Indonesian Journal of Electrical Engineering and Computer Science
Vol. 40, No. 2, November 2025, pp. 687∼699
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v40.i2.pp687-699

MQTT live performance on the INA-CBT communication system: a measurement-based evaluation

A. A. N. Ananda Kusuma[1,2], Tahar Agastani[1], Rifqi F. Giyana[1], Sakinah P. Anggraeni[1], Arfan R. Hartawan[1], Toto B. Palokoto[1], Widrianto S. Pinastiko[1]
[1]Research Center for Telecommunication, National Research and Innovation Agency, Gd. Teknologi 3 KST BJ Habibie, Tangerang, Indonesia
[2]Department of Informatics, Universitas Multimedia Nusantara, Tangerang, Indonesia

Article Info

Article history:

Received Oct 30, 2024
Revised Jul 9, 2025
Accepted Oct 15, 2025

Keywords:

Latency
Live measurement
MQTT
QoS level
Tsunameter

ABSTRACT

Cable-based tsunameters have been deployed in Indonesia under the name of the INA-CBT project. Currently, the system operated at the Labuan Bajo landing station works well and sends aggregated data from the seafloor sensors to a central or read down station in Jakarta for further processing. The current scheme makes use of a publish and subscribe indirect communication among the landing station (LS) as the publisher and various clients as subscribers for the sensor data. Message queue telemetry transport (MQTT) was selected as the application-layer protocol for implementing this communication scheme. This paper presents a measurement-based evaluation of the MQTT live performance by observing the MQTT messages' latencies received at the subscriber of the INA-CBT's MQTT broker. The results give insight on the general achievable performance of the INA-CBT communication system in providing reliable data for the tsunami detection system. Furthermore, the results obtained can be used as communication parameters for making a more realistic virtual testbed for designing a more appropriate and scalable CBT system.

Corresponding Author:

A. A. N. Ananda Kusuma
Department of Informatics, Universitas Multimedia Nusantara
Jl. Scientia Boulevard, Gading Serpong, Tangerang 15810, Indonesia
Email: ananda.kusuma@lecturer.umn.ac.id

1. INTRODUCTION

A disaster early warning system is necessary for every country to mitigate the disaster's severe and unpredictable impact. Indonesia is an archipelagic country with many volcanoes and seismic sites; thus, it has a high potential for several disasters, such as earthquakes, tsunamis, and volcanic eruptions. In response, Indonesia has implemented several systems for disaster early warning system, and one of them is a tsunami detection system based on fiber optic cables on the seafloor with several earth-monitoring and tsunami-related detection sensors. This is referred to as Indonesia's cable-based tsunameters (INA-CBT), and they were deployed at Labuan Bajo and Rokatenda sites in 2021. Figure 1 shows the locations of INA-CBT LSs at Labuan Bajo and Rokatenda in the province of East Nusa Tenggara. These sites are at distance of approximately 1,400 km and 1,700 km respectively from the read down station (RDS) in Jakarta, the capital city of Indonesia.

Several countries have similar systems for natural disaster monitoring and seafloor observation. Japan, through the National Research Institute for Earth Science and Disaster Resilience (NIED), operates the seafloor observation network for earthquakes and tsunamis along the Japan trench (S-NET) [1], the new S-NET [2], the dense ocean floor network system for earthquakes and tsunamis (DONET) [3], and the Nankai trough seafloor observation network for earthquakes and tsunami (N-Net) [4]. Those systems basically cover the Pacific Coast in Eastern Japan and the coast in western side of the country. Taiwan also operates a system called the marine cable hosted observatory (MACHO), which is used to monitor active volcanoes and detect earthquakes and tsunamis occurrences off the coast in the northeast of the country [5]. Other systems that are still in operation include the Canadian North-East Pacific underwater networked experiments (NEPTUNE) [6], considered as the world's first multi-node cabled ocean observatory, and the European multidisciplinary seafloor and water column observatory (EMSO) [7]. A recent development shows the interest for integrating environmental sensors in the repeaters of submarine telecommunication cables, which results in the system called scientific monitoring and reliable telecommunications (SMART) [8]. Such system provides data stream for various earth observation for seismic, tsunami and other early warning scenarios, alongside regular telecommunication traffic. Thus, future cabled-based tsunameter projects need collaboration with telecommunication industries.

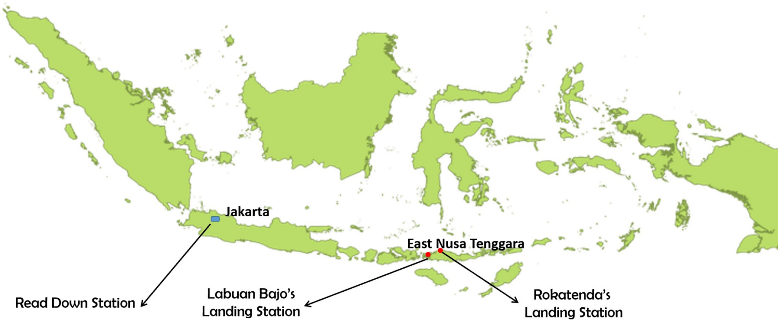


Figure 1. The INA-CBT with LS at Labuan Bajo and Rokatenda

The INA-CBT is still at its early stage but already showed some promises on its use of local engineering knowledge during its development. The INA-CBT's working scale, consisting of one LS and two ocean bottom units (OBUs), is considered much smaller than the systems described above, but any studies performed on it are worth it for learning experience, and will be useful to various related knowledge. Several studies have reported various aspects of INA-CBT, e.g. power supply considerations [9], fault-tolerance analysis in its switching networks [10], [11], data acquisition and its tsunami detection algorithm (TDA) [12], testbed development for its sub-communication system [13], and a related seabed morphology characterization [14].

The majority of literature, especially for large systems as described above, concern more about targets on connecting large numbers of OBUs through oceanfloor optical networks, whereas interconnecting systems to public wide area networks for transporting sensor data to a central or read down station (RDS) did not get much attention. A particular work on modeling and testbed development of message queue telemetry transport (MQTT) transmission on the INA-CBT's LS to RDS sub-communication in [13] investigated the impact of bottleneck bandwidth on the achievable message latencies of OBU's sensor data. Message latencies are critical for performance measure, especially for the effectiveness of the processing algorithm for detecting possible tsunamis. However, this work is considered lack of reality as it needs to be assessed and improved by the knowledge obtained from a live system. The MQTT protocol is widely used for iternet of things (IoT) services and shown to be robust in several contexts [15]–[19], and its performance for transporting CBT's data in a live system needs to be justified. Research work conducted on a live system is not only useful for CBT interest but also in general data communication systems that use an application layer's publish-subscribe mechanism like MQTT protocol. This paper then aims at addressing MQTT transmission issues on the INA-CBT's LS to RDS sub-communication, and provides some contributions as follows: presenting a specific sub-communication component of INA-CBT, discussing the network and application performance metrics that can be measured from a live network, describing measurement for MQTT message latencies and interpreting their results related to the requirement of TDA.

The remainder of this paper is organized as follows. Section 2 provides a general overview of the INA-CBT communication system. In section 3 experiment design and measurement procedures are explained. Section 4 presents some results, and their implications are discussed. Finally, this paper concludes with some remarks and future work.

2. INA-CBT COMMUNICATION SYSTEM

The INA-CBT communication system consists of the OBU to LS and LS to RDS sub-communication systems. Figure 2 shows a simplified view of the INA-CBT communication system at a particular LS. The system has two OBUs where each OBU hosts three sensors: 3-axes accelerometer (Acc), bottom pressure recorder (BPR), and environment (Env). Acc measures three-dimensional displacement as an indication of ground shaking, BPR measures pressure that is correlated to water column height, and Env measures OBU's internal conditions. Currently, the tsunami detection algorithm used is based on BPR data [12], using the well-known and popularly used DART algorithm [20]. Data from OBUs' sensors are aggregated at LS and then transported to RDS in Jakarta using an MQTT protocol for further processing.

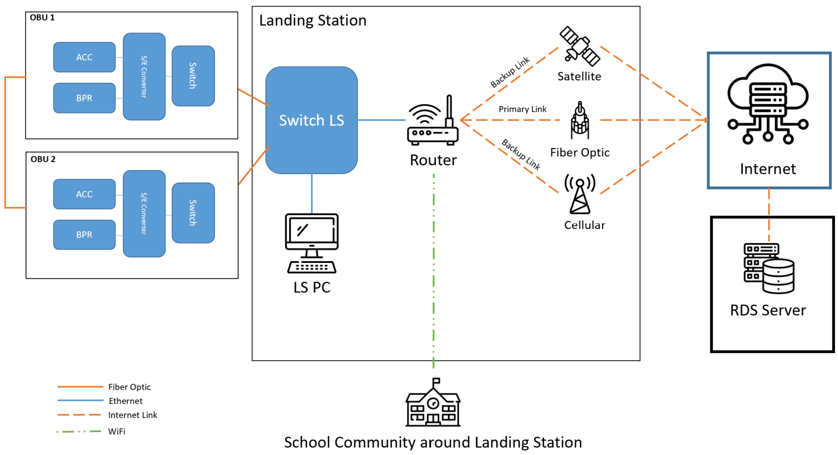


Figure 2. The INA-CBT communication system at a particular LS. Some icons used in this figure were retrieved from Flaticon.com [21]

In the case of Labuan Bajo, the OBUs are positioned at about 37 km and 57 km respectively from the shore; the one nearer to the shore was laid down around 2,110 meters of water depth and the other was laid down around 4,120 meters of water depth. The LS and the two OBUs are physically connected in a ring topology, so that redundant links are available if incident occurs, so data can still be sent using the alternate path. Providing redundant links requires a loop-avoidance mechanism, i.e. creating a spanning tree, to prevent looping in the reconfiguration process. The spanning tree mechanism in the context of INA-CBT has been studied and reported in [10], [11]; both of them investigated failover and failback times of OBUs' switches. Early investigation was conducted using real equipments and a proprietary turbo-ring protocol as the ones deployed by the INA-CBT project, whereas these later works used simulator and open spanning tree protocols for flexibility in future development [10], including arbitrary number of OBUs [11].

The deployed OBU's BPR and Acc sensors transmit data through their serial ports; their data in serial frame format are then converted to ethernet frame format by a serial-to-ethernet (S/E) converter. Based on the operational setting, BPR and Acc send data at frequencies 1 Hz and 125 Hz respectively. By having a switch connecting sensor devices, each of them can be identified by its IP address and associated port number. Sensor data acquisition can then be controlled by the related program run at the landing station computer (LS PC) based on IP address and port number; data from OBU's sensors are aggregated at the LS. The program running at LS updates the timestamp of sensor data and creates MQTT messages based on their OBU's number as the topic for the utilized publish-and-subscribe mechanism. The publisher program sends MQTT messages to the MQTT broker operated at RDS Jakarta via Internet. Any program that acts as a subscriber to the MQTT broker can receive MQTT messages sent from LS, and then retrieve sensor data based on the subscribed topics for further processing. The INA-CBT utilizes mosquitto version 1.6.9 as the broker supporting MQTT version 5.0/3.1.1; client software, publisher and subscriber, are custom-built programs based on paho-mqtt library version 1.6.1.

There are several alternatives for connecting LS to the Internet, depending on its location and available infrastructure. At Labuan Bajo the primary link is through the Internet service provider which provides fiber-optic connectivity, whereas backup links are provided by cellular and satellite operators. The INA-CBT project also has a mission to contribute to local communities around its LS, so its policy is to share its Internet connectivity. At Labuan Bajo, the school community around LS is allowed to access Internet via the LS's WiFi access point. This situation gives a mixed traffic scenario where MQTT-based disaster-related data blend with general Internet traffic [22].

The MQTT transmission between a publisher and subscribers needs to be analyzed as it impacts the quality of service (QoS) of INA-CBT's sensor data. The critical parameter for data processing is the timeliness of the received data; thus, MQTT message latency can be considered as the performance objective. MQTT supports three QoS levels: QoS 0 (at most once), QoS 1 (at least once), QoS 2 (exactly once); this QoS level gives an application's reliability option to users connecting in unreliable networks.

MQTT performance in delivering data based on their QoS level has been investigated from various points of view, such as the analyses that correlate QoS levels to packet errors [23], the investigation of control packets' behavior to communication delays and their impacts towards MQTT's data delivery [24], the use of deep-learning with MQTT to correlate its QoS with potential intrusion [25], adding additional MQTT's payloads for security or reliability reasons that increases latencies [26], [27]. However, there is still lack of information about MQTT performance for transporting CBT's sensor data.

One study aims at showing MQTT latencies for all QoS levels as a function of bottleneck bandwidth, and it was conducted in an idealized and simplified testbed of CBT's sub-communication system [13]. A related work using a virtual testbed for general MQTT transmission in [28] shows that latencies using QoS 2 increase significantly with respect to network delays. Results above show that investigation on data delivery's latencies due to QoS level selection and network parameters, such as bottleneck bandwidth and delay, needs further attention. Measurement results in live CBT system and their analyses are needed for better understanding on MQTT performance and its feasibility for transporting tsunami detection-related sensor data.

3. EXPERIMENT DESIGN

The experiment design is shown in Figure 3 that shows the LS-RDS part of the INA-CBT system at Labuan Bajo and the remote monitoring and measurement station set-up at ANP Lab, KST BJ Habibie, Tangerang Selatan (a satellite city southern of Jakarta). From the perspective of measuring MQTT performance, it can be seen that in general there are four major components to be considered: the MQTT publisher at LS, Internet connectivity, the MQTT broker at RDS, and the MQTT subscriber at ANP Lab. To control experiments by varying MQTT publishing parameters, a VPN connection was set-up between Control PC at ANP Lab and LS PC at Labuan Bajo's LS. The VPN remote access at LS is part of the remote monitoring and management system of INA-CBT infrastructure. For a limited time and research purposes, remote access to LS and data retrieval were permitted. The MQTT subscriber at ANP Lab (VM Subscriber) was set-up to subscribe a particular OBU's topic from the MQTT broker at RDS.

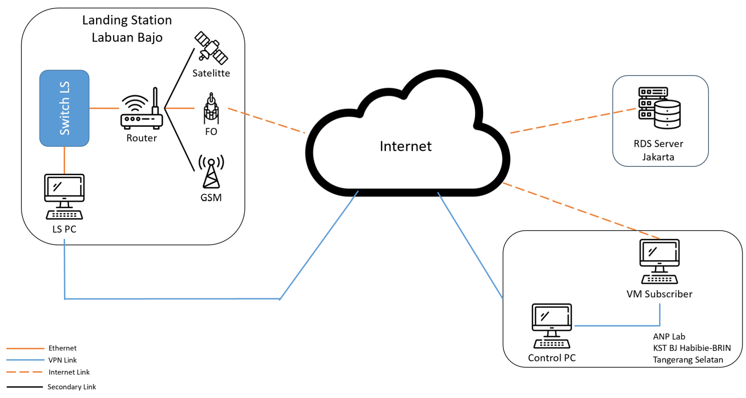


Figure 3. Live measurement setting. Some icons used in this figure were retrieved from Flaticon.com [21]

In this experiment, both Internet and MQTT broker are considered as blackboxes that our concerns are only on their interfaces; in other word, only end-to-end aspects of LS to subscribers are under consideration.

Both network and application related parameters are needed for understanding the system performance, and in this experiment the following end-to-end parameters measured are as follows: available bandwidth, communication delay, and MQTT message latency. Note that the available bandwidth and communication delay are parameters estimated at LS interface and based on packet transmission delay between LS and ANP Lab. They are not related directly to the path taken by MQTT messages from LS to subscribers via an MQTT broker at RDS. Nevertheless, the measured available bandwidth gives indication on the link quality at LS, and the communication delay gives the latency's lower bound. To accommodate extra traffic due to activities from communities around LS, measurements were conducted in three separate sessions: morning session (8.00 to 11.00), afternoon session (14.00 to 17.00), and evening session (20.00 to 23.00); these times are in Western Indonesian time zone.

At deployment in 2021, INA-CBT's landing station at Labuan Bajo was designed to use an optical network as its primary means of communication with RDS, as shown in Figure 2, and the bandwidth contract with the provider was 2.5 Mbps for both upstream and downstream. Because bandwidth is dedicated, at any given time the value must be very close to the agreement; however, measurement is still needed to verify its real-time value more accurately. The communication delay is estimated by taking end-to-end measurement between Labuan Bajo site and ANP Lab. Separate delay measurement was conducted to accommodate for the possibility of asymmetrical delay between uplink and downlink due to different load on upstream and downstream traffic. Each delay affects different parts of MQTT message transmission used for transporting sensor data; that is, the uplink delay affects MQTT data and signaling packets while downlink delay only affects MQTT signaling packets.

The estimated available bandwidth at Labuan Bajo site and the estimated end-to-end communication delay between Labuan Bajo site and ANP Lab provide indication on the path effectiveness for transporting sensor data. However, what matters to the applications that use sensor data is the latency of sensor data delivery to the application layer. Also, note that there exist extra transit time to RDS site, processing time at the MQTT broker, and extra time for final transmission and processing at subscriber site. Therefore, estimating latency at MQTT level is needed, and this is achieved by taking the difference of the subscribed MQTT messages' timestamps at the receiving end and their associated published timestamps. The published timestamps correspond to the data processing step at LS that adds timestamps to sensor data from each OBU [12].

Since all OBUs' data are aggregated at LS before being timestamped and published using MQTT, one may focus on one OBU's sensor data only, as their LS to RDS transmission characteristics are similar. Message latency measurement was taken in the morning, afternoon, and evening session; at each session, operating steps for gathering MQTT messages are shown in Figure 4. Based on measurement data, for each QoS level message latency samples from each sensor were obtained by taking the difference between subscribed timestamps and their associated published timestamps. Note that in contrast to research on testbed where all components can be fully-controlled [13], in live measurement study there are several things must not be interrupted, e.g. turning-off or restarting MQTT broker; therefore, any data anomaly received, typically at the beginning of transition, e.g. change in QoS level, will be considered as outliers.

1. **Activate VPN connection to LS Labuan Bajo**
2. **Connect Control PC to PC LS Labuan Bajo via ssh**
3. **Connect Control PC to VM Subscriber via ssh**
4. **Synchronize time at PC LS by executing ntpdate to ntp.bmkg.go.id**
5. **Synchronize time at VM Subscriber by executing ntpdate to ntp.bmkg.go.id**
6. **Subscribe to OBUs' topics at VM Subscriber**
7. **Publish OBUs' MQTT messages at PC LS**
8. **Run measurement for 30 minutes**
9. **Kill subscriber's program at VM subscriber**
10. **Kill publisher's program at PC LS**
11. **Repeat steps 4-10 for each QoS level (QoS 0,1,2)**

Figure 4. Operating steps for gathering MQTT messages at each session of measurement

4. RESULTS AND DISCUSSION

Measurement studies took available bandwidth, communication delay, and MQTT message latency; however, MQTT message latency is the main parameter that requires more discussion. The quality of sensor data streams processed by the associated applications is heavily affected by the achievable latency.

By using iperf3, the following results at LS were obtained: 2.88 Mbps downstream bandwidth and 2.53 Mbps upstream bandwidth. This confirmed that dedicated bandwidth is provided in the downlink and uplink link from LS at Labuan Bajo site. Note that measurement was taken as end-to-end connection from LS to ANP Lab, and one needs to ensure at ANP Lab site, the associated bandwidth is much larger. By making use of speedtest tool and its public server, the following results were obtained: 12.07 Mbps downstream bandwidth and 14.42 Mbps upstream bandwidth. Thus, LS to RDS links need further attention as their bandwidth is the potential bottleneck along the prospective end-to-end path. Measurement results also show that the available upstream bandwidth for CBT purposes is steady; the upstream is fully available for sensor data transmission. Different results were observed on the downstream; the available bandwidth drops in morning session. It can be inferred that intensive Internet activities in school communities around LS during school hours contribute to this drop. Not much downstream traffic was observed in afternoon and evening session. Bandwidth measurement shows an expected traffic and bandwidth usage of the CBT's LS to RDS links.

Measurement results show that communication delays are generally symmetrical at each session of measurement. Morning session data shows the statistical values for downstream are 28.080 ms on average, 117 ms on maximum, and 26 ms on minimum, whereas for upstream they are 28.106 ms on average, 163 ms on maximum, and 26 ms on minimum. Afternoon session data shows the statistical values for downstream are 27.650 ms on average, 40 ms on maximum, and 25 ms on minimum, whereas for upstream they are 28.468 ms on average, 223 ms on maximum, and 26 ms on minimum. Lastly, evening session data shows the statistical values for downstream are 26.753 ms on average, 42 ms on maximum, and 24 ms on minimum, whereas for upstream they are 28.272 ms on average, 126 ms on maximum, and 25 ms on minimum. It can be inferred that communication delays on LS to RDS sub-communication are considered stable, and not affected by surrounding traffic. The average communication delays are in the range of 26 to 28 ms, with some spikes due to network glitches along the path. However, even with these spikes, delays are considerably acceptable to tsunami detection as explained in later section. These delays are the lower bound for higher layer applications, e.g. latencies observed by MQTT message reception, and can be utilized as the additional communication parameters for INA-CBT testbed presented in [13]. Note that communication delays affect the behavior of TCP, which is the underlying protocol for MQTT, and have an impact on the characteristics of MQTT message latency [24]. The probability model regarding MQTT message latency also depends heavily on the underlying communication delay parameters [29].

The results of MQTT message latency are only based on messages from OBU 1 that were published and received on April 11, 2023 during three sessions of measurement based on the general procedure shown in Figure 4. It is understood that only certain time windows were allowed for doing live measurements in order to minimize potential disruption. These sensor data can be used in various INA-CBT related purposes, but in this paper they were used only for estimating MQTT message latency. Taking payload of MQTT messages showed that BPR and Enviro data size are 95 bytes and 92 bytes respectively. In general, it can be expected that BPR and Enviro data load the system almost similarly due to their comparably data size. On the other hand, Acc data size is much larger and in general varies across MQTT messages with the range from 7793 to 8049 bytes. The payload of Acc is about 82 to 85 times that of BPR. These sensor data are considered small, but its reliability and timeliness need to satisfy the application requirement, i.e. in this case a tsunami detection system.

Figures 5 to 7 show measured latencies for BPR, Acc, and Enviro data delivery. The latencies plotted are their average values with their confidence interval, measured in each session. Numerical values for these average values are presented in Table 1. As expected, the selected QoS level affects the achievable latency; a higher QoS level results in higher latency. This trend has also been observed in several other studies, although in different contexts, because the latency performance of MQTT depends on the application and use of the MQTT protocol itself. Several other related studies generally use testbed implementations [13], [23], [27], [28], [30], network simulations [31], [32], or a mathematical model [29], generally using local area network (LAN) scenarios, although in certain cases a simulated wide area network (WAN) is used. Meanwhile, in this paper, measurements were carried out by connecting the client to a real network, which is managed by the INA-CBT project, so that a real measurement environment is obtained on a WAN scale. This research contributes to MQTT performance measurements on tsunami-related WAN sensor networks.

In QoS 0, no guarantee in message delivery is provided; a publisher simply sends an MQTT message only once and does not check whether the message arrived at its destination. Even though QoS 0 provides the fastest message delivery, it is not advisable to use it for providing reliable sensor data transmission; some data might be lost when any kind of error occurs in the way, and an extra precaution in the application might be needed. In QoS 1, a publisher sends a message, and stores it until it gets a PUBACK message from the MQTT broker that acknowledges receipt of the message. Packet identifier in each message is used to match a published message to the corresponding PUBACK. However, when the PUBACK message is lost, it is possible that the same message being delivered twice. In terms of reliability, QoS 1 is more superior than QoS 0; however, extra protocol steps added result in higher latency. Note that for applications that make use of MQTT messages received using QoS 1, an extra program for reordering messages is needed. The most reliable one is QoS 2 where MQTT guarantees that each message is received only once by the intended recipients. It is accomplished by a four-way handshake between the sender and receiver pair in the path, e.g. the publisher and the broker. When a receiver gets a message from a sender, it processes the message accordingly and replies to the sender with a PUBREC message that acknowledges receipt of the message. If the sender does not get a PUBREC message, it sends the published message again with a duplicate (DUP) flag until it receives an acknowledgment. Once the sender receives a PUBREC message from the receiver, the sender can safely discard the initial published message. The sender stores the PUBREC message from the receiver and responds with a PUBREL message. After the receiver gets the PUBREL message, it can discard all stored states of the received message and answer with a PUBCOMP message. In this way, the receiver avoids processing the message a second time; thus, it ensures message delivery exactly once. After the sender receives the PUBCOMP message, the message delivery is complete. It can be seen that extra protocol steps are required for QoS 2 to achieve reliable and ordered message delivery; consequently, longer latency is expected. Receiving complete and in-order messages is useful for the application as it can focus more on its targeted computation. Using QoS 2 is desirable, as long as its achievable latency is within the application specification, as it will be discussed later.

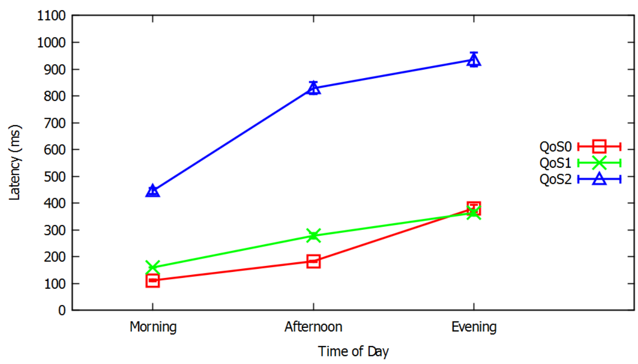


Figure 5. Average latencies for BPR data

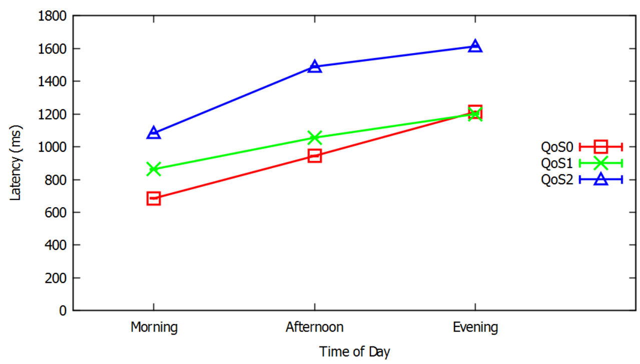


Figure 6. Average latencies for Accelerometer data

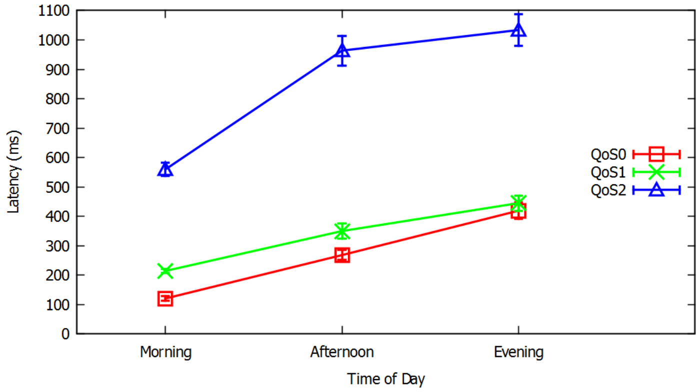


Figure 7. Average latencies for Enviro data

Table 1. Average latency results for three measurement sessions

Session	Message latency (ms)								
		BPR			Acc			Enviro	
	QoS 0	QoS 1	QoS 2	QoS 0	QoS 1	QoS 2	QoS 0	QoS 1	QoS 2
Morning	111.4	159.8	445.8	685.1	863.6	1083.5	120.2	214.0	559.4
Afternoon	183.0	278.1	828.6	944.4	1055.7	1489.4	268.1	349.8	963.5
Evening	380.7	363.7	935.4	1212.8	1200.3	1613.5	419.1	444.8	1033.5

Comparing latencies for BPR and Enviro data from Figures 5 and 7, it can be seen that their results are relatively similar. Note that the data payload for BPR and Enviro is almost the same size. When comparing the latencies for Acc data in Figure 6, it can be seen that much higher latencies are observed for Acc data. This is due to much larger data payload for Acc, i.e. about 82 to 85 times larger than BPR's data payload. All measured latencies show lower values in morning session, and their values increase further in afternoon and evening session. Since the LS to RDS sub-communication is considered steady with much available bandwidth for sensor data transmission, the plausible explanation for increasing latencies as the day progresses is the increase in Internet traffic over the RDS to ANP Lab path. Analyzing traffic at RDS to ANP Lab path was not conducted due to its complex and heterogeneous environment.

Each QoS level responds differently for different kind of sensor data. Latencies for BPR and Enviro respond almost similarly for each QoS level, and they need to be compared with Acc's latencies. The following discussion considers BPR and Acc only. For BPR data, increasing QoS level from the unreliable one (QoS 0) to the most reliable one (QoS 2) results in the following increase of latencies: 295.7% (morning session), 352.8% (afternoon session), 145.7% (evening session). In contrast, for Acc data much less latency performance degradation is observed. For Acc data, increasing QoS level from the unreliable one (QoS 0) to the most reliable one (QoS 2) results in the following increase of latencies: 58.2% (morning session), 57.7% (afternoon session), 41.1% (evening session). The reason that the impact of changing QoS level is worse for BPR data is due to the policy of aggregating all sensor data in publishing MQTT messages; each topic for MQTT transmission is set based on OBU's number. In this policy, BPR and Acc data are differentiated based on the field data type in MQTT messages; all sensor data from the same OBU will share MQTT resources, e.g. queues at the participating nodes (publisher, broker, an subscriber). Sharing resources like this is not fair for low-rate sensor data like BPR and Enviro. This transmission mechanism of INA-CBT needs to be revised so that each sensor data at each OBU gets its own MQTT resources.

MQTT behavior for each QoS level can also be inferred from the number of queued messages at the LS's publisher, as shown in Figure 8. Using QoS 0, a publisher sends messages without storing them, thus queued messages are zero. For higher QoS level, queued messages build-up since messages need to be stored for completing the required handshakes. It can be seen from Figure 8 that even for QoS 2 level, the average queued messages are still low; this indicates stability in MQTT transmission on the LS to RDS sub-communication system.

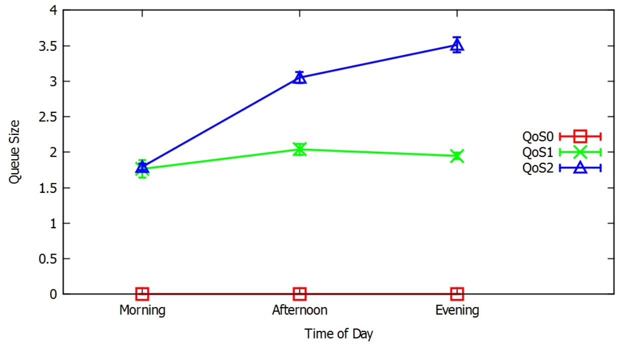
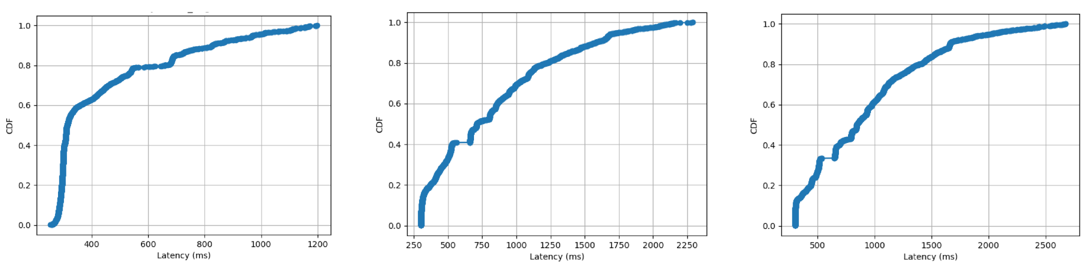


Figure 8. Average number of queued messages at the LS's publisher

Sensor data, particularly BPR data, are used by the TDA to detect the possible occurrence of a tsunami. The currently used algorithm is based on the algorithm developed by Mofjeld for the U.S. NOAA's deep-ocean assessment and reporting of tsunamis (DART) program [20]. This algorithm takes BPR data as input, and predicts incoming tides; if the predicted tide is above a certain threshold, then a tsunami alert is issued. The prediction uses a cubic polynomial based on BPR data stored over the past three hours, and updated with fresh data every 15 seconds. More advanced algorithm, e.g. the one that uses an artificial neural network (ANN) [33], also requires data updating every 15 seconds. Thus, one must ensure that BPR data latencies are much less than 15 seconds for satisfying the BPR-based TDA algorithms. In terms of average latencies, Figure 5 shows that all average latencies are well below 15 seconds; the worst case for QoS 2 shows average latency equal to 0.94 seconds. To ensure no data sample is above 15 seconds, cumulative distribution functions (CDFs) for latencies were created, and they are shown in Figure 9; subfigures are presented over three separate measurement seasons. Figure 9(a) shows the morning session, Figure 9(b) shows the afternoon session, and Figure 9(c) depicts the evening session. Only CDFs for QoS 2 are shown as QoS 2 level is the most reliable message delivery with the highest latency. It can be seen from Figure 9 that with certainty (probability equal to one) the highest latency data sample is less than 3 seconds. Thus, the current system has satisfied the data latency requirement for some popular BPR-based TDA algorithms. BPR data latencies can be further improved by making separate MQTT resources for BPR and Acc, as discussed before.

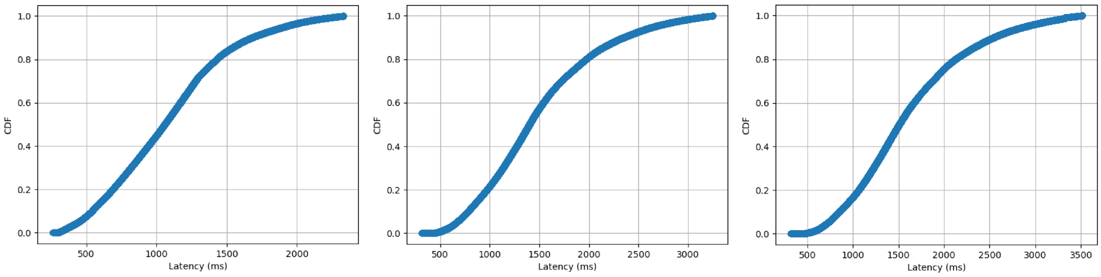
For Acc data transmission using QoS 2, CDFs for latencies are presented in Figure 10. The subfigures shows the latency during three separate measurement sessions. Figures 10(a) to 10(c) show the latency during three separate measurement sessions, namely the morning, afternoon, and evening sessions. It can be seen that latency data samples are below approximately 4 seconds. This will be suitable for algorithms that use both BPR and Acc data for tsunami prediction [34].

In general, measurement results show the effectiveness of using MQTT transmission for wide-area sensor networks for tsunami detection deployed by the INA-CBT project. Some aspects of the system may need further optimization, and consequently one needs to know the performance limit of the INA-CBT communication system. This research work is ideally conducted in a testbed, in line with the work reported in [13]; making various modifications in a testbed will not disrupt the live system.



(a) (b) (c)

Figure 9. Cummulative distribution functions (CDFs) for received BPR data latencies over three separate sessions: (a) morning, (b) afternoon, and (c) evening



(a) (b) (c)

Figure 10. Cummulative distribution functions (CDFs) for received Acc data latencies over three separate sessions: (a) morning, (b) afternoon, and (c) evening

5. CONCLUSION

This paper has presented live measurement results of transporting tsunami-related sensor data using MQTT protocol over the INA-CBT's wide-area operational network. To the best of our knowledge, this is the first paper that presents MQTT performance measurement of latency-critical sensor data for predicting tsunami over public Internet. It has been shown that the INA-CBT communication sub-system that transports sensor data from Labuan Bajo works well, and measured latencies have satisfied the target requirement of some TDA algorithms. The currently deployed MQTT application is not optimal yet, and can be improved by ensuring fairness for each type of sensor data. Future research work will be conducted in a laboratory-scale testbed by making use of some measured parameters during live measurement. Scalability of the system can be assessed by increasing sensor data payload, e.g. increasing the number of OBUs and sensors, and investigating its impact towards performance.

FUNDING INFORMATION

Authors state no funding involved.

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] T. Kanazawa, "Japan trench earthquake and tsunami monitoring network of cable-linked 150 ocean bottom observatories and its impact to earth disaster science," in *2013 IEEE International Underwater Technology Symposium (UT)*, Mar. 2013, pp. 1–5, doi: 10.1109/UT.2013.6519911.

[2] M. Shinohara, T. Yamada, S. Sakai, H. Shiobara, and T. Kanazawa, "New ocean bottom cabled seismic and tsunami observation system enhanced by ICT," in *2014 Oceans - St. John's*, Sep. 2014, pp. 1–6, doi: 10.1109/OCEANS.2014.7003045.

[3] N. Takahashi *et al.*, "Real-time tsunami prediction system using DONET," *Journal of Disaster Research*, vol. 12, no. 4, pp. 766–774, Aug. 2017, doi: 10.20965/jdr.2017.p0766.

[4] S. Aoi *et al.*, "Development and construction of Nankai trough seafloor observation network for earthquakes and tsunamis: N-net," in *2023 IEEE Underwater Technology (UT)*, Mar. 2023, pp. 1–5, doi: 10.1109/UT49729.2023.10103206.

[5] N.-C. Hsiao, T.-W. Lin, S.-K. Hsu, K.-W. Kuo, T.-C. Shin, and P.-L. Leu, "Improvement of earthquake locations with the marine cable hosted observatory (MACHO) offshore NE Taiwan," *Marine Geophysical Research*, vol. 35, no. 3, pp. 327–336, Sep. 2014, doi: 10.1007/s11001-013-9207-3.

[6] C. R. Barnes and V. Tunnicliffe, "Building the world's first multi-node cabled ocean observatories (NEPTUNE Canada and VENUS, Canada): science, realities, challenges and opportunities," in *OCEANS 2008 - MTS/IEEE Kobe Techno-Ocean*, Apr. 2008, pp. 1–8, doi: 10.1109/OCEANSKOBE.2008.4531076.

[7] P. Favali and L. Beranzoli, "EMSO: European multidisciplinary seafloor observatory," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 602, no. 1, pp. 21–27, Apr. 2009, doi: 10.1016/j.nima.2008.12.214.

[8] S. Lentz and B. Howe, "Scientific monitoring and reliable telecommunications (SMART) cable systems: integration of sensors into telecommunications repeaters," in *2018 OCEANS - MTS/IEEE Kobe Techno-Oceans (OTO)*, May 2018, pp. 1–7, doi: 10.1109/OCEANSKOBE.2018.8558862.

[9] A. Privadi, D. R. Damara, P. L. Widati, and F. R. Triputra, "Indonesia's cable based tsunameter (CBT) system as an earthquake disaster mitigation system in East Nusa Tenggara," in *2021 IEEE Ocean Engineering Technology and Innovation Conference: Ocean Observation, Technology and Innovation in Support of Ocean Decade of Science (OETIC)*, Nov. 2021, pp. 63–67, doi: 10.1109/OETIC53770.2021.9733734.

[10] M. Hamdani, D. Irawan, A. A. N. A. Kusuma, T. Agastani, and M. Iqbal, "Preliminary assessment of using spanning tree open protocols in INA-CBT communication system," in *Proceedings of the 2022 International Conference on Computer, Control, Informatics and Its Applications*, Nov. 2022, pp. 6–10, doi: 10.1145/3575882.3575884.

[11] M. Hamdani, A. A. N. A. Kusuma, D. Irawan, T. Agastani, and X. Xerandy, "Simulating spanning tree protocols in a cable-based tsunameter system with an arbitrary number of ocean bottom units," *Pertanika Journal of Science and Technology*, vol. 32, no. 4, pp. 1875–1890, Jul. 2024, doi: 10.47836/pjst.32.4.22.

[12] A. I. Nurwidya *et al.*, "Data analysis and visualization of INA-CBT Labuan Bajo system," in *2022 IEEE Ocean Engineering Technology and Innovation Conference: Management and Conservation for Sustainable and Resilient Marine and Coastal Resources (OETIC)*, Dec. 2022, pp. 17–22, doi: 10.1109/OETIC57156.2022.10176229.

[13] A. A. N. A. Kusuma, T. Agastani, T. Nugroho, S. P. Anggraeni, and A. R. Hartawan, "Estimating MQTT performance in a virtual testbed of INA-CBT communication sub-system," in *2022 International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET)*, Dec. 2022, pp. 73–77, doi: 10.1109/ICRAMET56917.2022.9991213.

[14] S. Ardhyastuti *et al.*, "Seabed morphology characterization for Indonesian cable-based tsunameter route in Cilacap Segment, Indonesia," *IOP Conference Series: Earth and Environmental Science*, vol. 1148, no. 1, p. 012009, Mar. 2023, doi: 10.1088/1755-1315/1148/1/012009.

[15] S. R. U. Kakakhel, T. Westerlund, M. Daneshtalab, Z. Zou, J. Plosila, and H. Tenhunen, "A qualitative comparison model for application layer IoT protocols," in *2019 Fourth International Conference on Fog and Mobile Edge Computing (FMEC)*, Jun. 2019, pp. 210–215, doi: 10.1109/FMEC.2019.8795324.

[16] S. Pooja, D. V Uday, U. B. Nagesh, and S. G. Talekar, "Application of MQTT protocol for real time weather monitoring and precision farming," in *2017 International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques (ICEECCOT)*, Dec. 2017, pp. 1–6, doi: 10.1109/ICEECCOT.2017.8284616.

[17] S. N. Swamy and S. R. Kota, "An empirical study on system level aspects of internet of things (IoT)," *IEEE Access*, vol. 8, pp. 188082–188134, 2020, doi: 10.1109/ACCESS.2020.3029847.

[18] D. Glaroudis, A. Iossifides, and P. Chatzimisios, "Survey, comparison and research challenges of IoT application protocols for smart farming," *Computer Networks*, vol. 168, no. 107037, p. 107037, Feb. 2020, doi: 10.1016/j.comnet.2019.107037.

[19] A. P.S., S. M. D. Kumar, and V. K.R., "MQTT implementations, open issues, and challenges: a detailed comparison and survey," *International Journal of Sensors, Wireless Communications and Control*, vol. 12, no. 8, pp. 553–576, Oct. 2022, doi: 10.2174/2210327913666221216152446.

[20] H. O. Mofjeld, "Tsunami detection algorithm," 1997. http://nctr.pmel.noaa.gov/tda documentation.html (accessed Jul. 21, 2023).

[21] "Freepik Company, S.L. Flaticon Free Icons." https://www.flaticon.com/ (accessed Jul. 21, 2023).

[22] M. Iqbal, T. B. Palokoto, A. A. N. Ananda Kusuma, A. R. Hartawan, T. Agastani, and W. S. Pinastiko, "Simulating Labuan Bajo Indonesia cable based tsunameter (INA-CBT) landing station network through the development of IPFIX-based traffic generator application," in *2022 International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET)*, Dec. 2022, pp. 166–170, doi: 10.1109/ICRAMET56917.2022.9991229.

[23] S. Lee, H. Kim, D.-K. Hong, and H. Ju, "Correlation analysis of MQTT loss and delay according to QoS level," in *The International Conference on Information Networking 2013 (ICOIN)*, Jan. 2013, pp. 714–717, doi: 10.1109/ICOIN.2013.6496715.

[24] B. Bendele and D. Akopian, "A study of IoT MQTT control packet behavior and its effect on communication delays," *Electronic Imaging*, vol. 29, no. 6, pp. 120–129, Jan. 2017, doi: 10.2352/ISSN.2470-1173.2017.6.MOBMU-311.

[25] S. Pawar, D. B. Jadhav, M. Lokhande, P. Raskar, and M. Patil, "Evaluation of quality of service parameters for MQTT communication in IoT application by using deep neural network," *International Journal of Information Technology*, vol. 16, no. 2, pp. 1123–1136, Feb. 2024, doi: 10.1007/s41870-023-01664-2.

[26] S. Alharby, N. Harris, A. Weddell, and J. Reeve, "The security trade-offs in resource constrained nodes for IoT application," *International Journal of Electrical, Electronic and Communication Sciences: 11.0.*, vol. 12, no. 1, pp. 56–63, 2018, doi: 10.1999/1307-6892/10008451.

[27] A. J. H. Hintaw, "Performance analysis of MQTT protocol in IoT environments: impact of payload size and QoS on key metrics," *Technium: Romanian Journal of Applied Sciences and Technology*, vol. 28, pp. 43–57, Mar. 2025, doi: 10.47577/technium.v28i.12649.

[28] D. Borsatti, W. Cerroni, F. Tonini, and C. Raffaelli, "From IoT to cloud: applications and performance of the MQTT protocol," in *2020 22nd International Conference on Transparent Optical Networks (ICTON)*, Jul. 2020, pp. 1–4, doi: 10.1109/ICTON51198.2020.9203167.

[29] J. Ali and M. H. Zafar, "Improved end-to-end service assurance and mathematical modeling of message queuing telemetry transport protocol based massively deployed fully functional devices in smart cities," *Alexandria Engineering Journal*, vol. 72, pp. 657–672, Jun. 2023, doi: 10.1016/j.aej.2023.04.014.

[30] J. J. Puthiyidam and S. Joseph, "Internet of things network performance: impact of message and client sizes and reliability levels," *ECTI Transactions on Electrical Engineering, Electronics, and Communications*, vol. 22, no. 1, pp. 1–9, Feb. 2024, doi: 10.37936/ecti-eec.2024221.252941.

[31] M. Handosa, D. Gracanin, and H. G. Elmongui, "Performance evaluation of MQTT-based internet of things systems," in *Proceedings - Winter Simulation Conference*, Dec. 2017, pp. 4544–4545, doi: 10.1109/WSC.2017.8248196.

[32] M. A. Salimee, M. A. Pasha, and S. Masud, "NS-3 based open-source implementation of MQTT protocol for smart building IoT applications," in *2023 International Conference on Communication, Computing and Digital Systems (C-CODE)*, May 2023, pp. 1–6, doi: 10.1109/C-CODE58145.2023.10139859.

[33] G. M. Beltrami, "An ANN algorithm for automatic, real-time tsunami detection in deep-sea level measurements," *Ocean Engineering*, vol. 35, no. 5–6, pp. 572–587, Apr. 2008, doi: 10.1016/j.oceaneng.2007.11.009.

[34] M. Nosov, V. Karpov, S. Kolesov, K. Sementsov, H. Matsumoto, and Y. Kaneda, "Relationship between pressure variations at the ocean bottom and the acceleration of its motion during a submarine earthquake," *Earth, Planets and Space*, vol. 70, no. 1, p. 100, Dec. 2018, doi: 10.1186/s40623-018-0874-9.

BIOGRAPHIES OF AUTHORS

A. A. N. Ananda Kusuma received the B.Eng. (Hons.), M.Eng., and Ph.D. degrees in 1993, 1998, 2005, from the University of Tasmania, RMIT University, and the University of Melbourne, Australia. He holds a position as a Principal Engineer and Research Group Leader at the Research Center for Telecommunication, National Research and Innovation Agency. His research interests include routing algorithms, resource allocation problems, QoS/QoE estimation, distributed systems, automata theory, and various problems related to network protocols. He is also a lecturer at the Department of Informatics, Universitas Multimedia Nusantara. He can be contacted at email: anak001@brin.go.id or ananda.kusuma@lecturer.umn.ac.id.

Tahar Agastani received the B.Eng. degree in electrical engineering in 1988 from University of Indonesia, Indonesia and the M.Sc. degree in computer science in 1995 from Oklahoma State University, USA. He holds a position as a Specialist Engineer and Research Group Member at the Research Center for Telecommunication, National Research of Innovation Agency. His research interests include network simulation, QoS/QoE estimation, and resource allocation problems. He has served as a Program Manager to some large-scale research projects related to air navigation. He can be contacted at email: taha001@brin.go.id.

Rifqi F. Giyana received the S.T. (B.Eng.) degree in electrical engineering with telecommunication specialization in 2017 from Gadjah Mada University. He holds a position as a Junior Engineer in Research Group of Advanced Network Protocol at the Research Center for Telecommunication, National Research and Innovation Agency. His research interests include network protocol, network data plane programming, and IoT network. He has participated in several projects such as Indonesian tsunami early-warning systems, autonomous-guided vehicles, and ADSB transmitter development. He is currently pursuing the M.Eng degree at the Department of Electrical Engineering, University of Indonesia. He can be contacted at email: rifq004@brin.go.id.

Sakinah P. Anggraeni graduated from the Applied Bachelor Program, Wireless Telecommunication Engineering Study Program, Bandung State Polytechnic, 2017/2018 with the final project title "Wireless control system for e-aquaponics: integrated monitoring of fish and plant cultivation with routing protocol data centric based on wireless sensors network" and received an award for Outstanding Final Project (best final project). She has been the employee of the Indonesian National Research and Innovation Agency (BRIN RI) since 2020, as a young Researcher in the Telecommunication Research Center, National Research and Innovation Agency, Serpong, Indonesia. She can be contacted at email: sakinah.puspa.anggraeni@brin.go.id.

Arfan R. Hartawan received the S.T (B.Eng). degree in telecommunication engineering in 2018 from Telkom University, Indonesia. Currently he holds a position as a Junior Engineer and Research Group Members of Advanced Network Protocol at the Research Center for Telecommunication, National Research and Innovation Agency. His research interests include various network security-related protocols and their governance mechanisms. He is currently pursuing the M.Eng degree at the Department of Electrical Engineering, University of Indonesia. He can be contacted at email: arfa001@brin.go.id.

Toto B. Palokoto graduated from the Applied Bachelor Program, Telecommunication Engineering Study Program, State Polytechnic of Semarang in 2017. He has been the employee of the Indonesian National Research and Innovation Agency (BRIN RI) since 2020, as a young Researcher in the Telecommunication Research Center, National Research and Innovation Agency, Serpong, Indonesia. His research interests include machine learning, network measurement, and software development. He is the principal investigator in applying machine learning techniques for refining the CBT network's traffic generator. He can be contacted at email: toto010@brin.go.id.

Widrianto S. Pinastiko received the B.Eng. Degree in Electronics Engineering in 1986 from University of Indonesia, Indonesia and the Master of Engineering Degree in Computer Science and Information Mathematics in 1992 from The University of Electro – Communications, Tokyo Japan. He holds a position as a Specialist Engineer and Research Group Member at the Research Center of Telecommunication, National Research of Innovation Agency. His research interests include network simulation, QoS/QoE estimation, resource allocation problems, and electronics navigation system. He has served as a Program Director to some large-scale research projects related to sea and air navigation. He can be contacted at email: widr001@brin.go.id.