Evolving Range and DISA Networks Using Pseudo Wire

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ABSTRACT

The Eastern and Western Ranges along with DISA share a similar vision around Net-Centricity such that "Anyone, anywhere can get to any data source and exploit the information they are authorized to access." Their legacy infrastructure is built around TDM and ATM transport networks, which are link based and connection oriented. To achieve the vision the infrastructure must evolve towards a packet switched network (PSN) that is meshed based. Consequently, a means to interwork non-IP enabled services is required. Pseudo Wire protocol encapsulation provides the means for extending telemetry, data, voice, and video services in native formats over Ethernet, IP, and MPLS networks in a reliable way that delivers greater operational efficiency and a smooth migration to a single converged network.

KEY WORDS

Pseudo Wire, Telemetry, Multiplexing, Ethernet, Packet Switched Networks

INTRODUCTION

One of the core missions for the Defense Information Systems Agency (DISA) is to provide communications for the defense community. A majority of command and control traffic, voice conferencing, intelligence dissemination, and combat support traffic are supported over their networks. The aggregate of these networks is referred to as the Defense Information System Network (DISN), which is a wide-area communications component of the Global Information Grid (GIG). The concept of Net-Centricity provides the guiding principles for the evolution of the GIG. Net-Centricity is about transforming the way information is handled in the defense community. It becomes the enabler for allowing access and sharing of information such that a collaborative environment can be created.

The Eastern and Western Ranges along with DISA share a similar vision around Net-Centricity such that "Anyone, anywhere can get to any data source and exploit the information they are authorized to access." In this way, information can be leveraged to allow users at all levels to make better decisions faster and act sooner.

The legacy infrastructure for DISA and the ranges has developed around time division multiplexing (TDM) and asynchronous transfer mode (ATM) transport networks, which are link based and connection oriented. Yet to achieve the vision of Net-Centricity this infrastructure must evolve towards a PSN that is meshed based. With substantial amounts of serial command, control, and communications along with analog telemetry, voice, and video traffic that cannot readily be handled over a PSN, a new means to interwork non-Internet protocol (IP) enabled services is required. Pseudo Wire protocol encapsulation provides the means for extending telemetry, data, voice, and video services in native formats over Ethernet, IP, and Multi-Protocol Label Switched (MPLS) networks in a reliable way that delivers greater operational efficiency and a smooth evolution to a single converged network.

NETWORK EVOLUTION OVERVIEW

The network evolution of the GIG has been progressing with bandwidth expansion to improve scalability, bandwidth, and physical diversity. A depiction of the GIG architecture along with the DISA's Net-Centricity vision statement is described in figure 1.

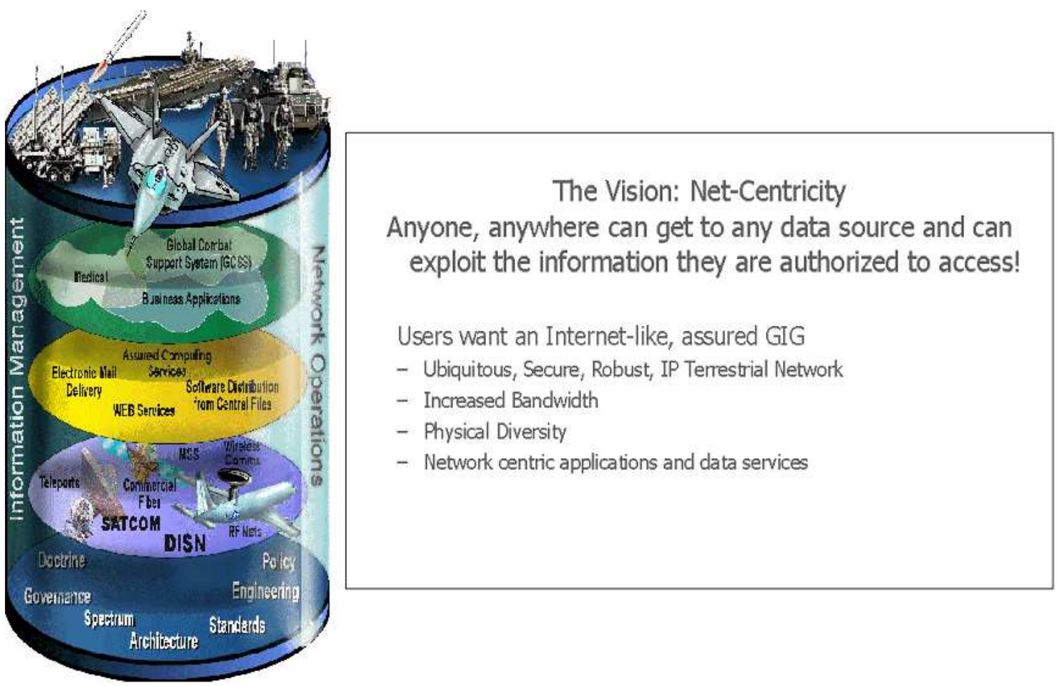

Figure 1: GIG and Net-Centricity Vision

In the GIG architecture, the aggregation of networks (e.g. satellite communications (SATCOM), MSS, Teleport Systems, RF Nets, Wireless Communications, Commercial Fiber, etc.) is referred to as the DISN. The SATCOM and Teleport components employ point-to-point, circuit-based communications technology, which is link based and makes inefficient use of bandwidth resources.

The teleport system has evolved to provide access to the GIG by linking the space and ground segments through a worldwide, pre-positioned military and commercial satellite communications infrastructure. The teleport strategy to converge all the voice, video, and data requirements into a single IP based transport system is depicted in figure 2 using satellite IP networking modems. During this evolution the teleports will be supporting the net-centric IP networks and circuit based legacy networks. An IP Gateway is envisioned to interwork the legacy applications so that they can be networked to the users. By using Pseudo Wire protocol encapsulation at the IP Gateway, legacy applications containing telemetry, data, voice, and video services in native formats can be transported across an IP network.

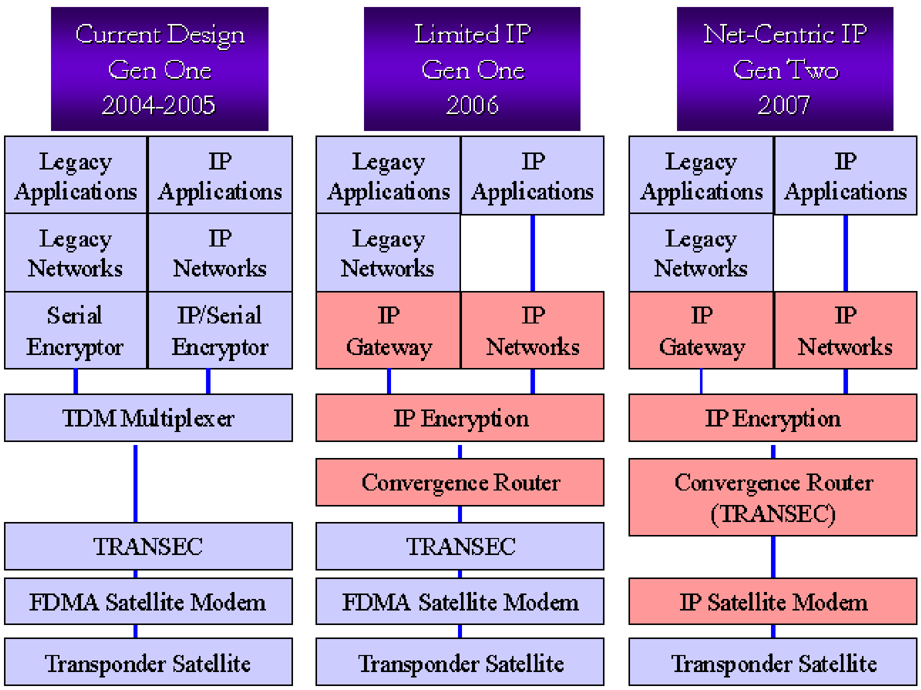

Figure 2: Teleport Vision

The Eastern and Western Ranges shown in figure 3 provide tracking, telemetry, communications, command/control and other support capabilities necessary to safely conduct civil, commercial and national security spacelift operations. In this capacity they use a combination of satellite and terrestrial networks to support launch operations for Delta, Atlas, Titan, Space Shuttle, Pegasus, and Athena space launch vehicles.

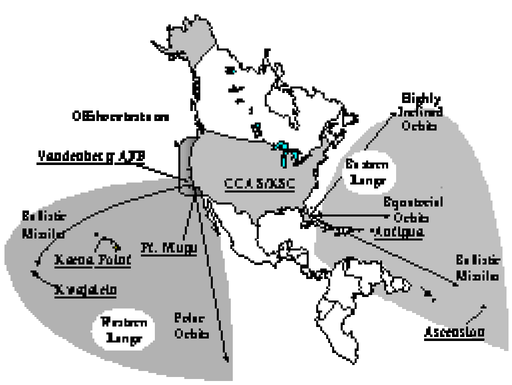

Figure 3: Eastern and Western Range

The range network infrastructure has the same limitations being link based and inefficient use of bandwidth. U.S. Air Force Spacelift Range System (SLRS) program is investigating modernization that could leverage the evolution of the DISN to support an IP infrastructure. In this way they would be able to network telemetry, command, control, analog, and voice communications using the Pseudo Wire approach.

PSEUDO WIRE APPROACH

Since the 1980's, layer 2 Ethernet interfaces have been the preferred interface for IP based local area network deployments. Over the past five years there have been significant improvements in the scalability, protection, Quality-of-Service (QoS), and service management of layer 2 Ethernet interfaces. This has led to the adoption of layer 2 Ethernet interfaces for Metro Ethernet Networks and in the wide area network by service providers.

The deployment of PSNs in the wide area networks has been an enabler for net-centric services, which have been primarily targeted to the on-net DOD community. Providing net-centricity services to off-net users has proven to be more challenging. Work was initiated in 2002 by the Metro Ethernet Forum to define the requirements for Circuit Emulation Services (CES) over Metro Ethernet Networks. Similar work was begun by the IETF around PSNs. These efforts have led to a layer 2.5 protocol using a Pseudo Wire approach to combine Ethernet and IP services with legacy services as depicted in figure 4.

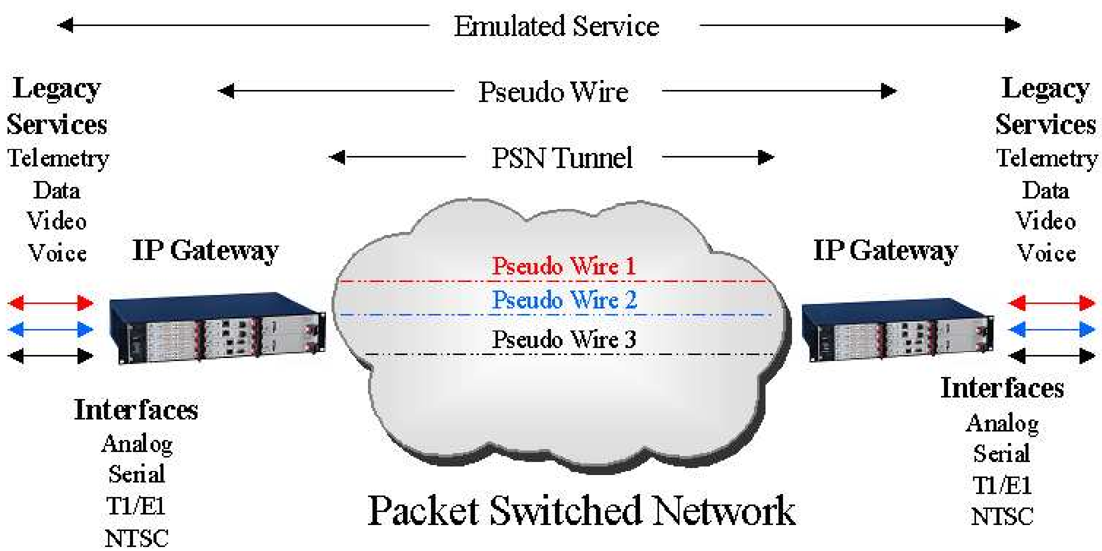

Figure 4: Pseudo Wire over PSN

The Pseudo Wire approach to providing CES over the PSN involves the emulation of each service type (voice, video, and data) in tunnels over a PSN. The term tunnel represents a "pseudo wire" which is a logical construct to explain in a symbolic sense the transmission of information across a wire. From the enterprise perspective, the pseudo wire is perceived as an unshared link or circuit (or the appropriate unit) of the chosen service. Each service type has different requirements (e.g. signaling, latency, timing, OAM) associated with emulation of the service.

In this approach the gateway provides interfaces for telemetry, data, voice, and video services in their native non-IP format. By using common service-specific techniques the traffic can be encapsulated into protocol data units (PDUs) and maintain the circuit emulation service characteristics. A PDU defines a frame of data transmitted over the data link layer (layer 2) in a communications network. Consequently the Pseudo Wire approach allows the PSN to simply transport PDUs for multiple services in lieu of performing the conversion/interworking functions per service pair.

The Internet Engineering Task Force (IETF) working group has developed architecture (RFC3985) and standards (RFC3916) for implementing pseudo wires. This effort has been focused on commercial applications around dedicated digital services (e.g. T1, E1, and T3 transmission). This communications architecture showing the relationship of pseudo wires to the other layers is depicted in figure 5.

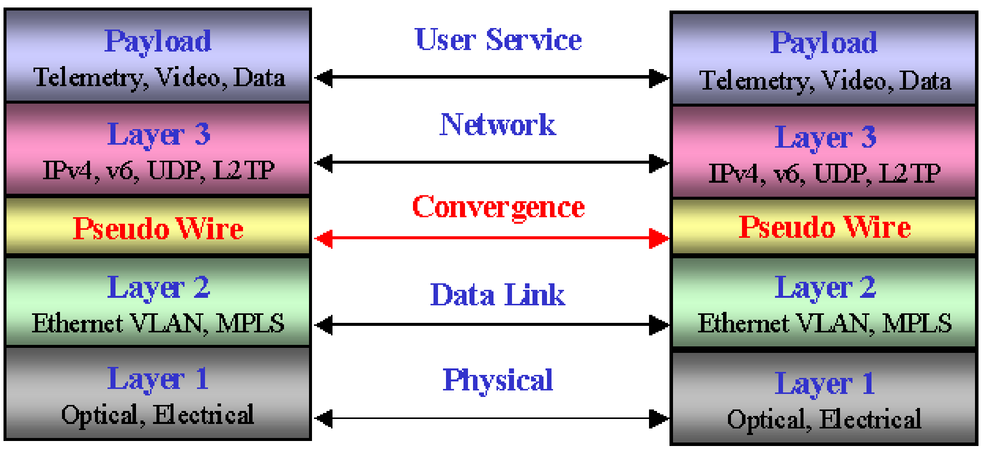

Figure 5: Communications Model

For the DISA and Range community we have used this framework and extended the standards to support other non-IP native interfaces and services. These interfaces include single-ended and differential serial communications and analog transmission using pulse code modulation (PCM) techniques. By using the Pseudo Wire approach these interfaces can support services such as the transport of analog data (e.g. FSK/PSK tones, IRIG signals), telemetry (e.g. single-ended and differential communications), real-time full motion video (e.g. NTSC and SDI), and analog voice (e.g. two wire and four wire) over the PSN instead of being restricted to legacy time division multiplexed (TDM) networks. In this way the Pseudo Wire approach extends the concept of Net-Centricity to off-net users and include non-IP native services.

Pseudo Wire Implementation

The Pseudo Wire approach is consistent with existing networking standards that support tunneling information across PSNs (e.g. routed IP, switched Ethernet, MPLS, L2TP). The pseudo wire implementation consists of service packetization (creating the PDUs), encapsulating the PDUs using the pseudo wire standard (using common service-specific techniques), and using standard network protocols for encapsulating pseudo wire packets to be tunneled across the PSN. The pseudo wire implementation is illustrated in figure 6.

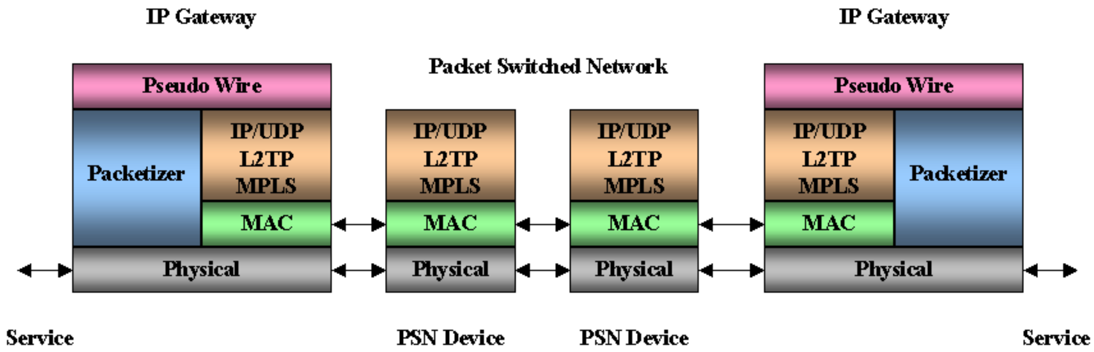

Figure 6: Pseudo Wire Implementation

Packetization refers to the process of converting single-ended and differential serial communications, analog services, and digital transmission traffic into fixed length PDUs using common service-specific techniques required to support characteristics of the service (e.g. signaling, delay, access protocol). The PDUs are encapsulated with a 32-bit control word header, which is illustrated in figure 7.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 0|L|R|RSV|FRG|    LEN    |       Sequence number         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 7: Pseudo Wire Control Word

The control word header supports detection of packet loss or misordering, differentiation between PSN and emulated circuit network faults, PSN bandwidth conservation during fault conditions, and signaling of faults detected at the pseudo wire egress to the pseudo wire ingress.

Bits 0-3 must be set in accordance with RFC4385, which must be zero unless they are being used to indicate the start of an Associated Channel Header (ACH). Bit 4 (L) indicates if there is an attachment circuit fault (e.g. loss of clock, loss of signal, AIS) so that payload data may be omitted at the pseudo wire ingress to conserve PSN bandwidth along with inserting filler data at the pseudowire egress. Bits 5 (R) indicates if there is a PSN fault (e.g. specific number of packets not received). Bits 6-7 (RSV) are reserved bits and set to 00. Bits 8-9 (FRG) must be set in accordance with RFC4623 with no fragmentation set to 00. Bits 10-15 are used to define the length of the packet including the pseudo wire control word. Bits 16-32 (sequence number) must be set in accordance with section 5.1 RFC3550 and provides the common sequencing function as well as being used for the detection of lost packets.

By design pseudo wire encapsulations use IP (v4 and v6), UDP, L2TP, or MPLS protocols for PSNs. The IETF's intent is that pseudo wire encapsulations must follow the same specification for all underlying PSN implementations. Pseudo wire encapsulations do not exert controls on the underlying PSN, but only function at the endpoints of the tunnel. In this way other features of the underlying PSN such as Class of Service (e.g. DiffServ code points) and RTP (e.g. clock recovery and other real-time signaling functions) are still supported.

For IP networks, UDP and IP headers or L2TP headers precede the payload and control word. The packet format is shown where Ethernet is used for layer 2 in figure 8.

Ethernet	IP Header	UDP Header	Control Word	PDU	CRC-32
14 bytes	20 bytes	8 bytes	4 bytes	16-1450 bytes	4 bytes

Based on MTU=1500 Byte Frame

Figure 8: UDP/IP Implementation

For MPLS networks, an inner label precedes the payload and control word. The packet format is shown where Ethernet is used for layer 2 in figure 9.

Ethernet	MPLS Header	IP Header	UDP Header	Control Word	PDU	CRC-32
14 bytes	4 bytes	20 bytes	8 bytes	4 bytes	16-1446 bytes	4 bytes

or

Ethernet	MPLS Header	Control Word	PDU	CRC-32
14 bytes	4 bytes	4 bytes	38-1474 bytes	4 bytes

Based on MTU=1500 Byte Frame

Figure 9: UDP/IP/MPLS or MPLS Implementation

The Pseudo Wire approach supported by PSN protocols together with the extended standards for pseudo wire encapsulation (using single ended and differential serial and analog interfaces for non-IP service types in their native format) provides the means for extending Net-Centricity to off-net users in the Range and DISA networks.

CES CONSIDERATIONS

Successful pseudo wire implementation requires the use appropriate techniques to emulate CES. The legacy TDM networks are highly deterministic. A source device transmits one or more octets to a destination device via a dedicated-bandwidth channel every 125 µs. The circuit delay through a TDM network is predictable for the duration of a connection. Timing is delivered along with the data, and the permitted variability (e.g. jitter and wander) of TDM clocks are controlled to stratum levels.

By comparison, PSNs (IPv4 or v6 and MPLS) are more efficient than TDM networks due to statistical multiplexing of the bandwidth but this leads to PSNs being inherently non-deterministic. Packets must compete for bandwidth at the switch/router ports, leading to packet delay variation (PDV) and potentially out-of-order or lost packets. To mitigate these effects in Range and DISA networks, the Pseudo Wire approach must include mechanisms to manage latency, packet delay variation (PDV), out-of-order or lost packets, clock recovery required for CES, and network faults.

These effects are well understood. Latency is measured from the point at which the traffic enters at the source to the point at which it leaves at the destination. Outside of distance between the source and destination the largest contributor to latency is the network (e.g. number of nodes or hops) and to a lesser degree packetization delay. In Range and DISA networks latencies less than 10 milliseconds are achieved. PDV is the variable delay from the asynchronous nature of PSN and the varying frame lengths in the network. Out-of-order and lost packets are caused by congestion in the network. Out-of-order and lost packets along with PDV will affect adaptive clock mechanisms and the associated settling time. Clock recovery and synchronous system timing are necessary for regeneration of CES. Typically the variations of recovered clocks are maintained between 25 nanoseconds to 18 microseconds even with PSN having PDV in the millisecond range to avoid bit slips and synchronization loss. Lastly any equipment or link failures in the network can disrupt traffic flow and affect clock recovery mechanisms.

There are techniques that will mitigate these effects. To alleviate packetization and network end-to-end latencies, PDV within the network, and out-of-order packets each pseudo wire tunnel must have selectable packet lengths and buffer depths The architectural trade-offs are packet length versus efficient bandwidth utilization and buffer depth versus overall end-to-end latency.

To maintain synchronous timing across a network or regenerate the output clock, gateways must contain inputs for external timing references, an adaptive timing algorithm with a phase-locked loop circuit, and the capability to insert specified data during buffer under run conditions or network faults. An adaptive timing algorithm is an "averaging" process that negates the effect of the random PDV and captures the average rate of transmission of the original bit stream. A phase-locked loop circuit can be used to lock onto the average bit rate and regenerate a clean clock signal that closely tracks the original bit rate. Pseudo wire egress interfaces must be capable of inserting programmed data during buffer under run conditions, lost packets, or network faults to continue emulating the CES and maintain TDM timing.

To resolve network faults and improve robustness, gateways must contain an OAM mechanism for status and statistics information, the means for continuity check for tunnels, one-way and round-trip delay measurements, and support for other performance measurement messages for remote diagnostics.

CONCLUSION

Gateways that support the Pseudo Wire approach have been designed and proven in commercial applications for transporting CES over a PSN. However in the last year, a gateway design using single-ended and differential serial along with analog interfaces has been designed and tested or deployed at spacelift sites on the Eastern and Western Ranges, DOD ranges, International Space Station complex, and NASA ground station facilities.

By extending the IETF pseudo wire standards to new types of interfaces, services such as the transport of analog data (e.g. FSK/PSK tones, IRIG signals), telemetry (e.g. single-ended and differential communications), and real-time full motion video (e.g. NTSC) have been successfully demonstrated over a PSN. With this new capability to extend telemetry, data, voice, and video services in native formats over Ethernet, IP, and MPLS networks in a reliable way, the vision of Net-Centricity can be extended to off-net users while at the same time delivering greater operational efficiency and a smooth migration to a single converged network.

Work in this area continues within several communities. The Telemetry over IP working group within the Range Commanders Council (RCC) will be submitting for approval changes to the Inter-Range Instrumentation Group (IRIG) standards to add telemetry over IP using the Pseudo Wire approach. The IETF Pseudo Wire Emulation End-to-End (PWE3) working group has the lead role for developing pseudo wire standards. Finally, the Metro Ethernet Forum was the original standards group that promoted CES over Ethernet based networks and has developed standards and infrastructure to support test and certification of commercial equipment.

REFERENCES

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IETF: RFC 791 "Internet Protocol (IP)"
IETF: RFC 2475 "An Architecture for Differentiated Services"
IETF: RFC 3550 “RTP: A Transport Protocol for Real-Time Applications”
IETF: RFC 3916 “Requirements for Pseudo-Wire Emulation Edge-to-Edge (PWE3)”
IETF: RFC 3931 “Layer Two Tunneling Protocol - Version 3 (L2TPv3)”
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NOMENCLATURE

ATM	Asynchronous Transfer Mode
CBR	Constant Bit Rate
CES	Circuit Emulation Services
CRC	Cyclic Redundancy Check
DISA	Defense Information Systems Agency
DISN	Defense Information System Network
GIG	Global Information Grid
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IRIG	Inter-Range Instrumentation Group
IP	Internet Protocol
ITU-T	International Telecommunications Union - Telecommunications
L2TP	Layer 2 Tunneling Protocol
MAC	Media Access Control
MPLS	Multi Protocol Label Switched
NTSC	National Television System Committee
PCM	Pulse Code Modulation
PCM	Pulse Code Modulation
PDU	Protocol Data Unit
PDV	Packet Delay Variation
PHY	Physical Layer
PSN	Packet switched Network
PWE3	Pseudo Wire Emulation End-to-End
RCC	Range Commander's Council
SDI	Serial Digital Interface
QoS	Quality-of-Service
SATCOM	Satellite Communications
TDM	Time Division Multiplexed
UDP	User Datagram Protocol