The 5G Era: A Comprehensive Review of Recent Advancements and Applications

Vanshika Saxena

ABSTRACT

The fifth generation is a promising and transformative leap in network capabilities, bringing out applications beyond traditional technologies. This review paper discusses the novel technologies shaping 5G, studying their impact and potential. We explore technological advancements like Network Function Virtualization (NFV) and Software-Defined Networking (SDN) for their role in creating flexible and efficient networks. Services like Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (uRLLC), and Massive Machine-Type Communication (mMTC) are also examined, along with their details, and role in shaping the benefits of 5G for various fields.

This paper also investigates how 5G addresses the aspects like energy efficiency enhancements and network security enhancements brought about in 5G. We discuss the details of integration of Artificial Intelligence (AI) for network optimization, security, automation and user experience, along with its impact in various domains like healthcare, manufacturing, education and transportation.

Further, the paper explores the incorporation of edge computing and its role in supporting real-time applications. Finally, we examine the growing importance of Non-Public Networks (NPNs) tailored for private use cases, another aspect that adds to the benefits and novelty of the fifth generation.

This review provides a comprehensive overview of the key technological advancements driving the 5G revolution, highlighting their role in transforming communication infrastructures and other key use cases, supporting a new era of communication.

RECENT ADVANCEMENTS IN 5G

1. EMBB

The global economy has encountered various growth challenges as a result of the Internet's rapid expansion and rising need for greater network connectivity. One of the key areas of 5G mobile network services is enhanced Mobile Broadband (eMBB), which intends to meet consumers' needs for an increasingly digital lifestyle while focusing on facilities that require more capacity.

The eMBB is one of the three main 5G New Radio use cases defined by the 3GPP. This addresses the human-centered use cases to access multimedia content, data and services. The eMBB service aims to increase data throughput while maintaining moderate reliability, with packet errors on the scale of 10^{-3}.

2. URLLC

One of the key aspects of the 5th Generation (5G) networks is the ultra-reliable and low latency communications (URLLC), which supports exceptional degrees of high reliability and low latency for end-to-end (E2E) communications.

It is characterised by extremely low latency combined with high availability, reliability, and security, which is required for mission-critical communications, such as those involving remote surgery, autonomous vehicles, or the Tactile Internet. This will have a significant impact on business and society, opening up a number of new opportunities for emerging technology markets and the provision of necessary public services. Other instances include remote medical operations, distribution automation in a smart grid, transportation safety, wireless control of industrial manufacturing or production processes, etc.

When it comes to connecting new services and applications from vertical sectors like factory automation and autonomous driving, URLLC will prove to be crucial. The three most important URLLC key performance indicators (KPIs) are availability, reliability, and latency.

3. MMTC

The current fifth generation (5G), also known as 5G New Radio (NR), is expressly designed to serve machine type communications (MTC) in addition to human type communications (HTC), whereas the first four generations of wireless networks prioritised HTC as the main use cas. D2D communication is implemented in the 4G MCS, but it is not commonly used because of performance limitations (latency, capacity, data rate, confidence, etc.).
MTC enables machine-to-machine (MTM) wireless communication between machines without human involvement, facilitating the development of a network of interconnected machine-type devices (MTDs), referred to as the Internet of Things (IoT). This opens up a broad range of applications across multiple vertical industries, from linking extremely basic low-cost, low-energy devices like sensors to intricate machine networks, such as those seen in industrial automation use cases.
The first step in creating a uniform network architecture to handle the variety of MTC connection needs is the introduction of URLLC and mMTC service classes in 5G NR. Although 5G NR and other wireless systems have made this possible in some situations, the full potential of an all-encompassing, flexible, and agile MTC network has not yet been achieved.

In order to satisfy the changing needs of the 2030s, a reliable, scalable, and effective sixth generation (6G) wireless network must be designed while 5G NR and other MTC systems continue to advance in the near future.
There are two basic reasons behind this. First off, starting from scratch can help designers create a network that is capable of overcoming the drawbacks of current systems. In addition, new use cases and applications requiring MTC connectivity in the next ten years will emerge due to societal needs and emerging developments. These applications and use cases will have more diverse and strict requirements than those considered for current systems, necessitating the integration of multiple radio access technologies (RAT) in order to ensure robustness.

A whole new suite of technologies is needed for mMTC, as opposed to the technologies included in LTE and earlier cellular generations, which are intended to support human-centric communications and do not address the uplink transmission of large numbers of low-rate devices. It is necessary to consider typical criteria in order to reduce the design space of possible mMTC technologies. Standard mMTC assumptions in the literature are;

- small packets upto a few bytes
- large number of user devices in a single cell
- low user data rates
- low complexity and battery constrained (low energy) MTC devices.

MMC communication and supporting IoT/IoE services delivered on the 5G platform will contribute to the development of a fully networked and connected society. mMTC aims to enable wireless communication for billions of low-power, low-complexity devices. The emphasis is on scalable connection for an increasing number of devices, wide-area coverage, and deep indoor penetration.

4. SECURITY ENHANCEMENTS

Security has become a major concern in many telecommunications industries nowadays, since flaws can have devastating consequences.
The security of 5G technology has been acknowledged as a major concern for both the current and future systems. Furthermore, the bulk of security models used in B5G networks cannot be easily adapted to 5G networks due to changes in architecture and services. However, with a few adjustments, certain security protections can be implemented.

The security of 5G and beyond networks is made up of three primary components. First, almost all of the security risks and requirements related with pre-5G mobile generations are still valid in 5G and beyond. Second, 5G will create new security challenges owing to the increased number of users, heterogeneity of connected devices, new network services, high user privacy concerns, extra stakeholders, and needs to support IoT and mission-critical applications. Third, network softwarization and the adoption of new technologies like as SDN, NFV, MEC, and NS will create whole new security and privacy issues.

Data confidentiality is one of the most important security needs in the 5G security architecture; it protects data transmission from disclosure to unauthorized entities as well as passive assaults (eavesdropping). Given the 4G-LTE and 5G architectures, any user plane data must be kept secure and shielded from illegal access. Standard data encryption algorithms are frequently used to ensure data security in 5G network applications.The symmetric key encryption algorithm can be used to encrypt and decrypt 5G data using a single private key. This is shared by the communication entities.

A further aspect of integrity is the prevention of tampering and loss of information during the transformation from one point to other. The integrity of 5G New Radio (NR) traffic is safeguarded in the same manner as 4G. The Packet Data Convergence Protocol (PDCP) layer in 5G NR ensures the integrity of wireless data flows. However, one notable advancement in 5G integrity protection is that 5G NR now protects the user plane. This is crucial, since 4G doesn't provide user-plane integrity protection. This new feature is handy for small data transfers, particularly with restricted IoT devices.

Technological advancements are causing dynamic changes to system architecture and network needs. The large number of linked devices in 5G communications increases the likelihood of new security concerns.

5. ENERGY EFFICIENCY ENHANCEMENTS

The exponential growth of network traffic and the number of connected devices make energy efficiency a growing problem for mobile networks in the near future.
Energy efficiency has lately acquired prominence as a performance metric and design restriction for 5G communication networks, posing new issues for the future. In particular, the use of AI/ML techniques will improve

5G's ability to achieve lower power consumption and, more crucially, dynamic adaptation of network elements to any type of energy requirement, ensuring successful operation.
Several strategies can be used to make future 5G networks more energy efficient. These strategies can be divided into three categories: employing energy efficient architectures, allocating energy efficiently, and using energy efficient radio technologies.

Machine learning has the potential to reduce energy efficiency difficulties while improving performance in future networks and under unpredictable network situations. If properly applied, machine learning has the ability to optimise the functioning of a 5G network while also boosting energy efficiency.
Several machine learning technologies can be used to increase the energy efficiency of 5G networks. In supervised learning, a model is trained using labelled data to anticipate the best solutions. Massive MIMO for energy efficiency is one example of a supervised learning application in which channel estimation and detection are difficult due to the large number of antennas. Unsupervised learning, unlike supervised learning, operates on unlabeled data and is appropriate for clustering and dimensionality reduction. Unsupervised learning, for example, can be used to cluster BS with similar characteristics in order to operate more efficiently in variable load conditions. Reinforced learning is ideal for energy-efficient solutions that require minimal prior data for processing.

MIMO has also become popular due to its energy efficiency and enhanced throughput. It does not require more power for transmission or bandwidth.
Beamforming is a technique for producing radiated beam patterns for antennas by completely building up processed signals in the direction of the target terminals and canceling out conflicting signals. This may be done using a finite impulse response (FIR) filter. FIR filters are beneficial because their weights may be adaptively altered and used for efficient beamforming. The use of beamforming in massive MIMO systems has the following advantages: increased energy efficiency, spectral efficiency, system security, and application to mm-wave bands. Increased energy efficiency.

The need for the energy-efficient network is adopted worldwide because of both economic and environmental concerns.

6. AI INTEGRATION

AI is playing a major role in the development of 5G networks, as it might be used to improve a range of elements of network performance;

(i) Network optimization: AI might be used to evaluate massive volumes of data generated by the network in order to detect patterns and trends. This data can subsequently be utilised to optimise the network for various traffic types and user counts. For example, AI might be used to forecast traffic patterns and alter the network accordingly, thereby reducing congestion and improving performance.

(ii) Network security: Artificial intelligence (AI) could be used to detect and mitigate security risks to 5G networks. AI could be used to detect and prevent cyberattacks or to monitor network traffic for unusual patterns.

(iii) Network automation: AI may be used to automate a wide range of network administration operations, including network provisioning, defect detection, and performance improvement. This can serve to minimise the strain of network operators while also improving overall network efficiency.

(iv) User experience: Artificial intelligence could be used to personalise the user experience on 5G networks. For example, AI might be used to propose content to users or to optimise network resources for various applications. AT&T is employing artificial intelligence (AI) to boost the efficiency of its 5G networks. The company uses AI to manage network provisioning, which has helped to cut the time required to launch new 5G services.

AI-based techniques used to improve 5G network performance have the following structure:

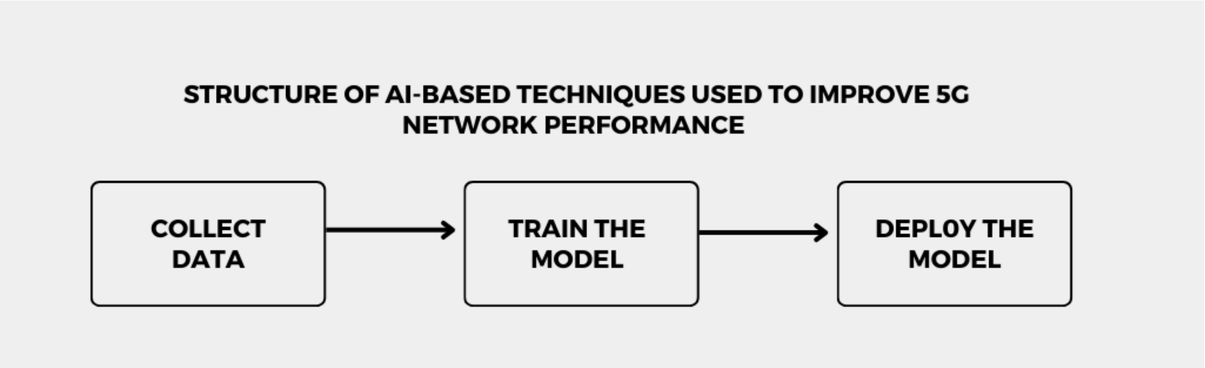

Figure 1: structure of AI-based techniques used to improve 5G network performance

1. Collect data: The algorithm initially gathers information on network traffic patterns, such as the number of customers, the type of traffic, and the time of day.

2. Train the model: Using the obtained data, the algorithm trains a machine learning model.

The model learns to predict traffic patterns and allocate network resources accordingly.

3. Deploy the model: The model is then propagated across the network. The model determines real-time network resource allocation, including base station selection and bandwidth allocation for each user.

AI appears as a significant solution because of its adaptability and seamless integration with existing systems. AI's ability in handling challenging challenges across multiple disciplines, from military defence to natural language processing, demonstrates its capabilities. Traditional approaches struggle to keep up with the increasing complexity of network performance and surroundings. Designing and optimising wireless communication networks becomes increasingly difficult, necessitating complex approaches and algorithms. AI, which learns from its environment and large datasets, is a tried and true way for dealing with such complexity.

AI has numerous practical applications in wireless communication, including resource management, signal processing, and channel modeling. These applications are critical in improving physical layer design, network management, and resource allocation. As mentioned in [9] (Figure 2), AI developments transcend beyond 5G to affect physical layer research, network optimization, channel measurements, algorithm development, and standardisation. The integration of AI and machine learning (ML) has the potential to transform communication systems beyond 5G. Their ability to adapt, learn from data, and make real-time judgments enables them to tackle complicated and changing problems. Ultimately, this results in more resilient, efficient, and user-centred communication systems.

AI approaches excel at predicting and detecting network performance, leading to improved scheduling.

Model systems more accurately than traditional methods, resulting in intelligent solutions.

Create opportunities for updating models based on changing traffic patterns.

These methods are commonly used to optimise design specifications and quickly uncover ideal solutions, similar to how they are used in manufacturing to improve processes, reduce costs, and increase income.

There are various challenges to using AI in 5G networks.

(i) Data privacy and security: AI models require a large amount of data to train. This data can be sensitive, such as user location or financial information. This data must be protected from unwanted access and handled responsibly.

(ii) Complexity: AI-powered algorithms can be complex and difficult to comprehend. This can make it challenging to diagnose and troubleshoot AI-powered systems. To properly deploy AI in 5G networks, a thorough understanding of how it works is essential.

(iii) Latency: AI-based algorithms can be computationally costly, causing latency difficulties in 5G networks. This is especially true for applications requiring real-time inference, such as network security and traffic control. It is vital to select AI-based algorithms built for real-time performance and guarantee that the network has the resources to support them.

(iv) Cost: Implementing AI in 5G networks requires high-performance processing resources and specialised software, which might be costly. It is critical to thoroughly assess the cost of AI before adopting it in 5G networks.

(v) Skill shortage: There is a dearth of skilled engineers with the necessary expertise and experience to implement AI in 5G networks.

It is important to invest in training and development programs to help engineers learn the expertise they need to work with AI in 5G networks.

Impact of AI integration in 5G on various sectors

Healthcare	Transportation	Education	Manufacturing
• TELEMEDICINE • REMOTE SENSING • WEARABLE DEVICES	• AUTONOMOUS VEHICLES • SMART TRAFFIC MANAGEMENT	• REMOTE LEARNING • AI POWERED LEARNING TOOLS	• SMART FACTORIES • PREDICTIVE MAINTAINCANE

Figure 2: Impact of AI integration in 5G on various sectors

Source: Kumar, K. (2024, June 18). *The impact of 5G technology with AI and cloud in various sectors by 2024*. Apeksha Telecom.

7. NETWROK FUNCTION VIRTUALISATION

NFV is a technology framework that virtualizes classic network operations like firewalls, routers, and load balancers, executing them as software instances on standard hardware. Instead of using specific hardware appliances for each network function, NFV separates network functions from proprietary hardware and consolidates them into software-based instances that can run on commodity servers, switches, and storage devices.

NFV uses virtualization technologies like hypervisors and containerization to generate virtual instances of network functions. These virtualized instances can be dynamically installed, scaled, and transferred between physical infrastructures, allowing for flexible resource allocation and efficient resource use.

The NFV orchestration platforms manage the entire lifetime of virtualized network functions, including instantiation, configuration, scaling, and decommissioning. Orchestration offers on-demand network service provisioning as well as dynamic service chaining and composition, allowing operators to design network architectures tailored to specific use cases or applications.

NFV improves service agility by separating network functions from the underlying hardware, allowing for faster service deployment and innovation. Virtualized network functions can be instantiated and adjusted dynamically in response to changing network circumstances or user demands, shortening the time-to-market for new services and lowering operational expenses.

8. SOFTWARE- DEFINED NETWORKING

SDN is an architectural solution that separates the control plane and data plane in networking devices, allowing network control and management to be centralised and programmatically specified using software-based controllers. SDN allows for dynamic network design, policy enforcement, and traffic optimization by abstracting network control operations from the underlying hardware devices.

SDN consolidates network control and management functions into software-based controllers that programmatically set network policies and configurations. SDN simplifies network management by separating the control and data planes, allowing for centralised policy enforcement and traffic direction.

It also supports programmable interfaces such as APIs (Application Programming Interfaces) and southbound protocols (e.g., OpenFlow), allowing network operators and administrators to set network policies and automate network operations. Programmability enables dynamic adaptability to changing network circumstances and application requirements, resulting in more flexible and responsive network management.

SDN allows for fine-grained traffic engineering and optimization using software-defined policies and algorithms. SDN improves network efficiency, resource utilisation, and Quality of Service (QoS) for end users by dynamically rerouting traffic flows, load balancing, and implementing traffic priority rules.

Network function virtualization (NFV) and software-defined networking (SDN) in 5G networks enable dynamic resource allocation, network programmability, and efficient management of network functions.

9. EDGE COMPUTING

A fundamental feature of 5G networks is the integration of edge computing, which enables the processing and analysis of data closer to the source or end-user devices at the network edge. Citing a pertinent paper, let's investigate how recent advancements in 5G technology facilitate edge computing integration: Integration of cutting-edge computing: Instead of relying on centralised data centres, edge computing is the decentralised processing of data at or close to the source of data generation. In order to facilitate low-latency, high-bandwidth data processing and analytics in 5G networks, edge computing integration entails putting computing resources like servers, storage, and networking components at the network's edge. In 5G networks, key aspects of edge computing integration include: Edge computing reduces the amount of time it takes for data to travel between end-user devices and central data centres by processing it closer to the source. Latency-sensitive applications like autonomous vehicles, augmented reality (AR), and industrial automation can now respond in real time or near real time thanks to this reduction.

Edge computing also makes it unnecessary to send a lot of raw data over the network to centralised data centres where it can be processed. By transmitting only relevant data or processed insights, instead, bandwidth consumption and network congestion are reduced. Applications with stringent requirements benefit most from this optimization. By allowing sensitive data to be processed locally, this technology reduces the risk of data breaches and privacy violations caused by transmitting data to centralised locations over public networks. Edge computing improves data privacy and security by storing data locally, ensuring compliance with regulatory requirements and safeguarding sensitive information. Computing resources can be dynamically provisioned and distributed across geographically dispersed edge nodes thanks to edge computing architectures' inherent scalability and adaptability. This adapts to changing demand and network conditions, enabling efficient resource utilisation and supporting a variety of workloads and application requirements. It is ideal for supporting latency-sensitive applications like video analytics, content delivery, and IoT data aggregation that require real-time or near-real-time processing. 5G networks are able to provide low-latency, high-bandwidth services that meet the performance requirements of applications and users by making use of the capabilities of edge computing.

10. NON PUBLIC NETWORKS

NPNs, also known as private networks, are customised mobile networks intended solely for the purpose of a single business or industry. This technique provides more control, security, and flexibility than typical public mobile networks. NPNs in 5G have the potential to change different industries, allowing innovative applications and optimising mission-critical operations.

NPNs are private mobile networks created for the exclusive use of a specific company or industry, as opposed to public cellular networks that are shared by everyone. This enables customisation to fulfil unique needs, such as high bandwidth requirements in manufacturing plants or increased security for government activities.
Compared to public networks, organisations that use NPNs have more control over network resources, security policies, and Quality of Service (QoS). This flexibility allows users to tailor the network to their individual needs and enhance performance for their specialised applications.

NPNs provide a more secure environment than public networks, which are by definition open. Organisations might employ tougher access controls and data encryption to secure sensitive information.
NPNs can be deployed in a variety of methods, depending on the unique requirements. NPNs are critical in realising 5G's full promise across a variety of businesses. They provide applications such as real-time monitoring in industries, remote control of robots in hazardous situations, and secure communication for public safety agencies.

Conclusion

The journey towards efficient connectivity has taken a revolutionary leap with the advancement of 5G. This review paper has covered the key technologies that support the 5G revolution, highlighting their capabilities and potential impact. We looked at the transformative role of Network Function Virtualization (NFV) and Software-Defined Networking (SDN) in creating software-driven network architectures. Emerging services like Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (uRLLC), and Massive Machine-Type Communication (mMTC) were also studied, along with their role, requirements and the solutions 5G offers.

The paper addressed different aspects of 5G, including advancements in energy efficiency and security mechanisms. We explored how Artificial Intelligence (AI) integration is used to optimise network operations, safety and personalise user experiences.

We also discussed the rise of edge computing and its potential to enable real-time applications. Finally, we examined the growing importance of Non-Public Networks (NPNs) tailored for private use cases for organisations.

In essence, 5G has been proved to be a catalyst for innovation which is capable of revolutionising industries, transforming human interactions with technology and shaping a better tomorrow. Even though the challenges persist, a deeper understanding of solutions and ensuring efficient infrastructure deployment will help overcome these challenges.

Beyond the technologies discussed here, future advancements in areas like millimetre wave communication, spectrum sharing and massive MIMO hold potential for further enhancements in 5G's capabilities. With continued research and development, 5G has the potential to shape an effortlessly connected world full of possibilities yet to be discovered.

References

[1] Abd El-Mawla, N., & Badawy, M. (2023, January). Eco-friendly IoT solutions for smart cities development: an overview. In 2023 1st International Conference on Advanced Innovations in Smart Cities (ICAISC) (pp. 1-6). IEEE.

[2] Patel, K., Vadher, A., Patel, M., Thaker, J., & Bhise, A. (2024, February). AI-Based Security System for 5G Enabled IoT. In 2024 Second International Conference on Emerging Trends in Information Technology and Engineering (ICETITE) (pp. 1-7). IEEE.

[3] Chochliouros, Ioannis & Kourtis, Michail & Spiliopoulou, Anastasia & Lazaridis, Pavlos & Zaharis, Zaharias & Zarakovitis, Charilaos & Kourtis, Anastasios. (2021). Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures. Energies. 14. 5392. 10.3390/en14175392.

[4] Xu, M., Jiang, C., Zhang, Y., & Huang, K. (2016). Multi-Access Edge Computing for 5G Networks: Concepts,Technologies, and Challenges.

[5] Chemouil, Prosper, et al. (2017). Network Functions Virtualisation (NFV): State-of-the-Art and Research Challenges.

[6] Akram Hakiria, Aniruddha Gokhale, Pascal Berthoumieu, Douglas C. Schmidt, and Gayraud Thierry. 2014. "Software-Defined Networking: Challenges and Research Opportunities for Future Internet." Computer Networks 74 (December): 360-376.

[7] Mahmood, N.H., Böcker, S., Moerman, I. *et al.* Machine type communications: key drivers and enablers towards the 6G era. *J Wireless Com Network* 2021, 134 (2021).

[8] 3GPP. (n.d.). Non-Public Networks (NPN).
pen_spark

[9] 5G-PPP. (2022, November). **Non-Public Networks – State of the art and way forward**. 5G Alliance for Connected Industries and Automation. 5g-ppp.eu

[10] GSA (2023, February). Non Public Networks | Private Mobile Networks [GSAcom].

[11] Mahmood, N.H., Böcker, S., Moerman, I. *et al.* Machine type communications: key drivers and enablers towards the 6G era. *J Wireless Com Network* 2021, 134 (2021).
[12] Hegazi Ibrahim; Nesma Abd El-Mawla. "AI-Powered 5G Networks: A Roadmap for The Future of Wireless Communications". *Nile Journal of Communication and Computer Science*, 7, 1, 2024, 1-14. doi: 10.21608/njccs.2024.360125

[13] Khan, Rabia & Kumar, Pardeep & Jayakody, Dush Nalin & Liyanage, Madhusanka. (2019). A Survey on Security and Privacy of 5G Technologies: Potential Solutions, Recent Advancements and Future Directions. IEEE Communications Surveys & Tutorials. 10.1109/COMST.2019.2933899.

[14] Jovovic, Ivan & Forenbacher, Ivan & Periša, Marko. (2015). Massive Machine-Type Communications: An Overview and Perspectives Towards 5G. 10.18638/rcitd.2015.3.1.73.

[15] Bockelmann, Carsten & Pratas, Nuno & Nikopour, Hosein & Au, Kelvin & Svensson, Tommy & Stefanović, Čedomir & Popovski, Petar & Dekorsy, Armin. (2016). Massive Machine-type Communications in 5G: Physical and MAC-layer solutions. IEEE Communications Magazine. 54. 10.1109/MCOM.2016.7565189.

[16] Chapter 6 – 5G key concept - 5GMF. (n.d.). https://5gmf.jp/wp/wp-content/uploads/2016/09/5GMF_WP101_06_5G_Key_Concept.pdf

[17] Rappaport, T.S. & Sun, Shu & Mayzus, Rimma & Zhao, Hang & Azar, Yaniv & Wang, Kangping & Wong, George & Schulz, Jocelyn & Samimi, Mathew & Gutierrez, Felix. (2013). Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!. IEEE Access. 1. 335-349. 10.1109/ACCESS.2013.2260813.

[18] Chochliouros, I.P. *et al.* (2019). Enhanced Mobile Broadband as Enabler for 5G: Actions from the Framework of the 5G-DRIVE Project. In: MacIntyre, J., Maglogiannis, I., Iliadis, L., Pimenidis, E. (eds) Artificial Intelligence Applications and Innovations. AIAI 2019. IFIP Advances in Information and Communication Technology, vol 560. Springer, Cham. https://doi.org/10.1007/978-3-030-19909-8_3

[19] Li, Zexian & Uusitalo, Mikko & Shariatmadari, Hamidreza & Singh, Bikramjit. (2018). 5G URLLC: Design Challenges and System Concepts. 1-6. 10.1109/ISWCS.2018.8491078.

[20] Ali, Rashid & Zikria, Yousaf & Bashir, Ali & Garg, Sahil & Kim, Hyung Seok. (2021). URLLC for 5G and Beyond: Requirements, Enabling Incumbent Technologies and Network Intelligence. IEEE Access. PP. 1-1. 10.1109/ACCESS.2021.3073806.

[21] Veeraraghavan, Malathi & Sato, Takehiro & BUCHANAN, Molly & Rahimi, Reza & Okamoto, Satoru & Yamanaka, Naoaki. (2017). Network Function Virtualization: A Survey. IEICE Transactions on Communications. E100.B. 10.1587/transcom.2016NNI0001.

[22] Mehmeti, Fidan & Porta, Thomas. (2022). Modeling and Analysis of mMTC Traffic in 5G Base Stations. 10.1109/CCNC49033.2022.9700727.

[23] Remmert, H. (n.d.). *What is 5G network architecture?*. Digi International. https://www.digi.com/blog/post/5g-network-architecture

[24] Network Slicing and Softwarization in 5G Mobile Networks: Potential Benefits, Use Cases, and Challenges" by Diego R. Lopez et al. (2017)