Fifth generation core: the performance enhancement of virtual private server and bare metal

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ABSTRACT

The fifth generation (5G) architecture represents the most recent advancement in mobile networks and is presently operational in various global places. Several new use cases and applications have been introduced, with a specific focus on improving throughput, reducing latency, minimising packet loss, optimising CPU usage, and maximising memory utilisation. In order to effectively address each scenario, it is necessary to integrate the most advanced technology, putting in significant effort to optimise resources and ensure system adaptability. This strategy will establish an architecture capable of accommodating many scenarios of a shared physical infrastructure by using techniques such as virtualization and cloud-based service deployment. Therefore, in this study, a test was carried out related to the performance of the 5G core network (CN) on bare metal servers and virtual private servers (VPSs). The quality of service (QoS) using Wireshark and Iperf3 is tested by utilizing 'cpustat' and free tools. The results of performance comparisons of these two methods on the 5G CN shows throughput values of ≥10 Gbps ≤20 Gbps, latency values of ≤4 ms, and packet loss values of 0%, in accordance with IMT 2020 standards. Thus, the ideal 5G CN services can be realized.

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1. INTRODUCTION

The mobile networks have undergone substantial development and transformation from a focus on voice communication to a focus on data transmission. This has resulted in major changes in both the radio and data components of the network since its initial widespread use in the late 1980s. Concurrent with the advancement of radio and transmission technology, a significant transformation in network management and operation has taken place. The move commences from human design and infrastructure configuration to autonomous systems that include advanced intelligence for enhanced adaptability [1]. Recent standards have incorporated all of these capabilities. The fifth generation (5G) system of mobile network standards, is the most recent upgrade based on the 15th release published by the 3rd generation partnership project (3GPP) consortium in 2019. Hence, the network infrastructure necessitates flexibility and the ability to adjust to diverse circumstances. The 5G network is built on three fundamental pillars: software defined networking (SDN), network functions virtualization (NFV), and automation. Conventional methods of managing networks may no longer be appropriate for the user plane of the 5G core network (CN) due to its stringent demands for low latency and high throughput. Consequently, there have been suggestions to employ artificial intelligence agents with the purpose of enhancing the management of 5G networks by achieving a more efficient allocation of resources [2].

Furthermore, this approach requires ongoing surveillance of the data passing through the CN. Furthermore, alongside the equitable dissemination of internet connectivity, there is a requirement for the advancement of infrastructure to support 5G technology services. The latest services of 5G technology can be achieved through three distinct use cases: enhanced mobile broadband (eMBB), ultra reliable low latency communication (URLLC), and massive machine type communication (mMTC) [3], [4]. eMBB primarily emphasises on the user experience on mobile devices by delivering greater data transfer rates, hence reducing the time delay [5]. URLLC places significant importance on traffic that has unique demands regarding latency and reliability. Mission-critical machine type communication (mMTC) specifically focuses on managing the significant volume of machine-to-machine (M2M) data generated by the increasing number of internet of things (IoT) devices [6].

In realizing these services, 5G has three elements in its architecture that support mobile communications such as user equipment (UE), gNodeB (gNB), and CN [7]. Furthermore, the gNB which is a radio component part is responsible for aggregating traffic from an end device called a UE. Typically a UE can be a smartphone, an IoT device, or generally any object that has a subscriber identity module (SIM) and is connected to a network. While CN is the CN that manages all services on the mobile communication network from the control plane and data plane sides before being connected to the data network (DN) [8]. These topologies will be implemented in this research.

The CN is perhaps the most important element, as it is expected to be able to handle large traffic and ensure lower latency than usual. The CN also aggregates data traffic from the UE and performs other functions so that the network can operate properly such as customer and device authentication, policy injection for subscribers, managing device mobility and routing traffic from the operator's network to the internet [9]. All of these features must be warranted under any circumstances, making this a complex task for the CN. Therefore, the performance of the 5G CN is the main element in supporting services on this 5G technology. The CN is also responsible for simulating the 5G network and all service-based architecture (SBA) components such as access and mobility management function (AMF) and policy control function (PCF) [10]. In this sense, SBA is an architectural concept that allows all the components necessary for an architecture to operate in a virtual manner [11]. Therefore, the 5G CN must be supported with good server performance as a container for processing its services [12]. Server is a computer system that is used to perform processing of an information technology service. Based on performance and performance testing, server architecture is divided into 3 types [13], namely bare metals, containers, and virtual machines [14].

A virtual private server (VPS) allows users to operate system instances with fine-grained control of private software and hardware resources. Therefore it is very important in choosing the right VPS host for the users and application service resources and performance requirements [15]. Performance measurements are the same control conditions for all three VPS hosts in a common unix benchmark application operating system–UnixBench [16]. Rad *et al*. [17], a series of experiments have been conducted on the application and performance of bare metal using hypervisor-based virtual machines and Docker containers [18]. These tests help to understand the performance impact of two major virtualization technologies: containers and hypervisors.

Based on the issues of achieving consistence performance for latency, throughput, packet loss, CPU and memory utilization which are the critical performance metrics in 5G CNs, therefore, in this research, the virtual servers and bare metal methods will be evaluated. Thus, the main contributions in this research are: i) the comparison and analysis of the performance of VPS and bare metal servers during the deployment on 5G CN, ii) the performance analysis of 5G CN on VPS and bare metal server, and iii) added views regarding the choice and guidelines of infrastructure in the 5G architecture, especially on the performance of the 5G CN. This paper is structured as follows, the guideline of building a 5G architecture, the implementation and its performance are explained in section 2. The analysis of the VPS and bare metal server simulation results, using network analyzer applications, Wireshark and Iperf is elaborated in section 3. In section 4, the results and discussion will be highlighted followed by a summary in section 5.

2. METHOD

2.1. 5G core network

The 5GC architecture relies on the service based architecture (SBA) framework, where architectural elements are defined in terms of network functions (NFs) which are divided based on their services [19]. The SBA approach allows for virtual deployments. The 5GC architecture can be seen in the image.

The operational mechanism of 5G networks is depicted in Figure 1. The AMF includes the termination functions for non-access stratum (NAS) signaling. NAS signaling is employed for several purposes including ciphering and integrity protection, registration management, authentication, authorization, security management, mobility management, and connection management. The session management function (SMF) is responsible for providing the UE with an IP address through the use of dynamic host configuration protocol (DHCP). Additionally, the SMF supports session management tasks such as session establishment, modification, and release. The PCF incorporates a portion of the policy and charging rules function (PCRF) capabilities found in the evolved packet core (EPC) domain. It provides a cohesive policy framework for making policy decisions in the UDR. The user plane function (UPF) is responsible for directly managing the user traffic. It facilitates the routing and forwarding of packets, inspects packets, handles quality of service (QoS), and manages user traffic to connect to the DN. The unified data management (UDM) possesses comparable features to the home subscriber server (HSS) in the EPC domain. The system facilitates the creation of authentication and key agreement (AKA) credentials, manages user identity, grants access authorization, and handles subscriber data subscription. The functionality and authentication server of the authentication server function (AUSF) bear resemblance to the authentication centre (AUC) in 2G/3G networks or the HSS in 4G networks. The network slice selection function (NSSF) is responsible for choosing the network slice instances that will service the UE. It determines the permitted network slice selection assistance information (NSSAI) and AMF that will serve the UE. The network repository function (NRF) facilitates the service discovery functions. The gNB serves as the radio access network (RAN) in the context of 5G technology. The UE refers to the mobile subscriber in the context of 5G technology [3], [20].

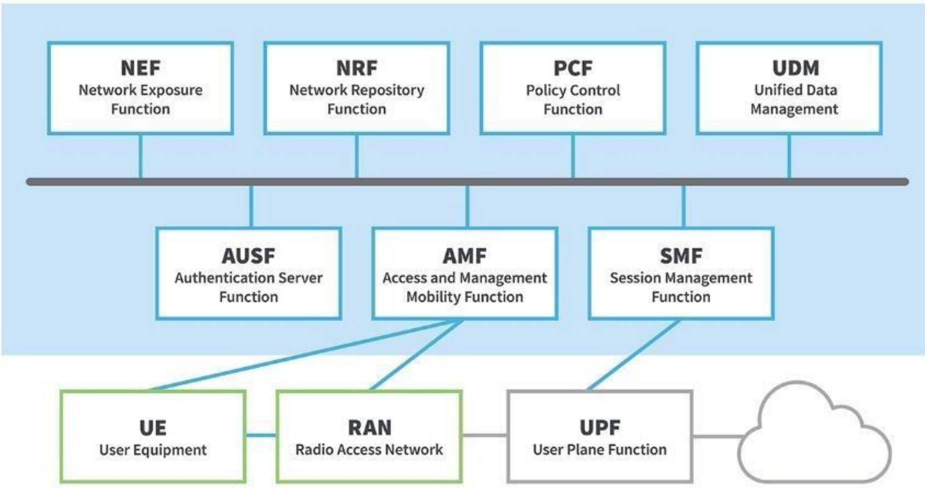

Figure 1. 5G CN [21]

2.2. VPS and bare metal server

There are two design modes that will be built in this study. The first mode is the 5G network architecture that has been designed on a VPS while the second mode is the bare metal server. These two-hosting environments will be tested to identify its comparison in term of the throughput, latency and packet loss. The installation is done by building a 5G CN using Free5gc and is supported by UERANSIM which plays a role in building its RAN network [22]. After the CN is built in both modes, the next step is to simulate the network and capture traffic using Wireshark and Iperf. Then the results of the traffic capture are stored in the form of a comma separated values (CSV) file, thus, the performance could be analyzed in terms of the network parameters that have been determined to compare the performance of the two modes [17].

The system design architecture is implemented in this study as shown in Figure 2. The operating system (OS) used for the installation is Linux Ubuntu server 20.04 LTS. There are 5G network simulator applications that will be installed on the OS, namely Free5gc and UERANSIM. Therefore, the 5G networks can be simulated on bare metal servers and VPS.

2.3. IP 5G core network

In the early stages of the simulation, the IP table will be determined in order to minimize collisions between IP destinations and devices with the same IP. This could simplifies the process of deploying the 5G CN [23]. The IP 5G CN table used in this research is presented in Table 1.

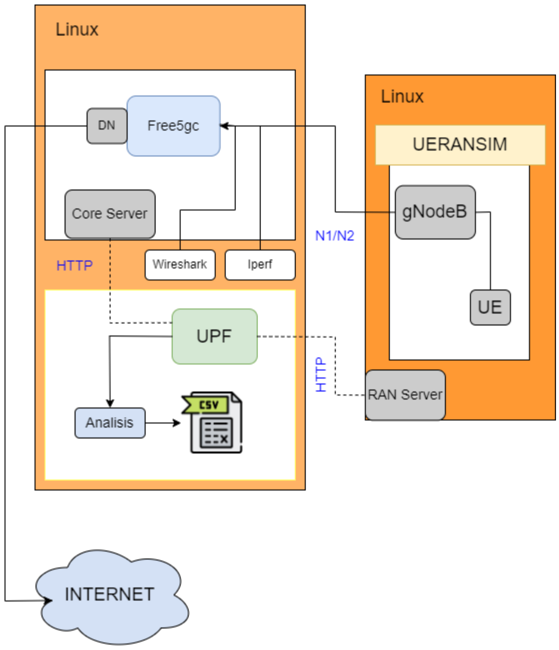

Figure 2. System model architecture [23]

Table 1. IP 5G CN [24]

No	Role	IP addresses		Prefix
		VPS	Bare metal	
1	Free5gc C-plane	192.168.88.2	192.168.144.2	/24
2	Free5gc U-plane (UPF)	192.168.88.3	192.168.144.3	/24
3	UERANSIM RAN gNB	192.168.88.11	192.168.144.11	/24
4	UERANSIM UE	10.60.0.0	60.60.0.0	/32

2.4. Topology and devices

The network topology of AMF, SMF, UE, gNB, and UPF will be used in this study as shown in Figure 3. This research uses supporting devices in the form of hardware and software. The specifications in term of CPU, RAM and storage that are built into VPS and bare metal servers are shown in Table 2.

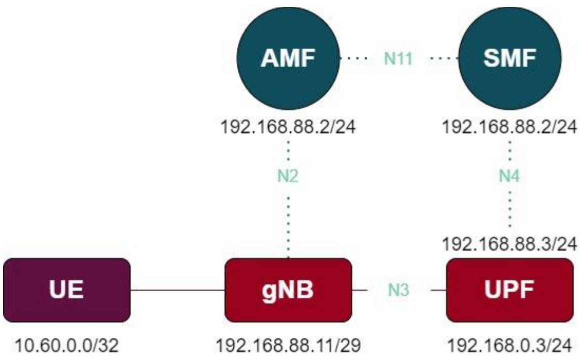

Figure 3. 5G architectural network topology [25]

2.5. Simulation

The following stage is to conduct a simulation using the procedures depicted in Figure 4 for the construction of the system model, network topology, and device specifications required in the testing. The free5gc and UERANSIM will be installed as shown in Listings 1 and 2. Several configurations on the bare metal server and VPS are necessary before testing UE connectivity with the CN, including the C-plane configuration with AMF, SMF, and UPF configurations. U-plane configuration, which includes PFCP, GTP-U configuration, and network data list, is then executed. A RAN configuration must be carried out before a UE configuration in the gNB settings created by UERANSIM. To be able to proceed to the testing phase, 5G CN connectivity is carried out on VPS and bare metal servers. Figure 5 shows that the UE has successfully connected to the IP control plane, namely 192.168.144.2 and can connect to the IP user plane, namely 192.168.144.3, thus, it can be connected to the 5G CN.

Table 2. Hardware specifications used [17]

	Component	Specification			
		Free5gc	Information	UERANSIM	Information
VPS	CPU	2 CPU	– 1 Thread per socket – 3.9 CPU GHz – Max speed 2000 MHz	1 CPU	– 1 Thread per socket – 3.9 GHz – Max speed 2000 MHz
	RAM	6 GB	Unknown	8 GB	Unknown
	Storage	40 GB	SSD	40 GB	SSD
Bare metal	CPU	2 CPU	– 1 Thread per socket – 3.9 CPU GHz – Max speed 2000 MHz	1 CPU	– 1 Thread per socket – 3.9 GHz – Max speed 2000 MHz
	RAM	6 GB	2400 MT/s	8 GB	2400 MT/s
	Storage	40 GB	HDD	40 GB	HDD

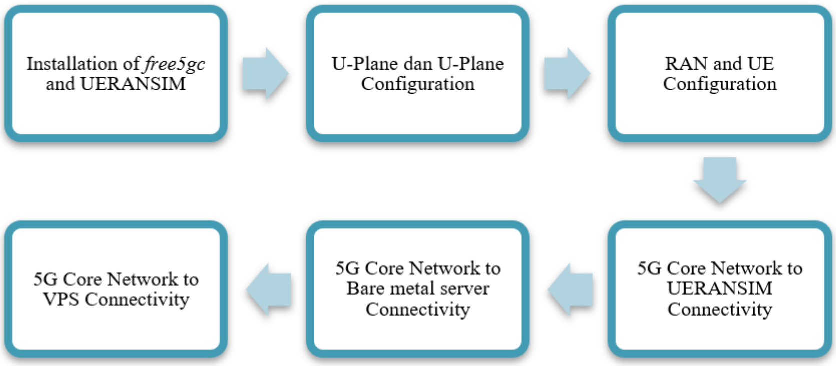

Figure 4. Simulation method

Listing 1. Installation of free5gc

```
wget https://dl.google.com/go/go1.17.8.linux-amd64.tar.gz
sudo tar -C /usr/local -zxvf go1.17.8.linux-amd64.tar.gz
mkdir -p ~/go/{bin,pkg,src}

echo 'export GOPATH=$HOME/go' >> ~/.bashrc
echo 'export GOROOT=/usr/local/go' >> ~/.bashrc
echo 'export PATH=$PATH:$GOPATH/bin:$GOROOT/bin' >> ~/.bashrc
echo 'export GO111MODULE=auto' >> ~/.bashrc
source ~/.bashrc

sudo apt -y update
sudo apt -y install mongodb wget git
sudo systemctl start mongodb

sudo apt -y update
sudo apt -y install git gcc g++ cmake autoconf libtool pkg-config libmnl-dev libyaml-dev
sudo apt-get update
sudo apt-get install cpustat

sudo apt-get update
sudo apt-get install free
```

Listing 2. Installation of UERANSIM

```
cd~
git clone --recursive -b v3.2.1 -j `nproc` https://github.com/free5gc/free5gc.git
cd free5gc

cd ~/free5gc
make
git clone -b v0.6.8 https://github.com/free5gc/gtp5g.git
cd gtp5g
make
sudo make install
"free5gc/config/upfcfg.yaml."

sudo apt remove cmdtest
sudo apt remove yarn
curl -sS https://dl.yarnpkg.com/debian/pubkey.gpg | sudo apt-key add -
echo "deb https://dl.yarnpkg.com/debian/ stable main" | sudo tee /etc/apt/sources.list.d/yarn.list
curl -sL https://deb.nodesource.com/setup_12.x | sudo -E bash -
sudo apt-get update
sudo apt-get install -y nodejs yarn

cd ~/free5gc
make webconsole
```

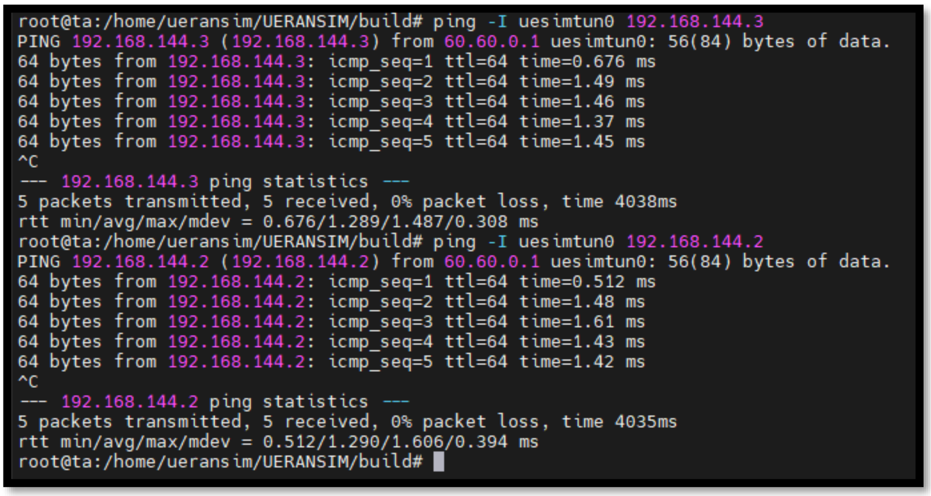

Figure 5. Ping UE to CN

3. RESULTS AND DISCUSSION

The testing is implementing using two tools which are Iperf3 and Wireshark. While the throughput testing is using Iperf3 tools. There are eleven test that has been carried out from the EU using IP 10.60.0.1/32 to the user plane side with IP 192.168.88.3/24 in 10 second time intervals in the respective test.

Based on the data from the simulation test results presented in Figure 6, it shows that the bare metal has a superior throughput as compared to VPS. The average throughput for the first test to tenth test on bare metal servers reaches 16.4 Gbps, while the average throughput on VPS is 16.3 Gbps. Thus, it can be concluded that bare metal servers outperform VPS at 0.1 Gbps.

According to the data from the test results shown in Figure 7, the fifth and tenth tests have the closest latencies to one another, in addition to these experiments, it can be noted that there is a large latency difference between VPS and bare metal servers. The average latency on the bare metal server is 1.462 ms, while the average latency on VPS is 1.452 ms. Therefore, VPS is 0.010 ms superior to bare metal servers.

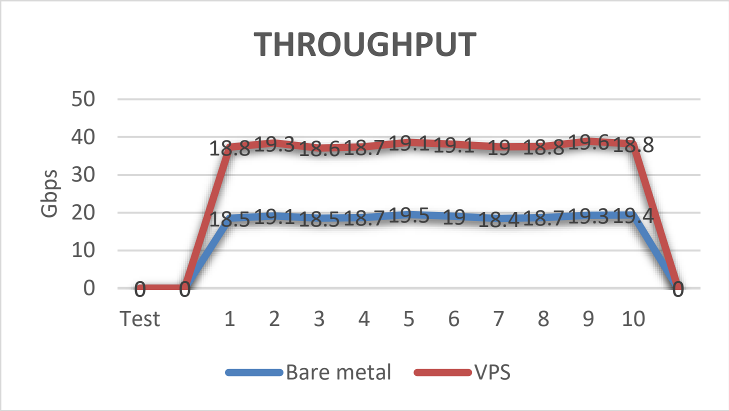

Figure 6. VPS vs bare metal throughput test results

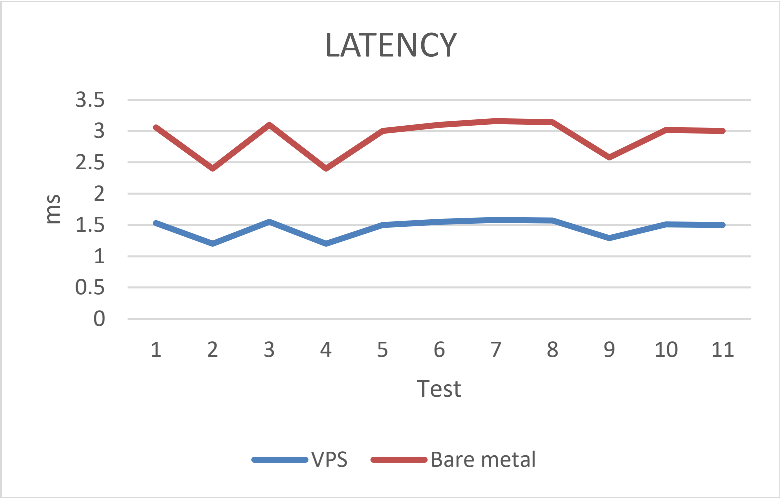

Figure 7. VPS vs bare metal latency test results

Based on the data from the test results presented in Figure 8, it is known that both VPS and bare metal servers provide good quality service. The reason is that none of the missing packages are discovered in any of the tests. As a result, all of the servers have excellent packet loss values of 0.0%.

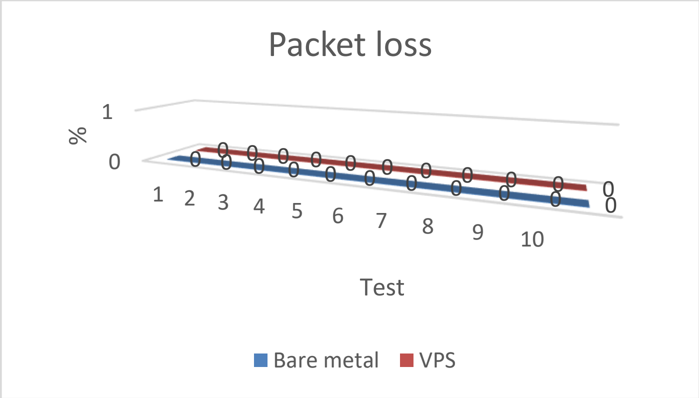

Figure 8. VPS vs bare metal packet loss test results

Based on the data from the test results presented in Figure 9, it can be seen that the average CPU usage on the bare metal server reaches 5.2%. Meanwhile, CPU usage on VPS is reaches 5.7%. Furthermore, the bare metal server has 0.5% superior CPU performance as compared to VPS.

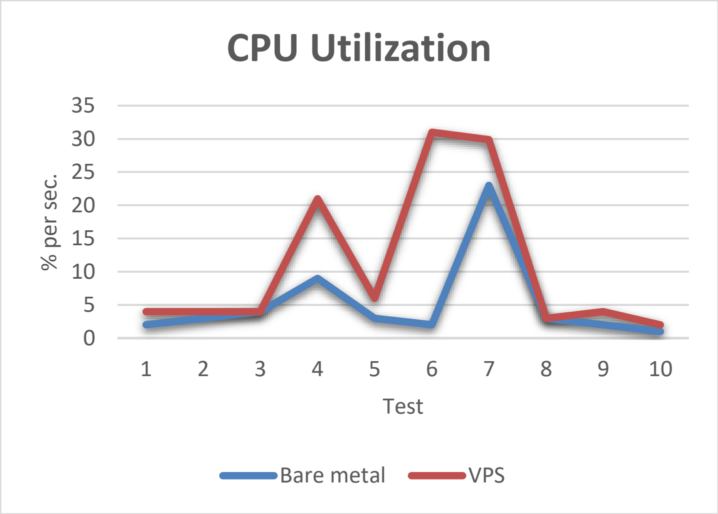

Figure 9. Results of testing CPU utilization VPS vs bare metal

Based on the data from the test results presented in Figure 10, it is obtained that the average memory usage on the bare metal server reaches 301.2 Mb. Meanwhile, the memory usage on the VPS reaches 273.2 Mb. Thus, VPS is 28 Mb superiors to bare metal servers.

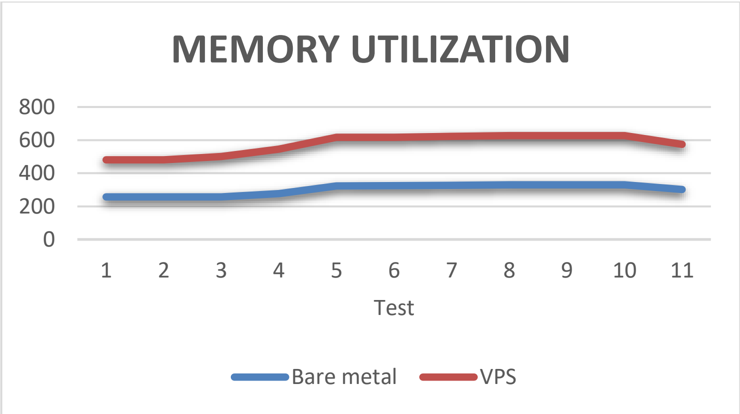

Figure 10. Results of testing memory utilization VPS vs bare metal

Based on the results of all ten tests, Table 3 summarized the performance comparison of bare metal servers with VPS. The comparison comprises of the throughput, latency, packet loss, CPU utilization and the memory utilization. Therefore, it shows that the different of throughput between two hosting type is only 0.1Gbps. Both servers have same latency and packet loss. In addition, bare metal has less CPU utilization as compared to VPS, however, VPS utilized less memory as compared to bare metal.

Table 3. Bare metal server vs VPS performance comparison

Comparison	Throughput (Gbps)	Latency (ms)	Packet loss (%)	CPU utilization (% per sec)	Memory utilization (Mb)
Bare metal server	16.4	1.5	0	5.2	301.2
VPS	16.3	1.5	0	5.7	273.2

4. CONCLUSION
Several conclusions can be made based on the outcomes of the design, testing, and analysis that was done. In the bare metal test, the average throughput reached 16.4 Gbps, while the latency reached 1.462 ms, and the packet loss result was 0%. Meanwhile, in the VPS test, the average throughput was 16.3 Gbps, while the latency was 1.452 ms, and the resulting packet loss was 0%. Based on the results of testing on resource utilization, it was found that the average CPU usage on bare metal servers reached 5.2% and memory usage reached 301.2 Mb. Meanwhile, CPU usage on VPS reached 5.7% and memory usage reached 273.2 Mb. In conclusion, by referring to the advantages and disadvantages of bare metal servers and VPS, it is found that VPSs have better performance than bare metal servers.

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