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# Simulate Real-World IP Networks

Impairments, Delay, Errors, Loss, Optical, Electrical

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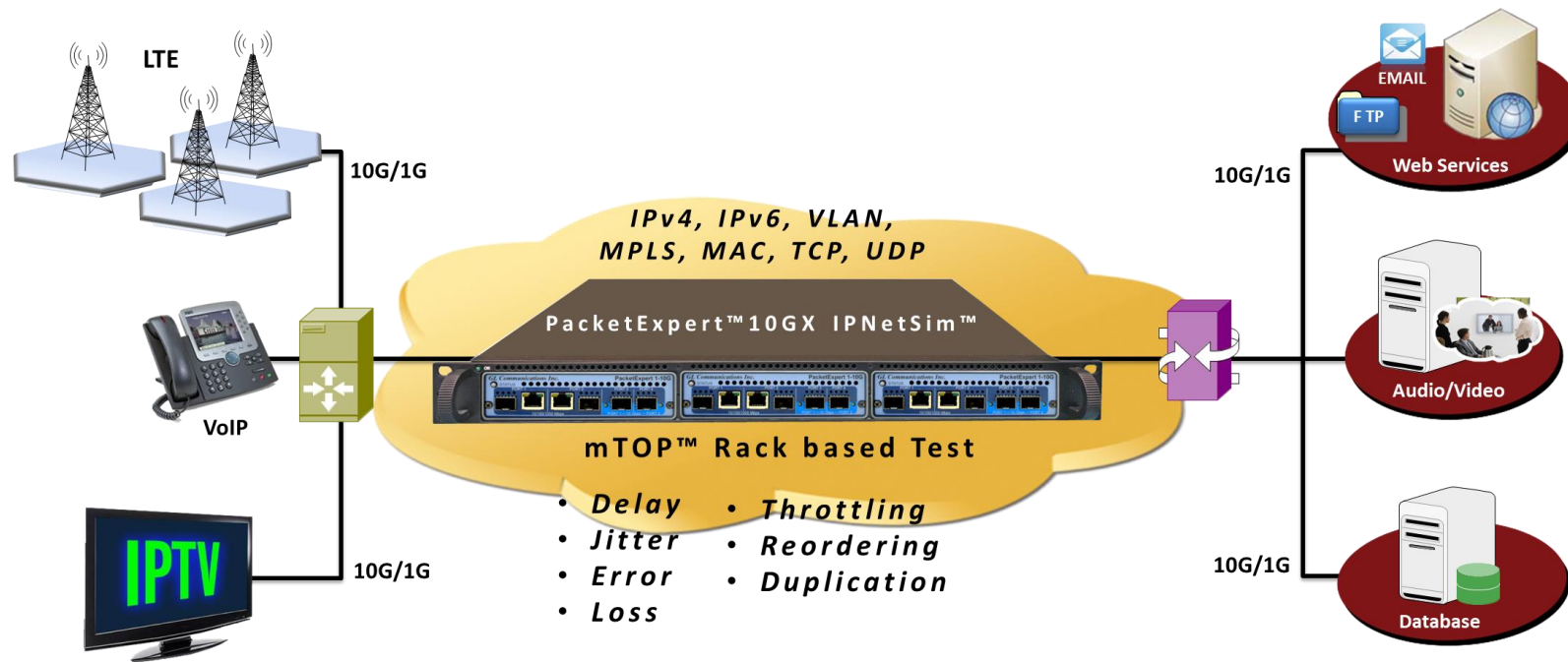


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# Overview

How does GL simulate real-world IP Networks? What is GL's IPNetSim?

- Lab Testing Solution - application and automation
- Emulate Full Duplex 1 Gbps and 10 Gbps networks
- Real-world network conditions by imposing impairments
- Multiple streams independently configured



# Portable Unit

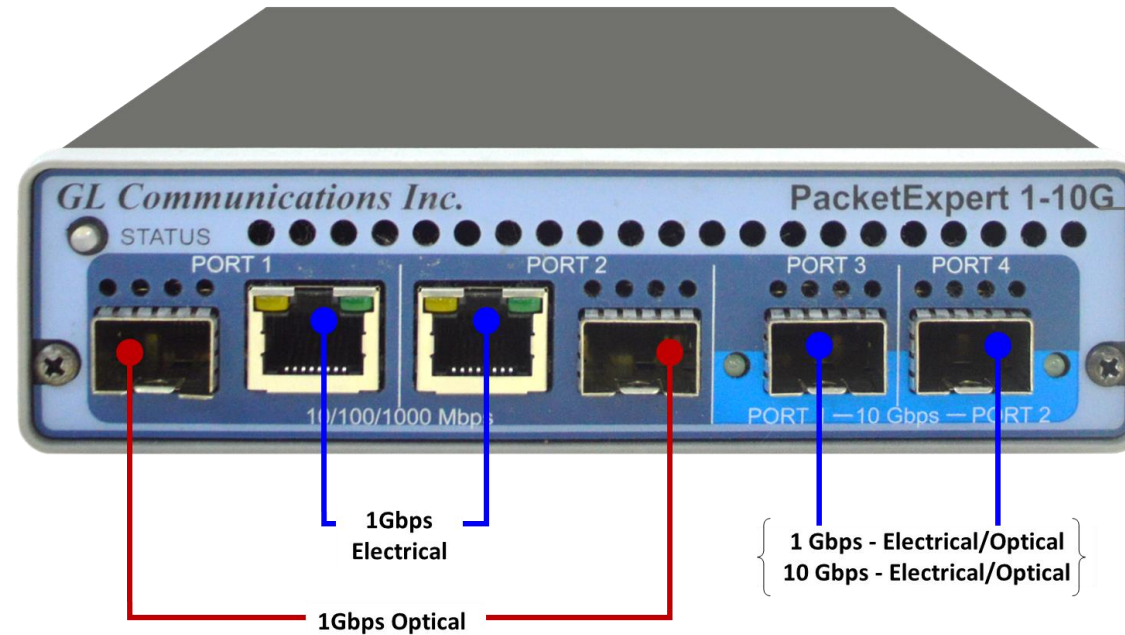


## PacketExpert™ 10GX Standalone

- 4 x 1 Gbps Optical or Electrical
- 2 x 10 Gbps Optical or Electrical

# Hardware Overview

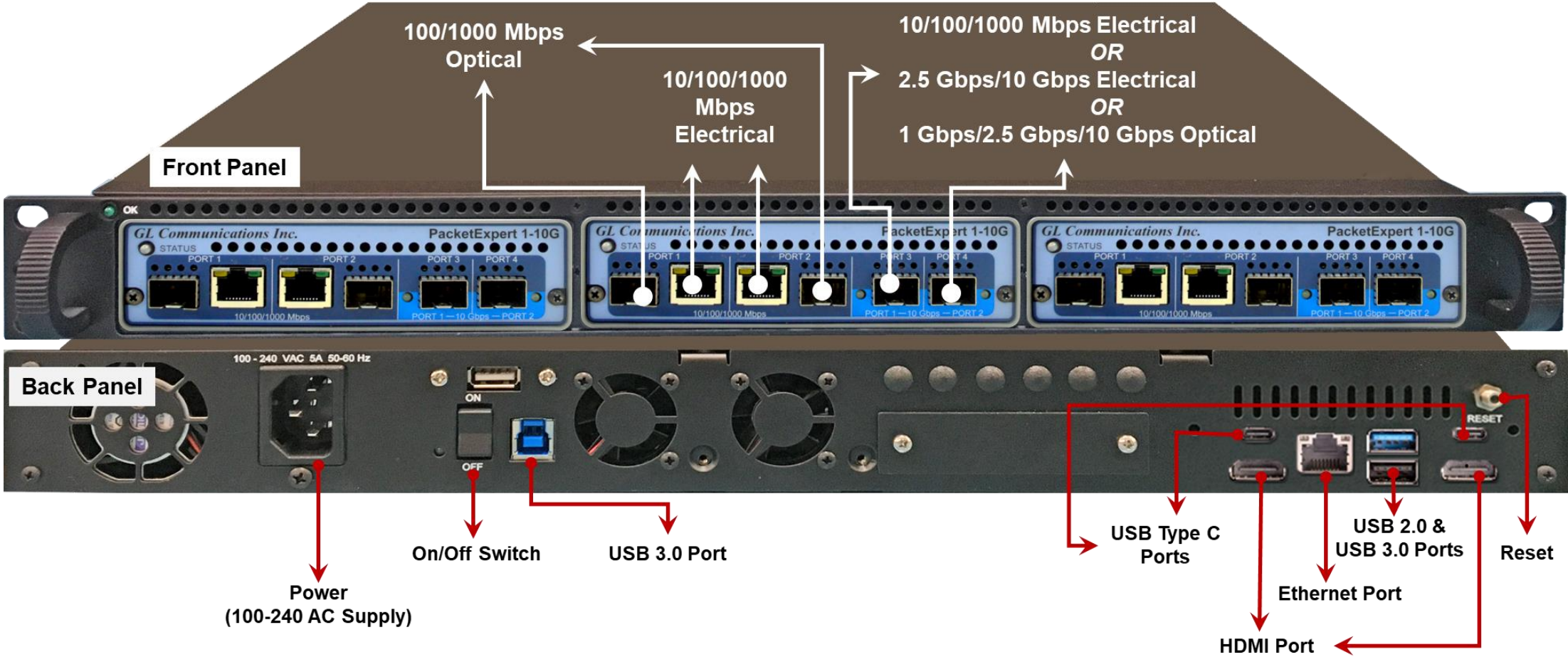
# Hardware Overview + Highlights



**IPNetSim™** is an optional application available within PacketExpert™ platform (PXN100).

- IPNetSim operates in both multi-stream and single stream mode.
- IPNetSim acts as a bridge between two network segments. As long as the hardware has power it allows frames to flow freely.
- IPNetSim allows users to define up to 16 different streams of traffic. Each of these streams can have its own independent set of impairments applied to them. More to come on streams and exactly how GL defines them.
- IPNetSim is hardware-based...meaning all impairments and timing controls happen at the hardware level.

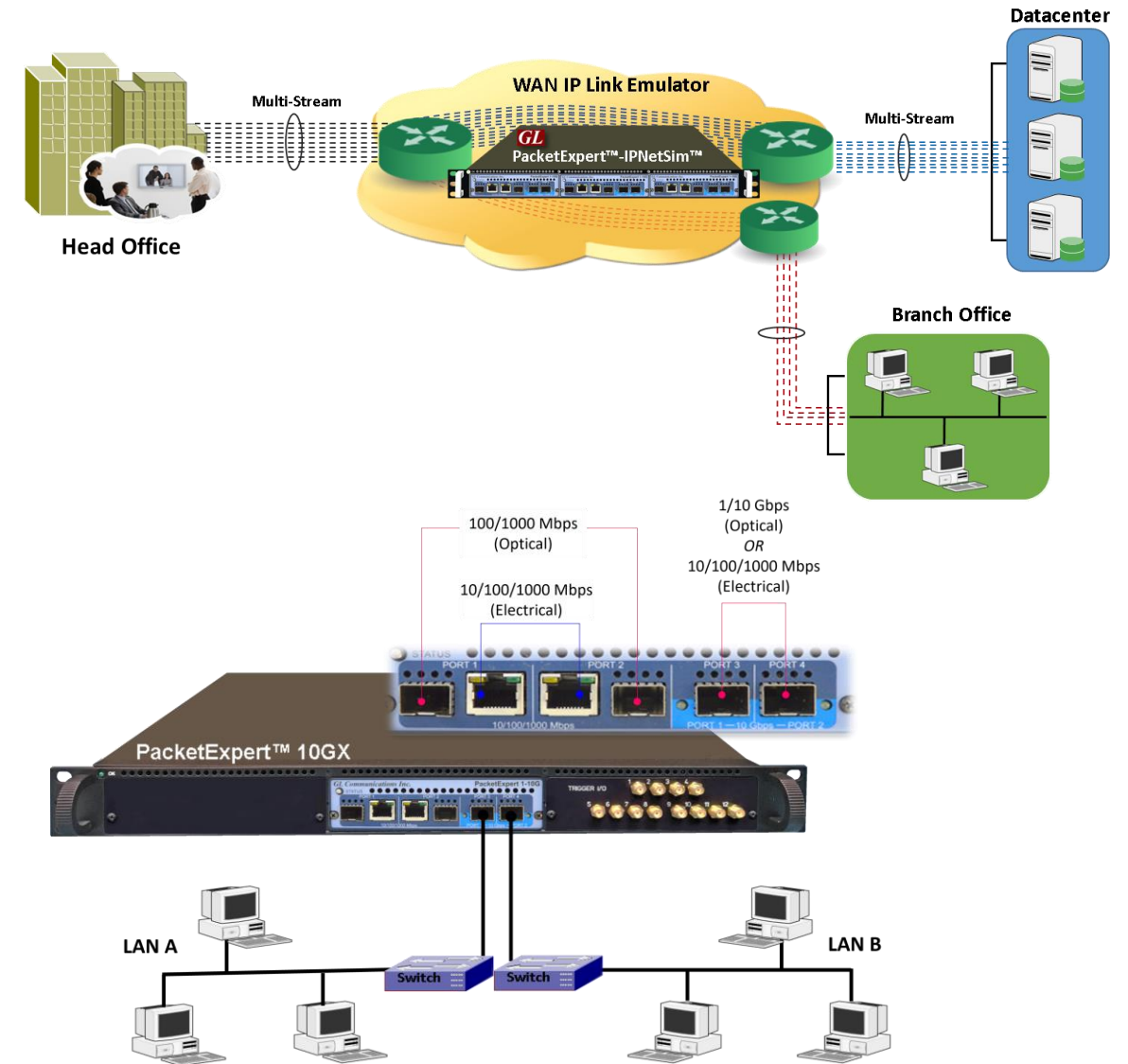
# Hardware Interfaces



# Application Overview

# Application Overview

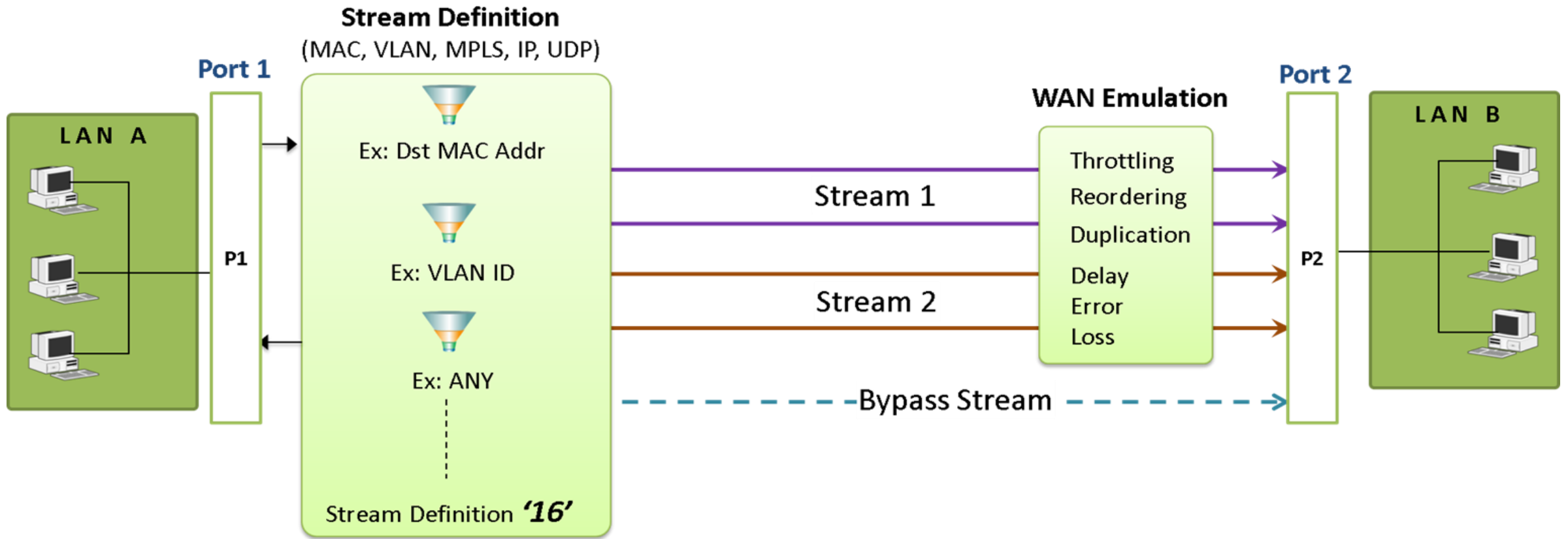
- Test Enterprise and Individual-level applications
  - Audio and video streaming (VoIP, IMS, HDT, IPTV)
  - Storage services (Critical Data Access)
  - Cloud and web services
  - FTP / HTTP
- Simulate backhaul network
  - Static and dynamic networks
  - Satellite + other long delay networks
- Test Quality of Service (QoS) and Quality of Experience (QoE)
- Evaluate the stability of network devices (switches, VoIP Phones, VoIP PBXs, Set-top boxes and VoD Servers).





# Stream Overview

# Stream Overview



# Define Streams in Packet Mode

Stream Definition **WAN Emulation Parameters** Scheduler

P1 -> P2

Filter Mode  
 Packet Mode  Raw Mode

MAC  VLAN  MPLS  IP  UDP

Layer (Click to edit)	Layer Summary
MAC	00-00-00-00-01-01 -> 00-00-00-00-01-02, Len/Type = XX-XX
VLAN	VLAN Id = 0 , VLAN Stack = 1
MPLS	MPLS Label = 0 , MPLS Stack = 1
<b>IP</b>	<b>192.168.1.11 - 192.168.1.16 --&gt; 192.168.2.11 - 192.168.2.16</b>

IPv4  IPv6

Source IP Address  
 Fixed  Range  Any  
From  To

Destination IP Address  
 Fixed  Range  Any  
IP Address

Apply

# Define Streams in Raw Mode

Stream Definition WAN Emulation Parameters Scheduler

P1 -> P2

Filter Mode  
 Packet Mode  Raw Mode Offset

Bytes	0	1	2	3	4	5	6	7
Bytes	0	1	2	3	4	5	6	7
Value	00	00	00	00	01	02	00	00
Mask	FF	FF	FF	FF	FF	FF	FF	FF

Apply

Bytes	Value	Mask
0-7	00 00 00 00 01 02 00 00	FF FF FF FF FF FF FF FF
8-15	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
16-23	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
24-31	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
32-39	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
40-47	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
48-55	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
56-63	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
64-71	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
72-79	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
80-87	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
88-95	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
96-103	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
104-111	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
112-119	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00

# Impairments

# Traffic Bandwidth

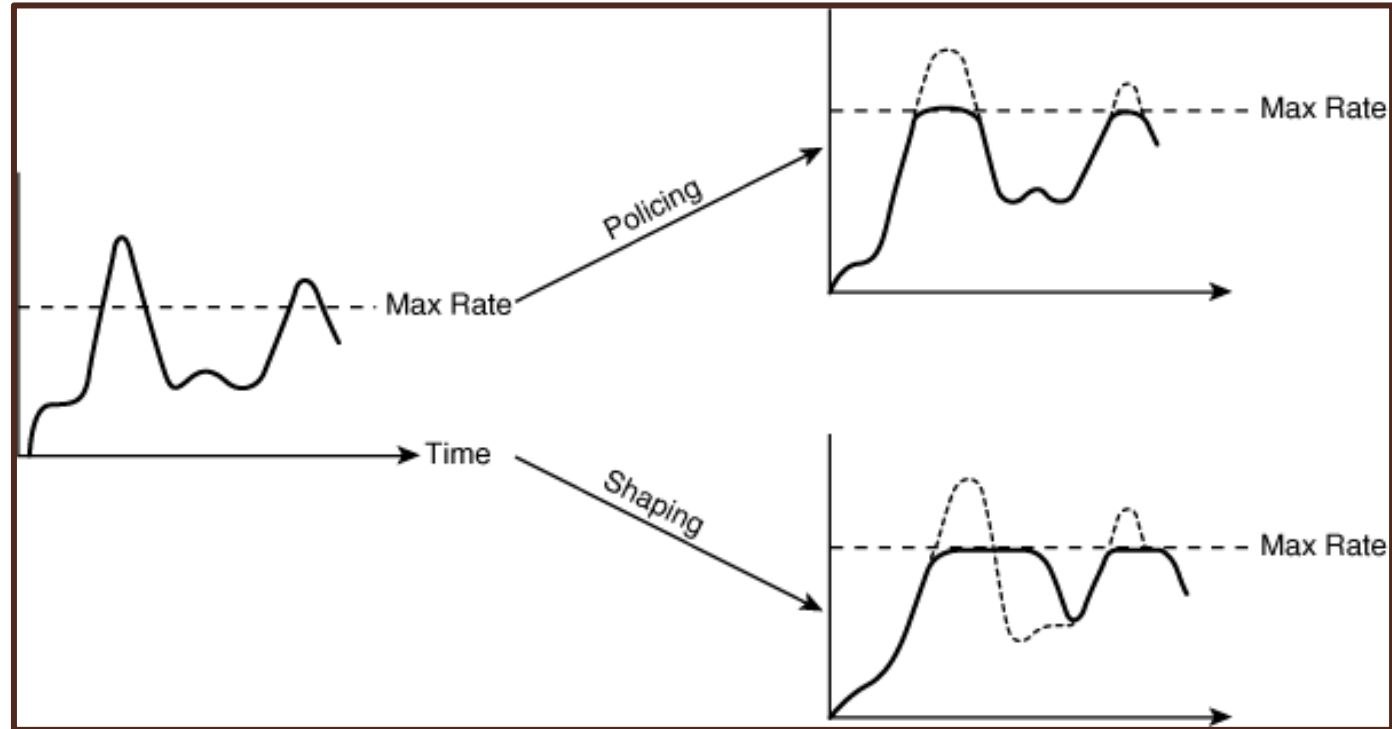
- Traffic which exceeds the stated rate is **silently dropped**
- UDP Applications will experience **data loss**
- TCP Applications should adapt via **congestion-avoidance algorithms**

The screenshot shows the 'WAN Emulation Parameters' tab in a configuration interface. At the top, there are three tabs: 'Stream Definition', 'WAN Emulation Parameters' (selected), and 'Scheduler'. Below the tabs, there is a section for 'WAN Stream Type' with two radio buttons: 'Symmetrical' (unselected) and 'Asymmetrical' (selected). Below this is a table with three columns: 'Parameters', 'P1 -> P2', and 'P2 -> P1'. The table contains the following data:

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	10000.00 Mbps	8000.00 Mbps
Latency	None	None
Packet Loss	None	None
Packet Reordering	None	None
Packet Duplication	None	None
Logic Error Insertion	None	None

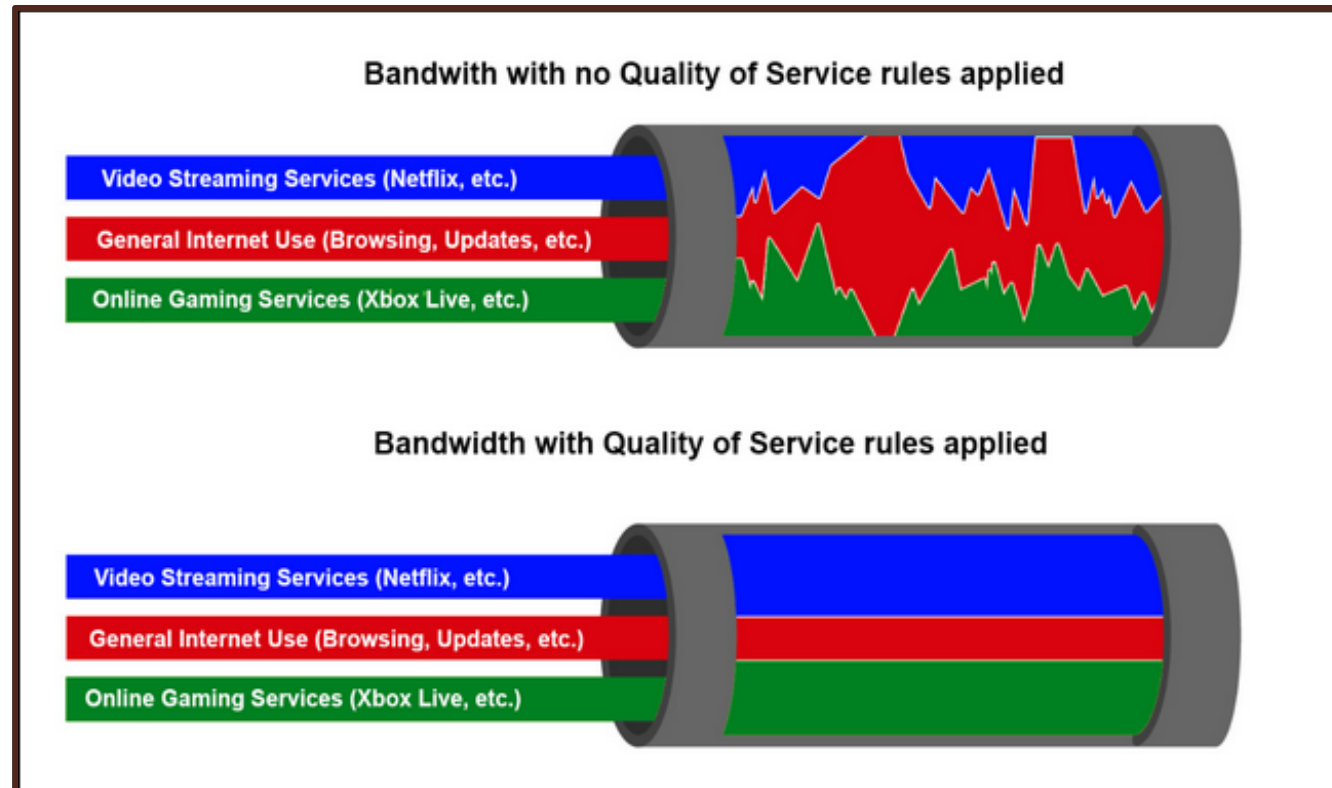
Below the table, there are two separate configuration sections for 'P1 -> P2' and 'P2 -> P1'. Each section has a 'Traffic Bandwidth' label and a text input field with a unit dropdown menu. For 'P1 -> P2', the input field contains '10000.000000' and the dropdown is set to 'Mbps'. For 'P2 -> P1', the input field contains '8000.000000' and the dropdown is set to 'Mbps'.

# Traffic Bandwidth (Contd.)



- Simulate WAN Applications where **Traffic Policing Policies** may be in effect, ie **Service Level Agreements** between Provider and Customer

# Traffic Bandwidth (Contd.)



- Simulate QoS settings by setting different bandwidth caps on different ports (or port ranges)



# Latency / Jitter

- Apply Static Delay, or a Uniform or Exponential distribution between a minimum and maximum
- Delay a packet up to 500 ms in 1ms increments for 10G ports

Stream Definition WAN Emulation Parameters Scheduler

WAN Stream Type  Symmetrical  Asymmetrical

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	10000.00 Mbps	8000.00 Mbps
Latency	Random Exp. , 0.000 msec - 500.000 msec	Random Exp. , 0.000 msec - 500.000 msec
Packet Loss	None	None
Packet Reordering	None	None
Packet Duplication	None	None
Logic Error Insertion	None	None

P1 -> P2

Latency

Single Delay

Min  msec

Uniform Distribution

Max  msec

Random Exponential Distribution

P2 -> P1

Latency

Single Delay

Min  msec

Uniform Distribution

Max  msec

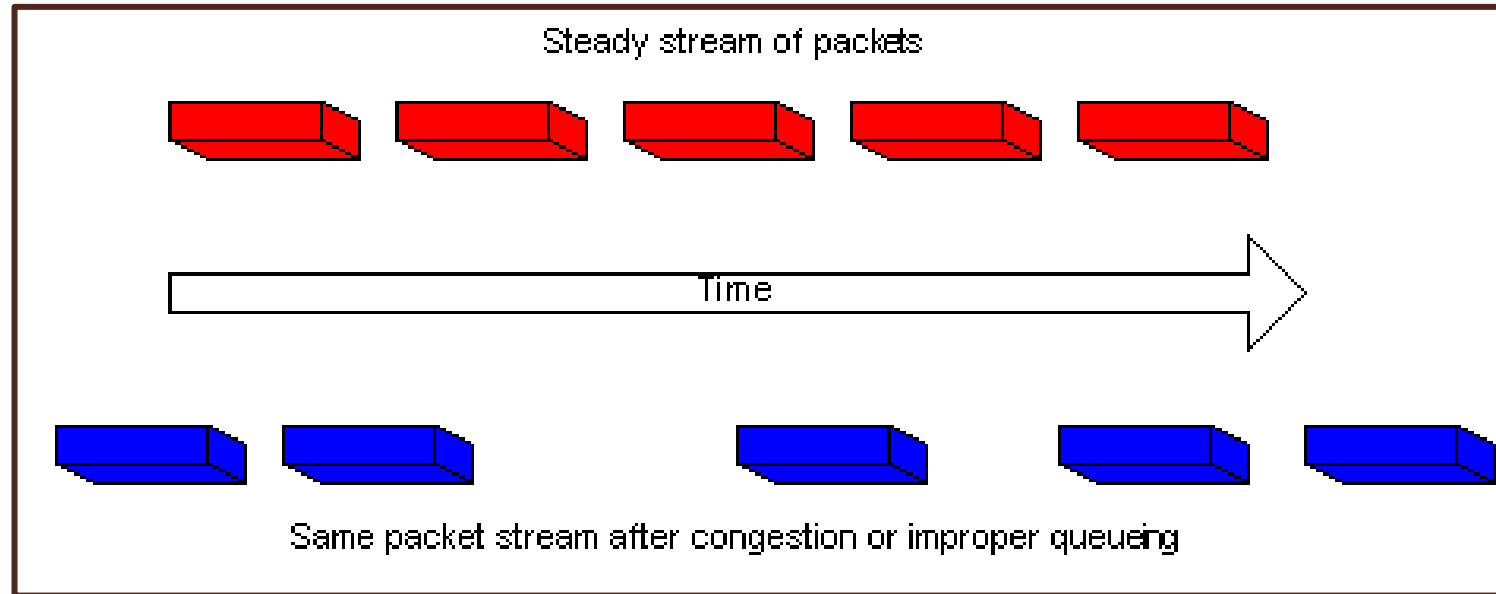
Random Exponential Distribution

# Latency / Jitter



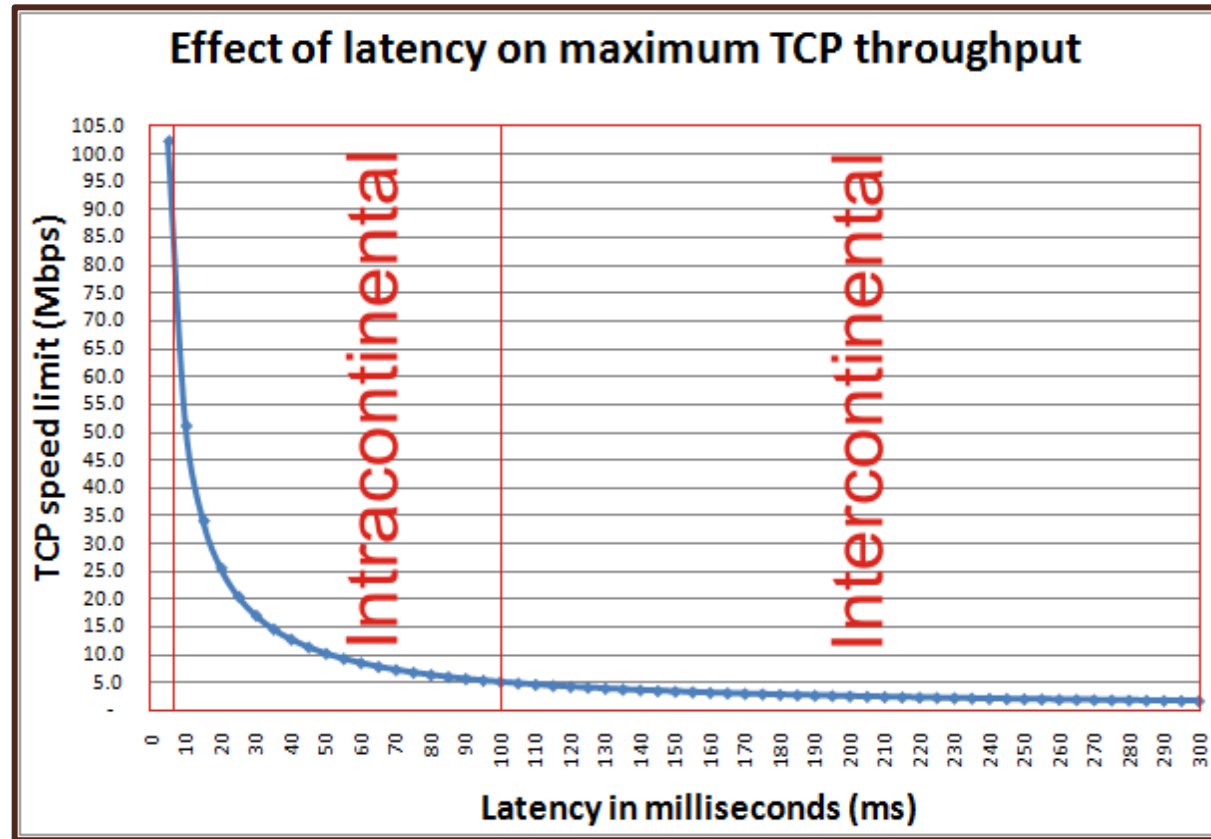
- Apply a large static delay to simulate **backhaul communication (satellite hops, etc.)**

# Latency / Jitter (Contd.)



- Apply Variable delay (ie, Jitter) to simulate Traffic Shaping policies and/or Network Congestion
- Jitter leads to packet discard (and therefore data loss) in Real Time UDP Applications

# Latency / Jitter (Contd.)



- Increased Latency causes TCP applications to spend increasing amounts of time idling while waiting for ACKs from the far side, thereby throttling throughput

# Packet Loss

Stream Definition | **WAN Emulation Parameters** | Scheduler

WAN Stream Type  Symmetrical  Asymmetrical

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	10000.00 Mbps	8000.00 Mbps
Latency	Single Delay, 100.000 msec	None
Packet Loss	10.000 %	20.000 %
Packet Reordering	1 out of 10 packets	1 out of 20 packets
Packet Duplication	1.000 %	5.000 %
Logic Error Insertion	10 <sup>-2</sup>	10 <sup>-5</sup>

P1 -> P2

Packet Loss

Single Packet  Burst Packets

Min  Frames Max  Frames

Rate

WARNING:  
For PacketLoss rate less than 0.099%, only rates which are multiple of 0.002 are allowed

Periodic  Random

Rate  %

P2 -> P1

Packet Loss

Single Packet  Burst Packets

Min  Frames Max  Frames

Rate

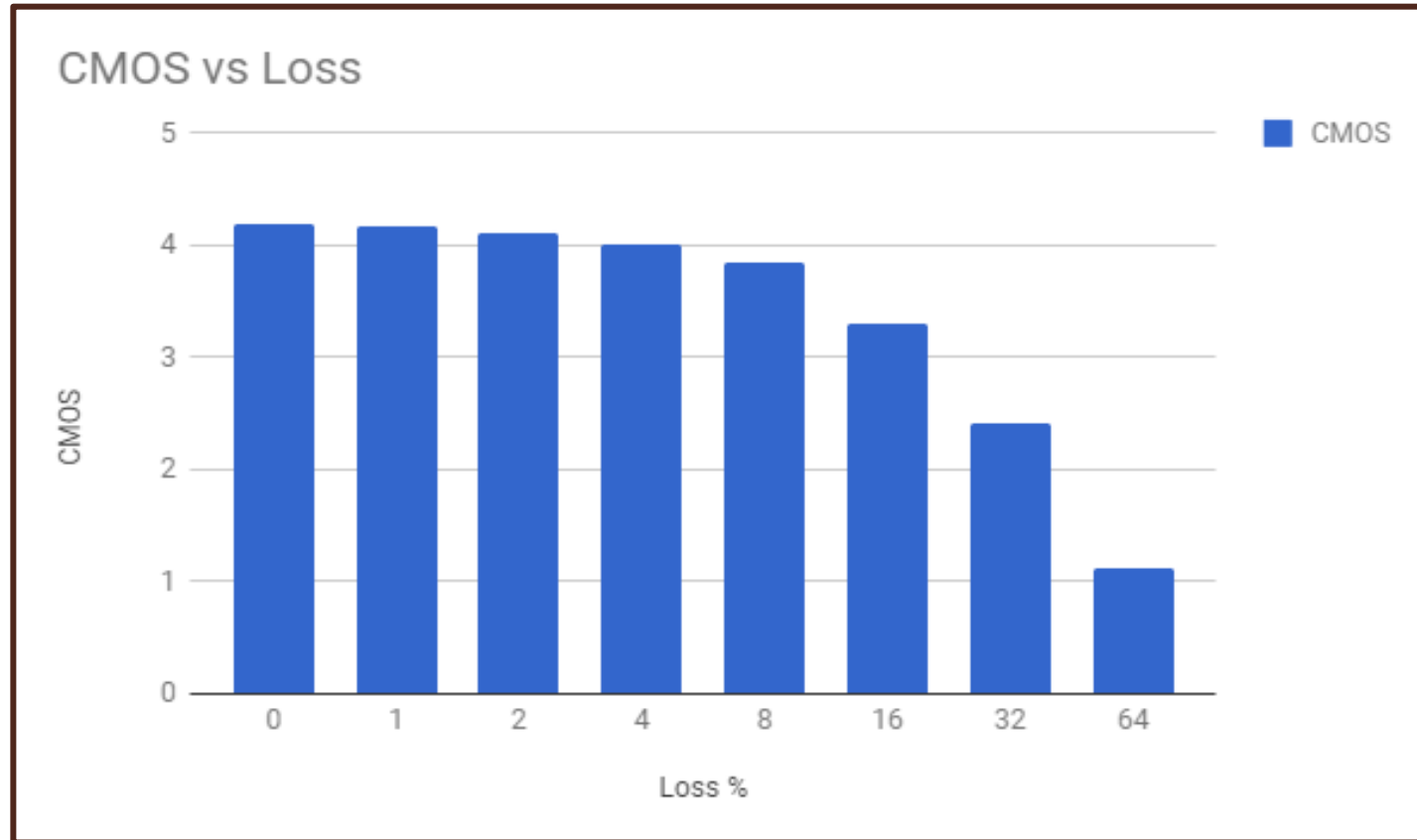
WARNING:  
For PacketLoss rate less than 0.099%, only rates which are multiple of 0.002 are allowed

Periodic  Random

Rate  %

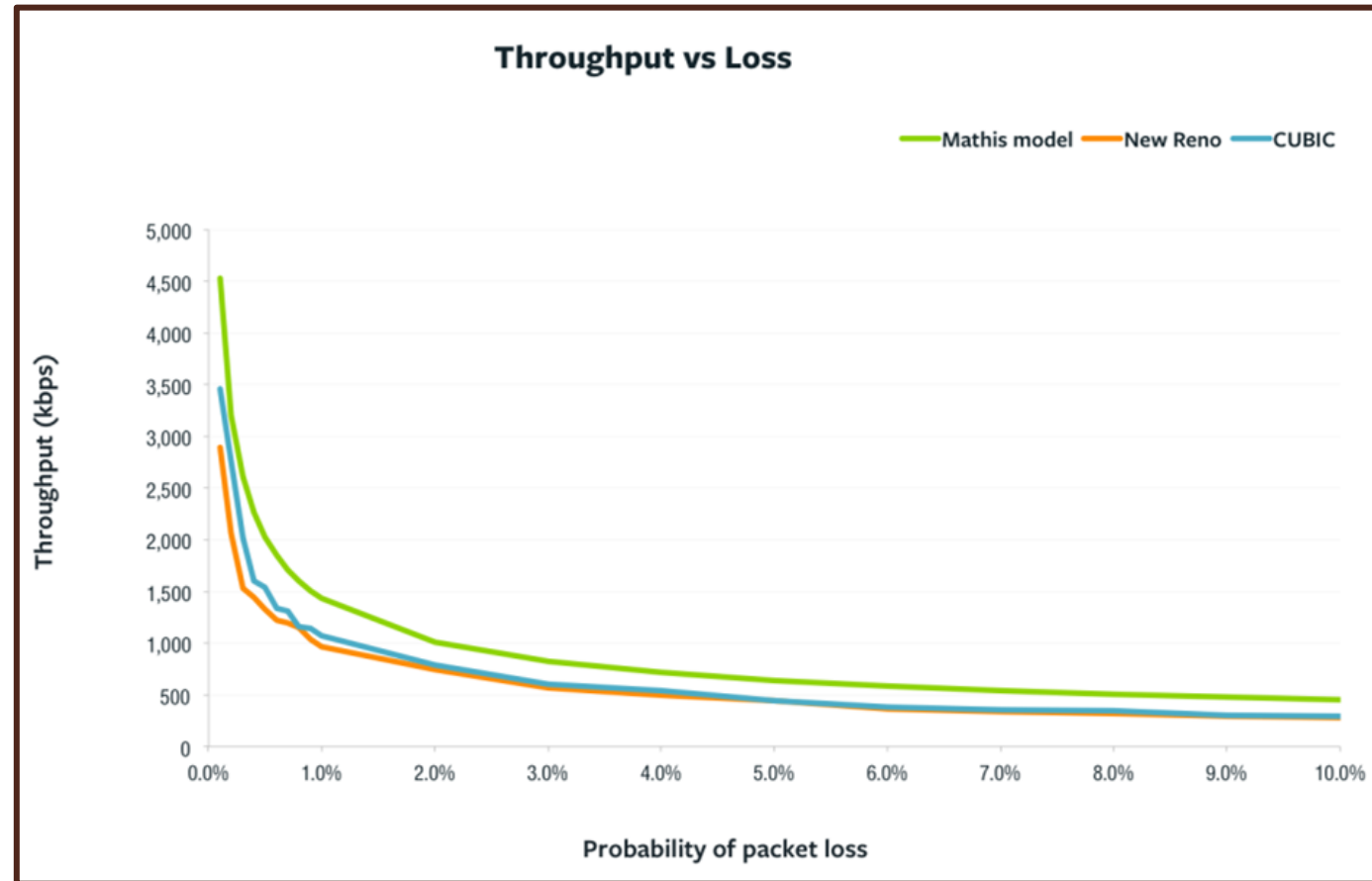
- Randomly drop from 0.01% to 100% of all Packets in the stream

# Packet Loss (Contd.)



- Real Time UDP Applications are resilient to minor loss, but vulnerable to heavy loss

# Packet Loss (Contd.)



- TCP Applications are vulnerable to even very minor loss rates as every loss results in retransmissions and reduced window sizes.

# Packet Reordering

- Reorder 1 out of every X packets.
- Set a minimum time in ms to hold the reordered packet
- Set a maximum time in ms to hold the reordered packet

Stream Definition | **WAN Emulation Parameters** | Scheduler

WAN Stream Type  Symmetrical  Asymmetrical

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	10000.00 Mbps	8000.00 Mbps
Latency	Single Delay, 100.000 msec	None
Packet Loss	10.000 %	20.000 %
Packet Reordering	1 out of 10 packets	1 out of 20 packets
Packet Duplication	None	None
Logic Error Insertion	None	None

P1 -> P2

Packet Reordering

Periodic  Random

Reorder 1 packet out of  packets

Delay Offset

Time  Frames

Min  ms Max  ms

P2 -> P1

Packet Reordering

Periodic  Random

Reorder 1 packet out of  packets

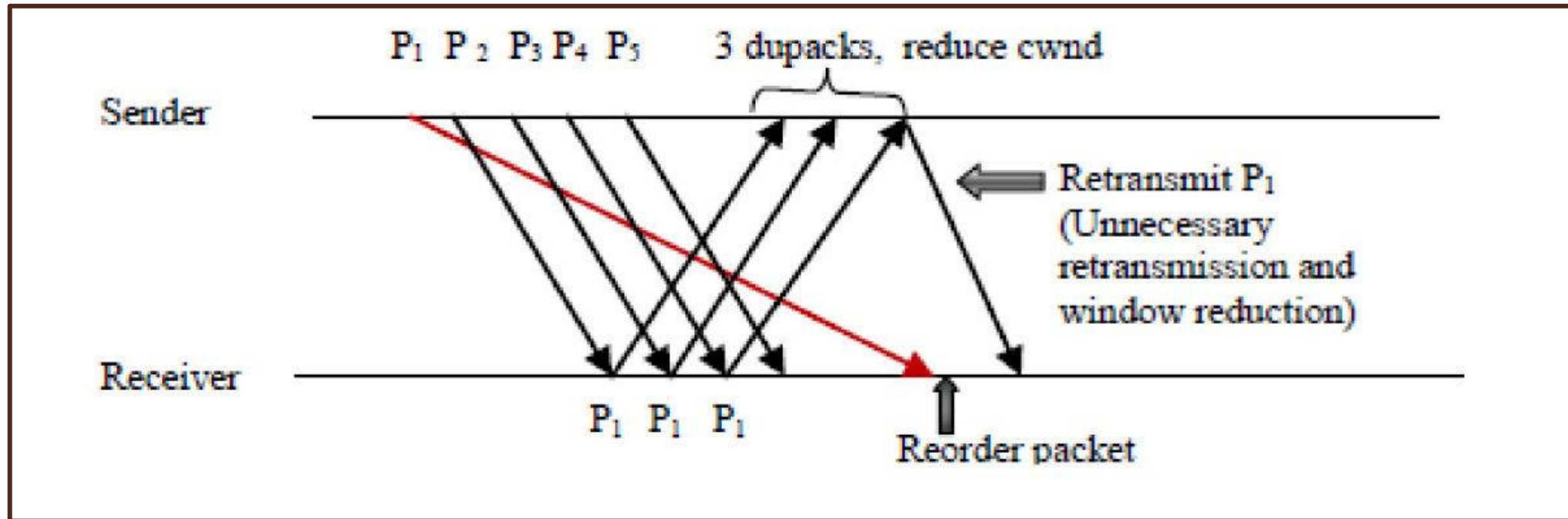
Delay Offset

Time  Frames

Min  ms Max  ms

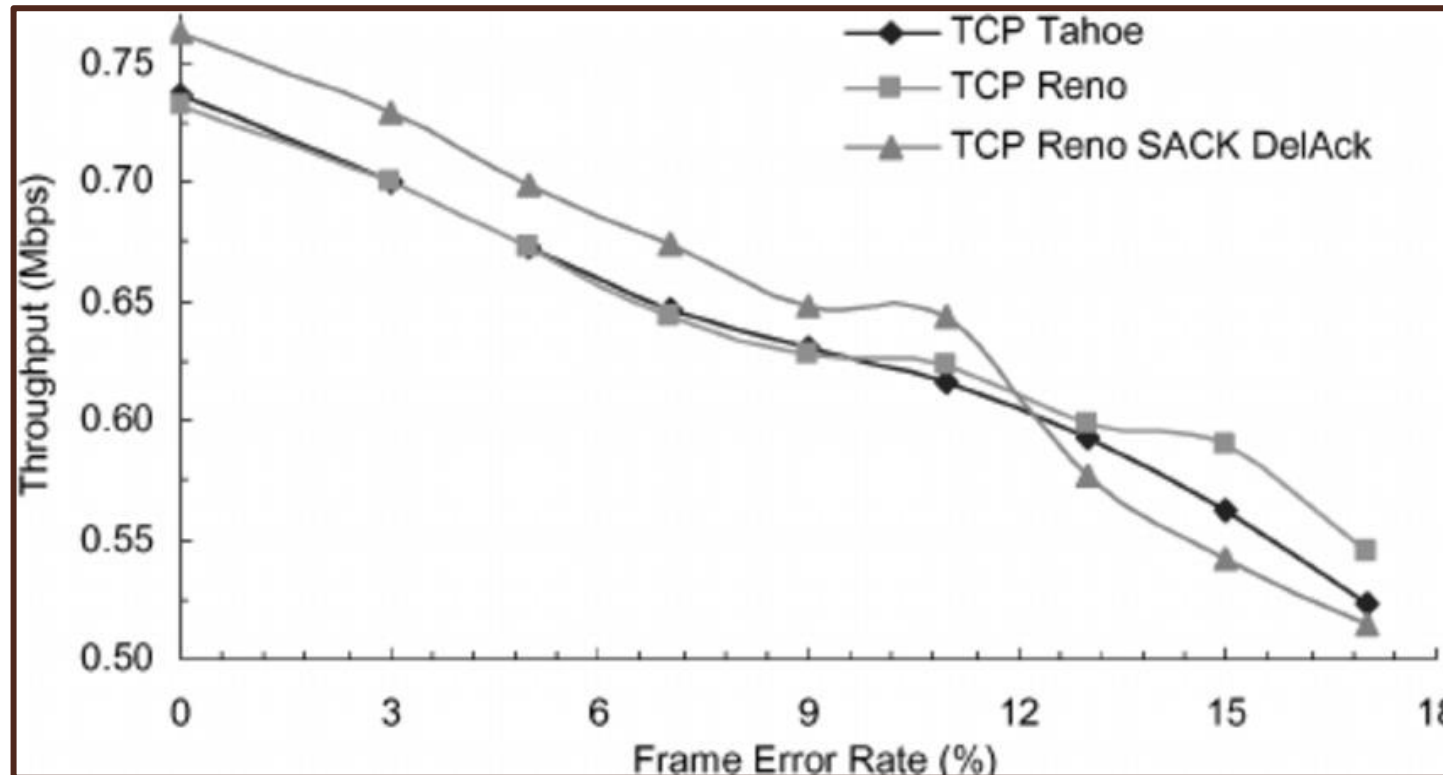


# Packet Reordering (Contd.)



- When a packet is out-of-order, TCP behaves exactly as though the preceding packets are lost resulting in duplicate ACKs, retransmissions and window reduction

# Packet Reordering (Contd.)



- TCP Selective Acknowledgement (SACK) can mitigate this issue by letting the receive side Acknowledge OOO packets.

# Packet Duplication

- Randomly duplicate from 0.01% to 100% of all Packets in the stream
- Emulate WAN applications where multiple paths are possible and Load Balancing may be present

Stream Definition **WAN Emulation Parameters** Scheduler

WAN Stream Type  Symmetrical  Asymmetrical

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	10000.00 Mbps	8000.00 Mbps
Latency	Single Delay, 100.000 msec	None
Packet Loss	10.000 %	20.000 %
Packet Reordering	1 out of 10 packets	1 out of 20 packets
Packet Duplication	1.000 %	5.000 %
Logic Error Insertion	None	None

P1 -> P2

Duplication

Rate

WARNING:  
For Duplication rate less than 0.099%, only rates which are multiple of 0.002 are allowed

Periodic  Random

Rate  %

P2 -> P1

Duplication

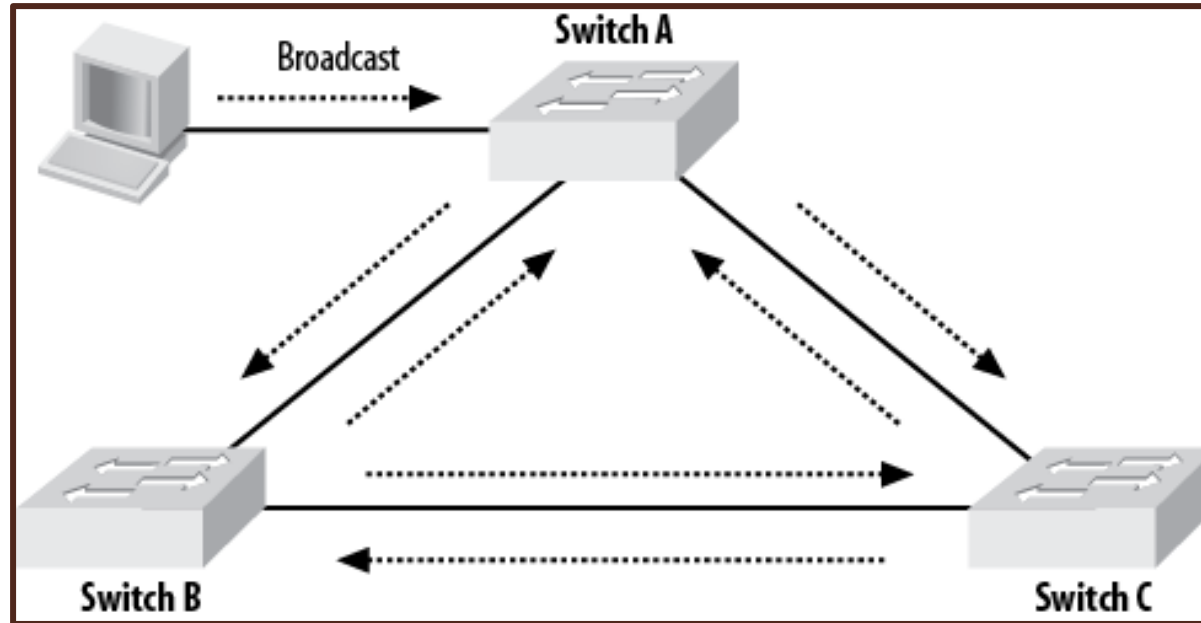
Rate

WARNING:  
For Duplication rate less than 0.099%, only rates which are multiple of 0.002 are allowed

Periodic  Random

Rate  %

# Packet Duplication (Contd.)



- Duplication can be fatal in broadcast situations (i.e, broadcast storm)
- Similarly dangerous in multicast applications where small network misconfigurations can have disproportionately large consequences
- Watch out for this in multipath Spanning Tree networks

# Logic Error Insertion

- Insert a single bit error every  $10^{-X}$  frames (  $-1 \leq X \leq -9$  )
- Use byte offsets to target particular parts of a frame

Stream Definition | **WAN Emulation Parameters** | Scheduler

WAN Stream Type  Symmetrical  Asymmetrical

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	10000.00 Mbps	8000.00 Mbps
Latency	Single Delay, 100.000 msec	None
Packet Loss	10.000 %	20.000 %
Packet Reordering	1 out of 10 packets	1 out of 20 packets
Packet Duplication	1.000 %	5.000 %
Logic Error Insertion	$10^{-2}$	$10^{-5}$

**P1 -> P2**

Logic Error Insertion

Rate

Periodic  Random

Packet Error Rate

Bytes Offset  Beginning of frame

Bytes Offset  End of frame

**P2 -> P1**

Logic Error Insertion

Rate

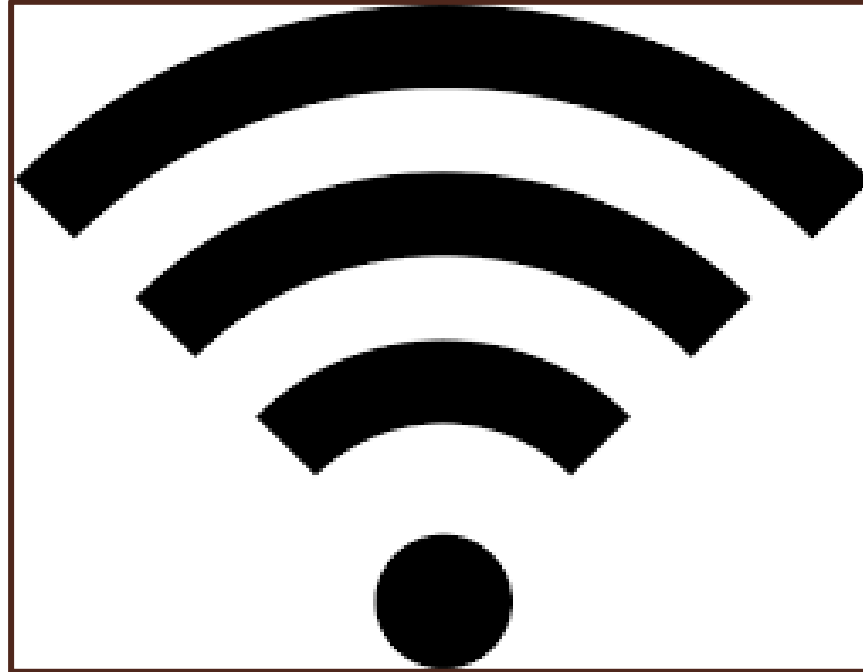
Periodic  Random

Packet Error Rate

Bytes Offset  Beginning of frame

Bytes Offset  End of frame

## Logic Error Insertion (Contd.)



- Cellular and WiFi links are very prone to bit errors (as well as latency and bandwidth issues)

# Application Examples

# VoIP

The screenshot shows the configuration interface for a SIP stream. On the left, a table lists stream names: 1 SIP, 2 RTP, and 3 Data. The main panel is titled 'WAN Emulation Parameters' and includes tabs for 'Stream Definition', 'WAN Emulation Parameters', and 'Scheduler'. The 'WAN Emulation Parameters' tab is active, showing 'P1 -> P2' and a 'Mirror >>' button. Under the 'Mode' section, 'Packet Mode' is selected. Below, checkboxes for MAC, VLAN, MPLS, IP, and UDP are shown, with 'UDP' checked. A table below lists layers: 'Layer (Click to edit)' and 'Layer Summary'. The 'UDP' layer is listed with a summary of '5060 --> 5060'.

- Configure SIP packets to be completely unimpaired

The screenshot shows the configuration interface for a SIP stream, focusing on the 'WAN Emulation Parameters' tab. The 'WAN Stream Type' is set to 'Asymmetrical'. Below this is a table with parameters for 'P1 -> P2' and 'P1 -> P2 Manual'.

Parameters	P1 -> P2	P1 -> P2 Manual
Traffic Bandwidth	1000.00 Mbps	100.00 Mbps
Latency	None	None
Packet Loss	None	None
Packet Reordering	None	None
Packet Duplication	None	None
Logic Error Insertion	None	None



# VoIP (Contd.)

The screenshot shows the configuration interface for a WAN Emulation Parameters tab. On the left, a table lists stream names: 1 SIP, 2 RTP (highlighted), and 3 Data. The main area is titled 'WAN Emulation Parameters' and shows 'P1 -> P2' with a 'Mirror >>' button. Under 'Mode', 'Packet Mode' is selected. Below, checkboxes for MAC, VLAN, MPLS, IP, and UDP are shown, with 'UDP' checked. A table below lists layers: UDP with a summary of '1000 - 5000 --> 1000 - 5000'.

- Apply loss and jitter to RTP streams

The screenshot shows the configuration interface for WAN Emulation Parameters, specifically the 'WAN Emulation Parameters' tab. The 'WAN Stream Type' is set to 'Asymmetrical'. Below is a table of parameters for P1 -> P2 and P1 -> P2 Manual.

Parameters	P1 -> P2	P1 -> P2 Manual
Traffic Bandwidth	1000.00 Mbps	1000.00 Mbps
Latency	Random Exp. , 0 - 120 ms	Random Exp. , 0 - 120 m
Packet Loss	2.000 %	2.000 %
Packet Reordering	None	None
Packet Duplication	None	None
Logic Error Insertion	None	None

# VoIP (Contd.)

The screenshot shows the configuration interface for a VoIP stream. On the left, a table lists stream names: 1 SIP, 2 RTP, and 3 Data. The main area is titled 'WAN Emulation Parameters' and shows 'P1 -> P2' with a 'Mirror >>' button. Under 'Mode', 'Packet Mode' is selected. Below are checkboxes for MAC, VLAN, MPLS, IP, and UDP. At the bottom, there is a table for layer configuration.

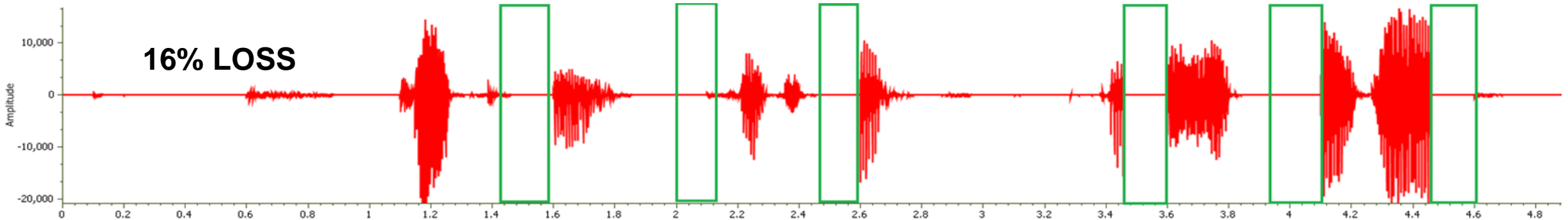
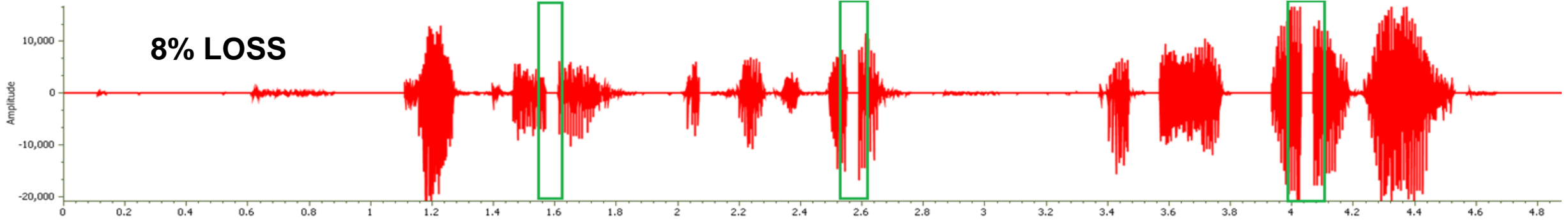
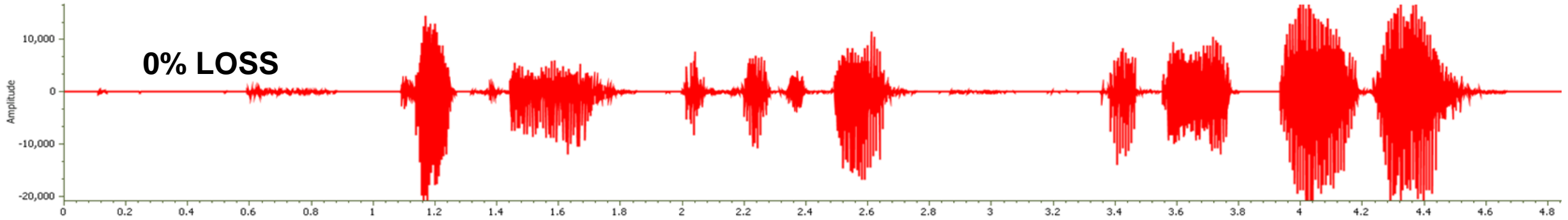
Layer (Click to edit)	Layer Summary

- Set an SLA style bandwidth cap on Data

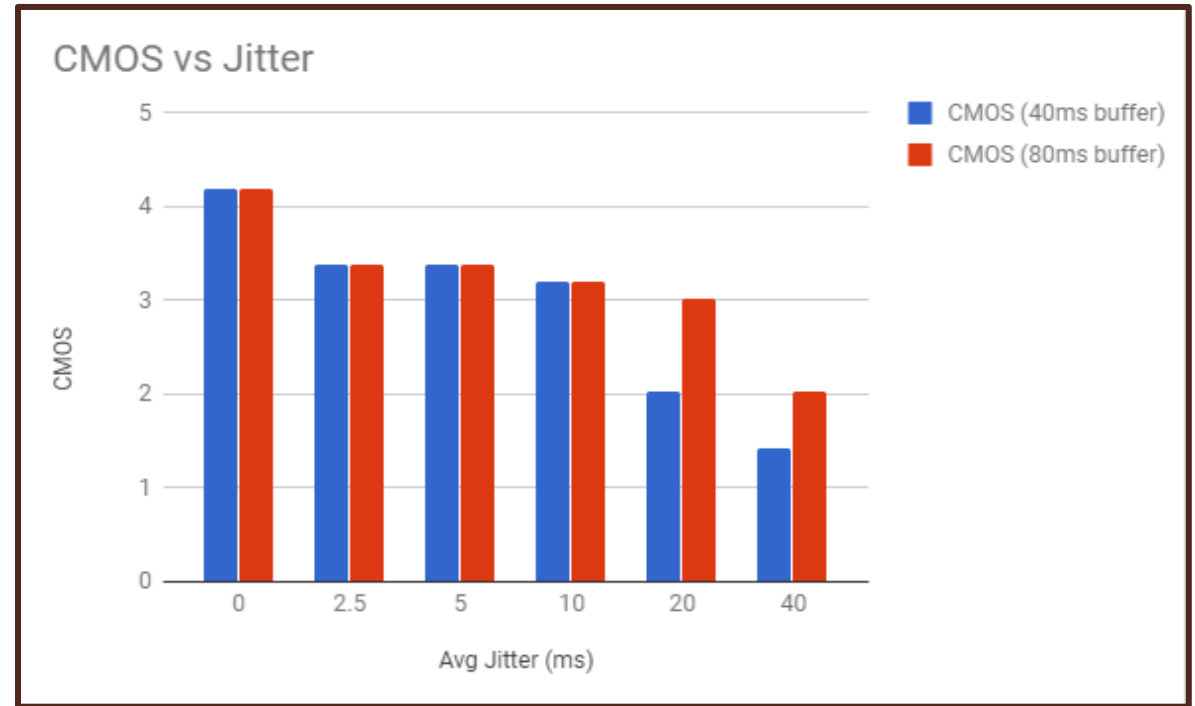
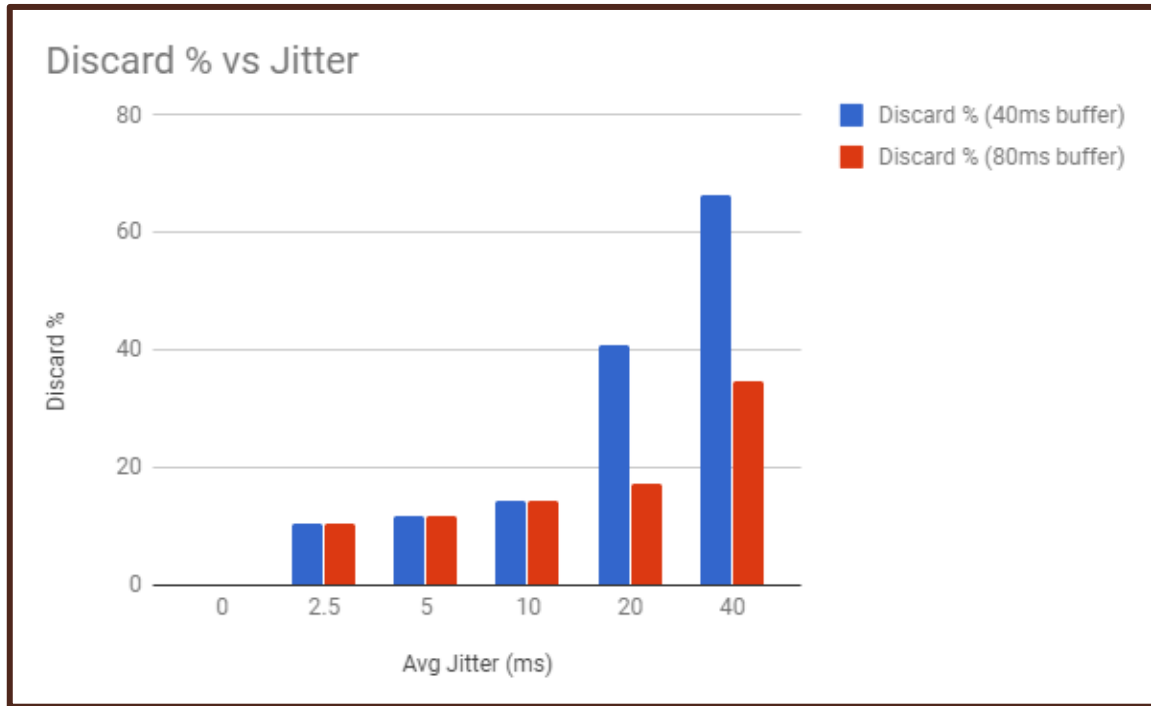
The screenshot shows the 'WAN Emulation Parameters' configuration page. The 'WAN Stream Type' is set to 'Asymmetrical'. Below is a table of parameters for P1 -> P2 and P1 -> P2 Manual.

Parameters	P1 -> P2	P1 -> P2 Manual
Traffic Bandwidth	200.00 Mbps	200.00 Mbps
Latency	None	None
Packet Loss	None	None
Packet Reordering	None	None
Packet Duplication	None	None
Logic Error Insertion	None	None

# VoIP (Contd.)

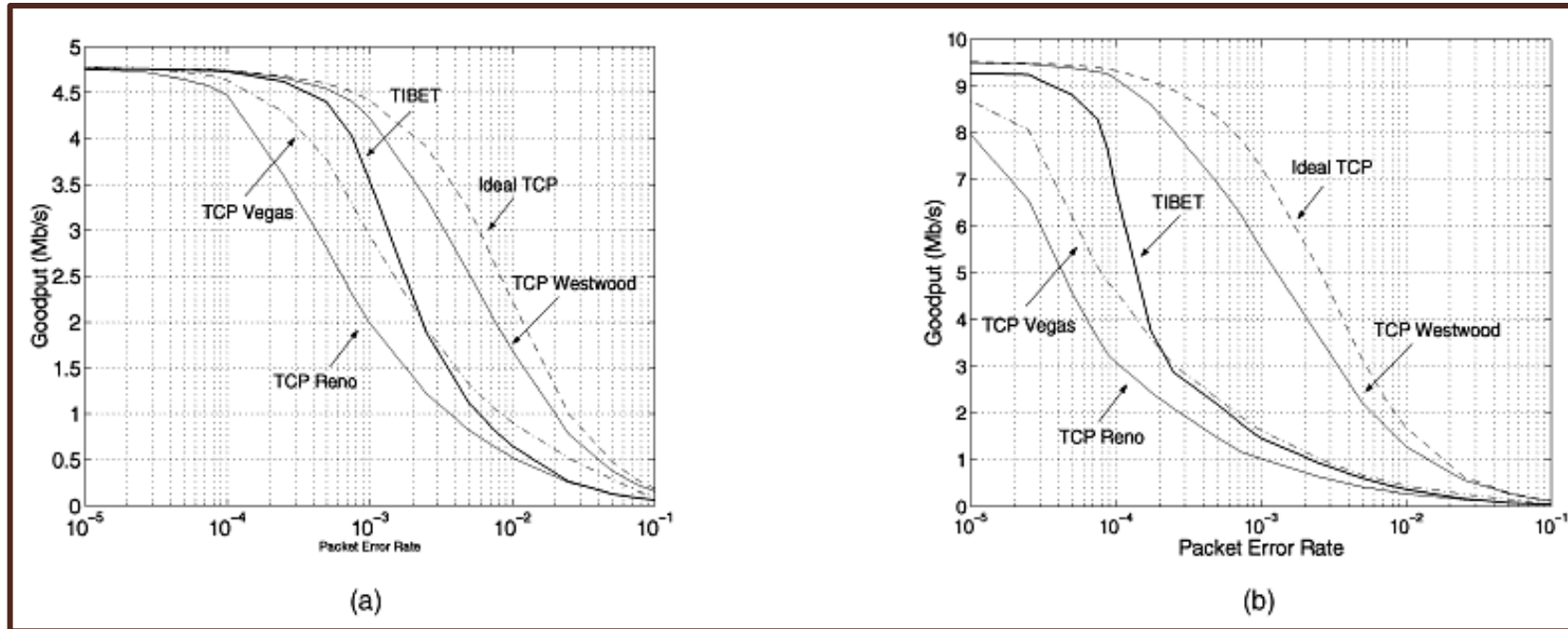


# VoIP (Contd.)



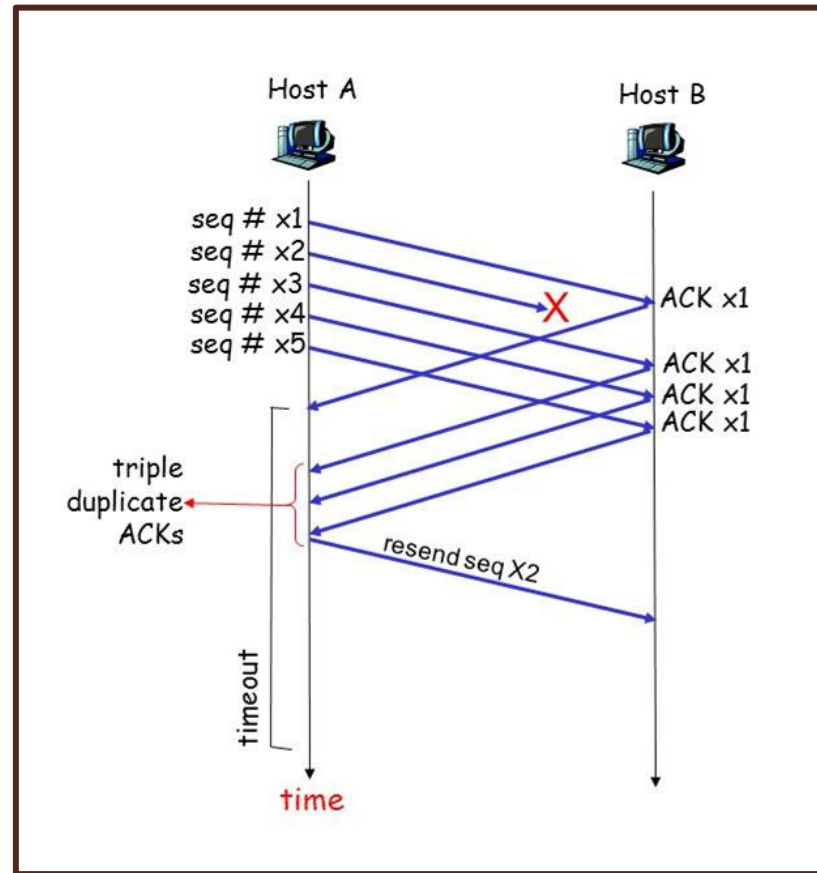
- Determine how your application will behave under expected (and unexpected) network conditions
- Determine what codecs you should use, what jitter buffers, etc.

# TCP Over Wireless



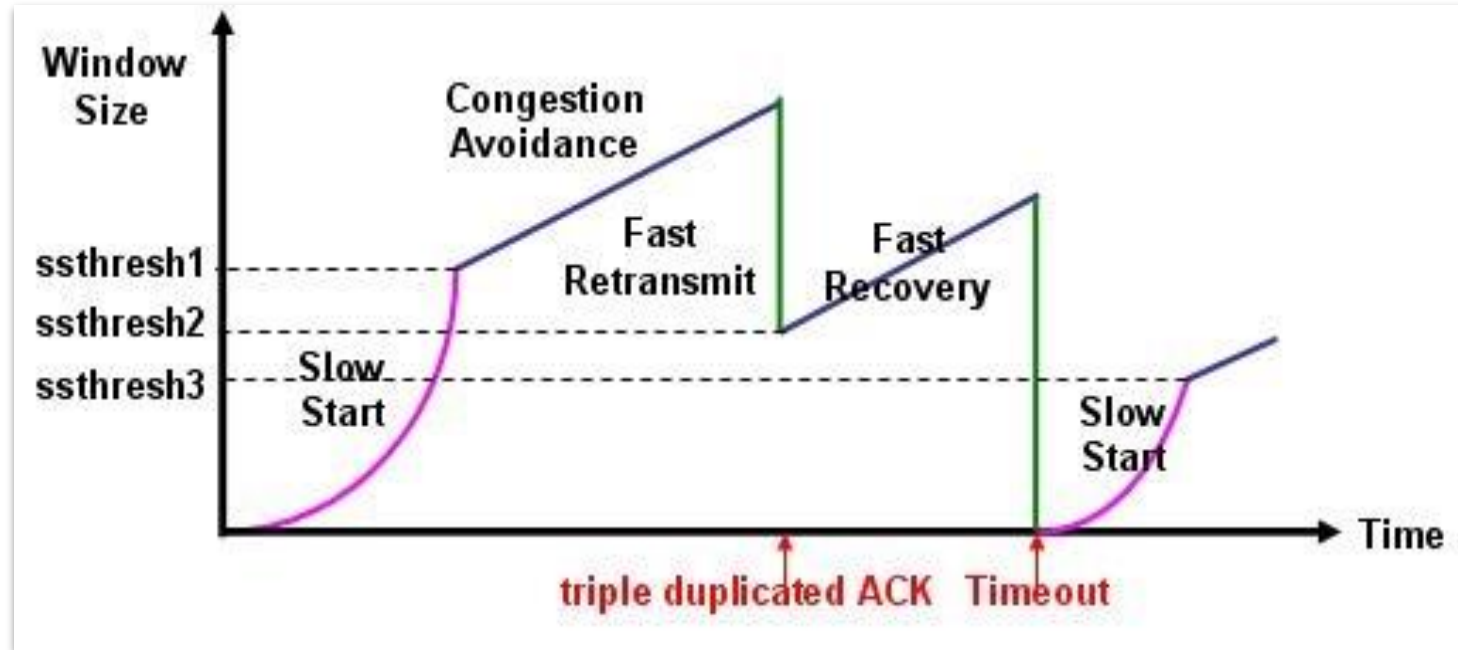
- TCP was first described in an IEEE paper written in 1974
- Ethernet was first standardized by the IEEE in 1983
- The first GSM Network went online in 1991

# TCP Over Wireless (Contd.)



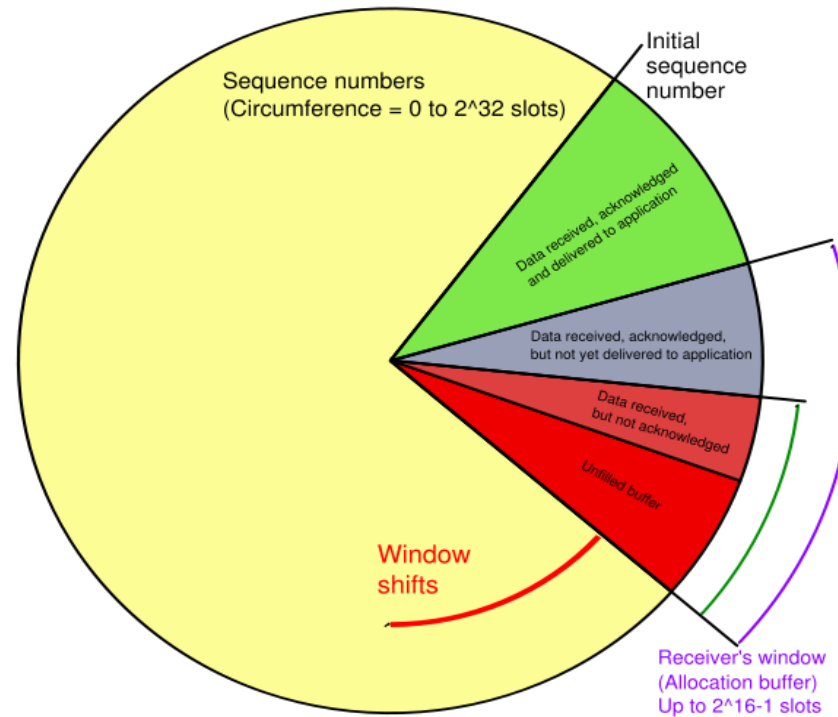
- Loss in a TCP application leads to duplicate ACKs, which lead to retransmissions

# TCP Over Wireless (Contd.)



- TCP assumes that Loss is due to Congestion
- When Loss occurs TCP automatically cuts throughput to avoid congestion

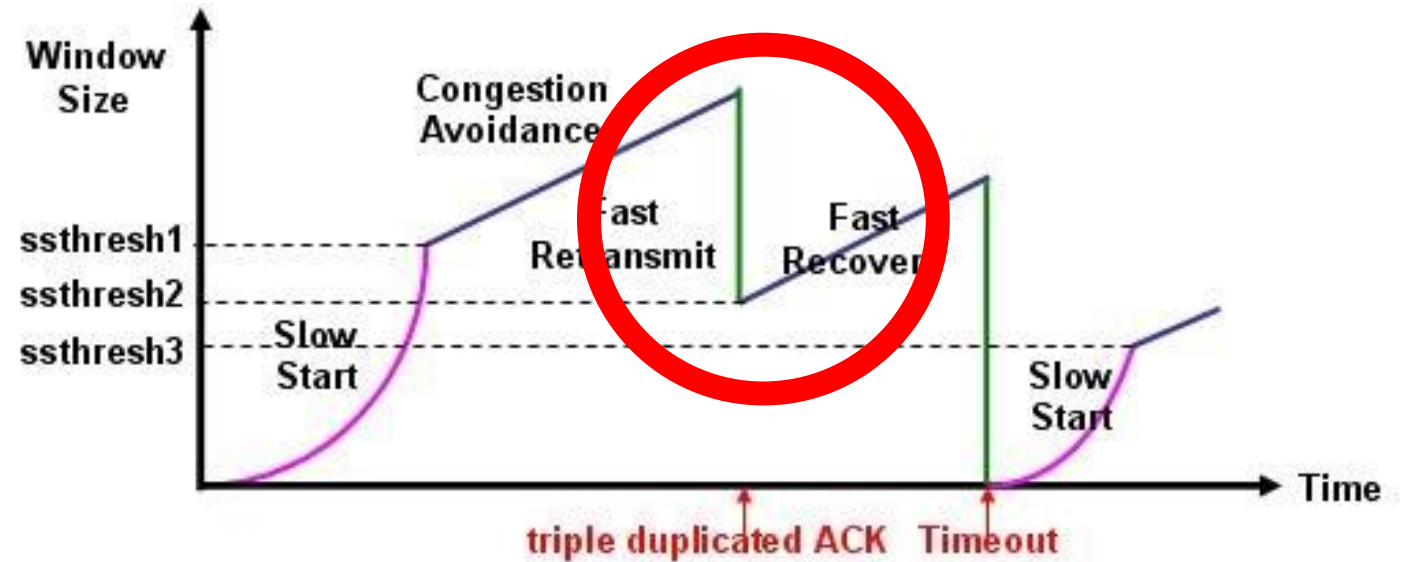
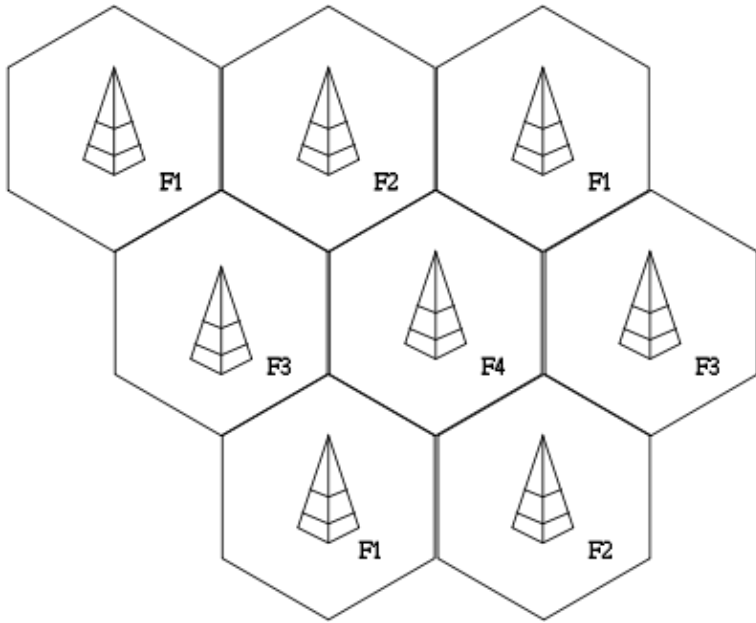
# TCP Over Wireless (Contd.)



- TCP uses a Sliding Window mechanism to limit how many unacknowledged bytes can be transmitted before the sender is forced to idle
- High Latency links slow ACKs, cause forced idle, and limit throughput

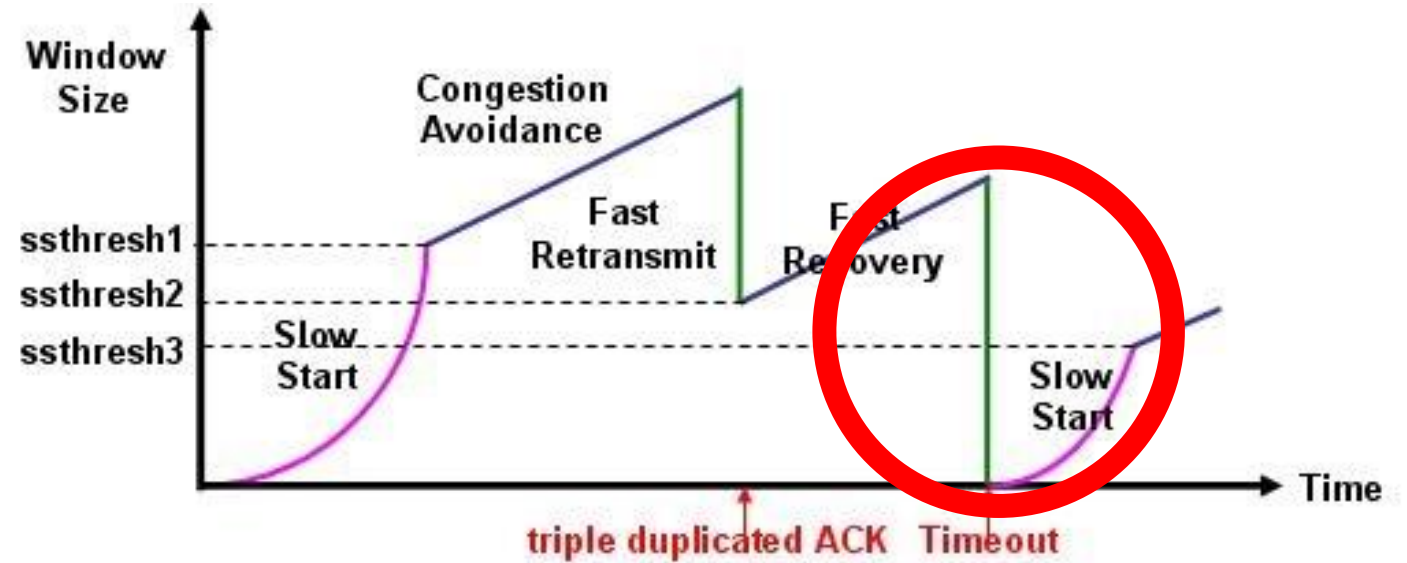
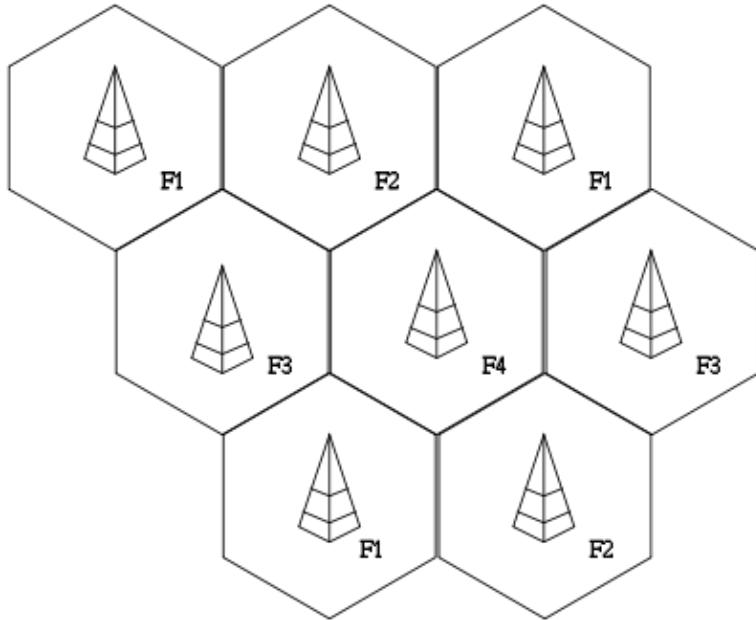


# TCP Over Wireless (Contd.)



- When a client moves between cells handoff will cause Loss
- TCP will interpret this as Congestion and cut throughput even if the exact same amount of bandwidth is still available (even if more bandwidth is now available)!

# TCP Over Wireless (Contd.)



- TCP has Retransmission Timeout mechanism that attempts to track the RTT of the connection
- If Latency suddenly increases (ie cell handoff), this can easily cause Timeouts to trigger, immediately cutting throughput to the minimum!

**THANK YOU!**