

Introduction to Circuit Emulation Services over Ethernet

Abstract

This paper provides an introduction to Circuit Emulation Services over Ethernet (CESoE) enabling the support of synchronous services such as T1/E1 over an asynchronous Ethernet infrastructure. The paper discusses the benefits of CESoE to service providers offering Ethernet access services, as well as to subscribers to those services in various applications. Finally, the paper discusses the current activities of MEF in standardizing and promoting CESoE.

Introduction to CESoE

Since its inception in 2001, the Metro Ethernet Forum has been developing technical specifications and implementation agreements for carrier-grade Ethernet infrastructure and services to benefit service providers, enterprises and residential users around the world. Since private T1/E1 and SONET/SDH private line services are widely available, the MEF initiated work in 2002 to define requirements for providing Circuit Emulation Services (CES) over metro Ethernet networks.

CES, as its name implies, allows the transport of synchronous circuits such as T1/E1 over asynchronous networks. Originally developed to allow T1/E1 to run over ATM, CES can be extended to work over Ethernet networks.

This paper provides readers of all backgrounds with an introduction to the motivation and business case for MEF's CESoE standardization work as well as the technical challenges overcome in the process.

Business Case for CESoE

Metro Ethernet infrastructures are enabling an array of new broadband data services. By adding CESoE to the portfolio of Metro Ethernet services, applications, including traditional TDM voice applications and legacy private line applications, can leverage the advantages inherent in Ethernet technology. These advantages include flexibility, simplicity, and cost-effectiveness. Studies sponsored by the Metro Ethernet Forum have shown that Ethernet-enabled infrastructures lower operating costs for the provider and enable faster service

delivery – results that ultimately benefit enterprises and spur user demand.

CESoE provides benefits to incumbent carriers, competitive operators, mobile/wireless service providers, and enterprise users. For example, CESoE enables providers to offer a complete service portfolio that integrates emerging Ethernet services along with full-featured TDM voice services and private-line services (for voice or data). This means that, for the first time, service providers can leverage business models based on all the advantages of Ethernet as a converged packet network, without sacrificing revenues from these widespread and still-growing legacy TDM services.

For next-generation competitive operators that have built Ethernet-only networks, CESoE's ability to enable full-featured voice and private-line services represents important incremental revenue opportunities. For incumbent carriers looking to move into greenfield markets, Metro Ethernet with CES allows the carrier to cost-effectively build an access infrastructure based solely on Ethernet, and to use that network to offer all of the services available in established markets. In markets where the networks have already been built out, carriers that utilize CESoE can now employ a "cap and grow" strategy that addresses the problems created by mature technologies and enables the continued growth of revenues from services deployed using those technologies. According to Joe McGarvey with Current Analysis, service providers can realize savings of approximately 30% in infrastructure costs and operating expenses by migrating to a unified Metro Ethernet architecture.

Ethernet also enables opportunities for competitive operators to reduce their backhaul costs. T1/E1 leased lines currently account for 40-60% of the operational expenses incurred by cellular operators. CESoE can reduce 2G/2.5G access costs since metro Ethernet connections cost a fraction of their native TDM counterparts on a per-Mbps basis. Because CESoE transports applications transparently, it can even be used to carry non-DS0 aligned voice traffic and pre-standard signaling protocols. This is of particular interest to mobile/wireless providers, and it is especially valuable as

providers migrate to the more bandwidth demanding 3G services. Metro Ethernet in the radio access network enables the provider to support this new traffic without the deployment of additional T1/E1 lines. The ability to flexibly utilize a single access technology for both the voice and data components of 3G services often yields an equipment payback measured in months.

Additional cost savings to the mobile operators are also achieved by grooming T1/E1s from separate remote cell sites onto a single network. Using cost-efficient and scalable Ethernet switching, the traffic is then converted back to TDM with T3/E3 or OC-3/STM-1 at the switch site effectively eliminating relatively expensive TDM aggregation equipment near the Radio Network Controller (RNC) and Mobile Switching Center (MSC) in the wireless operator's network.

CESoE offers compelling business drivers for enterprises as well. A case study [1], sponsored by the MEF, revealed a potential 70% savings to the enterprise based on using Ethernet service only for Internet access and standard data applications as compared to traditional private line and Frame Relay-based alternatives. With the addition of CESoE, Metro Ethernet services can also support voice applications, proprietary data applications, real time video applications and other circuit-switch applications at T1/E1 rates, including T3/E3 and OC-3/STM-1. The integration of CESoE into the overall Metro Ethernet service portfolio also benefits enterprise customers because it enables them to utilize a single service provider for all their communications needs, thereby simplifying administrative and billing processes.

Because CESoE carries TDM traffic transparently over the Ethernet, it can transport the full array of voice signaling protocols currently in use throughout the world. This includes the many extensions used to provide advanced features and services. For example, many enterprises have a large installed base of PBXs and have grown accustomed to the PBX's extensive feature set. For these enterprises, CESoE enables PBX-to-PBX tie line applications with no loss of features to the user. For service providers, the transparency attribute of CESoE means that the full range of features available from existing TDM-based Class 5 switches can be extended across the new MEN infrastructure. These features are critical to service providers deriving revenue from services such as Centrex and Custom Local Area Signaling Services (CLASS).

CESoE Applications

Metro Ethernet providers can use CESoE to provide bundled services for a fixed monthly charge that includes

data VPN access and flat rate local phone service within the network. Carriers can also use CESoE to provide enterprises with interworking to the PSTN at the PSTN central office.

Metro Ethernet enterprise customers can use CESoE to cut their subscriber costs, extend the lives of their TDM-based equipment and network architectures.

2G/2.5G cellular providers can use CESoE to cut their leased line costs and begin their migration towards 3G.

The Metro Ethernet Forum (MEF) has defined four general service types for CESoE functionality.

- TDM Access Line Service (TALS) in which the MEN provider provisions and manages TDM leased lines via CESoE, and at least one endpoint terminates in the PSTN
- TDM Line Service (T-Line) in which the MEN provider provisions and manages TDM private lines via CESoE between enterprise endpoints
- Customer-Operated CESoE in which enterprises and other classes of customers manage TDM private lines via CESoE over an E-Line (point to point Ethernet) service from the MEN provider.
- Mixed-Mode CESoE in which hybrid combinations of the other three service types are implemented.

TDM Access Line Service (TALS)

TALS enables metro Ethernet carriers to deliver T1, E1, T3, E3, OC-3, STM-1 based services for voice, Frame Relay and ATM over their Ethernet networks. TALS supports legacy voice and data applications transparently. Circuit quality matches that of traditional PSTN/circuit-based networks.

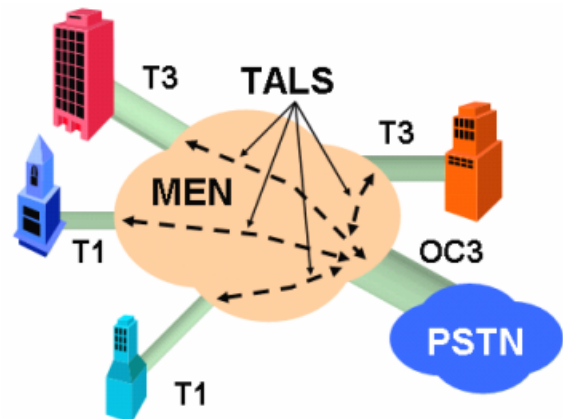


Figure 1: TALS

TDM Line (T-Line) Services

T-Line service supports all traditional TDM-based private line services over a metro Ethernet infrastructure. Enterprises can implement T-lines over metro Ethernet networks for:

- Private/Hybrid Frame, ATM, IP, voice, and video networking
- Centralized voice services
- Private line/toll bypass
- TDM Backup / Disaster Recovery for high uptime and regulatory compliance, e.g., Sarbanes-Oxley Act of 2002 in the U.S. [2]
- TDM PBX migration to Ethernet MAN

Customers get a range of inter-office bandwidth options including:

- Signal rates from 64kbps to 51.84Mbps
- Point-to-point and point-to-multipoint capability
- Clear-channel capability

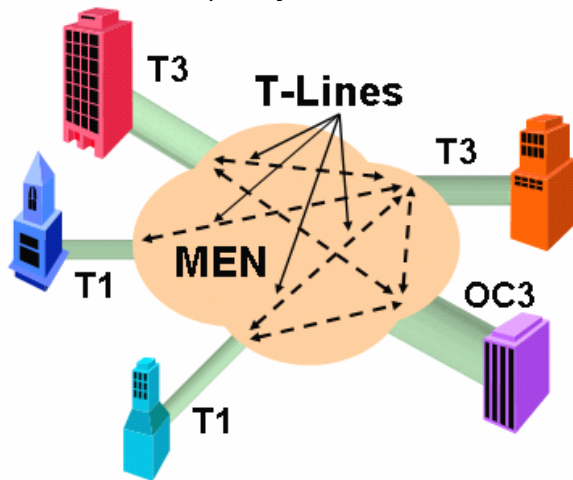


Figure 2: T-Line

Cellular Backhaul

Until now cellular operators have relied solely on traditional T1/E1 leased lines from the incumbents that have caused provisioning delays. E-Line, TALS, and Mixed-Mode CESoE enable a metro Ethernet network to be used to backhaul infrastructure traffic from cell site.

CESoE gateways can extend cellular base station T1/E1 circuits transparently over metro Ethernet networks, eliminating the need for TDM leased lines. Implementing CESoE also positions the cellular operator for future 3G network expansion.

Technical Challenges

Most, if not all, of the technical challenges facing CESoE result from replicating a Constant Bit Rate (CBR) service (thoroughly specified in ITU-T documents¹) over a Variable Bit Rate (VBR) Metro Ethernet Network (MEN). The performance of the MEN in terms of latency, errant and lost frames has a critical effect on the ability to support CESoE, especially on the ability to synchronize both ends of the synchronous CBR service.

Packetization

'Packetization' refers to the process of converting the synchronous bit stream traffic of PDH or SONET/SDH into Ethernet frames. CESoE requires that the delay introduced by packetization be as low as possible and nearly constant to maximize CESoE quality. It is also possible to encapsulate frames from multiple synchronous streams helping to reduce the latency of the packetization process.

The packetization process for CESoE also supports interfacing both structured and unstructured TDM modes of operation. Unstructured operation is when the TDM service is treated as a pure bit stream, without regard to the structure of the data within the circuit. For example, in unstructured mode, a T1 circuit is considered a bit stream at 1.544 Mbps, with no account taken of the position of the framing bits or data channels within the bit stream. The principal advantage of unstructured mode is that any signaling within the TDM traffic is transported transparently. This means that CESoE is appropriate for any type of TDM interface regardless of the particular signaling protocol implemented and hence dramatically simplifies the deployment of TDM over Ethernet.

Latency (Frame Delay)

Latency is one of the key elements to consider when transporting TDM traffic across an asynchronous network because of the sensitivity of voice applications running over the TDM. For example, cellular backhaul is very sensitive to latency, and in standard telephony networks, latency can result in the need for costly echo cancellation.

Latency is measured from the point at which the TDM traffic enters the MEN at the source, to the point at which it leaves the MEN at the destination. By far the most significant contributor to overall latency is the network. For CESoE services to work, the total latency needs to be both well controlled and low. With today's MENs, latencies of less than 10msec are easily achievable and are ideal for the emulation of CBR traffic and offering the

¹ Refer to Standardization Status section

ability to implement very cost effective solutions which do not require compression or echo cancellation.

Frame Delay Variation (FDV)

Frame Delay Variation (FDV) is the variable delay introduced by the MEN and is due to the asynchronous nature of switched Ethernet and the varying lengths of frames traversing the MEN. With networks carrying a range of network traffic types, from time sensitive voice traffic to simple Internet access traffic, the level of FDV can be quite significant and can adversely affect the ability of the CESoE connection to faithfully replicate the CBR service requirements specified by ITU¹.

The effects of high amounts of FDV may be neutralized, or at least mitigated, by the use of destination buffers (jitter buffers) that are used to accommodate late and early arriving packets. However, increasing the length of jitter buffers in order minimize the effects of FDV increases the latency of the CESoE service often resulting in adverse effects.

The rate of change of FDV also affects clock recovery. Filtering out lower frequencies of FDV may result in adversely affect the acquisition of the clock and the associated settling time.

Frame Loss and Resequencing

For some metro Ethernet network topologies, frames may occasionally not arrive in the order in which they were sent out. In some cases, the frames may arrive very late or not at all, resulting in frames being discarded or possibly misdirected. TDM and SONET/SDH networks do not have the concept of resending frames hence such frames are considered lost if they are not received within the window of the jitter buffer at the destination. This creates an under-run situation resulting in an adverse effect on the quality of the emulated circuit. There are various mechanisms available to compensate and maintain the TDM frame structure in the event of under-run.

The destination must also have the ability to re-sequence the arriving frames. This is achieved through the use of sequence numbers within the frame headers. Again, the jitter buffer plays a key role here since it must be able to check the sequence number of the arriving frames at wire speed, while at the same time maintaining the smallest jitter buffer size to ensure minimum latency.

Clock Recovery and Synchronization

Although mentioned last in this list of technical challenges, synchronization and clock recovery are key capabilities for the successful transport of TDM traffic over Ethernet networks.

Synchronization is the means of keeping all digital equipment in a communications network operating at the same specified clock rate. Differences in timing at nodes within a network cause the receiving node to either drop or reread information sent to it. This is referred to as a clock slip. For example, if the sender operates with a clock rate faster than the receiver's clock rate, the receiver cannot keep up with the incoming traffic. When the receiver cannot keep up with the sender, it will periodically drop some of the information sent to it resulting in reduced voice quality or retransmission of data if the source can support this.

To achieve the required synchronization of the TDM nodes across the asynchronous Ethernet network, a clock recovery mechanism must be employed at the receiver side of a CESoE connection. Clock recovery mechanisms need to withstand the potential latency, FDV and frame loss of Ethernet networks yet still comply with strict synchronization standard requirements¹. Variations of recovered clocks must be maintained within the range of 40ns to 18µsec, (depending on the TDM services) even though metro Ethernet networks may introduce frame delay variation in the order of milliseconds.

TDM Performance Monitoring

CESoE is also required to support the transparent operation of industry-standard mechanisms¹ for monitoring the performance of the TDM service and to detect loss of signal (LOS) at the level of the TDM interface type.

CESoE in Metro Ethernet Forum

The MEF has been developing requirements for circuit emulation services over Metro Ethernet Networks (MEN) and is finalizing these requirements in the 'MEF Circuit Emulation Service Definitions, Framework and Requirements in Metro Ethernet Networks Document'. This will be followed by a corresponding CESoE Implementation Agreement. The scope of the requirements document is to address the particular requirements of transport over MEN for edge-to-edge emulation of circuits carrying time division multiplexed (TDM) digital signals. The document references requirements and specifications produced by other standards organizations, notably the ITU, ANSI, IETF PWE3 and ATM Forum, and adapts these to address the specific needs of MEN.

More specifically, the MEF CESoE requirements document addresses the following topics:

- Operational modes of TDM Line Service (T-Line) and TDM Access Line Service (TALS)
- MEN requirements and bandwidth allocation
- Synchronization
- Performance monitoring and alarms
- Service impairment
- TDM signaling
- Loopbacks
- Protection
- Service quality and efficiency

By addressing these issues, the MEF enables service providers to ensure that standard PDH and SDH services can be delivered transparently using metro Ethernet networks without compromising the service quality. The MEF CES work will accelerate the implementation of CESoE and in turn, the use of metro Ethernet for the benefit of providers and customers alike.

The MEF is not only working on analyzing the technical aspects of CESoE. In June 2003, at SUPERCOMM in Atlanta, MEF created the largest and most ambitious public interoperability demonstration of Ethernet services ever seen. 28 members of MEF, including the biggest names in the industry, joined together to prove the reality of using Ethernet for carrier-grade, metro area networking. The demonstration also showcased live CESoE services including PBX tie lines and multiple T1s and OC3 trunking over a point-to-point Ethernet (E-Line) services.

Standardization Status

Standardization work for circuit emulation over packet is presently conducted in the MEF, IETF, ITU and MPLS forums.

The **Metro Ethernet Forum (MEF)** is in the final phases of formulating requirements for circuit-emulation services over Metro Ethernet Networks (MEN). The document details requirements for structured and unstructured PDH and SDH (SONET) services. Two implementation agreements for PDH and SDH circuit emulation are presently in progress.

Internet Engineering Task Force (IETF) work is conducted in the Pseudo-Wire-Edge-to-Edge-Emulation (PWE3) working group. Refer to [4], [5] and [7][6] for the related Internet drafts.

The **MPLS Forum** is working on various aspects of circuit emulation services. Refer to [7] for the released standard. The following lists work-in-progress:

- TDM transport over MPLS using Raw Encapsulation. Work initiated.
- SONET/SDH transport over MPLS. Work initiated.

The **International Telecommunication Union (ITU-T)** has begun work on circuit emulation in several of its study groups (SG). In particular:

- SG13 question 5:
 - Circuit emulation for PDH circuits over MPLS. Both AAL1 and raw methods are being considered. Y.TDMPLS
- SG15 question 13
 - Circuit emulation for PDH circuits over Ethernet. Work initiated.

Summary

As carrier-grade metro Ethernet services become increasingly available, private line services will inevitably yield to Ethernet-based services. Applications for CESoE range from carrier-supplied converged high quality voice and data services over Ethernet access infrastructure through to scalable backhaul for 2.5G/3G cellular operators, from branch to branch PBX connectivity over metro Ethernets to OC3 trunking over Ethernet backbones.

The technical challenges of CESoE are being overcome through a combination of availability of carrier-grade Ethernet services and the standardization work of MEF.

Through the efforts of MEF, service providers and enterprises worldwide will be able to enjoy the benefits of cost effective, rapidly provisioned wide area connectivity afforded by Ethernet, while at the same time preserving their investments in legacy TDM-based equipment and expertise of their technical support staff.

Appendix

Terminology

Term	Definition
ANSI	American National Standards Institute
ATM	Asynchronous Transfer Mode
CBR	Constant Bit Rate
CESoE	Circuit Emulation Services over Ethernet
E-Line	Ethernet Line
EVC	Ethernet Virtual Circuit
FDV	Frame Delay Variation
IEEE 802.3	Institute of Electrical and Electronic Engineers Standard 802.3™
IETF	Internet Engineering Task Force
IP	Internet Protocol
ITU	International Telecommunication Union

Term	Definition
LAN	Local Area Network
MAN	Metro Area Network
MEF	Metro Ethernet Forum
MEN	Metro Ethernet Network
MPLS	Multi-Protocol Label Switching
MSC	Mobile Switching Center (3G)
PBX	Private Branch Exchange
PSTN	Public Switched Telephone Network
PWE3	Pseudo-Wire Emulation Edge-to-Edge
QoS	Quality of Service
PDH	Pleisochronous Digital Hierarchy
PSTN	Public Switched Telephone Network
RTP	Real-Time Transport Protocol
RNC	Radio Network Controller (3G)
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network
TALS	TDM Access Line Service
TCP	Transmission Control Protocol
TDM	Time Division Multiplexing
T-Line	TDM Line services
UDP	User Datagram Protocol
VBR	Variable Bit Rate
VoIP	Voice over IP
WAN	Wide Area Network

References and Resources

- [1] "Comparison to Legacy SONET/SDH MANs for Metro Data Service Providers", http://www.metroethernetforum.org/WP_SPBusiness_Case_Final071403.pdf
- [2] Sarbanes-Oxley Act of 2002, <http://www.sarbanes-oxley.com/>
- [3] IETF draft "Requirements from PDH and SDH (SONET) emulation services", <http://www.ietf.org/internet-drafts/draft-ietf-pwe3-tdm-requirements-04.txt>
- [4] IETF draft "Emulation of SDH (SONET) structured services (VT1.5/2/3/6 up to STS-Nc for SONET and all VC levels for SDH)", <http://www.ietf.org/internet-drafts/draft-ietf-pwe3-sonet-03.txt>
- [5] IETF draft "Emulation of structure agnostic (unstructured) PDH services (T1/E1/T3/E3)", <http://www.ietf.org/internet-drafts/draft-ietf-pwe3-satop-01.txt>
- [6] IETF PWE3 Working Group, <http://www.ietf.org/html.charters/pwe3-charter.html>
- [7] MPLS and Frame Relay Alliance 4.0 Download the TDM Transport over MPLS using AAL1 Implementation Agreement", http://www.mplsforum.org/tech/tdm_ia_4.0.pdf
- [8] ITU-T recommendation G.702, "Digital Hierarchy Bit Rates"
- [9] ITU-T recommendation G.703, "Physical/electrical characteristics of hierarchical digital interfaces"

- [10] ITU-T recommendation G.707, "Network node interface for the Synchronous Digital Hierarchy (SDH)"
- [11] ITU-T recommendation G.823, "The control of jitter and wander within digital networks which are based on the 2048 kbps hierarchy"
- [12] ITU-T recommendation G.824, "The control of jitter and wander within digital networks which are based on the 1544 kbps hierarchy"
- [13] ANSI T1.101-1999, "Synchronization Interface Standard"
- [14] MEF "Metro Ethernet Services Overview", <http://www.metroethernetforum.org/Metro-Ethernet-Services-Overview.ppt>
- [15] "Metro Ethernet Networks - A Technical Overview", <http://www.metroethernetforum.org/PDFs/WhitePapers/metro-ethernet-networks.pdf>
- [16] Metro Ethernet Forum Membership Application, http://www.metroethernetforum.org/MEF_MemberApplication10-19-01.pdf

Disclaimer

This paper reflects work-in-progress within the MEF, and represents a 75% member majority consensus as voted by the 60 members in the MEF's October 2003 Vancouver Technical Committee meeting.

Some technical details may change in due course (by 75% vote) and this paper will be updated as deemed necessary to reflect such changes. The paper does not necessarily represent the views of the authors or their commercial affiliations.

About the Metro Ethernet Forum

The Metro Ethernet Forum (MEF) is a non-profit organization dedicated to accelerating the adoption of optical Ethernet as the technology of choice in metro networks worldwide.

The Forum is comprised of leading service providers, major incumbent local exchange carriers, top network equipment vendors and other prominent networking companies that share an interest in metro Ethernet. As of December 2003, the MEF had over 64 members.

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