University of Pisa

Department of Computer Science

Master's Degree in Computer Science and Networking

Network Traffic Simulation and Queue Length Analysis Using Mininet and Scapy

Teletraffic Models and Measurements

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Introduction

Project Objective:

- Simulate network traffic between hosts.
- Measure queue lengths and compare with theoretical model (MG1).

Key Tools

- **Mininet:** Network emulator.
- **Scapy:** Network traffic generator.
- **TCLink:** For bandwidth limitation.
- **Python**: For Programing

Main Focus

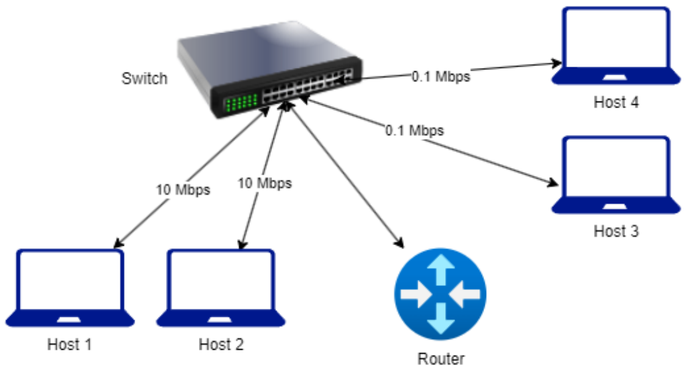
Analyze the effects of bandwidth limitations on queue buildup and traffic intensity.

Network Topology

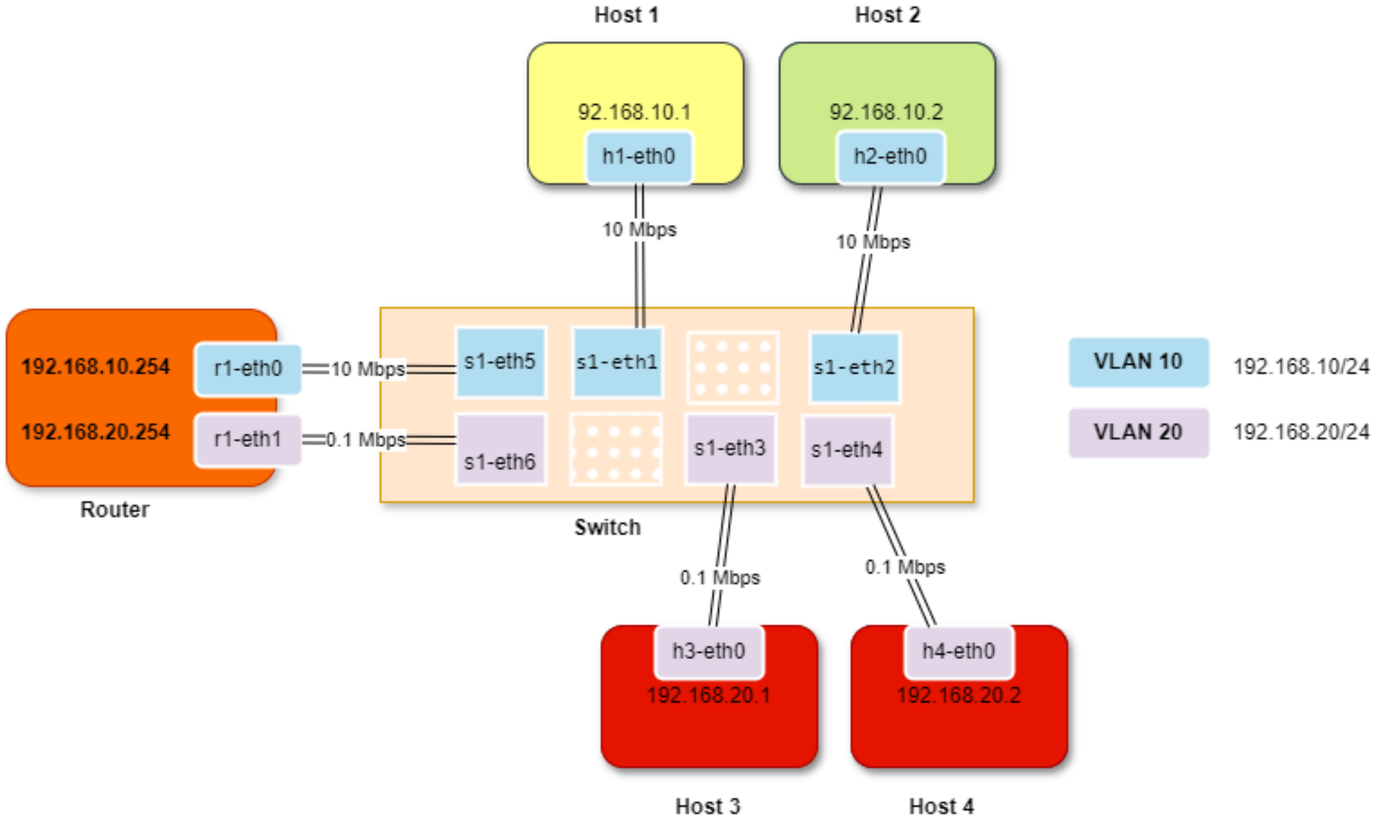
Key Components:

- Hosts: 4 hosts in 2 VLANs (VLAN 10 & VLAN 20).
- Router: Acts as the gateway between VLANs.
- Switch: Configured with VLAN tags to segregate traffic.
- Bandwidth:
  Hosts 1 & 2: 10 Mbps bandwidth.
  Hosts 3 & 4: 0.1 Mbps bandwidth.

Network Topology



Detailed Network Topology



Mininet Implementation

```
alessio@labns:~/Downloads/project/Project Hassan$ sudo python3 vlans.py
*** Creating network
*** Adding controller
*** Adding hosts:
h1 h2 h3 h4 r1
*** Adding switches:
s1
*** Adding links:
(10.00Mbit) (10.00Mbit) (h1, s1) (10.00Mbit) (10.00Mbit) (h2, s1) (0.10Mbit) (0.10Mbit) (h3, s1) (0.10Mbit) (0.10Mbit) (h4, s1) (r1, s1) (r1, s1)
*** Configuring hosts
h1 h2 h3 h4 r1
*** Starting controller
c0
*** Starting 1 switches
s1 ...(10.00Mbit) (10.00Mbit) (0.10Mbit) (0.10Mbit)
Enabling IP forwarding on the router (r1)...
Configuring routes on hosts...
Ping Test: h1 to h3 (VLAN 10 -> VLAN 20)
h1 -> h3
h3 -> h1
*** Results: 0% dropped (2/2 received)
Ping Test: h2 to h4 (VLAN 10 -> VLAN 20)
h2 -> h4
h4 -> h2
*** Results: 0% dropped (2/2 received)
Ping Test: h1 to h2 (same VLAN 10)
h1 -> h2
h2 -> h1
*** Results: 0% dropped (2/2 received)
Ping Test: h3 to h4 (same VLAN 20)
h3 -> h4
h4 -> h3
*** Results: 0% dropped (2/2 received)
*** Starting CLI:
mininet>
```

Traffic Generation with Scapy

Overview

- Traffic Pattern: Exponential inter-arrival times, representing a Poisson process.
- Packet Size: 1460 bytes.
- Traffic Rate: Variable to simulate different network loads.

Significance

This traffic pattern simulates random, real-world conditions, often observed in networking environments.

```python
def generate_packets_fixed_length(src_ip, dst_ip, iface, link_bw, lambda_arrival, packet_length, max_packets=50, backlog_threshold=50000):
    service_rate = (link_bw * 10**6) / (packet_length * 8)  # Service rate in packets/sec
    theoretical_queue_length_initial = calculate_theoretical_queue_length(lambda_arrival, service_rate)

    # Debugging output
    print(f"Service Rate: {service_rate:.2f} packets/sec")
    print(f"Theoretical Queue Length (Initial): {theoretical_queue_length_initial:.4f} packets")

    try:
        while generated_packets < max_packets:
            inter_arrival_time = random.expovariate(lambda_arrival)
            time.sleep(inter_arrival_time)  # Simulating packet arrival

            # Create a fixed-size payload
            packet_data = bytearray(random.getrandbits(8) for _ in range(packet_length))

            # Create the packet (Ethernet + IP + Raw payload)
            packet = Ether() / IP(src=src_ip, dst=dst_ip) / Raw(load=packet_data)

            # Track when the packet is sent (service starts)
            send_start_time = time.time()

            # Calculate waiting time
            waiting_time = max(0, send_start_time - previous_packet_end_time)
            total_waiting_time += waiting_time  # Add waiting time for this packet

            # Send the packet
            send(packet, iface=iface, verbose=False)
```

Bandwidth Limitation Using TCLink

Bandwidth Constraints

TCLink used in Mininet to simulate real-world conditions.

Configurations

- Hosts 1 & 2 (VLAN 10): 10 Mbps.
- Hosts 3 & 4 (VLAN 20): 0.1 Mbps (to simulate congestion).

```
# Add links between hosts and switch with bandwidth limits
self.addLink(host1, switch, cls=TCLink, bw=10)  # 10 Mbps for h1
self.addLink(host2, switch, cls=TCLink, bw=10)  # 10 Mbps for h2
self.addLink(host3, switch, cls=TCLink, bw=0.1)  # 0.1 Mbps for h3
self.addLink(host4, switch, cls=TCLink, bw=0.1)  # 0.1 Mbps for h4
```

Bandwidth Testing 10 Mpbs

```
root@labns:~/PycharmProjects/HassanProject/project/lab-04# iperf -s -p 5002
------------------------------------------------------------
Server listening on TCP port 5002
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 54540
[ ID] Interval       Transfer     Bandwidth
[  6]  0.0- 5.1 sec  5.38 MBytes  8.87 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 37176
[  6]  0.0-10.2 sec  10.8 MBytes  8.81 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 52468
[  6]  0.0-10.2 sec  11.0 MBytes  9.07 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 53954
[  6]  0.0-10.1 sec  10.6 MBytes  8.80 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 38110
[  6]  0.0- 1.1 sec  1.25 MBytes  9.18 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 49624
[  6]  0.0- 2.2 sec  2.25 MBytes  8.76 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 41774
[  6]  0.0-10.2 sec  10.8 MBytes  8.87 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 47488
[  6]  0.0-10.2 sec  10.8 MBytes  8.81 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 34084
[  6]  0.0-10.2 sec  10.9 MBytes  8.95 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 46498
[  7] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 46502
[  8] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 46514
[  9] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 46520
[  9]  0.0-10.8 sec  2.88 MBytes  2.24 Mbits/sec
[  6]  0.0-10.9 sec  3.00 MBytes  2.31 Mbits/sec
[  7]  0.0-10.9 sec  3.00 MBytes  2.31 Mbits/sec
[  8]  0.0-10.9 sec  3.00 MBytes  2.31 Mbits/sec
[SUM]  0.0-10.9 sec  11.9 MBytes  9.15 Mbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 48344
[  7] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 48358
[  8] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 48368
[  9] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 48378
[ 10] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 48390
[  6]  0.0-10.5 sec  2.25 MBytes  1.79 Mbits/sec
[  7]  0.0-10.5 sec  2.25 MBytes  1.79 Mbits/sec
[  8]  0.0-10.5 sec  2.25 MBytes  1.79 Mbits/sec
[ 10]  0.0-10.5 sec  2.25 MBytes  1.79 Mbits/sec
[  9]  0.0-10.7 sec  2.38 MBytes  1.87 Mbits/sec
[SUM]  0.0-10.7 sec  11.4 MBytes  8.95 Mbits/sec
```

```
mininet> h2 iperf -c 192.168.10.1 -p5002
------------------------------------------------------------
Client connecting to 192.168.10.1, TCP port 5002
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  3] local 192.168.10.2 port 34084 connected with 192.168.10.1 port 5002
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-10.1 sec  10.9 MBytes  9.07 Mbits/sec
mininet> h2 iperf -c 192.168.10.1 -p5002 -P 4
------------------------------------------------------------
Client connecting to 192.168.10.1, TCP port 5002
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  6] local 192.168.10.2 port 46520 connected with 192.168.10.1 port 5002
[  5] local 192.168.10.2 port 46514 connected with 192.168.10.1 port 5002
[  3] local 192.168.10.2 port 46498 connected with 192.168.10.1 port 5002
[  4] local 192.168.10.2 port 46502 connected with 192.168.10.1 port 5002
[ ID] Interval       Transfer     Bandwidth
[  6]  0.0-10.2 sec  2.88 MBytes  2.36 Mbits/sec
[  5]  0.0-10.4 sec  3.00 MBytes  2.42 Mbits/sec
[  3]  0.0-10.4 sec  3.00 MBytes  2.42 Mbits/sec
[  4]  0.0-10.4 sec  3.00 MBytes  2.42 Mbits/sec
[SUM]  0.0-10.4 sec  11.9 MBytes  9.56 Mbits/sec
mininet> h2 iperf -c 192.168.10.1 -p5002 -P 5
------------------------------------------------------------
Client connecting to 192.168.10.1, TCP port 5002
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  3] local 192.168.10.2 port 48344 connected with 192.168.10.1 port 5002
[  5] local 192.168.10.2 port 48368 connected with 192.168.10.1 port 5002
[  4] local 192.168.10.2 port 48358 connected with 192.168.10.1 port 5002
[  6] local 192.168.10.2 port 48378 connected with 192.168.10.1 port 5002
[  7] local 192.168.10.2 port 48390 connected with 192.168.10.1 port 5002
[ ID] Interval       Transfer     Bandwidth
[  4]  0.0-10.1 sec  2.25 MBytes  1.87 Mbits/sec
[  7]  0.0-10.1 sec  2.25 MBytes  1.87 Mbits/sec
[  3]  0.0-10.1 sec  2.25 MBytes  1.86 Mbits/sec
[  5]  0.0-10.2 sec  2.25 MBytes  1.85 Mbits/sec
[  6]  0.0-10.5 sec  2.38 MBytes  1.90 Mbits/sec
[SUM]  0.0-10.5 sec  11.4 MBytes  9.09 Mbits/sec
mininet>
```

Bandwidth Testing 0.1 Mpbs

```
root@labns:~/PycharmProjects/HassanProject/project/lab-04# iperf -s -p 5002
------------------------------------------------------------
Server listening on TCP port 5002
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 47626
[ ID] Interval       Transfer     Bandwidth
[  6]  0.0-20.7 sec   245 KBytes  96.8 Kbits/sec
[  6] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 55696
[  7] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 55714
[  8] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 55682
[  9] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 55708
[ 10] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 58302
[ 11] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 58318
[ 12] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 58324
[ 13] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 58326
[ 14] local 192.168.10.1 port 5002 connected with 192.168.10.2 port 58330
[  8]  0.0-58.6 sec   115 KBytes  16.0 Kbits/sec
[  9]  0.0-58.7 sec   117 KBytes  16.4 Kbits/sec
[  6]  0.0-61.9 sec   115 KBytes  15.2 Kbits/sec
[  7]  0.0-71.1 sec   136 KBytes  15.6 Kbits/sec
[ 10]  0.0-79.4 sec  93.3 KBytes  9.63 Kbits/sec
[ 13]  0.0-79.8 sec  93.3 KBytes  9.59 Kbits/sec
[ 14]  0.0-80.1 sec  93.3 KBytes  9.54 Kbits/sec
[ 11]  0.0-80.5 sec  93.3 KBytes  9.50 Kbits/sec
[ 12]  0.0-80.8 sec  93.3 KBytes  9.46 Kbits/sec
[SUM]  0.0-80.8 sec   949 KBytes  96.1 Kbits/sec
```

```
root@labns:~/PycharmProjects/HassanProject/project/lab-04# iperf -c 192.168.10.1 -p 5002
------------------------------------------------------------
Client connecting to 192.168.10.1, TCP port 5002
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  5] local 192.168.10.2 port 47626 connected with 192.168.10.1 port 5002
[ ID] Interval       Transfer     Bandwidth
[  5]  0.0-10.6 sec   245 KBytes   188 Kbits/sec
root@labns:~/PycharmProjects/HassanProject/project/lab-04# iperf -c 192.168.10.1 -p 5002 -P 4
------------------------------------------------------------
Client connecting to 192.168.10.1, TCP port 5002
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  7] local 192.168.10.2 port 55708 connected with 192.168.10.1 port 5002
[  5] local 192.168.10.2 port 55682 connected with 192.168.10.1 port 5002
[  6] local 192.168.10.2 port 55696 connected with 192.168.10.1 port 5002
[  8] local 192.168.10.2 port 55714 connected with 192.168.10.1 port 5002
[ ID] Interval       Transfer     Bandwidth
[  7]  0.0-10.3 sec   117 KBytes  93.7 Kbits/sec
[  5]  0.0-10.3 sec   115 KBytes  91.4 Kbits/sec
[  6]  0.0-10.3 sec   115 KBytes  91.4 Kbits/sec
[  8]  0.0-10.3 sec   136 KBytes   108 Kbits/sec
[SUM]  0.0-10.3 sec   482 KBytes   385 Kbits/sec
root@labns:~/PycharmProjects/HassanProject/project/lab-04# iperf -c 192.168.10.1 -p 5002 -P 5
------------------------------------------------------------
Client connecting to 192.168.10.1, TCP port 5002
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  5] local 192.168.10.2 port 58302 connected with 192.168.10.1 port 5002
[  8] local 192.168.10.2 port 58326 connected with 192.168.10.1 port 5002
[  6] local 192.168.10.2 port 58318 connected with 192.168.10.1 port 5002
[  9] local 192.168.10.2 port 58330 connected with 192.168.10.1 port 5002
[  7] local 192.168.10.2 port 58324 connected with 192.168.10.1 port 5002
[ ID] Interval       Transfer     Bandwidth
[  5]  0.0-10.1 sec  93.3 KBytes  75.4 Kbits/sec
[  6]  0.0-10.1 sec  93.3 KBytes  75.4 Kbits/sec
[  9]  0.0-10.1 sec  93.3 KBytes  75.4 Kbits/sec
[  7]  0.0-10.1 sec  93.3 KBytes  75.4 Kbits/sec
[  8]  0.0-10.1 sec  93.3 KBytes  75.4 Kbits/sec
[SUM]  0.0-10.1 sec   467 KBytes   377 Kbits/sec
root@labns:~/PycharmProjects/HassanProject/project/lab-04#
```

Queue Length Calculation (Theoretical)

Theoretical Model: M/G/1 queueing model

For 10 Mbps Bandwidth:

- Arrival Rate: 100 packets/sec.
- Service Rate: 856.16 packets/sec.
- Traffic Intensity (ρ): 0.1168.
- Queue Length: 0.0077 packets.

For 0.1 Mbps Bandwidth:

- Arrival Rate: 100 packets/sec.
- Service Rate: 8.57 packets/sec.
- Traffic Intensity (ρ): 11.68 (system overloaded).
- Queue Length: Infinite (overload condition).

$$Service\ Rate(\mu) = \frac{Bandwidth\ (bps)}{Packet\ Size\ (bits)}$$

$$\rho = \frac{Arrival\ Rate}{Service\ Rate}$$

$$\text{Service } Time = \frac{1}{\text{Service Rate}}$$

$$L_q = \frac{\rho^2}{2 \cdot (1 - \rho)}$$

Simulation Results (10 Mbps)

Observation

- Minimal queue buildup.
- No dropped packets or congestion.
- Traffic intensity ($\rho = 0.1168$) ensures smooth operation.

Key Metric

Queue length remained near 0.

```
### Packet 50 ###
Packet size: 1460 bytes
Service time: 0.001168 seconds
Waiting time before transmission (in system): 0.082601 seconds
Total time spent in the system: 0.083769 seconds
Elapsed time since start: 3.77 seconds
Current packet arrival rate: 13.26 packets per second
Average waiting time (across all packets): 0.073122 seconds
Current backlog size: 0 bytes
Theoretical queue length (initial parameters): 0.0077 packets
Theoretical queue length (current observed rate): 0.0001 packets
Actual queue length: 0.0000 packets

### Final Summary ###
Total packets sent: 50
Average packet length: 1460.00 bytes
Final packet arrival rate: 13.24 packets per second
Average waiting time (across all packets): 0.073122 seconds

Final Transmission Queue Stats:
qdisc htb 5: root refcnt 2 r2q 10 default 1 direct_packets_stat 0 direct_qlen 1000
 Sent 442440 bytes 5608 pkt (dropped 0, overlimits 0 requeues 0)
 backlog 0b 0p requeues 0

Exiting gracefully.
```

Simulation Results (0.1 Mbps)

Observation

- Queue buildup due to high traffic intensity ($\rho > 1$).
- System experienced congestion.
- Packet delays and queuing observed.

Key Metric

Queue length increased significantly but was controlled due to **system limitations**.

```
### Packet 50 ###
Packet size: 1460 bytes
Service time: 0.116800 seconds
Waiting time before transmission (in system): 0.000000 seconds
Total time spent in the system: 0.116800 seconds
Elapsed time since start: 3.61 seconds
Current packet arrival rate: 13.87 packets per second
Average waiting time (across all packets): 0.001115 seconds
Current backlog size: 28652 bytes
Theoretical queue length (initial parameters): inf packets
Theoretical queue length (current observed rate): inf packets
Actual queue length: 19.6247 packets

### Final Summary ###
Total packets sent: 50
Average packet length: 1460.00 bytes
Final packet arrival rate: 13.85 packets per second
Average waiting time (across all packets): 0.001115 seconds

Final Transmission Queue Stats:
qdisc htb 5: root refcnt 2 r2q 10 default 1 direct_packets_stat 0 direct_qlen 1000
 Sent 48496 bytes 55 pkt (dropped 0, overlimits 30 requeues 0)
 backlog 28652b 19p requeues 0

Exiting gracefully.
mininet>
Interrupt
mininet>
```

Conclusion

Key Findings

1. 10 Mbps Scenario: Minimal queue buildup, smooth operation.

2. 0.1 Mbps Scenario: Congestion, significant queue buildup.

3. Theoretical vs. Practical: Simulation closely matches theoretical predictions for the 10 Mbps scenario, while the 0.1 Mbps scenario highlights the effects of overload.

Takeaway

✓ Bandwidth management is critical to prevent network congestion and maintain performance.

Buffer Overflow Testing with Reduced Burst Size

Test Scenario: To evaluate how the system handles queued packets, I reduced the burst size from **1000 Kbits to 100 Kbits** under the same traffic conditions.

Observation: With the decreased burst size, the network experienced **buffer overflow**, indicating that the system could not process the queued packets within the allocated buffer limit.

```
### Packet 46 ###
Packet size: 1460 bytes
Service time: 0.023360 seconds
Waiting time before transmission (in system): 0.197067 seconds
Total time spent in the system: 0.220427 seconds
Elapsed time since start: 7.38 seconds
Current packet arrival rate: 6.23 packets per second
Average waiting time (across all packets): 0.136915 seconds
Current backlog size: 12064 bytes
Theoretical queue length (initial parameters): 0.0356 packets
Theoretical queue length (current observed rate): 0.0124 packets
Actual queue length: 8.2630 packets

Error occurred: [Errno 105] No buffer space available

Packet generation interrupted. Summary:

### Final Summary ###
Total packets sent: 46
Average packet length: 1460.00 bytes
Final packet arrival rate: 6.14 packets per second
Average waiting time (across all packets): 0.137413 seconds

Final Transmission Queue Stats:
qdisc tbf 8002: root refcnt 2 rate 50Kbit burst 12800b lat 49.9ms
 Sent 58854 bytes 40 pkt (dropped 1, overlimits 33 requeues 0)
 backlog 10556b 7p requeues 0
```

Thank
you