HF Network-Centric Performance Thresholds

TCP/UDP Data Transport to Remote HF Radio Sites

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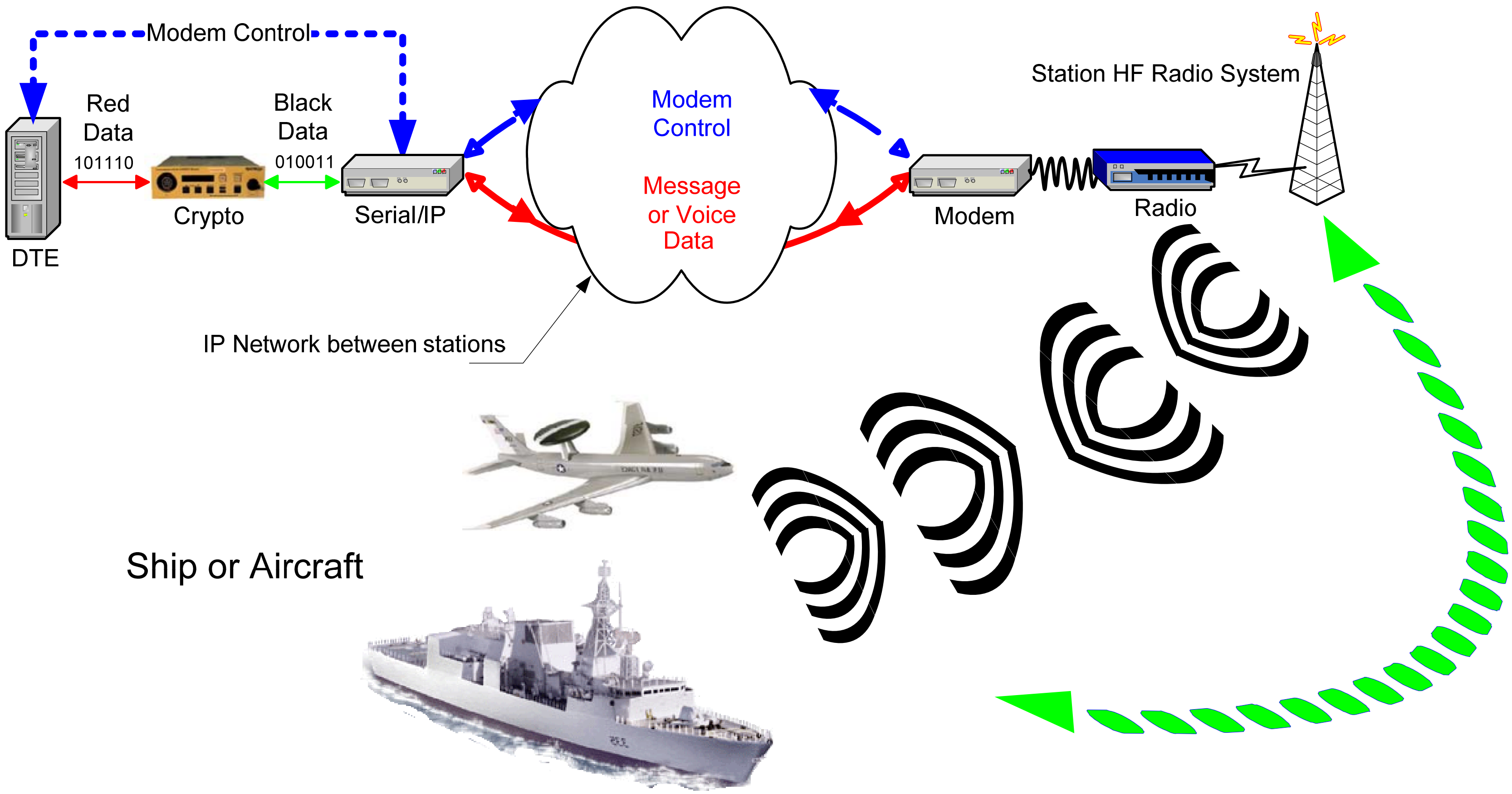
HF Data Transport over IP Links

- Secure military/DHS networks with T1/other media for serial data/digital voice transport to remote HF system sites growing in numbers (HFGCS & COTHEN examples)
- Network infrastructure performance metrics vary due to congestion, dropped packets, packet bit errors
- Data payload errors or dropped packets over network lines results in corrupted data transported over-the-air
- A study characterizing network performance thresholds and consideration of performance enhancements using draft Mil-Std 110C Appendix G network data interface definition

Typical HF Architecture with Ground Network



110C App G Draft Protocol Characteristics

- Transmission Control Protocol (**TCP**) establishes connection with target device prior to data transport

- TCP implementations retransmit lost or errored packets until target acknowledges successful reception

- User Datagram Protocol (**UDP**) does **<u>not</u>** negotiate connectivity with target device; in this implementation, a TCP connection **<u>is</u>** established with the **control port** of the target device before UDP data is sent

- The UDP implementation employs Reed Solomon FEC and interleaving to reconstruct late or missing packets; added FEC penalty is consumption of more bandwidth relative to TCP

110C Appendix G Data Transport Protocols

- HF Modem TCP Packet Format (within the TCP Payload)

Packet Header (8 bytes)	Payload (0 to 4086 bytes)	Payload CRC (16 bits)

- TCP Packet Header Format

Preamble 0x49	Preamble 0x50	Preamble 0x55	Packet Type (1 byte)	Payload Size (16 bits) 0 to 4086	Header CRC (16 bits)

110C Appendix G Data Transport Protocols

- HF Modem UDP Packet Format (within the UDP payload)

Packet Header (4 bytes)	Payload (0 to 1220 bytes)	Payload CRC (16 bits)

- UDP Packet Header Format

Version (4 bits)	Packet Type (4 bits)	Session Identification (24 bits)

UDP Reed Solomon (RS) Coding Rates

- RS coding rates varied relative to waveform data rates
- Shortened N-K values used in App G UDP FEC to compensate for limited bandwidth networks

Waveform Data Rate (Bits per Second)	N	K	Shortened N	Shortened K
50 to 2400	15	11	6	2
3200 to 28,800	15	12	7	4
32,000 to 76,800	15	12	8	5

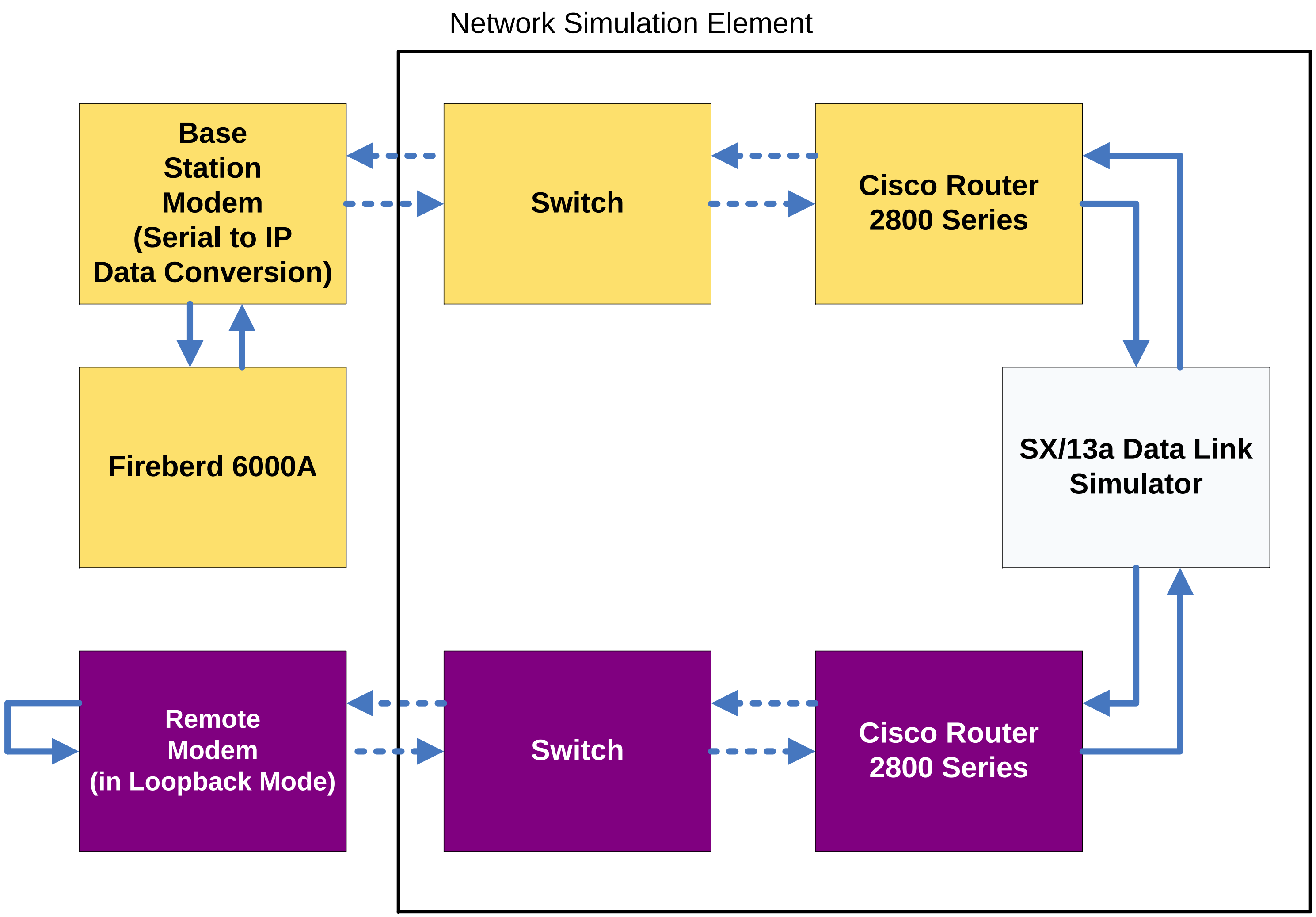
Congested Network Performance Thresholds of 110C Appendix G

Simulation Testing

Network Performance Test Conditions

- Centerpiece of the network performance threshold test bed is the Spirent SX/13a Data Link Simulator
- Cisco 2800 series routers and network switches on both the input and output of Network Simulator
- Two router-simulator interfaces studied, T1 interface and EIA-232 serial interface modules
- T1 router-simulator interfaces used for targeted bit error injections (headers and payload)
- EIA-232 router-simulator interfaces used for random bit error generation and injected throughput delays

Basic Network Test Bed: Round Trip Simulations



Network Performance Test Conditions (cont.)

- Rockwell Collins Q9604 modems with integrated draft 110C Appendix G network data interface used on both ends of test bed link; base station modem controls over IP remote modem
- Sync Serial data (via Fireberds) and digitized voice payloads examined for TCP and UDP performance thresholds
- Audio over IP (AoIP) thresholds subjectively measured for quality at receive side or loss of IP link connectivity
- Synchronous serial data over IP thresholds measured by Fireberd sync loss or loss of IP link connectivity
- Available bandwidth restricted (64 to 128 kHz) to simulate T1 and private networks

Network Injected Random Error & Delay Tests

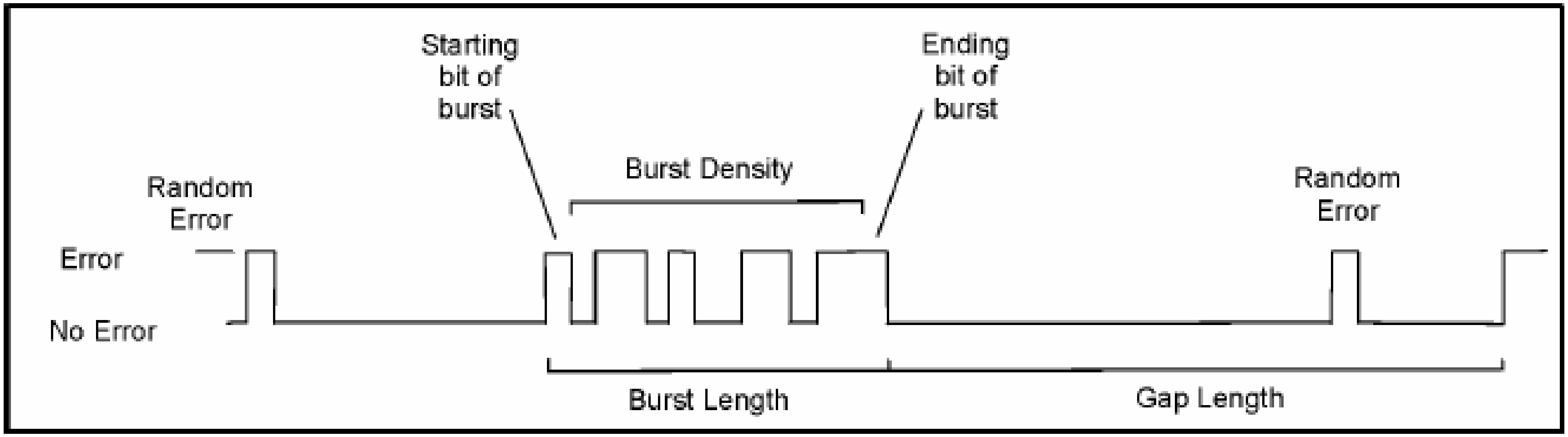
Serial Data Interface between Routers and Simulator

Rockwell Collins

Error Generation Test Parameters

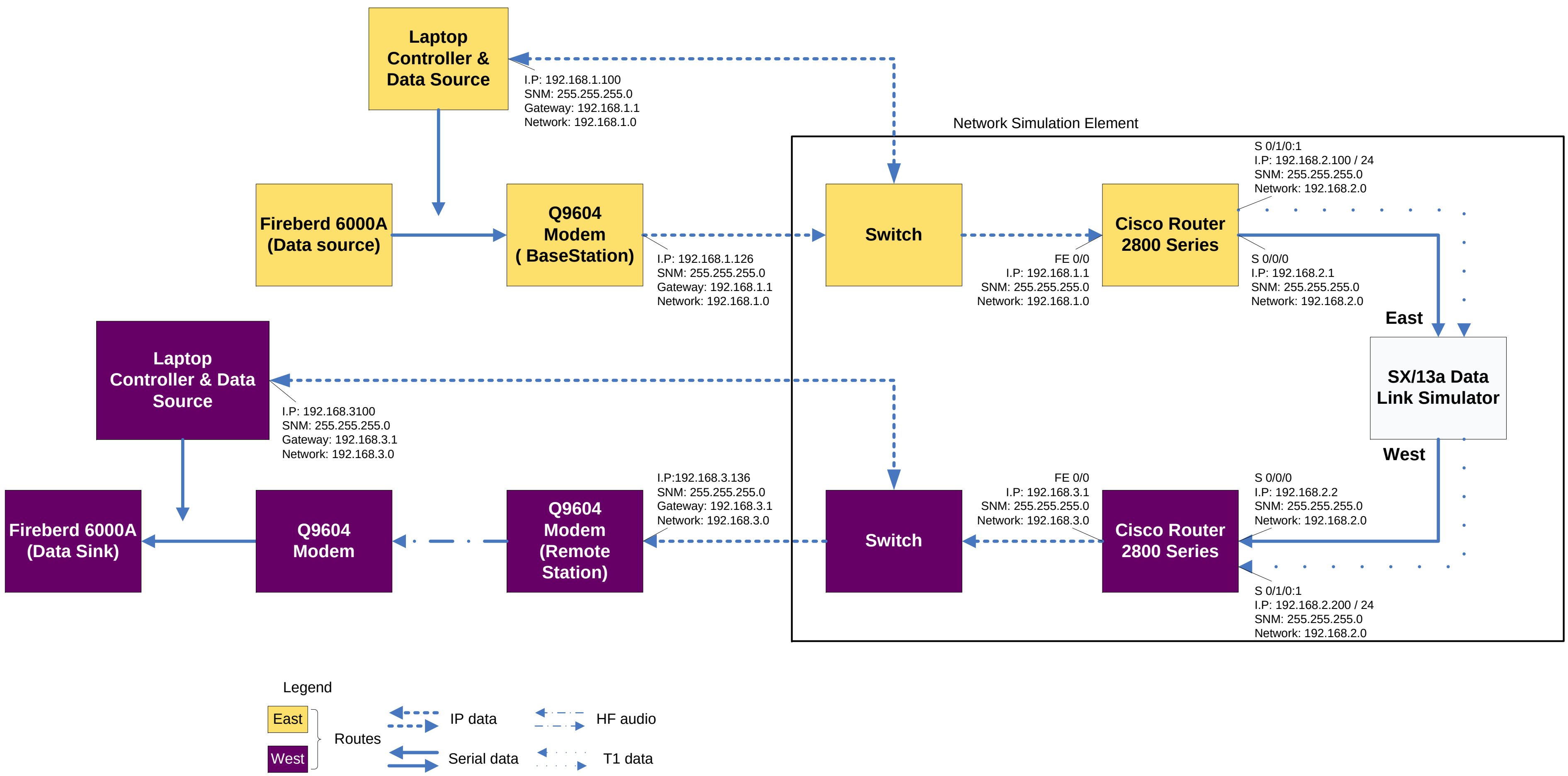
- The simulator delay parameter can be applied for one way traffic or for roundtrip communications
- Error bursts are forced errors characterized by:
  - Burst length – duration of burst error generation
  - Burst density – probability of a bit within the burst having an error
  - Gap length – time between burst error events and when random errors are generated
- Burst Error events are caused by voltage transients, lightning strikes and other natural or man-made phenomena
- The simulator random error rate is the probability of a bit having an error (active only in the gaps between error bursts)
- Trigger interval, used in T1 interface testing, is the time between error injections

Visualizing Errors in the Data Stream



From Spirent SX/13a Data Link Simulator Operating Manual

Network Simulation Flow Diagram: One Way

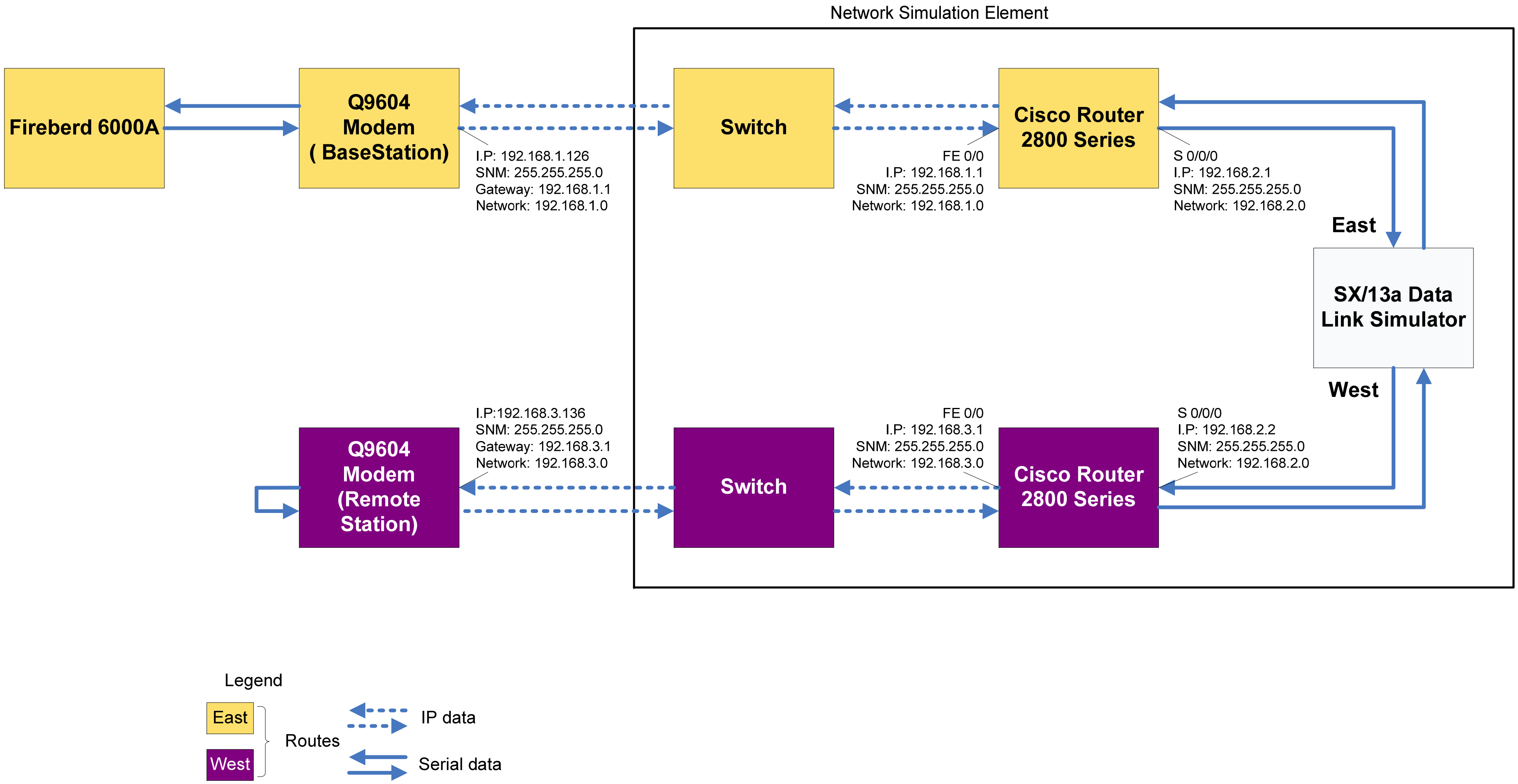


One-Way Delays

- Burst Density, Burst Length, Gap Length, and Random Error Rate were all held constant, and the delay was increased until the system lost synchronization (remote modem under run)
- RC Q9604 modem App G implementation includes latency buffering up to 5000 msec; parameter was set to the 5000 msec buffering maximum

	Burst Density	Burst Length (ms)	Gap Length (ms)	Random Error Rate	Delay (ms) – TCP	Delay (ms) – UDP
Control	1.00E-05	15	1000	1.00E-06	280	1050
Change Burst Length	1.00E-05	30	1000	1.00E-06	265	875

Network Simulation Flow Diagram: Two Way



Two-Way Delays

- All but the delays were held constant, and then the east and west delays were increased together until the system lost synchronization
- This was then repeated for various other initial conditions
- Both East and West channels had the exact same conditions in the control; the error test had delays in both directions, but error injection only in one direction

	Burst Density	Burst Length (ms)	Gap Length (ms)	Random Error Rate	Delay (ms) – TCP	Delay (ms) – UDP
Control	0	0	1	0	750	950
Err Test	1.00E-05	15	1000	1.00E-06	175	625

Minimizing Gap Length at Various Conditions

	Delay (ms)	Burst Density	Burst Length (ms)	Random Error Rate	Gap Length – TCP	Gap Length – UDP
Test 1A	20	1.00E-05	5	0	575	375
Test 1B	20	1.00E-05	25	0	760	450
Test 2A	20	1.00E-05	15	1.00E-05	800	575
Test 2B	20	1.00E-05	15	2.00E-05	1875	600
Test 3A	20	1.00E-05	15	1.00E-05	800	575
Test 3B	20	1.00E-03	15	1.00E-05	2050	2000

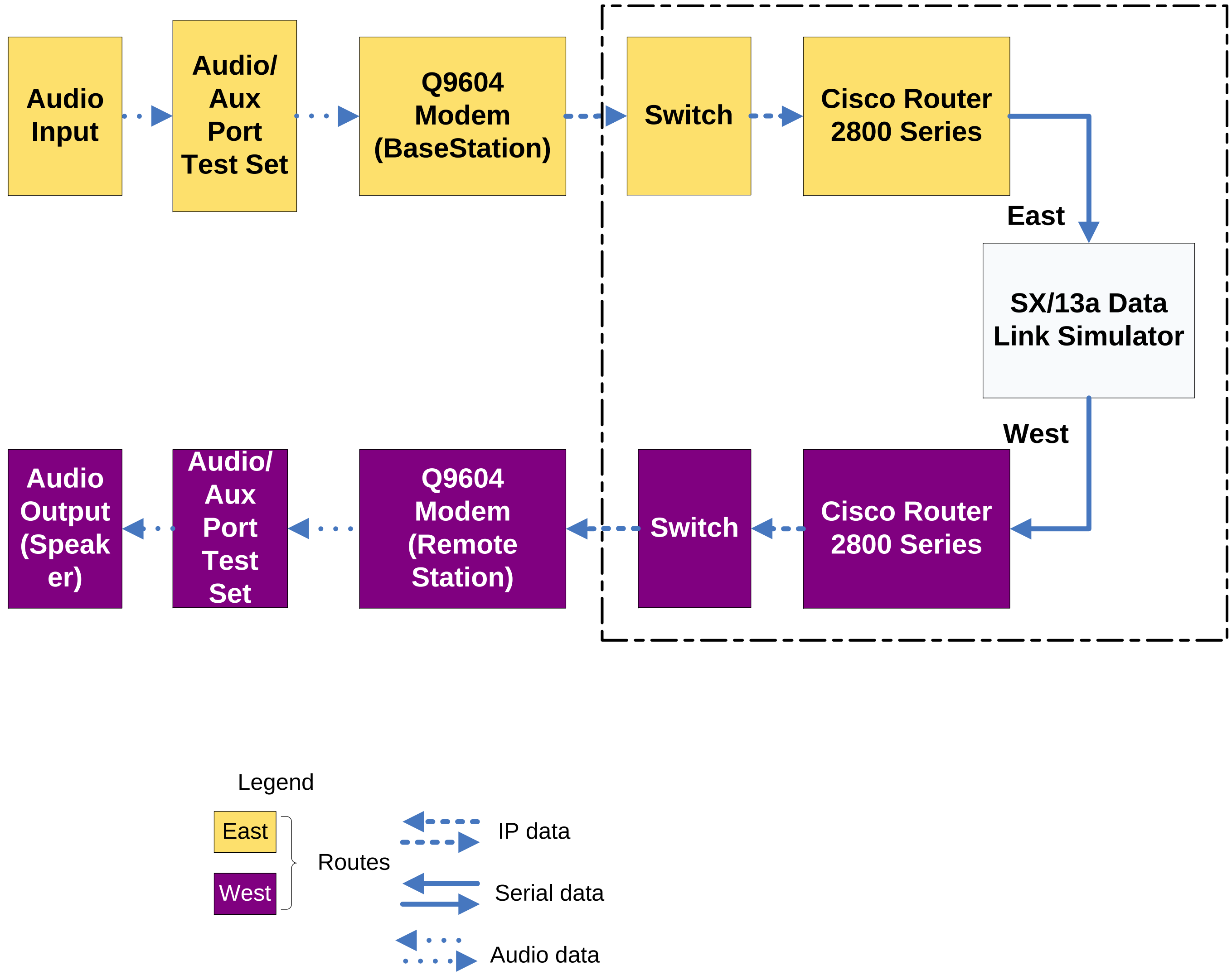
Network Random Error Injection Summary

- Simulator Random Error Rate, Burst Density/Length, and Gap Length (time between error events) parameters varied one at a time for network error tolerance impact
- MIL-STD-110C App G random error rate performance is well within the performance requirements of known network specifications, with App G UDP mode having edge over TCP
- UDP tolerates burst densities up to an order of magnitude with respect to bit error densities over TCP mode
- UDP tolerance of burst error duration (burst error length) over twice the burst error duration tolerance of TCP

RS-232 Simulator Interface Tests

Audio over Internet Protocol (AoIP)

Network Simulation Test Bed: AoIP



AoIP Parameter Thresholds – Random Error Rate

	Delay (ms)	Burst Density	Burst Length (ms)	Gap Length (ms)	Random Error Rate – UDP
Control	20	1.00E-05	15	1200	3.00E-05
Changed Burst Length	20	1.00E-05	30	1200	7.00E-06
Changed Gap Length	20	1.00E-05	15	600	5.00E-06
Changed Burst Density	20	1.00E-04	15	1200	5.00E-06

AoIP Network Performance Test Summary

- Three CODECs were examined: 16 kbps ADPCM, 32 kbps ADPCM, and 64 kbps µlaw PCM
- The 64 kbps CODEC was the most robust for tolerating random error injections and delays
- The 32 kbps mode was nominally more tolerant to random error and delay injections than the 16 kbps CODEC, but neither lower rate CODECs performed at the level of the 64 kbps mode
- Performance measurements subjective due to evaluation of test bed output audio by the human ear
- This AoIP implementation uses TCP for the control connection and only UDP for data transport.

T1 Interface Network Simulator Tests

Specific Bit Targeted Error Injections

T1 Interface Terms

- The **Facility Data Link** (FDL) allows a service provider to check error statistics on terminating equipment without intrusion
- The **Framing Pattern Sequence** (FPS) helps to synchronize the bit stream
- The **Cyclic Redundancy Check** (CRC) can be used as a checksum to detect accidental alteration of data during transmission or storage
- The T1 interface FDL, FPS, and CRC bit fields are extremely vulnerable to bit errors; a single error in these fields can compromise the transport of the entire data payload

Specific Targets in the T1 Interface

- T1 Interface Headers
  - No difference between TCP and UDP when corrupting the FDL or CRC
  - Bit errors in either the FDL or CRC fields are fatal to transport success
  - UDP more tolerant of FPS corruption

- TCP and UDP headers
  - TCP data cannot tolerate any corruption of any of its header components
  - UDP data can tolerate corruption of source port components

Specific Targets in the T1 Interface (cont)

- TCP and UDP Payload Targeted Error Injections
  - Configurable number of packet bytes targeted for errors by forcing the logic value of each bit to change
  - Selected number of injected packet byte error events programmable to occur at various interval times (in msec)
- For maintaining a link, injected errors into TCP payloads cannot be less than every 40 to 50 msec
- UDP payloads can tolerate hundreds of injected bit errors every 20 to 40 msec and maintain a link
- UDP is more robust than TCP for tolerating bit errors over short, but concentrated error event cycles

Summary

Performance Summary of 110C Draft App G TCP and UDP Protocols

Performance Comparison Summary

- Transmission of serial data using UDP mode, the system was less likely to experience connectivity problems than TCP
- During AoIP transport, UDP was able to tolerate higher error rate levels before the errors became noticeable in the audio stream on the receiving end
- Using the T1 interface for targeted bit error injections, UDP had fewer connectivity problems than TCP when targeting either the header or the payload with errors
- Network delay and error testing per conditions described in this investigation, suggests the 110C App G UDP mode provides a higher quality of service than TCP, but at the price of UDP consuming more network bandwidth

Enhancing 110C App G Performance Thresholds?

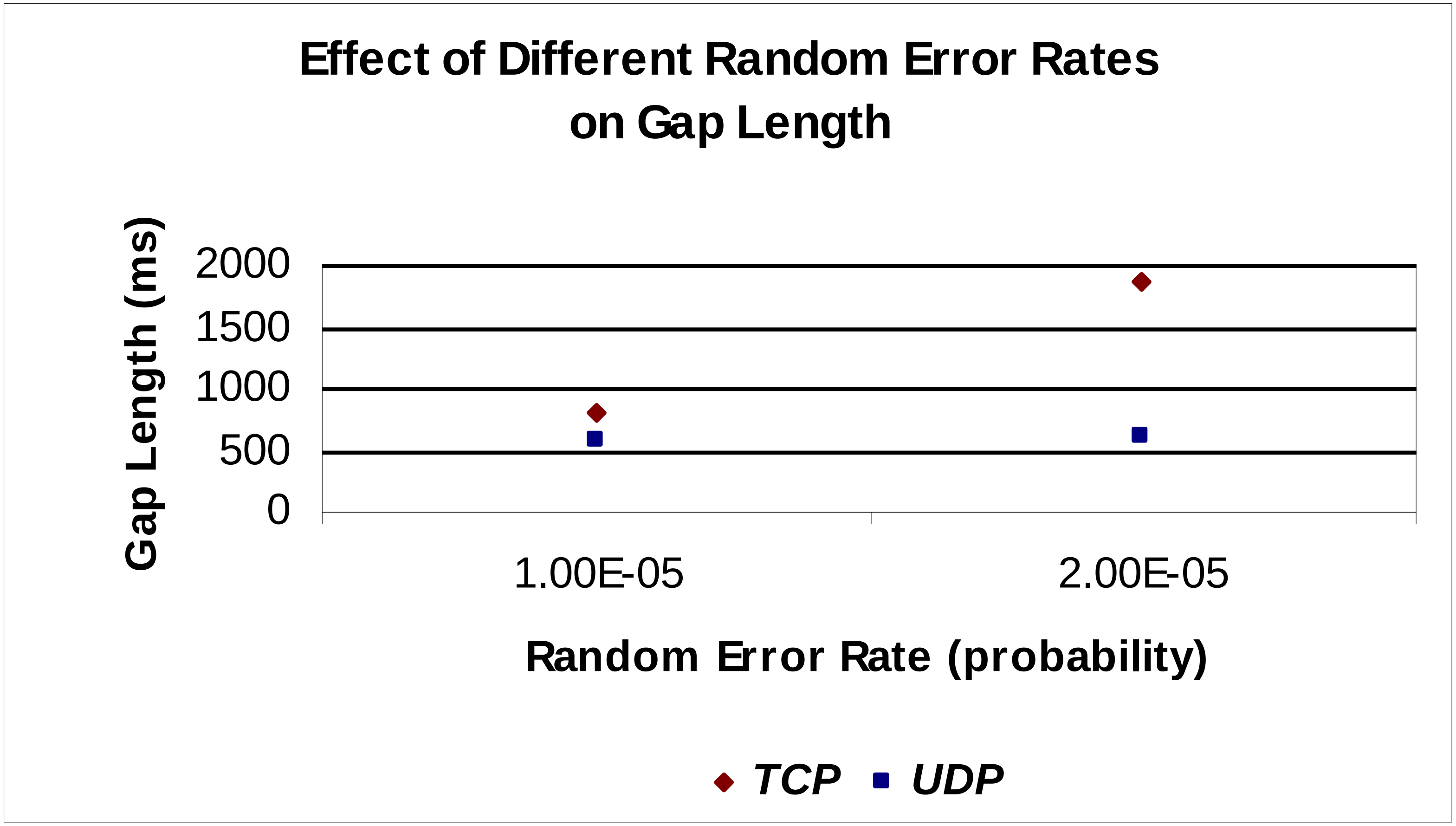
- **TCP & UDP:** when the receiver detects lost or dropped packets, insert "padded" packets into the stream for maintaining link connectivity and satisfying decryption algorithms, e.g. digital voice AES
- Padded packet insertion for missing/dropped packets would force dropping the actual packet if arrival is after replacement packet insertion

- **UDP:** Scalable RS FEC rate coding; if network bandwidth is sufficient, RS FEC coding could be increased for improved performance in high error rate circuits
- Limited network bandwidth would require lower rate FEC coding (higher rate FEC coding = higher bandwidth consumption)

Backup Slides

Network Performance Testing Details

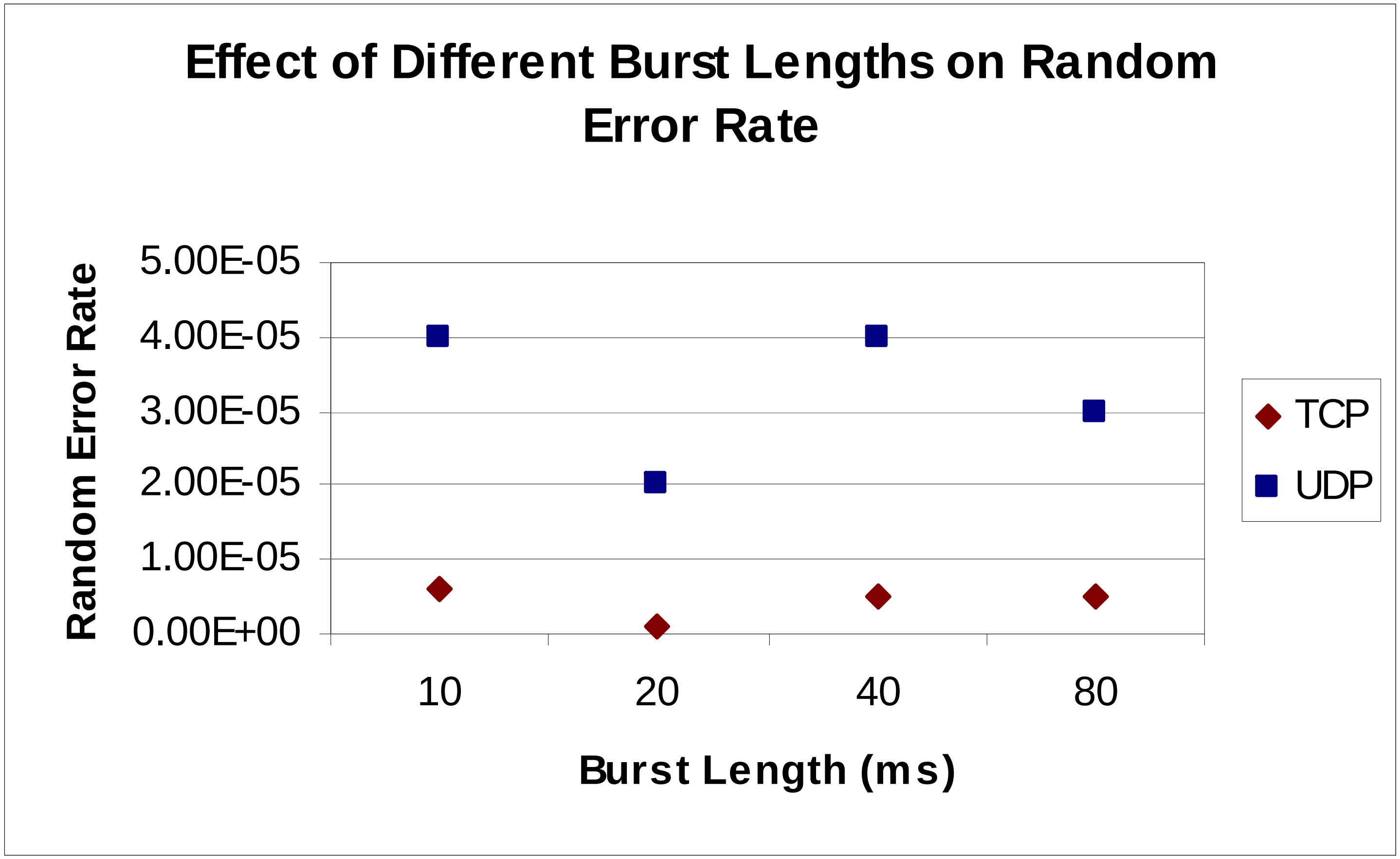
Parameter Thresholds – Gap Length, Tests



Maximizing Random Error Rate at Various Conditions

	Delay (ms)	Burst Density	Burst Length (ms)	Gap Length (ms)	Random Error Rate – TCP	Random Error Rate – UDP
Test 1A	20	1.00E-05	10	1000	6.00E-6	4.00E-5
Test 1B	20	1.00E-05	20	1000	1.00E-6	2.00E-5
Test 2A	20	1.00E-06	15	1000	7.00E-6	2.00E-5
Test 2B	20	1.00E-02	15	1000	4.00E-7	1.00E-6
Test 3A	20	TCP: 0.01 UDP: 0.0001	15	1100	5.00E-6	9.00E-6
Test 3B	20	TCP: 0.01 UDP: 0.0001	15	1600	2.00E-5	2.00E-5

Parameter Thresholds – Random Error Rate, Tests 1A and 1B



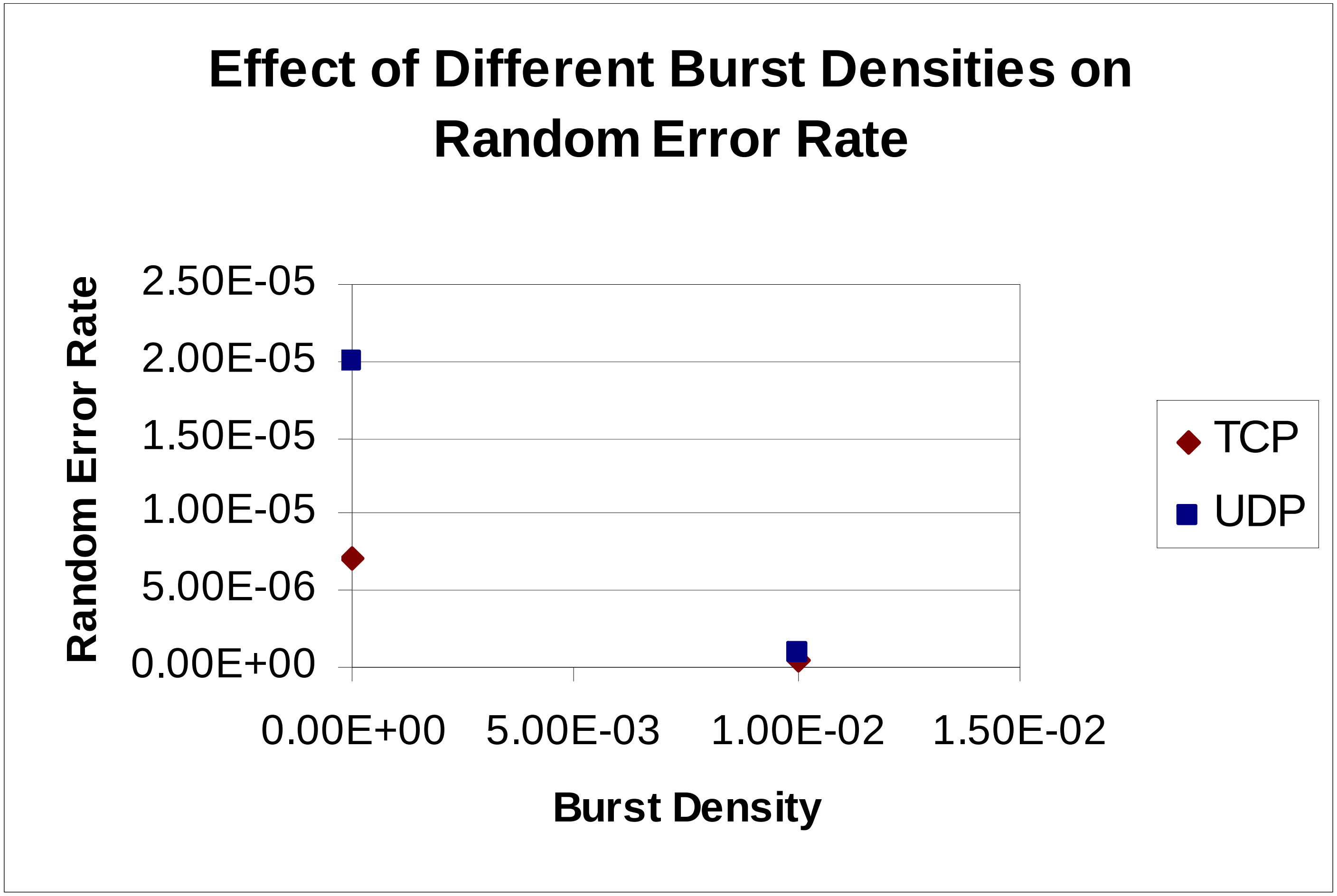
Maximizing Burst Density at Various Conditions

	Delay (ms)	Burst Length (ms)	Gap Length (ms)	Random Error Rate	Burst Density – TCP	Burst Density – UDP
Test 1A	20	5	1000	1.00E-05	5.00E-4	4.00E-1
Test 1B	20	15	1000	1.00E-05	2.00E-4	1.00E-3
Test 2A	20	15	1000	1.00E-05	Maximum	Minimum
Test 2B	20	15	1000	2.00E-05	1.00E-3	4.00E-4
Test 3A	20	15	1000	1.00E-05	2.00E-4	1.00E-3
Test 3B	20	15	800	1.00E-05	Minimum	3.00E-4

Maximizing Burst Length at Various Conditions

	Delay (ms)	Burst Density	Gap Length (ms)	Random Error Rate	Burst Length – TCP	Burst Length – UDP
Test 1A	20	2.00E-03	1000	1.00E-05	6	14
Test 1B	20	8.00E-03	1000	1.00E-05	2	13
Test 2A	20	1.00E-05	800	1.00E-05	Minimum	125
Test 2B	20	1.00E-05	1200	2.00E-05	5	575
Test 3A	20	1.00E-05	1000	1.00E-05	5	9
Test 3B	20	1.00E-05	1000	1.00E-06	575	Maximum

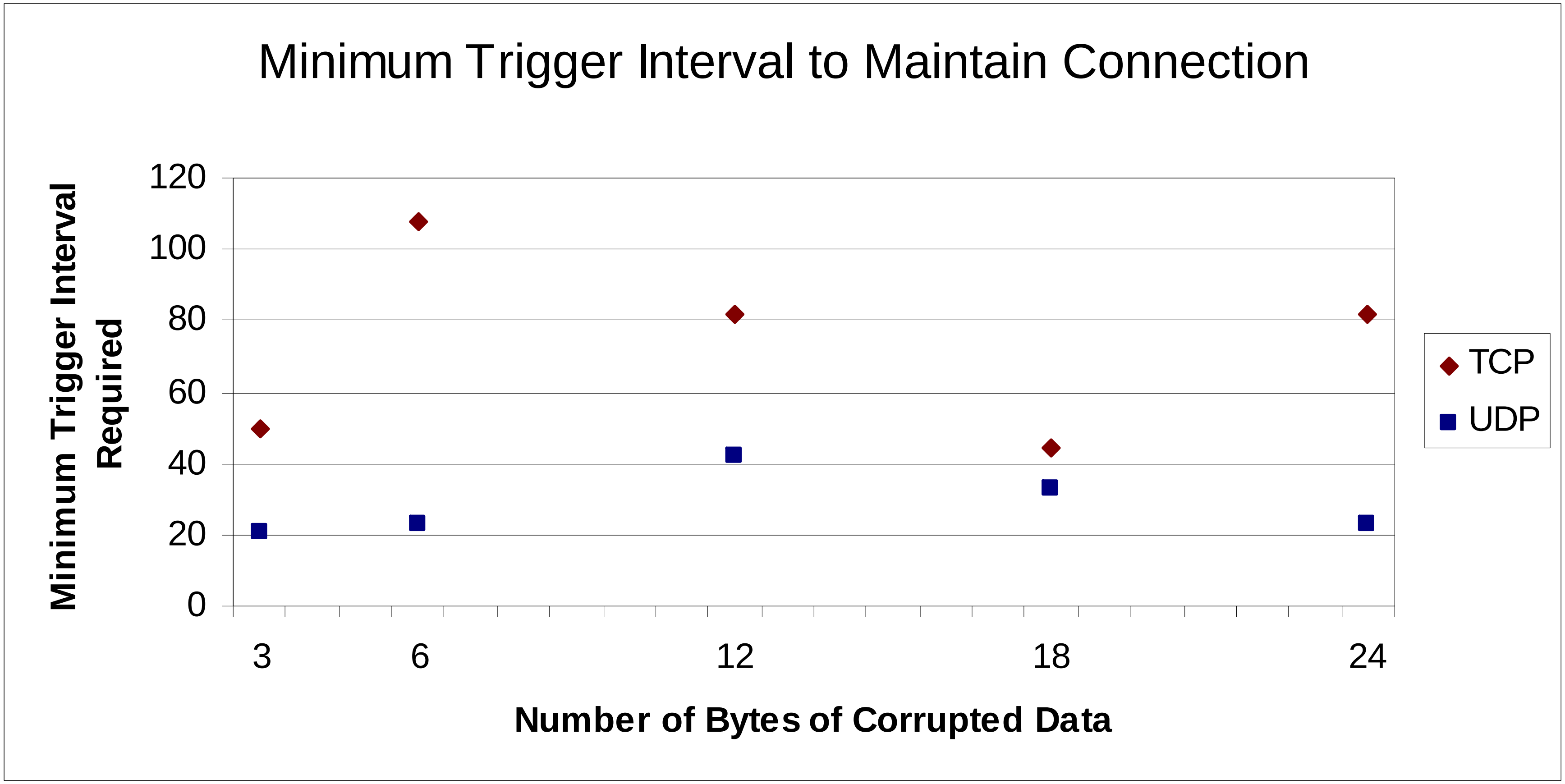
Parameter Thresholds – Random Error Rate Tests



AoIP Parameter Thresholds – Gap Length

	Delay (ms)	Burst Density	Burst Length (ms)	Random Error Rate	Gap Length – UDP
Control	20	1.00E-05	15	1.00E-6	700
Changed Burst Length	20	1.00E-05	30	1.00E-6	775
Changed Burst Density	20	1.00E-04	15	1.00E-6	700
Changed Random Error Rate	20	1.00E-05	15	1.00E-5	900

T1 Interface Payload Targeting



AoIP Parameter Thresholds – Burst Density

	Delay (ms)	Burst Length (ms)	Gap Length (ms)	Random Error Rate	Burst Density – UDP
Control	20	15	1200	1.00E-6	3.00E-4
Changed Burst Length	20	30	1200	1.00E-6	9.00E-6
Changed Gap Length	20	15	600	1.00E-6	Minimum
Changed Random Error Rate	20	15	1200	1.00E-5	Minimum

AoIP Parameter Thresholds – Burst Length

	Delay (ms)	Burst Density	Gap Length (ms)	Random Error Rate	Burst Length – UDP
Control	20	1.00E-05	1200	1.00E-6	23
Changed Gap Length	20	1.00E-05	600	1.00E-6	Minimum
Changed Burst Density	20	1.00E-04	1200	1.00E-6	6
Changed Random Error Rate	20	1.00E-05	1200	1.00E-5	Minimum