E2X Link Reliability for HD Radio™ Systems

Introducing a Reliable Real-Time Point-to-Multipoint E2X Transport Protocol

Broadcasters Clinic 2007

Madison, WI

Jeff Welton

Technical Sales Representative

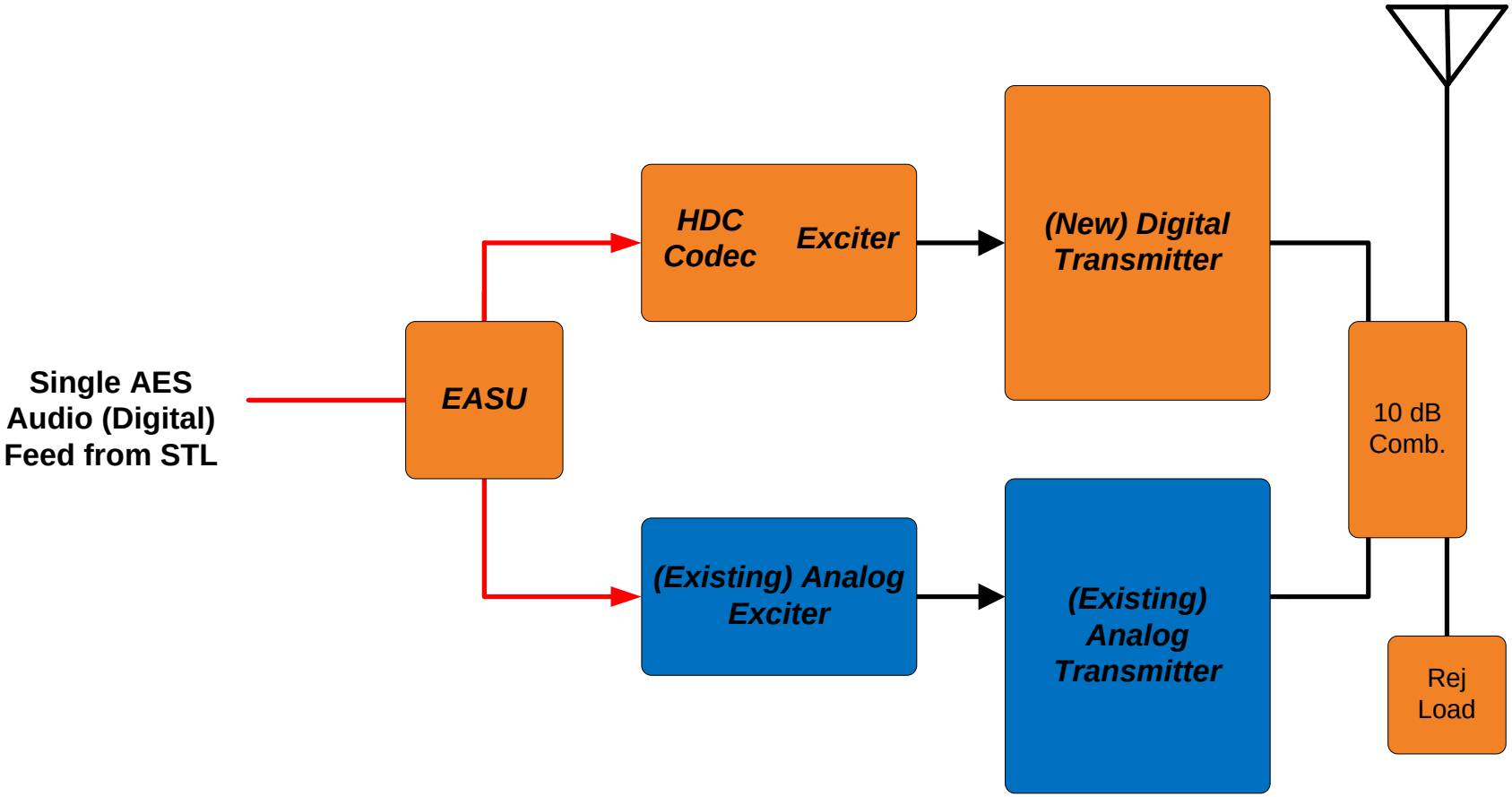
Overview

Presentation Topics:

- **2nd vs. 3rd Generation HD Radio Architecture**
- **E2X Data Link Performance Requirements**
- **E2X Synchronization**
- **E2X Transport Requirements**
- **A New E2X Transport Protocol:**

  Nautel Reliable HD Transport Suite
- **Test Results**
- **Application Examples**
- **Conclusions**

Gen. 2 FM Architecture



Gen 3 (Exgine) Terminology Review

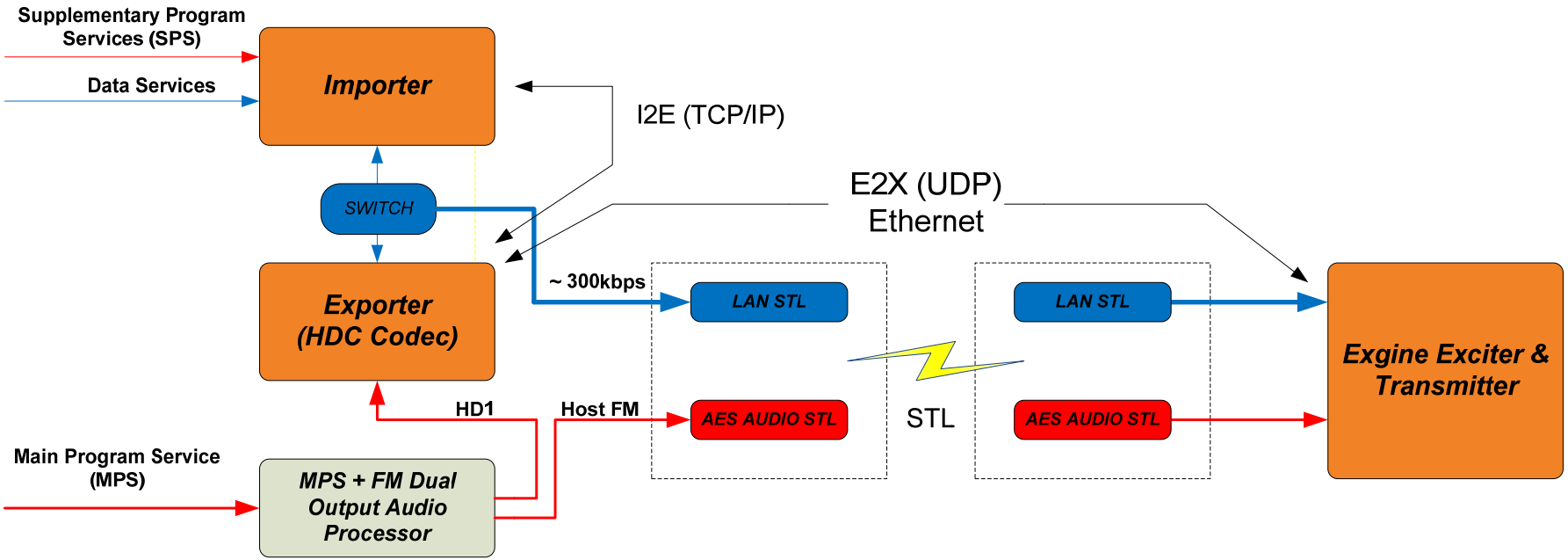
- **Exporter – Linux-PC based component designed to encode and compress MPS audio at the studio and assemble a single HD data stream, called E2X, to send to the Exciter across the (Ethernet) STL. Also multiplexes Importer data into this stream.**

- **Importer – Optional component, which encodes all AAS (Advanced Application Services) including Multi-channel audio, data services, etc., and sends I2E stream to Exporter. Normally located at studio end.**

Exgine Exciter

•**Exciter (Exgine)– Modulates and generates RF waveform for transmitter amplification. Accepts traditional inputs for the host FM audio, but only an Ethernet input for the HD Radio (E2X) stream.**

Exgine (Gen 3) Architecture



Exgine STL Requirements

Architecture requires 2 parallel functions for studio transmitter links:

1. **Analog FM Broadcast Audio link**
   - **normally 44.1kHz digital AES, may be dropped to 32kHz AES**

2. **Digital Ethernet LAN STL for E2X protocol:**
   - **Data packet multiplexing with reliable delivery**
   - **Clock synchronization with predictable latency**

The two functions may be independent or integrated into a single product.

STL is the Chokepoint

- **Must continue to carry analog signal**
- **Bandwidth (throughput) is limited (200-500 kbps)**
- **Most legacy STLs are unidirectional**
- **Many operate in noisy or fade prone RF environments**
- **STL traffic may contend with other data in addition to STL program**

E2X Performance Issues

2 Symptoms of a less than optimum Exgine link:

1. **Dropouts in MPS audio channel**
   - **Loss of a single packet results in loss of entire frame (1.48 seconds of audio!)**
2. **Inability to maintain consistent time alignment**

QoS Requirement

Because the native E2X protocol is UDP, the QoS requirement is extremely high.

***Quality of Service* (QoS) requirement:**

$$\frac{\text{good on-air IBOC transmission}}{\text{total on-air IBOC transmission}}$$

QoS of 99.999%: **5E-11 BER for E2X transmission**

3E -7 BER for AES transmission

QoS	Packet Loss	Effective BER	MTBF
99.999%	1 in 1.6 million	5 E-11	41.1 hours
99.99%	1 in 160,000	5 E-10	4.1 hours
99.2%	0.05%	4 E-8	3 minutes

E2X Data Link Requirements

Sources of E2X Dropouts

- **bit errors across STL**
- **complete loss of STL connection**
- **delayed packet delivery due to aggressor traffic**
- **Large (22 kByte) packet can cause 600 ms delay on 300 kps link**
- **insuffcient receive buffering on the exciter**
- **link protocol collisions: IEEE 802.11 - 0.05% packet loss**
- **packet discard due to congestion avoidance**
- **packet discard on mixed speed networks**

Bottom Line; Some packet loss is a fact of life across Ethernet networks, and must be accounted for.

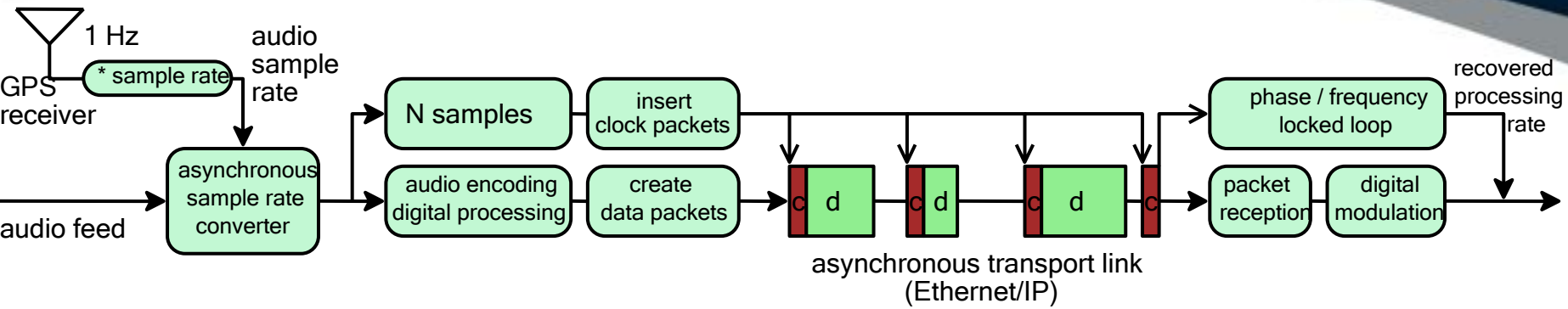
E2X Transport Protocol Options

- **User Datagram Protocol (UDP)**
  - **Currently the default protocol**
  - **best effort delivery (no guarantees)**
  - **requires very reliable data link**
  - **Is used because it works on unidirectional STLs**
  - **Low bandwidth utilization (which is good)**
  - **allows point-to-multipoint streaming through IP broadcast or IP multicast IP address = (x.x.x.255)**

E2X Transport Protocols

- **Transmission Control Protocol (TCP)**
  - **end-to-end reliable communciations using automatic repeat requests (ARQ)**
  - **addresses intermittent packet loss across STL**
  - **requires additional bandwidth overhead for re-transmission (up to 40%)**
  - **introduces additional latency due to retransmission**
  - **limited to point-to-point connections**
  - **flow control can starve the exciter**
    - **high latency links**
    - **high packet loss**

E2X Synchronization

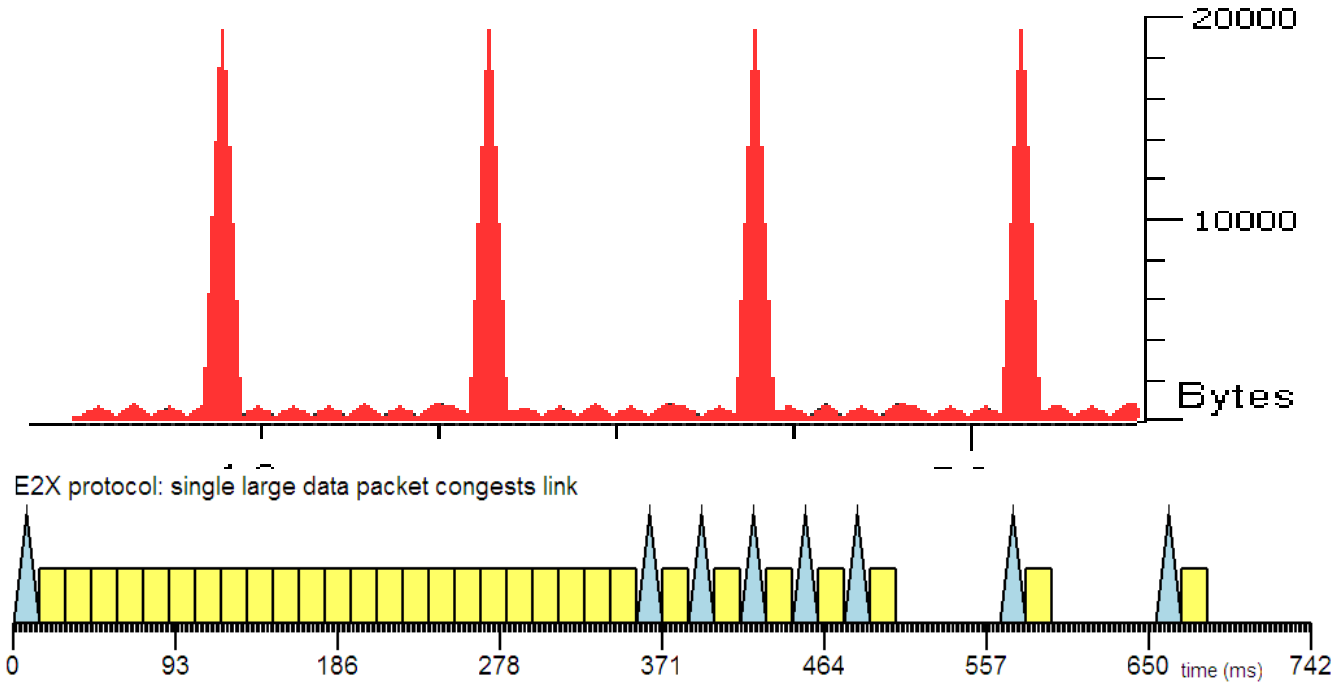


- **Basic timing derived from incoming audio sample rate (GPS locked)**
- **Small clock packet every 92.8 ms**
  - **asynchronous link introduces clock jitter**
- **Exciter is disciplined by clock packets**
  1. **lock transmitter processing rate to studio (within 1 ppm)**
  2. **establish a deterministic start-up time**

E2X Synchronization

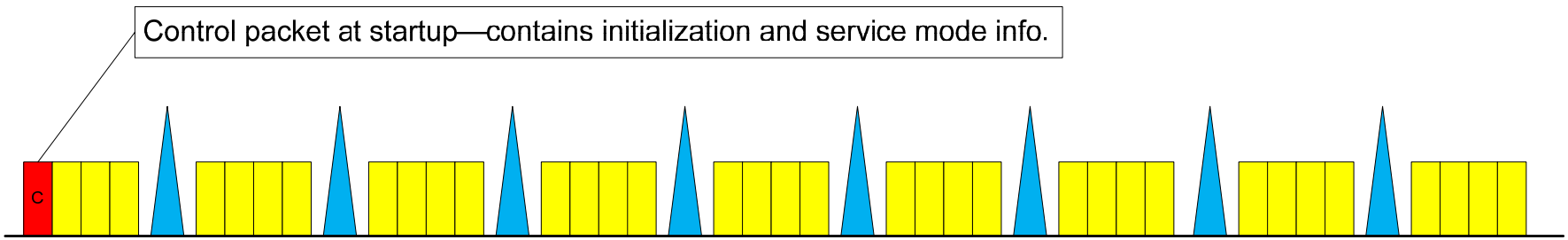
High Instantaneous E2X bandwidth (bursty) requirements

- **variable data packet sizes up to 19 kBytes**
  - **600 ms congestion on 256kbps link**
  - **19kB in 92.8 ms requires 1.5 Mbps link**
  - **Result = clock packet errors**



Control Packet

- Exciter depends on Control Packet presence for startup
- Without control packet system cannot restart properly
- Prior to iBiquity rel 2.4.2 control packet was sent only once



iBiquity Digital Corporation *Application Note*

HD Radio™
Data Network Requirements

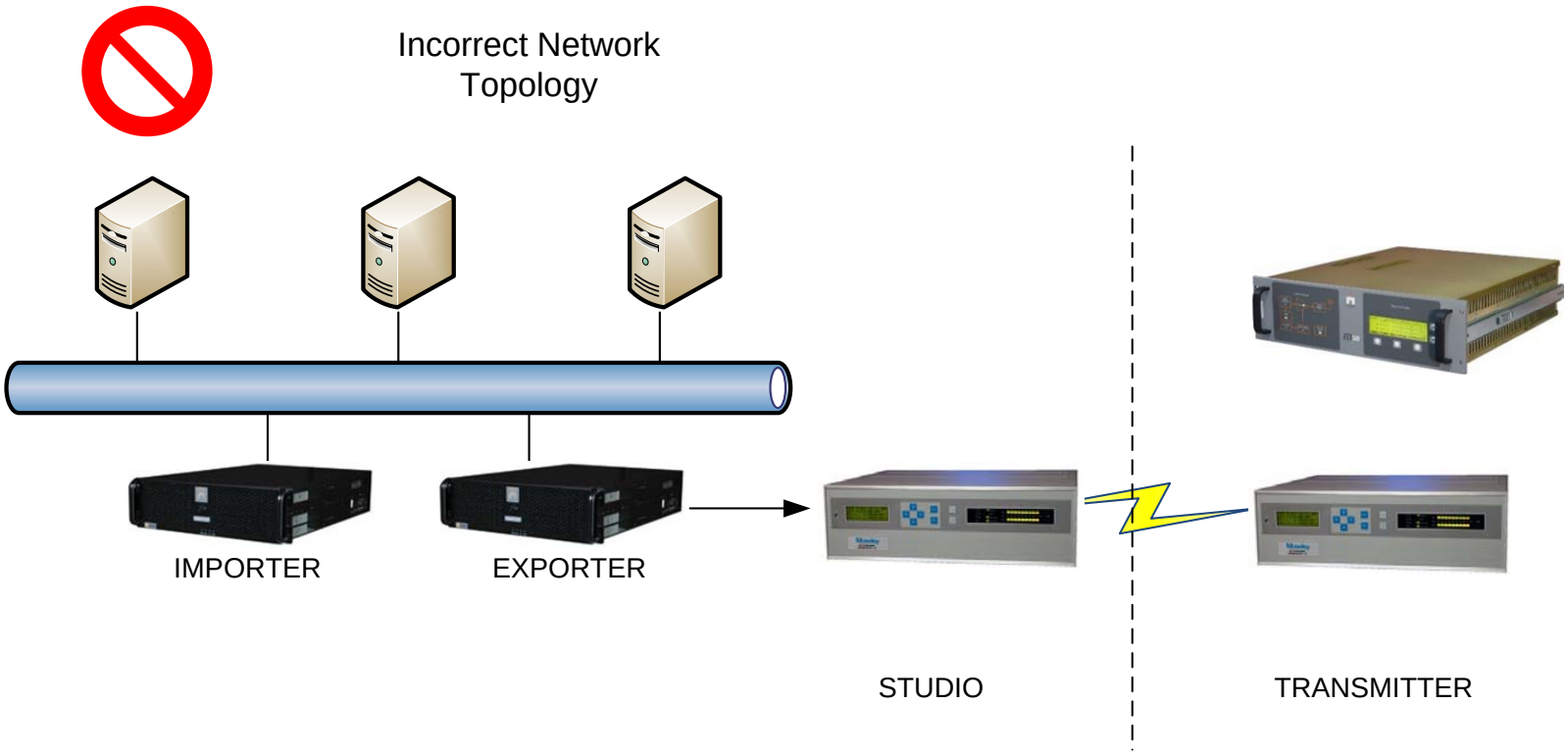
Rev. 09

October 23, 2006

Best Networking Practices

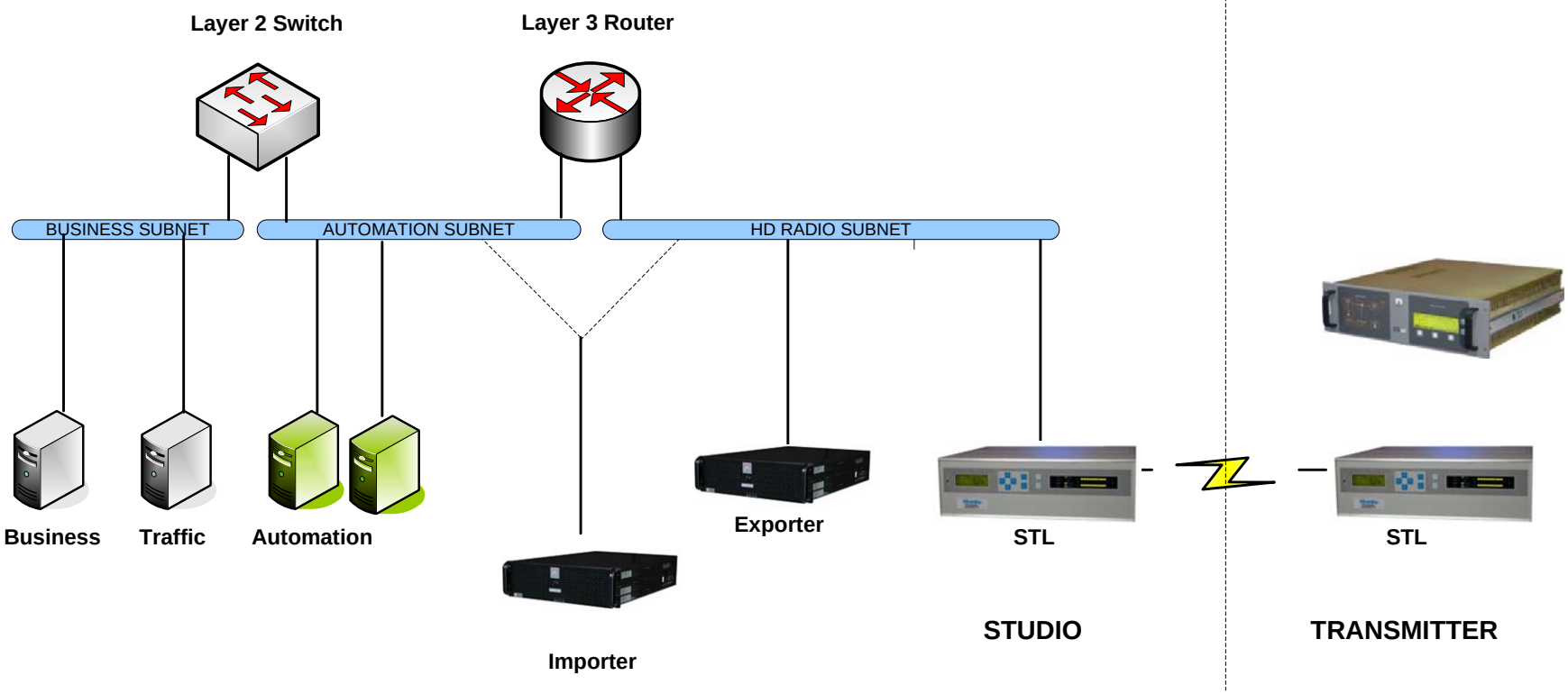
- Employ sub-netting and VLANs to segment traffic
- Assign a high QoS to E2X stream data
  - Can configure routers and smart switches to do this
  - OR can include IP Precedence feature in protocol
- Provision as much bandwidth as you have available (min. 300-500 kbps)
- Do not mix device speeds (10/ 100 Mps)

Worst Networking Practices



Sub-netting and VLANs

Correct Network Topology

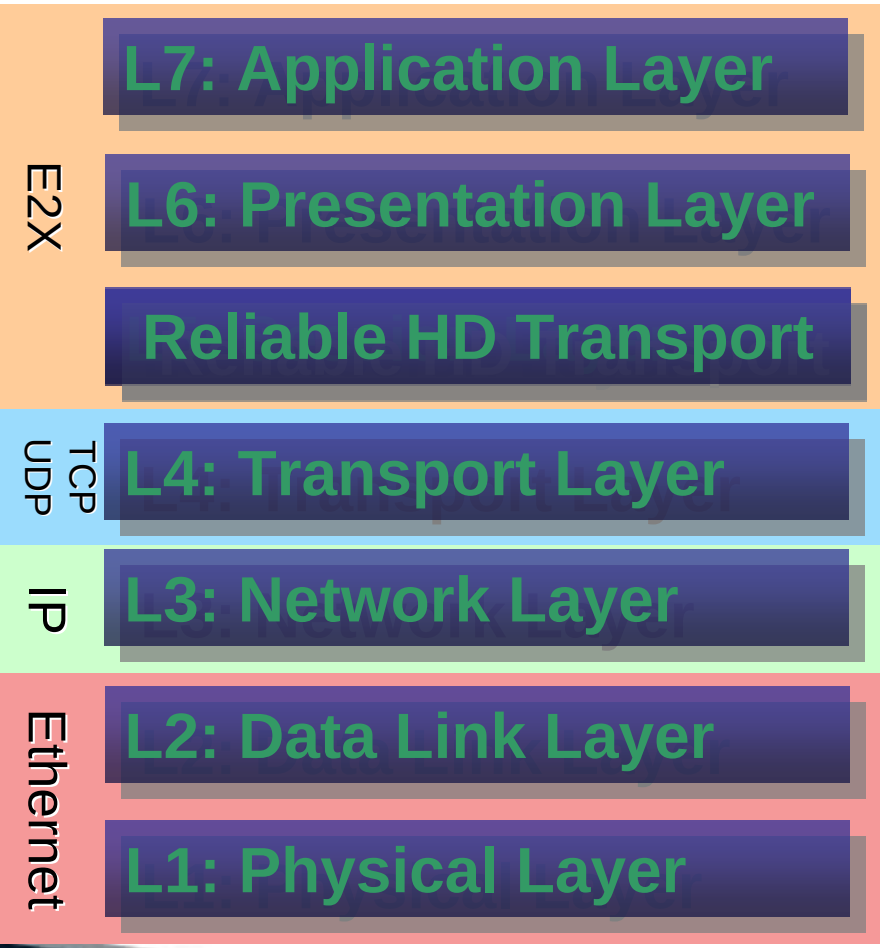


Summary Requirements

- Guaranteed delivery reliability of data packets
- Recognize that data packets valuable only before modulation
- Consistent on time delivery of clock packets
- Don’t retransmit clock packets (a late clock is of no value)
- Support for unidirectional and bidirectional STLs is required
- Better support for point to multipoint applications
- Support low bandwidth STLs (<300 kbps)
- Periodic repeat of control packet

!!! neither TCP nor UDP fulfill these requirements !!!

A New E2X Transport Protocol



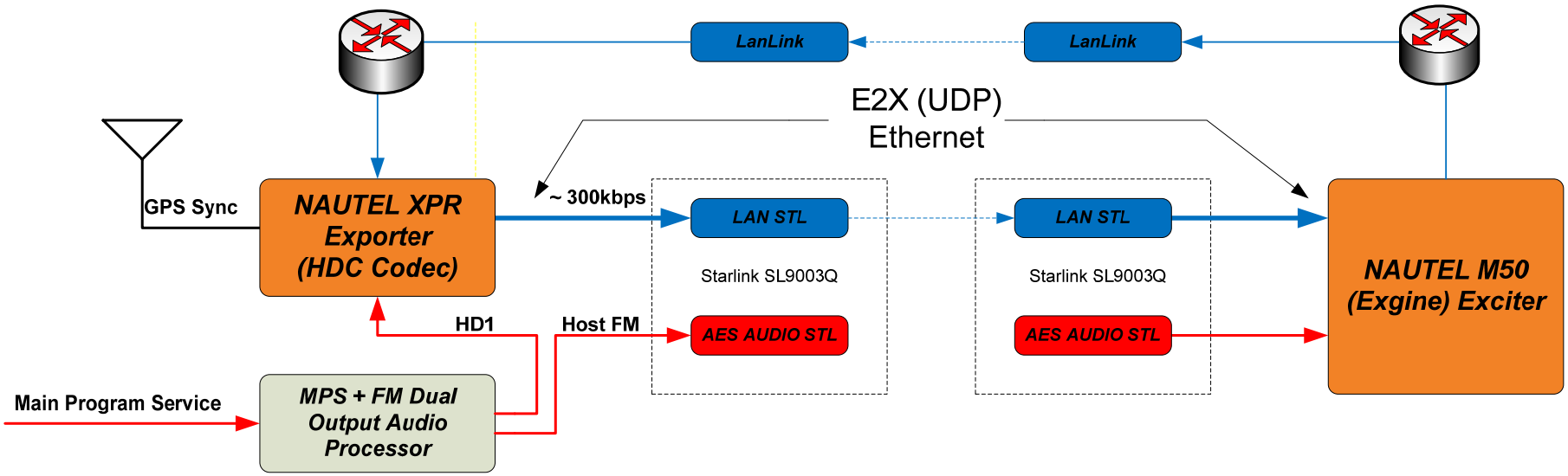
Nautel introduces

Reliable HD Transport Protocol

- **periodic repeat for guaranteed delivery, including control packet**
- **optional retransmission on lost data for limited guaranteed delivery**
- **low latency transmission of clock packets**
- **reliable point-to-multipoint communication**
- **manages available STL bandwidth**
- **allows traffic prioritization through IP precedence bits**

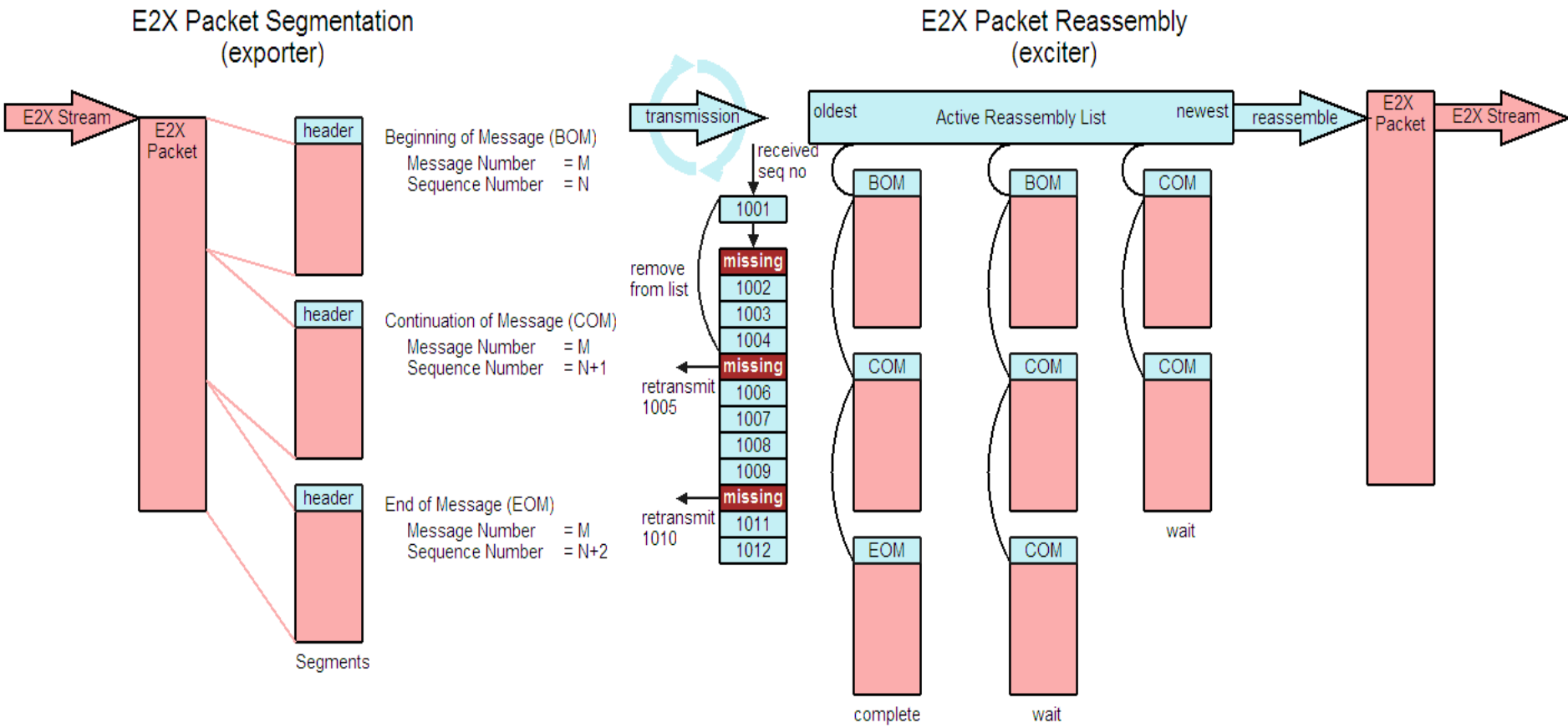
Optional Backhaul Channel

Use LanLink or built in bidirectional capability of a T1 based STL



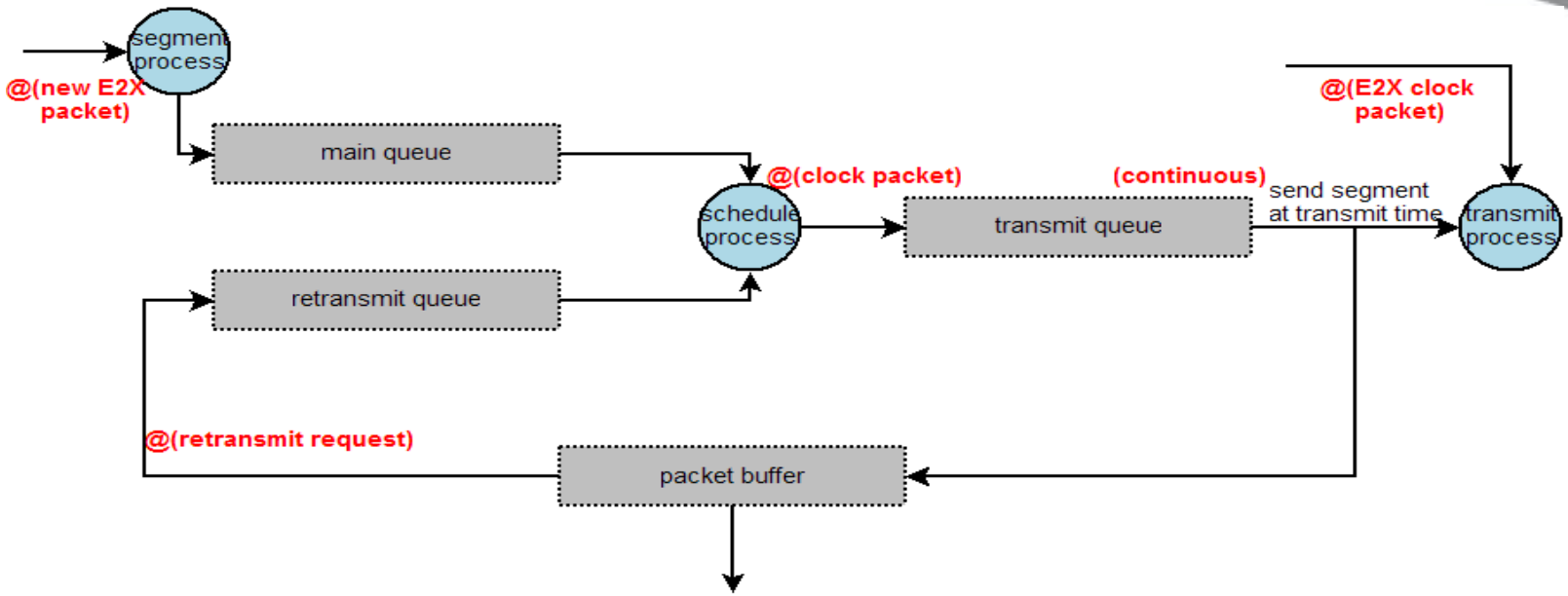
A New E2X Transport Protocol

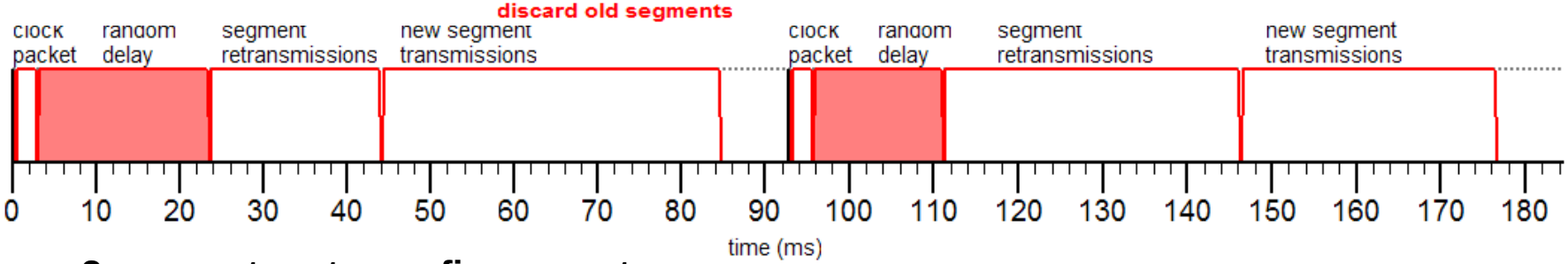
E2X packet segmentation and reassembly



A New E2X Transport Protocol

Bandwidth Management

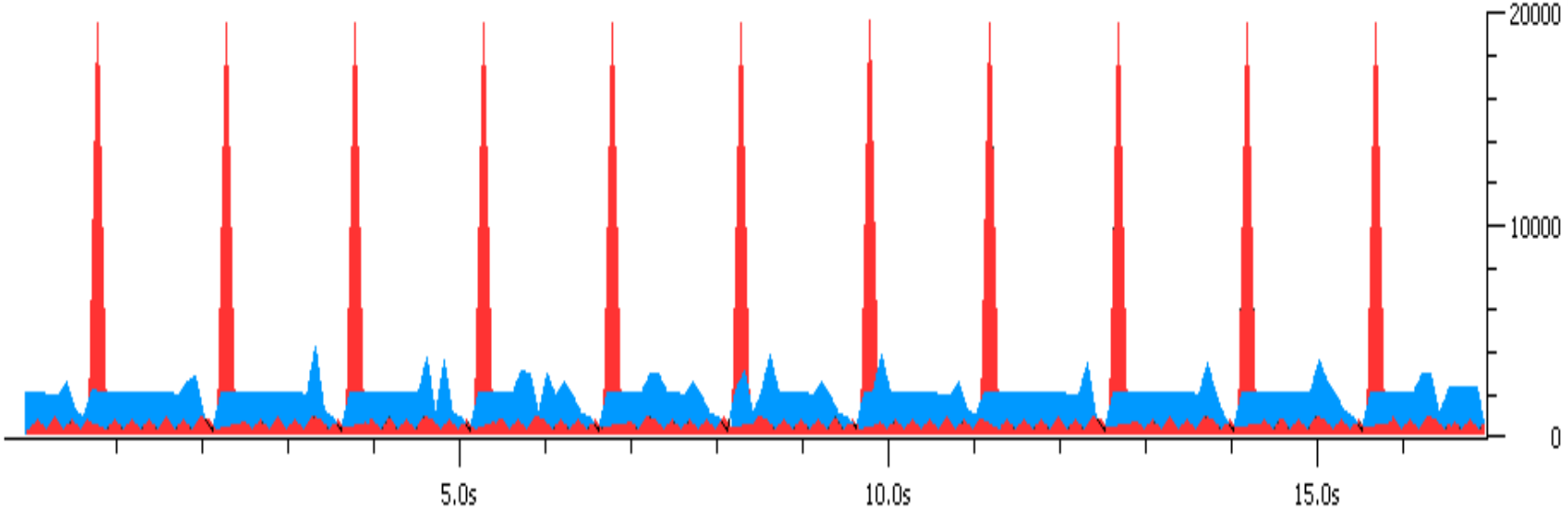




2 parameters to configure system:

1. **total available link bandwidth dedicated to E2X**
2. **bandwidth to sustain new segment transmission**

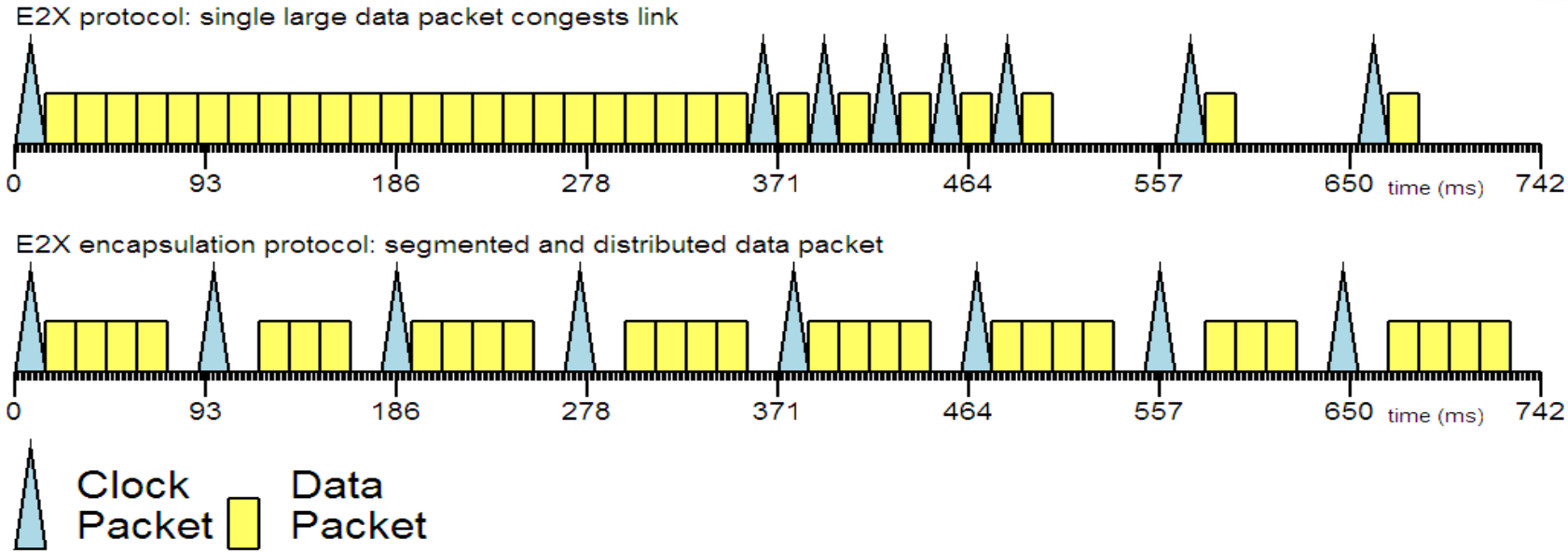
Data Rebalancing Results



Instantaneous bandwidth requirements are relaxed:

- **average bandwidth without re-transmission comparable to E2X specifications**
  - **low bandwidth overhead (around 8kbps)**
- **multiple E2X connections can co-exist on the same link**
  - **can impact synchronization of another stream (around 5ms)**
- **does <u>not reduce</u> receive buffer depth**

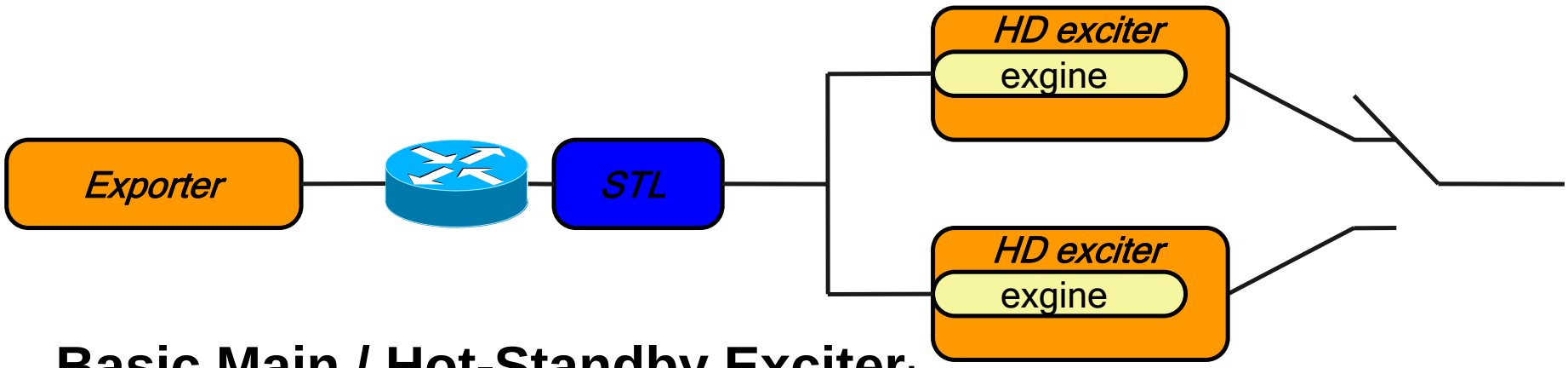
Clock Packet Tunneling Results



Protocol induced clock packet jitter is removed:

- **consistent clock packet delivery**
  - **700μs RMS jitter across simplex STLs (i.e. Moseley Starlink)**
  - **around 0.05 ppm frequency error**
  - **no separate GPS synchronization needed at exciter**
- **provides consistent diversity delay (30-60μs)**

A New E2X Transport Protocol



Basic Main / Hot-Standby Exciter:

- all exciters produce IBOC signal simultaneously
- exciters do not have to be co-located
- applicable to N+1 transmitter configuration
- applicable to multi-frequency networks
- STL path can be made redundant

Test Results

E2X Transport Protocol Burst Error Tolerance

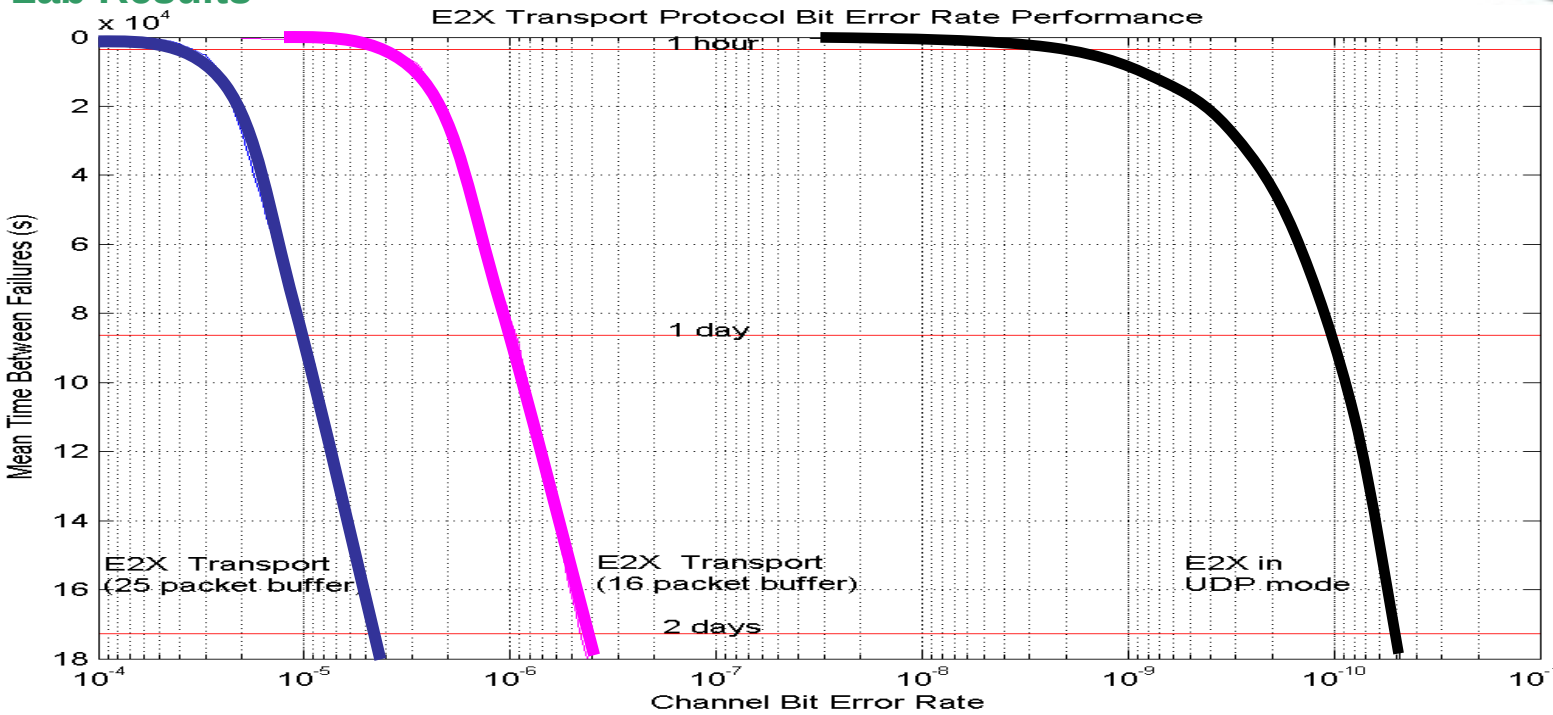
- 2 cases exist:
  1. complete loss of link and packets are lost
     - packets must be re-transmitted
     - retransmission may only work after link is re-established
  2. congestion or loss of link and packets are delayed
     - can be absorbed in receive buffer
     - may introduce clock packet errors

Buffer Depth (packets)	Buffer Depth (seconds)	Maximum Error Burst	Max Aggressor Traffic (300 kbps)
16	1.48s	200 ms	7.3 kB
25	2.32s	600 ms	22.0 kB
35	3.20s	1300 ms	47.6 kB
50	4.64s	2100 ms	76.9 kB
75	6.96s	3700 ms	135.5 kB

Maximum link interruption across 300kbps link without HD dropout

Test Results

Lab Results



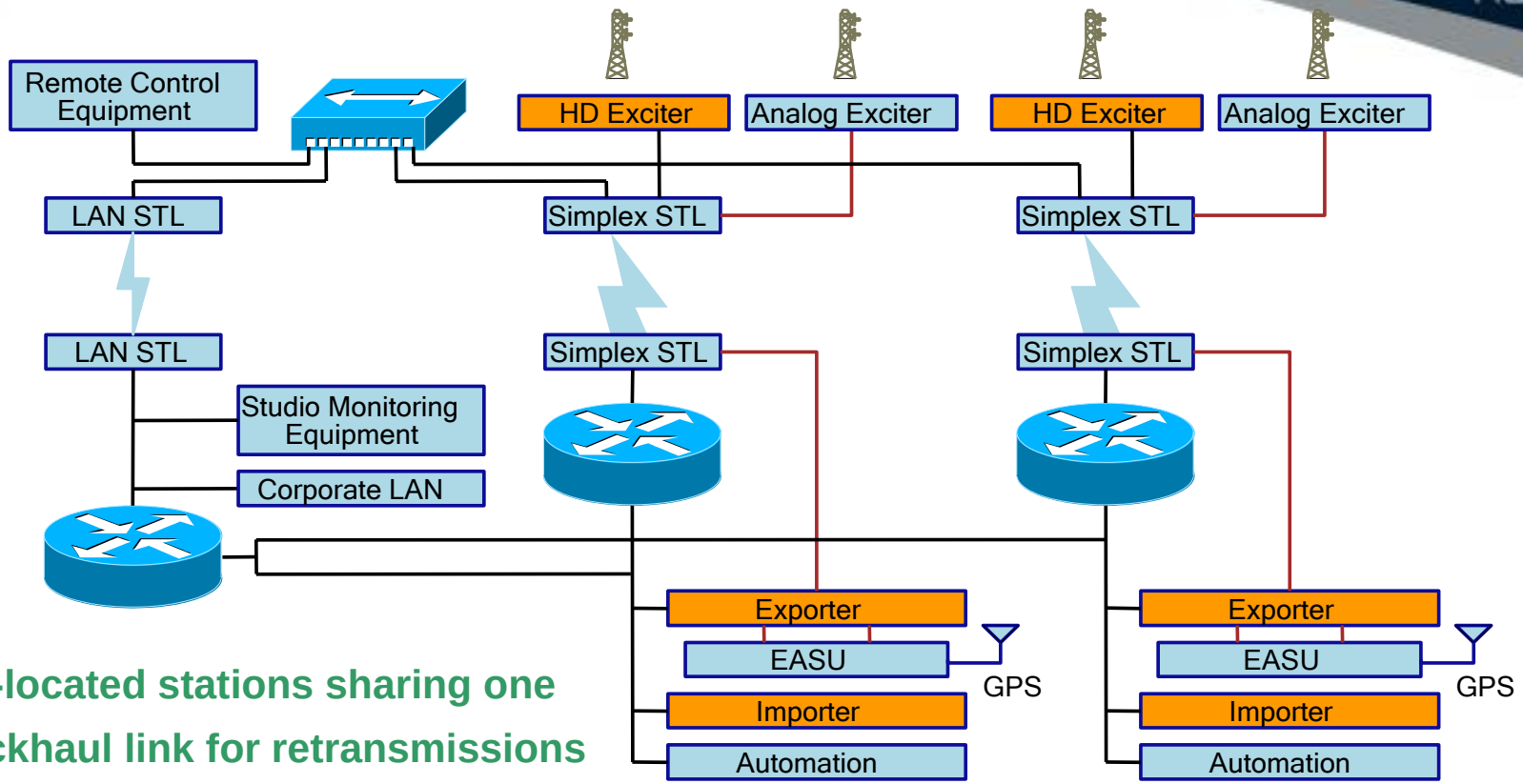
Field Results

KRCL Radio, Salt Lake City, Utah

STL:	**Moseley Lanlink**	**HD dropouts:**	**5 in 7 days**
Packet Loss:	**0.7%**	**MTBF:**	**1.4 days**
Effective BER:	**1.7E-6**	**QoS:**	**99.9988%**
Avg. clock jitter:	**32 ms**	**Digital drift:**	**2.4 ms**

courtesy of Lewis Downey at KRCL

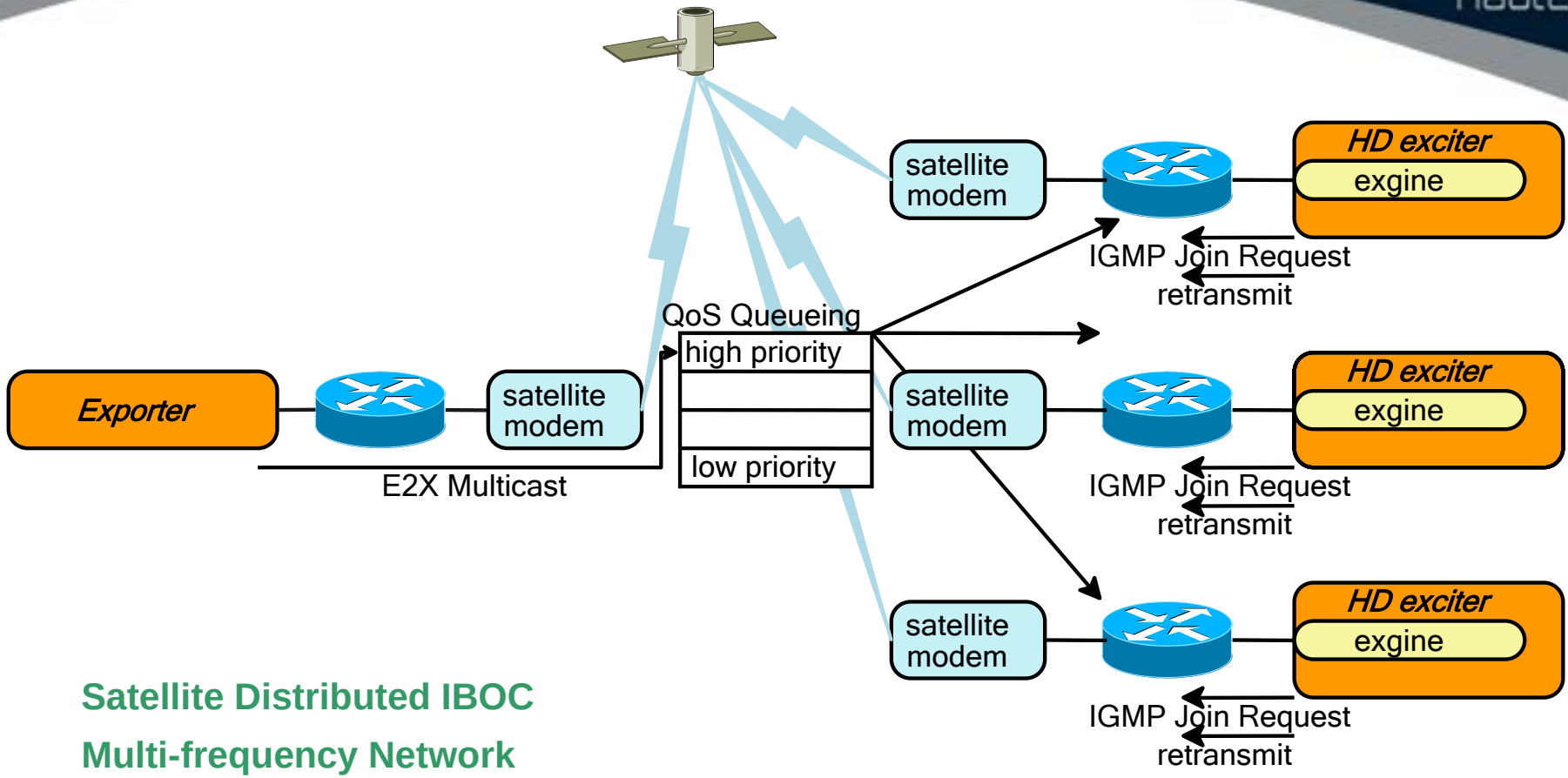
Application Examples



Co-located stations sharing one backhaul link for retransmissions

Nautel reference design available that has been applied at KZWY and KYTI in Sheridan, Wyoming

Application Examples



Satellite Distributed IBOC

Multi-frequency Network

- **satellite modems (Radyne DMD20) provides QoS queuing**
- **use IP multicast or broadcast to fan-out E2X protocol**
- **one-way transmission delay around 125ms**

Conclusions

The Problem

- STLs require a very low packet loss rate to minimize HD dropouts
- Latency issues affect delivery of clock sync packets on time
- Peak bandwidth requirements degrade performance

The Solution: Nautel Reliable HD transport:

- Addresses packet loss through retransmission more efficiently than TCP/IP
- Addresses time alignment slippage through improved clock packet latency (Clock packet tunneling)
- Performs data rebalancing and reduces instantaneous bandwidth requirements

*patent pending

Nautel Reliable HD Transport Suite

- Nautel Reliable HD Transport Suite is available now as a low cost option on all Nautel HD systems

- Can be configured for non-Nautel systems

Contact Info

Jeff Welton

Technical Sales Representative

NAUTEL

(877) 662-8835, ext. 127

jwelton@nautel.com

Paper reference:

E2X Bandwidth and Bit Error Requirements for Ethernet Synchronization

Introducing a Reliable Real-Time Point-to-Multipoint E2X Transport Protocol

By Philipp Schmid

NAUTEL

Bangor, Maine