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Digital Communications

Assignment 1A
SDH Communication System

Contents

Introduction

Assignment Brief

"You are a member of the development team in a company that manufactures and produces PCM systems. The company decides that it wants to expand into manufacturing Synchronous Digital Multiplexing (SDH) equipment. As part of the team your job is to write a report covering the methodology that must be followed, as recommended by the ITU, for the system to multiplex a number of different bit streams together into a single composite bit stream. The system must be capable of multiplexing PDH bit streams into the frames for conveyance over the system."

My Report

This report will cover the structure of the SDH system and its frames, the theory behind it, and the advantages/disadvantages of the system. I will also cover how the system can handle different bit streams at different speeds and how these streams can be removed and/or added at any point.

I will also be including my own view on whether SDH is best for communications equipment and finishing with a bibliography.

I would like to start by saying that this report does presume you have a good grounding in digital communication systems such as PCM.

Please note: Any words or terms that are being used for the first time that are in *italic* have an entry in the glossary near the end of this report. However some items for which there definition is too involved in the topic will be discussed 'in situ' as it were.

The SDH System: History

Before the SDH system was created, the standards for communication were *PCM*, and PDH, *Plesiochronous* Digital Hierarchy, chronologically speaking.

There were no real faults with these systems, the only major problem was bandwidth. PCM allowed for 2.048*Mbps*.

PCM was developed in the early 1970's and was a breakthrough for its time, but by the early 1980's digital systems were becoming more and more complex and there was an ever growing need for more bandwidth in channels. However, the demand was also due to a need of being able to multiplex signals of rates of up to 140Mbps or even 565Mbps in Europe.

This solution was called PDH. Again this was a breakthrough for its time, but it still had weaknesses. The two main weaknesses follow:

1. There was no world standard. In fact Europe, North America, and Japan were totally incompatible.
2. There was not much in the way of management in the PDH system.

A world standard **was** needed. So therefore a new system was.

This new system was called *SDH*.

Synchronous Digital Hierarchy (SDH) Introduction

SDH is a much faster, much more compatible system than its predecessors. Below is a short list of its highlights:

1. **First world standard in digital communications**
   This allows for communication at high speeds worldwide

2. **First optical interfaces**
   Quicker more reliable transmission

3. **The system allowed for more flexibility in the *multiplexing* structure**
   It is this flexibility that allows for the inclusion of different streams and adding and dropping

4. **Capability for adding and dropping streams**
   The ability to be able to add data streams in en-route as it were and then drop them off at anytime down the line

5. **Much more management capability**
   SDH allows for alarm, event, configuration, security and performance management

6. **Backwards and forwards compatible for including data streams**
   Can still include the older systems such as PDH.

As you can see clearly this system has many advantages and the ITU agreed when they standardized SDH in 1988. Some of these standards will be shown later.

Over the following few pages I will describe in more detail the items I have introduced above.

SDH and SONET

Before I start this discussion regarding the structure of SDH, I would like to clarify one point. SDH and SONET.

SDH, the Synchronous Digital Hierarchy communication system, the point of this report is the international version of *SONET*. SONET is the US version, the original effort to standardize optic fibre connections developed and accepted as standard in 1988 in America. In 1988 the standards were accepted by the CCITT (now ITU-T) with minor changes at the lower multiplexing levels for compatibility with regional networks in the UK.

I will not be delving into the SONET standards though they will be mentioned in passing. I will note however that the two systems are of course internationally compatible at some levels for interconnecting traffic.

There are many signal levels that SDH can transmit at, the base level of all these transmission speeds is **155.52Mbps**. This ‘envelope’ can carry transmissions of 1.5, 2, 6, 34, 45, and 140Mbps in various combinations.

The standard for SONET is 51.84Mbps (one third that of SDH) but as I have already mentioned SDH is required to be compatible with European streams of 140Mbps and as such a larger envelope was needed and 155.52Mbps was chosen. These signal levels can be seen in the table that follows shortly.

Despite this difference of base speeds, SONET and SDH are as I have said, compatible, albeit only by choosing certain options in connecting.

That base speed is just that, the lowest defined speed. There are many higher rates available on SDH, in the sequence of multiples of four. For example, 155.52Mbps, 622.08Mbps, 2488.32Mbps etc… The standards for SDH support network growth up to even higher rates, a 10Gbps line (for example) is possible.

I would like to point out that all the figures, times and precise details in this report are the values set in the ITU-T regulations, referencing details from the G701 through G713 standards in various places, but mainly the G707.

The following table shows the different SONET and SDH signals against there actual bit rates:

OC **Level**	**SONET** ***STS*** **Level**	**SDH** ***STM*** **Level**	**Signal Level (Mbps)**
OC-1	STS-1		51.84
OC-2	STS-2		103.68
OC-3	**STS-3**	**STM-1**	**155.52**
OC-4	STS-4	~STM-2	207.36
OC-9	STS-9	~STM-3	466.56
OC-12	STS-12	STM-4	622.08
OC-18	STS-18	~STM-6	933.12
OC-24	STS-24	~STM-8	1244.16
OC-36	STS-36	~STM-12	1866.24
OC-48	STS-48	STM-16	2488.32
OC-96	STS-96	~STM-32	4976.64
OC-192	STS-192	STM-64	9953.28

~ Please note: The only defined units for STM are 1, 4, 16, 64 and 256. The others are only shown for mathematical reasons and are not used,

The listed levels are only the first few of several more, higher levels that can be transmitted.

The SDH Frame and Payload

The transmitted signal contains two sections:

- **Overhead**
  This area contains the data for management facilities
- **Payload**
  Containing the actual data you wish to send

Regardless of what rate you are transmitting at these two streams can either be totally or partially filled.

With regard to the actual structure of the transmission now, the SDH frames are the same length in time as for PCM systems, a repetitive frame structure of 125 microseconds. The following diagram shows the SDH frame structure which is composed of two sections as mentioned above. The frame is shown graphically as a matrix and is transmitted one row at a time from left to right, from top to bottom.

I would like to say at this point that although the frame period time remains constant the frame size does not. This may not be immediately apparent but do remember that the transmission rate has many different levels, therefore different amounts of data per frame is required. The following diagram shows the frame structure for on STM-1 signal, 270 x 9 data bytes. The actual frame structure for an STM-N signal, where N is the data level is 9 rows by 270*N columns.

	The frame is 270 columns wide in total	
	Overheads 9 columns	**Payload** 261 columns
Row 1		
Row 2	Used For	
Row 3	Storing	
Row 4	Information	A Variety Of Signals For Transmission
Row 5	Such As Frame	Can Be Mapped And Stored Here
Row 6	Alignment And	
Row 7	Error Checking	
Row 8	Data	
Row 9		

Please note that one cell (where a row and column meet) is 1 byte.

Since this frame is 125 micro seconds in length that means that there are 8000 frames per second as $\frac{1}{125\mu S} = 8000$.

Now, as we have 270 columns and 9 rows, and each cell is 1 byte, the number of bits per frame is $270 \times 9 \times 8 = 19440$ and there are 8000 frames per second making $19440 \times 8000 = 155520000$ bits per second, or 155.52Mbps, we can see the rates work out.

Now, before I go into detail on the overheads I'm going to explain a little about the general layout of the frame diagram above. Shortly I will go into detail in the overheads area, but for now I would like to explain how the payload area is used. The area can be used dynamically, storing different streams at different rates as I have said previously.

Before I can really start to explain the overheads in full there are some definitions and descriptions I need to go through relating to the information in the payload and overheads sections:

- **Tributary**
  The name given to any signal taken in and used by an SDH system
- **Container – N**
  Once a signal has been mapped into a container (by mapped we mean altered for the SDH system to handle it, I will not be delving into the topic of network timing alterations by bit justification) it is ready to be used in the system. A container is simply a structure. N is one of a limited number of mapping standards.
- **Virtual Container – N (VC-N)**
  A VC is a container after the SDH system has added a Path Overhead. This overhead is shown later in the Overheads section. For now assume it simply some form of necessary instructions. N identifies the order and level of the signal, again don't worry about this yet.
- **Pointer**
  An indicator, the arithmetic value of which tells the system where in the payload a signal is with reference to the start of the frame. This system of pointers is one of the defining points of SDH as this allows for more flexibility as signals can be positioned anywhere instead of in fixed locations. In SDH only the pointers must have defined locations.
- **Tributary Unit – N (TU-N)**
  Each signal that is contained inside the multiplex of the SDH signal has its own area in the payload, occupying a column, or group of columns, known as the tributary unit. Each signal column contains nine bytes (one from each row). One column represents 576kbps, and three columns can hold a 1.5Mbps PCM signal. The N comes from the VC-N the TU is made up from. The TU also contains a VC and a pointer.

- **Tributary Unit Group**
  Several TUs can be considered together as a group but since no extra overheads are needed, its path must be tracked. There are several sizes of TUG, for example TUG-2 has 12 columns containing 3 * 2Mbps signals.
- **Administrative Unit – N (AU-N)**
  Once several TUGs are organised further by byte interleaving and more path overheads they form a higher order VC. Along with another pointer this together (the higher order VC and pointer) form an AU. The N comes from the VC it is made from.
- **Network Node Interface (NNI)**
  Network Node: This is simply defined as a point in an SDH network where two points cross.
  NNI: The interface at a network node, the point at which they join.
- **Concatenation**
  The assembling of two or more signals into one.

It would be difficult to include all these items in the glossary so they are being discussed here as the following topics will be using the given acronyms and terms greatly.

As I'm sure you can see from this, more and more information is packed into the payload bit by bit (no pun intended!) signal by signal being further multiplexed into ever growing groups. This is a lot of information to understand and sort, because of this I am now going to show an example. This example comes from the excellent Transmission Systems book listed in the bibliography and shows the multiplexing of a 2Mbps signal into an STM-1 structure.

The signal, as I stated starts with a **Tributary**. A signal you wish to add to the STM-1 signal. [Tributary]
Once this tributary is mapped successfully into a valid SDH signal, it is then referred to as a **Container**. Container for 2048kbps → [Container-1] C-12
The next step is for this container to have its path overheads (POH) added to become a basic **Virtual Container**. POH added here → [| Container-1] VC-12
The VC need not be totally synchronous with the STM-1 frame as a pointer is used, when a pointer is added to a VC it becomes a **Tributary Unit**. TU Pointer here → [| POH | Container-1] TU-12

TUs may then be assembled to form a **Tributary Unit Group**. Here we see three TU-12s being bit interleaved to form one TUG-2.

Byte interleaved 3 x TU-12

TU-12	TU-12	TU-12	TUG-2

These can then be further assembled by byte interleaving and by addition of more overheads to form a higher order VC, a **VC-4**.

Byte interleaved 21 x TUG-2, to put this in perspective, the whole TUG-2 signal from above is all in the section marked **'1'**.

21																		3	2	1

Once that interleaving is complete the **higher order VC-4 path overheads** are added.

HO VC-4 POH	21 x TUG-2	VC-4

This higher order VC is located in the STM by means of another pointer. The VC and the pointer constitute an **Administrative Unit**. To clarify addition of an AU pointer to VC-4 forms AU-4.

AU Pointer	POH	21 x TUG-2	AU-4

AU-4 forms the entire payload of the **STM-1** signal. Finally, the operation is complete by adding the **Section Overheads (SOH)** to the assembly.

SOH	AU Pointer	VC-4	STM-1

This is not the **only** way to multiplex an STM-1 together you could have, again for example, have taken the TUG-2, byte interleaved seven of them together, to eventually form an AU-3, then taken three of those byte interleaved together to form an Administrative Unit Group as the whole payload. Again, this is just another way, it all depends on how the network is configured, managed, and of course, what is the most cost effective way for the business to put it together.

OK, now we understand how the data is put in the payload, lets take a jump back to those overheads we were talking about earlier, the ones we now know as the section overheads from the final step of the process we just went through.

The Overheads

To try and keep things in perspective from that hideously complex multiplex example I will explain the layout quickly. We now know just how much data goes into the payload, shown in grey below. Attached to that we had the Higher Order VC-4 POH, the path overheads, they are now represented next to the payload in cyan and the AU pointers from before can now be seen in there real position in the frame, also in cyan. Finally the Section Overheads we added last actually come in two sections:

1. The Regenerator Section Overheads
2. The Multiplex Section Overheads

As I have already stated, not all the space in an STM-1 signal is available for us to use for data, SDH has those 9 columns for overheads. Below is a closer look at that overhead, as earlier one cell is 1 byte and the grid is nine rows high. The diagram below is the same as previously but enhances the view for the overheads.

So, now we've dealt with the actual data content, let me try to explain what those overheads are made up from.

A1	A1	A1	A2	A2	A2	J0		
B1			E1			F1		
D1			D2			D3		
AU Pointers								
B2	B2	B2	K1			K2		
D4			D5			D6		
D7			D8			D9		
D10			D11			D12		
S1					M1	E2		

J1	
B3	
C2	
G1	This Is
F2	The VC4
H4	Payload
Z1	
Z2	
Z3	

Key:	
	Regenerator Section Overheads
	VC-4 Path Overhead
	Multiplex Section Overheads

To start with, I will explain the **Regenerator Section Overheads**.

A1 and A2 are the frame alignment words to indicate the beginning of an STM-N frame where A1 is 11110110_2 and A2 is 00101000_2. Since the amount of columns changes with N the actual length is 3 columns for STM-1 and 3N for STM-N.

J0 is the regenerator section trace. When a transmitted signal reaches its next regenerator point this bit is used to identify to the receiver it is still connected to the correct transmitter.

B1 is a *BIP*-8 error monitoring code which is generated over all the bits of the previous STM-N signal and is placed in the current frame.

E1 provides a speaker channel for communication between regenerators.

F1 is a spare data channel that can be user configured.

D1, D2 and D3 are data communication channels used as a central location for alarms, control, monitoring and administration.

Next is the **Multiplex Section Overheads**.

B2 is a 24*N bit BIP error monitoring code. It is used to check if errors have occurred over multiplex sections of a transmission.

K1 and K2 area allocated for Automatic Protection Switching for the protection of the multiplex section.

D4 through D12 are data communication channels used as a central location for alarms, control, monitoring and administration of multiplexing functions.

S1 is a synchronisation status byte. Bits 5 through 7 are used to carry synchronisation messages.

M1 is allocated for use as a multiplex section remote error interface. It carries the number of bits in error detected by B2.

E2 provides a speaker channel for communication between regenerators.

Finally, the description and explanation of the **AU pointer** area of the frame.

As we learnt previously this pointer stores the location of a higher order VC in the payload. We can now see where it actually resides. The diagram below shows the structure of the pointer if the payload is made up from three AU-3 streams as I mentioned after the multiplex example.

H1	H1	H1	H2	H2	H2	H3	H3	H3

Where **H1, H2, and H3** contain the three separate pointers for the three separate AU-3 streams, which in this case are simply three offset values, where the first H1, H2, H3 set refers to the first AU-3 stream, the second set to the second, and the third set to the last.

However, if the payload was multiplexed in the way the example showed, in other words, you have one single AU-4 stream then the AU pointer is as shown below.

H1	Y	Y	H2	1*	1*	H3	H3	H3

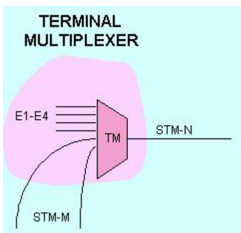
Where **H1, H2 and H3** contain the AU-4 pointer, **1*** means all 1's and **Y** is 1001XX11 (where X is unspecified).

The SDH Structure

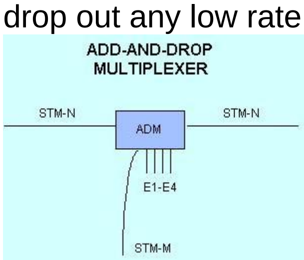
Now that the frame level detail is clear I would like to build up from the data level to the hardware level and where the data actually goes during transmission.

Here I am going to explain the elements that make up the SDH system and the connections that link them. The diagrams used here come from the "What Is SDH?" information, as listed in the bibliography.

The most common SDH elements are:

- **Terminal Multiplexer (TM)**
  This is used to multiplex tributaries together to the STM-N signal.
  

- **Regenerator**
  These are used when the distance the signal is being sent over is too large and is irretrievable at the receiver. The 'regen' is put in place in the transmission medium to regenerate the signal.

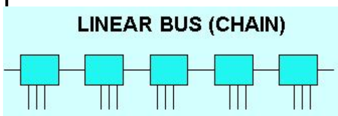
- **Add and Drop Multiplexer (ADM)**
  The ADM is one of the more remarkable elements of the SDH infrastructure, it has the ability to take in the STM-N signal and add to it or drop out any low rate tributary as requested or programmed.
  

- **Synchronous Digital Cross Connect (DXC)**
  The DXC allows for several STM-N signals to be passed through it and any tributary to be switched from one STM signal to another.

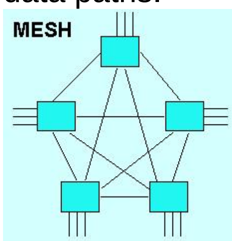
These are the basic elements which make up the following SDH layouts.

There are various ways in which the system can be laid out, various topologies that can be used:

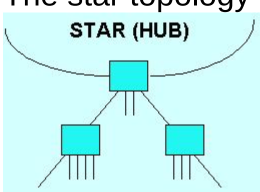
- **Linear Bus (Chain)**
  This type of network is used when no protection is needed and it is preferable to link the sites in a linear fashion.



- **Mesh**
  This topology silences even the most paranoid of managers interconnecting terminals and allowing for a high redundancy across the data paths.

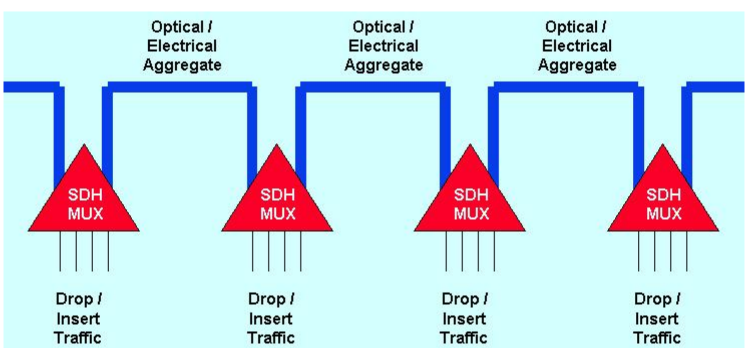


- **Star/Hub**
  The star topology is used for stations that are either far or less important.



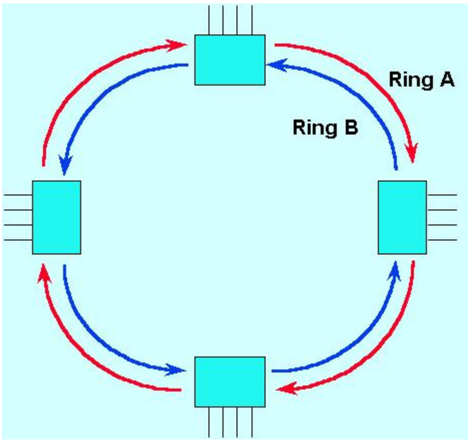
And in these systems there are various ways of interconnecting all of the above systems for larger areas. For example, several linear and mesh systems connected via a star network.

As I said, the elements build these up, an example being that a chain topology is built of add and drop multiplexers, as shown below.

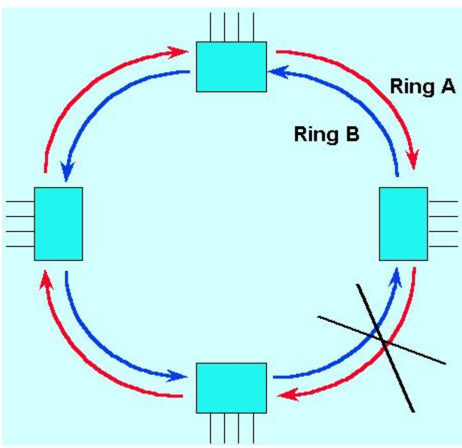


SDH networks can be protected in case of a link between two stations failing, below is an example.

Consider the following ring network, known as a Dual Unidirectional Ring as it is only one way traffic but there are two sets of traffic.



Here Ring A is used to carry the data and Ring B carries either any unprotected data (data lost in the event Ring A is broken) or carries no data at all.



Now the diagram shows a broken link, but as we have the redundant Ring B there is no need to panic as when the data gets to the bottom station Ring B takes over and the data flows in the reverse direction until it gets back to the station on the right when it returns to Ring A, thus the path is still complete. This is SDH protection.

At this point, now that everything necessary is slightly clearer, I would like to explain about one of the SDH features, the ability to multiplex streams of different speeds.

The old PDH system uses a Mesh structure where each station transmits according to its own clock, the problem comes when we consider that since there are several different speeds that want to be transmitted, so:

Which clock speed do we use?

Using a slower clock speed means that we can't send as much data, but if we use a faster clock then some of the data could be lost if we transmit too fast.

They developed what was called a **stuffing** algorithm, whereby using a fast clock any data could be transmitted and if the stream was slower, extra bits would be stuffed into the stream to keep it full.

Back with SDH, and now each element is synchronised to the same clock and there is also an improved stuffing algorithm that allows any rate of PDH signal to be directly mapped into the STM-N frame, it is the algorithm and mapping that allows for the SDH versatility. Thus any signal of any speed can be mapped in.

So far, there are a couple of things that I haven't mentioned with regard to SDH systems, they are the management facilities and the alarms that the data can carry. I will now briefly mention them.

The management facilities in SDH can be separated in to four groups:

- Alarm/Event Management
- Configuration Management
- Performance Management
- Access and Security Management

These allow for more sophisticated management than was ever possible before especially since the ability to add and drop streams means that the data stream can be managed anywhere along its transmission via a management terminal connected to the network.

The alarms in SDH are also more sophisticated and since the management facilities are also more sophisticated, many problems can be corrected en-route as it were.

Conclusions

I did say at the beginning of this assignment some introductory reasons for the SDH popularity but here I will be comparing the system to another and explaining what I think SDH is good for.

For optic fibre transmission, SDH is a very good transmission method.

That would have to be my summation for this, but that statement does have its condition, "for optic fibre transmission".

I would like to clarify before I go further that I am not going to compare PCM, PDH and SDH here, I am considering these three systems as upgrades respectively since there are no losses of service as you go up, even price is not that much of an issue and therefore will be comparing SDH only with ATM as I believe ATM is the main competitor.

Asynchronous Transfer Mode, ATM, is yet another very complex communications system which I would prefer not to go to into detail as it would, put simply, confuse the issue here. As stated in the bibliography I have read an article from the IEC on the ATM system. This paper describes the various details on the system as an introduction.

From what I currently understand about the system, ATM is not defined as something to rival SDH but as a system to co-exist and work alongside it. SDH, as I said, is the choice of systems for an optical link, ATM is however the choice for non-optical connections. The paper describes a system with ATM providing the connection between servers and access terminals for data but the actual transporting being done via SDH systems.

There are lots of benefits to using SDH over optic fibre links:

- speed of transmission
- low ratio of data to overheads (compared to ATM)
- the ability to include anything in the stream

These points have already been well stated over the report.

SDH however doesn't have ATMs versatility when it comes to broadband non-optical links.

For example, ATM can be used for:

- LAN/WAN emulation
- high performance via hardware switching
- dynamic bandwidth for ‘bursty’ traffic
- class-of-service support for multimedia
- end user applications

To conclude I believe SDH is a good choice for modern communications equipment, but not for all links, only optical links, for others ATM would seem to be a preferable choice. This is simply because ATM has all the points above, then when it comes to going to optical, SDH can take over.

Glossary

ATM
Asynchronous Transfer Mode. A similar system to SDH but with several significant differences.

BIP
Bit interleaved Parity. This is a form of error monitoring to see if the received signal was correctly received.

LAN
Local Area Networking.

Mbps
Mega ($x10^6$) bits (not bytes!) per second. Not to be confused with MBps (mega bytes per second) which would be eight times the amount of any coefficient used. For example 8Mbps = 1MBps.

Multiplexing
Multiplexing is the sending of multiple signals/streams of information on the same carrier signal in the form of a single complex signal and still being able to recover the separate streams/signals at the receiving end.

OC
Optical Carrier (OC) is the optical equivalent of an electrical SDH STM signal. This was originally an electrical signal but was converted to optical to transmit over the SDH system, and will be converted back again at the receiving end.

PCM
Pulse Code Modulation. The standard for transmission networks before *PDH* and *SDH*.

Plesiochronous
Almost synchronous. With reference to PDH, because bits are stuffed into the frames as padding and the calls location varies slightly from frame to frame.

SDH
Synchronous Digital Hierarchy. The UK slight variant on SONET.

SONET
Synchronous Optical NETwork. The original optic fibre connection in the US.

STS
Synchronous Transport Signal (STS) is the electrical equivalent of the SONET optical signal, also known as STM in SDH systems.

STM
Synchronous Transport Module (STM) is the electrical equivalent of the SDH optical signal, also known as STS in SONET systems. This is the signal that is converted to an optical signal to be transmitted and also the name for the received signal after it is converted back again. In the intervening (transmitting) time it is known as an Optical Carrier (*OC*) signal.

WAN
Wide Area Networking.

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