NS-3 Simulation: Building Custom Topology Network Performance Evaluation

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1 Objective

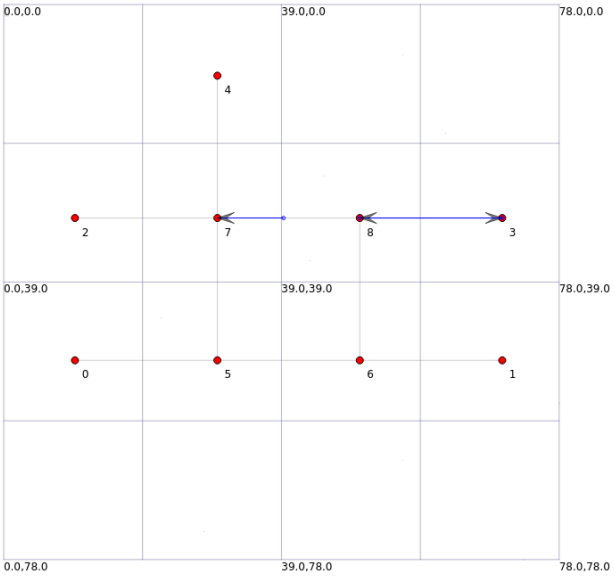
To simulate a computer network using the NS-3 simulator and evaluate its performance. The network consists of multiple nodes, which include workstations, servers, and intermediate routers. Data packets are routed through the network, and links may have different capacities, delays, and noise levels.

2 Topology

The network consists of:

- 5 Workstations/Servers (N1, N2, N3, N4, N5)
- 4 Routers (R1, R2, R3, R4)
- Point-to-point links with varying capacities

The chosen topology for the simulation is shown below:



2.1 Network Topology

The network consists of 5 nodes (N1, N2, N3, N4, N5) and 4 routers (R1, R2, R3, R4). The links between them have the following capacities:

Link	Capacity
N1 – R1	1 Mbps
N2 – R2	1 Mbps
N3 – R3	3 Mbps
N4 – R4	1 Mbps
N5 – R3	1 Mbps
R1 – R2	3 Mbps
R1 – R3	2.5 Mbps
R2 – R4	1 Mbps
R3 – R4	1.5 Mbps

Table 1: Network Topology with Link Capacities

2.2 Traffic Matrix

The traffic matrix below shows the traffic rates between each pair of nodes (in Mbps).

	$N1$	$N2$	$N3$	$N4$	$N5$
$N1$	0	120	132	144	160
$N2$	100	0	190	111	154
$N3$	101	100	0	199	108
$N4$	150	156	262	0	159
$N5$	140	188	285	171	0

2.3 Node Information

Node	Node Number	Type
N1	0	Client/Server
N2	1	Client/Server
N3	2	Client/Server
N4	3	Client/Server
N5	4	Client/Server
R1	5	Router
R2	6	Router
R3	7	Router
R4	8	Router

Table 2: Node Details and Classification

3 Explanation of Packet Transmission and Routing

3.1 Packet Transmission

Each workstation (N1, N2, N3, N4, N5) is connected to a router (R1, R2, R3, R4) via point-to-point links. The workstations generate or consume data packets, while the routers handle routing packets to the appropriate destination.

Example of Packet Flow

- **From N1 to N3**:
  - Packets from workstation N1 (Node 0) are sent to router R1 (Node 5) via the point-to-point link `n1r1`.
  - Router R1 forwards the packets through one of its links (`r1r3`) to reach the destination router for N3 (Node 2), which is R3 (Node 7).

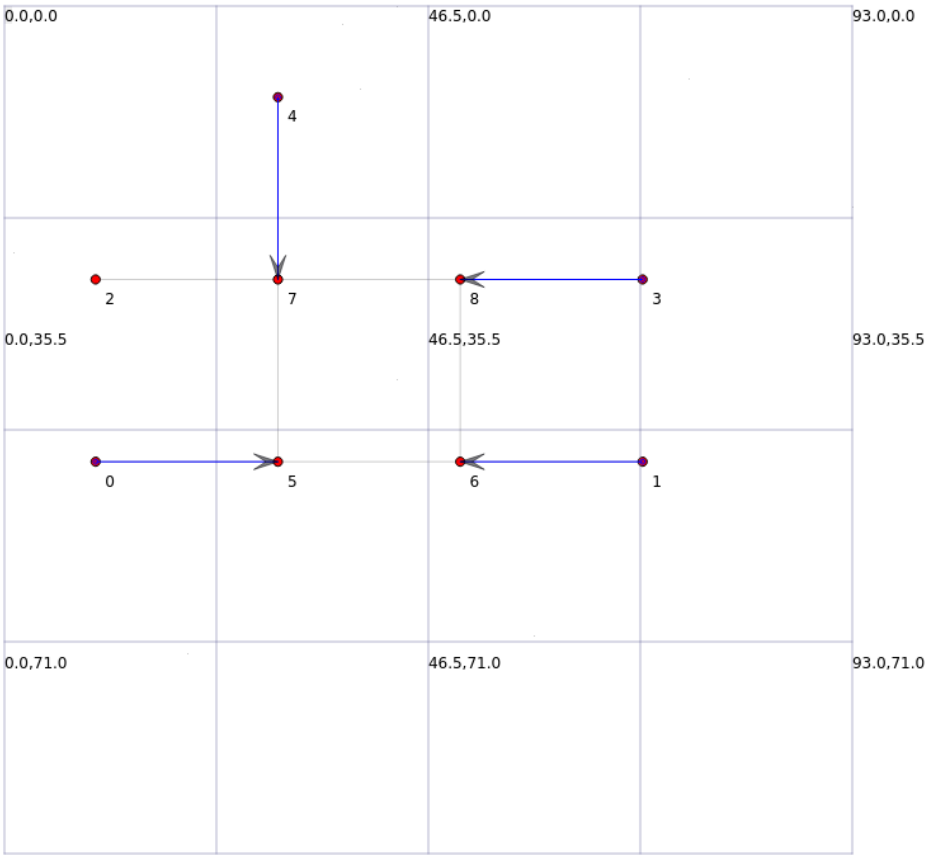


Figure 1: Example of packet flow towards N3 (node 2)

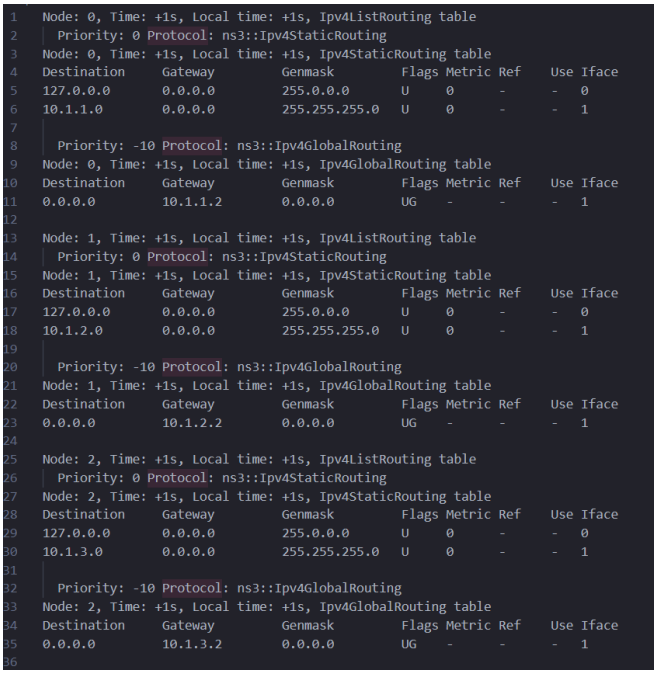
During the simulation, tracing was enabled for all network events, including packet transmission, reception, enqueuing, dequeuing, and drops. The trace data was logged in a `.tr` file for detailed analysis. The generated trace file was parsed to calculate various statistics including one-way end-to-end delay, queue length and packets dropped.

3.2 Routing Packets Between Routers

The routers (R1, R2, R3, R4) are connected by point-to-point links with varying capacities and delays. Routing decisions are made based on the global routing tables, which are populated using the function:

```
Ipv4GlobalRoutingHelper::PopulateRoutingTables();
```

Source	**N1**	**N2**	**N3**	**N4**	**N5**	**R1**	**R2**	**R3**	**R4**
N1	–	R1	R1	R1	R1	–	–	–	–
N2	R2	–	R2	R2	R2	–	–	–	–
N3	R3	R3	–	R3	R3	–	–	–	–
N4	R4	R4	R4	–	R4	–	–	–	–
N5	R3	R3	R3	R3	–	–	–	–	–
R1	N1	R2	R3	R2	R3	–	R2	R3	R2
R2	R1	N2	R4	N4	R4	R1	–	R1	R4
R3	R1	R4	N3	R4	N5	R1	R1	–	R4
R4	R2	R2	R3	N4	R5	R3	R2	R3	–



```
Node: 0, Time: +1s, Local time: +1s, Ipv4ListRouting table
  Priority: 0 Protocol: ns3::Ipv4StaticRouting
Node: 0, Time: +1s, Local time: +1s, Ipv4StaticRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
127.0.0.0       0.0.0.0         255.0.0.0       U     0      -      -   0
10.1.1.0        0.0.0.0         255.255.255.0   U     0      -      -   1

  Priority: -10 Protocol: ns3::Ipv4GlobalRouting
Node: 0, Time: +1s, Local time: +1s, Ipv4GlobalRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         10.1.1.2        0.0.0.0         UG    -      -      -   1

Node: 1, Time: +1s, Local time: +1s, Ipv4ListRouting table
  Priority: 0 Protocol: ns3::Ipv4StaticRouting
Node: 1, Time: +1s, Local time: +1s, Ipv4StaticRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
127.0.0.0       0.0.0.0         255.0.0.0       U     0      -      -   0
10.1.2.0        0.0.0.0         255.255.255.0   U     0      -      -   1

  Priority: -10 Protocol: ns3::Ipv4GlobalRouting
Node: 1, Time: +1s, Local time: +1s, Ipv4GlobalRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         10.1.2.2        0.0.0.0         UG    -      -      -   1

Node: 2, Time: +1s, Local time: +1s, Ipv4ListRouting table
  Priority: 0 Protocol: ns3::Ipv4StaticRouting
Node: 2, Time: +1s, Local time: +1s, Ipv4StaticRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
127.0.0.0       0.0.0.0         255.0.0.0       U     0      -      -   0
10.1.3.0        0.0.0.0         255.255.255.0   U     0      -      -   1

  Priority: -10 Protocol: ns3::Ipv4GlobalRouting
Node: 2, Time: +1s, Local time: +1s, Ipv4GlobalRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         10.1.3.2        0.0.0.0         UG    -      -      -   1
```

Routing Steps

1. The source router forwards the packet to the next-hop router based on the routing table.
2. The intermediate router examines the destination IP address and forwards the packet to the appropriate link.
3. This process continues until the packet reaches the destination workstation.

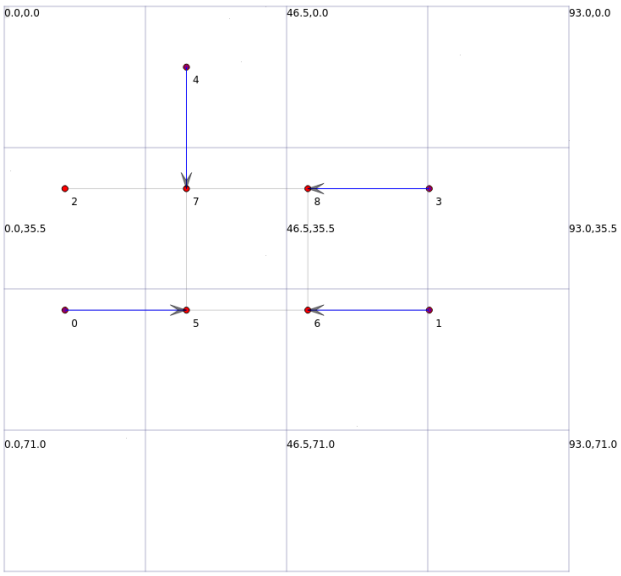
3.3 Queue Management

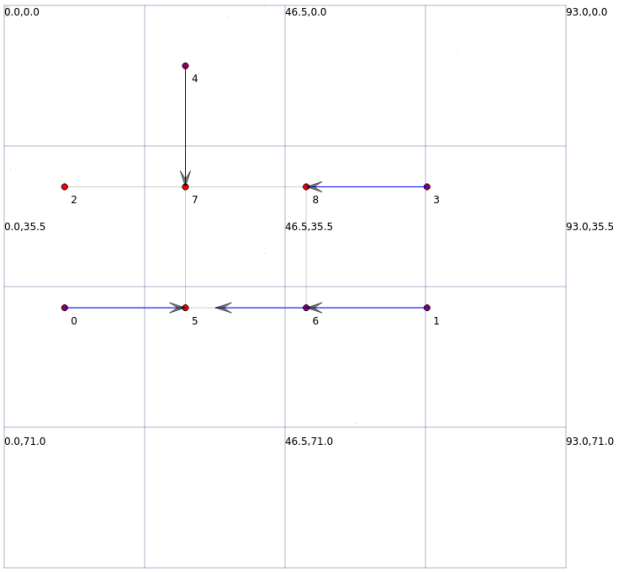
```
1837   Router 1 | Time: 42.5336 | Queue Length: 35
1838   Router 3 | Time: 42.5336 | Queue Length: 35
1839   Router 0 | Time: 42.5346 | Queue Length: 35
1840   Router 0 | Time: 42.5346 | Queue Length: 36
1841   Router 0 | Time: 42.5346 | Queue Length: 35
1842   Router 1 | Time: 42.5346 | Queue Length: 35
1843   Router 3 | Time: 42.5346 | Queue Length: 35
1844   Router 4 | Time: 42.5346 | Queue Length: 35
1845   Router 0 | Time: 42.5375 | Queue Length: 35
1846   Router 0 | Time: 42.5456 | Queue Length: 35
1847   Router 1 | Time: 42.5456 | Queue Length: 35
1848   Router 3 | Time: 42.5456 | Queue Length: 35
1849   Router 0 | Time: 42.5466 | Queue Length: 35
1850   Router 1 | Time: 42.5466 | Queue Length: 35
1851   Router 3 | Time: 42.5466 | Queue Length: 35
1852   Router 0 | Time: 42.5504 | Queue Length: 35
1853   Router 1 | Time: 42.5504 | Queue Length: 35
1854   Router 3 | Time: 42.5504 | Queue Length: 35
1855   Router 0 | Time: 42.5514 | Queue Length: 35
1856   Router 1 | Time: 42.5514 | Queue Length: 35
1857   Router 3 | Time: 42.5514 | Queue Length: 35
1858   Router 0 | Time: 42.5624 | Queue Length: 35
1859   Router 1 | Time: 42.5624 | Queue Length: 35
1860   Router 3 | Time: 42.5624 | Queue Length: 35
```

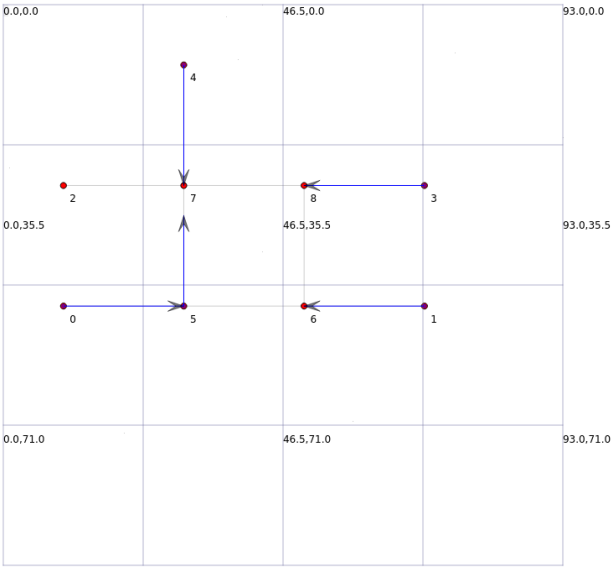
Figure 2: Queue lengths at a given time instance for various routers

3.4 Tracing a packet

Below are series of images that simulate the path followed by a packet from Node 1 (N2) to Node 2 (N3):

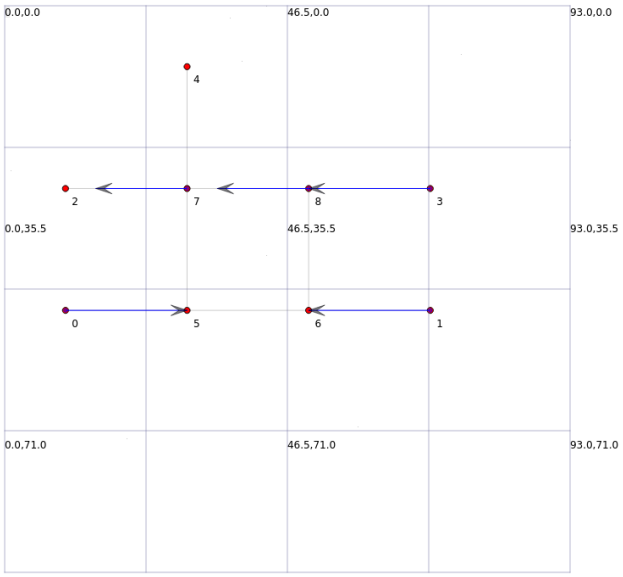



0.0,0.0
46.5,0.0
93.0,0.0
4
2
7
8
3
0.0,35.5
46.5,35.5
93.0,35.5
0
5
6
1
0.0,71.0
46.5,71.0
93.0,71.0


0.0,0.0
46.5,0.0
93.0,0.0
4
2
7
8
3
0.0,35.5
46.5,35.5
93.0,35.5
0
5
6
1
0.0,71.0
46.5,71.0
93.0,71.0

```
Packet Drops:
[[  0.   0. 270.   0.   0.]
 [  0.   0. 280.   0.   0.]
 [  0.   0.   0.   0.   0.]
 [  0.   0. 275.   0.   0.]
 [  0.   0. 250.   0.   0.]]
```

Figure 3: Packet Drop Matrix



3.5 Packet Dropping

Packets have been forced to drop with a 0.5% probability:

3.6 One way end-to-end Delay

```
Node: 0, Time: +1s, Local time: +1s, Ipv4ListRouting table
  Priority: 0 Protocol: ns3::Ipv4StaticRouting
Node: 0, Time: +1s, Local time: +1s, Ipv4StaticRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
127.0.0.0       0.0.0.0         255.0.0.0       U     0      -      -   0
10.1.1.0        0.0.0.0         255.255.255.0   U     0      -      -   1

  Priority: -10 Protocol: ns3::Ipv4GlobalRouting
Node: 0, Time: +1s, Local time: +1s, Ipv4GlobalRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         10.1.1.2        0.0.0.0         UG    -      -      -   1

Node: 1, Time: +1s, Local time: +1s, Ipv4ListRouting table
  Priority: 0 Protocol: ns3::Ipv4StaticRouting
Node: 1, Time: +1s, Local time: +1s, Ipv4StaticRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
127.0.0.0       0.0.0.0         255.0.0.0       U     0      -      -   0
10.1.2.0        0.0.0.0         255.255.255.0   U     0      -      -   1

  Priority: -10 Protocol: ns3::Ipv4GlobalRouting
Node: 1, Time: +1s, Local time: +1s, Ipv4GlobalRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         10.1.2.2        0.0.0.0         UG    -      -      -   1

Node: 2, Time: +1s, Local time: +1s, Ipv4ListRouting table
  Priority: 0 Protocol: ns3::Ipv4StaticRouting
Node: 2, Time: +1s, Local time: +1s, Ipv4StaticRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
127.0.0.0       0.0.0.0         255.0.0.0       U     0      -      -   0
10.1.3.0        0.0.0.0         255.255.255.0   U     0      -      -   1

  Priority: -10 Protocol: ns3::Ipv4GlobalRouting
Node: 2, Time: +1s, Local time: +1s, Ipv4GlobalRouting table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         10.1.3.2        0.0.0.0         UG    -      -      -   1

```

Figure 4: Average Delay and Variance of Delay

4 Simulation Parameters and Assumptions

4.1 Propagation Delay

In this simulation:

- A fixed propagation delay of **1 ms** is assumed for each point-to-point link.
- This delay is explicitly enforced in the code using the following configuration:

```
p2p.SetChannelAttribute("Delay", StringValue("1ms"));
```

- Every link in the topology is configured with this propagation delay, ensuring consistent timing behavior throughout the network.

4.2 Packet Generation Using Poisson Distribution

The arrival of packets in the simulation follows a **Poisson distribution**. Key characteristics of this distribution include:

- **Mean Interarrival Time (λ)**: The average time between the generation of two consecutive packets.
- The Poisson process is defined as:

$$P(k;\lambda) = \frac{\lambda^k e^{-\lambda}}{k!}$$

where $P(k;\lambda)$ is the probability of k packet arrivals in a given interval, and λ is the rate of packet arrivals which is determined using the traffic matrix.

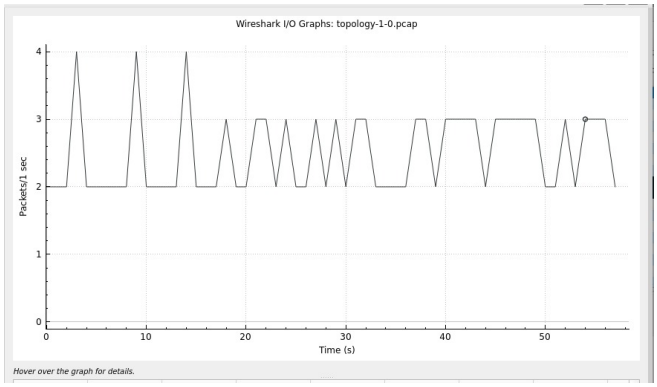


Figure 5: Poisson distribution for packet generation

- Packets are generated using an exponential inter-arrival time derived from the Poisson process:

```
ExponentialRandomVariable expRandomVariable;
double interArrivalTime = expRandomVariable.GetValue(meanArrivalRate);
```

5 Other Visualizations

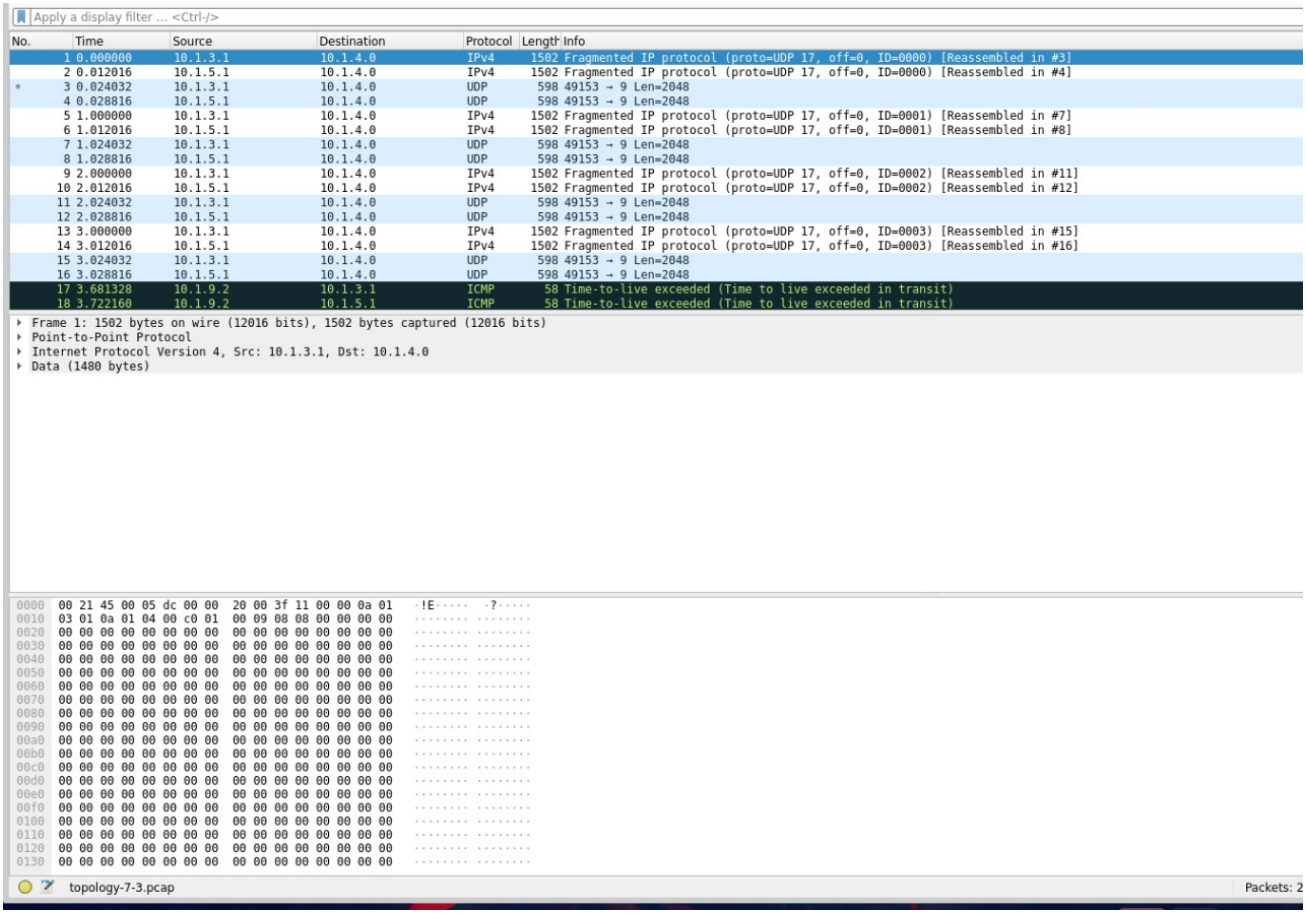
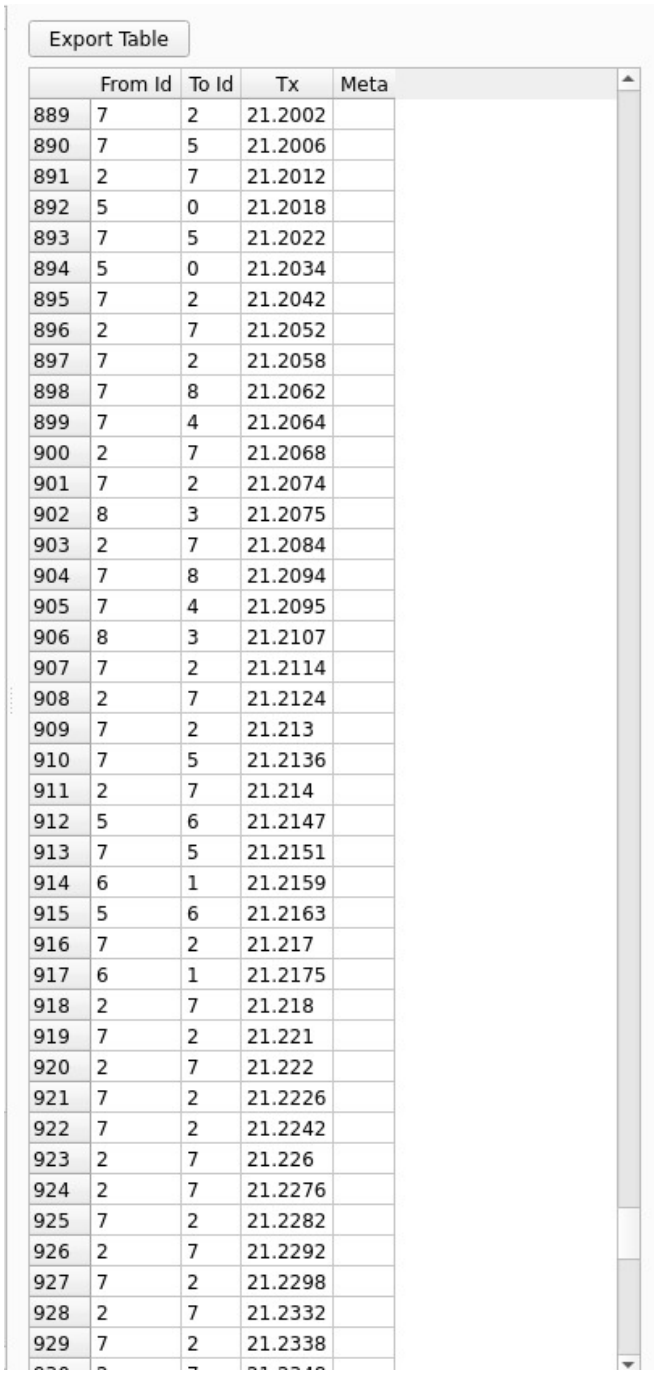


Figure 6: Reading .pcap files in wireshark



	From Id	To Id	Tx	Meta
889	7	2	21.2002	
890	7	5	21.2006	
891	2	7	21.2012	
892	5	0	21.2018	
893	7	5	21.2022	
894	5	0	21.2034	
895	7	2	21.2042	
896	2	7	21.2052	
897	7	2	21.2058	
898	7	8	21.2062	
899	7	4	21.2064	
900	2	7	21.2068	
901	7	2	21.2074	
902	8	3	21.2075	
903	2	7	21.2084	
904	7	8	21.2094	
905	7	4	21.2095	
906	8	3	21.2107	
907	7	2	21.2114	
908	2	7	21.2124	
909	7	2	21.213	
910	7	5	21.2136	
911	2	7	21.214	
912	5	6	21.2147	
913	7	5	21.2151	
914	6	1	21.2159	
915	5	6	21.2163	
916	7	2	21.217	
917	6	1	21.2175	
918	2	7	21.218	
919	7	2	21.221	
920	2	7	21.222	
921	7	2	21.2226	
922	7	2	21.2242	
923	2	7	21.226	
924	2	7	21.2276	
925	7	2	21.2282	
926	2	7	21.2292	
927	7	2	21.2298	
928	2	7	21.2332	
929	7	2	21.2338	

Figure 7: Communication Log table in NetAnim

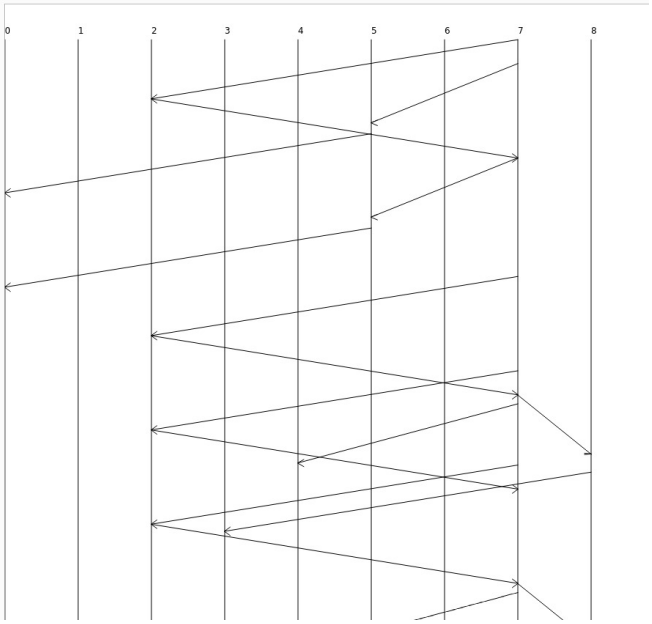


Figure 8: Sequence Diagram in NetAnim