S-72.3340 Optical Networks

Introduction to SDH Technology

TABLE OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND GLOSSARY

ADM Add-Drop Multiplexer
Equipment for combining virtual containers and for connecting them to SDH or PDH interface ports.

AIS Alarm Indication Signal
Signal structure which is sent forward in SDH network when a SDH network element is in alarm state.

APS Automatic Protection Switching
Switching which performs the protection of a connection of a part of it automatically.

Asynchronous mapping SDH mapping where justification bits are used.

ATM Asynchronous Transfer Mode

Transfer mode in which data is split in true to shape packets

AU Administrative Unit (AU-n, n=3...4)

Structural part of an STM-1 frame consisting of a higher order virtual container and an AU pointer.

AU-pointer Pointer added to a higher order virtual container for the location of information bits.

AUG Administrative Unit Group
Administrative unit or group of administrative units with a fixed position in an STM-1 frame.

BBE Background Block Error
Erroneous block which is not a part of SES.

Broadcast Switching mechanism for terminating a virtual container in an incoming signal and inserting a test signal in the corresponding virtual container of the outgoing signal.

BIP Bit interleaved parity check
Parity checking method used for monitoring bit errors in an SDH network. The abbreviation BIP is often accompanied by an integer (e.g. BIP-8) indicating how many sections the signal has been divided into for error checking. The length of the check bit string used in the method equals the number of these sections.

C Container
Structural part of an STM-1 frame consisting of a payload with a specified format. The different types of containers in SDH are denoted as follows: C-n (n= 1, 2, 3, 4, 11, 12)

CCITT Comité Consultatif International Télégraphique et Téléphonique
Consultative Committee for International Telegraph and Telephone. Predecessor of ITU-T.

Concatenation Association of several virtual containers with each other so that their combined capacity can be used as a single container. According to ITU-T recommendations, concatenation is possible on VC-2 and VC-4 levels. By concatenation it is possible to form e.g. a combination of four VC-4s (VC-4-4c) rate of which is 622 Mbit/s.

DCC Data Communications Channel
Auxiliary channel within section overhead which is used for network management related communication between operation systems and network elements. The two data communications channels in an STM-1 frame are the DCCR, consisting of three bytes of the regenerator section overhead, and the DCCM, consisting of nine bytes of the multiplexer section overhead.

DEG Degraded Signal

SDH system alarm which is given if the received signal contains too much errors.

DXC Digital Cross-Connect Equipment

Equipment for combining virtual containers and for connecting them to SDH or PDH interface ports.

EB Error Block

An error where the received BIP code is incompatible with the data it monitors.

EPS Equipment Protection Switching

Protection switching which is done by multiplying the amount of used network elements.

ES Error Second

A unit used to measure the quality of data transmission.

ETSI European Telecommunications Standards Institute

G.703 ITU-T recommendation: Physical/electrical characteristics of hierarchical digital interfaces.

G.707 ITU-T recommendation: Network node interface for the synchronous digital hierarchy (SDH)

G.708 ITU-T recommendation: Sub STM-0 network node interface for the synchronous digital hierarchy (SDH)

G.709 ITU-T recommendation: Synchronous multiplexing structure

Merged with ITU-T G.707 in 1993

G.826 ITU-T recommendation: Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate

HO path Path used as the server-layer for transfer of lower order virtual containers.

HOVC High Order Virtual Container
Virtual container which can be used in an STM-1 frame without other virtual containers. A higher order virtual container may consist of a single container (c-4/C-4) and path overhead, or a tributary unit group (TUG-2/TUG-3) and path overhead

ITU-T International Telecommunications Union - Telecommunication Standardization Sector

LOF Loss Of Frame
Error state caused by a situation where the position of frame alignment bytes in the incoming bit stream cannot be identified within a pre-defined period of time.

LOP Loss Of Pointer
Error state caused by a pre-defined number of successive unidentified pointer values.

LO path Path used as the client-layer for transfer of higher order virtual containers.

LOS Loss Of Signal
Error state caused by a drop in the signal level below specified limits for longer than a pre-defined period of time.

LOVC Lower Order Virtual Container
Virtual container which can be used in an STM-1 frame only when grouped with others. A lower order virtual container

consists of a single container the type of which can be C-1 (C-11/C-12), C-2 or C-3 and path overhead.

MS Multiplex Section
Section connecting two multiplexers or a multiplexer and a cross-connect. A multiplexer can be either a terminal multiplexer or an add-drop multiplexer.

MSOH Multiplex Section Overhead
Rows 5 - 9 of section overhead. Multiplex section overhead is used for communication between multiplexers or cross-connects in the multiplexer section and for management and control of the transmission.

NNI Network to Network Interface

Path Trail in a path layer network.

Payload Information which is to be transferred to the receiver end by the transmission system or a part of it.

PDH Plesiochronous Digital Hierarchy
Transmission technique in which the timing relationship of the corresponding significant instants of a signal is not limited. Greek word plesiokronous means "almost synchronous".

POH Path Overhead
Structural part of a signal which is added to a container for transfer. Path overhead is used for different purposes of connection control, e.g. for error control

Pointer Structural part of a signal used to locate the information-carrying bits of the signal.

PRC Primary Reference Clock
High-precision clock signal unit confirming to ITU-T

recommendation G.811. This clock signal is used to generate the central clock. Recommendation G.811 specifies an accuracy of $1x10^{-11}$.

RDI Remote Defect Indicator
Signal, which indicates to the network element that the defect status of the received signal of the transmission requires further checking.

Regenerator Equipment used to receive and reconstruct a digital signal so that the amplitudes, waveforms and timing of the signal elements are constrained within specified limits.

REI Remote Error Indication
Signal, which indicates the number of errors detected in the signal to the network element. Remote error indication is conveyed to the network element regardless of the number of errors.

RS Regenerator Section
Section connecting two regenerators or a multiplexer and a regenerator, or a cross-connect and a regenerator.

RSOH Regenerator Section Overhead
Rows 1 - 3 of section overhead. Regenerator section overhead is used for communication between multiplexers, cross-connects and regenerators and for management and control of the transmission.

SDH Synchronous Digital Hierarchy
Transmission technique in which there are specified limits to the timing relationship of the corresponding significant instants of a signal.

SDH cross-connect Equipment for combining virtual containers and for connecting them to SDH or PDH interface ports.

SDH mapping Adaptation of a signal into a virtual container when this signal is to be fed into an SDH network.

SDH node Point in an SDH network at which the signal is processed. An SDH node may be e.g. a multiplexer or a cross-connect.

SEC Synchronous Equipment Clock

Clock signal which is defined in the ITU-T recommendation G.813.

SES Severely Erroded Signal

Unit to measure the quality of transmission, sib-group to ES.

SOH Section Overhead

First 9 columns of an STM-1 frame. Section overhead comprises regenerator section overhead, multiplex section overhead and an AU-pointer (AU-4).

SONET Synchronous Optical NETwork

Standard used in the United States of America. This standard was used as an outline in designing SDH.

SSM Synchronization Status Message

Part of byte S1. It informs the neighbor network elements the status of clock signal.

SSU Synchronization Supply Unit

Clock signal which is defined in the ITU-T recommendation G.812.

STM Synchronous Transport Module

Signal following the structure of an STM-N frame.

STM-1 frame Signal structure which can be distributed as a two-dimensional array of 9 x 270 bytes and which is used for transferring basic-rate signals in an SDH network.

STM-N frame Signal structure consisting of N STM-1 frames. The value of N may be 1, 4, 16 or 64.

Synchronous mapping SDH mapping where justification bits are not required.

TM Terminal Multiplexer
Multiplexer used to insert the incoming signals to an STM-N frame.

TU Tributary Unit (TU-n, n=1…3)
Structural part of an STM-1 frame consisting of a lower order virtual container and a tributary unit pointer. The difference between AU and TU is that multiple AUs can be cross-connected to the network and transmitted between different STM-1 where as TU is a structural part of one certified STM-1 frame and therefore cannot be transferred between different STM-1 frames without higher order AU.

TUG Tributary Unit Group (TUG-n, n=2,3)
Tributary unit or group of tributary units with a fixed position in a higher order virtual container. There are two types of tributary unit groups: TUG-2 and TUG-3.

TU pointer Pointer added to a lower order virtual container for the location of information bits.

UAS Unavailable Second
Unit used to measure the quality of transmission. If a UAS occurs the data communications link cannot transfer data.

VC Virtual Container

Structural part of an STM-1 frame consisting of path overhead and a container. The different types of virtual containers are denoted as follows: VC-n (n= 1, 2, 3, 4, 11, 12)

1. INTRODUCTION

The definition of SDH: The SDH (Synchronous Digital Hierarchy) is a hierarchical set of digital transport structures, standardized for the transport of suitably adapted payloads over physical transmission networks [1].

Before going into SDH it is good to go through the situation preceding SDH.

1.1 PDH - Plesiocronous Digital Hierarchy

PDH was introduced in the 70's together with the digitization of the transmission networks. It is intended for the usage of telephone traffic. The basic transfer rate in PDH is 2.048 Mbit/s (E1), which is, made out of 30 64 kbit/s voice channels. This E1 signal is then multiplexed in the PDH network via 8.448 Mbit/s (E2) and 34.368 Mbit/s (E3) signals into 139.264 Mbit/s (E4) signal. This E4 signal contains 1920 multiplexed voice channels. The multiplexing of four E4 signals into one E5 signal, that is 565 Mbit/s, was introduced in the early 90's but it did not have great success mainly because of the widely spread SDH. Regardless of its name PDH is synchronous till the rate of 2.048 Mbit/s when 30 voice channels are multiplexed synchronously into one E1 signal.

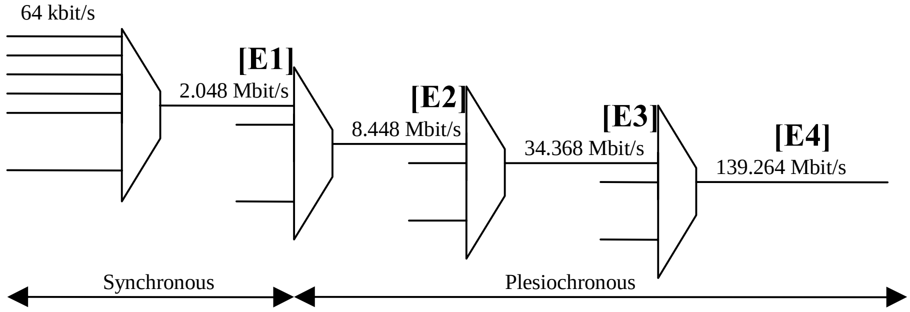


Figure 1. Multiplexing of PDH.

None the less there are some limitations in PDH. First of all the transmission rate for every input in the same multiplexer must be roughly taken similarly (this means e.g. when multiplexing E1 signals into an E2 signal). This causes the inconvenience in multiplexing when the difference in the local clock and the clock in each different input makes the bits randomly overlapping. This harness is handled by using fill bits. The inconvenience using this method is that every fill bit requires an address making it rather wearisome. Other limitation is that in order to get one 64 kbit/s signal out of the multiplexed signal whole signal must be demultiplexed into the lowest level. This brings double fees because the signal must be multiplexed back into the preceding level.

PDH is also a point-to-point hierarchy where there has to be a physical connection for each connection and therefore there is no space for the management of the system. This makes the connections between networks complex when one is using several different local area networks.

The network management and control is very limited in PDH networks because there are no free bits in the frame. Another problem are also the vendors making network elements by their own standards. This means that the interaction between networks of different vendors is impossible. In a few words PDH is a very rigid and expensive transport technique. There really was a need for a faster, more flexible and more economical transport technique.

1.2 History of SDH

When standardizing SDH the frame for the development was taken from the SONET, which was introduced in the Bellcore's laboratory in 1984. The goal of SONET was to make multiplexing easier, to control plesiochronous systems, to normalize optical interfaces, to ameliorate the control of optical network and to ensure a smooth transition into the ATM network. Not taking everything into account one might say that SDH is like SONET, which contains the PHD bit rates 2 Mbit/s and 34 Mbit/s.

Veritable work for the SDH standard begun in CCITT in June 1986 aiming to create a worldwide standard for synchronous data transfer systems and by using this standard the vendors could manufacture flexible and economical networks. The first standards for SDH were approved in December 1988. These standards were G.707, G.708 and G.709. Nowadays the development of SDH standards is done in two different standardization committees: ITU-T and ETSI.

1.3 The basic ITU-T recommendations for SDH

Recommendation G.707 defines the bit rates for STM-N signals in SDH technology, frame structure for STM-N signals, the mapping and multiplexing of PDH and ATM elements into a STM-N frame.

Table 1. Bit rates of STM-N signals

STM-1	155 520 kbit/s
STM-4	622 080 kbit/s
STM-16	2 488 320 kbit/s
STM-64	9 535 280 kbit/s

Recommendation G-708 defines the location of a node in the network, the structure of frame (STM-1 and its elements), the usage of overhead bytes in the frame and in the STM-N structure and the channeling a STM-1 into STM-N.

Recommendation G.709 defines how to construct signals accordant with North American or with European hierarchy into an STM-1 frame [2]. This recommendation enables the augmentation and the deduction of the reserved space in a frame so that the anomalous signals to SDH bit frequency (asynchronous and plesiochronous signals) may be transferred via a SDH system [3].

1.4 The benefits of SDH

Many improvements were introduced alongside with SDH. First of all the principles of direct synchronous multiplexing in SDH standard are the key to more economical and flexible data transfer system. This means that a single lower level signal can be directly multiplexed into a SDH signal with higher bit rate and this is done without any consequential multiplexings. The network elements in a SDH network can also be installed "directly" into the network in use. This brings substantial savings to operators.

SDH was also designed with an idea of network management and control and because of this about 5% of the signal structure in SDH is defined to support these procedures and the utilization of these procedures.

It is also possible to transfer all tributary unit signals used in different communications networks. For this reason it is very easy to take SDH into use in the networks currently in use. Using SDH it is possible to achieve greater flexibility.

2. SYNCHRONOUS DIGITAL HIERARCHY

2.1 STM-1 frame structure

Transmission of information in SDH is based on STM-1 frame structure. All data that is to be transmitted is aligned into 155.52 Mbit/s frames that contain also the address information. An STM-1 frame is constructed from 270 columns and 9 lines. This makes a total of 2430 bytes. Each byte contains 8 bits so the total amount of bits in one STM-1 frame is 19 440. The frame is read one line at time from left to right and from up to down 8000 times per second, which is the speed of 64 kbit/s channel. This is how we get the time for one frame that is 125 μs. Using this we can calculate the transmission rate of one STM-1 frame 19 440 bits / 125 μs = 155.52 Mbit/s.

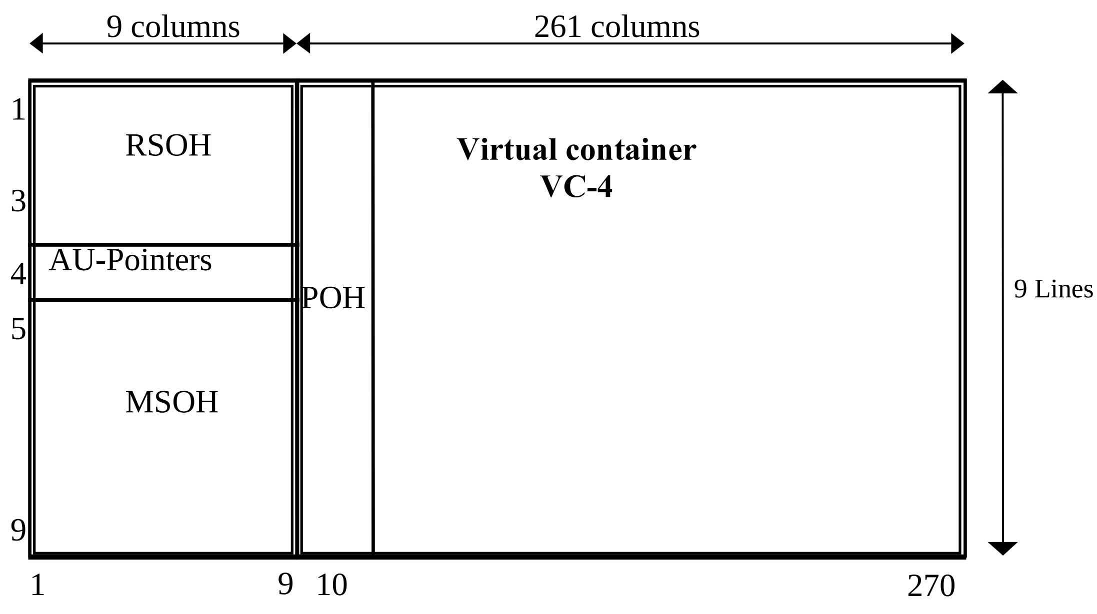


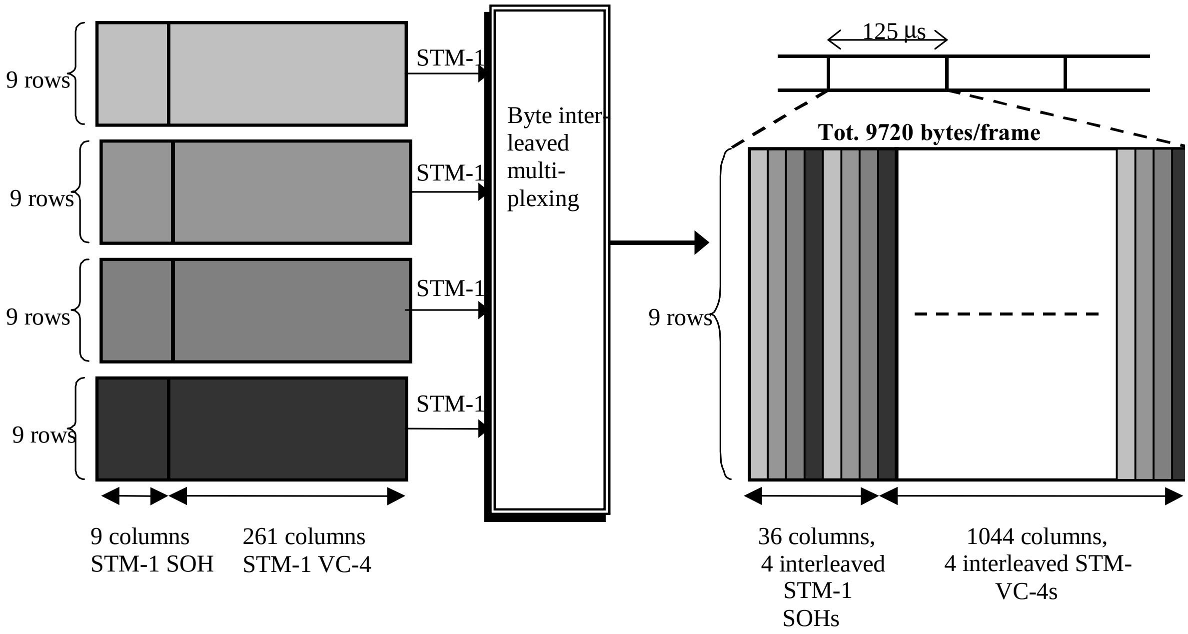
Figure 2. STM-1 frame

The first nine columns in STM-1 frame make the section overhead, SOH. The bytes in section overhead are used to e.g. for control of the network, for noticing the start of frame, to point the start of the payload and for notification of the errors. The first three rows in SOH form the regenerator section overhead, RSOH and the five lowest rows form the multiplexer section overhead, MSOH. The AU-pointers are situated in the fourth row of section overhead. AU-4 pointer is the only pointer standardized in SDH.

The last 261 columns form the virtual container 4, VC-4. This is divided into two parts, which are path overhead, POH and container, C-4. Path overhead is the first column in virtual container aka the tenth column in the whole STM-1 frame. It contains alarm and service information and routing information for end to end connections. It is always generated in the same SDH node where the payload enters SDH network. Path overhead is always routed with the payload and it is disassembled only when the payload exits the SDH network.

2.2 Higher level STM frames

When there is a need for greater transmission capacity than 155.52 Mbit/s STM-1 frame can offer, one can use transmission rates offered by the higher STM levels. By multiplexing byte interleaved STM-1 frames one can build transmission rates multiple to an STM-1 frame. When the higher-level transmission rates are exactly the multiplication of an STM-1 frame both the multiplexing and the de-multiplexing are simple operations. There is even no need for the manipulation of pointers. Byte interleaving means that bytes are collected one byte at the time from each subsystem. SDH interleaving is done one column at the time. E.g. the first column in STM-4 frame is the first column of the first STM-1 frame, the second column in STM-4 frame is the first column of the second STM-1 frame and so on. This is done till all the columns are interleaved.



9720 bytes/frame * 8 bits/byte * 8000 frames/s = 622.08 Mbit/s

Figure 3. Construction of STM-4 frame

STM-16 signal is multiplexed with the same manner from four STM-4 signals. Only the section overhead from the first STM-1 frame is used to monitor the higher-level frame. However each STM-1 frame has it own identifier in the section overhead. Even though the transmission rate is quadruple to the original every lower-level byte is still to be directly pointed from the higher-lever hierarchy frame. [4] For example it is easy to write and read one certain 2 Mbit/s time slot from STM-16 frame when necessary. Even a single 64 kbit/s speech channel is to be pointed providing that the 2 Mbit/s signal is mapped byte synchronously into an SDH frame.

2.3 Construction of an STM-1 frame

The most important part of a frame is virtual container VC-4, which consists of container C4 and path overhead. Container is meant to support the transportation of various tributary unit signals in SDH network. It provides with all 2340 bytes a transmission rate of 149.75 Mbit/s, which is especially designed for the transmission of 140 Mbit/s tributary unit signal. [5]

Construction of an STM-N frame is a complex process, which contains mapping, multiplexing and several different operations with overheads. It is best to start from the beginning.

The very first thing to do is to frame the tributary unit signal. Doing this forms the container. This is essential because the containers do the actual transmission of data in SDH networks. in order to ensure the consistency for all transmission capabilities in SDH the size of a container is slightly larger than the actual size of a tributary unit signal. The size of the original signal is increased to a well defined fixed speed in framing by positive bit based stuffing. Stuffing makes the signal synchronous. For example 140 Mbit/s tributary unit signal must be synchronized to a container with a transmission rate of 149.76 Mbit/s

Next the path overhead is added to a container. Only after this operation virtual container is formed. Virtual container forms a transparent channel in SDH network. The process where a tributary unit signal is packed into a virtual container is called mapping.

The phase compared to higher-lever virtual container is defined after mapping to lower-level virtual containers. The definition of location is also done before multiplexation into higher-lever virtual containers. The information on the location is stored into TU pointer. Virtual container together with TU address forms a tributary unit.

After the definition of tributary unit several tributary units are multiplexed into a tributary unit group, TUG. After this operation is done the location of a VC-4 compared to an STM-1 frame is defined. This information is stored into AU-4 pointer. Virtual container VC-4 and AU-4 pointer form together an administrative unit - 4, AU-4. The AU-4 pointer is always in a fixed position in STM frame. Instead VC-4s can float compared to an STM frame. This means that a VC-4 can slide comparison with STM frame. Because of this ability a VC-4 can be situated in two successive STM-1 frames. Same way can the lower level virtual containers slide within VC-4. The administrative unit group, AUG, is formed before the final deposition. This administrative unit group can be directly multiplexed into an STM frame with equivalent size.

Finally multiplexer section overhead, MSOH and regenerator section overhead, RSOH, are added into AUG. After this is done the STM-1 frame is ready. These STM-1 frames can be multiplexed into higher-level STM-N frames when needed. The multiplexing structure is showed in following figure.

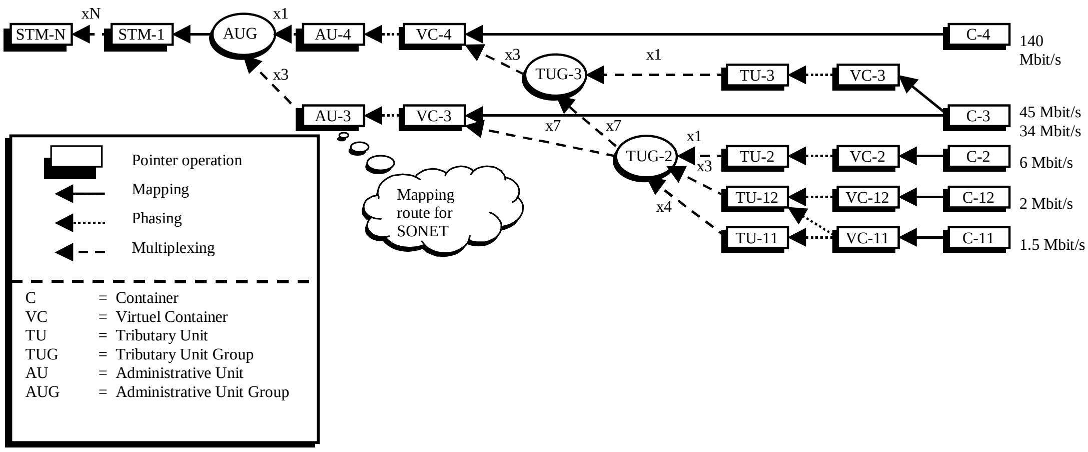


Figure 4. Multiplexing structure of an STM-N frame

2.4 Tributary Units

Tributary units are needed for the deposition of lower-level tributary unit signal, others than 140 Mbit/s signal. TUs are mentioned to support the transportation and the coupling of containers, whose capacity is considerably smaller than the capacity of VC-4. TU frame is designed to fit neatly into an STM frame. This gives substantial aid to multiplexing.

There are four different TU frames TU-11, TU-12, TU-2 and TU-3. These frames are presented in figure 5.

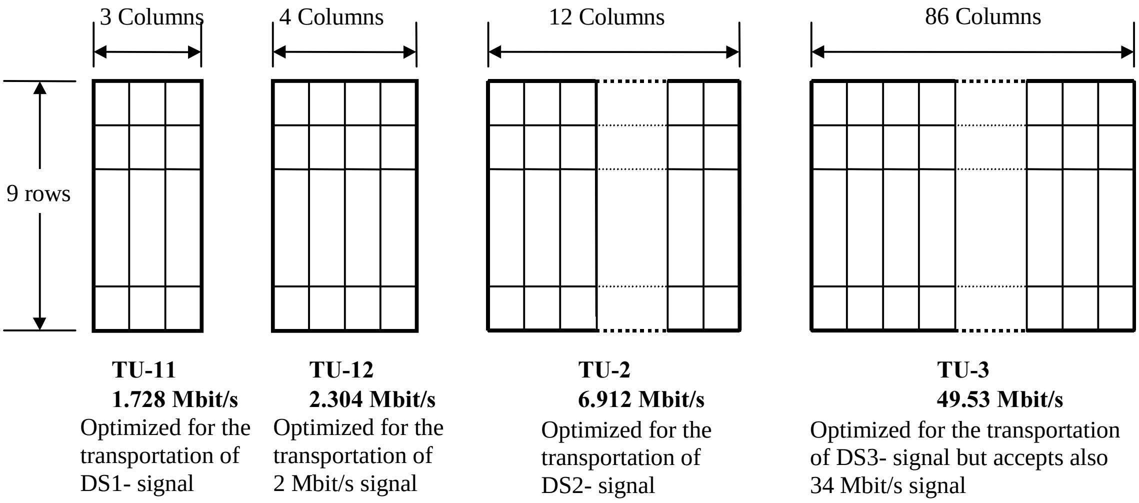


Figure 5. Tributary units

Different size tributary units can be multiplexed into a VC-4 container by the following way: 84 TU-11s, 63 TU-12s, 21 TU-2s and three TU-3s. Nothing prevents from multiplexing various tributary units into a same VC-4. One must only remember not to exceed the capacity of VC-4 and take TUG structures into account.

The frame structure of tributary unit resembles a miniature transmission frame structure. It is created by mapping a lower-level tributary unit signal into the "container" of tributary unit. In other words a low order path overhead is added into a lower-level tributary unit signal in order to create a virtual container (VC-11, VC-12, VC-2 or VC-3 depending on the type of tributary unit) for tributary unit. After this is done the virtual container is linked into tributary unit frame with a TU pointer.

TUs have two different types of action "floating" and "fixed". Floating mode is designed to minimize the delay in the network and to ensure effective cross-connections in TU level. This is reached by allowing the floating of each TU between the VC-4s. The downsize of this is that every TU requires its own pointer which was mentioned previously.

The locked mode is especially designed to minimize the complexity of interface and for the mass transportation of 2 Mbit/s signals in end to end connections. This is achieved by "locking" separate TUs into well-defined places in VC-4. This is the reason why there are no pointers required in this mode. This on the other hand makes it impossible to use locked mode in applications where TU-level cross-connections are required..

2.5 Overheads in STM-1 frame

There are three kinds of overheads in STM-1 frame: path overhead, POH, regenerator section overhead, RSOH and multiplexer section overhead, MSOH. These overheads are used for the control and the maintenance of the network. Figure 6 shows the overheads in STM-1 frame by byte.

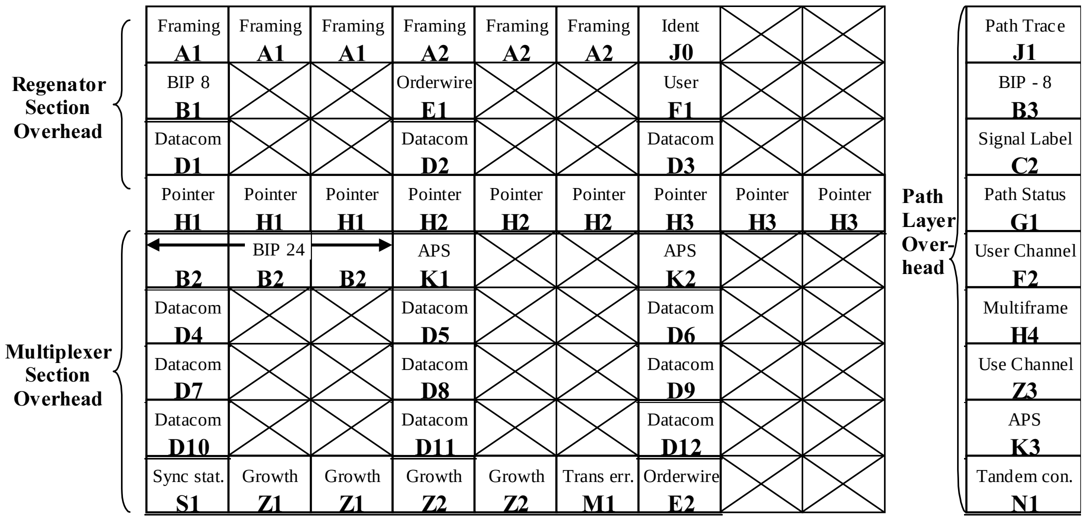


Figure 6. STM-1 overhead structure.

2.5.1 Path overhead, POH

Only the high order path overhead, HO-POH is discussed in this chapter. Low order path overheads, LO-POH , which are used with TU-11 and TU-12, are not discussed in detail. The information necessary to know about LO-POHs is that they have the length of four bytes and they lack the bytes to monitor the quality and the maintenance channels. Path overhead is used to monitor the quality and it also gives the information about the type of the container.

Table 2. Bytes in section overhead and their functions.

J1:	Path indication. This byte is used to send a 16 or 64 byte message byte per byte. Every route in SDH network has it own message.
B3:	Quality monitoring. A error check byte for route error.
C2:.	Container format.
G1:	Transmission error acknowledgement.
F2:	Maintenance channel between operator's terminal equipment.
H4:	Superframe indication.
F3:	Same as F2 but the utilization depends on the virtual containers in use.
K3:	Automatic protection switching for VC-4 paths.
N1:	Tandem connection monitoring.

2.5.2 Multiplexer Section Overhead

The information about checking parity and protection switching is transmitted via multiplexer section overhead. It contains also data and voice channels. AU pointers are also loosely connected into it.

Table 3. Bytes in multiplexer section overhead and their functions.

B2:	Quality monitoring, parity bytes.
K1 and K2:	Automatic protection switching (APS) control. The whole K1 byte and bits 1 to 5 in byte K2 are used to this.
D4-D12:	Data communications channel (DCCM) makes a 567 kbit/s data channel, which can be used to the transmission of user data or alternatively for the network management.
S1:	Clock quality indicator.
M1:	Transmission error acknowledgement.
E2:	Voice connection byte can used to communicate between multiplexers with a special maintenance phone.

2.5.3 Regenerator Section Overhead, RSOH

The most important task of regenerator section overhead is the alignment of the frame. It has also channels both to voice and data and a parity check.

Table 4. Bytes in regenerator section overhead and their functions.

A1 and A2	Frame alignment bytes are always in the beginning of every STM-1 frame. The content of these bytes is 11110110 00101000.
J0:	Trace identifier that is formed from 16 J0 bytes sent in row. Trace identifier is used to make sure that the message received is coming from the right place.
B1:	Quality monitoring byte is used to monitor bit errors.
E1:	Voice connection byte can be used to voice communication between regenerators.
F1:	User byte is freely available for temporary data and voice connections.
D1-D3:	Data communications channel (DCCR) makes a 192 kbit/s data channel, which can be used to the transmission of user data or alternatively for the network management.

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2.6 Network elements in SDH

Network elements in SDH are divided into three different groups: synchronous transmission equipment, multiplexers and cross-connect equipment. Standard for synchronous transmission equipment is divided into two recommendations: recommendation for optical interfaces and recommendation for optical transmission equipment. [2]

Terminal multiplexers, regenerators and synchronous transmission multiplexers belong to synchronous transmission equipment. Equipment is in reality more a part of a functional system than a separate physical unit.

2.6.1 Terminal multiplexer

Terminal multiplexers are used to combine plesiochronous and synchronous input signals into higher bit rate STM-N frames. Terminal multiplexer does not contain any functions for cross-connections. Lower bit rate signals are placed into a fixed place in output SDH frame. This place depends on the configuration of the node in use.

2.6.2 Regenerator

Regenerators, as the name implies, have the job of regenerating the clock and amplitude relationships of the incoming data signals that have been attenuated and distorted by dispersion. They derive their clock signals from the incoming data stream. Messages are received by extracting various 64 kbit/s channels (e.g. service channels E1, F1) in the regenerator section overhead. Messages can also be output using these channels. [6]

2.6.3 Add and Drop multiplexer

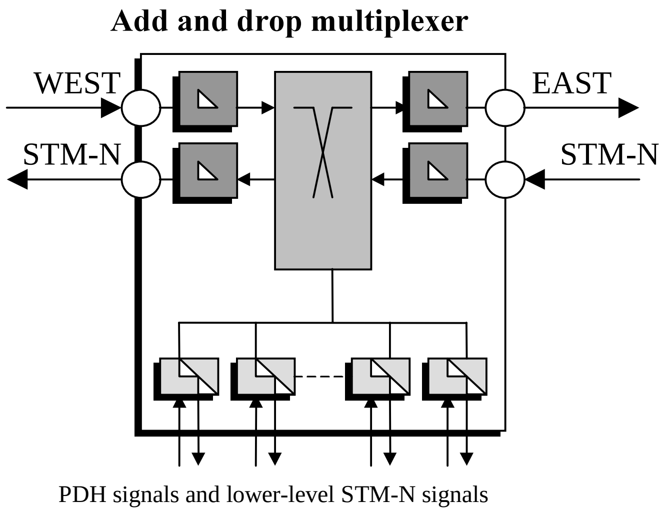


Figure 7. Add and Drop multiplexer

The most used multiplexer is add and drop multiplexer, ADM. This network element is especially designed to function as a network element in SDH ring. It has two bi-directional STM-N interfaces and a group of PDH and/or lower bit rate STM-N interfaces. Anyhow the main part of the traffic goes directly through ADM node from one STM-N interface into another. Multiplexer contains a limited amount of functions for cross-connections between STM-N interfaces and other interfaces. [4]

2.6.4 Digital cross-connect

Digital cross-connect, DXC, is the most functional of all network elements. They have interfaces for PDH and/or lower bit rate SDH signals and they can also manage these signals. Digital cross-connect disassembles the containers from all input signals. It can route all input signals (or parts of these signals) to any output signal, from one hierarchy level to another. It allows also mapping of PDH tributary signals into virtual containers and vice versa. Normally the switching is done with the usual containers (VC-12, VC-13, and VC-4). So this network element enables full cross-connections between the interfaces.

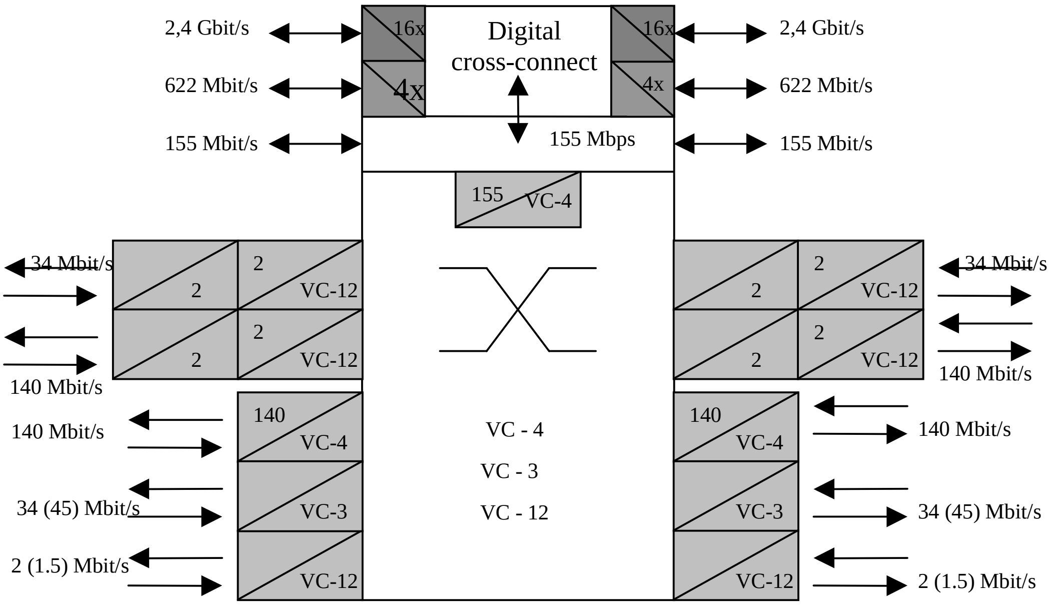


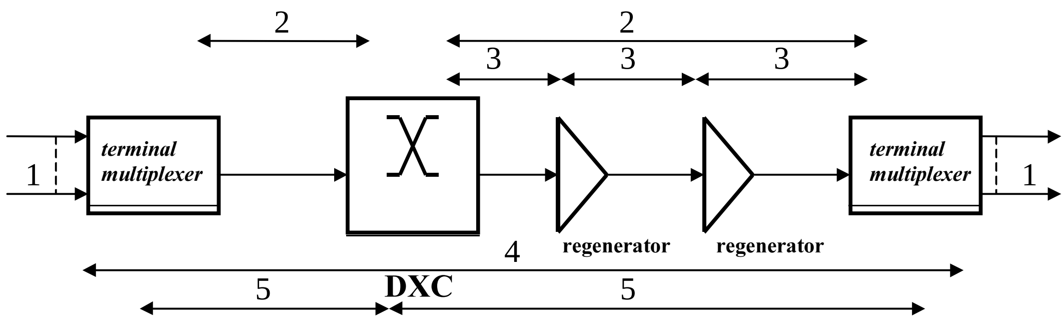
Figure 8. Diagram of digital cross-connect

Digital cross-connects are used in places where there are several different signal coming into a one place. Signals must be perfectly built up or otherwise cross-connect will generate alarms and the measurement of the network will be difficult or even impossible. [6]

Digital cross-connects are very complex network elements and therefore network operators try to minimize the use of cross-connects in their networks and try to replace them with cheaper add and drop multiplexers, where ever it is possible.

2.7 SDH network span

SDH networks are subdivided into various layers that are directly related to the network topology. These layers ease the management of network and make it also more flexible. The lowest layer is the physical layer, which represents the transmission of medium. This is usually a glass fiber or possibly a radio-link or satellite link. After this layers are referred to as segments. Each of these segments has its own overhead, which are RSOH, MSOH, POH and VC-POH. These segments are introduced it figure 9 with their overheads.



1. **tributary unit signal**
2. **Multiplex section (MSOH)**
3. **Regenerator section (RSOH)**
4. **Lower-level path (TU-POH)**
5. **Higher-level path (POH)**

DXC = Digital Cross-Connect

Figure 9. Paths and sections in a SDH network

Path in s SDH network is a logical connection between the point where the tributary unit signal is assembled into a virtual container and the point where the virtual container is disassembled. VC-4 level path is called a higher-level path and other VC-level paths are called lower-level paths. An example of a lower-level path is a path where 2 Mbit/s signal is assembled into a VC-12.

Regenerator section contains the transmission path and the network elements related to it. Regenerator sections can be situated between a regenerator and a node or between two regenerators. Regenerator section overhead is disassembled when the signal enters the regenerator and assembled when it leaves the regenerator.

Multiplex section contains the part of SDH link between two successive multiplexers (this means SDH multiplexers and digital cross-connects). Multiplexer section overhead is assembled in the first node from the arrival direction of signal and it is disassembled in the following node. These operations are not carried out in regenerators.

2.8 Pointing the payload from STM-1 and the pointer operations

Payload is pointed inside the STM-1 frame with the pointers. These pointers contain the information about the phase of the virtual container relative to the higher virtual container. This phase can alter in SDH equipment because of the cross-connection operations or because of the restart of the nodes. Adjustment of differences in transmission rates of different signals and non-synchronousity can also have some effect on the change of phase.

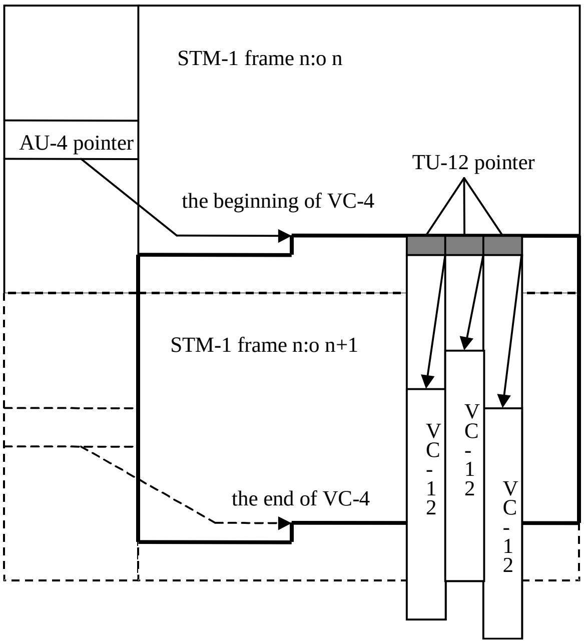
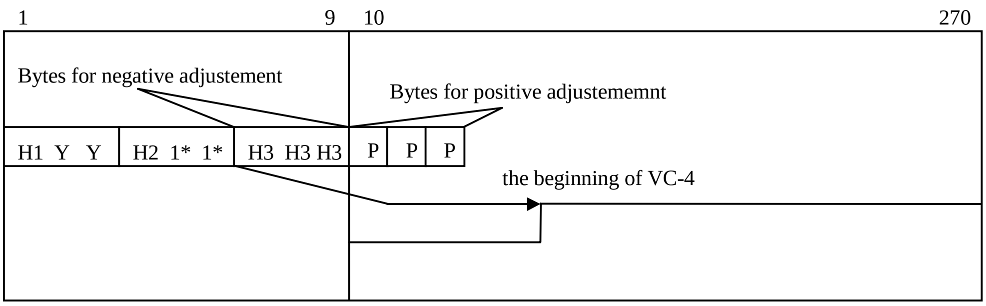


Figure 10. The principle of pointing the payload in STM-1 frame [7]

2.8.1 AU-4 pointer

Au-4 pointer is used to point the beginning of the payload in STM-1 frame. Strictly AU-4 pointer is used to locate the place of the first byte, J1, in VC-4. This byte is more often situated in different place in the STM-1 frame than the first byte of payload. One must notice that the value of this pointer can only be altered in every fourth frame.

One of the features of SDH network is the previously mentioned sliding of payload from one frame to another, when the signal is not synchronous enough. In this case the AU-4 pointer is used to adjust the bit rates of payload and STM-1 frame.



Y = 1001 SS11 (S bits undefined)

1* = 1111 1111

Figure 11. The use of AU-4 pointer [7]

Positive adjustment is used to compensate the smaller bit rate of payload compared to STM-1 frame. In order to have the correct bit rate for payload three bytes per adjustment are added after the H3 bytes. These three extra bytes contain only irrelevant information. The value of the next pointer is increased by inverting the I bits. After this operation the positive adjustment is done.

Negative adjustment is used to compensate the larger bit rate of payload compared to the bit rate of STM-1 frame. The payload is made to fit into the frame by filling the H3 bytes with payload, which does not fit into the container. The value of the next pointer is decreased by one by inverting the D bits.

The H1 byte in AU-4 pointer contains four New data flag bits (N bits) and two S bits. The s bits tell the type of AU pointer. The value "10" in S bits means that it is AU-4 pointer. The N bits can have two values "0110" and "1001". Value "0110" refers to a normal operating state. Situation where one of the bits in previously mentioned value is not correct is also interpreted as normal operating state. [7]

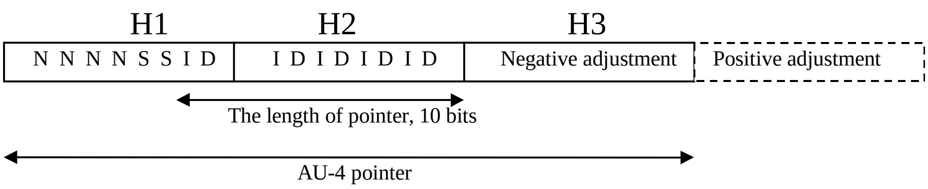


Figure 12. The structure H1 and H2 bytes in AU-4 pointer

When the N bits have the value of "1001" the pointer value is allowed to change into a completely new value. This kind of situation occurs when successive TUs are concatenated. One bit error is allowed also in this situation but all the other values are interpreted as false.

2.8.2TU-3 pointer

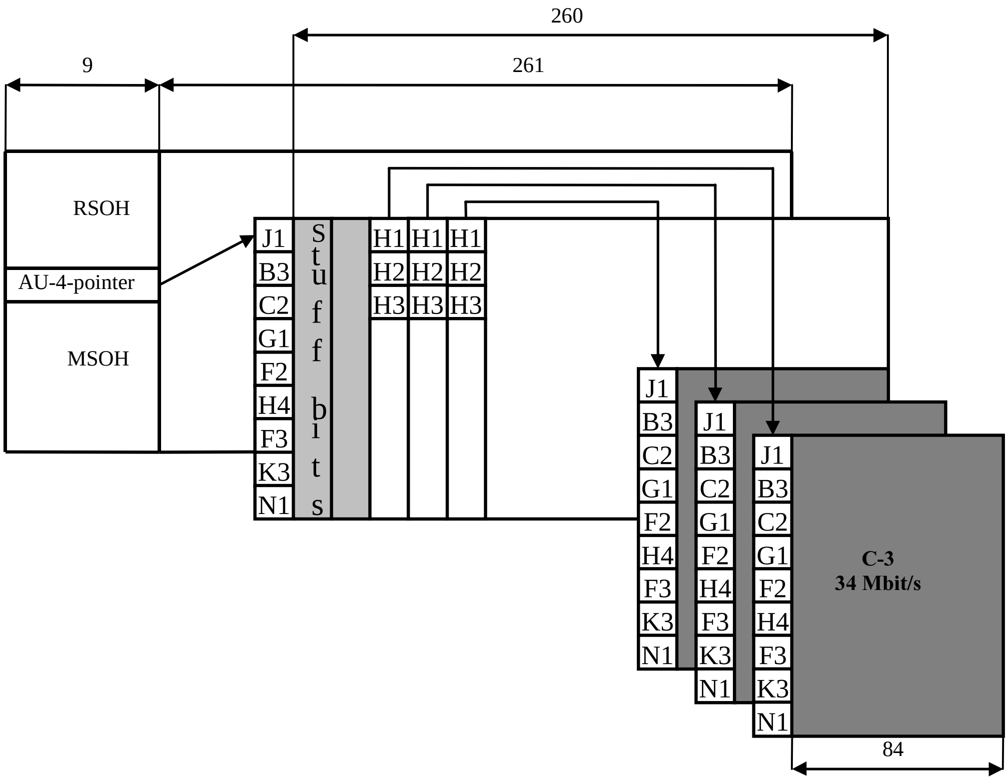


Figure 13. Structure of TU-3 pointer and C-3 mapping

H1 and H2 bytes in TU-3 pointer are used to point to the beginning of virtual container VC-3. H3 byte is used to negative adjustment as the H3 bytes in AU-4 pointer.

The bit rate adjustment and the processing of bits is done by the same principles as in AU-4 pointer. Processing is however done one byte at the time and not three bytes at the time as in AU-4 pointer.

2.8.3TU-1 and TU-2 pointers

TU-11, TU-12 and TU-2 pointers enable flexible placement of virtual containers VC-11, VC-12 and VC-12 into over frames TU-11, TU-12 and TU-

2. Over frame means that sub units in level TU-1 and TU-2 are spread into four higher level virtual containers. The duration of one over frame is the duration of four VC-4 that is 500 μs. When this spreading operation is done the pointer structure in TU-12, TU-11 and TU-2 sub units is disassembled. [7]

2.8.4 Concatenation of TU-2s

By concatenating one can raise the capacity of one channel by combining several virtual containers together. At the moment there are two standardized ways to do the concatenation with TU-2s. Those ways are virtual concatenation and concatenation of consecutive TUs.

The concatenation of consecutive TU-2s requires operations with the N bits. The common path overhead for all concatenated TU-2s is situated in the first TU-2. Allocation and flexibility of transmission capacity are weakly realized. [7] By concatenating successive TU-2 one forms a VC-2-mc structure, where there are *m* pieces of VC-2s belonging together. These VC-2s are being transmitted concatenated in *m* TU-2 sub unit.

In the virtual concatenation there is no need for the TU-2s to be situated consecutive. The limitation in this is that the concatenated sub units must be situated in the same VC-4. Other requirement is that the network elements in use must support this type of concatenation. Now there is no need to operate the N bits in TU pointers. Pointer value for each concatenated TU must be the same in the transmission end. There is also less capacity in the virtual concatenation because every TU-2 must have its own path overhead.

Also higher-level signals can be concatenated together. This happens when there is a need for greater capacity than the one provided by STM-1. Mostly the reason for this type of concatenation occurs when the transmitted signal is 622.08 Mbit/s ATM signal. The example is the concatenation of STM-4s.

Usually STM-4 signal is formed from four different STM-1 signals with byte interleaved multiplexing. The result of this is that there are four separate

VC-4s with their path overheads in the virtual container of STM-4 signal. Where as in the case of concatenated STM-4 (STM-4c) the whole virtual container is filled with one VC-4-4c, which has only one path overhead. By doing this one can transmit tributary unit signal up to the bit rate of 600 Mbit/s. When the VC-4-4s is formed the virtual container is transmitted through the whole network as one entity.

2.9 SDH network topologies and structures

SDH network as all other transmission networks has several different basic network topologies. When designing a network the things affecting the choice of the topology to be used are the network application, the complexity of the network, the wanted reliability, geographical aspects and the current network in use.

The structure of network is also affected if there is a need for unidirectional, bi-directional or broadcast network structure.

In the unidirectional structure the signal is transmitted only into one direction via one SDH network element. Distribution of video could be one application for the use of this type of coupling. In the bi-directional structure there are bi-directional cross-connects in the SDH network elements. Bi-directional structure is used for needs of telephony and communications.

In the broadcast structure the incoming virtual container is coupled in SDH network element into several outgoing virtual containers. For example The Finnish broadcasting company Yleisradio uses this structure as a part of its network.

2.9.1 Point-to-point connection

The simplest network type is the point-to-point connection. A network of this type consists of two nodes and the network between them. The special case in end to end connections is the star structure, where there is a cross-connect in the middle of several point-to-point connections starting from this cross-connect.

The type of protection with point-to-point connections can be either *1+1* or *n+1* protection, whenever it is needed. In *1+1* protection there are as many protection connections as there are connections in use. In *n+1* protection there is only one protecting connection per *n* connections.

There is also a third way to secure the connection so that there is no data going in the protecting connections, when the network is functioning normally. This protection type is called *n+m* protection. The marking means that there are *n* connections that are protected by *m* connections. This is by far the most complex way to do the protection of the connections and therefore the first two ways are the most frequent ways to do the protection.

Beside these explained ways to do the protection there are also *1:1* and *n:m* protections, where the non-prioritized traffic can be transmitted via the protecting line in situation where the network is functioning normally. [8]

2.9.2Chain network

The chain network is formed out of several consecutive network elements. Add and drop multiplexers can be used to take the tributary unit signal out from the network. Tributary unit signals can be added alike. Branching of the STM-1 level signals is done with the cross-connects.

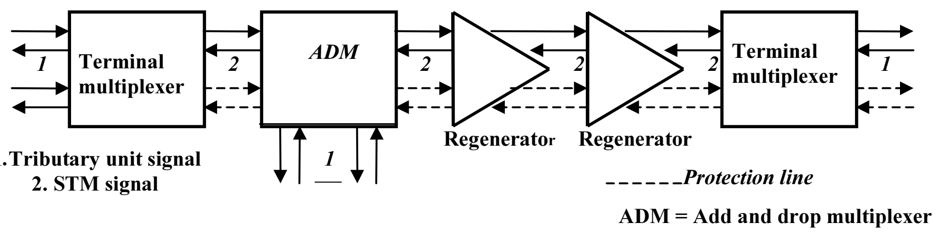


Figure 14. A chain network with 1+1 protection

2.9.3Ring network

The inherent protection feature is typical for the ring networks. Error in transmission medium or in node does not cut the traffic in bi-directional ring networks. This type of protection requires that the capacity of transmission is doubled in the case of error situations. [7]

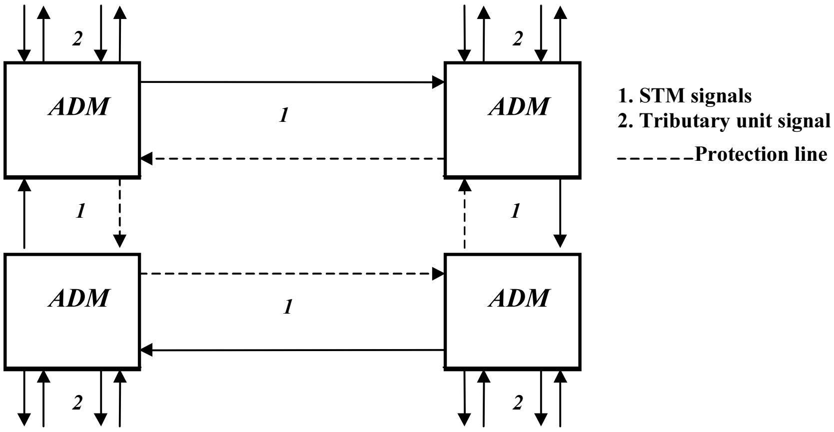


Figure 15. Ring network implemented using add and drop multiplexers.

2.9.4Mesh network

There are plenty of physical connections between the SDH network elements in network structured using mesh topology. The situation can be so radical that there are connections between every network element. This means that there are innumerable way to do the switching using mesh network solution and the network done like this has a very reliable and large capacity. This complexity makes it very hard to manage especially when it comes to synchronization.

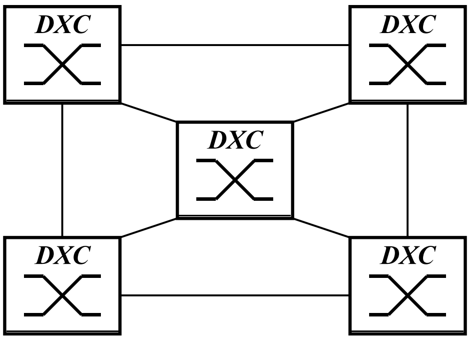


Figure 16. The principle of Mesh network topology.

2.10 Errors when transmitting data in SDH network

Transmission in SDH networks is mainly optical. Optical transmission is not as sensitive for faults as electrical transmission. Fiber optic cable has fewer interactions with the environment than electrical cable, where many different errors can be coupled. Fiber optic cable has anyhow errors caused by its physical characteristics such as: the attenuation in fiber optic cable, absorption, scattering, radiation losses and the distortion of optical signal. The greatest threat is anyhow the break of the fiber.

When a cable break or a failure similar to it happens, SDH network re-routes all traffic in few milliseconds. STM frame provides the information what to do if the frame cannot reach its recipient. This information is always added into well-defined bytes. The most common instruction in the case of cable brake is to go back the same route and try to reach the end point using different route. When this re-routing is done add and drop multiplexer notices the re-routed frame and it commands the switch to change all data going to this non-functioning line into an alternative route.

2.11 Overview of data transfer

There are several different quality parameters defined for data transfer. This study is founded on ITU-T recommendation G.826. According to this recommendation the performance observation is based on the allocation of bit stream into blocks. The whole performance observation will return into comparison of parameters and definition of some boundaries for these parameters. [9]

2.12 Definitions in error examination

Block

Block is a group of successive bits in transmission medium. Every bit belongs only to one block. The size of block and the number of bits in one block vary depending on the transmission rate of transmission medium. Every block is being supervised by a certain error identification code. Cyclic redundance check and bit interleaved parity are examples of those codes. The error definition codes can be physically situated in a different place than the block they are supervising.

Error Block, EB

Error block is a situation when the information in the error identification code is in conflict with the bit content of block. In principle there can be an error either in the code or in the block but the supposition is that, when the conflict occurs the reason is an error in the block.

Error Second, ES

Error second is a unit that has a length of one second and contains one or more error blocks.

Several Errors Second, SES

If a period of one second contains more than 30% of error blocks it is called several errors second. SES is a sub-group to error second, so it is also error second

Background Block Error, BBE

Background block error is a definition of an error that is not happening within several error second.

Unavailable Seconds, UAS

Unavailable seconds define the time of disuse. When ten successive several error seconds have occurred it is said that the transmission medium is in disuse state. These ten seconds are also counted into disuse time. When ten successive seconds without SESs occurs the transmission medium is again in usability state.

2.13 Alarms

Some most important alarms in SDH network are explained next. SDH equipment is set into alarm state if one specified error situation occurs. There are about twenty different alarms in SDH systems.

Los Of Signal, LOS

LOS alarm is given if the SDH equipment notices that the signal level is below some specification, usually so low that the information cannot be separated from noise. There is also usually a measurement in network elements for both optical and electrical power depending on the transmission medium.

Los Of Frame, LOF

When a SDH network equipment cannot receive correct frame bytes, the network element defines the frame lost. LOF alarm is given only if the frame bytes are incorrect during a certain time. When the network element recognizes the correct bytes again the alarm is removed.

Loss Of Pointer, LOP

LOP alarm is triggered if the network element receives certain amount of faulty pointers. This alarm is removed if three successive pointers are received perfectly or every bit in three successive pointers is ones. In the latter case the alarm is AIS.

Degraded Signal, DEG

DEG alarm is given if the amount of alarms in transmission medium exceeds some chosen value, which can vary between 1E5 – 1E9.

2.13.1 The consequences of the alarms

When a node in SDH network is set into alarm state. Information about this is sent both forwards and backwards to the network. Transmission medium is divided into downstream and upstream according to the direction of data transmission. When an alarm is noticed for example in the regenerator overhead it would be a waste of resources to analyze the same signal in lower-levels. Therefore in the section where the error is discovered all the bits are set to one. When a lower-lever section realizes that certain bits are one it admits the signal to continue straightforward after it has changed the bits concerning the section into one. This signal where all bits are eventually one is called alarm indication signal, AIS. AIS is therefore a result of error situation in downstream. [10]

The information about the error is sent also into upstream so that one can effect the cause of error. The signal sent to upstream is remote defect signal, RDI, which tell that the transmission medium cannot transmit any data.

2.14 Protection of connection

The type of protection depends largely on how much and how important the protected traffic in the connection is. If there is only little ”not so important” data going in the network (this is not the case usually) equipment protection switching, EPS, technique is used. In this technique the number of network elements in use is doubled. EPS *1+1* and EPS *n+1* are the types of EPS.

If the amount of traffic is big the protection to be used is cable protection or/and technique called automatic protection switching, APS. APS is further spread technique than EPS.

Two basic types of protection architecture are distinguished in APS. One is the linear protection mechanism used for point to point connections. The other basic form is the so-called ring protection mechanism that can take on many different forms. Both mechanisms use spare circuits or components to provide the back-up path. Switching is controlled by the overhead bytes K1 and K2.

2.14.1 Linear protection

The simplest form of backup is the so-called 1+1 APS. Here, each working line is protected by one protection line. If a defect occurs, the protection agent in the network elements at both ends switches the circuit over to the protection line. The switchover is triggered by a defect such as LOS. Switching at the far end is initiated by the return of an acknowledgment in the backward channel.

1+1 protection architecture includes 100% redundancy, as there is a spare line for each working line. Economic considerations have led to the preferential use of 1:N architecture, particularly for long-distance paths. In this case, a single back-up line protects several working lines. If switching is necessary, the two ends of the affected path are switched over to the back-up line. The 1+1 and 1:N protection mechanism are standardized in ITU-T Recommendation G.783.

The reserved circuits can be used for lower-priority traffic, which is simply interrupted if the circuit is needed to replace a failed working line.

2.14.2 Ring protection

The greater the communications bandwidth carried by optical fibers, the greater the cost advantages of ring structures as compared with linear structures. A ring is the simplest and most cost-effective way of linking a number of network elements.

Various protection mechanisms are available for this type of network architecture, only some of which have been standardized in ITU-T Recommendation G.841. A basic distinction must be made between ring structures with unidirectional and bi-directional connections.

2.14.3 Unidirectional rings

Figure 17 shows the basic principal of APS for unidirectional rings. Let us assume that there is an interruption in the circuit between the network elements A and B. Direction y is unaffected by this fault. An alternative path must, however, be found for direction x. The connection is therefore switched to the alternative path in network elements A and B. The other network elements C and D switch through the back-up path. This switching process is referred to as line switched. A simpler method is to use the so-called path switched ring (see figure 17). Traffic is transmitted simultaneously over both the working line and the protecting line. If there is an interruption, the receiver (in this case A) switches to the protection line and immediately takes up the connection.

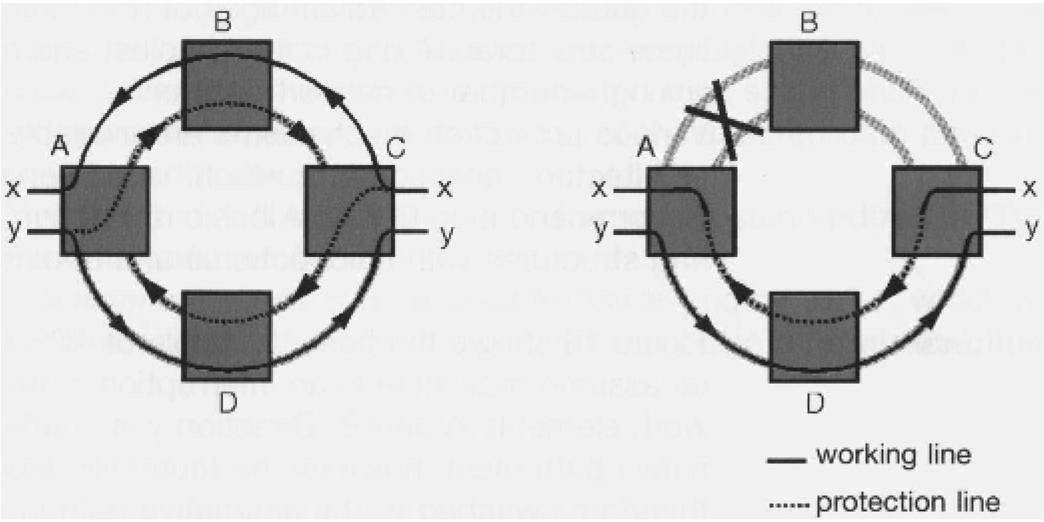


Figure 17 .Two fiber unidirectional path switched ring [6]

2.14.4 Bi-directional rings

In this network structure, connections between network elements are bi-directional. This is indicated in figure 18 by the absence of arrows when compared with figure 17. The overall capacity of the network can be split up for several paths each with one bi-directional working line, while for unidirectional rings, an entire virtual ring is required for each path. If a fault occurs between neighbor elements A and B, network element B triggers protection switching and controls network element A by means of the K1 and K2 bytes in the SOH.

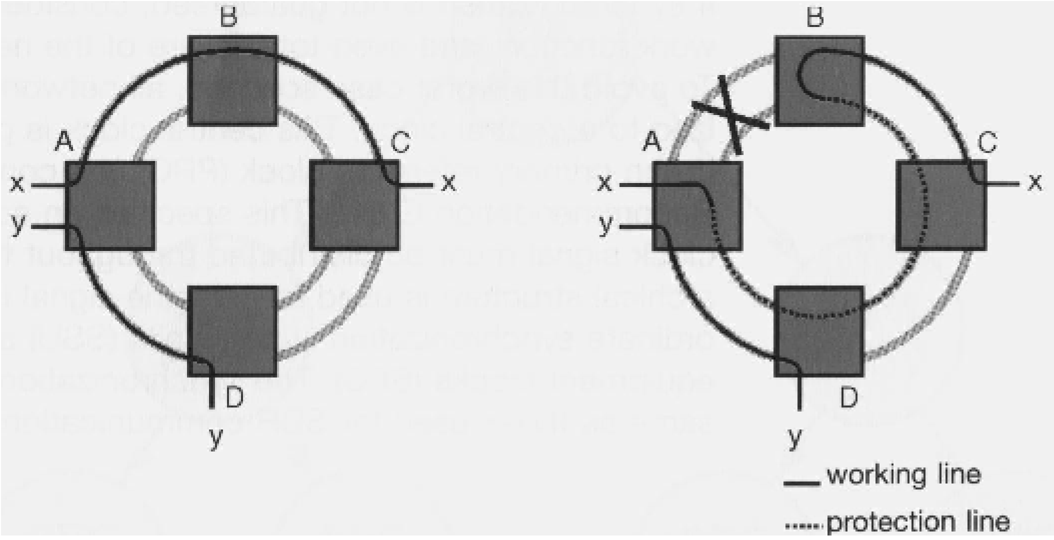


Figure 18. Two fiber bi-directional line-switched ring [6]

Bi-directional rings provide even greater protection with 4 fibers. Each pair of fiber transports working and protection channels. This results in 1:1 protection, which means 100% redundancy. This improved protection is coupled with relatively high costs.

2.15 Synchronization

Synchronous is the first word in the term SDH for a very good reason. If synchronization is not guaranteed, considerable degradation in network function, and even total failure of the network can be the result. To avoid this worst case scenario, all network elements are synchronized to a central clock. This clock is generated by a high-precision primary reference clock (PRC) unit confirming to ITU-T Recommendation G.811. This specifies an accuracy of 10^{-11}. This clock signal must be distributed throughout the entire network. A hierarchical structure is used for this; the signal is passed on by the sub-ordinate synchronous supply unit (SSU) and synchronous equipment clocks (SEC). The synchronization signal paths can be the same as those used for SDH communications.

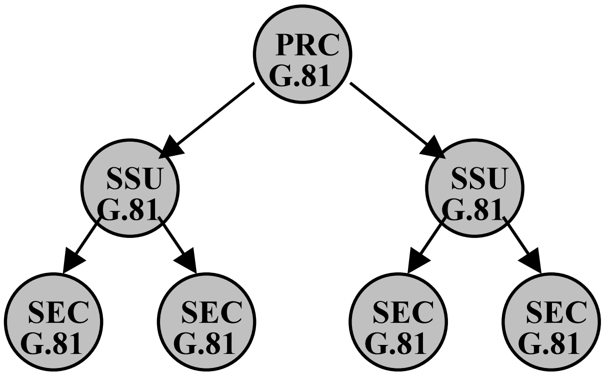


Figure 19. Clock supply hierarchy structure

The clock signal is regenerated in the SSUs and SECs with the aid of phase-locked loops. If the clock supply fails, the affected network element switches over to a clock source with the same or lower quality, or if this is not possible, it switches to holdover mode. In this situation, the clock signal is kept relatively accurate by controlling the oscillator by applying the stored frequency correction values for the previous hours and taking the temperature of the oscillator into account. Clock "islands" must be avoided at all costs, as these would drift out the synchronization with the passage of the time and the total failure disaster would be the result. Clock "island" is a situation where for example the clock signal coming out of SSU would be defined as its own higher-level clock signal via several network elements. Such islands are prevented by signaling the network elements with the aid of synchronization status message (SSM, part of byte B1). The SSM informs the neighboring network element about the status of the clock supply and is part of the overhead.

Special problems arise at gateways between networks with independent clock supplies. SDH network elements can compensate for clock offsets within certain limits by means of pointer operations. Pointer activity is thus a reliable indicator of problems with clock supply.

2.16 Compatibility and coupling of SDH networks

Some errors in compatibility between different SDH networks can be aroused, when new features are taken into use in new equipment and the old equipment does not support these features. Originally ITU-T and ETSI recommendations concentrated only on defining the optical and electrical interfaces. Afterwards new guidelines have been found to support the functionality of the network. These features concern for example the synchronization of the network, alarms when a false routing occurs, the protection of the traffic and monitoring of the performance in the networks of several network operators. [11]

An SDH operator using equipment and software only from one vendor can guarantee the compatibility easily by updating the equipment one at the time when a new features is taken into use. But problems arise when moving from one network to another and these networks are operated by different SDH operators. If these operators are also using different vendors crucial problems will arise and networks can support different features. [12]

To ensure compatibility signals from all levels should be tested, as well as the response of the network to these signals. For example if B2 errors are put into some section but the REI will not return one must test that the network element is functioning if a REI send to it too.

2.17 ATM over SDH

In SDH the ATM cells are mapped row by row into C1, C12, C3 and C4 containers. Pointer must point towards the place of J1 byte in floating payload. If the capacity of the container is not the same size with the capacity of ATM bandwidth, ATM bandwidth can be divided into to several STM frames by using either virtual or contiguous concatenation. These techniques were introduced previously. Interesting notification is that interfaces can be used asymmetrically. For example a user can send using bit rate of 622 Mbit/s and receive the same information using 155 Mbit/s. It is possible to put 44 ATM cells into one C-4 container. This leaves 8 bytes unused for the next cell.

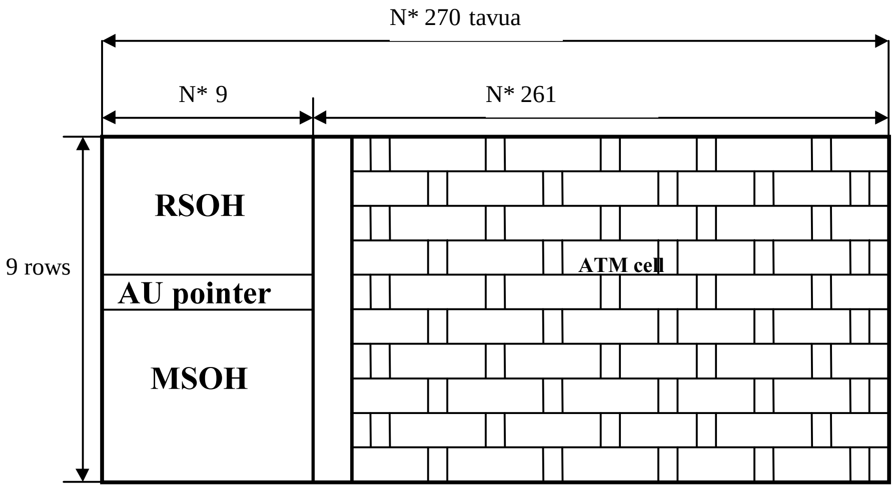


Figure 20. ATM cells in SDH container

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