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# SONET/SDH: Review of Technology and Developments

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***Abstract*—This paper attempts to describe how SONET/SDH works, down to the octet level. The SONET/SDH development for the current technology has been discussed and analyzed for better communication and improvement is SONET/SDH Technology. The STS-1 frame, Concatenation, VT's etc. Architectures will be discussed , analyzed and the ways that how we can implement by means of the FPGA and ARM-11 core will be formulated and reviewed. When the SONET/SDH comes in market and today's Telecommunication market has lots of differences. The differences are based on the technology, new ideas, Implementation algorithm, computing architectures etc. are evolutionary enhanced. What is the impact of technology on the SONET and what more we can implement to enhance the SONET/SDH architecture has been discussed in this paper.***

**Keywords**— *SONET/SDH, STS, Optical carrier, FPGA for SONET, ARM for SONET.*

## I. INTRODUCTION

When data is transmitted over a communication medium, a number of things must be provided on the link, including framing of the data, error checking and the ability to manage the link. For For optical communications these functions have been standardized by the ANSI T1X1.5committee as Synchronous Optical Networking (SONET) and by the ITU as Synchronous DigitalHierarchy (SDH).This paper attempts to describe how SONET/SDH works, down to the octet level. For a great many years, telephone calls were handled in the analog domain. Long distance calls wererouted over twisted pair, coaxial cable, or analog microwave between major switching offices. In 1962, AT&T began installing DS-1 T-carrier services between long distance switching centers.Basically, these were channel banks2 which took 24 analog telephone circuits, converted them to digitaland then transmitted them over copper to the other switching center, where they were converted back toanalog. This worked very well – it reduced the number of copper circuits required between switchingcenters and improved the quality of the telephone calls (less noise and crosstalk). As the volume of long distance grew, the number of T-carrier circuits required between switching centersincreased. Additionally, DS-1C and DS-2 signals began to be used to increase the capacity of a circuit.In the late 1970's optical communications became feasible, allowing higher speed communications,which meant that one circuit could carry many more telephone calls. For example, one of the firstcommercial fiber circuits was installed in Chicago in 1977 and operated at 45 Mbps (DS-3 rate).

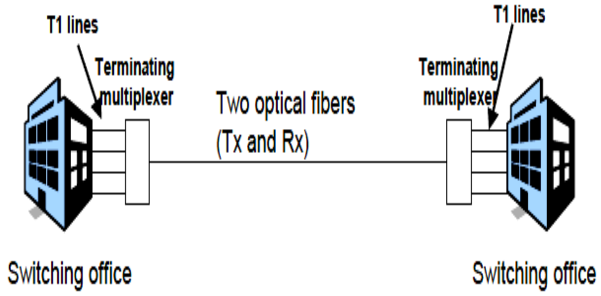


**Figure 1: Early use of optical communications to replace DS-1 links betweenswitching offices. The terminating multiplexers will be inside theswitching offices. This point-to-point link is subject to failure – ringswere eventually used to provide backup.**

In those days, the telephone companies looked at optical communications as simply a replacement for theolder wire or microwave communications they had been using for years. But then they encountered apractical problem. Vendors of optical communications equipment had used their own framing techniqueson the optical fiber. Once you selected a vendor, you were stuck with that vendor for all the equipment inthat optical network. Thus was born the concept of standards in optical communications.It's extremely important to recognize that the first standards for optical communications were focused onhandling voice circuits, and especially legacy plesiochronous channels like DS-1s and DS-3s. If we keepthis fact in mind, many of the odd things about SONET and SDH will make more sense. At the timethese standards were developed, the tremendous volumes of data traffic had not appeared and most peopledid not foresee it. Synchronous optical Network (SONET) offers cost-effective transport both in the access area and core of the network. For instance telephone or data switches rely on SONET transport for interconnection. The optical layer provides the foundation of transportservices for both metro and long-haul applications. It also directly supports data services. The optical layer is now evolving to provide the same level of sophistication that has been achieved with synchronous transmission, such as performance monitoring and network resilience. Till that discussion we can see the SONET/SDH architecture which has been shown in Fig. 2.

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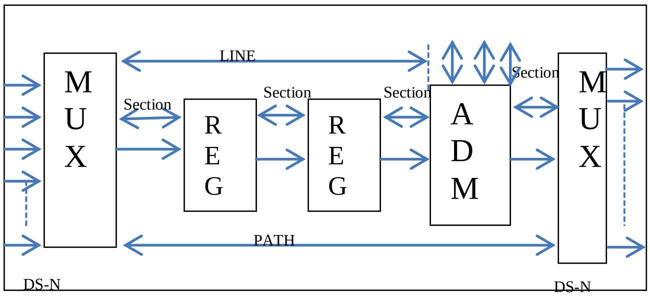


**Fig. 2: SONET/SDH Architecture**

In this paper, we will analyse the OC-N level signals and STS frames in section-II, as the frame structure knowledge is very much important as we said it's a standard. So according to the SONET standards, which type of the frame structures are here to communicate among the nodes of the communication elements (in this case the telecommunication hubs). Analysis of virtual concatenation and VTs in section-III, for low data rate signals.Analysis of Ethernet over SONET, Packet over SONET is also discussed and analysed in section-IV. In section V, Section –V about conclusion of the whole analysis and research of documents has been discussed.

## II. ANALYSIS OF STS-N FRAME

STS stands for synchronous transport signal. The STS –N frame is terms of electrical signal after interleaving the standards stands for the optical carrier OC-N. Here N stands for level of STS and OC frames. Table 1 shows the SONET/SDH frame structure.

**TABLE I STS-N FRAME RATES**

| SONET Frame | SDH FRAME | LINE RATE(Mbps) | SPE (Mbps) | TRANSPORT OH (Mbps) |
|---|---|---|---|---|
| STS-1 | None | 51.84 | 50.112 | 1.728 |
| STS-3 | STM-1 | 155.52 | 150.336 | 5.184 |
| STS-12 | STM-4 | 622.08 | 601.344 | 20.736 |
| STS-48 | STM-16 | 2,488.32 | 2,405.376 | 84.672 |
| STS-192 | STM-64 | 9,953.28 | 9621.504 | 331.776 |
| STS-168 | STM-256 | 39,813.12 | 38,486.016 | 1,327.104 |

More about SONET frame structures are discussed as follows:

### A. SONET/SDH INTERLEAVING

An STS-3 can be thought of as three STS-1 bit streams transmitted in the same channel so that the resulting channel rate is three times the rate of an STS-1. And when multiple streams of STS-1 are transmitted in the same channel, the data is octet multiplexed. For example, an STS-3 signal will transmit octet A1 of stream 1, then octet A1 of stream 2, and then octet A1 of stream 3, then octet A2 of stream 1, octet A2 of stream 2, etc. (see Figure 3). This multiplexing is carried out for all levels of SONET and SDH, including STS-192 and STS-768. Because of this, SONET/SDH maintains a frame time of 125 µs.

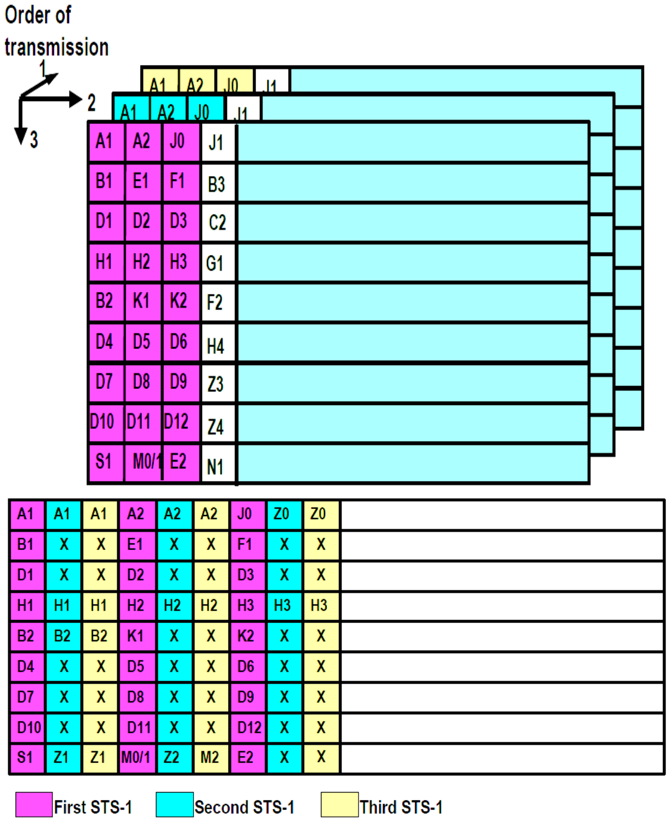


**Fig. 3: Interleaving of three SONET STS-1 frame into one STS-3 frame**

Let's look at this a bit closer. Figure 3 shows an STS-3 frame created from the interleaving shown. It consists of 9 rows and 270 columns, of which 27 columns are overhead. Now, let's zoom incloser on this overhead. We see that the first three octets in the first row are all A1 octets. This isbecause we took three frames and octet interleaved them. So we took thefirst octet from the first STS-1 frame (which is an A1 octet), then we took the first octet from the secondSTS-1 frame (which is an A1 octet), and then we took the first octet from the third STS-1 frame (which isalso an A1 octet). Then we took the second octet from the first frame (which is an A2 octet), then thesecond octet from the second frame (which is anA2 octet), and finally the second octet from the thirdframe (which is also an A2 octet), etc. For such a frame we can define a simple programming as follows:

```
for (row = 1; row <= 9; row++)
for (column = 1; column <= 90; column++)
for (bit = 1; bit <= 8; bit ++)
                /* bit 1 is the most significant bit */
                /* and bit 8 is the least significant bit */
bitTransmit = STSFrame[row][column][bit];
```

In spite of discussing about the whole transport overhead here we can discuss only too much important special octets which effects the transmission synchronization and other aspects need for the SONET/SDH architecture. These octets are as follows:



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### A. Parity (B1) –

The B1 octet is used by the receiver to estimate the bit error rate. This octet is known asthe Bit Interleaved Parity (BIP-8) octet. Since the octet has 8 bits, eight parities are computed, one foreach bit of the octets of the frame. That is, you take the first bit of all of all of the octets in the frame andthen set the first bit of the B1 octet so that the parity of these bits is even. Then you take the second bit ofall of the octets in the frame, and set the second bit of the B1 octet so that it gives even parity, etc. Theparity represented by this octet is the parity of the previous frame. It is used to estimate the bit error rate(BER) on the line. Note that the B1 parity is computed over all the octets in the frame, no matter howlarge the frame. Because of this, the B1 octet does not provide a good BER estimation for large frames(perhaps STS-48 and larger) under adverse error conditions. The B2 octet, described below, is computedover an STS-1 and provides better BER estimates. The B1 octet is only defined for the first STS-1 of anSTS-N signal (there's only one B1 octet in a frame, while there are N B2 octets). SDH uses this octet for the same purpose.

### B. Payload Pointer Processing –

*These octets are very important and will be described in a later section*. These octets point to the payload (SPE), provide flags to indicate when the payload location changes, and provide a location for a data octet when a negative pointer adjustment is made. The operation of these pointers will be described in more detail in a later section. SDH handles pointers in the same way; however, the minimum SDH rate of STM-1 contains three H1 octets, three H2 octets, and three H3 octets. Suppose that data is coming into a device slower (or faster) than it is being transmitted out the other side.While buffers can be used to mitigate the effect of different clocks, eventually something has to be doneto adjust for the difference between the receivers and transmit clocks. This is where the pointer and pointeraction octets (H1, H2, H3) come in.The H1, H2 octets are the pointer octets, comprising 16 bits. The first four bits are the New Data Flag(NDF) bits and are set to 0110 during normal operation. We'll see that one way to introduce a newpointer value is by setting the new data flag and including the new pointer. The next two bits have nomeaning in SONET but are used in SDH [12]. The last 10 bits are the actual pointer and can vary from 0 to 782. A value of zero indicates that thepayload (the SPE) starts at the first octet after the H3 octet. If the payload started at the second octet afterthe H3 octet, the pointer would have a value of one, etc. See Figure 4 which shows the layout of the H1,H2 pointers and Figure 5 which shows the location of the SPE for different values of the pointer. Forthe time being, ignore the "I" and "D" labels in Figure 4. The meaning of "I" and "D" will be explaineda little later in this section.

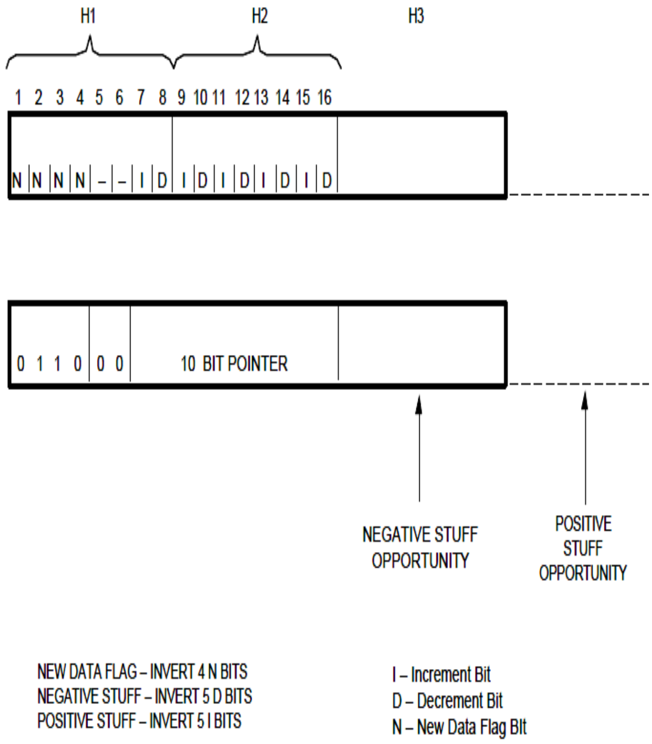


**Fig. 4: The usage of bits in the H1, H2 pointer octets. (source: Draft standard T1.105, Oct, 2010)**

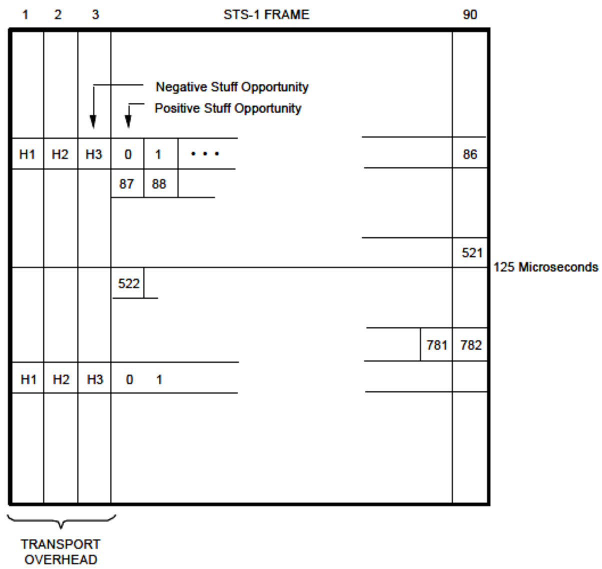


**Fig. 5: Pointer values for STS-1 SPE**

The other H3 pointer is used for the synchronization purpose i.e. for positive and negative justification. Using NDF we can also use pointer adjustment as in figure 6.

| Frame status | New Data Flag | | | | Unused | | I | D | I | D | I | D | I | D | I | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Normal frame | 0 | 1 | 1 | 0 | X | X | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| NDF indicator | 1 | 0 | 0 | 1 | X | X | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| New ptr value | 0 | 1 | 1 | 0 | X | X | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| New ptr value | 0 | 1 | 1 | 0 | X | X | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Normal frame | 0 | 1 | 1 | 0 | X | X | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Fig. 6: NDF use for pointer adjustment**

### C. Payload Overhead

The POH is the first column of the synchronous payload envelope (SPE). It consists of nine octets. Figure 7 has full description of that and shows that H1 and H2 provides the location of SPE.

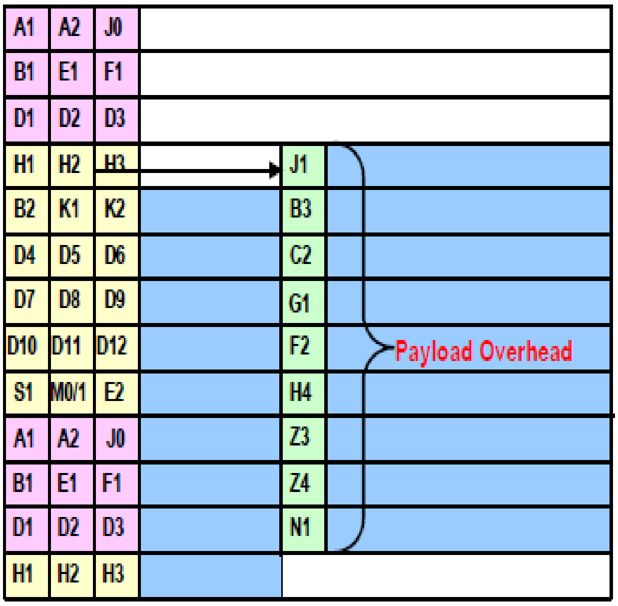


**Figure 7: Path/payload overhead**

Let's discuss about the Payload overhead's important bytes. B3 is same BIP-8 for providing the even parity. **STS path signal label (C2)** – This octet indicates the type of traffic carried in the payload. This octet may have a value of 0x02 to indicate floating VT mode, 0x04 for asynchronous mapping of a DS-3, 0x13 to indicate mapping of ATM, 0x16 for packet over SONET (POS), and 0x1b for generic framing procedure. There are many other values – see T1.105 for the complete list. This octet isused to identify the construction and content of the STS-level SPE, and for STS path payload defectindication (PDI-P). PDI-P is an application specific code that indicates to downstream equipment thatthere is a defect in one or more directly mapped embedded payloads in the STS SPE. SDH does notdefine codes for PDI-P. That's all about the SONET frame STS-1. STS-1 and OC-1 are the same things provided that STS is used for electrical signal and OC for optical carriers.

## III.VIRTUAL CONCATENATION AND VTS

Suppose, however, that we need a data stream faster than 51.84 Mbps. Then, there is a provision in SONET by which we can have more data rate than that of the 51.84Mbps. For this, we have to concentrate over STS-3 frame which was developed by interleaving the 3 different STS frames. In these frames when we analyze the SPE of STS-3, than it has 3 path overhead now lets remove two path overhead. Now the resultant frame is STS-3c. This is known as Concatenated payload. Similarly higher level of payload can be achieved. Now let's understand the mapping of SONET payloads and VTs

### A. Mapping of SONET/SDH Payloads

One way to look at the payload of SONET/SDH is simply as a bit stream. We could look at an STS-1stream as providing 86 columns of octets, by nine rows, 8,000 times per second, for a payload rate of49.536 Mbps. An STS-3c could be thought of as 260 columns of octets (270 total columns minus 9columns of transport overhead, minus one column of payload overhead), by nine rows, 8,000 times persecond for a payload rate of 149.76 Mbps. Within that payload, we could put any traffic we wanted. And actually we wouldn't be that far off if we looked at it that way. However, there are some additionalcomplexities in the payload area. The designersof SONET/SDH were concerned about carrying their plesiochronous traffic. So we need to look at whatfacilities were built into the payload area to handle the different DS-N and E rates and how the differingclocks of the plesiochronous traffic are accommodated. Handling the clocks is especially important SONET/SDH is specified as a synchronous system which means we should only have to accommodateclock jitter. But plesiochronous networks do not use the same clock – there are definitely differencesbetween clocks on different plesiochronous circuits and also between the plesiochronous traffic and theSONET/SDH clocks.So the first thing we're going to look at is how plesiochronous traffic is mapped into SONET. Later,we'll examine how non-plesiochronous traffic, such as asynchronous transfer mode (ATM), packet overSONET (POS), and generic framing procedure (GFP) is mapped.

### B. Virtual Tributaries

The specific traffic which the designers were interested in carrying is shown in Table 2. AlthoughSONET was designed in the American National Standards Institute (ANSI), note the specification of aEuropean rate, E1. This was done to reduce problems of cross border traffic.

**TABLE II Plesiochronous Data**

| Types of Digital Circuit | Bit Rate (Mbps) |
|---|---|
| DS-1(T1) | 1.544 |
| E1 | 2.048 |
| DS-1C | 3.152 |
| DS-2 | 6.312 |
| DS-3(T3) | 44.736 |

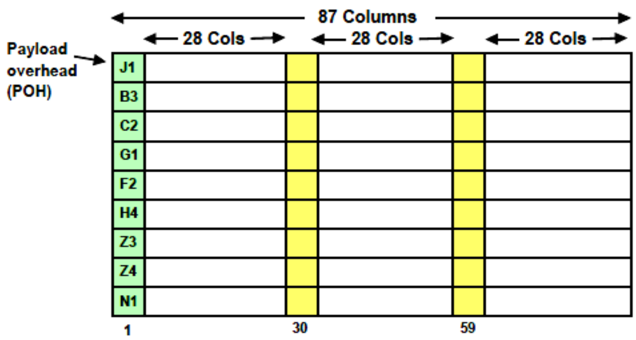


**Figure 8: The Payload (SPE) of an STS-1 SONET frame**

The payload area of an STS-1 SONET frame consists of 87 columns by 9 rows.

See Figure 8.One column is taken by the payload overhead (POH) leaving 86 columns. Next, we break the 86 columnsinto seven groups of 12 columns. Now seven groups of 12 columns is only 84 columns, leaving two extracolumns. These two columns are columns 30 and 5914, where the POH is counted as column 1. Allmappings of payloads into an STS-1 frame have these two columns “blocked out” meaning that the realpayload of an STS-1 SPE is really only 84 columns by 9 rows, by 8 bits, eight thousand times per secondor 48.384 Mbps. Each of these seven groups is called a Virtual Tributary Group (VTG). The seven VTGs are interleavedinto the 84 columns in the same manner as was discussed earlier for interleaving STS-1s into higherlevels of SONET, e.g., into an STS-3. That is, the first column of the first VTG goes into the columnafter the POH. See the figure 9 by which the matters can be better understood.

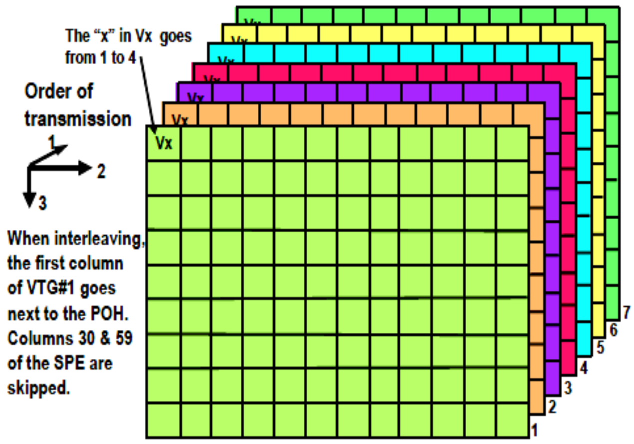


**Fig. 9: VTGs**

## IV. SUPPORT OF ATM, POS, AND GFP

Compared to carrying plesiochronous traffic, carrying asynchronous transfer mode [17] (ATM), packet overSONET [18] (POS), or generic framing procedure [19] (GFP) traffic is a piece of cake. For an STS-1, thepayload consists of 9 rows and 87 columns, one of which is the POH, and two are fixed stuff (columns 30and 50 numbered from the POH). This leaves 84 columns by nine rows for payload. All three types of traffic require that the octet boundary of the traffic be available. That is, the traffic isplaced in the SPE with the traffic octet aligned with the SONET payload octets. This is one reason thatPOS defines a shielding character instead of using zero bit insertion, as is done in ordinary HDLC. Ifzero bit insertion were done, octet alignment would be lost very quickly [20]. Beyond that one requirement, the payload of the SONET frame is simply viewed as an octet transportmechanism. The traffic is not examined in any way, nor is there any requirement for any kind ofalignment on SPE boundaries. As an example, ATM cells are taken one octet at a time with each octetplaced in the next available octet in the SPE without regard for any boundaries in the cell or the SPE,other than maintaining octet alignment. POS and GFP are handled in exactly the same way. As an aside, note that the SPE of an STS-1 always has columns 30 and 59 of the SPE stuffed andunavailable for payload traffic. If a customer had the option of putting traffic into three STS-1s or oneSTS-3c, it would be better to choose the STS-3c. Let’s see why. The SPE of an STS-3c consists of 261columns (270 columns minus 9 columns for transport overhead). The POH will take one column of theSPE leaving 260 columns for user traffic.

If the customer used three STS-1, he/she would receive three times 84 columns of payload, or only 252columns compared to 260 columns for the STS-3c. Eight columns of payload is equal to a little morethan 4.6 Mbps, or the equivalent of about three DS-1s. It’s one of the oddities of SONET/SDH that part of this extra bandwidth is only available at STS-3c and not at higher levels of SONET/SDH. For higherlevels of SONET, there are (N/3) - 1 columns of fixed stuffs, after the POH. This is true for SDH, also. Forall levels of SDH greater than STM-1, there are N-1 columns of fixed stuff after the POH (where Nindicates the STM level greater than 1).

## V. CONCLUSIONS

From our most of the discussion and analysis of SONET system we have analyzed the frame structure of the SONET. Now with the help of this knowledge of transmission and reception of the bits we can systematically derive the model of the SONET and SONET structure. As we studied that SONET is a standard. According to this standard we can design the SONET devices also. Algorithm Development and design depends on many aspects like which type of application we wish to simulate and for which application we are going to design the aspects of communication link. As we know that SONET mainly important Telecommunication so it may concern with high speed voice link but VTs allows us for lower data rate also.

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