
SIMULATE REAL-WORLD IP NETWORKS

Impairments, Delay, Errors, Loss, Optical, Electrical...



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Company Overview – GL Communications Inc.

- ❖ Headquarters: Gaithersburg, Maryland USA
 - Multiple GL Branch Offices and Worldwide Representatives
- ❖ Founded in 1986
- ❖ Test & Measurement Equipment
 - IP, VoIP, SONET-SDH, TDM & Wireless Solutions
 - Visualization, Capture, Storage, Portability, Cost-Effectiveness
 - Endpoints Devices & Core Network Elements
- ❖ Engineering Consulting Services (mainly for Transportation and Government agencies)

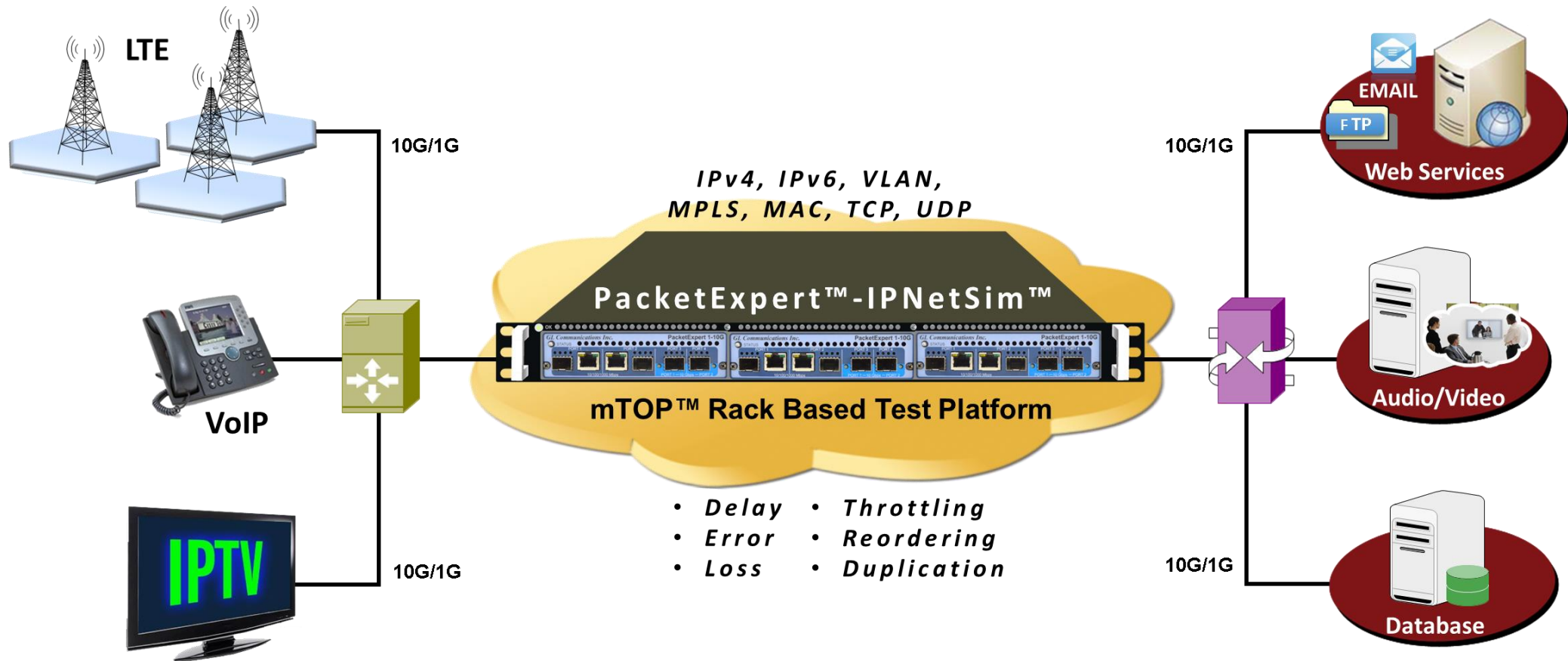


Overview

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

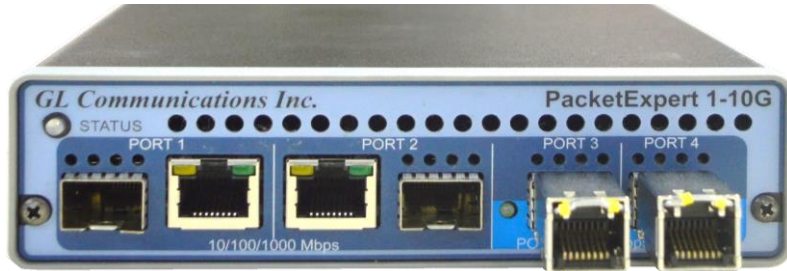
- ❖ Lab Testing Solution - application and automation
- ❖ Emulate Full Duplex 1 Gbps and 10 Gbps networks

- ❖ Real-world network conditions by imposing impairments
- ❖ Multiple streams independently configured



Hardware Overview

Portable Units

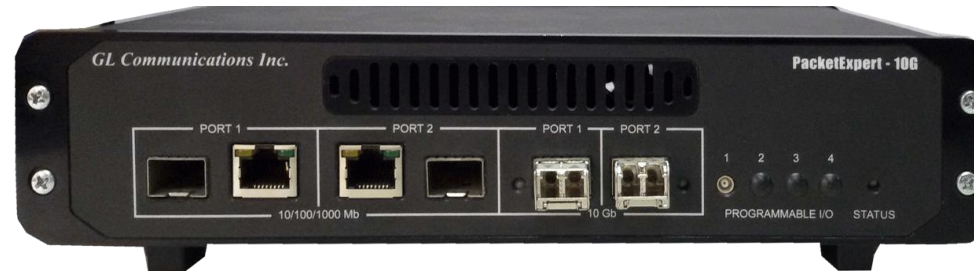


PacketExpert™ 10GX Standalone

- 4 x 1 Gbps Optical OR Electrical
- 2 x 10 Gbps Optical only



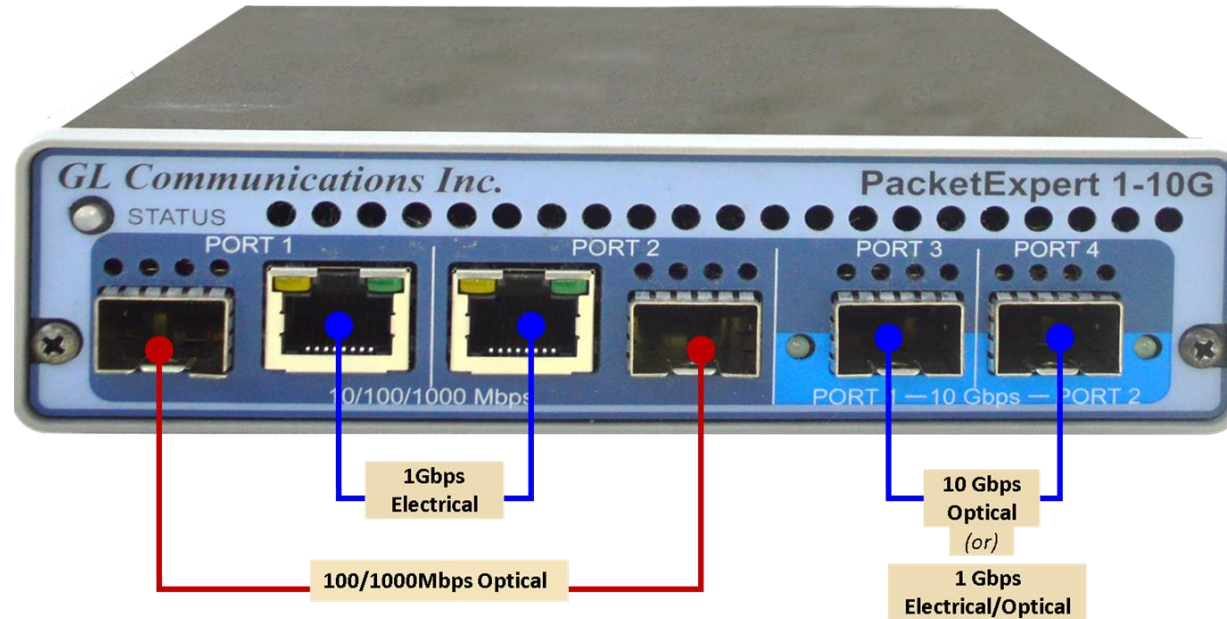
PacketExpert™ 1G (4 Port)



PacketExpert™ 10G Standalone

- 2 x 1 Gbps Optical OR Electrical
- 2 x 10 Gbps Optical only

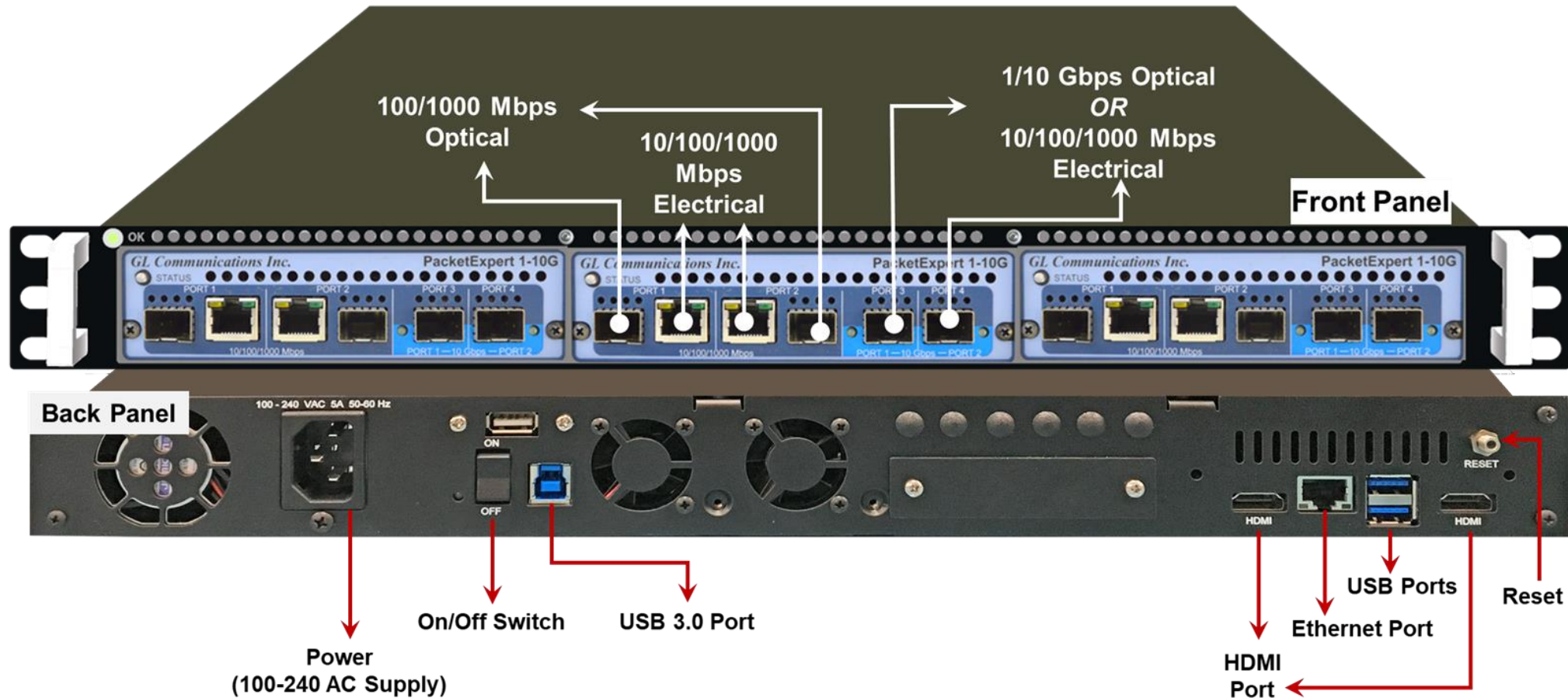
Hardware Overview + Highlights



IPNetSim™ is an optional application available within PacketExpert™ platforms (PXG100 and 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.

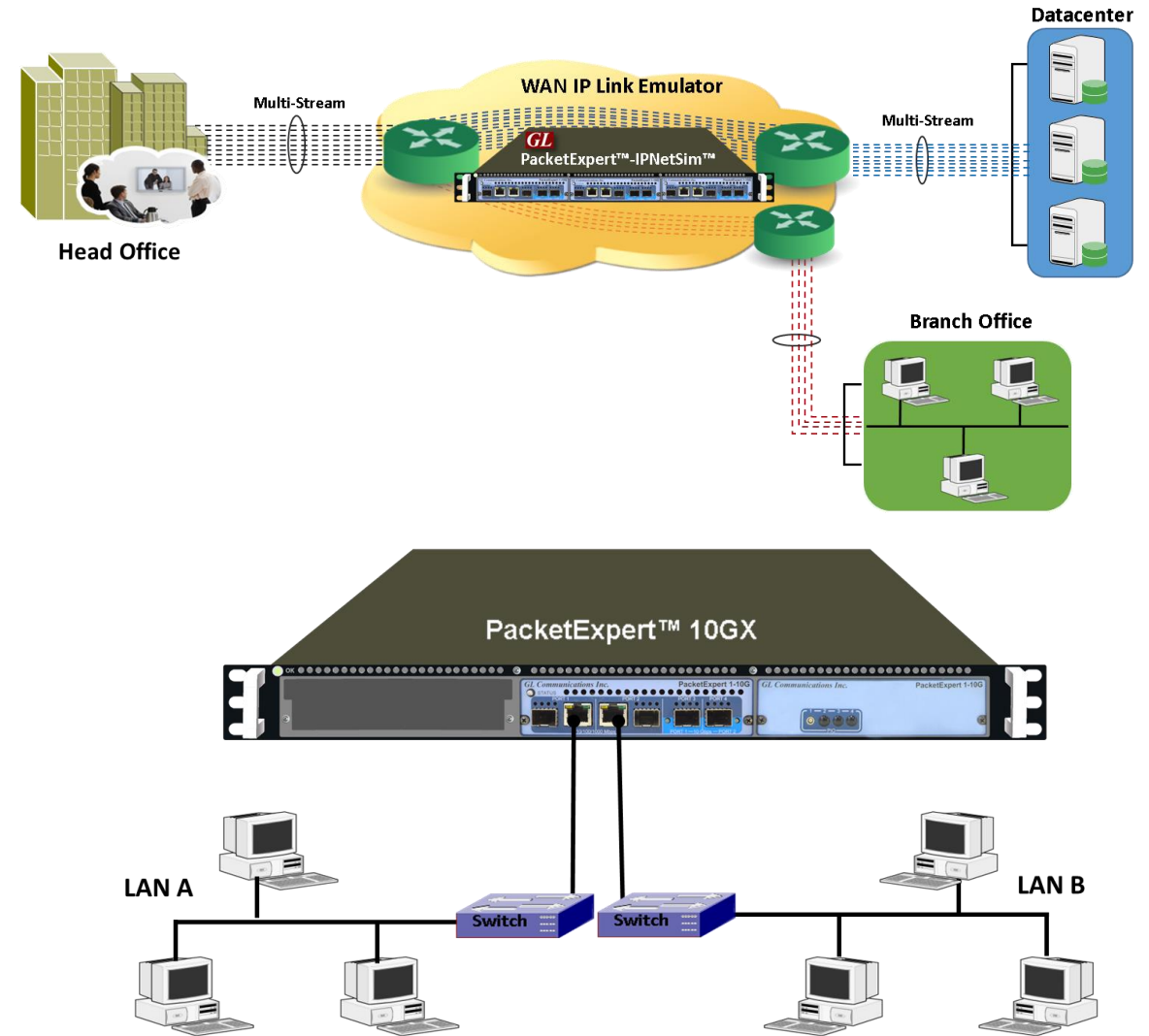
Hardware Interfaces



Application Overview

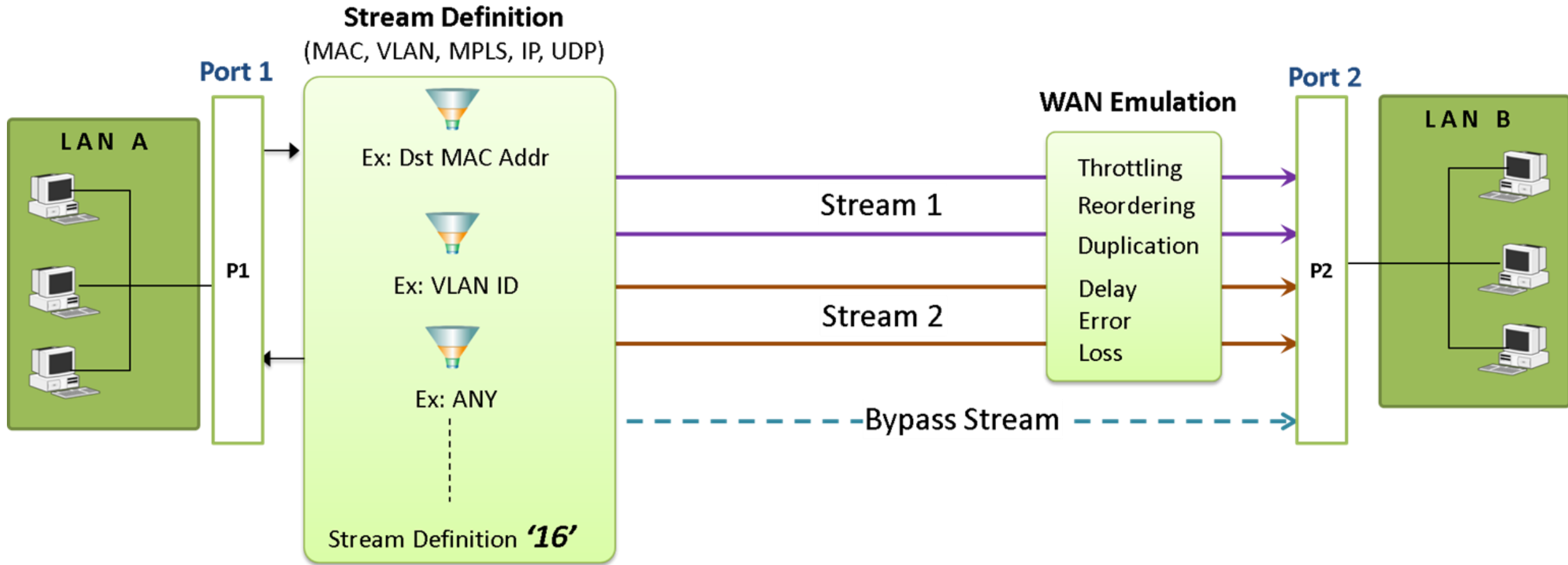
Application Overview

- ❖ 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

Mode

☒ Packet Mode ☐ Raw Mode

☒ MAC ☒ VLAN ☒ MPLS ☒ IP ☒ UDP

Layer (Click to edit)	Layer Summary
MAC	00-1F-D0-DC-20-A2 --> XX-XX-XX-XX-XX-XX
VLAN	100 - 200
MPLS	1234
IP	192.168.1.201 - 192.168.1.210 --> 192.168.1.101
UDP	20000 --> 30000

Source IP Address

☐ Fixed ☒ Range ☐ Any

From 192 . 168 . 1 . 201 To 192 . 168 . 1 . 210

Destination IP Address

☒ Fixed ☐ Range ☐ Any

IP Address 192 . 168 . 1 . 101

Apply

Define Streams in Raw Mode

Mode
☒ Raw Mode ☐ Packet Mode Offset

Bytes
Byte 0-7
Byte 8-15
Byte 16-23
Byte 24-31
Byte 32-39
Byte 40-47
Byte 48-55

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

Bytes	Value	Mask
0-7	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
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**

Stream Definition WAN Emulation Parameters Scheduler

WAN Stream Type ☐ Symmetrical ☒ Asymmetrical

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	100.00 Mbps	800.00 Mbps
Latency	Uniform, 0 - 8000 ms	
Packet Loss	None	
Packet Reordering	None	
Packet Duplication	None	
Logic Error Insertion	None	

P1 -> P2 P1 -> P2

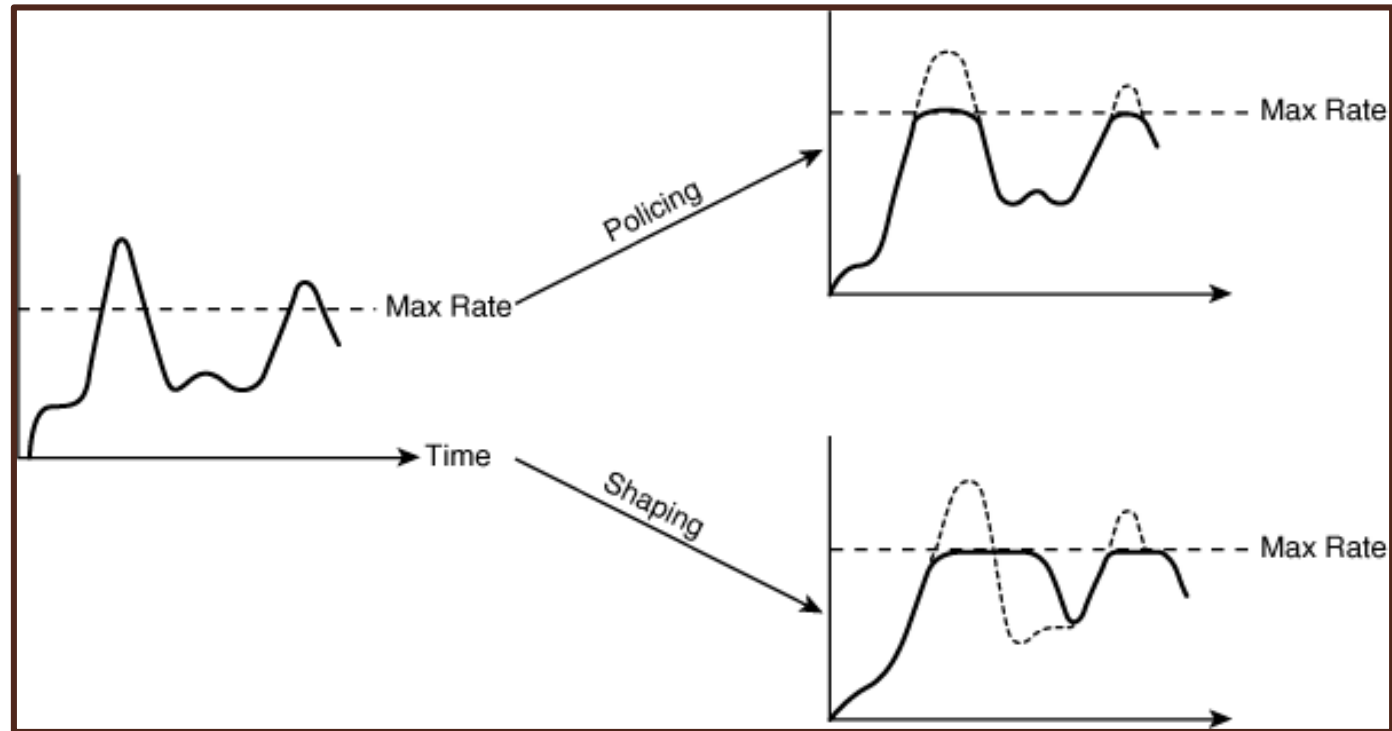
Traffic Bandwidth

100.000000 Mbps

Traffic Bandwidth

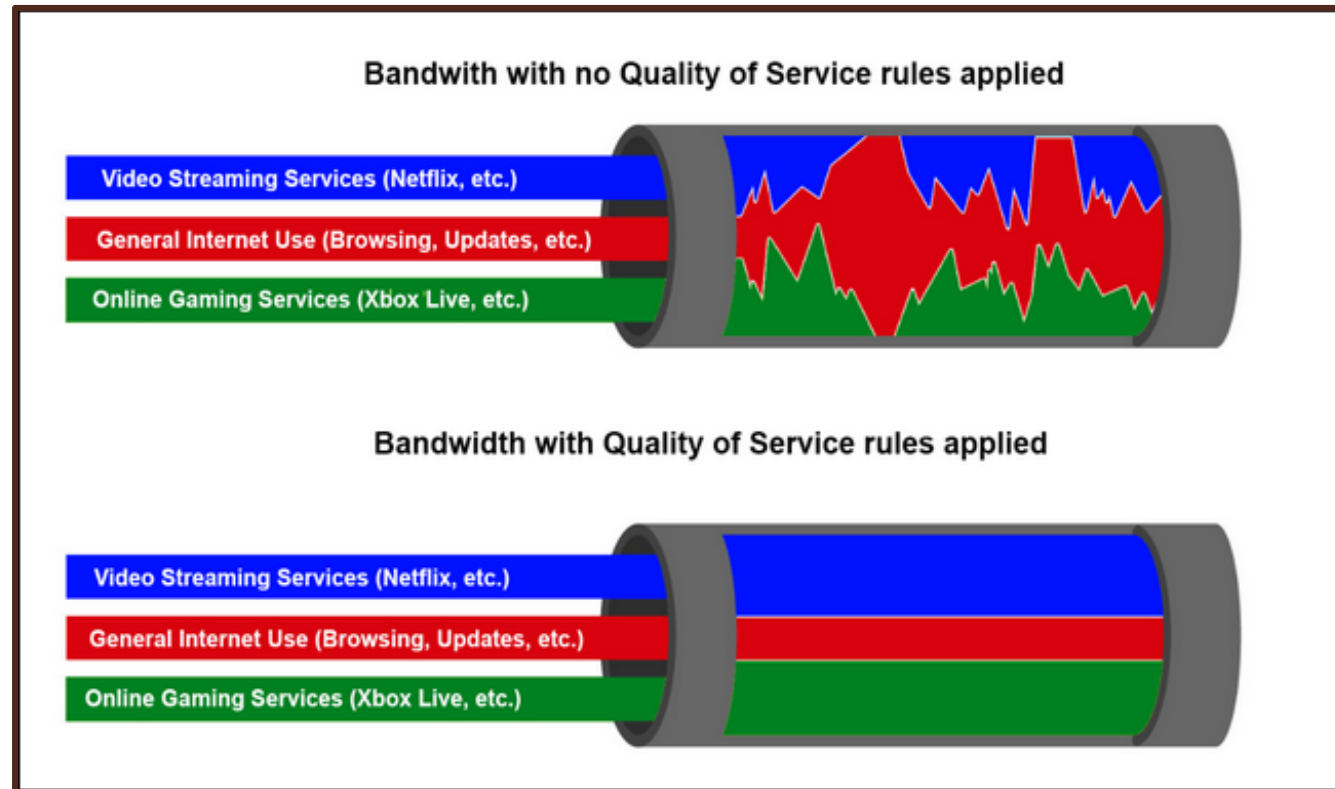
800.000000 Mbps

Traffic Bandwidth



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

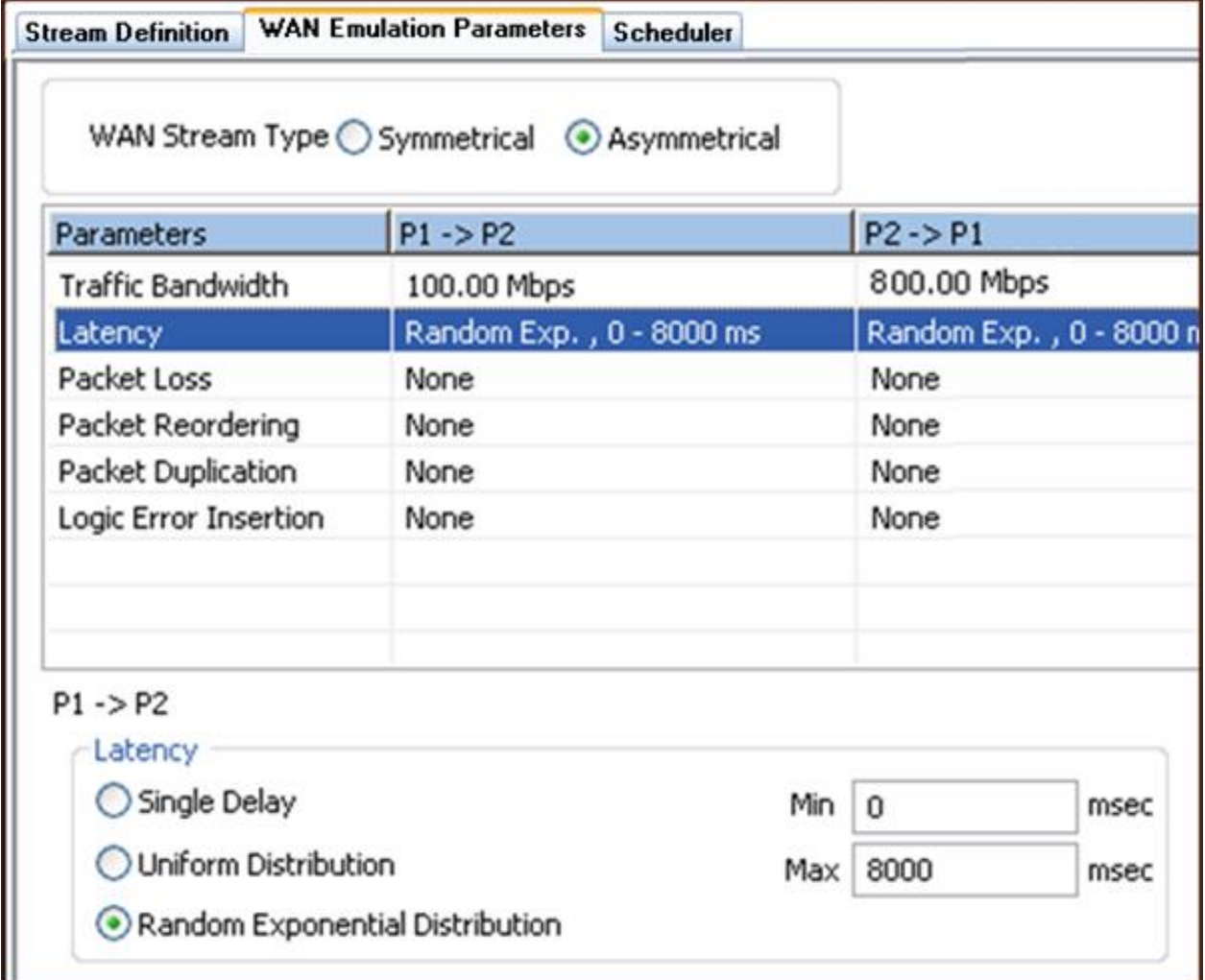
Traffic Bandwidth



❖ ***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 8000 ms** in 1ms increments



The screenshot shows a software interface for configuring WAN emulation parameters. It has three tabs: 'Stream Definition', 'WAN Emulation Parameters' (which is active), and 'Scheduler'. Under 'WAN Stream Type', 'Asymmetrical' is selected. A table below lists parameters for two directions: P1 -> P2 and P2 -> P1. The 'Latency' row is highlighted in blue. Below the table, there is a section for 'P1 -> P2' latency configuration, where 'Random Exponential Distribution' is selected, and the range is set from 0 to 8000 msec.

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	100.00 Mbps	800.00 Mbps
Latency	Random Exp. , 0 - 8000 ms	Random Exp. , 0 - 8000 ms
Packet Loss	None	None
Packet Reordering	None	None
Packet Duplication	None	None
Logic Error Insertion	None	None

P1 -> P2

Latency

☐ Single Delay

☐ Uniform Distribution

☒ Random Exponential Distribution

Min msec

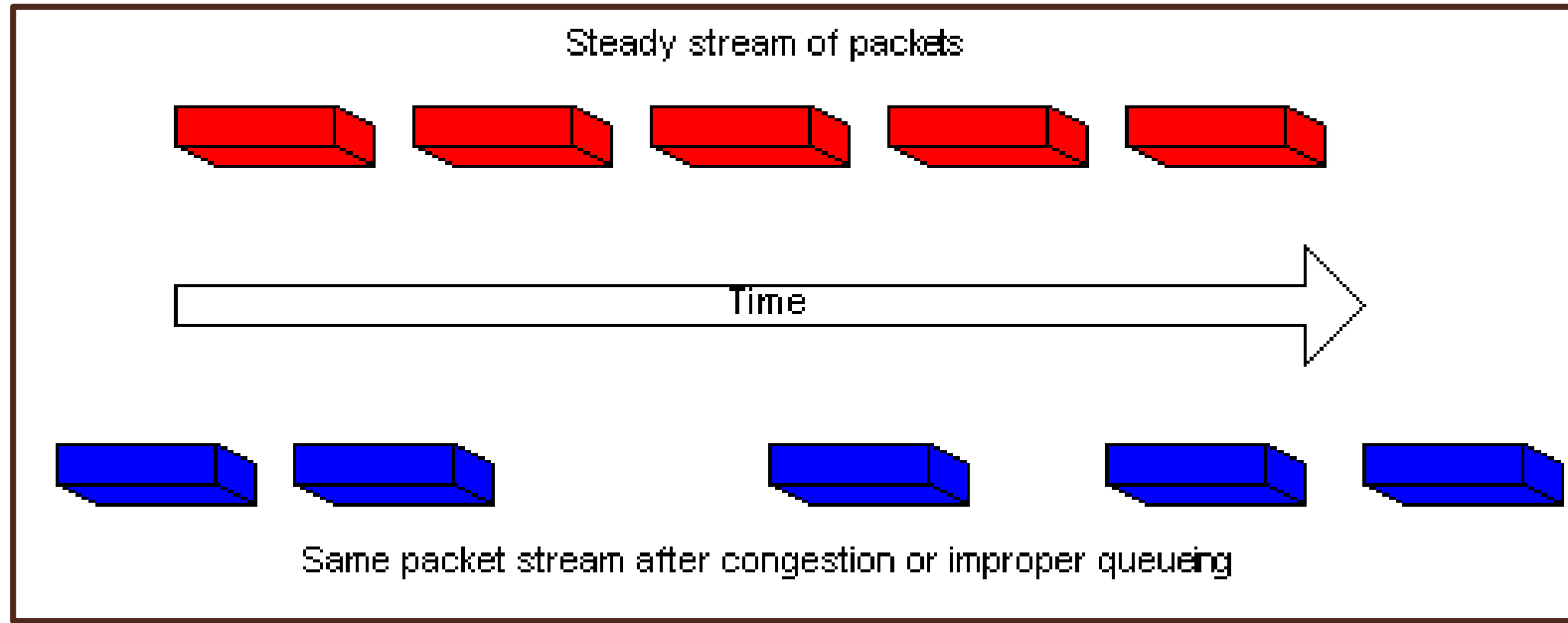
Max msec

Latency / Jitter



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

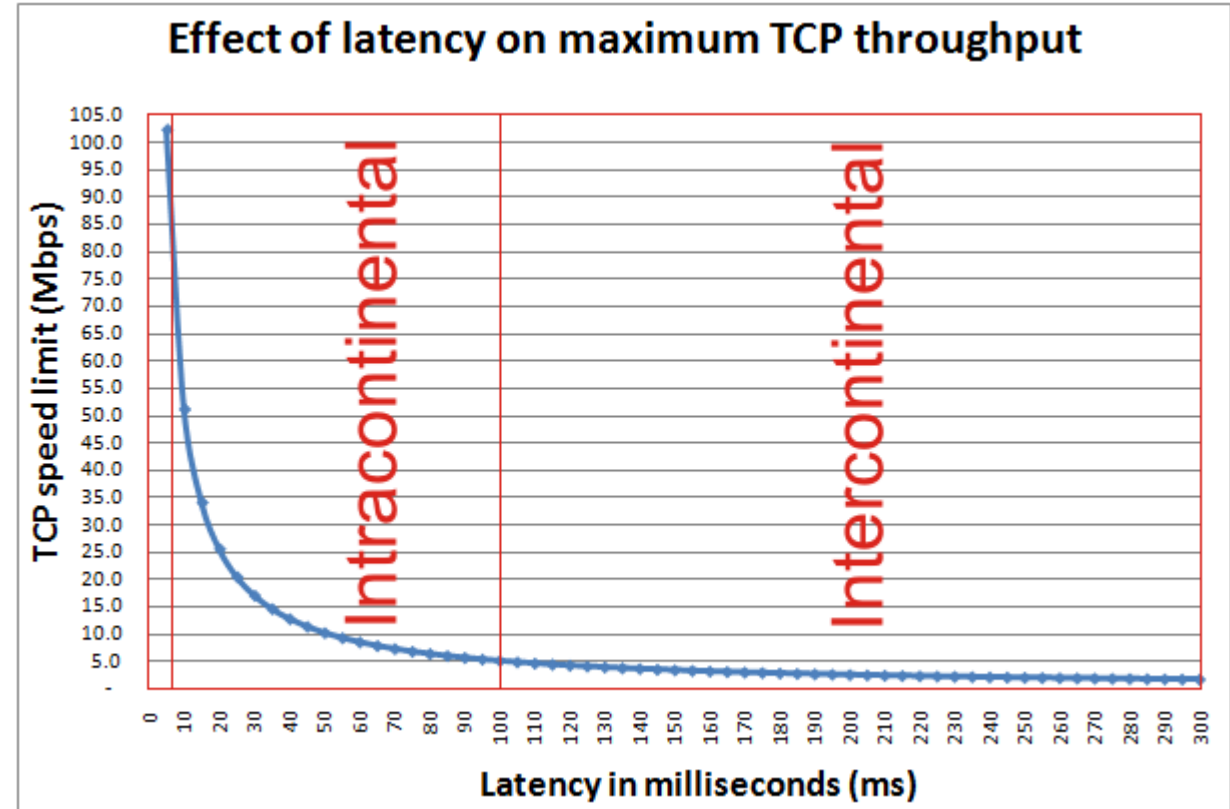
Latency / Jitter



- 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

- 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

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

Stream Definition

WAN Emulation Parameters

Scheduler

WAN Stream Type ☐ Symmetrical ☒ Asymmetrical

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	1000.00 Mbps	800.00 Mbps
Latency	Single Delay, 5 ms	Uniform, 3 - 5 ms
Packet Loss	5.000 %	10.000 %
Packet Reordering	None	None
Packet Duplication	None	None
Logic Error Insertion	None	None

P1 -> P2

Packet Loss(Single Packet)

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

Rate %

P2 -> P1

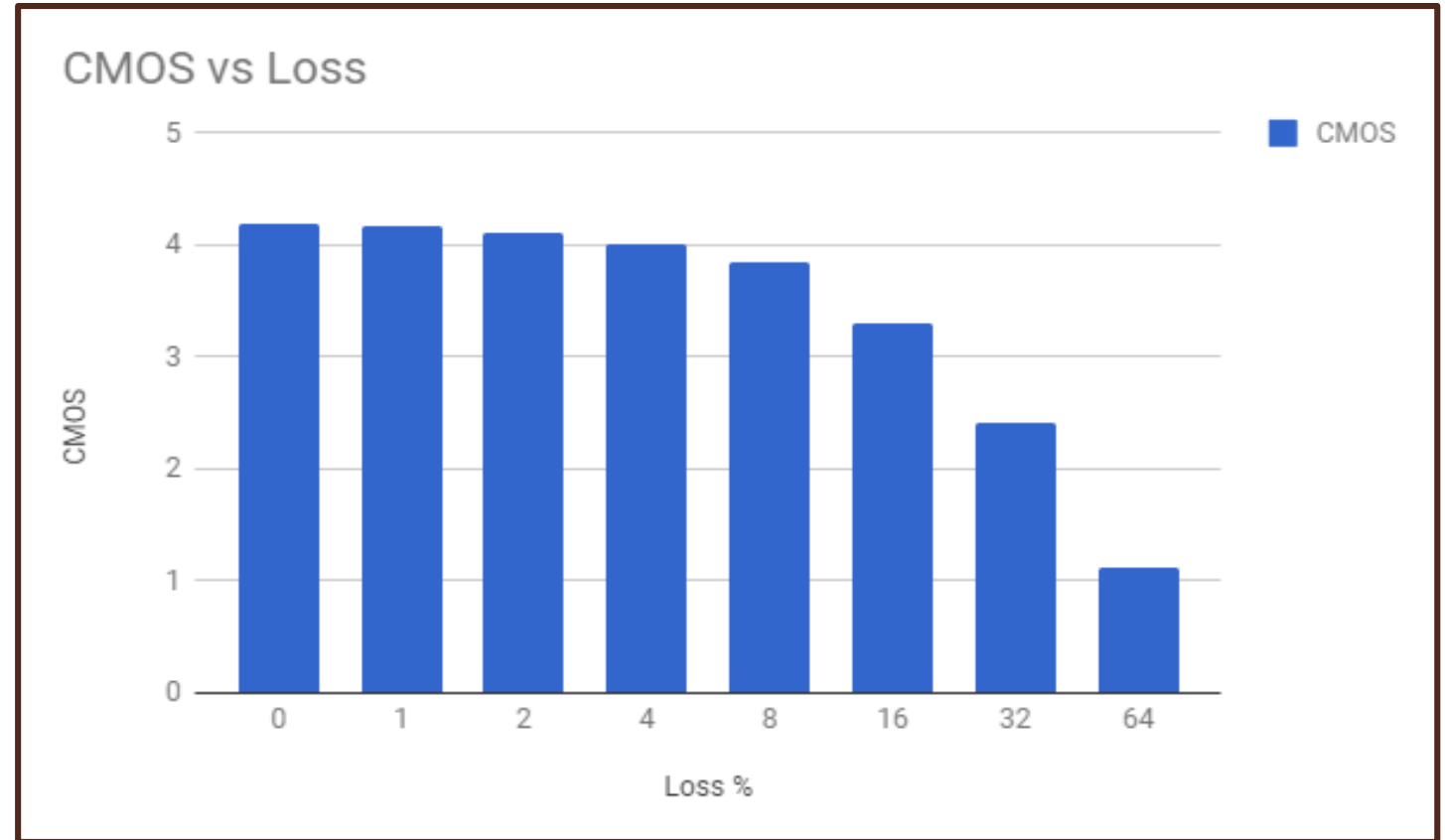
Packet Loss(Single Packet)

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

Rate %

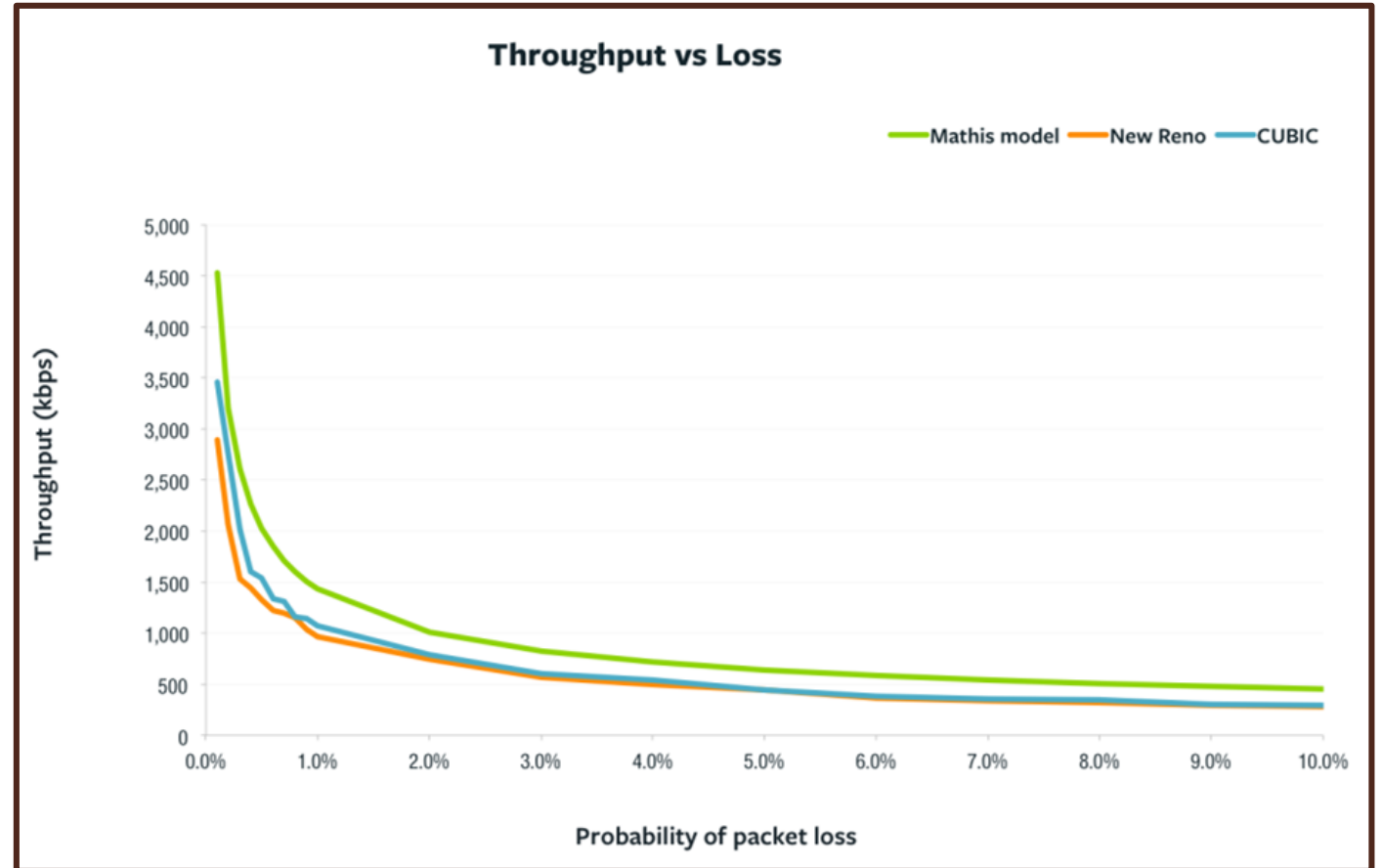
Packet Loss

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



Packet Loss

- 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	1000.00 Mbps	100.00 Mbps
Latency	Single Delay, 100 ms	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(Single Packet)

Reorder 1 packet out of 10 packets

Delay Offset (Time)

Min 0 ms Max 10 ms

P2 -> P1

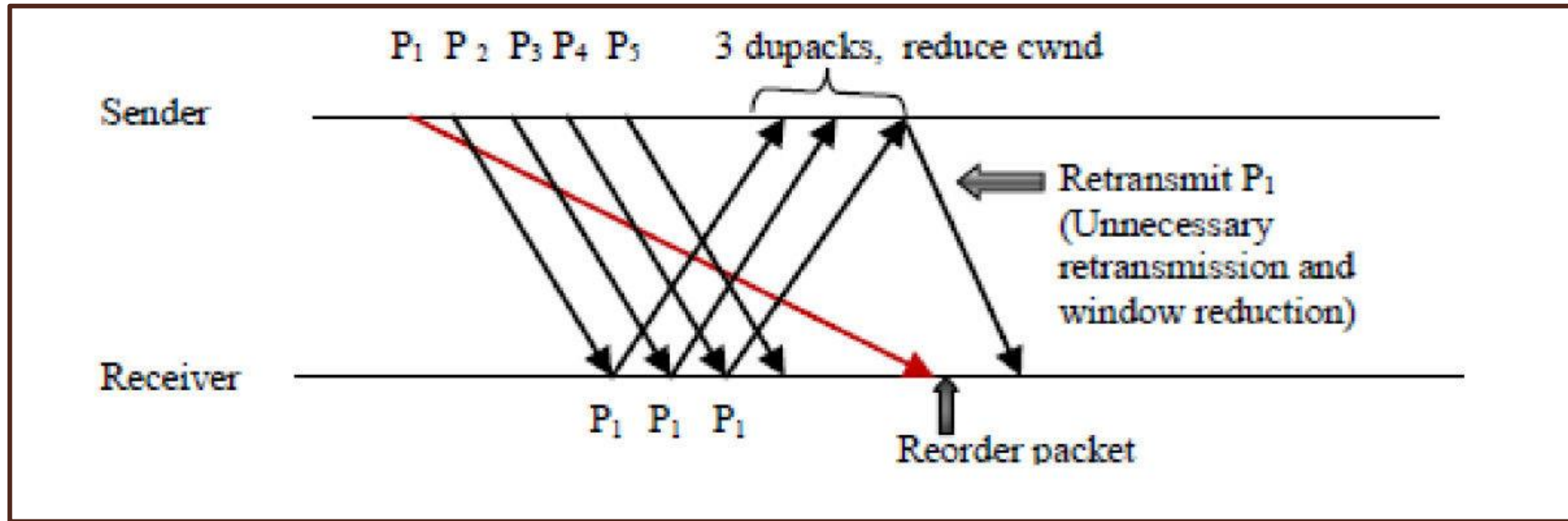
Packet Reordering(Single Packet)

Reorder 1 packet out of 20 packets

Delay Offset (Time)

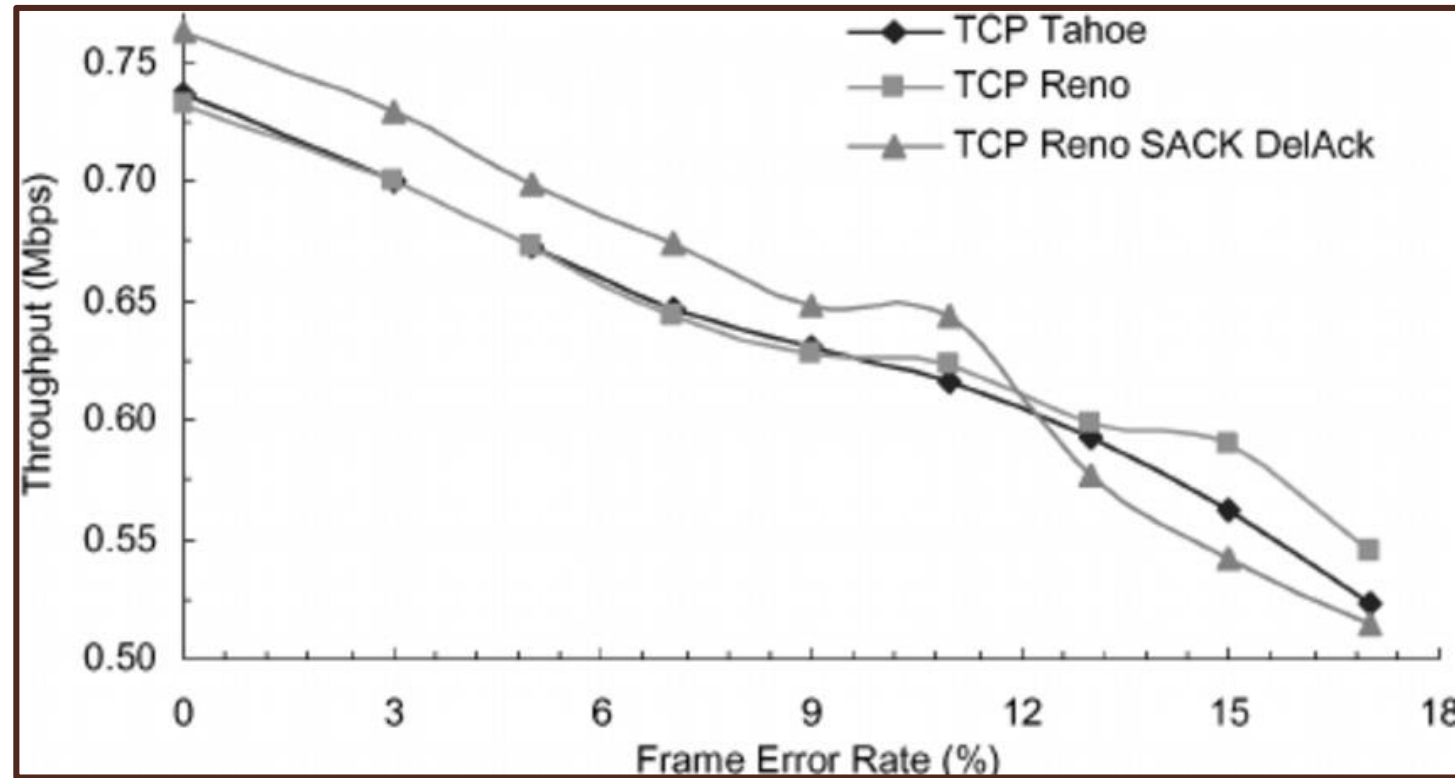
Min 0 ms Max 20 ms

Packet Reordering



- 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



- 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	1000.00 Mbps	1000.00 Mbps
Latency	Single Delay, 100 ms	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 (Periodic)

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

Rate %

P2 -> P1

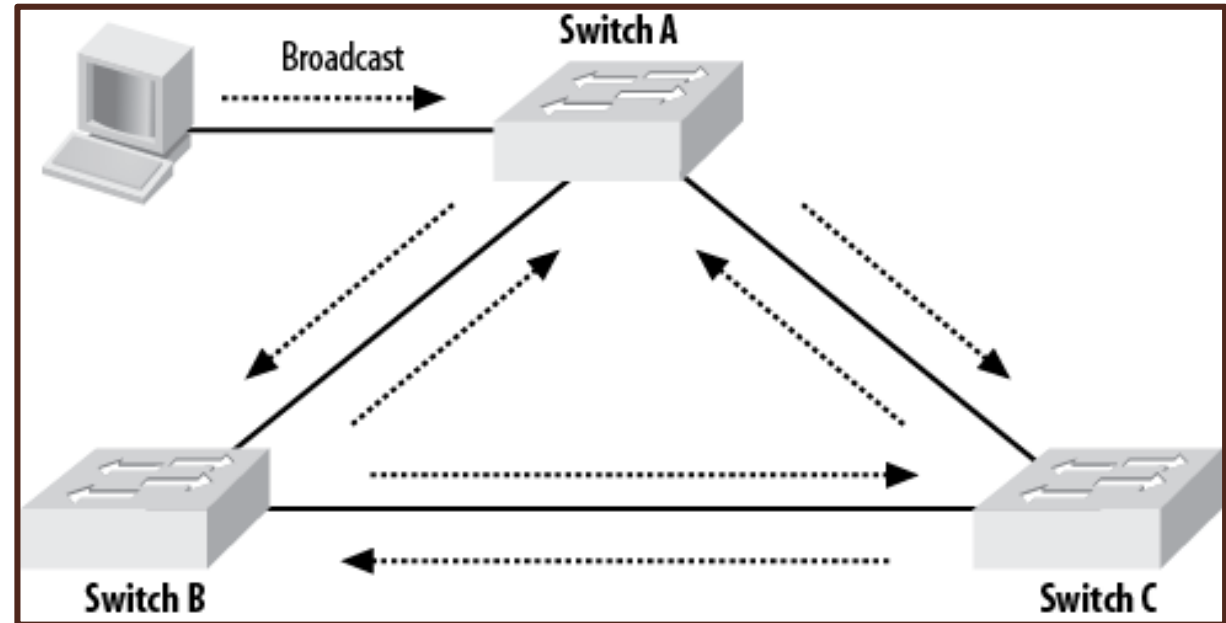
Duplication (Periodic)

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

Rate %

Packet Duplication

- Duplication can be fatal in broadcast situations (ie 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

The screenshot shows the 'WAN Emulation Parameters' tab in a software interface. At the top, 'WAN Stream Type' is set to 'Asymmetrical'. Below this is a table of parameters for two directions: P1 -> P2 and P2 -> P1. The 'Logic Error Insertion' row is highlighted with a red circle, showing values of 10^{-2} for P1 -> P2 and 10^{-5} for P2 -> P1. Below the table, there are two detailed configuration sections for 'Logic Error Insertion(Periodic)'. The left section for P1 -> P2 shows a 'Packet Error Rate' of 10^{-2} and two 'Bytes Offset' fields: 5 (Beginning of frame) and 10 (End of frame). The right section for P2 -> P1 shows a 'Packet Error Rate' of 10^{-5} and two 'Bytes Offset' fields: 15 (Beginning of frame) and 20 (End of frame).

Parameters	P1 -> P2	P2 -> P1
Traffic Bandwidth	1000.00 Mbps	1000.00 Mbps
Latency	Single Delay, 100 ms	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(Periodic)

Packet Error Rate: 10^{-2}

Bytes Offset: 5 (Beginning of frame)

Bytes Offset: 10 (End of frame)

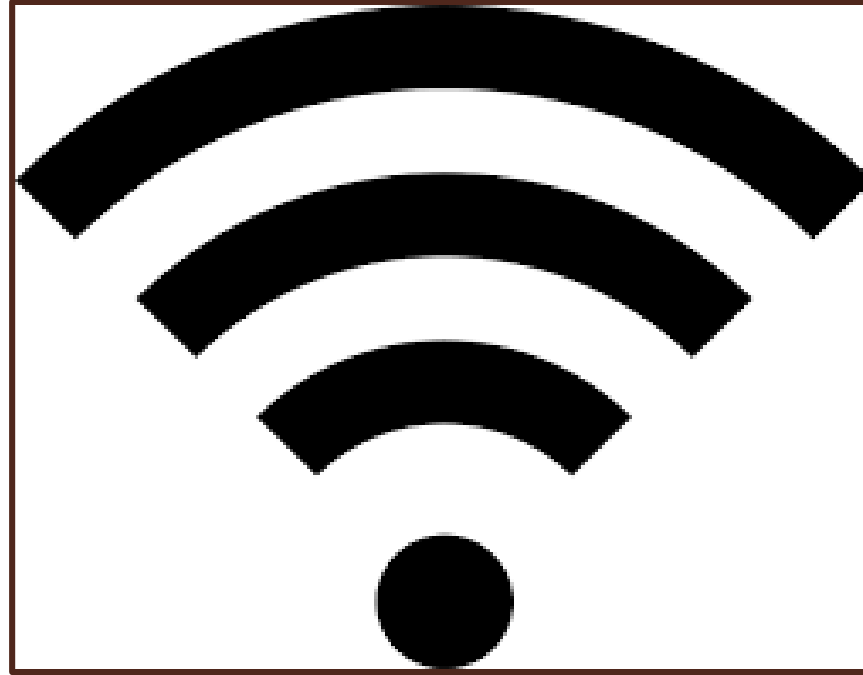
P2 -> P1 Logic Error Insertion(Periodic)

Packet Error Rate: 10^{-5}

Bytes Offset: 15 (Beginning of frame)

Bytes Offset: 20 (End of frame)

Logic Error Insertion



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

Application Examples

Application Example: VoIP

The screenshot shows the 'Stream Definition' tab in a configuration interface. On the left, a table lists three streams: 1 SIP, 2 RTP, and 3 Data. The main area is titled 'P1 -> P2' and includes a 'Mirror >>' button. Under the 'Mode' section, 'Packet Mode' is selected. Below this, a row of checkboxes shows 'MAC', 'VLAN', 'MPLS', 'IP', and 'UDP' (which is checked). At the bottom, a table shows the 'Layer (Click to edit)' and 'Layer Summary' for the selected UDP layer, with a summary of '5060 --> 5060'.

#	Stream Name
1	SIP
2	RTP
3	Data

Stream Definition | WAN Emulation Parameters | Scheduler

P1 -> P2 [Mirror >>]

Mode: ☒ Packet Mode ☐ Raw Mode

☐ MAC ☐ VLAN ☐ MPLS ☐ IP ☒ UDP

Layer (Click to edit)	Layer Summary
UDP	5060 --> 5060

- Configure SIP packets to be completely unimpaired

The screenshot shows the 'WAN Emulation Parameters' tab. It features a 'WAN Stream Type' section with 'Asymmetrical' selected. Below this is a table with three columns: 'Parameters', 'P1 -> P2', and 'P1 -> P2 Manual'. The table lists various parameters such as Traffic Bandwidth, Latency, Packet Loss, Packet Reordering, Packet Duplication, and Logic Error Insertion, all of which are set to 'None' or specific values like 1000.00 Mbps and 100.00 Mbps.

#	Stream Name
1	SIP
2	RTP
3	Data

Stream Definition | WAN Emulation Parameters | Scheduler

WAN Stream Type: ☐ Symmetrical ☒ Asymmetrical

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

Application Example: VoIP

The screenshot shows the 'Stream Definition' tab of the WAN Emulation Parameters configuration window. On the left, a table lists stream components: #1 SIP, #2 RTP (highlighted), and #3 Data. The main area 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'.

#	Stream Name
1	SIP
2	RTP
3	Data

Stream Definition | WAN Emulation Parameters | Scheduler

P1 -> P2 [Mirror >>]

Mode: ☒ Packet Mode ☐ Raw Mode

☐ MAC ☐ VLAN ☐ MPLS ☐ IP ☒ UDP

Layer (Click to edit)	Layer Summary
UDP	1000 - 5000 --> 1000 - 5000

- Apply loss and jitter to RTP streams

The screenshot shows the 'WAN Emulation Parameters' tab. It features a 'WAN Stream Type' section with 'Asymmetrical' selected. Below is a table with three columns: Parameters, P1 -> P2, and P1 -> P2 Manual. The parameters include Traffic Bandwidth, Latency, Packet Loss, Packet Reordering, Packet Duplication, and Logic Error Insertion.

Stream Definition | WAN Emulation Parameters | Scheduler

WAN Stream Type: ☐ Symmetrical ☒ Asymmetrical

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

Application Example: VOIP

#	Stream Name
1	SIP
2	RTP
3	Data

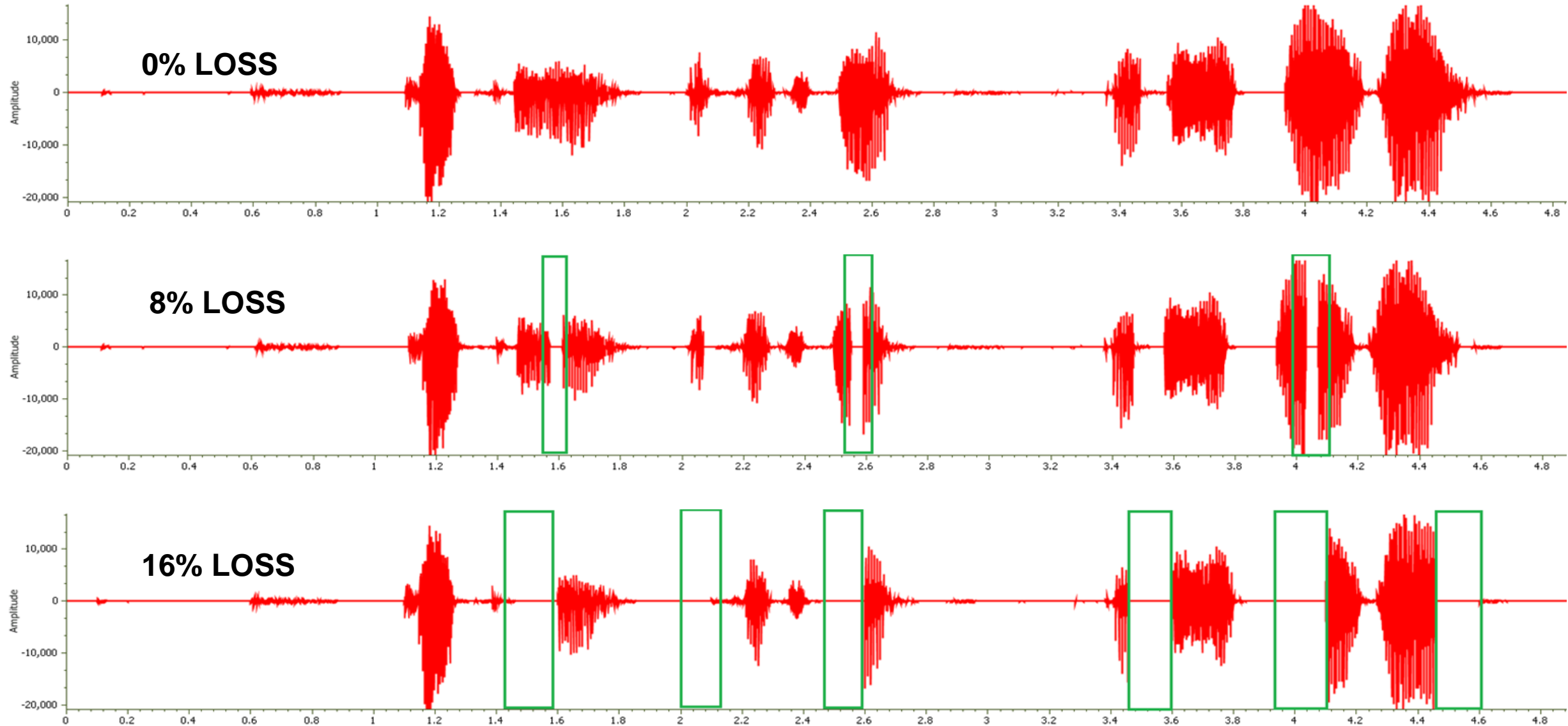
Stream Definition	WAN Emulation Parameters	Scheduler												
P1 -> P2 Mirror >>														
Mode <input checked="" type="radio"/> Packet Mode <input type="radio"/> Raw Mode														
<input type="checkbox"/> MAC <input type="checkbox"/> VLAN <input type="checkbox"/> MPLS <input type="checkbox"/> IP <input type="checkbox"/> UDP														
<table border="1"><thead><tr><th>Layer (Click to edit)</th><th>Layer Summary</th></tr></thead><tbody><tr><td> </td><td> </td></tr><tr><td> </td><td> </td></tr><tr><td> </td><td> </td></tr><tr><td> </td><td> </td></tr><tr><td> </td><td> </td></tr></tbody></table>			Layer (Click to edit)	Layer Summary										
Layer (Click to edit)	Layer Summary													

- Set an SLA style bandwidth cap on Data

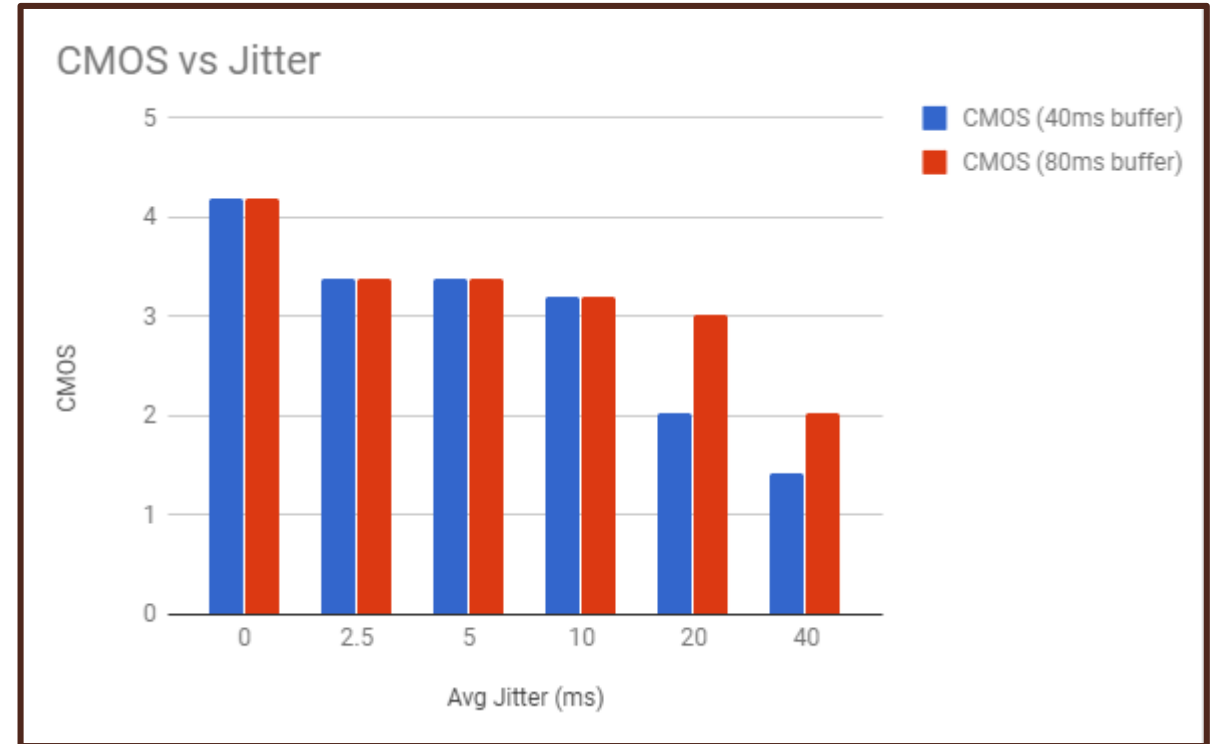
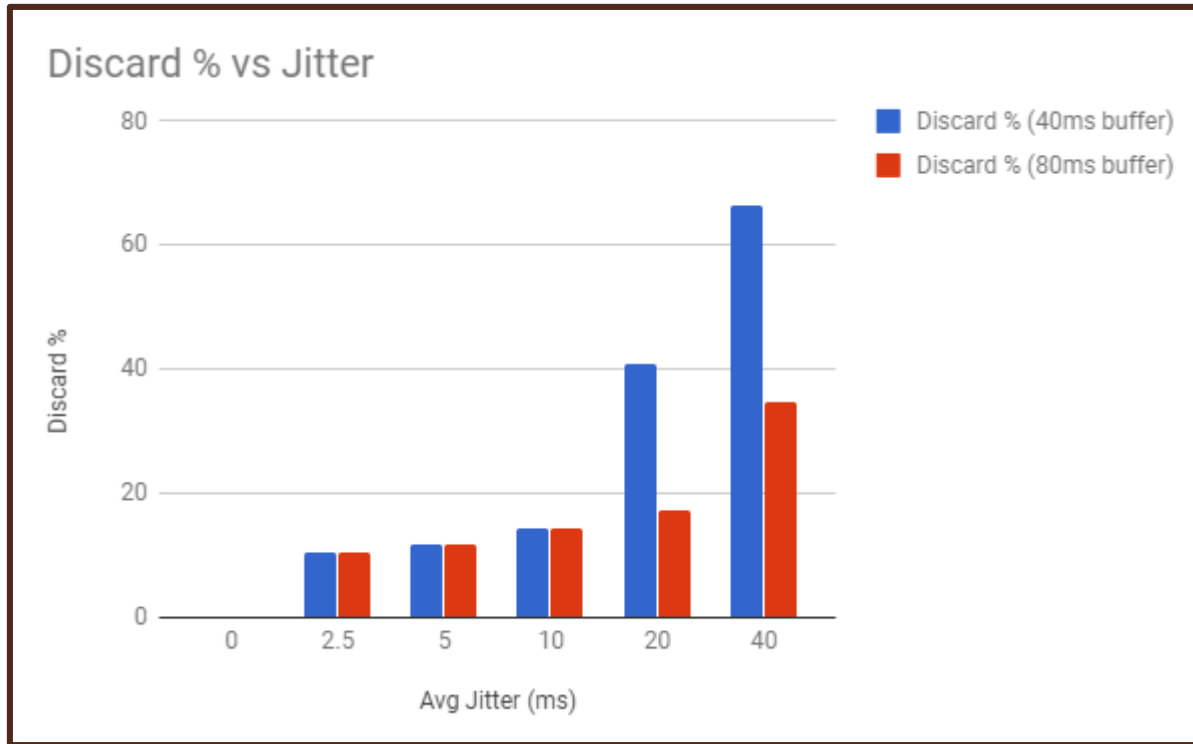
#	Stream Name
1	SIP
2	RTP
3	Data

Stream Definition	WAN Emulation Parameters	Scheduler
WAN Stream Type <input type="radio"/> Symmetrical <input checked="" type="radio"/> Asymmetrical		
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

Application Example: VoIP

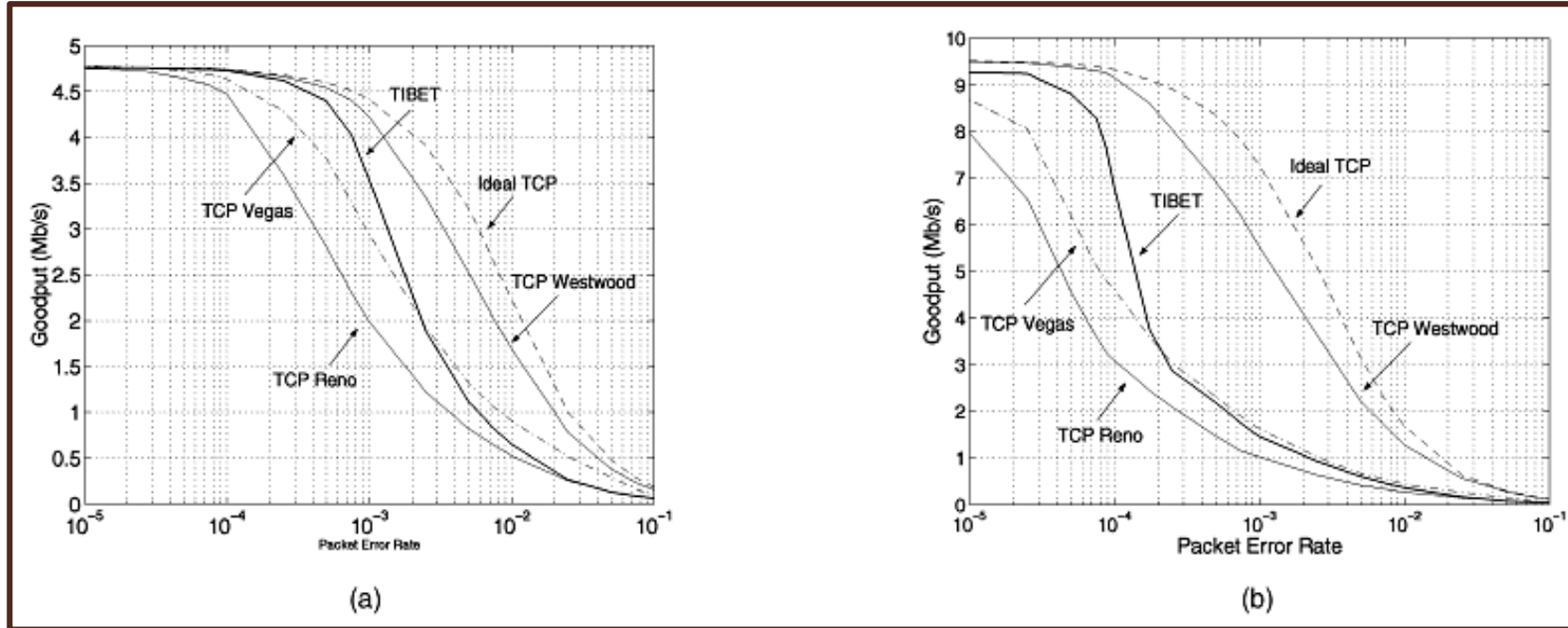


Application Example: VOIP



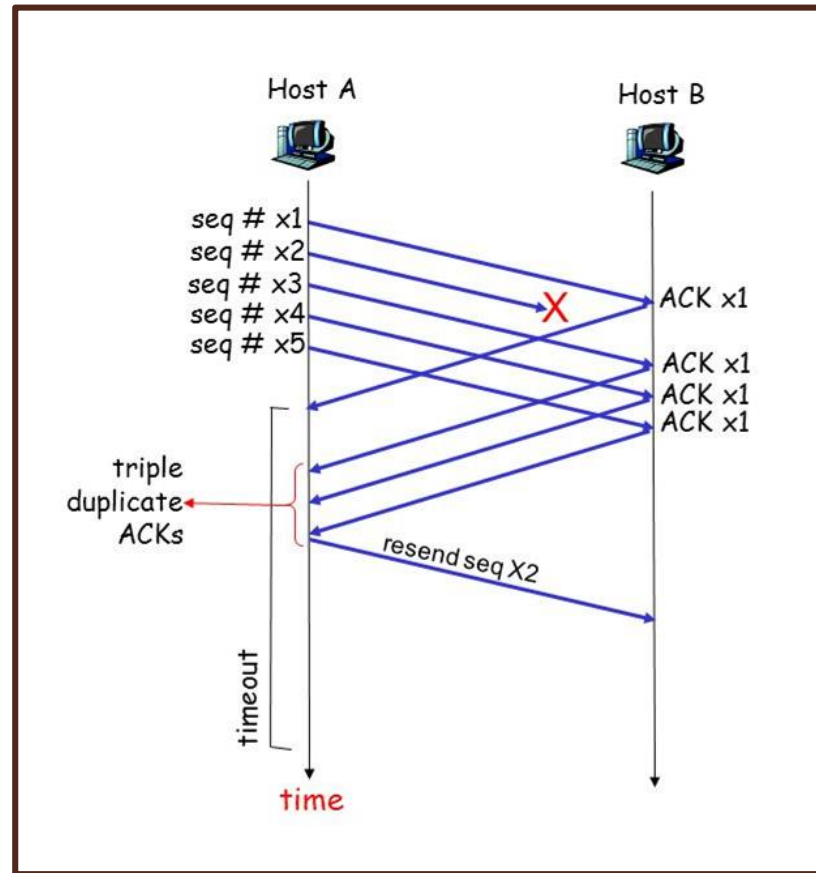
- Determine how your application will behave under expected (and unexpected) network conditions
- Determine what codecs you should use, what jitter buffers, etc.

Application Example: TCP Over Wireless



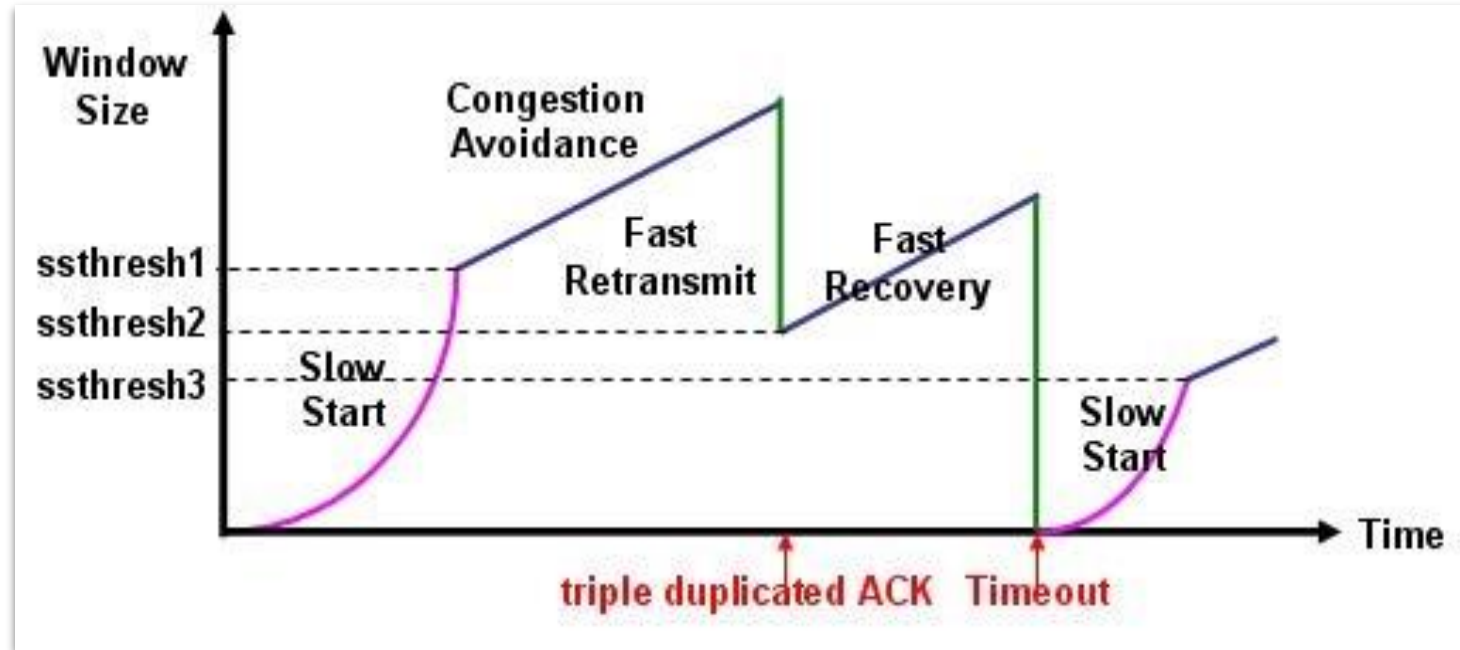
- TCP was first described in an IEEE paper written in 1974
- Ethernet was first standardized by the IEEE in 1983
- The first GSM Network went online in 1991

Application Example: TCP Over Wireless



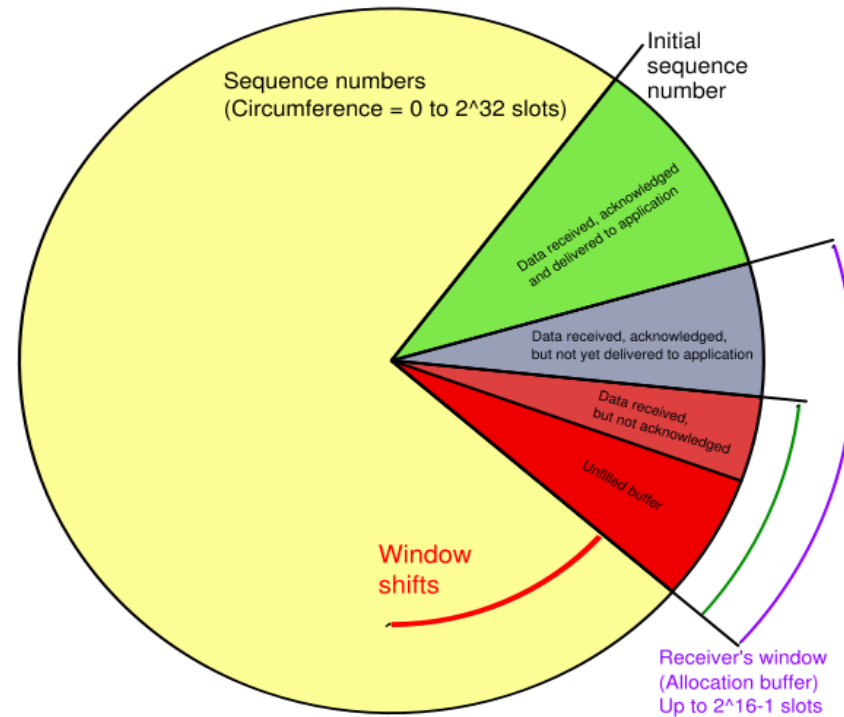
- Loss in a TCP application leads to duplicate ACKs, which lead to retransmissions

Application Example: TCP Over Wireless



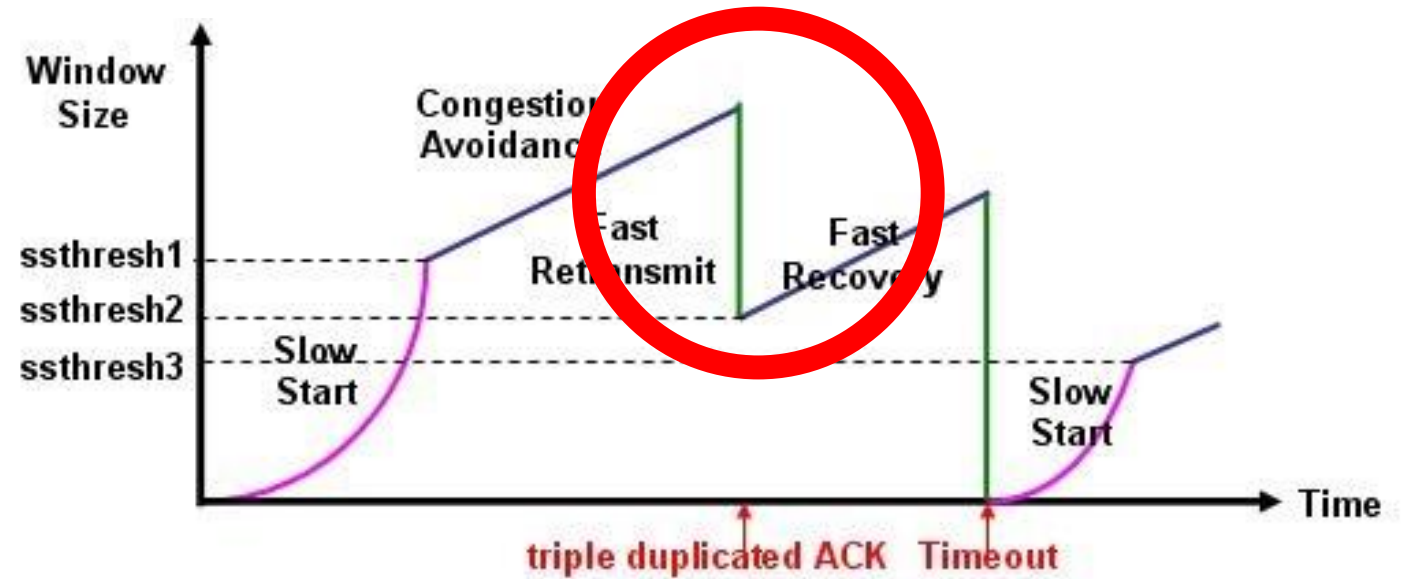
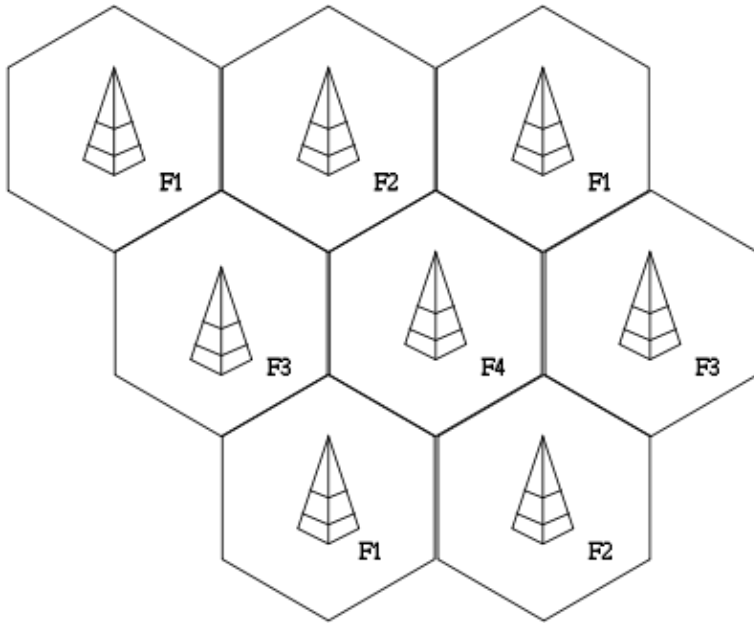
- TCP assumes that Loss is due to Congestion
- When Loss occurs TCP automatically cuts throughput to avoid congestion

Application Example: TCP Over Wireless



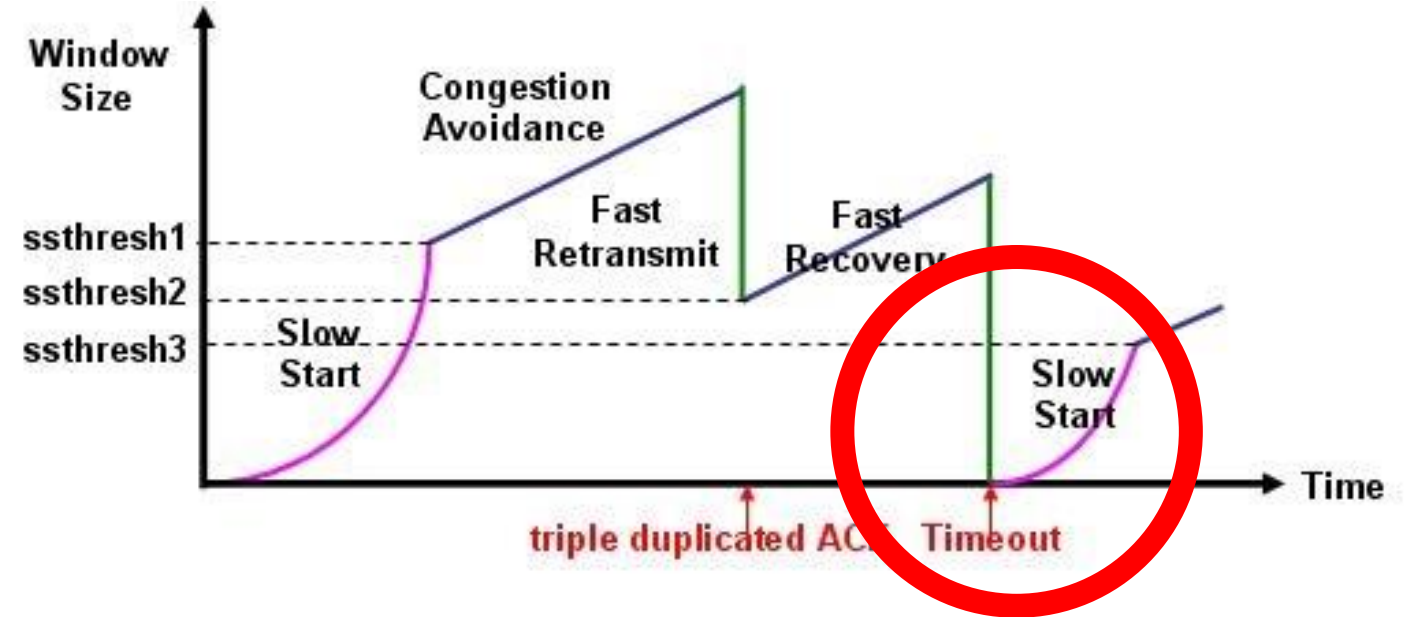
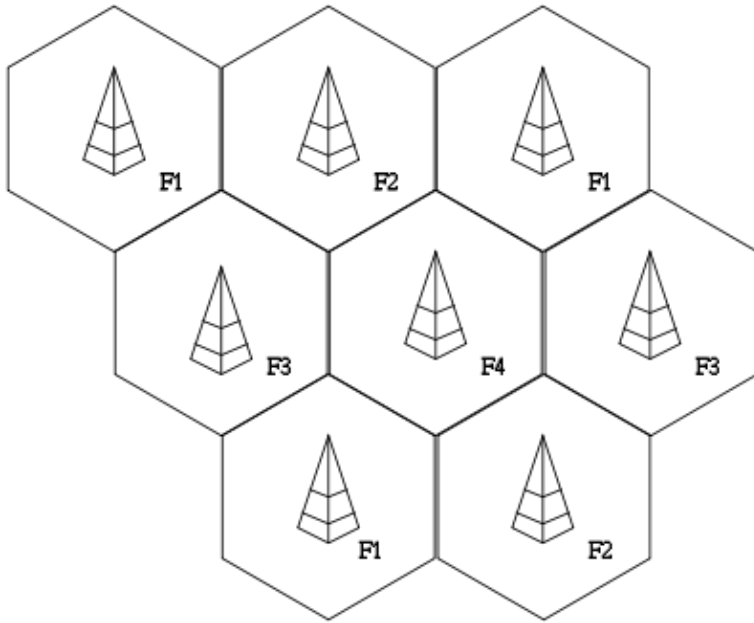
- TCP uses a Sliding Window mechanism to limit how many unacknowledged bytes can be transmitted before the sender is forced to idle
- High Latency links slow ACKs, cause forced idle, and limit throughput

Application Example: TCP Over Wireless



- 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)!

Application Example: TCP Over Wireless



- 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!

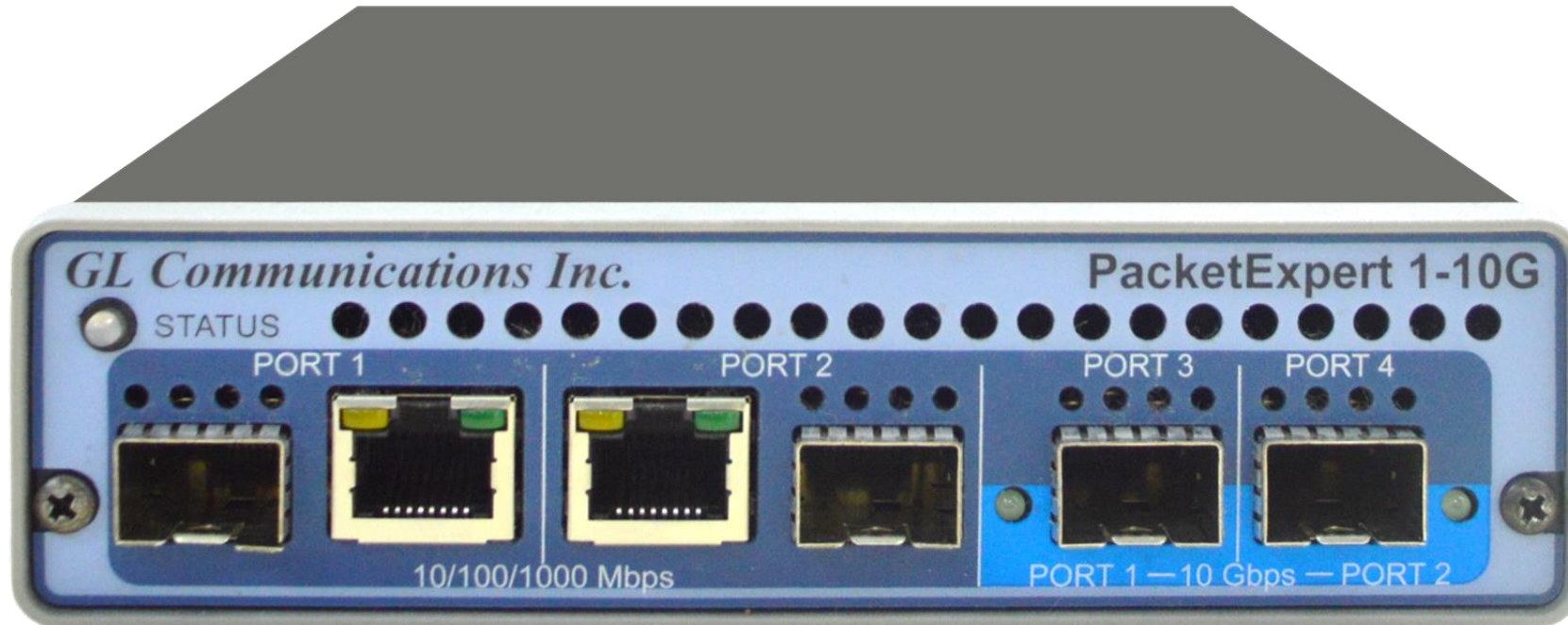
Application Example: TCP Over Wireless



- Wireless communication is High Latency
- Wireless communication is prone to Packet Loss and Packet Corruption
- Applications that work perfectly in the lab can be crippled by a wireless link

Automation Options

Automation Options



- Automate with C/C#, TCL, Python and Java

THANK YOU - Any Questions?