Investigation on 5G Techniques for a College Scenario

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MASTER´S THESIS
DEPARTMENT OF ELECTRICAL AND INFORMATION TECHNOLOGY
FACULTY OF ENGINEERING | LTH | LUND UNIVERSITY

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Abstract

With the development of telecommunication technology, the mobile networks are being updated. 5G is the fifth generation mobile communication, which can provide a higher data rate, lower latency, more connections, higher security insurance, and more flexible business deployment capabilities than 4G.

The purpose of this master's thesis is to study the advantages of using 5G networks under different obstacles in a university scenario environment. In the thesis, we target the university office scene, including two different settings, indoor and outdoor.

We used real-world measurements to obtain relevant parameters and data, established a remote base station with the company's help, and then went to different locations in different environments selected by the university after we made the preset points. With the use of tools such as Signal to Interference plus Noise Ratio (SINR) and Reference Signal Receiving Power (RSRP), we measured the received signal strength, and then compared and analyzed the performance of the 5G network with a 4G network. Also, we compare our measurement results with theoretical results under the same conditions.

Popular science summary

Nowadays, cellular networks and wireless networks have become an essential part of human life. It is widely used in daily life and industry, agriculture, and various aspects of life. All vertical industries have multiple requirements of network functions that can be resolved into network bandwidth, connections, delay, reliability, and other demands. Mainly, mobile phones are Internet-based tools that individuals cannot take out of their lives. People use mobile phones to order meals, socialize, searching information, and even play games. The mobile phones are inseparable from the use of wireless networks and cellular networks. In addition, laptops are other important devices that use the mobile networks.

Compared with wired networks, cellular networks and wireless networks are more convenient. Nowadays, 4G networks are dominant in the market.

However, the 4G network has limitations in many places. For example, in streets with high-rise buildings, the 4G network signal is weak, which means that the applications need longer loading time. Also, under the subway, or in high mountains, the 4G network cannot carry out reliable transmission, which often has some negative effects. This will result in speed reduction and no reliable transmission and communication.

With the development of the Internet of things (IoT), the 5G network appears. The 5G network connects different things and people, flourishing millions of connections. A single 5G node needs to access thousands of devices simultaneously and ensure that each device has enough transmission capacity. Therefore, people began to research 5G networks that can replace 4G. The 5G network aims to meet the diversified needs of people, living, working, transportation, entertainment, etc., so that people can freely use the network no matter what scene they are in, dense residential areas, offices, open-air stadiums, highways, or especially in some commercial scenarios, such as VR, telemedicine, etc. In addition, 5G can also be deeply integrated with various fields, such as industrial facilities, medical instruments, and transportation tools, to effectively meet the diversified business needs of the vertical industry realize the actual interconnection of everything.

In this thesis, my purpose is to study 5G network technology, which can support data transmission in different scenarios, while maintaining its quality. This survey includes a real-time scenario test in colleges to determine the potential of 5G network technology. These investigations will face challenges, such as obtaining the characteristics of 5G network technology, comparing the differences between existing 4G networks and 5G networks, obtaining the coverage and penetration of 5G networks, etc. The company has established base stations to facilitate our testing and later data analysis. We will describe the technical performance of the 5G network under different scenarios and illustrate the statistical results with examples.

Acknowledgments

This Master's thesis would not exist without the support and guidance of William and Maria. Under their supervision, I can understand the topic more smoothly and learn more deeply. I also appreciate my supervisor, Ms. Yang Xi from China Mobile Beijing Branch, for her support and guidance during my graduation project. I thank her for her support of Lund University. Last but not least, I would like to thank my family and friends who supported and encouraged me as always and encouraged me during my whole study period.

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Contents

1. Introduction

1.1 Background

5G networks have many advantages over 4G networks, such as better transmission speed, lower delay, etc. 5G networks have two unique capabilities, network slicing and edge computing.

Network slicing is a way of on-demand networking, which aims to provide an independent logical network for specific users and business needs, in order to provide end-to-end support for services with differentiated SLA requirements and make various business scenarios coexist in one network. Network slicing uses a virtualization technology to virtualize the main resources according to different scenario requirements, in order to form multiple parallel network slices. Each network slice has a complete and logically independent network, providing a corresponding service guarantee for different business requirements [1]. The network slicing mechanism will adapt to multiple services and significantly reduce construction costs compared with an independent network. Network slicing has become the cornerstone for operators to enter the vertical industry with decisive advantages [2].

Edge computing is a new computing model after distributed computing, grid computing, and cloud computing. The core mode of edge computing is mainly a combination of cloud computing and modern communication networks. The edge computing method performs data analysis and processing at the network edge near the data source, in order to optimize the cloud computing system. Edge computing can reduce unnecessary data storage in the cloud, transmission bandwidth required between sensors, central data centers during analysis, and knowledge generation [3]. Edge computing is an essential supplement to cloud computing and a new generation of distributed computing. The combination of edge computing and 5G networks can help solve many challenges, such as bandwidth, data rate, and security problems in case of sudden and continuous traffic surges.

1.1.1 Networks evolution

With the rapid development of the society, the Internet of things, big data, 5G network, and other new emerging technologies, the technology is rapidly changing human life, improving people's living standards and surrounding environment. Unmanned Aerial Vehicles (UAVs), automatic pilots, and other technologies requiring 5G networks can be realized, completely subverting the mode of production.

The 1G network was originated in 1980. The mobile phone is the product of 1G network. The technology of the 1G network is an analog communication system. One disadvantage of the 1G network was that it could only be used for voice calls, and since the signal is unstable, the calling quality is poor. Also, roaming between different countries were impossible [4].

The 2G network was originated in 1991, and it was mainly designed for voice services. A mobile phone is a voice communication terminal. The second-generation mobile communication system (2G) has a high degree of confidentiality and greater system capacity than 1G. The function of mobile phones are no longer limited to calls, but can also be used for sending short messages, browsing web pages, and even playing games. However, there are still many defects, such as unstable networks, slow data rate, etc.

The 3G network was originated in 1998. Data communication developed rapidly when new traffic management procedures appeared. The International Telecommunication Union (ITU) defines three mainstream wireless standard interfaces: W-CDMA, CDMA2000, and TD-SCDMA. In addition, 3G improves the rate of data transmission, with which mobile phones can process images, music, video, other media quickly, provide e-commerce, video calls, and other information services.

The 4G network was originated in 2008, which opened data services. The maximum transmission rate of the 4G network can reach 1Gbs, and various applications and business models derived on this basis, such as short video, live broadcast, game, social media, e-commerce, e-payment, etc. The 4G network era is known as the video era. It has many characteristics such as high data rates, high communication quality, and low cost. However, 4G networks are still insufficient to meet the needs of increasingly affluent people.

The 5G network proposes the goal of "everything connected" and it has three application scenarios: Enhanced Mobile Broadband, Massive Machine Type Communication, Ultra-Reliable Low Latency Communication. The 5G technology experience data rate is more than ten times of 4G. 5G can flexibly slice the network according to the demand [5].

According to a survey of China Mobile, the demand for mobile traffic has shown explosive growth. In the 2G era, each person only needs a little traffic to meet reading and other applications. In the 3G era, the average monthly traffic of each person is ten times more. Starting from 4G network, the widespread of the Internet is getting higher and higher, resulting in the continuous expansion of data demand. According to the rough statistics of experts, the average monthly Internet data of users is about 20GB [6].

1.1.2 Cellular Networks

Multiple base stations are neatly arranged together, and each regular hexagonal "hive" is called a "Cell". A system composed of numerous such cells is called a Cellular Network. However, when multiple base stations are connected to the same cellular network, the mutual communication between each base station will lead to much lower autonomy efficiency. Hence, a central control point needs to be introduced for unified management. In the 2G and 3G eras, multiple base stations are managed by one controller, and multiple controllers are managed by the core network, forming a three-tier pyramidal architecture. The core network is a complex network that connects and works with all base stations and controllers.

The 2G controller is called BSC (Base Station Controller) and the 3G controller is RNC (Radio Network Controller). In the 4G era, to reduce latency and simplify the architecture, the base station controller is removed, and the core network directly manages the base station. However, this architecture, while simple, is not convenient. If the core network manages everything, the load will be too large. If the power is delegated to allow the base stations to coordinate with each other in point-to-point resource scheduling, interference, and other issues, the efficiency will be low [7].

In the 5G era, we have learned the lessons of the 4G era and returned to the model in the 2G and 3G eras, splitting the base station into a centralized unit (CU) and a distributed unit (DU). One CU manages multiple DUs, and the core network manages a smaller number of CUs .

1.2 Problem Formulation and Objectives

Everything can be connected in the 5G era — water cups, cars, air conditioning, television sets, etc. So, if we select the same scene and fix the base station under different preset conditions, is the signal quality obtained by the 5G network excellent, or is the signal quality of the widely used 4G network better? What are the advantages and disadvantages of 5G network signals from the same signal source under different obstruction conditions? Why do people need 5G networks? This article's main objective is to test the use of 5G networks in different situations and locations in a university environment. The main research question is whether the 5G network can completely replace the 4G network in the complex environment of colleges and universities (indoor occlusion, outdoor, No line of sight (NLOS),etc., and whether it can extend from the college experiment scene to the rest of the world. The thesis will conduct a comparative analysis with 4G networks to explain why 5G networks are necessary and irreplaceable for personal and public needs.

1.3 Methods

In the university environment, the location of the base station is fixed. The signal quality is measured at different measurement points in different backgrounds, including outdoor, Line of sight (LOS), No line of sight (NLOS), and other places. Signal to Interference plus Noise Ratio (SINR) and Reference Signal Receiving Power (RSRP) are the primary tools for measuring signal quality in mobile technology standardization [8]. The 5G performance data under different obstacle environments can be calculated, and compared with the signal quality of the 4G network.

1.4 Challenges and Limitations

In the whole process of this paper, we have encountered the following limitations. Due to the time constraints of the thesis project, we cannot measure other multi-address scenarios, such as more representative large scenarios, subway stations, airports, etc. We select the institutions with the most negligible impact on the other party's experimental site and are most easily accessible for fixed-point measurements. This environment requires only one base station. Therefore, the handover between multiple base stations is not considered, nor whether the test meets the theoretical expectations in other scenarios. Therefore, the measurements will be limited.

The author conducted experiments with the base station established by the company. The transmitted power of the base station is not completely constant for various reasons of the actual test environment. To facilitate calculation and obtain data, it is assumed that the transmitted power is constant, and that the obtained data is only a similar value, which is not accurate. In addition, the 5G network structure includes 5G, 4G, WLAN, and other wireless access networks. We only use 5G and 4G network base stations for data measurement and analysis, and will not discuss them in-depth.

In this thesis, we only involve indoor fixed-point measurements, which penetrates some walls and windows, and will not discuss them in depth. Due to the penetration loss of high-rise buildings, the outdoor radiation of the directional antenna greatly reduces the coverage efficiency. We set loss and noise as fixed values here to facilitate calculation and drawing charts, but the results will deviate.

1.5 Outline

This report is organized as follows. Chapter 2 introduces some related work. Chapter 3 summarizes the technical characteristics and measurement parameters of 5G NR. Then, Chapter 4 describes the experimental setup and experimental process. Chapter 5 introduces and discusses the project's results, including the comparative analysis of 4G and 5G networks. Chapter 6 summarizes the work of the experiment and gives some suggestions for future work.

2. Related Work

With the evolution of social networks, 4G and 5G networks have gradually penetrated people's daily lives. Many researchers have conducted network tests in different environments, in order to verify the necessity of 5G networks, including indoor network tests, 5G coverage tests, 5G indoor and outdoor comparison tests, 4G and 5G network comparison tests etc. For example, in [9], researchers built a floor plan model for actual measurements, and they used high-frequency outdoor deployment of base stations and analyzed indoor coverage. However, the implementation is relatively complex due to the nature of high frequencies (susceptibility to penetration loss). Additional in-depth experiments are required to consider smaller cells, higher user data rates, user densities, etc.

2.1 Basics

In the 4G era, 80% of business takes place indoors. In the 5G era, indoor scenarios are still the main area of mobile data services. Indoor scenes mainly refer to office buildings, shopping malls, railway stations, airport terminals, subways, underground garages, tunnels, government agencies, residential quarters, etc. These places are generally closed, and the signals are attenuated dramatically. When the frequency of the wireless signal is higher, the wavelength becomes shorter, and the reflection and diffraction ability becomes weaker. However, the penetration becomes stronger. On the contrary, for low frequencies, the wavelength is longer, and the reflection and diffraction ability is stronger, but the penetration to obstacles becomes weaker [10]. In an indoor environment, walls, ceilings, floors, planted plants, and the roughness of the surface of objects will affect the reflection, diffraction, refraction, and other capabilities of wireless signals. Outdoor macro station signals reach some indoor areas, but if coverage is not possible, it is necessary to add a Distributed Antenna System to cover the room [11].

In addition, the ability to accurately estimate the radio coverage is the basis for planning wireless networks, and the 5G coverage analysis index mainly adopts the metric Reference Signal Received Power (RSRP) [12]. Researchers will also use different characteristics such as signal-to-noise ratio, throughput, etc., to study the characteristics of 5G network coverage and penetration.

2.2 Signal Test

The following are network tests conducted by other researchers in different locations, including coverage tests, penetration tests, etc. The aim of the measurements is to analyze the network's performance in different scenarios from various aspects.

2.2.1 Coverage Test

In [13], the researchers simulated and analyzed the Tampere University of Technology network layout in Finland. The frequency bands 1.8 GHz, 2.6 GHz, and 3.5 GHz and 28 GHz for 5G systems were selected, assuming that all transmitters transmit at full power.

The test results show that the average SINR reaches 24.23dB and 21.97dB in the 28GHz band, 20MHz, and 200MHz bandwidth. The researchers found that if the received signal strength increased with the number of cells, even with a large bandwidth of 200 MHz, the SINR would not decrease much. The average SINRs at 1.8GHz, 2.6GHz, and 3.5GHz are 20.35dB, 20.35dB, and 20.91dB, respectively, which is good coverage. The experimental results found that the 5G 3.5 GHz frequency can be used with existing indoor solutions in the current cellular frequency band, with only adjustments. However, the basic indoor antenna solutions at this stage can only provide sufficient coverage at the lower frequencies of 5G. If stable operation at 28 GHz is desired, other coverage solutions such as Distributed Antenna System (DAS) solutions are still required to provide better coverage.

Reference [14] selected the measurement area of the office building lobby and parking lot of NTT DOCOMO R&D Center in Japan for short-distance testing. The lobby area of the office building is a multi-path-rich environment, and the parking lot is an open space LOS environment. The test method uses the best mobility reference signal received power (MRSRP) and throughput measurement together. Measurements showed that MRSRP over -45 dBm with good coverage even in non-line-of-sight (NLoS) environments in office building lobby pillars and behind elevators. Test results show a high MRSRP of over -22 dBm and low antenna correlation, with a throughput of over 15 Gbps in indoor and outdoor environments excellent near-field coverage.

The experimental campaign in [15] was conducted in an urban area in Yokohama, Japan. The measurement point location includes the LOS environment and the NLOS location behind the building. The literature evaluates the reliability of the signal-to-noise ratio at several different locations to verify the network coverage, and this measurement is performed without movement. The signal-to-noise ratio of each antenna port is measured by using a demodulation reference signal (DMRS), which is the average signal-to-noise ratio of all received antenna ports.

The test results found that the required signal-to-noise ratio difference between 32-byte and 200-byte packets was between 9.8 dB and 15.7 dB. Although 5G coverage will vary slightly with packet size, but it will not affect 5G coverage too much.

2.2.2 Comparison Test

There are many ways to evaluate the network's performance in modern society, for example, some mobile applications can perform a wide range of measurements, including received power, throughput, and latency. Metrics such as Reference Signal Received Quality (RSRQ), Reference Signal Received Power (RSRP), and Received Signal Strength Indicator (RSSI) can be quantified by the network during mobile video streaming [16].

In [17], the test site was located in West Melbourne, Brevard County, Florida, U.S.A., in a building. The devices used for testing were scanners and the LTeneScan app for mobile phones. From the results, the RSRP value recorded by the scanner is more accurate than that of the mobile phone.

The second comparative test was conducted in the same location as the indoor scene, but outside the building to demonstrate the network's performance in an open space. The average RSRP values of indoor different equipment test results are -84.621dbm and -85.380dbm, and the RSRP average values of outdoor different equipment test results are -76.014dbm and -76.493dbm. It can be seen that the penetration of the wall affects the coverage performance of the network.

Reference [18] studied the network performance on Thailand's national highways. User Equipment (UE) is a smartphone with a service model. The test sites are located at three mobile phone operators on Thailand's National Highway 3 and National Highway 361 in the Maeang Chumburi district of Thailand's Chumburi province. The RSRP along the highway was also tested using Gaussian distribution's probability density function (PDF) and cumulative distribution function (CDF).

The RSRPs of the three operators at Thailand's National Highway 3 are the minimum -112 dBm, -111 dBm, and -114 dBm, respectively, and the maximum is -70 dBm, -68 dBm, and -71 dBm, respectively. In the data of three points on Highway 365 in Thailand, the minimum RSRPs are -112 dBm, -115 dBm, and -111 dBm, respectively, and the maximum RSRPs are -77 dBm, -71 dBm, and -68 dBm, respectively. The reference signal received power is fluctuating.

The RSRP modeling under Gaussian distribution shows that the average RSRP of the three operators on Thailand National Highway 3 is -93.96 dBm, -92.12 dBm, and -90.63 dBm. The average RSRP values of the three operators on National Highway 361 in Thailand are -96.87 dBm, -95.53 dBm, and -92.49 dBm, respectively. From these results, there is no significant difference in RSRP of several adjacent operators along the national highway in Thailand. The mobile phone connection quality and switching performance on Thailand's National Roads 3 and 361 are good, and the roads are open and not affected by other obstacles.

2.2.3 Field Experiments

Reference [19] configures a 5G testbed transmitter and receiver base station (BS) and user equipment (UE). The occupied transmission bandwidth of the OFDM signal in the uplink and downlink is 90 MHz, and the subcarrier spacing is 75 kHz.

The field test results of the parking lot show that the RSRP of -40dBm in front of the base station antenna measured in the parking area is the best-received power. When the UE leaves the base station antenna, the RSRP gradually decreases. The RSRP of the 4th floor is better than the 1st floor because of the reflection of a 12m high metal wall building on the 4th floor. The peak throughput in the area in front of the base station antenna is 2.8 Gbps with an RSRP of -40 dBm.

Field test results in courtyards and aisles showed an RSRP of -25 dBm to -30 dBm for the first basketball court in front of the base station antenna. Since the second basketball court is outside the direction of the BS antenna, the RSRP is lower than the first court, although the second court is also in the courtyard. When we focus on the RSRP in the interior passages of the building, it is confirmed that the building penetration loss of the window glazing is about 10 dB. Outside the BS coverage area, such as the racetrack in the channel, RSRP is particularly low. In addition, the RSRP of the 2nd floor of the courtyard is better than that of the 4th floor because the 2nd and 4th floors are isolated from the courtyard with window glass and building walls, respectively. In front of the base station antenna with RSRP over -30 dBm, the maximum throughput reaches 3.6 Gbps, and the minimum throughput reaches 2.5 Gbps in the courtyard area. The RSRP in the channel is about 10 dB lower than the RSRP in the courtyard.

This document clarifies the propagation characteristics and throughput performance of the 5G cellular radio access downlink in the 15 GHz band. A peak throughput of 3.6 Gbps can be achieved in courtyards enclosed by walls, outdoor environments with high RSRP, and outdoor-to-indoor environments with low RSRP due to penetration loss through glazing.

2.2.4 Other Tests

Reference [20] studies the performance of a 28 GHz Massive MIMO 5G New Radio (NR) test system with 400 MHz bandwidth and one transmit/receive point in a semi-open square environment. Evaluated from coverage and dissemination perspectives. In the line of sight, the peak throughput is 6.2 Gbps. One transmit/receive point is sufficient to provide good coverage.

To assess the non-line-of-sight (NLOS) effects caused by obstacles or building corners, the researchers also conducted tests along streets away from open squares. Before the corner, two light poles briefly dropped in signal strength because they suddenly blocked the direct path. As the corner passes, the intensity of the signal representing diffraction and scattering at the corner drops rapidly. The difference between non-line-of-sight and visible distance can also be seen from this.

Reference [21] analyzes indoor coverage in the frequency range above 6 GHz and compares it with the outdoor deployment of base stations and single building scenarios under low load conditions. Specific frequencies such as 10 GHz, 30 GHz, and 60 GHz were used in the simulation.

Under the low deployment density of 10 GHz, outdoor-to-indoor coverage with user throughput higher than 100 Mbps can be achieved. Outdoor-to-indoor coverage at 30 GHz and 60 GHz shows a similar pattern, requiring more base stations to meet the throughput threshold. Outdoor-to-indoor coverage can be challenging at 60 GHz and above. Reference [21] also emphasizes using high-gain antennas at high frequencies. Studies have shown that building type, exterior wall materials, interior layout, etc., are also critical at high frequencies.

In [22], the test site selects towns covered by 5G signals, and researchers walk in each area and each public street around the 5G device to measure the received Synchronization Signal Reference Signal Received Power (SS-RSRP). The 5G UE is at the height of 1.5m above the ground, the mapper app is open on top, and the measurements are performed during off-peak hours. The researchers continuously monitors 5G connectivity and stores SS-RSRP observations. The area was divided into square pixels of size 10 × 10 m^2, and each measurement was associated with the corresponding pixel, and the average SS-RSRP detected in each pixel was calculated.

The results are as follows, the SS-RSRP indicator is not constant and varies greatly; most pixels have SS-RSRP >−90 dBm within 250m from the generation nodeB (gNB) location. The presence/absence of buildings/obstacles between the 5G UE and the gNB will cause abrupt changes in the measured SS-RSRP values. After the distance from the gNB exceeds 500m, the SS-RSRP value is not higher than −80dBm. It can be seen from the experiments that the increase of distance tends to decrease the measured SS-RSRP value, which is due to the rise of propagation loss. The SS-RSRP value decreases rapidly when non-straight aiming is dominant. Propagation conditions (line-of-sight vs. non-line-of-sight, distance to gNB, etc.) play an important role in determining the coverage level of a 5G gNB.

2.3 Network performance comparison

The 5G network has developed more advantages and key performance based on the 4G network. According to some relevant references and the above experimental analysis, basic theoretical and key performance can be described.

2.3.1 Theoretical Performance

The spectrum efficiency of 5G is more than three times higher than that of LTE. Under continuous wide area coverage and high mobility, the user experience rate can even reach 100 Mbps [23].

Both 4G and 5G are licensed and use Time/Space/Frequency multiplexing. 4G uplink and downlink are used for single-carrier Frequency-Division Multiple Access (SC-FDMA) and Orthogonal Frequency Division Multiple Access (OFDMA). The OFDMA technology under LTE standards can maintain the high mobility and high-frequency spectral efficiency of 3G and provide higher network capacity and greater bandwidth. SC-FDMA has a structure and performance similar to OFDMA, but it can reduce the power consumption of mobile terminals and prolong the endurance time. 5G uses Cyclic Prefix-Orthogonal Frequency Division Multiplexing (CP-OFDM) [23]. CP-OFDM technology uses multiple parallel narrowband carriers to transmit information. It can extend to the receiver with low complexity and has good time-domain control. It is of great significance for deploying low delay and time division duplex (TDD) etc.

2.3.2 Key Capabilities

According to references and materials [24], it can be seen that the most basic key performance differences between 4G and 5G networks are connection density, delay, mobility, user peak rate, etc. 5G uses a higher frequency band and larger bandwidth than 4G.

Connection Density is the sum of online devices supported per unit area. End-to-End Delay means the time from when a data packet is transmitted from the source node to when the target node correctly receives it. When meeting specific performance requirements, the maximum relative movement speed between the sender and receiver is mobility, the highest transfer rate available for a single user named user peak rate. The approximate value range of 4G network and 5G network in these performances shows that the 5G network has dramatically improved based on the 4G network, with lower latency, higher peak rate, broader connection, etc. Table 1 presents these key capabilities data of 4G and 5G include approximately frequency band and bandwidth.

	4G	**5G**
Connection Density	$1000/km^2$	$1000000/km^2$
End-to-End Delay	10 ms	<1 ms
Mobility	350 km/h	>500 m/h
User Peak Rate	1 Gbps	10 Gbps
Frequency Band	400 MHz-4 GHz	600 MHz-6 GHz 28 GHz-86 GHz
Bandwidth	1.4 MHz-100 MHz	50 MHz-400 MHz

Table 1. 5G and 4G key capability comparison

In theory, other researchers have given various performances, disadvantages, and advantages of 5G networks. However, we need to know whether these excellent performances align with the expected theory when 5G networks are used in different locations in a fixed university environment, which requires experiments.

In this thesis, researchers of China Mobile Company conducted site selection, established and configured network base stations, and provided us with multiple measurement tools and equipment. After that, we selected different condition points according to the test environment and the expected results. According to the measurement distance and obstacle conditions, fix multiple test points, we carry out multi-point fixed-point test, and then perform data calculation and summary, draw charts, and compare the experimental results with the theoretical results.

3. Theory

The previous chapter introduces some related work. This chapter aims to introduce some main features of 5G NR. The first part explains the key performance technologies of 5G NR. The second part briefly introduces the relevant technologies required for SINR, RSRP, and other experiments.

3.1 5G Enhancements

5G technology can be defined by a series of critical technologies and symbolic performance indicators: including 1 million per square kilometer connection density, user network data rate up to 100-1000 Mbit/s, end-to-end network delay lower to milliseconds, the peak rate of the user terminal can reach 10 Gbit/s, mobility up to 500 km/h and other characteristics [25]. 5G application scenarios are more diverse than current cellular mobile communication, and the network is used more widely. According to the specific requirements of the International Telecommunication Union (ITU) for 5G, 5G needs to meet three use cases, enhanced mobile broadband (EMBB), Massive Machine Type Communication (MMTC), and Ultra-Reliable Low Latency Communication (URLLC) [26].

EMBB is the most basic way of mobile communication, including continuous wide area and local hot spot high-capacity coverage to meet the requirements of mobility continuity, high speed, and high density. EMBB is mainly used for high bandwidth demand scenarios, where the data rate reaches 10 Gbps, for example virtual reality applications.

MMTC is used for environmental monitoring, intelligent meter reading, intelligent agriculture, and other sensor and data acquisition scenarios. It has small data grouping, low power consumption, low cost, and massive links required to support the connection density of 1 million devices per km^2 and a connection scale of 1 million connections per km^2.

URLLC is facing special application requirements of the vehicle network, industrial control, intelligent manufacturing, intelligent transportation logistics, and vertical industries. URLLC provides users with ms level end-to-end delay and a nearly 100% business reliability guarantee [27]. URLLC provides ultra-low delay up to 1ms and high-reliability communication capability.

3.2 mmWave

The frequency band below 3GHz is fully occupied, and there is no spare frequency bands for 5G. Therefore, 5G is developing towards high frequency. Millimeter-wave frequencies in the 30 to 300 GHz spectrum range is a new feature in 5G NR that can help improve bandwidth and data rates [28]. With wavelengths ranging from 1mm to 10mm, millimeter wave technology can support an ultra-high transmission rate. Since its beam is narrow, flexible, and controllable, it can connect many devices.

3.3 Massive MIMO

MIMO technology has been widely used in WiFi, LTE, and other network technologies. Theoretically, the more antennas, the higher spectral efficiency, and higher transmission reliability. Multiple antenna ports transmit and receive simultaneously, resulting in diversity gain. In the 4G era, the base station usually uses four antennas and eight antennas, which are arranged horizontally to form a horizontal beam. When the number of antennas is large, the horizontal arrangement makes the overall size of the antenna too large, resulting in complex installation. For 5G large-scale MIMO, by placing antennas in the horizontal and vertical directions, the beam dimension in the vertical direction is increased, multiple antennas transmit and receive simultaneously, and the isolation between different users is improved.

3.4 Beamforming

Beamforming is a technology for high-frequency directional signal transmission in NR. The base station sends similar reference signals to all directions, which will be added to a focused directional beam. The terminal detects and feeds back to the base station, which is realized by combining the elements in the phased array [28].

5G brings mobile networks with higher connection quality and lower connection costs. 5G will realize the relationship between people and things, things to something, which means objects in home, office, and the city will recognize the connection, moving towards wisdom and intelligence. The number of Internet of things connections per square kilometer can exceed one million under 5G network [29].

5G uses beamforming, which is a signal pre-processing technology based on the antenna array. By adjusting the weighting coefficient of each element in the antenna array, it can generate a directional beam to change the signal transmission trajectory and achieve "point-to-point" targeted signal transmission.

3.5 Reference Signal Receiving Power

In LTE, the measurement of power is basically about Reference Signal Receiving Power (RSRP) and Reference Signal Receiving Quality (RSRQ). The RSRP and RSRQ of 5G NR are almost the same as LTE, but they are also different. In LTE, RSRP and RSRQ are defined based on the cell reference signal (CRS), and there is no CRS in NR. RSRP and RSRQ are determined based on Synchronization signal and Physical Broadcast Channel block (PBCH), and Channel State Information - Reference Signal(CSI-RS) in 5G NR[30]. RSRP is the average power of 5G NR cell synchronization signal in each RE, which is used to measure the receiving strength of the cell downlink synchronization signal [31]. RSRP (reference signal receiving power) is one of the key parameters of wireless signal strength and physical layer measurement requirements in the communication network. The average value of signal power received on all resource particles (RE) carrying reference signal in symbol. The value ranges from - 44 to -140 dBm [32].

3.6 Signal to Interference plus Noise Ratio

Signal to Interference plus Noise Ratio (SINR) is the average SINR value of the synchronization signal for each Resource Element (RE) in the NR cell, which is used to measure the reception quality of the downlink synchronization signal of the cell. Coverage is a threshold index of RSRP and SINR, which is used to evaluate the quality of regional networks in network optimization [33].

Signal to noise ratio (SNR), which refers to the ratio between useful signal level and electromagnetic noise level measured under specified conditions. The ratio is the amplitude of the valid signal to noise signal at the same issue, expressed in dB. The peak value is related to impulse noise, and the effective value is related to random noise. Generally, the bigger is better. Signal to interference plus noise ratio is the ratio that strength of the received signal to the intensity of received interference signal (noise and interference) [34].

3.7 Penetration Loss

5G NR system works in a high-frequency band and the antenna array size is inversely proportional to frequency, directly proportional to wavelength. A high-frequency band can form a more extensive array antenna to compensate for coverage [35].

In actual wireless communication network planning and deployment work, we mainly focus on comprehensive penetration loss, the degree of indoor coverage signal caused by dielectric penetration loss, multi-path reflection diffraction loss, indoor propagation loss in certain depth, and other factors [36]. The penetration loss of media refers to the power reduction caused by reflection and refraction after the wireless signal passing through different media. The higher frequency is, the smaller the penetration loss. Pure dielectric penetration loss can be obtained through penetration tests of different media in the laboratory, which will not be detailed here [36].

According to Huygens's principle [37], an electromagnetic wave will diffract at the edge of the obstacle when it encounters an obstacle whose size is much larger than its wavelength. It will spread to the shadow area of obstruction in the form of secondary waves. The higher frequency is, the higher the diffraction loss. 5G NR frequency is higher than 4G LTE frequency, Theoretically, its dielectric penetration loss is smaller, and indoor propagation loss is higher. However, the performance of comprehensive penetration loss needs to be verified in practice.

Therefore, the dielectric penetration loss is smaller, and indoor propagation loss is higher. The commonly used verification method is to compare the signal strength difference between the measured signal strength outside the building wall and signal strength at different depths inside the building wall. 4G network penetration is usually better than 5G network penetration.

3.8 Signal Quality

In the process of single station verification, the fixed-point test is used to verify the standards of signals in different scenarios. According to the official definition of China Mobile, the description value of signal quality is defined as in Table 2 [33]:

	RSRP	SINR
Excellent site	≥-85dBm	≥25dB
Better site	-85dBm>RSRP≥-95dBm	25dB>SINR≥16dB
mid site	-95dBm>RSRP≥-105dBm	15dB>SINR≥11dB
bad site	-105dBm>RSRP≥-115dBm	10dB>SINR≥3dB
worst site	≤-115dBm	<3dB

Table 2. Signal quality defined as RSRP and SINR

3.9 Test Tools

WirelessMon can display real-time information of surrounding wireless access points or base stations, list the signal strength, and monitor the transmission speed of the wireless network in real-time, so that we can know the network's download speed or its stability. In addition to the wireless signal scanning function, it also provides functions such as signal strength detection and monitoring the transmission speed of the wireless network so that we can understand the download speed or stability of the network. It is a necessary testing tool for wireless coverage projects.

inSSIDer is a wireless WiFi signal scanning software, through which users can detect whether their own wireless network access points conflict with others, effectively ensuring the user's network security. It also supports searching for nearby wireless networks and provides detailed information that can be used to troubleshoot and optimize WiFi networks. Through a search, you can see each hotspot's MAC network name (SSID), wireless signal strength, the address used, the encryption method, the wireless transmission rate, the network type, etc. It is very comprehensive.

Fatu is a real-time and convenient software for users. We can monitor the network signal of the community at any time, and the network data is very detailed.

Speedtest is an influential and well-known global test website. Using a Flash loading interface, there are hundreds of test nodes worldwide. As an online and visual network speed test tool, it is easy to use and provides multiple data tests such as network speed test, network quality test, 5G speed test, and Ping test.

4. Implementation and Experiments

This chapter describes the details of the experiment. Sections 4.1 and 4.2 introduce the establishment and limitations of the experimental environment. Four single-station SINR and RSRP measurements were performed, described in Sections 4.3 and 4.4, to detect 5G coverage and permeability. Then, Sections 4.5 and 4.6 compare the measurement results of 4G and 5G networks in LOS environment and indoor environment, respectively.

4.1 Set up Equipment

The test site is mainly in the University. The horizontal direction is open and there are unobstructed roads, in order to meet testing needs. The campus includes complex environments such as commercial buildings and teaching buildings, which are convenient for indoor and outdoor coverage testing. There are 4G stations for comparative testing. The network topology map of test points of the campus central station network topology is shown in Figure 1. The blue dot on the right side shows the base station. Multiple different positions for measurement were selected, illustrated by the red dots.

There are eight main test stations on campus, from 119m to 324m away from the central station. A ninth test point was added to test the 5G network coverage capacity and other performance. The ninth test point is LOS, and the distance is about 470m.

Fig. 1. Campus main station test point map network topology.

4.2 Limitation

As the test site is selected in college environments, the total area of the test is limited. The farthest measurement point is the ninth LOS test point 470m away from the central station, and the nearest test point is only 119m. Therefore, only indoor and outdoor coverage scenarios, LOS / NLOS scenarios, and 4G / 5G scenarios comparison are considered. Measurements were done at the university.

4.3 Coverage Test

5G network coverage is one of the key performances of 5G network, the coverage distance will be affected by the height, power of the cell phone antenna, and other external factors [4].

The output power of the base station is fixed, considering that the farthest distance of the eight test points selected in the test area is only about 320m, a ninth test point is added based on the eight basic test points to measure the coverage capacity of 5G network. If the SINR values of the four points are similar, according to the signal quality standard defined by China Mobile, single-cell 5G has an advantage at the distant point.

The ninth test point is located in the LOS scene in the normal direction of the master station, with a distance of 470m. The first test point is 119m away from the base station, and the SINR is 21.53 dB. The second test point is 309m away from the base station, and the SINR is 21.03 dB. The third test point is 324m away from the base station, and the SINR is 22.33 dB. The fourth test point is 470m away from the base station, and the SINR is 26.75 dB. SINR test results are shown in Figure 2.

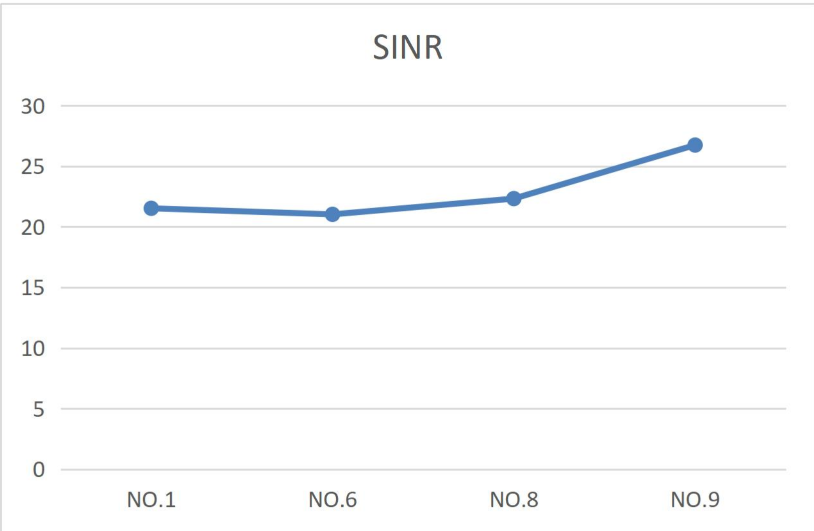

Fig. 2. SINR .

4.4 Penetrability Test

Nine points are selected in the penetrability test. The 4G (2.6GHz) / 5G (3.5GHz) RSRP (measurement cell RX level value) is analyzed in each point test record. The first point is the LOS scene. The second point is the LOS scene separated by one window. The third and fourth points are the scene separated by one window at different locations. The fifth and sixth test points are the scene separated by two walls. The seventh test point is the scene separated by one wall and one window. The eighth and ninth test points are LOS scenes separated by one window at different distances. The test measured RSRP coverage, and SINR coverage based on relevant 5G cell RSRP sample statistics. The RSRP and SINR values measured from several test points through the wall and window are compared with the experimental penetration analysis of signal quality in relevant work. The RSRP comparison is in Figure 3. The SINR comparison is in Figure 4.

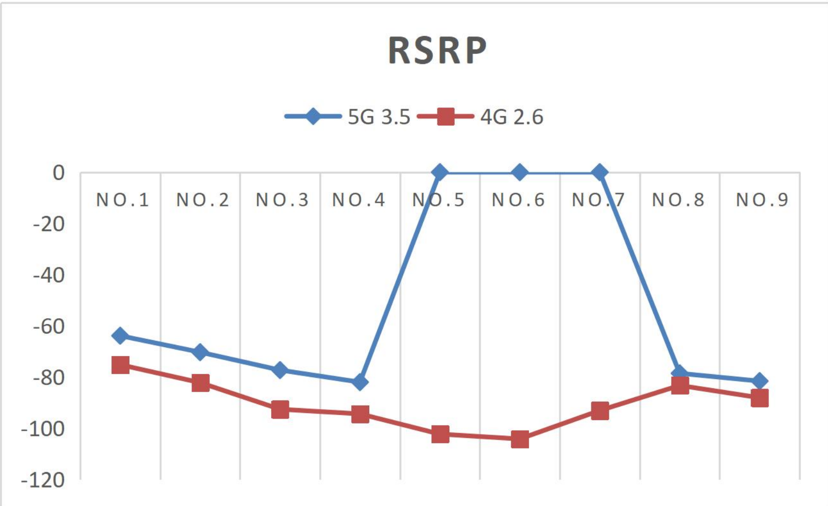

Fig. 3. RSRP comparison.

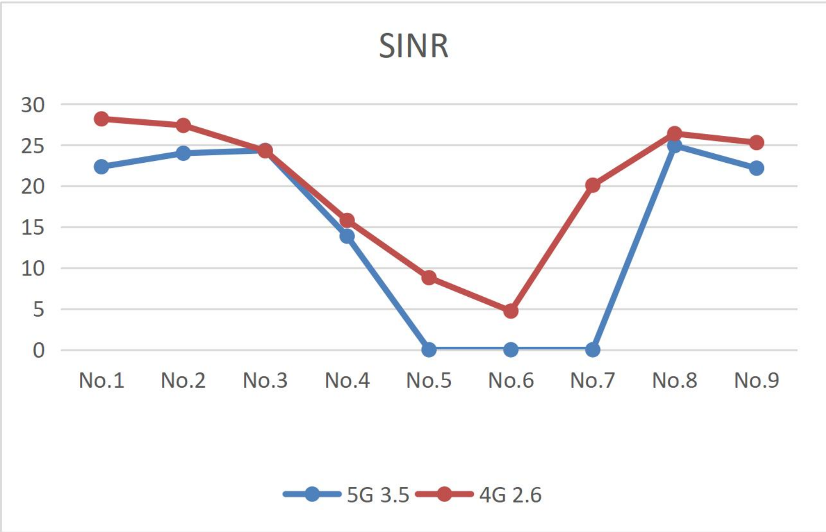

Fig. 4. SINR Comparison.

4.5 Performance Comparison Between 5G and 4G

We selected three test points to conduct comparative experiments on the quality of received 4G and 5G network signals. We measured the RSRP and SINR of two network signals in the same LOS scenario, draw curves, and compared and analyzed the results. The RSRP of the LOS scenario test is shown in Figure 5, and the SINR of the LOS scenario test is shown in Figure 6.

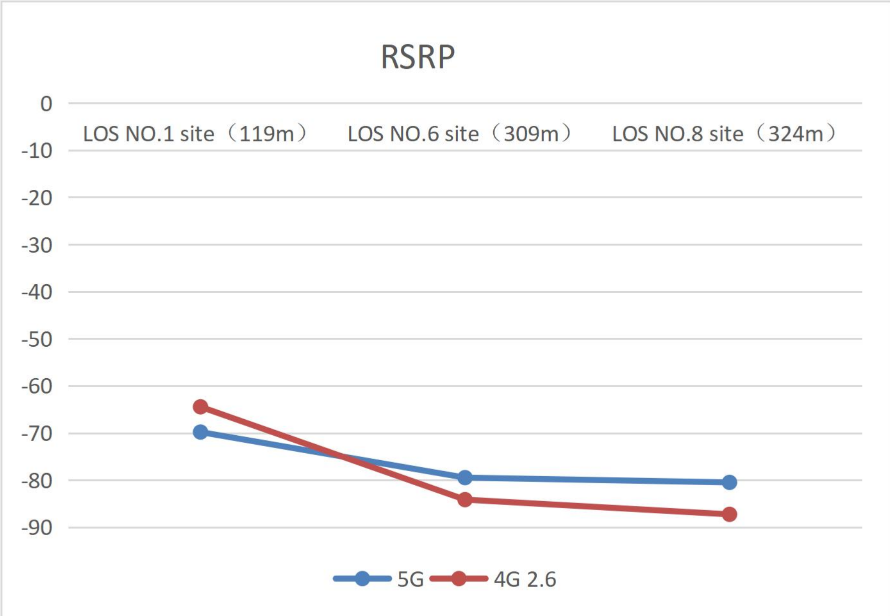

Fig. 5. RSRP LOS scenario.

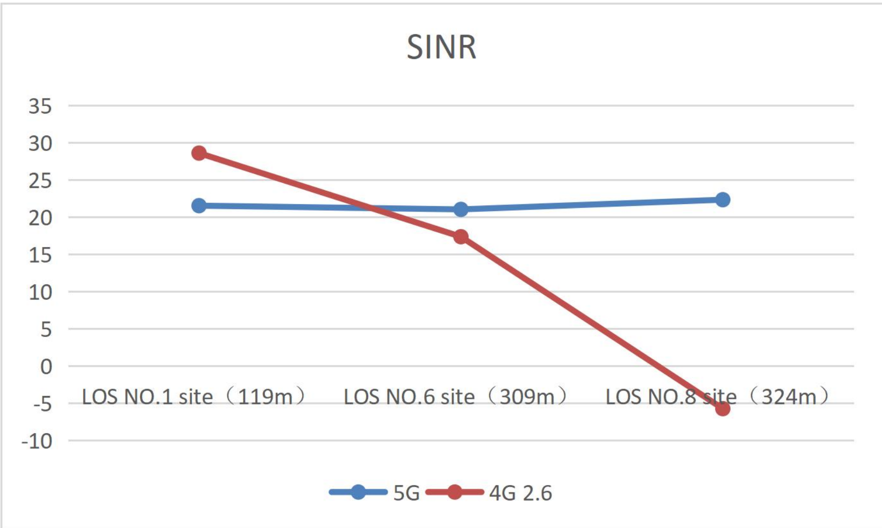

Fig. 6. SINR LOS scenario.

4.6 Indoor/Outdoor Penetration Analysis

Indoor/outdoor penetration analysis of coverage gives a data comparison analysis under various blocking conditions, which can be used as a reference for indoor construction density in the 5G network construction process. Different blocking points were selected in the indoor environment to test RSRP and SINR of 4G and 5G networks. The RSRP of 4G and 5G networks test are shown in Figure 7. The SINR of 4G and 5G networks tests are shown in Figure 8.

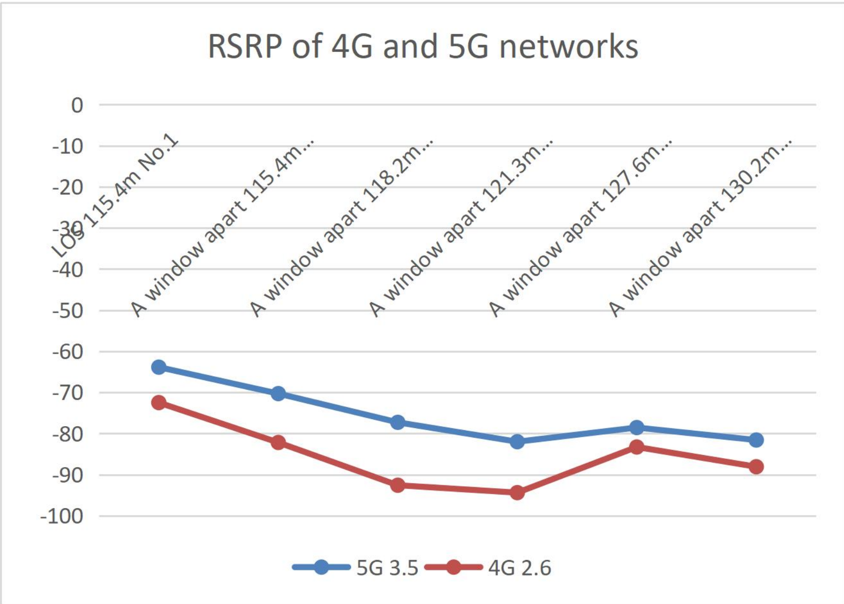

Fig. 7. RSRP of 4G and 5G networks.

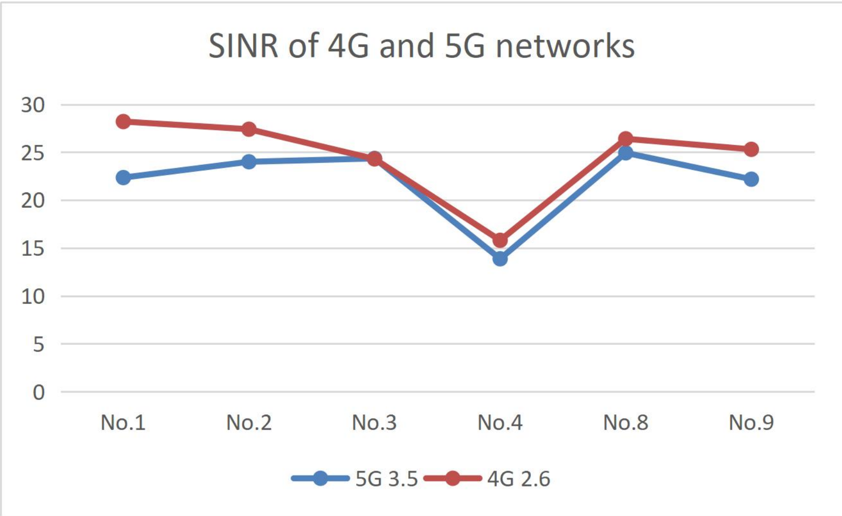

Fig. 8. SINR of 4G and 5G networks.

5. Results and Discussion

5.1 Coverage and Penetrability Results

During the single station verification process officially defined by China Mobile, the signal quality standard is described in relevant work. When testing four points with a single SINR, the SINR measured at the great point should be between 16 ~ 25dB, and the excellent point should be greater than 25dB. The SINR measured at the LOS scene with the farthest result is the best, reflecting the advantage of 5G coverage.

Furthermore, the higher the frequency band of the wireless signal, the higher the data bandwidth that can be transmitted, but this will lead to greater signal attenuation and lower penetration ability. Therefore, 5G penetration ability is poor in theory. When separated by a window or LOS, the measured 5G network RSRP is better than the 4G network RSRP. 5G RSRP is 5 ~ 10dB higher than 4G RSRP. When there is a certain included angle, the difference decreases. If two walls are separated, the 4G network RSRP is lower than - 100 dBm, and 5G UE cannot access the network at all. The RSRP test results are consistent with the theoretical analysis. 5G 3.5G coverage is better than 4G 2.6G, but the penetration ability is weaker. In an excellent wireless environment, the measured SINR is basically between 22 and 24.

After changing some measurement conditions, it is concluded that 5G RSRP is better than the 4G 2.6G frequency band in most measurement samples. In the LOS scenario, blocked scenario, and other scenarios, the compared SINR change between 5G and 4G, which also conforms to the theoretical analysis, reflecting the advantages of 5G network beamforming. For example, in the slightly blocked environment, the 5G measurement results in the normal direction comply with LOS, and the coverage capacity is better than 4G. 4G and 5G will have severe attenuation in the severely blocked environment, while 5G has poor penetration and weak coverage.

5.2 Performance comparison between 5G and 4G

Theoretically, because of the 5G beamforming, 5G coverage should be better than 4G coverage in LOS scenarios, and near SINR should be close to 4G, whereas far SINR should be better than 4G. The measured data shows that 5G network RSRP is better than 4G network RSRP under most sample scenarios in the same conditions. The measured SINR meets the expected theoretical analysis and can reflect the advantages of 5G beamforming. In addition, in the case of slight blocking, 5G should conform to LOS, better than 4G; in the severe siege, both 4G and 5G networks will have severe attenuation, 5G penetration ability is worse, and coverage ability is weaker than 4G networks.

From the above comparative experiments of 4G and 5G in colleges and multi-scenario reference, we can draw conclusions about the difference between the 4G network and 5G in different scenarios. In scenes like hospitals and gymnasiums with significant traffic, many rooms, or dense crowds, 4G network cannot satisfactorily meet people's needs for a large number of phones, Internet access, or video and image upload. Still, the stability, low delay, and large bandwidth of the 5G network can meet the needs of intelligent medical services and better meet the needs of similar scenes [38].

A simple service comparison is shown below. In the hospital, it is challenging for the 4G network to meet the requirements of patients, family members, and medical staff for a large number of telephone calls, Internet access, and video. 5G networks can meet the needs of medical services with stable, low delay, and large bandwidth. In the gym, when the audience is dense and the demand is concentrated, especially at goal time, the video upload and picture sending will happen simultaneously, and the 4G network interaction can lead to a splashed screen. Live broadcasting requires large bandwidth and low delay, and users have high requirements for an experience, and 5G networks can meet users' needs. For 4G networks in a factory scene, the factory area is densely populated with employees, network occupation time is concentrated, shift work and dining times are consistent, and bursts are significant in short time periods. The 5G network meets the requirements of industrial control services in a factory, which is extremely sensitive to packet loss and delay. It will not cause production downtime and accidents.

For the performance of 4G and 5G networks, as shown in Table 3 below, where the data was obtained in 2016 and 2021 respectively, the 4G delay is about 10ms, which cannot meet the requirements of VR, automatic driving, and other scenarios [39]. Therefore, a 5G network is required to realize these applications, since the delay of 5G networks is less than 1ms. In addition, in the test in 2016, the 4G networks can connect about 8 billion devices, and by 2021, the 5G networks can reach 11 billion connections [38][40]. 5G bandwidth and frequency bands are also different compared with 4G.

	4G (2016)	**5G (2021)**
Number of Mobile Connections	8 billion	11 billion
Bandwidth	200 MHz	100MHz (Below 6 GHz) 400 MHz (Above 6 GHz)
Frequency Band	600 MHz-5.925 GHz	600 MHz-mmWave

Table 3. 4G / 5G performance comparison.

6. Conclusions and Future Work

This project analyzes the implementation of 5G networks in a college scene. In the future of intelligent manufacturing and automation, modern wireless technologies such as LTE and 5G networks can primarily meet the efficiency and flexibility of different working environments. The main purpose of this project is to evaluate whether 5G networks can replace 4G networks in different scenarios, in order to better meet the needs of people's daily life. Based on the results obtained, the overall conclusion is that 5G networks can be used to replace the LTE network in some scenarios. Compared with 4G networks, 5G networks have many advantages such as low delay and high peak rate. Due to the high working frequency band of 5G NR system, there are some disadvantages in propagation loss and indoor comprehensive penetration loss. For example, in the experiments, the signal strength of the 5G network measured through one window is stronger than that of the 4G network. However, the 5G signal can hardly be measured when penetrating multiple windows or walls, which indicates that 5G penetration loss is high. Therefore, if individual devices want to use 5G network, telecommunications companies need to establish more 5G base stations. It can be concluded that in some industrial facilities or crowded gymnasiums and other outdoor environments, the 5G network can be well realized by establishing a small number of base stations. Still, the locations, such as hospitals and office buildings with many rooms, need to be optimized. On the other hand, the antenna array size is inversely proportional to frequency (directly proportional to wavelength). The high-frequency band can form a more extensive array antenna to compensate for the coverage. The terminal side uses more antennas to improve the coverage capacity. It can be seen that the 5G system has increased the control channel beam, the number of large-scale antenna arrays, and the number of transceiver antennas at the terminal side, the maximum transmit power of the terminal, and the number of Physical Downlink Control Channels (PDCCH) to enhanced coverage. In this experiment, single-cell coverage can reflect the advantages of 5G line of sight and far point. In the LOS scene, blocked scene, far, and short distance scene, 5G coverage is better than 4G, due to 5G having beamforming.

In addition, ideally, 5G end-to-end delay is 1ms， in general, and the end-to-end delay is 5-10ms. For 4G networks, the ideal end-to-end delay is about 10 ms, and the typical end-to-end delay of LTE is 50-100 ms [41]. In this experiment, the average delay is less than 4 ms to comply with the EMBB standard.

4G changed the way humans live, while 5G changes the society. 5G will open a new chapter of e-commerce, promote economic, inject mighty power into industrial transformation and high-quality economic development [42]. In the future, the construction quantity of 5G base stations will exceed 4G, and full sharing of existing resources can realize 5G low-cost, rapid distribution networks. With the increase of transmission distance, the 5G rate is reduced rapidly compared with 4G, which needs to establish more base stations to reduce frequency reduction due to passing through solid structures. Nowadays, micro base stations have been developed. These base stations are installed in street lights and other places to transmit data to users, increasing the density of signal, avoiding the problem of poor penetration, and enabling 5G to communicate long distances.

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List of Figures

List of Tables

List of Acronyms

3GPP	3rd Generation Partnership Project, Established in December 1998.
SA/NSA	Standalone/Non-Standalone
gNB	generation nodeB
2G	GSM, Global System for Mobile Communications
UMTS	Universal Mobile Telecommunications System，
LTE	Long Term Evolution
5G	5th generation mobile networks or 5th-Generation
eMBB	Enhanced Mobile Broadband
mMTC	Massive Machine Type Communication
uRLLC	Ultra Reliable Low Latency Communication
VR	Virtual Reality
AR	Augmented Reality
UE	User Equipment
UAV	Unmanned Aerial Vehicle
C-RAN	Cloud-Radio Access Network
VOLTE	Voice over Long-Term Evolution
MEC	Multi-access Edge Computing
C-V2X	Cellular Vehicle-to-Everything
LOS	Line of sight
NLOS	Not line of sight
4K	4K Resolution
SC-FDMA	Single-carrier Frequency-Division Multiple Access
CP-OFDM	Cyclic Prefix-Orthogonal Frequency Division Multiplexing
ITU	International Telecommunications Union
BS	base station
SINR	Signal to Interference plus Noise Ratio
IMT-2020	5G names “IMT-2020”
PDCCH	Physical Downlink Control Channel

TDMA Time Division Multiple Access
FDMA frequency division multiple access
OFDMA Orthogonal Frequency Division Multiple Access
W-CDMA Wideband Code Division Multiple Access
CDMA2000 Code Division Multiple Access 2000
TD-SCDMA Time Division-Synchronous Code Division Multiple Access
WAN Wide Area Network
LAN Local Area Network
RSRP Reference Signal Receiving Power
RSRQ Reference Signal Receiving Quality
RSSI Received Signal Strength Indicator
RE Resource Element
SLA Service Level Agreement
HARQ Hybrid Automatic Repeat Request
CRS Cell Reference Signal
PSS Primary Synchronization Signals
SSS Secondary Synchronization Signals
PBCH Physical Broadcast Channel
CSI-RS Channel State Information - Reference Signal
BSC Base Station Controller
RNC Radio Network Controller
CU Centralized Unit
DU Distributed Unit
DAS Distributed Antenna System
CBD Central Business District
DMRS Demodulation Reference Signal
MRSRP Mobility Reference Signal Received Power
PDF Probability Density Function
CDF Cumulative Distribution Function
SS-RSRP Synchronization Signal Reference Signal Received Power

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