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Performance Analysis of Mobile Broadband Technologies and 5G Trends and Beyond Networks in Malaysia

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ABSTRACT—This paper analysis and investigate the performance of Mobile Broadband (MBB) cellular networks based on the drive tests for suburban areas (at four states) in Malaysia. The data were collected from three main national Mobile Network Operators (MNOs) by using unbranded Samsung Galaxy S6 smartphone handsets, while the period of data collection was between January and February. Two MBB services were considered which are the video streaming and web browsing. For each MNO, the performance data of one MBB service was collected through one a dedicated smartphone. One smartphone was used to browse three different webpages, and One smartphone was employed to stream two YouTube videos with two different resolutions. The study considered four MBB Key Performance Indicators (KPIs), namely: latency, coverage, speed and satisfaction. As per the results, the performance of Fourth Generation (4G) is found superior than that of Third Generation (3G) networks. For instance, a vMOS score of above 3.3 was achieved by 4G networks for MBB video-streaming service, while, score of below 2.6 was attained by 3G networks across all the four studied areas. In addition, it was observed that an enhancement factor of up to 2.86 and 2.83 in download speed was presented by 4G technology in case of video streaming and web page browsing respectively as compared to 3G technology. Examining the performance of current MBB networks is supportive before the deployment of the 5G network. The efficient development of 5G networks in Malaysia can be realized through these study findings, where the existing 4G infrastructures will contribute to supporting the 5G and 6G networks.

Index Terms—Mobile Broadband, MBB, Mobile Networks, 3G, 4G, 5G, 6G, Performance Evaluation, network planning, future Mobile, Drive Test, Suburban, Coverage, Latency, and Throughput.

I INTRODUCTION

The past decade has witnessed several new technological advancements in mobile communication systems. Different technologies, services, and applications have been emerged in various environments leading to a massive increase in data traffic demands. These developments and requirements will be supported by the Fifth Generation (5G) of mobile communication technology and later one by 6G technology. Several improvements were promised to be

provided by this new technology such as the quality of service, system capacity, coverage expansion, higher data rate, lower latency and other more mobile devices. Even though, there are several issues in the current MBB networks, such as the service interruption, poor internet connectivity and denial of service are some of the drawbacks or unsettled issues, which need to be addressed properly. One of the root causes of such issues is the poor network planning. The key performance indicators of the Third Generation (3G) and Fourth Generation (4G) networks need to be thoroughly investigated, so that these issues could be addressed in an effective manner. Hence the professionals will get basic information on the network performance, through which, improvement initiatives could be enabled. The high network performance, ubiquitous coverage and user Quality of Experience (QoE) are now being offered by the Mobile Broadband (MBB) Networks, which is of the primary interest for mobile network operators [1-5]. Thus, the engineers and researchers are inspired to upgrade the capabilities of MBB networks through new tools and technologies, which will play a significant role in the growth of mobile traffic volume and for a broad range of user devices and applications.

The evaluation of data offloading techniques to improve mobile networks depends upon the understanding of mobile data traffic demands. Furthermore, telecom companies can set subscription plans and timely plan allocation of network resources as a result of the dentition of a usage pattern. The gap between the users' ever-growing demands and expectations as well as the performance of the current MBB networks needs to be understood by the experts. After gaining an insight with this gap, the MBB networks can further be extended to address the challenges that leading to increase demand for larger network capacity, higher data rates and higher spectral efficiency as projected for future 5G cellular services. The rural, urban and suburban areas are having the broadband availability and its adoption at the different rates. As compared to metropolitan cities, the wireless technologies are generally accessible to suburbs vs regional areas with considerably lower data rates and less dense arrangements. In contrast, there is higher vehicle speed across the regional areas. Therefore, for effective network planning, researchers should perform wide-ranging measurements at different morphologies.

As compared to the wired networks, the MBB networks have highly challenging performance assessment. Because of the large number of factors affecting performance, the simplest test, i.e., a "speedtest- like" measurement of the single Transmission Control Protocol (TCP) download speed using a

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Hypertext Transfer Protocol (HTTP), may become insufficient to be explain the complete MBB networks. The measurement outcomes are influenced by the mobility, physical impairments, presence of Performance Enhancing Proxies (PEP) [6], variety of devices, different access network configurations, etc., and the overall picture becomes even complicated. When adopting performance calculations, a communal method is to depend on end users, and their devices, to run tests by browsing a website [7], or running a specific application [8]. For different mobile networks with different operators, one of the effective solutions to identify performance gaps or coverage holes is none other than the drive test.

The system level and link level are referred to as the two different levels or platforms [9][10]: on which the researchers carry out performance assessment of service quality in mobile networks. The first one deals with macroscopic aspects, for example, admission control, shadowing, handover, etc. Its aim is to evaluate the performance of network at the signal level, while, the characteristic of radio link transmission is managed by the other one at the bit level aiming to assess network performance. Furthermore, there is still a lack of study related to the performance evaluation of mobile networks.

In [11], researchers performed a comparative study and analysis on the network performance of four mobile operators in Nigeria. The network was evaluated by considering numerous key performance indicators (KPIs) specified by the Nigerian Communications Commission (NCC). One of the mobile operator's networks was fairly better as per the study findings and the network with the thorough information was preferred for optimization, the aim of which will be to enhance its performance attributes.

In [12], a research on the association among four Long Term Evolution (LTE) measurements namely; the received signal strength indicator (RSSI), referenced signal received quality (RSRQ), the referenced signal received power (RSRP) and the signal to interference plus noise ratio (SINR) were presented. Moreover, during data transfer, the authors investigated the impacts of signal to noise ratio (SNR) on the throughput performance. At this point, the experiment witnessed the occurrence of handover and further investigation was done based on how the handover was influenced by the four LTE measurements.

In [13], the researchers offered techniques to enhance the throughput of a live LTE network. The throughput was enhanced by modulating numerous parameters such as channel quality offset, power, interference and channel traffic load. They optimized these parameters, which led to enhance throughput of the LTE network.

In [6], a comparative analysis was conducted on 3G (UMTS) and 4G (Mobile WiMAX) mobile networks. At this point, the two mobile systems were evaluated through a simulator called QUALNET. After the measurements, the parameters were analyzed to get the average end-to-end delay, the Packet Delivery Ratio (PDR), collision and throughput. As compared to 3G, the 4G resulted in higher PDR and throughput network. As per the research finding, 4G network possesses desirable quality of service (QoS) as compared to 3G mobile network.

In [14], a study was conducted based on a drive test within 2 km area for one cell coverage size. The study was performed based on various KPIs such as: the RSRP, SINR and throughput. The results show reported that there is a disturbance in all the performance of the three parameters, as the user equipment was moved towards the cell edges and away from the site area. The low power relay nodes can be deployed to address this issue, i.e., one of the encouraging methods to improve the coverage of LTE advanced networks besides advancing towards the latest technology, i.e., 5G networks.

Apart from these studies, literature contains many research studies that have determined the MBB performances of Second Generation (2G), 3G and 4G networks [15-24]. Researchers have performed these studies with the help of diverse systems under different environments. While these studies would have a significant impact on the MBB networks, these networks need to be further investigated keeping in view the future planning. The rural and urban areas were mainly taken into account with respect to aforesaid studies. Until now, this level of research has not been conducted adequately for suburban areas.

Gaining an insight with the MBB performance and the actual experience of user in the suburban areas is the key objective of this study. Besides understanding the issues of the current MBB networks in the tested area, this helps consumers to identify the outperformance of 4G versus 3G technology. With this information, the relevant agencies will be enabled to make strategic plans to carry on or even upgrade the existing MBB services in Malaysia, particularly when the mobile traffics are likely to grow exponentially. The performance data from the three Malaysia MNOs' networks was collected through the research conducted on mobile broadband performance. The data collected between January and February has yielded in the presented outcomes.

For suburban morphology, four different states in Malaysia, namely: Klang Valley and Selangor, Johor Sarawak, and Sabah were taken into consideration to obtain measurements. Samsung smartphone Galaxy S6 was used for measurement purpose. The two different MBB services, namely: the video streaming services and the web browsing were included in the measurements. As far as the web services are concerned, the Google, Instagram and mStar were among the frequently browsed webpages. While, in the case of video streaming services, two videos were frequently watched that contained different resolutions, 1080p high and 720p low resolution video. The real communication scenarios were simulated, where the smartphones cannot be locked to any mobile technology. The coverage, satisfaction, latency and speed were the four KPIs, which were measured on behalf of the KPIs. Subsequent to the designed research set up, the 2G, 3G and 4G technologies were included in the MBB data being collected for every tested area.

On the basis of numerous KPIs, the 4G networks have reported greater performance than that of 3G networks as per the presented results. For example, for MBB video-streaming service, a vMOS score of above 3.3 was achieved by 4G networks, while 3G networks attained below 2.6 across all the four studied areas. Moreover, as compared to 3G technology, an improvement factor of up to 2.83 and 2.86 was revealed by

the 4G technology in download speed, when a web page browsing and a video streaming were taken into account. Based on these study findings, the 5G networks can be planned efficiently in Malaysia, where the current 4G infrastructures will continue to support the 5G networks. The first step in the direction of the deployment of 5G mobile technology in Malaysia is to examine the 4G coverage performance.

Keeping the smartphones in view, the performance of 3G and 4G networks were focused in this research. Our research did not undertake the following factors: (i) mobile broadband services provided to other devices (such as dongles, MiFi devices and tablets); (ii) mobile messaging and mobile voice; (iii) careful study of public WiFi services. (Some mobile broadband tariffs were reportedly integrated with these WiFi services and can affect the quality of experience offered to a consumer), and (iv) Research team overlooked the 2G network, since the amount of data collected for 2G network was insignificant.

The rest of this paper is divided as follows: Section 2 describes the research limitations and future direction; Section 3 explains the methodology and system model; Section 4 and 5 explores the average performance of Web Browsing and Video Streaming respectively. The MBB performance is subsequently compared with different areas and then our testing results were discussed. At the end, the conclusion of this study will be given at Section 6.

II METHODOLOGY AND SYSTEM MODEL

The researchers provided a detailed review of the performance of 4G vs 3G mobile networks. There is no comparable study that incorporates several suburban areas in Malaysia as per our knowledge. On the basis of drive tests, real measurements and scenarios, the research team has considered two diverse mobile applications with different KPIs. The performance of measured mobile networks is analyzed in this paper. Attributed to the different applications and various KPIs, this study aims to evaluate network performances. Hence, the development of 5G mobile networks will be enabled in Malaysia across suburban areas, especially the zones experiencing data speed rate and coverage latency issues. In addition, the operators will also be encouraged to enhance data rates, coverage and overall mobile network throughput across the area where reception is generally poor. Throughout the deployment of 5G mobile networks, the operators can successfully identify the regions that require further improvement.

For that, this section presents the research methodology used for collecting data and conducting this study. That entails the software and hardware employed, the test processes, the tested geographical areas, quality control characteristics, MBB services, and MNOs. As presented in our earlier works [25-27], the rural and urban areas of Malaysia have witnessed the implementation of this methodology. Nevertheless, the testing areas and the morphology type are totally different in this research. The team has witnessed the unique results, findings, discussions and concluding remarks.

The metrics pertaining to the user experience of using mobile broadband will be gauged by our test methodology. Owing to its careful configuration, it has the potential to generate a statistically robust dataset, which handles each MNO on neutral basis.

We have designed our test processes to make sure that every network was examined on an equal basis:

- Same handsets were employed for each network.
- Each network was tested in parallel to observe the uniform environmental conditions for each operator.
- Besides ensuring that simultaneous tests were not run on the similar network, undue debate was prevented by simultaneously testing the networks.

A proprietary software testing application was used for data acquisition, Speed video was employed for video streaming services and MBB explorer for web browsing services. Huawei Technology was our supplier. The selection of two software is based on the reasons given below:

- Modification of the handsets is not needed by the testing app itself.
- An app loaded on to the test device can determine and test the Speed video and MBB explorer apps, through which, the customized test sets become close to the consumer experience of mobile broadband use.
- As a result of the test apps, the test continues to run in cycle, which makes it convenient as less interaction is happened between the phones and the tester.
- In Thailand and Singapore, the web and video MBB user experiences have been determined through both the softwares. Compared with our bordering countries in South East Asia regions, we can thus make fair benchmarking on the user experience across Malaysia.

The MBB explorer app measures the following KPIs of web browsing services:

- Total Service Attempt (Count) and Average Page Display Success Ratio
- Cellular signal strength (dBm)
- Average Page Download Throughput (kbps)
- Average Page Response Latency (ms)
- Average of Ping RTT Delay (ms)
- Average Page Display Latency (ms)

The Speed video app measures the following KPIs of video streaming services:

- Cellular signal strength (dBm)
- Average Mobile vMOS Score (Scale 1 to 5; Worst = 1; Best = 5)
- Total Service Attempt (Count) and Average Initial Buffering Success Ratio
- Average Video Total Download Rate (kbps)
- Average Initial Buffering Latency (User perceived delay) (ms)
- Average Total Rebuffering Latency (ms)
- Average of Average Ping RTT Delay (ms)

A. Our Test Process

To experimentally evaluate the web-browsing MBB services, access to 3 different websites is required in each use cycle of the MBB explorer application: Google, Instagram and mStar

Fig.1. The main structure of test process with the considered MNOs, mobile applications, and service types used in the suburban Area

that are categorized as light, medium and heavy sized websites, respectively. The general testing structure for test process used is demonstrated in Figure 1. The reason for categorizing Google as light-sized is that just the homepage of the search engine is accessed by the testing application. Since Instagram is a photo-sharing website, it is classified as medium-sized. mStar is a famous news website in Malaysia and as it consists of texts, images and videos, it is considered as heavy-sized.

The testing of video-streaming services, which is performed by using the Speed video application, was carried out by including YouTube video streaming with high-resolution (1080p) and low-resolution (720p) in each testing cycle. The MBB explorer can be fixed at 100 testing cycles whereas Speed video can run for any number of cycles fixed by the user.

B. Quality Control

For additional processing, the MBB data gathered by the two mobile applications was automatically stored in a database. Also, A pre-test exercise including a 10-minutes' drive test was carried out to check whether the data obtained is stored properly or not. The time stamps were also used to check whether the previous MBB data measurements were successfully stored. It is ensured through this quality control exercise that there is no data loss or missed attempts while collecting MBB data.

C. Test Types

Measurements for outdoor environments were obtained. A drive test is carried out on the main roads of the specified towns and cities and across the inter-town main roads and various highways. The drive speed is fixed at below 60 km/hour for

cities/towns and inter-towns federal road measurements, whereas it can be up to 80 km/hour for highway.

D. MNO SIM Cards

This research considers three MNOs. The three MNOs are classified as X, Y and Z because the aim of the study is to understand the mobile user experience served by various MBB networks in Malaysia and not to create a benchmark for the performance of the MNO networks. For each MNO, the consumer prepaid sims were bought from its particular store to make sure that they represented the given consumer tariffs. Two SIMs were brought from each MNO as two kinds of tests would be carried out in the research

E. Tested Areas

The MBB tests were carried out in January and February in four Malaysian states, which are Klang Valley/Selangor, Johor, Sabah and Sarawak. These intensive measurements would be carried out in the given time periods by two teams of researchers. The first team would obtain measurements in the states of Johor and Klang Valley/Selangor and the second team would perform the test in Sarawak and Sabah. The suburban morphologies are examined using 14 drive test areas across the four states. The regions of the drive tests are shown in Table 1.

Figures 2 to 5 show the GPS route records we performed in the four considered places. The application of GPS Trip Recorder was installed on another mobile phone that was used only to obtain the GPS route record. The GPS route was recorded by the phone with the GPS Trip Recorder, while the MBB test parameters were measured with the Samsung Galaxy 6 phone.

TABLE 1. Morphologies Areas: Tested Areas in the Suburban Morphologies

Morphologies	Klang Valley (KV) and Selangor	Johor	Sabah	Sarawak
Suburban	<ol style="list-style-type: none"> 1. Kajang and Hulu Langat; 2. Rawang 	<ol style="list-style-type: none"> 1. Segamat; 2. Muar; 3. Kluang; 4. Batu Pahat 	<ol style="list-style-type: none"> 1. Keningau; 2. Ranau; 3. Kudat; 4. Sandakan; 5. Lahad Datu; 6. Tawau 	<ol style="list-style-type: none"> 1. Bintulu; 2. Sibu

(a) Kajang and Hulu

(b) Langat; Rawang

Fig.2. GPS Route Measurements Record in Suburban of Klang Valley State, Malaysia

(a) Segamat

(b) Muar

(c) Kluang

(d) Batu Pahat

Fig.3. GPS Route Measurements Record in Suburban of Johor Bahru State, Malaysia

(a) Keningau

(b) Ranau

(a) Kudat

(b) Sandakan

(a) Lahad Datu

(b) Tawau

Fig.4. GPS Route Measurements Record in Suburban of Sabah Kota Kinabalu Areas.

(a) Bintulu

(b) Sibul

Fig.5. GPS Route Measurements Record in Suburban of Sarawak State, Malaysia

III PERFORMANCE OF WEB BROWSING

The findings show the network performance for the periods in which the tests were carried out and for the areas from which we obtained the measurements. Each network was tested at the same time at every testing location to make sure that the comparison between the three MNOs was impartial. All the smartphones used were generic and unaltered, with the same specifications, build and the operating system. It was also ensured that no bias was introduced into the outcomes due to this. Either 3G or 4G technologies are used to access the data gathered from the Samsung Galaxy smartphones in suburban morphologies. No data is collected using 2G technology.

In this section, only the findings obtained from the WEB Browsing application are presented and discussed. In the subsections, various KPIs are used, and these will be elaborated. The overall findings from KPIs of web browsing services are discussed in the subsequent subsections, including: (1) cellular signal strength; (2) total service attempt (count) and average page display success ratio; (3) average page response latency; (4) average page download throughput; (5) average of ping RTT delay and (6) average page display latency.

A. Network Signal Coverage

The measured cellular signal strength represents the mobile network signal coverage. Figures 6 and 7 show the distributions of cellular signal strength for 4G and 3G mobile networks, respectively. In these figures, the Y-axis represent the number of web access cycles, while the X-axis represents the cellular signal strength of web services. The number of web access cycles refers to the number of cycles that the Google, Instagram and mStar pages are accessed by the MBB explorer application. One web access cycle represents browsing one of these pages.

Results in Figure 6 show that, the received signal power of 4G mobile networks is ranging between -120 dBm and -50 dBm for all the four states. Majority of the recorded signal power is, however, between the range of -105 dBm and -75 dBm. In contrast, the results in Figure 7 show that the received signal power of 3G mobile networks is ranging between -110 dBm and -55 dBm in the four states. Majority of these recorded signal power is between the range of -110 dBm and -70 dBm. Moreover, the results show that the number of recorded access cycles for the 4G networks is greater than the accesses to 3G mobile networks. This may happen due to two different reasons. First, better coverage is provided by 4G compared to that of 3G mobile networks. Secondly, more resources are provided by 4G in comparison to the 3G mobile networks in the measured four states.

Table 1 shows a statistical comparison between the two mobile technologies in the four states. It can be seen in the table that 80% coverage in the tested region is stronger compared to the given web cellular signal strength. Separate findings are given for each operator. According to the given results, better performance is shown by a few operators compared to others; however, these differences are only minor. It can be deduced from these findings that better coverage is offered by the 4G networks in comparison to the 3G networks for all the suburban regions. In addition, in the given suburban area, more 4G networks are deployed compared to the 3G networks, suggesting that 4G was the dominant network in these regions.

B. Network Satisfaction

This subsection discusses the overall number of web access attempts and the overall page display success ratio for browsing websites services. The total counted number of cycles signifies the total web access attempts. Getting the highest total number of web access attempts means that serving network provide good mobile connection. The overall page display success ratio is the ratio of the overall number of pages displayed successfully to the overall number of mobile web access attempts. It is not necessary for the overall web access attempts to be the same for both the 3G and 4G networks. Slightly, it relies on the network availability and to which the mobile is connected.

Figure 8 show the total attempts made to access web services through the drive test experiments. According to the findings, to access the internet for web services, 4G technologies are predominantly used, with 90.4%, 84.7%, 78.5% and 89.9% for Klang Valley, Johor, Sabah and Sarawak, respectively. It is also confirmed in Figure 9 that out of the three web pages, the best performance is noted for Google for all places using the 4G mobile technology. The performance of 3G networks all over Malaysia is clearly inadequate for accessing web pages at the given suburban regions.

C. Network Download Speed

In this subsection, the network download speed of web services for suburban areas in the four tested states is discussed. Achieving the maximum download speed suggests that good mobile speed is being provided by the network for the given serving network at that particular tested region. The network download speed offered by 4G networks should theoretically be more than what the 3G network can offer. However, if the network download speed offered by the 4G networks is less than that offered by 3G networks, it may be because 4G technology is not widely available in that particular region.

Figure 10 presents the experimental findings of the average page download throughputs of web services for all states, MNOs and networks. The findings show that the highest web browsing speed using 4G is provided by the state of Sabah. On the whole, an improvement of 3.8, 2.2, 1.5 and 1.6 times is observed in the 4G web download speed compared to the 3G web download speed in Klang Valley, Johor, Sabah and Sarawak, respectively.

According to these findings, the actual download speed is less than the theoretical LTE download speed. The actual download speed reaches a maximum of 6.02 Mbps, whereas the highest LTE speed that can be theoretically obtained by mobile users is 100 Mbps. The key factor for achieving this practical speed is the overall cell load traffic. When the number of users in the cell increase, the number of resources in the cell will decrease linearly.

The findings of the overall page display success ratios for every 3G/4G technology and MNO are depicted in Figure 9. The page display success ratio refers to the proportion of successful display of web pages from the total number of attempts made to access the web pages. The success scenario is demonstrated by the two figures, while also clearly showing the proportion of failed attempts. The failed attempts ratio is a lower ratio compared to the success ratio. For example, when the success ratio is 0.98% and the failed attempts ratio is 0.02%,

Fig.6. PDF of the received cellular signal strength of 4G mobile technology for web browsing measured at four suburban morphologies

Fig.7. PDF of the received cellular signal strength of 3G mobile technology for web browsing measured at four different suburban morphologies.

TABLE 2. The 80% of the measured coverage in the tested suburban morphologies is stronger than the given web cellular signal strength stated in this table.

MNO	NETWORK TYPE	AREA			
		KLANG VALLEY	JOHOR	SABAH	SARAWAK
X	4G	-101 dBm	-101 dBm	-93 dBm	-91 dBm
	3G	-91.6 dBm	-91 dBm	-89 dBm	-90.4 dBm
Y	4G	-99 dBm	-95 dBm	-92 dBm	-95 dBm
	3G	-93 dBm	-91 dBm	-91 dBm	-87 dBm
Z	4G	-97 dBm	-96 dBm	-95 dBm	-91 dBm
	3G	-97 dBm	-95 dBm	-91 dBm	-93 dBm

it shows that there is satisfactory Quality of Service (QoS) of the network. According to the experimental findings, for the kinds of MNO reviewed in the study, 4G exhibits better network performance compared to 3G. This result was expected because 4G technology has distinct features with respect to throughput and technology, as depicted in the subsequent subsections.

D. Network Latency

The outcomes for three kinds of network latencies are presented in this section, which are the web page response latency, web page display latency and web page ping average RTT. The three types of networks latencies are explained subsequently and shown in Figures 6, 7 and 8, respectively.

The average web page response latency for suburban morphology situated in four distinct states of Malaysia is depicted in Figure 11. Compared to 3G networks, 4G networks were found to have lower page response. In all of the tested states, the average latency of 4G networks on all the networks tested were 576.4 ms, 731.6 ms, 1008.5 ms, and 818.0 ms. On the contrary, the latency for 3G networks were found to be 2717.4 ms, 1689.1 ms, 1599.2 ms and 1543.0 ms for Klang Valley, Johor, Sabah and Sarawak, respectively. It is evident from this figure that lower latency is offered by the 4G networks compared to the 3G networks in the areas being tested.

The average web page display latency of all 3G and 4G operators in the testing regions is presented in Figure 12. It can be seen that there was lower average page display latency in suburban 4G networks compared to 3G networks. On the contrary, the lowest latency of 6305 ms is found for the 3G network in Johor for network operator Z. An average latency on the 4G network for all the networks tested in the test states was found to be 4860.8 ms, 5793.2 ms, 6098.7 ms, and 7946.6 ms. On the other hand, for the 3G network, it was found to be 6722.9 ms, 6853.8 ms, 7052.8 ms and 17357.7 ms for Klang Valley, Johor, Sabah and Sarawak, respectively.

The average ping average RTT latency for the testing areas is shown in Figure 13. This figure shows the delay of a 2-way journey of a packet from the source to the destination. This performance measure determines the latency on the basis of a ping. The ping average RTT latency for 4G networks was generally less compared to the 3G networks. The average of all networks tested across the test states showed latency on 4G to be 6.5 ms, 63.2 ms, 96.5 ms, and 86.6 ms and on 3G to be 9.4 ms, 95.9 ms, 120.1 ms and 118.0 ms for Klang Valley, Johor,

Sabah and Sarawak, respectively. The average latency of the page response, page display and RTT for all the 4G operations is found to be nearly at the same levels for every testing area in contrast to the rest in 3G. The reason for this is that all operators in this region have similar 4G network infrastructures because of which there is low latency of page response. Better performance and consistency is shown by the 4G networks in all testing regions in contrast to 3G networks.

The average latency levels of the page response, RTT and page display for all 4G levels is almost the same for every testing area in comparison to those of 3G network. This is a valid finding because the operators in these regions all have similar 4G infrastructures, due to which there is low latency for page responses. As compared to 3G, the 4G networks offer better and consistent performance in all of the tested regions.

E. WEB Results Summary

Web service findings for the suburban morphology is concisely summarized in Table 3. The results are categorized in accordance with the different MNOs. The first, second and third sub-tables present findings for three distinct operators, X, Y and Z, respectively. The results for six distinct KPIs in four different states are given in each sub-table. A clear comparison between 3G and 4G network is presented in the table. Also, A **vertical** comparison between the measurement findings has first been performed across different operators for the same KPIs, state and technology, which are highlighted as **red and blue boxes**.

As **horizontal comparison** of the measurement findings is presented across the four states for the same operators, technology and KPIs, where the table legend includes blue box and red box colors.

According to **Operator X** performance, for 4G technology, the operator X offered the best performance in KV state much better than the other all states. But for 3G technology, the Operator X offered the best performance in KV and Sabah states better than the other states.

According to **Operator Y** performance, for 4G technology, the operator Y offered the best performance in KV state much better than the other all states. But for 3G technology, the Operator Y offered the best performance in JOHOR and SARAWAK states better than the other states.

Fig.8. The total web access attempt measured at four different suburban morphologies and classified based on mobile technologies, MNOs and morphologies.

Fig.9. The overall page display success ratio measured at four different suburban morphologies located in four different states

Fig. 10. The average page download speed measured at four different suburban morphologies located in four different states, and categorized based on technologies

Fig. 11. The average of web page response latency measured at four different suburban morphologies located in four different states, and categorized based on technologies

Fig.12. The average of web page display latency measured at four different suburban morphologies located in four different states, and categorized based on technologies

Fig.13. The average of web ping average RTT measured at four different suburban morphologies located in four different states, and categorized based on technologies

According to Operator Z performance, for 4G technology, the operator Z offered the best performance in KV state much better than the other all states. But for 3G technology, the Operator Z offered the best performance in JOHOR and SARAWAK states better than the other states.

A vertical comparison, a comparison between the operators for the both technologies are performed. It can be seen that for 4G technology operator X offered better overall performance compared to Y and Z operators, with respect to web services overall states. That has been indicated by green circle around the highest values over all operators. Low 4G performance is exhibited overall by operator Z as compared to operators X and Y. On the contrary, it can be also seen that for 3G technology operator Z offered better overall performance compared to X and Y operators, with respect to web services overall states.

That has been indicated by pink circle around the highest values over all operators. Low 3G performance is exhibited overall by operator X as compared to operators Y and Z.

In general, 4G network have been seen to outperform 3G network with respect to every KPI, as illustrated in the table. However, the KPI of average cellular signal strength did not show the outperformance of 3G by 4G network. Hence, signal strength for web services in 4G network may be improved by expanding the expanse of 4G networks coverage areas. Moreover, each of the three service providers was found to depict competitive performance with reference to each KPI in each state.

In short, the outcomes tabulated in sub-tables highlight the outperformance of 3G networks in all testing areas by 4G network.

Fig.14. Summary of web services for four different suburban morphologies and three different MNOs.

Morphology: Suburban		Operator: X				MBB service: WEB			
		KV		JOHOR		SABAH		SARAWAK	
		3G	4G	3G	4G	3G	4G	3G	4G
Overall Page Display Success Ratio	[Higher is better]	0.73	0.99	0.72	0.96	0.82	0.95	0.98	0.99
Average Page Response Latency (ms)	[Lower is better]	2968.4	536.7	804.0	725.7	1702.1	1122.4	1191.4	898.0
Average Page Display Latency (ms)	[Lower is better]	6955.0	4768.1	7318.9	5843.3	6957.4	5941.2	15765.0	8476.4
Average Page Download Speed (kbps)	[Higher is better]	2026.3	6022.5	1989.6	4738.8	2676.2	4322.1	2191.7	4025.3
Average Ping Average RTT (ms)	[Lower is better]	84.1	50.4	107.3	84.9	122.2	96.8	125.8	118.2
Average Cellular Signal Strength (dBm)	[Higher is better]	-86.0	-92.5	-85.7	-91.45	-81.3	-85.7	-82.4	-84.7

(a)

Morphology: Suburban		Operator: Y				MBB service: WEB			
		KV		JOHOR		SABAH		SARAWAK	
		3G	4G	3G	4G	3G	4G	3G	4G
Overall Page Display Success Ratio	[Higher is better]	0.72	0.99	0.70	0.97	0.82	0.96	0.99	1.00
Average Page Response Latency (ms)	[Lower is better]	2521.0	583.5	1450.5	742.5	1736.6	944.5	2409.0	691.0
Average Page Display Latency (ms)	[Lower is better]	6827.1	5026.8	6937.5	5869.1	6998.0	6103.3	19085.1	7682.0
Average Page Download Speed (kbps)	[Higher is better]	1461.2	5954.2	2083.8	5992.2	2865.4	4165.3	699.9	4712.5
Average Ping Average RTT (ms)	[Lower is better]	133.2	42.4	110.6	55.2	124.7	91.5	137.8	67.5
Average Cellular Signal Strength (dBm)	[Higher is better]	-87.8	-89.9	-80.1	-87.1	-86.0	-85.3	-71.2	-86.3

(b)

Morphology: Suburban		Operator: Z				MBB service: WEB			
		KV		JOHOR		SABAH		SARAWAK	
		3G	4G	3G	4G	3G	4G	3G	4G
Overall Page Display Success Ratio	[Higher is better]	0.63	0.98	0.68	0.93	0.82	0.96	1.00	1.00
Average Page Response Latency (ms)	[Lower is better]	2663.0	609.0	1812.8	726.7	1359.0	958.5	1028.6	685.1
Average Page Display Latency (ms)	[Lower is better]	6386.7	4787.5	6305.0	5667.1	7202.9	6251.7	17223.1	7681.3
Average Page Download Speed (kbps)	[Higher is better]	1128.0	5932.0	2521.3	4956.3	2830.8	4091.4	2056.2	4347.8
Average Ping Average RTT (ms)	[Lower is better]	81.0	46.8	69.9	59.4	113.4	101.3	90.3	74.0
Average Cellular Signal Strength (dBm)	[Higher is better]	-82.1	-90.6	-88.3	-88.4	-83.5	-87.3	-84.3	-84.9

(c)

IV PERFORMANCE OF VIDEO STREAMING

The performance of both 3G and 4G were assessed in terms of video streaming. The performance for both networks was evaluated in each testing area. For unbiased outcomes, the same time and area were used in the assessment of network of each of the 3MNOs. Moreover, the assessment involved use of only generic and unmodified smart phones running similar operating systems so as to prevent bias in outcomes. The assessment was done in suburban morphologies using Samsung Galaxy S6 smartphones which revealed no use of 2G and sole dependence of users on 3G and 4G networks.

The network performance in context of video streaming is considered in this assessment. This assessment involved the assessment of a number of KPIs.

A. Network Signal Coverage for Video

In this part of the article, the VIDEO streaming experience was assessed to evaluate the network signal coverage. The network signal coverage is measured by the cellular signal strength. Figures 14 and 15 depict the performance of 4G and 3G technologies accordingly with respect to their cellular signal strength distribution when using video streaming applications. Moreover, assessing the performance of the 3 network service providers in the domain of video streaming through 4G networks, the performance of the service providers X and Z apparently outshined that of Y service provider in each testing site as seen in Figure 14. Similarly, considering the performance of service providers in 3G technology in 4 testing sites, the network operator Y outperformed X and Z. A contrast of 4G and 3G technologies in terms of network signal coverage at Johor, Sarawak and Klang Valley as depicted in Figure 14 with Figure 15. In the area of Sabah, 3G networks provided more strong signals than 4G. Moreover, assessment revealed that 4G signals proved to be stronger than 3G ones in other areas; however, the significance of 3G signals cannot be undermined since these offer support to the 4G networks by connecting various 4G coverage areas thus serving the purpose of backbone or core network.

Figure 15 depicts the range of signal power of 4G networks received in 4 states which is from -110 dBm to -50 dBm. But, as far as recorded signal strength is concerned, it ranged from -105 dBm to -75dBm. Conversely, the range of signal strength of 3G networks in the 4 states was from -110 dBm to -30 dBm as per the same figure while the recorded strength ranged from -100 dBm to -60dBm. The results also revealed the outperformance of 3G networks by the 4G networks not only in received signal strength but also in terms of the number of recorded access cycles. The difference was found to exceed 200%. Moreover, Johor was the area found to have received highest number of access cycles for each kind of network.

B. Network Satisfaction for Video

The network signal strength may be evaluated in suburban morphologies within the 4 states by presenting the ratio between the total requests for total video access made and the total access of video streaming. The total number of cycles attempts made for watching and streaming videos are termed

as total video access attempts while the ratio of total watched videos to the number of video access attempts is termed as overall video access ratio. This ratio can be used as a KPI for evaluation of performance of the network signal. In case of web browsing, the evaluation can be done by determining the ratio of successfully viewed web page to the browsing attempts.

In this study, various attempts were made to get access to video services. The Samsung Galaxy S6 was used in all the attempts to determine the video streaming performance. The results have been presented in Figure 16. The results showed that 4G technology allowed 67.1% access to video services in Klang Valley region, 71.7% successful access to video services in Johor, 62.8% access in Sabah and 73.4% access in Sarawak region. The 4G networks allowed greater number of successful video access attempts than the 3G network probably owing to expansive deployment of 4G networks and higher resourcefulness associated with these networks.

The video access ratio evaluated for suburban morphologies in all the 4 states have been depicted in Figure 17. The outcomes showed video access ratio from 0 to 1 (0, 1). Simply, the video access ratio is higher at the value of 1 and lowest at 0. Moreover, when using 3G technology, the range of video access ratio was found to be from 0.82 to 0.983 for all states and service providers as per Figure 17. Conversely, when using 4G services, all the states and service providers depicted the video access ratio between 0.995 and 1. Hence, it can be said that irrespective of the state and MNOs (measured in this study), the performance depicted by 4G networks outshined that of 3G in terms of video access ratios.

C. vMOS

Another KPI of vMOS will be employed in this part of the study to evaluate the performance of network. The HUAWEI-developed KPI will evaluate the video quality and thus help in assessment of performance of networks in terms of video services provided by these networks.

The network performance was evaluated in terms of the vMOS scores of each included MNO on the basis of technological classification as evident from Figure 18. State-wise outcomes of vMOS were also stated. In suburban morphologies, each of the 3included MNOs depicted higher scores and consequently better performance in the 4G networks than the 3G networks.

The scores of vMOS noted for 4G networks were found between 3.12 and 3.63. Conversely, the scores for 3G were found between 1.31 and 2.64. This may be attributed to a couple of things: 4G networks have a wide deployment and better coverage; moreover, the resourcefulness of 4G networks is far greater than those 3G networks.

D. Network Download Speed for Video

In this part of the study, the network download speed will be discussed in context of video services. The network download speed will be evaluated as average rate of video download in the suburban areas of the considered states. Such data includes webpages, applications, games and videos. The download speed varied with each mobile technology. Download speed may be defined as the rate of data transfer between source and

Fig.15. PDF of the received cellular signal strength of 4G mobile technology for video streaming measured at four different suburban morphologies.

Fig.16. PDF of the received cellular signal strength of 3G mobile technology for video streaming measured at four different suburban morphologies.

TABLE 1. The 80% of the measured coverage in the tested suburban morphologies is stronger than the given video cellular signal strength stated in this table.

MNO	Network type	Area			
		Klang Valley	Johor	Sabah	Sarawak
X	4G	-100 dBm	-101 dBm	-92 dBm	-92 dBm
	3G	-87.6 dBm	-91 dBm	-91 dBm	-89 dBm
Y	4G	-100 dBm	-92 dBm	-93 dBm	-92 dBm
	3G	-91 dBm	-91 dBm	-103 dBm	-91 dBm
Z	4G	-96 dBm	-96 dBm	-95 dBm	-89.9 dBm
	3G	-91 dBm	-94 dBm	-91 dBm	-89 dBm

mobile phone. In this study, we will focus on video downloads speed in the four considered states to analyze the network performance in terms of video download speeds for both 3G and 4G networks.

The total average video download rate was calculated for each of the 4 included states and presented in Figure 19. In suburban areas, 4G significantly outperformed 3G and was found to depict about 1.32 times higher video download speed than 3G in Klang Valley, 1.23 times in Johor, 1.35 times in Sabah and 1.24 times in Sarawak regions. This implies that the faster video download rate enable 4G users to download their desired content without long hours of wait and disruptions and allows them to instantly download and view some web page.

Hence, 4G users do not have to face buffering and interruptions during their video streaming which is usually the case in 3G networks. In 4G networks, the 3 included service providers X, Y and Z depicted different values of average download speeds which are as follows: X (1.86 Mbps), Y(1.94 Mbps) and Z(1.83Mbps) . Conversely, the same service providers depicted the following speeds for video services; X (1.48Mbps), Y (1.53Mbps) and Z (1.49Mbps). This implies better performance and faster download speed of 4G in contrast with 3G in context of video services.

E. Network Latency for Video

While comparing the average initial buffering latency for both 3G and 4G networks, it was found that 4G outperformed 3G by a significant margin for each MNO considered in the study. The use of 4G network rendered the average latency values of 1220.7 ms, 1378.5 ms, 1787.5 ms, and 1654.63 ms for the regions of Klang Valley, Johor, Sabah and Sarawak. Conversely, the 3G network rendered the average latency values of 13076.2 ms, 6618.5 ms, 8653.9 ms and 8428.1 ms for the regions of Klang Valley, Johor, Sabah and Sarawak. The average values were based on the latency values obtained from all the 3 MNOs.

It was also revealed that 4G network again outperformed 3G networks with its lower average video E2E RTT-Ping server latency. 4G networks rendered average latency values of 45.2 ms for Klang Valley, 52.7 ms for Johor, 74.3 ms for Sabah, and 69.9 ms for Sarawak. Conversely, the 3G networks rendered average latency values of 838.2 ms for Klang Valley, 282.7 ms for Johor, 413.2 ms for Sabah and 521.1 ms for Sarawak. The average values were based on the values obtained for all MNOs.

All the 3 included MNOs across all the included states rendered lower total re-buffering latency values for 4G networks. However, only the operator Y at suburban Sarawak

rendered higher latency values with 4G in contrast with 3G networks. The 4G network rendered the values of 3870.6 ms for Klang Valley, 4111.0 ms for Johor, 5747.1 ms for Sabah, and 11214.1 ms for Sarawak. The average values were based on the values obtained from all the considered networks from the 4 test states. For 3G networks, the obtained average latency values were 19113.2 ms for Klang Valley, 11460.0 ms for Johor, 13737.8 ms for Sabah and 10534.6 ms for Sarawak.

The network; latency is a significant factor in networking. It determines the quality of experience enjoyed by a user. There are various kinds of latencies including initial buffering latency, initial E2E RTT-Ping server latency and re-buffering latency. All these latency types will be covered subsequently. The network latency is defined as the delay in the initial server response to a request made by the user to transfer data from source to device. User is only enabled to download something from the internet when the server allows it by responding to it. The server response initiates the downloading process immediately. Figure 20 shows the average video initial buffering latency, Figure 21 shows the average video initial E2E RTT-Ping server latency and finally Figure 22 shows the average video total re-buffering latency.

The average value of initial video buffering latency was determined for all the 3 MNOs across all the 4 states. The values obtained are shown in Figure 20. These values indicated that 4G outperformed 3G in terms of average initial buffering latency in each of the 3 considered MNOs. The average of the latency values of all networks in a specific region was found; Klang Valley region showed an average latency of 1220.7 ms, Johor showed an average of 1378.5 ms, Sabah rendered average of 1787.5 ms and Sarawak gave average values of 1654.63 ms when using 4G. Conversely the use of 3G networks depicted average latency values of 13076.2 ms, 6618.5 ms, 8653.9 ms and 8428.1 ms in Klang Valley, Johor, Sabah and Sarawak regions accordingly. Moreover, the same areas and MNOs were again evaluated for the values of average video's initial E2E RTT-Ping server latency for 3G and 4G networks. These values have been depicted in Figure 21. The results indicated lower values of average video E2E RTT-Ping server latency for 4G in comparison to 3G networks. Similarly, in comparison to 3G, lower values of average video E2E RTT-Ping server latency was recorded for 4G networks. Moreover, the average latency value evaluated for 4G networks for each of the 4 included states were 45.2 ms for Klang Valley, 52.7 ms for Johor, 74.3 ms for Sabah, and 69.9 ms for Sarawak. On the other hand, the average latency value for 3G were found to be 838.2 ms for Klang, 282.7 ms for Johor, 413.2 ms for Sabah and 521.1 ms for Sarawak.

Fig. 17. The total video access attempt measured at four different suburban morphologies and classified based on mobile technologies, MNOs and morphologies.

Fig. 18. The overall video access ratio measured at four different suburban morphologies located in four different states

Fig.19. vMOS score measured at four different suburban morphologies located in four different states, and categorized based on technologies #

Fig.20. The average video total download rate measured at four different suburban morphologies located in four different states, and categorized based on technologies

Fig.21. The average of video initial buffering latency measured at four different suburban morphologies located in four different states, and categorized based on technologies

Fig.22. The average of video initial E2E RTT-Ping server latency measured at four different suburban morphologies located in four different states, and categorized based on technologies

The average video's total re-buffering latency values recorded in all states and for all MNOs are given in Figure 22. It is evident from the figure that the values recorded for average total re-buffering latency in 4G networks are lower than in 3G networks. However, the MNO Y showed a different result in suburban Sarawak. 4G networks showed overall average latency values of 3870.6 ms for all tested networks in Klang Valley, 4111.0 ms in Johor, 5747.1 ms in Sabah, and 11214.1 ms in Sarawak. On the other hand, the 3G network depicted values of 19113.2 ms in Klang Valley, 11460.0 ms in Johor, 13737.8 ms in Sabah and 10534.6 ms in Sarawak. The novel technologies associated with IoT and Big Data require high-speed transfer of data which can be achieved through low-latency communications. These technologies will not be effective in case of absence of low latency leading to inferior service quality and unsatisfied user.

F. Summary For Video

The performance of networks in terms of quality of video services was evaluated and the results have been tabulated in Table 4. The services were provided in the suburban morphology by the three MNOs considered in the study. The MNOs were denoted by X, Y and Z. The values were obtained by applying 8 KPIs to four different states for both 3G and 4G.

The values obtained have been subjected to **horizontal** and **vertical** analysis for comparison as shown in the table. The **blue and red boxes** indicate the values to be compared.

As **horizontal comparison** of the measurement findings is presented across the four states for the same operators, technology and KPIs, where the table legend includes blue box and red box colors.

According to Operator X performance, for 4G technology, the operator X offered the best performance in KV state much better than the other all states. But for 3G technology, the Operator X offered the best performance in Sarawak state better than the other states.

According to Operator Y performance, for 4G technology, the operator Y offered the best performance in KV and Johor states much better than the other all states. But for 3G technology, the Operator Y offered the best performance in JOHOR and SARAWAK states better than the other states.

According to Operator Z performance, for 4G technology, the operator Z offered the best performance in KV state much better than the other all states. But for 3G technology, the Operator Z offered the best performance in JOHOR state better than the other states.

The vertical analysis of the values is followed by horizontal analysis to compare the network performance of a specific MNO, applying the same KPI and same network in different states. From the comparison between the operators for the both technologies, it can be seen that for 4G technology operator Y offered better overall performance compared to X and Z operators, with respect to video services overall states. That has been indicated by **green** circle around the highest values over all operators. Low 4G performance is exhibited overall by operator X as compared to operators Y and Z. On the contrary, it can be also seen that for 3G technology operator Z offered better overall performance compared to X and Y operators, with respect to video services overall states. That has been indicated by pink circle around the highest values over all operators. Low 3G performance is exhibited overall by operator X and Y as compared to operator Z.

Fig.23. The average of video total re-buffering latency measured at four different suburban morphologies located in four different states, and categorized based on technologies

TABLE 2. The final summary of video services measured at four different suburban morphologies located in four different states, and categorized based on technologies

(a)

Morphology: Suburban	Operator: X				MBB service: VIDEO			
	KV		JOHOR		SABAH		SARAWAK	
	3G	4G	3G	4G	3G	4G	3G	4G
Initial Buffering Success Ratio <i>[Higher is better]</i>	0.87	1.00	0.97	1.00	0.92	1.00	0.87	1.00
Average vMOS Score <i>[Range = 1 to 5] [Higher is better]</i>	1.31	3.59	1.76	3.47	2.21	3.43	2.26	3.36
Average Video Total Download Rate (kbps) <i>[Higher is better]</i>	1386.5	1842.9	1356.7	1777.1	1443.4	1849.1	1493.4	1771.7
Average Video Maximum Download Rate (kbps) <i>[Higher is better]</i>	6074.1	19736.2	5405.1	15036.7	5773.0	17055.6	6165.5	15781.7
Average Initial Buffering Latency (ms) <i>[Lower is better]</i>	17931.7	1302.2	7532.0	1639.7	7112.5	1642.2	7226.9	1885.1
Average Video E2E RTT Ping (ms) <i>[Lower is better]</i>	1323.8	53.0	312.8	65.4	413.8	60.4	470.6	78.7
Average Total Re-buffering Latency (ms) <i>[Lower is better]</i>	21980.0	3925.8	16812.7	8313.7	10720.9	5697.6	9277.0	6220.5
Average Cellular Signal Strength (dBm) <i>[Higher is better]</i>	-72.9	-90.4	-84.3	-91.0	-82.9	-84.5	-80.6	-84.6

(b)

Morphology: Suburban	Operator: Y				MBB service: VIDEO			
	KV		JOHOR		SABAH		SARAWAK	
	3G	4G	3G	4G	3G	4G	3G	4G
Initial Buffering Success Ratio <i>[Higher is better]</i>	0.90	1.00	0.93	1.00	0.83	1.00	0.98	1.00
Average vMOS Score <i>[Range = 1 to 5] [Higher is better]</i>	2.11	3.62	2.32	3.63	1.48	3.38	2.35	3.12
Average Video Total Download Rate (kbps) <i>[Higher is better]</i>	1376.8	1822.8	1469.4	1854.5	1279.5	1802.0	1417.7	1843.3
Average Video Maximum Download Rate (kbps) <i>[Higher is better]</i>	6382.5	19150.2	6223.4	18434.1	4487.4	14386.2	6237.0	18353.7
Average Initial Buffering Latency (ms) <i>[Lower is better]</i>	9513.9	1123.6	6760.6	1187.8	7842.9	1754.0	7046.2	1461.4
Average Video E2E RTT Ping (ms) <i>[Lower is better]</i>	543.5	33.3	348.8	44.4	244.2	66.7	353.5	60.8
Average Total Re-buffering Latency (ms) <i>[Lower is better]</i>	15513.2	4472.8	10273.5	1620.2	16907.0	4384.4	10843.5	25009.2
Average Cellular Signal Strength (dBm) <i>[Higher is better]</i>	-84.3	-90.5	-81.6	-85.8	-86.0	-85.4	-77.0	-84.7

(c)

Morphology: Suburban	Operator: Z				MBB service: VIDEO			
	KV		JOHOR		SABAH		SARAWAK	
	3G	4G	3G	4G	3G	4G	3G	4G
Initial Buffering Success Ratio <i>[Higher is better]</i>	0.95	1.00	0.93	1.00	0.82	1.00	0.96	1.00
Average vMOS Score <i>[Range = 1 to 5] [Higher is better]</i>	1.49	3.61	2.64	3.59	1.80	3.40	1.85	3.48
Average Video Total Download Rate (kbps) <i>[Higher is better]</i>	1401.1	1821.7	1583.3	1812.2	1340.5	1839.3	1470.0	1813.5
Average Video Maximum Download Rate (kbps) <i>[Higher is better]</i>	6176.0	22167.5	8911.0	18275.1	5824.7	14594.6	6096.7	15281.8
Average Initial Buffering Latency (ms) <i>[Lower is better]</i>	11783.2	1236.3	5563.0	1303.0	11006.3	1966.4	11011.3	1617.4
Average Video E2E RTT Ping (ms) <i>[Lower is better]</i>	647.2	49.2	186.5	43.2	581.7	95.7	739.2	70.2
Average Total Re-buffering Latency (ms) <i>[Lower is better]</i>	19846.6	3213.3	7293.6	2399.0	13585.6	7195.3	11483.3	2412.6
Average Cellular Signal Strength (dBm) <i>[Higher is better]</i>	-78.5	-88.4	-85.3	-87.2	-83.1	-87.6	-78.3	-83.4

In short, we discovered better performance of 4G in comparison to 3G networks. 4G outshined 3G in services provided by all the 3 considered MNOs in each of the 4 states. Moreover, the application of all the 8 KPIs also indicated outperformance of 3G by 4G networks. However, 3G depicted better performance than 4G only in terms of average cellular signal strength. This calls for the extension of 4G coverage areas to render better signal strength to users. Moreover, all the 3MNOs depicted almost similar performance on application of all the 8 KPIs, for both networks and all 4 states.

V KEY FINDINGS

The network performance measurement is evaluated in this study through the 4 metrics of coverage, latency, satisfaction, and speed. These factors affect the user experience while he avails various mobile broadband services. Coverage – It is defined as the strength of the cellular signal during video streaming and browsing activities. User experience is highly dependent on the coverage specifically when he wants to browse or download videos. Latency – it refers to the time taken for network response. It is evaluated as the delay in data transmission from source to device. Latency is specifically significant for users interested in video calls, games and browsing. Satisfaction – The network transmission speed affects the video and gaming activities; in case of low network transmission speed, the users experience difficulty in their gaming and video activities and hence, user satisfaction is low. Conversely the situation is reversed for high network transmission speed. This network transmission speed and the consequent satisfaction of the user may be evaluated through a metric called vMOS of mobile video services. The metric is evaluated using a 5-points scale. The scores of successfully downloaded games and videos determine the user experience and satisfaction. Speed –Speed is the rate at which data transfers from source to device. The download rate determines the rate of total rate of data transfer between source and device while the data throughput determines the amount of data transferred. According to the YouGov research, most of the users switch to 4G networks in anticipation of higher speed of internet browsing and faster video streaming. The user expects high speed net surfing matching to that of home broadband. In short, this factor is crucial for network performance. The main research findings have been given below:

A. Performance In States

From the obtained these results it can be stated that overall, the measured states in Malaysia, the all operators invest more for 4G technology in KV state much more as compared to the other suburban area in the measured states.

B. Performance Of 4G and 3G Networks

4G networks evidently outshined 3G networks in almost all aspects for each considered MNO in all the 4 states as evident in our results. This extraordinary performance by 4G networks for various MNOs in different states clearly indicate that the

future of networking lies in 4G which can revolutionize the world of broadband services.

C. Coverage

The network coverage can be evaluated from the strength of received signal. Users can easily and quickly get access to MBB services when the coverage is wider and the signal is stronger. In order to avoid any bias in results, the distribution of signal strength will be assessed in different testing areas to get a better picture of network coverage. The data indicated that the 3G and 4G received signal strengths remained almost consistent across 3 considered MNO networks.

D. Latency

Latency is the network response time. Latency may be evaluated through a ‘ping test’ whereby the time taken by unit data to reach a point and respond to user’s request is recorded. In case of web browsing and applications, the time taken for accessing and loading a requested webpage gives the web browsing speed. This speed depends on the response and latencies in page display. Users can experience better quality of video services, gaming and web browsing if the latency performance is better. The ping test results indicated the web ping average RTT latency of at least 42.4ms for 4G network while a minimum of 69.9 ms for 3G network. Similarly, as low as 33.27 ms of the average E2E RTT ping server latency was recorded for 4G networks while a minimum of 122.98 ms was recorded for 3G network.

E. Satisfaction

User satisfaction (specifically for the users interested in web-browsing and video streaming) is dependent on network performance in context of successful access to a webpage and uninterrupted video streaming. In context of video services, stalling time and buffering time play an important part in network performance. The performance indicator vMOS gives a score ranging from 1 to 5 depending on the network performance with respect to stalling and buffering time such that higher vMOS score is allocated to better network performance. The outdoor drive test conducted at all the test areas indicated vMOS scores higher than 3 for 4G networks and lower than 3 for 3G networks. The scores indicated the network performance in context of both web browsing and video streaming.

F. Speed

Speed, as defined earlier indicates the rate and amount of data transfer between the source and the device on user’s request. It is the rate of download of a video or web page. Speed may determine the time taken in accessing a webpage. According to YouGov’s research, the main service availed by users in 4G network usually involves web browsing. This study indicated that the 4G network showed 4.2 times better performance than 3G network in terms of downloading speed in browsing activities while the 4G network showed 1.6 times better downloading speed in video streaming activities.

VI LIMITATION AND FUTURE DIRECTIONS

In the current research, MBB services used for streaming videos and browsing websites have been analyzed for their performance levels and insights are presented. The research study scope does not include assessing the performance carrying out voice calls or sending the short message service (SMS). The limitations present in the present study as follows:

A. Further KPIs

1. In the present paper, the information stated is within the context of mobile broadband download speeds, web browsing speeds and latency. The research does not take into account consumer experience variables for making use of mobile services like billing, customer services, data allowances, traffic management policies, prices and others. Aspects such as text messaging, call quality, voice services and others have not been tested.
2. The research study may also integrate the analysis of the MBB networks performance when several combinations are being accessed like photo-and-video-based website contents, web-browsing and video-streaming testing applications, MBB networks and KPIs, and research area diversified suburban regions.
3. Within various operator networks, assessment can be made for the delay variation (jitter) parameters.

B. Network Availability

1. The mobile broadband service performance is highly dependent upon network availability and it is the serving network and smart phone which decides it. As the research does integrate coverage data, it does not analyze the network availability. This network availability depends upon various factors such as base station distance, keeping in mind that the user could be outdoors or in the building, or they could be in motion or stationery. For example, when the 3G technologies are locked into the smartphone, it would not indicate that there wouldn't be any 4G network coverage at that specific place and time.
2. Network availability plays a significant role in the MBB services performance levels. Even though, there is limited coverage data present within the current research, there is no analysis present on the network availability levels that are based upon various factors like the base station distance present, the user availability which may be outdoor or indoor and if the user has been in motion or remained stationery.
3. For the stated MNO, the present research doesn't take into account the network availability. For example, when the 4G network is connected to a device, it would not mean that there is unavailability of the 3G network. The present research method would not provide instructions to the device regarding the technology it must connect to at the time of the driving test.
4. Performance of service is also influenced by the amount of people, present in the same location, who are

concurrently making use of the mobile network. This, along with the coverage fluctuations refers to the variation in the performance availability for the individual customers in terms of location as well as time.

5. The performance of MBB networks is also affected by the number of users present that may access the network system during the specific time period. Hence, the spatial-temporal aspects related to the user number for service access should be considered as a variable which is to be analyzed in the future research studies.

C. Extension Of Testing

1. There are only four states present in the current research and for the morphologies, the complete Malaysian performance has not been stated.
2. The performance of the MBB networks is influenced by the number of people who use the mobile network within the same location. Hence, for each individual customer, the performance would be different in terms of location and time. The present research can expand based on these aspects.
3. For the future, it is possible to analyze the MBB networks that are delivered to devices apart from smartphones along with the Virtual Mobile Network Operators (VMNOs).
4. When the 4G/3G networks are accessed, when various mobile devices are used, it does not influence the experience of the user if the speed of the user is faster as compared to the channel speed. On the other hand, if the device speed is slower than the channel speed, then there will be a negative influence on the experience of the users. Generally, factors which influence the mobile browsing experience of the users are the state, websites, network infrastructure, browser application, mobile device and context of the user. The current research does not completely assess these factors.
5. There is a need for the time duration of the drive test to be longer. A larger area must be covered so that completion of measurements is possible. It is a time-consuming approach.
6. At the time of the drive test, measurement devices should be used to download the measurement logs and for processing it should be uploaded. There is high data amount needed.
7. For the future research, there would be different morphologies applied for the analysis of the MBB performance, like indoors, and dense urban.
8. Not long from now, the MBB network performance of the rural areas will have to be enhanced further since there is drastic development in the MBB networks of these areas. This development is caused by the smart IoT application expansion like smart farms, smart grading, smart homes, and other smart solutions [28-31]. Hence, there is need for additional research and analysis for the rural area 5G network planning.

9. There is limited research present upon the suburban areas within three Malaysian states. Hence, the MBB network performance cannot be generalized for the complete nation using the various morphologies.

D. Inclusion Of GIS

The geographical areas MBB services have correlation aspects which can be presented by the Geographical Information System (GIS) solutions. Their infrastructure and natural attributes are quite similar in nature. For the future, it sounds like a significant research topic as the service providers would be able to gain a thorough understanding of the rural areas MBB performance. Hence, the forecasting models built for the MBB performance would be realistic in nature.

E. Mobility Management

For future research, mobility management also seems to be an essential subject. The measurement information attained from the drive test can be used. Simulation has been used for all information presented earlier upon mobility management [32-36]. Hence, now, by using the measurement data from the drive test, the researchers would be able to establish mobility management algorithms and models that are efficient in nature. Effective planning can be carried out by the regulators and operators for their mobile users, specifically for the ones in need of connections that are highly reliable.

F. Handover

The current research can be expanded by including handover problems taking place in the suburban regions over the heterogeneous networks. For the ultra-dense networks in the future, it would be highly recognized since the small base stations would increase in numbers and complexity in the network specifications would be observed. Hence, the mobility management problems would observe a drastic increase [34, 36-38].

G. Propagation Study

1. It is necessary to take into account several channel propagations influence like fading caused by rain, small scale fading, large scale fading and blockage. Within the current research, the measurement period was only of two months because of which the network performance has not been tested within altering climatic circumstances.
2. As the research has been carried out within the context of an outdoor localization system [39], it has been recommended that the methodology applied should be similar to the one earlier so that an efficient indoor localized system algorithm can be developed.

H. Drive Test

1. Measurement devices should be used for downloading of the measurement logs and uploading for processing at

the time of the drive test. There is significant amount of data required.

2. It is quite costly to carry out the drive test solution since there is a need to integrate the vehicle rent, the fuel cost as well as the maintenance.
3. The time duration for the drive test should be long. The area covered must also be bigger so that a complete measurement is attained. Hence, the process becomes time consuming.

I. Implementation of 5G

1. From the current research, a measured data set has been attained which is now used for the prediction of latency, download speed, signal strength and others in real time. Through this information, the reliability of the 5G network in the future can be enhanced.
2. To effectively implement the 5G variables, it is necessary to analyze the trees. Along with trees, there are various issues which may could provide passive interference while detonating the link performance caused by rain or rest of the channel impairments due to long buildings.
3. The average latency in 5G networks is approximately 1ms. In order to understand the speed of this aspect, it should be considered that 10ms are taken by the human eye to capture an image and process it in the brain. Hence, real-time critical applications like low latency or remote surgery would prove to be quite crucial. Later technologies and 5G advancements are very much dependent upon the latency performance. In the future, it would be essential to carry out research upon the 5G network latency using the drive test research. It would help analyze how real-time critical applications can be supported through this reliable new technology.
4. Lastly, when the 5G technology has been widely deployed in Malaysia, the present research may take into account the 5G MBB service provider performance so that the superiority levels can be measured as compared to the earlier generations of MBB. This seems to be quite an interesting aspect as implementation is carried out using millimeter-wave bands with characteristics of cell size support that is small and path loss which is high [40-43].

VI CONCLUSION

Within the current research, the 4G and 3G mobile network performances of the Malaysian suburban morphology have been stated using drive test measurements. There are four variables applied for the assessment of the mobile network performance which are coverage, latency, satisfaction and speed. There are two kinds of MBB services being used and they are web browsing and video streaming. As part of the present research, the 4G and 3G technologies performances have been compared to three kinds of MNOs network present at four kinds of sites which are Klang Valley, Johor, Sarawak, and Sabah. Analysis suggests that, for all the three networks, as compared to the 3G networks, the 4G networks had a more

efficient performance level on average. Additionally, for the suburban areas taken into account, the 4G networks have been deployed higher as compared to the 3G networks and this means that for the tested area, the dominant network present is 4G. For all mobile operators, this difference remained consistent. The current research would allow an upgrade of the current MBB networks within the Malaysian suburban areas for aiming to meet the enhanced 5G technology traffic demand. For the suburban areas, the results presented allow a general course for efficient planning of the 5G network.

APPENDIX

Appendixes, if needed, appear before the acknowledgment.

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A black and white portrait of Dr. Hani Al-Hayek, a man with a beard and mustache, wearing a dark suit, white shirt, and patterned tie. He is looking directly at the camera with a slight smile. [illegible]

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