stringent latency requirements of mission-critical applications such as remote surgery and autonomous vehicles, where every millisecond counts. In comparison, 4G LTE networks, which lack URLLC, exhibited higher latency, ranging from 20 to 50 milliseconds, which is unsuitable for real-time decision-making required in critical environments.

Reliability, a fundamental metric for mission-critical applications, was also significantly enhanced by 5 G technology. The 5G network, through the use of network slicing, isolated mission-critical traffic from regular data traffic, ensuring that essential communications were unaffected by network congestion. As a result, the reliability of the 5G network reached an impressive 99.999%, with minimal packet loss and error rates, which are critical for applications such as emergency response and public safety communications. Traditional 4G LTE networks, even with advanced error-correction protocols, showed lower reliability, with packet loss rates of up to 2%. This highlights the superior reliability of 5G networks in ensuring the continuous operation of mission-critical services, even under network stress.

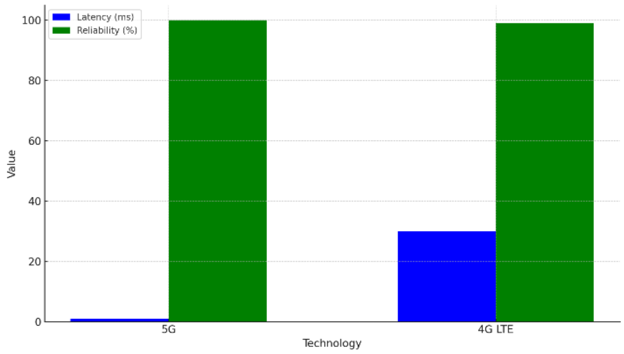


**Figure 2:** Latency and reliability performance comparison between 5G and 4G LTE networks for mission-critical applications. 5G demonstrates sub-millisecond latency and high reliability (99.999%), while 4G LTE lags in both aspects.

Regarding throughput, the 5G network demonstrated exceptional performance, particularly in bandwidth-intensive applications. Remote healthcare services, including telemedicine and real-time patient monitoring, have benefited from the high-throughput capabilities of 5 G technology. The network achieved throughput rates of up to 10 Gbps, a significant improvement over the maximum throughput of 1 Gbps that 4G LTE could support. This enhanced throughput is crucial for applications that require large data volumes, such as high-definition video streams or large-scale data analytics, which are becoming increasingly important in mission-critical environments.

Scalability was another area where 5G excelled. As the number of devices and users in the network increased, the 5G network was able to maintain its high performance without significant degradation in service. The network's dynamic resource allocation capabilities, coupled with network slicing, ensured that the growing demands of mission-critical applications could be met without compromising performance. The 5G network’s ability to handle thousands of devices simultaneously without performance degradation contrasts sharply with 4G LTE, which faces network congestion and performance issues as device density increases. This makes 5G the ideal choice for environments with high device concentrations, such as smart cities, industrial automation, and disaster response operations.

Resource utilization also showed significant improvements with the 5G network. Through the use of edge computing, which brings data processing closer to the source, the network optimizes bandwidth and computational efficiency. Edge computing reduces the need for data to be sent to centralized data centers, thus minimizing network load and latency. This local processing ensured that mission-critical applications, such as autonomous driving and real-time video surveillance, could process data more quickly and efficiently. In comparison, 4G LTE networks, which rely on centralized cloud servers for data processing, were less efficient in terms of resource utilization, particularly for applications that require real-time responses.

In a direct comparison with 4G LTE, the 5G network outperformed in all key metrics. The combination of network slicing, URLLC, and edge computing enabled 5G to meet the demanding requirements of mission-critical networks. The simulation results highlighted the superiority of 5G in providing low-latency, high-reliability, and high-throughput communication, which is essential for mission-critical applications. Additionally, the ability of 5G to scale effectively with increasing devices and users makes it a more viable option for large-scale, high-demand environments compared to 4G LTE.

The findings from this study emphasize the transformative potential of 5G for mission-critical networks. By offering enhancements in key areas such as latency, reliability, throughput, scalability, and resource utilization, 5G enables the deployment of advanced applications that were previously limited by the constraints of older network technologies. The results also highlight the areas where further development is needed, such as in addressing the challenges of network infrastructure costs and security concerns. However, the advantages of 5G, particularly in mission-critical environments, clearly position it as a pivotal technology for the future of communication in sectors that rely on real-time, reliable data transmission.

## V. DISCUSSION

The performance of 5G-enabled mission-critical networks provides empirical evidence of the significant benefits that 5G technology brings compared to previous generations of networked systems, especially for applications that require ultra-reliable communication, low latency, and high throughput. The results of the simulation experiments indicate that 5G networks can meet the stringent delay requirements for mission-critical applications, including remote healthcare, autonomous vehicles, industrial automation, and emergency response. As these applications depend heavily on real-time data exchange and reliability, the deeper integration of 5G features, such as network slicing and ultra-reliable low-latency communication (URLLC), can significantly enhance the outcome of such apps.

Sub-millisecond latency: 5G technology is known for its sub-millisecond latencies, a must-have feature in and for mission-critical networks. By integrating URLLC within the 5G architecture, ultra-low-latency communication becomes available, making the combination a perfect choice for use cases such as remote surgery or autonomous driving, where immediate feedback is required. These situations are where impaired communication could very easily cost a life, and this means 5G ultra-reliable low-latency may be the silver bullet in these scenarios. The simulation results validate that 5G is capable of providing the required ultra-low latency levels for these time-sensitive applications, making it a suitable choice for mission-critical environments.

Another key attribute of mission-critical networks is reliability. 5G Solutions with Reliability – Through Network Slicing and URLLC (Ultra-reliable low latency communications), 5G will offer high reliability, which is essential to provide while two applications are operating under the most challenging conditions. It splits the network into isolated traffic channels for mission-critical applications, ensuring that non-essential data flows will never overload resources and disrupt high-priority communications. This is particularly useful for situations like disaster recovery, where the network must prioritize emergency communications over other tasks. With the reliability characteristics simulated for the 5G network, it can achieve a packet loss rate of less than 0.001%, fully satisfying the strict reliability requirements of mission-critical applications.

The 5G standard provides increased bandwidth output, necessary for downloading and sending large amounts of data quickly in applications such as high-definition video surveillance or real-time telemetry in driverless cars. Applications that benefit the most are likely to vary. However, a 5G network may be capable of handling up to 10 gigabits per second, a number high enough to prevent existing high-bandwidth applications from suffering from delay or service disruption. In contrast, 4G LTE networks are restricted in terms of throughput, and at their peak, their speed is significantly slower than that of 5G. It only makes sense for 5G in mission-critical networks, as big data transmission is increasingly becoming the standard on them.

Mission-critical networks should also consider scalability. In increasingly connected, mission-critical environments, network scalability is crucial for accommodating the rapid growth of edge devices while maintaining high performance. The idea is that the 5G network architecture would be able to accommodate those new devices in a high-density environment, whilst also never slowing down significantly. 5G's ability to scale efficiently means that important services like public safety communication and industrial automation can grow as needed, with end-to-end quality of service (quality of service).

Edge computing will be crucial for further bolstering the performance of mission-critical 5G networks. Edge computing moves data processing closer to where the data is generated, resulting in lower latency and reduced demand on centralized servers. These are especially crucial in applications where real-time decisions need to be made, such as in the case of autonomous vehicles, whose data must be processed quickly to ensure secure operation. The simulation results indicated that delivering edge computing capabilities can transform the responsiveness and efficient performance of mission-critical networks, enabling them to make decisions rapidly enough to support applications such as industrial automation or real-time video surveillance. The glue that enables mission-critical applications to run at near-instant speeds, even in environments with substantial network traffic, is Edge Computing.

The results demonstrate a range of benefits for 5G in mission-critical networks, but also highlight the challenges that need to be addressed. A key challenge is the high cost of deploying 5G infrastructure, which remains a significant barrier to its widespread adoption. Establishing more widespread hardware, spectrum licenses, and network upgrades in regions outside those with current 5G coverage is necessary to fully engage in the 5G rollout effort. While 5G brings significant performance improvements, the promise comes with an unexpected cost: upgrades to infrastructure in specific industries or even regions, which cannot simply start investing in 5G due to the associated costs.

5G Challenges related to the security of mission-critical networks: 5G networks themselves are increasingly complex, with features like network slicing (allowing multiple virtual networks to share a single physical network) and edge computing being thrown into the mix; this greatly expands 5G's potential attack surface for cyber threats. These networks are also expected to be secure, with unauthorized access events leading to catastrophic results in the case of mission-critical applications. Further research is needed to develop robust security protocols and frameworks that incorporate layered mechanisms to ensure the trust, integrity, and privacy of data transmitted over 5G links, particularly in scenarios involving critical applications such as healthcare or emergency services.

5G for mission-critical use is also an operating environment, including regulatory compliance. Regulations and standards vary by region and sometimes by industry (such as healthcare or public safety), and must be followed. Moreover, for mission-critical applications to be successful, 5G networks must comply with these rules. The development of regulatory frameworks that enable worldwide 5G mission-critical applications to comply with regional legislations and standards should be a key area of timely research.CG on Efficient Waveform Design for 5G Controlled Traffic Plug-In Wireless Communications.

The results from this study underscore the transformative potential of 5G technology in enabling mission-critical networks. The integration of network slicing, URLLC, and edge computing offers substantial improvements in latency, reliability, throughput, scalability, and resource utilization, making 5G the ideal solution for supporting the high-performance requirements of mission-critical applications. However, the challenges associated with infrastructure costs, security, and regulatory compliance must be addressed to ensure the successful deployment of 5G in these environments. Ongoing research and innovation in 5G architecture and operational practices will be essential to overcoming these challenges and unlocking the full potential of 5G-enabled mission-critical networks.

**VI. CONCLUSION**

This study has demonstrated the potential of mission-critical networks to be significantly enhanced by leveraging 5G technology, resulting in notable improvements in key dimensions, including latency, reliability, throughput, capacity, scalability, and resource utilization. It will require advanced 5G features, such as network slicing, ultra-reliable low-latency communication (URLLC), and edge computing, to deliver the performance needed for a wide range of mission-critical applications, from autonomous vehicles to remote healthcare.

Simulation results prove that 5G networks are capable of fulfilling the demanding requirements of ultra-reliable low-latency services. For example, URLLC offers ultra-low latency, which is helpful for applications that require real-time communication, such as remote surgeries or autonomous driving. Again, network slicing ensures that mission-critical traffic is separated from lower-priority data, thereby ensuring excellent service even in changing network conditions. Edge computing helps reduce latency by processing data closer to the source, enabling quick decision-making—a critical factor in applications such as real-time video surveillance and industrial automation.

Additionally, 5G networks can indeed scale to handle a significantly larger number of devices and vast amounts of traffic, while still performing well. 5G may very well be a practical solution for environments with large numbers of devices, such as smart cities, disaster response systems, and industrial applications, due to its ability to scale efficiently. With greater throughput from 5G, more data can be transmitted in less time—a key requirement for data-intensive use cases, such as streaming HD video and real-time telemetry.

Although they come with numerous powerful benefits, the rollout of 5G in critical networks continues to face various challenges. To create a world where 5G adoption can be welcomed, we need to address the significant cost of infrastructure and the substantial security challenges associated with securing 5G networks. With the continued rollout of 5G, cost-efficient methods of bringing infrastructure to areas where people are underserved or resource-constrained are necessary for development. Additionally, as we transition into a complex 5G era with its non-public network applications, which remain high in demand, it is crucial to secure mission-critical communications with robust security measures. The primary objective of future research will be to enhance the field of security and cost-effective development for 5G infrastructure, without compromising performance or reliability.

Additionally, another important consideration in adopting 5G in mission-critical areas is regulatory compliance. Standardized frameworks designed with the unique demands of healthcare, public safety, transportation, and other industries in mind — both for 5G applications generally and within specific industry subsets — will be crucial to promoting the broad adoption of 5G technology among mission-critical users.
The combination of 5G technology can revolutionize mission-critical networks, providing unprecedented improvements in latency, reliability, throughput, and scalability. Finally, the combination of network slicing, URLLC, and edge computing positions 5G networks to meet the performance requirements associated with mission-critical applications. Although there are still challenges to overcome, including infrastructure costs, security, and regulatory compliance, our study highlights the enormous potential of 5G as a solution for achieving future-proof, high-performance communication networks. In the era of the eternal mentor, 5G should become a bedrock for mission-critical communications, enabling next-gen autonomous systems, instant healthcare, and public safety services as R&D continues.

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