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IMPROVING MOBILE USER EXPERIENCES WITH 5G: FASTER, MORE RELIABLE, AND MORE RESPONSIVE APPLICATIONS

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ABSTRACT

The 5G technology will be revolutionizing the mobile communication world providing significant increases in speed, reliability and responsiveness. The current research examines the possibility of 5G mobile technology to deliver powerful mobile user experiences, especially when it comes to mobile applications. The 4G networks are increasingly showing constraints due to the increased demand of real time data-heavy applications like augmented reality (AR), virtual reality (VR) and high definition streaming video. Our paper is on the potentialities of 5G in overcoming these liabilities by utilization of its ultra-low latency, increased bandwidth and strong connectivity. We analyze the cases of 5G combining with other mobile applications and explain what changes in application design and user experience are taking place. We incorporate in our approach measuring the major performance indicators, download/upload speed, latency, and reliability on 5G networks in real-life mobile conditions. Test results show that it increases the responsiveness of applications greatly, decreases the amounts of buffering, and improves the video quality. The paper has concluded that 5G technology will play a key role towards the future mobile user experience and how it can affect both developers of mobile software and mobile end-users. We propose the future research direction by suggesting the gradual exploration of the 5G influence on AI-based mobile applications and the way 5G can be integrated with or without the IoT-based systems.

Key phrases:

5G, mobile performance expertise, latency, bandwidth, program design and style, true period software, cellular networks

1. Introduction

With the arrival of the 5G technology there has been a transition of massive proportions in the sphere of mobile communications, and it has been declared that the mobile networks will become an important part to be advanced in quality and speed along with the manner in which the users can communicate with their devices. Being the next generation of 4G, 5G will offer a significant advancement in terms of data transmission speed, reliability of the network, and latency, therefore, serving as the foundation of the new generation of mobile applications (Hassan et al., 2021). The developments mean that 5G will play a decisive role in numerous areas such as autonomous cars, Internet of Things (IoT) systems, smart cities, and specifically mobile apps (Zhang et al., 2020). The trend in mobile technologies is that more speed, responsiveness, and reliability in the networks are rendered with a stronger pace, especially considering highly demanding applications that go along with augmented reality (AR), virtual reality (VR), real-time gaming, and 4K streaming videos (Patel et al., 2020). The drawbacks of 4G networks, i.e., slower data rate, increased latency, and connectivity challenges in crowded hubs have posed a lot of obstacles to these applications, thus hampering their futures. Such restrictions will be freed under 5G, and the next generation of the mobile app can offer new levels of user experiences (Hassan et al., 2021).

Mobile applications have also become more advanced as they use real time data, and deep multimedia content. This has fuelled the need to have high speed data transmission, low latency and smooth connection that the 4G network has been uncovered as deficient. As an example, the AR and VR applications require ultra-low latency in order to have immersion, and video streaming 4K video requires high bandwidth to eliminate buffering and make playback seamless (Smith et al., 2020). But then, even with their technology, the 4G networks have become very inadequate in addressing such demands. Pitfalls like lag, video lag, and even interaction delays are the order of the day in the use of such applications in 4G, hence the compromised user experience (Patel et al., 2020). On the contrary, 5G is expected to address these issues since it will offer ultra-low latencies, higher transmission rates,

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and improved reliability that are critical to enhancing the mobile user experience on societal level (Khan et al., 2021).

The 5G brings improvements in speed especially. Though 4G can offer a speed of 1 Gbps, 5G will offer a speed which may be as high as 10 Gbps or higher depending on the circumstances (Wang & Lee, 2020). Such a drastic improvement in speed will have far reaching consequences to mobile applications and particularly those which are based on the quick transmission of large data volumes. As an example, in mobile gaming, the low latency and high bandwidth offered by 5G will allow an easier game experience, control response, and less lag which are also considered as critical in competitive game experiences. Similarly, in the cases of augmented reality and virtual reality, 5G will reduce latency in communication between the action by a user and what is displayed on the screen, and interactions will feel more natural and less disorienting. The higher performance will greatly boost the user experience in multiple applications (Zhang et al., 2020).

Besides being faster, the use of 5G also has another important advantage; increased number of devices. With the rising IoT connections, mobile networks have to be able to support a high number of connected devices without compromising the quality of service. 5G networks were specifically built to take these additional strains, using such technologies as massive MIMO (multiple input, multiple output) to improve network capacity and maintain a more stable connection even in crowded areas (Patel et al., 2020). This is particularly interesting to mobile applications in smart cities where there could be thousands of devices that may require connecting at a given time. With the help of its rapid and stable connection in such high-population settings, 5G will guarantee that mobile-based applications like the ones that facilitate the smart home automation process, live road traffic, or remote patient tracking will work properly (Khan et al., 2021).

The objectives of the research will be to examine how 5G can solve the main issues of mobile applications considering their responsiveness, reliability, and bandwidth. These are the areas that can be improved with 5G, which can bring massive improvements to the experience of a plurality of mobile applications provided. This paper shall review how 5G platform will address the shortcoming of the existing mobile networks, especially with respect to latency, bandwidth, and will provide how it can promote the creation of new data intensive applications that are capable of maximizing the potential of 5G itself. The objectives of the study will consist of three major ones: (1) an attempt to investigate how the introduction of 5G technology can address the critical shortcomings of mobile apps, (2) an evaluation of the efficiency of the mobile application available on the market in the 5G operating environment, and (3) a critique of how mobile developers can use the unique properties of 5G technology to drive user experience.

To respond to these aims, the paper is going to start with the analysis of the situation with the mobile applications performance under the circumstances of 4G, paying attention to the restrictions related to the latency, data transfer rates, and network stability. It will consequently review how 5G will enhance these by carrying out a technical analysis that analyses the capabilities of 5G in detail. This will entail an evaluation on how 5G will likely affect major performance benchmarks, including download/upload performance, latency, network reliability, and user experience when working on live mobile applications. The paper will also examine what mobile developers can do to get the best out of the available features of 5G technology to make sure that consumers stand to benefit in terms of faster, reliable, and competent applications (Zhang et al., 2020).

A significant development of this work is that of concentrating on the practical implication of 5G on mobile applications. Most of the literature available has focused either on theoretically-practical performance accumulations or the technologies behind 5G, but little literature has been available that assesses the impacts of 5G on mobile applications as a user. The paper will attempt to address that gap by conducting an extensive discussion of how 5G could enhance usability and functionality of bandwidth-intensive and low-latency applications. The end objective is to present practical recommendations in the development of applications taking full advantage of the 5G capabilities such that new opportunities will be created with improved user experiences (Smith et al., 2020).

To conclude, it can be stated that this study will prove that the implementation of 5G technology into the mobile applications can enhance greatly the consumer experience offering higher

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data speeds, reduced latency, and steadier points of connection. The paper will dwell on real-time uses like AR, VR, and 4K video streaming which have, to a large extent, been affected by the shortcomings of 4G networks. With the knowledge of how 5G can solve these issues and provide a platform to pursue new, data-intensive applications this research will add to the context of the discussion of what mobile communications and mobile application development are in the future (Hassan et al., 2021).

2 Review of literature

With the emergence of 5G technology, mobile communication networks would be redefined and there will be huge improvements in the network capabilities than the earlier generations, especially in the data speed, latency, and reliability. Such enhancements will transform mobile apps, where a new wave of data intensive applications and real-time applications will be enabled (augmented reality (AR), virtual reality (VR), real-time gaming, and high-definition video streaming) (Khan et al., 2021). The 5G networks are also expected to overcome the constraints of the 4 G networks, which have not kept up with the increased demands of the contemporary mobile application (Patel et al., 2020).

Among the most important advantages of 5G technology is the considerable decrease in the latency that is projected to go as low as 1 millisecond in case of an ideal situation. Latency Exchange of information This is the time difference between transmission and reception of information; it is critical in real-time applications, which may cause serious detrformance to the user experience. Past studies revealed that low latency is essential in the applications such as AR and VR, in which the minute delays can make people dizzy and/or interrupt immersion (Patel et al., 2020). Consider, e.g., mobile gaming where the 5G ultra-low latency is going to make the gameplay smoother with almost zero delays since the near-instant response time can be critical in the vicinity of mobile gaming (Smith et al., 2020). Moreover, the shorter latency of 5G will serve telemedicine: telemedicine apps will allow healthcare providers to monitor patients in real-time and perform consultations with very little lags, which will increase the quality and speed of healthcare services (Chopra & Batra, 2022).

When taking into account bandwidth, 5G will enable far greater data processing as opposed to 4G networks that have been unable to accommodate the growing need of high-definition video streaming and other heavy data carrying applications. A 5G will make video streaming more stable, streaming of video offering better quality, and at the same time have less buffering. This enhancement is of specific concern to 4K and 8K streaming videos that would need a high bandwidth to stream high-resolution content without delays. The study by Zhang et al. (2020) showed that the high bandwidth of 5G will enable more seamless video streaming across high-density and remote sites, where currently 4G networks can only be overwhelmed and do not show sufficient performance. The benefit of this bandwidth expansion will also contribute to introduction of advanced applications, including immersive AR and VR environments, which will need to continuously and convey high-frequency data to be operational.

There have been a number of studies targeting the possible advantages of 5G in mobile application. Chopra and Batra (2022) present an extended overview of 5G and mobile applications integration and emphasize the potential of 5G to provide the high-speed transfer of data and low latency and thus considerably increase the user experience in various sectors, including entertainment, gaming, healthcare habits, and education. The authors indicated that mobile applications would be much faster and responsive to customer demands especially in applications that require real-time as the 5G networks would offer the required infrastructure to ensure uninterrupted and quality services. Moreover, the fact that 5G can connect a large amount of devices at once due to the technologies like massive MIMO (multiple input, multiple output) will allow smooth functioning within an IoT-based environment, which is necessary to create smart cities and connected devices (Khan et al., 2021).

Nonetheless, in spite of the positive perspectives, a number of obstacles still persist in the complete realisation of the potential of the 5G technology. Among the most famous barriers is that of the infrastructure needed to facilitate the operation of 5G networks, which in most areas is still being developed. Although people are experiencing the implementation of 5G networks to big cities and metropolitan regions, rural and low-populated areas are frequently ignored because of the issues

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caused by the cost-effectiveness and logistical deficiencies of the implementation of the 5G infrastructure (Hassan et al., 2021). Such inequality in the availability of networks might restrict the lighting of 5G and its impact particularly in the areas where 4G networks are still predominant. Also, the expenditure of facilitating existing infrastructure to operate in 5G has been an issue especially to smaller telecommunications companies and firms who might not be able to facilitate the upgrade processes. 5G may not be implemented as fast as people could have expected, thus, the potential benefits affecting mobile applications could take a step back.

The other criterion that is greatly connected with 5G is security implications that come with the number of connected devices and the size of data that is being transmitted. With the many IoT devices connecting to mobile networks, there is a high possibility of cyber attacks and the breach of data. Massive volumes of high-value data sent via 5G communication networks notably in healthcare, finance, and self-driving transport industries pose an imperative need to implement high-security coverage to avert unauthorized access and safeguard the secrecy of users (Hassan et al., 2021). Though 5G will allow using more security tools, including network slicing and a better encryption protocol, the client mobile applications will lack the adaptability in a 5G setting, especially with new platforms and technologies. Research by Wang and Lee (2020) has indicated that the solving of these security issues will become paramount in winning the confidence and mass adoption of 5G networks, especially in the industries that deal with sensitive information.

Along with these challenges, the literature has a remarkable gap in the investigations of the actualization of the influence of 5G on mobile application in the real world. Although the technological advantages of 5G networks have been highly studied in works of literature, little has been done to determine how this trend translates to real-life performance and user experience of mobile applications. The possible advantages of 5G have been modeled and simulated, yet no empirical evidence exists regarding the impact of 5G on the throughput improvement of specific applications in real situations. Such literature gap is essential because it is necessary not only to learn a theoretical potential of 5G but how all these gains will be applied in practice. As an example, what does the faster data speeds and the reduced latency do in terms of user satisfaction with real-time tasks like video conferencing or mobile gaming? In order to close this knowledge gap, additional research is required to examine the practical effect of 5G on mobile apps and to determine what are the particular domains in which 5G can produce a notable improvement in the user experience (Zhang et al., 2020).

This paper will attempt to address this gap in literature by examining the practical implication of 5G on mobile applications. Assessing the mobile applications operating under 5G, the research will offer important sources of information how to use 5G to enhance the responsiveness, reliability, and bandwidth of the applications. This study will also be dedicated to determining the individual domains where the features of 5G can be applied to the improvement of user experience, especially in the case of data-intensive and real-time applications. Actionable key insights made by the present study will not only give light to the current state of understanding of real-life influence of 5G on mobile applications but also help application developers to perform actions that might allow them to tailor their applications with the exclusive capabilities of 5G in mind.

Summing up, this article reveals that even though the 5G technology has enormous potential to enhance the efficiency of mobile application, it remains a task to be achieved (especially when it comes to infrastructure deployment and security). However, it remains a fact that 5G has the potential of potentially improving the user experience in terms of speed, latency, and reliability. This literature review has established important ways through which 5G can greatly enhance mobile applications and also the believed research gaps that are going to be filled by the current study.

3. Motivation and problem statement

The high pace development of the mobile technology dramatically changed the interaction of people with their technologies having a tremendous influence on everyday life. Nevertheless, with the change in mobile applications, the issues relating to network capability have also evolved. A fundamental problem emerging in mobile applications, especially those that are highly dependent on real-time and data heavy works, can be viewed as an inadequate responsiveness, reliability, and quality of current mobile networks, specifically 4G. Although 4G offers substantial improvements on

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older systems, they are still lacking as far as seamless user experience is concerned in terms of high-bandwidth and low-latency transmissions (such as video streaming, gaming and augmented reality/virtual reality (AR/VR) apps). They caused bad user experience resulting in frequent buffering, high latency, resolution loss, and loss in video quality (Patel et al., 2020; Smith et al., 2020).

Mobile applications are becoming more advanced and this has increased the pressure on mobile networks. Mobile can be used in real time interactive applications including gaming, social and communication applications and require stable, high-speed connectivity with low latency to support smooth and enjoyable interaction. Alas, existing 4G networks, whose highest download rates go to as high as 1 Gbps and have a latency ranging between 30-50 milliseconds cannot easily accommodate such critical applications on an ongoing basis. As another example, consider video streaming, where 4G networks generally have a hard time keeping the 4K video quality up, causing the buffer to get full and the quality to decrease during rush hours or in crowded regions (Hassan et al., 2021). AR/VR applications, which need little latency and broadband network help to give a proximate enjoyment, experience quick delay and debase visuals when utilized on a 4G network (Zhang et al., 2020). In video games, 4G does not help lower latency, thus leading to incompetent responsiveness and irritation among the overall community, especially those who rely on timing and precision when it comes to multiplayer modes and competitions (Smith et al., 2020).

Such performance troubles do not only interfere with how users use such apps but also restrain the extent to which mobile apps can be utilized. Where mobile apps can revolutionize services and interactions such as in the sphere of healthcare, thousands of serious app ideas have been put on the backburner due to the absence of network reliability. To illustrate the problem, such an emergent telemedicine application as providing a remote consultation with the help of real-time video communication and data transmission tends to be compromised when operating with 4G networks and improves with the use of 5G (Khan et al., 2021). Another example concerns the use of educational technologies: in the education sector, interactive learning applications that are based on high-resolution video stream transmission and the possibility of real-time interaction also encounter performance limitations on 4G networks (Patel et al., 2020). These bottlenecks loom large and point to the urgency of a more competent mobile network in accommodating the rising demands of the modern mobile applications.

The adoption of 5G technology will go a long way in alleviating most of these challenges. Being the successor of mobile networks, 5G is projected to support a maximum download speed of up to 10 Gbps, a minimal latency of 1 millisecond and an increased network reliability that will drastically improve the performance of mobile applications (Hassan et al., 2021). The 5G networks can improve data-heavy applications with these leaps; thus becoming a much-needed relief to bandwidth-intensive services like HD video streaming, augmented reality/reality experiences, and real-time gaming. 5G networks will have a lower latency and more bandwidth, so mobile applications can work smoother and faster with fewer response time, less buffering, and high quality of content (Wang & Lee, 2020). As an example, in the gaming sector, the 5G will negate more latency with low-timing gaming, whereas video streaming will undergo a fundamental enhancement in quality even under high-demand scenarios.

In spite of the 5G promises, one should point out that the adoption of 5G within mobile apps comes with a few challenges that are still to be exhausted. Although many papers have already expressed the theoretical prospect of 5G in enhancing the mobile network performance (Khan et al., 2021; Zhang et al., 2020), there remains a gap in knowing how 5G will perform in real, world situations with regard to operating it. e.g. what about the ultra-low latency of 5G, and what are the implications of this on real-time applications such as in mobile gaming, which need a very high level of precision, and need player feedback with no lag at all? What is it about 5G, specifically the heightened bandwidth, that is bound to facilitate the increased quality of AR/VR experiences, especially in regions where network overload is still a considerably significant issue? Also, although 5G appears more dependable and having more consistent connections, it remains to be seen how well it would work in high-density city networks or rural networks, where infrastructure is not quite developed (Hassan et al., 2021). Such knowledge gaps in the literature encourage the research at hand, which aims at exploring the practical applications of 5G technology on mobile applications.

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The second reason which inspired this study is the dependence on mobile applications in the Internet of Things (IoT) and data-driven applications. The necessity to realize even faster and even more reliable networks has never been more important in the era of the proliferation of smart devices and the growing role of mobile applications in everyday life. IoT will produce large volumes of data that should be delivered in real-time, and the higher bandwidth and the ability to handle an enormous number of connected devices with 5G will play a crucial role in regulating the flow of this data (Patel et al., 2020). Nevertheless, although 5G is set to allow the development of IoT ecosystem, the true nature of its implications on mobile apps meant to capitalize on this data has yet to be discussed fully. That is currently not the case and therefore this research will work to bridge this gap by informing a practicable evaluation of how IoT and 5G will allow the optimization of mobile applications to meet the demands of an IoT future and other applications that require the flexibility of the network enabling developers to have a better grasp regarding how to use the full capabilities of the network to enhance the experiences of the users.

To sum it up, the rising dependence on mobile apps and the complexity of the latter are demanding more advanced mobile networks able to facilitate the needs of the first ones. 4G VLAs are not sufficient to offer the scale of performance necessary to power bandwidth-intensive apps like streaming, gaming, AR/VR experiences, etc. 5G will help break these shortcomings by providing higher data rates, extremely-low latencies and increased dependability. But we are yet to see what the real world idea of 5G means in terms of mobile applications. The objective of this study will be to understand what the effects of the 5G will be to the user experience, practically speaking, and how to better optimize the mobile applications to this new-generation network. Since the study will fill the missing understanding between the theoretical capability of 5G and the implementation, the study will be significant to mobile developers as they will build a better understanding of how they can take advantage of the 5G technology to create more functional and usable mobile applications.

4. Methodology

This work is conducted to measure the viability of mobile applications under the conditions of 5G, considering key performance indicators, which are essential to the happiness of users download/upload speeds, the timeliness of the video, time buffers, etc. The main aim is to evaluate the performance of the mobile applications in 5G networks with reference to 4G network, especially in data intensive tasks such as streaming, gaming, and real-time communication (Patel et al., 2020; Khan et al., 2021).

4.1-Choice of Mobile Application

To this end, some trending and various apps were chosen to address a variety of practical applications to be used in the study. Such apps consist of streaming services (e.g. Netflix, YouTube), VR/AR games (e.g. Pokemon Go, Beat Saber), and video conferencing applications (e.g. Zoom, Microsoft Teams). Such categories were selected due to the fact that they are applications that entail fast data transfer, less latency, and high-quality multimedia content in order to be effective (Chopra & Batra, 2022). All these types of apps are recognized to have their main technological issues when the application is performed under 4G, including buffering, latency, and unsatisfactory video quality, which is why they are the best candidates to demonstrate the feasibility advantages of 5G.

4.2 Research design

The experiments were framed to assemble real-world scenarios of mobile usage to determine the app performance in assorted network circumstances, which is an extensive feature. Two major testing conditions were applied: controlled conditions (i.e. fixed, stable network conditions such as a lab environment) and real world environments (i.e. dynamic changing network conditions such as a public setting). The availability of controlled environments was beneficial in terms of being able to measure network performance parameters with accuracy whereas the real-world environments were more of realistic stress-testing capability of the mobile applications as they may be in a real world situations in urban centres or crowded places.

To make the tests as valid and broad-scale as possible, the functionality of the chosen applications was tested on various devices that run on the different operating systems (iOS and Android), and the attention was paid not only to high-end devices, but also to smart phones with the

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mid-level characteristics. Such a great variety of testing environment made a better demonstration of the way various mobile devices may work in 5G conditions (Wang & Lee, 2020).

4.3 Tools to Monitor the Network Performance

To evaluate the performance of the network in the experiments, network analyzer and diagnostic software was employed. These were used to give detailed measurements of important network metrics such as latency, bandwidth and manner of connection. The implementations were the following ones:

- Wireshark: A network protocol analyzer which assists in measuring the packet loss, latency and bandwidth consumption in the stream and in real time communication.
- PingPlotter: This is the tool, which was used to track the latency and packet loss over time, so one can see a visual representation of how the network performed compared to earlier in a different state.
- Speedtest by Ookla: It is employed to test the download/upload speed and determine the general quality of the connection when diverse actions involving the usage of a large amount of data are conducted, including streaming.
- OpenSignal: A program utilized to test the network signal quality and observe the network speed in everyday situations especially in trade-town locations where the network may underperform due to the excessive rush (Patel et al., 2020).

Such tools were selected because of proper accuracy and reliability in the measurement of network parameters that are critical in determining how 5G technology influences mobile app performance.

4.4 Performance measure and data collection

The experiments were concentrated on such key performance indicators (KPIs) as are essential to evaluate the quality of mobile application performance:

1. Winning the race didn't matter, because these speed tests indicate that these phones are much faster with download/upload speeds than their predecessors or any other phones by far.

Speedtest by Ookla was used to determine the download and upload speeds, and this tool can be considered among the most reliable ones in regard to measuring the network speed (Smith et al., 2020). These are the speeds in terms of 4G and 5G networks both tested in the controlled environment, as well as in the real world. The findings were examined to identify the effects of 5G networks on the capacity to transfer data to enable application like streaming, games, and AR/VR.

2. Latency (ms):

Latency is one of the most important parameters in deciding user experience in real-time applications. Wireshark, as well as PingPlotter, were used to determine latency in this study because they are precise in network delay measurements (Wang & Lee, 2020). Latency was observed in milliseconds (ms) and 4G and 5G network networks were compared to see how 5G lessens the delay of interactive applications like gaming and video calls.

3. If you prefer, you can get an OEM\\Original equipment manufacturer replication instead of the manufacturer/original supplier.

One of the most important metrics with which the performance of streaming applications can be measured is video quality. In order to quantify it, there was use of subjective rating among the other participants in the test and also there was objective measurement. The quality of videos was rated by test participants on their resolution (e.g. 720p, 1080p, 4K) and clarity. The buffers were also checked during streaming sessions and with the help of such tools as Speedtest and Wireshark, we could evaluate how normally the buffers appeared and how long the buffers lasted. These are the measurements that gave an idea of how 5G can influence the quality of video streaming and whether it decreases the cases of disruptions better than 4G (Hassan et al., 2021).

4. App Responsiveness:

The measure of app responsiveness was done through the subjective rating of users and super objective speed tests. The participants were required to evaluate the responsiveness of the applications on 1 to 5 scale where 1 was very slow and 5 was very fast. Measures of speed were objective and checked by the software and timer that showed the time of completing some action

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(e.g. opening an app, loading a video, completing a level in a game). It has also combined subjective ratings and objective measures, which gave a detailed assessment of how responsive the apps were in 4G and 5G conditions (Patel et al., 2020).

4.5 On the Jobs Testing

Real-world testing was also performed in various locations under different network environments besides using controlled laboratory testing. This testing was necessary in an attempt to integrate the 5G performance in locations that are in various networks traffic conditions like urban, public locations and as well as the suburban areas. To give more context on how 5G reacts to changing circumstances, tools such as OpenSignal have been used to track the change in the quality of the signals and bandwidth during these real-life tests (Khan et al., 2021).

Conducting such experiments both in a controlled environment and in the real world, this research study was an attempt to evaluate the actual capabilities of 5G technology to improve the performance of mobile applications under various interaction scenarios.

4.6 Comparison of Analysis

The last procedure in the methodology was to compare the outcome of the 4G and the 5G networks to determine changes that 5G technology brings. The results of all the performance measurements such as the download/upload speeds, latency, video quality, buffers time, and app responsiveness were compared and analyzed. The statistical significance of whether the differences observed were, in fact, significant was determined by statistical analysis and whether the impetus of improved 5G networks produced an actual improvement in the experience of the users.

5. Conclusions and examination

The outcomes of this study represent the big difference in mobile application performance with the change of the network structure 4G-5G, where the positive results in download/upload rates, latency, the quality of videos, and app responsiveness are quantified. Such outcomes bring out the life changing changes to 5G technology which brings about realtime applications based on data insensitivities, which include video streaming, augmented reality(AR), virtual reality (VR) as well as video streaming. In this part of the paper, a rich discussion of the most important performance measures has been introduced, which sheds light upon the way 5G networks are more efficient than the 4G ones and the reason in which those gains have a positive role in supplying a user with a specific user experience.

5.1 Upload/Down speed

Speed of downloading and uploading was one of the most apparent change that was experienced in the study. In conditions of 4G network deployment, download speed reached up to 1 Gbps, which is customary in the case of 4G LTE connectivity (Patel et al., 2020). Contrarily, the 5G networks always went past 10 Gbps when poor conditions applied, which was 10 times the speed of 4G. This made a significant change in the speed of downloading especially in applications that require high data transfer especially when streaming videos and playing games fast data transfer is crucial in ensuring the sustained quality of the content and the smoothness of the operations of users.

The higher upload rates, which even managed to improve over 1 Gbps in 5G, are also essential to the applications that need real-time communication, like video calls and games with AR/VR. Users with 5G realized that they could achieve a significant decrease in the lag during a video stream in their live video calls and virtual meetings and, therefore, easier communication and video sharing of a higher quality (Smith et al., 2020). Mobile applications with the capacity to transfer vast amounts of information very fast would enable prompt real-time content and interaction delivery that is important in user interaction in mobile gaming, live streaming, and remote communication.

Figure 1: Downloading speed comparison of 4G and 5G Networks (Mbps)

Type of Network Downloading speed (Mbps)

4G	150
5G	10 000

This enhancement in terms of download/upload speed coincides with results of the past studies, with 5G proving to have significantly faster data transfer rates, considerably benefiting 4G networks regarding efficiency and user experience (Hassan et al., 2021).

Latency 5. 2

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The driving factor of applications that require real-time interactions is latency or the duration consumed by some data to reach its destination in relationship to the sending point. The experiments demonstrated that there was a huge decrease in latency between 4G and 5G switching in such a way that there was a reduction in latency of about 75 percent in the 5G networks. Take the video streaming as an example, it only took 120 milliseconds (ms) in 4G and just 15 ms in 5G making the video loading and stalling time almost imperceptible. On the same note, in AR/VR gaming, latency is of major concern in delivering an immersive game, where 150 ms of latency on 4G was reduced to 25 ms on 5G (Patel et al., 2020).

The significant decrease in latency has serious implications towards user experience. Latency is lower in mobile gaming, for example, which results in quicker response time and reduced lag time, allowing a more exciting game experience. In the same way, in the video conferencing application, the low latency increases the quality of the real time communication, enlarging the number of interruption-free natural-sounding conversations. In AR/VR software, a low-latency rate is necessary to ensure the level of immersion and avoid motion sickness, especially in situations with a large amount of latency (Zhang et al., 2020). The low latency in 5G networks facilitates the applications of AR/VR as it allows operating them more efficiently and providing customers with a comfortable experience in the virtual space.

Table 1: contrast of Latency (in milliseconds)

Application type	4G Latency (ms)	5G Latency(ms)
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Video streaming	120	15
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virtually presents as being present in an environment.

video conferencing	110	20
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Such latency improvements comply with the theoretical forecasts of 5G performance and enable making the following claim: 5G networks are significantly more effective in supporting real-time, latency-sensitive applications than 4G networks (Hassan et al., 2021).

5.3 Quality of videos and Video Buffering Times

Other boosts in mobile application performance were video quality and buffering. When the user is using a 4G environment, they are often faced with the issue of buffering especially when heavy traffic set in or high resolution streaming. Most videos were downscaled to simpler resolutions (e.g. 720p or 1080p) to match their low bandwidth capacity so they were not viewed optimally.

Conversely, 4K and even 8K video streaming was not animated with any detectable buffering as made possible by the 5G networks. The streaming video apps like Netflix and YouTube also worked exceptionally well under the 5 G conditions without bugs and fallible video quality even during busy locations. This was especially present when playing high-quality videos on public places full of people whose 4G network is not capable enough of providing a stable connection (Khan et al., 2021).

The increases in video quality were not restricted to the resolution; rather the color accuracy, sharpness, and smoothness of video feed were also very improved. The application being able to offer a more steady and even higher quality streaming process even in hard situations using the increased bandwidth of 5G. Moreover, the buffering to close to zero was achieved even where there is peak usage time and thus more uninterrupted and pleasant user experience when a video consumer is watching through the internet (Smith et al., 2020).

5.4 Responsiveness of the application

Lastly, responsiveness of mobile applications with the help of 4G and 5G networks was also studied. The user experience was measured in a subjective way (user ratings) and in an objective one (using speed tests or time-to-interaction parameters). The findings showed a general tendency of the users to rate 5G applications as much more responsive than their 4G versions. Apps opened quicker, operations were seamless and switching between the various functionalities of the apps did not come with much of a delay.

With video calling services such as Zoom, users stated a more fluent and natural-like feel when communicating using 5G, as the delay between speech and audio/video feedback was minimal. The same thing applied to the gaming applications, with users enjoying an abridged loading period, faster shifts and more accurate control signals, equaling into a more fulfilling overall gaming experience. Such a reaction speed of the applications emphasizes the worth of the low latency and

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high-speed functions of 5G that enables a more streamlined interaction between the user and the mobile application (Patel et al., 2020).

6. Discussion

Based on the findings of this study, it is evident that 5G networks yield significant gains in terms of the performance of mobile applications in regard to some of the key performance indicators in comparison with the 4G. Specifically, the higher download speeds, the lower latency, and the ability to enjoy videos of higher quality are directly positively impacting the user experience in turn. Such optimizations are particularly useful in high-bandwidth, low-latency applications of digital use, a range of which include gaming, real-time communication, augmented reality (AR) and virtual reality (VR). Possessing the capacity to reduce the time lag and the speed by which data is transfer to a higher instance, 5G allows delivering smooth, immersive, and responsive user experience previously limited by the characteristics of 4G networks (Hassan et al., 2021).

6.1 Improvements Performance

Among the most considerable signs of progress that were found in this study are the download and upload speeds: they were consistently a higher value in 5G networks than in non-5G ones in this study (Patel et al., 2020). To illustrate, high bandwidth of 5G allows streaming in ultra-high definition video (4K and 8K) without buffering and resolution loss that is a challenging problem in 4G networks. It has become particularly relevant in the more video-focused digital community of today, where consumers are expecting continuous streaming, be it to watch shows or attend lectures and corporate meetings.

Besides enhancing the obtained speeds, another essential aspect that leads to the enhancement of the user experience is the decreased latency, which is experienced with 5G networks. The importance of latency is especially key to applications involving interaction with a human such as games and video conferencing where real time is important. As demonstrated in this research, 5G has lessened the latency by around 75 percent in merriment of 4G which is the reason it can result in the faster reaction speed, game systems and more natural and uninterrupted talk during video communications (Smith et al., 2020). Such decrease in latency makes it possible to have more immersive AR/VR applications, whereby the visual response should be close to non-existent to feel present and realistic.

The dense latency of 5G, together with fast data transmission, also implies heavy use in the spheres of telemedicine and remote monitoring. As an example, low latency and high bandwidth of 5g in telemedicine will allow high-quality video consultations, real-time patient monitoring, and transmission of bulky medical data without any delays or interruptions. This is particularly important when it comes to the healthcare applications where data transmission must be timely, and the video feed quality may have a direct impact on the quality of care (Khan et al., 2021).

6.2 Enhancement in User Experience

These technical enhancements, especially the raising of the speed of downloads, lowering latency as well as enhancing the quality of videos directly lead to more reliable and responsive user experience. Applications based on real-time interaction, such as video conferencing applications like Zoom and Microsoft Teams have visible improvements in a 5G environment. These enhancements lead to a decrease in dropped calls, a higher quality of video connection, and audio clarity, which improves the quality of communication in general (Patel et al., 2020).

It is not only in entertainment and communication, but also in mobile gaming that there will be an improved performance. 5G can be used to support the low-latency/high-bandwidth connection that make gaming activities faster and more seamless, especially on competitive multiplayer games. 5G networks offer players less latency, quicker load speed and smoother control, which are essential elements in retaining a competitive advantage in online gaming (Smith et al., 2020). This brings a chance to develop more advanced gaming applications that could not be efficiently implemented on the basis of 4G systems as they are limited.

Despite these advancements in terms of performance, however, there remain various critical issues that need to be overcome until 5G can be actualized at an international level.

6.3 Challenges of infrastructure Deployment

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One of the first issues is related to the common implementation of the 5G infrastructure in order to achieve its full potential. In contrast to the 4G, the 5G will involve more sophisticated infrastructure such as installation of small cells, dense cell towers and/or implementations of regular network upgrade. This is because of the short coverage of 5G high frequency spectrum that needs additional infrastructure to guarantee coverage and signal strength in the crowded areas (Hassan et al., 2021).

As the use of 5G realizes in major cities and other well-developed areas, rural and underserved locations might lag in implementing infrastructure because of the cost and delivery issues related to installing the network infrastructure (Wang & Lee, 2020). Implication is that such unequal distribution of 5G infrastructure availability may also mean that the benefits of 5G will not be distributed evenly regionally or across the different users. Moreover, to implement 5G, it might take technological firms and governments a lot of resources that will eventually postpone the realization of 5G services on a wide scale.

6.4 Security issue in 5G networks

The other issue that 5G networks present is the elevated security threats of these capabilities. Since 5G allows millions of connections to the Internet of Things (IoT) ecosystem, the possible attack area will expand dramatically compared to cyber threats. The increased count of connected gadgets and the amount of data that 5G networks convey cause new frailties that should be mitigated in order to guarantee users privacy and security (Hassan et al., 2021). Such weaknesses may involve threats of data interception, dealing with unauthorized access of sensitive personal data, and threats to basic infrastructures like smart cities and auto vehicles.

The 5G networks are also more than just complex which poses a challenge to its network security. Although 5G enables better security including encryption and network slicing, the release of unfamiliar technologies and protocols can establish unexpected security risks that are hard to recognize instantly (Wang & Lee, 2020). The task of organizations and industry leaders will be to work out effective security standards and protocols in order to guarantee the security of 5G networks against new threats.

6.5 Future Directions of research

The other issues in 5G implementation should be addressed as a target of future study; here, the scope of research should regard infrastructure deployment and security. The long-term sustainability investigation of 5G network, especially in rural or the lesser developed regions should be carried out to understand how 5G can be deployed universally. Further research on the inverse effect of 5G on mobile programming efficiency and user pattern and on its long-range effect on regions like IoT, augmented reality, autonomous systems, should be conducted as well.

In addition, the evident trend is that security research within 5G networks has to remain advanced and any new threats should be addressed with the adoption of 5G infrastructure. The study ought to embrace the investigation of novel ways of encryption, authentication, and discovering anomalies, and constructive approaches of securing not only the devices but also the net itself (Khan et al., 2021).

7. Conclusion

The evidence provided by this learning operation affirm the notion that the 5G technology could remarkably boost the experiences of mobile users by enhancing core features that demand high attention such as speed, reliability, and responsiveness of mobile app services. As our experiments have shown, the shift between 4G and 5G entails significant advantages especially to real-time data-intensive apps, including augmented reality (AR), virtual reality (VR) and the high-definition video streaming. Such gains can be felt not only in the terms of an increased speed of data transfer and lower latency but also in the improved and more immersive experiences of users in different applications.

7.1 Faster Data and Speed Transfer

The increased download and upload speeds are one of the most remarkable benefits of 5G since they mark a huge step forward compared to the features of 4G networks. Vice versa, the 5G networks throughout the test were considerably more versatile than 4G, demonstrating a maximum speed of 10 Gbps (depending on the test settings), as opposed to the 1 Gbps represented by 4G (Patel

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et al., 2020). This has boosted the fast streaming of ultra-high-quality videos (4K and 8K) and improved the mobile games that give them faster and better data speeds. Such advancements are of utmost importance especially in the face of increasing popularity of mobile applications reporting high data consumption needs like live streaming services, multiplayer real-time games, and augmented/ virtual reality.

In mobile applications that demand high data throughput, including video conferencing applications and media sharing, faster data communication rates supported by 5G lessen the uploading and downloading time, thus making the users very contented. This means in such programs as Zoom or Google Meet, the video calls would become less interrupted and allow them to have clearer visuals and steady connection. Such enhancements are especially critical in the context of remote work and telemedicine where the quality of communications will have the direct impact on the level of effectiveness and user satisfaction (Khan et al., 2021).

7.2 Low Latency and better responsiveness

The other important determination of this analysis relates to the huge latency decrease as a result of 5G networks. Latency, i.e., time delay between transmission and reception of data, is vital in real-time applications especially those related to gaming, augmented reality or virtual reality, or video conferencing among others. 5G cut down the latency by around 75% to as low as 1 millisecond versus 30-50 milliseconds in 4G (Wang & Lee, 2020). This decrease in latency is critical to applications that need to be responsive, so they do not lose the so-called AR/VR applications to a sense of movement leading to disorientation and disrupting the sense of immersion (Patel et al., 2020).

In mobile gaming, there is also an essentiality of low latency during competitive gameplay, because all the difference is in milliseconds. In 5G, users enjoyed quicker responses times, less delays, and an interactive gaming experience. These advancements can do a solid deal of improving the quality of mobile gaming in general, making it more fun and engaging both to casual and to competitive gamers. To complete the task with video conferencing or telemedicine, the decrease in the latency aspect provides the naturalness of the conversation as there are no breaks, which makes such remote communication very similar to real interaction (Chopra & Batra, 2022).

Besides, in the framework of smart cities or an IoT system, where a large number of devices are connected with each other, and the exchange of real-time data occurs all the time, the low latency of 5G allows such devices to exchange information in the absence of delays and quickly respond and perform their tasks more effectively in the system of urban infrastructure, transportation, and healthcare systems (Khan et al., 2021). It shows the future of 5G in transforming not just the mobile applications but also in new applications and services which use real time data transmission between equipment.

7.3 High quality Video Streaming

The next possible improvement that 5G can bring to the user experience is the video streaming quality. Due to the high bandwidth offered by 5G networks, entertainment-based video streaming services like YouTube, Netflix and Hulu gain massive leverage in their overall performance (Hassan et al., 2021). 4K streaming is also subjected to frequent interruptions during high demand periods or in busy areas due to limited bandwidth innate in 4G networks resulting in buffering or overall lower quality video output (Hassan et al., 2021). In comparison, 5G networks will also have the required bandwidth that will ensure that video services experience undistorted, high traffic content delivery even in high traffic volumes.

Ultra-high-definition (UHD) streaming without having to buffer, and the resulting resolution increase is a big plus to consumers and providers of content. As an illustration, 4K and even 8K video streams take exceptionally little time to be disrupted with the help of 5G due to its expanded bandwidth, rendering 5G a suitable location option to the consumers looking to retrieve high-quality video content on their mobile devices (Smith et al., 2020). Moreover, the increased data rate ensures the faster loading of the content and the fluidity of transition between the frames, which leads to a more overall pleasant watching experience.

The enhancement also plays a significant role in integrating immersive technology, especially VR, which demands high-quality video feedback to enable a user to feel present in a virtual world (Zhang et al., 2020). 5G can thus benefit AR/VR systems immensely because it supports high-quality

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video streaming without significant latency thus providing more realistic and smoother experiences to a user.

7.4 Privacy and security Considerations

Although the findings of this research prove that 5G has great benefits, there is still a number of obstacles that have to be overcome, especially due to infrastructure implementation and security. Additional security issues emerge as interconnectivity, speed, and capacity available with 5G pose new security concerns to be solved to keep the data and privacy of users secured (Hassan et al., 2021). With 5G networks making the Internet of Things (IoT) possible on a level of higher connectedness, there is a greater vulnerability of cyberattacks and data intrusions, which might lead to the breach of personal data as well as vulnerability in the overall infrastructure.

There are more devices that are now linked to the 5G networks exposing a greater number of entry points to possible threats, and the significant amount of data circulating over the networks makes its security a priority. Development of new encryption algorithms, authentication systems, and systems with better anomaly detection will play a major role in reducing these risks (Patel et al., 2020). The following task in further research would be the development of such security mechanisms and the ability of 5G networks to resist the new type of threats while staying both highly private and intact.

7.5 Directions of future research

Considering the swerve rate at which 5G networks are being put in place in the future, one of the areas to be researched ought to be about the long-term impacts of 5G on mobile applications and user behavior. The combination of 5G with the new technologies like artificial intelligence (AI) and IoT is one of the many areas that require investigation. Even more personalization, efficiency, and responsiveness of technical solutions in the mobile area can be made possible by the combination of both 5G and AI, with the AI-based insights further improving real-time decision-making and automation (Khan et al., 2021). In another example, the resources of the network could be optimally allocated in real-time, and users would have the best possible experience with changing conditions.

Besides, 5G in combination with IoT systems might trigger the creation of new applications in other industries like smart cities, healthcare, and self-driving cars. Real-time processing of enormous data volumes and the high bandwidth and extremely low latency of 5G may revolutionize industries like the healthcare field, allowing the use of telemedicine so that patients can be remotely monitored and diagnosed in real-time or the safe operation of autonomous vehicles due to the low-latency communication channel (Zhang et al., 2020).

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