EVALUATION OF BANDWIDTH AND LATENCY OF WIRELESS SENSOR NETWORKS USING JPERF SIMULATION

Nadiatul Safana[1*], Novan Pazrian[2], Muhammad akhyar Hafidha[3], Yeni Yanti[4]

[1,2,3,4] Computer Engineering, Faculty of Engineering, Serambi Mekkah University, Jl. Unmuha, Batoh, Kec. Lueng Bata, Kota Banda Aceh, Indonesia

Article Information
Received: 21-11-2024
Revised: 28-11-2024
Published: 05-12-2024

Keywords
WSN,Bandwidth,Latensi, TCP,UDp

Correspondence Email:
Nadiatulsafana415@gmail.com

Abstract
WSN is a sensor network that uses wireless communication to connect sensor nodes This research discusses the evaluation of wireless sensor networks (WSN) which was a case study carried out at the Banda Aceh Mayor's Office, with a focus on measuring bandwidth and latency using the JPerf application. Testing is carried out through star topology simulation, where the server and client are connected to each other via an access point. The TCP protocol is used for bandwidth measurements, while the UDP protocol is used for latency measurements. Test results show the average bandwidth ranges from 7,518-8,029 Kbits/s with significant fluctuations due to network interference. Network latency was recorded as stable at 996 Kbits/s with low jitter. This evaluation provides recommendations for improving network performance through optimizing QoS management and strategic device placement. With this implementation, network reliability can be increased to support operational activities efficiently.

1. Introduction

The technology of Internet of Things (IoT) has reached its peak of popularity in recent years. IoT is a network that connects physical objects to the Internet. These objects can be devices, sensors, or other devices that can collect and transmit data. The data collected from these objects can be used for various purposes such as monitoring, control, and analysis (Khanna & Kaur, 2020). One of the key components of this IoT ecosystem is a wireless sensor network (WSN) that allows data collection from the environment (Gulati et al., 2021). WSN is a sensor network that uses wireless communication to connect sensor nodes. Sensor nodes are small devices that can collect data from their environment. Data collected by sensor nodes can be sent to a sink, a device that collects and processes the data. WSN has unique features such as large and limited resources (e.g. power, computing capacity, storage capacity) and dynamic environments (Mahmuddin et al., 2019; Olufemi Olakanmi & Dada, 2020)

Wireless Sensor Networks (WSNs) have gained attention for their diverse applications and transformative potential. This study evaluated WSN performance using the Wireless Power Management (WPM) method, focusing on key metrics like Coverage and Connectivity, Data Accuracy, Latency, Throughput, Fault Tolerance, and Robustness. Results showed Wireless Communication excelled in Coverage (102.25), Data Aggregation led in Accuracy (132.16), Routing Protocols performed well in Latency (66.15), and Fault Tolerance scored 105.56. IoT achieved outstanding performance across all metrics, with a perfect score of 1.000 in the Weighted Normalized Decision Matrix. Wireless Communication ranked first in overall Preference Score(Amuda et al., 2021).

The research by (Kurniawati et al., 2023) presents high-throughput and low-latency wireless transmission with efficient bandwidth, especially for medical Internet of Things (MIoT) applications. The proposed method is realized by using shorter orthogonal frequency division multiplexing (OFDM) symbol periods, which corresponds to shorter packet transmission. This can be achieved by reducing the distance between carriers while maintaining the sample rate frequency, thus allowing fewer data samples to be used in the time domain. In addition, the proposed scheme can transmit more data frames in twice the original time slot period, thereby increasing the throughput without increasing the bandwidth utilization. The evaluation results for 20MHz and 40MHz bandwidths show that the throughput has been improved by about 2.3 times and 2.6 times compared to the previous model, respectively. In addition, the proposed method reduces the transmission time by about 50%, thus enabling low-latency transmission.

This further research will evaluate network performance, measure bandwidth and latency under various test conditions at the Banda Aceh Mayor's Office with TCP and UDP protocols and then simulate using Jperf on a wireless sensor network.

1.1 Literature Review

1.1.1 Understanding Wireless Sensor Networks

A wireless sensor network (WSN) is a network consisting of several sensors connected wirelessly for the purpose of collecting and exchanging information. Each sensor in this network usually consists of integrated hardware with measurement sensors, wireless communication modules, and energy resources. A wireless sensor network is a network with a distributed collection of sensor nodes. Sensor nodes in a wireless sensor network have the ability to collect data, communicate with other sensor nodes and convey data to the sink node. One of the Internet of Things (IoT) applications currently developing is utilizing wireless sensor networks. Data from sensor nodes connected in a network can be sent to the cloud via the internet which can then be displayed via a smartphone or personal computer connected to the internet. Wireless sensor networks for environmental monitoring with IoT utilize wirelessly connected sensors to collect data on environmental parameters such as air quality, water quality, noise levels, temperature, humidity, and more. This data is then sent via the IoT network to be analyzed , processed and used for better decision making in environmental management(Adinda, 2022)

There are several parameters that can be tested to determine the performance of a wireless sensor network, such as data transmission delay, communication distance between sensor nodes, throughput, number of installed sensor nodes or Received Signal Strength Indicator (RSSI). The quality of a system based on a wireless sensor network depends, in part, on the transceiver module used as a data transmission medium. The selection of the transceiver module will depend on the needs of the system itself. Therefore, the results of testing the transceiver module are deemed necessary so that it can be used as a basis for designing a system that uses a wireless sensor network. (SUSANA et al., 2021)

The main goal of WSN is to provide wireless communications based on low-cost sensor networks with very limited power consumption. So energy consumption is a challenging problem in WSN. To reduce energy consumption in WSNs, routing protocols must be implemented. One of the challenges in routing involved in WSN, is that the data traffic created has significant redundancy (unnecessary/needed data) in most cases. In addition, WSN devices depend on their batteries as a power source, so the lifetime of the network depends on the remaining battery level at each node. The technology used by each node to communicate with each other also affects the existing energy consumption (Adinda, 2022)

Wireless communication was developed into a Wireless Sensor Network (WSN). A kind of technology combined from many nodes spread within the scope of a system that implements a wireless network. The application of this technology is for tracking, monitoring and controlling devices, then exchanging data via wireless networks with interconnected nodes. The development of WSN in wireless communication, has low-power electronics, battery technology, and power harvesting capabilities which have made it possible at low costs. WSNs are also characterized by limited power, unreliable communications, need for self-configuration and scalability, harsh environmental conditions, small size, cooperative network behavior, data centricity (as opposed to address centricity), very small packet sizes, operation unsupervised, and random distribution. Characteristics of WSN applications in general for environmental monitoring, health monitoring, terror threat detection, terrestrial and underwater habitat monitoring, military surveillance, seismic oil and gas exploration, inventory tracking, process monitoring, acoustic detection, object localization and tracking, homeland security domestically, disaster prevention and disaster recovery (Pratama et al., 2021).

1.1.2 Bandwidth

Bandwidth is a measure of the distance of the weighting function and the distance of influence of one observation location on other locations. Small bandwidth values produce large variance. However, if the bandwidth value is very large, it causes a small variance. Therefore, it is necessary to select an appropriate bandwidth to avoid inhomogeneous variance caused by increased parameter estimates (Mulyani, 2023). Bandwidth Management is the process of measuring and controlling communications (network traffic and data packets) on network traffic, to avoid traffic congestion. The purpose of bandwidth management is how we implement bandwidth allocation or management using a Mikrotik Router. Bandwidth management provides the ability to manage network bandwidth and provide service levels that suit needs and priorities according to customer demand(Tukino, 2022). And also the aim of bandwidth management is to optimize network performance so that network performance can be guaranteed. Without bandwidth management, many computers can use the internet irregularly, causing other computers not to get a fair share of bandwidth(Tukino, 2022).

Bandwidth management is a technique used to manage a network with the aim of providing fair and satisfactory network performance for users. Bandwidth management is very important for every network because the number of links used correlates with the number of applications the network can serve. Existing links must be able to meet user application needs even when traffic is high . and Bandwidth is the capacity, volume, or quota of an internet network used to send and receive data per second. Bandwidth units use bps (bits per second)(Syuhada, 2024).

Table 1 Bandwidth Categories

Category	Bandwidth
Good	> 1 Mbps
Currently	= 1 Mbps
Not good	< 1 Mbps

(Source: TIPHON)

1.1.3 Latency

Latency is the time lag when the memory first requests data until the request message arrives. The higher the latency, the higher the data reading speed and that means better memory performance. Between bandwidth and latency do not affect each other. The higher the bandwidth, the higher the memory performance, the lower the latency (Hakim et al., 2021).

Network latency is the time it takes for data to travel from one point to another in a network. In the context of the internet, latency refers to the time it takes for data to travel from a sending device to a receiving device, usually measured in milliseconds (ms). The user experience in various situations is affected by network latency, this includes when making voice or video calls, playing online games or accessing websites. The less latency, the faster user response. For example, 5G networks have lower latency than previous technologies, allowing for more responsive applications and services. In short, network latency is the amount of time it takes for data to move from one place to another on the network. Latency is affected by things like physical distance, network infrastructure, traffic levels, and network protocols. Low latency is critical for a fast and responsive user experience in a variety of applications and services (Prasetyo et al., 2023). Latency is the time required for data to travel the distance from origin to destination. Latency can be affected by distance, physical media, congestion or long processing times.

Table 2 Latency Categories

Categories Latency	Large Latency (ms)	Indeks
Very good	< 150 ms	4
Good	150 ms s/d 300 ms	3
Currently	300 ms s/d 450 ms	2
Not Good	> 450 ms	1

(Source: TIPHON)

1.1.4 Protocols

A protocol is a rule or standard that regulates or allows connections, communication and data transfer between two or more computer points. Protocols in the computer world are rules or regulations so that one or more devices can communicate with each other. Meanwhile, Computer Network Protocol is a rule so that one device can communicate with another device according to the existing computer network system. Protocol is a rule that defines several functions in a computer network, for example sending messages, data, information and other functions that must be fulfilled by the sending side (transmitter) and the receiving side (receiver) so that communication takes place correctly. rules or standards that regulate or allow connections, communication and data transfer between two or more computer points. (Bangun et al., 2021).

And then The definition of network topology is a technique for connecting one computer to another computer to form a network, where the use of network topology is based on cost, data access speed, size and level of connectivity which will affect the quality and efficiency of a network. There are various types of network topologies. Computers that are widely used today include Bus Topology, Star Topology, Ring Topology, Mesh Topology, Linear Topology (Ofrianky, 2022)

There are 3 protocols used in wireless sensor networks, including:

a TCP/IP (Transmission Control Protocol/Internet Protocol). TCP/IP is an open standard that was created freely without being tied to hardware and operating systems, based on this, support for

TCP/IP is ideal and broad for connecting different network devices. With TCP/IP, communication between network devices such as computers is possible even though there are differences in characteristics from the software and hardware side. The four-layer concept known as the Department of Defense (DoD) is a model followed by TCP/IP which aims to create a network that can survive in any condition. Until now, TCP/IP has been used as a basic model that continues to be used and used as a standard. for example, the internet is made using the TCP/IP model (Ardhiansyah et al., 2020)

b UDP (User Datagram Protocol) is one of the main protocols above IP and is a simpler transport protocol compared to TCP. UDP is used for situations that do not prioritize reliability mechanisms, meaning that in this UDP protocol, communication will continue regardless of the connection between the source and destination. The protocol that works on the Transport Layer, began to be used and developed by the US Department of Defense (DoD) to be used with the IP Protocol in the Network Layer. The UDP protocol provides an alternative Transport for processes that do not require reliable delivery (Satra & Fattah, 2021).

c Internet Protocol version 6 (IPv6), also known as IPng (Internet Protocol next generation), is the latest third layer protocol designed as a replacement for IPv4. The main reason behind the development of IPv6 is to overcome the management challenges experienced in the previous version, namely IPv4. Along with the increasing demand for Internet addresses, IPv6 was developed to provide more addresses than IPv4, but still maintain connections with existing IP addresses. Although the addressing concept in IPv6 is similar to IPv4, IPv6 is further expanded to accommodate the rapid growth of the internet and the use of more advanced applications in the future. One of the main changes that occurred in IPv6 is in the header section, where the number of address bits increased from 32 bits (in IPv4) to 128 bits in IPv6 (Anwar et al., 2024).

2. Research Methods

In collecting data and understanding the problems related to practical implementation to support the smooth writing of reports to complete one of the practical work courses in the computer engineering faculty, the author uses several methods, including:

a Field Observation

The author conducted a direct field survey at the Banda Aceh Mayor's office to obtain the information and data needed for the report

b Library studies

To run smoothly in preparing this practical work report, the author uses the literature method, namely by reading and taking theory in collecting material from the internet which can help the author in completing this report.

c Discussion and Interview

Conduct direct discussions and interviews with network administrators and employees regarding matters related to the object under review.

This network topology describes how devices are connected in a network-centric Router/Gateway test. This router acts as a communication center. All other devices, such as access points, servers, and clients, are connected to the router. The Access Point (AP) connects to the router and transmits Wi-Fi signals to the surrounding area and provides wireless connections for devices such as servers, clients, and wireless sensors. Server (Laptop) running JPerf and connects to the wireless network and runs the JPerf application to send and receive data to measure bandwidth and latency. This server is connected to the network via an access point. Client (Laptop) which also runs JPerf as a packet recipient and runs JPerf to test connectivity with the server. This client receives data packets and measures transfer speed (bandwidth) and network latency. Just like servers, clients connect via access points. Networked wireless sensors Wireless sensors connect directly to the access point and communicate over the network to transmit the data they collect.(Fig.1)

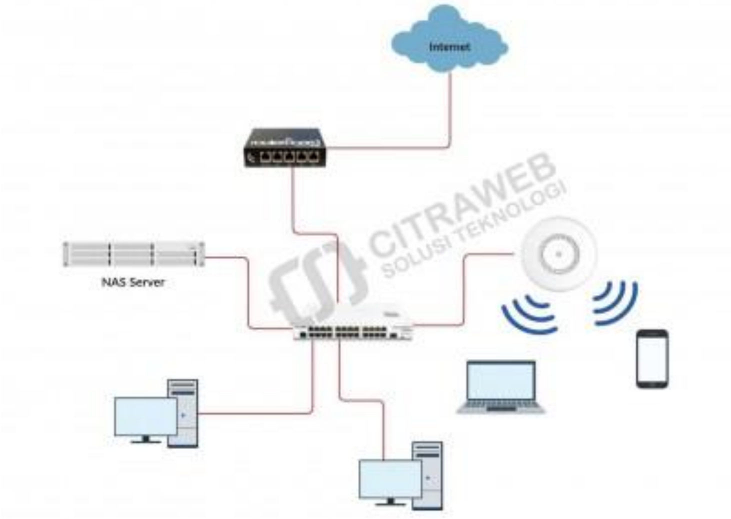


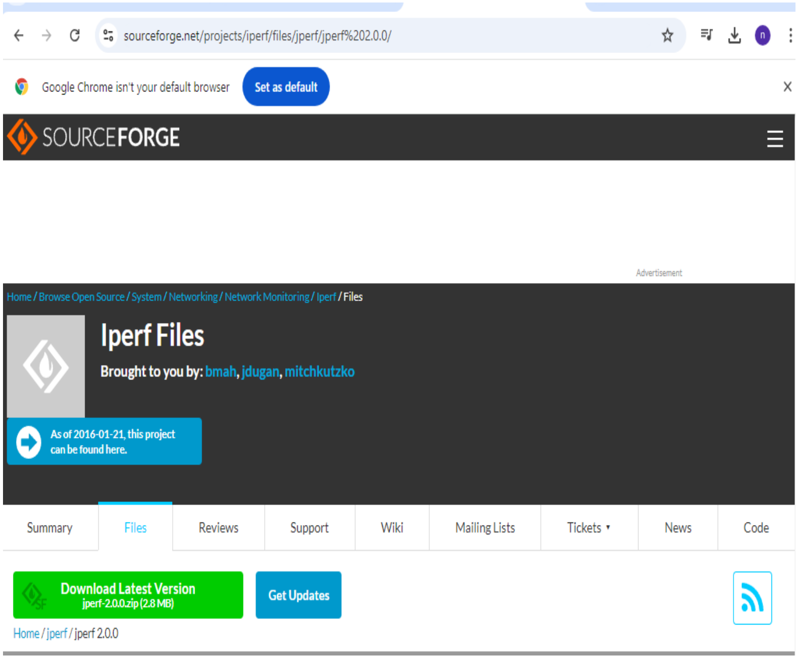
Fig.1. Simulation Design

3 Result and Discussion

3.1 Jperf Installation Process

The jperf installation process is carried out using two computers, namely a server and a client which are connected to the network in the Banda Aceh Mayor's office. The stages carried out in the process of retrieving data captured from the JPERF application are as follows:

The installation begins by downloading the jperf 2.0.0 installer file in zip format at sourceforge.net so that it displays a web page as shown in Figure 2, the installer file is adapted to the operating system used by server and client computers, such as Windows or Linux.



sourceforge.net/projects/iperf/files/jperf/jperf%202.0.0/

Google Chrome isn't your default browser

Set as default

SOURCEFORGE

Advertisement

Home / Browse Open Source / System / Networking / Network Monitoring / Iperf / Files

Iperf Files

Brought to you by: bmah, jdugan, mitchkutzko

As of 2016-01-21, this project can be found here.

Summary | Files | Reviews | Support | Wiki | Mailing Lists | Tickets ▾ | News | Code

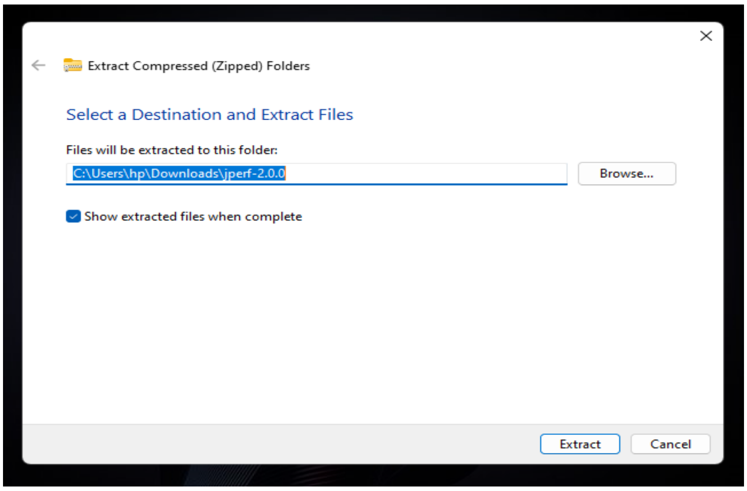
Download Latest Version jperf-2.0.0.zip (2.8 MB)

Get Updates

Home / jperf / jperf 2.0.0

Fig. 2. Web Page Downloading Jperf

After the installer file has been downloaded, it is necessary to extract the file to produce an extract interface page, and continue by selecting the extract button as shown in Figure 3.



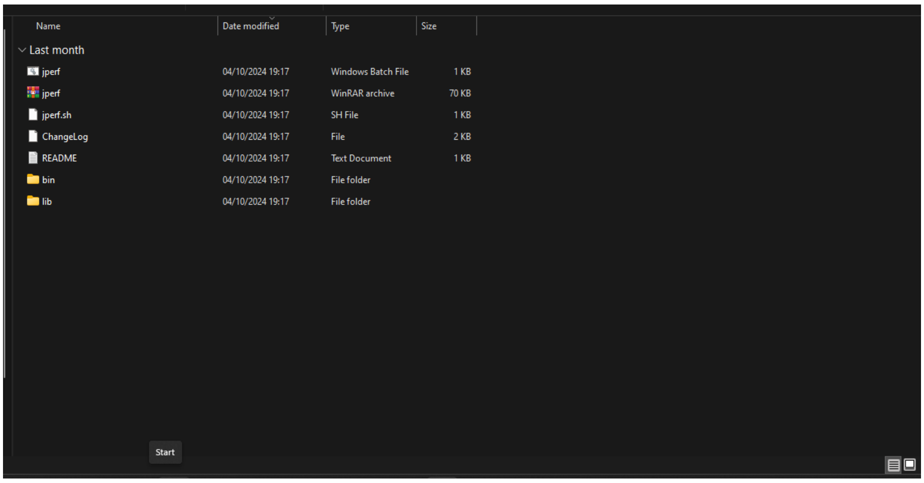
Select a Destination and Extract Files

Files will be extracted to this folder:
C:\Users\hp\Downloads\jperf-2.0.0

☑ Show extracted files when complete

Fig.3. Page Extracting jperf files

After the file has finished extracting, it will produce a folder containing the required JPerf files, as shown in Figure 4.

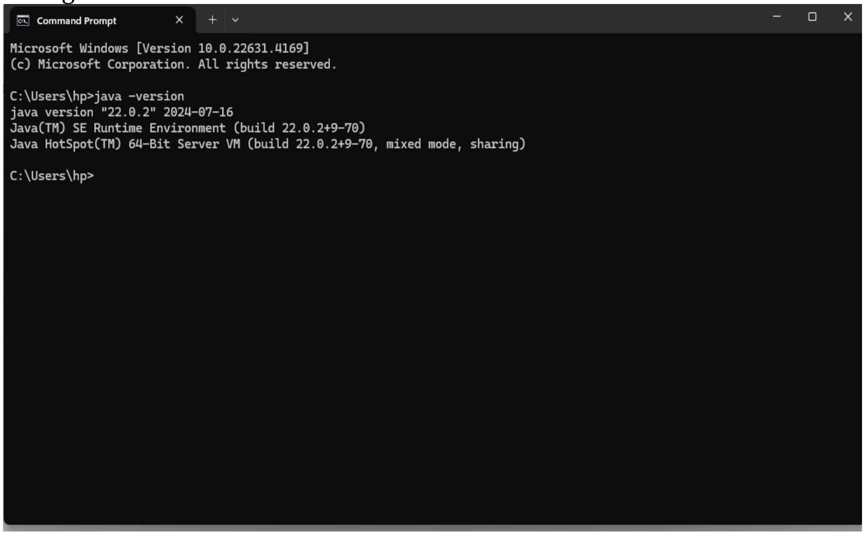


Last month

Name	Date modified	Type	Size
jperf	04/10/2024 19:17	Windows Batch File	1 KB
jperf	04/10/2024 19:17	WinRAR archive	70 KB
jperf.sh	04/10/2024 19:17	SH File	1 KB
ChangeLog	04/10/2024 19:17	File	2 KB
README	04/10/2024 19:17	Text Document	1 KB
bin	04/10/2024 19:17	File folder	
lib	04/10/2024 19:17	File folder	

Fig.4. Folder Page Containing Jperf Files

To run JPERF you need Java. Java is a platform that allows Java-based applications to run on various operating systems. To ensure Java is installed, you need to run the java -version command in the Command Prompt, as shown in Figure 5.



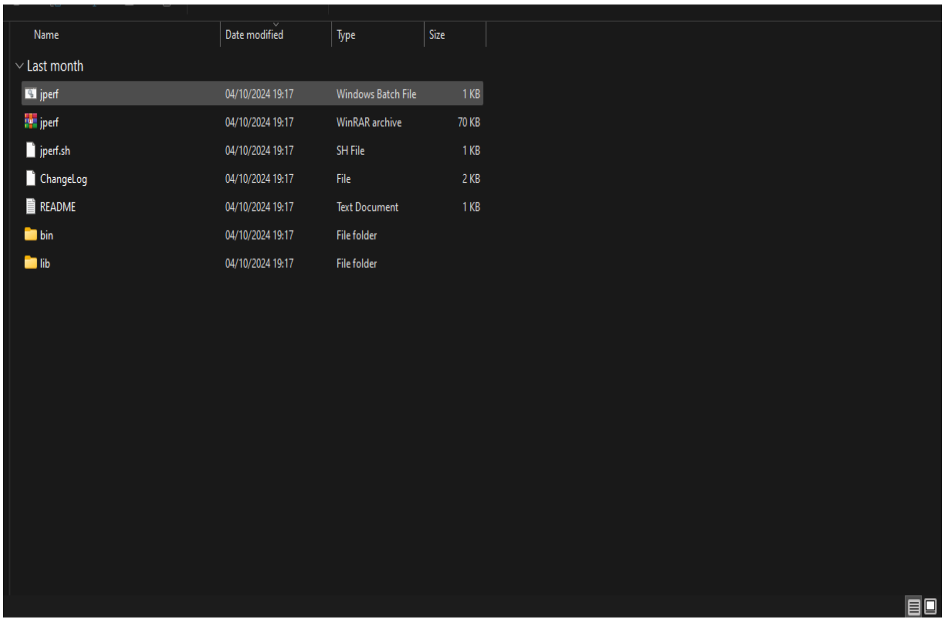
```
Microsoft Windows [Version 10.0.22631.4169]
(c) Microsoft Corporation. All rights reserved.

C:\Users\hp>java -version
java version "22.0.2" 2024-07-16
Java(TM) SE Runtime Environment (build 22.0.2+9-70)
Java HotSpot(TM) 64-Bit Server VM (build 22.0.2+9-70, mixed mode, sharing)

C:\Users\hp>
```

Fig. 5. CMD page to ensure Java is installed

3.2 Jperf Configuration Process

The jperf configuration process is carried out using two computers, namely a server computer and a client computer which is connected to the network in the Banda Aceh Mayor's office. The jperf configuration stages are as follows:

After the installation and extracting files are complete, click on the extracted folder then double click on the jperf windows batch file to create a jperf configuration, as shown in Figure 6.

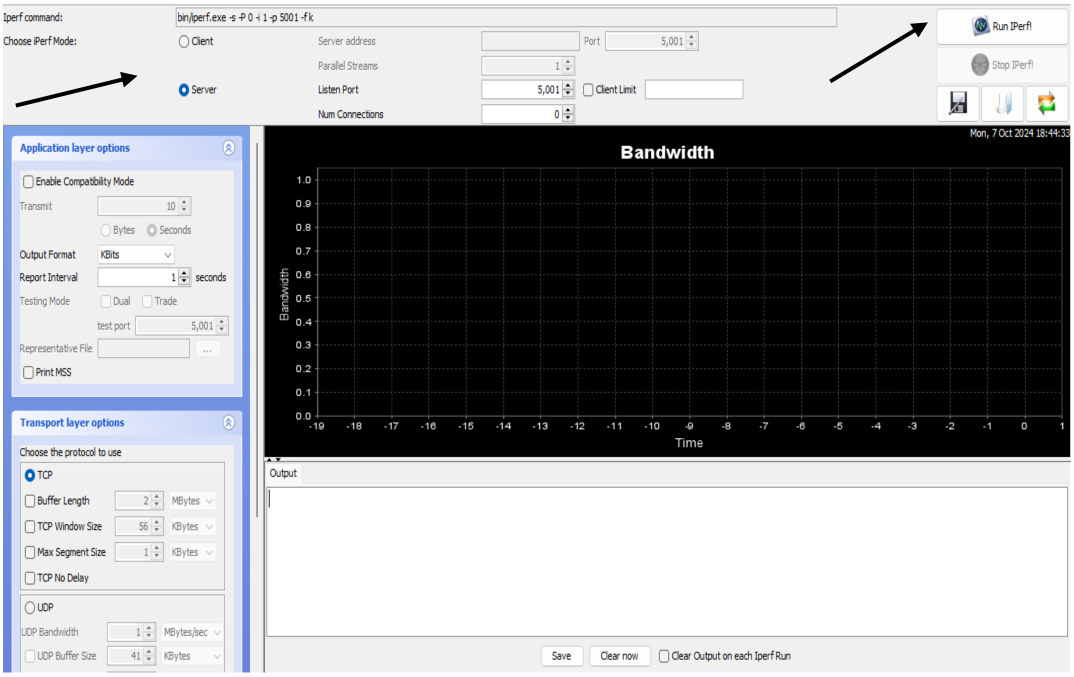


Last month

Name	Date modified	Type	Size
jperf	04/10/2024 19:17	Windows Batch File	1 KB
jperf	04/10/2024 19:17	WinRAR archive	70 KB
jperf.sh	04/10/2024 19:17	SH File	1 KB
ChangeLog	04/10/2024 19:17	File	2 KB
README	04/10/2024 19:17	Text Document	1 KB
bin	04/10/2024 19:17	File folder	
lib	04/10/2024 19:17	File folder	

Fig.6. File for Jperf Configuration

The first configuration is to run JPerf as a server on the first computer. Select the Server option to set up JPerf on the first computer to accept connections from clients. Click Run jperf to start the server, as shown in Figure 7.



Iperf command: bin/iperf.exe -s -P 0 -i 1 -p 5001 -f k

Choose iPerf Mode: ○ Client ● Server

Server address: | Port: 5,001

Parallel Streams: 1

Listen Port: 5,001 □ Client Limit

Num Connections: 0

Application layer options

□ Enable Compatibility Mode

Transmit: 10 ○ Bytes ● Seconds

Output Format: KBits

Report Interval: 1 seconds

Testing Mode: □ Dual □ Trade

test port: 5,001

Representative File:

□ Print MSS

Transport layer options

Choose the protocol to use

● TCP

□ Buffer Length: 2 MBytes

□ TCP Window Size: 56 KBytes

□ Max Segment Size: 1 KBytes

□ TCP No Delay

○ UDP

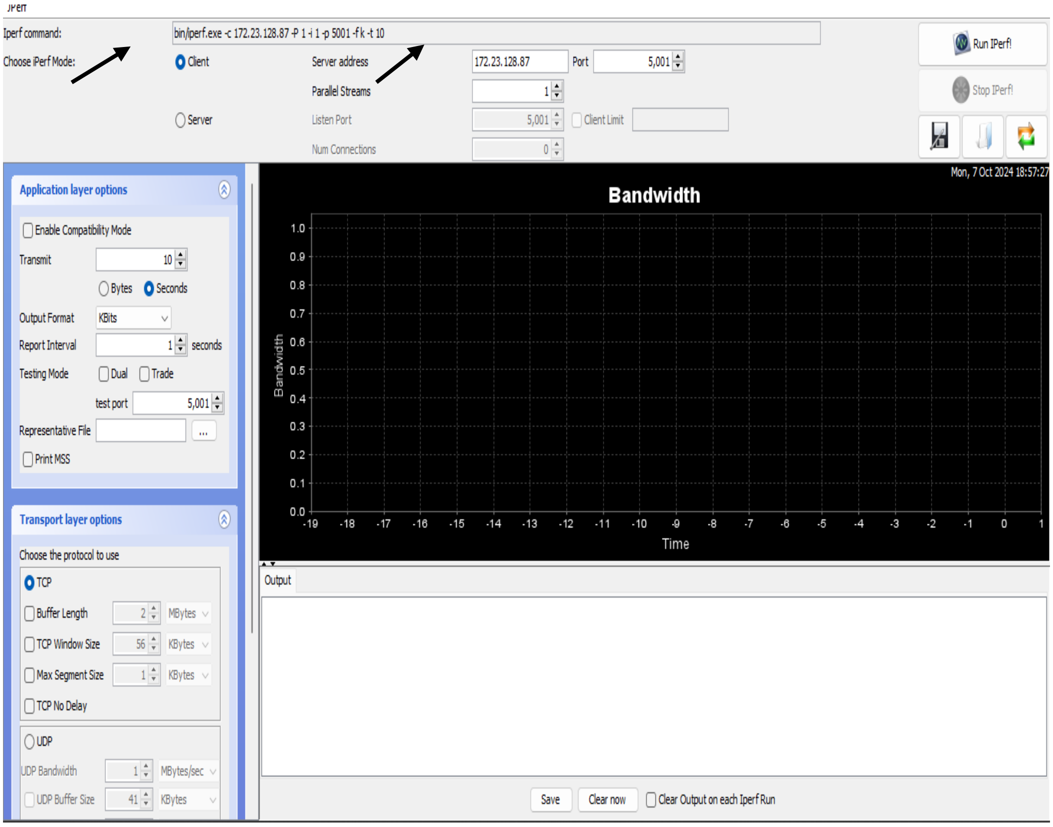
UDP Bandwidth: 1 MBytes/sec

□ UDP Buffer Size: 41 KBytes

Mon, 7 Oct 2024 18:44:33

Fig.7 Configuration Select the Server option and click Start

Next, the configuration is done by running jperf as a client on the second computer. Select the Client option. Enter the IP address of the server that has been running, as shown in Figure 8.



JPerf

Iperf command: bin/iperf.exe -c 172.23.128.87 -P 1 -i 1 -p 5001 -f k -t 10

Choose iPerf Mode: ● Client ○ Server

Server address: 172.23.128.87 Port: 5,001

Parallel Streams: 1

Listen Port: 5,001 □ Client Limit

Num Connections: 0

Application layer options

□ Enable Compatibility Mode

Transmit: 10 ○ Bytes ● Seconds

Output Format: KBits

Report Interval: 1 seconds

Testing Mode: □ Dual □ Trade

test port: 5,001

Representative File:

□ Print MSS

Transport layer options

Choose the protocol to use

● TCP

□ Buffer Length 2 MBytes

□ TCP Window Size 56 KBytes

□ Max Segment Size 1 KBytes

□ TCP No Delay

○ UDP

UDP Bandwidth 1 MBytes/sec

□ UDP Buffer Size 41 KBytes

Output

Save | Clear now | □ Clear Output on each Iperf Run

Fig. 8 .Configuration select the client option and enter the server IP

3.3 Jperf Testing

After installing and configuring jperf, the next step is to test jperf that has been connected between the server and client. The following is the jperf testing process.

1. Bandwidth simulation testing using the TCP Windows Protocol size 256 KB, with a test durationof 60 seconds with parallel streams 3 and. as shown in the graph in Figure 9.

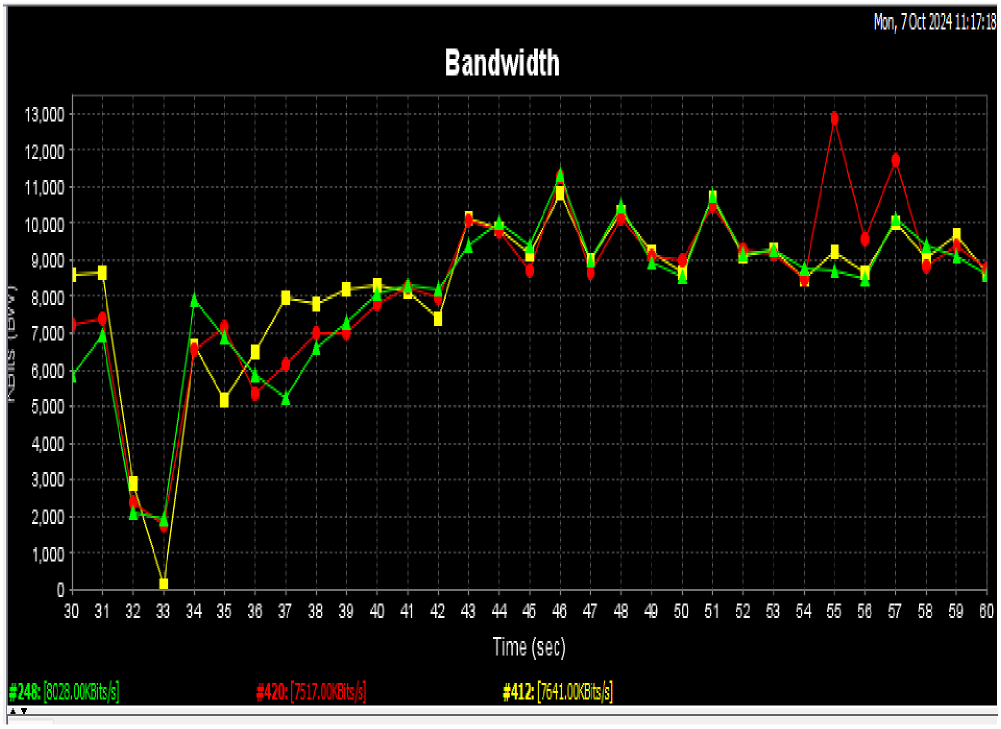


Fig.9. Bandwidth Test Graph with TPC Protocol

The graph above shows that the network bandwidth evaluation is within 60 seconds. The bandwidth in this graph is measured in KBits/s (kilobits per second), with several different lines, namely green, red, and yellow, which represent three data streams with different bandwidths. Each data stream has a different average bandwidth:

- Green (248) Has an average bandwidth of around 8,028 KBits/s.
- Red (420) Has a lower average bandwidth, which is around 7,517 KBits/s.
- Yellow (412) Average bandwidth is around 7,641 KBits/s.

All three flows show similar fluctuations, but the red path experiences more drastic drops, as seen from several sharp drop points on the graph. From this graph, it can be seen that the bandwidth is unstable and experiences significant fluctuations between the 30th and 60th seconds. On the Y-axis, the bandwidth values range from around 0 to 13,000 KBits/s. There are several peaks around 11,000–12,000 KBits/s (for example, at the 45th and 57th seconds), but there is also a drastic drop at the 32nd second where the bandwidth drops to near zero.

One striking thing is the sharp drop in bandwidth around the 32nd second, especially on the yellow and red paths. This may be caused by Network Congestion due to the large number of packets that must be sent simultaneously or Packet Loss, where some packets do not reach their destination or have to be resent, causing a momentary drop in speed. This graph shows that the bandwidth in wireless networks fluctuates due to factors such as network congestion, signal interference, and packet loss. A drastic drop at 32 seconds is an indication of a temporary problem affecting network performance, but bandwidth generally recovers and stabilizes after some time.

Table 3 Bandwidth Test Results with TCP Protocol

No	Duration (Seconds)	Data Transfer	Bandwidth
1	0.0-60.1 sec	56072 KBytes	7641 Kbits/sec
2	0.0-60.1 sec	58912 KBytes	8029 Kbits/sec
3	0.0-60.1 sec	55168 KBytes	7518 Kbits/sec
	Total	170152 KBytes	

$$\text{Bandwidth} = \frac{\text{Total Data (bits)}}{\text{Total time (seconds)}}$$

$$= \frac{\text{170152 Kbytes x 1024 bytes x 8 bits}}{\text{60 seconds}}$$

$$= \frac{\text{1393885184 bits}}{\text{60 seconds}}$$

$$= \text{23231419 MBits/sec}$$

Latency simulation testing using the UDP Protocol. With UDP Buffer data size of 256 KB, with a test duration of 20 seconds with parallel streams 1. As shown in the graph in Figure 10.

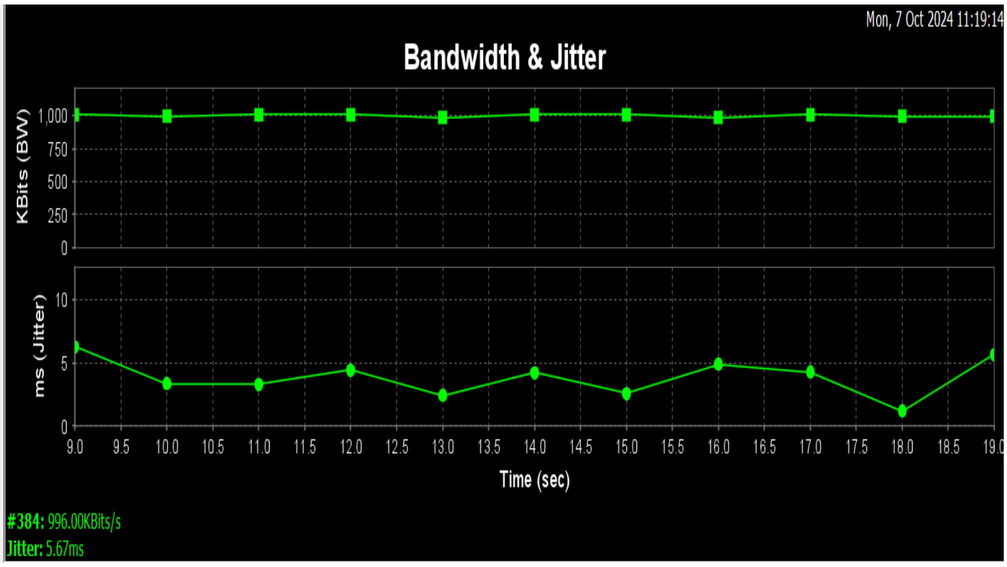


Fig. 10. Latency Testing Graph with UDP Protocol

The graph shows stable bandwidth at around 996 KBits/s over 20 seconds, with minimal fluctuations indicating consistent and optimal network performance. Jitter values range from 0 to 6 ms, reflecting stable packet reception times. At the 9th second, jitter peaks at 5.67 ms, decreases to 0 ms at several points (seconds 11, 13, 15, and 17), and rises slightly to around 6 ms by the 19th second. These low jitter levels indicate excellent network stability, essential for smooth performance in wireless sensor networks and real-time communication.

Table 4 Bandwidth and Latency Test Results with UDP Protocol

No	Durasi (Detik)	Data Tranfer	Bandwidth	Jitter	Lost/Total Datagrams
1	0.0-19.9 sec	2448 KBytes	1007 Kbits/sec	6841 ms	-3/ 1668 (-0.18%)

$$\text{Latency} = \frac{\text{Total Data (bits)}}{\text{Bandwidth (bits/sec) } + \text{Jitter}}$$

$$= \frac{\text{2448 kbytes x 1024 bytes x 8 bits}}{\text{1007 kbits/sec x 1000 } + \text{6,841 Second}}$$

$$= \frac{\text{20054016 bits}}{\text{1007 kbits/sec x 1000}+ \text{6,841 second}}$$

$$= \text{19,91 Second} + \text{6,841 Secon}$$

$$= \text{26,75 Second}$$

4. Conclusions

The results that can be concluded in this study The evaluation of the wireless sensor network at the Banda Mayor's Office shows that performance is greatly influenced by management and environmental conditions; strategic device placement and minimal interference result in stable bandwidth and low latency, while less than optimal management causes decreased performance, with low bandwidth and high latency that hinder operational efficiency

5. Reference

Adinda, P. R. (2022). Jaringan sensor nirkabel untuk pemantauan lingkungan dengan IoT. Portaldata.Org, 3(1), 2022.

Amuda, K. K., Kumbum, P. K., Adari, V. K., Chunduru, V., & Gonepally, S. (2021). Performance evaluation of wireless sensor networks using the wireless power management method. https://doi.org/10.15226/2474-9257/6/1/00151

Anwar, M. S., Ruuhwan, R., & Sumaryana, Y. (2024). Integrasi jaringan IPv4 dan jaringan IPv6 pada local area network (LAN) dengan menggunakan tunnel broker. Digital Transformation Technology, 4(1), 186–195. https://doi.org/10.47709/digitech.v4i1.3827

Ardhiansyah, M., Noris, S., & Andrianto, R. (2020). Modul jaringan komputer Universitas Pamulang (Issue 1). Retrieved from http://dhoto.lecturer.pens.ac.id/publications/book/2008/Dhoto-JaringanKomputer2.pdf

Gulati, K., Kumar Boddu, R. S., Kapila, D., Bangare, S. L., Chandnani, N., & Saravanan, G. (2021). A review paper on wireless sensor network techniques in Internet of Things (IoT). Materials Today: Proceedings, 51, 161–165. https://doi.org/10.1016/j.matpr.2021.05.067

Hakim, A. R., Tjahjamooniarsih, N., & Suryadi, D. (2021). Analisis kualitas jaringan internet dengan sinyal 4G LTE dengan metode QOS. Jurnal Teknik Elektro Universitas Tanjungpura, 2(1), 1–9. https://jurnal.untan.ac.id/index.php/jteuntan/article/view/48187

Khanna, A., & Kaur, S. (2020). Internet of Things (IoT), applications and challenges: A comprehensive review. Wireless Personal Communications, 114(2). https://doi.org/10.1007/s11277-020-07446-4

Kurniawati, A. M., Sutisna, N., Zakaria, H., Nagao, Y., Mengko, T. L., & Ochi, H. (2023). High throughput and low latency wireless communication system using bandwidth-efficient transmission for medical Internet of Things. International Journal of Technology, 14(4), 932–947. https://doi.org/10.14716/ijtech.v14i4.5234

Mahmuddin, M., Alabadleh, W. A., & Kamarudin, L. M. (2019). WM-LEACH: An improved network lifetime LEACH protocol for wireless sensor networks. IOP Conference Series: Materials Science and Engineering, 551(1). https://doi.org/10.1088/1757-899X/551/1