OPEN ACCESS

ISAR Journal of Multidisciplinary Research and Studies
Abbriviate Title- ISAR J Mul Res Stud
ISSN *(Online)*- 2583-9705
https://isarpublisher.com/journal/isarjmrs
Vol-2, Iss-6 (June- 2024)

OPEN ACCESS

5G-AdHoc: Enabling Ultra-Reliable Low Latency Communication (URLLC) in Ad Hoc Networks

Gani Timothy Abe[1], Siman Emmanuel[2*]

Federal University Wukari, Nigeria.

***Corresponding Author**
Siman Emmanuel
Federal University Wukari, Nigeria.

Article History
Received: 01.05.2024
Accepted: 06.06.2024
Published: 20.06.2024

Abstract: The emergence of 5G technology has opened new possibilities for communication systems, particularly in the context of ad hoc networks. This paper explores the concept of 5G-AdHoc, which aims to enable Ultra-Reliable Low Latency Communication (URLLC) in ad hoc networks. We begin by introducing the fundamentals of -AdHoc technology and the challenges it addresses in providing URLLC capabilities. We 5G discuss the architecture and key components of 5G-AdHoc networks, along with the underlying technologies that enable URLLC. Performance evaluation metrics and use cases are examined to showcase the benefits and practical applications of 5G-AdHoc URLLC. The summary focuses on how 5G's URLLC capabilities ensure stability and efficiency in vehicle clusters, with one scenario showcasing reliability and low latency and another emphasizing scalability and continued reliability. Overall, URLLC plays a crucial role in coordinating connected vehicles within 5G networks for smooth operations in various scenarios. Furthermore, we delve into security and privacy considerations crucial for the deployment of 5G-AdHoc networks. Finally, we outline future trends and potential developments in 5G-AdHoc technology, highlighting its significance in advancing communication systems for diverse applications.

Keywords: Ultra-Reliable; Low Latency; Ad Hoc Networks; 5G-AdHoc; Communication.

Cite this article:
Abe, G. T., Emmanuel, S., (2024). 5G-AdHoc: Enabling Ultra-Reliable Low Latency Communication (URLLC) in Ad Hoc Networks. *ISAR Journal of Multidisciplinary Research and Studies*, *2*(6), 36-45.

1. Introduction

5G-AdHoc technology represents a significant advancement in wireless communication systems, particularly in the domain of ad hoc networks. As the demand for high-speed, reliable, and low-latency communication continues to grow across various sectors such as transportation, healthcare, and Industry 4.0, there is a need for efficient solutions that can meet these requirements in dynamic and rapidly changing environments (Abdullah, M., et al 2021). Traditional ad hoc networks, which are characterized by decentralized and self-configuring nodes, have limitations in terms of reliability and latency, especially when supporting critical applications such as autonomous vehicles or real-time industrial automation. The introduction of 5G technology brings forth a new paradigm for ad hoc networks, offering enhanced performance and capabilities that enable Ultra-Reliable Low Latency Communication (URLLC). 5G-AdHoc technology leverages the key features of 5G networks, including high data rates, massive connectivity, ultra-low latency, and network slicing, to address the challenges faced by ad hoc networks (Mae, M., et at 2020). By integrating these capabilities, 5G-AdHoc networks can deliver seamless connectivity, robustness, and responsiveness required for mission-critical applications. In this paper, we delve into the architecture, components, technologies, and applications of 5G-AdHoc technology, aiming to provide a comprehensive understanding of its potential impact on communication systems and the broader digital ecosystem. We also discuss the implications of 5G-AdHoc technology in enabling innovative services and driving digital transformation across various industries (Deka, K., et at 2020).

2. Literature Review

ltra-Reliable Low Latency Communication (URLLC) is a key feature of next-generation communication systems like 5G and beyond, designed to meet the stringent requirements of applications demanding ultra-reliable connectivity and minimal latency. URLLC plays a crucial role in enabling real-time and mission-critical services across various sectors, including healthcare, transportation, manufacturing, and public safety (Hong, T., et at 2021).

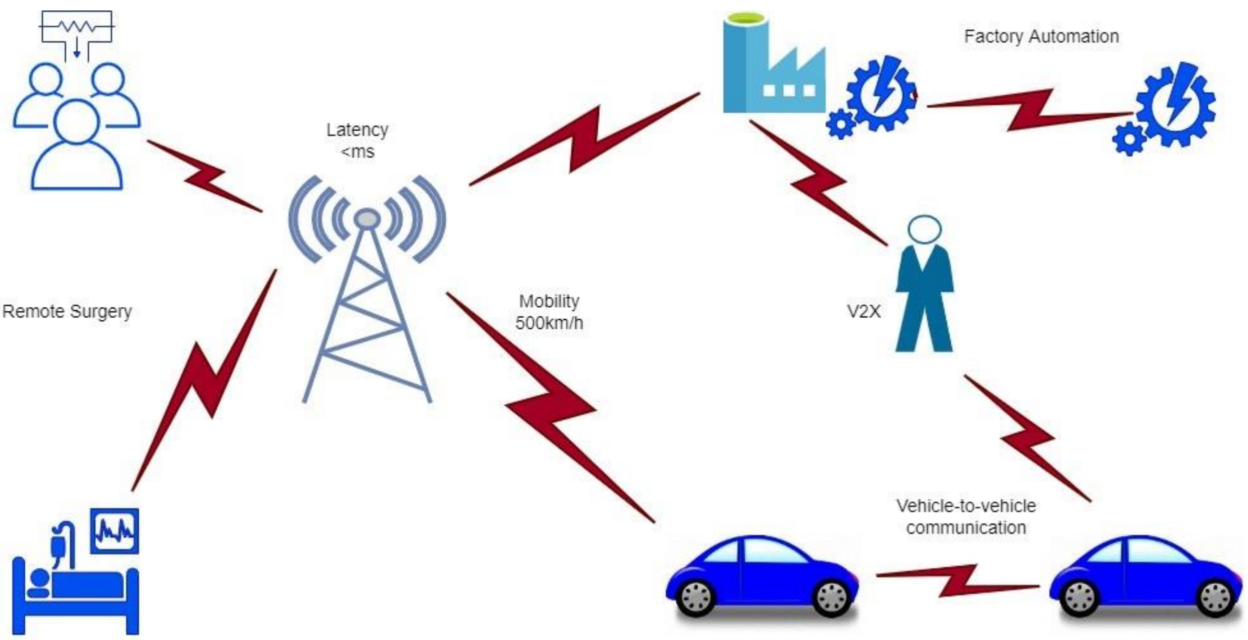

Figure 1: Ultra Reliable Low Latency (URLLC)

URLLC ensures extremely high reliability in data transmission, with minimal packet loss and error rates. This level of reliability is essential for applications where even a small disruption or data loss could have significant consequences, such as remote surgery in healthcare or autonomous driving in transportation. URLLC guarantees ultra-low latency, which refers to the time it takes for data packets to travel between sender and receiver. In URLLC scenarios, latency is typically reduced to milliseconds or even microseconds, enabling real-time interactions and instantaneous response times (Slalmi, A., et at 2021). This is critical for applications like industrial automation, where timely data exchange is vital for operational efficiency and safety. URLLC offers predictable communication performance, ensuring consistent latency and reliability levels across different network conditions and traffic loads. This predictability is essential for applications that require deterministic behavior, such as real-time control systems and emergency response services (Kaur, J., et at 2021). URLLC solutions are designed to scale efficiently to support a large number of devices and connections simultaneously. This scalability is crucial for deploying URLLC-enabled services in densely populated areas or industrial environments with a high concentration of IoT devices and sensors, Figure 1.

Such as beamforming, massive MIMO (Multiple Input Multiple Output), and mmWave (millimeter-wave) communication, which improve spectral efficiency and enable high data rates with low latency. This allows the creation of isolated virtual networks optimized for specific URLLC applications, ensuring resource allocation and QoS (Quality of Service) guarantees tailored to individual requirements (Suomalainen, J., et at 2020). By processing data closer to the point of origin or consumption, edge computing reduces latency and improves responsiveness for URLLC applications, especially those requiring real-time analytics or decision-making. Therefore, URLLC represents a paradigm shift in communication technology, offering unprecedented levels of reliability, low latency, and predictability essential for supporting a wide range of mission-critical and latency-sensitive applications in the era of digital transformation (Bashir, A. K., et at 2020).

3. Ad Hoc Networks and Their Challenges

Ad hoc networks are decentralized wireless networks where devices communicate directly with each other without the need for a fixed infrastructure like base stations or access points. These networks are highly dynamic, self-configuring, and well-suited for scenarios where traditional infrastructure-based networks are impractical or unavailable, such as disaster recovery operations, military deployments, and IoT (Internet of Things) sensor networks. However, ad hoc networks also come with several challenges that need to be addressed to ensure their reliable and efficient operation (Tayyaba, S. K., et at 2020). Ad hoc networks have constantly changing topologies due to the mobility of devices. Nodes may join or leave the network at any time, causing fluctuations in connectivity and network paths. Managing such dynamic topologies is a significant challenge, especially for maintaining routing efficiency and avoiding network partitions. Devices in ad hoc networks often have limited resources such as battery power, processing capabilities, and bandwidth. Efficient resource management strategies are required to optimize resource usage, prolong device battery life, and prioritize critical network activities (Sevgican, S., et at 2020). Ad hoc networks need to scale seamlessly to accommodate a large number of devices and maintain performance as the network grows. Scalability issues can arise in terms of routing overhead, network congestion, and communication delays, particularly in dense ad hoc environments.

hoc networks operate in shared wireless spectrum, leading to potential interference from other nearby networks or devices. Moreover, varying channel conditions, such as fading, noise, and signal attenuation, can impact communication reliability and throughput, necessitating adaptive transmission techniques. Ad hoc networks are susceptible to security threats such as eavesdropping, data manipulation, and denial-of-service attacks due to their open nature and lack of centralized control (Abidi, M. H., et at 2021). Implementing robust security mechanisms, authentication protocols, and encryption techniques is crucial to protect sensitive data and ensure network integrity Providing adequate QoS guarantees, especially for real-time and multimedia applications, is challenging in ad hoc networks with limited bandwidth and varying network conditions. QoS management mechanisms are needed to prioritize traffic, allocate resources efficiently, and maintain service-level agreements.

Ad hoc networks rely on dynamic routing protocols to establish and maintain communication paths between nodes (Bhatt, C., et at 2021). Designing efficient routing algorithms that can adapt to changing network conditions, minimize overhead, and prevent routing loops is essential for optimal network performance. Addressing these challenges requires a combination of advanced networking protocols, optimization techniques, adaptive algorithms, and robust security measures tailored to the unique characteristics of ad hoc networks (Pavlenko, A., et at 2020). Research and development efforts continue to focus on improving the reliability, scalability, efficiency, and security of ad hoc networks to unlock their full potential in diverse applications and environments.

4. 5G-AdHoc Architecture and Components

The 5G-AdHoc architecture is designed to support Ultra-Reliable Low Latency Communication (URLLC) in ad hoc networks by integrating key components and functionalities tailored to meet the stringent requirements of mission-critical applications (Kholod, I., et at 2020). Here is an overview of the architecture and its components:

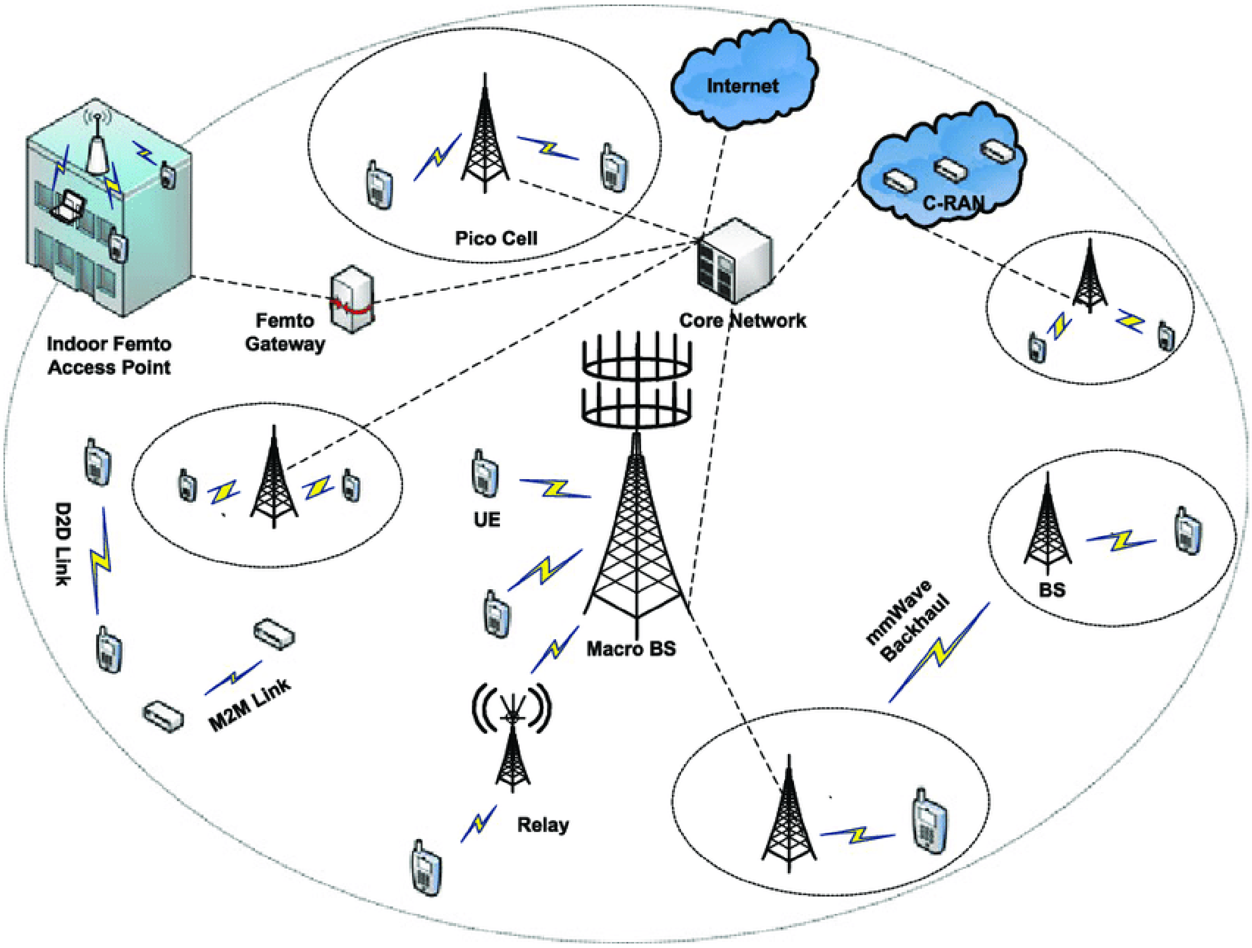

Figure 2: Architecture of 5G network

UEs are the endpoint devices in the 5G-AdHoc network, such as smartphones, IoT devices, or specialized equipment used in industrial settings, in Figure 2. UEs are capable of communicating directly with each other without relying on a centralized infrastructure, forming ad hoc connections based on proximity and network availability. Unlike traditional cellular base stations, 5G-AdHoc BSs are deployed in a distributed manner throughout the ad hoc network area. These BSs serve as access points for UEs, facilitating connectivity and providing access to the 5G core network when necessary (Kim, H., et at 2020). 5G-AdHoc BSs may employ advanced radio access techniques such as beamforming and massive MIMO to enhance coverage, capacity, and reliability. The 5G core network provides the backbone infrastructure for managing and orchestrating communication services in the 5G-AdHoc architecture. It includes core network functions such as the User Plane Function (UPF), Session Management Function (SMF), and Network Slice Selection Function (NSSF). The core network ensures seamless connectivity, quality of service (QoS) enforcement, and network slicing capabilities tailored to URLLC requirements (Kasturi, G. S., et at 2020). Network slicing is a fundamental component of the 5G-AdHoc architecture, enabling the creation of isolated virtual networks (slices) optimized for specific URLLC applications. Each network slice is tailored with dedicated resources, QoS parameters, and security policies to meet the performance demands of different ad hoc services. Network slicing allows for efficient resource allocation, traffic isolation, and customization of network behavior based on application requirements.

Adaptive routing algorithms are employed in 5G-AdHoc networks to dynamically establish and maintain communication paths between UEs. Relay nodes play a crucial role in extending coverage, improving connectivity, and enhancing network resilience by relaying data between distant or obstructed UEs Edge computing capabilities are integrated into the 5G-AdHoc architecture to support real-time data processing, analytics, and decision-making at the network edge (Lal, N., et at 2021). Distributed processing reduces latency by performing computations closer to the data source, enabling rapid response times for URLLC applications. Robust security mechanisms, including authentication, encryption, and intrusion detection, are essential components of the 5G-AdHoc architecture to protect data confidentiality, integrity, and availability. Secure communication channels and access control mechanisms are implemented to mitigate security threats and ensure trustworthiness in ad hoc network operations (Park, J. H., et at 2021). By integrating these components and leveraging advanced technologies, the 5G-AdHoc architecture provides a scalable, reliable, and low-latency communication framework tailored to the unique requirements of ad hoc networks, especially for supporting critical applications in diverse industries.

5. Key Technologies Enabling URLLC in Ad Hoc Networks

Several key technologies play a crucial role in enabling Ultra-Reliable Low Latency Communication (URLLC) in ad hoc networks, especially within the framework of 5G and beyond (Nowaczewski, S., et at 2020). Here are some of the key technologies that contribute to achieving URLLC objectives:

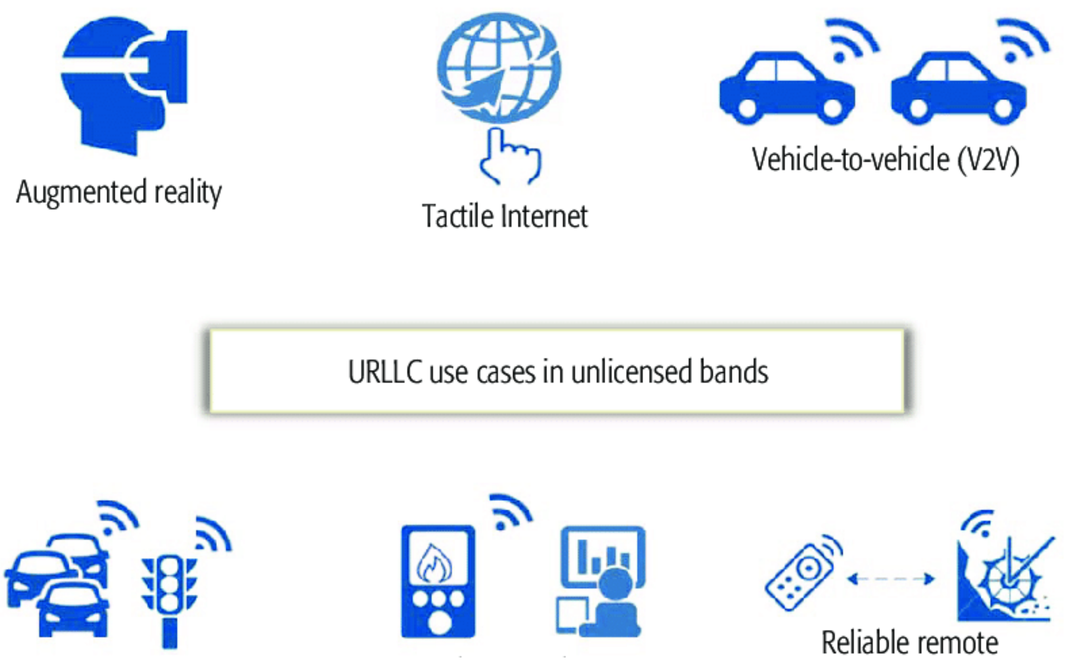

Figure 3: Promising URLLC use cases in unlicensed bands.

Beamforming technology focuses radio signals toward specific directions, enhancing signal strength and reliability for targeted communication, particularly in ad hoc scenarios with dynamic node movements. Massive MIMO utilizes a large number of antennas at the base station to serve multiple users simultaneously, increasing spectral efficiency, capacity, and reliability in ad hoc networks (Abhishta, A., et at 2020). mmWave communication operates at higher frequency bands, offering increased bandwidth and data rates suitable for URLLC applications in Figure 3, albeit with challenges related to signal propagation and coverage. A short-term scheduler optimizes resource allocation and prioritizes critical traffic to minimize latency in ad hoc communication, ensuring timely delivery of data packets (Wong, S. K., et at 2020). Adaptive modulation and coding techniques dynamically adjust transmission parameters based on channel conditions to optimize data throughput and reduce latency. Protocol optimizations at various layers (e.g., MAC layer, transport layer) streamline communication procedures and minimize protocol overhead, contributing to low-latency networking in ad hoc environments.

Edge computing brings computation and data storage closer to the network edge, enabling real-time processing and decision-making for URLLC applications without relying solely on centralized cloud resources (Jasim, A. H. H., et at 2020). Fog computing extends edge computing capabilities by leveraging distributed computing resources deployed at intermediate network nodes, enhancing scalability, responsiveness, and reliability for latency-sensitive services in ad hoc networks. Network slicing partitions the physical infrastructure into multiple virtual networks, each customized with dedicated resources, QoS parameters, and security policies tailored to specific URLLC use cases, ensuring efficient resource utilization and service differentiation. Virtualized network functions replace traditional hardware-based network elements with software-based counterparts, facilitating dynamic service provisioning, scaling, and management in ad hoc environments. DSA enables opportunistic utilization of available spectrum bands, mitigating interference and enhancing spectrum efficiency in ad hoc networks by dynamically allocating frequencies based on demand and environmental conditions. Cognitive radio technology intelligently senses and adapts to the radio environment, optimizing spectrum utilization, minimizing latency, and improving reliability for URLLC applications in dynamic and congested wireless environments (Lee, J., et at 2020). Predictive analytics techniques analyze historical data and network patterns to anticipate future network conditions, proactively manage resources, and optimize communication performance for URLLC services in ad hoc networks. Machine learning algorithms enable intelligent decision-making, anomaly detection, and adaptive optimization in real-time, enhancing network reliability, security, and efficiency for URLLC applications. By leveraging these advanced technologies and integrating them into the architecture and protocols of ad hoc networks, the industry can unlock the full potential of Ultra-Reliable Low Latency Communication (URLLC) for a wide range of critical applications and use cases.

6. Performance Evaluation and Metrics for 5G-AdHoc URLLC

Performance evaluation and metrics play a vital role in assessing the effectiveness and suitability of Ultra-Reliable Low Latency Communication (URLLC) in 5G-AdHoc networks (Naser, M. Z., et at 2021). Here are key metrics and evaluation techniques commonly used to measure the performance of URLLC in such networks in Table !.

Table 1: Performance Metric

Parameter	Value
Enhanced Mobile Broadband (eMBB) Experience	Minimum speed: 50-100 Mbps everywhere
	Peak speeds: >10 Gbps
	Service latency: <1 ms at >300 mph
Massive Machine-Type Communications (IoT)	Scalability for IoT devices with >10 years of battery life
Ultra-Reliable Low-Latency Communications	End-to-end system delay: <5 ms
(URLLC)	Reliability requirement (32-byte packet): 1-10-5
	Maximum block error rate (BLER): 10-5 or 0.001%
	User plane latency: 1 ms

Measures the total time taken for a packet to travel from the source to the destination, including processing, queuing, transmission, and propagation delays. Low end-to-end latency is critical for URLLC applications. Calculates the time required for a signal or packet to travel from the sender to the receiver and back. Minimizing RTT is essential for real-time interactions and responsiveness in ad hoc networks (Kwon, H., et at 2020). Evaluates the percentage of packets lost or corrupted during transmission. URLLC applications demand extremely low PER to ensure reliable data delivery and integrity. packets to the total transmitted packets, reflecting the network's reliability in delivering data without loss. Indicates the amount of data transferred per unit time, typically measured in bits per second (bps) or packets per second (pps). High data rates are essential for supporting bandwidth-intensive URLLC applications. Represents the actual useful data throughput, excluding protocol overhead and retransmissions. Goodput metrics provide a more accurate measure of effective data transfer in ad hoc networks. Quantifies the variation in packet arrival times, affecting the consistency and predictability of data delivery. Low jitter is crucial for maintaining smooth and real-time communication in URLLC applications. Measures the percentage of time the network or service is operational and accessible to users. High service availability is necessary for ensuring continuous connectivity and reliability.

Evaluates the amount of signaling and control messages required for routing and managing ad hoc network operations. Minimizing routing overhead improves network efficiency and reduces latency. Assesses the level of traffic congestion and its impact on data transmission, latency, and reliability. Effective congestion control mechanisms are essential for maintaining optimal network performance. Measures the amount of energy consumed by network nodes and devices during communication activities (Lei, J., et at 2021). Optimizing energy efficiency is crucial for prolonging battery life and sustainability in ad hoc networks. Tracks the number and types of security incidents, such as unauthorized access, data breaches, or denial-of-service attacks, to assess the effectiveness of security measures in protecting URLLC data and communications. Evaluates the level of privacy protection and data confidentiality measures implemented in the network to safeguard sensitive information and user identities. Evaluation methodologies for 5G-AdHoc URLLC performance may include simulation-based studies using network simulators (e.g., ns-3, OMNeT++) or experimental evaluations in real-world ad hoc network deployments. By measuring and analyzing these performance metrics, researchers and network engineers can optimize system design, protocols, and configurations to meet the stringent requirements of Ultra-Reliable Low Latency Communication (URLLC) in ad hoc networks.

7. Use Cases and Applications of 5G-AdHoc URLLC

The integration of Ultra-Reliable Low Latency Communication (URLLC) within 5G-AdHoc networks opens up a wide range of use cases and applications across various sectors. Here are some notable examples. URLLC enables precise and responsive control of industrial processes, robotics, and machinery, facilitating automation in manufacturing and production environments. Ad hoc URLLC networks support remote monitoring of equipment, predictive maintenance, and instant alerts for critical faults or anomalies in industrial systems (Wijewardhana, U. L., et at 2021). URLLC enables ultra-low latency communication between vehicles (V2V) and infrastructure (V2I), supporting collision avoidance, traffic management, and cooperative driving applications. Ad hoc URLLC networks facilitate rapid communication and coordination among emergency vehicles, traffic lights, and control centers, enhancing response times and safety in emergency situations. URLLC enables high-fidelity, real-time communication between surgeons, medical devices, and remote operating rooms, supporting tele-surgery and minimally invasive procedures (Tao, Y., et at 2020). Ad hoc URLLC networks facilitate continuous monitoring of patients' vital signs, alarms for critical events, and instant communication with healthcare professionals for timely interventions.:

URLLC networks enable precise monitoring of power grids, rapid detection of faults or outages, and automated control of energy distribution for optimized grid performance Ad hoc URLLC facilitates real-time communication between renewable energy sources (e.g., solar panels, wind turbines) and grid infrastructure, supporting dynamic energy management and grid stability (Chen, M., et at 2020). URLLC networks provide resilient and instant communication for first responders, law enforcement, and emergency services during natural disasters, accidents, or public safety incidents. Ad hoc URLLC facilitates rapid deployment of temporary communication networks in disaster-affected areas, supporting search and rescue operations, logistics, and coordination efforts. URLLC networks enable real-time traffic monitoring, adaptive traffic signal control, and congestion management for efficient urban mobility and transportation (Li, X., et at 2021). Ad hoc URLLC supports sensor networks for environmental monitoring, air quality assessment, and early detection of environmental hazards or pollution events. URLLC enables high-quality, low-latency streaming of VR/AR content, interactive gaming, and immersive multimedia experiences over ad hoc networks. Ad hoc URLLC supports virtual meetings, collaborative workspaces, and remote training sessions with real-time interaction and synchronized content sharing.

7.1 5G Low Latency Requirements

5G integrates a new radio (NR) with a cloud-native 5G core (5GC), employing a service-based architecture through microservices deployed in containers. This architecture ensures a clear separation of control plane (CP) and user plane (UP) functionalities, facilitating advanced network slicing for diverse use cases with varying network service requirements (bandwidth, latency, jitter, connections, persistence, etc.).

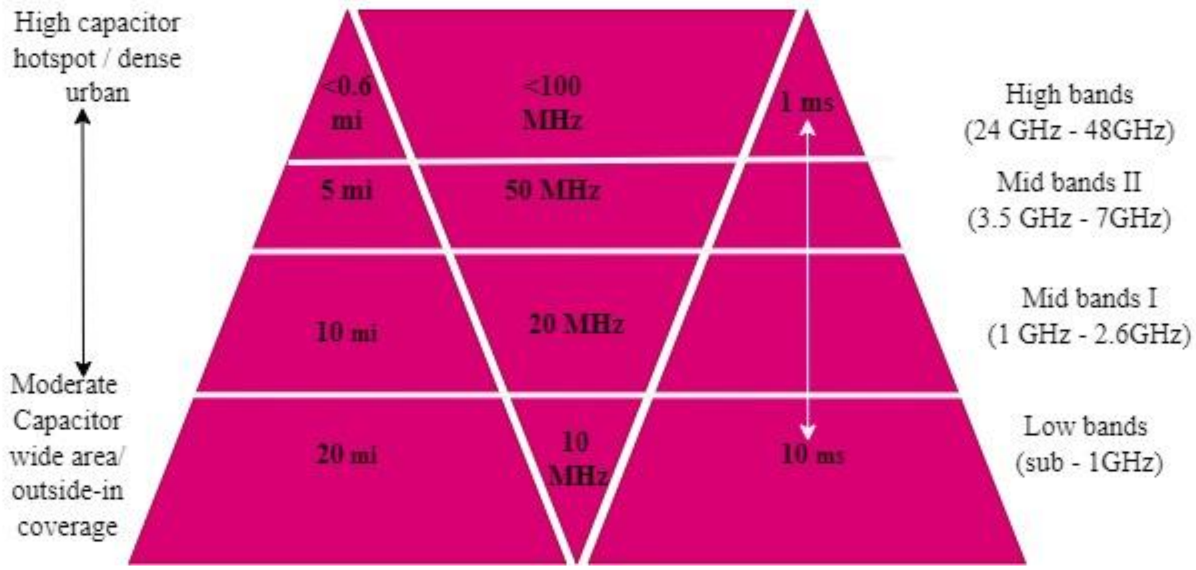

Figure 4: 5G Low Latency Requirements |

The design aims for an enhanced mobile broadband (eMBB) experience, targeting speeds of at least 50-100 Mbps universally and peak speeds surpassing 10 Gbps, with latency below 1ms even at speeds exceeding 300 mph (Deng, R., et at 2021). Beyond improving mobile broadband, 5G caters to massive machine-type communications for scalable IoT deployments with long-lasting device battery life. Another key focus is ensuring extreme availability above 99.999% and supporting ultra-reliable, low-latency communications (URLLC) with less than 5 ms end-to-end delay and a 1-10-5 reliability requirement for 32-byte packet transmissions. Deploying URLLC services involves various considerations such as spectrum selection, RAN transport, and 5G core network architecture, in Figure 4. Choosing the right spectrum range or combination is crucial for any 5G service deployment, especially for low-latency services (Huang, Y., et at 2021). While high-band spectrum often offers wide channel bandwidths (50 MHz or 100 MHz), 5G is not restricted to specific spectrum bands and can utilize multi-layer and carrier aggregation techniques across all bands, presenting 5G as an adaptable evolution leveraging diverse spectrum assets. These use cases highlight the diverse applications and transformative potential of Ultra-Reliable Low Latency Communication (URLLC) in 5G-AdHoc networks, revolutionizing industries, enhancing services, and driving innovation in the digital era.

8. Security and Privacy Considerations in 5G-AdHoc Networks

Certainly! In Figure 4, we observe the cluster stability status specifically tailored for a scenario involving 50 vehicles within a 5G network environment (Talha, M., et at 2021). This depiction provides a detailed insight into how the ultra-reliable and low-latency communications (URLLC) capabilities inherent in 5G technology contribute to maintaining stability and efficiency within the cluster of vehicles. Expanding upon this, Figure 5 extends this analysis to encompass a larger scale, focusing on the cluster stability status when dealing with a fleet of 100 vehicles (Zhao, Z., et at 2021). This broader perspective showcases the robustness and scalability of URLLC functionalities within the 5G infrastructure, highlighting its ability to sustain reliable and low-latency communications even as the number of vehicles increases significantly. These figures collectively underscore the pivotal role of URLLC features in ensuring the seamless operation and coordination of connected vehicles within a 5G-enabled ecosystem, reinforcing the network's capacity to handle diverse and demanding scenarios with precision and reliability.

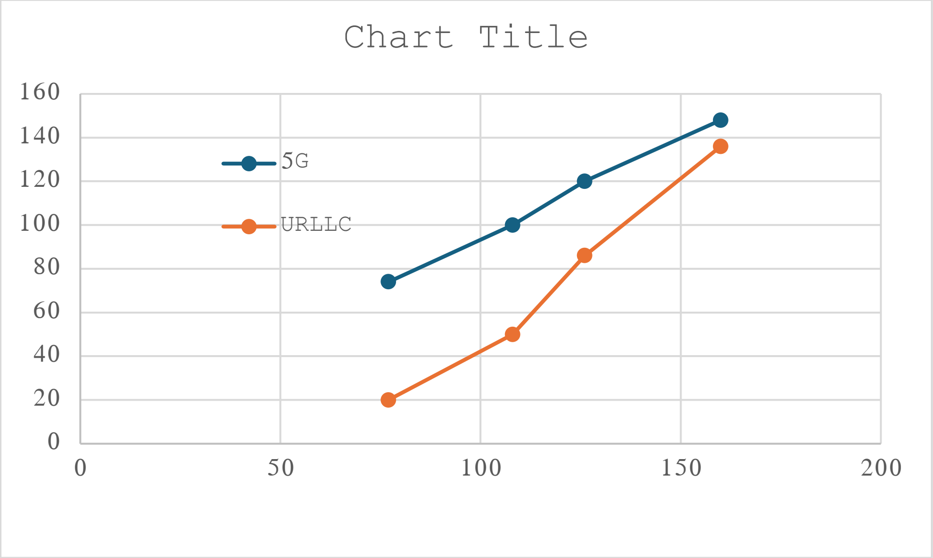

Figure 4: illustrates the cluster stability status for 50 vehicles in a 5G network

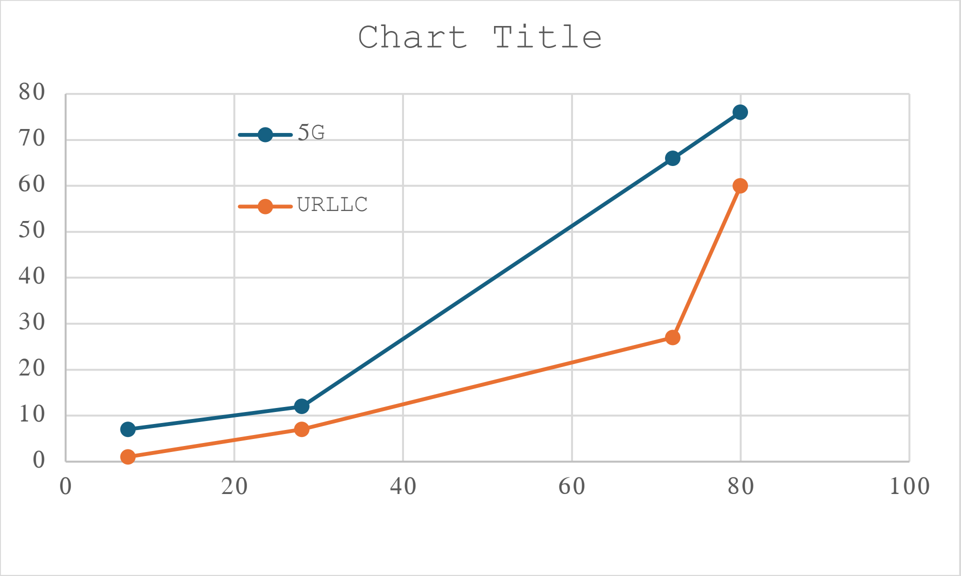

Figure 5: portrays the cluster stability status for 100 vehicles

Security and privacy considerations are paramount in 5G-AdHoc networks, especially when dealing with Ultra-Reliable Low Latency Communication (URLLC) and the dynamic nature of ad hoc connections. Here are some key aspects to consider. Strong authentication mechanisms, such as mutual authentication, digital certificates, and biometric authentication, are essential to verify the identities of devices and users in ad hoc networks. Access control policies should be enforced to restrict unauthorized access to network resources, ensuring that only authenticated and authorized entities can participate in communication) (Tang, J., et at 2021). End-to-end encryption (e.g., using protocols like TLS, IPsec) safeguards data confidentiality and prevents eavesdropping or unauthorized interception of sensitive information transmitted over ad hoc connections. Message authentication codes (MACs) and digital signatures are employed to ensure data integrity, verifying that messages have not been tampered with during transmission. Robust key management protocols and practices are crucial for generating, distributing, and revoking cryptographic keys used for encryption, authentication, and secure communication in 5G-AdHoc networks. Key establishment protocols (e.g., Diffie-Hellman key exchange) should be secure against key compromise, man-in-the-middle attacks, and key replay attacks.

Ad hoc routing protocols (e.g., AODV, DSR) should be designed with security considerations in mind, incorporating mechanisms for route authentication, route discovery integrity, and protection against routing attacks (e.g., black hole attacks, spoofing). Secure routing updates and message authentication can help mitigate routing protocol vulnerabilities and ensure reliable communication paths in ad hoc networks (cHo, T. V., et at 2021). Intrusion detection systems (IDS) and intrusion prevention systems (IPS) monitor network traffic, detect suspicious activities or anomalies, and take proactive measures to block or mitigate potential threats in real-time. Anomaly-based detection, signature-based detection, and behavior analysis techniques are used to identify and respond to security incidents in 5G-AdHoc networks. Privacy-enhancing technologies (PETs), such as anonymous communication, pseudonymization, and data anonymization, protect user privacy and confidentiality in ad hoc communications. Differential privacy techniques can be applied to aggregate and anonymize sensitive data while preserving statistical utility for analysis and decision-making. Secure bootstrapping, firmware validation, and over-the-air (OTA) updates ensure the integrity and authenticity of devices connected to 5G-AdHoc networks, preventing unauthorized access or compromise of network assets. Device attestation mechanisms verify the trustworthiness and compliance of devices before allowing network access, reducing the risk of malicious activities and rogue devices (Wang, Y., et at 2021). Adhering to industry standards, best practices, and regulatory requirements (e.g., GDPR, HIPAA) regarding security, privacy, and data protection is essential for ensuring legal compliance and minimizing liability in 5G-AdHoc deployments. Regular security audits, vulnerability assessments, and penetration testing help identify and address security gaps, vulnerabilities, and compliance issues in ad hoc network infrastructure (Khan, M. N., et at 2021). By integrating these security and privacy measures into the design, implementation, and operation of 5G-AdHoc networks, organizations can mitigate risks, safeguard sensitive data, and build trust in the reliability and security of ad hoc communication systems.

9. Future Trends and Developments in 5G-AdHoc URLLC

Future trends and developments in 5G-AdHoc Ultra-Reliable Low Latency Communication (URLLC) are poised to revolutionize various industries and drive innovation in wireless communication technologies. Here are some key trends and advancements expected in the future. AI and machine learning algorithms will play a crucial role in optimizing resource allocation, predicting network behavior, and enhancing security in 5G-AdHoc URLLC networks. AI-powered anomaly detection, adaptive routing, and dynamic spectrum management will improve network efficiency, reliability, and resilience against emerging threats (Lei, I. S., et at 2020). Edge computing capabilities will evolve to support intelligent decision-making, data analytics, and real-time processing at the network edge, reducing latency and enhancing responsiveness for URLLC applications. Edge intelligence platforms will enable distributed intelligence, context-aware services, and dynamic workload orchestration in ad hoc networks, fostering autonomous and adaptive communication environments (Kim, T. H., et at 2021). Advanced network slicing techniques will enable dynamic creation, management, and orchestration of isolated virtual networks tailored to specific URLLC use cases, ensuring customized QoS, security, and resource allocation (Liang, L., et at 2020). Network slice orchestration platforms will streamline slice lifecycle management, service composition, and automated provisioning, empowering operators to deliver diverse URLLC services efficiently. Integration of multiple radio access technologies, including 5G, Wi-Fi 6/6E, and LPWAN (Low-Power Wide-Area Network), will create heterogeneous ad hoc networks with seamless connectivity, coverage optimization, and spectrum efficiency. Multi-RAT aggregation and handover mechanisms will enable intelligent network selection, load balancing, and spectrum sharing across different access technologies, enhancing performance and user experience.

Quantum-safe cryptographic algorithms and quantum-resistant security protocols will be integrated into 5G-AdHoc URLLC networks to protect against future quantum computing threats, ensuring long-term data confidentiality and integrity. Quantum key distribution (QKD) and quantum secure communication channels will provide ultra-secure communication links, immune to brute-force attacks and quantum decryption algorithms (Meng, W., et at 2020). Blockchain-based solutions and distributed ledger technologies will enhance trust, transparency, and auditability in ad hoc network transactions, identity management, and data sharing among decentralized entities. Smart contracts and decentralized consensus mechanisms will automate and secure transactions, resource allocation, and service agreements in 5G-AdHoc URLLC networks, enabling new business models and peer-to-peer interactions (Vijayakumar, P., et at 2021). Advanced security architectures, such as secure enclave technologies, hardware-based trust anchors, and zero-trust network models, will strengthen IoT device security and data privacy in ad hoc networks. Privacy-preserving IoT frameworks, including differential privacy, homomorphic encryption, and federated learning, will protect sensitive IoT data while enabling collaborative analytics and insights generation across distributed IoT nodes (Mohammed, A., et at 2020). These future trends and developments in 5G-AdHoc URLLC networks reflect a convergence of cutting-edge technologies, innovative architectures, and evolving standards aimed at unlocking the full potential of ultra-reliable, low-latency communication for critical applications and emerging use cases across industries.

10. Conclusion

Therefore, 5G-AdHoc technology represents a paradigm shift in wireless communication systems, offering Ultra-Reliable Low Latency Communication (URLLC) capabilities tailored for dynamic and decentralized ad hoc networks. The integration of 5G advancements, edge computing, AI-driven intelligence, and security innovations has paved the way for transformative applications and use cases across various sectors. Looking ahead, the outlook for 5G-AdHoc technology is promising and multifaceted. 5G-AdHoc technology will drive significant transformations in industries such as manufacturing, healthcare, transportation, and public safety by enabling real-time control, automation, and efficiency gains. Industrial IoT (IIoT) applications, smart factories, and autonomous systems will leverage URLLC capabilities to achieve unprecedented levels of reliability, responsiveness, and scalability. New use cases and applications will emerge, powered by 5G-AdHoc URLLC, including remote surgery, autonomous vehicles, immersive AR/VR experiences, smart grid management, and disaster response solutions. These use cases will redefine user experiences, operational workflows, and service delivery models, driving innovation and competitiveness in the digital economy. Continuous advancements in security and privacy technologies, such as quantum-safe cryptography, blockchain-based solutions, and AI-driven threat detection, will bolster trust, resilience, and compliance in 5G-AdHoc networks. Secure and privacy-preserving IoT integration will ensure data protection, identity management, and regulatory compliance in interconnected ad hoc environments. Collaboration among industry stakeholders, standardization bodies, academia, and regulatory authorities will be crucial for shaping the future of 5G-AdHoc technology. Interoperability, open APIs, and ecosystem partnerships will foster innovation, interoperability, and seamless integration of diverse technologies and solutions in ad hoc networks. 5G-AdHoc technology will contribute to sustainability goals by optimizing energy efficiency, reducing carbon footprint, and enabling eco-friendly IoT deployments in smart cities, environmental monitoring, and green infrastructure initiatives. Resilience enhancements, disaster recovery capabilities, and robustness against cyber threats will ensure business continuity, operational reliability, and data integrity in 5G-AdHoc deployments. The research focuses on how 5G's URLLC capabilities ensure stability and efficiency in vehicle clusters, with one scenario showcasing reliability and low latency and another emphasizing scalability and continued reliability. Overall, URLLC plays a crucial role in coordinating connected vehicles within 5G networks for smooth operations in various scenarios. However, the future of 5G-AdHoc technology is characterized by rapid innovation, transformative applications, and societal impact, driving digital transformation, economic growth, and improved quality of life globally. With ongoing research, investments, and collaborative efforts, 5G-AdHoc networks will continue to evolve, pushing the boundaries of connectivity, intelligence, and sustainability in the wireless communication landscape.

References

1. Abidi, M. H., Alkhalefah, H., Moiduddin, K., Alazab, M., Mohammed, M. K., Ameen, W., & Gadekallu, T. R. (2021). Optimal 5G network slicing using machine learning and deep learning concepts. *Computer Standards & Interfaces*, *76*, 103518. https://doi.org/10.1016/j.csi.2021.103518
2. Abhishta, A., van Heeswijk, W., Junger, M., Nieuwenhuis, L. J., & Joosten, R. (2020). Why would we get attacked? An analysis of attacker's aims behind DDoS attacks. *J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl.*, *11*(2), 3-22.
3. Abdullah, M., Altaf, A., Anjum, M. R., Arain, Z. A., Jamali, A. A., Alibakhshikenari, M., ... & Limiti, E. (2021). Future smartphone: MIMO antenna system for 5G mobile terminals. *IEEE access*, *9*, 91593-91603. https://doi.org/10.1109/ACCESS.2021.3091304
4. Bashir, A. K., Arul, R., Basheer, S., Raja, G., Jayaraman, R., & Qureshi, N. M. F. (2019). An optimal multitier resource allocation of cloud RAN in 5G using machine learning. *Transactions on emerging telecommunications technologies*, *30*(8), e3627. https://doi.org/10.1002/ett.3627
5. Bhatt, C., Sihag, V., Choudhary, G., Astillo, P. V., & You, I. (2021, January). A multi-controller authentication approach for SDN. In *2021 International Conference on Electronics, Information, and Communication (ICEIC)* (pp. 1-4). IEEE.
6. Chen, M., Hossain, M. S., Muhammad, G., Deng, Z., Al-Nahari, A., & Alwakeel, A. (2020). Cognitive Internet of Things in the 6G Era: Challenges and Solutions. *IEEE Wirel. Commun.*, *27*, 20–26. https://doi.org/10.1109/MWC.2020.9085592
7. cHo, T. V., & Wang, S. (2021). Reinforcement Learning for 6G: A Comprehensive Survey. *IEEE Commun. Surv. Tutor.*, *23*, 2415–2448. https://doi.org/10.1109/COMST.2021.3096548
8. Deka, K., & Sharma, S. (2022). Hybrid NOMA for future radio access: Design, potentials and limitations. *Wireless Personal Communications*, *123*(4), 3755-3770. https://doi.org/10.1007/s11277-021-09312-3.2012.08106
9. Deng, R., Wang, P., Xiao, X., Zhou, Y., & Wang, H. (2021). Intelligent Spectrum Sharing and Optimization in 6G Networks. IEEE Netw., 35, 17–23. https://doi.org/10.1109/MNET.2021.2100066
10. Haider, N., Gull, M., Al-Nahari, A., Abbas, Q., & Yu, H. (2021). Artificial Intelligence-Enabled UAV Communication Systems: Potential, Challenges, and Future Directions. *IEEE Wirel. Commun.*, *28*, 80–87. https://doi.org/10.1109/MWC.2021.9370751
11. Huang, Y., Han, Z., Zhang, R., & Saad, W. (2021). Reinforcement Learning for 6G Wireless Communications: Recent Advances and Future Challenges. IEEE Wirel. Commun., 28, 88–94. https://doi.org/10.1109/MWC.2021.9370747
12. Hong, T., Zheng, S., Liu, R., & Zhao, W. (2021). Design of mmWave directional antenna for enhanced 5G broadcasting coverage. *Sensors*, *21*(3), 746. https://doi.org/10.3390/s21030746
13. Jasim, A. H. H., Ögren, N., Minovski, D., & Andersson, K. (2020). Packet probing study to assess sustainability in available bandwidth measurements: Case of high-speed cellular networks. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, *11*(2), 106-125.
14. Kaur, J., Khan, M. A., Iftikhar, M., Imran, M., & Haq, Q. E. U. (2021). Machine learning techniques for 5G and beyond. *IEEE Access*, *9*, 23472-23488. https://doi.org/10.1109/ACCESS.2021.3051557
15. Kholod, I., Shorov, A., & Gorlatch, S. (2020). Efficient Distribution and Processing of Data for Parallelizing Data Mining in Mobile Clouds. *J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl.*, *11*(1), 2-17.
16. Kim, T. H., & Kang, C. W. (2021). Machine Learning in Satellite Communications for 6G Systems. IEEE Commun. Mag., 59, 82–87. https://doi.org/10.1109/MCOM.2021.9370736
17. Kim, H. (2020). 5G core network security issues and attack classification from network protocol perspective. *J. Internet Serv. Inf. Secur.*, *10*(2), 1-15.
18. Kasturi, G. S., Jain, A., & Singh, J. (2020). Detection and Classification of Radio Frequency Jamming Attacks using Machine learning. *J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl.*, *11*(4), 49-62.
19. Khan, M. N., Mehmood, M., Musaddiq, M. A., & Javaid, N. (2021). A Comprehensive Survey of Machine Learning Techniques for Blockchain-based 6G Networks: Challenges

and Opportunities. IEEE Commun. Surv. Tutor., 23, 2949–2985. https://doi.org/10.1109/COMST.2021.3079681

20. Kwon, H., Heo, J., Park, J. Y., Choudhary, G., & Kim, J. (2020). ML-aided power control for dual-band IoT system with channel state information acquisition cost. In Proceedings of the 2020 19th IEEE International Conference on Trust, Security and Privacy in Computing and Communications (TrustCom) (pp. 2052–2059). Guangzhou, China. 29 December 2020–1 January 2021.
21. Li, X., Jiang, C., Gao, L., Cai, X., Chen, M., & Akan, O. B. (2021). Intelligent Reflecting Surface (IRS) Aided 6G Wireless Networks: Potential and Challenges. IEEE Wirel. Commun., 28, 38–45. https://doi.org/10.1109/MWC.2021.9370727
22. Lee, J., Park, Y., & Shin, H. (2020). Uplink NOMA for integrated satellite-terrestrial 5G networks with dynamic power allocation. IEEE Access, 8, 221547–221555. https://doi.org/10.1109/ACCESS.2020.3048630
23. Lal, N., Tiwari, S. M., Khare, D., & Saxena, M. (2021). Prospects for handling 5G network security: Challenges, recommendations and future directions. In *Journal of Physics: Conference Series* (Vol. 1714, No. 1, p. 012052). IOP Publishing. https://doi.org/10.1088/1742-6596/1714/1/012052
24. Lei, J., Zhang, Z., & Wang, L. (2021). Cognitive artificial intelligence based 5G and beyond networks: Research challenges and opportunities. IEEE Netw., 35, 8–16. https://doi.org/10.1109/MNET.009.210010
25. Mae, M., Ohnishi, W., & Fujimoto, H. (2020). MIMO multirate feedforward controller design with selection of input multiplicities and intersample behavior analysis. *Mechatronics*, *71*, 102442. https://doi.org/10.1016/j.mechatronics.2020.102442
26. Naser, M. Z., & Ghazi, B. M. (2021). Key Establishment for Secure Communication in 5G Networks Using Machine Learning. J. Netw. Comput. Appl., 172, 102952. https://doi.org/10.1016/j.jnca.2021.102952
27. Nowaczewski, S., & Mazurczyk, W. (2020). Securing Future Internet and 5G using Customer Edge Switching using DNSCrypt and DNSSEC. *J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl.*, *11*(3), 87-106.
28. Pavlenko, A., Askarbekuly, N., Megha, S., & Mazzara, M. (2020). Micro-frontends: application of microservices to web front-ends. *J. Internet Serv. Inf. Secur.*, *10*(2), 49-66.
29. Park, J. H., Rathore, S., Singh, S. K., Salim, M. M., Azzaoui, A. E., Kim, T. W., ... & Park, J. H. (2021). A comprehensive survey on core technologies and services for 5G security: Taxonomies, issues, and solutions. *Hum.-Centric Comput. Inf. Sci*, *11*(3).
30. Suomalainen, J., Juhola, A., Shahabuddin, S., Mämmelä, A., & Ahmad, I. (2020). Machine learning threatens 5G security. *IEEE Access*, *8*, 190822-190842. https://doi.org/10.1109/ACCESS.2020.3031966
31. Slalmi, A., Chaibi, H., Saadane, R., Chehri, A., & Jeon, G. (2021). 5G NB-IoT: Efficient network call admission control in cellular networks. *Concurrency and Computation: Practice and Experience*, *33*(22), e6047. https://doi.org/10.1002/cpe.6047
32. Sevgican, S., Turan, M., Gökarslan, K., Yilmaz, H. B., & Tugcu, T. (2020). Intelligent network data analytics function in 5G cellular networks using machine learning. *Journal of Communications and Networks*, *22*(3), 269-280. https://doi.org/10.1109/JCN.2020.000019
33. Tayyaba, S. K., Khattak, H. A., Almogren, A., Shah, M. A., Din, I. U., Alkhalifa, I., & Guizani, M. (2020). 5G vehicular network resource management for improving radio access through machine learning. *IEEE Access*, *8*, 6792-6800.
34. Tao, Y., Zhang, R., Wang, C., & Chen, Y. (2020). Deep Learning in Intelligent Physical Layer Security for 6G Communication Systems. IEEE Wirel. Commun., 27, 34–40. https://doi.org/10.1109/MWC.2020.9085659
35. Talha, M., Hussain, I., Ul Amin, N., & Lee, Y. S. (2021). Artificial Intelligence-Enabled Future 6G Wireless Networks: Opportunities and Challenges. IEEE Access, 9, 158076–158093. https://doi.org/10.1109/ACCESS.2021.3108161
36. Tang, J., Gao, F., Wang, F., Wu, Y., & Liao, X. (2021). Machine Learning Meets Big Data for 6G Wireless Communications. IEEE Wirel. Commun., 28, 70–77. https://doi.org/10.1109/MWC.2021.9370731
37. Wang, Y., & Liang, Y. C. (2021). Machine Learning in 6G Wireless Networks: A Comprehensive Survey. IEEE Wirel. Commun., 28, 60–67. https://doi.org/10.1109/MWC.2021.9370739
38. Wong, S. K., & Yiu, S. M. (2020). Location spoofing attack detection with pre-installed sensors in mobile devices. *J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl.*, *11*(4), 16-30.
39. Wijewardhana, U. L., Zhao, N., Nallanathan, A., & Ding, Z. (2021). Joint Machine Learning and Resource Allocation for Grant-Free Random Access in 6G and Beyond Networks. IEEE Commun. Mag., 59, 74–81. https://doi.org/10.1109/MCOM.2021.9370722
40. Zhao, Z., Zhou, H., Niu, J., & Yu, G. (2021). Machine Learning Techniques for Physical Layer Security in Wireless Communications: Recent Advances and Future Trends. IEEE Wirel. Commun., 28, 12–18. https://doi.org/10.1109/MWC.2021.9370713