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Performance Analysis of Line Operation Parameters and Customer Premises Equipment over a Very High-Bit-Rate Digital Subscriber Line 2 Network

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Abstract

Even though fiber networks have gained popularity today, Internet access via copper cable networks is still necessary in Malaysia, particularly in the suburban areas. This paper aims to examine the line operation parameters (LOPs) and customer premises equipment (CPE) performances over a very-high-bit-rate digital subscriber line 2 (VDSL2) network. These data are crucial in monitoring and preventing network faults and can be used as benchmarks during troubleshooting. In this paper, the LOPs data was obtained from the multi-service access node (MSAN) using the Xshell program. Data acquisition and extraction from the Huawei HG655m modem's Graphical User Interface (GUI), the CPE under investigation, was performed using a Python programming script. The statistical performance of network parameters, such as actual line rate, line and signal attenuation, and signal-to-noise ratio (SNR) margin, was then analyzed. In addition, the length of a bundle of ten twisted pairs of copper cable was varied for several distances: 100 m, 300 m, 500 m, 700 m, and 1000 m, with the operational bandwidth set to 17.664 MHz. The findings demonstrated an increment in the net data rates and packets by the Huawei HG655m modems received when a high-performance throughput is injected into the access network.

1. Introduction

In the access network infrastructure, a multi-service access node (MSAN) plays a vital role as interfacing equipment to connect customer lines to the service provider (SP) that provides telephone, integrated services digital network (ISDN), and broadband networks such as digital subscriber line (DSL) [1]. Fig. 1 shows the hybrid fiber-copper access network infrastructure deployed in Malaysia [2]. The main components of this access network infrastructure consist of the central office, the MSAN cabinet, distribution points (DP), and customer premises equipment (CPE). The fiber-optic cable connecting the central office to the MSAN cabinet is the backbone of the access network systems. This connection is commonly known as fiber to the cabinet (FTTC). In metropolitan areas, the MSAN, the DP, and the CPE connections are usually accomplished by a fiber-optic cable called fiber to the home (FTTH). However, copper cable bundles remain as a transmission medium in suburban or less populated areas to avoid high deployment costs [3], [4].

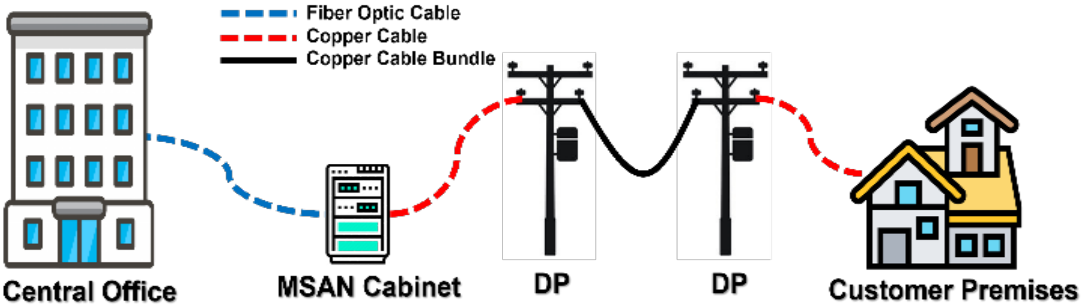


Fig. 1 *Typical hybrid access network infrastructure in Malaysia* [2]

The fiber network is one of the future-proof technologies as it can meet future demands. It can generally provide better performance, including high data transfer rates, faster transmission rates, wide bandwidths, low attenuation, invulnerability to common radio frequency interference, and the ability to transmit data over long distances in the Internet access network [5]. However, copper cable utilization is still crucial to the Internet access network due to its suitability in terms of deployment cost and reliability for suburban area applications.

In Malaysia, traditional telephone services based on twisted copper cables are still used for most access networks in suburban areas [2], [6]. Since the traditional copper network infrastructure has been widely deployed, enhancing the existing access network to meet the high demand for high-speed data rates and more significant bandwidth allocation for customers has resulted in a hybrid network called xDSL technology. An integrated connection or hybrid structure between fiber and pre-existing copper cable has introduced very high-bit-rate digital subscriber line 2 (VDSL2) technology [2] that allows triple-play services (data, video, and voice) and high-definition television (HDTV) [7]. In VDSL2 technology, copper cables deliver and transmit higher data rates of up to 100 Mbps for downstream and upstream traffic with an operating frequency range of up to 30 MHz [7].

In addition, VDSL2 technology employs differential encoding signals for data transmission over twisted-pair cables, which aids in reducing the crosstalk effect between different pairs in the same copper cable bundles [4], [8] and minimizing the loop area of the copper wires to lessen mutual inductive coupling [9]. Crosstalk is an unwanted event in a communication system that will degrade its overall performance. Several factors limit the data transmission rate performance in an access network, such as higher noise, which reduces the channel capacity, the copper cable length deployed between MSAN and CPE, and the copper cable quality.

The twisted-pair cable, also known as network cable, can be categorized into various categories, such as Category 1 (CAT 1) and Category 7 (CAT 7); both types have different numbers of twisting rates, the capability of maximum data rates, and the operating frequency [9]. Fig. 2 shows the twisted pairs with different twists per meter; as for pair (a), the crosstalk in the copper cable bundle is lower as it has a more significant number of twisting rates between the pair. Meanwhile, the crosstalk power level for pair (b) will be significant as there are fewer twisting rates between each pair.

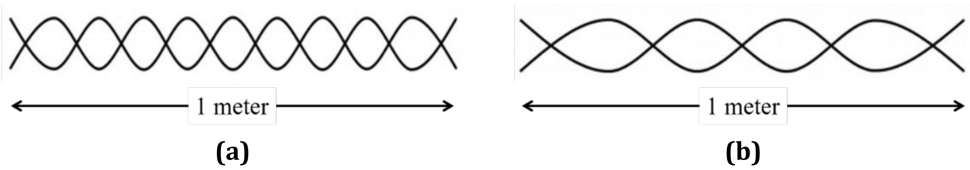


Fig. 2 *Twisted pairs cable with a different number of twisting rates per meter (a) High; (b) Low* [9]

Malaysian internet access networks still rely on a copper cable network, particularly in suburban areas[10]. Meeting the customers' high-speed data rate demand during heavy utilization is a must. Suppose that there is a network downtime. As a result, the network connectivity between MSAN and CPE and the data rate speed for the CPE will be dropped or lost. Gathering information and diagnosing the current state of the network using network troubleshooting tools is crucial. Since various types of CPE devices, such as modems, usually have different operating systems, specifications, and features, the LOPs and CPE data provide essential tools for identifying network issues. Therefore, this paper analyses the LOPs and CPE (Huawei HG655m modems) performances over the VDSL2 network. The results of this study are likely helpful as a guide for the service providers or network engineers during the network troubleshooting process.

2. Methodology

This section explains how the experimental setup, DSL parameter categorization, and LOPs data collection are carried out.

2.1 Experimental Setup

In this paper, an experimental setup is configured by replicating the existing VDSL2 access network infrastructure provided by Telekom Malaysia (TM), as shown in Fig. 1. Fig. 3 presents the schematic configuration of the access network setup in the laboratory. It consists of the Mini MSAN, DP or tag block, six modems that support VDSL2 technology, the Ixia Network simulator, and the switch.

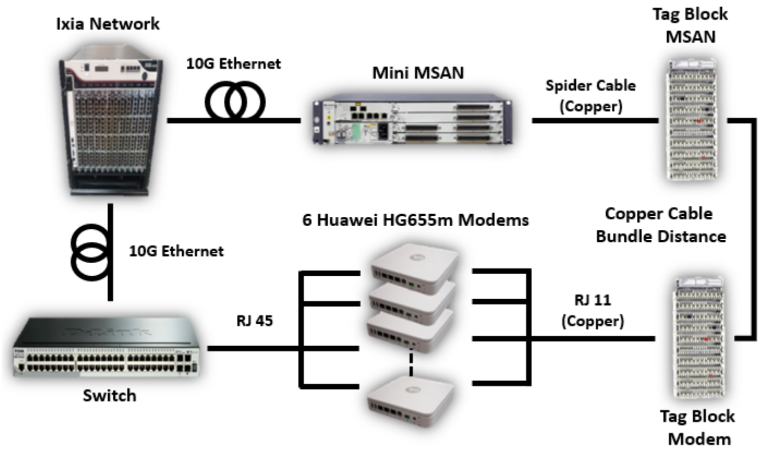


Fig. 3 *Access network experimental setup*

In actual application, the Mini MSAN is usually built inside a telephone exchange that connects customers' telephone lines to the core network. A DP, represented by a tag block, is used in the experimental setup to simulate the different network line distances, starting with a short distance, 100 m, to a maximum distance supported by the VDSL2 technology, which is less than 1500 m. The CPE used in this setup is six Huawei HG655m modems connected via six pairs of unshielded twisted-pair copper cables. The twisted-pair cable utilized in the network line configuration falls under Category 5e (CAT 5e) with a twisting rate of 1.5 to 2 twists per cm, maximum data rates up to 1 Gbps, and 100 MHz of operating frequency. The Ixia network simulator and switch equipment are added to the experimental setup to inject real network traffic with the necessary parameters at the customer's site. The main parameters configured are the timing record and bytes sent per timing record. In this paper, the actual data network traffic means the Internet access usage by customers, such as accessing the web browser and video conferencing (Zoom, Google Meet, and others).

The network traffic applied in the experimental work is divided into three main categories: low-performance, medium-performance, and high-performance throughput. Performance throughput can be classified as the total amount of packet data transmitted and received in the access network between MSAN and CPE devices within a time duration [11]. Observing the throughput is a way to measure and identify the overall performance of the access network connection. The total number of packets that successfully arrive at the receiver destination is measured by throughput. Fig. 4 shows the differences between each of the performance throughputs that have different bandwidth capacities. A larger bandwidth capacity offers more throughput data to the access network line.

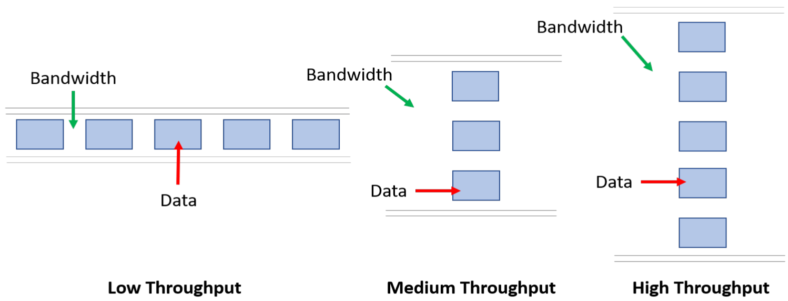


Fig. 4 *Differences between low, medium, and high-performance throughput*

According to Fig. 4, low-performance throughput has the smallest bandwidth in a single transmission or network line compared to medium-performance. In contrast, high-performance throughput has the most significant transmission bandwidth. Hence, the access network line can provide more packet data during a single transaction. However, the bandwidth capacities only consider the theoretical measurements of the maximum capabilities or number of packets of data that can be delivered in a single network line, while throughput is how much of the data successfully arrives at the receiver destination within a period, considering other parameters such as latency or time delay, network speed, and packet loss.

2.2 DSL Parameters Categorization

LOPs are measurement data that represent the diagnostic performance of the VDSL2 access network. The LOPs data can be captured from the MSAN and CPE, consisting of the actual line rate, maximum attainable rate, signal and line attenuation, and signal-to-noise ratio (SNR) margin. The MSAN's actual line rate indicates the highest data rate fed into the network line. In contrast, the maximum attainable rate is the network line's maximum capability in achieving the MSAN's actual line rate.

The signal and line attenuations are the two types of access network attenuation, and their parameters are nearly identical [10]. Noise on the network line, physical surroundings, and the network line distance are some examples of attenuations. These will cause a loss of signal strength measured in decibels, resulting in a distorted and degraded transmission signal between the MSAN and CPEs. Radio frequency interference, electrical currents, copper cable leakage, and other network line faults [6], [12] such as short, open, and bridge taps, can all cause noise.

Finally, the SNR margin is an important parameter used to set a minimum limit for the access network system to ensure that the signal level in the network line is greater than the noise level. The SNR margin is one of the options for assessing the access network line quality, with a standard minimum limit of 6 dB for the VDSL2 access network [13]. If the SNR margin is set below the minimal limit, frequent disruptions may occur [13]. In general, the SNR margin can be calculated by using the following equation [7].

$$\text{SNR Margin } (dB) = \text{ Actual Measured SNR } (dB) - \text{ SNR to Synchronous at Specific Speed } (dB) \quad (1)$$

Downstream and upstream traffic are standard representations of the access network system or traffic. These terms are used by network experts who monitor the operation of the access network depending on bandwidth utilization. The flow of data packets from the end-user (CPE site) to the access network system provider or internet service provider (ISP) is called upstream traffic. On the other hand, downstream traffic refers to the data packets traveling from the ISP to the CPE site [14]. Normally, the downstream and upstream terms are referred to for download and upload purposes.

2.3 LOPs Data Collection

The data is extracted from MSAN using the Xshell software, a remote connectivity program. Xshell software will capture various data parameters in the access network system, such as LOP, Loop Line Test (LLT), and Hlog. The LOPs data are the only focus of this paper, and the details of the LOPs data are discussed in the previous section. Following the successful data gathering from MSAN, these data are categorized into their types using Python, the primary programming language used in the TM Research and Development. First, Python programming modifies and classifies the original raw data into different parameter groups: the LOP, LLT, and Hlog. Second, Python programming saves this data in the Comma Delimited (*.csv) file format.

The precise technique of LOPs data collection and extraction from the MSAN is employed to gather data from the CPE device, a Huawei HG655m modem. The data from the modems' GUI is collected and extracted using a web scraping technique. The available data from the Status of Wide-area Network (WAN) navigation in the modems' GUI are collected using Python since this project concentrates on LOPs data. Regarding downstream and upstream traffic, an ideal condition of LOPs data obtained from MSAN and CPE is assessed and studied. It recognizes and monitors a CPE device's overall performance and ability as the network line's endpoint, determining whether it can or cannot acquire the approximate data rates supplied from the MSAN.

Web scraping is a technique for extracting text material or data from a website using bots and then exporting the data in a comma-delimited (*.csv) file format, which can be used to save the data in tabular form. A Python programming script is developed to extract and capture the needed LOPs and network performance statistical data from the Huawei HG655m modems web page. A manual clustering approach clusters the gathered LOPs data from MSAN and Huawei HG655m modems. The network line distance of the MSAN to the CPE devices is the focus during the clustering process. Then, based on the clustered data, correlation analyses are carried out to determine whether the LOPs data from MSAN are correlated with the LOPs data present from the CPE device.

3. Result and Analysis

This section evaluates and discusses the analysis of results obtained from the experimental measurement. Generally, the evaluation process was conducted in two steps. First, is an evaluation of the LOPs data. Second, is the statistical performance of the CPE under study, which is the Huawei HG655m modems in terms of throughput.

3.1 LOPs Data Analysis

Experimental measurements were carried out using the setup shown in Fig. 3 with a 17a profile in the VDSL2 technology configuration for both downstream and upstream traffic. Generally, the Mini MSAN can provide 30 ports in this experimental setup; however, six ports are considered as only six pairs of twisted-pair copper cable from the cable bundle are accessible for data collection.

Fig. 5 compares downstream and upstream traffic of the actual line rate delivered by the MSAN and the line rate achieved by the Huawei HG655m modems at different copper cable lengths: 100 m, 300 m, 500 m, 700 m, and 1000 m. It can be observed that the MSAN offers the highest actual line rate for the VDSL2 access network, with 115832 kbps (115.8 Mbps) and 45337.3 kbps (45.3 Mbps) for downstream and upstream traffic, respectively, as the copper cable length between MSAN and modems is at 100 m. On the other hand, the Huawei HG655m modems can attain the highest line rate capabilities at this copper cable length of 100009 kbps (100 Mbps) for downstream traffic and 41921 kbps (41.9 Mbps) for upstream traffic. As the length of the network line increases, the data rate performance of both MSAN and Huawei HG655m modems graphs degrades because of increments in the channel line attenuation and signal attenuation. This result implies that CPE proximity to the ISP improves internet connection speed.

The percentage difference between the data rate transmitted by the MSAN and the data rate received by the Huawei HG655m modems from a short to a longer copper cable length is illustrated in Fig. 6. It is calculated based on the difference values between the data rate transmitted and data rate received, divided by the average of these two values, and multiplied by 100. This information is crucial in understanding how significantly close the data rate transmitted and data rate received or as an indication of the degree of data rate. According to Fig. 6, the percentage difference fluctuates between 8% and 16% for an ideal network at different copper cable lengths.

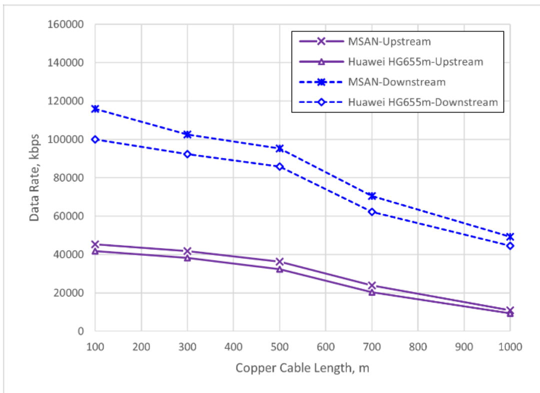


Fig. 5 *Actual line rate of MSAN and line rate of Huawei HG655m modems for both downstream and upstream traffic at different copper cable lengths*

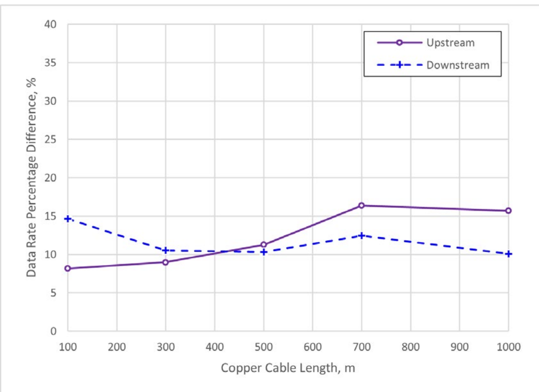
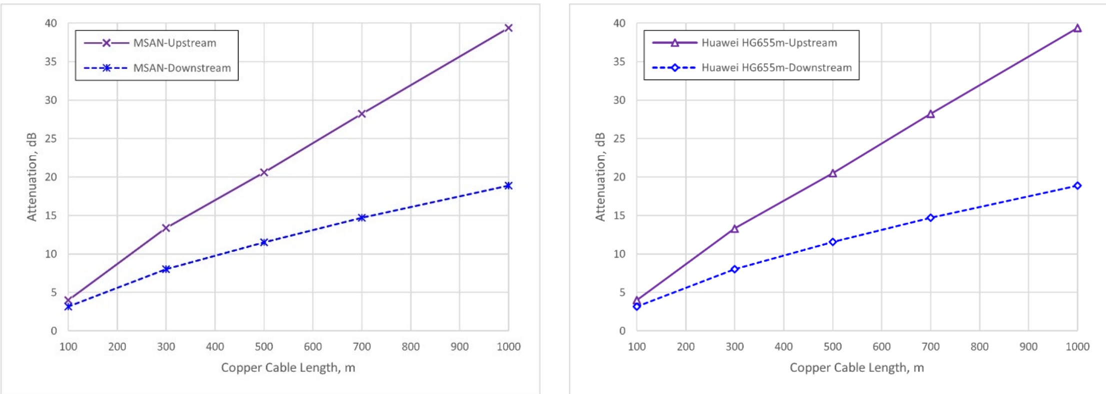


Fig. 6 *The percentage difference between the data rate transmitted by the MSAN and the data rate received by the Huawei HG655m modems for downstream and upstream traffic*

Since the MSAN's maximum downstream actual line rate and Huawei HG655m modems' maximum downstream line rate are 115832 kbps (115.8 Mbps) and 100009 kbps (100 Mbps), respectively, the percentage difference for 100 m copper cable length is the highest at approximately 14.7 %. On the other hand, upstream traffic received the least, with an 8.2 % disparity between the actual line rate from MSAN and the line rate at the Huawei HG655m modems. When the network line distance between MSAN and CPE device is 300 m, the optimal data rate in the access network for both downstream and upstream traffic is achieved, with about 10.5 % and 9 % percentage differences for downstream and upstream, respectively. The percentage difference for upstream traffic continues to rise beyond 500 m of network line distance. At longer distances and higher frequencies, attenuation is anticipated to dominate due to crosstalk.

Before any connections to the CPE are established, the twisted-pair copper cable end line will be linked to the DP in the telephone and network lines. As a result, the original signals sent from MSAN to the CPE or Huawei HG655m modems will almost certainly experience severe loss and noise, resulting in increased line and signal attenuation. On high-frequency communication lines, signal attenuation is significant, resulting in data corruption.

Fig. 7 and Fig. 8 depict the line and signal attenuation between the MSAN and the Huawei HG655m modems over various copper cable lengths. It can be observed that both line and signal attenuations are nearly identical. As the copper cable extends from 100 m to 1000 m, there is a considerable increase in line and signal attenuation in the network line, causing a drop in the net data rates as in Fig. 5. According to Fig. 7 (b), the Huawei HG655m modems obtained excellent net data rates at a short distance of 100 m as the access network experienced the least downstream and upstream attenuation, 3.14 dB and 3.98 dB, respectively. Meanwhile, at 1000 m, the Huawei HG655m modems at the customer premises site suffered a more significant loss of net data rates as the line and signal attenuation are the highest, with 18.9 dB and 39.4 dB for downstream and upstream, respectively. The findings imply that the lower the line or signal attenuation is, the better for higher data rates. Line or signal attenuation of 40 dB and below is considerably very good for achieving higher data rates, 100 Mbps and 41.9 Mbps for downstream and upstream traffic, respectively.



(a) **(b)**

Fig. 7 *Line attenuation for downstream and upstream traffic (a) MSAN; (b) Huawei HG655m modems*

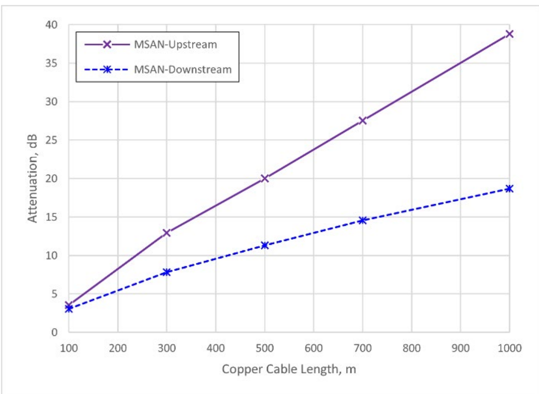


Fig. 8 *Signal attenuation for downstream and upstream traffic of MSAN*

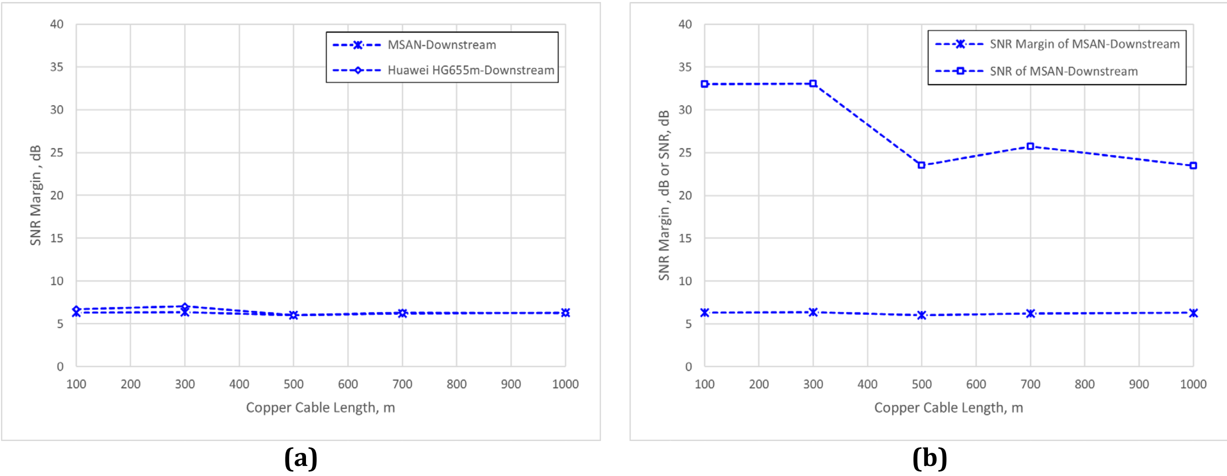


Fig. 9 *SNR margin and SNR data for downstream traffic (a) SNR margins of MSAN and Huawei HG655m modems; (b) SNR margin and SNR data of MSAN*

The SNR margin data in the experimental access network is evaluated based on the variation of copper cable length, as plotted in Fig. 9 (a). The SNR margin varies between 6 dB and 7 dB for downstream traffic. The MSAN and Huawei HG655m modems exhibit better SNR margin values with 6.9 dB and 6.68 dB, respectively, when the copper cable length is 100 m, while the SNR margin appears to decline as the network line distance extends to 1000 m. MSAN and Huawei HG655m modems had the lowest SNR margin when the data were collected at 500 m, with 6.1 dB and 6.03 dB, respectively. However, the network system remained in decent condition, as the SNR margin minimum limit in an access network should be at least 6 dB, thus leading to higher and better data rate speeds offered by the MSAN and Huawei HG655m modems. Fig. 9 (a) and (b) show the SNR margin and SNR data of MSAN for downstream traffic. The SNR to synchronous in dB at the speed of 115.8 Mbps (100 m of copper cable length), and 100 Mbps (300 m of copper cable length), for an ideal network line can be calculated using Eqn. (1) and the data from Fig. 9 (b) as 26.73 dB.

3.2 Huawei HG655m Modems Statistical Performance Analysis

In this section, the Ixia network equipment is configured to inject genuine network traffic. Low-performance, medium-performance, and high-performance throughputs are the three types of network traffic applied during experimental measurement. Throughput is the number of data packets successfully delivered from the source, MSAN, and received at the CPE or Huawei HG655m modems. Throughput data is an indication for determining and measuring the overall performance of a network connection.

As a result of the varying copper cable lengths in the network line, the signal transmission will have a latency or time delay; hence, a longer time is needed to finish the transmission process from MSAN to Huawei HG655m modems, leading to a degradation of the data rate speed. Aside from that, there is a correlation between throughput and bandwidth; whereas the system required a higher throughput, it also needed a larger bandwidth, and vice versa. However, in this section, the Huawei HG655m modems statistical performance analysis focused on a copper cable length of 500 m between MSAN and Huawei HG655m, with 1050 seconds of time duration for the data packet transmission, as there is a slight data rate percentage difference between MSAN and Huawei HG655m modems at this distance.

Fig. 10 shows a bar graph comparing the total data packets the Huawei HG655m modems received with various throughput options over 500 m of copper cable. At low-performance throughput, the Huawei HG655m modems only received 156496 data packets within 1050 seconds, while with medium-performance throughput, the CPE obtained approximately four times that amount, 645866 data packets. Meanwhile, the Huawei HG655m modems received the most data packets with high-performance throughput data injection, with 839311 data packets within 1050 seconds. Based on the findings, it is apparent that increased bandwidth in the access network line aids in optimizing data packet transmission between the ISP and the CPE, lowering network latency. Aside from that, as shown in Fig. 11, it can be confirmed that when the access network's throughput is more significant, data rate speeds for both downstream and upstream traffic will also increase.

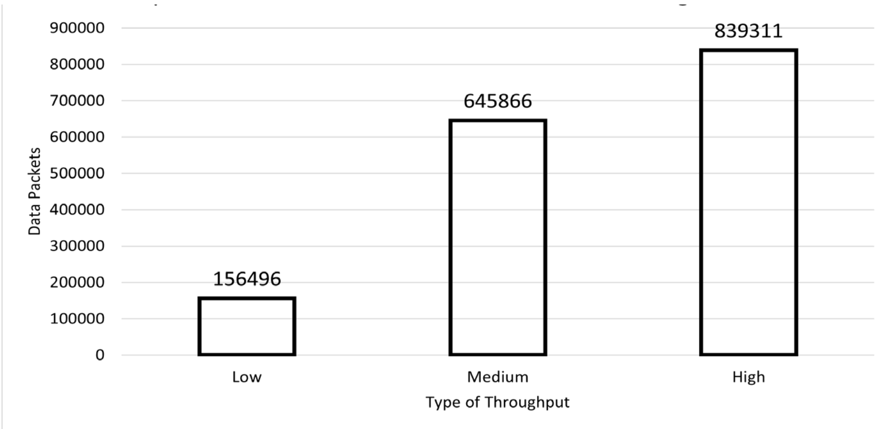


Fig. 10 *Comparison of data packets received by Huawei HG655m for different throughputs at 500 m*

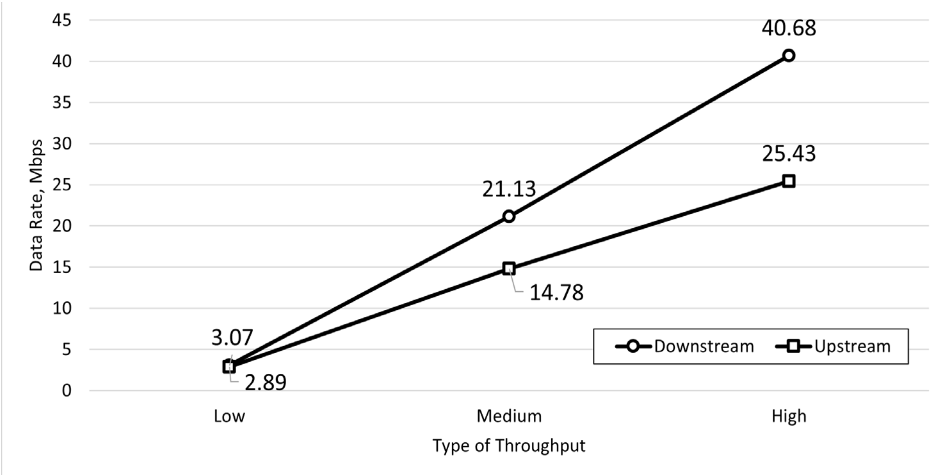


Fig. 11 *Comparison of actual line rate for Huawei HG655m for different throughputs at 500 m*

4. Conclusion

In this paper, the LOPs data and statistical performance of the Huawei HG655m modems have been analyzed and studied. This statistical data on LOPs and Huawei HG655m modems over a VDSL2 network is vital in assisting an engineer during their troubleshooting effort. The access network is configured with VDSL2 technology with a 17a profile, which offers a maximum operating bandwidth of 17.664 MHz and net data rates of 100 Mbps. Various copper cable lengths between MSAN and Huawei HG655m modems are deployed to predict and study the actual line rate, line and signal attenuation, and SNR margin that the Huawei HG655m modems can support. As the distance between MSAN and Huawei HG655m modems increases, the probability of the actual line rate for downstream and upstream traffic being degraded is higher due to the factor of line and signal attenuation. Besides that, the network throughput is also injected into the access network line, and the network throughput is categorized into three conditions: low, medium, and high. High-performance throughput offers better performance as it has higher data rate speeds for downstream and upstream traffic and can have higher data packet transmission rates than low- and medium-performance throughputs.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Fauziahanim Che Seman, Saizalmursidi Md Mustam, Khalid Isa, Zuhairiah Zainal Abidin, Khairun Nidzam Ramli;* ***data collection:*** *Raden Mohamad Syaifullah Raden Sumarto, Dang Fillatina Hashim;* ***analysis and interpretation of results:*** *Raden Mohamad Syaifullah Raden Sumarto, Saizalmursidi Md Mustam, Fauziahanim Che Seman;* ***draft manuscript preparation:*** *Raden Mohamad Syaifullah Raden Sumarto, Saizalmursidi Md Mustam. All authors reviewed the results and approved the final version of the manuscript.*

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