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Performance Evaluation of 5G in Sub-6GHz

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Abstract: As a successor to the present 4G technology, 5G is a modern technology with a new interface that is being developed. The main purpose of 5G is to deliver a diversified collection of services to clients worldwide, including fast data speeds, wider coverage, low latency, cheap cost, high system capacity, and a variety of connectivity alternatives. Every major carrier intends to build both millimetre wave and sub-6 5G networks, but they choose to start with the lowest frequency bands and work their way up the frequency spectrum. The sub-6 spectrums are a better option for 5G. The recent deployments of the 5G networks are focused on the sub-6GHz spectrums. However, there are limited works reported on the 5G in sub-6GHz and this has motivated us to evaluate the performance of the 5G network in sub-6GHz spectrums. This project evaluates the performance of a 5G sub-6GHz network and the performance of the 5G is compared with the 4G Long-Term Evolution (LTE) network. The Vienna 5G System Level Simulator is a numerical model of wireless communication networks that is used to develop and improve mobile communication standards. It allows the community to do repeatable simulations of crucial scenarios in preparation for 5G and beyond. The performance of the 5G sub-6GHz throughputs is evaluated using the Vienna 5G Simulator. Extensive simulation works that considered a variety of factors, i.e., bandwidths, the number of users, users speed, and carrier frequencies were carried out to evaluate the performance of the 5G sub-6GHz network. The numerical findings indicate that 5G sub-6GHz performance is always better than LTE performance under identical simulation circumstances, demonstrating that 5G always outperforms LTE. The average cell throughput of the 5G sub-6GHz is 8 times more than the 4G network. The average peak throughput dropped when the mobility speed of the users increased. The throughput of the 5G network is directly proportional to the frequency bandwidth allocated.

Keywords: *5G Sub-6GHz, carrier frequency, LTE*

1. Introduction

The scientific community has a lot of interest and focus on the 5G network because of its functionality and improvements over 4G-LTE. 5G is the most exciting and sought-after issue in the world of mobile carriers these days. This is predictable, considering that 5G, like 4G-LTE and 3G before it, is the next generation of mobile technology.

The first-generation (1G) cell phone was based on analog technology and functions similarly to a landline phone. It suffers from a variety of issues. In 1G, the greatest feasible speed was 2.4 kbps. The 1G mobile communication technology had limited capacity, and supported only a small number of niche customers such as the military, government agencies, and users in specialized sectors. This service was geographically restricted in the 1960s and 1970s, and the mobile equipment was too big to be put in vehicles or trucks. Because of the limited capacity to serve the general population, the limited technological capabilities to cover broad regions, the huge size of the mobile device, and the high costs of mobile devices and tariffs, this kind of mobile communications was not suitable for mass growth.

The second-generation (2G) of GSM-based mobile networks is known as 2G. 2G networks utilized digital radio frequencies. The use of digital signals rather than analog (1G) offered data rates of up to 64 kbps. The ability to enable services such as SMS (Short Message Service) and MMS (Multimedia Message) and the usage of a bandwidth of 30 to 200 kHz were all major advancements of 2G. The greatest possible speed in 2G was 1 Mbps.

The third-generation (3G) network was introduced with the support of enhanced spectrum coherence. 3G enabled Internet Service Providers (ISPs) to offer a broader selection of services to their clients while also growing the size of their network. Furthermore, it supported High-Speed Data Packet Access (HSPA) data transfer [5]. 3G combined high-speed mobile connections with IP-based services and provided faster internet access rates. The International Telecommunication Union had set a frequency band rate of 2000 MHz for 3G cellular technology to deliver a single global wireless communication standard.

4G refers to the fourth-generation mobile wireless communication technology, which became commercially

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available in 2010. 4G is a technical system based on the Internet protocol that provides authorization over many radio frequency platforms. 4G may deliver speeds ranging from 100 Mbps to 1 Gbps, as well as a high level of Quality of Service (QoS) and security [6]. Users can use 4G to access a wide range of services at any time and from any location. Some of the key qualities of 4G wireless technology are improved video conferencing, GPRS services, increased security, faster speeds, and cheaper operating costs. LTE offers greater bandwidth of up to 100 Mhz. Various efforts were proposed to enhance the LTE network performance and extra effort is needed to enhance the 5G network [13][14].

Modern communications have advanced tremendously in recent years because of their ability to transmit information quickly and effortlessly over short and long distances. The current approaches are insufficient to fulfil consumers' growing data demands. As a result, consumers have a greater desire for high-quality service, better data rates for audio/video streaming, and lower energy consumption for wireless devices. According to [1] as more and more gadgets become available, the need for faster internet rates will grow dramatically. Total traffic has grown to at least 800 Mbps/subcarrier in the year 2020, according to the Universal Mobile Telecommunication System (UMTS) [1]. All these issues may be addressed by 5G, which provides faster connection rates, more device capacity, and lower latency.

In the year 2020, it was estimated that 80 percent of all traffic have been produced inside [2]. The applications that are frequently used are video streaming and require extremely high data rates. Web surfing and voice calls, among other outdoor uses, are the most popular. Cellular networks are now designed and adjusted to provide identical services in both outdoor and inside environments.

The 5G wireless technology is said to be a fully packaged wireless communication technology or architecture that has no defects and provides a faultless Worldwide Wireless Web experience [7]. 5G is the next major thing in mobile communications technology standards after 4G or International Mobile Telecommunications, IMT-Advanced Standards. Telecommunication standardisation bodies such as the WiMAX Forum, International Telecommunication Union – Radio communication （ITU-R）, and 3rd Generation Partnership Project （3GPP）have yet to define 5G as a language or technology [8]. The most recent version will increase efficiency and capabilities even further with 26 new application scenarios. Among the most recent software enhancements are smart homes, security, smart transportation, and better security. In the architecture of the 5G mobile network, all IP-based technologies, also known as All-IP Network (AIPN), would be used [9]. AIPN would be able to handle the ever-increasing demands of the sector. It is a popular scene for radio access systems. The AIPN employs packet switching, and its ongoing expansion allows for greater efficiency and cheaper costs [7]. The 5G network technology includes a user terminal, which is an important component of the future architecture, as well as a large number of Radio Access Technologies (RAT) [8].

5G is predicted to have speeds up to 100 times faster than 4G and it beats the past network generations. The advantages of 5G, on the other hand, go beyond speed. Another advantage of 5G is its low latency, which allows apps and services to connect and transfer data in near real-time. One of the driving causes behind the Fourth Industrial Revolution, which will be fuelled by 5G, will be the blurring of the lines between the physical, digital, and biological worlds.

The potential gains in the social sector are another reason why we need 5G technology. Although 5G's essential capabilities are obvious, how the next-generation network may contribute to the settlement of long-standing societal challenges is unique and complex. Understanding the importance of 5G technology leads to a better understanding of its potential influence on industrial and environmental developments.

Furthermore, mmWave frequencies (28-100 GHz) will be used in 5G communications, which would have a substantial influence on signal coverage owing to building propagation. There is also the mid and low-frequency band that falls below 6 GHz, also known as sub-6GHz. mmWave refers to high-frequency radio bands that range from 24 GHz to 100 GHz. Low-frequency bands range from 0 GHz to 1 GHz, whereas mid-frequency bands (sub-6GHz) are from 2 GHz to 6 GHz.

According to [3], although mmWave 5G networks are tremendously fast, their range is quite restricted. To enjoy the full potential of mmWave technology, one must be as close as possible to a 5G tower, which is not practical. The mmWave signal is obstructed and obscured by doors, glass, trees, and buildings, further limiting its range, and since it requires far too many towers for coverage. It is costly for carriers to deploy mmWave 5G networks.

Even though sub-6 5G requires just minimal tower renovations, several 5G carriers throughout the world have been able to swiftly build "national" networks utilising their existing towers and spectrum. They only need to upgrade their towers to meet 5G criteria so that 5G can coexist with 4G in most areas of the nation. Furthermore, because these carriers currently have spectrum in lower frequencies (around 6 GHz), they will be able to provide high throughput with 5G technology without jeopardising their current 4G capabilities. Hence, the recent 5G network deployment is utilising sub-6GHz frequency bands.

According to [4], the only notable gain in experience with sub-6 mid-frequencies, which are between 2 GHz and 6 GHz and where 4G networks have previously failed but 5G networks may succeed. Because it has a lot of vacant spectrums, little rivalry from the existing 4G networks, and new network technologies. Thus, the mid-frequencies in 5G are a superb network that balances speeds with range and object avoidance.

While the majority of the recent 5G communications research works provided a broad overview of 5G networks as a collection of important radio technology and architectural approaches, the specifics of a 5G sub-6GHz mobile network remain unknown. The goal of this study is to evaluate a 5G sub-6GHz network in MATLAB and compare the performance of the 5G sub-6GHz network with a 4G-LTE network.

According to a recent survey [11], the average 5G download speed is currently 59 Mbps, which is not significantly quicker than a standard 4G network. Depending on the carrier, this varies slightly. For example, AT&T has a 53 Mbps average download speed, T-Mobile has a 47 Mbps average download speed, and Verizon has a 44 Mbps average download speed. According to [11], the average speed is just 2.7 times that of 4G, well short of the hundreds of times quicker than we may someday achieve.

The paper is arranged in the following manner. The detailed methodology for the simulation works is illustrated in section 2. Extensive simulation results to evaluate the performance between the 4G and 5G networks are reported in section 3. Finally, a conclusion is drawn in section 4.

2. Methodology

The methodology to carry out the simulation using the Vienna 5G Simulator in order to obtain the throughput of the 5G network under different parameters is presented in this section. Scenario files are used to define simulations. BasicScenario.m is in the +scenarios folder and contains all the settings required to run a simulation. All the scenario files are editable to model the scenario required to carry out the simulation analysis for this project. The default values will be used for all the undefined parameters. In the scenario file +scenarios/example.m, the default settings are stated. As a result, all settings are centralised in one location rather than being dispersed over hidden configuration files. A function in a scenario file requires one of the type parameters as an argument. argument and returns a parameter object containing the scenario's needed values.

The existing scenario file is modified to model and simulate the new 5G network scenario. The basicScenario file is changed to model the preferred scenario for this work. A list of all parameters that may be set, as well as their default settings, can be found in the scenario file example.m. All parameters in the modified file are set to their default settings. This served as a guide to which parameters do not need to be modified because they are set to the desired value by default. The default parameters used in the example.m are shown in Figure 1.

Figure 2 shows the configuration of the 5G bandwidth in the Vienna 5G Simulator. The frequency bandwidth for the downlink is configured to 100 MHz (100e6). The scheduler used in the simulation is round-robin. The Vienna 5G Simulator allows the user to configure the positions, moving speed, transmit power, channel mode and traffic type of the 5G users. Figure 3 shows the parameters configurated for the 5G users. The mobility of the 5G users is configured in the Vienna 5G Simulator in order to evaluate the impact of the users' mobility on the 5G network performance. The configuration is shown in Figure 4.

```
params = parameters.Parameters;

%% time
params.time.numberOfChunks              = 1;    % default value
params.time.slotDuration                = 1e-3; % default value
params.time.slotsPerChunk               = 10;   % default value
params.time.timeBetweenChunksInSlots    = 50;   % default value
params.time.feedbackDelay               = 3;    % default value

%% region of interest
params.regionOfInterest.interferenceRegionFactor    = 1;
params.regionOfInterest.interference                = parameters.setting.Interference.none;
params.regionOfInterest.origin2D                    = [0; 0];
params.regionOfInterest.xSpan                       = 1000;
params.regionOfInterest.ySpan                       = 1000;
params.regionOfInterest.zSpan                       = 1000;
```

Fig. 1. The default parameters used in the simulation

```
%% transmission parameters
params.transmissionParameters.DL.bandwidthHz = 100e6;

% scheduler
params.schedulerParameters.type = parameters.setting.SchedulerType.roundRobin;
```

Fig. 2. The 5G bandwidth configuration in the Vienna 5G Simulator

```
predefinedUsers = parameters.user.PredefinedPositions();
predefinedUsers.positions               = [0; 0; 0];
predefinedUsers.nRX                     = 4;
predefinedUsers.indoorDecision          = parameters.indoorDecision.Static(parameters.setting.Indoor.indoor);
predefinedUsers.speed                   = 1/3.6;
predefinedUsers.transmitPower           = 1;
predefinedUsers.channelModelTypes       = parameters.setting.ChannelModel.PedA;
predefinedUsers.trafficModelType        = parameters.setting.TrafficModelType.FullBuffer;
params.userParameters('predefUsers')    = predefinedUsers;
```

Fig. 3. The parameters configurated for the 5G users

```
movingUsersRandom = parameters.user.Poisson2D();
movingUsersRandom.nRX                   = 4;
movingUsersRandom.nElements             = 99;
movingUsersRandom.height                = 1.5;
movingUsersRandom.indoorDecision        =  parameters.indoorDecision.Static(parameters.setting.Indoor.indoor);
movingUsersRandom.speed                 = 1/3.6;                                % select high sp
movingUsersRandom.channelModelTypes  = parameters.setting.ChannelModel.PedA;
movingUsersRandom.userMovement.type  = parameters.user.MovementType.ConstSpeedRandomWalk;   % random consta
movingUsersRandom.trafficModelType   = parameters.setting.TrafficModelType.FullBuffer;
params.userParameters('poissonUser') = movingUsersRandom;
```

Fig. 4. The mobility configuration of the 5G users

3. Simulation Results

The extensive simulations were carried out under a range of situations with a variety of factors such as user speed, carrier frequency, number of users, and bandwidth to analyze the performance of the 5G sub-6GHz. The scenarios are designed to evaluate the performance between the 5G sub-6GHz and 4G throughput performance. The parameters used in the simulation for both 4G and 5G sub-6 are listed in Table 1. This is done to verify that the simulation parameters are all the same so that the results can be compared equitably. Throughout the simulations, the Vienna 5G System Level Simulator was used.

Table 1. The parameters used in the simulations

Technology	**4G**	**5G sub-6GHz**
Number of eNodeBs	3	3
Number of users per eNodeB	20-100	20-100
Bandwidth (MHz)	20	20,40,60,80, 100
Carrier frequency (MHz)	800, 1800, 2100	800, 1800, 2100
UE speeds (km/h)	5, 50, 100	5, 50, 100

3.1. Peak Throughput

Peak throughput is the figure determined for users closest to cell centres, and it has the most impact on the overall cell throughput. When compared to other users, users that are nearest to the cell centre have the least fading channels and have the highest channel quality. As a result, communication between central users and the eNodeB improves. The simulation results for the average peak user throughput vs the number of users is shown in Figure 5. When there are 20 users on a network, the peak throughputs for 4G and 5G are 1.9 Mbps and 15.886 Mbps, respectively. This is because the resources are divided among the 20 users. In a nutshell, as the number of users grows, the peak throughput falls. This can be seen when the number of users is 100, the average peak throughputs for 4G and 5G are 0.38 Mbps and 3.098 Mbps, respectively.

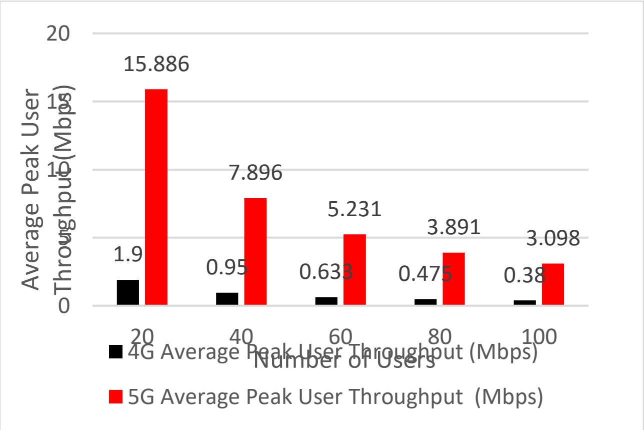

Fig. 5. Average Peak User Throughput with Different Numbers of 4G and 5G Users

3.2. Average Cell Throughput

Average cell throughput is one of the most essential performance metrics in the resource allocation for 4G LTE and 5G systems. High user throughput implies that the users have better network service and experience. The average cell throughput vs. the number of users is shown in Figure 6. It shows that the 5G sub-6GHz has an average cell throughput of 8 times more than the 4G network. The average cell throughput for 5G sub-6GHz is roughly 310 Mbps, while the average cell throughput for 4G is around 38 Mbps.

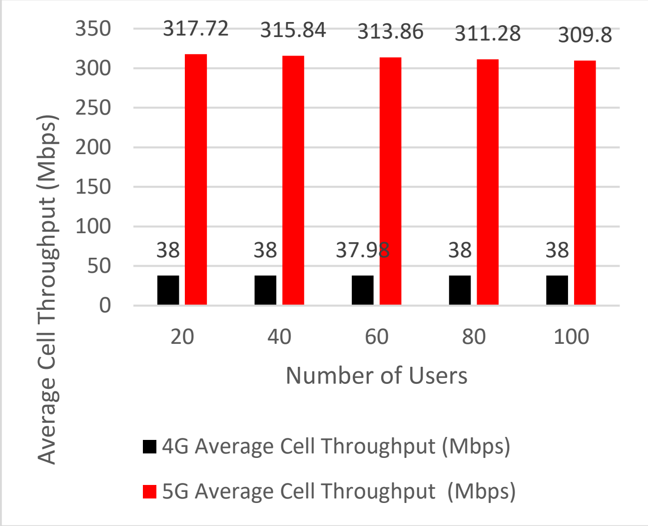

Fig. 6. Average Cell Throughput with Different Numbers of 4G and 5G Users

3.3. Mobility of Users

The LTE network was designed to function effectively at a variety of user speeds ranging from 0 to 350 km/h. Furthermore, the 5G network shall also incorporate high mobility requirements as an integral part, providing satisfactory service to users travelling at a speed up to 500 km/h. Three levels of user speeds are used in the simulations to evaluate the performance of the 4G and 5G networks with 5 km/h for average human walking pace, 50 km/h for urban driving speed, and 100 km/h for highway driving speed.

Figure 7 shows that when the mobility speed of the users increases, the average peak throughput drops. This is a natural consequence of mobility because the faster a user moves, the more difficult for the user to maintain an acceptable channel quality between the user and the eNodeB.

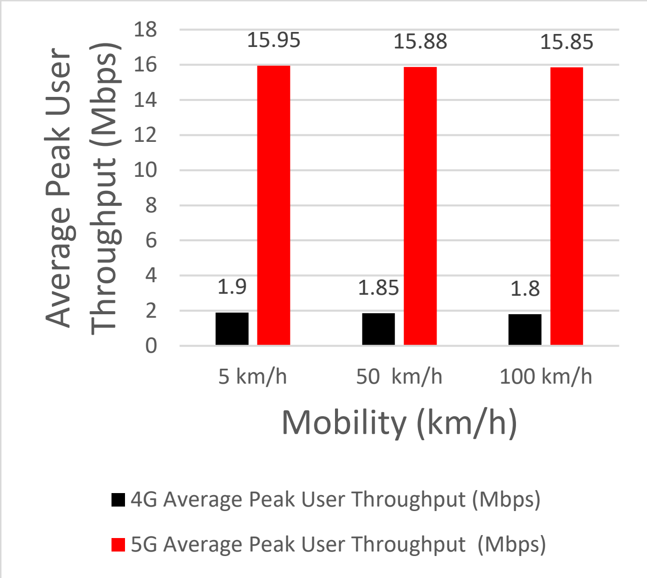

Fig. 7. Average Peak User Throughput in Different Users' Mobility Speeds

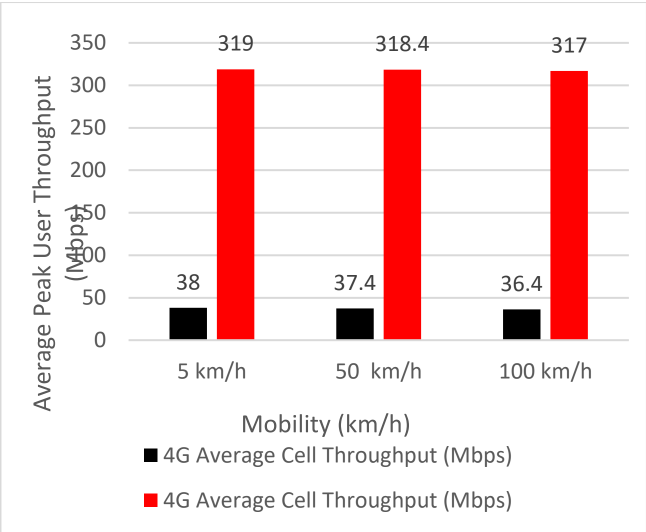

Fig. 8. Average Cell Throughput in different Users' Mobility Speeds

Another significant metric for demonstrating the consequences of user mobility is average cell throughput. Figure 8 shows the average cell throughput of the 4G and 5G networks at three different mobility speeds. It can be shown that as speeds increase, user channel conditions decrease. The average peak and average cell throughputs suffer as a result. However, the reductions in throughput are not considered significant because the Average Cell Throughput of the 4G and 5G networks decreases by 1.6 Mbps and 2 Mbps, respectively, when the speed increased from 5 km/h to 100 km/h. This is because a 4G network can support user speeds of up to 350 km/h, while a 5G network can support speeds of up to 500 km/h.

3.4. Carrier Frequency

LTE networks in different nations operate on different carrier frequency bands spanning from 700 to 3500 MHz [12]. Wherever possible, 5G sub-6GHz networks operate in frequency ranges below 6GHz. The frequency bands 800, 1800, and 2100 MHz were used in the simulations to show the impacts of carrier frequency on throughput so that 4G and 5G findings could be compared equitably.

Figure 9 shows that when the carrier frequency values increase, average peak user throughput tends to rise. The average peak user throughput values for the 5G 2100 MHz and 1800 MHz are 38% and 15% higher than the 800 MHz carrier frequency, respectively. The same trend is observed for the 4G network. The average peak user throughputs for 2100 MHz and 1800 MHz are 31.6% and 15.8% higher than the 800 MHz, respectively.

The average cell throughput of the 4G and 5G networks with the carrier frequencies of 800, 1800, and 2100 MHz are shown in Figure 10. As a result, as the frequency increased, the average peak user throughput increased, but the average cell throughput remained the same. This is because higher frequencies give more bandwidth, allowing for the transmission of significantly more data in a shorter amount of time, resulting in higher peak throughput while the average cell throughput remains the same. The simulation results indicate that the average cell throughput remains consistent and is unaffected by carrier frequency ranges.

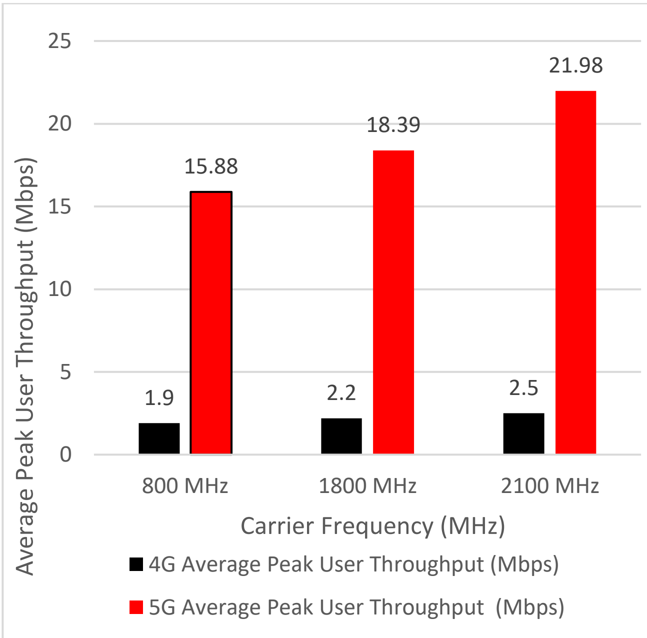

Fig. 9. Average Peak User Throughput Performance under Different Carrier Frequencies

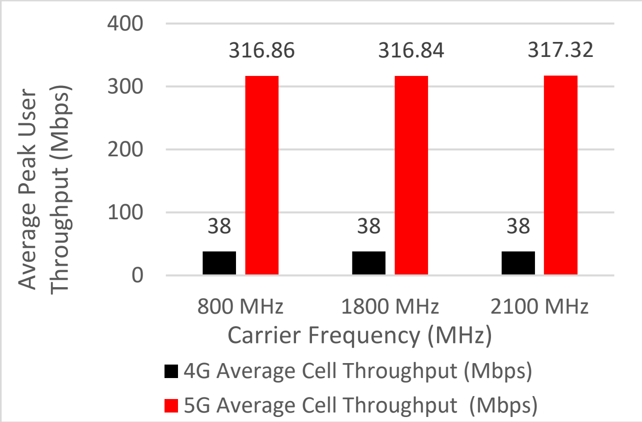

Fig. 10. Average Cell Throughput for Different Carrier Frequencies

Individual frequency channels in 4G networks might range from 1 MHz to 20 MHz, while in 5G, individual channels could be as broad as 400 MHz. The maximum bandwidth in the sub-6 GHz range is 100 MHz, whereas the maximum bandwidth in the millimetre wave area is 400 Mhz. In theory, a sub-6GHz network may provide up to five times the bandwidth of a 4G connection. Indeed, this one distinction in the 5G NR (New Radio) standard. This is likely the most fundamental reason why the 5G networks can be quicker than the 4G networks. Figure 11 compares the performance of a sub-6GHz network with the frequency channel bandwidth of 20, 40, 60, 80 and 100 MHz and the number of users increased from 10 to 100 (in a step of 10). It shows that more channel bandwidths improve the throughput performance whereas a larger number of users reduces the throughput performance. The maximum average peak user throughput of the 5G sub-6 network is 159.9 Mbps with a network configuration of 100 MHz frequency bandwidth and 10 users. The lowest average peak user throughput of the 5G sub-6 network is 3.104 Mbps with a network configuration of 20 MHz frequency bandwidth and 100 users.

As shown in Figure 12, the throughput ratios of the 5G with the frequency channel bandwidths of 40 MHz, 60 MHz, 80 MHz and 100 MHz compared to 20 MHz are 2, 3, 4 and 5 times, respectively. The throughput of the 5G network is directly proportional to the frequency channel bandwidth. Thus, as the frequency channel bandwidth increases, so does the throughput. The throughput is inversely proportional to the number of users in a network cell.

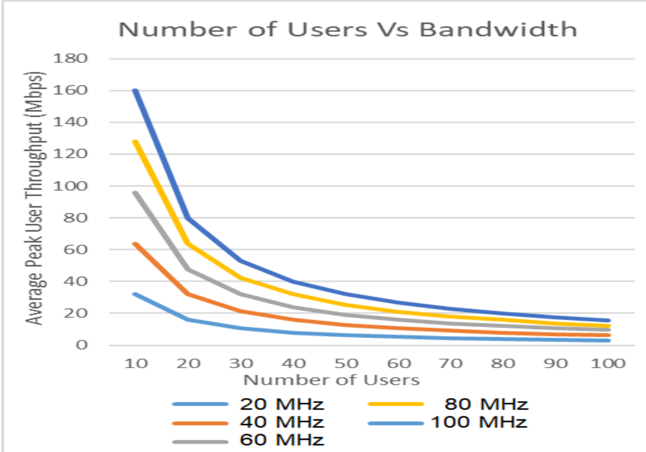

Fig. 11. The Average Peak User Throughput for Different 5G Frequency Channel Bandwidths

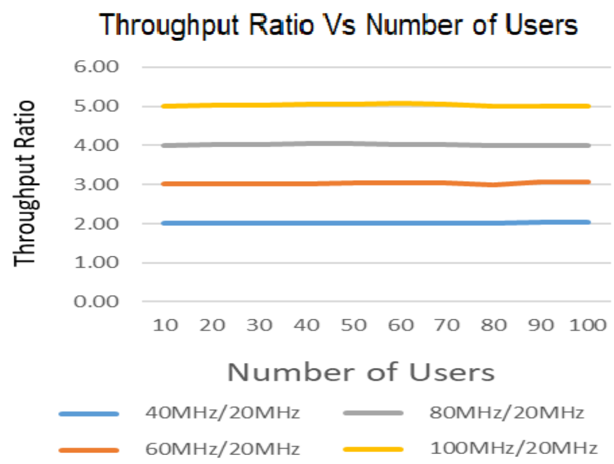

Fig. 12. The Throughput Ratio for Different 5G Frequency Bandwidths

4. Conclusion

5G Sub-6GHz is faster than 4G, but it lacks the blazing-fast speeds that mmWave can provide. It is far more economical for carriers to deploy the 5G network in sub-6GHz because it has greater coverage. It has a lot of vacant spectrums, little rivalry from existing 4G networks, and certain new network technology, 5G sub-6GHz can be a fantastic network that balances higher speeds with reasonable range and object avoidance. Mid-band 5G frequency will be a vital component of any carrier's entire 5G strategy. The 5G sub-6GHz has an average cell throughput of 8 times more than the 4G network. The average peak throughput dropped when the mobility speeds of the users increased. The average peak user throughput increased when the carrier frequency value increased. The throughput of the 5G network is directly proportional to the frequency bandwidth. Sub-6 is today's 5G, but mmWave is unquestionably the 5G of the future. But it is not quite that straightforward. We will have to combine sub-6 with mmWave at some point. Both are strong in various aspects. Sub-6 is good at consistency and coverage, while mmWave is good at speed and density and both may be used in tandem. Carriers can utilise their strengths and give a better overall experience by combining the two.

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Author contributions

Wai Leong Pang: Conceptualization, Methodology, Writing-Reviewing and Editing **Gwo Chin Chung:** Data curation, Writing-Original draft preparation **Kah Yoong Chan:** Software, Validation **Mardeni Roslee:** Visualization, Writing-Reviewing and Editing **Arvindraj A/L Ravi Chandran:** Field study, Visualization, Investigation, Software

Conflicts of interest

The authors declare no conflicts of interest.

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