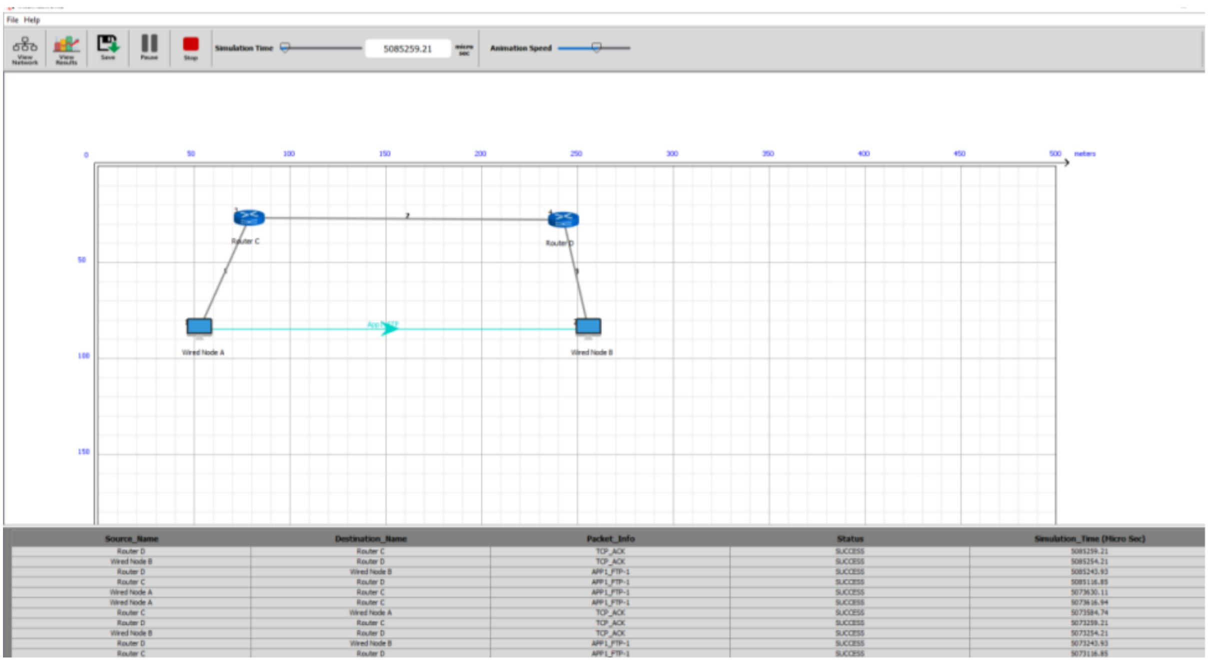
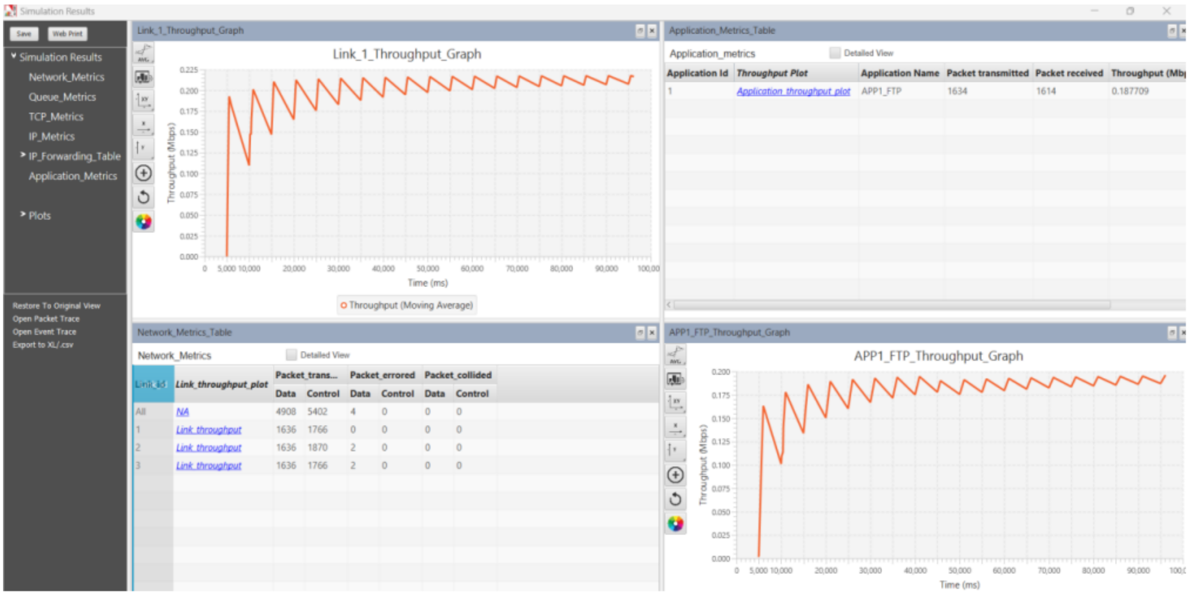
IT – 304 | CN | LAB-4

(Harsh Gajjar – 202201140)

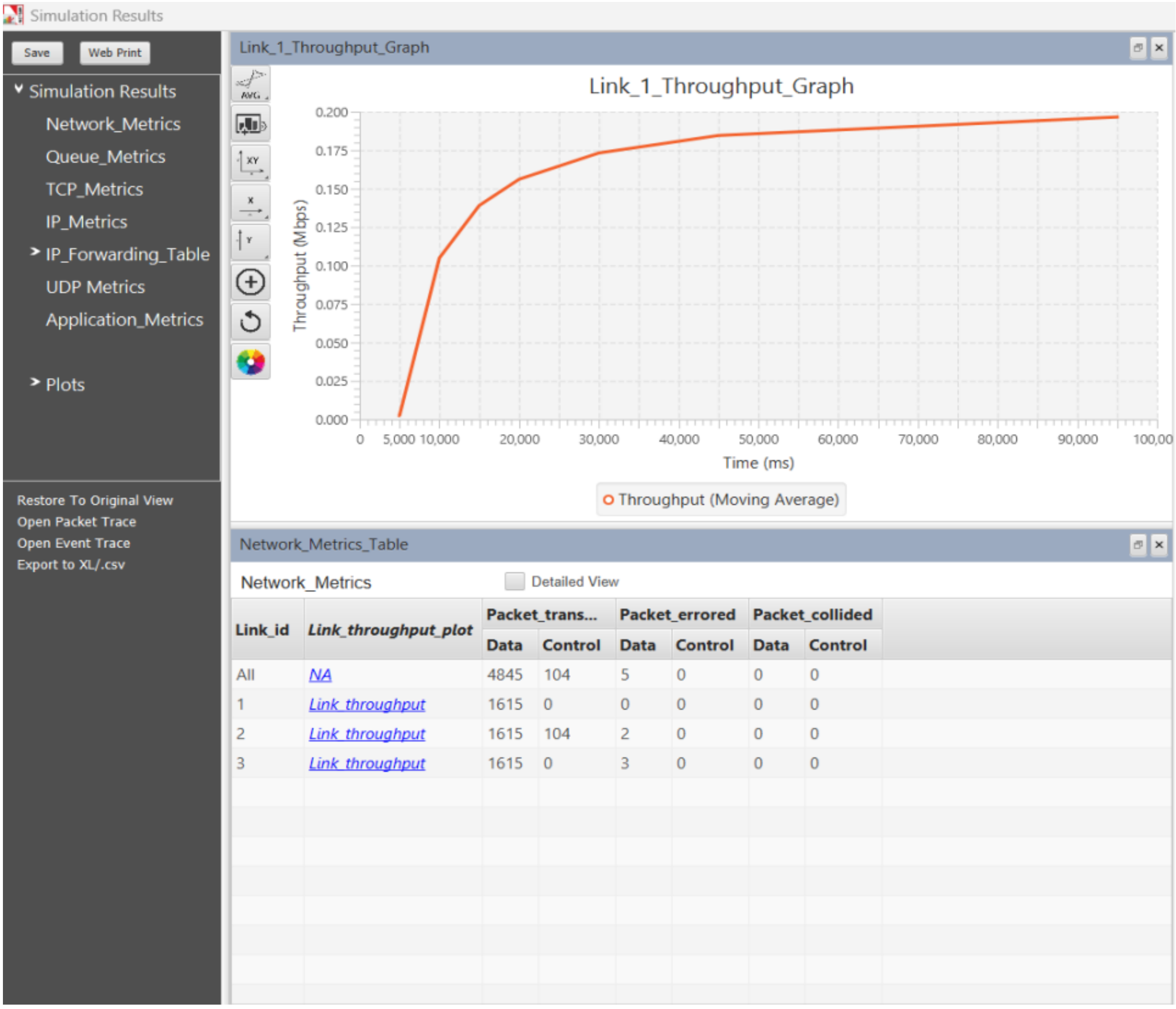
Experiment 2: Understanding Measures of Network Performance: Throughput and Delay

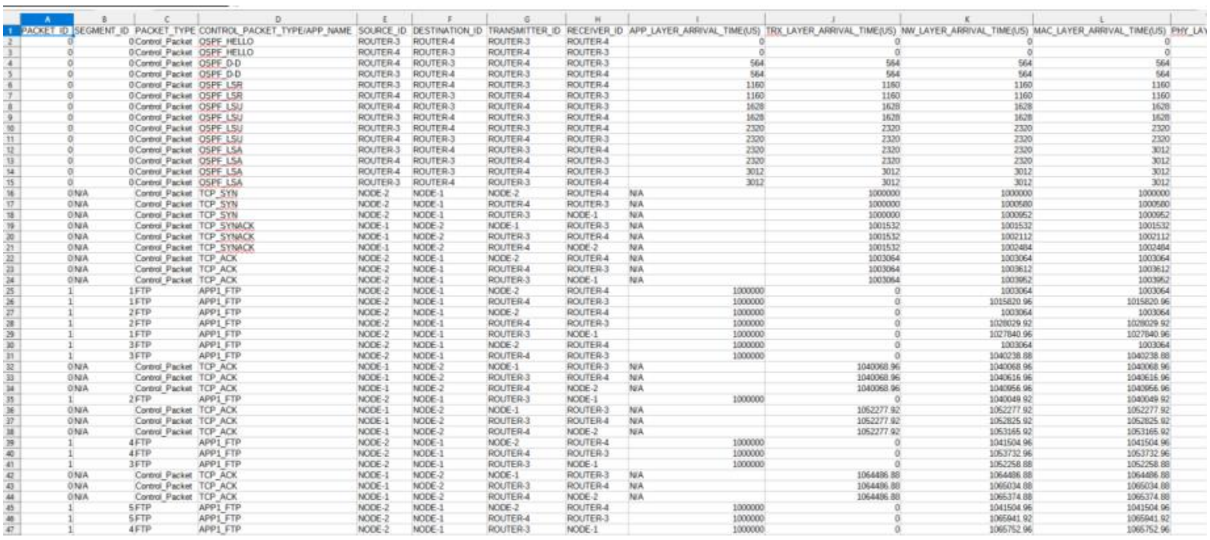


Plot for **TCP:**



Plot for **UDP:**





	A	B	C	D	E	F	G	H	I	J	K	L	
1	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	APP_LAYER_ARRIVAL_TIME(US)	TRX_LAYER_ARRIVAL_TIME(US)	NW_LAYER_ARRIVAL_TIME(US)	MAC_LAYER_ARRIVAL_TIME(US)	PHY_LAY
2	0	0	Control_Packet	OSPF_HELLO	ROUTER-3	ROUTER-4	ROUTER-3	ROUTER-4	0	0	0	0	
3	0	0	Control_Packet	OSPF_HELLO	ROUTER-4	ROUTER-3	ROUTER-4	ROUTER-3	0	0	0	0	
4	0	0	Control_Packet	OSPF_D-D	ROUTER-4	ROUTER-3	ROUTER-4	ROUTER-3	564	564	564	564	
5	0	0	Control_Packet	OSPF_D-D	ROUTER-3	ROUTER-4	ROUTER-3	ROUTER-4	564	564	564	564	
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7	0	0	Control_Packet	OSPF_LSR	ROUTER-4	ROUTER-3	ROUTER-4	ROUTER-3	1160	1160	1160	1160	
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11	0	0	Control_Packet	OSPF_LSU	ROUTER-4	ROUTER-3	ROUTER-4	ROUTER-3	2320	2320	2320	2320	
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13	0	0	Control_Packet	OSPF_LSA	ROUTER-4	ROUTER-3	ROUTER-4	ROUTER-3	2320	2320	2320	3012	
14	0	0	Control_Packet	OSPF_LSA	ROUTER-4	ROUTER-3	ROUTER-4	ROUTER-3	3012	3012	3012	3012	
15	0	0	Control_Packet	OSPF_LSA	ROUTER-3	ROUTER-4	ROUTER-3	ROUTER-4	3012	3012	3012	3012	
16	0	N/A	Control_Packet	TCP_SYN	NODE-2	NODE-1	NODE-2	ROUTER-4	N/A	1000000	1000000	1000000	
17	0	N/A	Control_Packet	TCP_SYN	NODE-2	NODE-1	ROUTER-4	ROUTER-3	N/A	1000000	1000580	1000580	
18	0	N/A	Control_Packet	TCP_SYN	NODE-2	NODE-1	ROUTER-3	NODE-1	N/A	1000000	1000952	1000952	
19	0	N/A	Control_Packet	TCP_SYNACK	NODE-1	NODE-2	NODE-1	ROUTER-3	N/A	1001532	1001532	1001532	
20	0	N/A	Control_Packet	TCP_SYNACK	NODE-1	NODE-2	ROUTER-3	ROUTER-4	N/A	1001532	1002112	1002112	
21	0	N/A	Control_Packet	TCP_SYNACK	NODE-1	NODE-2	ROUTER-4	NODE-2	N/A	1001532	1002484	1002484	
22	0	N/A	Control_Packet	TCP_ACK	NODE-2	NODE-1	NODE-2	ROUTER-4	N/A	1003064	1003064	1003064	
23	0	N/A	Control_Packet	TCP_ACK	NODE-2	NODE-1	ROUTER-4	ROUTER-3	N/A	1003064	1003612	1003612	
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27	1	2	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	ROUTER-4	1000000	0	1003064	1003064	
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29	1	1	FTP	APP1_FTP	NODE-2	NODE-1	ROUTER-3	NODE-1	1000000	0	1027840.96	1027840.96	
30	1	3	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	ROUTER-4	1000000	0	1003064	1003064	
31	1	3	FTP	APP1_FTP	NODE-2	NODE-1	ROUTER-4	ROUTER-3	1000000	0	1040238.88	1040238.88	
32	0	N/A	Control_Packet	TCP_ACK	NODE-1	NODE-2	NODE-1	ROUTER-3	N/A	1040068.96	1040068.96	1040068.96	
33	0	N/A	Control_Packet	TCP_ACK	NODE-1	NODE-2	ROUTER-3	ROUTER-4	N/A	1040068.96	1040616.96	1040616.96	
34	0	N/A	Control_Packet	TCP_ACK	NODE-1	NODE-2	ROUTER-4	NODE-2	N/A	1040068.96	1040956.96	1040956.96	
35	1	2	FTP	APP1_FTP	NODE-2	NODE-1	ROUTER-3	NODE-1	1000000	0	1040049.92	1040049.92	
36	0	N/A	Control_Packet	TCP_ACK	NODE-1	NODE-2	NODE-1	ROUTER-3	N/A	1052277.92	1052277.92	1052277.92	
37	0	N/A	Control_Packet	TCP_ACK	NODE-1	NODE-2	ROUTER-3	ROUTER-4	N/A	1052277.92	1052825.92	1052825.92	
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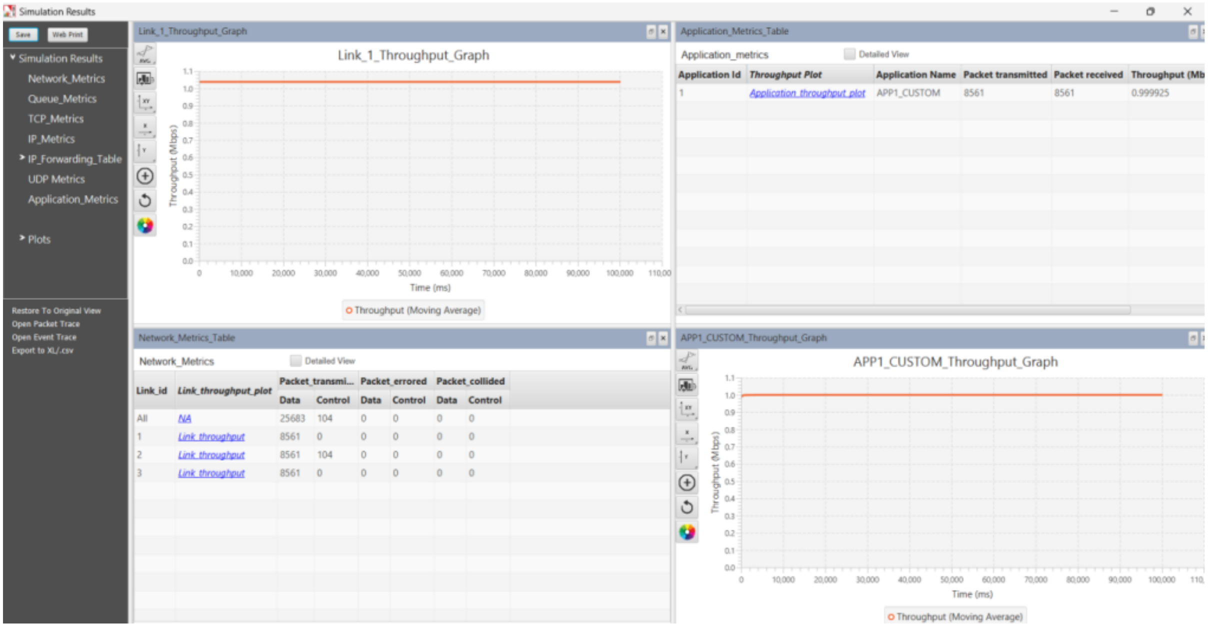
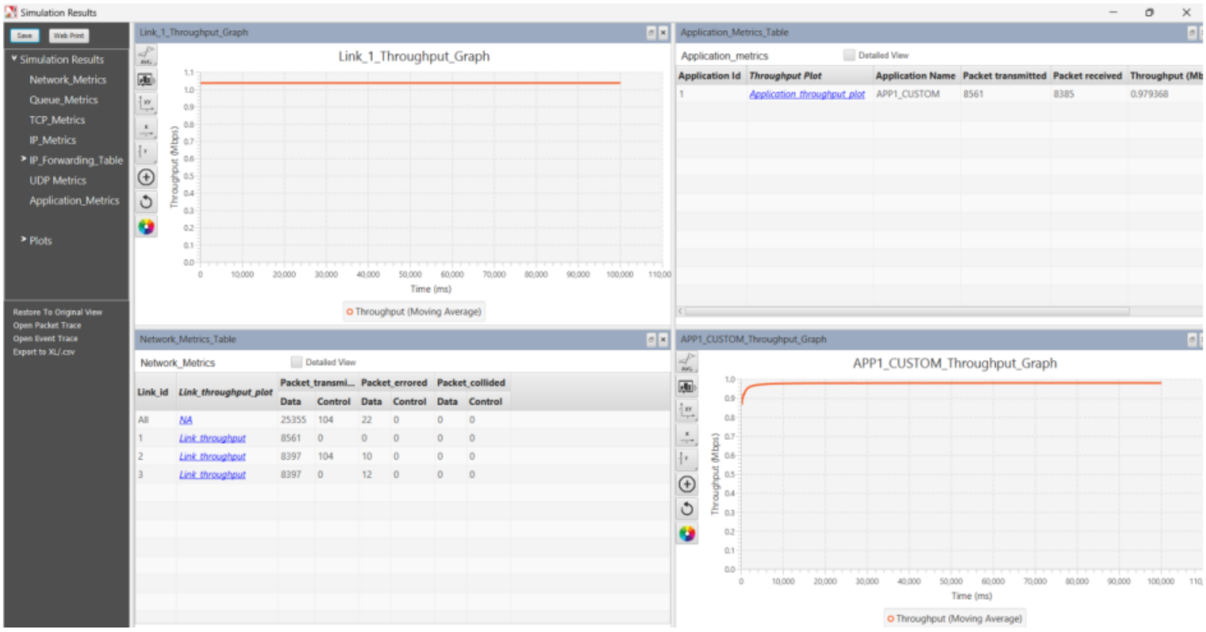
43	0	N/A	Control_Packet	TCP_ACK	NODE-1	NODE-2	ROUTER-3	ROUTER-4	N/A	1064486.88	1065034.88	1065034.88	
44	0	N/A	Control_Packet	TCP_ACK	NODE-1	NODE-2	ROUTER-4	NODE-2	N/A	1064486.88	1065374.88	1065374.88	
45	1	5	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	ROUTER-4	1000000	0	1041504.96	1041504.96	
46	1	5	FTP	APP1_FTP	NODE-2	NODE-1	ROUTER-4	ROUTER-3	1000000	0	1065941.92	1065941.92	
47	1	4	FTP	APP1_FTP	NODE-2	NODE-1	ROUTER-3	NODE-1	1000000	0	1065752.96	1065752.96	

Experiment 3: Throughput and Bottleneck Server Analysis





Experiment 4: Delay and Little's Law

PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	APP_LAYER_ARRIVAL_TIME(US)	TRX_LAYER_ARRIVAL_TIME(US)	NW_LAYER_ARRIVAL_TIME(US)	MAC_LAYER_ARRIVAL_TIME(US)	PHY_LA
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1	4	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	SWITCH-3	5000000	5000000	5000000	5000000	
1	4	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
1	5	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	SWITCH-3	5000000	5000000	5000000	5000000	
1	5	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
1	6	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	SWITCH-3	5000000	5000000	5000000	5000000	
1	6	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
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1	7	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
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1	13	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	SWITCH-3	5000000	5000000	5000000	5000000	
1	13	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
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1	14	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
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1	18	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	SWITCH-3	5000000	5000000	5000000	5000000	
1	18	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
1	19	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	SWITCH-3	5000000	5000000	5000000	5000000	
1	19	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
1	20	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	SWITCH-3	5000000	5000000	5000000	5000000	
1	20	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
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1	21	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
1	22	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	SWITCH-3	5000000	5000000	5000000	5000000	
1	22	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	
1	23	FTP	APP1_FTP	NODE-2	NODE-1	NODE-2	SWITCH-3	5000000	5000000	5000000	5000000	
1	23	FTP	APP1_FTP	NODE-2	NODE-1	SWITCH-3	NODE-1	5000000	5000000	5000000	5000000	

Exercise-1: Bottleneck Analysis with Varying Bandwidth on Server Links

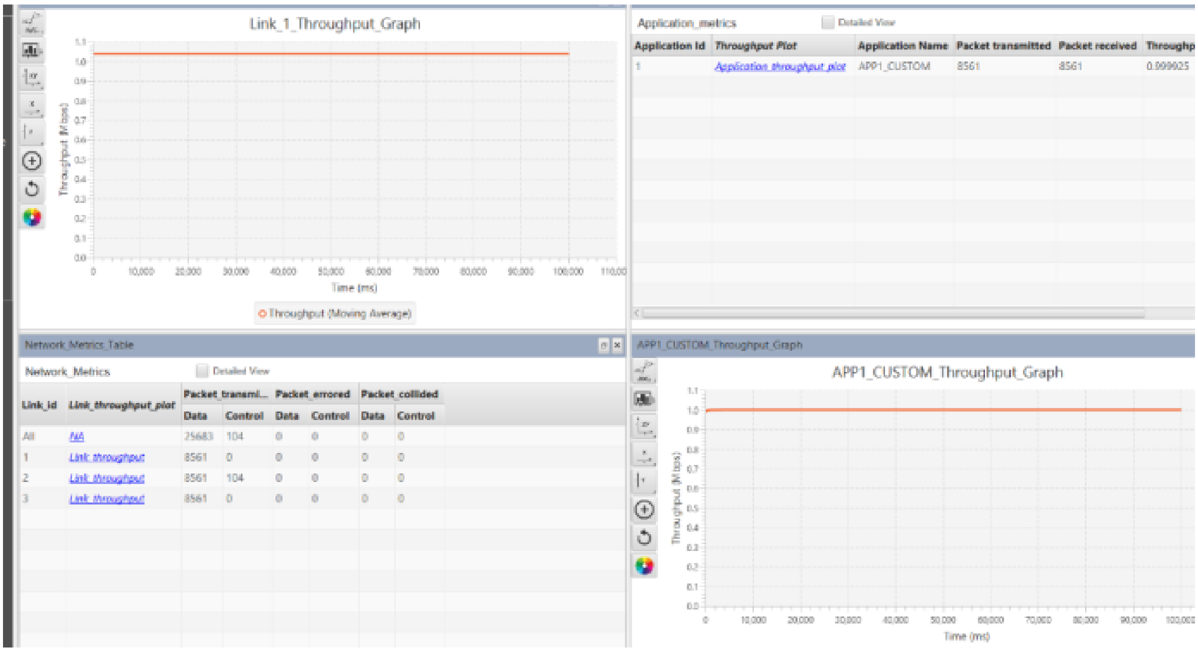
→ Set configuration used in experiment 3 and reduce bandwidth of links one by one.

→ Bandwidth:

- Link 1 = 10 Mbps
- Link 2 = Link 3 = Link 4 = Link 5 =10 Mbps

→ Propagation delay:

- Link 3 = 10 μs
- Link 2 = Link 1 = Link 4 = Link 5 = 0 μs

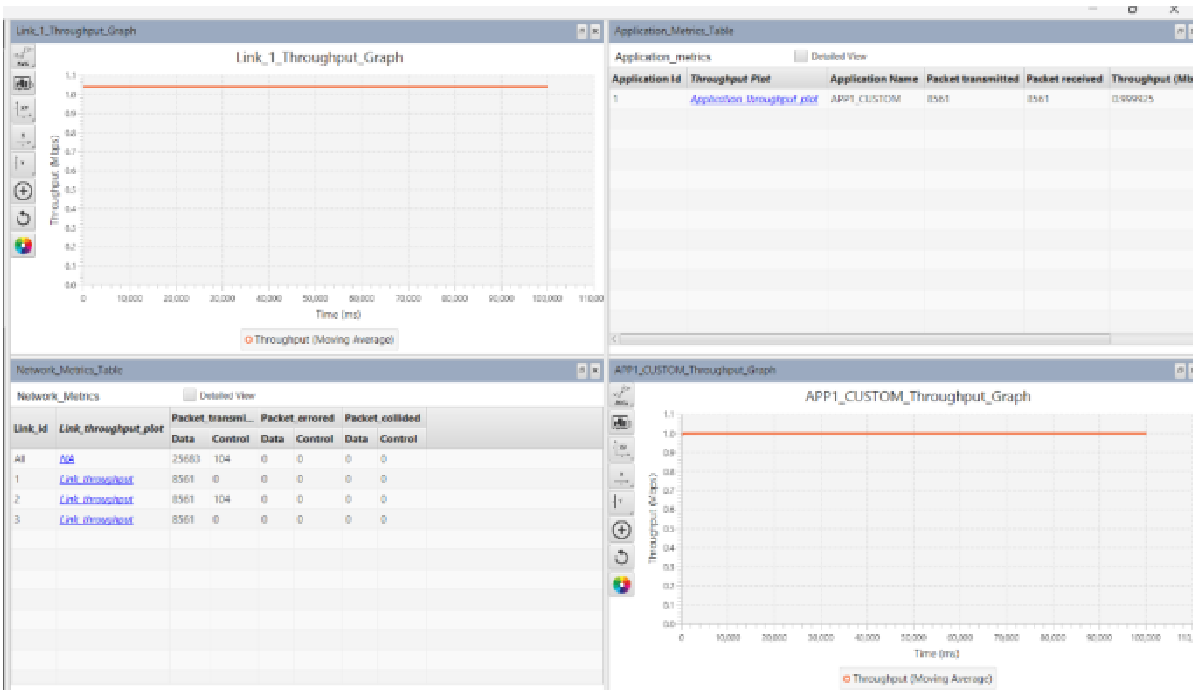


→ Bandwidth:

- Link1 = 8 Mbps
- Link2 = Link3 = Link4 = Link5 = 10 Mbps

→ Propagation delay:

- Link3 = 10 µs
- Link1 = Link2 = Link4 = Link5 = 0 µs



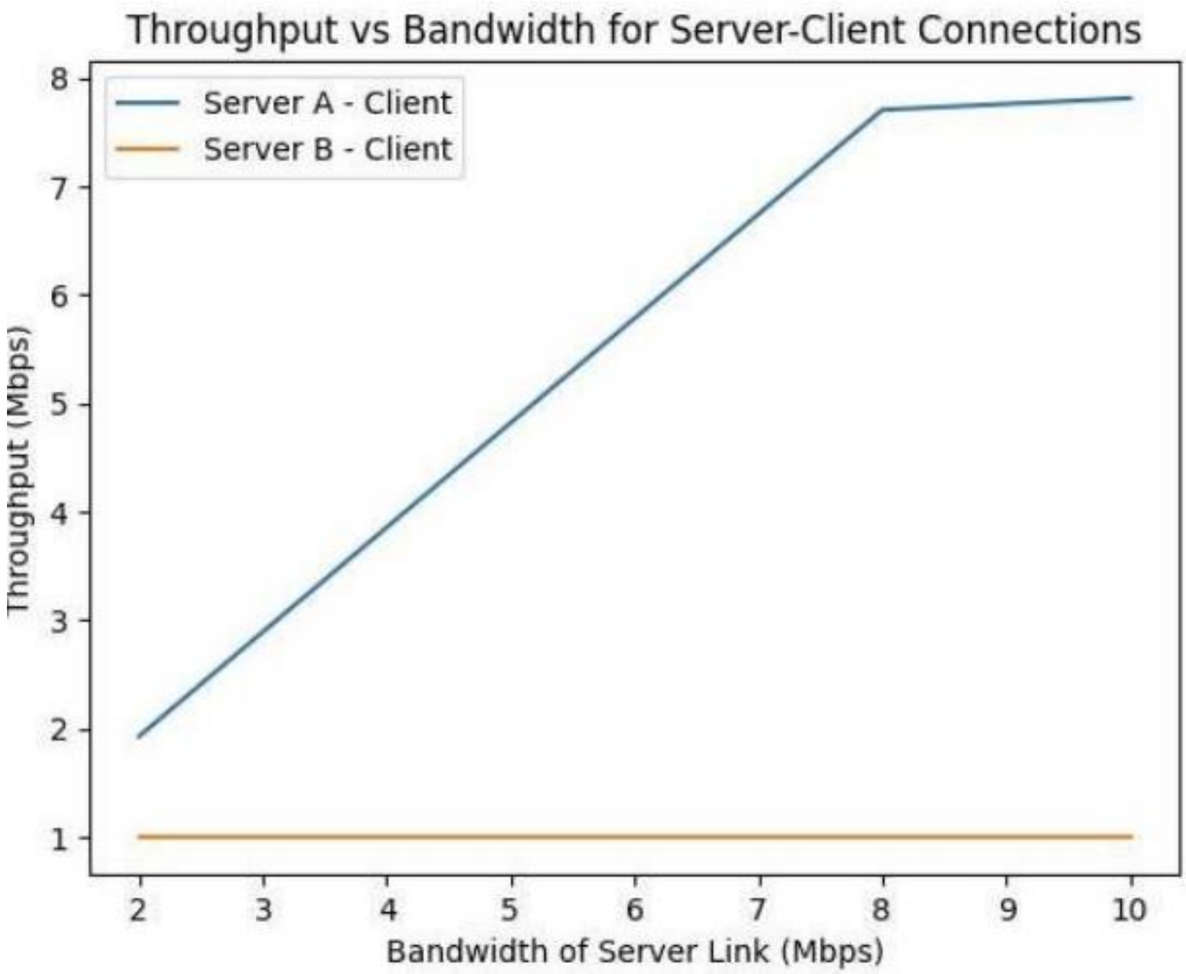
→ Bandwidth: Link1 = 2 Mbps
  - Link2 = Link3 = Link4 = Link5 = 10 Mbps

→ Propagation delay:
  - Link3 = 10 μs
  - Link1 = Link2 = Link4 = Link5 = 0 μs

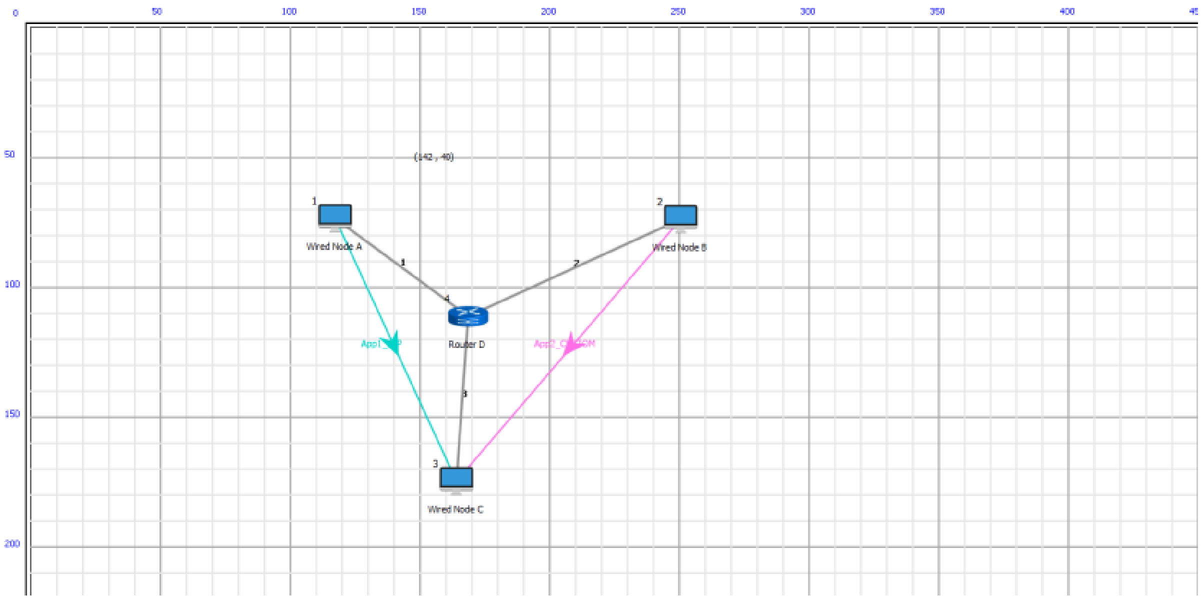
→ Bandwidth:
  - Link1 = 6 Mbps
  - Link2 = Link3 = Link4 = Link5 = 10 Mbps

→ Propagation delay:
  - Link3 = 10 μs
  - Link1 = Link2 = Link4 = Link5 = 0 μs

→ Graphs:


Throughput vs Bandwidth for Server-Client Connections
Server A - Client
Server B - Client
Throughput (Mbps)
Bandwidth of Server Link (Mbps)
1
2
3
4
5
6
7
8
2
3
4
5
6
7
8
9
10

Exercise 2: Exploring the Relationship Between Traffic Intensity and Delay Using Little's Law



→ Excel data:

Network Metrics

Link_id	Link_throughput_plot	Packet_transmitted Data	Packet_transmitted Control	Packet_errored Data	Packet_errored Control	Packet_collided Data	Packet_collided Control	Bytes_transmitted(bytes)	Payload_transmitted(bytes)	Overhead_transmitted(bytes)
All	NA	25683	104	0	0	0	0	38668652	37502276	1166376
1	NA	8561	0	0	0	0	0	12961354	12499060	462294
2	NA	8561	104	0	0	0	0	12745944	12504156	241788
3	NA	8561	0	0	0	0	0	12961354	12499060	462294

Queue_Metrics

Device_id	Port_id	Queued_packet	Dequeued_packet	Dropped_packet
3	1	8561	8561	0
3	2	52	52	0
4	1	8613	8613	0
4	2	0	0	0

TCP_Metrics

Source	Destination	Local Address	Remote Address	Syn Sent	Syn-Ack Sent	Segment Sent	Segment Received	Segment Retransmitted	Ack Sent	Ack Received	Duplicate segment received	Out of order segment
ROUTER C	ANY_DEVICE	11.1.1.1:0	0.0.0.0:0	0	0	0	0	0	0	0	0	
ROUTER D	ANY_DEVICE	11.3.1.2:0	0.0.0.0:0	0	0	0	0	0	0	0	0	

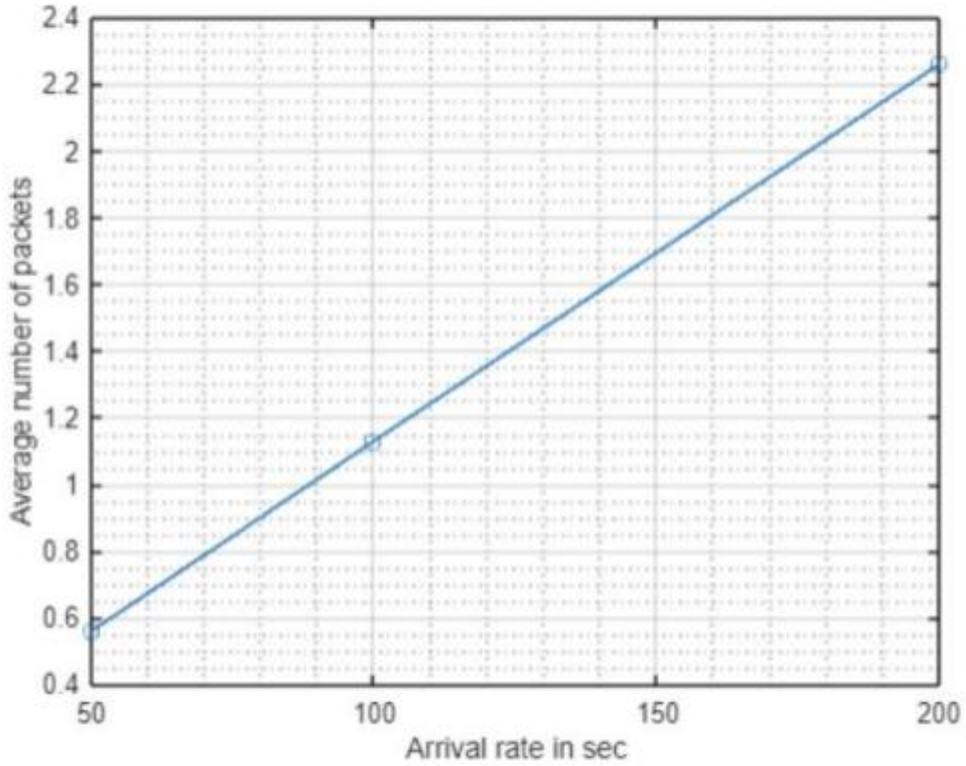
IP_Metrics

Device Id	Packet sent	Packet forwarded	Packet received	Packet discarded	TTL expired	Firewall blocked
1	0	0	8561	0	0	0
2	8561	0	0	0	0	0
3	8613	8561	52	0	0	0
4	8613	8561	52	0	0	0

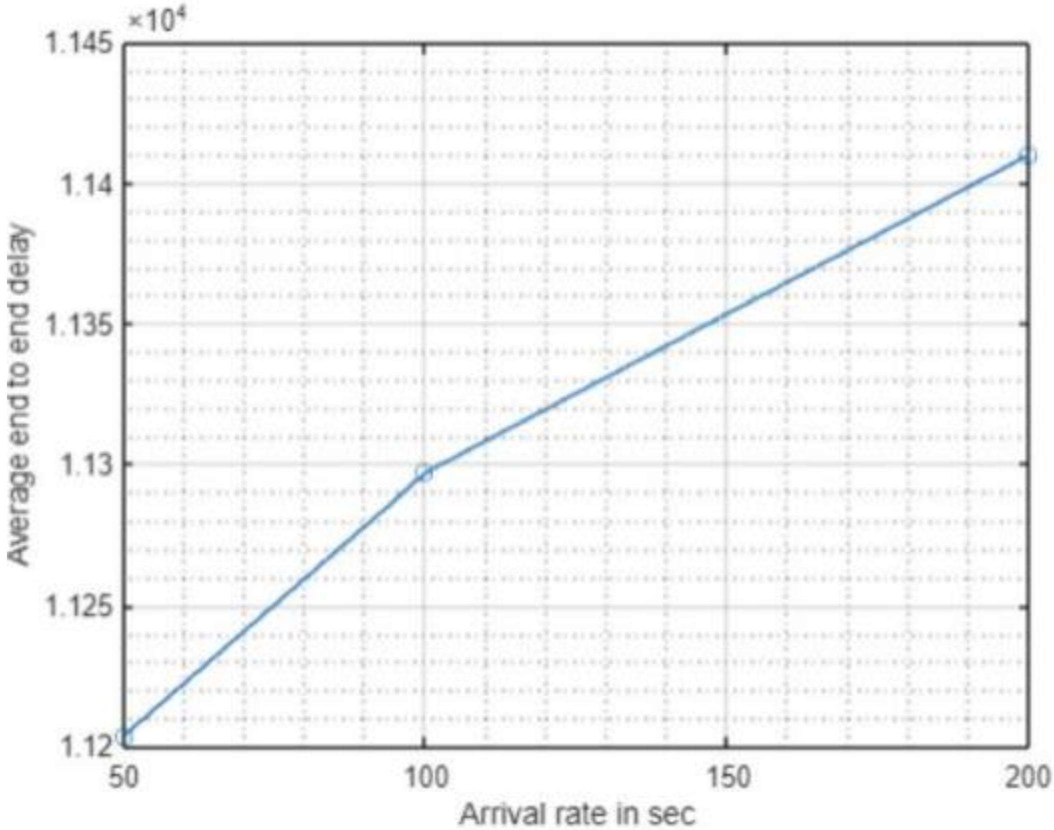
WIRED NODE A

Network Destination	Netmask/Prefix len	Gateway	Interface	Metrics	Type
11.1.0.0	255.255.0.0	on-link	11.1.1.2	300	LOCAL

→ Graph for packet arrival rate and average number of packets:



→ Graph for packet arrival rate and average number of packets:



→ What we may infer: Littles Law is confirmed by the fact that both delay and the average number of packets in the system grow proportionately as packet arrival rate (traffic) rises. This demonstrates that arrival rate, packet count, and latency have the predicted connection.

Sample Questions

Q1. How does varying traffic load affect throughput and delay? What is the expected relationship between these metrics?

→ Throughput increases in direct proportion to the increase in traffic load until the network reaches its capacity. After this, when the system gets overwhelmed, throughput stabilises or even drops. Under light traffic conditions, delay stays modest but rises sharply when the load gets closer to capacity. Due to congestion and queuing, delays increase exponentially once the network reaches its capacity. Throughput and latency are predicted to rise in situations with moderate traffic. On the other hand, throughput plateaus and delay increases sharply when load surpasses capacity.

Q2. How can reducing server link bandwidth create bottlenecks, and how does this impact network performance?

→ Packets queue up at the server as a result of the data transmission rate being restricted by decreasing server link bandwidth. The server-client connection's performance is decreased and delays are increased due to the expanding queue. The server and client's communication is slowed down by this bottleneck. In addition to packet loss, retransmissions, and increased delay, congestion can lower network efficiency. Performance may be further deteriorated if the server link is essential to operations because it may become a bottleneck that spreads to other areas of the network.

Q3. What effect does decreasing the bandwidth of one server link have on the throughput of other connections in the network?

→ When the bandwidth of a server link is reduced, it results in a bottleneck that slows down data flow, generating congestion and delays that impact the network as a whole, particularly if the server link is the hub of several connections. As a result, other connections that are sharing network resources may experience a decline in performance.

Q4. How is Little's Law ($L = \lambda W$) used in network performance analysis? Provide an example calculation for delay based on packet arrival rates.

→ The average number of packets in a system (L), the packet arrival rate (λ), and the average duration (W) a packet spends in the system (including delay) are related by Little's Law ($L = \lambda W$). It aids in performance estimation in various traffic scenarios.For instance: Assume the average number of packets in the system (L) is 50 and the arrival rate (λ) is 100 packets per second. We may find the delay (W) by using the formula $L=\lambda W$: $W=L/\lambda$, $W=50/100=0.5$ seconds per packet.

Q5. How does network delay change with increasing packet arrival rates? How can you verify this relationship with simulation data?

→ There are more delays as a result of longer lines and processing times when arrival rates rise. Run simulations at several rates, gather delay data, and plot delay vs. rate to confirm this. The data ought to indicate a slow increase in delays at first, followed by a sudden spike when the system gets closer to capacity.

Q6. Compare the impact of increasing traffic load versus increasing server link bandwidth on network performance. What key factors should be considered?

→ Evaluating the effects of increasing bandwidth versus load
As capacity is achieved, increasing load usually results in increased delays, congestion, and decreased throughput. Increasing bandwidth, on the other hand, decreases latency and increases throughput by managing traffic more effectively.Important elements:
1. Network Capacity: More bandwidth reduces congestion, but higher loads can overwhelm capacity.
2. Delay: Longer delays are caused by more traffic, but shorter wait times are caused by increased bandwidth.
3. Throughput: If capacity is exceeded, load lowers throughput; additional bandwidth raises it.
4. Bottlenecks: Increased bandwidth can aid in removing bottlenecks caused by heavy traffic.

Q7. What trends are expected in graphs of throughput vs. traffic load and delay vs. packet arrival rate? How do these graphs aid in understanding network performance?

→ Throughput vs. Load: As capacity is reached, throughput first increases with load before levelling off or declining to indicate maximum efficiency. Arrival Rate vs. Delay: Congestion is indicated by a dramatic increase in delay as the rate rises, which starts out low. These graphs aid in understanding capacity restrictions, efficiency, and the effects of congestion on performance.