

Performance Analysis of 5G Mobile Networks in Urban

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Abstract— 5G networks are expected to provide significant improvements in mobile communication performance, especially in dense urban environments. This research aims to analyze the performance of 5G networks in urban areas with a focus on throughput, latency, and user satisfaction. The methodology used includes field measurements in several strategic locations in major cities, as well as simulations to predict performance under various conditions. The results show that 5G networks are capable of achieving an average throughput of 1.5 Gbps with latency of less than 10 ms, which is much better compared to 4G networks. Nonetheless, challenges such as signal interference and more complex infrastructure requirements still need to be overcome to maximize the potential of these networks. The research also identified factors that affect user satisfaction, including access speed and connection stability. These findings provide important insights for developers and service providers in designing and implementing more efficient 5G networks in urban environments. With a better understanding of the performance and challenges of 5G networks, it is expected to improve user experience and support the development of future communication technologies.

Keywords—Performance Analysis, Urban Environment, Throughput, Latency.

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I. INTRODUCTION

Mobile communication technology has been progressing, especially with the introduction of 5G networks. These networks promise higher data rates, lower latency, and greater capacity compared to the previous generation (4G) [4]. With the increasing demand for faster and more reliable data services, especially in dense urban areas, 5G is expected to fulfill these needs [5].

5G networks use technologies such as MIMO (Multiple Input Multiple Output) and beamforming to improve spectrum efficiency and reduce interference [6]. However, the implementation of these networks in urban environments faces various challenges, including signal interference, more complex infrastructure requirements, and issues related to user mobility [7].

This research aims to analyze the performance of 5G networks in urban areas with a focus on throughput, latency, and user satisfaction. By conducting field measurements and simulations, it is expected to provide a deeper insight into the potential and challenges faced by 5G networks in urban environments. The findings from this research are expected to contribute to developers and service providers in designing networks that are more efficient and responsive to user needs.

II. LITERATURE REVIEW

This literature review aims to provide a deeper understanding of the development of 5G network technology, network performance, and applications supported by this

technology. This research will also discuss the challenges faced in the implementation of 5G networks in urban areas.

A. 5G Technology Development

5G networks are the fifth generation of cellular technology designed to meet the increasing communication needs. According to *Andrews et al.* (2014), 5G not only offers increased data rates, but also lower latency and greater capacity compared to previous generations. It uses a wider spectrum of frequencies, including millimeter frequencies, to achieve better performance [8].

B. 5G Network Speed, Capacity and Latency

Speed and latency are two key parameters in assessing network performance. Research by *Zhang and Wang* (2020) shows that 5G networks can achieve speeds of up to 10 Gbps with very low latency, which is between 1 to 10ms. This is especially important for applications that require fast response, such as autonomous vehicles and augmented reality (AR) applications [1].

Meanwhile, the capacity of 5G networks is essential to support simultaneous connections in high-density areas. *Li and Chen* (2021) revealed that 5G can support up to 1,000,000 connections per square kilometer, much higher compared to 4G which is only able to support about 100,000 connections per square kilometer. This increased capacity allows more devices to be connected without compromising the quality of service [9].

C. 5G Network Applications

5G networks offer a wide range of applications that can revolutionize the way we interact with technology and our

surroundings. One of the most prominent applications is the Internet of Things (IoT), where millions of devices can connect simultaneously and communicate with each other with extremely low latency. This enables the development of smart cities, where infrastructure such as traffic lights, transportation systems, and public services can be optimized to improve efficiency and convenience. In addition, 5G also supports augmented reality (AR) and virtual reality (VR) applications, which require high bandwidth and low latency to provide an immersive user experience. In the healthcare sector, 5G enables telemedicine and remote surgery, where doctors can perform medical procedures with the help of connected robots in real-time, improving healthcare accessibility in remote areas[10].

In addition, 5G also has the potential to transform the automotive industry by supporting autonomous vehicles that require fast and reliable communication between vehicles and road infrastructure. With the ability to send and receive data in milliseconds, vehicles can adapt to traffic conditions in real-time, improving transportation safety and efficiency. In the industrial sector, 5G enables factory automation and the use of advanced robotics, which can increase productivity and reduce operational costs. Thus, 5G network applications are not only limited to personal communications, but also cover a wide range of sectors that can improve quality of life and operational efficiency in various fields[7].

D. Challenges of 5G Network Implementation

While the potential for 5G networks is huge, their implementation in urban areas faces significant challenges. One of the main challenges is the need to build denser infrastructure, including cell towers and small antennas, to support the millimeter frequency (mmWave) used by 5G. These frequencies have a shorter range and are more susceptible to physical obstacles, such as buildings and trees, requiring more access points to ensure adequate coverage. In addition, the cost of building and maintaining this infrastructure can be a burden for telecom operators, especially in large cities with high density. Strict regulations and lengthy licensing processes can also slow down the development of the necessary infrastructure[1].

Another challenge that needs to be addressed is the issue of security and privacy. With the increasing number of devices connected through 5G networks, the risk against cyberattacks and data breaches also increases. Therefore, it is important to develop robust security protocols to protect user data and ensure network integrity. In addition, public awareness and education about 5G technology also needs to be improved, given the concerns and misinformation circulating in the community. To overcome these challenges, collaboration between the government, telecom operators, and other stakeholders is essential to create an ecosystem that supports the development and implementation of 5G networks effectively and safely[11].

III. RESEARCH METHODOLOGY

A. Research Design

This study aims to analyze the performance of 5G mobile networks in urban areas with a quantitative approach and descriptive design. The research was conducted in three strategic locations in big cities that have implemented 5G networks, namely business centers, residential areas, and public areas. The selection of these locations aims to obtain representative data on network performance in various environments

A quantitative approach was used to objectively measure and analyze the data. The descriptive design allows researchers to describe the performance characteristics of 5G networks without intervening. Data was collected through direct measurement using signal and internet speed measurement devices[12].

B. Research Location

In this journal, the author raises research located in 3 different places with different population densities with different characteristics. among them are such as in the location of the Business Center where the area is high density and intensive network usage. then there is a location in the Residential area which is an area with a variety of network usage by various groups of people. then there is the location of the Public Area which is a public place that is often visited, such as parks and shopping centers.[13]

C. Data Collection Technique

Data collected using mobile networks 5G smartphones to measure download, upload and latency speeds. Signal Measuring Device To analyze signal strength and network quality. Measurements were taken during peak and off-peak hours to get a more comprehensive picture of network performance. Each location was measured three times to ensure data consistency.

Observations made are by In this journal, the author takes an example from a journal with the author *Muhammad Anas Masa* and his team in his journal which reveals and is located in South Sulawesi. South Sulawesi. Furthermore, data on the number of villages that can access BTS signals and the internet availability in village offices. Both of the above Table 1 and Table 2, respectively. Then mapping the challenges and opportunities in the application of spectrum and regulation as shown in table 3.[14]

IV. RESEARCH RESULTS AND DISCUSSION

D. 5G Technology Standard

Currently, the key requirements of 5G technology have been agreed upon. Globally, the technology development and the vision of 5G is to provide or support 1000x the the data capacity capability possessed by Long Term Evolution (LTE) or 4G technology with a speed of 1 Gbps on the user side under high network density conditions [15]. The ITU has several requirements for 5G which focuses on fulfilling three main performance indicators[5], which are as follows:

1. Data rates of up to 10 Gb/s for enhanced mobile broadband (eMBB),
2. 1 M/km² connection on large machine type communication (mMTC),
3. Latency 1 ms pada ultra-reliable low latency communications (URLLC).

The three service indicators mentioned above require a diverse frequency spectrum, including low, mid, and high bands. At low frequencies below 1 GHz, 5G communication will serve wide area coverage. Meanwhile, the mid-frequency range of 3–4 GHz provides high-capacity services capable of connecting many users with higher speeds. On the other hand, high frequencies above 24 GHz (e.g., mmWave) will offer extremely large capacities with very low latency, but with limited coverage, making them ideal for areas with extremely high traffic demand, requiring very high capacity or specific zones [8]. These different spectrums will deliver high-speed and high-capacity services using heterogeneous networks along with diverse connectivity, while still ensuring QoS on the user side. Such heterogeneous networks will drive infrastructure evolution, where 5G technology will rely on small cells due to the spectrum used by mmWave and D2D connections [16].

The prerequisites for 5G must be defined across several dimensions of perspective: user perspective, performance perspective, architecture perspective, operational perspective, and management perspective. Among these, the viewpoints of users, networks, and services are of primary importance [6]. Users expect 5G technology to offer attractive features, including reliable communication channels during disasters or evacuation efforts, consistently available high-speed internet connectivity in all areas, seamless video streaming, artificial intelligence, and real-time interactive holograms without freezing or interruptions, even inside buildings or in crowded environments. Additionally, massive IoT connectivity for applications such as CCTV, smart homes, smart cities, smart farming, telemedicine, and other innovative services is also anticipated [17].

E. Migration from 4G to 5G

Network migration refers to the evolution of a new network from the existing one. The development of telecommunication technology can be classified into two criteria: its architecture and component technologies [18]. The migration process from 4G to 5G technology takes approximately a decade, as illustrated in Figure 1 below.

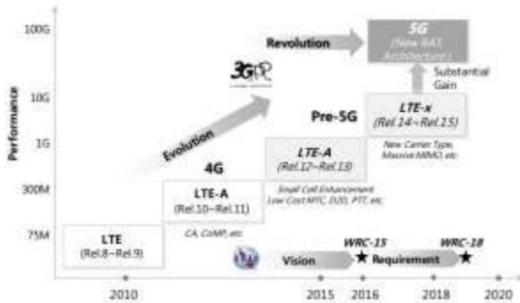


Fig. 2 4G to 5G Evolution [13]

The migration from 4G to 5G differs from the development of previous technologies because 5G infrastructure can be

implemented on a 4G network by leveraging the existing 4G architecture. This migration can be categorized into two models: Non-Standalone (NSA) and Standalone (SA). The architectural changes during the migration from 4G to 5G in the NSA model [18] are as follows:

1. SGW: In 4G communication, the Serving Gateway (SGW) connects the User Plane Function (UPF) to the Mobility Management Entity (MME). However, in 5G communication, UPF and the Access and Mobility Management Function (AMF) are interconnected without the need for an SGW.
2. MME: In 4G communication, the MME acts as the main control element in the Evolved Packet Core (EPC) for operations on the control plane.
3. AMF: In 5G communication, the AMF performs a similar function to the MME in 4G but is further optimized to enhance its capabilities.
4. E-UTRAN: This technology in 4G communication handles radio access from User Equipment (UE) to the core network.
5. NG-RAN: Similar to E-UTRAN, NG-RAN is optimized for radio access in 5G, utilizing a higher frequency spectrum than 4G.

With the increasing number of villages and sub-districts in South Sulawesi served by 4G BTS signals during 2019–2021, the likelihood of these areas experiencing 5G technology is significantly enhanced.[19]

F. Data Processing

Once the data is collected, the next step is to process it. The data will be selected according to the research needs. Data processing for implementing 5G involves identifying supporting factors to leverage strengths and opportunities, as well as recognizing obstacles in the form of weaknesses and threats.

TABLE I
POPULATION AND INTERNET PENETRATION DATA IN SOUTH SULAWESI [19]

Projecti on Year	Population	Internet Users
2018	8,771,970	3,253,524
2019	8,851,200	3,886,562
2020	9,073,509	4,499,554
2021	9,139,531	5,455,387

TABLE II
NUMBER OF VILLAGES/SUB-DISTRICTS COVERED BY INFRASTRUCTURE[20]

Infrastructure	2018	2019	2020	2021
BTS	1,370	1,507	1,614	1,683
4G BTS	-	1,248	1,474	1,584
Office	936	1,048	1,437	1,695
Internet Facilities				

Meanwhile, the strategies include utilizing all existing strengths to leverage identified opportunities, addressing weaknesses by taking advantage of those opportunities, using all strengths to

avoid mapped threats, and minimizing weaknesses while avoiding all threats [7].

TABLE III
CHALLENGES AND OPPURTUNITIES [21][22]

Aspect	Opportunity	Challenge
Spectrum and Regulation	Availability of frequency spectrum: 1.5 GHz, 3.4–3.8 GHz, 24.25–27 GHz, 27–29 GHz; ITU: 1–100 GHz	Spectrum in Indonesia, including South Sulawesi, is heavily utilized for other services.
Satellite Communication	Satellite supports 5G services by providing high-speed direct connectivity for remote coverage.	Potential loss of one of Indonesia's satellite orbits; spectrum may not be fully utilized.
Spectrum Utilization	Can adopt the concept of spectrum pooling to optimize usage.	Possible resistance from primary users, potentially leading to legal disputes.
Infrastructure Sharing	Industry support reduces capital expenditures.	Regulatory changes may be required.
Adoption of Technologies	Indonesia adopts all technologies, offering diverse technological options.	Requires significant resources; low coordination between ministries due to differing visions.
Regulatory Preparation	Supportive regulations promote technological development and adoption.	Changes in regulations may require stakeholders to adapt anew.
Local Content	Boosts local telecommunication industries beyond software focus.	Temporary decline in foreign investment while the government is encouraging their entry.

The processed data serves as a reference for implementing 5G opportunities based on the current infrastructure availability in South Sulawesi, supporting the migration to 5G technology [18]-[22]. The SWOT method is used to analyze these aspects.

G. Regulatory Aspect

The opportunities and challenges of telecommunications in South Sulawesi based on regulations and spectrum are illustrated in Table 3. From a regulatory perspective, inter-ministerial coordination is crucial due to differences in institutional visions, which can lead to misaligned regulations. The transition from 4G to 5G technology necessitates adjustments in telecommunications regulations. One of the key technical aspects recommended for regulation by the government is spectrum allocation.

5G technology operates across low, mid, and high frequency bands.

1. Low-band frequencies below 1 GHz have been utilized for TV broadcasting services (including analog TV broadcasts). The government has introduced regulations for the gradual deactivation of national analog TV broadcasts.
2. Mid-band frequencies, in the range of 3.4–4.2 GHz, are currently allocated for commercial satellite communication using the C-band. Given Indonesia's tropical geographical location, including South Sulawesi, and its high rainfall, the C-band is particularly reliable for satellite communication.

However, satellite communication can still operate using other commercial frequencies, such as the Ku-band and Ka-band [23]. With appropriate frequency selection, satellite communication can effectively support 5G technology.

H. Industrial Aspect

The telecommunications support industry plays a crucial role in the journey toward 5G implementation in South Sulawesi. As such, the supporting industries must adhere to specific standards for its implementation [5]. Below are the 5G network technology standards with indicators for the supporting telecommunications industry [24].

1. User Perspective: Users desire longer battery life and improved battery efficiency in devices, which indirectly relates to the supporting 5G technology industry.
2. Operational Perspective: Issues or concerns regarding personal data protection fall under the regulatory domain, while operational aspects such as comfort and security are directly related to Human Resources (HR).

V. CONCLUSION

Based on the research findings, the following conclusions can be drawn:

First, the migration from 4G to 5G under the Non-Standalone (NSA) model involves several architectural changes. These changes include the transition from SGW, MME, and AMF in the 4G architecture to the integration of E-UTRAN and NG-RAN, which are optimized for 5G technology.

Second, the key standards required for the implementation of 5G networks are recommended by the International Telecommunication Union (ITU) through the IMT-2020 program. These standards include eMBB (enhanced Mobile Broadband), URLLC (Ultra-Reliable Low Latency Communications), and mMTC (massive Machine Type Communications), all of which are essential for the successful deployment and operation of 5G networks.

Third, internet penetration in South Sulawesi has shown significant growth. In 2018, 37% of the population had internet access, which increased to 67.7% by 2021. This expansion is aligned with the growth of 4G infrastructure in the region, where the number of villages/sub-districts covered by BTS increased by 335% in 2021 compared to two years earlier. Of

the total BTS in the region, 94% were 4G, supporting the migration from 4G to 5G communication technology. Lastly, to implement 5G networks effectively, a recommended strategy is to maximize the use of D2D (Device-to-Device) technology. This communication allows User Equipment (UE) to communicate directly with each other, either with or without supervision from evolved Node B (eNB, the BTS in 4G networks), and operates on frequencies above 24 GHz, which is crucial for supporting the high capacity and low latency required by 5G.

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