Hybrid NarrowBand-internet of things protocol for real time data optimization

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ABSTRACT

The level of dependence on data communication in the modern era is increasing exponentially. The internet of things (IoT) plays a very important role in the advancement of the industrial revolution 4.0 that utilizes data communication systems. IoT deployments require data communication protocols, such as hypertext transfer protocol (HTTP), and message queuing telemetry transport (MQTT) as well as network communication protocols (wireless) to meet the network needs of devices with limited resources. Optimization of data communication in IoT is needed to maintain the quality of sending and receiving data in real time. This research proposes a hybrid NarrowBand-IoT (NB-IoT) protocol designed using NarrowBand communication network technology with optimization of data communication using MQTT and HTTP protocols. In this research, the hybrid NB-IoT protocol has the best packet loss value of 0.010% against the HTTP NB-IoT protocol which has a value of 0.017%, and the MQTT NB-IoT protocol of 0.024%. The hybrid NB-IoT protocol has a latency value of 8.7 seconds compared to the HTTP NB-IoT protocol which has a latency of 10.9 seconds. Meanwhile, the throughput value of the hybrid NB-IoT protocol is 158906.1 byte/s and is better than the MQTT NB-IoT protocol which is only 158898.6 bytes/s.

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1. INTRODUCTION

The world population growth rate according to the United Nations (UN), is expected to reach 9.8 billion people by 2050 [1]. The highest population level is in urban areas, which is around 75%, and is dominated by developing countries [2]. Meanwhile, 53% of Indonesians live in urban areas, and it is projected to increase to 71% by 2050 [3]. The rapid rate of population growth in urban areas will increase the burden on cities, especially communication service providers to the problem of speed of internet data communication. This condition encourages various parties to always make a breakthrough in optimizing data communication in real time.

Humans have a higher level of dependence on the internet [4]. This can be proven by the graph of internet usage, which is increasing yearly [5]. This increase in internet use is due to the technological revolution 4.0, where the use of the internet of things (IoT) is increasingly widespread [6]. Fast and accurate data communication protocols are needed in IoT applications. Data communication protocols in IoT consist of hypertext transfer protocol (HTTP), constrained application protocol (CoAP), and message queuing telemetry transport (MQTT) protocols [7], [8], while the IoT communication network protocols include long range (LoRa), long term evolution (LTE), Wi-Fi, Bluetooth, Sigfox, and the latest is NarrowBand (NB)-IoT [9], [10].

The MQTT protocol plays a very important role in IoT-based data communication systems, which are used in wireless sensor networks and low power wide area networks (LPWAN) to carry out control and monitoring functions of a system [11], [12]. MQTT is an IoT connectivity protocol that applies to the use of small, low-power sensors [13]. MQTT runs on top of the transmission control protocol/internet protocol (TCP/IP) [14]. NB-IoT is the latest data communication technology in LPWAN which has characteristics of reliable, efficient, and low infrastructure costs as well as the evolution of cellular network technology, namely 2G, 3G, and 4G [15], [16]. NB-IoT has the characteristics of high network coverage (20 dB increase from GPRS) [17], low power consumption [18], and large connection capacity [15], and supports LTE connection [19].

In recent years, many researchers have implemented various communication protocols. One of them is the integration of NB-IoT with several communication protocols. Khan and Pirak [20] conducted research at different locations analyzing the quality of data transmission using NB-IoT technology for packet loss parameters on smart meter devices, which use the MQTT protocol, and CoAP. The results obtained in his research are the quality of services (QoS) parameters for packet loss using the CoAP protocol are slightly better than those using the MQTT protocol. Wukkadada *et al*. [21] conducted research by making modular devices that can control other devices remotely, using the best protocols that have low latency. The results of the research can be seen that the power consumption for the process of sending data and receiving data using the MQTT protocol is lower than the HTTP protocol. So, MQTT is the best protocol for IoT communication. Nwankwo *et al.* [22] conducted a study presenting an NB-IoT system for monitoring and controlling electrical appliances connected to smart networks. The results of this study produce NB-IoT-based devices that can be controlled. The QoS parameter value for latency produces a value of 11 seconds indoors and 9.5 seconds outdoors.

This research proposes a new communication protocol, namely the hybrid NB-IoT protocol. Hybrid NB-IoT protocol is an IoT data communication protocol that combines HTTP and MQTT protocols with normal REST APIs and adds MQTT messages for REST endpoints that result in state changes. This research aims to analyze the data transmission capabilities of the MQTT, HTTP, and hybrid NB-IoT protocol on the NB-IoT network and analyze the data bandwidth requirements used in the MQTT, HTTP, and hybrid NB-IoT protocols.

2. RESEARCH METHOD

This research started from several stages. The first is the planning stage of the entire system consisting of internet gateway devices and the hybrid NB-IoT protocol algorithm. The second stage is implementing the results of the planning stage. and the last one is the whole system testing phase. The testing stage is the stage carried out to determine the performance of the system being built. The test was carried out in five stages, namely hardware testing, NB-IoT hybrid protocol algorithm testing, NB-IoT network connectivity testing, cloud server testing, and testing of the entire system.

2.1. Internet gateway device

Internet gateway device consists of several main parts, namely the Arduino microcontroller and the SIM7000 module that supports the NB-IoT network. The whole system can be seen in Figure 1. The internet gateway device will send sensor data in real time using the NB-IoT hybrid protocol. Data from the BME280 sensor will be sent to a microcontroller with an I2C communication system. The Arduino microcontroller will process the data with the hybrid Nb-IoT algorithm. Data that has been processed in JSON format will be forwarded to the SIM7000 module and sent to cloud-based storage media via the NB-IoT hybrid protocol using the NB-IoT network. Figure 1 describes the overall outline of the research system.

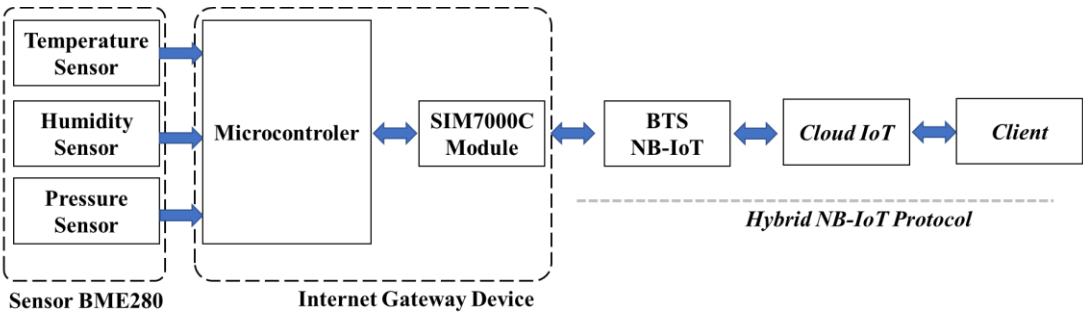


Figure 1. Research system block diagram

2.2. NB-IoT hybrid protocol design

The hybrid NB-IoT protocol consists of MQTT and HTTP-based data communication protocols that run alternately or simultaneously through the Narrowband IoT communication network, using a hybrid algorithm on internet gateway devices based on previous research by Nwankwo *et al.* [22]. The internet gateway device will send data in the form of a JSON file to a cloud server that supports two communication protocols at once, namely HTTP and MQTT. In this research, a cloud server from ANTARES is used, which is a horizontal IoT platform using a RESTfull approach in developing APIs and APIs that support the MQTT protocol by supporting JSON and XML file formats [23], [24]. Table 1 describes the hybrid NB-IoT protocol algorithm.

Table 1. NB-IoT hybrid protocol algorithm

```
Algorithm: Realtime data communication using hybrid NB-IoT protocol
Input: Sensor BME280 [temperature, humidity, pressure]
Output: Sensor Data on JSON File [S, H, T]
Start
    Initialization BME280 Sensor [I2C Communication]
    Initialization NB-IoT Network [SIM7000, Access Point Name]
    Initialization Cloud Server [Access Key, Port 8080, Port 1883]
    Set HTTP Protocol on Cloud Server
    Set MQTT Protocol on Cloud Server
    Read Data Sensor BME280 [temperature, humidity, pressure] ... d1, d2, d3
    Convert to JSON File....jwt
    Connect Cloud Server Port 1883
   If Cloud server Acknowledge then
        Connect Cloud Server Port 8080
        If Cloud server Acknowledge then
             Wait Request Subscribe [Topic] from Cloud Server
   Publish Topic and Data .... jwt
   POST Topic and Data .... jwt
   Acknowledge Response from cloud server
   Delay 5000 millisecond
End
```

This research uses two data flow scenarios. The first scenario uses a periodic data transmission scheme, where all data sent by the sensor within a certain time will be stored in a JSON file first. The JSON file is sent after the specified time range. After the delivery is complete, the data in the JSON file is deleted, this is done so that the data that has been stored on the storage media is not sent back by the internet gateway device so that there is no accumulation of the same data on the cloud storage media.

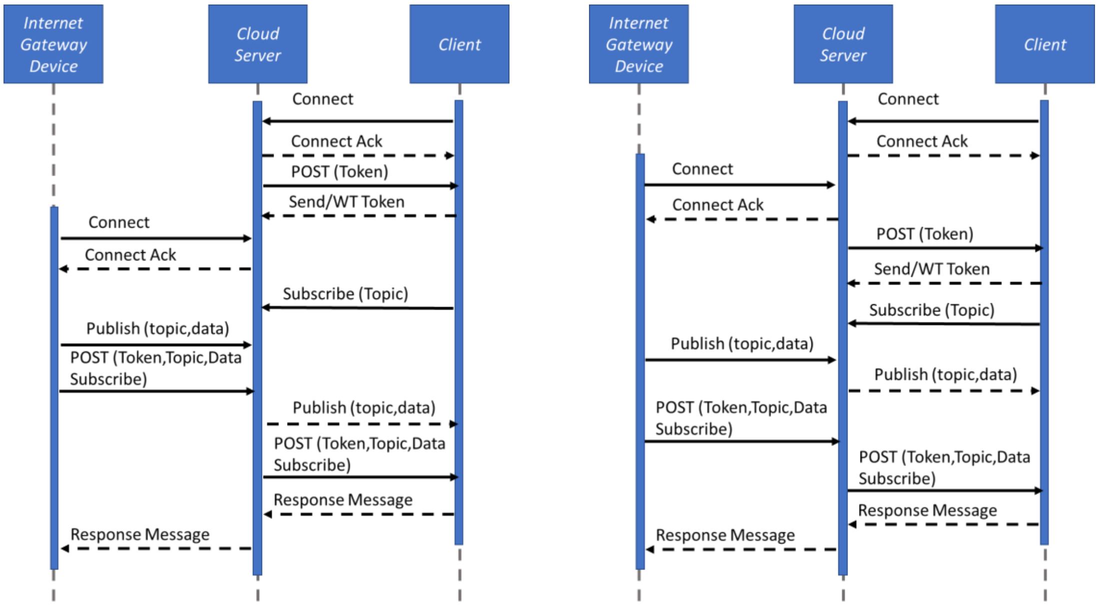
In the second scenario, the cloud server device subscribes to the topic of sensor parameters (temperature, humidity, and pressure) on the internet gateway device, then the internet gateway device will send data in real time according to the subscribed topic and the internet gateway device will directly send the data received from the internet gateway device. sensors to cloud-based devices. The storage media on the cloud server uses the JSON format.

Figure 2(a) illustrates the data flow for sending data periodically from the internet gateway device to the client via the cloud server using the NB-IoT hybrid protocol. Figure 2(b) depicts a real time data stream using the hybrid NB-IoT protocol. Payload data design as in previous research conducted by Nguyen *et al.* [7] and Lin *et al.* [25]. The data used is BME280 sensor data (temperature, humidity, and air pressure) received through the internet gateway device in the form of JSON. Table 2 describes the payload of sensor data sent with the NB-IoT protocol.

The storage media as the destination for sending data from the internet gateway device is a cloud server that is capable of receiving data with HTTP and MQTT protocols. This research uses the cloud server configuration method that has been developed [7] and [25]. Cloud servers Antares have login and authentication features using access keys to receive data [23], [24]. Internet gateway devices must be able to log in and know the access key to publish with and PUT data using the HTTP POST method. Cloud servers can receive data sent by internet gateway devices. Login can be done by creating an account on the cloud server. Access key the accessible obtained after registering the device on the cloud server.

2.3. Testing system

Testing of the entire system is carried out after the initial testing has been carried out. Initial testing consists of several stages. The first stage is testing the performance of the BME 280 sensor. This test is used to verify whether the sensor can read the environmental conditions correctly or whether not sends data via the I2C protocol to the internet gateway device. Figures 3(a) to 3(c) are the measurement and calibration results for the BME 280 sensor connected to the internet gateway device.

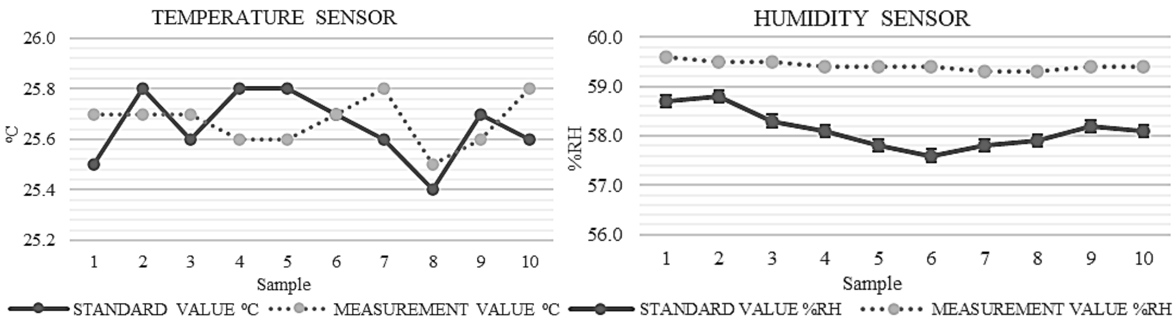


(a) (b)

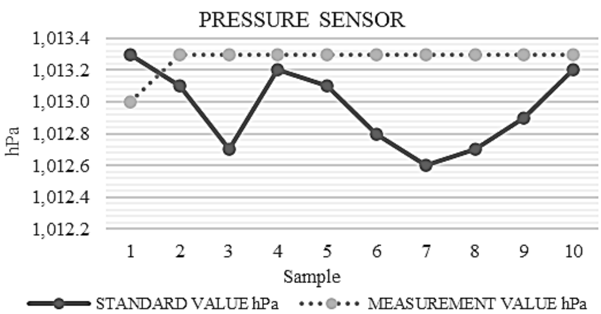
Figure 2. Data flow (a) periodic and (b) real time

Table 2. Payload data

No.	Protocol	Data *Payload*
1	MQTT	{“sensor”:{“module”:”temp”,”type”:”nbiot”,”index”:7345636,”ip”:”192.168.18.18”},”protocol”:”mqtt”, ”topic”:”office/roomA15”,”temp”:{“value”:”32.0”,”unit”:”celcius”},”timestamp”:1022026551,”humidity”:{“value”:”59.0”,”unit”:”%”},”timestamp”:1233137662”pressure”:{“value”:”1.0”,”unit”:”bar”}}
2	HTTP	{“sensor”:{“module”:”temp”,”type”:”nbiot”,”index”:7345636,”ip”:”192.168.19.31”},”protocol”:”http”, ”topic”:”office/roomA16”,”temp”:{“value”:”32.0”,”unit”:”celcius”},”timestamp”:1022026559,”humidity”:{“value”:”59.0”,”unit”:”%”},”timestamp”:1233137669”pressure”:{“value”:”1.0”,”unit”:”bar”}}



(a) (b)



(c)

Figure 3. Graph of BME280 sensor test results: (a) temperature sensor, (b) humidity sensor, and (c) pressure sensor

A sampling of data was carried out 10 times with an interval of 5 seconds between samples. Tests are carried out using reference standards that are calibrated and traceable to the Metrology Agency under the auspices of the Ministry of Trade of the Republic of Indonesia. The devices used in this test are described in Table 3. Calculations to determine the value of the standard deviation uses (1),

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad (1)$$

where n is amount of data, $\bar{x}$ is sample average, and x_i is sample data to i.

Table 3. Sensor testing device

Testing Device	Remark
Sensor BME280	Temperature module for taking temperature, humidity, and pressure readings
Calibrator BEAMEX MC5	Used as a digital display device for sensor standards
Sensor PT-100 Standard ISOTECH Model 935-14-16	The standard sensor used to read the temperature
Beamex Barometric Pressure Modul INT2C	Standard sensor module used to read pressure
Rotronic Model HF532-WBA3D1XX	Standard sensor module used to read humidity
Mini PC – HP EliteDesk Intel Core i5*8500T CPU@2.10 Ghz RAM 8 GB	Used to display the value of the BME280 sensor reading through a serial monitor on an Arduino-based Internet gateway device

The results of the calculation of the standard deviation for the measurement of the temperature sensor are 0.095 °C, the humidity sensor is 0.092%, and the pressure sensor is 0.095 hPa. The next stage of testing is testing the NB-IoT network connectivity, which aims to validate the exact and ideal location and time in carrying out the last stage of testing (the whole system). This research uses the NB-IoT network owned by Telkomsel. To validate the existence of the NB-IoT network, measurements and location mapping are carried out. Measurements are carried out using the PuTTY application. The putty terminal port used is port 25 with a baud rate of 115200. The signal level at the time of measurement is 25 out of 31 with the access point name (APN) name for Telkomsel's NB-IoT network being "NB1INTERNET".

In the mapping of the location obtained 3 coverage areas with a fairly high level. Where for location A with a distance of 5 km from the center of the NB-IoT network, the level of connectivity is number 12 out of 31. For location B with a distance of 7 km, the level of connectivity shows the number 9 and for location C with a distance, it shows a connectivity level of 6 out of 31. Figure 4 describes the throughput value of the NB-IoT network with 3 different locations and was carried out within 7 full days, using a dummy data upload of 200 kilobytes. Measurement of QoS parameter values is done using Wireshark software [26].

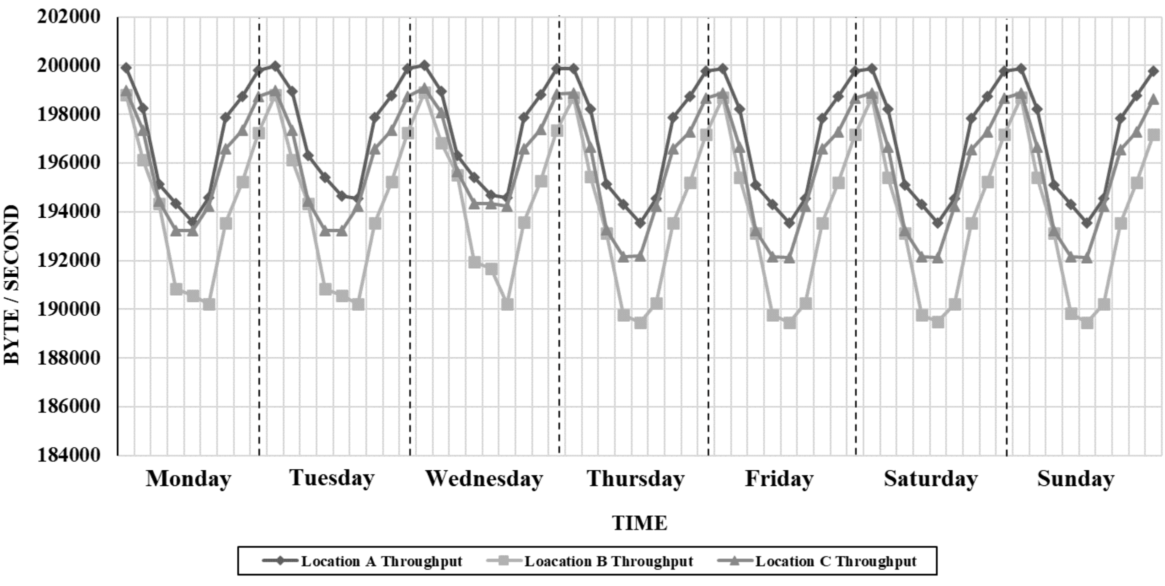


Figure 4. NB-IoT Network throughput measurement chart

The measurement results at location A show that on Wednesday from 01.00 to 05.00 the throughput value is the best in 7 days during the measurement. The throughput value obtained is 199,997 bps, the latency value is 8 seconds, and the packet loss value is 0%. Testing of the entire system can be carried out on that day and hour because it has stability and low data communication traffic. On Wednesday, QoS parameters were also measured for indoor and outdoor conditions.

Testing the cloud server using the ANTARES platform which also functions as a broker. The testing stage starts by logging into the ANTARES account and adding devices and configuring to get an access key. The test was carried out by sending dummy data of 200 kilobytes, using the HTTP and MQTT protocols to the cloud server via the NB-IoT network. Data transmission is carried out periodically for 10 seconds and in real time. Where the maximum throughput capacity of the NB-IoT network is 250 kbps.

Testing the entire system used QoS parameters consisting of latency, throughput, and packet loss for each communication protocol, and data sampling was carried out 20 times. Figure 5 describes the overall system test flow. The final test for the whole system focused on 3 communication protocols, namely HTTP, MQTT, and hybrid NB-IoT through an NB-IoT-based network, and data transmission models were carried out periodically and in real-time. Testing the entire system using additional devices in the form of an HP EliteBook 830 G7 brand laptop with an Intel Core i5 processor, and 8 GB of RAM memory. The test parameters used are throughput, latency, and packet loss.

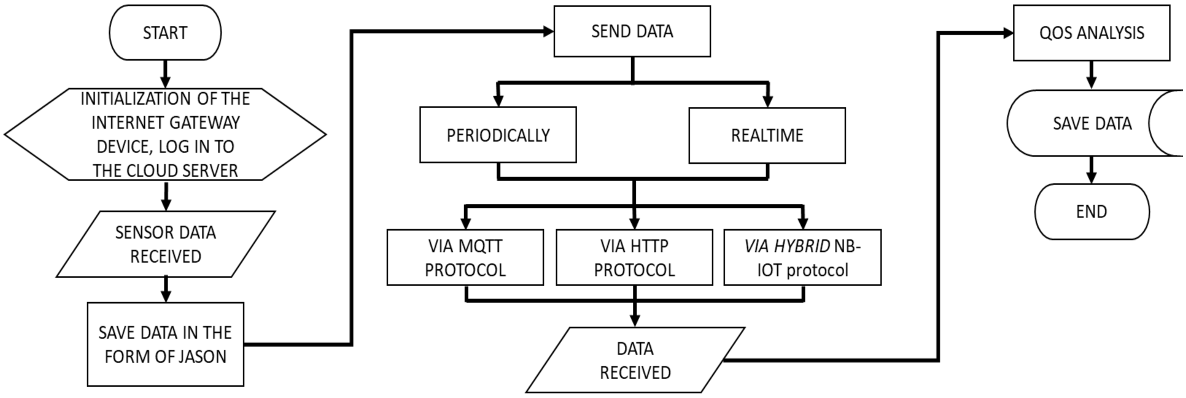


Figure 5. Overall system testing flowchart

3. RESULTS AND DISCUSSION

The results of the first overall system test are using the MQTT protocol, HTTP, and the hybrid NB-IoT protocol with a periodic data transmission model. Figure 6 shows the results of the comparison of protocols with throughput parameters in Figure 6(a), latency parameters in Figure 6(b), and packet loss parameters in Figure 6(c) all of which were tested with data transmission times ranging from 5, 10, 15, and 20 seconds. The sampling process (data capture) was carried out 20 times with a time adjusted to the data transmission period.

From testing the whole system with periodic data transmission over a period of 20 seconds, we found that the HTTP NB-IoT protocol has the best/largest throughput value of 156,550 bytes per second. Then the latency value for the NB-IoT MQTT protocol has the best/smallest value, which is 6.7 seconds. Furthermore, the hybrid NB-IoT protocol has the best/smallest packet loss value of 0.009%.

The advantages of the hybrid NB-IoT protocol in sending data periodically can optimize data transmission in real time. The next test result is testing the entire system by transmitting data in real time using the NB-IoT MQTT protocol, NB-IoT HTTP protocol, and NB-IoT hybrid protocol. Based on Figure 7(a), the throughput value of real time data transmission from the tests that have been carried out, where the HTTP NB-IoT protocol has the best/largest value of 158,909.7 bytes per second. Then the hybrid NB-IoT protocol with an average value of 158906.1 bytes per second, then the MQTT NB-IoT protocol with an average value of 158898.6 bytes per second.

Figure 7 shows the test results in real time, where in Figure 7(a) the value of data transmission throughput in real time for the HTTP NB-IoT protocol which has the best/largest value of 158,909.7 bytes per second. Then, in Figure 7(b), the latency value for data transmission in real time, shows that the NB-IoT MQTT protocol has the best/smallest value of 6.8 seconds. While Figure 7(c) shows that the hybrid NB-IoT protocol has the best/smallest packet loss value of 0.010%.

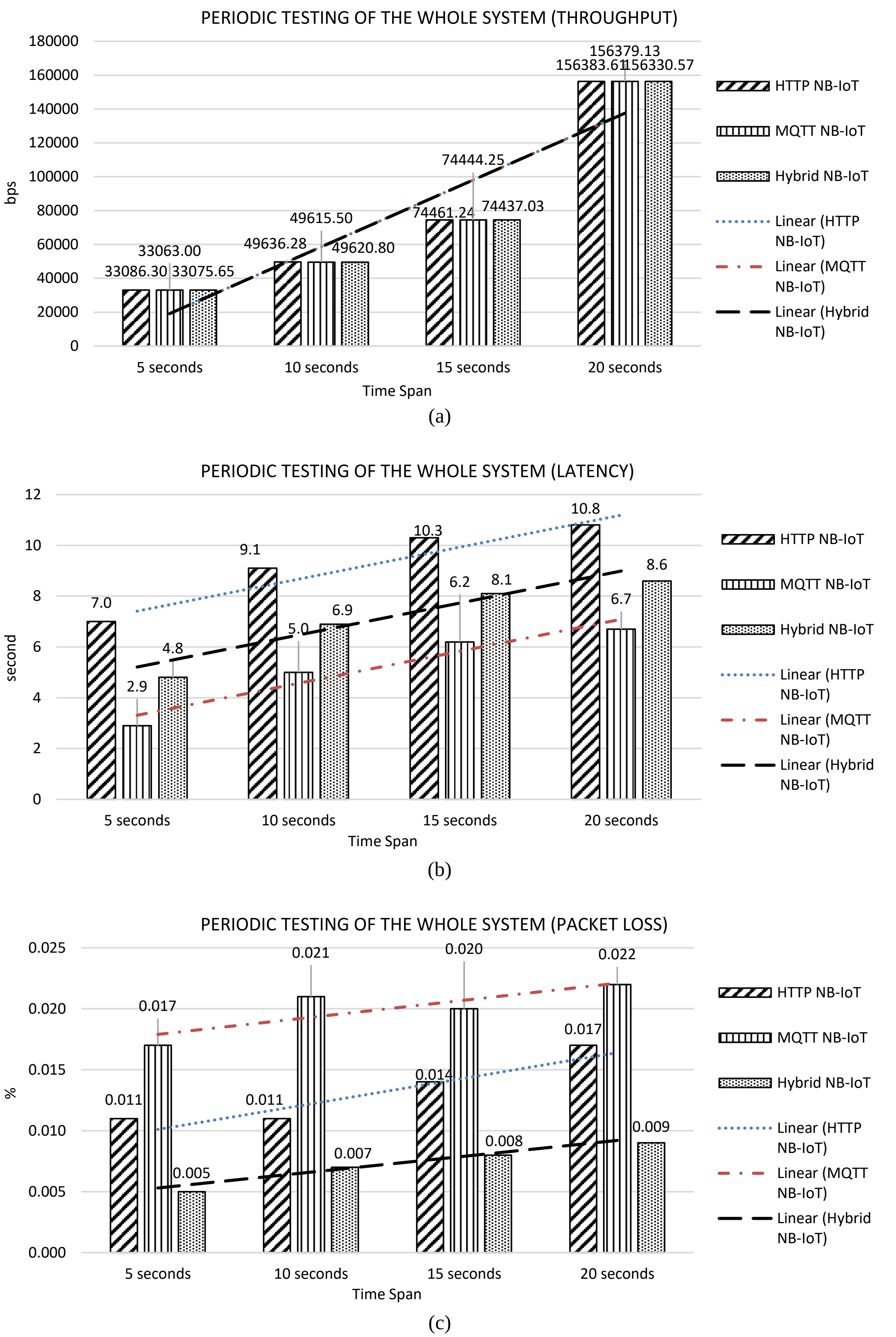
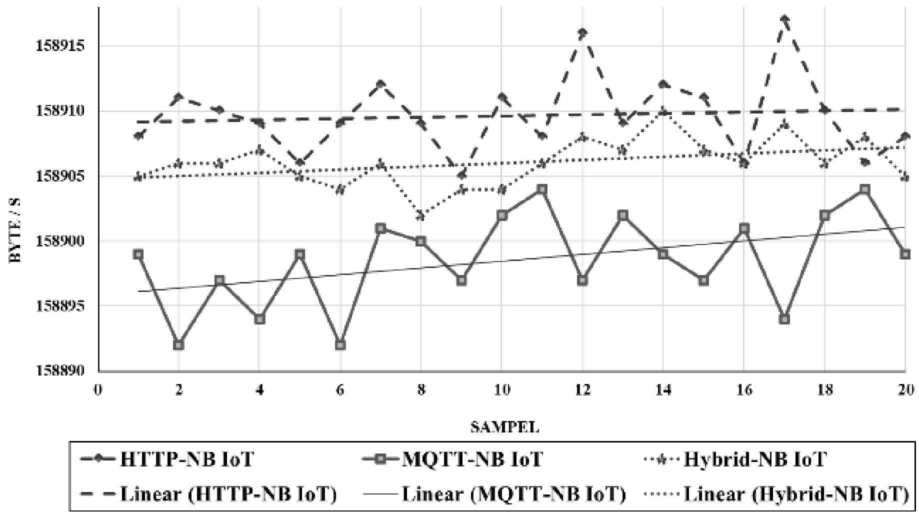
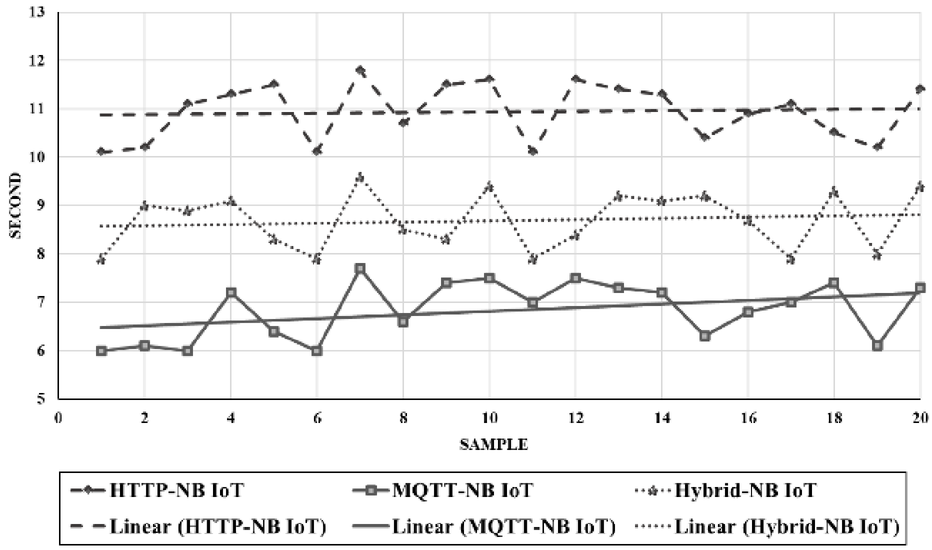


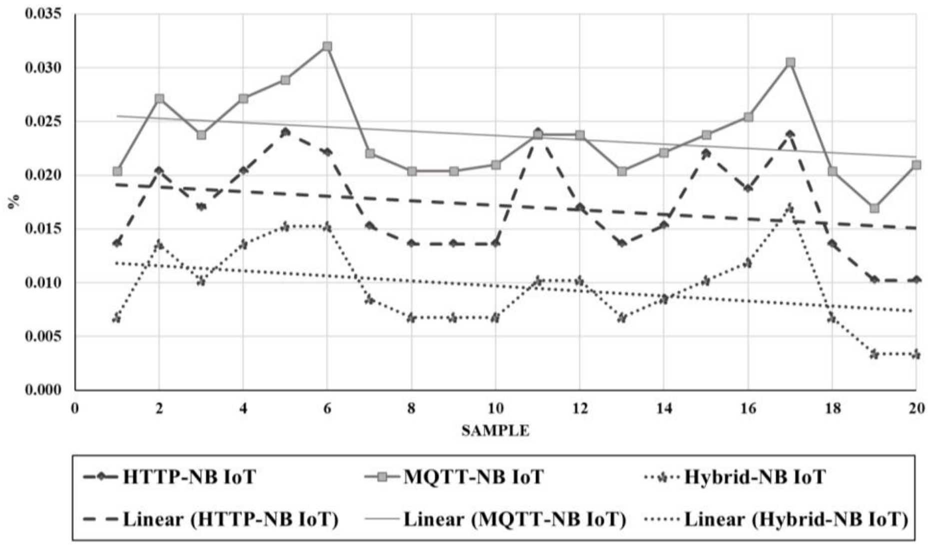
Figure 6. Graph of periodic overall system testing: (a) throughput, (b) latency, and (c) packet loss



(a)



(b)



(c)

Figure 7. Real time overall system testing; (a) throughput, (b) latency, and (c) packet loss

In this study we found that overall, data transmission is both periodic and real-time, the HTTP NB-IoT protocol excels in throughput, the NB-IoT MQTT protocol excels in latency, and the hybrid NB-IoT protocol excels in packet loss. It can be proven that the hybrid NB-IoT protocol can handle data transmission in real time better than the NB-IoT MQTT protocol for throughput parameters and better than the HTTP NB-IoT protocol for latency parameters. Data transmission between periodic and real time has the same performance for latency and packet loss parameters. For throughput parameters, data transmission in real time is better. The real-time data transmission method from the research results is better and recommended.

4. CONCLUSION

In this research, the internet gateway device can send data periodically and in real time using the hybrid NB-IoT protocol with a packet loss value of 0.010%, which is better than the HTTP NB-IoT and MQTT NB-IoT protocols in real time data communication. Overall, the hybrid NB-IoT protocol is better than the MQTT NB-IoT protocol in terms of throughput, which is 158906.1 bytes per second in real time data communication, and the hybrid NB-IoT protocol is better than the HTTP NB-IoT protocol in terms of latency, which is 8.7 seconds in real time data communication

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