16 Circuit and Packet Conversions at the Service Access Point

16.1 Packet Over TDM

Transporting Ethernet packets in a time domain multiplexed channel across SDH/SONET communication networks gives a fully dedicated communication channel with high predictability comparable to a dedicated fiber or wavelength, while providing the advantage of a shared transport network infrastructure with its inherent path redundancy and fault tolerance.

Many power utilities use at present SDH networks for transporting operational traffic as E1 or sub-E1 digital multiplexed channels. Migration of these services to packet-based Ethernet can be performed in the first step and with minimal transformation through Ethernet over SDH (EoS).

Despite its lack of scalability, needed mainly at the core of the transport network, Ethernet over SDH provides a very adequate solution in terms of ease of deployment, service migration, field maintenance, and central management for substation access and aggregation layer communications.

Ethernet over SDH (EoS) is of a set of industry standards developed for more optimized mapping and control of Ethernet traffic over SDH. It provides mechanisms for sharing bandwidth with improved granularity and guaranteed Quality of Service. These standards, replacing previous proprietary mapping schemes, provide interoperability and flexibility. The most important ones for Ethernet encapsulation along with TDM transport over SDH networks are listed below:

- Generic Framing Procedure (GFP), ITU-T G.7041, provides a generic mechanism to map variable length Ethernet data streams over SDH synchronous payload. GFP assures that SDH equipment from different vendors transport Ethernet traffic in the same manner.
- Virtual Concatenation (VCAT), ITU-T G.707 allows SDH channels to be multiplexed together in arbitrary arrangements and hence to create pipes at any rate.

C. Samitier (ed.), *Utility Communication Networks and Services*,
CIGRE Green Books, DOI 10.1007/978-3-319-40283-3_16

- Link Capacity Adjustment Scheme (LCAS) is a standard for adjusting dynamically the amount of bandwidth allocated to an Ethernet service.

The simple replacement of an old generation end-of-life SDH system by a new one with enhanced data capabilities responds in many cases to the limited packet-switching requirements in electrical substation networks (e.g., migration of existing SCADA and voice applications into IP/Ethernet in a standard vendor-independent manner).

A very simple and low-cost solution for adding Ethernet into the substation would therefore be the deployment of newer SDH equipment with a service aggregation Ethernet switch separating VLANs for different substation applications.

SDH is indeed no longer the technology of choice for mainstream "operator" telecom deployment, but the lower end constituents of the hierarchy (<STM-16) still remain for some time a valid option for time-sensitive private networks or for their substation access component.

16.2 Circuit Emulation Over Packet

Diagonally opposite to Packet over TDM discussed in the previous section, one can find TDM over Packets which is the possibility of transporting some limited amount of circuit-type traffic over a packet-switched transport network or substation access interface. In electrical power utility telecom networks, TDM over Packet provides a way to transport legacy applications, originally designed for TDM transport, over a network which is transformed into packet-switching. This is a race of packet-transformation between Application Networks and the Transport Network.

The most critical example for TDM over Packets is the case of protection relay over a packet network. Despite the recent introduction of IEC61850, the protection relays in operation today are designed for circuit-mode communications and will remain on the network still for many years. If the only available transport network is packet-based, then the conversion can be performed at different levels as shown in Fig. 16.1:

- Protection can be connected to a TDM aggregation device (Access Multiplexer) together with other legacy circuits and transformed into a 2 Mbps E1 interface. The transport network undertakes the delivery of an E1 Service Access Point which it transports over a packet-switched network (PSN) incorporating TDM circuit interfaces in its User-to-Network interface (UNI). The transport network SLA is that of the E1 with appropriate qualities (delay, loss, etc.).
- The aggregation device, a multi-service access platform, performs the necessary transformations to present a packet interface (e.g., Ethernet) requiring an Ethernet Tunnel (Ethernet Line Service) from the transport network.

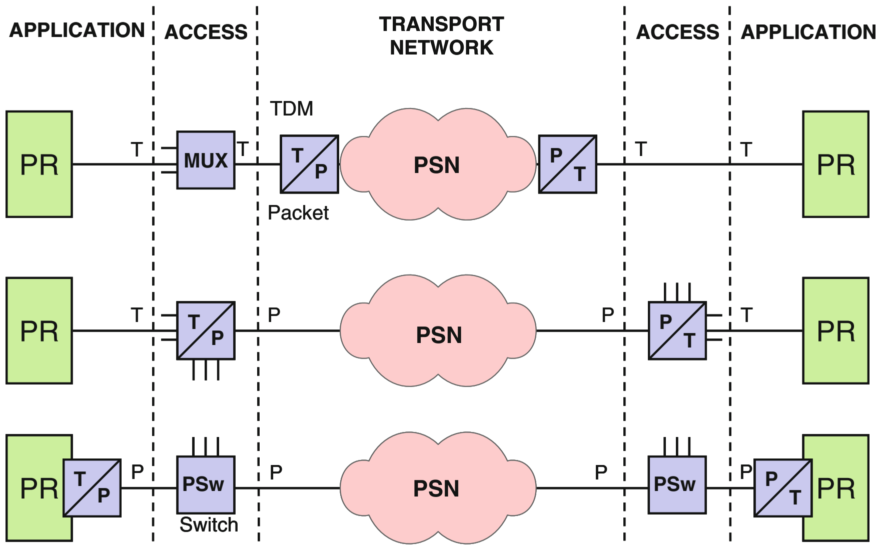

Fig. 16.1 Transporting legacy protection over a packet-switched network (T = TDM, P = Packet)

- An Ethernet encapsulation device can be inserted into the protection communication port at the application side presenting an Ethernet interface to service aggregation (Ethernet Aggregation Switch) for presenting an aggregated Ethernet stream at the Service Access Point.

TDM Pseudowire Emulation Principles

Time division multiplexing can be emulated across a packet-switched network through encapsulation of synchronous data into non synchronous packets at the emitting side, and buffering of asynchronous data to reconstitute the synchronous TDM signal at the receiving side (de-jittering buffer). TDM Pseudowire Emulation (PWE) mechanisms emulate the attributes of a TDM service such as an E1, T1 or a fractional $n \times 64$ service. These are described in a number of IETF RFCs, the most appropriate for time-sensitive communications being RFC4553—Structure-Agnostic Time Division Multiplexing over Packet (SAToP). This is currently implemented into various packet-based multi-service access and transport nodes (e.g., Ethernet Switch, MPLS Router, etc.).

The quality of the resulting TDM interface depends on "how well the TDM channel is being emulated" (i.e., channel performance) and consequently on adequate parameter adjustments, traffic engineering, buffer dimensioning, and bandwidth resource allocation.

The main constraint discussed here is the time behavior of the channel, although channel availability and behavior upon failure can also be decisive especially when one has to rely upon an external provider's Service Level Agreement (SLA).

Packet Encapsulation

An important factor in PWE for time-sensitive legacy applications is the Packet Encapsulation Delay (PED). This is the time delay introduced by buffering of data before transmitting them as Ethernet Packets (e.g., minimum 64 Bytes). The more TDM data samples we pack into each PSN packet (e.g., Ethernet frame) the higher will be the PED (due to wait time in the transmission buffer), but also the higher will be the bandwidth efficiency (due to reduced idle capacity in each packet). On the other hand, we can pack very little TDM data (e.g., only one sample) into each packet so that it can be expedited faster, but in this case, the remaining capacity (e.g., of the Ethernet frame) is wasted and a lot of bandwidth is required for each TDM communication channel.

Typically, a 64 kbps channel is emulated by sending 2 bytes of TDM data in one Ethernet frame, which results in an Ethernet frame rate of 4 kHz. The resulting Ethernet frames will have a length of 64 bytes, which corresponds to the minimal length of such a frame, meaning that a protection system requiring 64 kbps of TDM capacity shall require at least 2 Mbps of Ethernet bandwidth in PWE (i.e., a bandwidth efficiency of 2/64 or 3 %). The remaining bytes may be used for sending auxiliary information (e.g., management and monitoring) which do not necessarily exist in any evolved manner in legacy application systems. Sending more bytes of primary information results in increased transfer delay due to transmit side buffering. It can be seen from Fig. 16.2 that the packet encapsulation is feasible when high bandwidth is available and low efficiency can be afforded.

Clock Recovery and Jitter Buffer Delay

Packet-switched data networks, not being initially designed to transport TDM signals, do not have any inherent clock distribution mechanism and the clock signal inherent to TDM transmission is lost in the encapsulation process. When transporting TDM, the receiver must therefore reconstruct the transmitter clock by phase-locking a clock to the fill level of a Jitter Buffer (receiver data buffer) as shown in Fig. 16.3. Threshold detection in the "de-jittering" reception buffer is employed to construct a synchronization signal. The buffer size used for this purpose must be such that no underflow causing synchronization slips can occur. The buffer size is therefore dependent upon the maximum delay variation of the communication channel which is to be absorbed through buffering. The jitter buffer, however, generates absolute delay (Jitter Buffer Delay or JBD). No need to say that the larger the buffer, the more it introduces absolute delay. In order to maintain a

Packetization (bytes/packet)	Bandwidth (kbps)	PED (ms) for 64 kbps TDM signal
2	2048	0,25
4	1024	0,5
8	512	1
16	256	2

Fig. 16.2 Packet encapsulation

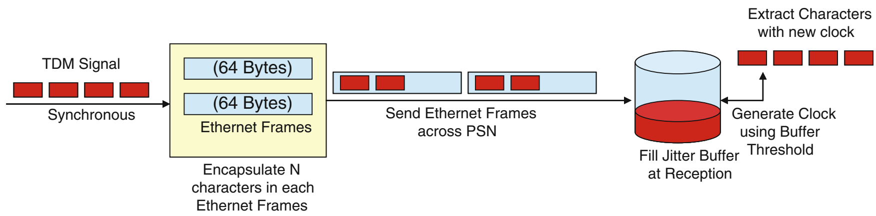

Fig. 16.3 TDM pseudowire emulation

low buffer size and hence the JBD, it is essential that the delay variation of the packet-switched network be kept as low as possible. A dedicated point-to-point Ethernet connection over fiber or an Ethernet over SDH (EoS) typically provides a very low delay variation and therefore a fairly low JBD. On the other hand, a large packet network with many concurrent users may give considerable delay variation and hence a large JBD.

Moreover, it should be noted that clock recovery through Jitter Buffer threshold detection may be vulnerable to packet loss in the transport network although different techniques have been employed to overcome this issue.

In a private dedicated packet network it is also possible to associate a synchronization clock to each packet-switching node and hence to render the Ethernet packet network fully synchronous. This technique, known as Synchronous Ethernet (SyncE), is further discussed in Part 4 on network implementation. With a jitter buffer size of 8 Ethernet frames (64 bytes each), and an Ethernet connection at 2048 kbps, the JBD shall be 2 ms and it shall be capable of absorbing a maximum delay variation of up to ±1 ms.

To conclude on circuit emulation over a packet network, the total time delay (TD) is given by

$$TD = PED + JBD + T_P + ND$$

TD	Total delay	PD	Processing Delay = typically 10 μs
PED	Packet encapsulation delay	SFD	Store and Forward Delay = FS/BR
JBD	Jitter buffer delay	FS	Frame size (FS_{max} = 1500 bytes)
T_P	Propagation time	BR	Link bit rate
ND	Network delay (QD + PD + SFD) × N	N	Number of PSN nodes
QD	Queuing Delay = SFD_{max} × Network load		

Meeting a tight level of Time Delay and Delay Symmetry, as for Protection communications, requires careful adjustments and dimensioning of parameters across the packet-switched network.