

ECE [REDACTED] - LAB 2 A

Determining Quality of Service

Due Date for Lab Report

Due Session 29 (April 28), Outreach (Extension on permission)

Terms

- QoS: Quality of Service – the quality of service the network provides to its end users.
- SEL-2730M: Managed Ethernet Switch
- RSTP: Rapid Spanning Tree Protocol
- Spanning tree convergence time: The time it takes the RSTP algorithm & hardware to re-establish a new spanning tree topology after a network link failure.
- IPG: Interpacket gap – the time between when datagram[n-1] finished transmission & datagram[n] starts transmission.
- 100BASE-TX: 'Fast Ethernet' capable of data transmission rates up to 100Mbps.
- 1000BASE-TX: 'Gigabit Ethernet' capable of data transmission rates up to 1000Mbps.
- Bps: Bytes per second. (1 Byte = 8 bits)
- Bps: bits per second.

Objectives

In this lab, students will use Rapid Spanning Tree Protocol (RSTP), offered as a feature of the SEL-2730M, to develop loop-free networks with redundant links. A method for observing the 'spanning tree convergence time' is described.

Students will also be introduced to metrics commonly used to evaluate the performance of copper Ethernet communication networks. Students will gain an understanding of the minimum allowable performance of substation communication networks. To evaluate our system's 'Quality of Service' (QoS), 5 performance metrics are focused on: lost packets, throughput, latency, jitter, and spanning tree convergence time.

Using the methods described in lab 1 students will observe the Quality of Service (QoS) offered by the loop, and ladder network topologies.

Lab Procedure

Log into System Computer

Establish Remote Desktop Connection with Raspberry PI 2 (A & B)

- 1) Navigate to the following file path:
 - a) Remote Desktop Connection with Raspberry PIs
- 2) Double-check all Raspberry PI are powered on (or we won't be able to establish a connection). The raspberry PIs use a USB connection for power, toggle that switch ON.
- 3) Establish remote desktop connection with RPI (A)
 - a) Computer: (Raspberry PI (A) static IP address)
 Credentials (should be saved)
 User:
 Pass:
- 4) Establish remote desktop connection with RPI (B)
 - a) Computer: (Raspberry PI (B) static IP address)
 Credentials (should be saved)
 User:
 Pass:

Connect a 'Loop' Network Topology

Using figure 1 below, connect the SEL-2730M Ethernet switches together to form a looped topology. We will use Ports 1-8 to form the connections between Ethernet switches since these ports support 1Gbps links. This forms an information 'highway' and allows information to be shared quickly through the loop topology. Ports 9-24 only support 100 Mbps links & should be used for connecting to IEDs using 100BASE-TX Ethernet technology (100 Mbps max).

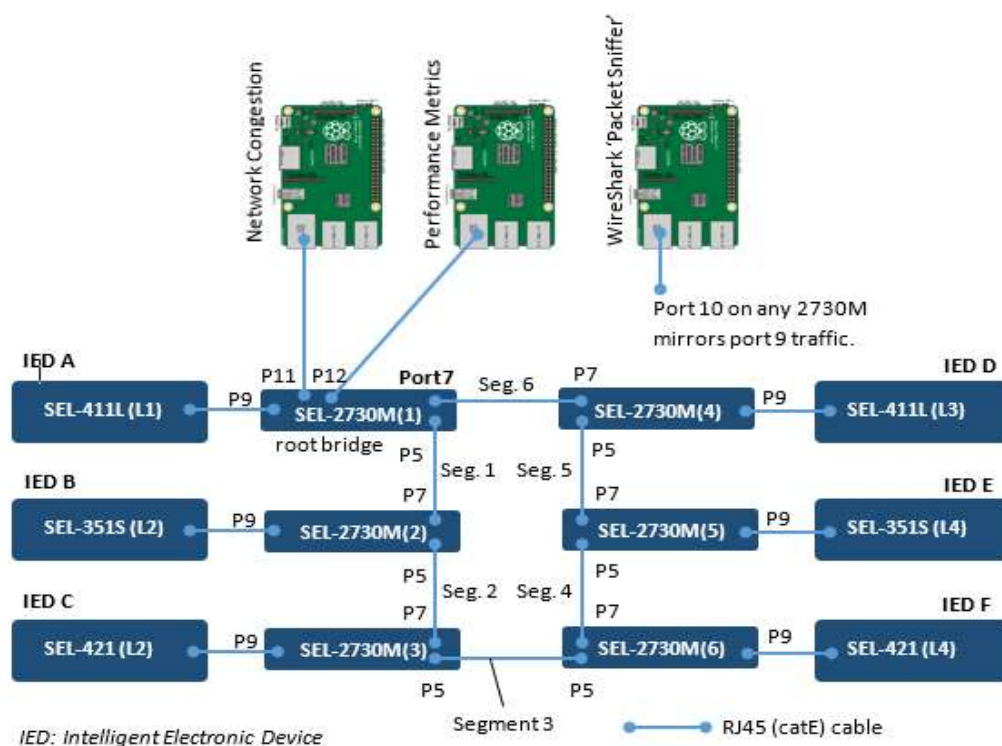


Figure 1: Physical Connection of Looped Topology

Observe Impact of creating Loops in a network without RSTP enabled

Try to interact with the raspberry Pis through the remote desktop connection. If the network hasn't crashed yet, start measuring QOS metrics by running a flood ping test for 20s.

Since switches 'repeat' datagrams through the network, loops in a communication network will cause datagrams to endlessly circulate and multiply in number eventually causing the network to completely fail.

Spanning tree protocol 'breaks' these loops but allows them to be re-enabled if there is a topology change in the future.

Until we enable RSTP, we have to remove a network segment for the network to function.

- Unplug network segment #6 to restore network functionality.

Enable the RSTP feature in each SEL-2730M

For each Ethernet switch, repeat the following procedure to enable Rapid Spanning Tree Protocol.

- 1) Using a RJ45 ([cat5](#)) cable, connect the system computer (SEL-3355) Ethernet port (ETH 2) to the front-panel Ethernet port (ETH F) on the SEL-2730M(1).
- 2) Using a web-browser, navigate to <https://> to access the setting's page.
- 3) On the left menu navigate to 'Global Settings'
- 4) Enable RSTP.
- 5) Navigate to 'RSTP Settings' >> edit settings.
- 6) Set the Bridge priority to select the 'root bridge.' Set the SEL-2730M(1) bridge priority to the lowest available priority number & the rest of the SEL-2730Ms to their default bridge priority.

Find resulting 'Spanning Tree Topology'

Once the Rapid Spanning Tree Protocol is enabled for all Ethernet switches we need to reconnect network segment #6. Use a flood ping test to observe that the network is functioning properly now.

The RSTP algorithm has disabled a link in one of the Ethernet switches to establish a 'loop-free' topology.

We can see which links are active by looking at the 'RSTP Settings' link on the SEL-2730M web-based GUI.

For each switch, record the port 5 & 7 statuses by repeating the following process:

- 1) Login to SEL-2730M web-based settings page.
- 2) Navigate to the 'RSTP Settings' page.
- 3) Record the 'port statuses for ports 5 & 7.

SEL-2730M(X)	Port 5 Status	Port 7 Status
1		
2		
3		
4		
5		
6		

Based on the recorded port status, draw the 'spanning tree diagram' for the loop topology

Measuring Spanning Tree Convergence Times

The spanning tree convergence time is often the source of the largest latencies for a substation communication networks. When a link or switch fails, a topology-change-notice BPDU is propagated through the network. Each switch (bridge) is alerted of the topology change and immediately re-runs the Spanning Tree Protocol algorithm to determine a new spanning tree. The time it takes for this process to fully occur, and the system to restore to full operation is considered the spanning tree convergence time. Any users (relays) below the link failure in the branch will experience a communications outage during this time.

To measure the worst-case spanning tree convergence time during a link failure, we can follow the following steps:

- Using PI (A) start 6 instances of the flood ping test from Root Bridge to each IED a wait interval 'i' of 1mS.
 - Sudo ping -f -i 0.001 (-f: flood ping, we need 'Sudo' to choose a ping wait interval lower than 1s.)
- With the flood-ping tests running, walk around to the back of the relay rack and unplug a network segment (CAT5e cable). Keep it unplugged.
- Returning to the system computer, stop the test ('Ctrl' + 'c'), and observe the number of lost ping echo request packets based on the decimals printed to each terminal window.
- We want to record the worst-case spanning tree convergence time.
To calculate the spanning tree convergence time, first calculate the number of packets lost with:

$$LostPackets = PacketsTX - PacketsRX$$

- To calculate the spanning tree convergence time (t_{STC}) we multiply the number of packets lost by the average inter-packet-gap (IPG).

$$t_{STC} = LostPackets * ipg$$

6. Plug the removed network segment back in to restore the original spanning tree topology.

Measure and Record QOS metrics for the Loop Topology

Refer to lab 1 for detailed steps on (1) generating network congestion using ostinato on PI (B), (2) measuring QOS metrics using the flood ping test from PI (A), and (3) observing port throughput using Ostinato on PI (C).

- 1) Using PI (B) inject 20 Mbps of simulated network congestion at the root bridge.
- 2) Using PI (A) start 6 instances of the flood ping test from Root Bridge to each IED.
- 3) After 20 seconds, stop the test ('Ctrl' + 'c') and record lost packets, max and avg latency, and jitter (mdev of latency).
- 4) Measure IED throughput: Restart the network simulated congestion from PI (B). Using PI (C) connect PI (C)'s CAT5e cable to port 10 on the SEL-2730M(1) managed switch. Use Ostinato's 'statistics' window to monitor throughput (Bytes Received (Bps)) for IED A. Repeat step 4 for each Ethernet switch to find the throughput for each IED.
- 5) Measure 'spanning tree convergence time':
 - Restart 6 instances of the flood ping test from Root Bridge to each IED.
 - Disconnect any one network segment. Record the disconnected segment in table 2.
 - Record the number of lost packets lost during spanning tree convergence (table 2).
 - Record inter packet gap (table 2).
 - Multiply the number of packets lost by the inter packet gap (IPG) time to measure spanning tree convergence time. Record the convergence time (table 2)
- 6) Stage 2: Repeat steps 1-5 with a simulated network congestion of 40 Mbps.
- 7) Stage 3: Repeat steps 1-5 with a simulated network congestion of 60 Mbps.

Table 1: Stage 1 Quality of Service Metrics (20Mbps)

Stage 1 QoS	root -> IED A	root -> IED B	root -> IED C	root -> IED C	root -> IED D	root -> IED E
Throughput [Bps]						
Max Latency [mS]						
Avg Latency [mS]						
Jitter [mS]						

Table 2: Spanning Tree Convergence QoS Metrics

Spanning Tree Convergence QoS	Disconnected Segment	Lost Packets (worst case)	IPG [mS]	Convergence Time [mS]
Stage 1				
Stage 2				
Stage 3				

Table 3: Stage 2 Quality of Service Metrics (40Mbps)

Stage 2 QoS	root -> IED A	root -> IED B	root -> IED C	root -> IED C	root -> IED D	root -> IED E
Throughput [Bps]						
Max Latency [mS]						
Avg Latency [mS]						
Jitter [mS]						

Table 4: Stage 3 Quality of Service Metrics (60Mbps)

Stage 3 QoS	root -> IED A	root -> IED B	root -> IED C	root -> IED C	root -> IED D	root -> IED E
Throughput [Bps]						
Max Latency [mS]						
Avg Latency [mS]						
Jitter [mS]						

- i) Describe what happens if RSTP is not enabled in a communication network and a loop topology is connected?
- ii) Describe how BPDU's are used in accordance with rapid spanning tree protocol?
- iii) Define "Spanning tree convergence time" and describe how it is calculated?