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MAPPING OF PLESIOCHRONOUS DIGITAL HIERARCHY SIGNALS INTO SYNCHRONOUS TRANSPORT MODULE FRAME FOR SYNCHRONOUS DIGITAL HIERARCHY SYSTEM

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Abstract
Optical Communication System (OCS) is a technology that employs optical fibers for information transmission. Internet service providers use different OCS technologies to support different types of traffic and service requirements. Some of the technologies include Plesiochronous Digital Hierarchy (PDH), Synchronous Digital Hierarchy (SDH), Dense Wavelength Division Multiplexing (DWDM) and Ethernet. SDH technology defines a synchronous frame structure for transmitting Time Division Multiplexing digital signals. The first building block of the SDH has a bit rate of 155.52 Mb/s and is referred to as Synchronous Transport Module one (STM-1). Information being transmitted is organized into frames. These frames are continuously transmitted one after the other. Each frame consists of a collection of overhead fields and a payload. Mapping, the algorithms used in internet service provisioning, automatically compute the signal path to satisfy a given service request. This paper overviewed the mapping of PDH signals to the synchronous transmission standard of STM. Three methods of mapping; 140, 34 and 2 Mb/s PDH signals, to the STM-1 frame were presented. Also discussed is the knowledge on how SDH equipment constructs STM frames in the electrical domain before it is optically transmitted.

Keywords: *Optical communication systems, synchronous optical network, synchronous digital hierarchy, synchronous transport module, plesiochronous digital hierarchy*

Introduction

Current high-speed communications, network operators and Internet Service Providers (ISP) are facing huge demand for data and bandwidth. An optical communication system (OCS) utilizes a fiber optics medium for the transfer of signals from one end to another using light signals to meet this demand (Ramaswami *et al.*, 2009; Abolade *et al.*, 2021; Tooki *et al.*, 2022). The service provider requires optical solutions for transport networks capable of providing the capacity, reliability, flexibility and scalability to efficiently meet the data requirement of clients (Zhang *et al.*, 2018). The demand for adding capacity has led to the development of different transport technologies such as Plesiochronous Digital Hierarchy (PDH), Synchronous Digital Hierarchy (SDH), Dense Wavelength Division Multiplexing (DWDM) and Ethernet (Ramachandran and Sivalingam, 2020). PDH system is based on Time Division Multiplexing (TDM) technology. For years, SDH has been a proven technology for the OCS backbone. PDH and SDH systems are based on TDM technology. SDH provides deterministic and much reduced latency (Hartono *et al.*, 2019; Manivasakan *et al.*, 2020). Transport technologies such as Optical Transport Network require optoelectronic devices as sources and detectors of such light, and they need modulators to impress the telecommunication signals onto the light (Iovanna *et al.*, 2016).

In OCS, Synchronous Transport Module-1 (STM-1) is a fiber-optic network standard for SDH. Before any transmission of the STM frame, signals whether Synchronous or plesiochronous must be interleaved into a container (Carritech, 2021). The transmission format is considered the main building block for SDH. Transmission rates of up to gigabits per second (Gbit/s) can be achieved in today's SDH systems and the 40 Gbit/s systems are possible. SDH systems are fully compatible with Synchronous Optical Network (SONET) systems. When data is transmitted over a communications medium, several things must be provided on the link, including framing of the data. For optical communications, these functions have been standardized by the International Telecommunications Union (ITU) as SDH. SDH is a technology for synchronous data transmission. It is the international equivalent of SONET. Both technologies provide faster and less expensive network interconnection than traditional PDH systems (Truchly and Beragg, 2007). A useful feature of SDH is that higher levels have a bit rate that is an exact multiple of the basic bit rate (Tooki, 2022).

The remaining part of the paper is organized as follows; Section III gives background information on the evolution of the PDH and SDH technologies. Section IV outlined signal transmission in SDH frame. In Section IV, comparative analysis of signal multiplexing procedures in SDH were highlighted and evaluated while Section V is the concluding section.

Evolution of Plesiochronous Digital Hierarchy and Synchronous Digital Hierarchy Technologies

a. Plesiochronous Digital Hierarchy System

Plesiochronous Digital Hierarchy (PDH) or nearly synchronous is a Time-Division Multiplexing (TDM) standard initially designed for telephone networks that required a bit rate of 64 kb/s (Olabenjo and Mbarouk, 2014). Different hierarchies were adopted for PDH. Table 1 gives the classification of PDH signals to the adoption. PDH has no standard beyond 140Mbit/s (E4) (Ibrahim *et al.*, 2019).

b. Synchronous Digital Hierarchy System

Synchronous Digital Hierarchy (SDH) is a transmission system, protocol, for high-speed, high-capacity optical telecommunication systems which defines the characteristic of digital signals including frame structure, multiplexing method, digital rates hierarchy, and interface code pattern. SDH technology is a European standard for data transmission over an optical fiber network which is equivalent to the SONET of North America (Olabenjo and Mbarouk, 2014). This European Telecommunications Standards Institute was formalized by ITU in G.707, G.783, G.784, and G.803 standards.

Table 1: PDH Signals Classification

S/N	PDH Signal Code	PDH Signal (Mb/s)	Equivalent
1	E0	0.064	-
2	E1	2.048	32 E0
3	E2	8.448	128 E0
4	E3	34.368	16 E 1
5	E4	139.264	64 1

Some of the characteristics of SDH, according to ITU-T specifications, firstly is the bit rate of the lowest level SDH base signal is 155.52 Mb/s which is known as STM-1 which is the smallest module for signal transmission in the SDH technology. In addition, byte interleaved multiplexing which is a technique used in SDH. By this method, higher-level signals are obtained. Moreso, SDH provides an international standard that is well adopted for optical transmission. Table 2 shows the SONET optical carrier and SDH capacity. Note that The Optical Carrier 24 (OC-24) transmission rate is not adapted to the SDH standard (Janson, 2014; Olalere *et al.*, 2014).

Table 2: SDH and SONET Hierarchies with Equivalent Data Rates Based on ITU-T Standard

S/N	SONET Signal	SDH Signal	SONET Capacity	SDH Capacity	Bit Rate (Mb/s)
1	OC-1	STM-0	28 DSC1s or DSC3	21 E1s	51.84
2	OC-3	STM-1	84 DSC1s or 3 DSC3s	63 E1s or E4	155.52
3	OC-12	STM-4	336 DSC1s o 12 DSC3s	252 E1s or 4 E4s	622.08
4	OC-24	Not adapted	Not Adapted	Not Adapted	1244.16
5	OC-48	STM-16	1,344 DSC1s or 48 DSC3s	1,008 E1s or 16 E4s	2488.32
6	OC-192	STM-64	5,376 DSC1s or 192 DSCs	4,032 E1s or 64 E4s	9953.30
7	OC-768	STM-256	21,504 DSC1s or 768 SC3s	16,128 E1s or 256 E4s	39813.12

Methods

The basic transmission format for the SDH solution is the STM-1 frame. The frame structure consists of 9 rows and 270 columns of bytes. The frame lasts for 125 µs (microseconds). This is equivalent to 8,000 frames per second. The SDH frame consists of 270 columns. The STM-1 frame consists of overhead and Virtual containers (VCs). The first nine columns of each frame make up the Section Overhead, and the last 261 columns make up the VC capacity. The VC and the pointers (H1, H2, H3 bytes) are called the Administrative Unit (AU), carried within the VC capacity, which has its frame structure of nine rows. Overview of SDH and 261 columns is the Path Overhead (POH) and the

Container. The first column is for POH it is followed by the payload container, which can itself carry other containers. The VC can have any phase alignment within the Administrative Unit, and this alignment is indicated by the Pointer in row four. Within the Section Overhead, the first three rows are used for the Regenerator Section Overhead, and the last five rows are used for the Multiplex Section Overhead. The STM frame is transmitted in a byte-serial fashion, row-by-row, and is scrambled immediately before transmission to ensure adequate clock timing content for downstream regenerators. The function of crossconnection in the SDH system is to connect associated POH for network management.

a. SDH Frame Structure

An STM-1 frame structure is illustrated using Figure 1. It is a rectangular block that consists of 9 rows and 270 columns of bytes, summing to 2,430 bytes. The byteorientated arrangement has a bit rate of 155.52 Mb/s. As the frame is transmitted at 125 µs resulted in the transmission of 8,000 frames per second on the circuit. The bytes are transmitted bit-by-bit, from left to right and from top to bottom.

To calculate the bit rate of a framed digital signal, Equation (1) was used:

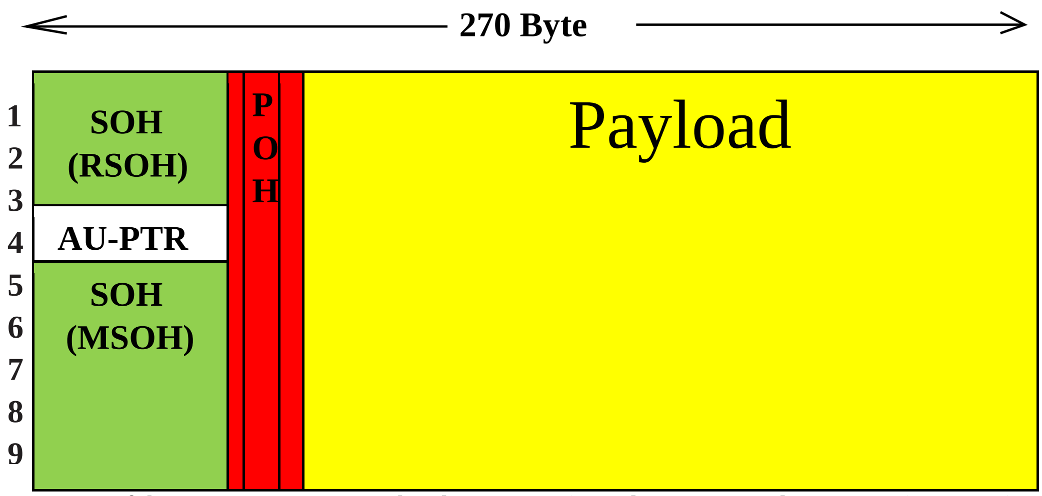
$$\text{Bit rate} = NM' \qquad (1)$$

where, M is the Frame rate (8,000Frames/Second) and N is the Frame Capacity

For SDH to be easily integrated into the existing digital services, it operates at the basic rate of 8 kHz or 125 microseconds per frame, so the frame rate is 8,000 frames per second.

The frame capacity of a signal which is the number of bits contained within a single frame of SDH rate is calculated using Equation (2):

$$NXM = 9\text{rows } 270\text{columns} 8\text{bits/byte x } M = 155520000 b/s = 155.52 Mb/s \qquad (2)$$



STM frame consists of three parts Section Overhead (SOH), Administrative Unit Pointer (AU-PTR) and Payload. SOH has auxiliary bytes to implement Operation, Administrative and Maintenance (OAM) functions. SOH is further divided into Regenerative SOH (RSOH) and Multiplex SOH (M-SOH). POH can be further classified into two; Higher Order POH (HO-POH) and Lower Order POH (LO-POH). SOH ensured that there is automatic protection switching alarm information and STM-1 identification.

Row 1-3 and Column 1-9 as shown in Figure 1 is the RSOH

Row 5-9 and Column 1-9 as shown in Figure 1 is the M-SOH

Row 4 and Column 1-9 as shown in Figure 1 is the AU-PTR

Row 1-9 and column 10-270 are as shown in Figure 1, is the Payload.

Row 1-9 in Column 10 is as shown in Figure 1 is the POH

The VC is the sum of the POH and payload.

The following PDH signal can be transmitted in an STM-1 frame; C-4 (140 Mb/s), C-3 (34Mb/s), and C-12 (2Mb/s) signals are as shown in Figure 2(a) to 2(c), respectively. The size of the container C-12 amounts to 34 bytes. This is expressed from Equations (3) to (8)

$$C-4 = 9\ rows \times 260\ columns \times 8bits \times M = 149.7\ Mb/s \quad (3)$$
$$C-3 = 9\ rows \times 84\ columns \times 8bits \times M = 48.38\ Mb/s \quad (4)$$

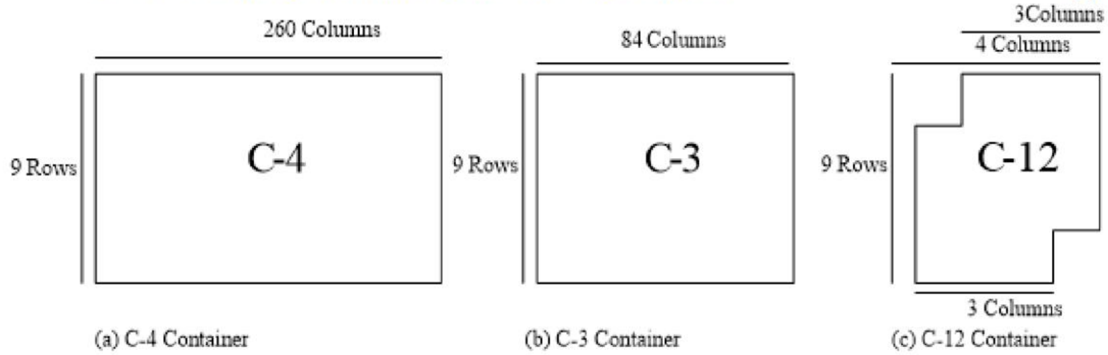


Fig. 2: Container Types

$$VC-4 = POH + C-4 \quad (5)$$
$$VC-4 + AU-PTR = AU-4 \quad (6)$$
$$VC-4 + AU-PTR = AU-4 \quad (7)$$
$$AU-4 + SOH = STM-1\,frame \quad (8)$$

a. Mapping 140 Mb/s PDH signal into STM-1 Frame

Procedure of Mapping C-12 into STM-1 Frame

Step 1: PDH signal of 140 Mb/s is interleaved into a container C-4
Step 2: POH is added to C-4 to get Virtual Container 4, VC-4 Step 3:
AU-PTR is added to VC-4 to get AU-4
Step 4: To complete the STM-1 frame, SOH (ROH and M-SOH) is added to the AU-4.
The procedure is graphically presented in Figure 3.

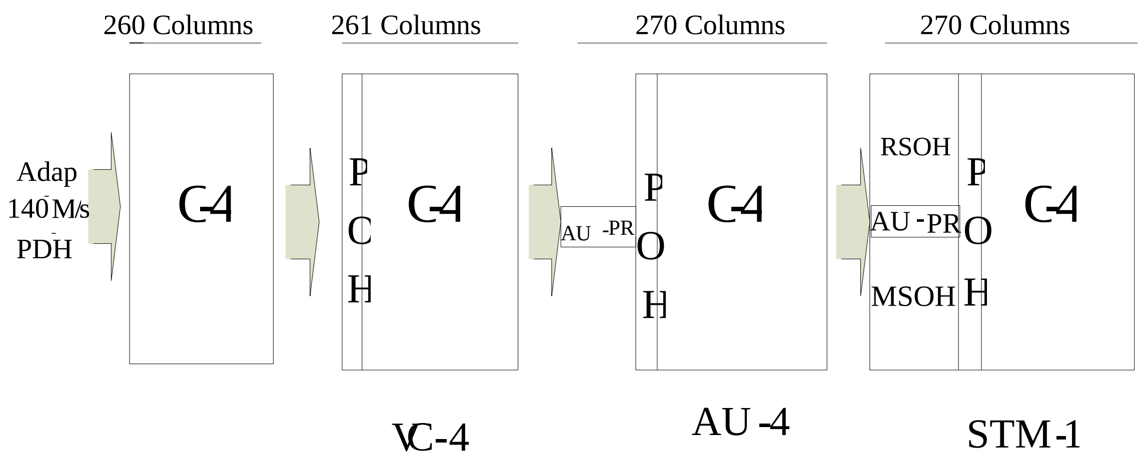


Figure 3: 140Mb/s PDH signal Mapped into STM-1 Frame

a. Mapping 34 Mb/s signals into STM-1 Frame
Understanding the mapping of 34 Mb/s, three 34 Mb/s, PDH signals, into STM-1 frame becomes complex with the reduction in the size of PDH signals; in this case from 140 to 34 Mb/s (C-3 container). In this category, three 34 Mb/s are mapped into one STM-1 signal. Firstly, the 34Mb/s PDH signal is interleaved via bit rate adaptation into container C-3 (9-rows and 84-column). A column of POH is added in front of every three C-3 containers to ensure real-time monitoring over the 34 Mb/s. Every VC-3 is assigned a three-byte Tributary Unit Pointer (TU-PTR) which allows VC-3 to float. Since TU-3 is incomplete, six bytes of pseudo-random data (R) are stuffed to fill the gap of the TU-3. The resulting block is called Tributary Unit Group 3

(TUG3). Three TUG-3s are interleaved to form C-4 and the resulting structure has only 258 columns (3×86). This procedure for the 34 Mb/s was illustrated in Figure 4(a). However, another two columns of stuffed byte, R, are added to complete the AU-4 structure. This is as shown in Figure 3 (b). SOH is then added to AU-4 to get STM-1. SOH performs parity check and frame alignment functions.

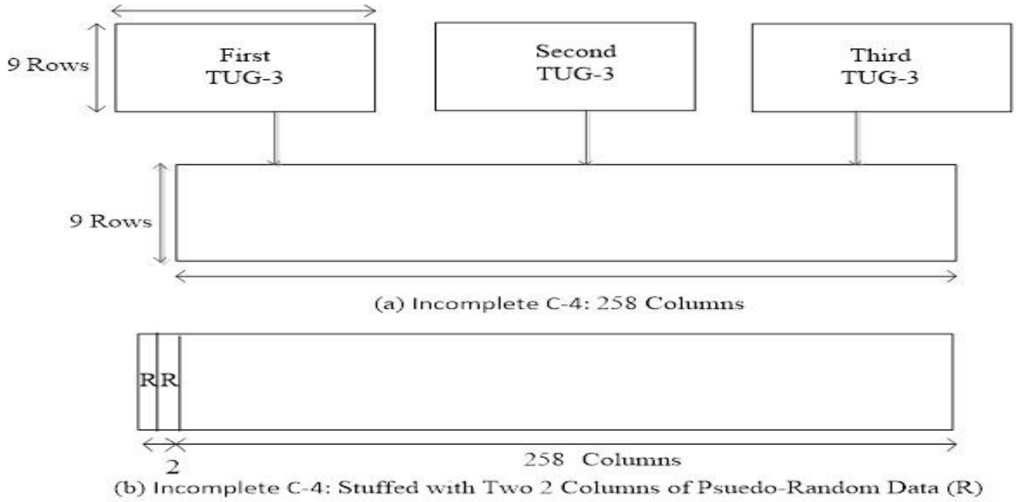


Figure 4: Complete STM-1 Frame multiplexed by three 34 Mb/s PDH signals

Procedure of Mapping C-3 into STM-1 Frame

Step 1: Three PDH signals of 34Mbls Mb/s are interleaved into a separate container, C-3
Step 2: Add POH to each of the three C-3 containers to get three VC-3s.
Step 3: Add three TU-PTR signals to get TU-3
Step 4: Stuffed the gap with R to get TUG-3
Step 5: Add AU-PTR to VC-4 to get AU-4
Step 6: To get STM-1, SOH (ROH and M-SOH) is added to the AU-4

d. Mapping 2Mb/s Signals into STM-1

To multiplex 2Mb/s signals into STM-1, 63 of 2Mb/s PDH signals are required. Firstly, the 2Mb/s signal is adapted into C-12 container. The size of the container C-12 amounts to 34 bytes. It is worthy to note that the C-12 multi-frame is 2000 frames/second instead of 8000 frames/seconds in C-4 and C-3. POH can be further classified into Higher Order POH (HO-POH) and Lower Order POH (LO-POH). The LO-POH bytes are V5, J2, N2 and K4. The multiplexing structure of 2Mb/s is 3-7-3. That is three TU-12s were multiplexed into one TUG-2; seven (7) TUG-2s were multiplexed into one TUG-3 and three TUG-3s were multiplexed into one VC-4.

Procedure for Mapping C-12 into STM-1 Frame

Step 1: 63 PDH signals of 2 Mb/s are interleaved into a separate container, C-12
Step 2: Add LO-POH to each of the 63 C-12 containers to get 63 VC-12s.
Step 3: Add TU-PTR signals to VC-12 to get TU-12
Step 4: Three TU-12 frames are mapped into TUG-2
Step 5: Seven TUG-2 frames are mapped and two columns of stuffed bytes to get TUG-3
Step 6: Three TUG-3 frames are mapped and columns of stuffed bytes are added to get C-4
Step 7: HO-POH is added to C-4 to get VC-4
Step 8: Add AU-PTR to VC-4 to get AU-4
Step 9: SOH (ROH and M-SOH) is added to the AU-4 to get the STM-1 frame.

Conclusion

This paper presented an overview on procedures of mapping PDH signal into STM-1 frame for SDH system. It also, focuses on the SDH frame structure, mapping and multiplexing process from low-order to high-order signals. Three step-by-step methods of mapping PDH signals into an STM-1 frame were show cased. Adequate understanding of this paper enhances knowledge of how to synchronize systems with advanced optical network technology and high-speed transmission systems such as SDH networks. This will guarantee high-performance levels to meet the ever-increasing demand of clients for data and the design of future telecommunications systems.

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