2024 IEEE International Conference on Big Data and Smart Computing (BigComp) | 979-8-3503-7002-7/24/$31.00 ©2024 IEEE | DOI: 10.1109/BIGCOMP60711.2024.00093

Performance Metrics and Strategy for Evaluating Internet Speed Tests in Fixed Broadband Networks

Anuparp Boonsongsrikul
Faculty of Engineering
Burapha University
Chonburi, Thailand
anuparp@eng.buu.ac.th

Norrarat Wattanmongkhol
Faculty of Engineering
Burapha University
Chonburi, Thailand
norrarat@eng.buu.ac.th

Athita Onuean
Faculty of Informatics
Burapha University
Chonburi, Thailand
athita@it.buu.ac.th

Krisana Chinnasarn
Faculty of Informatics
Burapha University
Chonburi, Thailand
krisana@it.buu.ac.th

Nuttaporn Phakdee
Faculty of Informatics
Burapha University
Chonburi, Thailand
nuttaporn@go.buu.ac.th

Teerapol Silawan
Faculty of Engineering
Chulalongkorn University
Bangkok, Thailand
Teerapol.S@chula.ac.th

Anirut Kantasa-ard
Faculty of Logistics
Burapha University
Chonburi, Thailand
anirut.ka@go.buu.ac.th

***Abstract*— The performance metrics play a crucial role in evaluating a Service Level Agreement (SLA) between Internet Service Providers (ISPs) and their customers. This paper introduces indicators designed for monitoring a network's performance over both short and extended periods. In the short term, the performance indicators encompass ping, jitter, download speed, and upload speed. Meanwhile, for the long term, the suggested indicators include average download percentage, average upload percentage, continued network functionality, and network reliability. These performance indicators can serve as criteria for establishing a new SLA while considering all stakeholders involved.**

Keywords*—*Measurement and Instrument, FTTx Networks, Reliability, SLA, Performance

I. Introduction

Recently, a survey encompassing over 750 internet users from diverse backgrounds and locations was conducted to pinpoint their primary concerns regarding internet access. C. Smith (2023) noted that reliability and internet speed emerged as the main pain points for internet customers [1].

Government bodies like the Federal Communications Commission (FCC) in the US, Autorité de Régulation des Communications Électroniques et des Postes (ARCEP) in France, and the National Information Society Agency (NIA) in South Korea have begun relying on internet speed tests to gauge broadband internet speed. Various performance metrics and methodologies are utilized to assess internet performance, yielding different speed test results.

In the US, average download speeds in 2021 ranged between 100 Mbps to 1,000 Mbps. Participating ISPs showed an average download speed of 193.9 Mbps, marking a 33% increase from the previous report (edition 10) and a 43% increase from edition 9. During peak hours (7:00 pm to 11:00 pm local time), ISPs predominantly exceeded advertised speeds. This report evaluated 10 broadband service providers using 12 different technologies nationwide, observing that 8 out of 12 technologies delivered speeds surpassing advertised rates. The speed metrics employed an 80/80 system, considering satisfaction rates based on at least 80% of the advertised speed for upload or download speeds [2].

In France, webpage loading times for different access types were recorded. For instance, Asymmetric Digital Subscriber Line (ADSL2+ or VDSL2) took 2.5 to 3 seconds to load a webpage, while Hybrid Fiber-Coaxial (HFC) or Fiber-To-The-Last-Amplifier (FttLA) networks took around 2 seconds. On the other hand, Fiber-To-The-Home (FttH) networks loaded a webpage in about 1.4 seconds, boasting a download speed of approximately 325 Mbps and an upload speed of roughly 120 Mbps [3].

In South Korea, a grading system for broadband internet service was introduced, classifying the transmission rate into five grades for evaluation: 'S' (superior), 'A' (excellence), 'B' (normal level), 'C' (insufficient level), and 'D' (quite insufficient) based on scored percentages [4].

This paper addresses two primary concerns. Firstly, the variability in performance metrics used by different countries to assess internet speed tests in fixed broadband networks poses a challenge in standardization and cross-regional compliance. Secondly, consumer understanding of internet speed tests may be limited, potentially leading to misconceptions about their internet service. Educating users on how speed tests function and the factors influencing results is crucial for a more informed interpretation.

The paper's objectives are to present performance metrics based on latency, internet speed, and network reliability, and to propose a strategy for evaluating internet speed tests. The contribution lies in presenting a conceptual framework for assessing network reliability in fixed broadband networks in the long term.

Therefore, this paper aims to present performance metrics based on latency, internet speed, and network reliability. Additionally, it aims to propose a strategy for evaluating internet speed tests. The contribution of this paper lies in presenting a conceptual framework for evaluating network reliability in long-term in fixed broadband networks.

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DOI 10.1109/BigComp60711.2024.00093

II. PERFORMANCE METRICS FOR INTERNET SPEED TEST

Performance metrics can be categorized into two groups. First, the evaluation of short-term internet speed tests includes measurements such as ping, jitter, download speed, and upload speed. Second, the evaluation of extended-period internet speed tests involves factors like download percentage average, upload percentage average, continued functionality, and network reliability.

A. Ping

A ping (Packet Internet or Inter-Network Groper) measures the round-trip time for data packets sent from a source computer to a destination computer and back again. The 'ping' command, by default, sends only four packets and data sizes of merely 32 Bytes to prevent burdening the internet network. Nevertheless, in sending each packet from the source to the destination, there might be differing times due to various routes and traffic. Therefore, there needs to be an average time taken into account for the transmissions. The computation of a ping average can be demonstrated using equation (1).

$$Ping = \frac{1}{n}\sum_{i=1}^{n} P_i \tag{1}$$

Ping is an average time taken by the tested packets to travel, measured in milliseconds. P_i represents a time taken by the packet in sequence i that has been tested and measured in milliseconds. The i is an integer ranging from 1 to n, where n represents the maximum sequence of packets tested.

B. Jitter

Jitter refers to the variation in the delay of packet arrival times. It measures the inconsistency or fluctuations in latency over a period of time. Its value close to 0 signifies stability, while a significantly higher value indicates reduced stability, potentially leading to internet usage issues. For instance, music streaming may experience disjointed audio, or gaming visuals could intermittently lag. Such occurrences can stem from multiple factors, including an unstable internet network or excessive signal sharing causing transmission interference. Therefore, it's crucial for Jitter to maintain a low value close to 0. The computation of jitter can be demonstrated using equation (2).

$$Jitter = \frac{1}{m}\sum_{i=1}^{m}\left(P_{i+1} - P_i\right) \tag{2}$$

Jitter is an average time of (P_{i+1} - P_i) presented in milliseconds. The i is an integer ranging from 1 to m, where $m = n$-1 and n is the sequence number of the last packet sent to the destination.

C. Download speed

To measure download speeds, the amount of data can vary from 2 KBytes to 128 Mbytes [5]. Let Y Bytes represent the data quantity for measuring download speeds. When data is transmitted from a cloud server on the speed test platform to a PC, Y is divided into 'n' packets. While these packets might have slight differences in size, the majority of packet sizes usually remain consistent. Therefore, the calculation of download speed requires consideration of bit sizes rather than byte sizes, as shown in equation (3).

$$dl = \frac{\sum_{i=1}^{n} BZ_i}{\sum_{i=1}^{n} t_i} \tag{3}$$

dl signifies the download speed rate, measured in Mbps. BZ_i refers to the number of bits in the packet sequence of 'i', measured in Mbits. 'n' represents the total number of packet transmissions. 't' indicates the time taken for downloading each packet.

D. Upload speed

For measuring upload speeds, the amount of data can range from 480 Bytes to 105 Kbytes [5]. Let Y Bytes denote the amount of data used to measure upload speeds. As data is transferred from a PC to a cloud server on the speed test platform, Y is fragmented into 'n' packets. While these packets might exhibit slight variations in size, the majority of packet sizes generally remain consistent. Therefore, to accurately calculate upload speed, it's crucial to consider bit sizes instead of byte sizes, as depicted in equation (4).

$$ul = \frac{\sum_{i=1}^{n} BZ_i}{\sum_{i=1}^{n} t_i} \tag{4}$$

ul denotes the upload speed rate, measured in Mbps. BZ_i represents the number of bits in the packet sequence of 'i', measured in Mbits. 'n' signifies the total number of packet transmissions. 't' signifies the time taken for uploading each packet.

E. Download percentage average

Download Percentage Average (DPA) is useful for comparing with the Advertised Internet Package (ADP) and determining the traffic intensity on different days. The download speed rate (*dl*) is accumulated, and the cumulative dl is averaged over a 24-hour period. 'n' represents the number of *dl* measurements taken within 24 hours. The computation for *dl* can be derived using equation (3), while DPA is presented in equation (5).

$$DPA_{24hr} = (\frac{1}{ADP}) \times (\frac{1}{n}\sum_{i=1}^{n} dl_i) \times 100 \tag{5}$$

F. Upload percentage average

Upload Percentage Average (UPA) is similarly beneficial for comparing with the Advertised Internet Package (ADP) and evaluating traffic intensity on different days. The upload speed rate (*ul*) is accumulated and then averaged over a 24-hour period. 'n' signifies the number of *ul* measurements within 24 hours. The computation for *ul* can be derived using equation (4), while UPA is demonstrated in equation (6).

$$UPA_{24hr} = (\frac{1}{ADP}) \times (\frac{1}{n}\sum_{i=1}^{n} ul_i) \times 100 \tag{6}$$

G. Continued network functionality

To monitor network functionality, internet speed tests should be conducted periodically at a sampling rate of X. For example, a sampling rate of X=5 means that the program conducts internet speed testing every 5 minutes. Let n_{EX} denote the expected number of data entries in the internet speed test database, and n_S represent the actual number of recorded data entries in the internet speed test database. The non-continued network functionality can be intuitively expressed in equation (7) and alternatively presented in equation (8) where n_U represents the unsent data, calculated as $|n_{EX}-n_S|$.

$$NC = \left| \frac{n_{EX} - n_S}{n_{EX}} \right| \tag{7}$$

$$NC = \frac{n_U}{n_{EX}} \tag{8}$$

The continued network functionality, derived from equation (8), is expressed as equation (9). A value of 'C' equal to 1 indicates that there is no difference between the numbers of n_{EX} and n_S. This signifies that no data has been lost for the sent data.

$$C = 1 - NC \tag{9}$$

H. Network reliability

Network reliability is often correlated with sampling rates in testing because higher sampling rates can offer a more accurate representation of the network's performance over time. Network reliability must fulfill the commitment of the advertised internet package, ensuring consistency in both download and upload speeds as well. Network reliability can be divided into three types. First, it is based on the advertised internet package represented by equation (10).

$$NR_{ADP} = C\left(\frac{DPA_{24hr} + UPA_{24hr}}{2} \right) \tag{10}$$

Second, network reliability relates to the connection between the OLT (Optical Line Terminal) and ONT (Optical Network Terminal). In FTTx networks, the bidirectional communication between the OLT and ONT, as illustrated in Fig. 1, occurs through fiber-optic cables. The OLT is responsible for overseeing multiple ONTs, managing bandwidth allocation, and regulating data flow to ensure uninterrupted connectivity and effective service provision. Conversely, the ONT receives signals transmitted by the OLT and disseminates them to end-users, maintaining the quality of service promised by the ISP. The high bandwidth requirements might lead to unreliability, indicating the correlation between the ONT and OLT, as depicted in equation (11).

$$UR_{FTTx} = \left| \frac{NR_{OLT} - NR_{ONT}}{NR_{OLT}} \right| \times 100 \tag{11}$$

Hence, the network reliability based on the relationship between the OLT and ONT, derived from equation (11), can be denoted as equation (12).

$$NR_{FTTx} = 100 - UR_{FTTx} \tag{12}$$

Third, the network reliability relationship between the OLT and ONT, in conjunction with the advertised internet package, derived from equations (12) and (10), is presented in equation (13).

$$NR = \left(\frac{1}{100} \right) \times NR_{FTTx} \times NR_{ADP} \tag{13}$$

III. A Proposed Stretegy in Evaluating Internet Speed Test in Fixed Broadband networks

Reliability and internet speed have emerged as the primary concerns for internet customers. To verify and address these issues, the proposed measurement strategy focuses on evaluating both the operator's office and their customers' homes. The measured results from the operator's office serve as a benchmark, while measurements from customer homes validate reported customer experiences.

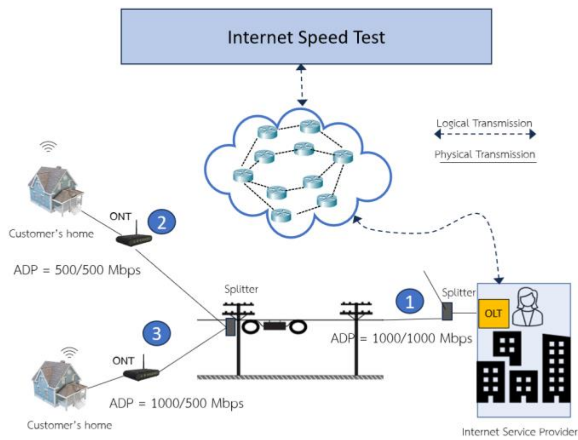

Fig. 1. A scenario in evaluating internet speed test in fixed broadband networks.

As shown in Fig. 1, let's consider the benchmark as 1000/1000 Mbps. The advertised internet package for the first customer is 500/500 Mbps, and for the second customer, it is 1000/500 Mbps. Download and upload speeds are calculated using equations (3) and (4), respectively. These daily average results are derived using equations (5) and (6).

Network reliability is evaluated using equations (10)-(13). The benefits of employing the performance metrics and proposed strategy include: 1) identifying days with higher unreliability, 2) determining the effectiveness of advertised internet packages, and 3) pinpointing locations causing slow or unreliable internet connections.

In addressing location-based issues, Z. Abdellaoui (2021) highlighted two physical reach options, 10 and 20 km, where physical reach refers to the maximum distance between the ONT and the OLT [6]. Therefore, according to the proposed strategy, the measured points between No.1 and No.2, or between No.1 and No.3 in Fig. 1, should fall within the specified physical reach range.

To establish a new Service Level Agreement (SLA) while considering all stakeholders, the proposed grading system using performance metrics can be categorized into four grades for evaluating internet speed tests in fixed broadband networks.

Grade 'A' signifies excellence, scoring over 90%. Grade 'B' indicates a good level, scoring between 90% and 75%. Grade 'C' signifies a normal level, scoring between 75% and 50%. Lastly, Grade 'D' represents an insufficient level, scoring below 50%.

IV. Preliminary Findings

Between June 27 and September 1, 2023, internet speeds were measured at the ONT locations using different advertised internet packages by 200 customers residing in the Eastern region of Thailand. The preliminary findings indicate that the advertised internet package offering speeds of 501-750 Mbps provided an average PDA_{24hr} of 124.95 and an average UDA_{24hr} of 99. These values were higher than advertised and were the highest compared to other advertised internet packages, as illustrated in Fig. 2 and Fig. 3.

Similarly, between June 27 and September 1, 2023, internet speeds were measured at 30 distributed OLT locations, with the advertised internet package of 1000/1000 Mbps serving as a benchmark. The preliminary findings showed that the averaged DPA_{24hr} and UPA_{24hr} were 85.75 and 83.3, respectively. These early results indicate that a gap in internet speeds between the ONT and OLT locations still exists. Specifically, the difference in DPA_{24hr} between the ONT and OLT locations at 750-1000 Mbps is approximately less than twice.

Fig. 2. Comparison of DPA_{24hr} among various advertised internet packages

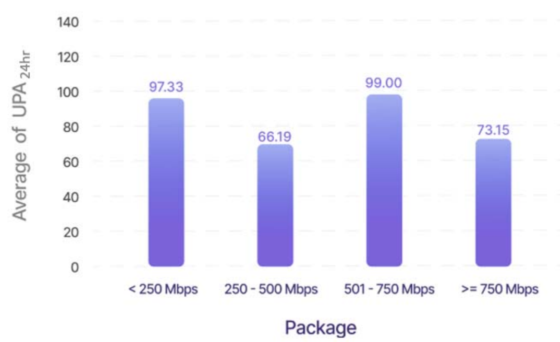

Fig. 3. Comparison of UPA_{24hr} among various advertised internet packages

V. Discussion

Network reliability stands as the primary factor in evaluating internet quality. Our methodology offers measurements and a strategy to pinpoint the location of issues causing slow internet speeds. Implementing our approach allows operators to promptly address problems, thereby saving time and budget allocated to issue identification. While OTDR (Optical Time Domain Reflectometer) can precisely identify power loss positions in optical cables without requirements of multiple measured points, it's rarely used for continuous network traffic monitoring throughout the day. Conversely, our method is applicable for consistent monitoring of network traffic in fixed broadband networks. This advantage enables daily monitoring and yields yearly network traffic results [7].

Our approach also exhibits scalability by expanding the number of cloud servers to record data entries from internet speed tests. A prior study by A. Kantasa–ard (2023) highlighted the optimal positioning of cloud servers for an internet speed test platform [8]. Similarly, N. Feamster (2020) stressed the importance of native applications or running speed tests on embedded devices for accuracy with increasing network speeds, aligning with the hardware and software of our approach [9].

Contrarily, K. MacMillan (2022) proposed utilizing two web applications to assess internet quality [10]. However, this scheme lacks performance metrics for evaluating network reliability. In contrast to our methodology, it provides comprehensive performance metrics to evaluate network reliability and operates on native applications. A comparative analysis between work [10] and our scheme is presented in Table I.

TABLE I. Comparison of two approaches.

Performance metrics	K. MacMillan (2022)	Our scheme (2023)
Strategy	Comparing between two web applications	Comparing between the OLT and ONT
Latency	☑	☑
Jitter	N/A	☑
Download speed	☑	☑
Upload speed	☑	☑
DPA	N/A	☑
UPA	N/A	☑
NR_{FTTX}	N/A	☑
NR_{APD}	N/A	☑
NR	N/A	☑
Running on	Web-applications	Native-applications

VI. Conclusion

This paper has introduced performance metrics and a strategy for assessing internet speed tests within FTTx networks. Specifically, it focused on conducting internet speed tests between the OLT and ONT locations. Network reliability remains pivotal in evaluating internet quality. The proposed scheme offers measurements and a strategy to monitor locations causing slow internet speeds. Implementing this approach enables operators to expedite the resolution of issues. Moreover, the performance indexes introduced can aid in establishing a new Service Level Agreement (SLA) that considers the perspectives of all stakeholders.

ACKNOWLEDGMENT

The research would not have been possible without the support of the NBTC-Broadcasting and Telecommunications Research and Development Fund for Public Interest (BTEP) in developing the system for quality broadband internet of the operator (B2-005/4-2-64). Gratitude is extended to all the experts, consultants, and sample users in Thailand who contributed to this research and helped achieve its goals. Furthermore, acknowledgment goes to the Faculty of Informatics, Burapha University, for their financial support.

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