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EMPIRICAL STUDY OF SIGNAL STRENGTH PATH LOSS IN A UNIVERSITY CAMPUS ENVIRONMENT

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Graphical abstract

Abstract

Conducting performance analysis can be a valuable tool for mobile network operators (MNO) in optimizing network performance, improving user experience, and ensuring services, such as voice calls, data transmission, and video streaming, as well as to adhere to quality standards. This approach facilitates capacity planning, resource allocation, and the prompt identification and resolution of network congestion, hardware failures, or security breaches. In this paper, the performance of three MNOs around Papua New Guinea University of Technology (PNGUoT) is examined. The downlink frequency signal was measured and collected using the MST207T spectrum analyzer. The allocated frequency spectrum for each mobile network evolution from 3G to 4G-LTE was analyzed and calculated for signal strength path loss utilizing Free Space Path Loss (FSPL) and the Cost 231 Hata Model methods. 5G is not discussed in this paper as the technology is awaiting PNG market entry approval. The findings indicate that Digicel towers exhibit a decrease in downlink signal intensity and quality in areas with poor signal reception. Certain technical issues were observed to be responsible for the identified poor performances, including overcrowding of base stations (BS). The signal strength qualities of Bmobile Vodafone and Telikom exhibit variations, suggesting a moderate to poor level of quality. The data results from the path loss calculation also show an increase in fading signal strength quality. The findings of this empirical study would provide valuable insights for enhancing the efficiency and coverage of mobile communication networks around PNGUoT. Additionally, recommendations were also made to improve the overall quality of both voice and data services.

Keywords: Signal strength, path loss, quality of service, network planning, mobile coverage

Abstrak

Analisis prestasi merupakan salah satu kaedah pengukuran bagi pengendali rangkaian mudah alih (MNO) dalam mengoptimumkan prestasi rangkaian, meningkatkan pengalaman pengguna, dan memastikan perkhidmatan, seperti panggilan suara, penghantaran data dan penstriman video berjalan dengan baik serta mematuhi piawaian kualiti. Pendekatan ini memudahkan perancangan kapasiti, peruntukan sumber, dan pengenalpastian segera serta penyelesaian kesesakan rangkaian, kegagalan perkakasan atau pelanggaran keselamatan. Dalam makalah ini, prestasi tiga MNO di sekitar Universiti Teknologi Papua New Guinea (PNGUoT) telah dikaji. Isyarat frekuensi pautan laluan menurun diukur dan dikumpulkan menggunakan penganalisis spektrum MST207T. Spektrum frekuensi yang diperuntukkan untuk setiap evolusi rangkaian mudah alih daripada 3G sehingga 4G-LTE telah dianalisis dan dikira untuk kehilangan laluan kekuatan isyarat menggunakan kaedah Free Space Path Loss (FSPL) dan Cost 231 Hata Model. Rangkaian 5G tidak dibincangkan dalam makalah ini kerana teknologi itu sedang menunggu kelulusan kemasukan pasaran PNG. Hasil analisa menunjukkan bahawa menara Digicel mempamerkan penurunan dalam intensiti dan kualiti isyarat laluan menurun di kawasan yang mempunyai penerimaan isyarat yang lemah. Isu teknikal tertentu dikenalpasti bertanggungjawab terhadap prestasi yang kurang baik, termasuk kesesakan stesen pangkalan (BS). Kualiti kekuatan isyarat Bmobile Vodafone dan Telikom mempamerkan variasi, mencadangkan tahap kualiti yang sederhana hingga rendah. Data pengiraan kehilangan laluan juga meningkat dan ini menunjukkan kualiti kekuatan isyarat semakin lemah. Penemuan kajian empirikal ini dapat membantu MNO meningkatkan kecekapan dan liputan rangkaian komunikasi mudah alih di sekitar PNGUoT. Selain itu, pengesyoran juga dibuat untuk meningkatkan kualiti keseluruhan kedua-dua perkhidmatan suara dan data.

Kata kunci: Kekuatan isyarat, kehilangan laluan, kualiti perkhidmatan, perancangan rangkaian, liputan mudah alih

1.0 INTRODUCTION

Mobile communication networks play an important role in facilitating modern connectivity for both personal and business purposes [1, 2]. Over the years, mobile networks have evolved significantly, progressing from basic voice communication systems to complex platforms that facilitate high-speed data services, multimedia messaging, internet connectivity, and a wide range of applications. This evolution has seen the development of mobile networks spanning from the first generation (1G) to the fourth generation (4G), with the latest technological advancement being the fifth generation (5G) [3]. Technological progress, improvements in data transmission speed, and enhanced network capabilities are characteristic features that accompany each successive generation. These technologies are important for more than just making our lives easier, as they provide a basis for emergency services, contribute to economic growth, facilitate education and healthcare, and promote technological innovation such as augmented reality (AR), virtual reality (VR), and Internet of Things (IoT) applications [4, 5, 6, 7].

Signal strength is a critical factor in ensuring Quality of Service (QoS) in various mobile communication systems, especially in wireless networks and telecommunications. QoS parameters are a set of network performance measures and configurations used to ensure the reliable and predictable transmission of data, audio, and video traffic across a network [8, 9]. A strong signal ensures that data packets are transmitted with minimal errors or interference, helps maintain a stable and consistent connection, and has low latency, which allows for higher data throughput rates. More data can be transmitted over the network, for example, to allow for downloading of large files or streaming high-definition (HD) video in a very short time, or for online gaming, video conferencing, and voice over IP (VoIP) calls. In situations where there are many access points or base stations present, the appropriate connection for a device is determined based on signal strength. Proper load balancing based on signal strength can help distribute network traffic efficiently, improving QoS for all users. There are several strategies that can be employed to enhance signal strength, including the utilization of signal boosters, the adjustment of antenna placements, and the careful selection of the most optimal access point [10, 11].

Researchers have conducted investigations on the QoS of mobile networks utilizing various approaches such as regular assessments of network performance, end-user surveys, health impacts regarding signal power, and many others [12, 13, 14]. Most studies offer a comprehensive analysis of the QoS dimensions related to signal strength in cellular networks. Certain parameters should also be considered when measuring and analyzing the QoS, such as throughput, bandwidth, delay, latency, low data rate, blocked call, dropped call, packet loss, and packet error rate. According to [15]; operators should prioritize the satisfaction of end users as a crucial and competitive parameter to maintain stability in the rapidly evolving and demanding technological environment. A study by [16]; shows that the lack of effective regulatory monitoring and enforcement poses significant challenges for Nigerian mobile network operators in achieving video streaming and low-latency communication capabilities.

Signal strength is indeed a critical factor in ensuring QoS. The signal strength measurement and evaluation in an indoor environment were performed by [17]. The findings indicate that the variability of signal strength is impacted by factors such as the number and positioning of access points, the presence of physical obstacles, and the impact of multipath propagation. The actual capability of 5G to deliver high QoS for remote collaboration has been evaluated in a recent study [18]. The investigation considers various environmental factors such as signal quality, frequency band, handoff procedures, geographic conditions, and mobility patterns. The 5G network requires more cell towers in close proximity due to its higher frequency bands [19, 20]. Some cell towers have directional antennas that focus signal strength on specific directions. The signal strength may be weakened if the devices are outside the primary beam of a directional antenna.

Given the growing need for IoT-based sensor systems, it also becomes imperative to evaluate the efficacy and performance of wireless sensor networks. A series of experiments were conducted primarily in indoor settings to assess the efficiency and coverage of wireless sensor networks by varying the height and orientation of the antennas [21]. It has been observed that these two factors have a significant impact on the value of signal strength. Furthermore, [22]; evaluates various QoS delivery models in the context of next-generation wireless sensor networks. The parameters that were evaluated were packet loss and latency. In addition, [23]; conducted a series of empirical studies to gather data on the relationship between signal strength and the distance between the end device and the LoRa gateway. The data collected facilitates comprehensive studies that determine which best represents the behavior of LoRa communication signals.

The Papua New Guinea University of Technology (PNGUoT), in response to the COVID-19 outbreak and in line with Papua New Guinea's long-term goal of 2050 [24], has made a significant investment in establishing online programs as an alternative to ensure the education system remains unaffected. However, students and staff have encountered connectivity challenges that have affected the delivery of online courses. This paper conducts a comprehensive analysis of mobile signal strength, examining its influence on QoS at the PNGUoT. The main contribution of this paper is the analysis of downlink signal intensity and quality using empirical data and the Cost 231 Hata Model and Free Space Path Loss (FSPL) methods. These methods can be utilized to assist in capacity planning, resource allocation, and network optimization strategies. This study holds significant value for stakeholders in Papua New Guinea, particularly the NICTA and local mobile network operators (MNO), by providing practical recommendations and workable solutions. These include optimizing base station locations and implementing 5G technology, which can enhance the efficiency and coverage of mobile communication networks.

The following sections of this paper are structured as follows: The subsequent section describes the user survey and the methods employed to calculate path loss in this study. Additionally, the experimental setup is detailed in Sections 2. The results are presented in Section 3, followed by the conclusion in Section 4.

2.0 METHODOLOGY

Figure 1 displays the process flows and approach used to conduct an empirical study of signal strength path loss in PNGUoT. The study involves various research methodologies, including surveys, measurements, and data analysis. The major MNOs in Papua New Guinea include Digicel, Bmobile and Telikom. Table 1 shows the variation of MNOs involved in this study. Note that this paper does not include the latest MNO, Digitec Vodafone.

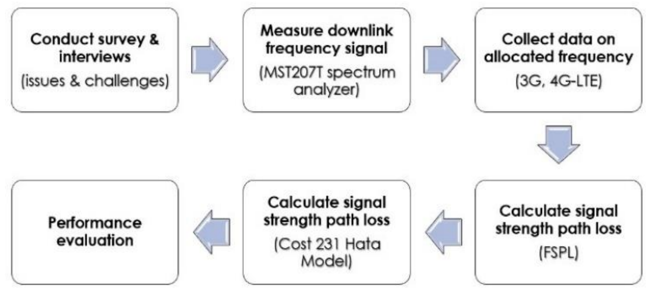


Figure 1 Process flows and approach for empirical study of signal strength path loss in PNGUoT

Table 1 Variation of MNOs for empirical study at PNGUoT

MNO	Technology	Frequency
Digicel	3G	900 MHz
	4G	700 MHz
	4G	1800 MHz
Telikom	4G	1800 MHz
Bmobile	3G	900 MHz

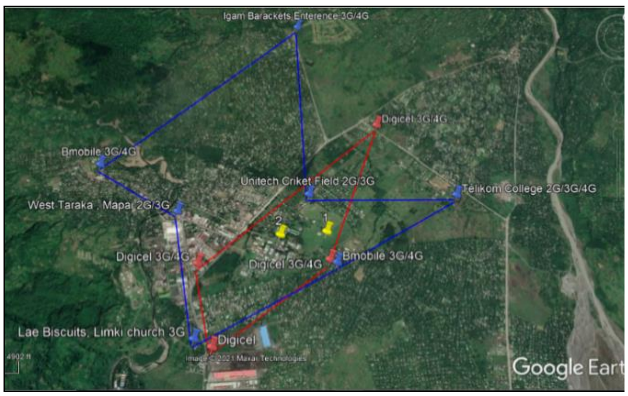
2.1 User Survey

A questionnaire survey was carried out, with about 2000 copies distributed to students and staff, to gain a comprehensive insight into the QoS provided by the MNOs on PNGUoT campus. 1500 copies were in paper format, while the remainder involved interviewing random users of mobile cellular networks. The interview and questionnaire included questions regarding various aspects of mobile network usage at PNGUoT. These investigations covered issues including the generation of mobile networks utilized and the category of MNO. In addition, participants were queried regarding challenges encountered while using the mobile communication network and their assessment of the internet browsing experience while on campus. The purpose of this investigation is to determine the current concerns affecting the signal strength for PNGUoT staff and students.

2.2 Measurement Environment and Data Collection

The PNGUoT campus is located 10 km from the central business district of Lae, the second-largest city in Morobe Province, Papua New Guinea. High network traffic, especially in densely populated areas or during peak usage times, can lead to congestion. The available bandwidth per device may decrease, causing slower data speeds and reduced signal quality when many devices are connected to the same cell tower. The campus population itself could reach 15,000 people, thereby impacting the use of the cellular signal coverage network. Additionally, the campus's landscape, characterized by tall trees, poses propagation challenges for all MNOs.

Figure 2 illustrates the base stations available on the campus. In Figure 2(a), blue markers represent the 3G/4G mobile towers operated by Bmobile and Telikom, while red markers denote the locations of 3G/4G mobile towers operated by Digicel. Yellow markers indicate additional towers installed to serve campus users. Specifically, yellow marker 1 represents a newly installed Vodafone tower located approximately 800 meters northeast of the Digicel site. Yellow marker 2 denotes a Digicel site installed on the building, Haus Europa, situated at the center of the campus.



(a) Location of base station at PNGUoT: blue markers – Telikom Towers, red markers – Bmobile Towers

(b) Measurement location point: red marker, large (L_n), green markers, small (S_n) measurements points

Figure 2 Location of the field study setup

2.3 Equipment Setup

Portable spectrum analyzer (Anritsu MST207T) was used to conduct measurements on campus. The aim of the measurements was to examine downlink carrier frequencies for each of the 11 cell sites or towers located both within and around the campus, as depicted in Figure 2(a). The signal data was measured from a total of 15 different locations as shown in Figure 2(b). The data collected was assembled with its respective MNO cell sites for the $700MHz$ band, the $900MHz$ band, and the $1800MHz$ band. The allocated frequency spectrum for each mobile network evolution (GSM, 3G-WCDMA and 4G-LTE) was analyzed, and data for signal intensity path loss was generated. The path loss values were determined using the Free Space Pathloss (FSPL) and the Cost 231 Hata model.

2.4 Path Loss Analysis

In wireless communication, path loss is a condition in which the signal strength of a radio signal decreases as it propagates through space [25]. It has significant implications for designing and operating wireless communication systems. Free Space Path Loss (FSPL) and the Cost 231 Hata model are two methods to estimate path loss in wireless communication systems. Each method has its own set of equations and assumptions for predicting signal attenuation over distance.

The FSPL model is a basic path loss model that implies ideal conditions, such as the signal propagating through free space, the antennas radiating uniformly in all directions, and no atmospheric absorption or scattering. The FSPL model uses the following equation to calculate path loss (PL) in decibels (dB) [26]:

$$FSPL(dB) = 20log_{10}(d_{km}) + 20log_{10}(f_{GHz}) + 20log_{10}(4\pi/c) \quad (1)$$

where c represents the speed of light, d is the distance between the transmitter and receiver measured in kilometers, and the frequency, f in gigahertz.

The Cost 231 Hata model is a more complex radio propagation model to calculate the path loss that considers urban, suburban, and rural environments. This incorporates the signal experiencing ground reflection and diffraction over buildings and structures and is applicable for the frequency range $150\ MHz$ to $1500\ MHz$. The Hata model comprises a range of equations that depend on the environment and frequency band under consideration. The basic equation to calculate the path loss is [27]:

$$PL(dB) = 46.3 + 33.9\log f - 13.82\log h_t - a(h_r) + (44.9 - 6.55\log h_t)\log d + C_m \quad (2)$$

where f is the frequency in MHz, d is the distance between transmitting and receiving antennas in km, h_t is the transmitting antenna height above ground level in meters. The correction factor C_m is defined as $0dB$ for suburban or open environments and $3dB$ for urban environments. The term $a(h_r)$ is defined for urban and suburban environments respectively, as:

$$a(h_r) = 3.2(\log 1\,1.75h_r)^2 - 4.97 \quad for \quad f \geq 400MHz \quad (3)$$

$$a(h_r) = 1.1(\log f - 0.7)h_r - (1.56\log f - 0.8) \quad (4)$$

where h_r is the receiving antenna height above ground level.

In this paper, the signal strength pathloss based on the service downtime and spectrum control by the mobile network operators (MNO) at PNGUoT is investigated. These path losses were calculated using FSPL and the Cost 231 Hata model methods. This paper will explore the factors affecting signal strength and assess their impact on network performance. The study aims to provide insights into signal strength optimization strategies, ultimately enhancing QoS in mobile communication networks. It is intended that the present research findings be incorporated into the development of MIMO and Artificial Intelligence systems of future systems proposed [28, 29].

3.0 RESULTS AND DISCUSSION

3.1 Survey Results

Figure 3 presents the distribution of subscribers among MNOs based on the survey results. About 82% of respondents utilize the services of Digicel, whereas Bmobile and Telikom have a comparatively lower number of subscribers. Digicel is widely used for data downloads due to its cost-effectiveness; nonetheless, the network may encounter occasional instability. The challenges associated with internet usage, such as live streaming and downloading, often result in frequent interruptions, slow performance, and poor quality. These issues may be caused by an excessive number of Digicel users, leading to congestion, reduced download speeds, interruptions while livestreaming, and dropped network calls.

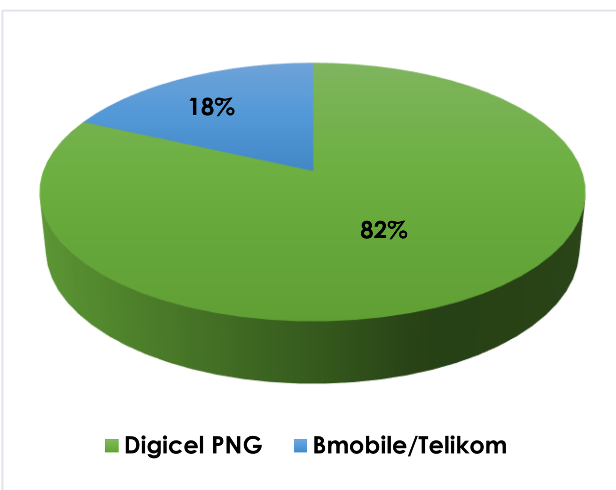
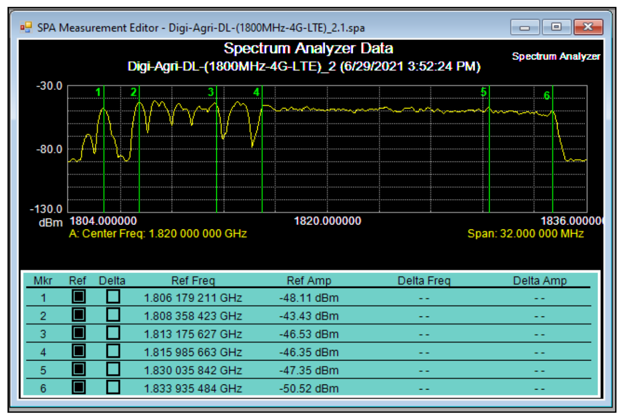


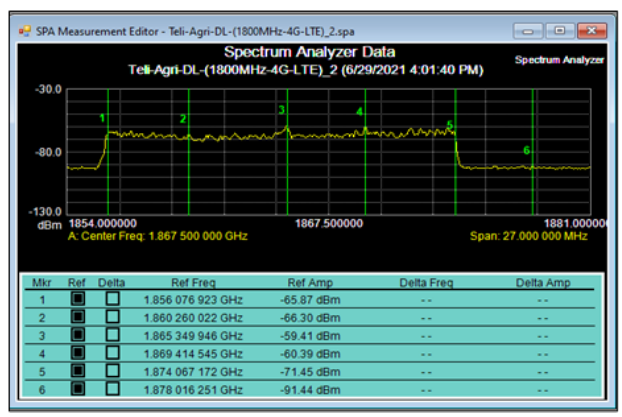
Figure 3 Mobile network users in PNGUoT, Taraka Campus

3.2 Path Loss Simulation Results

Figures 4(a) and 4(b) shows spectrum readings obtained from 4G network measurements conducted for Digicel and Telikom, respectively, at the Agriculture Junction. In this location, Digicel's 4G network signal strength is substantially stronger than Telikom's, but not in the case of LTE. Telikom transmits 4G and LTE signals and is considered to have a strong signal for both technologies. The spectrum analyzer power maximum was set at $-30dBm$ to avoid signal interference with nearby base stations. It has been observed that the downlink carrier frequency utilizes a single bandwidth of $18\ MHz$ as opposed to $20\ MHz$. This is because the MNO has reduced the bandwidth band to avoid latency. Digicel's downlink telephony voice calls exhibit very strong peaks between markers 1 and 4, indicating good signal reception. The indicator between 4 and 6 represents downlink signal carrier frequency band data. There were no voice communications for Telikom, but some data received on the downlink stream at $1800\ MHz$ is shown. The frequency indicated by marker 6 $(1878\ MHz, -91.44\ dBm)$ indicates a poor or noisy signal received.



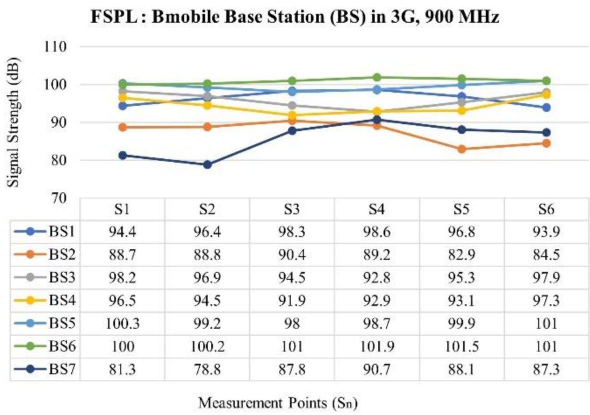
(a) Digicel, 4G, 1804 to 1836 MHz



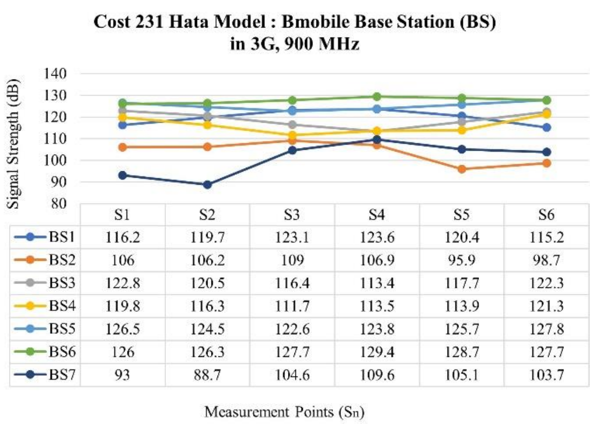
(b) Telikom 4G, LTE, 1857 to 1881 MHz

Figure 4 Signal strength measurement at Agriculture Junction

The FSPL and the Cost 231 Hata Model were employed to calculate the signal strength path loss, considering factors such as frequency, distance, and line-of-sight. The signal is calculated from each of the 11 base station towers at the 16 measurement locations surrounding the PNGUoT. Large measurement points (L_n) and small measurement points (S_n) are used to categorize the signal strength measurement locations from each tower. The L_n covers a total of 9 measurement points, whereas S_n covers only 6 points as depicted in Figure 2(b). Figure 5 to Figure 7 show the calculated signal path loss for Bmobile 3G ($900\ MHz$), Digicel 4G ($700\ MHz$) and Telikom 4G-LTE ($1800\ MHz$).



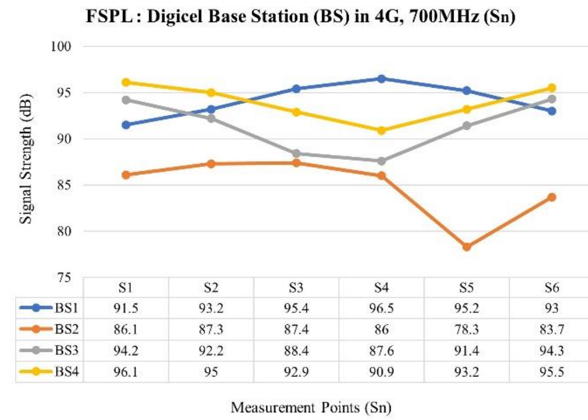
(a) Signal path loss by FSPL method from S_n



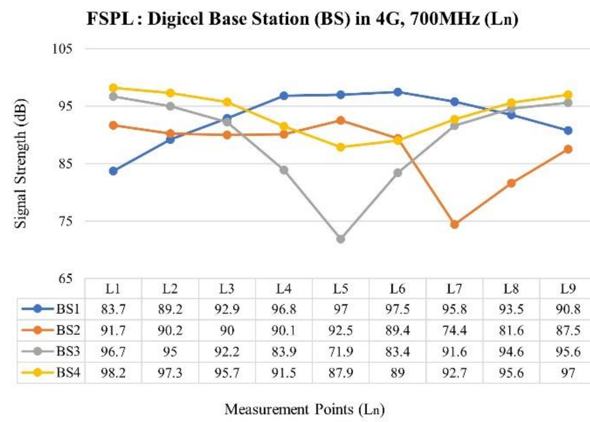
(b) Signal path loss by Cost 231 Hata Model from S_n

Figure 5 Comparison of small (S_n) signal path loss from 7 3G Bmobile base stations in *900MHz* band using FSPL and Cost 231 Hata Model

Figures 5(a) and 5(b) show the signal path loss calculated by using the FSPL and Cost 231 Hata Model methods from 7 base stations of Bmobile 3G ($900MHz$) from S_n, respectively. The data indicates that base stations 5 and 6, depicted in Figure 4(a), exhibit poor signal strength across the measurement points. Other base station data shows medium to poor signal strength. The calculated results based on the Cost 231 Hata model, on the other hand, indicate that all base station signals were weak. In many regions, the 3G networks, including those operating at $900MHz$, have been progressively phased out as MNOs transition to more advanced technologies such as 4G-LTE and 5G. Consequently, the availability and strength of 3G signals may vary by location and may not be as robust as newer network technologies.



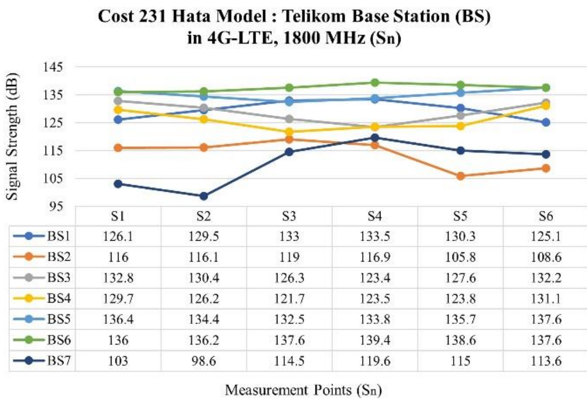
(a) Signal path loss by FSPL method from S_n



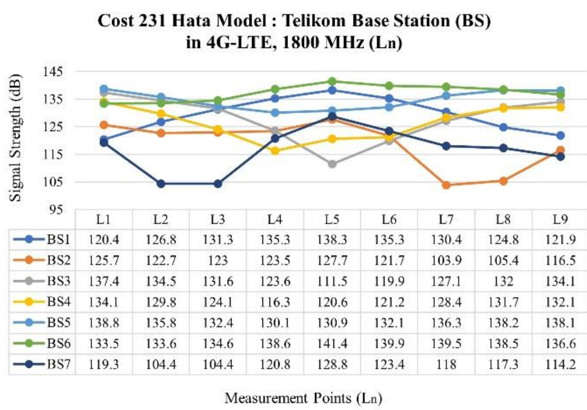
(b) Signal Path Loss by FSPL Method from L_n

Figure 6 Comparison of small (S_n) and large (L_n) measurement of signal path loss from 4 4G Digicel base stations in $700MHz$ band using FSPL Model

Figures 6(a) and 6(b) show the signal path loss calculated by using the FSPL method from 4 base stations of Digicel 4G in $700MHz$ band taken at S_n and L_n, respectively. Note that the FSPL calculation does not incorporate any obstacle or interference material. It is observed that as the distance from the nearest base station increases, the signal strength tends to weaken or get connected to the next closest congested base station.



(a) Signal path loss by Cost 231 Hata Model from S_n



(b) Signal path loss by Cost 231 Hata Model from L_n

Figure 7 Comparison of small (S_n) and large (L_n) measurement of signal path loss from 7 4G-LTE Telikom base stations in the $1800 MHz$ band using Cost 231 Hata Model

Figures 7(a) and 7(b) show the signal path loss calculated by using the Cost 231 Hata Model method from 7 base stations of Telikom 4G-LTE in $1800MHz$ band taken at S_n and L_n, respectively. During the measurement, it was discovered that the signal quality at the Markham roundabout location (L_9) is significantly low, indicating a significant signal failure at all seven base stations. Markham is the centre of the base stations surrounding the area. Therefore, this scenario exemplifies the problem of congestion, wherein the transmission of downlink data is characterized by prolonged delays, network disconnections, and data loss.

3.3 Measurement Results

Table 2 shows the signal strength observed for each MNO at Agriculture Junction measurement point (refer to Figure 1). The marker numbers represent the frequency points at radiating power from the transmitter (cell sites) was measured. Table 2 shows that the measured power from Digicel towers exhibits higher received power across all three technologies, 3G, 4G ($700\,MHz$), and 4G ($1800\,MHz$) with power levels ranging from $-38.3\,dBm$ to -92.7 dBm. Measured power from Telikom and Bmobile towers ranges from -59.14 to $-91.44\,dBm$ and -43.72 to -70.65 dBm respectively. Observe from Figure 4, that Digicel offers a bandwidth of 19 MHz compared to Telikom, which offers 18 MHz which is almost the same. Despite the comparable bandwidth offered by all MNOs, Digicel seems to offer better signal power on mobile equipment than with a significant difference at the $1800\,MHz$ band. It can also be observed from Table 1 that, except for the $700\,MHz$ band, all other frequency bands have a lower change of power between each frequency point to confirm the consistent power supplied throughout the transmission bandwidth.

Table 2 Summary of each MNO's signal strength at Agriculture Junction

MNO	M1	M2	M3	M4	M5	M6
3G Digicel (900 MHz)	-38.29	-39.61	-47.72	-49.99	-52.21	-55.78
4G Digicel (700 MHz)	-49.28	-43.20	-39.60	-43.94	-56.67	-92.73
4G Digicel (1800 MHz)	-48.11	-43.43	-46.53	-46.35	-47.35	-50.52
4G Telikom (1800 MHz)	-65.87	-66.30	-59.41	-60.39	-71.45	-91.44
3G Bmobile (900 MHz)	-43.72	-48.20	-60.11	-62.59	-70.65	-62.01

4.0 CONCLUSION

In this paper, varying properties of path loss were observed for each MNO operating within the PNGUoT campus. The primary factor contributing to the degradation of network service quality is the path loss attenuation of signal intensity in the coverage areas, together with the interference from buildings and trees on campus that affect the propagation of signals. More research into the technical aspects of base station signal propagation, particularly of raw 4G digital signals, can help improve the quality of the signal strength. The installation of a base station in an appropriate location to reduce obstructions would enhance signal quality for the PNGUoT community. Alternative options include the installation of signal boosters by MNOs to amplify the signal intensity in the event that the installation of BS is prohibitively expensive. Additionally, 5G technology, using MIMO and AI techniques, should be introduced by MNOs at PNGUoT in order to enhance mobile communication services in the area to handle online teaching and laboratory experiments.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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