ExpertTCP™ - TCP Throughput Testing up to 1 Gbps Rate (per RFC-6349)

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- **Background**
  - RFC-2544, Y.1564 (SAM), RFC-6349, SLA
- **TCP Principles**
  - TCP Throughput Inter-Relationships
  - Bandwidth * Delay Product
  - Bottleneck Bandwidth (BB)
  - TCP Congestion Window (TCP CWND) and TCP Receive Window (RWND)
  - Packet Loss Rate
  - Retransmission Schemes (Go Back N, Selective Repeat)
- **GL Hardware Platforms**

Performance Testing of Packet / Ethernet Connections and Networks

For Predictable

Managed Networks

- RFC-2544
- ITU Y.1564 (SAM)
- RFC-6349 (TCP)

Service Level Agreements

from Network Providers, a must

User Experience,

Application-Network Sensitive,

TCP Tuning

SAM – Service Activation Methodology

TCP – Transmission Control Protocol

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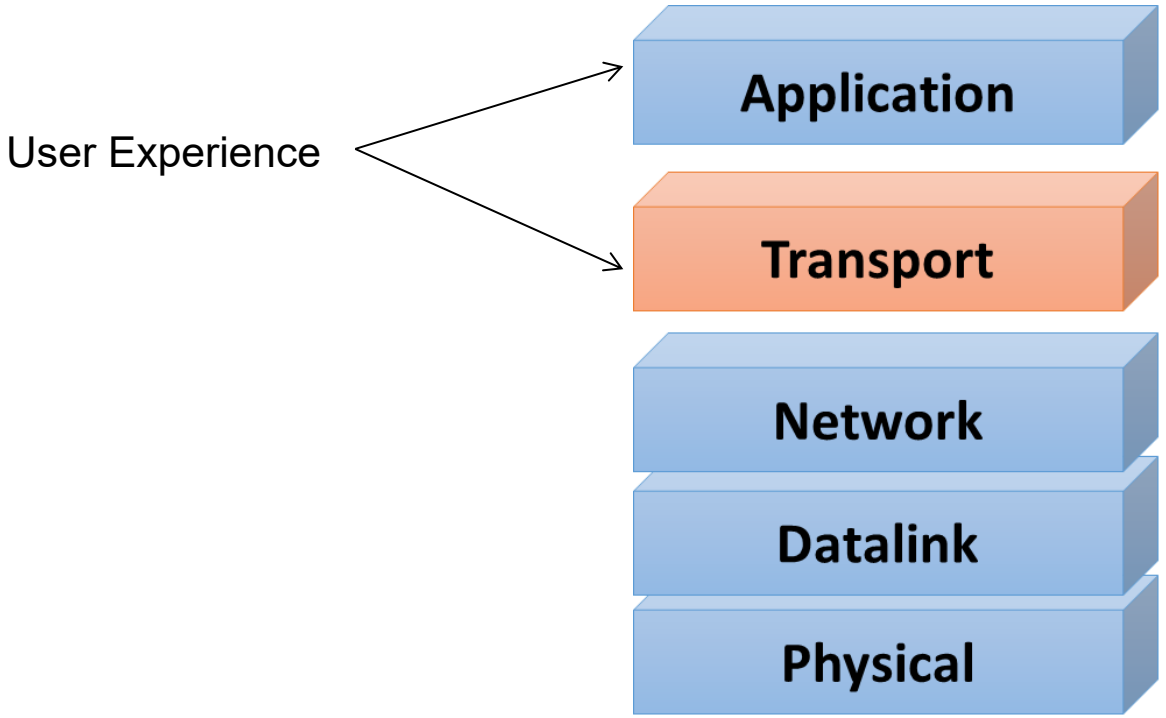
Packet / Ethernet Testing



HTTP, FTP, Email,
Facebook, Youtube, etc.

ExpertTCP (RFC 6349 testing)

- End-to-End Throughput

RFC 2544
ExpertSAM (Y.1564 testing)

- Network Throughput
- Latency
- Packet Loss
- Back-to-Back
- Jitter

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Typical SLA

Typically

Packet Loss

0.0005 % to 1%

Latency

36 to 75 ms

Availability

99% to 99.9%

EXHIBIT D – Service Level Agreements

1. Service Level Agreement Matrix

Category/Service	Service Level Agreement Metrics				
	Mean Time To Repair	Availability	Packet Delivery or Loss	Jitter	Latency
Internet Services					
Internet Dedicated (North American IP Network Only)	4 hrs to 8 hrs depending on access	99.90%	≥ 99.50%	≤ 1 ms	≤ 45 ms
SOHO Services					
Internet Cable	24 hrs (Excludes Weekends and Holidays)	99.00%	99.00%	≤ 4 ms	≤ 75 ms
Internet DSL – Office & Solo					
Internet Satellite Enterprise & Office	N/A	99.90%	≤ 1 %	N/A	N/A
Managed PBX and VoIP Services					
Hosted IP Centrex	≤ 4 hrs	99.90%	EF- ≥ 99.995%, AF4x - ≥ 99.99% depending on access	≤ 1 ms	≤ 36 ms
IP Flexible T1, IP Integrated Access, IP Trunking					

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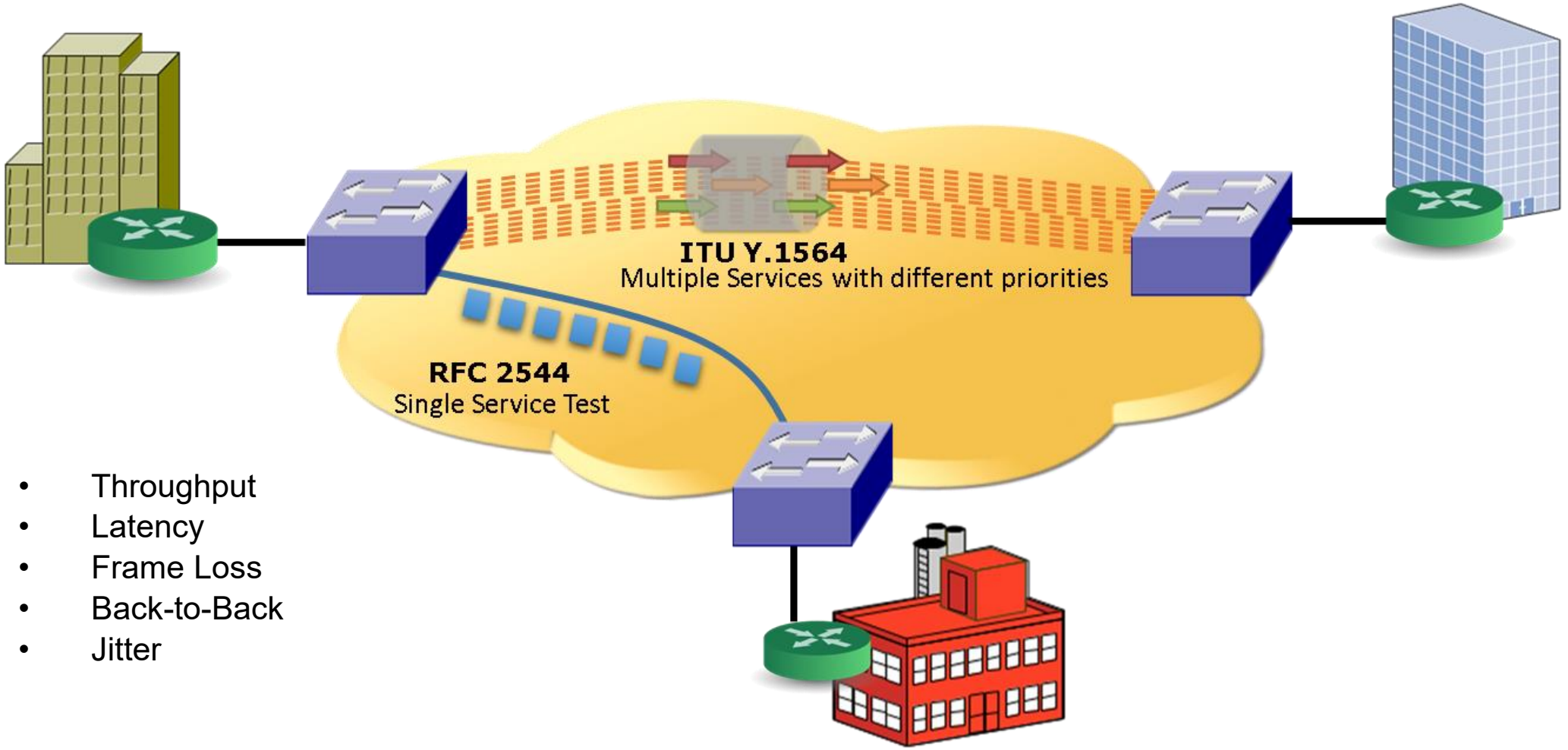
RFC-2544 vs. ITU Y.1564 (ExpertSAM™)

Both are Connectionless



- Throughput
- Latency
- Frame Loss
- Back-to-Back
- Jitter

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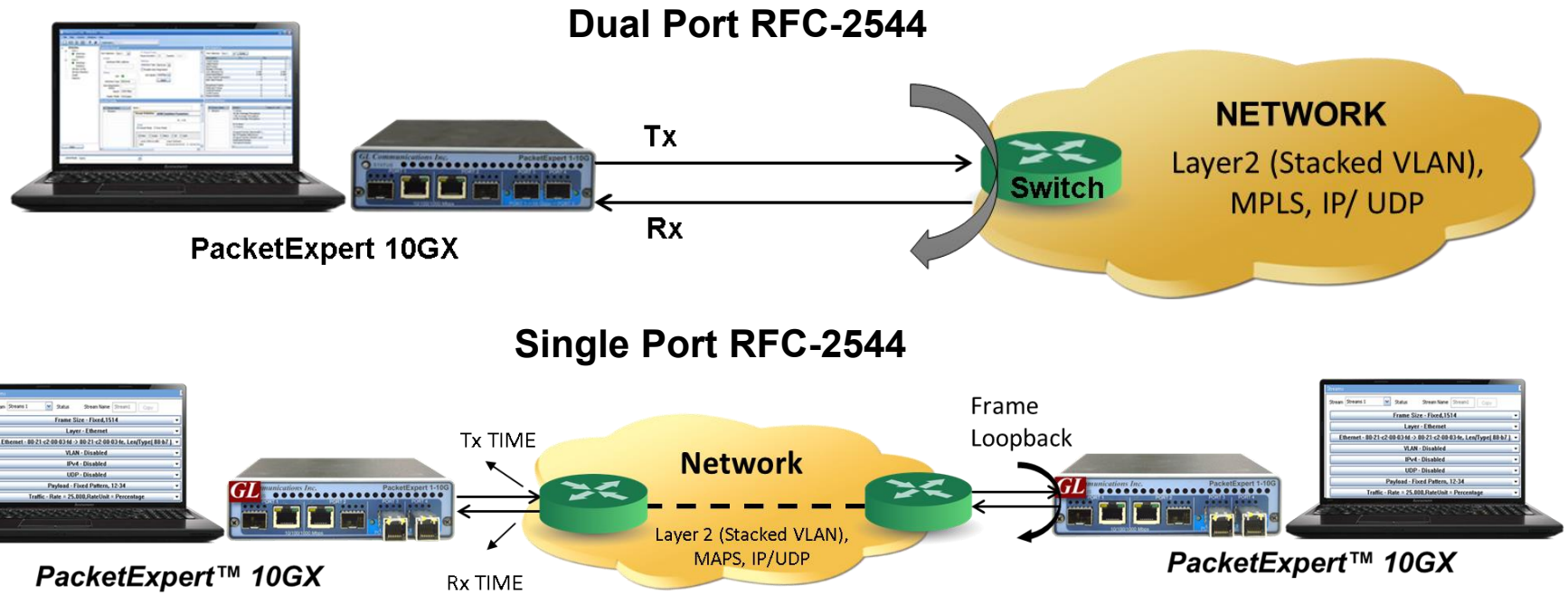
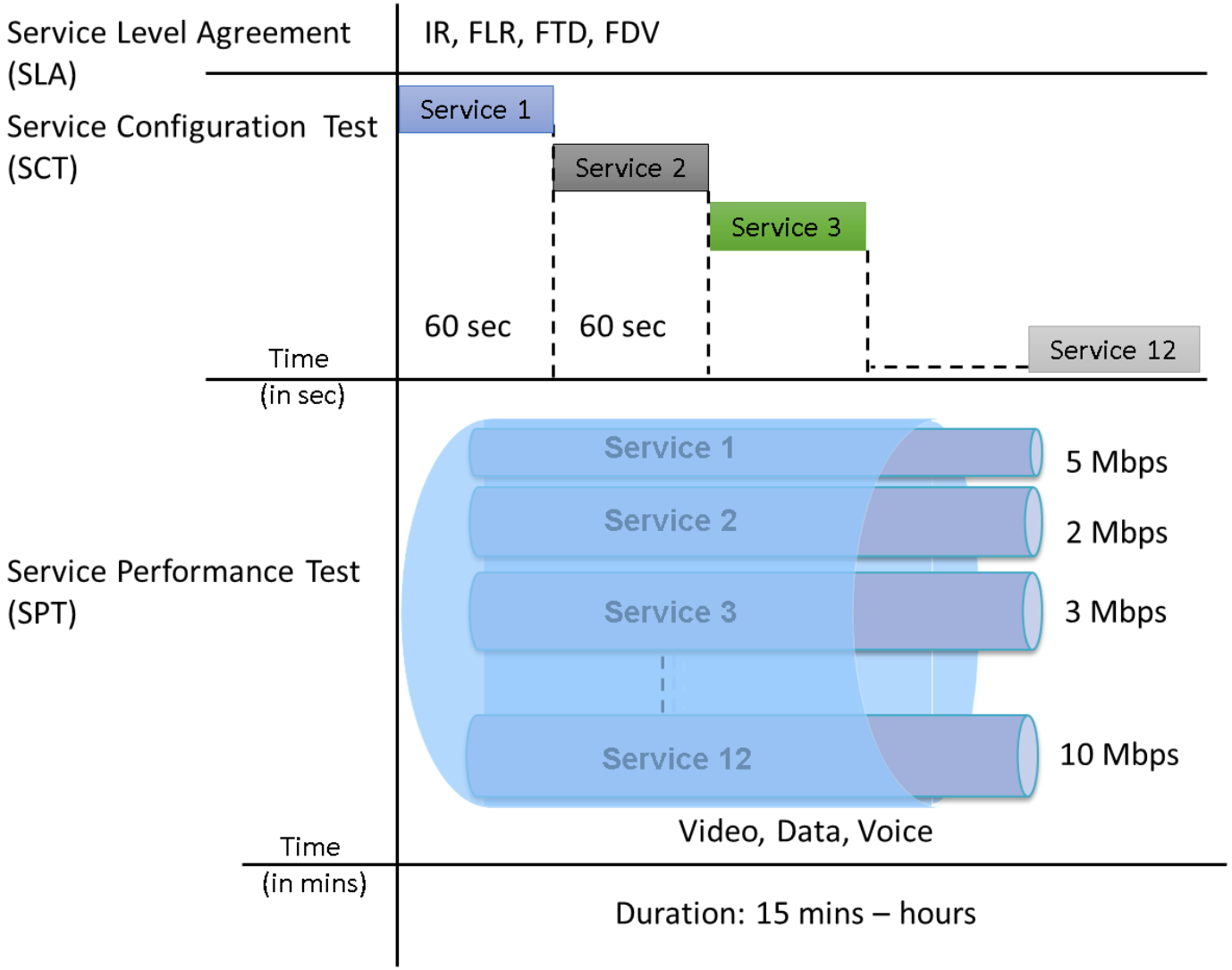
RFC-2544 Testing



- ExpertTCP™ testing is performed using the **RFC 6349** standard
- To conduct this test, users need two PacketExpert™ devices — one as the client and the other as the server
- The ExpertTCP™ test covers both upload (Client to Server) and download (Server to Client), measuring TCP throughput and efficiency
- RFC-2544 test application includes the following tests:
  - Throughput - Maximum number of frames per second that can be transmitted without any error
  - Latency - Measures the time required for a frame to travel from the originating device through the network to the destination device
  - Frame Loss - Measures the network's response in overload conditions
  - Back-to-Back - It measures the maximum number of frames received at full line rate before a frame is lost

ITU Y.1564 (ExpertSAM™)



Multi-Stream

- Throughput
- Latency
- Packet Loss
- Jitter

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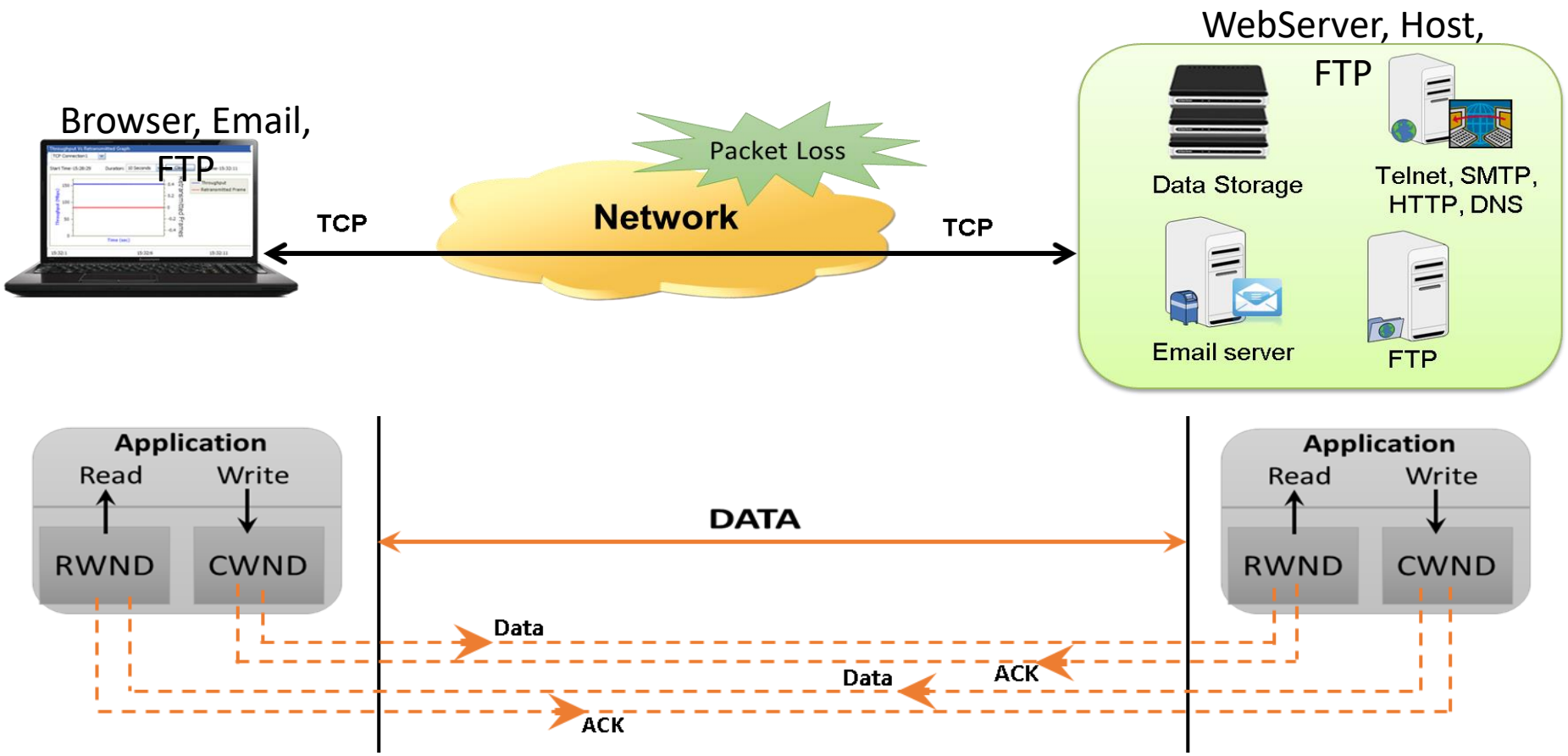
Testing Relevance

Problems	RFC-2544	Y.1564	RFC-6349
Single-service Layer 2/ 3/ 4 SLA Issues like loss, jitter	Yes	Yes	N/A
Multi-service Layer 2/ 3/ 4 SLA Issues like loss, jitter	No	Yes	N/A
TCP window sizes (CPE issues)	No	No	Yes
Excessive retransmissions due to policing	No	No	Yes

- Running RFC-2544, Y.1564 or another L2/L3 layer test is always first step
- However, even after these performance tests are passed with good results, end-customers can still complain that the “network is slow” and the cause of poor application performance (i.e., FTP, web browsing, etc.)
- Lack of TCP testing is a turn-up gap because end-customer applications are transported using TCP
- Save operating expense costs by eliminating or quickly resolving painful end-customer finger pointing scenarios

TCP Principle
(Packet Loss and Waiting for ACK Reduces Throughput)



Major TCP Throughput Inter-Relationships

- Bandwidth of Applications
- Latency/Delay of Networks
- Packet Loss Networks
- TCP Retransmission Scheme
- Maximum Transmit Unit of Network
- Transmit/Receive Windows of TCP
- # of TCP Simultaneous Connections

Bandwidth Delay Product (Bits or Bytes)

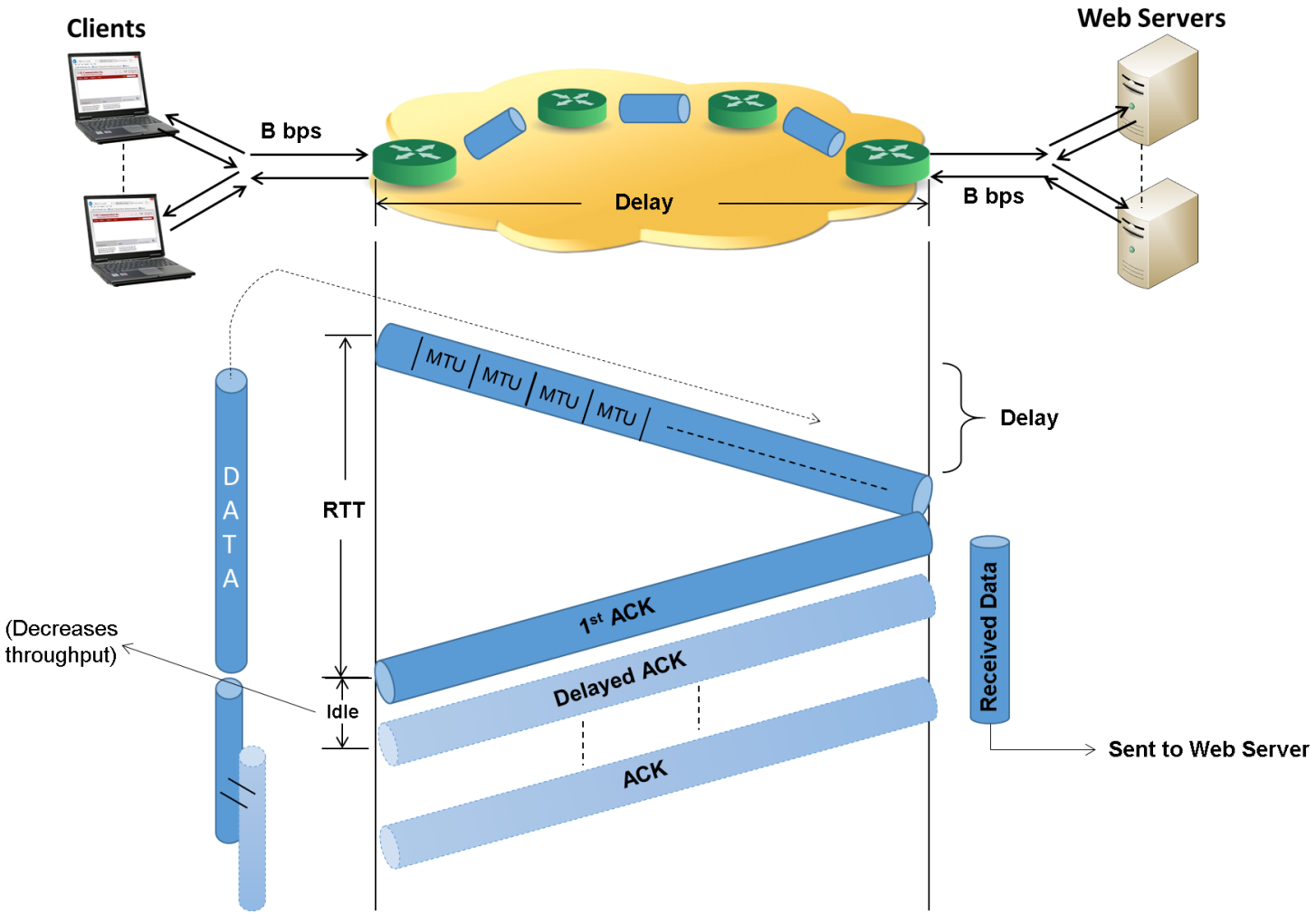
Application and Network are Matched, TCP is Tuned

B= 10 Mbps
RTT = 50 ms

B*50 = 500,000 bits
or 62,500 Bytes

65,535 Bytes is max window

Achieving max throughput



Bandwidth (B) - Bandwidth (bps), Mbps, the maximum rate at which an application can transmit or receive data (the smaller of the two). Line rate may be shared among applications

Bandwidth Delay Product (BDP) - measured in bits or bytes (divided by 8), the number of bits (or bytes) in the network that are unacknowledged (in transit), B (bps) * RTT (secs) = BDP bits

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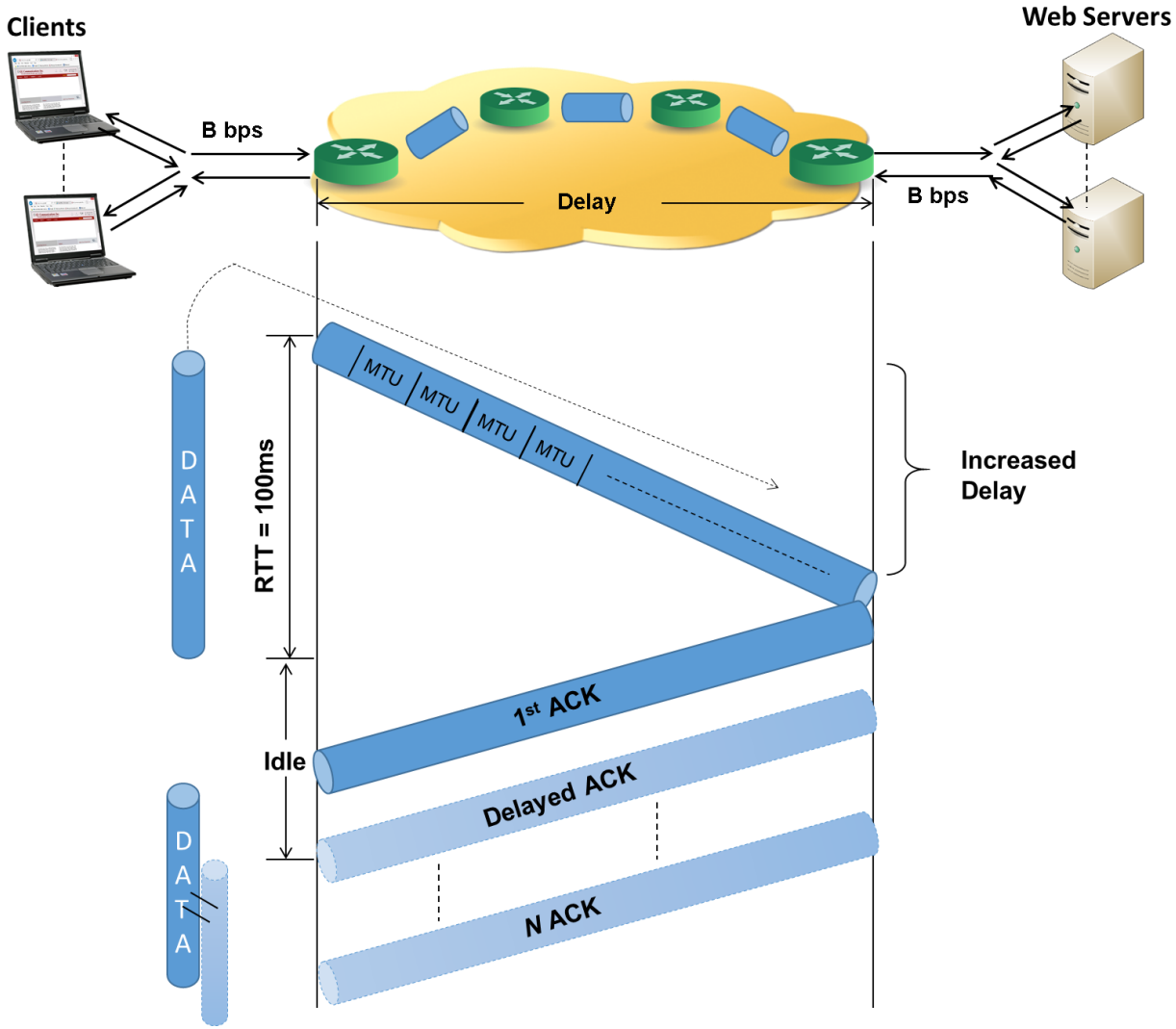
Effect of Increased Network Delay or Smaller Tx or Rx Buffers

B = 10 Mbps
RTT = 100 ms

B*100 = 1,000,000 bits
or 125,000 Bytes

But 65,535 Bytes is max window

NOT Achieving max throughput, 50% or less



Latency, Delay, Round Trip Time (RTT) - in seconds (secs), or milliseconds (ms), round trip time includes acknowledgement delay

TCP Throughput - bits/second (bps), million bits/second (Mbps), One way throughput (RFC2544, Y.1564), Round-trip throughput (RFC-6349) is a different story since retransmissions and acknowledgements are involved.

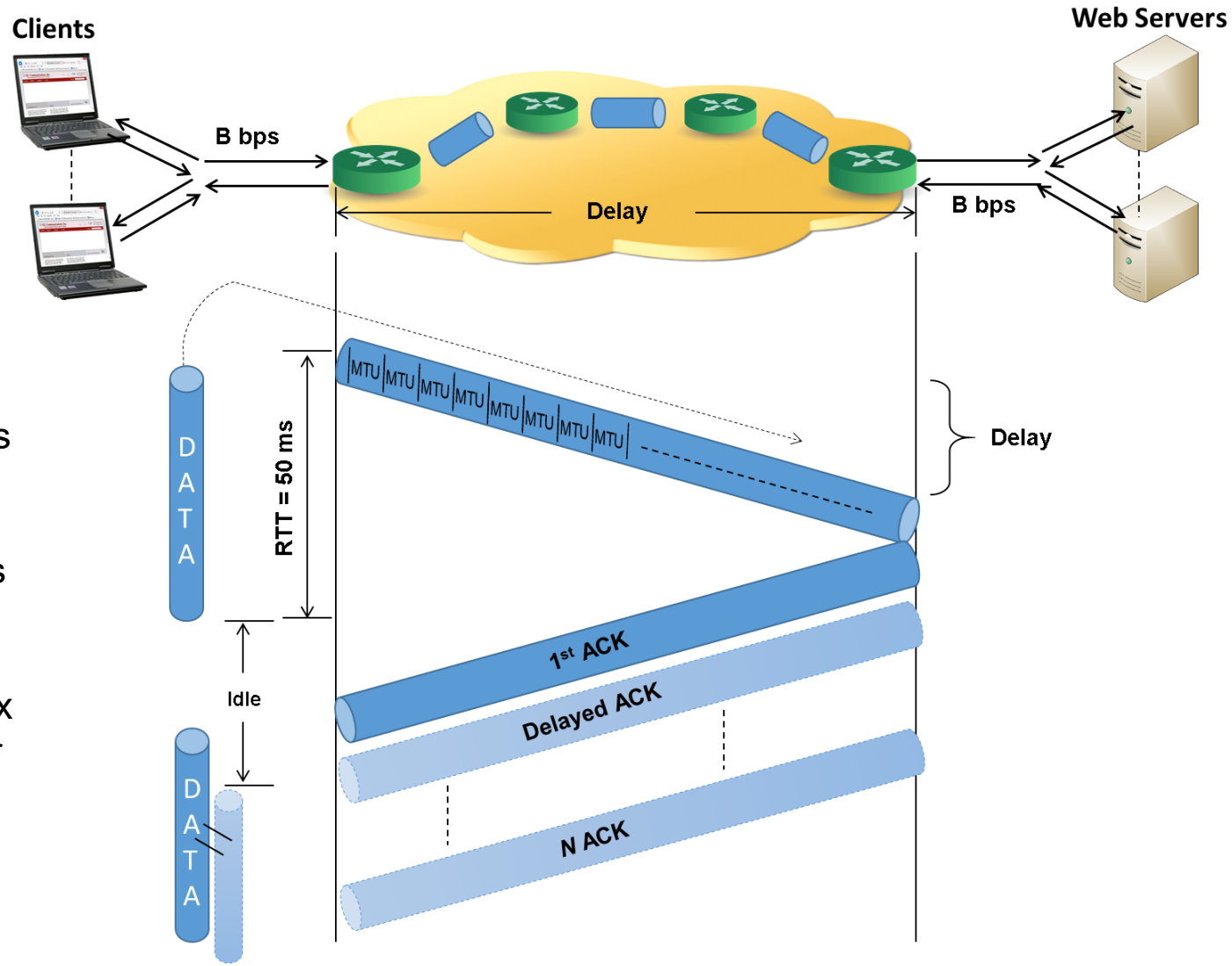
Effect of Increased Application Bandwidth

B = 20 Mbps
RTT = 50 ms

B*50 = 100,000 bits or 125,000 Bytes

But 65,536 Bytes is max window

NOT Achieving max throughput, 50% or less



Excess Bandwidth may be used for additional TCP Connections

Maximum Transmission Unit (MTU) - Approx. 1500 bytes, max packet size

Jitter - Instantaneous variation in RTT, e.g. if RTT is nominally 100 ms, but varies from 80 ms to 120 ms, then jitter is +/- 20ms, or 40 ms. Since jitter affects ACK time, TCP throughput is affected

Packet Loss Rate - Very important factor affecting TCP throughput, could be as high as 2%

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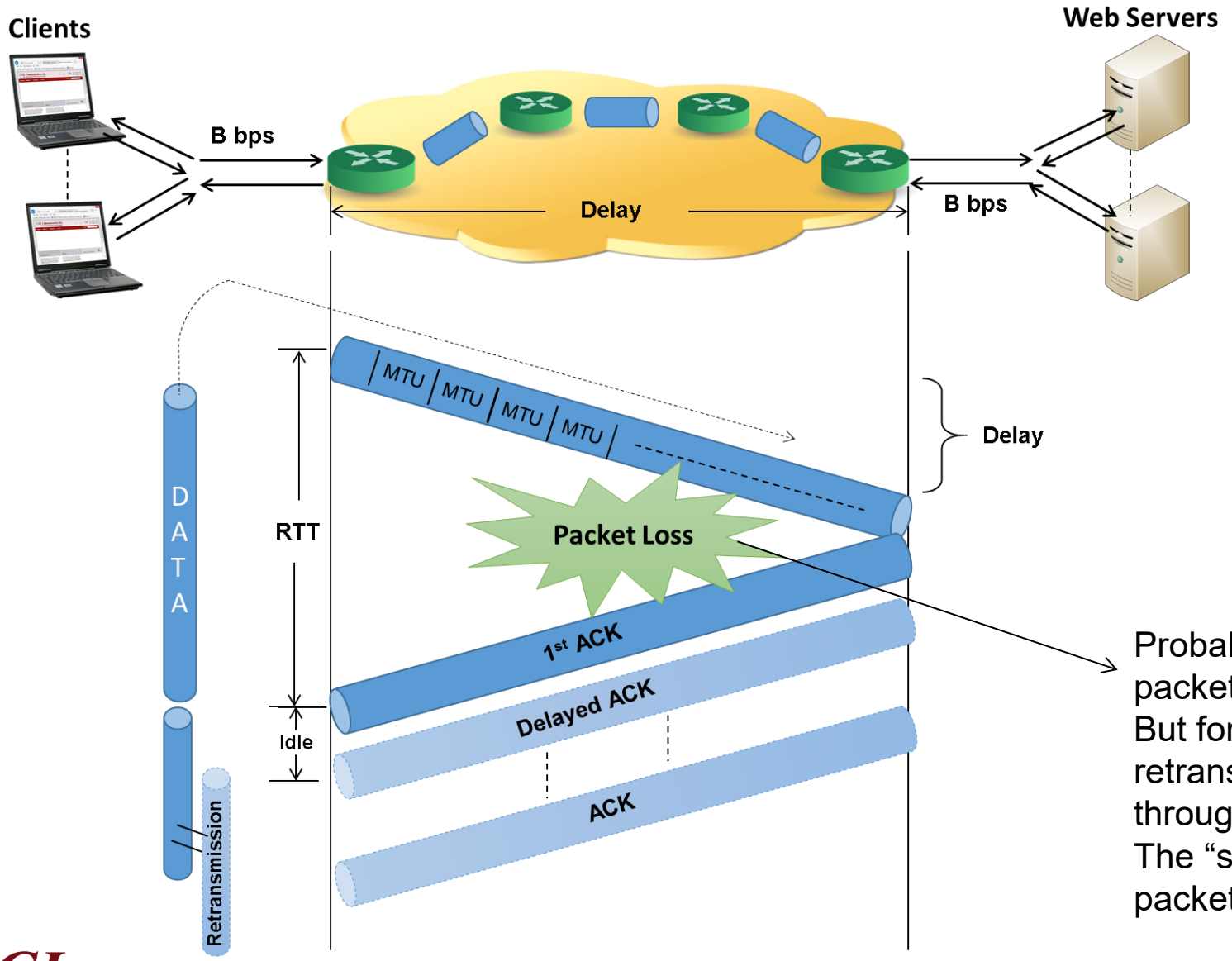
Effect of Packet Loss Rate and Retransmission Scheme



For **Go Back N** retransmission scheme, and if unacked packets is maximum ~ 43 or 44, then Packet Loss effects are very serious!

Packet Loss	TCP Throughput
0 %	100%
0.1 %	< 50%
1 %	< 10%
2 %	0 %

Probability that one or more MTU packets or ACK packets is lost is very high!! Can be 1 !!!
But for every lost MTU packet or ACK packet, 43 retransmissions occur. This results in near zero throughput.
The “slow start phase” results in very few “in flight” packets.

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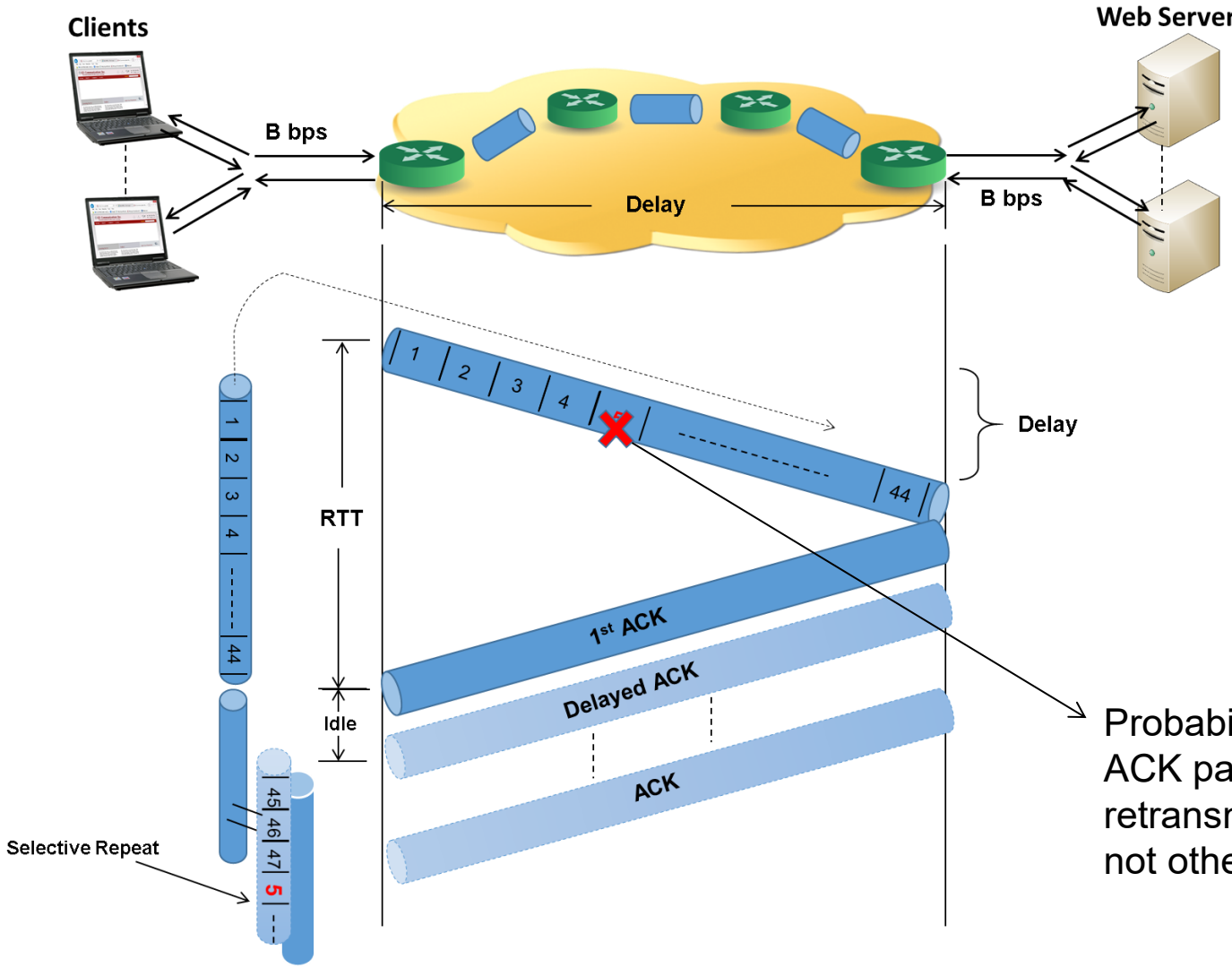
Effect of Packet Loss Rate and Retransmission Scheme (Contd.)



For **Selective Repeat** retransmission scheme, and if unacked packets is maximum ~ 43 or 44, then Packet Loss affects TCP Throughput linearly for "low" Packet Loss rates

Packet Loss	TCP Throughput
0 %	100%
0.1 %	> 99 %
1 %	> 95 %
2 %	? %

Probability that one or more MTU packets or ACK packets lost is very high! But the retransmission only affects the lost packets, not other packets.

ExpertTCP™ (RFC-6349 Testing)

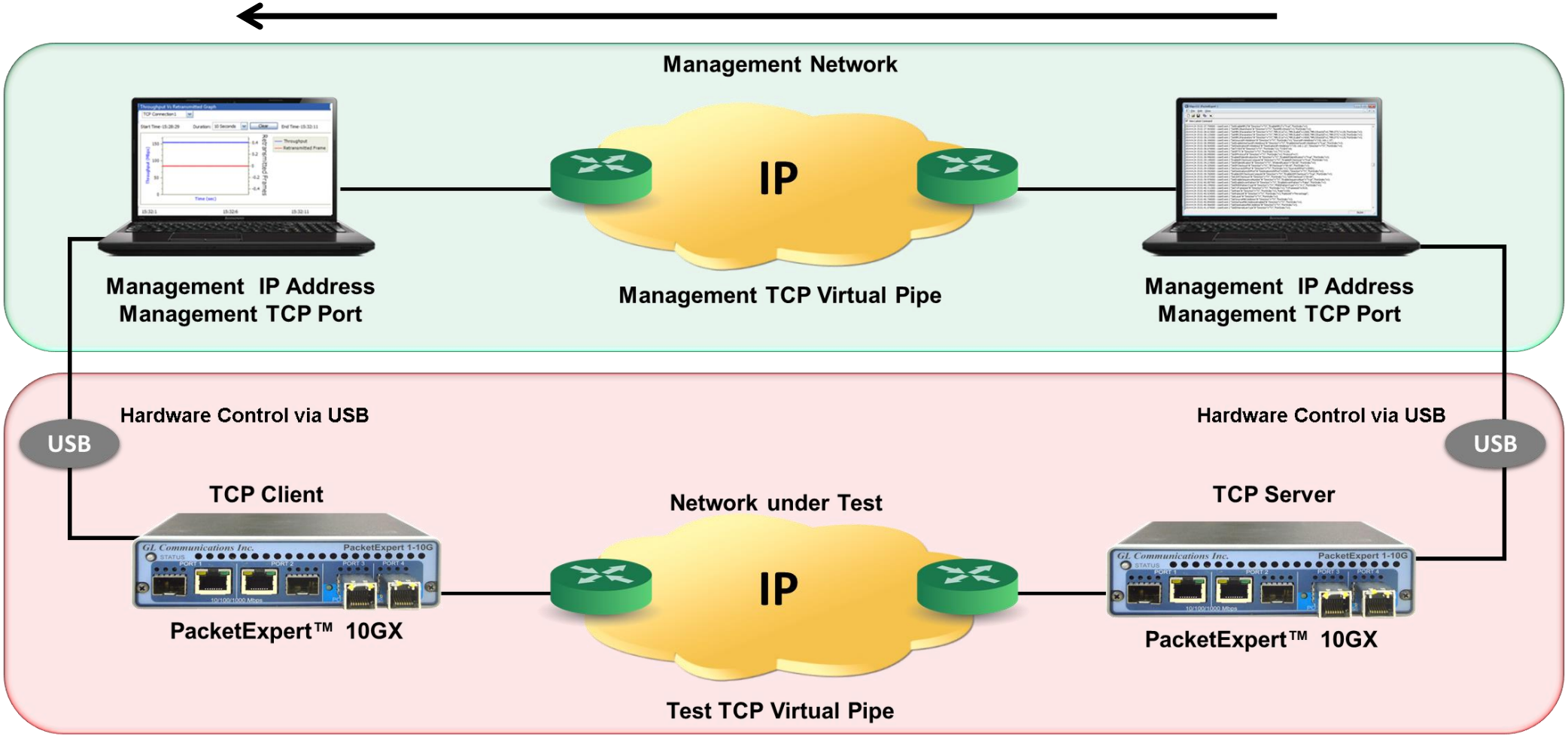
The TCP Throughput Testing is conducted in 3 steps simultaneously on up to 16 application streams:

- Path MTU Discovery - What is the maximum packet size that can successfully traverse the network?
- Round Trip Time (RTT) Measurement - Timestamp based RTT discovery of transmitted packet until acknowledgement packet arrives from far end.
- Measure TCP Throughput - Complete measurements per RFC-6349 definitions to provide TCP Throughput results.

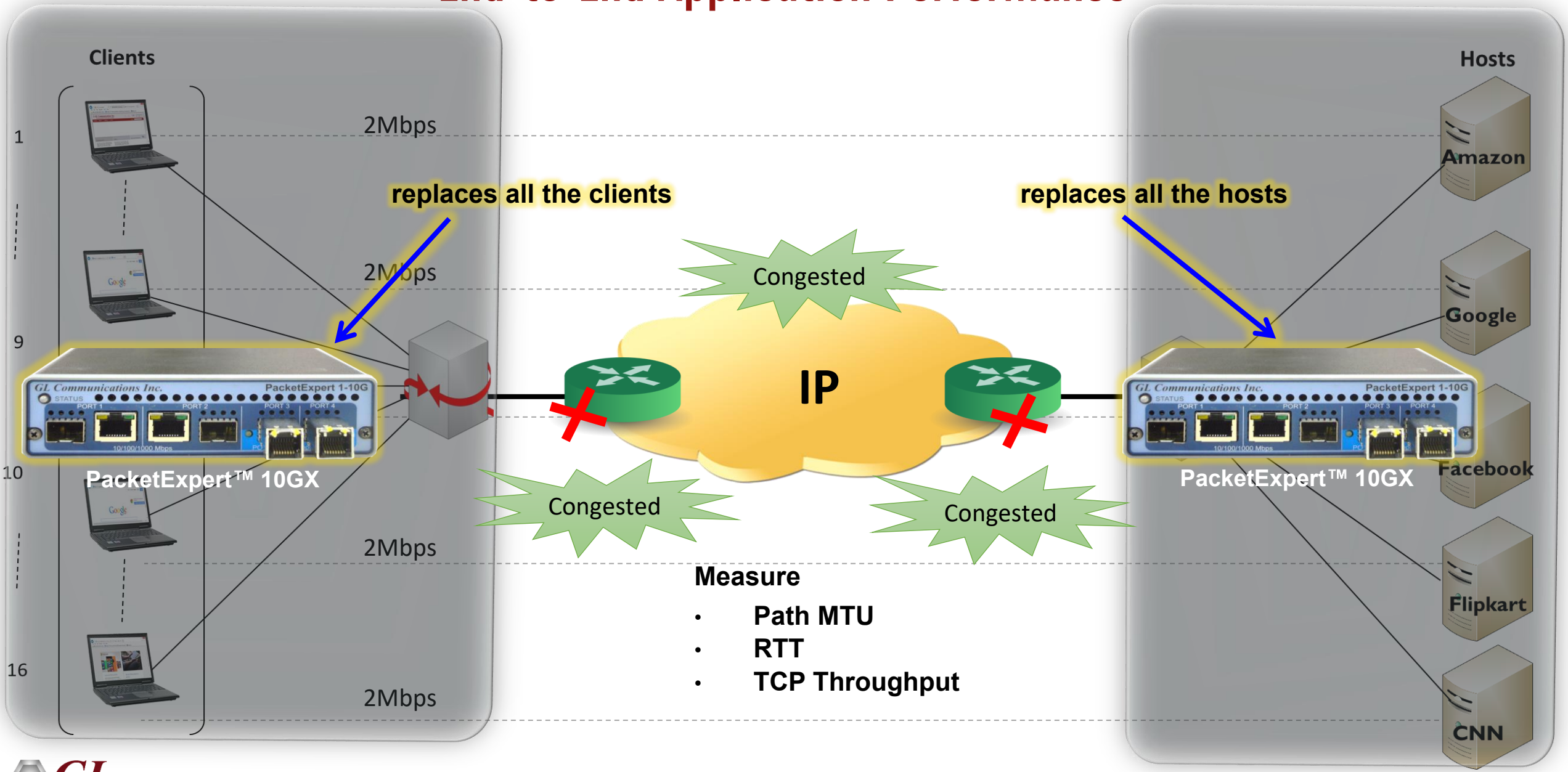
GL Hardware/Software
ExpertTCP™

Basic Setup

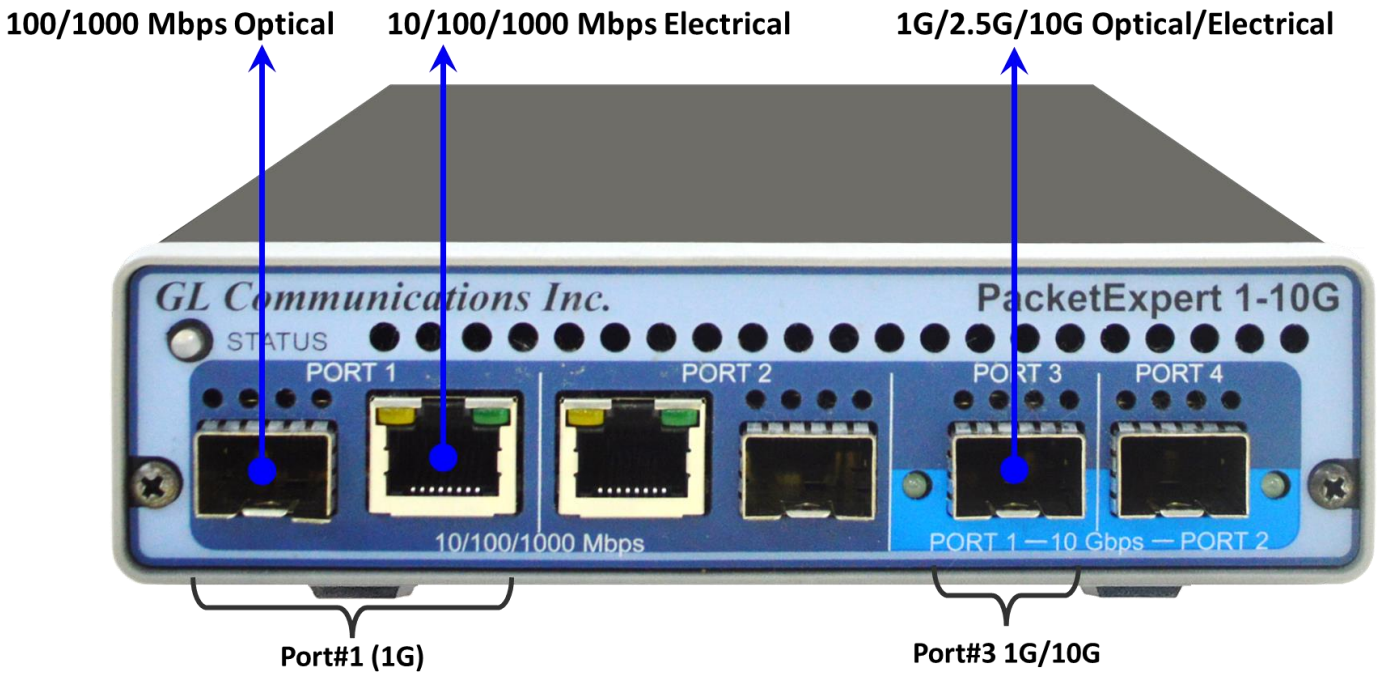
Test Configuration of Client and Server
Measurement Results from Server to Client



End-to-End Application Performance

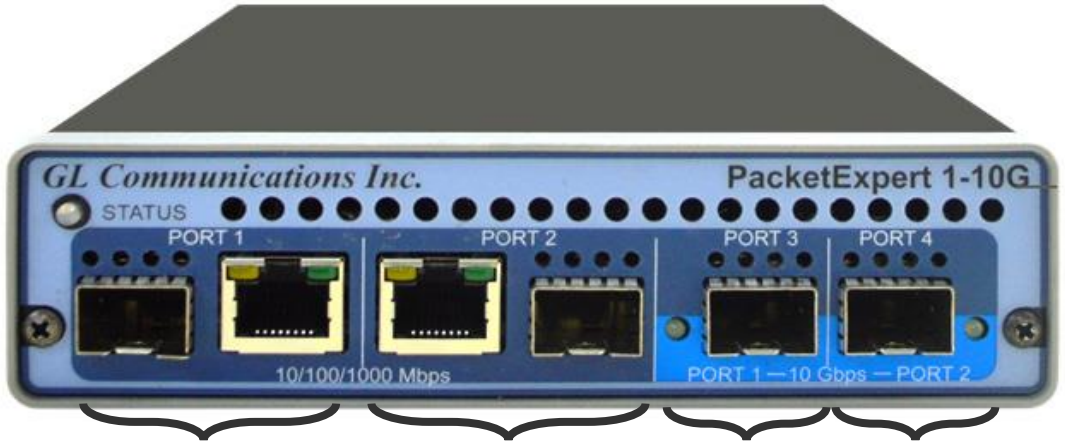


ExpertTCP™ 1G/2.5G/10G Ports



- **TCP Client and Server** will be supported in different applications
  - For 1G, **Port 1 is** used
  - For 10G, **Port 3** is used

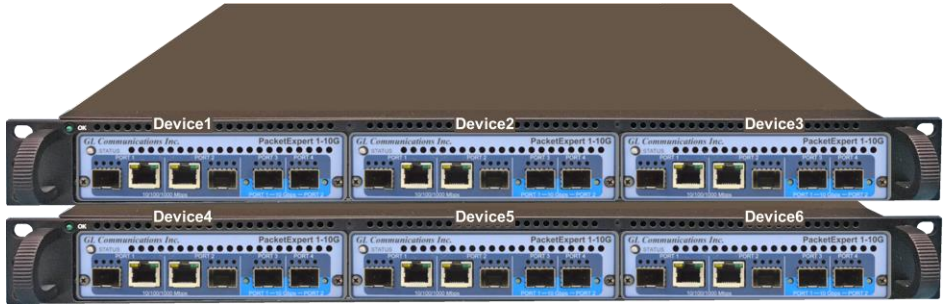
PacketExpert™ 10GX - Portable Unit (PXN100, PXN101)



Physical Specifications	• Length: 8.45 in (214.63 mm) • Width: 5.55 in (140.97 mm) • Height: 1.60 in (40.64 mm) • Weight: 1.713 lbs
External Power Supply	• +12 Volts (Medical Grade), 3 Amps (For portable units having serial number ≥ 188400) • +9 Volts, 2 Amps (For portable units having serial number ≥ 188400)
BUS Interface	• USB 3.0 • Optional 4-Port SMA Jack Trigger Board(TTL Input/Output)
Protocols	• IEEE 802.3ae LAN PHY compliance • RFC 2544 compliance

MTOP™ Rack Units

High Density 1U Rack option



Stacked High Density 1U Rack option

Physical Specifications	• Length: 16 in (406.4) • Width: 19 in (482.6) • Height: 1U / 2U
External Power Supply	• ATX Power Supply
BUS Interface	• 1U mTOP™ (MT001 + 3x PXN100) ➢ Rackmount Enclosure can support up to 3 PXN100s • 2U Rack Mount (with 6x PXN100) ➢ Rackmount Enclosure can support up to 6 PXN100s • Optional 4 to 12 Port SMA Jack Trigger Board (TTL Input/Output)
SBC Specifications	• Intel Core i3 or optional i7 NUC Equivalent, • Windows® 11 64-bit Pro Operating System • USB 3.0 and USB 2.0 Ports • USB Type C Ports, Ethernet 2.5GigE port • 256 GB Hard drive, 8G Memory (Min) • Two HDMI ports

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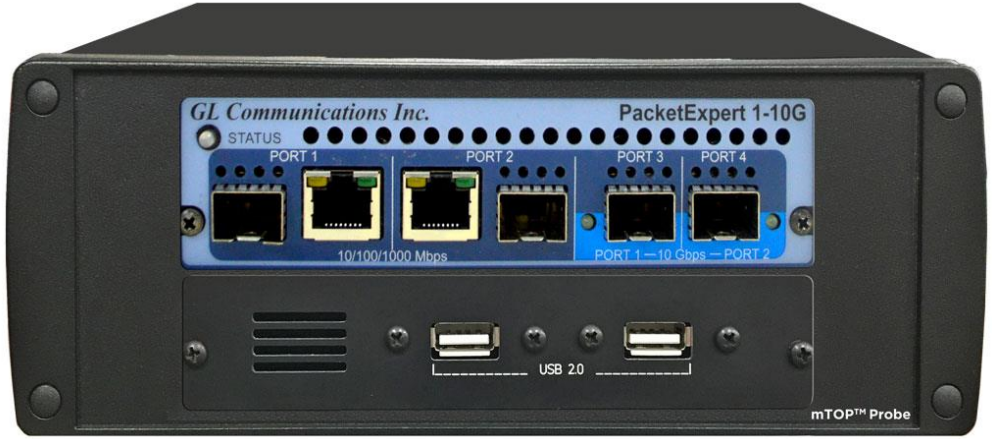
mTOP™ Probe with 10GX Hardware Unit + SBC



Physical Specifications	• Length: 10.4 in. (264.16 mm) • Width: 8.4 in. (213.36 mm) • Height: 3.0 in. (76.2 mm) • Optional 4-Port SMA Jack Trigger Board (TTL Input/Output) • External USB based Wi-Fi adaptor
External Power Supply	• +12 Volts (Medical Grade), 3 Amps
SBC Specifications	• Intel Core i3 or optional i7 NUC Equivalent, • Windows® 11 64-bit Pro Operating System • USB 3.0 and USB 2.0 Ports • USB Type C Ports, Ethernet 2.5GigE port • 256 GB Hard drive, 8G Memory (Min) • Two HDMI ports

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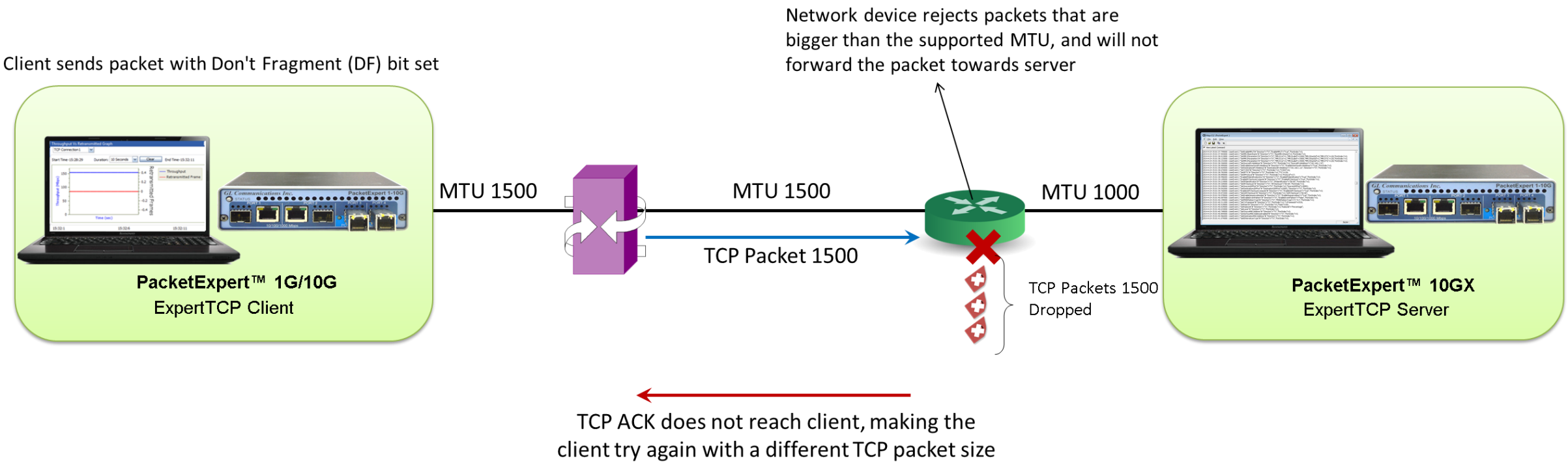
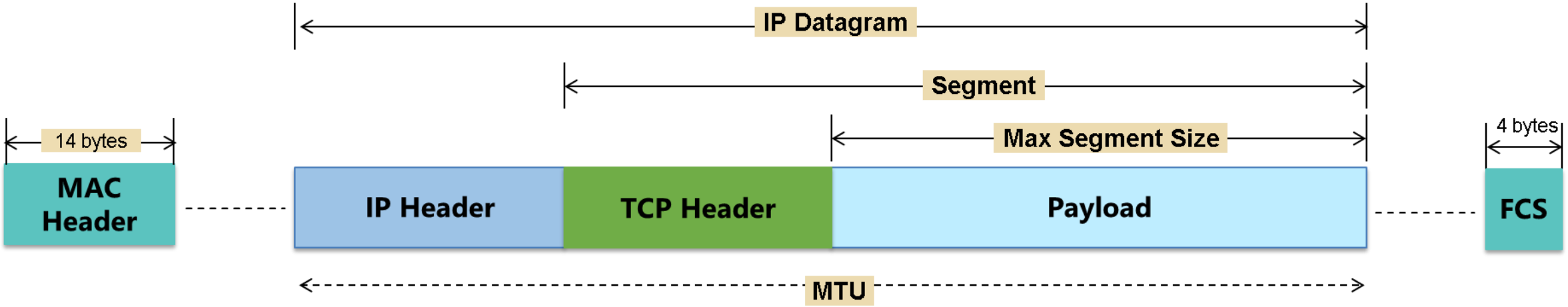
Step 1. Path MTU Discovery

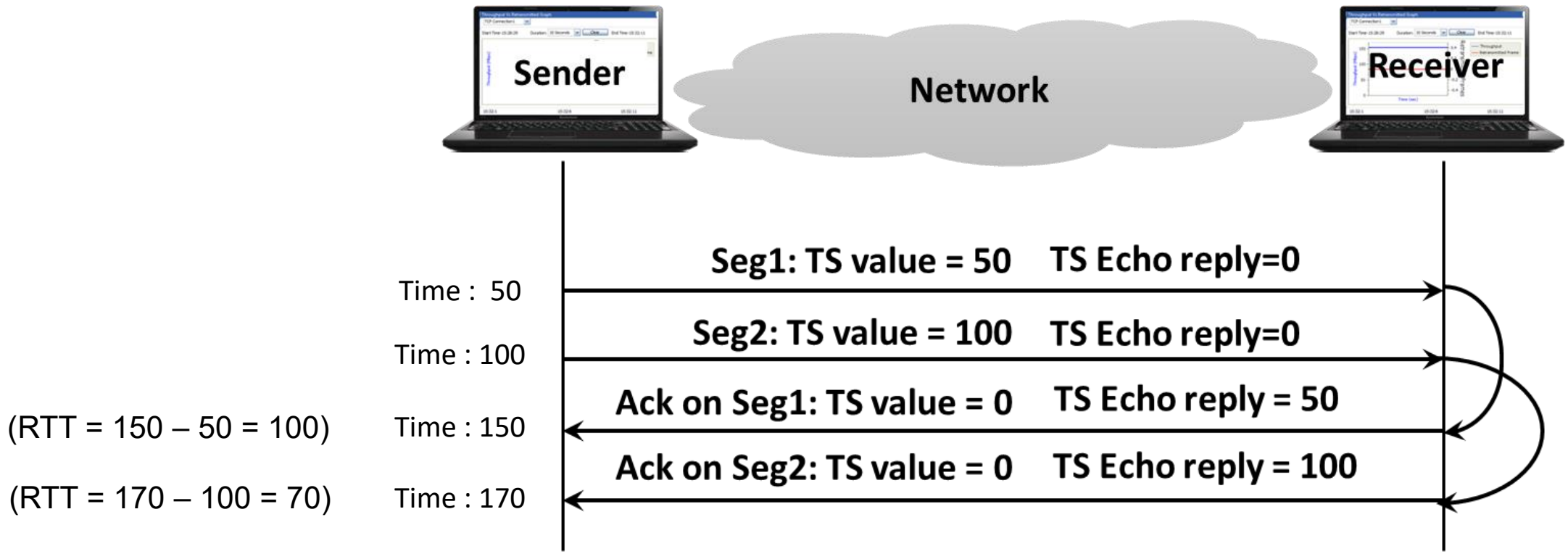


Step 1. Path MTU Discovery (Contd.)



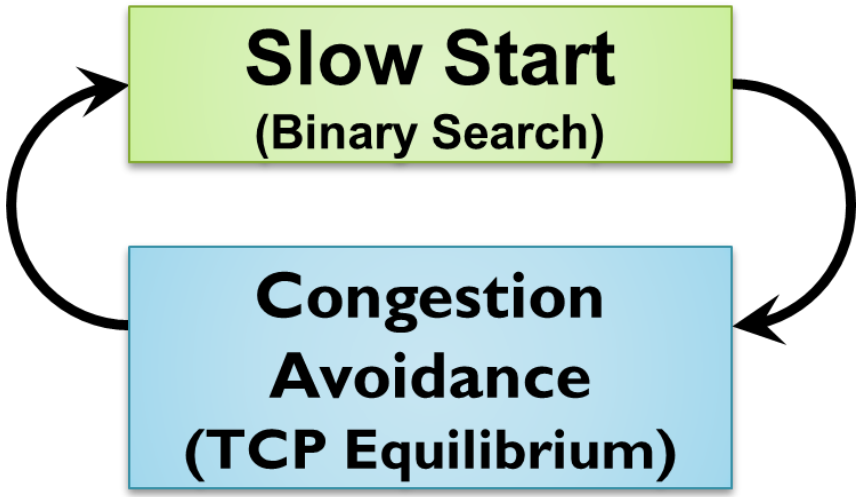
- Path MTU discovery as per RFC 4821 - PLPMTUD - Packetization Layer Path MTU Discovery
- DF (Do Not Fragment) bit is set to avoid fragmentation when traversing through network
- The algorithm uses TCP retransmit conditions to search for the MTU
- Each conclusive probe narrows the MTU search range, either by raising the lower limit on a successful probe or lowering the upper limit on a failed probe
- Path MTU is discovered for both directions in case of bi-directional test

Step 2. Timestamp based RTT Measurement

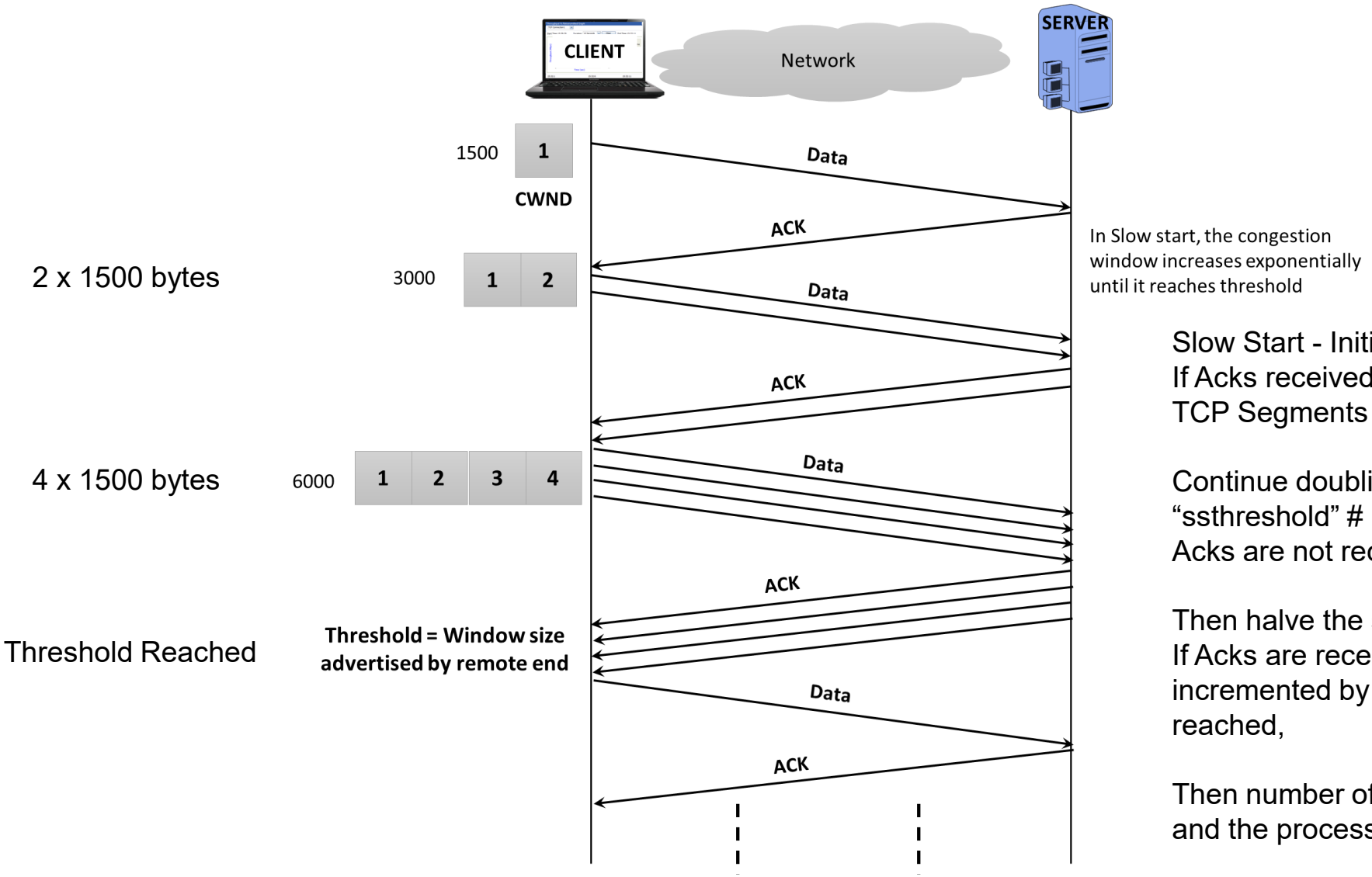


- Timestamp based RTT Measurement (RFC1323)
- Tx segment includes current time in option field, Receiver echoes timestamp in ACK

Step 3. Now Ready to Measure TCP Throughput



Step 3. Slow Start TCP Throughput Measurement



Slow Start - Initially send two TCP Segments
If Acks received, then send double the number of TCP Segments

Continue doubling until the Receiver "ssthreshold" # is reached, or
Acks are not received and Timeout is reached,

Then halve the send TCP segments
If Acks are received send TCP segments are incremented by one, until again Timeout is reached,

Then number of send TCP segments is halved and the process continues

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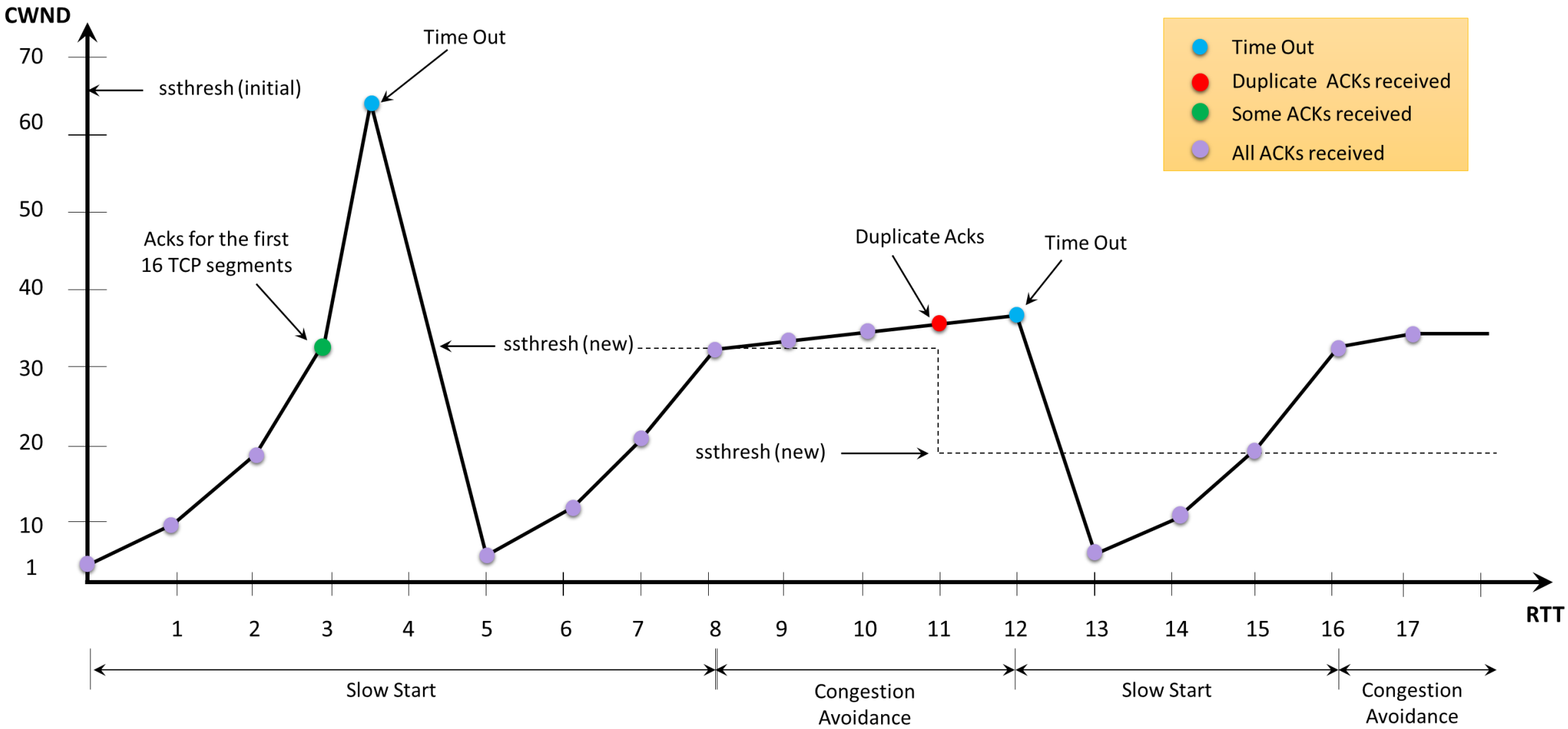
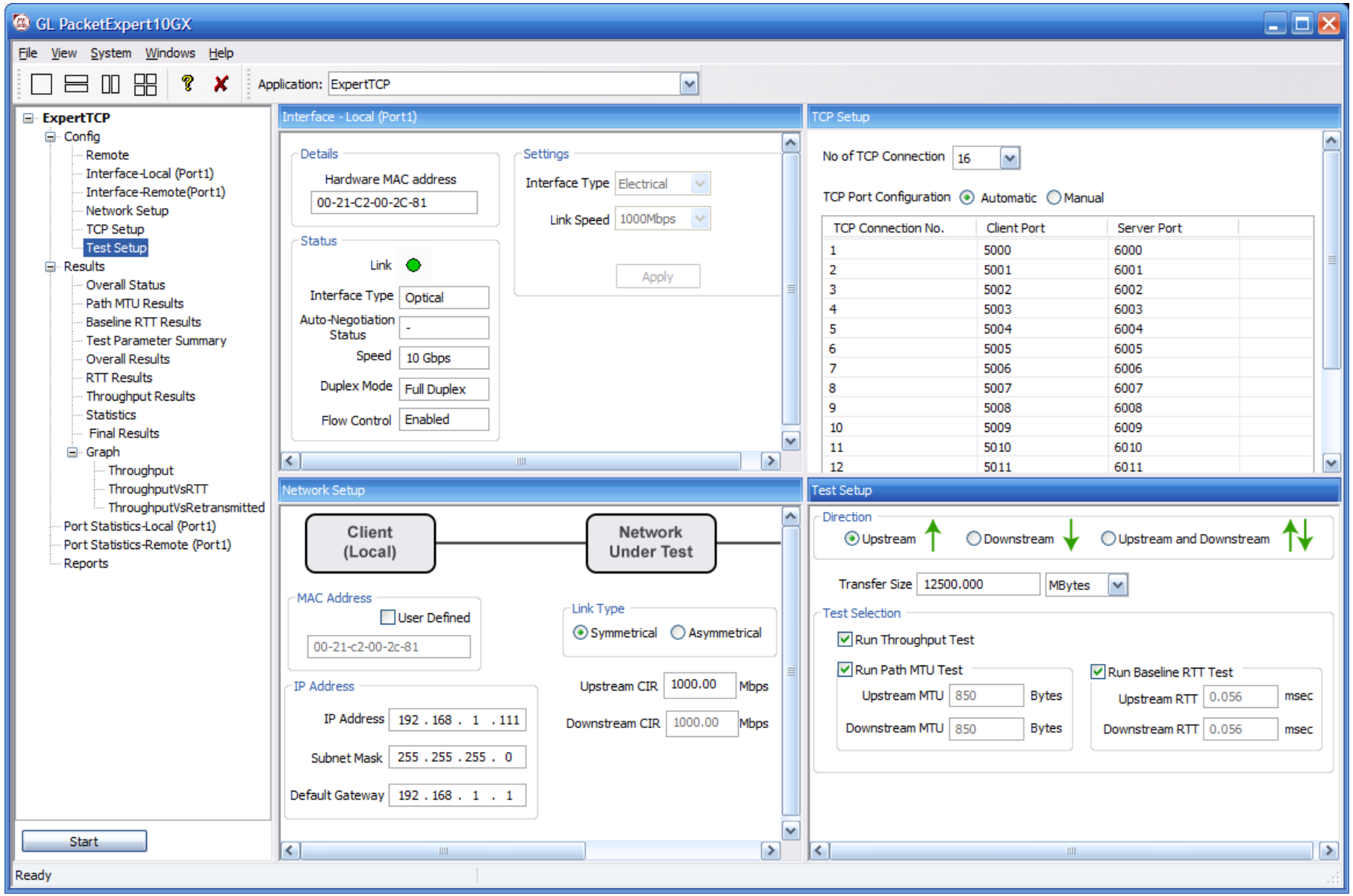
Step 3. TCP Throughput Equilibrium



Software Operation

ExpertTCP™



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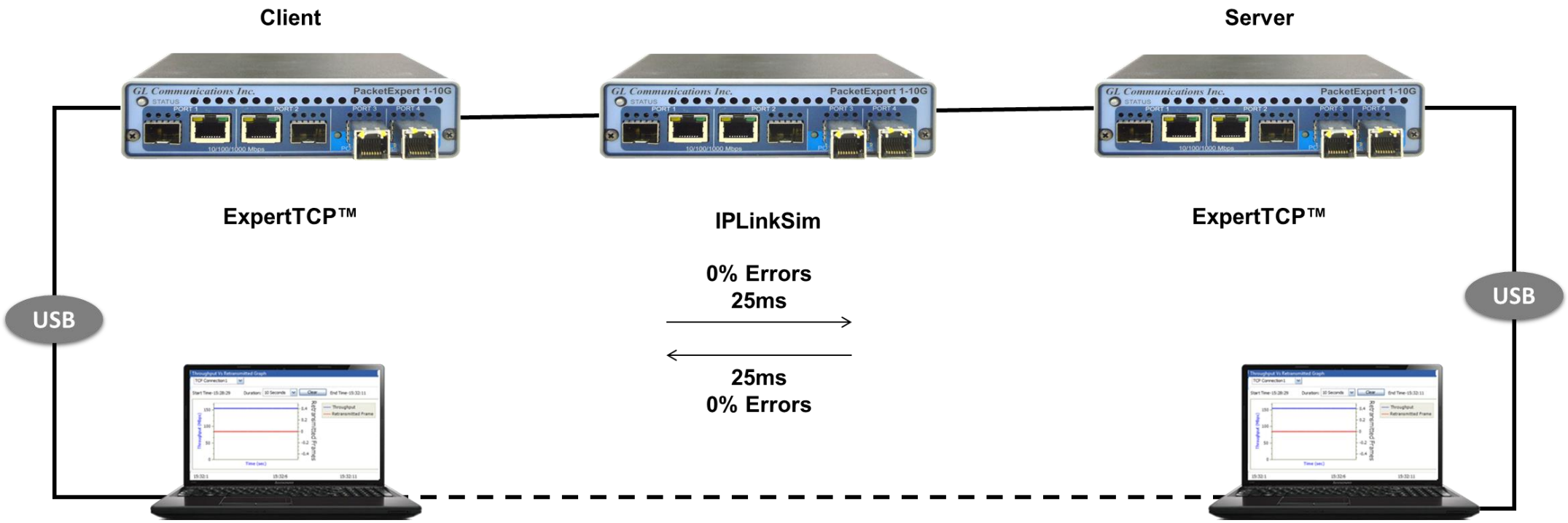
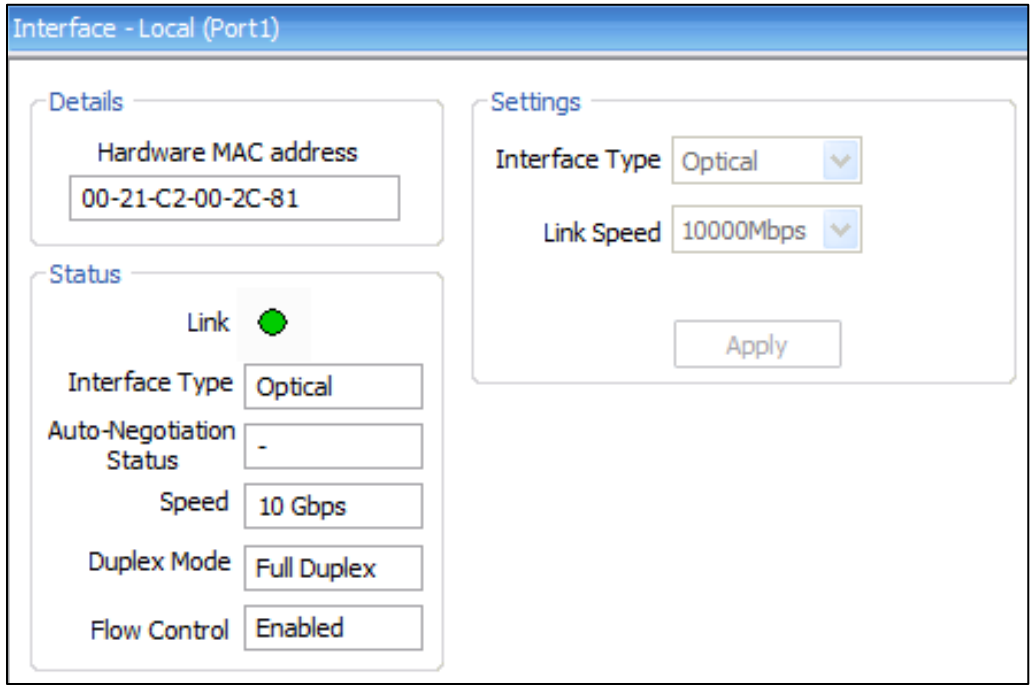
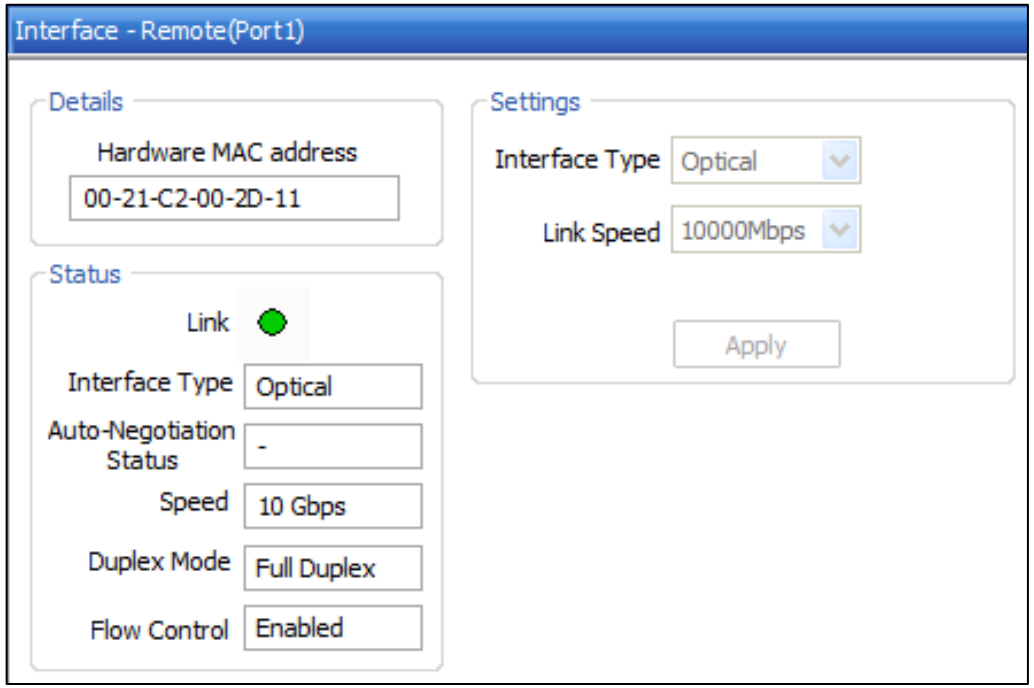
Test Setup with Impairments



Network Setup

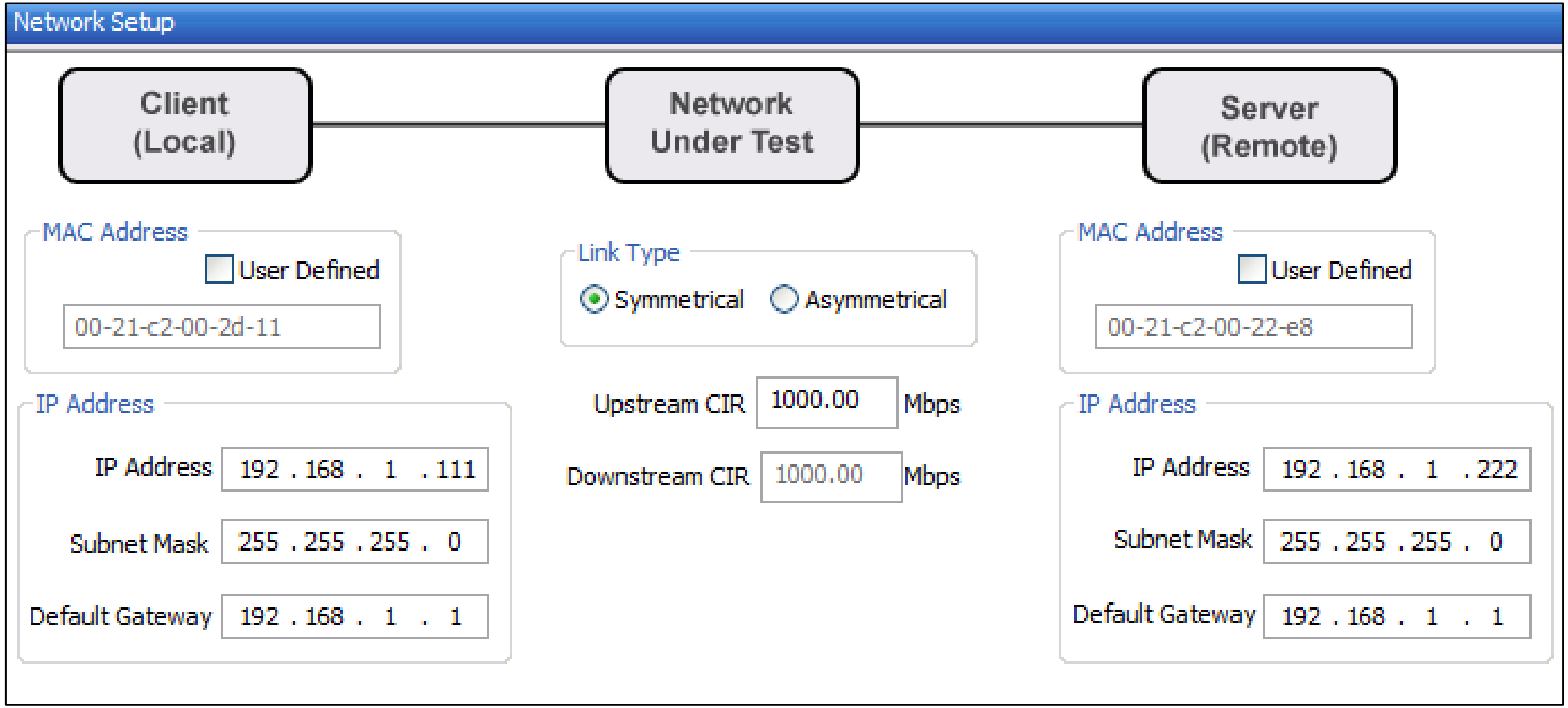
All settings configured locally on the client side.





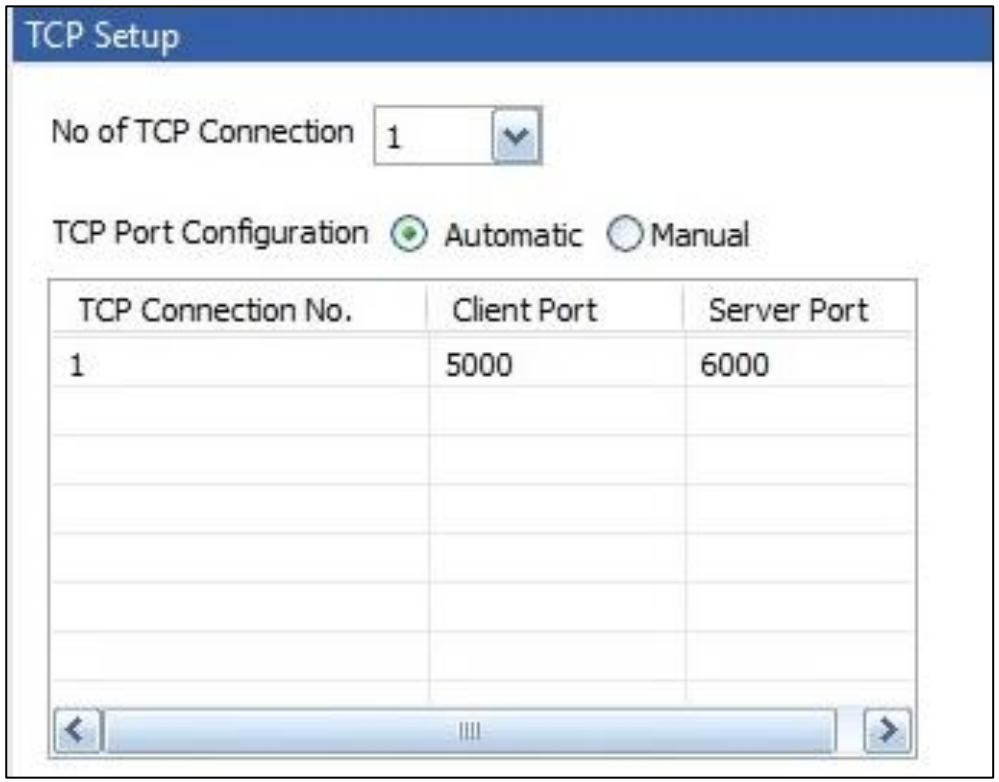
Network Setup (Contd.)

Separate Upstream and Downstream bandwidths configurable for asymmetrical path

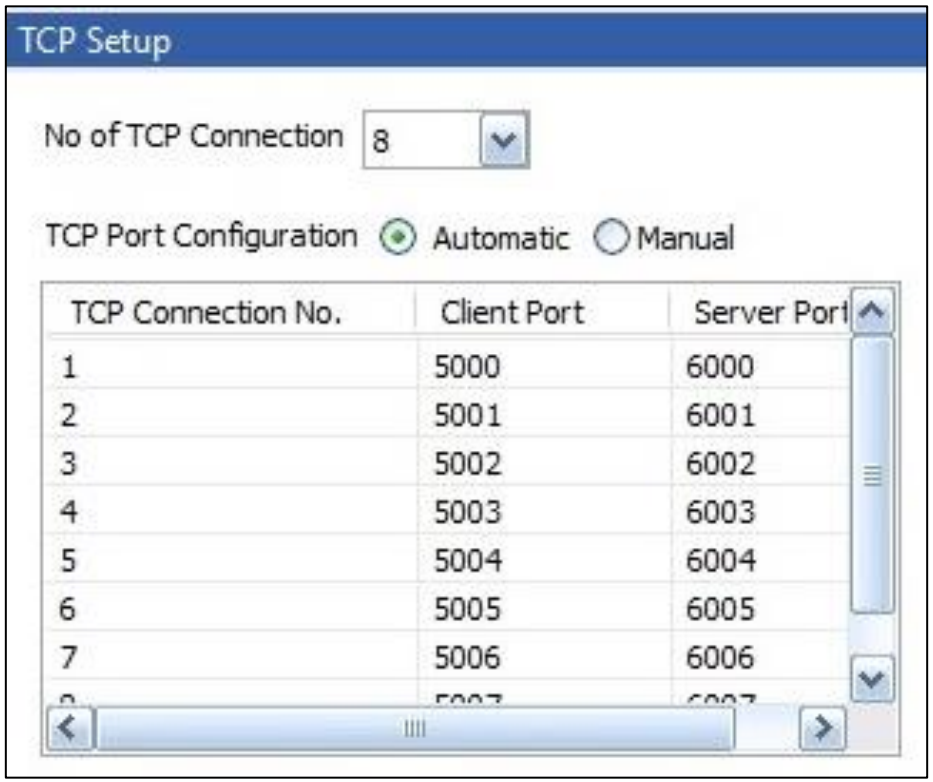


TCP Setup

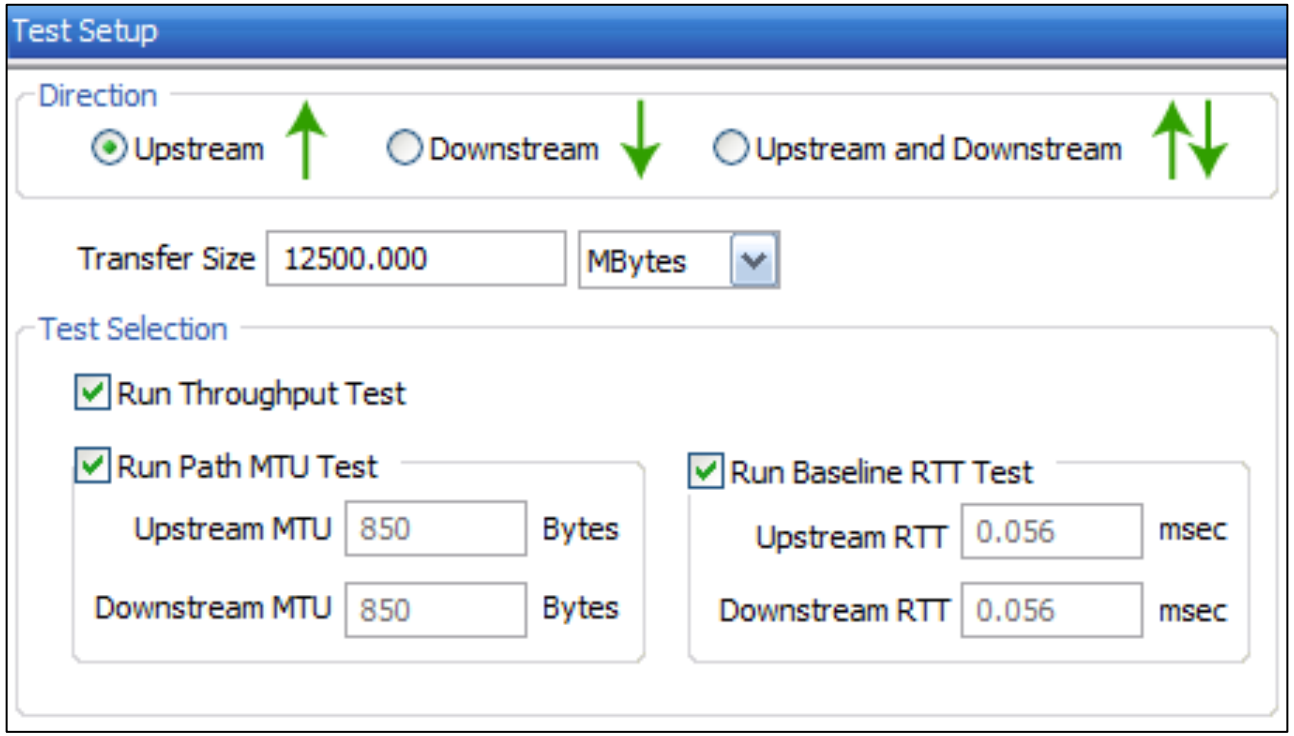
Single TCP connection



Multiple TCP connections

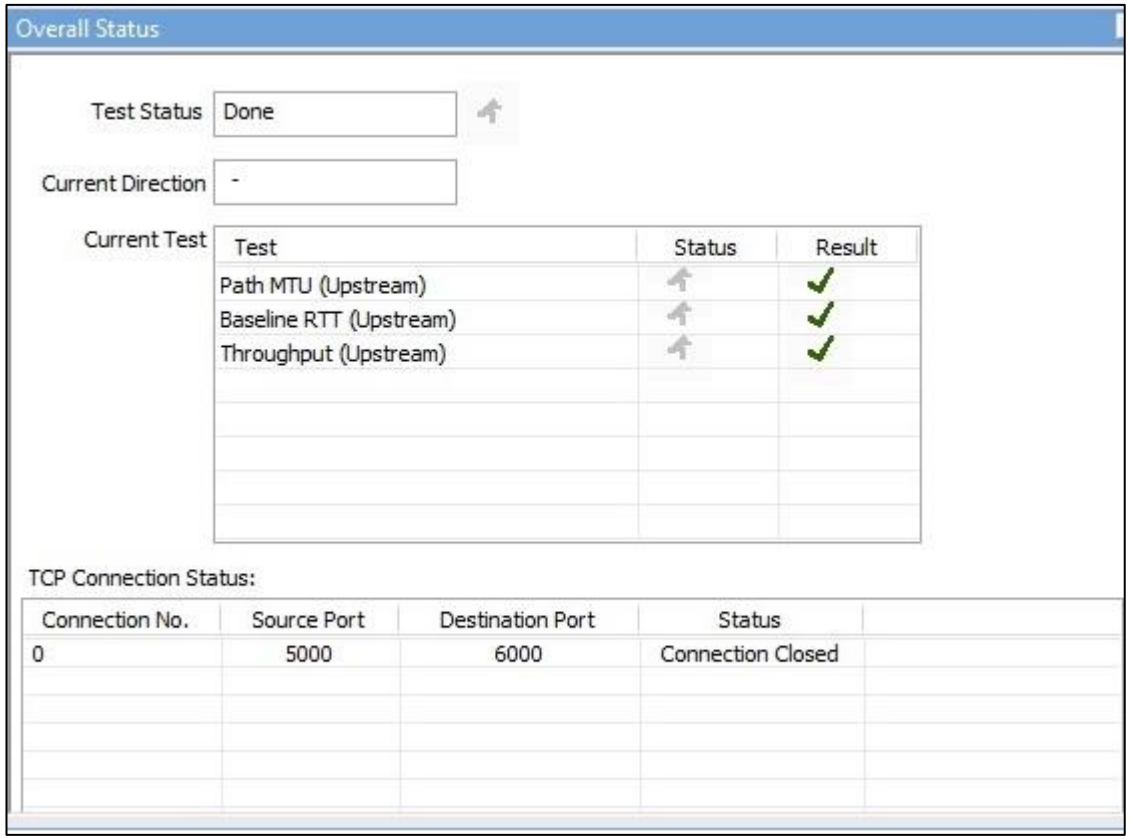


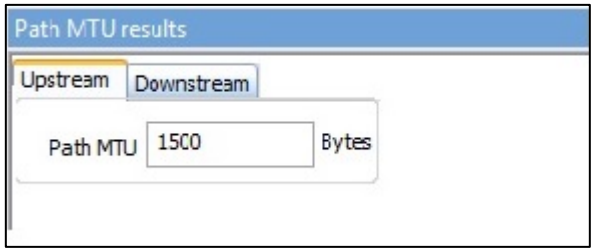
TCP Setup (contd.)

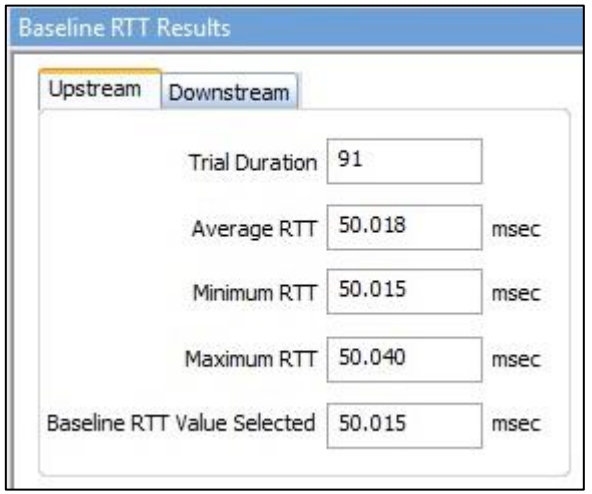


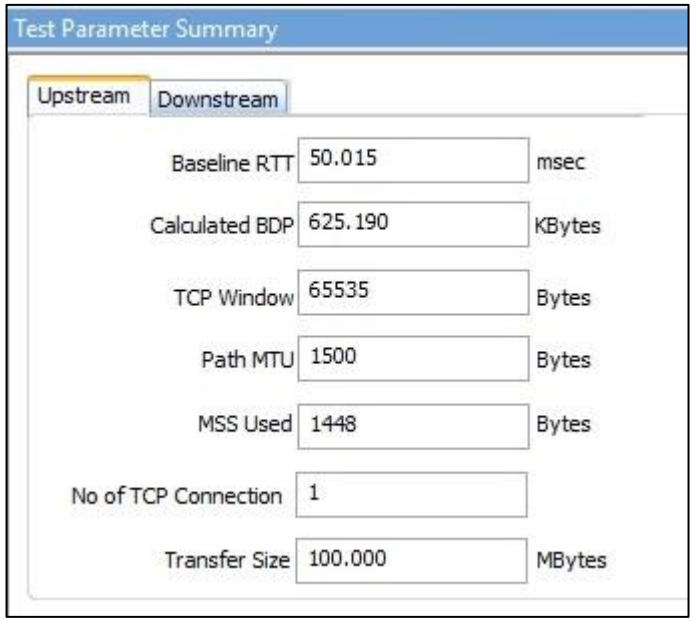
- Upstream/Downstream/Bidirectional
- Path MTU - run test and discover or user can enter manually
- Baseline RTT - run test and find out or user can enter manually
- Separate Path MTU/Baseline RTT configuration for Upstream/Downstream directions for asymmetrical paths

Status and Results









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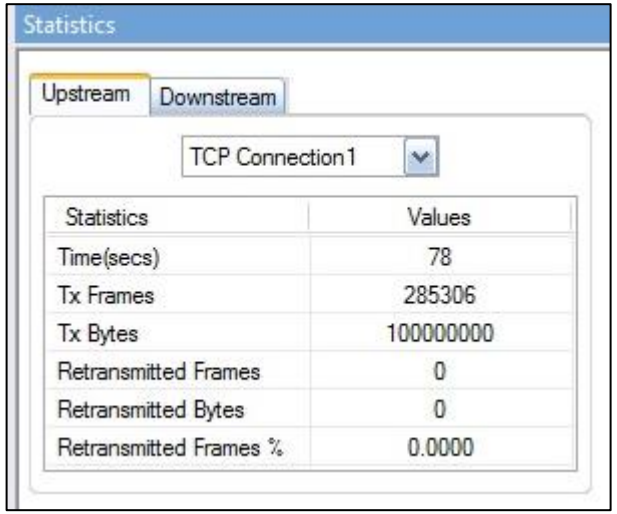
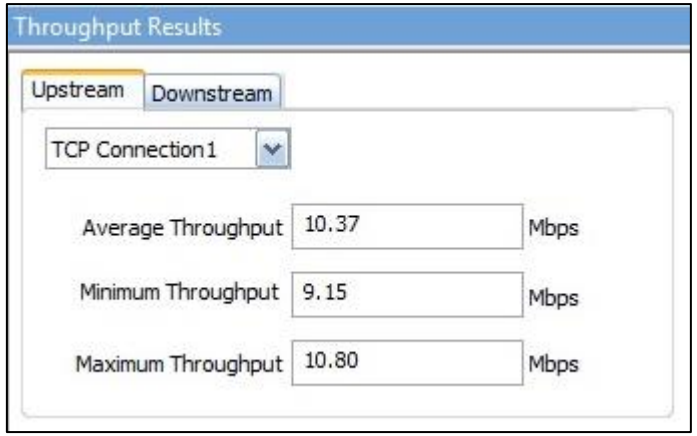
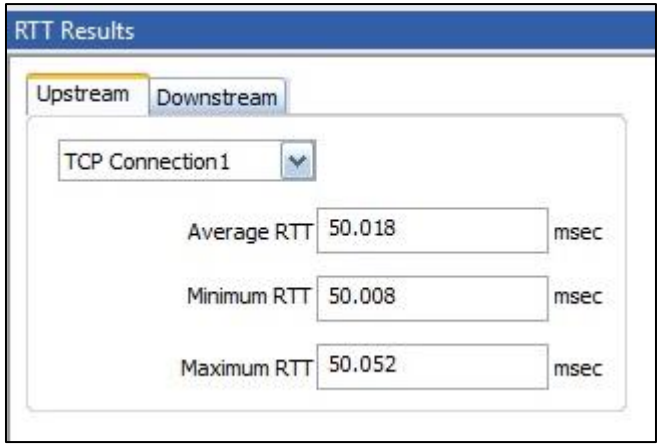
Statistics and Periodic Results



Statistics are updated every second and includes -

- TCP Transmitted Frames/Bytes
- TCP Retransmitted Frames/Bytes
- Retransmitted Bytes Percentage

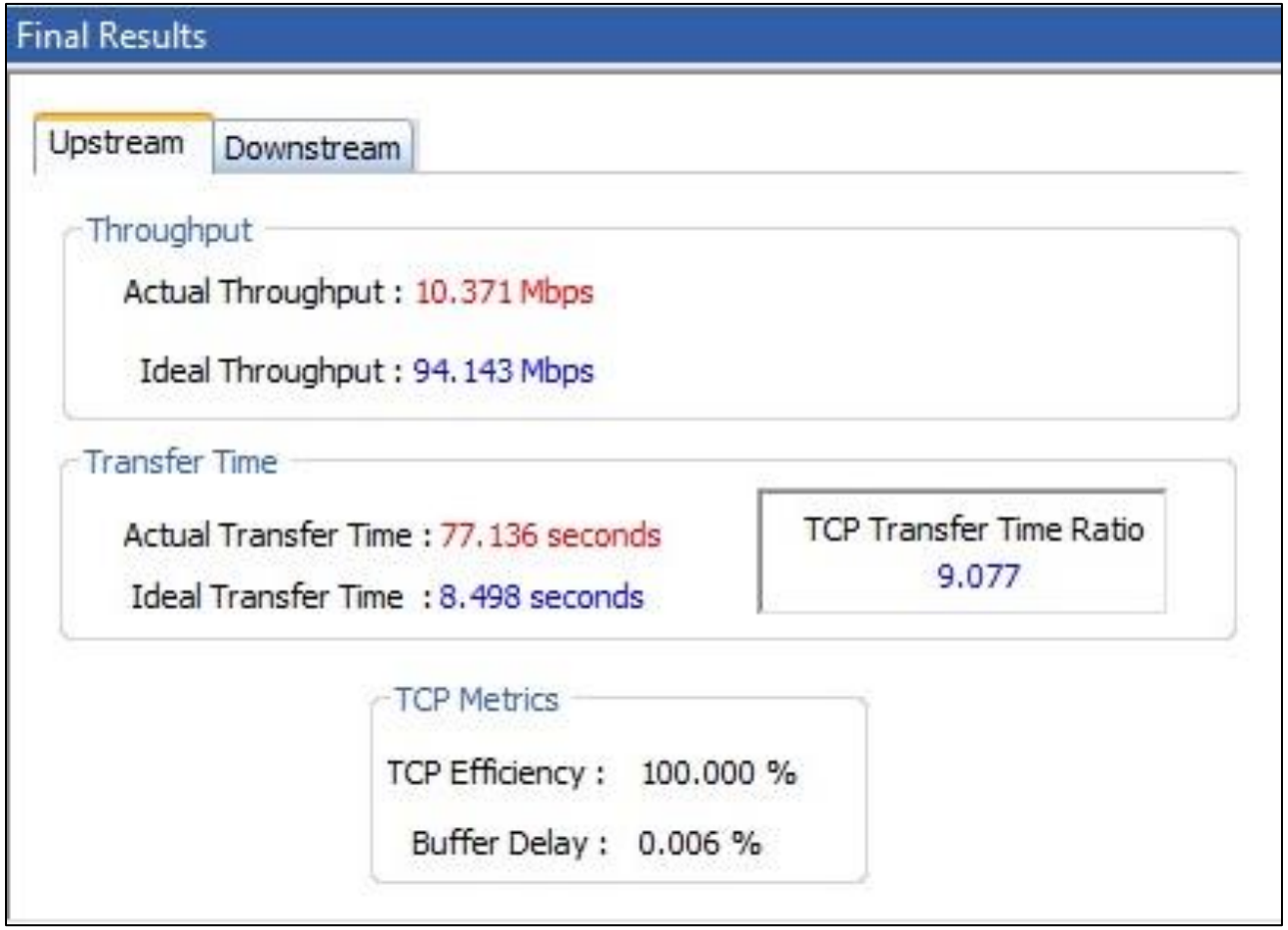




Throughput and RTT values are calculated every second and displayed. Minimum, Maximum and Average Values are displayed

Final Results

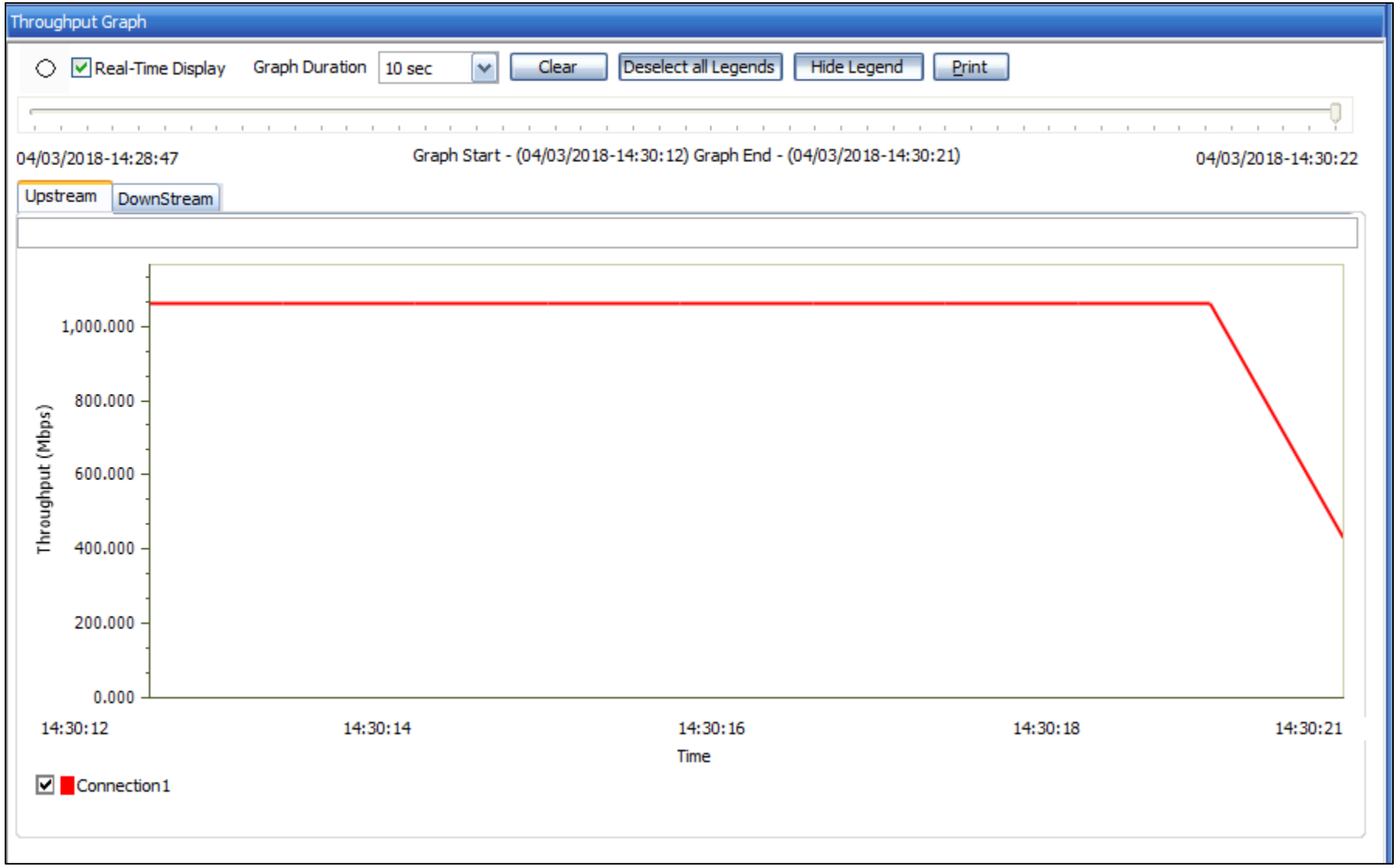
- **Ideal Throughput -** the maximum possible TCP throughput for the given CIR
- **Ideal Transfer Time -** the time taken to transfer the test data size at the ideal throughput
- **TCP Transfer Time Ratio -** Measure of how much Actual transfer time is greater than the Ideal transfer time
- **TCP Efficiency -** measure of the number of Transmitted bytes compared to the retransmitted bytes
- **Buffer Delay -** measure of how much the RTT increases during the actual TCP Throughput test compared to the Baseline RTT



GL Communications

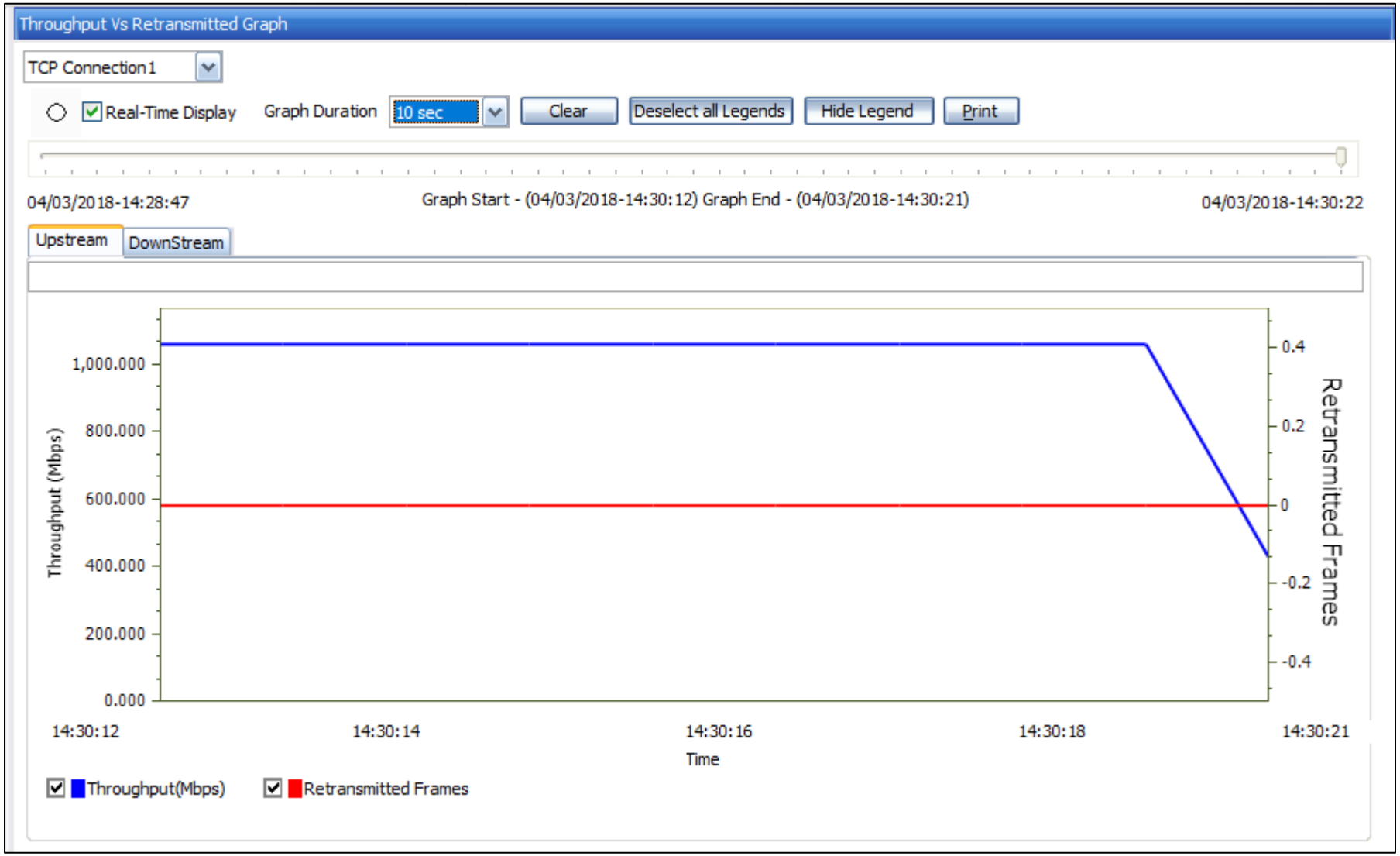
Throughput Graph

With 0.1% Packet Loss



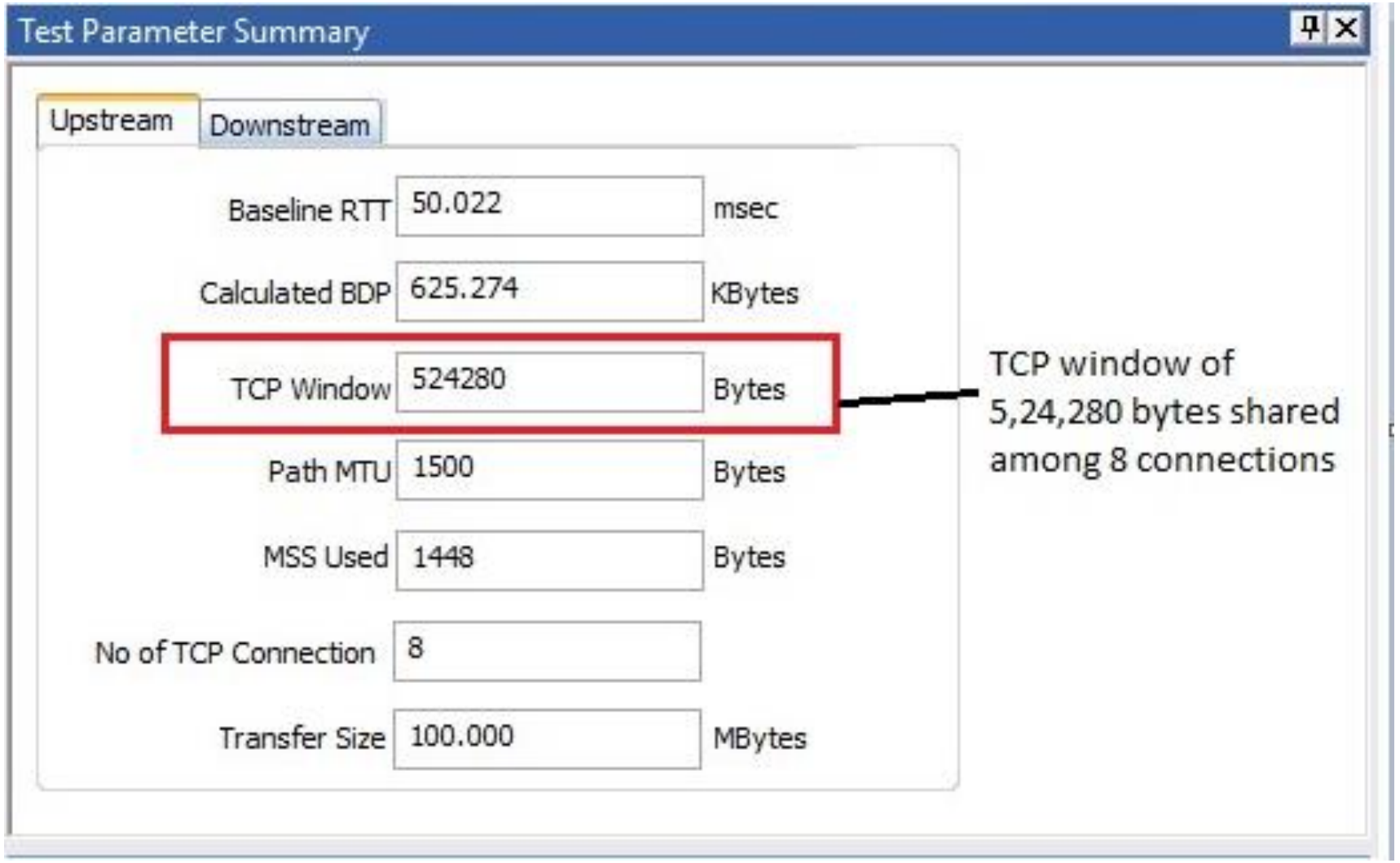
Throughput vs. Retransmitted Frames Graph

With 0.1% Packet Loss



Multiple TCP connections

With 8 TCP connections



Thank You