Digital Guide

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Addressing Packet Loss in HD Transmission

As more stations move to digital transmissions, transporting the IBOC signal from the studio to the transmitter is proving to be more of a challenge than anticipated. The manufacturers have identified various problem areas, and solutions are starting to filter out to the field.

OVERCOMING THE STL BOTTLENECK

A studio-transmitter link must be able to carry Ethernet/IP based traffic along with traditional audio streams, making a digital STL mandatory. Many stations have already transitioned to digital STLs, and most STL vendors now provide upgrade paths to share the existing digital STL bandwidth between audio paths and Ethernet-based paths.

However, since most STLs have traditionally been unidirectional in nature, many digital STLs today only provide a unidirectional Ethernet path.

Digital signal paths are notoriously fragile. Signal fades, ducting, multipath, etc. are challenging enough with analog STLs, but digital streams are unforgiving. A single bit error on the STL can cause an entire data packet to be dropped, which translates to one to two seconds of dead air on all digital program channels (HD dropout).

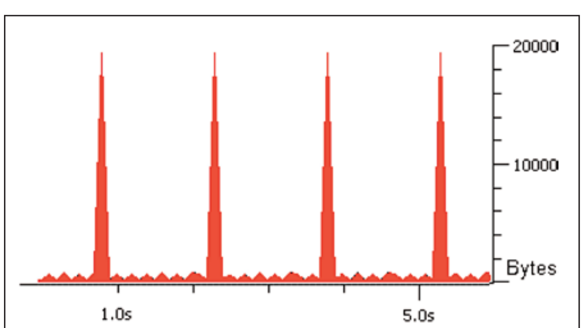
THE E2X PROTOCOL

An IBOC deployment today uses the iBiquity exporter to exciter (E2X) protocol, which requires IP transmission for the studio-transmitter link. It is frequently deployed using UDP, which is fast and has a reasonably low overhead in terms of bandwidth.

Service Mode	On Air Bandwidth	Average E2X Bandwidth	Required E2X Bandwidth
MP1	98.4 kbps	119.7 kbps	159.9 kbps
MP2	110.8 kbps	132.1 kbps	176.1 kbps
MP3	123.2 kbps	149.3 kbps	199.0 kbps

Table 1: E2X UDP Bandwidth Requirements
[taken from iBiquity Network Requirements]

The required bandwidth shown in Table 1 is sufficient to establish a data connection. However, peak throughput can be as much as 1.8 Mbps, causing transmission congestion, in turn requiring extensive buffering and breaking the studio to transmitter synchronization, which makes it necessary to use additional GPS synchronization at the transmitter.



The peak throughput can greatly exceed the typical STL bandwidth, causing problems.

Re-transmission of such HD data is problematic; the packets only convey meaningful information prior to the time that they are intended to be on the air. Retransmission requests beyond that time are useless and may unnecessarily congest the STL; late delivery of a packet results in the same effect as packet loss.

FROM UDP TO TCP/IP?

There is some talk in the industry of switching from a UDP transport layer to TCP/IP (something supported in the Nautel M50 for the past 14 months). This would enable better re-transmission of packets but creates a different set of problems.

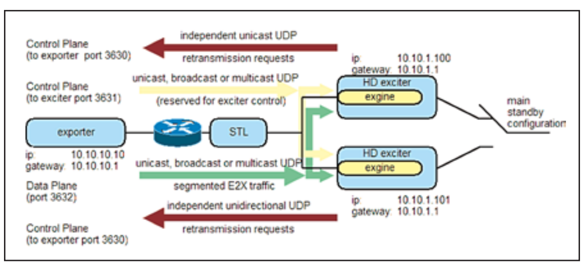
Here is why: TCP/IP is limited to point-to-point connections; it does not work on unidirectional STLs; it is not well suited for high latency links or links with even intermittent packet loss greater than 1%; and it retransmits packets well past their usable transmission window or terminates the connection altogether.

In looking at the various options for transporting HD signals, Nautel engineers decided that neither traditional UDP nor TCP/IP was the solution. Instead, they wrote a new protocol that allows bidirectional communication for retransmission requests and can use multiple links for communication.

NAUTEL'S IMPLEMENTATION OF E2X

The Nautel protocol buffers the IBOC data by a user-configurable amount of time to allow for retransmission, reducing the chance of losing packets on the receive end. It also restructures the data stream so that instead of sending one large burst followed by several frames of almost no data, the data is repackaged into a continuous stream that occupies a constant bit rate.

This new method of transporting HD reduces the demanding reliability constraints placed on STLs, thereby reducing the chance of dead air.



Nautel's E2X signal flow.

The Nautel protocol is addressable; it can operate point-to-point or point-to-multipoint at the user's discretion. This allows an Exporter to address a specific exciter for a retransmission or to address several exciters for booster, translator, main/standby applications, or network broadcasting applications. Directed broadcast can be used to avoid flooding every other device on the net.

The Nautel protocol also allows for a dedicated unidirectional path for the HD data to the transmitter site, with retransmission requests being handled on a second path. An example would be the use of a Moseley Starlink for transmission of HD data and a Lanlink used for other data such as retransmission requests, site remote control/telemetry, and Internet/intranet/Ethernet connections at the transmitter site.

Although the Nautel HD Transport protocol was written originally for use with Nautel HD transmitters, it will operate with other manufacturers' HD transmitters that have been equipped with Nautel interface units.

A LAYER ON TOP OF UDP

The Nautel E2X transport protocol implementation is layered on top of UDP, since UDP allows broadcast and multicast communication. The preceding diagram shows one possible main/standby exciter configuration across a generic STL.

The protocol is broken into a control plane and data plane. The data plane carries the encapsulated and segmented E2X protocol to all exciters. With a bidirectional STL, the Exporter can directly communicate with a single exciter using unicast IP, which directly maps a single IP address to a unique MAC address. (In the case of a unidirectional STL, the intermediate router can be programmed with a static MAC entry.)

To address multiple exciters simultaneously the Exporter must resort to either the broadcast mode (without an intermediate router), directed broadcast (through the router), or multicast IP (scheduled for implementation soon by Nautel) to address only a subset of exciters.

The control plane communication from the Exporter to the exciters follows the same communication modes as the data plane, but the Exporter may choose to directly address only one of several exciters. For example, the Exporter may grant the ability to issue a retransmission request only to a subset of listening exciters, allowing for a highly scalable point-to-multipoint deployment of this protocol.

PASSING REQUESTS BACK TO THE EXCITER

The control plane communication from the exciters back to the Exporter is always unicast directly to the Exporter.

However, in the case of a unidirectional STL, this communication stream will not make it back to the Exporter, so the transport protocol cannot make the assumption that retransmission requests will in fact reach the Exporter. This will result in an HD dropout, but the E2X protocol will continue to operate correctly.

On the other hand, the Nautel engine implementation is specifically designed to handle data loss by repeating known good content on air in the case of data loss. This ensures maintaining your analog diversity delay, as well as maintaining power levels and spectral compliance during and after the data loss.

Some packet types, such as the Exporter's control packet, require guaranteed delivery in order for the exciter to start modulation with correct operating parameters. Rather than relying on stored parameters, which could cause a configuration mismatch between the Exporter and the exciter, the reliable HD transport protocol maintains a copy of the most recent control packet and periodically retransmits the control packet to the exciter.

MEETING THE NEED

Using the configuration shown in the diagram, both HD exciters are always ready to transmit HD and the digital modulator is not aware whether it is active or in hot-standby mode. The Exporter also is not aware which exciter is currently active.

Both exciters independently issue retransmission requests back to the Exporter. If only a single exciter has lost a packet, it will issue a corresponding retransmission request. If both exciters lose a packet, both will issue a retransmission request but if the retransmission requests have been received close enough in time, the Exporter will only retransmit the same data packet once.

Retransmitted packets are delivered to both exciters just like a regular data transmission. An exciter knows, based on sequence numbers, whether it has already received a packet and will discard duplicate data packets. Retransmission requests are made continuously until the data packet arrives or until the operation times out.

This approach not only allows for redundancy in the exciters, it also allows the entire data path between Exporter and exciters to be split and made redundant. This is an option when employing two unlicensed STLs – when one STL link is lost due to interference the transmitter can switch over to the working link by switching exciters.

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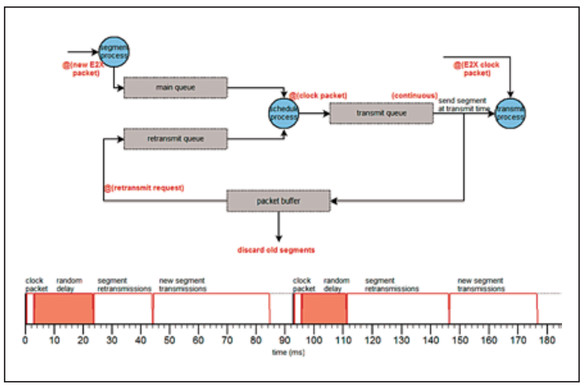
SEGMENT SCHEDULING

In order to maximize transport bandwidth, the E2X data stream has been segmented. Standard UDP provides segmenting functions already; however, most STLs operate at a much lower network bandwidth compared to most LAN deployments.

Consequently, all UDP segmented packets will likely be placed on FIFO queues effectively negating the effect of segmentation unless the STL provides more sophisticated queuing. The following diagram presents a queuing structure that can effectively utilize the segments and compute packet dispatch times that match the reduced STL throughput rate.



A look at the segment scheduling.

On the Exporter, every new E2X packet is segmented right away and all resulting segments are placed on the main queue; each segment is treated independently from that point on. The reception of a clock packet triggers the scheduling process that is controlled by two parameters:

1. The main bandwidth parameter sets the bandwidth required to sustain the regular E2X data stream without retransmissions. It determines how many segments may be transmitted in one clock interval and causes any instantaneous bandwidth variations to smooth out over time;

2. Overall STL bandwidth dedicated to this E2X stream dictates the rate at which segments are dispatched from the Exporter. It also governs how much additional bandwidth is available for retransmissions.

The scheduling process places segments from both the main queue and the retransmit queue onto the transmit queue as shown on the diagram. However, clock packets bypass the transmit queue and are directly sent to the exciter with a flag set to disable retransmissions for clock packets.

KEEPING THE TIMING RIGHT

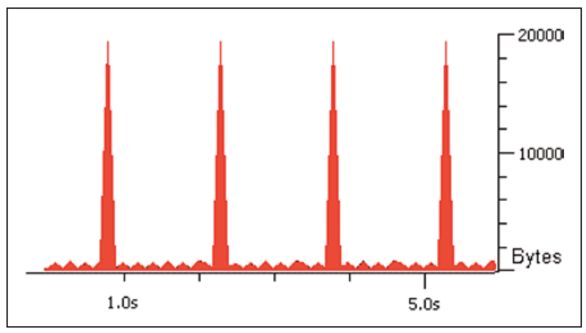
As each segment is placed on the transmit queue a dispatch time stamp is attached to it. The transmit process only dispatches segments after the given time stamp has elapsed.

The scheduler may first insert a random delay where no segments are scheduled. This minimizes the impact of one E2X stream onto another on the same STL, as it allows the two streams to interlock better while minimizing the synchronization impact. The scheduler first determines how much bandwidth is used up by new segments, but it schedules retransmissions prior to new segments, since retransmissions are more time critical.

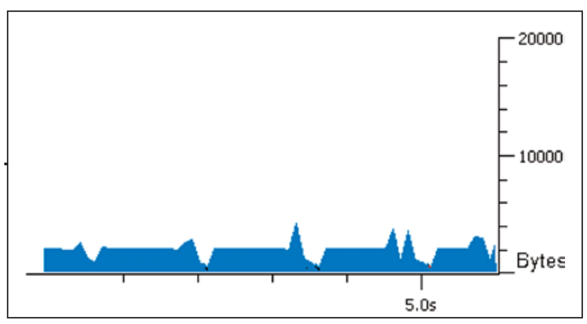
All dispatched segments are placed on the packet buffer until they get too old to be of interest (in other words, greater than the exciter receive buffer depth). A retransmission request from any destination searches the packet buffer for the given sequence number and places it on the retransmit queue. If two or more requests for the same sequence number from different exciters are received, only the first request is serviced since the same packet is delivered to both destinations.

BANDWIDTH BENEFITS

The following diagrams show the marked improvement in bandwidth utilization that is achieved, compared to standard E2X bandwidth utilization, and demonstrates how multiple E2X streams can coexist on the same STL much more easily.



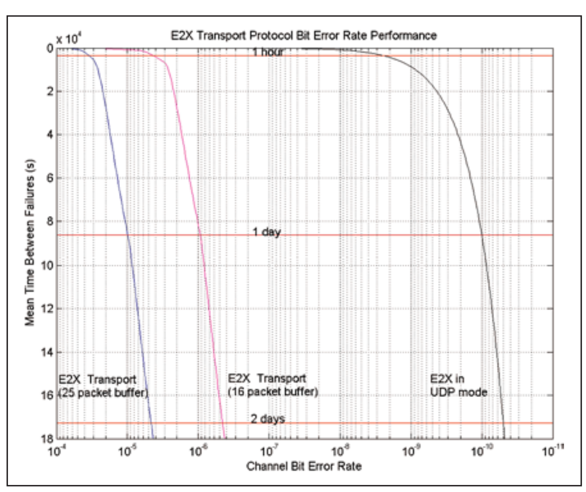
E2X Instantaneous Bandwidth



E2X Transport Protocol Bandwidth

BIT AND BURST ERROR PERFORMANCE

In order to evaluate the effectiveness of this retransmission scheme, random bit errors are intentionally introduced at the segment level rather than causing discards. That way bandwidth resources are still consumed while not conveying any useful information.



A comparison of Bit Error Rates shows the benefits of the Nautel E2X Transport Protocol.

In the above diagram, the data contrasts the transport protocol's bit error performance with the E2X protocol in UDP mode based on the relationships discussed earlier. The exciter has a configurable receive buffer depth that allows the station operator to choose between increased protocol performance and total signal propagation delay.

Two buffer levels of 16 packets (1.48 seconds) and 25 packets (2.32 seconds) are illustrated. Keep in mind that the E2X stream is spread almost over an entire L1 IBOC frame depending on how much bandwidth is allocated for it, reducing the effective buffer depth to a degree. This means that not every segment has the same chance of successful retransmission.

With a buffer depth of 16 packets some packets may only be retransmitted once or twice; a buffer depth of 25 packets provides increased reliability due to a greater chance of successful retransmission.

The number of retransmissions depends on the throughput delay across the STL. The presented data takes this delay into account as it has been collected using a Moseley Starlink / Lanlink combination in this instance.

MATCHING STL PERFORMANCE

Engineers should analyze the effective bit error performance of their STL equipment and select the desired quality of service. This identifies the operating point on this chart.

If necessary the exciter's buffer depth can be adjusted. High quality RF/T1 based STLs are available with bit error rates sufficient for good quality IBOC transmission. However, the STL itself is not the only source of data loss.

Intermediate network equipment can contribute to packet loss due to congestion conditions or other circumstances and most network equipment is not designed to provide extremely high reliability. These symptoms will manifest themselves as packet loss which can be lumped into an effective bit error rate when averaging over a long enough time period.

USING THE BIT ERROR INFORMATION

Bit errors are a good way of characterizing the effectiveness of this protocol, but uniform random bit errors are almost an ideal error distribution, if they happen infrequently enough.

In reality, bit errors are not uniformly distributed and usually occur due to an interference condition or fading. So it makes sense to investigate the maximum amount of time the exciter can maintain a steady data stream and replenish the data due to a complete STL interruption and associated packet loss. The following table outlines the burst tolerance of the protocol with respect to a configured receive buffer depth.

Buffer Depth (packets)	Buffer Depth (seconds)	Maximum Error Burst	Max Aggressor Traffic (300 kbps)
16	1.48 s	200 ms	7.3 kB
25	2.32 s	600 ms	22.0 kB
35	3.2 s	1300 ms	47.6 kB
50	4.64 s	2100 ms	76.9 kB
75	6.96 s	3700 ms	135.5 kB

With a greater packet depth, the stream is more resilient to errors or brief interruptions.

Of course, the leading reason for an STL interruption may not be the RF path at all. Instead the STL may experience a congestion condition due to other traffic, which could lead to packet loss or severe packet delay with the same consequences.

The last column shows how much aggressor traffic can cause a corresponding STL interruption given an effective throughput rate of 300 kbps. The speed differential caused by inadequate network design can easily allow these amounts of aggressor traffic to be injected into the STL if no precautions are taken.

The benefits of the Nautel E2X Transport Protocol are robust, drop-out free program stream and can be adapted to any manufacturer's digital transmission system.

There is a great deal of additional material describing this E2X transport system and its operation in a White Paper by the author that has been published by Nautel. Covering all aspects of the new HD transport system, the White Paper may be found on the Nautel website, www.nautel.com

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