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Performance Analysis of Mobile Broadband Networks With 5G Trends and Beyond: Rural Areas Scope in Malaysia

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ABSTRACT This paper presents a multidimensional performance analysis of existing Mobile Broadband (MBB), Third Generation (3G) and Fourth Generation (4G) networks, of rural morphology in Malaysia. The MBB performance analysis is carried out based on measurement data obtained through Drive Tests (DT) conducted in rural areas located in three Malaysian states: Johor, Sarawak, and Sabah. The measurement data pertains to the performance of three national Mobile Network Operators (MNOs) in rural areas: Maxis, Celcom, and DiGi. The MBB performance measurement data was collected between January and February using modified Samsung Galaxy S6 smartphone handsets. The measurement data of the 3G and 4G MBB networks are associated with four performance metrics (coverage, latency, satisfaction, and speed) for two MBB services: web browsing and video streaming. During the measurements, each smartphone collected the performance data of only one MBB service. Several classifications were identified to comprehensively monitor the performance of the two MBB services. For the data measurement of the MBB video streaming service, the same YouTube video was alternately played by the same smartphone, but with two different resolutions: 720p (low) and 1080p (high). For the data measurement of the MBB video streaming service, three different webpages (i.e., google, Instagram, and mstar) are sequentially browsed in a loop using another smartphone. This research work is designed to mimic real scenarios where the smartphone in use is not exclusively locked to a single technology while streaming a video or browsing a website. This allows the identification of the coverage for 2G, 3G, and/or 4G technologies within the tested areas. Due to the small amounts of 2G data, we omitted the analysis of 2G technology in the present study. The MBB performance analysis shows that, on average, the 4G network performed much better than the 3G network for all three MNOs throughout all measurement areas considered in this research. For instance, the 4G technology achieved a minimum of 42.4 ms on the web ping average RTT latency, while the 3G only achieved a minimum of 69.9 ms. For the average E2E RTT ping server latency, 4G achieved as low as 33.27 ms, while 3G obtained a minimum of 122.98 ms. The vMOS scores for 4G technology for both web browsing and video streaming services are larger than 3, while the 3G technology had a score of less than 3. The 4G technology can provide an improvement up to a factor of 4.2 and 1.6 in the download speed when browsing a web and streaming a video, respectively, in comparison to the 3G technology. These observations were found to be consistent across all mobile operators. This is unsurprising because we would expect consumers to experience a noticeable improvement when using a mobile broadband service over a 4G network as compared to a 3G network. The presented results provide a general direction for efficiently planning the Fifth Generation (5G) network in rural areas.

INDEX TERMS Mobile broadband, performance evaluation of MBB, 3G, 4G, 5G networks, rural morphology, coverage, throughput, drive test.

I. INTRODUCTION

Society's increased reliance on MBB networks has led to significant challenges for service providers in terms of delivering uninterrupted coverage, high network performance, and increased user Quality of Experience (QoE) [1]–[13]. These challenges motivate MBB stakeholders in the academia and industry to understand the gap between the performance of current technologies and users' ever-increasing demands and expectations. A thorough understanding of the present gap will help service providers to further enhance the capabilities of their MBB networks. Designing new technologies will provide innovative applications and services which can cope with the growth in traffic volume using a wide variety of devices and applications [14]–[20].

Measuring the actual MBB performance is a critical issue which is relatively influenced by physical impairments, mobility, variety of user devices, presence of Performance Enhancing Proxies (PEP) [21], different access network configurations, etc. [22], [23]. When conducting a performance analysis of MBB services based on measurement experiments, a common approach is to rely on end users and their devices to run tests by visiting a website or running a specific application [24]. Network operators and independent agencies sometimes perform drive tests to identify coverage holes or performance problems. However, these tests are expensive, do not scale well, and have little information about their used methodology.

In [25], the impact on system performance due to the network upgrade from Second Generation (2G) to third generation (3G) to Long Term Evolution (LTE) systems using Nokia Siemens Network Flexi multi-radio base stations is discussed. Measurements of the Reference Signal Received Power (RSRP), Signal to Interference plus Noise Ratio (SINR), and throughput were accomplished by a drive test within 2 Km of the deployed site area. All three parameters were affected since the user equipment moved away from the site area and towards the cell edges. This problem can be addressed by the deployment of low power relay nodes which can extend the coverage of LTE-Advanced networks. This technique seems to be a promising solution that positively contributes to the performance of future LTE, 5G systems, and beyond. Signal strength measurement is accomplished in a selected building in Damansara, Malaysia for 2G, 3G, and LTE services using a software called Nemo Handy that was installed on a smartphone. It is claimed that the measurement results of the MBB services within such an exemplary building will help service providers determine a suitable number of antennas to be deployed inside the building to provide a seamless and outstanding performance of services to users even during peak time. Performance analysis of a 4G LTE network in and around shopping malls and campus environments in Lagos is presented in [26]. Propagation measurements of several key performance indicators (KPIs) were observed at an operating frequency of 1876.6 MHz using Huawei Technologies drive test equipment. Test results were extracted using the MapInfo tool and analyzed in MATLAB. To examine the goodness of fit, a ninth-order degree polynomial was employed for the curve fitting of the measured data. These results favorably compare with the specific KPIs provided by the Nigerian Communication Commission (NCC). Overall, the fitted models could be very useful for the characterization of radio channels in similar environments. Although there are several drive test measurements that have been conducted worldwide, an insufficient number of MBB studies in rural areas is noticeably present. Not sufficiently understanding the performance of MBB services in rural areas may lead to improper network planning and deployment in future. In addition to the discussed studies, there are several other related researches that have been conducted for measuring the MBB performances of 2G, 3G, and 4G networks [26]–[33]. These studies were accomplished in different environments, utilizing diverse systems. Although they contribute to enhancing future MBB networks, further investigations are needed for assessing MBB networks in various morphologies. This will lead to efficient planning for the future. Additionally, the MBB performance in rural areas in Malaysia based on real measurement data are lacking. As a result, several rural areas are suffering from slow MBB communication services. Therefore, an extensive drive test measurement study is needed to properly plan for future wireless networks in rural areas.

The aim of this study is to comprehend the actual user MBB experience in selected rural areas in Malaysia in terms of four performance metrics: network coverage, latency, satisfaction, and speed. This study further investigates the MBB performance in Malaysia and determines the locations that require MBB system upgrade to 4G and 5G networks. Having this knowledge allows relevant bodies and agencies to lay out plans for sustaining and even refining current MBB services in rural areas in Malaysia and worldwide, especially since mobile traffic is forecasted to exponentially increase over the years. Moreover, this study allows consumers to appreciate the performance enhancement of 4G over 3G networks, enabling them to understand the performance differences between local MNO networks in Malaysia. Being an independent study conducted by a third party, this research significantly contributes to the planning and deploying of 5G networks by a given service provider so as to address potential performance degradation, especially in rural areas. The results are benchmarked with the performance of other service providers. This research is designed to collect the performance data of three Malaysian MNOs. The results in this paper were collected between January and February. Researchers from Universiti Teknologi Malaysia (UTM) and Istanbul Technical University (İTÜ) measured the performance of mobile networks across three states in rural areas using Samsung Galaxy S6 smartphones. Our measurements cover two MBB services: web browsing and video streaming. The video service was assessed via 720p low and 1080p high resolution videos, while three distinctive webpages (google,

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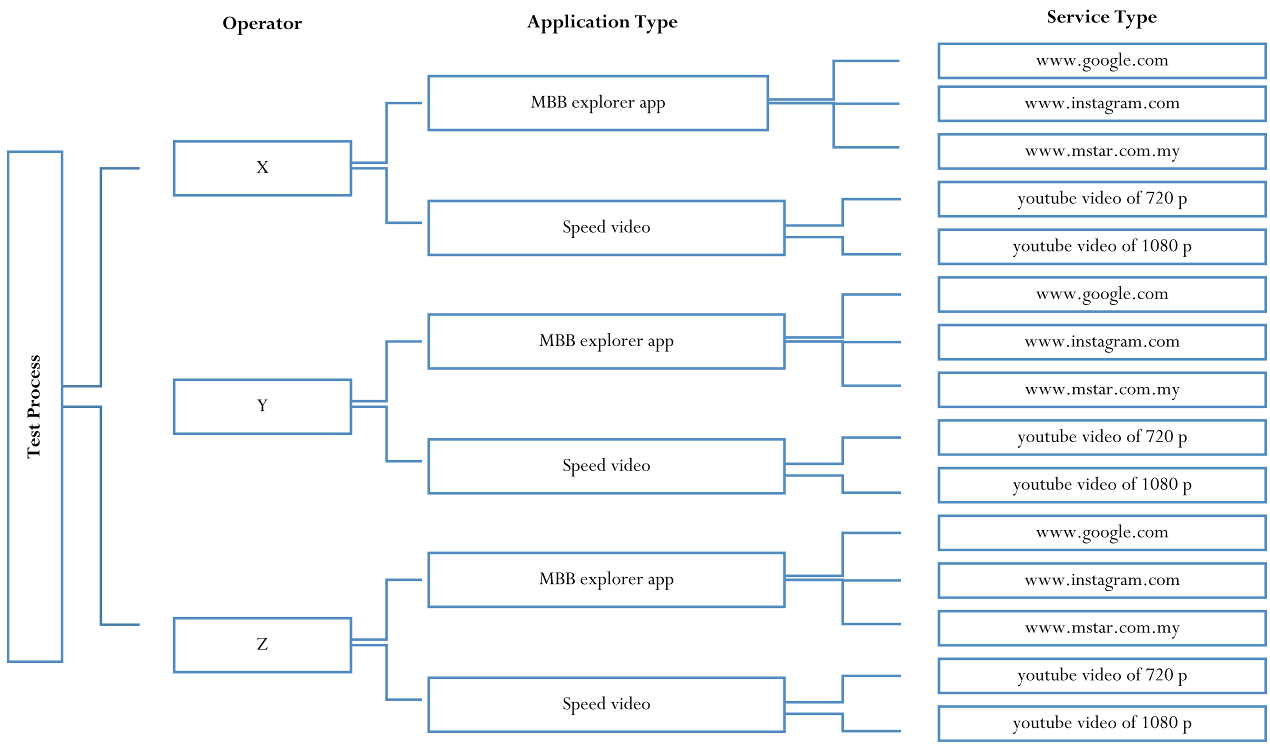

FIGURE 1. Structure of test process with the operators, applications, and service types used.

Instagram, and mstar) were browsed to evaluate web services. The analysis mimics real scenarios where smartphones of mobile users cannot be locked to any particular technology. The fieldwork for this project was conducted between January and February in three Malaysian states: Johor, Sarawak, and Sabah. The data were compiled from the experimental measurements during the drive tests in outdoor (in-vehicle) locations using consumer Samsung Galaxy S6 handsets. With this experimental setup, the MBB data were compiled from three different geographical areas for two MBB video streaming and web browsing services. Four distinct performance metrics were employed: coverage, latency, satisfaction, and speed.

The rest of this paper is structured as follows: the methodology and system model used in the present study are described in Section 2; the results of our tests, including performance analyses and comparisons, are explained and discussed in Section 3; the research finding and the future direction are highlighted in Sections 4 and 5, respectively; and finally the conclusion of the study is drawn in Section 6.

II. METHODOLOGY AND SYSTEM MODEL

Our test methodology has been designed to measure performance metrics relevant to the consumer experience when using mobile broadband. To ensure that each network was tested on an equal basis, our test processes were designed with the following assumptions and settings:

(i) The MBB networks were tested simultaneously to ensure that environmental conditions were the same for each service operator.

(ii) Identical handsets were employed for each network.

(iii) Undue contention was avoided by testing networks in parallel and ensuring that no concurrent tests were run on the same network.

The data collection was accomplished using proprietary software testing applications: the MBB explorer for web browsing services and the Speedvideo for video streaming services, both supplied by Huawei Technology (Huawei mLab). These applications were reliably used to test the MBB performance, and the obtained results were officially published by Huawei in [34]–[36]. Thus, we believe that these two applications have been thoroughly tested in terms of their efficiency to measure the parameters contributing to the MBB user experience studied in this work. In addition, these two applications are selected due to the following reasons:

(iv) The MBB explorer and Speedvideo apps allow customized test sets, close to the consumer experience of MBB access. These datasets are then tested locally in the test device.

(v) The test app itself requires no modification of the handsets.

(vi) The test apps are set to continuously run the test in the testing cycle. This makes the testing process more practical and convenient as there is less interaction required between the tester and the phones.

(vii) Both apps have been used to measure web and video MBB user experiences in Singapore and Thailand. This allows us to fairly benchmark the MBB user experience in Malaysia relative to our neighboring countries in South East Asian regions.

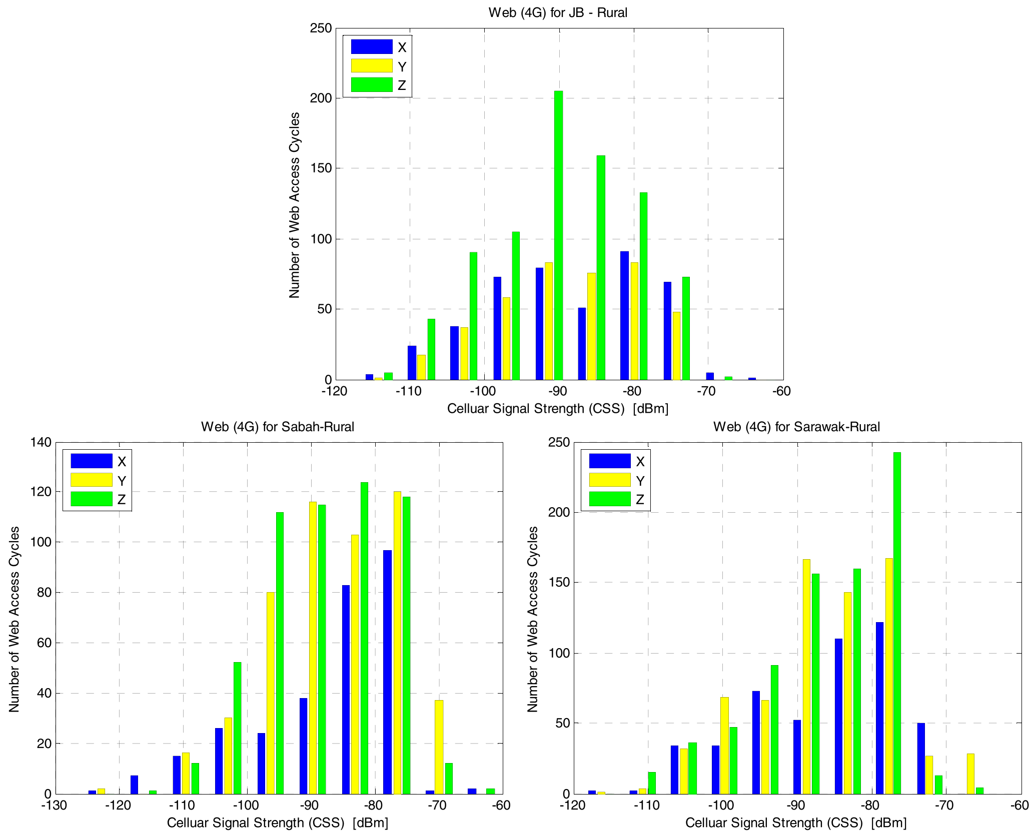

FIGURE 2. PDF of cellular signal strength of 4G technology web browsing for rural morphologies.

A. OUR TEST PROCESS

For the MBB explorer app test, each test cycle involves accessing and browsing three webpages that are different in terms of their contents and access speeds, as illustrated in Figure 1. The first site (www.google.com) is classified as a light-sized website since the testing app only accesses Google's homepage. The second (www.instagram.com) is classified as a medium-sized website as it is a photo-sharing site. The last (www.mstar.com.my) is classified as a heavy-sized website since it dispenses news via texts, photos, and videos. For the Speedvideo app test, each test cycle includes streaming of a similar YouTube video with a low resolution of 720p and a high resolution of 1080p. The MBB explorer is set to run 100 cycles of tests before the app is restarted, while Speedvideo can be set to run any number of user input cycles.

B. MNO's SIM

Three MNO networks in Malaysia are selected for this research. As the objective of this research is to understand the MBB user experience in Malaysia and benchmark the performance of MNO networks, the three MNOs are labelled as X, Y, and Z in this paper. The consumer prepaid SIMs of each MNO were purchased from each MNO's store to ensure that they are representatives of available consumer tariffs. Since there are two types of tests, two SIMs were purchased from each MNO for the purpose of this research.

C. TEST ENVIRONMENT

The measurements were accomplished in the outdoor environment. A drive test is conducted to cover the main roads of the considered cities and towns, as well as along the inter-town roads and highways. For town and inter-town federal road measurements, the drive speed is set to be less than 60 km/hour, while for the highway, the drive speed is set to 80 km/hour.

D. DATA COLLECTION

Following the test completion at each testing site, we checked that the data have been uploaded twice to the database. Every day before the real measurement is conducted, we first begin with a ten-minute pre-test and ensure that the pre-test data are fully recorded in the database. At the end of the day, using the time stamp recorded during the measurement, we also ensure that the last data collected is also recorded in the database.

III. KEY PERFORMANCE INDICATORS

In this study, the Key Performance Indicators (KPI) are used to illustrate the findings of this research. Several KPIs were utilized to assess MBB services. The various KPIs have been grouped into four main indicators, which are relevant to the experience consumers would have when accessing different MBB services in rural areas. The four metrics are coverage,

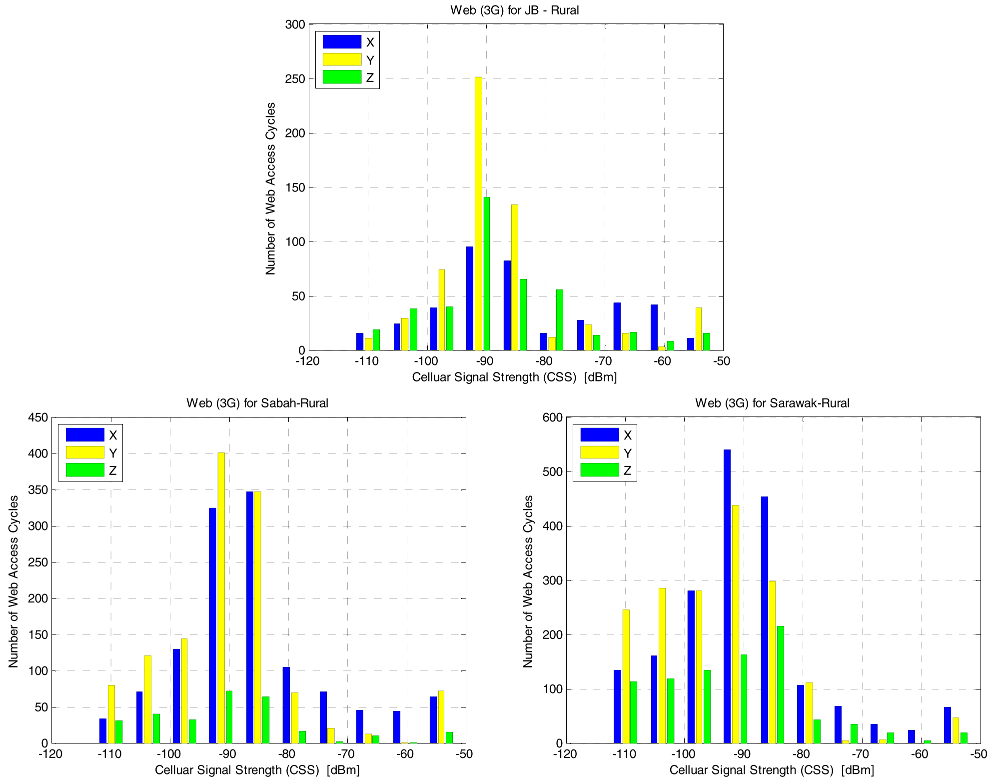

FIGURE 3. **PDF of cellular signal strength of 3G technology web browsing for rural morphologies.**

latency, satisfaction, and speed. They are further explained in the following subsections:

A. COVERAGE

The received signal strength is associated with the network coverage area. This is most likely the main factor that contributes to consumer experience when accessing the two types of MBB services: web browsing and video streaming. Strong signal strength provides better consumer experience when accessing MBB services.

B. LATENCY

Latency represents the responsiveness of the network measured by a 'ping test'. It is calculated by recording the time it takes for a small piece of data to travel to a point and send a response to the user's device. Strong latency performance will improve the consumer experience of video streaming, web browsing, video calls, and real-time online gaming.

C. SATISFACTION

For web and video services, from the user's perspective, the number of successful attempts to upload a webpage and stream an uninterrupted video measures the network performance. From the overall test, the ratio for successful web browsing and video streaming reflects on the level of user satisfaction. For video services, several factors determine the network performance, such as the stalling time and buffering time, when streaming a video. The vMOS indicator considers these factors and provides a comprehensive performance score on a scale of 1 to 5. Here, a higher vMOS number represents better network performance.

D. SPEED

The video and web download speed/throughput are the rates at which data can be transferred from the internet to a user's device. These metrics signify the consumer's experiences in terms of speed when accessing MBB services. The speed is one main attribute of 4G technology, and it largely influences internet browsing and video streaming. Our web browsing speed metric also shows the time taken to load a standard web page.

IV. MBB PERFORMANCE MEASUREMENT RESULTS

The results obtained in this section represent the network MBB performance based on the times and geographical areas at which the measurements were carried out. To ensure a fair comparison of the three MNOs, we tested each network simultaneously at each testing location. The smartphones used are all generic and unmodified, of identical specifications and build, and running the same operating system. We have examined the data to ensure that no bias has been introduced in the results. The MBB test is conducted from January to February in three states of Malaysia: Johor, Sabah,

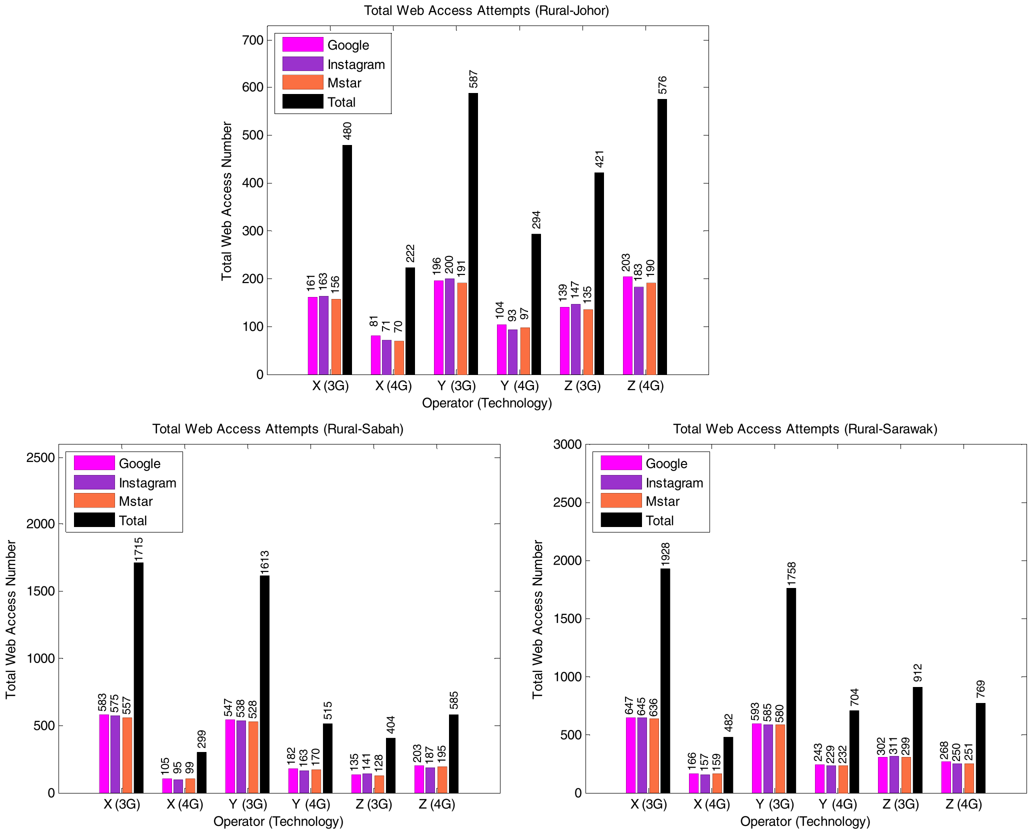

FIGURE 4. The total web access attempt classified based on technologies, MNOs and areas.

TABLE 1. Morphologies areas.

Morphologies	Johor	Sabah	Sarawak
Rural	Johor federal road; PLUS and Second Link Highway	Inter-town roads	Inter-town roads

and Sarawak. The classification of the test areas according to morphologies are summarized in Table 1.

For rural morphologies, all data collected from the Samsung Galaxy S6 smartphones have access to the internet by either using 4G, 3G, and 2G technologies. However, due to the small number of obtained samples for 2G data, only the analysis for 3G and 4G are presented in this paper. The results are discussed in the following two subsections. In the first subsection, the WEB BROWSING EXPERIENCE results are presented and discussed. In the second main subsection, the VIDEO STREAMING EXPERIENCE results are presented and discussed.

A. WEB BROWSING EXPERIENCE

1) NETWORK SIGNAL COVERAGE

The distributions of the cellular signal strength for web services are depicted in Figures 2 and 3 for 4G and 3G technologies, respectively. Table 2 illustrates that 80% of

TABLE 2. 80% of the coverage in the test area is stronger than the given web cellular signal strength stated in this table.

MNO	NETWORK TYPE	AREA		
		JOHOR dBm	SABAH dBm	SARAWAK dBm
X	4G	-97	-94	-96
	3G	-93	-93	-97
Y	4G	-96	-95	-94
	3G	-93	-97	-103
Z	4G	-98	-95.9	-94
	3G	-97	-103	-103

coverage in the test area is stronger than the given web cellular signal strength. We see that 4G networks provide better coverage as compared to 3G networks.

2) NETWORK SATISFACTION

The number of attempts for web services using the Samsung Galaxy S6 smartphones during DT is presented in Figure 4. For rural areas, our web browsing attempts show that smartphones mainly access the internet via 4G technologies with only 36.3%, 27.3%, and 29.8% of web services for Johor, Sabah, and Sarawak, respectively.

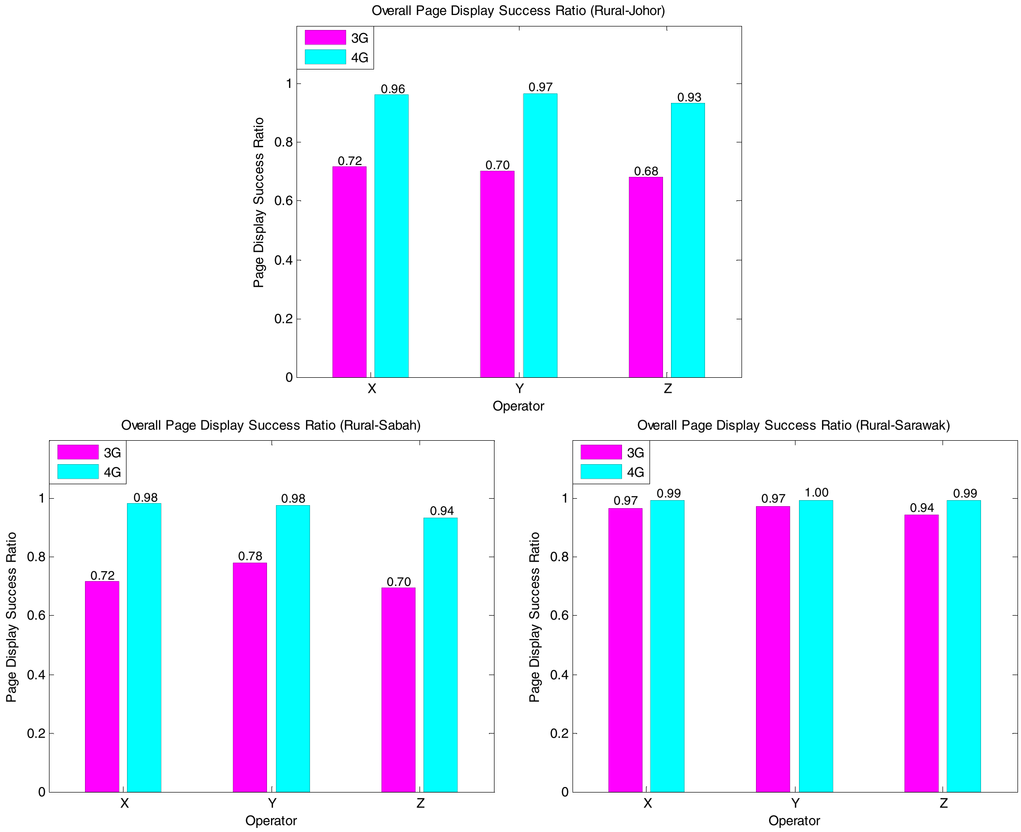

FIGURE 5. The overall page display success ratio for rural morphologies in each state.

The number of successful attempts for smartphones to browse a webpage is a test metric that measures the network performance for each 3G/4G technology of each MNO. In this research work, this test metric is termed as the overall page display success ratio, as captured and depicted in Figure 5. Our results indicate that on average, the 4G networks outperform the 3G networks for all three MNO networks considered in this study. This observation was unsurprisingly consistent across all MNOs since MBB consumers expect to experience a noticeable improvement when using MBB services over a 4G network as compared to a 3G network.

3) NETWORK DOWNLOAD SPEED

For web services, the average page download throughputs across the three MBB networks for all three test locations/states are presented in Figure 6. Our results show that Sabah has the highest 4G web browsing speed improvement as compared to 3G. The 4G web download speed improved 2.97, 2.47, and 2.21 times faster than the speed of 3G web browsing for Johor, Sabah, and Sarawak, respectively.

4) NETWORK LATENCY

The latency indicators for web services are given in Figures 7, 8, and 9. Figure 7 presents the average web page response latency for rural morphology. 4G networks have lower page response latency than 3G networks. Across all our tested states, as an average of all networks tested, the latencies for 4G are 880.33 ms, 847.50 ms, and 924.51 ms; while for 3G, they are 2072.67 ms, 2217.56 ms, and 4396.28 ms for Johor, Sabah, and Sarawak, respectively.

Figure 8 displays the average web page display latency for the rural morphology. The results indicate that 4G networks have lower average web page display latency than 3G networks. Across all of our tested states, as an average of all networks tested, the latencies for 4G are 5364.7 ms, 5657.1 ms, and 8031.7 ms; while for 3G, they are 6799.3 ms, 7206.1 ms, and 17769.9 ms for Johor, Sabah, and Sarawak, respectively.

Figure 9 presents the web ping average RTT for the rural morphology. On average, 4G networks have lower ping average RTT latency than 3G networks. Across all our tested states, considering the average of all networks tested, the latencies for 4G are 57.3 ms, 86.0 ms, and 74.6 ms; while for 3G, they are 96.2 ms, 160.3 ms, and 117.2 ms for Johor, Sabah and Sarawak, respectively.

a: ANALYSIS SUMMARY FOR WEB SERVICES

The results for web services obtained from the three Malaysian MNOs of rural morphology are tabulated in Table 3. As can be observed, the overall latency in different states for 4G is lower than 3G which verifies the previous analysis accomplished. This lower latency results in better communications and increased customer satisfaction,

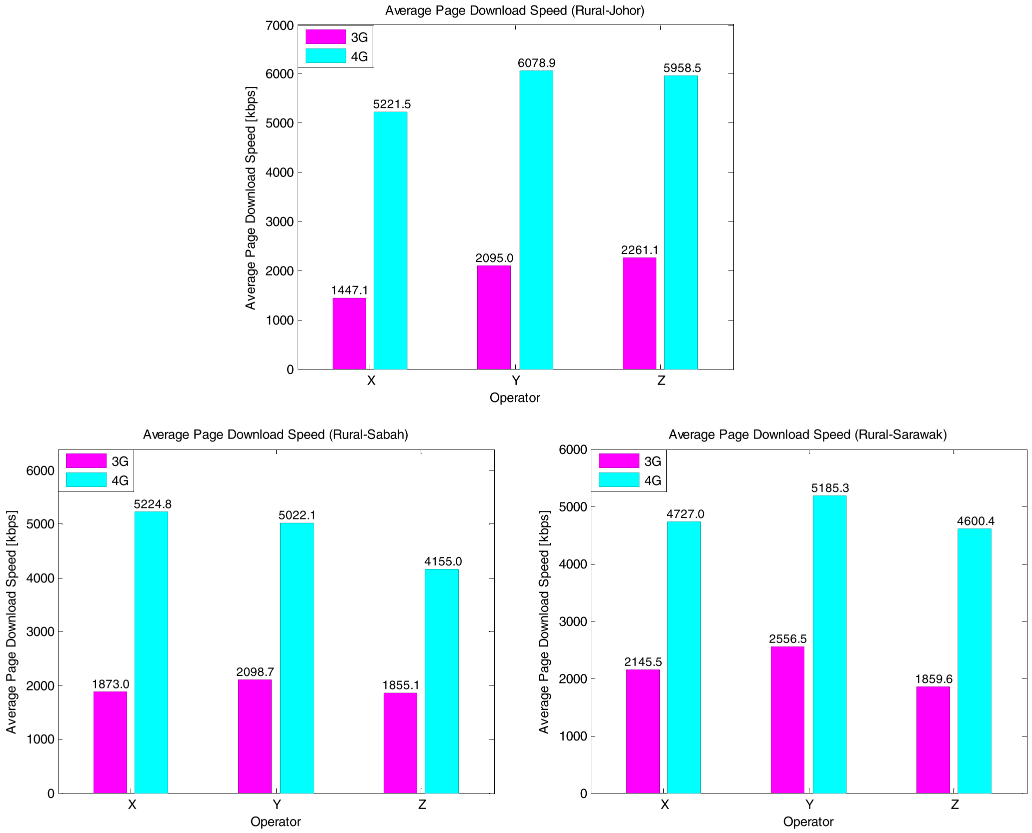

FIGURE 6. The average page download speed categorized based on technologies and test areas.

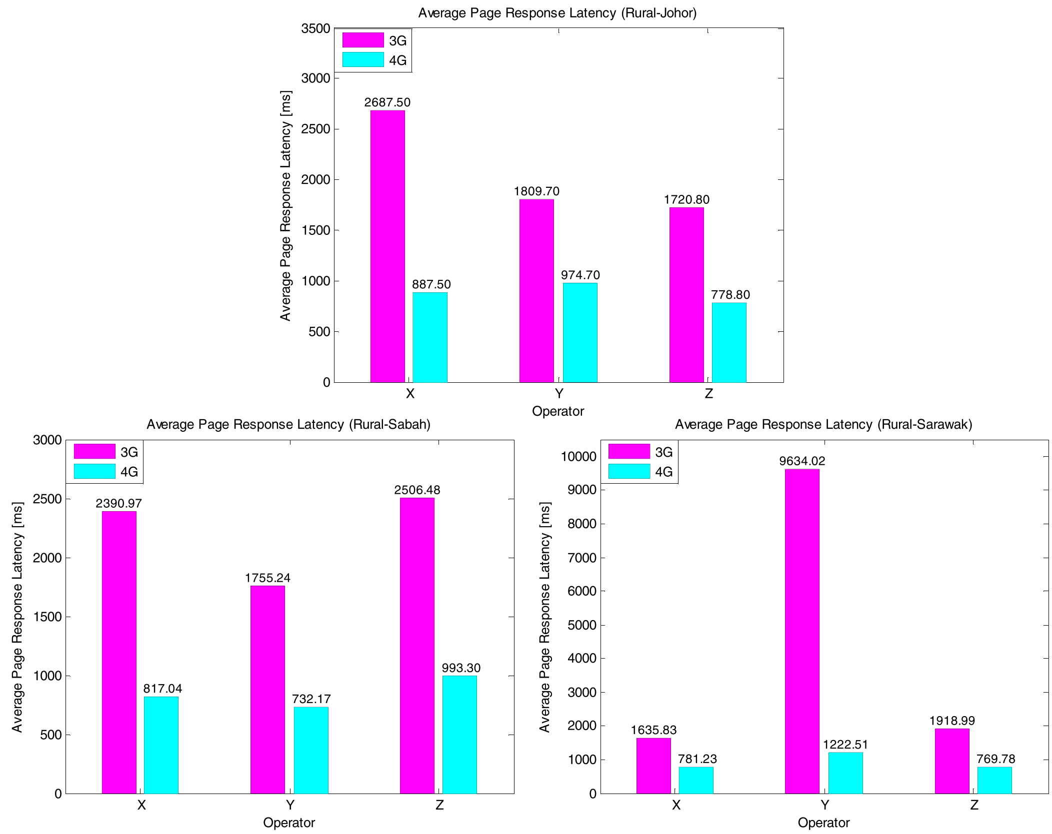

FIGURE 7. The average of web page response latency for rural morphology.

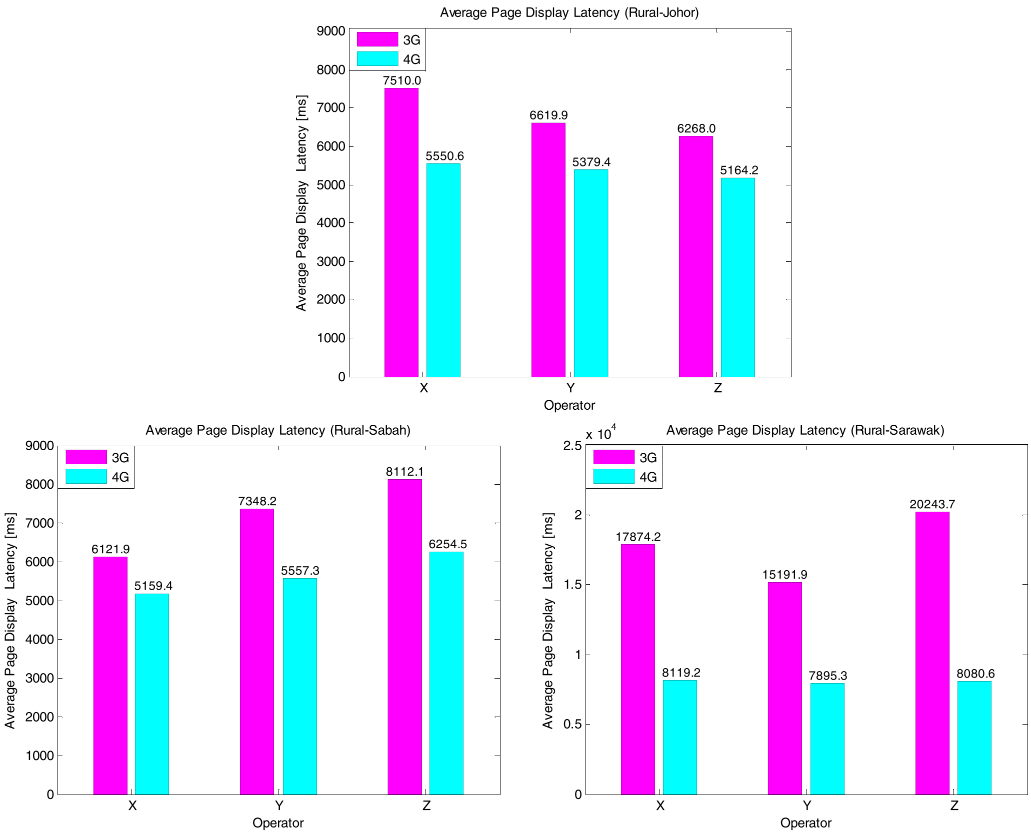

FIGURE 8. The average of web page display latency for rural morphology.

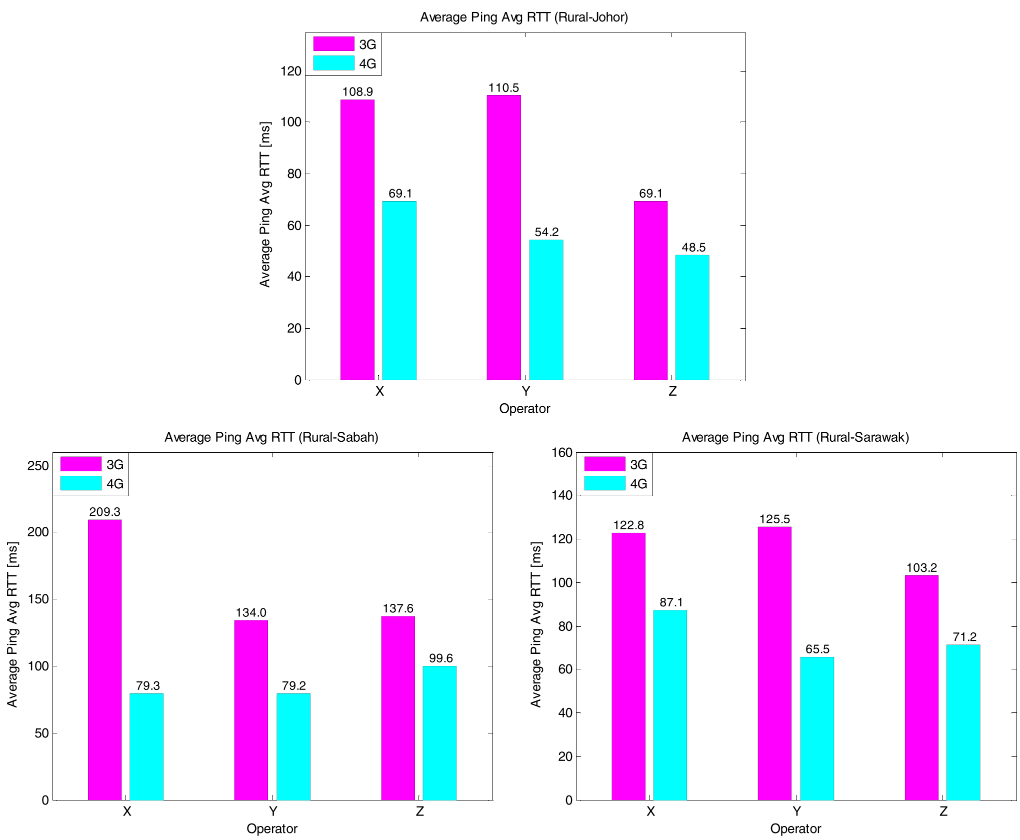

FIGURE 9. The average of web ping average RTT for rural morphology and each test area categorized by MNOs.

TABLE 3. Summary of web services for rural morphology classified according to MNOs.

Morphology: Rural	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]	-	-	0.72	0.96	0.72	0.98	0.97	0.99
Average Page Response Latency (ms) [Lower is better]	-	-	2687.5	887.5	2391.0	817.0	1635.8	781.2
Average Page Display Latency (ms) [Lower is better]	-	-	7510.0	5550.6	6121.9	5159.4	17874.2	8119.2
Average Page Download Speed (kbps) [Higher is better]	-	-	1447.1	5221.5	1873.0	5224.8	2145.5	4727.0
Average Ping Average RTT (ms) [Lower is better]	-	-	108.9	69.1	209.3	79.3	122.8	87.1
Average Cellular Signal Strength (dBm) [Higher is better]	-	-	-84.6	-89.5	-84.8	-87.0	-89.2	-86.1

Morphology: Rural	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]	-	-	0.70	0.97	0.78	0.98	0.97	1.00
Average Page Response Latency (ms) [Lower is better]	-	-	1809.7	974.7	1755.2	732.2	9634.0	1222.5
Average Page Display Latency (ms) [Lower is better]	-	-	6619.9	5379.4	7348.2	5557.3	15191.9	7895.3
Average Page Download Speed (kbps) [Higher is better]	-	-	2095.0	6078.9	2098.7	5022.1	2556.5	5185.3
Average Ping Average RTT (ms) [Lower is better]	-	-	1100.5	54.2	134.0	79.2	125.5	65.5
Average Cellular Signal Strength (dBm) [Higher is better]	-	-	-88.5	-88.1	-88.7	-86.2	-93.6	-85.8

Morphology: Rural	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]	-	-	0.68	0.93	0.70	0.94	0.94	0.99
Average Page Response Latency (ms) [Lower is better]	-	-	1720.8	778.8	2506.5	993.3	1919.0	769.8
Average Page Display Latency (ms) [Lower is better]	-	-	6268.0	5164.2	8112.1	6254.5	20243.7	8080.6
Average Page Download Speed (kbps) [Higher is better]	-	-	2261.1	5958.5	1855.1	4155.0	1859.6	4600.4
Average Ping Average RTT (ms) [Lower is better]	-	-	69.1	48.5	137.6	99.6	103.2	71.2
Average Cellular Signal Strength (dBm) [Higher is better]	-	-	-88.2	-89.9	-88.8	-88.0	-93.8	-86.1

especially in high-load data transmission. With advancements in internet technology and big data communications, the requirement of low-latency communications is vital in new technologies.

B. VIDEO STREAMING EXPERIENCE

1) NETWORK SIGNAL COVERAGE

The distributions of the cellular signal strength for video services are depicted in Figures 10 and 11 for 4G and 3G

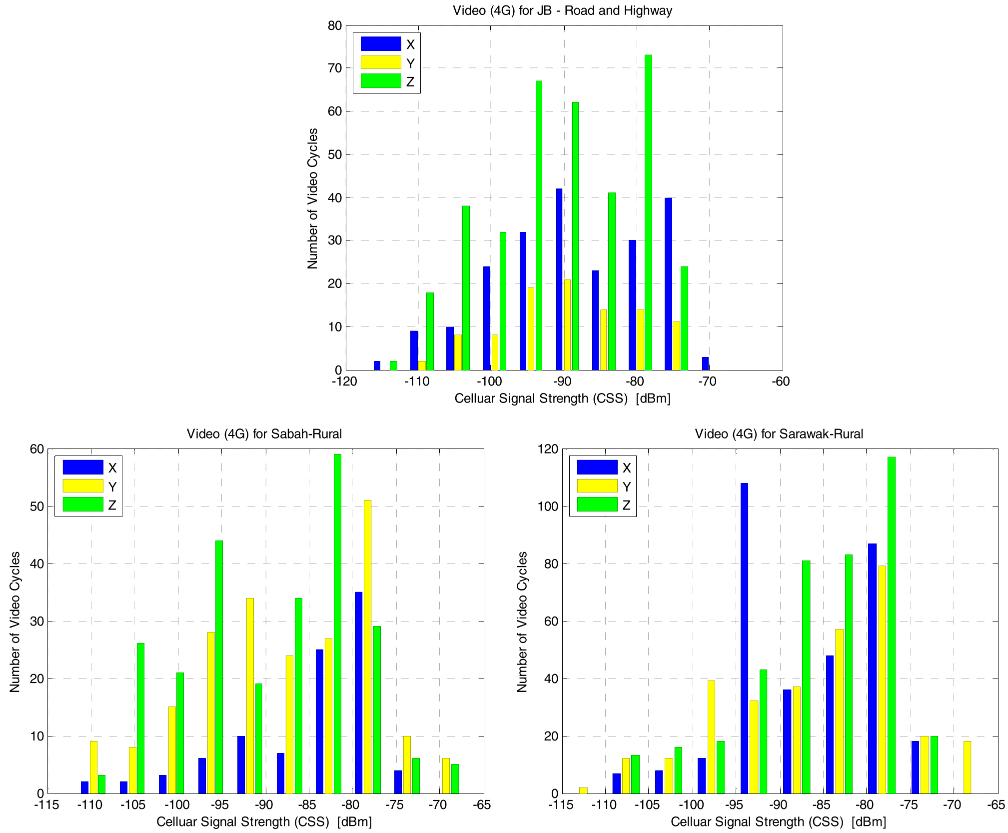

FIGURE 10. PDF of cellular signal strength of 4G technology video streaming for rural morphologies.

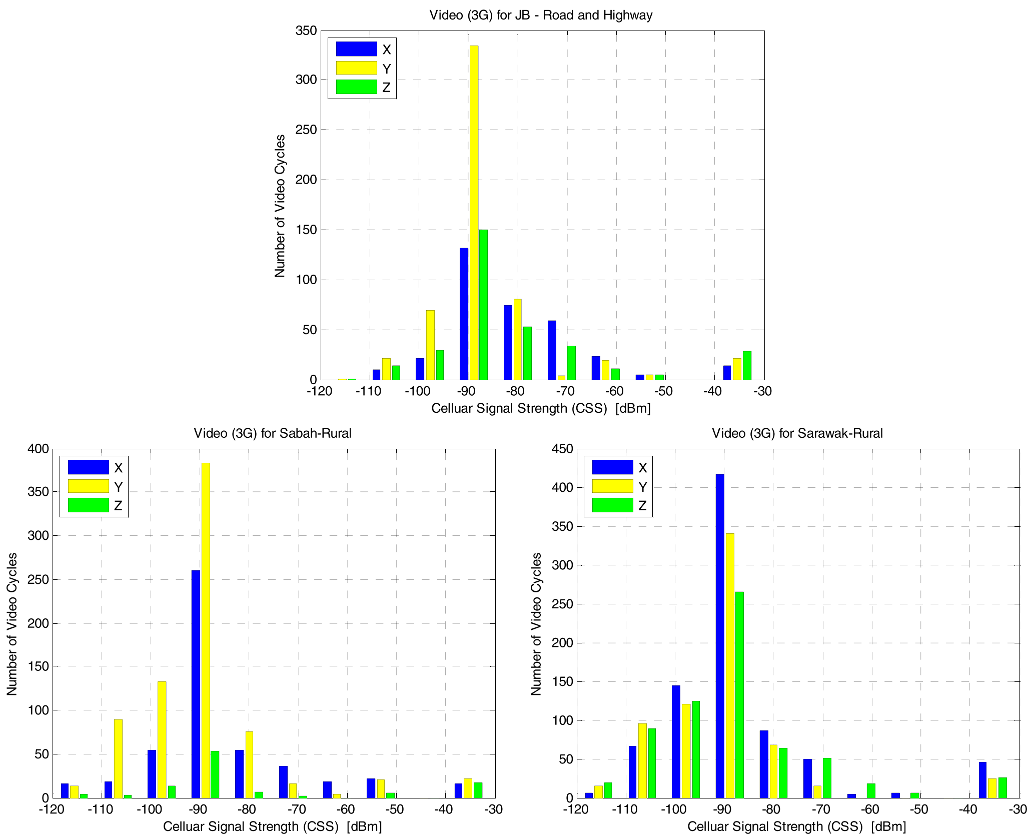

FIGURE 11. PDF of cellular signal strength of 3G technology video streaming for rural morphologies.

TABLE 4. 80% of the coverage in the test area is stronger than the given video cellular signal strength stated in this table.

MNO	NETWORK TYPE	AREA		
		JOHOR	SABAH	SARAWAK
X	4G	-97 dBm	-91 dBm	-94 dBm
	3G	-89 dBm	-93 dBm	-97 dBm
Y	4G	-96 dBm	-96 dBm	-96 dBm
	3G	-91 dBm	-99 dBm	-101 dBm
Z	4G	-99 dBm	-99 dBm	-92 dBm
	3G	-92.4 dBm	-94.4 dBm	-101 dBm

technologies, respectively. Table 4 reveals that 80% of coverage in the tested area is stronger than the given video's cellular signal strength. The results signify that 4G networks provide stronger coverage compared to 3G networks.

2) NETWORK SATISFACTION

For video services, the number of attempts using the Samsung Galaxy S6 during DT is depicted in Figure 12. Our video streaming attempts show that the internet accesses by smartphones via 4G technologies are 30.3%, 27%, and 31% for video services in Johor, Sabah, and Sarawak, respectively.

The number of successful attempts for a smartphone to stream a video provides an indicator of the network performance for each 3G/4G technology with each MNO. This metric indicator is given by the overall page display success ratio, as illustrated in Figure 13. The results from the graphs suggest that 4G networks have better overall video access ratio compared to 3G networks for all three networks across all tested areas considered in this research.

The vMOS scores for the comprehensive network performance of all MNOs categorized based on technologies are described in Figure 14. The 4G networks for all three MNOs have higher vMOS scores compared to their respective 3G networks. In general, the 4G networks have a vMOS score ranging between 3.22 and 3.61, while 3G networks have a score ranging between 1.69 and 2.41.

3) NETWORK DOWNLOAD SPEED

For video services, the average video total download rate for all three tested states is presented in Figure 15. On average, the 4G average video total download rate improved by around 1.23, 1.27, and 1.19 times faster than the rate provided by 3G for Johor, Sabah, and Sarawak, respectively.

4) NETWORK LATENCY

The latency records for video services are given in Figures 16, 17, and 18. Figure 16 shows the average video's initial buffering latency achieved by MNOs for each tested area. The results reveal that there are significant performance improvements in the average initial buffering latency for 4G over 3G for all three MNOs tested. Taking the average of all networks, the latency measures for 4G are 1928.36 ms, 1920.31 ms, and 1684.39 ms; while for 3G, they are 9046.89 ms, 9950.34 ms, and 6667.74 ms for Johor, Sabah, and Sarawak, respectively.

Figure 17 presents the achievement of the average video's initial E2E RTT-Ping server latency with the same test locations and MNOs. It is again noticed that 4G networks have lower average video E2E RTT-Ping server latency than 3G networks. Taking the average of all networks tested, the latency measures for 4G are 102.88 ms, 83.03 ms, and 67.56 ms; while for 3G, they are 521.75 ms, 599.00 ms, and 359.68 ms for Johor, Sabah, and Sarawak, respectively.

In Figure 18, the average video's total re-buffering latency is presented for the test locations and MNOs under consideration. The results signify that 4G networks have lower average total re-buffering latency than 3G networks, except for operator Z in Sarawak. Across all test locations, as an average of all tested networks, the latency records for 4G are 8022.22 ms, 10367.09 ms, and 9255.78 ms; while for 3G, they are found to be longer with 14717.03 ms, 13071.31 ms, and 11646.73 ms for Johor, Sabah, and Sarawak, respectively. Low-latency communications can guarantee the high-speed data transmission that is largely needed in new technologies of IoT and big-data communication. Without this feature, big-data transmission is degraded, and the quality of service would be undesirable in the view of networks and customers.

5) ANALYSIS SUMMARY FOR VIDEO SERVICES

The results for video services for the rural morphology classified in accordance to the three Malaysian MNOs are tabulated in Table 5.

V. KEY FINDINGS

The key findings of this research are outlined in this section. Overall, these findings are based on the assessment of MBB services using four main performance metrics that are relevant to the experience consumers would have when accessing different MBB services in rural areas. These four metrics are coverage, latency, satisfaction, and speed. Below are the summaries of key findings acquired from this research work:

A. COVERAGE

The network coverage area is associated with the received signal strength. Thus, strong signal strength provides better consumer experience when accessing MBB services. Based on the analysis results of the measured MBB data, it has been observed that the network coverage is better for 4G services compared to 3G services for both web browsing and video streaming.

B. LATENCY

In this study, the 4G technologies of the considered MBB MNOs have been found to achieve a minimum of 42.4 ms on the web ping average RTT latency, while 3G only achieves a minimum of 69.9 ms. For the average E2E RTT ping server latency, 4G achieved as low as 33.27 ms, while 3G acquired a minimum of 122.98 ms.

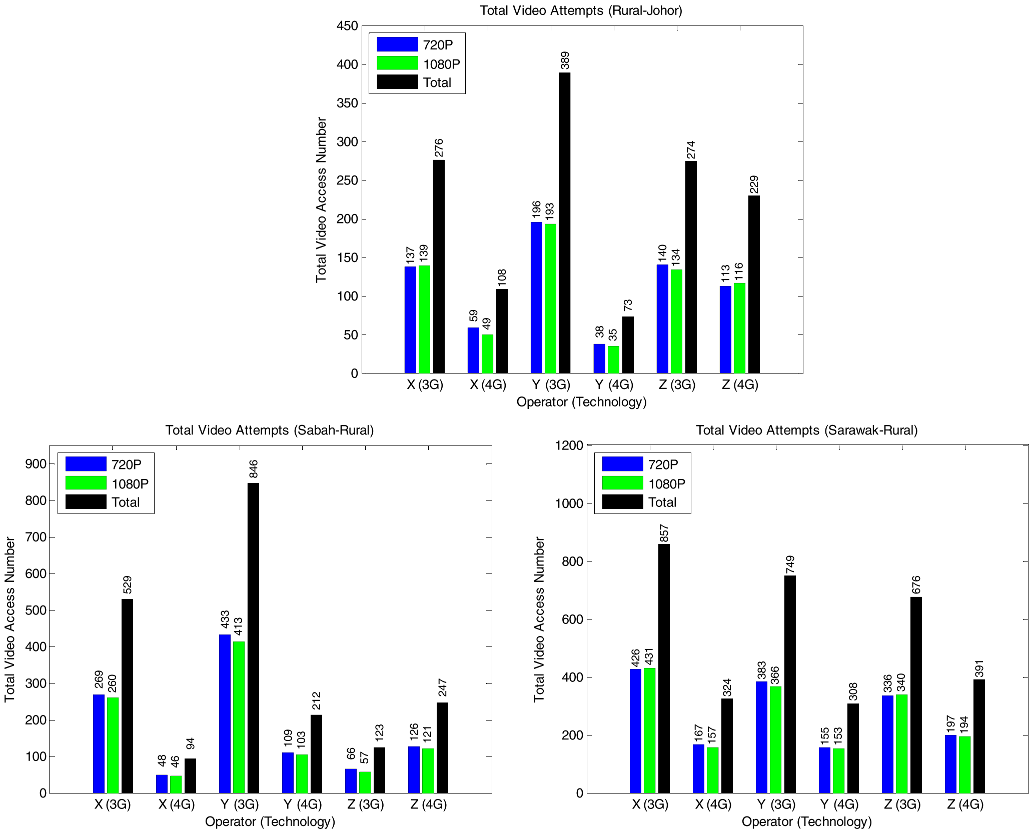

FIGURE 12. **The total video access attempt classified based on technologies, MNOs and areas.**

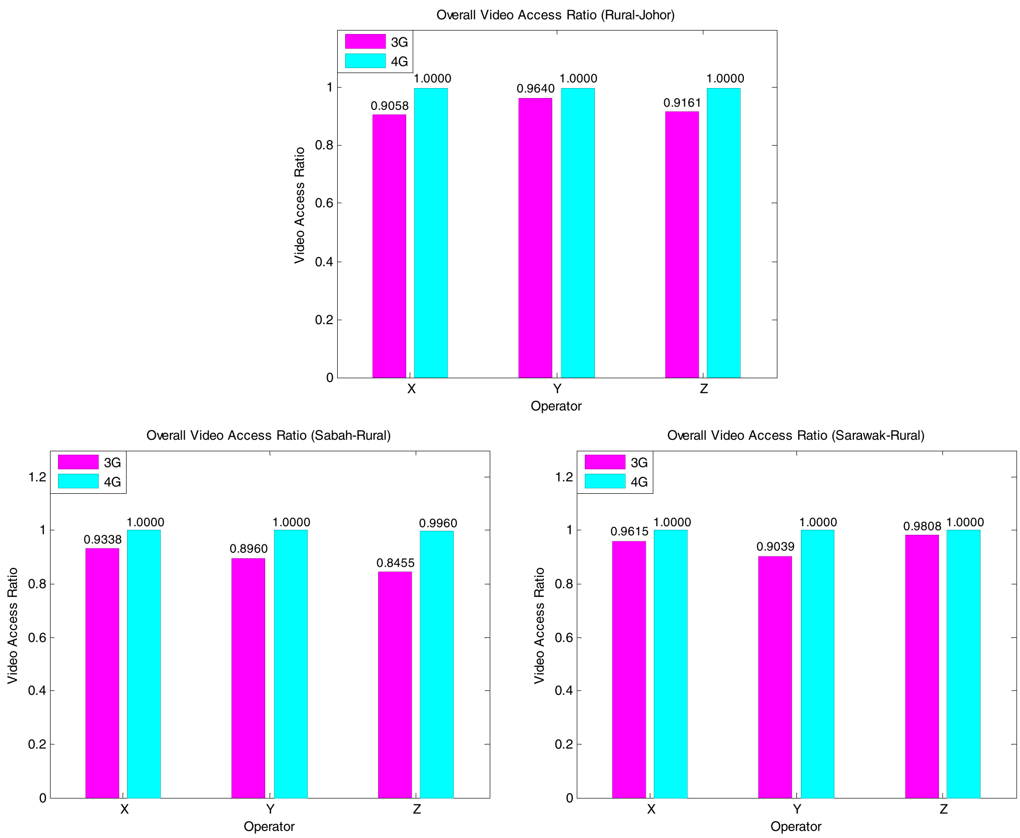

FIGURE 13. **The overall video access ratio for rural morphologies in each state.**

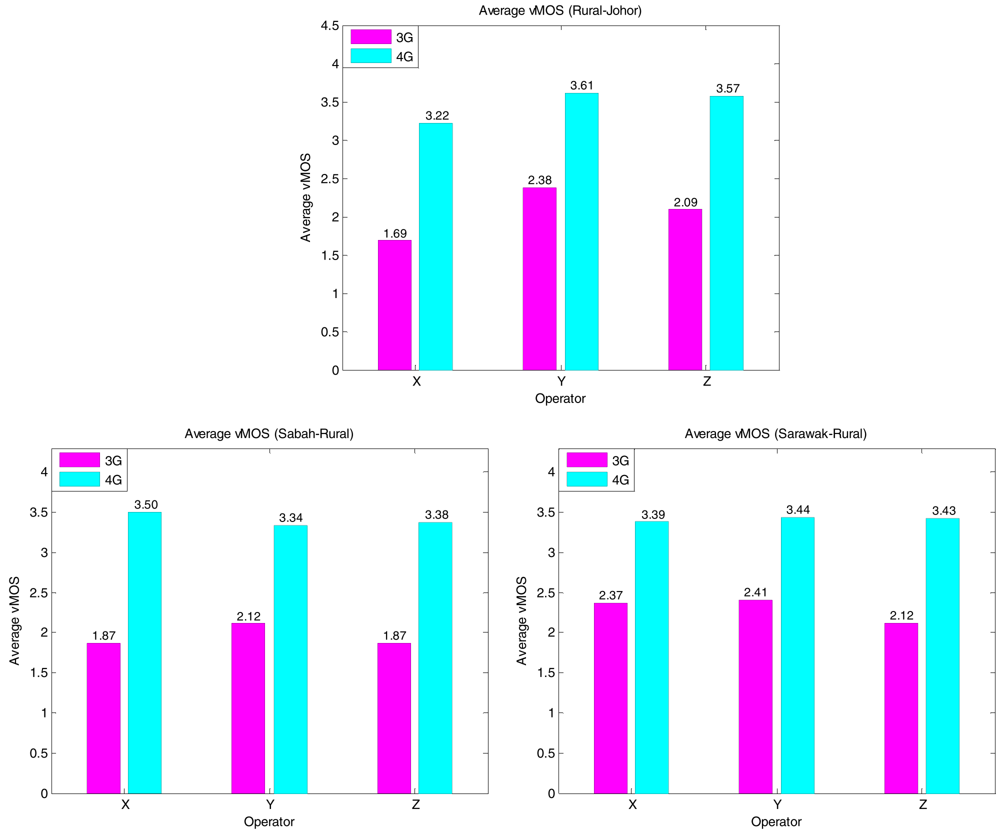

FIGURE 14. **vMOS score for the rural morphologies.**

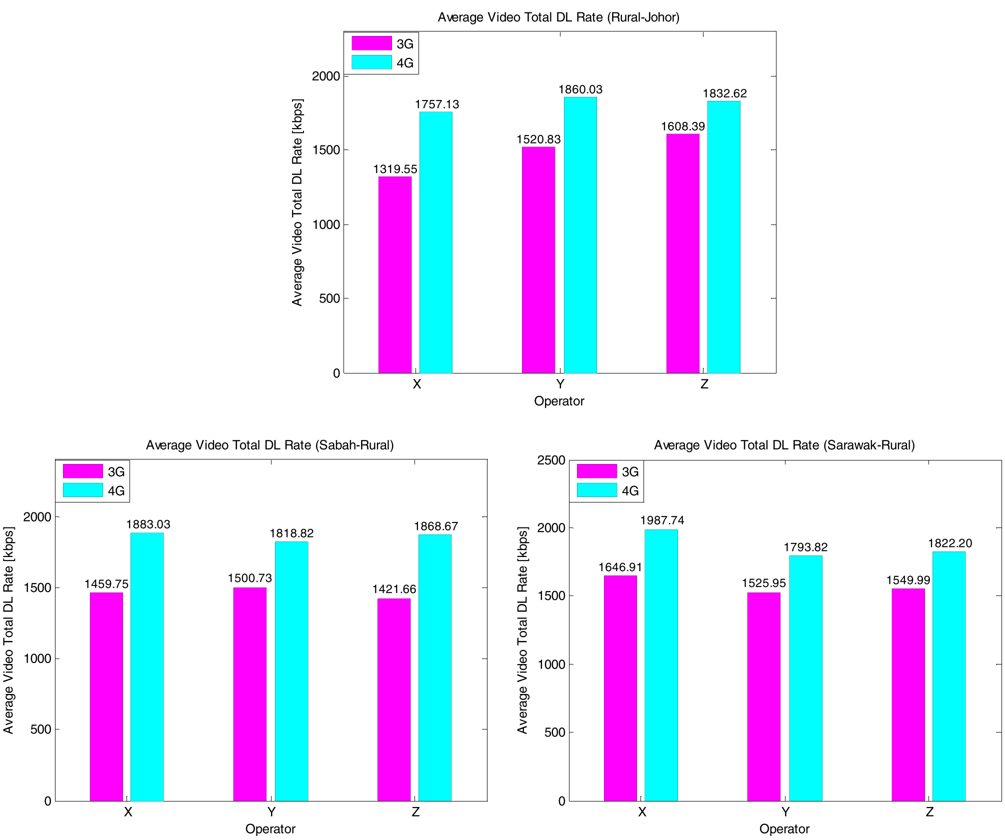

FIGURE 15. **The average video total download rate categorized based on technologies and test areas.**

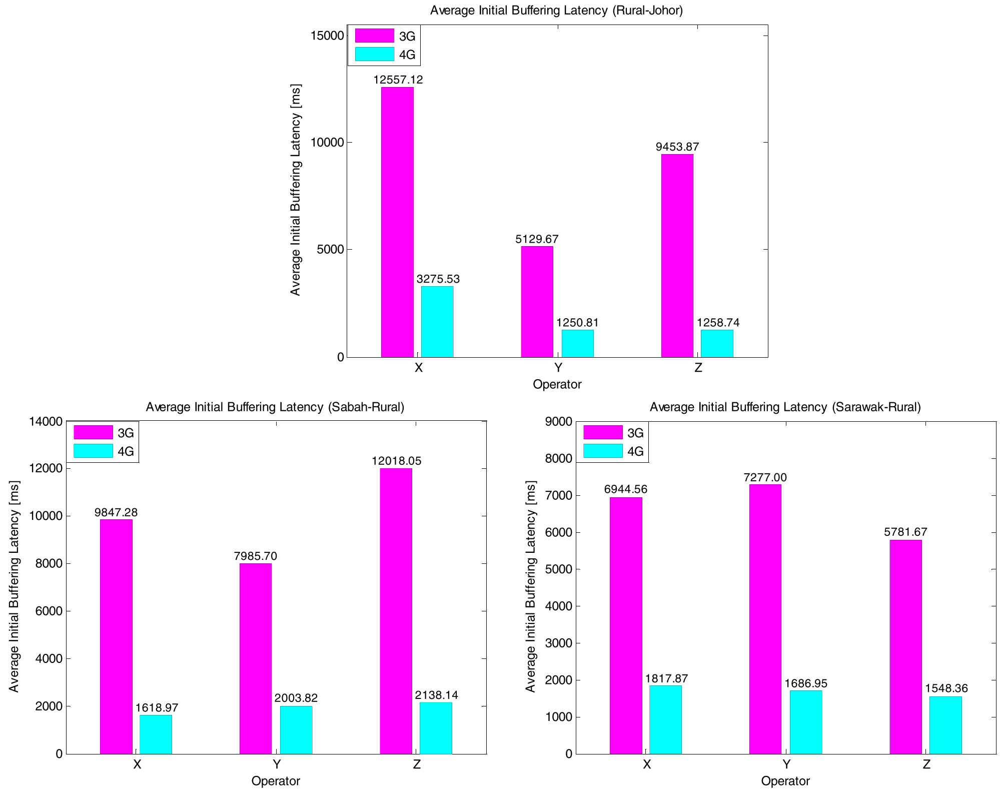

FIGURE 16. The average of video initial buffering latency for rural morphology and each test area categorized by MNOs.

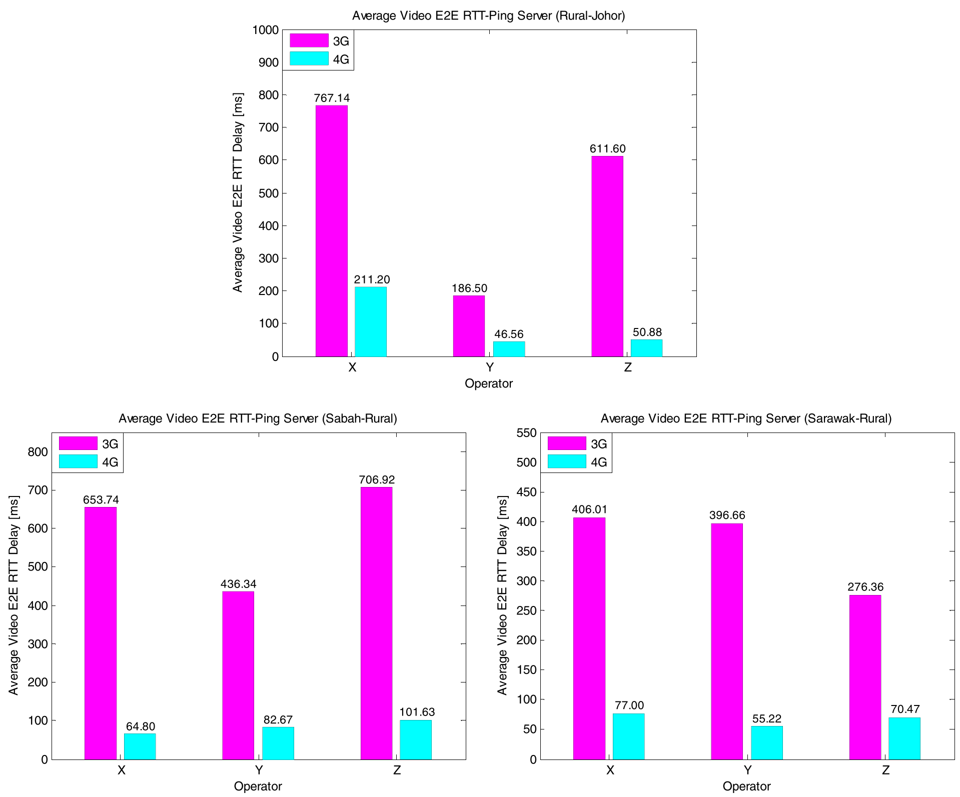

FIGURE 17. The average of video initial E2E RTT-Ping server latency for rural morphology and each test area categorized by MNOs.

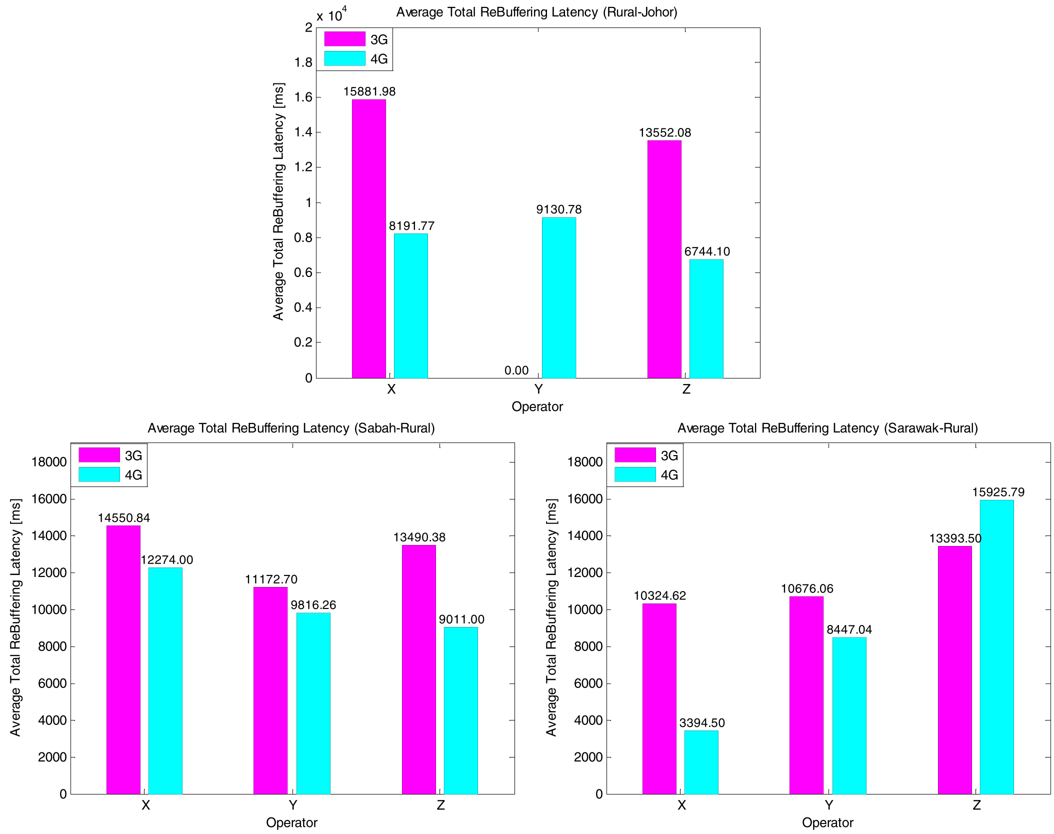

FIGURE 18. **The average of video total re-buffering latency for rural morphology and each test area categorized by MNOs.**

C. SATISFACTION

The main indicator used to measure network satisfaction is the vMOS indicator. It considers these factors and provides a comprehensive performance score on a scale of 1 to 5. Here, a higher vMOS number represents better network performance. Regarding the outdoor drive test for all tested areas, the vMOS scores for 4G technology for both web browsing and video streaming services are larger than 3, while the 3G technology has a score of less than 3.

D. SPEED

The speed is one main characteristic of 4G, 5G, and 6G technologies and it largely influences internet browsing, video streaming, and ultra-reliable services. Based on our analysis, 4G technology can provide an improvement in the download speed of up to a factor of 4.2 and 1.6 when browsing a web and streaming a video, respectively, as compared to the 3G technology.

VI. LIMITATIONS AND FUTURE DIRECTIONS

The following points are not covered in the present paper and can be considered for future works to extend this study:

(i) The information discussed in the present paper deals with the MBB download speeds, web browsing speeds, and latency. Other factors relating to consumer experiences when using mobile services such as price, traffic management policies, data allowances, customer services, billing, etc., are not covered. Also, the present study does not test voice services, call quality, text messaging, etc.

(ii) As an extension, the analysis of MBB services delivered to other devices than smartphones and the performance of Virtual Mobile Network Operators (VMNOs) may be considered in future.

(iii) To a large extent, the performance of MBB services depends on network availability. Although the present study includes some coverage information, it does not assess the levels of network availability which is dependent on several factors such as the distance from the base station, indoor/outdoor user availability, and whether the user is stationary or in motion.

(iv) The number of people concurrently using a mobile network in the same location can affect the MBB service performance, in addition to coverage fluctuations and instability. This means that the performance available to any individual consumer will vary both by time and by location. Such issues can be considered to extend the current study.

(v) The study field of this research work is limited to rural areas in three states of Malaysia only, thus it does not represent the performance of MBB networks across the entire country with its different morphologies.

TABLE 5. Summary of video services for rural morphology classified according to MNOs.

Morphology: Rural	Operator: X				MBB service: VIDEO			
	KV		JOHOR		SABAH		SARAWAK	
	3G	4G	3G	4G	3G	4G	3G	4G
Initial Buffering Success Ratio [Higher is better]	-	-	0.91	1.00	0.93	1.00	0.96	1.00
Average vMOS Score [Range = 1 to 5] [Higher is better]	-	-	1.69	3.22	1.87	3.50	2.37	3.39
Average Video Total Download Rate (kbps) [Higher is better]	-	-	1319.6	1757.1	1459.8	1883.0	1646.9	1987.7
Average Video Maximum Download Rate (kbps) [Higher is better]	-	-	5373.7	1525.7	5607.0	1968.3	6057.4	15227.0
Average Initial Buffering Latency (ms) [Lower is better]	-	-	12557.1	3275.5	9847.3	1619.0	6944.7	1817.9
Average Video E2E RTT Ping (ms) [Lower is better]	-	-	767.1	211.2	653.7	64.8	406.0	77.0
Average Total Re-buffering Latency (ms) [Lower is better]	-	-	15882.0	8191.8	14550.8	12274.0	10324.6	3394.5
Average Cellular Signal Strength (dBm) [Higher is better]	-	-	-81.8	-90.7	-85.1	-83.9	-86.5	-86.8

Morphology: Rural	Operator: Y				MBB service: VIDEO			
	KV		JOHOR		SABAH		SARAWAK	
	3G	4G	3G	4G	3G	4G	3G	4G
Initial Buffering Success Ratio [Higher is better]	-	-	0.96	1.00	0.90	1.00	0.90	1.00
Average vMOS Score [Range = 1 to 5] [Higher is better]	-	-	2.38	3.61	2.12	3.34	2.41	3.44
Average Video Total Download Rate (kbps) [Higher is better]	-	-	1520.8	1860.0	1500.5	1818.8	1526.0	1793.8
Average Video Maximum Download Rate (kbps) [Higher is better]	-	-	6420.1	21525.3	6142.9	17917.1	7580.7	18450.5
Average Initial Buffering Latency (ms) [Lower is better]	-	-	5129.7	1250.8	7985.7	2003.8	7277.0	1687.0
Average Video E2E RTT Ping (ms) [Lower is better]	-	-	186.5	46.6	436.3	82.7	396.7	55.2
Average Total Re-buffering Latency (ms) [Lower is better]	-	-	-	9130.8	11172.7	9816.3	10676.1	8447.0
Average Cellular Signal Strength (dBm) [Higher is better]	-	-	-85.7	-87.7	-87.0	-87.1	-89.8	-85.4

Morphology: Rural	Operator: Y				MBB service: VIDEO			
	KV		JOHOR		SABAH		SARAWAK	
	3G	4G	3G	4G	3G	4G	3G	4G
Initial Buffering Success Ratio [Higher is better]	-	-	0.96	1.00	0.90	1.00	0.90	1.00
Average vMOS Score [Range = 1 to 5] [Higher is better]	-	-	2.38	3.61	2.12	3.34	2.41	3.44
Average Video Total Download Rate (kbps) [Higher is better]	-	-	1520.8	1860.0	1500.5	1818.8	1526.0	1793.8
Average Video Maximum Download Rate (kbps) [Higher is better]	-	-	6420.1	21525.3	6142.9	17917.1	7580.7	18450.5
Average Initial Buffering Latency (ms) [Lower is better]	-	-	5129.7	1250.8	7985.7	2003.8	7277.0	1687.0
Average Video E2E RTT Ping (ms) [Lower is better]	-	-	186.5	46.6	436.3	82.7	396.7	55.2
Average Total Re-buffering Latency (ms) [Lower is better]	-	-	-	9130.8	11172.7	9816.3	10676.1	8447.0
Average Cellular Signal Strength (dBm) [Higher is better]	-	-	-85.7	-87.7	-87.0	-87.1	-89.8	-85.4

(vi) The Geographical Information System (GIS) solutions can provide useful correlation details of MBB services for geographical areas that share similar natural and infrastructural attributes. This may be a hot research topic in future that can help service providers in obtaining an insightful understanding of MBB performance in rural areas. This will help them build realistic MBB performance forecasting models.

(vii) In the near future, rural areas will require further enhancements since there will be a radical growth in mobile broadband services and smart IoT applications such as smart farms, smart grading, smart home, and other smart applications [23], [38]–[40]. In 2023, 5G networks will cover more than 20% of the world's population [41]. Thus, further investigations and studies must be conducted for planning 5G networks and beyond in rural areas.

(viii) Mobility management is also a significant topic to be studied in future researches based on the drive test measurement data. All our previous research related to mobility management done are based on simulation [42]–[46], but conducting research based on drive test measurement data will leading to develop more efficient mobility management models and algorithms. This will enable operators and regulators to efficiently plan for mobile users, especially those who require ultra-reliable connections.

(ix) The parameter of delay variation (jitter) can be analyzed for different operators in the network.

(x) Various channel propagation effects such as blockage, large- and small-scale fading, and rain induced fading may be considered. In the present study, since only a two-month measurement period was taken, network performance was not tested in varying climatic conditions.

(xi) Also, in our future research papers, the MBB performance will be analyzed in different morphologies such as dense urban, urban, suburban, and indoors.

(xii) Since we have conducted research related to the accuracy in an indoor localization system [47], thus, we recommend to use the same methodology has been used in the paper to develop a more efficient algorithm for indoor localization system.

(xiii) While accessing 4G/3G services, utilizing different mobile devices will not impact the user's experience as long as the user's speed is faster than the channel speed. In contrast, if the channel speed is faster than the device speed, the user's experience will be negatively affected. In general, the mobile-browsing user experience can be influenced by the user's state, context, mobile device, browser application, network infrastructure, and web sites.

This work is limited to three states only and does not represent the performance of the entire country for all morphologies.

VII. CONCLUSION

The present work has been carried out to measure the consumer experience of using MBB services and to produce statistically robust datasets that represent the performance of three Malaysian MNOs in the rural morphology on a fair and equivalent basis. This is to particularly compare the performance of specific 3G and 4G services of MNO networks. The data are collected through drive tests conducted in three Malaysian states of rural morphology: Johor, Sarawak, and Sabah. The measurement data are collected using proprietary testing applications; MBB explorer for web browsing services and Speedvideo for video streaming services. Four performance metrics (network coverage, latency, satisfaction, and speed) have been considered in this research. Our results indicate that on average, the 4G networks have unsurprisingly performed much better than the 3G networks for all three MNOs throughout all three measurements of rural areas considered in this research. These observations are found to be consistent across all mobile operators. The presented results declare that enhancements of MBB services in rural areas are very much necessary, especially when IoT-empowered and smarter lifestyle are to be realized in the near future. The obtained results critically call for innovative solutions and initiatives that must be taken into consideration when planning for the deployment of future 5G networks in rural areas. The presented results also provide a general direction for efficiently planning 5G networks in rural areas.

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