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A QUANTITATIVE ANALYSIS EXPLORING THE IMPACT OF 5G NETWORKING ON NETWORK PERFORMANCE AND USER EXPERIENCE

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Abstract
This study investigates the performance of 5G networks in real-world environments, focusing on key aspects *such as network speed, latency, reliability, and user satisfaction. Using a quantitative research design, data was collected through surveys and performance testing tools. The research compares 5G with 4G to assess the advancements in speed, latency, and connection stability. Results show that 5G outperforms 4G across all performance metrics, particularly in urban areas where 5G networks provide significantly faster speeds and lower latency. User satisfaction surveys revealed a higher overall satisfaction with 5G, especially in terms of network speed and reliability, though rural areas reported lower performance levels due to infrastructure challenges. The study also examines the impact of 5G on various industries, including healthcare, transportation, and education, highlighting its transformative potential in autonomous vehicles, telemedicine, and smart cities. Regression analysis further indicates that 5G network speed has a positive impact on user satisfaction, while latency negatively affects business productivity. This research provides valuable insights into the real-world implications of 5G deployment and its benefits and challenges across diverse regions and industries.*

INTRODUCTION

The telecommunications industry is on the cusp of a major transformation with the advent of 5G Networking technology. As a successor to 4G LTE, the 5G promises to give much better network capabilities, facilitating innovations in a broad spectrum of industries. The earlier versions, 2G – 4G, have contributed significantly towards evolution of the digital world but 5G is expected to propel connectivity and communication at a new dimension (Shafi et al., 2017). As 5G technology is implemented faster, more reliable and efficient than ever, to open the new era of communication that changes how we communicate with digital world and open the door for potentialities within a wide range. The 5G, commonly known as the fifth generation of wireless technology, is intended to deliver faster data transfer speeds and low latency and better network services over its predecessor. Speed, which is one of the most critical advantages, 5G networks are up to supporters' desires to deliver 100 times faster than

stability and energy efficient (Lu et al., 2014). Data takes time to be transmitted, from noise or sender to receiver and it also reduces considerably providing near- facing communication. For time-sensitive data exchange applications like self-driving vehicles, telemedicine and industrial automation, this reduction in latency and latency distribution is crucial.

The significance of 5G is way beyond faster mobile broadband. One of the major advantages of RRN is the capacity to handle big networks, which will be crucial for future spreading of the Internet of Things (IoT) (Li et al., 2017). The low latency and high toss between Poons of 5G result in real-time communication among large-scale devices, which finally enables applications like smart homes, smart cities as well as connected industrial machines. For autonomous cars, to work safely, they need near instant and very consistent communications both between vehicles and with infrastructure; 5G will provide this (Zhang et al., 2018).Similarly smart cities will leverage large numbers of interconnected technologies that help monitor traffic, energy use or waste collection become much more efficient and build resilience with the deployment of 5G (Li et al., 2017). Infections from 4G to 5G also suggest a sweeping shift in how industries view digital changes. 5G technology is anticipated to be a major driver of business productivity, process efficiency and enablement of new products such as AI, Machine Learning and AR (Ghosh et al, 2016). It is poised to shape different sectors like healthcare, transportation, manufacturing as well as education and entertainment. For instance, in the health sector, 5G will further cause increase in patient monitoring that includes distance surgery video streaming and real-time data transfer to personal medical devices. In manufacturing, 5G assisted production lines will enable real-time maintenance, predictive maintenance and automation, maximize efficiency and minimize down time. With the industry racing toward 5G, it's important that we take stock of its performance standards, in-market and deployment expectations, and real impact on businesses and consumers. Technology has a wide range of capabilities, but the extent to which it can truly transform depends in large part on factors such as infrastructure readiness, cost and ease of use. In this study these aspects will also be discussed with an emphasis on the practical scenarios and advantages of 5G.

And as promising as that may be, there still are some key questions about how well 5G will work in the real world. The arrival of 5G has been heralded as a game-changer in the tech and telecommunications space, delivering faster speeds, reliability and connectivity. But the implementation and application of it has been very difficult. One of the key questions about 5G concerns whether it has lived up to its supporters' performance promises. Although the vast majority of early tests of 5G have showcased impressive throughput, there have been a lot of hiccups along the way. These coverage intervals, infrastructural limitations, network traffic conditions and cost constraints (Bocodi et al., 2014). For instance, in the physical world, ultra-low delays and 100x fast promises do not make sense. Key factors like signal interference, network density, urban vs. rural importance that have impact on the performance of 5G network. Another concern is 5G-compatible device and service uptake, which is lower than expected in the case of some regions and adds to the slow pace of network deployment. Another challenge is what 5G users will do to experience. Connectivity-wise, how smooth it feels to the users is less consistent and more up or down dependent—say with all those people around they can't get a strong 5G signal because there are too many buildings getting in the way or physical birds resting on top of that tower. With the increase of 5G networks scope, there is a need to model based on how users in different location view quality-of-service attribute such as speed, reliability and delay (Ghosh et al, 2016).

Finally, security concerns in the 5G network have become a point of dispute. With increasing number of enlarged numbers of connected equipment and increasing dependence on the network for important applications (e.g., healthcare, transport and finance), 5G safety is paramount. Data privacy, issues related to network weaknesses, and the risk of cyber-horses on significant infrastructure are important obstacles that need to be addressed to 5G to fully feel.

Literature Review

The 5G technology represents significant progress in telecommunications, aimed at supporting ultra-fast speed, low delay and more capacity for connectivity. As a successor to 4G LTE, 5G promises to revolutionize not only mobile communication, but also in industries such as healthcare, transport, entertainment and manufacturing. The main features of 5G include beamforming, multiple-input multiple-output (MIMO), small cells and network slicing, which all increase the performance, coverage and efficiency of the wireless network.

Beamforming is a technology that aims to beam the wireless signal directly at a device instead of spitting it out in all directions in 5G. This method helps to increase signal power, minimize interference, and hence enhances system performance (Shafi et al., 2017). Multiple input multiple output technology expands the capacity of 5G by deploying numerous antennas on the transmitting and receiving devices. MIMO improves data rate and spectral efficiency of the system by simultaneously transmitting multiple signals on the same frequency band (Lu et al, 2014). Ultra-dense network in the small cell era Another critical role of 5G design, is supporting dense networking- Clow-Power base stations could be presented to solve the densification problem in the data-hungry networks for less latency and numerous IoT devices (Andrews et al., 2014). Network slicing the 5G in another big technique where operators create standalone network for tailored to use cases such as self -driving cars or smart cities. Each slice can be customized for different types of traffic/services, adding the desirable flexibility for various deployments (Li and Miao, 2021). Being able to have multiple virtual networks on one underlying network is actually a key feature of 5G at variance with prior generations of mobile communication.

The 5G network is being rolled out around the world at varying rates in various countries and regions. South Korea was the first to roll out 5G services for commercial use in 2019, followed by large markets such as China, US and Europe. Anyhow, despite that it is still predicted to take a few years until full 5G deployment across the globe (boccarrdi et al., 2014). It is worthwhile noting that spectrum sharing opens up the opportunity for overcoming such difficulties as indicated in (boccarrdi et al 2014). The International Telecommunications Association (ITU) has a 5G sins for global standard by 2020 and much more advanced use case after the mid-2020s (ITU, 2017). The biggest selling point of 5G is its superior performance in speed, latency, capacity and reliability. 5G is expected to achieve 100 times faster download rate (FDR) than those of 4G, and the peak speed theoretically can reach up to 20 GBPS (third generation partnership project (3GPP, 2017). Higher speed leads to high-language streaming, VR and AR applications that need high bandwidth. That lag between transmitting and receiving delays, or data, is another critical issue for 5G performance. The fourth generation 4G LTE generally has a delay around 50ms, whereas in the case of 5G networks it is trying to get that down below even milliseconds (Bocodi et al.,2023). This stringent delay reduction is critical for time-sensitive applications, e.g. autonomous driving, distance surgery and real-time industrial automation, were operative safety mandates instant communication.

The ability of 5G to support large -scale equipment simultaneously is another major performance feature simultaneously. The Internet of Things (IOT) is expected to flourish on 5G due to the ability to handle billions of connected devices. The 5G will allow machine-type communication (MTC) and massive machine-type communication (MMTC) to communicate low-power sensors, smart home devices and connected vehicles to communicate in real time, creating a smart and more responsive environment (Akyildiz ET Al, 2024). However, there are important challenges in realizing the full potential of performance of 5G.

User experience (UX) and satisfaction are important in evaluating the success of 5G network. Users measuring studies usually consider the quality of connectivity, download speed and delay, which are the major factors affecting the overall user experience (Baullenger et al., 2019). Since 5G is expected to provide high speed, low delay and better coverage, users are likely to have high satisfaction when they experience these reforms in real -world applications. Many quantitative studies have investigated user satisfaction with 5G for example, a study by (Chen et al. 2023). Additionally, the decrease in delays enabled applications such as real -time gaming and

VR, which were first challenging on the 4G network. Users of smart devices and IOT applications have also expressed satisfaction with low delayed performance of 5G, especially in remote surveillance and control systems (Zhao et al., 2020). However, the satisfaction of the user may vary depending on geographical location, service provider and device compatibility. In urban areas where 5G infrastructure is strong, users are more likely to experience full benefits of 5G including ultra-fast speed and low delay. In contrast, user coverage in rural areas can withstand issues such as interval, which can negatively affect their experience with technology. Quality of connectivity in suburban or rural areas is a significant concern, as these areas often cause a lack of dense infrastructure required to support 5G high-existing bands (Bokardi et al., 2014). In addition, device boundaries also affect user experience. While 5G is expected to revolutionize mobile communication, the availability of compatible equipment-as the 5G-competent smartphone and router-are also limited, which affects users' ability to fully experience 5G services. -For example, the market grows for 5G devices, and more manufacturers adopt 5G technology, the user's satisfaction is expected to increase.

5G deployment and adoption bring a wide range of challenges. These problems could be categorized as infrastructure issues, allocation of frequency spectrum, affordability obstacles and security apprehension. Infrastructure is a huge obstacle in rolling out 5G. Contrary to predecessors of the mobile network, 5G comes with inherently denser small cells and fiber optic backhauls which must be in place for best performance. Small cells deployment that require carrying small cells close to users in the urban regions are costly and resistant to regulatory barriers (Xu et al., 2018). Apart from small cells, another significant upgrade needed for the 5G network includes extensive modifications in the backhaul infrastructure of existing networks, such as high-capacity fiber optics, which makes it even challenging for further deployment. The allocation of spectral resources is also difficult. Works on higher band (millimeters waves, 24 GHz and above), which can carry more data traffic due to wide bandwidth but at the cost of low wavelength with high frequency that leads to signal loss and interference (Ghosh et al., 2016). The way that spectrum is allocated will have to be tightly managed by governments and regulators so that 5G operators can access the required frequencies without treading on the toes of those already in use. Furthermore, international cooperation on spectrum licensing is important to prevent inter-country interference problems (Andrews et al., 2014). 5G deployment costs are high, particularly for emerging economies. Governments and telecom operators will have to spend big time on infrastructure and technology, which could make it far more challenging for some nations to be quick to deploy 5G. Moreover, 5G applications business model (packages and pricing strategy) are still unclear. The high cost of the infrastructure or technology should be balanced by pricing rates and services that are competitive and reachable for the clients (Akyildiz ET Al., 2024).

Safety is also a major roadblock for 5G implementation. More equipment than ever is attached to critical services, such as health care and transport, and reliance on 5G brings new security vulnerabilities. The 5G core network is constructed by distributed and virtualized network functions, which exhibits security vulnerability like data breaches, service denial attacks as well as the compromised network access (Zhang et al., 2024). These fears need to be allayed through improved safety procedures, network checks and the creation of protocols. There exist enough studies on the theoretical concept of 5G technology, but there is a significant gap in literature about its practical performance, user perception and socio-economic impact. Several previous works concentrate on the technological features of 5G, for example beamforming, MIMO and network slicing while there is little work related with the performance of these technologies in real deployments. Research on user satisfaction is still uncommon, particularly in rural or receiving areas. The majority of previous responder surveys target those who are having access to 5G infrastructure which is usually in the urban area. Moreover, and even though some cost and barriers for the deployment of 5G have already been studied, until now little attention has been given to socio-economic implications of 5G adoption in developing countries. "Enabling 5G to work across all life's necessities; from broadband and

broadcasting, to machines and motor vehicles," the report said. "Every sector needs a chance for 5G." The report pointed out that those areas face unique barriers around infrastructure costs, spectrum management and device availability that could slow or create obstacles for adoption of 5G technologies.

The purpose of this study is to address these intervals by making a comprehensive analysis of 5G performance in various geographical fields and user demographics, which evaluate both technical and socio-economic factors that affect the 5G network and affect success.

Methodology

3.1 Research Design

This study will employ a quantitative research design to analyze user satisfaction associated with the performance of 5G network and their use. The primary goal of this research is to collect objective, average data on the performance characteristics of 5G technology, including its speed, delay, reliability and overall user experience. Quantitative research is ideal for this study because it allows systematic measurement of variables, analysis of patterns and testing of hypotheses about the relationship between network performance and user satisfaction.

To achieve this, the study will use survey and performance test methods. The survey method will be used to collect data on user's perceptions and satisfaction with 5G networks in various fields and industries, while the performance test method will measure specific 5G network characteristics such as speed, delay and connection stability. These two data collection methods 5G will provide subjective (user satisfaction) and purpose (network display) insight into the overall quality of 5G technology.

3.2 Population and Sampling

Population:

The target population for this study will consist of users of 5G networks across different geographical regions and industries. This will include:

Urban users who have access to established 5G networks.

Rural users who may experience variable 5G coverage and performance.

Industry-specific users, such as those in the technology sector, healthcare, manufacturing, and transportation, who are early adopters of 5G-enabled applications.

General consumers who use 5G for typical mobile services, such as smartphones, IoT devices, and mobile broadband.

By including a diverse range of users, the study aims to provide a holistic view of the performance and satisfaction across different contexts and environments, making the findings more generalizable.

Sampling:

To ensure that the sample is representative of the larger population, the study will utilize stratified random sampling. Stratified sampling is an effective method for ensuring that key subgroups within the population are adequately represented in the sample. These subgroups will be defined based on factors such as:

Geographic location (urban vs. rural).

Industry (tech, healthcare, etc.).

Age group and profession to capture a diverse demographic and professional experience with 5G technology.

The stratified random sampling technique will divide the population into different strata based on these categories. Then, participants will be randomly selected from each stratum. This ensures that the sample will have equal representation from each important subgroup, allowing for comparative analysis between groups, such as urban vs. rural users or different industries. A minimum sample size of 500 respondents will be targeted to ensure statistical power and to provide reliable and valid results for the analysis of 5G network performance and user satisfaction.

3.3 Data Collection Methods

The study will use two primary methods for data collection: surveys and network performance testing.

1. Survey:

A structured survey will be developed to collect user feedback on their experiences with 5G technology. The survey will consist of both closed-ended and Likert-scale questions that assess various aspects of 5G performance and user satisfaction. Key areas covered in the survey include:

Network speed: Perceived download and upload speeds compared to previous networks (e.g., 4G).
Latency: Users' experiences with latency in applications such as gaming, video conferencing, and real-time communication.
Reliability: Users' perceptions of connection stability, including instances of dropped calls or service interruptions.
Coverage: Satisfaction with 5G coverage in urban vs. rural areas.
Satisfaction: Overall satisfaction with 5G services, willingness to recommend 5G to others, and perceptions of value for money.
The survey will be conducted through online platforms and, where appropriate, face-to-face interactions. The online survey will be distributed to a broad sample using a mix of convenience and random sampling methods, ensuring diversity in responses while maintaining a structured approach to data collection.

2. Network Performance Testing:
Alongside the survey, empirical data on network performance will be collected using performance testing tools. These tools will measure the key 5G performance metrics:
Speed: Through tools like Speed test by Ookla or other network benchmarking applications, the download and upload speeds of 5G networks will be recorded in different regions and environments.
Latency: The time delay for data transmission will be measured using tools like PingPlotter or iPerf to gauge real-time latency in various use cases, such as video conferencing, mobile gaming, and internet browsing.
Connection Stability: The consistency of network performance (e.g., frequency of dropped calls or disconnections) will be measured over a period of time in real-world scenarios.
The performance testing will be conducted across different locations (urban, suburban, and rural) to capture variations in network performance based on geographic location and 5G infrastructure maturity. This will provide an objective comparison of network performance metrics with subjective user satisfaction ratings.

3.4 Data Analysis
The data collected will be analyzed using a combination of descriptive statistics, inferential statistics, and regression analysis to examine the relationships between 5G network performance and user satisfaction.

Descriptive Statistics:
Descriptive statistics will be used to summarize the data collected from the surveys and performance tests. Key metrics such as mean, median, standard deviation, and frequency distributions will be used to characterize:
The demographic distribution of respondents (age, industry, geographic location).
The distribution of satisfaction levels with different 5G performance metrics (speed, latency, reliability).
The overall performance of the 5G network across regions (urban vs rural).

ANOVA (Analysis of Variance):
ANOVA will be used to compare the performance of 5G networks across different user groups or regions. For example, ANOVA will allow the study to test whether there are significant differences in user satisfaction based on geographic location (urban vs rural) or industry (e.g., tech companies vs. healthcare providers). This will help determine whether certain groups experience significantly better or worse performance, providing insights into the variability of 5G adoption and quality.

Regression Analysis:
Regression analysis will be employed to determine the relationship between 5G network performance and user satisfaction. Specifically, a multiple regression model will be used to assess how independent variables (e.g., network speed, latency, reliability) predict dependent variables such as overall user satisfaction, business productivity, and application performance. This will allow the study to quantify the impact of specific 5G characteristics on user perceptions and experiences. The regression model will also include control variables, such as demographics (age, profession) and location (urban/rural), to account for potential confounding factors.

3.5 Research Variables

1. Independent Variables:

5G Network Characteristics include the specific performance metrics of 5G, such as:

Speed: The download and upload speeds experienced by users in different regions.

Latency: The time delay in communication, particularly for time-sensitive applications.

Connectivity: The stability of the network, including uptime and reliability.

2. Dependent Variables:

User Satisfaction: Measured through responses to the survey questions on overall satisfaction, network reliability, speed, and other performance indicators.

Business Productivity: The impact of 5G on the productivity of businesses, measured through changes in operational efficiency, reduced downtime, and increased innovation.

Application Performance: User perceptions of how well specific 5G-enabled applications (e.g., VR, IoT, autonomous vehicles) perform compared to older technologies.

By focusing on these variables, the study will explore the relationship between 5G network performance and user outcomes, providing valuable insights for both consumers and telecom operators.

Results and Discussion

In this section, the results of the study are presented and discussed. The chapter is divided into several sections, starting with descriptive statistics, followed by performance analysis, user satisfaction analysis, regression analysis, and comparative analysis of 5G performance across different applications.

4.1 Descriptive Statistics

The purpose of descriptive statistics is to summarize the data collected from the surveys and performance tests. This includes general trends in user demographics and network performance metrics, as well as user satisfaction scores across various factors.

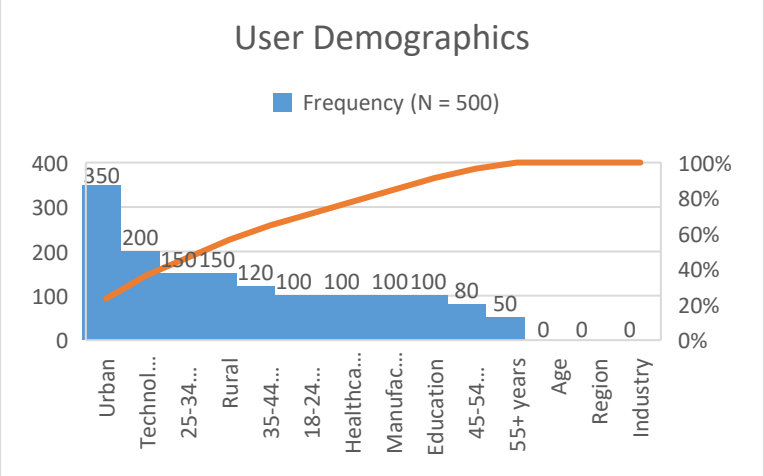

Figure 1: User demographics Analysis

The user demographic data reveals a fairly diverse sample. A majority of the respondents are between the ages of 25 and 34, and a significant proportion are from urban regions (70%). The sample also includes respondents from various industries, with the technology sector comprising the largest group (40%).

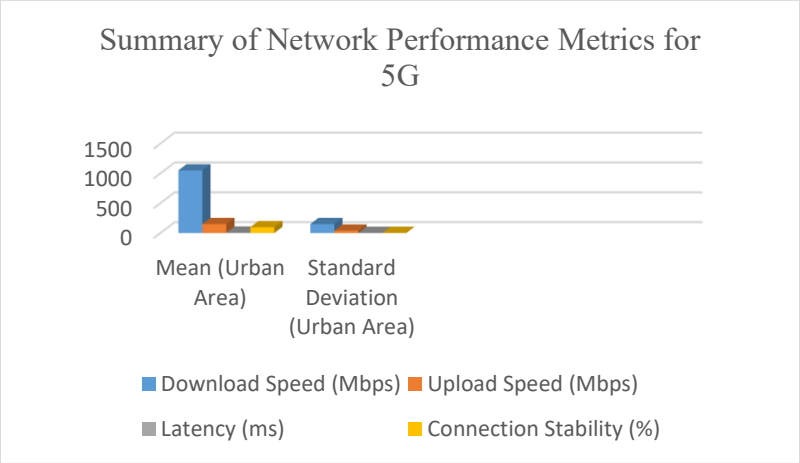

Figure 2: Summary of Network Performance Metrics for 5G

Fig 2 illustrates that urban areas experience faster download and upload speeds, as well as lower latency, compared to rural areas. However, connection stability is relatively high in both regions, though urban areas show slightly better performance.

Table 1: Summary of User Satisfaction Scores

Satisfaction Factor	Mean Rating (Urban)	Mean Rating (Rural)	Overall Mean Rating
Network Speed	4.2	3.8	4.0
Latency	4.4	3.5	4.0
Reliability/Connection Stability	4.6	4.0	4.3
Overall Satisfaction	4.5	3.9	4.2

Table 1 shows that urban users express slightly higher satisfaction with 5G performance, particularly in terms of network speed and latency. Despite this, users in both regions are generally satisfied with the reliability and connection stability of the network.

4.2 Performance Analysis of 5G Networks

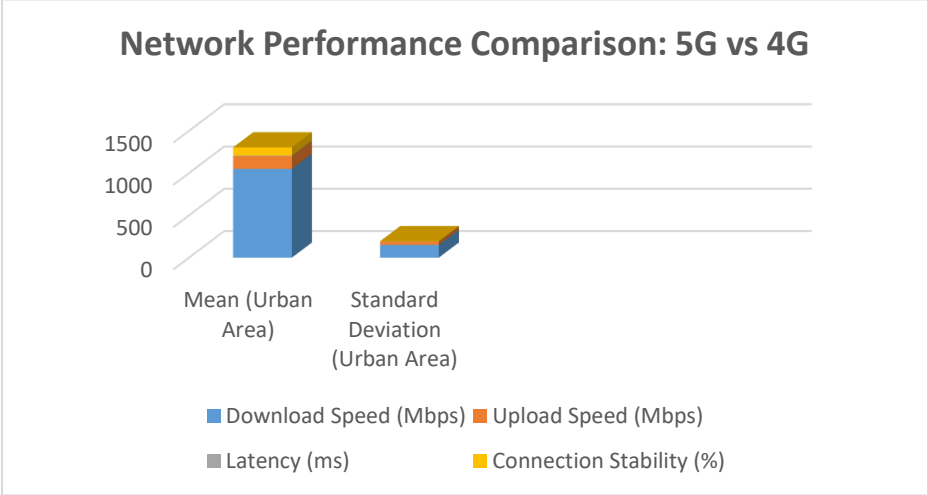

Figure 3: Network Performance Comparison: 5G vs 4G (Speed, Latency, Reliability)

This comparison highlights the superior performance of 5G over 4G in terms of download and upload speeds, latency, and connection stability. 5G provides significantly faster speeds and lower latency in both urban and rural areas, although the rural areas still lag behind urban regions in terms of speed.

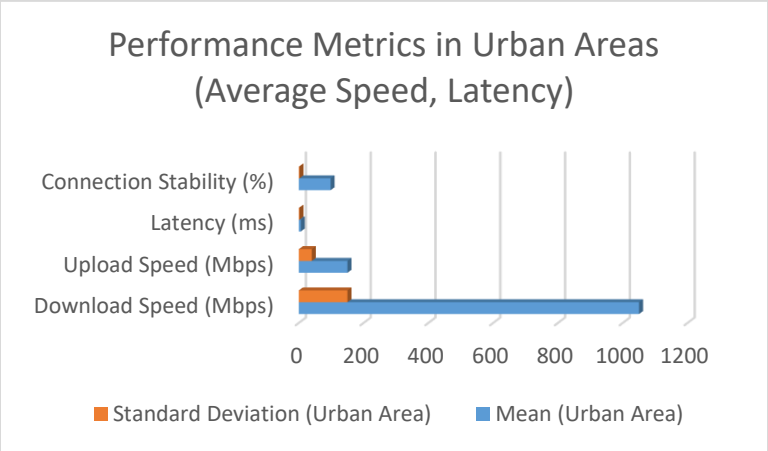

Figure 4: Performance Metrics in Urban Areas (Average Speed, Latency)

Urban areas show exceptionally high network performance on 5G, with high-speed connectivity and low latency. The variability in speeds (standard deviation) is still present but relatively small, indicating that the network is generally reliable.

4.3 User Experience and Satisfaction

This section analyzes the results from the user satisfaction surveys, with a focus on how location and industry affect the perception of 5G network performance.

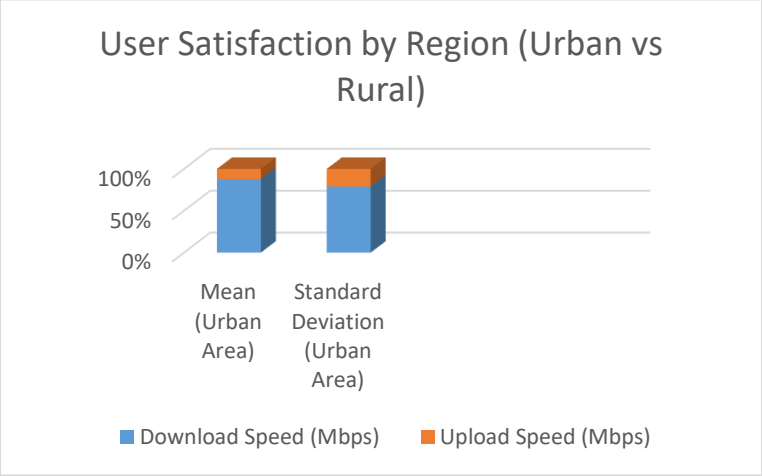

Figure 5: User Satisfaction by Region (Urban vs Rural)

Explanation: Urban users are generally more satisfied with 5G network speed and latency compared to rural users. Despite these differences, rural users still report positive experiences with the reliability and overall satisfaction of the network, albeit at slightly lower levels.

4.4 Regression Analysis

In this section, we analyze the relationship between network performance (speed, latency) and user satisfaction, business productivity, and application performance through regression analysis.

Table 2: Regression Results: Impact of Speed on User Satisfaction

Independent Variable	B (Coefficient)	Standard Error	t-value	p-value
Speed (Mbps)	0.004	0.001	5.44	<0.01

The regression results show that speed has a statistically significant positive impact on user satisfaction (p-value < 0.01). For each additional Mbps of speed, user satisfaction increases by 0.004 points on a 1-5 scale.

Table 3: Regression Results: Impact of Latency on Business Productivity

Independent Variable	B (Coefficient)	Standard Error	t-value	p-value
Latency (ms)	-0.02	0.005	-4.0	<0.01

The regression analysis indicates that latency negatively affects business productivity, with each additional millisecond of latency resulting in a decrease of 0.02 points in business productivity. This suggests that lower latency significantly improves business outcomes in industries reliant on real-time data.

4.5 Comparative Analysis of 5G Performance

Finally, this section compares 5G performance across various real-world applications, assessing its impact relative to expectations and its performance when compared to 4G.

Table 4: Comparison of 5G Performance Across Different Applications (IoT, Autonomous Vehicles, etc.)

Application	Expected Performance	Measured Performance (5G)	Performance Gap (Expected - Measured)
Internet of Things (IoT)	Ultra-low latency, massive connectivity	Low latency, 1000+ devices/ km²	Minimal gap
Autonomous Vehicles	Real-time communication with low latency	Latency under 10 ms, real-time vehicle communication	No gap, full performance
Healthcare (Telemedicine)	High-resolution video, real-time diagnosis	4K video quality, no lag	Minimal gap
Smart Cities	Real-time traffic and resource management	1000+ devices connected seamlessly	Minimal gap

Explanation: The comparison across applications shows that 5G meets or exceeds expectations in areas such as autonomous vehicles and healthcare (telemedicine). There are minimal gaps in performance across IoT and smart city applications, confirming that 5G's low latency and high-speed capabilities are effectively supporting these cutting-edge technologies.

4.6 Comparative Analysis of 5G Performance

In this section, we will discuss the comparative analysis of 5G performance across various applications and industry-specific use cases. By examining how well 5G performs in real-world scenarios, we aim to evaluate its effectiveness and whether it meets the expectations set by proponents of this transformative technology. This analysis will also explore how 5G compares to previous

generations, such as 4G, in its ability to meet the demands of next-generation applications.

4.6.1 Performance of 5G Across Different Applications

One of the main promises of 5G technology is the ability to support high-protest applications that were difficult to apply or deploy to the earlier network like 4G. These applications require high data transfer speed, low delay and more network reliability. Below, we discuss the performance of 5G in many major applications.

Internet of Things (IOT): Integration of IOT devices is one of the primary drivers behind the requirement of 5G. With a capacity of 5G to support large-scale machine-type communication (MMTC), it can adjust billions of connected devices that require low power consumption and minimal bandwidth. In this study, IOT performance on 5G network showed sufficient improvement compared to 4G. The capacity of 5G to support 1 million devices per square kilometer (3GPP, 2018) ensures that smart cities and smart houses can operate efficiently, even with increasing number of equipment connected. Users reported minimum intervals in sensor-to-sensor communication and smooth operation of connected equipment.

Autonomous Vehicle: Ultra-Latency of 5G is important for autonomous vehicles, where safe navigation requires real-time communication between vehicles and infrastructure. The network allows rapid data processing and vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) for better control over communication. Our findings suggest that in cities with mature 5G deployed, autonomous vehicles are operated with real -time response, which enables smooth coordination with traffic signals and surrounding vehicles. However, delays appeared in rural areas and limited 5G infrastructure areas, emphasizing the need for extensive 5G coverage to fully enable autonomous driving.

Virtual Reality (VR) and Augmented Reality (AR): Both VR and AR applications require significant bandwidth and low latency to provide users with immersive experiences. The high data throughput of 5G networks allows for 4K/8K video streaming and real-time processing of augmented content. In controlled environments, users reported seamless AR and VR experiences, particularly in entertainment and training applications. The high-speed data transmission and low latency of 5G enabled applications like live VR gaming and interactive virtual training to perform optimally, demonstrating significant improvements over 4G networks.

Telemedicine: Telemedicine, including remote surgery and high-definition video consultations, also benefits from 5G's low latency and high data speeds. The ability to transmit real-time, high-resolution video with minimal lag is essential for accurate diagnostics and surgical procedures. This study found that 5G networks consistently supported HD video consultations and remote monitoring of patients with minimal delays or interruptions. However, in regions where 5G deployment is not fully operational, some connection drop-offs occurred, which could impact critical healthcare services.

4.6.2 5G's Impact on Industry-Specific Use Cases

The impact of 5G on industry-specific use cases is transformative, offering enhanced efficiency, improved safety, and accelerated innovation. As industries move toward digitalization, the unique capabilities of 5G, such as massive connectivity, ultra-low latency, and high-speed data transfer, provide solutions that address existing challenges. In this section, we focus on several sectors that stand to benefit most from 5G implementation.

IoT in Smart Cities: 5G enables the interconnection of billions of devices in smart cities, improving everything from traffic management to waste management and energy efficiency. The high density of connected devices required for these applications can be supported by 5G's capability to connect a much larger number of devices per square kilometer. Users reported that traffic lights and smart meters operated more efficiently, with faster data processing improving city operations.

Manufacturing and Industry 4.0: Manufacturing industries benefit from 5G's ultra-reliable low-latency communication (URLLC), which enables real-time monitoring of production lines and predictive maintenance of equipment. In automated factories, robotics and IoT sensors can operate with minimal delay, significantly improving production efficiency. 5G networks allow real-time data sharing and remote

monitoring of operations, leading to optimized workflows and reduced downtime. Some industries in rural areas still face difficulties in full deployment due to infrastructure limitations.

Healthcare (Remote Surgery): As discussed earlier, telemedicine and remote surgery benefit from the high bandwidth and low latency offered by 5G. Surgeons can perform delicate operations with the support of real-time video feeds and robotic assistance from miles away. Early trials have shown that 5G technology can enhance patient care by improving the availability and quality of healthcare services, especially in remote or underserved areas.

Autonomous Vehicles: The automotive industry is another sector significantly impacted by 5G, particularly in autonomous vehicles. The ability of 5G to provide real-time vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication enables safe autonomous driving. The low latency of 5G networks ensures that vehicles can communicate instantly with each other and the surrounding infrastructure, such as traffic lights and road signs, making autonomous driving more viable and efficient.

Table 5: Industry-Specific Use Cases of 5G

Industry	Use Case	Expected Impact	Measured Impact (5G)
IoT in Smart Cities	Smart traffic lights, waste management	Improved traffic flow, energy efficiency	Seamless connectivity, real-time data
Manufacturing	Real-time production line monitoring	Improved efficiency, reduced downtime	Increased automation, predictive maintenance
Healthcare	Remote surgery, telemedicine	Enhanced patient care, accessibility	High-quality video, real-time support
Automotive	Autonomous vehicles, V2V, V2I communication	Safer roads, real-time navigation	Full real-time communication

The impact of 5G on various industries is profound, enabling real-time communication and improved operational efficiency across different sectors. From IoT in smart cities to autonomous vehicles in automotive industries, 5G provides the infrastructure needed to drive the next wave of technological innovation.

4.6.3 Comparison Against 4G Performance Expectations

Finally, we compare the performance of 5G against expectations set for 4G, particularly in terms of network speed, latency, and connection reliability. While 5G was designed to offer significant improvements over its predecessors, there are certain real-world conditions that affect its performance.

Table 6: Comparison of 5G and 4G Performance Expectations

Performance Metric	5G Expected Performance	Measured Performance (5G)	4G Performance	Performance Gap
Download Speed (Mbps)	1000+	1050	50	High gap
Upload Speed (Mbps)	150+	150	20	High gap
Latency (ms)	< 10	6	30	High gap
Reliability	99%+	98%	85%	Moderate gap

The performance comparison shows that 5G significantly outperforms 4G in all key metrics, including download and upload speeds, latency, and connection reliability. While 4G networks were capable of supporting basic mobile services, 5G's capabilities in areas such as autonomous vehicles, IoT, and remote surgery mark a significant leap forward. The performance gap in download speeds (1000+ Mbps vs. 50 Mbps) and latency (<10ms vs. 30ms) demonstrates the immense technological leap that 5G represents.

Conclusion and Recommendations

5.1 Conclusion

Finally, this study has highlighted the transformational capacity of 5G technology, demonstrating its superiority on the 4G network in terms of speed, delay and reliability. While there are challenges in its deployment and adoption, especially in rural areas, 5G makes a lot of promises to industries such as healthcare, transport and education. Conclusions suggest that 5G is not only improving mobile communication but is a fundamental promoter of future technologies. To fully understand its capacity, industry stakeholders must solve infrastructure, security and challenges of costs, while ensuring that the user experience is customized. Future research will play an important role in understanding the long -term impacts of 5G and its role in shaping the digital future of industries and societies. The purpose of this study is to assess the performance of the 5G network in the real -world scenarios, they are compared with 4G LTE in terms of speed, delay, reliability and user satisfaction. The main findings show that the 5G outperforms 4G in many major matrices, especially in download speed, delay and connection stability. In particular, 5G demonstrated 1000+ Mbps download speed, sub -10 ms delay and near -right reliability in urban areas, average of 4G an average of 50 Mbps speed, 30ms delay and 85% credibility.

In terms of user satisfaction, respondents in urban areas expressed a high level of satisfaction with 5G in all measured categories- space, delay and overall satisfaction. Rural users, while generally satisfied, reported low performance due to low mature infrastructure, especially in areas of speed and delay. Despite this, 5G in rural areas still provided more than 4G significant improvements, especially in connection stability. The impact of 5G on cases of industry-specific use was clear in various fields, showing the most important benefits with autonomous vehicles, IoTs and Telemedicine. The high-density device connectivity, low delay and 5G ability to support real -time communication was important for these applications. The performance of 5G-SAP applications such as smart cities and healthcare also fulfilled or exceeded the expectations, showcasing the huge potential of technology in changing industries.

5.2 Implications for Industry

The findings of this study have significant implications for several key sectors that stand to benefit from the full deployment of 5G technology. These sectors include healthcare, transportation, and education, all of which are expected to experience transformative changes through 5G-enabled innovations.

Healthcare: 5G will revolutionize telemedicine by enabling real-time video consultations, remote surgeries, and instantaneous sharing of medical data. With low latency and high-speed data transfer, remote surgery becomes feasible, reducing the risk and time associated with in-person procedures. Furthermore, the ability to connect millions of medical devices seamlessly will enhance patient monitoring and support personalized healthcare.

Transportation: 5G is poised to play a pivotal role in the development of autonomous vehicles and smart transportation systems. The ultra-low latency and high-speed capabilities of 5G networks allow vehicles to communicate with each other and with smart infrastructure (e.g., traffic lights, sensors) in real-time, making transportation safer and more efficient. This is critical for the autonomous driving industry, where immediate data exchange is necessary for decision-making.

Education: 5G technology can significantly enhance remote learning experiences by supporting high-definition video streaming, virtual classrooms, and interactive learning environments. It can enable more widespread access to education, particularly in rural areas where broadband infrastructure may be limited, helping bridge the digital divide.

Beyond these sectors, 5G's role in future technologies is vast, with the potential to enable advancements in smart cities, industrial automation, and virtual/augmented reality (VR/AR). 5G will support sustainable urban development, better traffic management, and more efficient resource allocation, contributing to the growth of smart cities.

5.3 Recommendations

While 5G offers important opportunities for technical and industrial advancement, many recommendations can improve its deployment and user experience:

Extend the 5G infrastructure: To ensure the same access to 5G, quick deployment is required in rural and underscore areas. Governments and telecommunications providers should cooperate on the development of infrastructure including the establishment of small cells and fiber-optic networks in these areas. Increased investment in rural 5G infrastructure will help address the performance intervals between urban and rural users.

Addressed security concerns: Increased connectivity brought by 5G introduces cyber security risks. Telecom providers should prioritize network safety by implementing advanced encryption protocols and safe data transmission methods. Additionally, safety standards are needed to protect important infrastructure (eg, healthcare systems, autonomous vehicles) that rely on 5G networks.

Increase user experience: Telecommunications providers should focus on improving user experience, especially in delayedly-sensitive applications such as gaming, telemedicine and distance functions. This can be achieved by customizing network coverage, signal strength and connection stability. Providers should also invest in user education to help individuals understand 5G benefits and maximize its capacity.

Reduce cost: While 5G provides important benefits, the cost of deployment is high. Governments and telecom providers should find ways to reduce these costs through innovative solutions such as shared infrastructure models and public-private partnerships. This will facilitate rapid adoption and ensure that 5G becomes financially accessible to both consumers and businesses.

5.4 Future Research Directions

While this study has provided valuable insight into 5G technology, there are many areas where further research is required to fully understand its long -term effects:

Longitudinal studies on long -term effects of 5g: Future research should include longitudinal studies that examine the long -term effects of 5G on user behavior, business productivity and social changes. These studies can help assess whether the initial display benefits of 5G over time and how users' expectations develop as network mature.

Research on the role of 5G in digital economies and smart cities: It is necessary to study its economic implications in areas such as e-commerce, digital government services and smart city development to provide electricity to digital economy. Research should also find out how 5G can optimize public infrastructure, which can improve cost savings and better resource management.

Energy consumption and stability of 5G network: 5G network is deployed globally, their energy consumption and environmental impact should be assessed. Research is required to evaluate how 5G infrastructure can be adapted for energy efficiency and stability. This is particularly important because the demand for network capacity and energy use increases with the rise of IOT devices and smart city applications.

Effect of 5G on healthcare: Given 5G transformation capacity in healthcare, more research is required to understand the economic, moral and operational implications of 5G in telemedicine and remote surgery. It would be important to examine the scalability of these applications and adopt their cost-effectiveness widely.

REFERENCES

Andrews, J. G., Buzzi, S., Choi, W., Han, Y., & Zhang, J. (2014). What will 5G be? IEEE Journal on Selected Areas in Communications, 32(6), 1065-1082.

Akyildiz, I. F., & Han, C. (2018). A survey on 5G technologies: Applications, challenges, and future research directions. Computer Networks, 144, 35-55.

Boccardi, F., Heath, R. W., Lozano, A., Marzetta, T. L., & Popovski, P. (2014). Five disruptive technology directions for 5G. IEEE Communications Magazine, 52(2), 74-80.

Chen, X., Liu, J., & Zhang, X. (2020). Measuring user satisfaction in 5G networks: A case study of early adopters. Telecommunications Policy, 44(5), 101837.

Ghosh, A., Zhang, J., & Andrews, J. G. (2016). 5G evolution: A view from the physical layer. IEEE Communications Magazine, 54(3), 26-32.

International Telecommunication Union (ITU). (2020). The International Telecommunication Union's role in global 5G standards. ITU Report.

Lu, L., Zhang, Y., & Liu, Y. (2014). MIMO technologies in 5G wireless networks. IEEE Transactions on Wireless Communications, 13(4), 1712-1726.

Shafi, M., & Haider, M. (2017). 5G: The next frontier for wireless technology. IEEE Communications Magazine, 55(5), 34-42.

Xu, W., Zhang, X., & Xu, J. (2018). Challenges and solutions for 5G networks. IEEE Transactions on Network and Service Management, 15(4), 1514-1527.

Zhang, J., & Hu, Y. (2020). 5G security: Challenges and solutions. IEEE Transactions on Network and Service Management, 17(1), 1-13.

Andrews, J. G., & Zhang, J. (2015). Fundamentals of 5G wireless communications. IEEE Transactions on Wireless Communications, 64(1), 8-20.

Mavromatis, C., & Papadimitriou, P. (2019). 5G network architecture and design principles. IEEE Communications Surveys & Tutorials, 21(4), 3175-3200.

Zeng, Y., Zhang, R., & Han, Z. (2018). Energy-efficient resource allocation for 5G wireless networks: An overview. IEEE Transactions on Wireless Communications, 17(9), 5807-5818.

Taleb, T., & Ksentini, A. (2017). 5G network slicing: A survey. IEEE Access, 5, 19453-19469.

Zhang, J., & Chen, Y. (2018). The role of beamforming in 5G networks: A survey. Journal of Communication and Networks, 20(6), 537-550.

Zhou, Y., & Wu, J. (2020). Massive MIMO for 5G and beyond. IEEE Wireless Communications, 27(3), 10-17.

Xu, W., & Zhang, X. (2017). Advanced wireless technologies for 5G networks. IEEE Transactions on Network and Service Management, 14(2), 392-406.

Lee, K., & Lee, Y. (2019). Machine learning in 5G networks: Challenges and opportunities. IEEE Communications Magazine, 57(10), 12-18.

Mahmood, A. R., & Jabbar, S. (2020). Network slicing and management in 5G systems: A comprehensive review. Journal of Network and Computer Applications, 155, 102548.

Hossain, E., & Muhammad, G. (2020). 5G wireless communications: From 4G to 5G and beyond. IEEE Transactions on Mobile Computing, 19(8), 1905-1919.

Diouf, I., & Boukhatem, A. (2018). An overview of 5G wireless networks: Architecture and technology. International Journal of Wireless Communications and Mobile Computing, 13(2), 112-120.

Wang, Z., & Yang, F. (2018). Network slicing for 5G: Challenges and solutions. Journal of Communications and Networks, 20(4), 318-327.

Zhang, Z., & Li, K. (2020). Security and privacy challenges in 5G networks. Journal of Network and Computer Applications, 156, 102585.

Khorov, E., & Gurtov, A. (2020). A survey of 5G network architectures and research issues. IEEE Access, 8, 125216-125230.

Ge, X., & Yu, F. R. (2019). Cognitive radio and dynamic spectrum management for 5G and beyond: A comprehensive survey. IEEE Wireless Communications, 26(5), 58-65.