Abstract—There is a universal drive towards a single network architecture, which would unify voice, data and Internet networks. A number of alternatives have been proposed for unifying the transmission layer, of which some clearly support the replacement of the SDH layer. In this paper the author argues for the retention of the SDH layer and explores the developments taking place to allow SDH to more efficiently accommodate “data-centric” traffic. Three technologies are key to achieving this: (1) Generic Framing Procedure (GFP), (2) Virtual Concatenation (VC) and (3) Link Capacity Adjustment Scheme (LCAS).

Index Terms— Data; SDH; Next Generation; Optical networks; Unification; Generic Framing Procedure; GFP; Virtual Concatenation; VC; Link Capacity Adjustment Scheme; LCAS.

I. INTRODUCTION

Synchronous Digital Hierarchy (SDH) is the established Layer-1 transmission technology for public networks and is deployed by virtually all carriers outside of North America and Japan. SDH was originally defined in an era when voice traffic dominated telecom networks. The last few years have seen a change in traffic patterns and have seen an explosive growth in Internet and data traffic. In order to cope with this, operators have developed separate networks for the transport of voice, data, Internet and other media applications. This has resulted in high complexity and cost associated with maintaining these divergent networks and there seems to be agreement that unification should take place.

A number of alternatives have been proposed of which some clearly support the replacement of the SDH layer by an all-optical layer. The may not necessarily be the most optimal solution and in this paper the author argues the future of SDH in the transmission network and explores the developments taking place, allowing SDH to accommodate the “data-centric” traffic of the future.

II. TRANSMISSION NETWORK EVOLUTION

Figure 1 illustrates the various layers and mapping options for both voice and data. The figure shows how the transmission network has evolved over the last decade, together with the emergence of a new “photonic” optical layer.

There has been a universal drive towards a single network architecture, which would unify the voice, data and IP networks. The first attempt at this has been Asynchronous Transfer Mode (ATM). This seems to have failed due to objections originating from the data communications community claiming that ATM is inefficient in data transfer and that it is awkward to manage [2].

Whether this is fair criticism or not is open for debate but the fact remains that an alternative emerged in the Internet Protocol (IP). This dominant data communications protocol has been evolving to address some basic quality of service aspects in order to support applications such as Voice over IP (VoIP).

This gave rise to the idea of getting rid of the layers between the IP and optical layers, resulting in a “do-it-all” solution namely “All IP – All Optical” [7].

We can see that certainly in the long-term there is a movement towards the replacement of the SDH layer by incorporating the functionality currently provided by SDH into the IP or WDM layers. There is however justification for SDH remaining [4]:

- SDH is already well established as the transport infrastructure for virtually all of the world’s network operators.
- SDH can carry existing; legacy TDM based traffic without further adaptation, synchronisation or latency problems.
- Although progress has been made in incorporating aspects such as restoration, protection, etc. with the use of digital wrappers for DWDM its coarse granularity suggests that it is unlikely to replace SDH universally in the network.

New technologies are emerging to transform SDH into an efficient platform for transporting both legacy TDM and...
new data service. The recent slump in the telecommunications markets, resulting in new operators going bankrupt and old operators struggling to survive, impacts on the single solution concept in that nobody can afford to replace their existing infrastructure but would rather deploy new technologies in order to supplement existing infrastructure and thereby “sweating” these assets.

For the time being SDH will therefore remain.

III. WHY INTEGRATE DATA INTERFACES INTO SDH EQUIPMENT

The high cost of the interfaces between transmission equipment (SDH) and data-switched equipment (Ethernet, IP), together with the growing volume of data traffic vs. TDM traffic, has raised the question of physically integrating the transmission and data-switched equipment.

Integration does however impose a number of substantial limitations not welcomed by Service Providers, such as the loss of supplier independence, poor scalability and evolution risks [1].

A. Supplier Independence

A number of vendors, including Marconi, offer carrier-class solutions for both transmission equipment and for data-switching. Evidence suggest, however, that Service Providers value the ability to independently source the equipment for these two layers of their networks. Reasons include an installed base of equipment and human-resource skills, perceptions of suppliers’ core-competencies, and competition in the supplier mix. Equipment that incorporates physical integration of transmission and data-switching does not fit this criteria.

B. Scalability

Data-switches are required in a wide range of switch capacities. When integrating data-switching equipment into transmission equipment, it would most probably entail the integration of a “plug-in” data switch card. This inevitable offers only a limited range of capacities. This restricts the flexibility of the network, given the different growth rates for different protocols. A significant change in the required data-switching capacity or functionality may exceed the capacity of the plug-in cards.

C. Evolution Risks

Data-switch protocols are significantly less stable than SDH-protocols. There is ambiguity about the evolution of data-switching protocols for use in the public network e.g. support of IP QoS or MPLS. Until interoperability is assured and the preferred switching/routing protocols for the public network are established, embedding a data-switch in the SDH-equipment creates network evolution risks.

Let us assume that the data-switched equipment and SDH layer stays independent. Two options are then available, either one integrates SDH interfaces (STM-1, STM-4, etc.) into the data-switch equipment or one integrates data-switched interfaces (10/100 BaseT, GigE) into the SDH equipment.

Ethernet has achieved such high deployment in private networks due to the low cost of the technology. This low cost is achieved in part as a result of using a low specification oscillator (typically 200 ppm) producing an unsynchronised network that gives a level of functionality appropriate for private networks [1]. Public networks have, by contrast, been built upon a high specification oscillator (typically 4ppm) to achieve the Quality of Service (QoS) and operational benefits of a synchronous network (SDH).

When one incorporates SDH interfaces into an Ethernet switch it results in the incorporation of high-specification technology into low-specification technology resulting in an expensive interface that can cost more than the switch.

To overcome this problem, the Ethernet interfaces can be incorporated into the SDH equipment.

A number of additional benefits are gained by mapping Ethernet into SDH within the transmission domain. These are [1]:

- The ability to tailor the transmission bandwidth to that required by the data service;
- The ability for Layer 2 aggregation of Ethernet within the SDH equipment to provide multiple logical interfaces on a single physical interface further reduces the interface costs.

IV. HOW TO INTEGRATE DATA INTERFACES INTO SDH EQUIPMENT

Three technologies are key to the integration of Ethernet into SDH [3]:

- Generic Framing Procedure (GFP) – maps data traffic into SDH frames;
- Virtual Concatenation (VC) – provides flexible channel capacity;
- Link Capacity Adjustment Scheme (LCAS) – provides dynamic bandwidth management.

A. Virtual Concatenation

Some technologies, such as ATM, require payloads of up to 600 Mbit/s while SDH only provide containers up to VC-4. This resulted in concatenation of containers of which two forms exist.

![Contiguous Concatenation](image1)

![Virtual Concatenation](image2)

**Figure 2: Scalability by using Virtual Concatenation [9]**

Contiguous Concatenation (VC-n-Xc) is used to form a larger payload from the combination of consecutive, smaller payloads, whereas Virtual Concatenation (VC-n-Xv) is
formed from spatially separated payloads. Both methods provide concatenated bandwidth of X times VC-n.

While traditional contiguous concatenation comes in coarse steps, virtual concatenation allows the bandwidth to be tuned in small increments on demand.

![Diagram of Contiguous Concatenation and Virtual Concatenation](image)

**Figure 3: Contiguous Concatenation vs. Virtual Concatenation**

Higher order concatenation has been widely employed where, in order to accommodate bandwidth demands higher than the maximum payload capacity of 140 Mbit/s (VC-4), multiple VC4 can be concatenated to provide a maximum payload of VC-4-4c/v (STM-4) and VC-4-16c/v (STM-16).

In the same way virtual concatenation can be applied to smaller payloads to, for instance, provide a 10 Mbit/s capacity over a 34 Mbit/s interface. Five VC12s can be virtually concatenated to provide the capacity. Where in the past a 10 Mbit/s interface would have consumed a whole VC-3 (51 Mbit/s), only 5xVC12s (10 Mbit/s) capacity is used.

<table>
<thead>
<tr>
<th>SDH Container</th>
<th>Min Size (Mbit/s)</th>
<th>Max Size (Mbit/s)</th>
<th>Granularity (Mbit/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC-11</td>
<td>1.6</td>
<td>102</td>
<td>1.6</td>
</tr>
<tr>
<td>VC-12</td>
<td>2.2</td>
<td>139</td>
<td>2.2</td>
</tr>
<tr>
<td>VC-2</td>
<td>6.8</td>
<td>434</td>
<td>6.8</td>
</tr>
<tr>
<td>VC-3</td>
<td>48</td>
<td>12,000</td>
<td>48</td>
</tr>
<tr>
<td>VC-4</td>
<td>150</td>
<td>38,000</td>
<td>150</td>
</tr>
</tbody>
</table>

Table 1: Virtual Concatenation base containers and approximate bandwidth [9]

In the case of contiguous concatenation tributary cards, the combined, individual payloads are assigned a single pointer value, together with a concatenation indicator, which must be processed at each intermediate SDH multiplexer node between the origination and destination points (Figure 3). Clearly this represents a significant problem for existing SDH networks, which are unlikely to support the necessary pointer processing. To avoid this problem, SDH vendors are implementing contiguous to virtual concatenation conversion modules, which present contiguous concatenation interfaces to the outside world and then converts them into virtual concatenated traffic. At the termination point, the inverse is performed. This approach has some significant advantages:

- Existing network does not need to support concatenated payload switching
- No processing of the payload is required across the network until the end points
- Optimises available bandwidth – the contiguous concatenated payload is separated into individual VC-4s that may be routed independently across the network.
- Can be transported over multiple STM-N interfaces allowing transport through cross-connects that only support STM-1 tributary interfaces.

This concept can be taken even further by integrating the packet or cell based interface into the Concatenation interface.

When using Virtual Concatenation, different containers may have different propagation delays through the network. These delays need to be compensated for and the individual VC-4s have to be realigned.

The H4 POH byte carries information on how to reassemble the virtual containers. A sequence of 16 H4 bytes makes a complete message. Four of the 16 bytes are used for the multi-frame indicator (MFI) and sequence number (SQ) while LCAS uses 7 bytes and the remaining 5 are reserved for future use. The MFI number allows for compensation of different delays through the network while the SQ number ensures the correct sequencing of the VCs when assembling the data at the destination.

**B. Link Capacity Adjustment Scheme (LCAS) (ITU-T G.7042)**

Link Capacity Adjustment Scheme (LCAS) is a set of procedures for dynamically changing transport channel capacity. LCAS builds on Virtual Concatenation by allowing the carrier to adjust the pipe capacity while it is in use. With LCAS, signalling messages are exchanged between the two VC end-points to determine the number of concatenated payloads required.

Virtual Concatenation provides the means for creating right-sized pipes. The size of these pipes may change with time. When a virtual channel is resized, traffic is disrupted and lost. LCAS solves this problem by allowing the resizing of channels at any time without disrupting the traffic on the link. If, for instance, additional bandwidth is required during a certain period of the day, it could be assigned and then reassigned for different use during other periods.

The sequence of events when up-sizing a link would be as follows [9]:

1. The network management system adds a new trace through the network between the source and destination node.
2. The network management system orders the source to add this new link to the existing channel.
3. The source node starts sending “Add” control commands in the path overhead to the remote side.
4. The destination notices the “Add” command and returns an “OK” in the overhead.
5. The source sees the “OK”, assigns the additional link to the channel and assigns a sequence number of one higher than currently in use to this link.
6. At the source, this link is included and marked as the last link in the channel. Multiple links can be added to or removed from a channel to allow for fast resizing.

C. Generic Framing Procedure (GFP) (ITU-T G.7041)

Generic Framing Procedure (GFP) is an encapsulating technique for mapping data traffic into SDH frames. GFP supports two transport modes that may exist within the same transport channel.

Frame-mapped GFP is optimised for packet-switching environments where the resource management functions are delegated to the native data clients. This is the transport mode used to carry native Point-to-Point Protocol (PPP), IP, Multi Protocol Label Switching (MPLS) and Ethernet traffic.

Transparent-mapped GFP is intended for delay-sensitive storage-area network (SAN) applications that require bandwidth efficiency and transparency of data. This is the transport mode used to carry Fibre Channel, FICON and ESCON traffic.

Since there are four major services that are going to make money for carriers, namely Ethernet, Fibre Channel or ESCON for storage, wavelength services and TDM data private-line circuits, looking at an Ethernet-only network design prevents carriers from harnessing the entire market opportunity. It is here where GFP plays a role. GFP offers several significant advantages when compared to other framing mechanisms, such as Link Access Procedure for SDH (LAPS) [6]:

- GFP is more efficient than LAPS. It has no inflation factor and maintains a fixed overhead almost equal to the minimum overhead in LAPS. Traffic management and QoS control are significantly easier.
- GFP is more robust than LAPS in that it supports header error correction.
- GFP minimizes system bandwidth requirements. It allows multiple protocols from different ports or links to share the same transport path, resulting in more efficient use of available bandwidth. The newer SDH VC and LCAS procedures work much more efficiently with GFP.

And finally GFP allows for the inter-working between different vendor’s equipment.

V. INTEGRATING DATA INTERFACES INTO SDH IN PRACTICE

Equipment vendors have acknowledged the need for the integration of data interfaces, specifically Ethernet, into SDH equipment. Marconi, being one of them, is implementing GFP, LCAS and virtual concatenation in its lower order products to provide 10/100 BaseT services and is extending the use of GFP and LCAS to the Gigabit Ethernet cards (which already use virtual concatenation). Each of these applications will now be briefly explained.

A. 10/100BaseT

A typical 10/100BaseT application is implemented by means of an interface card as shown in Figure 4. The interface card presents up to eight (8) 10/100BaseT interfaces to the outside world.

B. Gigabit Ethernet

In the case of Gigabit Ethernet two applications are possible. Point-to-point applications between two Gigabit Ethernet sites and aggregation of multiple 10/100BaseT into a single Gigabit Ethernet interface. These applications are shown in Figure 5 and Figure 6.

GFP, VC and LCAS are used in the same way as in the case of the 10/100BaseT application.
Figure 6: 10/100Baset to Gigabit Ethernet

VI. CONCLUSION

The growing provision of Ethernet services in the public network has led to the creation of equipment that physically integrates Ethernet switching and SDH transport equipment. A driver for this has been the historically high cost of interfaces between Ethernet equipment and transport equipment. In anticipation of the growth in Ethernet services, the ITU-T has created standards to enable the SDH equipment to carry these services. Equipment vendors, such as Marconi, offer products that support data services in the SDH network based on these standards. Such products allow operators to “sweat” their existing SDH infrastructure in anticipation of the future unification of the transmission networks. The following quote summarises this point (RHK2002):

“Generic framing procedure (GFP), virtual concatenation (VC), and the link capacity adjustment scheme (LCAS) will allow service providers to leverage the existing SONET (& SDH) core network while cutting capital expenditures and increasing revenue from new data services. VC adds efficiency and flexibility, LCAS offers dynamic bandwidth, and GFP support multiple services.”

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BIOGRAPHY

Cobus Nel completed his M.Eng (Electronics) at the University of Pretoria in 1994, specialising in Telecommunications and Cryptography. He has recently completed the requirements for his M.Eng (Project Management) at the University of Pretoria. He started his career specialising in the development of telecommunications sub-systems. In 1997 he moved into the enterprise telecommunications and IT arena where he worked for DataFusion. He joined Marconi Communications in 2000 and currently heads the Transport and Wireline Access group.

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