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A Framework for Geospatial Speed Test Platform using Holistic Approach

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ABSTRACT

This study proposes a framework for a geospatial internet speed test platform, specifically designed to assess the broadband network experience in Thailand. The novelty of this research lies in its comprehensive approach to broadband internet quality assessment, uniquely measuring internet performance from ISPs sources to end-users using custom-designed reTerminal hardware devices based on Raspberry Pi 4. Tests were conducted involving four major broadband service providers. Data were collected from 30 speed test devices, which were installed at the source of each service provider network, and 200 internet user devices. The total number of data records collected was 25,000. The results indicated that the Download Percentage Average was 64.30%, while the Upload Percentage Average was 71.84%. The average latency and jitter were 11.82 ms and 16.53 ms, respectively. All speed test parameters at the source of the ISPs network were found to reach almost 100% compared to the speed test network devices of the ISPs. This means that ISPs provide internet quality according to the standards set by the NBTC. These results can assist the NBTC for setting relevant policies or strategies to improve the quality of broadband internet services at user's sites.

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Keywords: Broadband Internet Speed Test, Holistic Approach, Geo-special Platform, Sustainable Digital Infrastructure, Government Regulated Service

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1. INTRODUCTION

Broadband Internet service plays a pivotal role in the advancement of national development, serving as a cornerstone of modern telecommunications. It empowers citizens by providing them with rapid and efficient access to a myriad of information sources and digital services, which are essential in today's fast-paced world. This accessibility not only enhances individual knowledge and skills but also fosters economic growth and innovation within the broader society. As highlighted by DataReportal [1], at the beginning of 2023, Thailand boasted an impressive 61.21 million internet user, reflecting a substantial internet penetration rate of 85.3%. This statistic underscores the widespread adoption of digital technologies nationwide, indicating that a significant majority of the population is now connected to the online world. Furthermore, the data reveals that there were approximately 52.25 million social media users in January 2023, which constitutes a remarkable 72.8% of Thailand's total population. This high engagement with social media platforms illustrates the increasing importance of digital communication and social interaction in the lives of Thai citizens.

In addition to internet and social media usage, the landscape of mobile connectivity in Thailand is equally noteworthy. With a staggering 101.2 million active cellular mobile connections reported at the start of 2023, the country has achieved a mobile connection rate that exceeds its total population, reaching an extraordinary 141.0%. This phenomenon indicates not only the prevalence of mobile devices but also highlights the critical role that mobile technology plays in facilitating communication, commerce, and access to information across diverse demographics. Overall, the statistics paint a compelling picture of Thailand's digital landscape, showcasing the vital role of broadband Internet in driv-

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ing national development and enhancing the quality of life for its citizens. As the country continues to embrace digital transformation, the implications for economic growth, social connectivity, and educational opportunities are profound.

As a regulatory authority tasked with the oversight of telecommunications networks, the National Broadcasting and Telecommunication Commission (NBTC) has advocated advancements, stimulated competitive practices, and facilitated the establishment of comprehensive telecommunications networks across the whole country. Consequently, Thailand attained the 6th position in the global ranking for fixed broadband internet speed services in 2023 [2]. Nonetheless, the findings derived from the survey originate from a private organization, which operates independently of the NBTC's regulatory framework and, as such, lacks access to user' broadband internet speed data. Hence, NBTC seeks to gain comprehensive access to accurate data regarding the service quality experienced by distinct user groups. Therefore, this research has been undertaken to evaluate the quality and standards of broadband internet services through the development of the NBTC Speed Test Platform (NBTC-STP). This platform aggregates various Quality of Service (QoS) metrics including download and upload speed metrics, bandwidth, latency, jitter and packet loss which are essential for ensuring that data transmission meets the required standards for applications [3]. The NBTC-STP is designed to directly gather those data from users to ensure the acquisition of genuine information. It is also designed to collect additional information consisting of user registration, Internet Service Providers, geographical locations, and service packages. The accumulated data will subsequently prove essential for the analysis and examination of broadband internet service quality. In addition, that data can also be used as a reference database for future policy formulation and strategic planning for effectively supervising service standards among providers by the NBTC.

The research gap identified from the limitations of existing systems includes the lack of testing from the ISPs source. Many studies only test from the end-users' side, which prevents the identification of issues arising from network management comprehensively. Additionally, the use of low-performance tools, such as smartphones or general devices not specifically intended for measuring internet signals, limits the ability to reflect the actual quality of service provided by ISPs accurately. Previous research also failed to detect network-related technical issues effectively, such as the packet loss at the ISPs source. In this regard, we come up with the problem statement no. 1 as follows:

Question 1: What is the actual quality of network performance provided by ISPs versus the quality of network received at the end-users' sites?

In addition, many studies lack geospatial data analysis, which would help provide an overview of internet quality across various regions or areas. They also overlooked user behaviour data that impacts internet speed and stability at different times. Moreover, existing systems cannot support long-term usage or continuous data collection. In this regard, we come up with the problem statement no. 2 as follows:

Question 2: Is there any discrepancy in internet quality across various regions or areas?

This research, therefore, proposes solutions to address the above two issues, aiming to improve the accuracy and comprehensiveness of internet quality.

This paper is organized as follows. Section 2 provides an overview of the components of internet broadband speed tests, platforms, and related works. The proposed approach and framework, called "NBTC Speed Test Platform", is described in Section 3. Section 4 summarizes and discusses the service quality and internet performance of Thailand's broadband networks. The conclusion and future work are presented in the final section.

2. BACKGROUND AND RELATED WORKS

The advancement of internet technology and the growing demand for high-speed connectivity have led to the development of various tools and platforms to measure and evaluate broadband performance. This section explores the critical components that define internet broadband speed tests. Additionally, it provides an overview of popular speed test platforms and discusses relevant studies and advancements in the field, highlighting their contributions to understanding and improving broadband services.

2.1 Background

2.1.1 The National Broadcasting and Telecommunication Commission (NBTC)

NBTC holds significant responsibilities in regulating the broadcasting and telecommunications sectors. Its primary duties encompass ensuring compliance with legal and administrative frameworks, maintaining accountability, and balancing the interests of various stakeholders [4]. The NBTC manages several key areas to maintain and improve telecommunications services throughout the country: Licensing, Spectrum Management, Consumer Protection, Telecom Infrastructure Development, and Monitoring Competition. The NBTC serves as a key mechanism in driving the advancement of Thailand's information technology infrastructure. One of the NBTC's critical goals is to ensure that every village in Thailand has access to these essential services, both mobile broadband and fixed broadband. NBTC is empowered to provide basic telecommunications services, covering both the spatial dimensions: ensuring services reach all geographic areas, and the social dimension: making services available to all social groups, regardless of economic background.

2.2 Component of Internet Broadband Speed Test and Platforms

The critical components of an internet broadband speed test platform consist of various technical aspects that ensure accurate and comprehensive measurements of internet performance. These elements enable real-time analysis of key factors that contribute to the overall quality of an internet connection. As discussed by Feamster, N. and Livingood, J. [5] the essential components include the following:

Download and Upload Speed Measurement: These measurements determine how fast data can be transferred from the internet to the user's device (download) and from the device to the server (upload). Most platforms use multiple parallel TCP connections to test this component.

Latency and Jitter: Latency refers to the time it takes for a data packet to travel from source to destination and back (round-trip time), while jitter is the variation or inconsistency in latency over time. Both metrics are critical for ensuring a smooth and reliable network experience.

Server Selection and Network Bottlenecks: This component refers to how speed test platforms choose a server and manage potential network bottlenecks. Platforms often select the closest available server to minimize latency, but factors such as cross-traffic (other data being transmitted simultaneously) and the user's local network - especially if they are on Wi-Fi - can affect the results.

Hardware and Software Limitations: Device factors like older network cards, CPUs, or even operating systems can limit speed test results, even if the ISPs provides higher speeds.

These components work together to provide accurate insights into internet performance, though results can vary based on network congestion, device limitations, and other factors. Various platforms have been developed to measure internet speed, with the goal of providing unbiased assessments. Some well-known platforms among users include: Ookla Speedtest, Fast.com, nPerf, M-Lab, and Iperf.

However, all the platforms mentioned above are software-based and they can only measure speed test metrics at the end-users locations. As a result, they lack validation of the actual capacity provided by ISPs in their services. The comparative results of the proposed approach and the current platforms [6 - 11] are demonstrated in the Table 1.

2.3 Related Works

In 2019, Jantavongso, S., and Chimmanee, S. [12] shed light on the methodology and the results pertaining to the efficacy of 4G technologies for mobile internet services in Bangkok, Thailand. The experimental framework comprised internet services assessed in both stationary and mobile contexts to analyze latency, user data rates, and speed metrics. Comparative performance assessments were executed among three predominant mobile network operators, namely AIS, DTAC, and TrueMoveH, during December 2016. The outcomes of the investigation may facilitate operators in establishing benchmarks for their existing internet services, at the same time concurrently assisting consumers in selecting appropriate services that align with their requirements devoid of commercial prejudices. Subsequently, in 2020, Daengsi, T. et al. [13] performed a comparative analysis of 4G average download speeds in Thailand leveraging data sourced from the OpenSignal application, which is provided by the analytics firm, alongside the Mobile Internet Quality (MIQ) platform, a local framework for measuring mobile internet quality. OpenSignal ranked Thailand at 77th position, reporting an average speed of 5.7 Mbps following the analysis of Q1/2019 data. Conversely, results derived from MIQ's server utilizing Q1/2019 data indicated an av-

Table 1: *Comparison of the proposed approach and existing software-based speed test platforms.*

Key Features	The Proposed Framework	Ookla Speedtest	M-Lab	OpenSpeedTest
Test Type	Hybrid (Hardware + Software)	Software only	Software only	Software only
Test Equipment	Dedicated hardware device (reTerminal based on Raspberry Pi CM4) for ISPs and User's own device	User's own device	User's own device	User's own device
Measurement Points	Both ISPs source and end-users	End-users only	End-users only	End-users only
Automated Data Collection	Every 30 minutes (ISPs-side),	User-dependent	User-dependent	User-dependent
Data Visualization	Geospatial dashboard (maps, charts, detailed data)	Individual results only	Limited public data	Individual results only
Server Location Optimization	Hybrid Partitional Clustering	N/A	N/A	N/A
Use in Regulatory Oversight	Directly supported (NBTC)	Not directly supported	Indirectly supported	Not directly supported

erage download speed of 10.7 Mbps, which stands in contradiction to OpenSignal's findings. Nevertheless, this value remains below the global average download speed of 17.6 Mbps. Mok, R. K. P. *et al.* [14] created a cloud-based application for speed testing that harnessed the infrastructure of Ookla, Comcast, and M-Lab to conduct network throughput measurements of both upload and download speeds. Data were systematically gathered over a five-month period from May to September 2020 from a total of 458 servers located in the United States and Europe. The performance outcomes indicated that between 30% -70% of the evaluated Internet Service Providers (ISPs) demonstrated substantial throughput deterioration from the peak throughput recorded during the day.

In 2021, Daengsi, T. *et al.* [15] explored mobile internet speeds employing three speed testing applications: SpeedTest, OpenSignal, and nPerf. Their research evaluated the Quality of Service (QoS) on the concourse level of 60 BTS Sky Train stations. A stationary assessment was conducted utilizing 5G equipment from a single service provider across all three speed testing platforms. Each application collected data 180 times. The results of the tests disclosed discrepancies in performance with respect to speed and latency among the applications. The download rates were 403.5 Mbps for SpeedTest, 326.4 Mbps for OpenSignal, and 291.6 Mbps for nPerf. Upload velocities were documented at 97.2 Mbps, 83.4 Mbps, and 183.9 Mbps for SpeedTest, OpenSignal, and nPerf, respectively. In 2021, Deng, X. *et al.* [16] proposed a sophisticated platform designed for the analysis and visualization of extensive datasets derived from internet speed test data collected through M-Lab in Australia, the United Kingdom, and the United States. The datasets consist of 17 million observations collected between 2015 and 2016. The analysis considered various quality of service indicators, including speed, latency, and loss, across a range of geographical locations and time intervals.

Paul, U. *et al.* [17] utilized internet speed data sourced from the Ookla platform, spanning the period from 2020 to early 2021 for all 50 states, together with demographic data obtained from the U.S. Institute for Economic and Social Research. Their primary aim was to examine internet performance including geographical locations and income levels. The analysis was systematically divided into six quarters, incorporating median values and interquartile range (IQR) metrics. The findings indicated that variations in states, geographical contexts, and income significantly influence the performance of internet download speeds.

In 2022, Han, J. *et al.* [18] conducted a comparative analysis to assess the validity of various internet speed performance measurement platforms, namely Ookla, Fast, and iPerf3. The evaluation was performed under a range of conditions, encompassing variations in test duration, thread quantity, congestion control algorithms, and server locations. Speed test data were gathered in Australia and the United Kingdom. The results revealed significant discrepancies in measurement outcomes across diverse Internet Service Providers (ISPs), levels of technological accessibility, and geographic locations. In 2022, Jembre, Y. Z. *et al.* [19] reported that the National Information Association (NIA) of the Republic of Korea implemented multiple methods to assess the quality of mobile broadband internet services. For Method 1, evaluators traveled by vehicle and on foot to measure performance using an application installed on assessment devices. The measurement locations were randomly sampled to represent the entire country. The device used for testing was the Galaxy Note 8, selected as the assessment device for 2018. Method 2 involved the use of an RF scanner tool by evaluators to verify ISPs coverage claims. Method 3 utilized data from a statistically sampled population through an application designed to assess customer satisfaction. These comprehensive methods were performed to ensure a thorough evaluation of internet service quality across diverse situations.

In 2023, Daengsri, T. *et al.* [20] investigated the service quality of 5G networks offered by two service providers in Thailand. The evaluation encompassed testing internet speed again at 60 BTS Skytrain stations utilizing mobile applications including nPerf, OpenSignal, SpeedTest, and SpeedMaster. The findings revealed average download and upload speeds of 240.3 Mbps and 87.3 Mbps, respectively. The latency and jitter averages were recorded at 19 ms and 8 ms, respectively. The analysis within the study also noted variances in signal performance between the 5G networks of the two service providers. Also in 2023, MacMillan, K. *et al.* [21] provided an in-depth analysis of Ookla, the largest speed test platform, focusing on server deployment strategies and their impact on Internet speed measurements. By capturing monthly server metadata snapshots over three years. The analysis also highlights how server availability and locations are affected by factors like consumer protection policies and geopolitical tensions. Notably, over 64% of Ookla servers were removed from Russian ISPs due to geopolitical issues, and Japanese user lost 53% of on-net server access because of policy changes. These shifts emphasize the influence of geopolitical and regulatory factors on server distribution and user access. The methodology involved reverse-engineering Ookla's API to identify over 12,000 servers worldwide, with a focus on the platform's crowdsourced deployment model that maximizes geographical diversity. Results showed significant regional variations, with Brazil hosting the most servers, followed by the US and EU. Countries like Mexico and the Philippines achieved nearly full population coverage with fewer servers, underscoring disparities in server distribution. The study's findings reveal the complexities of server placement and its implications for broadband measurement accuracy, while future work aims to actively assess server effectiveness in light of these dynamic changes.

In the year 2024, Das, S., and Kalafatis, S. [22] compare iPerf TCP and OB-UDPST for network performance, focusing on their ability to improve communication speed and reduce packet loss under various conditions. iPerf and OB-UDPST were selected for their industry relevance and represent different protocols for performance analysis. Using a virtual testbed network (Mininet), the study evaluates metrics such as throughput, stability, jitter, latency, bit error rate (BER), round-trip time (RTT), and time to first byte (TTFB). Cross-traffic scenarios were introduced to assess each tool's effectiveness in real-world conditions, revealing how network congestion and speed testing interact. The findings indicate that OB-UDPST achieves higher throughput and stability compared to iPerf in cross-traffic situations and reduces network overhead, making it suitable for low-latency applications. While iPerf reaches stability quickly, OB-UDPST performs better under bottleneck conditions, highlighting the growing importance of UDP-based testing methods due to increased UDP traffic. However, OB-UDPST is not a direct replacement for iPerf; instead, it excels in specific scenarios, especially where low latency and minimal setup time are crucial.

3. METHODOLOGY

This section introduces the proposed framework for the development of Internet signal quality measurement devices, the NBTC Speed Test Platform (NBTC-STP). The NBTC-STP is designed to provide a comprehensive solution for measuring and analyzing internet speed and quality at both ISPs (source-terminal) and end-users (end-terminal) locations. The proposed framework integrates advanced speed test components with user-friendly features, allowing consumers, operators and regulatory authority to monitor broadband service quality. This section outlines the architecture, functionalities, and key components of the proposed framework used in developing speed test platform.

Ethical Approval: This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Burapha University IRB Committee at Burapha University, Thailand. The study was assigned approval number IRB1-072/2565.

Informed Consent: Informed consent was obtained from all participants involved in this study. The participants were fully informed of the purpose of the research, the procedures involved, the use of their data, and their right to withdraw from the study at any time without any consequences.

3.1 Concept of the Holistic Approach using reTerminal

This research designed a protocol to work on "reTerminal", built upon the Raspberry Pi Compute Module 4 (CM4). The primary purpose of this device is to precisely measure and assess broadband internet quality directly at the source—within the Internet Service Providers' (ISPs) premises. In this research, we customized the device for accurate data collection. The reTerminal is engineered to support high-speed Gigabit Ethernet communication. In particular, reTerminal, is used in this research work because we need compact and versatile computing solutions. As shown in Figure 1, the reTerminal RPi CM4 32GB is a compact HMI device powered by the Raspberry Pi Compute Module 4, featuring a quad-core ARM Cortex-A72 CPU, 4 GB RAM, and 32 GB eMMC storage. It integrates a LCD touchscreen via MIPI-DSI, dual-band Wi-Fi, Bluetooth 5.0, and a USB hub with USB 2.0 and USB-C interfaces. Onboard peripherals include an audio jack, microphone, motion and light sensors, and a TPM 2.0 for secure operations. A 40-pin GPIO header enables hardware expansion. Its modular design is well-suited for embedded, edge, and industrial IoT applications.

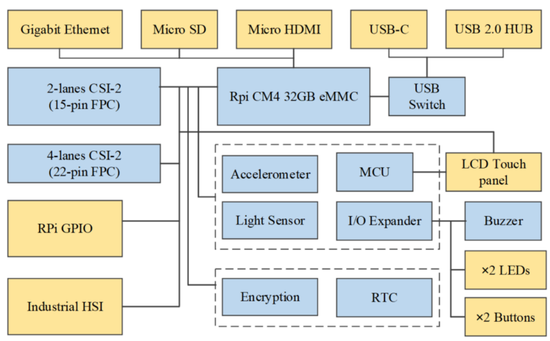


Fig.1: *Block diagram of the reTerminal RPi CM4 32GB.*

The reTerminal device significantly enhances data security and privacy by utilizing open-source software. This enables all measurement data to be securely stored on dedicated project servers, thereby eliminating the need to transmit data externally and reducing potential risks of data leakage or unauthorized manipulation. Additionally, the reTerminal operates automatically, conducting continuous measurements every thirty minutes for a specific schedule throughout the day. This method ensures comprehensive data collection reflecting actual ISPs service performance across different time intervals. Consequently, this innovative device substantially contributes to elevating Thailand's capabilities for regulating and maintaining broadband internet quality standards.

This study is experimental research involving volunteers who use the service, as well as internet service providers, participating in the research. The main objective of this study is to measure the quality of the internet at the source of ISPs network and the destination. As illustrated in Figure 2, at the source of ISPs' network, internet speed test devices (End Device No. 1 and No. 2) are installed at the central office or base station by connecting between the Optical Line Terminal (OLT) and the dotted line No.2 and 5. The operator provides the speed internet for downloading and uploading as 1000/1000 Mbps. At the destination, the internet speed test platform will be installed on a user computer by connecting between the Optical Network Terminal (ONT) of user and Docker server via dotted line No. 3. The internet speed data will be stored on a Docker server and forwarded to the main server, which collects data from the Docker server, as shown in dotted line No. 4. The results of the internet signal quality are displayed on a website connected to the main server, as indicated by dotted line No. 6.

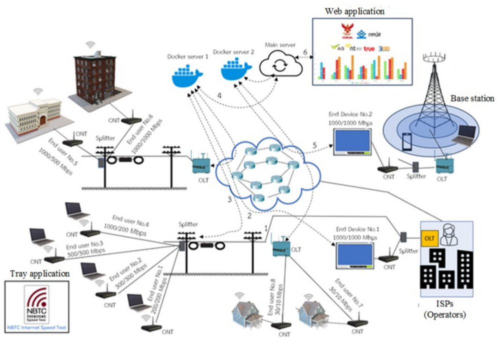


Fig.2: *A framework of the source-to-end speed test environment.*

To ensure confidence and fairness for all stakeholders, this research employs neutral instruments. The number of devices measured at each point by the operator must be equal or as close as possible. The testing program uses the same setup across all points. The workload is divided between two Docker servers for internet speed testing. Therefore, this experimental research requires the development of a comprehensive system, as shown in Figure 2, which includes: 1) the development of an internet speed testing platform, 2) the development and installation of 30 internet speed test devices (is called "end device") within the operators, and 3) the collection of internet speed data from 200 volunteers (is called "end user").

In this research, the test data files were embedded into the application to facilitate data transfer between the test machine and the Docker server. Specifically, a 100 MB file was used to test download speeds, while a 50 MB file was used for upload speed testing. Each test session lasted approximately 20–30 seconds. The use of various data file sizes aimed to evaluate internet quality under varying conditions, such as different internet plans, time of day, test locations, and shared bandwidth scenarios. This is because the variation in data sizes is one of the primary reasons for discrepancies in speed test results across platforms. Platforms that utilize larger test files generally yield more accurate and consistent speed measurements, better reflecting actual data usage based on the user's internet package.

3.2 The setup of reTerminal at ISPs sites

The internet speed test device is implemented on the reTerminal board, which is developed from the Raspberry Pi 4. The specifications of the reTerminal board are as follows: 4 GB RAM, microSD storage, ARMv8 x64 architecture, Quad-Core 1.5GHz processor, Ethernet and Wi-Fi connectivity, and a touch screen display, as shown in Figure 3. It is an industrial-grade board designed for high-speed performance. Additionally, it includes a cryptographic IC for security (Crypto Authentication) and a library that facilitates remote management. The device supports over-the-air (OTA) updates, enabling the process of sending new software, firmware, or other updates in a way that improves security and ensures convenience and speed. The program can run even without an internet signal, allowing it to keep track of time. It has a feature to set an on-off time for resetting temporary data in RAM, which helps the program run more stably. The device can also be configured to call various functions at specific times, and it can save data based on the desired date and time for analysis. The program installation creates an environment on the Raspberry Pi OS (64-bit) to support the installation of the NBTC_Speedtest program, which is designed and developed to facilitate communication between the end device and the Docker server. The installed components include Node.js, NVM, PM2, and VPN. Figure 3, illustrates the installation of the reTerminal devices at operators' sites.

Fig.3: *The installation of reTerminal devices at operators' sites.*

3.3 NBTC Speed Test Platform (NBTC-STP) Design

The NBTC-STP comprises two main components: the first component is the personal computer-based application, known as the “Tray-App”, and the second component is the web-based application, referred to as the “Web-App”. The “Tray-App” is installed on the user’s computer and sends the test results to cloud servers. On the other hand, the ‘Web-App’ is designed to present all user test results through a user-friendly dashboard for NBTC staff to monitor and regulate the service quality of each service provider. In addition, the ‘Web-App’ also allows each operator to access information about their service quality monitored by the NBTC-STP platform.

Figure 4 illustrates the overall operation of the internet speed test platform, with four components highlighted in the figure. Number 1 represents the testing section using the Tray App, which supports testing from 200 end users and 30 end devices. Data from the end devices are sent to the second component, the Docker Server (or Speed Test Server), which is installed in two locations. We have divided the testing areas and the locations where the internet signal quality measuring devices are installed into clusters. Docker Server 1 covers Mueang District, Chonburi Province, and supports internet speed tests for devices in Clusters 2 and 4. Docker Server 2 covers Mueang District, Chanthaburi Province, and supports internet speed tests for devices in Clusters 1, 3, and 5.

After the tester fills in their registration information to begin using the system for the first time, the system will automatically select a Docker Server to connect to the cluster number of the testing device, which is determined from the tester’s registration details. The distance between the testing device and the Docker Server will not affect the data transmission time for testing. Additionally, the Docker Server is designed to be powerful enough to support testing from both end devices and end users within each connected cluster, ensuring it can handle simultaneous tests from multiple users. The speed test data will be stored in a database called Postgres DB, located on a central server (Server Centre) temporarily installed on KYD’s platform in Chonburi. This server acts as the central hub for speed test data, displaying all data received from both Docker Servers. It also manages data access rights for different user groups: 1) NBTC officers, who serve as system administrators and can view all internet signal quality results; 2) service providers (operators), who can view the internet speed data for their customers and locations where their company’s end devices are installed; and 3) testers, volunteers, and general internet users who have registered in the system, who can only view their own internet signal quality results. The fourth component is the web application, which displays results through data visualization.

Both the ‘Tray-App’ and ‘Web-App’ components operate within the NBTC-STP are depicted in Figure 5. As indicated in the figure, Module No. 1 shows all the features available to the end user for interacting with the Speed Test Platform. As mentioned earlier, the ‘Tray-App’ is installed on individual end-users computers. The ‘Tray-App’ is used to directly collect data from 200 volunteers at their residences to verify the quality of the internet broadband received. The collected data is transmitted to Module No. 2, the Docker Server, for analysis of internet speed test quality. The Docker Server is deployed in two locations:

- Docker Server No. 1, located in Mueang District, Chonburi Province, supports user clusters 2 and 4, covering areas in Chonburi, Chachoengsao, and Prachinburi provinces.
- Docker Server No. 2 supports user clusters

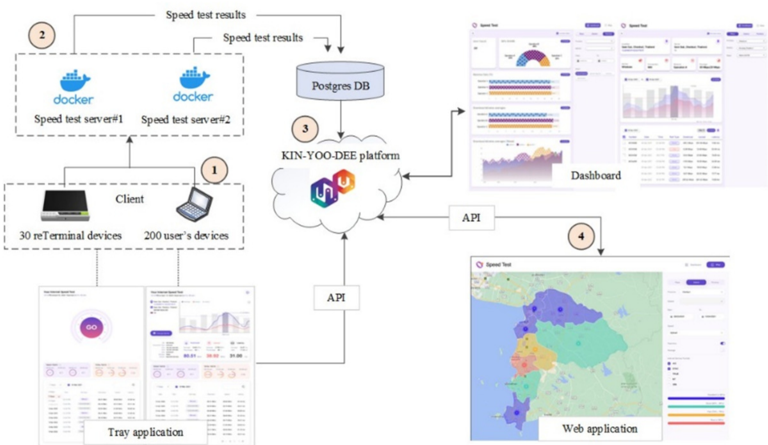


Fig.4: *System architecture diagram showing speed test data collection from client devices, processed via Docker servers and Postgres DB, and visualized through tray and web applications using KYD’s platform APIs.*

1, 3, and 5, encompassing regions of Chonburi Province (specifically Sattahip District), Rayong, Chanthaburi, Trat, and Sa Kaeo.

All the test data from volunteer users is then stored in the Postgres database (Module No. 3), temporarily hosted on KYD's platform in the Chonburi area during the project period. Finally, Module No. 4 represents the Web Application that consolidates all test results and presents them visually on the Dashboard to be used by either NBTC staff or ISPs operators.

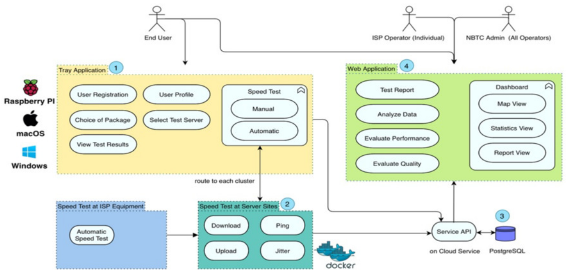


Fig.5: *System diagram showing interactions between tray applications and web applications.*

The NBTC-STP provides a geospatial-based interactive map to display the locations of the internet speed testing equipment. Alongside the map, there is a panel that indicates information about the place, district, province, and a time selection option. Users can also select which metrics of the speed test they want to view. In the lower section of the panel, there is a horizontal bar that indicates the summarized performance information of each location. The summarization of the quality levels of the internet speed is based on the average internet speed measured at end users' residences compared to the internet speed at the source of each service provider. The quality of internet service is denoted using four levels of download and upload percentage average speed.

- Level 1: Excellent quality (> 90%).
- Level 2: Good quality (80% to 89%).
- Level 3: Fair quality (50% to 79%).
- Level 4: Poor quality (< 50%)

3.4 Docker server location using hybrid partitional clustering

In this research, purposive sampling was employed in the eastern region of Thailand, allowing us to collect data and closely monitor the volunteers throughout the research process. We proposed the method hybrid partitional clustering to locate the Docker cloud server in our previous work [23]. We identified the applicable positions of cloud servers by using the Cluster Quality Index with Hopkins statistics [24]. Then, the K-Means technique was employed for clustering areas due to its ability to yield the highest index value, measuring the most significant data similarity within the same cluster (Silhouette width value). We set the value of K as five because the NbClust index [25] had the highest value as shown in Table 2.

Table 2: *The Result in Partitional Clustering.*

No. of cluster	NBClust index	Silhouette width value	
		K-Means	K-Medoid
2	5	0.26	0.32
3	7	0.32	0.39
4	1	0.41	0.40
5	**10**	**0.45**	**0.40**

We then used the centre-of-gravity method to locate the cloud servers in each significant group. Due to the limitation of establishing the cloud servers in this study, we had to merge adjacent clusters into one cluster, starting from five clusters that would cover all areas in the eastern region as shown in Figure 6. Then, cluster no. 2 and cluster no. 4, which included nine districts, were merged into Cloud Server no. 1. Likewise, cluster no. 1, no. 3, and no. 5, which included seventeen districts, were merged into Cloud Server no. 2. The first Docker server is situated in Chonburi Province (red star symbol), supporting connections to testers from cluster areas 2 and 4. The second Docker server is in Chanthaburi Province (blue star symbol), supporting connections to testers from cluster areas 1, 3, and 5 as shown in Figure 7. Selecting optimal locations for the two cloud servers involves considering crucial factors such as the number of testers in the area, latitude and longitude coordinates, and balancing the distance between the testers' locations and the Docker servers.

Fig.6: *The cluster visualization using the principal component analysis.*

Once we locate the Docker cloud server location, we then determine the sample group. We use the Proportional Allocation Method, as discussed in our previous work [23], to select the sample group. The sample size of broadband internet users in each cluster is determined by Equation 1.

$$n_i = \frac{nN_i}{N} \quad (1)$$

which n is a total sample size, N_i is a population size in each stratum, and N is total population size. This paper will implement this method to decide the suitable size of sample users in each cluster.

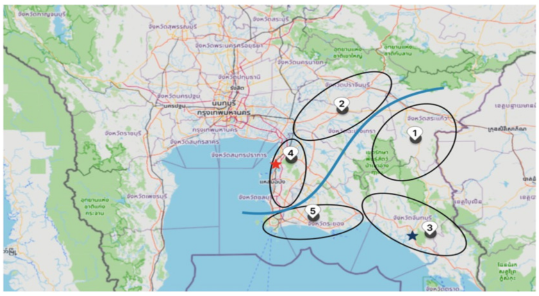


Fig.7: *Geospatial map of five clusters representing groups of end users.*

The main concept of proportional allocation [26, 27] is to identify the sample size in each stratum equal to the proportion of the sample units in the same stratum. However, we implement each variable in this way. The output variable denotes the quantity of user samples, denoted as n_i, in each respective district. Furthermore, the parameter n represents the aggregate number of user samples as defined in the terms of reference established by the NBTC, while N_i signifies the quantity of customer service units within each district, and N refers to the cumulative number of customer service units in the eastern region. The Proportional Allocation Method enables us to obtain the sample size for each Docker cloud server. For the Docker server locations in Chonburi Province (Cloud server no. 1), we derived 126 testers (the total sample users from clusters 4 and 5), and for the Docker server in Chanthaburi Province (Cloud server no. 2), we derived 74 testers (the total sample users from clusters 1, 2, and 3), as shown in Table 3. As a result of this sample size, we can effectively collect 10,000 data points from 200 users (volunteers).

Table 3: *Number of users in each cluster based on server location.*

Docker Server Position	Cluster Number	Number of Users
Chonburi	2	37
	4	97
Chanthaburi	1	16
	3	21
	5	29
Total		200

3.5 Performance metrics in the NBTC-STP

To evaluate system performance, general metrics such as latency, jitter, throughput [29, 30] and custom-defined mean download percentage, and mean upload percentage are employed, as described in the following discussion.

Download Percentage Average (DPA) is particularly valuable for benchmarking against the Advertised Internet Package (ADP) and for identifying variations in network load across days. The download rate (Dl) is measured repeatedly within a 24-hour timeframe, and the cumulative Dl values are averaged. The symbol n indicates the number of Dl measurements during this interval. The formulation of Dl is given in equation (2), whereas equation (3) specifies the computation of DPA.

$$Dl = \frac{\sum_{i=1}^{n} B_i}{\sum_{i=1}^{n} t_i} \tag{2}$$

Dl is defined as the download throughput, quantified in Mbps. Bi represents the bit volume of the $i-th$ packet sequence, measured in Mbits. The variable n corresponds to the aggregate number of packet transfers considered, whereas t reflects the elapsed time associated with downloading each packet.

$$DPA = \frac{1}{ADP} \cdot \frac{\sum_{i=1}^{n} Dl}{n} \cdot 100\% \tag{3}$$

Upload Percentage Average (UPA) functions as a useful metric for assessing compliance with the Advertised Internet Package (ADP) and identifying fluctuations in traffic conditions over multiple days. The upload speed (Ul) is recorded continuously within a 24-hour span, with cumulative values averaged. The notation n corresponds to the count of Ul measurements obtained during this period. Equation (4) specifies the computation of Ul, whereas equation (5) outlines the calculation of UPA.

$$Ul = \frac{\sum_{i=1}^{n} B_i}{\sum_{i=1}^{n} t_i} \tag{4}$$

Ul denotes the throughput of the upload process, measured in Mbps. B_i indicates the number of bits contained within the $i-th$ packet sequence (in Mbits). The variable n is used for the total packet transmission count, whereas t reflects the time interval taken for each packet upload.

$$UPA = \frac{1}{ADP} \cdot \frac{\sum_{i=1}^{n} Ul}{n} \cdot 100\% \tag{5}$$

Latency describes the round-trip delay experienced by packets transmitted from a source node to a destination node and back. The formulation for determining the average latency is presented in equation (6).

$$Latency = \frac{\sum_{i=1}^{n} P_i}{n} \tag{6}$$

P_i refers to the time associated with the $i-th$ packet in the test sequence, recorded in milliseconds. The parameter i assumes integer values from 1 to n, where n specifies the total sequence length of packets under measurement.

Jitter refers to the degree of variation in latency, measured as fluctuations in the time it takes for packets to travel from sender to receiver. Jitter values are expressed in milliseconds; smaller values imply stable transmission, while larger values signal reduced reliability. Its computation is described in equation (7).

$$Jitter = \frac{1}{n}\sum_{i=1}^{n}(P_{i+1} - P_i) \qquad (7)$$

Quality levels of internet service are defined using DPA and UPA indicators and divided into four ranges: Excellent (90–100%), Good (75–90%), Moderate (50–75%), and Poor (under 50%). For latency and jitter, an excellent level of service corresponds to values under 20 ms.

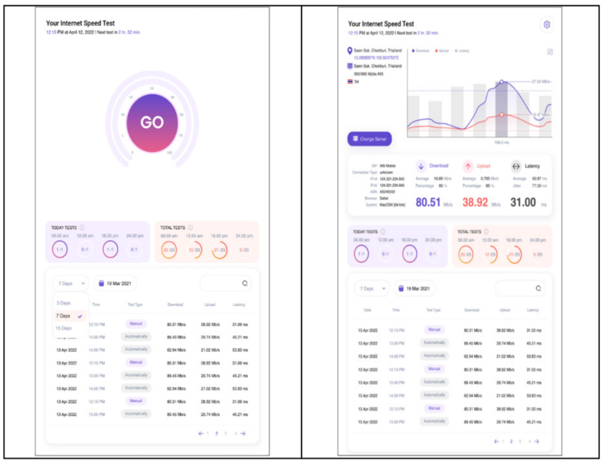
4. RESULTS AND DISCUSSION

Our framework and methodologies provide the measurements and strategies to identify areas with slow internet speeds, which can be used to respond efficiently and can optimize both time and financial resources if the improvement needed to be taken. Our research carried out in eight provinces within the eastern region of Thailand, according to geospatial distribution and diversity of service providers. Test participants were classified by urban and suburban settings. Internet signal quality measurement devices (end devices) were deployed and tested at the service provider's end to evaluate data transmission. Two Docker servers are used for collecting and calculating performance and quality of services provided to users for each individual service provider. The NBTC-STP dashboard displays geospatial internet speed performance data while controlling access by granting rights only to authorized individuals.

According to the features provided in 'Tray-App' Users must first register by providing the required details: name, photo (optional), phone number, password, and address information. To facilitate the data collection process of our research, users must select their home location on the interactive geospatial map. Once the location is selected, the coordinates of their home location are displayed automatically. Then users must specify the current service package by selecting the operating system (Mac, Windows, Raspberry Pi), connection type, internet service provider network, and download/upload speed package. These details are needed to make a comparison with the internet service they receive during the day. After completing all the necessary information, the 'Tray-App' will display a window for testing internet speed. This window will show statistical reports of download/upload speeds and latency compared to the current service package. It also includes data on the number of tests conducted in each period and the total tests performed, as shown in Figure 8.

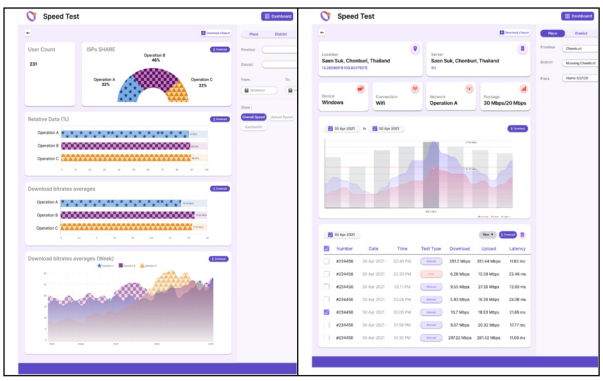
'The Web-App' as shown in Figure 9 (a) is designed as a dashboard for both NBTC staff and ISP operators. A Half-Donut Graph is used to illustrate the proportion of users for each service provider. A Horizontal-Bar Chart is used to select and display the average download/upload speeds and latency. It is also used to present the percentage of internet speed used compared to the purchased package (relative data). Users can select the period they want to view the information. Lastly, a line graph is used to show the trend of average speeds, categorized by operator. Additionally, the dashboard can also be used to view user information of registered users in this project, which totals 200 individuals. It presents users' locations, operating systems, connection types, network providers, and packages used. It includes graphs depicting the historical results of internet speed tests, as shown in Figure 9 (b).

Volunteers (end users) assessed internet signal quality using 200 personal computers, conducting tests in three time slots daily, with each test performed five times to transmit data to the Docker server. A total of 25,929 records of data were collected, with daily test results displayed.



(a) (b)

Fig.8: *Two screenshots of an internet speed test application. (a) Before testing: shows a "GO" button (b) After testing: displays ISPs and location info, speed results, graph, and test history.*



(a) (b)

Fig.9: *(a): Dashboard showing internet speed test analytics by province (b): Internet speed test dashboard showing results for a selected location.*

The results of testing the internet signal quality of the sample group covering all 5 clusters of service areas found that the average DPA was 64.30%, the standard deviation was 41.01, the average UPA was 71.84%, the standard deviation was 39.74, the average latency value was 11.82 ms, and the standard deviation was 4.88. The average jitter is 16.53 ms, and the standard deviation is 25.68, as shown in Table 4. The analysis revealed that Cluster 3 offers the highest level of service for downloading, followed by Cluster 2, while Cluster 4 trails behind. Conversely, to achieve excellent service provision, enhancements are recommended in Clusters 1, 4, and 5, as the potential for improvement exceeds 40%. In addition, there is an observation that Cluster 3 in Zone 2 (consisting of Clusters 1, 3, and 5), with the lowest population number, has the highest DPA value. Likewise, Cluster 2 in Zone 1 (consisting of Clusters 2 and 4) has the highest UPA value. This finding indicates that the lower number of populations and their geographical areas [28], as shown in Table 5, may influence the DPA and UPA values, which need further investigation.

In addition, the interface of 'Web-App' facilitates with the interactive geospatial map elements, of the testing area which employs colour coding to differentiate the five clusters, as shown in Figure 10. Moreover, a pin marker designating the user's locations and emblematic of the active service provider also are shown. Upon selecting the pin, pertinent volunteer details and the latest test metrics are disclosed, containing the volunteer's identity, test site, geographical coordinates, IP address, upload and download speeds, latency and jitter durations, as well as the timestamp of the most recent test. This interface offers an extensive array of geospatial map-based information, which is complemented by precise test locations.

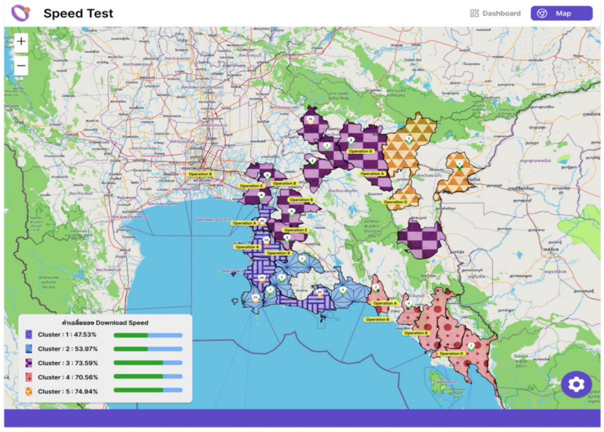


Fig.10: *The Geospatial map showing five user clusters.*

5. CONCLUSION AND FUTURE WORK

In conclusion, this research has provided insights into the measurement of broadband internet quality by utilizing reTerminal, a customized hardware device, to assess performance at both the ISPs source and at the end-users' site. While the study presents a comprehensive approach, there are several areas where future work can expand upon these findings. One important direction for future research is to expand the geographic scope to include more regions with varying infrastructure and ISPs quality, which would allow for broader generalization of the results. Additionally, although the use of reTerminal proved effective, future studies could investigate the scalability and replicability of the system using a wider variety of devices to assess its reliability and performance in different settings. The scalability of data collection could be further improved by increasing the number of reTerminal devices and testing across various ISPs and environments.

Furthermore, while this research focused on mea-

Table 4: *Average and Standard Deviation (S.D.) of Internet Service Quality by Cluster.*

Cluster	DPA		UPA		Latency		Jitter	
	Average	S.D	Average	S.D	Average	S.D	Average	S.D
1	63.31	39.09	64.14	26.08	13.51	3.05	19.53	30.39
2	77.76	38.10	**85.30**	41.33	11.76	3.97	19.44	29.54
3	**83.30**	40.21	78.80	36.28	12.50	2.51	16.69	20.34
4	56.45	41.72	66.59	40.87	11.43	6.04	15.76	26.25
5	62.32	37.47	73.37	40.43	11.72	3.01	13.33	17.82
Average	**64.30**	**41.01**	**71.84**	**39.74**	**11.82**	**4.88**	**16.53**	**25.68**

Table 5: *Number of populations in each cluster.*

Cluster	Province	Est. Population (2024)	Est. Area (sq.km.)	Est. Population Density
5	Rayong	~784,000	3,552	~220
3	Chanthaburi	~555,000	6,338	~88
4	Chonburi	~1,670,000	4,363	~383
2	Chachoengsao	~745,000	5,351	~139
1	Sa Kaeo	~570,000	7,195	~79

surements from the ISPs source, technical limitations, network congestion, and discrepancies between the ISPs' infrastructure and actual user experience could be further explored in future studies. Future work may consider the influence of environmental factors such as weather, physical obstructions, and interference from neighbouring networks, which could affect internet performance. More granular data collection over longer periods and during different conditions could also help capture intermittent issues that were missed in this study. It would also be beneficial to incorporate a more diverse user sample to account for variability in user behaviour, such as activities that demand different bandwidth levels, like streaming, gaming, and working from home. Finally, future research could incorporate non-ISP factors, such as the performance of local routers and end-users' hardware, to provide a more comprehensive view of internet quality. By addressing these aspects, future work can build on this research and offer even more accurate and actionable insights into internet quality measurement.

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References

[1] S. Kemp, "Digital 2023: Thailand," *DataReportal*, 2023. [Online]. Available: https://datareportal.com/reports/digital-2023-thailand/. Accessed: Jan. 12, 2024.

[2] Statista, "Countries with the fastest average fixed broadband internet speeds as of April 2023 (in Mbps)," *Statista*, 2023. [Online]. Available: https://www.statista.com/statistics/896772/countries-fastest-average-fixed-broadband-internet-speeds/ . Accessed: Jan. 12, 2024.

[3] M. Y. Simargolang and A. Widarma, "Quality of Service (QoS) for Network Performance Analysis Wireless Area Network (WLAN)," *CESS (Journal of Computer Engineering, System and Science)*, vol. 7, no. 1, pp. 162-171, 2022.

[4] T. Suzuki and K. Tanaka, "A New Scheduling Algorithm for Shortening Response Time of Static Priority Task," *ECTI-CIT Transactions*, vol. 16, no. 2, pp. 208–221, Jun. 2022.

[5] National Broadcasting and Telecommunications Commission, "Powers and Duties of the NBTC," *NBTC*. Accessed: Jan. 15, 2023. [Online]. Available: https://www.nbtc.go.th/About/PowerNBTC.aspx

[6] N. Feamster and J. Livingood, "Measuring Internet Speed: Current Challenges and Future Recommendations," *Communications of the ACM*, vol. 63, no. 12, pp. 72-80, 2020.

[7] Ookla, "About Ookla Speedtest," *Speedtest by Ookla*. Accessed: Nov. 11, 2022. [Online]. Available: https://www.speedtest.net/about

[8] Ookla, "Ookla Speedtest methodology," *Speedtest by Ookla*. Accessed: Nov. 11, 2022. [Online]. Available: https://help.speedtest.net/hc/en-us/articles/360038679354

[9] Fast.com, "Fast—The Fast Speed Test (Powered by Netflix)," *Fast.com*. Accessed: Nov. 10, 2022. [Online]. Available: https://fast.com/

[10] nPerf, "nPerf speed test," *nPerf*. Accessed: Nov. 10, 2022. [Online]. Available: https://www.nperf.com/th/

[11] Measurement Lab, "Speed Test by Measurement Lab," *Measurement Lab*. Accessed: Nov. 10, 2022. [Online]. Available: https://speed.measurementlab.net/

[12] iPerf, "iPerf: The ultimate speed test tool for TCP, UDP and SCTP," *iPerf*. Accessed: Nov. 13, 2022. [Online]. Available: https://iperf.fr/

[13] S. Jantavongso and S. Chimmanee, "Performance Comparison of Internet 4G Service Providers in Bangkok, Thailand," in *Proceedings of the Sixth International Conference on Green and Human Information Technology*, pp. 19-24, 2018

[14] T. Daengsi, S. Chatchalermpun, P. Praneetpolgrang and P. Wuttidittachotti, "A Study of 4G Network Performance in Thailand Referring to Download Speed," *2020 IEEE 10th Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, Malaysia, pp. 160-163, 2020.

[15] R. K. P. Mok, H. Zhang, R. Yang, T. Kompella, E. Katz-Bassett and K. C. Claffy, "Measuring the network performance of Google Cloud Platform," in *Proceedings of the 21st ACM Internet Measurement Conference (IMC'21)*, pp. 54–61, 2021.

[16] T. Daengsi, P. Ungkap, P. Pornpongtechavanich and P. Wuttidittachotti, "QoS Measurement: A Comparative Study of Speeds and Latency for 5G Network Using Different Speed Test Applications for Mobile Phones," *2021 IEEE 7th International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)*, Bandung, Indonesia, pp. 206-210, 2021.

[17] X. Deng, Y. Feng, T. Sutjarittham, H. H. Gharakheili, B. Gallego and V. Sivaraman, "Comparing broadband ISP performance using big data from M-Lab," *arXiv preprint* arXiv:2101.09795, 2021.

[18] U. Paul, J. Liu, V. Adarsh, M. Gu, A. Gupta and E. Belding, "Characterizing performance inequity across US Ookla Speedtest users," *arXiv preprint* arXiv:2110.12038, 2021.

[19] J. Han, M. Lyu and V. Sivaraman, "On the validity of internet speed test platforms and broadband measurement programs," in *Proceedings of the 17th Asian Internet Engineering Conference (AINTEC '22)*, pp. 1–9, 2022.

[20] Y. Z. Jembre, W.-Y. Jung, M. Attique, R. Paul and B. Kim, "Mobile broadband performance evaluation: Analysis of national reports," *Electronics*, vol. 11, no. 3, p. electronics11030485, 2022.

[21] T. Daengsi, P. Ungkap, and P. Wuttidittachotti, "5G Quality of Service: A case study of BTS Skytrain station areas," *Journal of Digital Communications*, vol. 7, no. 1, pp. 81–105, 2023.

[22] K. MacMillan, T. Mangla, J. Saxon, N. P. Marwell and N. Feamster, "A comparative analysis of Ookla Speedtest and Measurement Labs Network Diagnostic Test (NDT7)," in*Proceedings of the ACM on Measurement and Analysis of Computing Systems*, vol. 51, no. 1, pp. 41–42, 2023.

[23] S. Das and S. Kalafatis, "Speed Testing for Measuring Network Traffic in a Smart Network Switch," *2024 International Conference on Computing, Networking and Communications (ICNC)*, Big Island, HI, USA, pp. 446-450, 2024.

[24] B. Umsura, K. Chaidee, K. Puansurin, D. Manoruang, P. Wimooktayone, K. Boontasri and W. Kaenmueng "Enhancing Smart Farming Capabilities for Small-Scale Cattle Farmers in Chiang Rai, Thailand," *ECTI-CIT Transactions*, vol. 18, no. 1, pp. 1–13, Jan. 2024.

[25] A. Kantasa–ard, N. Phakdee and N. Wattanamongkhol, cInvestigating the applicable position of established cloud servers using the hybrid partitional clustering," *2023 International Electrical Engineering Congress (iEECON)*, Krabi, Thailand, pp. 20-24, 2023.

[26] A. Banerjee and R. N. Dave, "Validating clusters using the Hopkins statistic," *2004 IEEE International Conference on Fuzzy Systems (IEEE Cat. No.04CH37542)*, Budapest, Hungary, vol.1, pp. 149-153, 2004.

[27] M. Charrad, N. Ghazzali, V. Boiteau and A. Niknafs, "NbClust: An R package for determining the relevant number of clusters in a data set," *Journal of Statistical Software*, vol. 61 no. 6, pp. 1–36, 2014.

[28] K. Kempf-Leonard, *Encyclopedia of Social Measurement*. Amsterdam, The Netherlands: Elsevier, 2004. [Online]. Available: https://philpapers.org/rec/KEMEOS. Accessed: Sep. 3, 2022.

[29] R. Arnab, *Survey Sampling Theory and Applications*. Cambridge, MA, USA: Academic Press, 2017. [Online]. Available: https://books.google.co.th/books?id=8_IbDQAAQBAJ. Accessed: Sep. 3, 2022.

[30] AIMultiple, "30 network performance metrics to measure network health," Oct. 4, 2023. [Online]. Available: https://aimultiple.com/network-performance-metrics. Accessed: Aug. 21, 2025.

[31] Obkio, "19 network metrics: How to measure network performance," Mar. 12, 2024. [Online]. Available: https://obkio.com/blog/how-to-measure-network-performance-metrics/. Accessed: Aug. 21, 2025.

[32] Department of Provincial Administration, Ministry of Interior, "Population registration statistics, 2024," 2024. [Online]. Available: https://stat.bora.dopa.go.th/. Accessed: Aug. 10, 2025.

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