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MULTI-AREA OSPF ANALYSIS USING VIRTUAL LINK AND GRE TUNNEL

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ABSTRACT

This study discusses the implementation and analysis of network performance using multi-area OSPF (Open Shortest Path First) with the application of Virtual Link and GRE Tunnel. OSPF is a dynamic routing protocol that is often used in large networks due to its ability to find the shortest path quickly and efficiently. However, on large networks, the use of OSPF in a single area can increase routing overhead and slow down convergence times. Therefore, multi-area OSPF is a solution by limiting the spread of routing information only to related areas. This study uses an experimental method with the PNETLab simulator running five Cisco routers. The test was carried out by measuring QoS parameters such as throughput, packet loss, jitter according to TIPHON standards and OSPF convergence time using iPerf3 and Wireshark software. The results show that multi-area OSPF with Virtual Link has a more stable performance than GRE Tunnel in terms of jitter and convergence time, namely the average convergence time of Virtual Link is 24.1166 seconds while GRE Tunnel is 28.6144 seconds. Nonetheless, GRE Tunnel shows lower packet loss at large data sizes. This study provides practical guidance for network professionals in optimizing multi-area OSPF configurations.

KEYWORDS *OSPF, Multi Area, Virtual Link, GRE Tunnel, QoS, TIPHON.*

INTRODUCTION

In the development of computer networks that are increasingly complex today, routing protocol technology is needed that can support communication between network devices dynamically and effectively. With the increasing number and complexity of connections between network devices to be connected, effective routing protocols are becoming increasingly important. There are many routing protocol options that can be chosen to route data transmission within the network, namely Static Routing and Dynamic Routing (EIGRP, RIP, ISIS, OSPF, BGP). Static can be an option when the network is still small and does not require dynamic data transmission route movement (Gatra & Sugiantoro, 2021).

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One of the dynamic routing protocols that is widely used in various organizations and institutions is Open Shortest Path First (OSPF). OSPF is known for its ability to find the shortest path quickly and efficiently. In addition, OSPF is widely used because it uses standard or open protocols, as well as an unlimited number of routers connected so it is very possible to implement it in many router devices of different types and types (Okonkwo & Emmanuel, 2020).

OSPF (Open Shortest Path First) is an interior routing protocol that uses the Dijkstra algorithm to find the shortest path in an IP network. These protocols are part of the IGP (Interior Gateway Protocol) protocol group and are designed to distribute routing information within a local area network (LAN) or wide area network (WAN)(Soomro et al., 2023). In OSPF, the network can be formed into a single area or single area i.e. area 0 (backbone) and can also be made into multi areas (area non backbone). However, in large network implementations, the use of a single OSPF area can lead to increased routing overhead and longer convergence times. Therefore, a solution is needed that is able to optimize network performance, namely by utilizing multi-area OSPF.

The purpose of OSPF being formed into a multi-area is to improve the scalability and efficiency of the network. By dividing the network into multiple areas, OSPF can limit the deployment of routing information to only related areas, thereby reducing overhead and accelerating convergence(Yahya et al., 2024). This is especially important in large networks where topology changes can occur frequently. Each area has its own routing table, which allows for the division of workloads and isolation of topology changes into specific areas. The main area in OSPF is called Area 0 or backbone area, which connects all other areas.

OSPF Multi area requires that all areas are directly connected to area 0 (Backbone). Connections between areas that are not directly connected to Area 0 can cause problems in the distribution of routing information. Without a direct connection to the backbone area, routing information may not be spread correctly, causing the network to not converge efficiently. The solution if there is an area that is not directly connected to area 0 is to use Virtual Link and GRE Tunnel (tunnelling).

Virtual Link is a method in OSPF that allows the connection of non-backbone areas to backbone areas. This is done by creating a virtual link that connects routers within a non-backbone area to the backbone router(Khalifeh et al., 2011). GRE Tunnel is a tunneling technique used to encapsulate various network protocols in a virtual point-to-point link. This allows OSPF connections over networks that do not support OSPF directly(Rahman, 2017).

In this study, it will be discussed how the network quality when using multi-area OSPF with the implementation of Virtual Link and GRE Tunnel. This study will analyze network performance based on TIPHON's QOS standards, namely jitter, throughput, packet loss, and also OSPF convergence time when there is a failure. The results of this study are expected to provide practical guidance for network professionals in optimizing multi-area OSPF configurations.

Research related to the analysis of the use of OSPF routing protocol has previously been conducted by [1] discussing the analysis of the use of static routing protocol with OSPF protocol in the UIN Sunan Kalijaga Yogyakarta Network. With the test results for LAN and one routing line, the use of static routing protocol is more optimal than the OSPF protocol.

In the research (Shah & Kang, 2022) Discussing the comparison of the implementation of RIP, EIGRP and OSPF routing protocols with GNS3 simulations, the results of the study are that RIP is most suitable for small networks due to its simplicity and limited scalability, while EIGRP is more suitable for medium networks, and OSPF is most effective for large networks because of its ability to handle complex and extensive network topologies.

In the study [4], it discusses the comparison of single area OSPF with multi-area with Cisco Packet Tracer simulation. It is mentioned that single-area OSPF is suitable for small to medium-sized networks due to its simplicity, while multi-area OSPF is recommended for larger, more complex networks due to its efficient resource management, albeit with increased management complexity.

Research on the analysis of packet loss calculations in WAN networks with OSPF routing protocol conducted by T.Diansyah showed excellent performance results with packet loss of 2.09%(Diansyah et al., 2019). Research by R. Tri Susilo also discusses the comparison between Virtual Link and Generic Routing Encapsulation (GRE) in multi-area OSPF using GNS3 simulations (Tri Susilo, 2019) The results of the average delay and jitter parameters showed that GRE Tunnel had a lower jitter value of 1.11 ms compared to 3.43 ms virtual link. However, there is no indication yet on which convergence time is better between virtual link and GRE Tunnel.

RESEARCH METHOD

This research was conducted using an experimental method, namely using the PNETLab simulator, which will run 5 Cisco routers with multi-area OSPF protocol. The experimental method is an approach to find an effect or outcome on a particular condition(Budiman et al., 2021), namely by testing the OSPF Multi Area virtual link and GRE Tunnel and its effect on Quality of Services (QOS) and OSPF convergence time. The stages in this study are divided into several parts, namely the design of the network topology, then the tools and materials needed, then the analysis and design of the system and standards used in the test. Testing is carried out by analysis throughput, packet loss, jitter with the TIPHON model and the convergence time required by multi-area OSPF using virtual links and GRE tunnels.

Network Topology Design

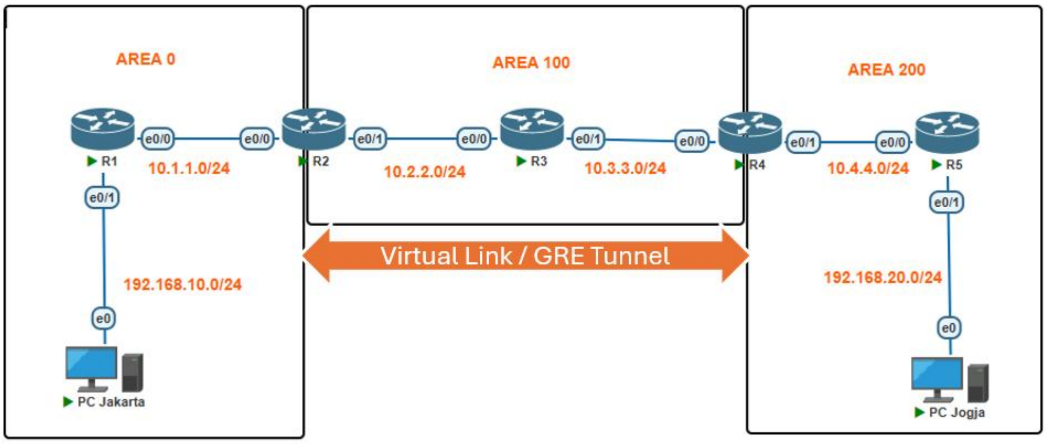


Figure 1. Multi-area OSPF topology with Virtual link and GRE tunnel

The Topology Design for this study uses a total of 5 Cisco Routers running using multi-area OSPF routing. The OSPF area is divided into 3, namely the backbone area or area 0, area 100 as a transit area, and area 200 which will be connected to area 0 using a virtual link and GRE Tunnel. Area 0 consists of R1 and R2, Area 100 consists of R2, R3, R4, and Area 200 consists of R4, R5. Virtual links are carried out on R2 and R4 routers as Border Router Areas or areas that connect more than one area.

Specification of Tools and Materials

To conduct this research, a hardware device in the form of a server is needed that functions as a container to run network simulator software. The Software & Hardware Specifications used for testing are as follows:

Table 1. Hardware Specifications

No	Device Name	Sum	Specifications
1	Server Dell	1	Manufacturer: Dell Inc. Model: PowerEdge R630 CPU: 44 CPUs x Intel(R) Xeon(R) CPU E5-2699 v4 @ 2.20GHz Memory: 511.78 GB

Table 2. Software Specifications

No	Software Name	Sum	Specifications
1	VMWare ESXi	1	ESXi-7.0U3l-21424296standard (VMware, Inc.)
2	PNETLab	1	Version 5.3.11
3	IOS Router Cisco	5	i86bi_Linux-L3AdvEnte priseK9M2_157_3_May_2018.bin

4	Windows OS for Client	2	Windows 10 Pro 22 H2
5	Wireshark	1	Version 3.4.8
6	IPerf3	1	Version 3.17

System Analysis and Design

The analysis and design of the system describes the steps carried out in this study, starting from the design of the network topology, the configuration of multi-area OSPF, the implementation of Virtual Link and GRE Tunnel, to the testing and analysis of performance.

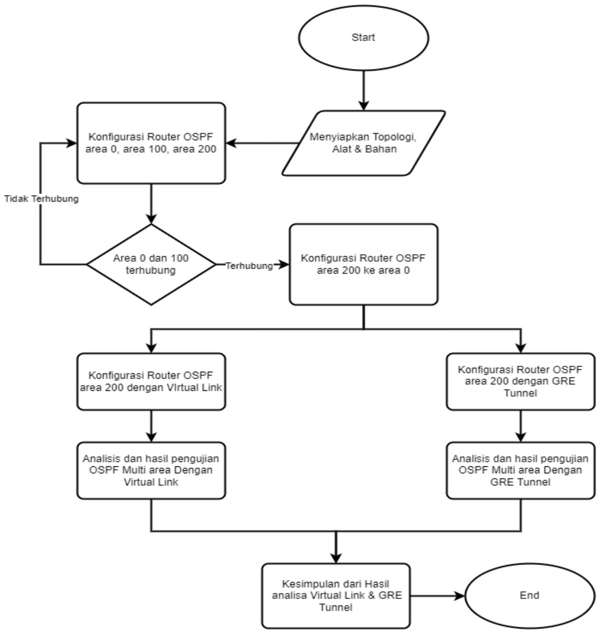


Figure 2. Research flow chart

The stages of analysis and system design for research include:

a. Network topology design is to create a network topology design with 5 Cisco routers.
b. Multi-area OSPF configuration is to configure OSPF on the router for area 0, area 100, and area 200.
c. The implementation of the solution is to implement virtual links and gre tunnels for area 200.
d. Performance testing by conducting tests with tiphon standards and measuring the ospf convergence time.
e. Analyze the test results data to compare network performance with virtual link and gre tunnel.

Evaluation Metrics

TIPHON (Telecommunications and Internet Protocol Harmonization Over Networks) is a framework used to evaluate Quality of Service (QoS) in telecommunications and internet networks(Nisa et al., 2024). TIPHON provides a method to measure several important parameters that affect the quality of communication in a network. In this study, measurements will be made using iPerf3, namely software to measure the achievable Throughput, Packet Loss, Jitter in IP networks. iPerf3 supports protocols (TCP, UDP, SCTP with IPv4 and IPv6) and was developed by ESnet/Lawrence Berkeley National Laboratory and released under the BSD license. Some of the key parameters in the QoS evaluated are:

1. **Jitter**: The variation in the delay time between the packets received. High jitter can cause interference in data transmission, sound or video quality. Jitter measurements are also made in milliseconds (ms) as is the following equation no (1):

$$Jitter = \frac{total\ delay\ variation}{total\ recieved\ package}\ (ms) \tag{1}$$

2. **Packet Loss**: The proportion of packets lost during transmission compared to the total packets sent. The packet loss value is expressed in percentage terms and is an important indicator for assessing network reliability. The jitter measurement is also done in percent (%) as in equation no (2) as follows:

$$Packet\ loss = \frac{package\ shipped - package\ received}{package\ shipped}\ x\ 100\%$$

(2

3. **Throughput**: The amount of data successfully transmitted in units of time, typically measured in kilobits per second (kbps) or megabits per second (Mbps). High throughput indicates the efficiency of the network in handling data traffic. The formula for calculating throughput is as shown in equation (3) as follows:

$$Throughput = \frac{total\ data\ packets\ sent}{data\ packet\ delivery\ time} \tag{3}$$

Convergence OSPF (Open Shortest Path First)

The process by which all routers in an OSPF area achieve a stable and consistent state after a change in network topology or routing information. This process involves several stages where OSPF routers update and align their routing information to reflect the latest network topology.

OSPF Convergence Time

The duration required by the OSPF protocol to achieve a stable state after a change in topology. Short convergence times are important to ensure the network can quickly adapt to changes and minimize downtime. The time of convergence is measured from the time a topology change (such as a path break) to the time the network reaches a stable state again with updated routing information. The formula for calculating the OSPF convergence time can be calculated by the following equation (4):

$$Total\ Konvergensi = Hello\ interval + LSA\ Propagation\ Time \quad (4)$$

Hello Interval is a fixed time for OSPF to manage OSPF neighbors, hello interval is 10 seconds. LSA Propagation Time may vary depending on network size and device capacity (measured using wireshark)

Implementation and Measurement

Measurements were made using tools such as Wireshark to calculate OSPF convergence and Iperf3 to analyze QoS on the network. The collected data will be analyzed using Excel to present the results in the form of tables and graphs.

RESULT AND DISCUSSION

The stages of results and discussion are explained about the process after designing the topology, namely the configuration of OSPF Multi Area without Virtual Link and GRE tunnel, then the configuration and verification of OSPF Multi Area with Virtual Link and GRE Tunnel. The last stage is the discussion of the test results between OSPF Multi Area using Virtual Link and GRE Tunnel

Multi Area OSPF Configuration

R1	R2
router ospf 10 router-id 1.1.1.1 network 1.1.1.1 0.0.0.0 area 0 network 10.1.1.1 0.0.0.0 area 0 network 192.168.10.0 0.0.0.255 area 0	router ospf 10 router-id 2.2.2.2 network 2.2.2.2 0.0.0.0 area 100 network 10.1.1.2 0.0.0.0 area 0 network 10.2.2.1 0.0.0.0 area 100

R3	R4
router ospf 10 router-id 3.3.3.3 network 3.3.3.3 0.0.0.0 area 100 network 10.2.2.2 0.0.0.0 area 100 network 10.3.3.1 0.0.0.0 area 100	router ospf 10 router-id 4.4.4.4 network 4.4.4.4 0.0.0.0 area 100 network 10.3.3.2 0.0.0.0 area 100 network 10.4.4.1 0.0.0.0 area 200

R5
router ospf 10 router-id 5.5.5.5 network 5.5.5.5 0.0.0.0 area 200 network 10.4.4.2 0.0.0.0 area 200 network 192.168.20.0 0.0.0.255 area 200

Verify once OSPF Multi Area is configured without using Virtual Link or GRE Tunnel

```
R1#show ip route ospf | b Gateway
Gateway of last resort is not set

      3.0.0.0/32 is subnetted, 1 subnets
O IA     3.3.3.3 [110/21] via 10.1.1.2, 00:02:02, Ethernet0/0
      4.0.0.0/32 is subnetted, 1 subnets
O IA     4.4.4.4 [110/31] via 10.1.1.2, 00:02:07, Ethernet0/0
      10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
O IA     10.2.2.0/24 [110/20] via 10.1.1.2, 00:02:02, Ethernet0/0
O IA     10.3.3.0/24 [110/30] via 10.1.1.2, 00:02:02, Ethernet0/0
R1#
```

Figure 3. R1 Routing Table before Virtual Link and GRE Tunnel

```
R5#show ip route ospf | b Gateway
Gateway of last resort is not set

R5#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
4.4.4.4           1   FULL/BDR        00:00:32    10.4.4.1        Ethernet0/0
R5#
```

Figure 4. R5 Routing Table before Virtual Link and GRE Tunnel

The verification results show that the routing table in R1 has not received the routing table from the OSPF router area 200, and the routing table in R5 has not received the routing table from area 100 or area 0. Area 200 cannot be connected to OSPF because it is not directly connected to area 0, for that it is necessary to configure OSPF Multi Area with Virtual Link and GRE Tunnel.

Multi-Area OSPF Configuration with Virtual Link

The configuration is done to connect area 200 with areas 0 and 100, through the Virtual link configuration in R2 and R4:

R2	R4
Router ospf 10 area 100 virtual-link 4.4.4.4	Router ospf 10 area 100 virtual-link 2.2.2.2

Verification after configuring OSPF Multi Area using Virtual Link

```
R5#show ip route ospf | b Gateway
Gateway of last resort is not set

      1.0.0.0/32 is subnetted, 1 subnets
O IA     1.1.1.1 [110/1021] via 10.4.4.1, 14:01:05, Ethernet0/0
      3.0.0.0/32 is subnetted, 1 subnets
O IA     3.3.3.3 [110/21] via 10.4.4.1, 16:26:23, Ethernet0/0
      4.0.0.0/32 is subnetted, 1 subnets
O IA     4.4.4.4 [110/11] via 10.4.4.1, 3d12h, Ethernet0/0
      10.0.0.0/8 is variably subnetted, 6 subnets, 3 masks
O IA     10.1.1.0/24 [110/1020] via 10.4.4.1, 14:01:05, Ethernet0/0
O IA     10.2.2.0/24 [110/30] via 10.4.4.1, 16:26:23, Ethernet0/0
O IA     10.3.3.0/24 [110/20] via 10.4.4.1, 3d12h, Ethernet0/0
O IA     10.10.10.0/30 [110/1010] via 10.4.4.1, 3d12h, Ethernet0/0
O IA  192.168.10.0/24 [110/1030] via 10.4.4.1, 14:01:05, Ethernet0/0
R5#
```

Figure 3. R5 Table Routing with GRE Tunnel

The results of the Traceroute from PC Jakarta to PC Jogja show the path with the GRE Tunnel through R1→, R2→, R4→, R5

```
C:\Users\user> tracert -d 192.168.20.2
Tracing route to 192.168.20.2 over a maximum of 30 hops
1    1 ms    <1 ms    1 ms  192.168.10.1
2    1 ms    <1 ms   <1 ms  10.1.1.2
3    2 ms     2 ms    2 ms  10.10.10.2
4    2 ms     2 ms    2 ms  10.4.4.2
5    3 ms     2 ms    3 ms  192.168.20.2
Trace complete.
C:\Users\user>
```

QoS Testing with TIPHON Standard

The test results in this study were carried out by sending experiments 10 times each for 10 seconds for OSPF Virtual Link and GRE Tunnel with various types of data sizes sent. The test was carried out with iperf3 software running on PC Jakarta as a server and PC Jogja as a client.

The test was carried out from PC Jogja to PC Jakarta through a network that uses multi-area OSPF with Virtual link and GRE Tunnel, with an output file containing the test results at each experiment.

Table 3. iperf3 testing for OSPF multi area virtual link

No	Multi-Area QoS Testing with Virtual Link	Output
1	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 1M --logfile Test1-1Mb.txt	Test1-1Mb.txt
2	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 5M --logfile Test2-5Mb.txt	Test2-5Mb.txt
3	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 10M --logfile Test3-10Mb.txt	Test3-10Mb.txt
4	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 15M --logfile Test4-15Mb.txt	Test4-15Mb.txt
5	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 20M --logfile Test5-20Mb.txt	Test5-20Mb.txt
6	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 25M --logfile Test6-25Mb.txt	Test6-25Mb.txt
7	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 30M --logfile Test7-30Mb.txt	Test7-30Mb.txt
8	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 35M --logfile Test8-35Mb.txt	Test8-35Mb.txt
9	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 40M --logfile Test9-40Mb.txt	Test9-40Mb.txt
10	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 45M --logfile Test10-45Mb.txt	Test10-45Mb.txt

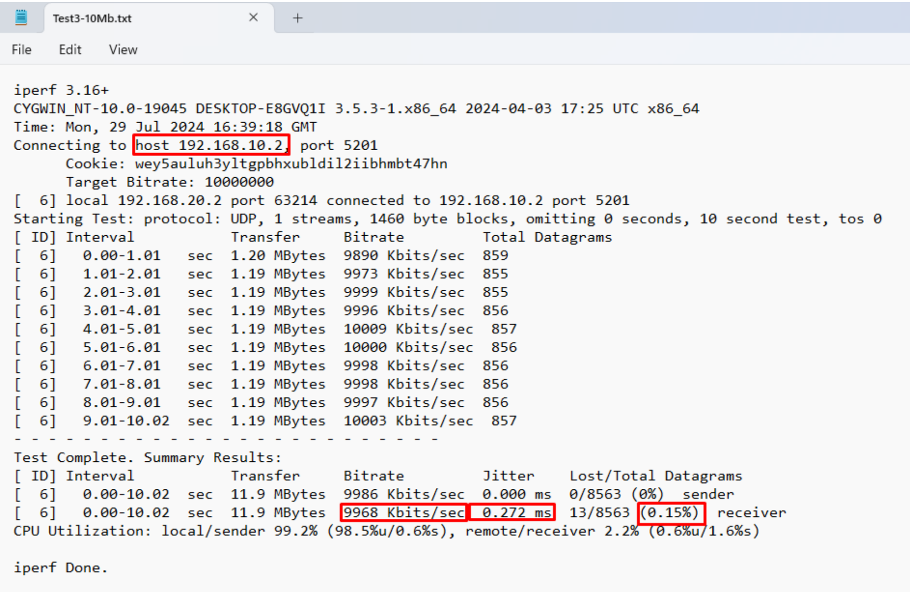
Table 4. iperf3 testing for OSPF multi area GRE Tunnel

No	Multi Area OPSF QoS Testing with GRE Tunnel	Output
1	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 1M --logfile Coba1-1Mb.txt	Coba1-1Mb.txt
2	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 5M --logfile Coba2-5Mb.txt	Coba2-5Mb.txt
3	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 10M --logfile Coba3-10Mb.txt	Coba3-10Mb.txt
4	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 15M --logfile Coba4-15Mb.txt	Coba4-15Mb.txt
5	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 20M --logfile Coba5-20Mb.txt	Coba5-20Mb.txt
6	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 25M --logfile Coba6-25Mb.txt	Coba6-25Mb.txt
7	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 30M --logfile Coba7-30Mb.txt	Coba7-30Mb.txt
8	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 35M --logfile Coba8-35Mb.txt	Coba8-35Mb.txt
9	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 40M --logfile Coba9-40Mb.txt	Coba9-40Mb.txt
10	C:\iperf>iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 45M --logfile Coba10-45Mb.txt	Coba10-45Mb.txt

Command iperf3 :
iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 10M --logfile Test3-10Mb.txt

-c 192.168.10.2 : The target server tested is 192.168.10.2 (PC Jakarta)
-u : using UDP protocol
-f kbits : format the data in kbits
-V : displays the output in detail
-t 10 : test interval for 10 seconds
-10M : the data sent is 10Mb
--logfile Test3-10Mb.txt: saves the test results into a

Sample iperf test result output (iperf3 -c 192.168.10.2 -u -f kbits -V -t 10 - 10M --logfile Test3-10Mb.txt)



```
Test3-10Mb.txt
File  Edit  View

iperf 3.16+
CYGWIN_NT-10.0-19045 DESKTOP-E8GVQ1I 3.5.3-1.x86_64 2024-04-03 17:25 UTC x86_64
Time: Mon, 29 Jul 2024 16:39:18 GMT
Connecting to host 192.168.10.2, port 5201
      Cookie: wey5auluh3yltgpbhxubldil2iibhmbt47hn
      Target Bitrate: 10000000
[  6] local 192.168.20.2 port 63214 connected to 192.168.10.2 port 5201
Starting Test: protocol: UDP, 1 streams, 1460 byte blocks, omitting 0 seconds, 10 second test, tos 0
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  6]   0.00-1.01   sec  1.20 MBytes  9890 Kbits/sec  859
[  6]   1.01-2.01   sec  1.19 MBytes  9973 Kbits/sec  855
[  6]   2.01-3.01   sec  1.19 MBytes  9999 Kbits/sec  855
[  6]   3.01-4.01   sec  1.19 MBytes  9996 Kbits/sec  856
[  6]   4.01-5.01   sec  1.19 MBytes  10009 Kbits/sec  857
[  6]   5.01-6.01   sec  1.19 MBytes  10000 Kbits/sec  856
[  6]   6.01-7.01   sec  1.19 MBytes  9998 Kbits/sec  856
[  6]   7.01-8.01   sec  1.19 MBytes  9998 Kbits/sec  856
[  6]   8.01-9.01   sec  1.19 MBytes  9997 Kbits/sec  856
[  6]   9.01-10.02  sec  1.19 MBytes  10003 Kbits/sec  857
- - - - - - - - - - - - - - - - - - - - - - - - -
Test Complete. Summary Results:
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  6]   0.00-10.02  sec  11.9 MBytes  9986 Kbits/sec  0.000 ms  0/8563 (0%)  sender
[  6]   0.00-10.02  sec  11.9 MBytes  9968 Kbits/sec  0.272 ms  13/8563 (0.15%)  receiver
CPU Utilization: local/sender 99.2% (98.5%u/0.6%s), remote/receiver 2.2% (0.6%u/1.6%s)

iperf Done.
```

Figure 4. Example of test results using iperf

From the results of tests carried out 10 times for OSPF Virtual link and 10 times with OSPF GRE Tunnel, the following results were obtained:

Table 5. Multi-Area OSPF QoS Results with Virtual Link

Data Size	OSPF Multi Area Virtual Link Testing		
(Mbit)	Troughput (Mbps)	Packet Loss (%)	Jitter (ms)
1	0.999	0	0.194
5	4.989	0.07	0.14
10	9.968	0.15	0.272
15	14.885	0.61	0.337
20	19.677	1.4	0.531
25	24.969	2.6	0.277
30	28.98	3.3	0.11
35	33.796	3.3	0.615
40	39.892	20	0.331
45	44.954	29	0.436

Table 6. Multi Area OSPF QoS Results with GRE Tunnel

Data Size	OSPF Multi Area GRE Tunnel Testing		
(Mbit)	Troughput (Mbps)	Packet Loss (%)	Jitter (ms)
1	1	0	0.227
5	4.965	0.55	0.197
10	9.87	1.1	0.267
15	14.886	0.6	0.268
20	19.134	4.1	0.269
25	24.172	3.1	0.378
30	28.881	3.6	0.373
35	34.973	3.8	0.093
40	39.955	8.3	0.123
45	44.992	19	0.549

Throughput Comparison between Multi-area OSPF with Virtual link and GRE Tunnel.

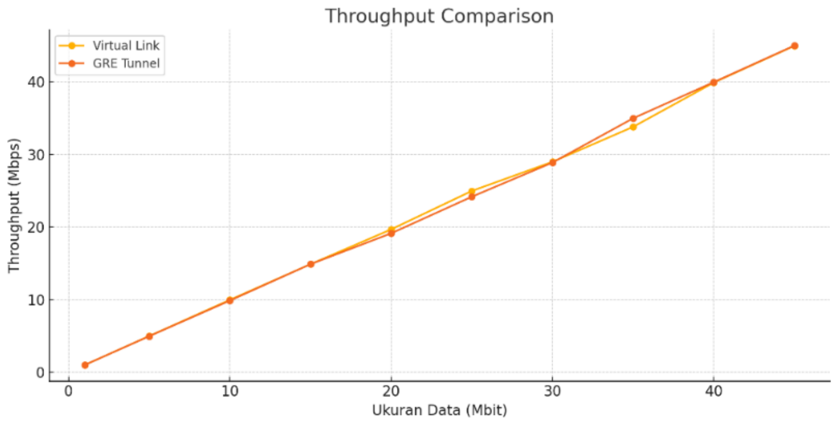


Figure 5. Comparison of Virtual link and GRE Tunnel Throughput

Both methods show almost the same throughput on most data sizes.
Comparison of Packet Loss between Multi-area OSPF with Virtual link and GRE Tunnel

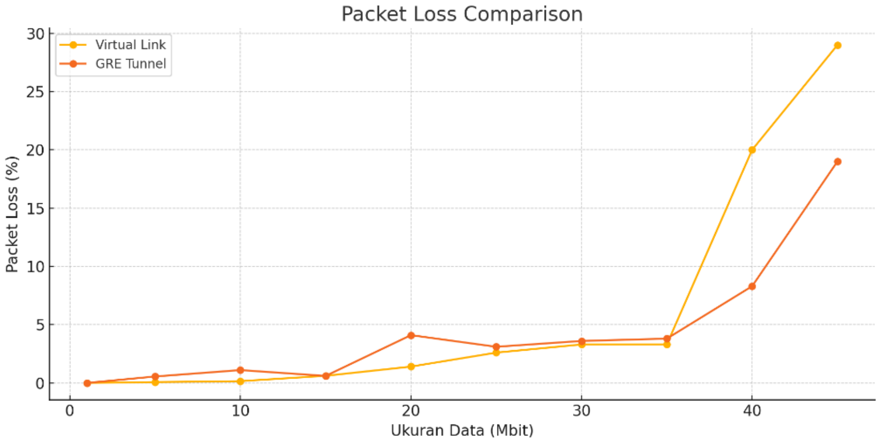
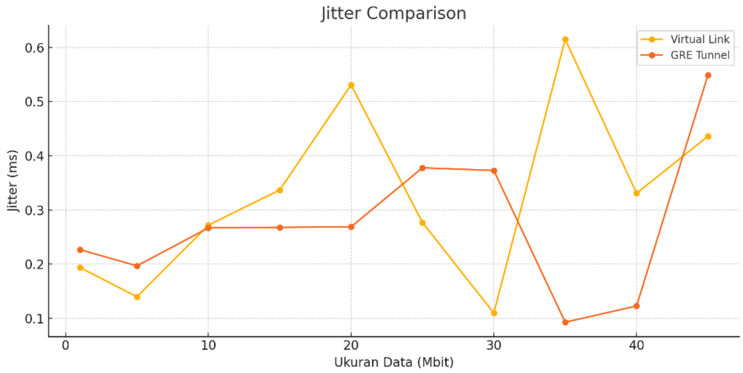


Figure 6. Comparison of Packet Loss between OSPF Virtual Link and GRE Tunnel

a. At small data sizes (1 Mbit to 15 Mbit), both methods show low packet loss.
b. At larger data sizes, GRE Tunnels tend to have lower packet loss than Virtual Links, especially at 40 Mbit and 45 Mbit, where Virtual Links experience very high packet loss (20% and 29%).

Comparison of Jitter between Multi-area OSPF with Virtual link and GRE Tunnel



a. OSPF Multi Area Virtual Link has a more stable jitter and tends to be lower than GRE Tunnel on most data sizes.
b. GRE Tunnel shows a significant increase in jitter at larger data sizes, especially at 25 Mbit and 30 Mbit.

OSPF convergence time testing

The test was carried out by turning off the link on the router running OSPF for 5 attempts. then calculate the time it takes for OSPF to converge until it recovers.

Comparison of convergence time on Multi-area OSPF with Virtual link and GRE Tunnel, OSPF packet capture is done with wireshark to see from the process of turning off to turning back on.

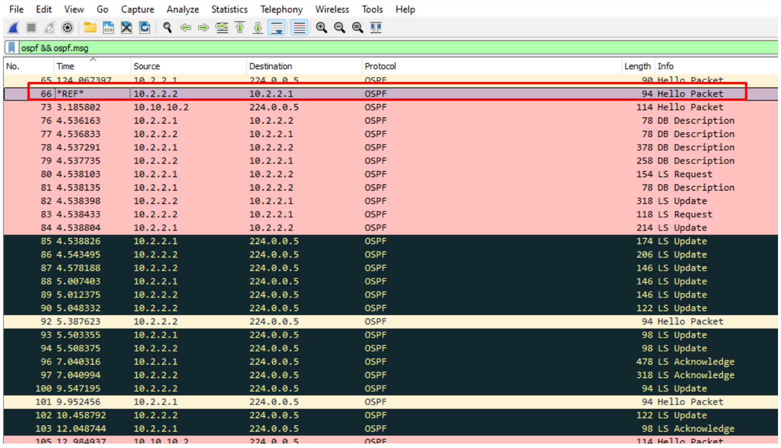


Figure 7. Wireshark for packet capture ospf

Count the time When the OSPF Link is Off then on until there is a perfect convergence in the OSPF. The analysis is done by calculating the time between the first hello packet and the completion of LSA propagation.

LSA Propagation: the time interval between the first hello packet and the last LS Aknowledge.

Table 7. OSPF Virtual Link & GRE Tunnel Time Convergence Results

It	Testing	LSA Propagation Time (second)	
		OSPF Virtual Link	OSPF GRE Tunnel
1	1st test	30.105	25.555
2	2nd test	23.017	32.518
3	3rd test	23.012	33.863
4	4th test	23.048	26.012
5	5th test	26.401	25.124

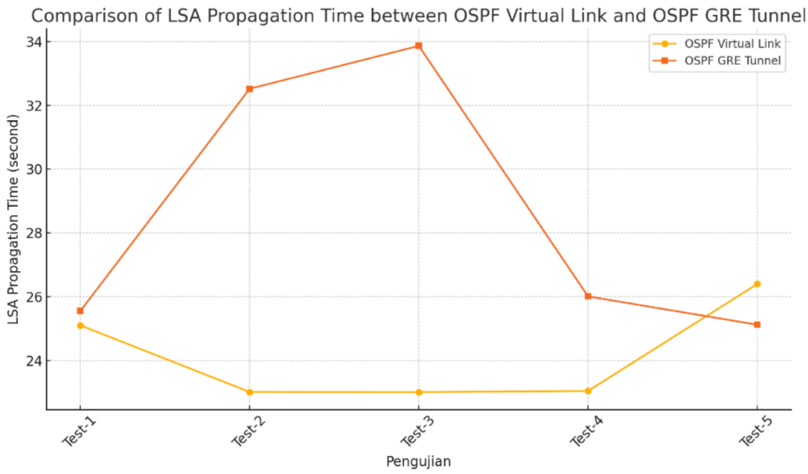


Figure 8. Difference between LSA Propagation virtual link and GRE tunnel

The graph above shows the comparison of LSA propagation times between OSPF Virtual Link and OSPF GRE Tunnel based on the tests performed. OSPF Virtual Link in general, propagation time is more consistent and tends to be lower compared to OSPF GRE Tunnel. The average propagation time of LSA Virtual Link is 24.1166 seconds, while the GRE tunnel is 28.6144. OSPF GRE Tunnel propagation time tends to be higher and varies in some tests, especially seen in Test-2 and Test-3 tests which show a significant increase in propagation time.

From the graph, it can be concluded that OSPF Virtual Link shows a more stable and fast performance compared to OSPF GRE Tunnel in terms of LSA propagation time. This is important to consider in selecting the optimal OSPF network configuration method.

CONCLUSION

From the research that has been conducted, it can be concluded that the implementation of multi-area OSPF using Virtual Link and GRE Tunnel has different characteristics and performance in several aspects. Convergence Time: Multi-area OSPF with Virtual Link shows faster and more consistent convergence times compared to GRE Tunnel. This is important in large networks that undergo frequent topological changes, as short convergence times will reduce downtime and improve network reliability. Throughput: Throughput test results show that both methods, Virtual Link and GRE Tunnel, have nearly the same throughput performance on most data sizes. However, Virtual Link is slightly superior at smaller data sizes. Packet Loss: GRE Tunnel shows lower packet loss compared to Virtual Link especially at larger data sizes. This signifies that GRE Tunnel is more effective in reducing packet loss on large data transmissions, which is especially important for applications that require high data integrity. Jitter: Virtual Links have a more stable jitter and tend to be lower compared to GRE Tunnel on most data sizes. Jitter stability is important for time-sensitive applications, such as VoIP and video streaming. Conformance to TIPHON Standard: QoS testing with TIPHON standard shows that both methods can be well implemented in multi-area OSPF networks. However, the choice between Virtual Link and GRE Tunnel should consider the specific needs of the network, such as the need for convergence time, throughput, packet loss, and jitter. Based on these results, it is recommended for network professionals to consider using multi-area OSPF with Virtual Link for networks that require fast convergence times and stable jitter. Meanwhile, GRE Tunnel is more suitable for networks that prioritize minimal packet loss, especially in large data transmissions. This study provides practical guidance in optimizing the configuration of multi-area OSPF and can be used as a reference in the development of more efficient and reliable networks.

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