Circuit Emulation Tutorial

INTRODUCTION

As packet based Ethernet and IP networks become ever more pervasive, the advantages of using these networks have to be considered in any communications project. Advantages such as:

- Lower cost transport (Metro Ethernet, xDSL, MPLS, etc.) than conventional networks;
- More choices for service offerings (Satellite, Radio, Cable, etc.)
- Rapid provisioning of new services;
- Connectivity to more economical IP based equipment;

Many of these projects involve existing communication networks that are not packet based, but instead use circuit technology such as T1/E1, T3/E3, serial and non-routable protocols. One approach to deploying a packet based network is a forklift replacement of the existing circuit infrastructure. However, this can be prohibitively expensive not only from an equipment CapEx perspective, but also from the perspective of training, operations, procurement standards and new tariffs. A more effective approach would be to preserve the investment in circuit technology while using packet based networks for connectivity. Circuit emulation specifically addresses this need by converting circuit based traffic into packets that can be transported over packet networks.

Circuit equipment, as introduced above, transmits and receives fixed rate data streams. For example, a T1 circuit consists of 1.544 Megabits per second of continuously flowing data. The T1 transmitter produces a new bit every 647 nanoseconds while the receiver must receive a new bit every 647 nanoseconds. Any disruption in this continuous flow of bits will create errors and could lead to a catastrophic communication failure. Packet transport, on the other hand, is “bursty” in nature. Prior to transmitting a data bit, a large number of bits are stored to form the packet payload. Once the packet has been created and is ready for transport, it may still have to wait for another packet to complete transmission or higher priority packets to be sent. The result, a non-continuous bit stream with variable delay that is not inherently compatible with the continuous communication needs of circuit based traffic. However, by making a packet network emulate the continuous data flow required by circuit based communications (circuit emulation) it is possible to use circuit technology over packet based networks.

The first step in circuit emulation is to convert the continuous transmit bit stream into a series of continuous transmit packets. Although there are various circuit emulation packet formats (CESoIP, SAToP, TDMoPSN, ADP, etc.), they all use UDP over IP packets. The packet payload consists of a fixed number of bits from the transmit circuit bit stream and the header includes the source and destination IP address as well as a packet sequence number to ensure proper packet ordering at the receive end. Figure 1 shows a generic Circuit Emulation packet.

Packet Switch Network Headers (UDP over IPv4 or IPv6; MPLS; L2TPv3; Ethernet)
Circuit Emulation Info (RTP, Specialized Header; or both)
Adapted Payload (fixed number of bits from circuit)

Figure 1

The resulting packet is then transported over the packet network followed by another packet containing the next group of bits and so on. At the receive end of the emulated circuit, the payload bits are removed from each packet to create a continuous serial bit stream at the same data rate as the original signal. To ensure this bit stream is uninterrupted and the bits are in the right order it is necessary to buffer a number of packets prior to processing. The depth of the packet buffer should compensate for worst case variable delay of the packet network (packet delay variation or packet jitter) to ensure no bit pump starvation occurs (i.e. no interruption in the continuous bit stream at the receiver). Timing is often important in circuit based networks and most circuit emulation solutions provide adaptive clocking where the receiver can recover transmitter timing by averaging the rate packets are received. Other methods of ensuring receiver synchronization include GPS based timing or highly reliable internal clocks at both ends of the emulated network. Additional approaches for passing circuit timing through a packet network are IEEE 1588v2 and SyncE. Both are relatively new and have trade-offs between network efficiency and compatibility.

CIRCUIT TYPES AND IMPACT ON CIRCUIT EMULATION

A circuit can be categorized as structure agnostic or “structured”. Structure agnostic is defined as a bit stream with no underlying sub-structure as far as the circuit emulation process is concerned. In other words a continuous string of bits transported in its entirety to the receive circuit over a packet network. Examples of this include serial data (RS232, RS530, RS449, X.21 and V.35) entire T1/E1 circuits and entire T3/E3 circuits. Structured circuits, on the other hand, have a sub-structure the circuit emulation process must be aware of. T1/E1 circuits, for example, typically contain 24 (T1) or 31 (E1) payload sub-channels carrying individual sub-circuits (DS0s) or groups of sub-circuits (NxDS0s). These sub-circuits may be destined for different circuit end-points or may consist of different traffic types such as voice, video and data. In the case of fractional T1/E1 only some of these sub-circuits are used.

For these cases, the circuit emulation payload is typically constructed on T1/E1 frame boundaries with a programmable number of frames assigned to each packet. Sub-circuits destined for different locations are transported in separate packet flows with each flow having the appropriate destination IP address as shown in Figure 2.

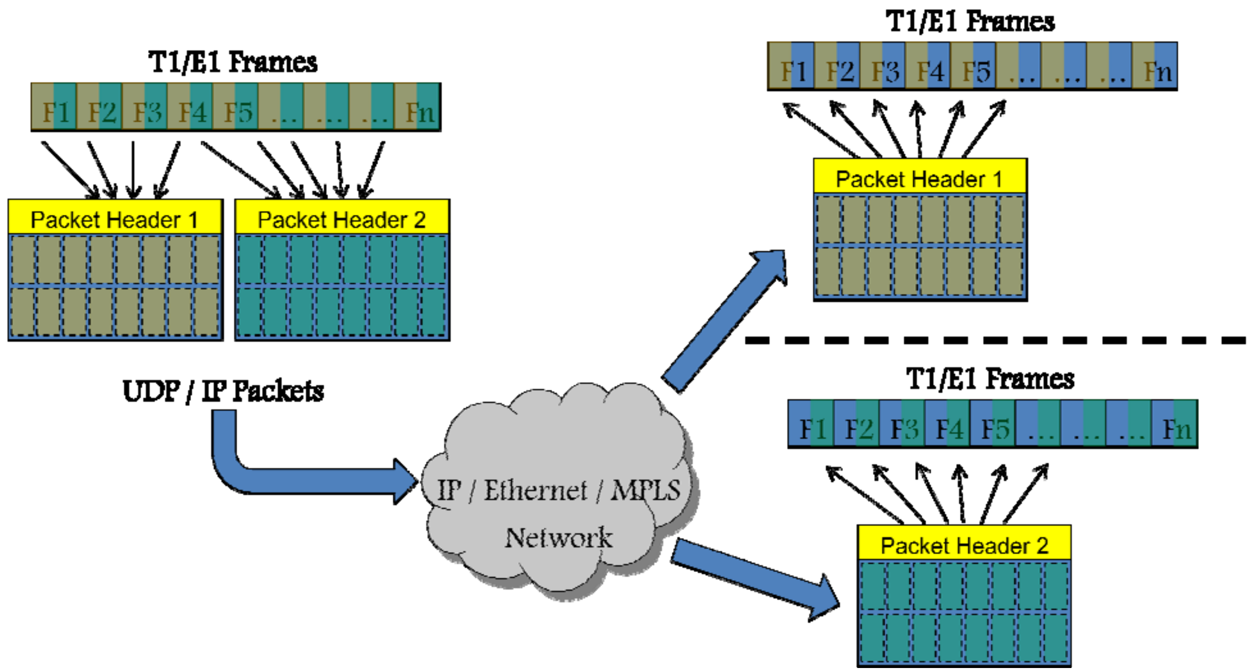

Figure 2

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In real time applications such as voice, delay can be an important consideration in circuit emulation solutions. Delay is introduced by the packet formation process at the transmitter as well as receiver buffering used to counteract network packet jitter. For voice applications, the transmit packet size should be minimized to avoid excessive packet formation delay. But bandwidth efficiency and network processing must also be considered as smaller packets result in more packets to process and reduced payload to packet header ratio. As delays accumulate in a circuit emulation network, voice circuits may encounter far-end echo issues and circuit emulation end points may need to apply echo cancellation techniques prior to re-constructing the remote circuit.

Of course, for fractional T1/E1 circuits, there is no reason to transport the entire T1/E1 circuit, and knowledge of the T1/E1 sub-structure allows for transport of only the DS0s used, saving on packet bandwidth consumption and associated costs.

OTHER IMPORTANT CONSIDERATIONS

Circuit emulation is an important and powerful technique for preserving the investment in existing infrastructure, equipment, and networks, while taking advantage of the significant benefits of packet networks. Consequently, numerous additional capabilities have been developed to further enhance the performance and reliability of these networks, including:

- Assured Delivery Protocol (ADP): Some applications require robust communications and ADP improves the quality of UDP transport by applying packet out of sequence detection and reordering, duplicate packet skipping and lost packet retransmission.

- Compression and Optimization: Applications with limited bandwidth, or where bandwidth costs need to be minimized, are best served by not transmitting duplicate or idle traffic. Removing this traffic at the transmitter and then re-inserting at the receiver achieves this objective.

- Customized Packet Size: As mentioned previously, some applications will benefit from using smaller sized packets, while others larger; customizing the packet size for specific applications should not be overlooked.

- Rate Limiting: Ensuring circuit emulation end points provide the bandwidth necessary for real time traffic can be key to predictable operation. Rate limiting non-real time LAN traffic so it doesn't interfere with real time traffic achieves this objective.

- Automatic Protection Switching: Providing multiple circuit emulation paths through one or more packet networks, and the ability to detect a failure on the primary path and switch to the secondary path, can be key to high availability applications. The ability to receive and buffer both paths simultaneously can provide for lossless switch over.

- Enhanced Packet Efficiency: When transporting multiple circuits between two locations, it is preferable to combine these circuits into a single packet versus requiring a packet for each circuit. This reduces packet overhead, increases network efficiency and enhances reliable delivery.

- Load Balancing: If a single packet network connection is insufficient to support the bandwidth needs of a circuit, the circuit traffic can be balanced onto two independent IP/Ethernet networks.

- Encryption: Circuit emulation should support the serial interfaces typically used by encryption equipment to ensure secure communication applications. In addition, applications requiring the secure transport of circuit traffic currently "in the clear" over packet networks should be supported.

TYPICAL APPLICATIONS

Circuit emulation is beneficial to numerous applications and is often used for the following:

- PBX connectivity
- T3 / E3 backhaul trunking
- Cellular Radio Access Network backhaul
- Ethernet radio connectivity
- Satellite applications
- Government security
- Public safety