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4G LTE Network Performance along Mass Rapid Transit (MRT) Putrajaya Line Track

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ABSTRACT

With advancements in mobile communication technologies, including the deployment of 4G LTE networks, end-users now expect consistent, high-quality and seamless connections during their commutes on public transit. Due to the high demands placed on cellular networks, users often experience abrupt and unexpected changes in connection quality. These fluctuations in 4G LTE performance need to be anticipated and mitigated to maintain a constant and reliable connection. Therefore, this study focuses on constructing a dataset of 4G LTE network performance, including information on Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ). This data is collected along the Mass Rapid Transit (MRT) Putrajaya Line Railway Track using the Android network monitoring application, G-Net Track Pro. Subsequently, based on these network parameters, the Quality of Service (QoS) is analyzed by measuring download speed, upload speed, latency, jitter and throughput using nPerf SpeedTest software. The analysis of the data and discussion on the signal strength are presented, and various 4G LTE issues along the test route are identified. Since the measurements have not yet met the standards specified by the 3GPP standard, this project also discusses recommendations for network operators to enhance network performance along the route. With the dataset prepared and measurement results provided in this project, telco operators and researchers in Malaysia can benefit from future LTE deployments along the railway track.

Keywords:
4G LTE performance; quality of service; mass rapid transit; 4G LTE issues and challenges

1. Introduction

The volume of traffic over mobile networks has dramatically increased over the years. The advancements of 4G LTE networks technology have directly brought broadband speeds to mobile phones. With such speeds, mobile users can access high-speed internet services such as web browsing, social networking, audio, video, software downloading while using public transportation such as the MRT. Consequently, the demand on cellular networks has greatly increased, leading to varying loads on network traffic. Cellular network operators are continuously seeking new ways to meet users' expectations in order to keep up with the increasing demand. However, this endeavor comes with difficulties as it necessitates efficient scheduling, network load balancing, and

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appropriate resource allocation. The achieved network quality is influenced by several variables, including the user's location, cell tower locations, and the time of day [1]. These elements have been thoroughly researched in the literature in recent years.

Various methodologies have been employed by researchers to analyze these characteristics and forecast network quality. Nevertheless, most effort were hindered by the insufficient amount of readily available cellular network data [2]. Consequently, the use of current prediction or optimization techniques was limited, as many of these processes require a significantly large dataset. To tackle this issue, researchers directed their efforts toward collecting their own data. However, the data collection and analysis primarily focused on 3G networks, as seen in corresponding studies [3-5]. The majority of research projects undertaken did not address connectivity concerns on public transportation, and there was a notable absence of analysis related to 4G LTE networks [6].

Due to their use of data-hungry applications like online surfing, HD on-demand video conferencing, and file downloading, public transportation users generate substantial volumes of mobile traffic. Given the predefined routes, such as railway tracks and MRT stations, it is possible to monitor and observe the traffic flow while traveling by train and identify the correlation between 4G LTE performance and network Quality of Service (QoS). MRT systems are considered ideal subjects for cellular network studies due to the reasons mentioned above. Accurate and reliable data are essential to conduct a precise analysis of 4G LTE network performance within public transit trains [7]. Consequently, a network survey and assessment of 4G LTE performance were necessary for the relatively new MRT Putrajaya Line. A dataset of 4G LTE network performance, including information on RSRP and RSRQ was constructed along the MRT Putrajaya Line using G-net Track Pro. Following this, nPerf SpeedTest software was utilized to conduct an analysis of the QoS by measuring network parameters such as download speed, upload speed, latency, jitter, and throughput.

The remainder of this paper is organized as follows: Section 2 presents the literature review, followed by the methodology performed for this study in Section 3, which is then verified by the simulation results and discussed in Section 4. Finally, concluding remarks are summarized in Section 5.

2. Literature Review

To address the issue of fluctuating wireless network connectivity in mobile environments, various data collection campaigns have been documented in the literature. The speed of mobile internet connection is influenced by a variety of factors, including the network technology available in the specific area (such as 3G or 4G), the capabilities of the user's terminal device (e.g., CPU), and the number of users sharing the connection. Additionally, as a user changes locations, their connection speed may vary due to fluctuations in signal strength, which is influenced by the coverage area and can affect both the quality and speed of the connection [8]. In this context, paper [9] proposed a new anonymous intelligent authentication protocol, which addresses potential security concerns in mobile networks, such as the impact of fluctuating connection speeds and network changes. The protocol enhances user privacy by generating a new IMSI (International Mobile Subscriber Identity) for each session, ensuring that even as users move between areas with varying signal strengths, their identities remain protected. Furthermore, this approach replaces the concept of a permanent key with a variable key for each user through the use of a key list, adding an additional layer of security in dynamic network conditions. The protocol also ensures confidentiality by encrypting all messages, including those exchanged during the authentication process, safeguarding data integrity despite variations in network quality.

In a study by previous research [6], an Android application was developed to measure 74,000 records of throughput and other network quality parameters, such as RSRP, RSRQ, SNR, and CQI. To measure throughput, the application sent and received a 750KB data packet train to a dedicated server. Another study [10] used the G-NetTrack Pro application to measure a 4G LTE dataset that included various network performance metrics. The data captured a range of mobility scenarios, including stationary, walking, driving, riding a bus, and riding a train. Additionally, a network survey conducted by [11] collected data over 1000 km with two vehicles, comparing signal level samples. The study aimed to characterize radio signal strength fluctuations on a medium scale by comparing signal level samples taken at the same geographic location but at slightly different times. This approach allowed for an understanding of how factors such as shadowing, environmental conditions, and handover influence signal level fluctuations received from the serving cell.

A study by [12] measured throughput of 4G WiMAX data in real-world environments from end users and evaluated performance using OOKLA as a primary network monitoring tool. To predict future throughput based on previous data, the researchers proposed an intelligent monitoring system integrating both Iperf and OOKLA. In another study [13], a test platform for Vehicle-to-Vehicle (V2V) communication was established, integrating two DSRC On-Board Units (OBUs) and two LTE-4G terminals, with associated software tools for performance measurement. The research was conducted across various weather and road conditions, including urban, campus, highway, downtown, residential, and rural areas. Finally, research by [14] focused on modeling key features like RSRP, RSRQ, and SNR for evaluation and prediction purposes. The study utilized a Gradient Boost Tree for experimentation, with results showing RMSE, correlation, and accuracy values of 0.312, 0.972, and 97.5%, respectively.

3. Methodology

The project aims to identify and recommend appropriate actions for telecommunication operators in the case of poor 4G LTE performance and QoS, as analyzed previously. This involves the collection and construction of a large 4G LTE dataset of UE-related wireless network parameters, including signal strength measurements and QoS measurements such as downlink and uplink throughput, delay, and jitter. RSRP represents the power of the signal received from the eNodeB to User Equipment (UE) [15]. RSRP measurement is based on the power level of the reference signals transmitted by the base station, which the mobile device uses to estimate the received signal strength. It provides an essential indication of the proximity and signal quality from the serving cell tower, assisting in cell selection, handover decisions, and overall network optimization. A higher RSRP value indicates a stronger received signal, signifying better signal strength and potentially improved network performance. Standard RSRP value are outlined in [16] as shown in Table 1.

Table 1
RSRP standard

Range (dBm)	Signal Strength
-80 to -44	Excellent
-90 to -80	Good
-100 to -90	Fair
-110 to -100	Poor
-140 to -110	Very Poor

RSRQ is the ratio between RSRP and wideband power. RSRQ represents the signal quality that the UE receives [17]. The RSRQ is also affected by the signal, and the noise as well as interference received by the UE. Table 2 indicates the standard RSRQ values.

Table 2
RSRQ standard

Range (dBm)	Signal Strength
-10 to -3	Excellent
-12 to -10	Good
-14 to -12	Fair
-17 to -14	Poor
-20 to -17	Very Poor

Latency refers to the time needed for data to travel the distance from its source to destination across a network. It is often measured as the round-trip time (RTT). Lower latency values indicate faster response times and more efficient communication [18]. Jitter is caused by variations in in the delay or latency of packet delivery in a network. It represents the inconsistency or irregularity in the timing packets reaching their destination. Excessive jitter can result in packet loss, out-of-order packets, and a degraded user experience [18]. Table 3 shows the latency jitter category with ITU-T standardization [19].

Table 3
Latency and jitter

	Size (ms)	Category
Latency	< 150	Very Good
	150 to 300	Good
	300 to 450	Fair
	> 450	Poor
Jitter	0 to 20	Good
	20 to 50	Fair
	> 50	Poor

The data was collected along MRT Putrajaya Line covering a total of 57.7 km as shown in Figure 1. The Putrajaya Line, consisting of 44.2km of elevated tracks and 13.5km underground tunnels. has 36 operational stations, of which 27 are elevated and 9 underground. The collected dataset is to made available on the publicly accessible data repository. This will also enhance the process of reproducibility and validation needed by the research community.

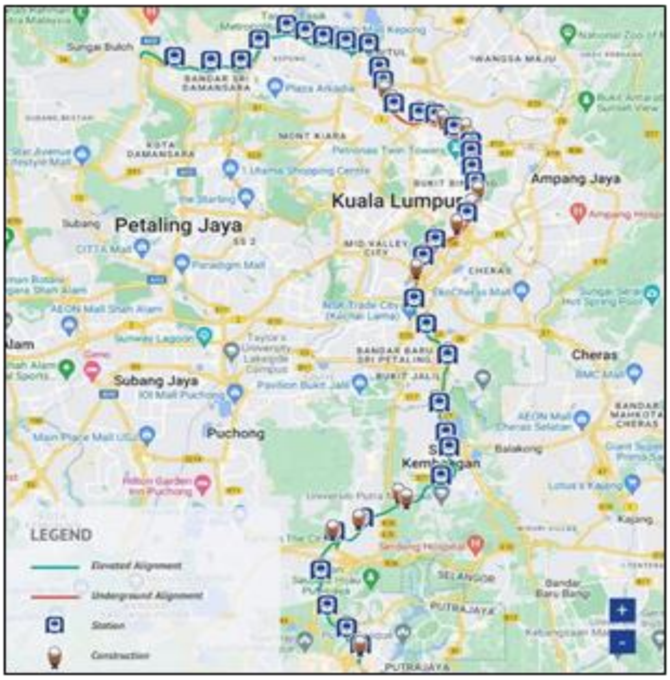

Fig. 1. Test route i.e. MRT Putrajaya line railway track

The project performed a thorough analysis on the collected measurements, and investigated the effects of time, location and number of passengers on the signal strength and QoS measurements. The project studied the variations of the signal strength and throughput values at different times of the day and analyzed the relationship between the different wireless network parameters and the throughput. This extensive analysis to be carried out over 4G LTE networks along MRT railway tracks for urban and suburban areas reflecting the various dynamics of the route. To this end, the measurement for this study is conducted two times a day for three weekdays. The trip from the Putrajaya station to Kwasa Damansara Station took around 1 hour and 30 minutes.

The measurements were conducted in a drive test approach where all the data are collected while the train is moving. All tests were made utilizing a frequency division duplex system with a bandwidth of 20 MHz in Band 3 (FDD LTE frequency band allocations), where the DL frequency is between 1735 and 1760 MHz and 1830 and 1855 MHz [20]. Figure 2 presents the methodology of the measurement. The drive-test device used for field measurement is Samsung Galaxy A52 mobile phone with integrated 4G LTE Advanced World Mode and DiGi is the chosen as the network provider.

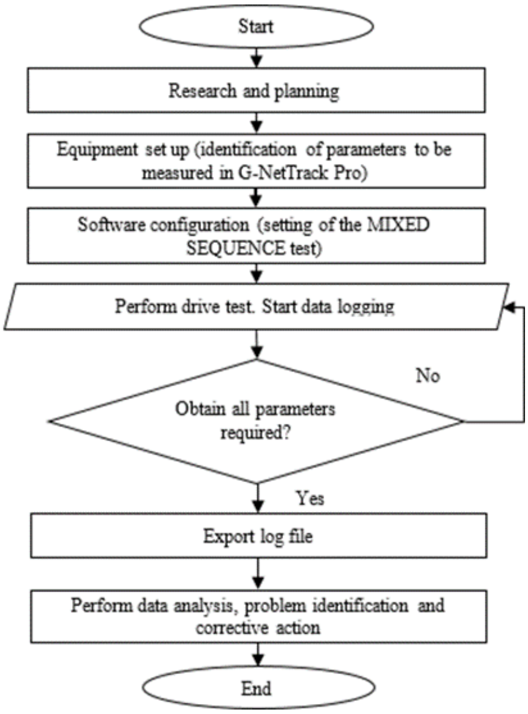

Fig. 2. Flowchart of taking measurement for this project

Configuration and setup of the devices/software are described prior to taking the measurement. The project utilized Android phones as the measuring device in order to make the data we collected comparable to the findings of other research studies. Since the G-NetTrack Pro Android app is capable of tracking a variety of network quality parameters, downlink and uplink throughput, as well as certain context-related data, the project used it to collect UE measurements. Consequently, Google Earth in order to analyze log files obtained from G-NetTrack Pro. For QoS analysis, nPerf Speedtest application is used. nPerf Speedtest is another application used in this project. Figure 3 showed the interface of the application where the download speed, upload speed, latency and performance rate during browsing and streaming test can be measured.

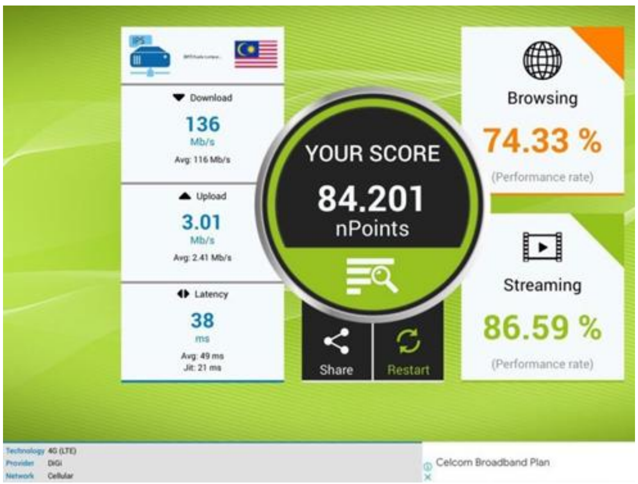

Fig. 3. QoS score using nPerf Speed test application

Fig. 4. Interface of G-NetTrack Pro application

Figure 4 shows that there are five tabs with different information namely CELL, NEI, MAP, INFO and DRIVE. The information displayed on each tab is:

- CELL tab shows network and geographical information. It also shows history log of the serving cells
- NEI tab shows information about neighbor cells measurements
- MAP tab shows geographical view of the measurements and mobile network base stations
- INFO tab provides information of the Log Status which shows if the log recording has been started or not

In order to begin the drive test, this project implements the use of MIXED SEQUENCE settings in the G-NetTrack Pro. Mixed sequence allows including multiple types of test which are data/voice/SMS in a test sequence. The settings for each type of test is taken from respective sequence settings. Once the setting is configured, the log can be started by pressing the START LOG tab. Measurement is conducted along the test route and the UE is set up as shown in Figure 5.

Fig. 5. Set up of UE during drive test

4. Results and Discussion

This part analyses the performance of 4G LTE for the test route in term of RSRP and RSRQ. For QoS analysis, the upload speed, download speed, latency, jitter and throughput are discussed.

4.1 The Data Set

The log files generated from the drive test are then uploaded to G-NetLook for visualization of the network. GNet-Track Pro app provided logged measurements such as follow;

- Contextual: Timestamp, Longitude, Latitude, Altitude, Speed, Operator
- Call-related: CellID, LAC, NCell
- Signal performance: RSRP, RSSI, RSRQ, SNR, NRxLev, NQual
- QoS related: Uplink bitrate, Downlink bitrate, PING

This project categorized the demographic and physical characteristics of the MRT stations into suburban, urban and underground categories as shown in Table 2. These categories are subsequently used to show the average throughput measurement. The measurements were recorded by taking 2 trips i.e. during peak hours and off-peak hours for 3 weekdays.

4.2 Data Analysis

Fig. 6. RSRP along the test route

Figure 6 illustrates the RSRP value along the test route. It can be observed that the level dropped to -150 dBm (marked with color grey) when the train passing through the underground tunnel starting from Kuchai station. The signal just getting worse i.e. more than -150 dBm (marked with black color) as the train moving. The loss of 4G LTE signal when passing through the underground tunnel is primarily due to the nature of radio wave and the shielding effect of the tunnel construction materials. The shielding effect of the tunnel's construction materials prevents the signal from reaching the test device effectively. The MRT tunnels which made up of concrete attenuate radio waves, causing signal loss and degradation. Besides, being underground meaning that another layer of obstruction for radio waves is presence hence added the difficulty to penetrate thorough the soil and other geological barriers. Additionally, the underground tracks may have limited access points for cellular towers or base stations to transmit and receive signals. The RSRP values normalize once the underground track ended which is at Jalan Ipoh Station.

The RSRP distribution can be seen in Fig.7. RSRP values were measured for 3782 samples. Most of the samples (75.5%) show good and excellent coverage. However, the area within the poor coverage is about 11.4% of total samples which are spotted mainly along the underground stations stating from Kuchai to Jalan Ipoh.

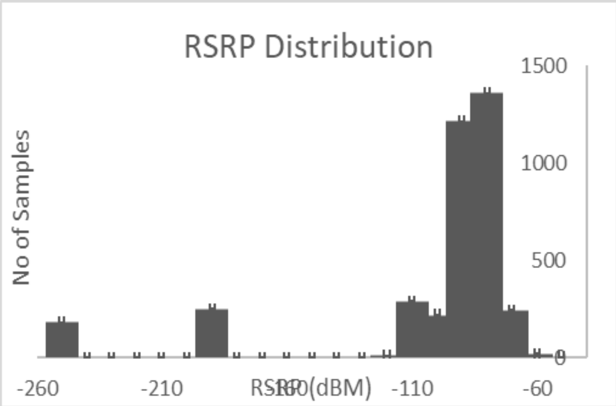

Fig. 7. RSRP Distribution

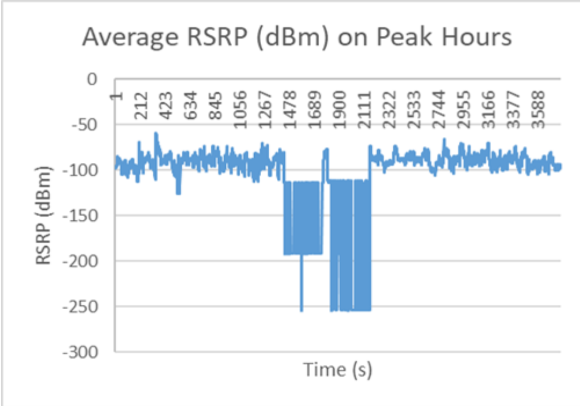

Fig. 8. RSRP measurement during peak hour

Figure 8 shows the scatter plot of RSRP measurement for the test route. From time 1 to 1444(s), which is when the train is moving from the Putrajaya Sentral to Kuchai station, the RSRP values vary from -65 dBm to -126dBm. By referring to Table I, it can be inferred that the RSRP measurement can be as high as excellent but there is time when the signal dropped to poor range. The sudden drop of RSRP (-126 dBm) is spotted before reaching UPM station where the train had to pass through a short tunnel. However, as the train moving in underground tunnel after 1444(s), the RSRP values plummet to more than -150dBm which signify a very poor signal strength and total signal loss. This happened since the underground tunnel contributed to signal obstruction. This also resulted from the absence of access points there. In 4G LTE, this issue identifies as black spots area. The problem is caused by when the radio wave is propagated through multipath environment and experiences various loss and degradation. This low RSRP measurements only recover when the train is back on elevated track before arriving at Jalan Ipoh station. From there, the RSRP values did not indicate any drastic variations which is from - 66dBm to -106dBm.

Figure 9 indicates that only 40% of the samples having good up to excellent signal quality i.e. being greater than -10 dB (>10dB). However, 24.5% of the samples suffer from fair to poor signal quality and the other 39.5% experienced disconnection where the RSRQ measured less than -20 dB (<-20dB).

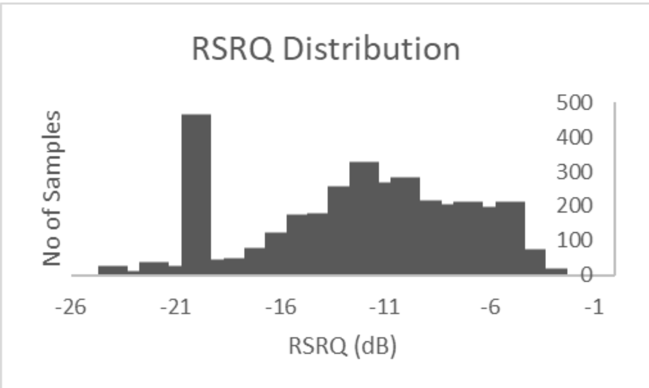

Fig. 9. RSRQ distribution

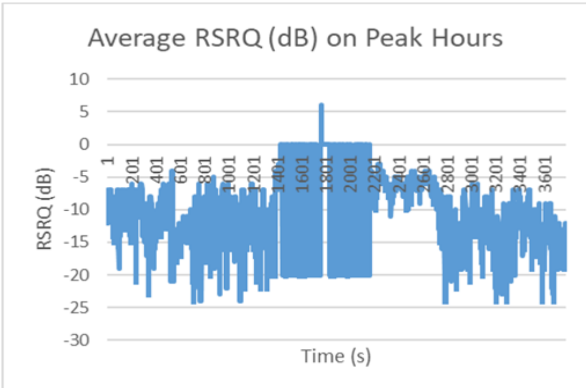

Fig. 10. RSRQ measurement during peak hour

The variation of RSRQ values is as shown in Fig. 10. In general, the RSRQ values vary from -3dB to as low as - 24dB. By referring to the RSRQ standard Table II, it can be deduced low measurement of RSRQ occurred at almost along the test route and not limited to just when the train is passing through underground tracks. Despite having good to excellent RSRP, low RSRQ indicated the higher presence of noise in the signal. From example, the RSRQ can be seen at 24dB at time 800s. This is the time when the train is moving across area of Serdang Raya Utara and Serdang Raya Utara Station. Demographically, the areas characterized as urban area where possible numbers of interference would happen. As observed from the log file, the ping-pong pattern occurred and affected the handover. From these parameters, we can deduce the occurrence of overshooting within the cell. This issue commonly happened at urban areas which has many high-rise buildings, commercial and residential areas. Each building equipped with its own cell towers or antenna which contribute to this signal interruption. RSRQ values from time 1444s to 2112s considered unusual since RSRQ are expressed in negative numbers. The misinterpretation of RSRQ measurement happen due to low RSRP suffered at the region.

Table 4 portrayed the uplink and downlink data transfer rate, latency and jitter for stations along MRT Putrajaya Line. By referring to ITU-T standard as shown in Table III, stations at suburban areas have the highest uplink and downlink data bitrate at 27.24 and 57.19 kbps respectively. Similarly, the latency and jitter for the suburban areas fall under very good category. In contrast, for underground stations, the measurement for uplink and downlink bitrate is relatively low at 7.23 and 16.48kbps respectively. The values of the uplink and downlink average data transfer rate are not provisioning the standard of LTE [21]. The data rate required to meet the standard are 768 kb/s at the edge of the cell, and up to 100 mb/s when UE is close to the eNodeB according to 3GPP standard. The latency of 165s is high compared to the one for urban and suburban stations. For average jitter, underground region recorded 68ms which categorized as poor in the standard. In terms of the relationship between latency and jitter, high levels of jitter can contribute to increased latency. When packets arrive at irregular intervals or out of order, additional time is needed to rearrange and process them, leading to higher latency. Conversely, low jitter values contribute to more predictable and consistent latency, resulting in smoother and more reliable network communication. For underground stations, high network congestion is one of the factors that resulted in the low UL, DL data transfer rate while having high latency and jitter. Underground stations located at the most densely populated location in Kuala Lumpur hence the highest number of users boarding the train. This means excessive number of packets being transmitted simultaneously which cause queuing of data. Other than that, the low QoS also due to insufficient network bandwidth. Inadequate network bandwidth can contribute to higher latency and jitter. If the available bandwidth is limited, it may not be able to handle the amount of data being transmitted, leading to delays in packet delivery and increased variation in timing. Lastly, as discussed previously, being underground limit the QoS due to overall signal obstruction and degradation.

Table 4
Area of stations

Data Transfer bitrate	Suburban	Urban	Underground
Uplink Data Transfer Rate Average (kbps)	27.24	24.56	7.23
Downlink Data Transfer Rate Average (kbps)	57.19	46.43	16.48
Average Latency (ms)	35	91	165
Average Jitter (ms)	9	23	68

4.3 Recommendations for the 4G LTE Challenges

Indoor radio planning is utilized within the building to get over the blank spot issue. Small antennas, limited coverage, and low transmit power from the base station side are some of the features of indoor networks [21]. When a building or railroad tunnel is isolated, the coverage area is expanded using a distributed antenna system (DAS). The coverage issue has been resolved using this method frequently. Different types of DAS exist, such as passive DAS, which is frequently used for GSM networks. In a passive DAS, coaxial wire connects each component to the others. In comparison to passive DAS, active DAS uses active components, and each component is connected via fibre optic cable, improving performance. Active and passive DAS are combined to create hybrid DAS [22].

The main unit (MU), expansion unit (EU), remote unit, and antenna are the four components of an active DAS. The main unit is connected to the repeater or base station. All signals that are received from the base station will be distributed to all systems. The DAS network has to be watched over by MU [23].EU and MU are linked through fibre optics. In turn, the DAS network will grow. The EU will convert electric to optical and vice versa. Coaxial cable connects the EU and RU. It was fixed close to the antenna. An antenna is a crucial component of wireless communications. Its purpose is to transmit radio waves into space and to receive radio waves from free space and to convert electric signal to RF and vice versa.

For the second challenge i.e. the overlapping or overshooting issue, through checking the base station layer of the present network including the actual terrain and etc., telco operators can assess whether the density of the base stations is suitable, especially whether it is too high caused by unreasonable planning. If it is, some stations can be considered to be demolish.

Omnidirectional and high-power antennas are frequently employed during the early network building, which will cause the overshooting issue. The directional antenna's coverage is more concentrated than that of the omni antenna. The coverage of small-power antenna is also often less than high-power antenna’s. Therefore, telco operators can apply directional antenna may in lieu of the omnidirectional one while the small power antenna can be replaced with high-power antenna to prevent overshooting [24]. In general, the coverage of an antenna is big when its height is high. By properly reduce the antenna height of the base station which causes overshooting can decrease the coverage of the base station, and consequently the overshooting phenomenon will be relieved. When the antenna heights of two base stations are equal, the base station with the lesser down tilt angle will have a wider coverage area. The overshooting situation can be alleviated by raising the antenna's electrical or mechanical down tilt angle [25-26], which will also decrease the base station's coverage.

The approaches on improving QoS involved multiples key entities other than network operators. One of those is the that need telecommunication regulatory authorities need to oversee this matter. The issue on poor QoS can be mitigated through proper scheduling. Scheduling primarily refers to the process of distributing and assigning resources, such as bandwidth availability, latency and etc., among users engaged in the data transmission process. To provide improved QoS, several scheduling strategies are employed. All of these scheduling algorithms strive to deliver higher throughput, link utilization, fairness, and complexity performance. In LTE, SC-FDMA is primarily utilized for uplink transmission whereas downlink transmission uses OFDMA. The major emphasis of these two scheduling approaches is the mobile terminal's power consumption problem. To provide improved QoS in the network, a better scheduling method must be selected [27].

Other than that, power control mechanism plays an important role for better QoS. It mostly refers to the process of adjusting power levels with certain objectives in mind, such as enhancing system capacity, coverage, data rates, and power consumption reduction. SC-FDMA is mostly used for uplink transmission, however it might encounter certain issues. Therefore, a system's or network's QoS may be enhanced by a better uplink power control method [28]. Additionally, a stronger rate policing mechanism must be included in the LTE network system for both uplink and downlink transmission in order to improve QoS. The main target of the rate policing system is each bearer. The maximum bit rate (MBR) in LTE sets the upper limit for GBR (Guaranteed Bit Rate) bearers, whereas AMBR (Aggregate Maximum Bit Rate) sets the top limit for a group of non-GBR bearers [29].

5. Conclusions

In this paper, this project is focusing on constructing a dataset of 4G LTE network performance that consists of information on the reference signal received power, RSRP and reference signal received quality, RSRQ. The drive test route for this project is conducted along the relatively new transit in Malaysia i.e. Mass Rapid Transit, MRT Putrajaya Line Railway Track using an Android network monitoring application, G-Net Track Pro. This project achieved the objective where the dataset measures for this project are made available to public on figshare. Secondly, from these network parameters, quality of service, QoS are analyzed by measuring the download speed, upload speed, latency, jitter and throughput using nPerf SpeedTest software. The analysis of the data and discussion on the signal strength is the presented. The project analyzed the performance of 4G LTE along MRT Putrajaya track based on RSRP and RSRQ values. The QoS does not meet the standard of 768 kb/s at the edge of the cell, and up to 100 mb/s when UE is close to the eNodeB according to 3GPP standard. From the data analysis, the project identified three major challenges along the test route which is the presence of blank spot area when the train is passing through the underground tunnel from Kuchai to Jalan Ipoh station. Other that than, especially at urban area with a lot of high-rise buildings, the networks suffer from overlapping and overshooting issue. Besides, the recorded results on data rate indicates poor QoS for end users. From all this issue identified, the project discussed recommendation for network operators for enhancement of network performance along the route. This included using Distributed Antenna System (DAS) to overcome blank spot issue, using directional antenna with accurate tilting to overcome cell overlapping/overshooting and various scheduling, control mechanism and policing to improve QoS. For future works, the recommend techniques can be validated with appropriate experiments and simulation. Conclusively, the project aimed to give insight for future telco operators and researchers to provide better 4G LTE and QoS performance for every public vehicle routes especially transit tracks in Malaysia.

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