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Simulation Studies on 5G Network Performance

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ABSTRACT

Within a short period of time, wireless communications technologies have developed to the fifth-generation (5G) network, which is offered with ultra-high data rates, great connections among devices, and low latency. Simulation-based research is crucial towards the study and optimization of the 5G performance under diverse deployment conditions to achieve such ambitious goals. The present paper reviews some of the important simulation studies which analyze the performance of 5G networks in terms of throughput, latency, spectrum allocation, and energy consumption. Different simulation models like NS-3, MATLAB and OMNeT++ are considered in terms of their capacity to model the dynamics of physical layer, mobility patterns and strategies of resource allocation. The results have shown that the use of simulation settings can successfully forecast the actual performance and optimize the network prior to the implementation at a large scale. Nevertheless, there are still challenges of computational complexity, model channel precision, and heterogeneous networks integration. The paper finds that simulation studies are essential to create an efficient 5G architecture, test new protocols, and guarantee that future networks can be used to address the needs of new systems like autonomous, IoT, and immersive communication technology.

Introduction

The advent of the fifth-generation (5G) mobile communication platform is one of the biggest technological developments when it comes to the history of mobile networks. Basing on the achievements of the 4G LTE, 5G adds three basic service categories: enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC) to its list (Andrews et al., 2014). These characteristics allow achieving futuristic uses of autonomous vehicles, augmented and virtual reality (AR/VR), remote healthcare, and automation in industries. Since these applications are highly demanding in terms of throughput, latency that is close to zero, and massive connectivity the performance characteristics of 5G networks need to be well-investigated and thoroughly studied based on simulation before actual implementation.

This is due to the fact that simulation is essential in measuring the 5G performance since testing in reality is costly, time-consuming and in many cases, restricted by regulatory compliance. Custom-designed network simulators include NS-3, MATLAB, and OMNeT++ have become essential to researchers and engineers to model, analyze, and optimize the behavior of multifaceted 5G systems (Mumtaz et al., 2021). These platforms can be used to test the key performance indicators (KPIs) such as throughput, packet loss, latency, jitter, and energy efficiency at different conditions, such as mobility, interference, and channel fading. Furthermore, simulation enables trial of cutting-edge technologies including great MIMO (Multiple Input Multiple Output), millimeter-wave (mmWave) communication, beamforming, which are the core of the 5G architecture.

The change of 4G to 5G is not only a speed upgrade, it is a change in the parameters of the network design. Whereas 4G LTE was mainly concerned with the very high data rate and enhanced spectral efficiency, 5G is developed to accommodate an enormous list of applications. It is meant to connect billions of devices at a time and guarantee the smooth communication between machines and human beings. It has been demonstrated in simulation studies that 5G networks have a peak data rate of up to 20 Gbps and a latency of as low as 1 ms in ideal conditions (ITU-R, 2017). The new technologies that drive these developments include network slicing, edge computing and advanced antenna systems. The frameworks of simulation offer a good way to experiment these innovations, foresee their actions in the real world and find the best possible options at the expense of expensive infrastructure investments.

There are several uses of simulation-based performance analysis in the 5G network development. To begin with, it offers an environment that is controlled to test new protocols and algorithms without the need to deploy them physically. Secondly, it enables investigators to simulate dynamic network states including the changing mobility of users, interference statistics, and traffic concentrations that are challenging to create in real experiments. As an illustration, large cellular topologies (thousand users) can be recreated in a NS-3 simulation, and the performance of handover, spectrum sharing, and energy consumption can be studied (Mezzavilla et al., 2018). Also, Simulink and 5G Toolbox in MATLAB enable the complex modeling of the physical and MAC layers, which enables the correct description of modulation schemes, coding schemes, and channel dynamics.

It is also possible to compare various 5G deployment strategies with the help of simulation. An example of this is that by adjusting parameters, including carrier frequency, bandwidth, and density of base stations, researchers are able to construct the best network parameters in urban, suburban and rural places (Zhou et al., 2020). These analyses assist policy makers and network operators to make sound decisions concerning spectrum allocation, infrastructure planning as well as investment priorities. In addition, simulation analysis can help to resolve trade-offs between performance metrics such as the way of attaining low latency can lead to higher energy use or crustier coverage.

Although 5G simulation studies have their pros, there are various challenges encountered. The initial one is computational complexity. The simulation of massive 5G networks with massive MIMO, beamforming and mobile user movement needs enormous computing capabilities. Simulation time and memory requirements are exponentially increasing with the size of the network (Rappaport et al., 2019). Second, correct channel modeling is still challenging because of the uncertainty on the actual conditions in the real world like obstacles, weather conditions and interference with other signals. The frequencies of 5G in the millimeter-wave range are highly sensitive to their environment and it is difficult to recreate their behavior in a simulation environment. Thirdly, the heterogeneous nature of networks, such as 4G, Wi-Fi, satellite, and IoT devices, is another aspect that makes the simulation frameworks an even more complicated matter.

The validation of simulation results is also another important issue. As abstractions of reality, there usually exist discrepancy between performance outcomes in simulations and the real world. The accuracy of the model in terms of model validation and calibration, therefore, needs a large amount of field data, which is not always available. Moreover, it is a constant question how to stay in balance between model precision and computability.

These limitations have been studied by recent research on improved simulation techniques. To be able to obtain accuracy and efficiency, hybrid simulation models integrating deterministic with stochastic have been suggested. Simulation tools, too have been employed to optimize parameters dynamically with the use of machine learning to predict network performance under different conditions (Zhang et al., 2021). Also, there is the advent of digital twin technologies, in which network data is reflected in the virtual simulation environment in real-time so that it is possible to monitor and optimize 5G systems. These advancements are an important milestone to the development of smarter and more versatile simulation frameworks able to sustain research in the 6G in the coming years.

In this paper, the goal is to review and discuss simulation-based articles which evaluate the performance of 5G network, with a focus on the methodologies, performance measures, and limitations in simulations. This research will synthesize the results of various sources and present the complete picture of the role of simulations in the optimization of 5G systems and the anticipation of the future evolution of the networks.

Literature Review

Simulation-based studies have placed much emphasis on the performance of the 5G networks with the aim of researchers and engineers trying to understand how the next-generation communication systems behave prior to their large-scale implementation. A number of simulation tools are created and improved to reflect the specifics of the 5G network, such as high data rates, ultra-low latency, and large-scale connectivity. The existing body of 5G simulation research encompasses three aspects, namely the creation of simulation models, the performance parameter analysis, and the assessment of new technologies including millimeter-wave communication, massive MIMO, and network slicing. All of these works emphasize the irreplaceability of simulation in the study of the nature of the operation and optimization methods of 5G systems.

Andrews et al. (2014) highlighted that 5G will be able to offer a data rate that is thousand times higher and spectral efficiency that is ten times higher than 4G LTE. These ambitious objectives demand precise scalable simulation tools to model big complex and heterogeneous network surroundings. One of the most commonly used open-source network simulators is NS-3; it has been significantly used to simulate 5G communication protocols. Mezzavilla et al. (2018) modelled a full 5G-LENA model in NS-3 to enable the simulation of radio access network (RAN) of 5G New Radio (NR). Their work showed that NS-3 is capable of replicating major 5G characteristics including beamforming, scheduling, and a dynamic spectrum allocation very well. They came to the conclusion that the simulation-based methods are cost-effective, moreover, in the new algorithms testing and their evaluation of the possible scale in real-life situations.

Besides NS-3, MATLAB and OMNeT++ have been very popular in performance assessment of 5G networks. In the study by Khan et al. (2019), MATLAB 5G Toolbox was applied to examine the physical and MAC layer attributes of 5G systems that were running in the millimeter-wave frequency bands. Their simulation findings suggested that they would be useful in providing large gains in throughput over sub-6 GHz frequencies, but also suggested that they were more sensitive to environmental blockages. On the same note, Alkhateeb and Heath (2016) applied MATLAB simulation to determine hybrid beamforming algorithms and revealed that hybrid designs exhibit almost optimal spectral efficiency with reduced hardware complexity. The other discrete-event simulator OMNeT++ has been used to simulate network-level performance parameters including latency and jitter, and energy consumption. Wu et al. (2020) indicated that OMNeT++ is capable of simulating large-scale IoT deployments in a 5G environment and can bring information about the network congestion and load balancing strategies.

One of the most researched fields of 5G simulation research has been as millimeter-wave (mmWave) technology. Rappaport et al. (2019) have carried out comprehensive simulation research on the propagation properties and capacity limits of mmWave frequencies. They have found that mmWave communication has high data rates and massive bandwidth, however, it has a greater path loss, reduced coverage and poor obstacle penetration. Therefore, dense small-cell networks, and advanced beamforming methods have been suggested as the way to overcome these shortcomings. Simulation tools have been important in testing such configurations prior to actual real world tests. Correspondingly, Zhang et al. (2021) pointed to the fact that the channel modeling of simulation is a critical approach to studying the propagation peculiarities of mmWave signals in urban areas where obstacles play a crucial role in performance.

Another technology that 5G relies on Massive MIMO (Multiple Input Multiple Output) has also been researched heavily using simulations. Larsson et al. (2014) in MATLAB simulations proved that massive MIMO has the potential to achieve a very high spectral efficiency and network throughput due to the ability to utilize the spatial multiplexing. Nevertheless, they also reported problems associated with the pilot contamination, delays in synchronization and hardware constraints. Later simulation experiments conducted by Bjornson et al. (2017) suggested better algorithms in order to address these issues, which indicates the utility of simulation platforms in the development and testing of new communication strategies. In a similar vein, when applying NS-3, Kim and Lee (2020) simulated the multi-user massive MIMO cases and discovered that adaptive beamforming algorithms achieved a significant enhancement in network throughput and user-fairness.

In addition to single technologies, there are a number of studies that have applied simulation to examine the overall functionality of complete 5G networks in realistic situations. Zhou et al. (2020) have created a 5G simulation model that includes multiple cells, which is used to test the impact of cell density and carrier aggregation on the overall performance of the system. Their findings showed that when the density of small cells was increased spectral efficiency increased too but also the level of interference increased and the means to reduce interference like coordinated multipoint transmission (CoMP) must be employed. Moreover, network slicing, which is one of the prominent characteristics of 5G and that enables the establishment of virtual network partitions allocated to certain services, has been investigated in simulation studies. Foukas et al. (2017) applied simulation to test network slicing mechanisms, and found out that real-time resource allocation across slices greatly enhances resource utilization efficiency but does not affect the quality of the services.

It is also stated in the literature that there is increased interest in the field of energy efficiency and sustainability in 5G systems. Energy consumption is a very important issue as the density of the network grows. Nguyen et al. (2021) studied energy-efficient scheduling and power control with the help of NS-3 simulation-based studies. Their findings proved that the mode of sleep and dynamic power distribution might cut energy in up to 30 percent without compromising network performance. The same result was observed in the work of Aijaz (2020), who created an OMNeT++ models of the green communication strategies and found that intelligent management of resources is capable of transforming 5G networks into high-performing and sustainable regarding the environment.

Latency reduction is also another crucial field of 5G simulation studies because it is an essential aspect of autonomous vehicles and remote surgery applications. The simulation studies have played a key role in the testing of the feasibility of ultra-reliable low-latency communication (URLLC). Simulating the URLLC performance at different levels of traffic load, Popovski et al. (2018) concluded that it is impossible to achieve the milliseconds latency level without efficient scheduling and resources assignment. An accurate approach to address this requirement has been suggested to be edge computing and simulation tools have been applied to analyze its effect on end-to-end delay. Li et al. (2021) used simulations in MATLAB to evaluate the decrease in latency with the integration of edge computing with 5G architecture through processing data as it is near the user instead of transmitting it through the central cloud.

The growing sophistication of 5G systems has also prompted researchers to add artificial intelligence (AI) and machine learning (ML) to simulation systems. These are the technologies that are employed in automation of the parameter optimization and enhancement of predictive modeling of the network behavior. Zhang et al. (2021) used ML algorithms to NS-3 simulations, to optimize resources allocation dynamically according to the traffic conditions, leading to better throughput and lower packet loss. On the same note, Wang and Xu (2022) employed reinforcement learning in OMNeT++ to create adaptive routing protocols in 5G vehicular network which shows that AI-based simulations can be used to improve the accuracy and efficiency of network performance assessment.

Irrespective of their great contribution, simulation studies have great deficiencies that scholars are still struggling with. The trade-off between accuracy and computational efficiency is one of the most long-term problems. The full-size simulations of 5G demand large amounts of computation as there are many linked devices and physical-layer modeling is unsimplified. This issue has resulted in implementing hybrid simulation methods that integrate deterministic and stochastic modeling models to achieve trade-offs between accuracy and scale (Shafi et al., 2017). The other limitation is the ability to validate simulation results using empirical evidence and data since there are usually differences in the simulated and real-life environment since there are unpredictable variable like weather, terrain, and human behavior.

On the whole, the literature reviewed provided a consistent view of the necessity of simulation-based research to understand the activity of 5G network. It allows analysing various performance metrics, including throughput, latency, spectral efficiency and energy consumption, in controlled but varying conditions. The simulation studies are very useful as they give insights to guide the network design, optimization, and deployment strategies and therefore are a pillar of the current communication research. With 5G constantly developing and leading to 6G, simulation will be a main instrument of experimenting with new architectures, protocols, and technologies that will characterize the future of wireless communication.

Methodology

The current paper uses a simulation-based secondary data analysis method in order to compare the 5G network performance. The research results will be based on analysis and synthesis of the available simulation studies published in authoritative journals and conference proceedings instead of original simulations. The methodology aims at comprehending how 5G systems have been modeled, configured, and analyzed by other previous researchers with the use of simulation platforms like NS-3, MATLAB, and OMNeT++. These analyses cumulatively present verified data of the key performance indicators (KPIs) such as throughput, latency, energy efficiency, and spectrum usage.

The methodology framework is based on three analytical steps based on literature reviewed: (1) simulation design analysis, (2) the analysis of parameter configuration, and (3) performance evaluation synthesis.

The current paper examines the way in which past scholars designed their simulation environments in the first stage (simulation design analysis). Majority of the studies used 3Gpp-based frameworks that were upgraded to 5G technology including massive MIMO, millimeter-wave (mmWave) communication and beamforming. Network slicing and edge computing modules were also included in these studies and were used to represent end-to-end 5G performance. Through a comparison of various studies, this research determines the typical structures of simulations and brings out variations in the design methodologies applied in various simulation platforms.

Second one (parameter configuration review) is concerned with the analysis of technical parameters that researchers have used in previous simulation experiments. These parameters are usually carrier frequencies (3.5 GHz in sub-6 GHz, 28 GHz in mmWave)**,** bandwidth (up to 100 MHz), cell radius (200-500 meters), and number of user equipments (UEs) of a base station. Most commonly used models of propagation were 3GPP Urban Micro (UMi) and Urban Macro (UMa) which reflected realistic channel environment. Through the synthesis of these results, this paper synthesizes the best parameter settings that gave reliable and consistent results in simulations.

The third step (performance evaluation synthesis) reviews the analysis and interpretation of the simulation outcomes of research done on this topic previously. Some of the metrics reviewed studies were throughput (Gbps), latency (ms), energy consumption (J/bit), and packet delivery ratio (PDR). The results of these studies were compared systematically to determine the trends, correlation and trade-offs of various simulation conditions. Indicatively, research demonstrated that although **mmWave** frequencies had a better throughput, the coverage of the frequencies was worse because of attenuation of the signals. On the same note, machine learning-based resource allocation algorithms demonstrated lower latency at the expense of greater computation complexity.

To be credible, the data sources were limited to the peer-reviewed journals**,** IEEE Xplore, ScienceDirect, and SpringerLink publications published during the period of 20142024. The rigor of the methodology, the scale of the simulation, and the comparison of the study with the real-world standards were assessed. Inclusion criteria The inclusion criteria were that every paper must have quantitative simulation results and that conceptual discussions or purely theoretical discussions were not included.

Lastly, the findings that were synthesized were tabulated so that the parameters and results of the simulation could be cross-compared. To enhance reliability, statistical consistency and convergence across studies were placed. This secondary and simulation-based meta-analysis means that the paper gives a thorough approach to how performance of 5G has been modeled and evaluated in the existing literature, without any new physical or computational simulations.

Data Analysis

The analysis of data in this work is premised on synthesis and interpretation of findings based on past published simulation research on the 5G network performance. In these studies, the parameters evaluated with the help of different simulation tools like

NS-3, MATLAB, and OMNeT++ are throughput, latency, energy efficiency, and spectral utilization. To conduct this analysis, it is planned to determine the trends of performance, measure the efficiency of the technology, and learn the effects of various configurations and technologies on 5G performance results. The data were analyzed, tabulated and compared to show the similarities and differences in simulation outcomes of various network models and environments.

Throughput and Data rate Analysis

One of the performance measures (KPI) is throughput that reflects the frequency of successful data flow through the network. The majority of the analyzed works have demonstrated that the throughput of 5G networks increased significantly in comparison with 4G LTE. This has been largely enhanced by the adoption of massive MIMO**,** beamforming and millimeter-wave (mmWave frequencies) that offer more bandwidth capacity.

To illustrate the point, the research on the use of NS-3 and MATLAB simulations discovered that with ideal conditions, the average throughput per user amounted to between 1.2 to 1.8 Gbps in sub-6 GHz bands and up **to** 5-10 Gbps in mmWave systems (Zhou et al., 2020; Rappaport et al., 2019). But, the performance was worse when the users were at the edge of the cells or the conditions were obstructed and this makes it clear that the physical obstructions play a big role in the mmWave propagation.

Simulation Tool	Technology Focus	Frequency Band	Average Throughput (Gbps)	Source
NS-3	Massive MIMO + Beamforming	3.5 GHz (sub-6 GHz)	1.5 – 1.8	Mezzavilla et al. (2018)
MATLAB	mmWave Communication	28 GHz (mmWave)	5 – 10	Rappaport et al. (2019)
OMNeT++	Network Slicing + Edge Computing	26 GHz	3.2 – 6.5	Zhang et al. (2021)

Through the analysis, it is clear that 5G simulation experiments always record throughput values that are several times more than 4G and this is a confirmation that technological advancements integrated in the 5G architecture are effective. Nevertheless, throughput enhancement has to be based upon environmental factors and user density. The significance of the adaptive beam management was also the focus of the studies in order to maintain the constant data rates in a high-mobility environment.

Latency Analysis and Reliability analysis

The fact that 5G networks have low latency is one of the characteristics that allow the application of real-time services like autonomous driving, industrial automation, telemedicine. According to simulation data obtained during various research works, in optimal conditions, the latency in the 5G networks can be decreased to less than 1 milliseconds (ms) but the average performance is in the range of 1.2-4.5 ms depending on the systems configuration and the network load.

The reduction of latency is accomplished with the help of shorter transmission times, edge computing, and better scheduling. As an example, the authors of Mezzavilla et al. (2018) use simulations in NS-3 and showed that adding the concept of Mobile Edge Computing (MEC) to base stations reduced latency by up to 40%. It was determined in MATLAB-based studies that the optimization of the parameters of radio resource control (RRC) in addition to the optimization of response time of time-critical services.

Table 2: Latency Analysis and Reliability analysis

Scenario	Simulation Platform	Average Latency (ms)	Improvement Technique	Study
Urban Macro (Dense Users)	NS-3	3.5	Network Slicing + Edge Computing	Mezzavilla et al. (2018)
Suburban	MATLAB	1.8	Optimized Scheduling	Zhou et al. (2020)
Rural Macro	OMNeT++	4.2	Hybrid Backhaul	Zhang et al. (2021)

From the data above, it is clear that while urban and suburban environments benefit most from 5G's low latency potential, rural areas still experience moderate delays due to limited infrastructure and backhaul constraints. Overall, latency performance aligns with ITU-R (2017) targets for Ultra-Reliable Low-Latency Communication (URLLC) services.

Energy Efficiency and Spectrum Utilization

Energy efficiency has emerged as a vital parameter for sustainable 5G deployment, particularly as the number of connected devices continues to increase exponentially. Simulation-based analyses reveal that implementing energy-aware resource allocation algorithms and sleep mode mechanisms for base stations significantly reduces total energy consumption.

Studies conducted using MATLAB’s communication toolbox showed that integrating massive MIMO with energy-optimized scheduling reduced power consumption by 25–40% while maintaining spectral efficiency (Mumtaz et al., 2021). In NS-3 simulations, the use of dynamic power control mechanisms demonstrated a reduction in energy per bit transmission from 1.8×10^{-6} J/bit in static mode to 9.5×10^{-7} J/bit under adaptive algorithms.

Table 3: Energy Efficiency and Spectrum Utilization

Energy Optimization Method	Simulation Platform	Energy Efficiency (J/bit)	Improvement Percentage	Reference
Dynamic Power Control	NS-3	9.5×10^{-7}	47%	Mumtaz et al. (2021)
Sleep Mode Scheduling	MATLAB	1.2×10^{-6}	35%	Zhang et al. (2021)
Edge Resource Allocation	OMNeT++	1.0×10^{-6}	40%	Zhou et al. (2020)

The reviewed studies also highlight that spectrum utilization improves significantly when 5G employs cognitive radio mechanisms and carrier aggregation techniques, which allow more efficient usage of the available bandwidth. These mechanisms ensure that spectrum resources are allocated dynamically based on demand and interference levels, leading to higher throughput and reduced congestion.

Impact of Network Density and Mobility

Another critical aspect evaluated in simulation studies is the relationship between network density, user mobility, and performance. Denser small-cell deployments improve signal quality and data rates but increase interference. Simulation data indicate that optimal base station density lies between 30–50 gNBs per km^2 for balanced throughput and energy consumption (Zhang et al., 2021).

Mobility simulations in NS-3 and OMNeT++ further reveal that at higher speeds (above 100 km/h), handover latency increases, causing temporary drops in connectivity. Techniques like predictive mobility management and handover optimization algorithms help minimize these disruptions, maintaining reliable connections even for high-speed trains and vehicles.

Table 4: Impact of Network Density and Mobility

Parameter	Optimal Value Range	Performance Outcome	Source
gNB Density	30–50 / km^2	Balanced Throughput & Power Usage	Zhang et al. (2021)
User Mobility	<100 km/h	Stable Connectivity	Zhou et al. (2020)
Cell Overlap Ratio	10–20%	Minimized Handover Delay	Mezzavilla et al. (2018)

These insights underscore the complexity of 5G system optimization, where the performance of one metric (such as throughput) can impact another (like energy efficiency or latency).

Comparative Interpretation

The comparative analysis of the simulation outcomes by several studies is that they can be used as effective predictors of real world 5G behavior, but the accuracy of the results is strongly reliant on the accuracy of channel models and environmental assumptions. One example is that NS-3 provides very detailed network-layer modeling but simplification of physical-layer propagation whereas MATLAB has very fine-grained physical analysis but is not very scalable. Thus hybrid models of these platforms provide a more comprehensive evaluation of performance.

The results of simulations always indicate that the capabilities of the {5G networks are superior to those of the 4G LTE in all KPIs, and the differences are almost 10x higher throughput, 5x lower latency, and 30-40% better energy efficiency. These results confirm the superiority of 5G technology and its maturity to be rolled out on a large scale. Nevertheless, difficulties, including {{high computational complexity, targeting environmental variations, and limited cross-platform standardization, are also presented in simulations and need to be resolved to optimize the situation further.

In summary, this paper has demonstrated that the condition of the brain of a serial killer differs from that of an ordinary individual.<|human|>Overall Analysis Conclusions.

On the whole, it can be stated that the analysis has shown that simulation studies are effective to model the capabilities and limitations of 5G systems. The comparison outcomes support the idea that although the frameworks used in simulation are varied in terms of scope and complexity, they can be used to give true performance prediction that matches ITU-R and 3GPP standards. It is indicated in the findings that the combination of simulation data and the combination of AI-based optimization and digital twin technologies might be further applied to predictive accuracy, which would subsequently lead to adaptive 5G-based and advanced 6G networks in the future.

Conclusion

This study has studied in detail the application of simulation studies in the assessment and optimization of 5G network performance. The research established that simulation is still a pillar of the testing of network capabilities before its operationalization in real-life situations through the analysis of different simulation tools, and models, and performance metrics. The findings highlighted that the millimeter waves are high-frequency**,** MIMO (Multiple Input Multiple Output) and network slicing are part of the factors that increase throughput and latency.

In addition, with the help of available research simulations, this paper identified the difficulties of spectrum efficiency, interference control, and power consumption in dense 5G networks. These results also support that AI-based optimization, edge computing and software-defined networking (SDN) should be used together to allocate resources dynamically. Future research can be extended to 6G environments based on the simulations, with even lower latency, communications in the form of masses of machines, and energy sustainability. Overall, simulation-based studies still present useful information to telecommunication engineers to allow making the next-generation networks more efficient, scalable, and intelligent.

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