Packet Services and TDM support

Revision 1.0

May 18, 2004

Greg Wetzel, Chief Network Architect

1. Introduction

The architecture of Packet Services, particularly Internet Protocol (IP), is defined in a layered model roughly corresponding to the ISO 7-layer model[1]. In the modified layered model supporting IP, generally the 3 lowest layers are described:

1. Physical Layer
2. Link Layer
3. Network Layer

In this model, the Physical Layer is responsible for ensuring the transport of transparent bit-streams, that is, without the knowledge of frame or packet boundaries and without interpretation of the meaning of the bits in the bit-stream. Examples of Physical Layers are T1[2] channels, Synchronous Optical Network (SONET)[3], Ethernet 10BaseT definition, Gigabit Ethernet fiber and light frequency definitions. The Physical Layer is not responsible for re-transmission of data found to be in error, but it is responsible for reporting service events such as loss-of-signal, loss-of-synchronization, etc., but not bit-errors. Physical Layers are defined by a set of specifications that separate the truly physical aspects (e.g., frequencies used, wire types and maximum lengths, pin assignments on plugs) and the logical aspects (e.g., how synchronization is obtained and its loss detected).

The Link Layer is responsible for ensuring the correct transport of *frames* across a given physical layer channel and are generally *protocols* which define procedures and conventions of operation. The Link Layer is involved in such things as checksums to detect errors in transmission (but is not involved in retransmission of errored data), flow control, etc. An example of a Link Layer protocol is High-Level Data Link Control (HDLC), Point-to-Point Protocol (PPP).

The Network Layer is responsible for various control functions, particularly routing. The Network Layer is a generally a suite of protocols that define a number of these control functions ranging from the addressing scheme used, how the addresses are located within a network, how a network determines the path used to route a *packet* from the

---

[1] ISO/IEC 7498-1. 1993. "Information Processing Systems—Open Systems Interconnection—Basic Reference Model." Also published as ITU-T Recommendation X.200.

[2] ANSI T1.403-1995, – *Telecommunications – Network to Customer Installation – DS1 Metallic Interface*

[3] Telcordia GR-1230-CORE, "SONET Bidirectional Line Switched Ring Equipment Generic Criteria (a module of TSGR, FR-440), Issue 4 (Bellcore, December 1998)."

source to the destination. Examples of Network Layer protocols include Signaling System 7 (SS7) and Internet Protocol Suite.

Network technologies define how they operate across all the ISO model layers. For example, Asynchronous Transfer Mode (ATM) defines what physical layers it uses, how cells (ATM's layer 2 frames) are transported over those physical layers, and how end-to-end routing is accomplished (using ATM virtual connections).

2. Packet Services Transport

Many Packet Services began based on Ethernet[4] technology, and Ethernet is today the most common Layer 1 and 2 technology used for packet services and IP in the Local Area Network. In the past few years, Ethernet has been extended so it can be used in Metro Area Networks (MANs), although its use as a MAN technology is quite small compared with other technologies.

IP networking was developed within university campuses and later was used by enterprise networks. When IP needed to leave a building or campus (where it was carried on Ethernet or other LAN technologies), it was nearly always carried over Time Division Multiplexed (TDM) Physical Layers such as T1 in conjunction with Link Layers such as HDLC, Frame Relay, or ATM. These TDM Physical Layers are the transport standard that originally AT&T, and later the Incumbent Local Exchange Carriers (ILECs) have sold for over 30 years. The packet model was adopted by Enterprises and Internet Service Providers: IP over Ethernet is used in the LAN and IP over HDLC, FR, or ATM over a TDM transport layer is used in the Wide-Area Network (WAN). Today, TDM provided by the ILECs and various CLECs remains the dominant transport technology used as the basis of Internet Protocol networks in the Wide-Area.

Ethernet has expanded its scope in the past few years. As Ethernet has matured, the speeds at which Ethernet can be run have increased from the original 10Mbps, to 100Mbps, and now to 1Gbps and 10Gbps. Simultaneously, the cost of equipment implementing Ethernet has dropped. Service Providers of Metro-Area Networks (MANs) have also begun to base their networks on Ethernet technology (e.g., Yipes, On-Fiber, Telseon, Cogent). In these MAN networks, Gigabit Ethernet standards provide for direct use of fiber. Until recently, it was unusual to see any MAN transport that wasn't based on TDM. For the huge bulk of MAN traffic today, TDM remains the transport technology underlying IP.

Another technology, Multi-Protocol Label Switching (MPLS), has been developed to address a number of issues at Layer 2. This technology generalizes from both Frame Relay and ATM. Both FR and ATM have been criticized because they do not integrate well with IP networks. MPLS addresses these criticisms, but remains a Layer 2 technology. While the IETF has defined how MPLS can operate directly over fiber, there are very few, if any, networks built using that standard. Instead, virtually all service providers using MPLS operate it over TDM networks (mostly SONET-based). It

---

[4] IEEE 802.3-2002, "Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications," Jan 2002.

is difficult to operate WAN networks without using TDM technology for transport because many of these newer protocols (e.g., MPLS) did not take into account the difficult management issues in operating a WAN network. For example, with SONET, a conscious effort was made from the beginning to build in mechanisms to detect fiber breaks, equipment failures, etc., and to report these failures to the service provider while simultaneously healing itself to allow nearly uninterrupted service. MPLS was not designed with this attention to management issues (these issues are being addressed now, but it will be nearly impossible to incorporate them as seamlessly and completely as was done with SONET).

Thus it is clear that while other non-TDM technologies are useful in the LAN and even in some MAN applications, TDM will remain the dominant WAN technology for some time.

3. Emulating T1 and other T-carrier channels using Packet Services

TDM networks are composed from a hierarchy of communications channels. In the US, the hierarchy consists of Digital Signal level 0, 1, 3 (DS0, DS1, DS3) that operate at speeds of 64kbps, 1.544Mbps, and 45Mbps, respectively. In this hierarchy, 24 DS0 channels can be multiplexed into a single DS1 channel. Similarly, 28 DS1 channels can be multiplexed into a single DS3 channel. This hierarchy was defined by AT&T before divestiture and continues to be used by the ILECs.

Higher rates are also available using Optical Carrier signals. Again, in the US, the typical Optical Carrier levels are 1, 3, 12, 48, and 192 (OC-1, OC-3, OC-12, OC-48, and OC-192). These are associated with SONET Transport Signal levels STS-1, STS-3, STS-12, STS-48, and STS-192 and operate at approximately 155Mbps, 612Mbps, 2.48Gbps, and 10Gbps, respectively. ANSI Standards have been defined to allow DS1 and DS3 signals to be mapped into STS-1. STS-1 signals can be aggregated in to STS-3, STS-12, STS-48, and STS-192 signals (3 STS-1s can be carried in an STS-3, 12 STS-1s in an STS-12, etc.).

All of this multiplexing at higher and higher speeds also leads to lower utilization of the highest rate signal. This is due to what can be called “internal breakage”. Suppose a carrier decides that it needs to carry 12 DS0s from point A to B and uses a single DS1 for that purpose. Also assume it needs 14 DS1s from point A to B and uses a single DS3. The effective utilization of the DS3 is 14/28 or 50%. In fact it’s even lower than that because at least one of the DS1s is carrying only 12 of the 24 DS0s it could carry.

This problem is multiplied by the number of combinations of A to B pairs in the carrier network. Some time ago, the carriers thought that if they could flatten the hierarchy, they could increase the utilization of the highest speed transport. To do this, they defined how a single DS0 and a single DS1 could be emulated over a packet service (e.g., ATM or IP). These were called DS0 and DS1 emulation over ATM or IP.

After the standards were defined and lab tests were done, they discovered that it was very difficult to achieve the same levels of performance with an emulated DS0 or DS1 as with the usual TDM hierarchy. Part of the problem was that if a single packet were dropped, a significant amount of data from the DS0 or DS1 was lost compared to the normal TDM mechanism (where perhaps a single byte would be lost compared to 10s or 100s of bytes in an emulated circuit).

Another part of the problem is that equipment and networks were not built or designed to meet the same 99.999% availability numbers that TDM equipment made the norm.

This meant that carriers would not be able to meet the same Service Level Agreements (SLAs) with emulated DS0s and DS1s as their customers are used to. So while standards exist and it is technically possible to transport a T1 (DS1) from point A to point B across an ATM or IP network, either the packet network would have to be significantly over-designed to meet the common TDM SLAs (making it too costly) or the customers would have to accept lower performance metrics in their SLAs. In the end, most carriers decided that continuing to use TDM was more cost-effective and made for higher customer satisfaction levels.

4. Conclusion

Transport networks relying on Time Division Multiplexing (TDM) technologies remain the underpinning at Layer 1 of nearly all MAN and WAN networks today. These networks are predominantly provided by the ILECs, CLECs, and IXCs. Gigabit Ethernet has shown some promise as a Layer 1 replacement in some MANs, but this will allow carriage of only data traffic, since TDM emulation remains a difficult operational and technical challenge. TDM or FR or ATM over TDM will remain the Layer 1/2 technologies of choice for most Enterprises to interconnect their IP-based intranets and to connect to other networks (e.g., for Internet services).