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Telecommunication Networks
Transport Networks

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Transport Networks

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Basic Characteristics

- Transport networks are intended for creating a switched infrastructure, using which it is possible to organize quickly and flexibly a permanent point-to-point channel between two end devices. Transport networks employ the circuit switching technique. Overlay networks, such as computer or telephone networks, operate on the basis of circuits formed by transport networks at the OSI physical layer.
- The channels provided by transport networks to their subscribers are distinguished by high bandwidth – usually ranging from 2 Mbit/s to 10 Gbit/s.
- There are three generations of transport networks:
  1) Plesiochronous Digital Hierarchy (PDH),
  2) Synchronous Digital Hierarchy (SDH) (and SONET in USA),
  3) Dense Wavelength Division Multiplexing (DWDM).

- PDH and SDH use Time Division Multiplexing (TDM) for sharing the link capacity and transmitting data in digital form. Each of these technologies supports a transmission rate hierarchy, so the user can choose the desired rate for the channels on the basis of which the overlay network will be built. The SDH technology ensures higher rates than PDH; therefore, when building a large transmission network, its backbone is usually based on the SDH technology and the access network employs the PDH technology.
- DWDM networks are the latest achievement in the creation of fast communication channels. They provide their users with a separate optical wavelength for information transmission.

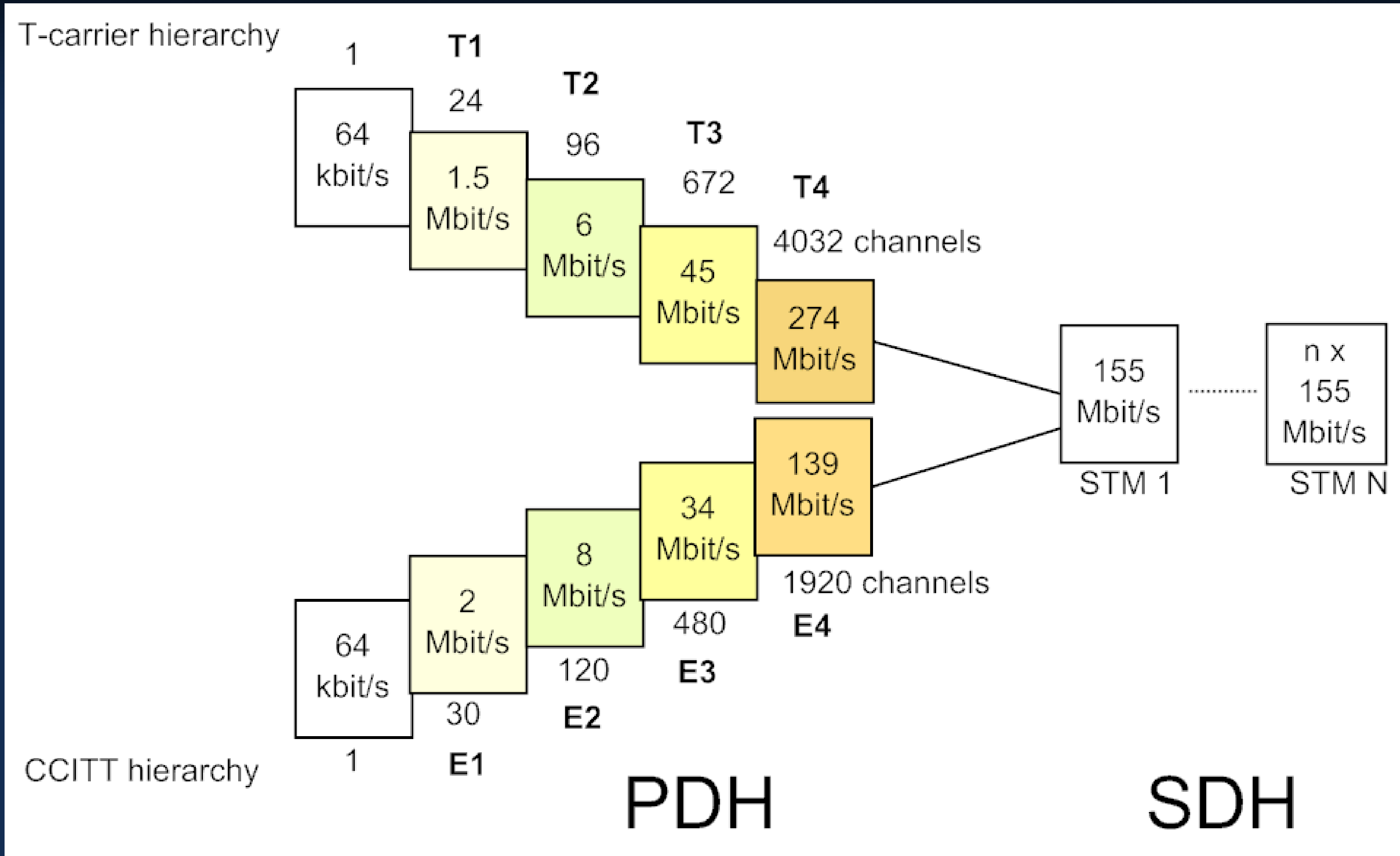
PDH (Plesiochronous Digital Hierarchy)

- PDH was developed in the late 1960s by AT&T to solve the problem with interconnecting telephone exchanges of large telephone networks. FDM (Frequency Division Multiplexing) channels, which were used previously for solving this problem, had exhausted their possibilities of organizing high speed multichannel communications through a single cable by that time.
- The starting point of the PDH technology evolution was the development of the T-1 multiplexer, which can multiplex, switch and transmit (continuously) voice traffic in digital form from 24 subscribers. Since subscribers continued to use standard phone sets, which meant that voice transmission took place in an analog form,

T1 multiplexers automatically sampled voices at a rate of 8000 Hz and encoded voices using pulse code modulation. As a result, each local loop formed a 64 kbit/s digital data flow and the entire T-1 line ensured bandwidth of 1.544 Mbit/s.

- T-1 links were not sufficiently powerful and flexible multiplexing tools for connecting large automatic exchanges. Therefore, the idea of forming communication links with a rate hierarchy was implemented. Four T-1 links were joined to form the links of the next level of digital hierarchy – T-2, transmitting data at a rate of 6.312 Mbit/s. The T-3 link created by joining seven T-2 links has a rate of 44.736 Mbit/s. The T-4 link joins six T-3 links; as a result, its rate is 274.176 Mbit/s. This technology becomes known as T-carrier system. It allows the transmission not only of voice but also of computer data.

- The T-carrier systems technology was standardized by ANSI and CCITT (today's ITU-T) as PDH. As a result of modifications introduced by CCITT, American and international versions of the PDH standards became incompatible. In the international standard, the analogues of the T-links are E-1 (2.048 Mbit/s), E-2 (8.488 Mbit/s), E-3 (34.368 Mbit/s) and E-4 (139.264 Mbit/s) links. The international standard is in use in Europe. Despite the differences of both versions, they use the same notation for designating the hierarchy of speeds – digital signal level n (DS-n) (e.g., DS-1 represents both, T-1 and E-1).
- In practice, the E-1/T-1 and E-3/T-3 links are most widely used.



Hierarchy of transmission rates in PDH technology

- PDH has several drawbacks:
  - The inefficiency of multiplexing and demultiplexing operations – PDH has a lack of full synchronization (plesiochronous means „nearly synchronous“) when multiplexing slow channels into faster ones. Initially, the plesiochronous approach to frame transmission makes it necessary to insert synchronization bits between frames. As a result, to retrieve user data from a multiplexed channel, it is necessary to demultiplex fully the frames from the aggregate channel.
  - PDH does not provide built-in network management and fault tolerance tools.
  - PDH has slow bit rates to be used in backbone networks.

SDH (Synchronous Digital Hierarchy)

- All drawbacks of the PDH technology were taken into account and eliminated by the developers (ANSI) of the Synchronous Optical Network (SONET). The first version of this standard appeared in 1984. Later an international standard known as Synchronous Digital Hierarchy (SDH) was created. The goal was to create technology capable of transmitting the traffic of all existing digital channels of the PDH level (E-1 – E-4 and T-1 – T-3) using high speed backbone based on fiber-optic cables and to ensure a speed hierarchy that would continue the PDH hierarchy to the rates of several gigabits per second.
- SDH (used in Europe) and SONET (used in USA) networks are compatible but not identical.

SDH	SONET	Bit rate [Mbit/s]
	STS-1, OC-1	51.84
STM-1	STS-3, OC-3	155.52
STM-3	OC-9	466.56
STM-4	OC-12	622.08
STM-6	OC-18	933.12
STM-8	OC-24	1 244
STM-12	OC-36	1 866
STM-16	OC-48	2 448
STM-64	OC-192	9 953
STM-256	OC-768	39 810

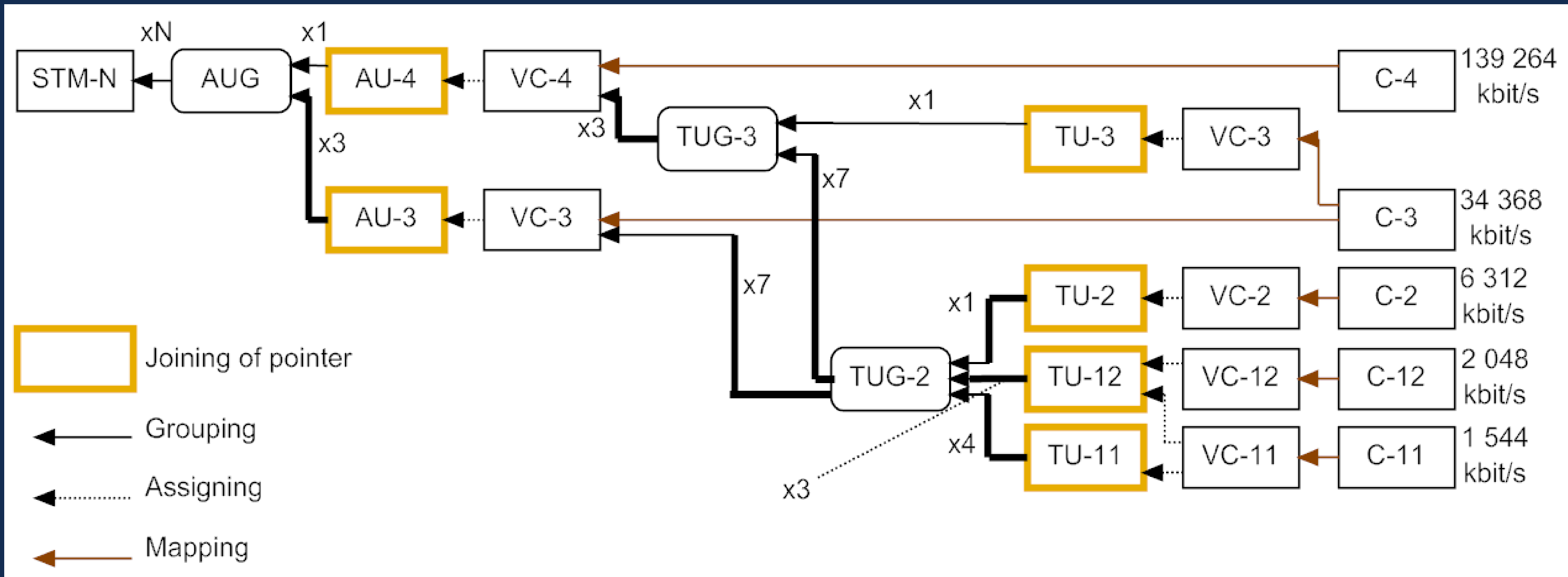
Hierarchy of transmission rates in SDH technology

- In the SDH standard, all rate levels (and, accordingly, the frame formats for these levels) have a common name: synchronous transport module level N (STM-N). In the SONET technology, there are two designations for the speed levels: synchronous transport signal level N (STS-N), used for transmission by electric signals, and optical carrier level N (OC-N), used when data is transmitted by fiber-optic cable.
- STM-N frames have a complicated structure allowing the aggregation of SDH and PDH streams of different rates into the common backbone stream and the performance of add/drop operations without full demultiplexing of the backbone stream.

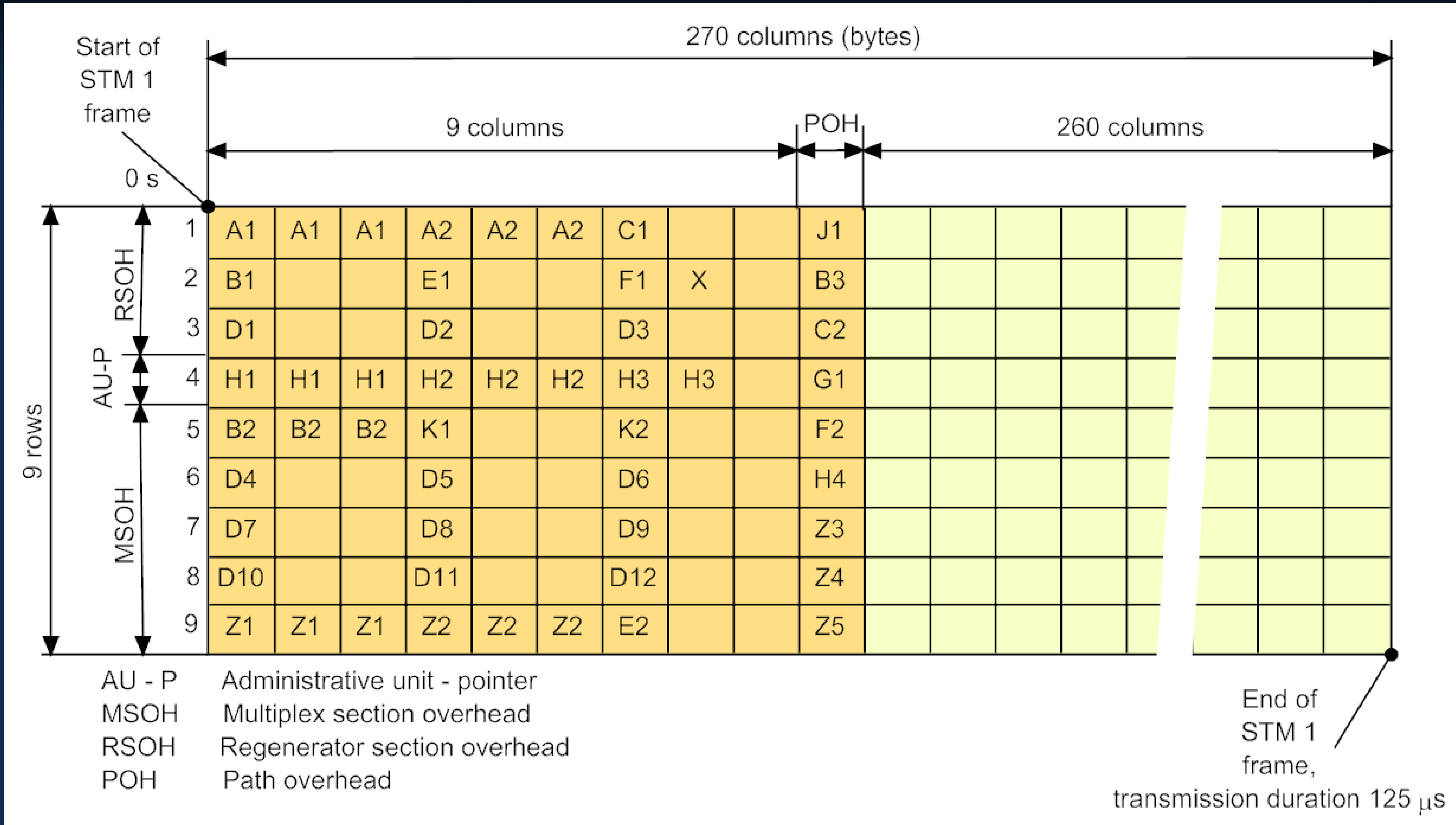
- Multiplexing and add/drop operations use virtual containers in which PDH data blocks can be transported through the SDH network. Besides PDH data blocks, auxiliary control information is placed into virtual containers, including the container’s path overhead header. This header contains statistic information on the process of passing the container along its route from source to destination (error messages) as well as control data, such as an indicator of connection establishment between the end points. As a result, the size of virtual container is larger than the corresponding PDH payload that it carries.
- In each multiplexer, there is a connection table that specifies, for example, that VC-12 of the P1 port is connected to VC-12 of the P5 port. These connection tables are configured by the network administrator.

- To combine the synchronous transmission of STM-N frames with the plesiochronous nature of PDH frames, the SDH technology uses pointers. The pointer determines the current position of a virtual container in the higher layer structure – a tributary unit and an administrative unit. The main difference of these units from virtual containers is the presence of an additional pointer field. Because of the use of pointers, a virtual container can “float” within certain limits inside its tributary or administrative unit, which, in contrast, has a fixed position within a STM-N frame. Because of the system of pointers, the multiplexer is able to find the position of user data in the synchronous byte stream of the STM-N frame and to retrieve it.
- Tributary units are joined into groups, which are grouped into administrative units. The group of N administrative units makes up the payload of the STM-N frame.

- At each step of user data transformation, several control bytes are added to the source data. These auxiliary bytes help to recognize the structure of the block or group of blocks and then, using pointers, determine the starting point of the user data.



Method of data multiplexing in SDH



Start of
STM 1
frame
0 s
270 columns (bytes)
9 columns
POH
260 columns
9 rows
RSOH
AU-P
MSOH
1 A1 A1 A1 A2 A2 A2 C1 J1
2 B1 E1 F1 X B3
3 D1 D2 D3 C2
4 H1 H1 H1 H2 H2 H2 H3 H3 G1
5 B2 B2 B2 K1 K2 F2
6 D4 D5 D6 H4
7 D7 D8 D9 Z3
8 D10 D11 D12 Z4
9 Z1 Z1 Z1 Z2 Z2 Z2 E2 Z5
AU - P Administrative unit - pointer
MSOH Multiplex section overhead
RSOH Regenerator section overhead
POH Path overhead
End of
STM 1
frame,
transmission duration 125 μs

STM-1 frame

Equipment Types

- The main element of the SDH network is the multiplexer. Usually, it is equipped with a certain number of PDH and SDH ports. Ports of the SDH multiplexer are classified into aggregate (often called as line) and tributary (often called as add/drop). SDH multiplexers are divided into two types: 1) Terminal multiplexer – terminates an aggregate channel by multiplexing numerous tributary channels in it. 2) Add/drop multiplexer – takes an intermediate position in the backbone. It has two aggregate ports for transmission of the aggregate data stream. Using a small number of tributary ports, such as multiplexer adds or drops the data of tributary channels to or from the aggregate stream.
- Sometimes there are digital cross-connectors – multiplexers that carry out switching operations over arbitrary virtual containers. In such multiplexers, there are no differences between aggregate and tributary ports, since such multiplexer is intended for operation in the mesh topology, where it is impossible to single out aggregate streams.

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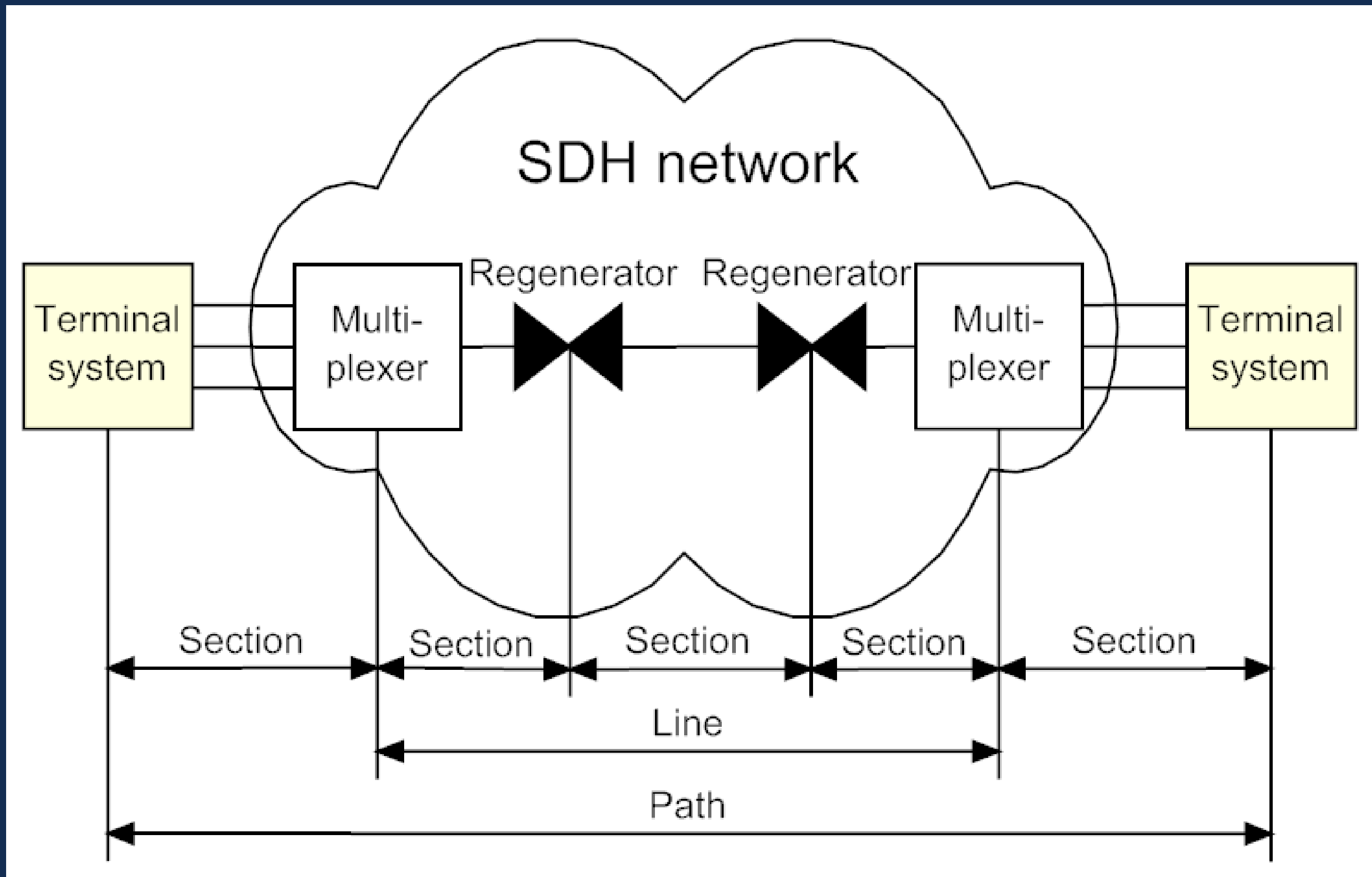
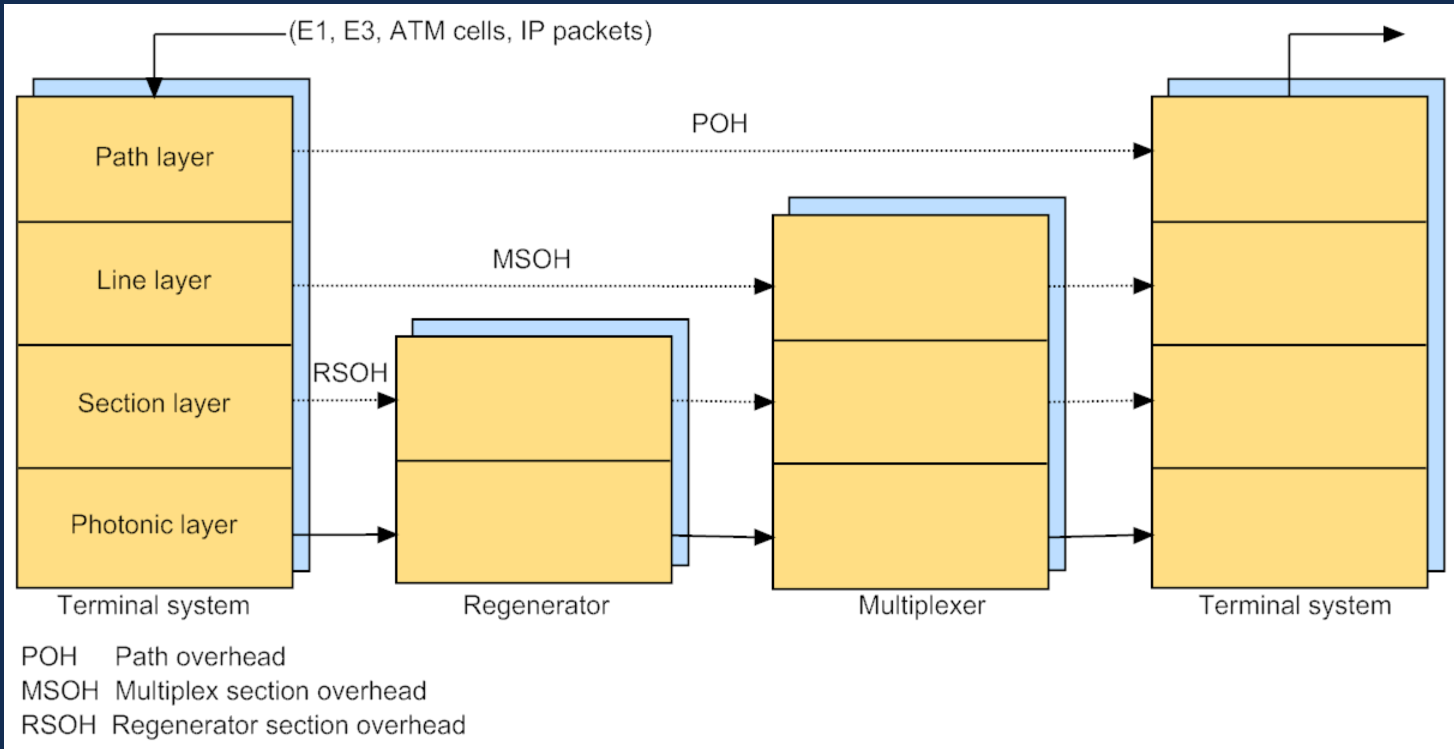
- Besides multiplexers, the SDH network can contain regenerators that are used to regenerate optical signals, when they are transmitted over a long distance.



SDH network architecture

SDH Protocol Stack

- The SDH protocol stack comprises four layers but the whole SDH technology lies at the RM OSI physical layer:
  1) Photonic layer
  2) Section layer
  3) Line layer
  4) Path layer



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Topologies of SDH Networks

- Ring of add/drop multiplexers.
- Linear sequence of add/drop multiplexers with terminal multiplexers at the ends of the network.
- Mesh network with digital cross-connectors.

DWDM (Dense Wavelength Division Multiplexing)

- The DWDM technology is intended for creating optical backbones of the new generation, operating at multigigabit or terabit rates. Such performance leap is ensured by multiplexing method, principally different from the one used in SDH networks. In DWDM networks, information in an optical fiber is transmitted simultaneously by numerous light wavelengths (λ).
- DWDM networks operate according to the circuit switching principle and each light wavelength is a separate spectral channel. Each wavelength carries its own information.
- DWDM equipment is not directly engaged in solving the problems of data transmission on each wavelength – that is, in choosing the method of information encoding and protocol of its transmission.

- Its main functions are multiplexing and demultiplexing operations, namely, combining different wavelengths within the same signal beam and separating the function of each spectral channel from the aggregate signal. The most advanced DWDM devices can also switch wavelengths.
- The first application of the DWDM technology were the long-distance backbones intended for connecting two SDH networks. With this simplest point-to-point topology, the capability of DWDM devices to accomplish wave switching is redundant. However, as technology evolves and the topology of DWDM networks becomes more sophisticated, this function becomes necessary.
- All multiplexing and switching operations are carried out over light signals without transforming them into an electric form (like in SDH technology or optical Ethernet).

Operating Principles

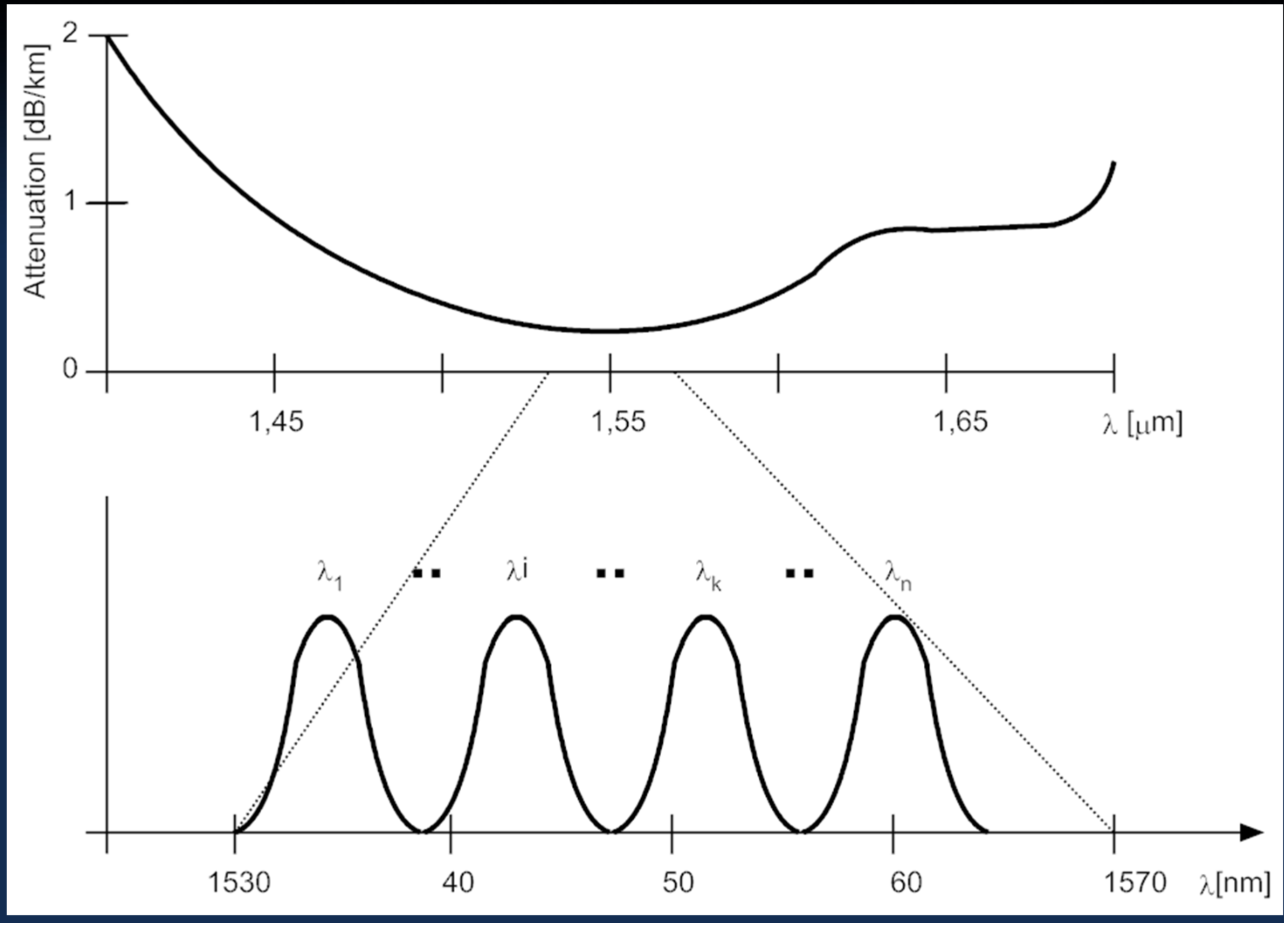
- The DWDM equipment allows transmission using one optical fiber with many various wavelengths in the transparency window of 1 550 nm, each wavelength being capable of carrying information at a rate up to 10 Gbit/s. Research work in progress aims to increase the information rate at each wavelength to between 40 Gbit/s and 100 Gbit/s.
- The predecessor of DWDM was the wavelength division multiplexing (WDM) technology, which uses four spectral channels in transparency windows of 1 310 nm and 1 550 nm, with spacing between the 800 GHz and 400 GHz carriers.
- DWDM multiplexing is called dense because it uses a significantly smaller distance between wavelengths than that is used by WDM:

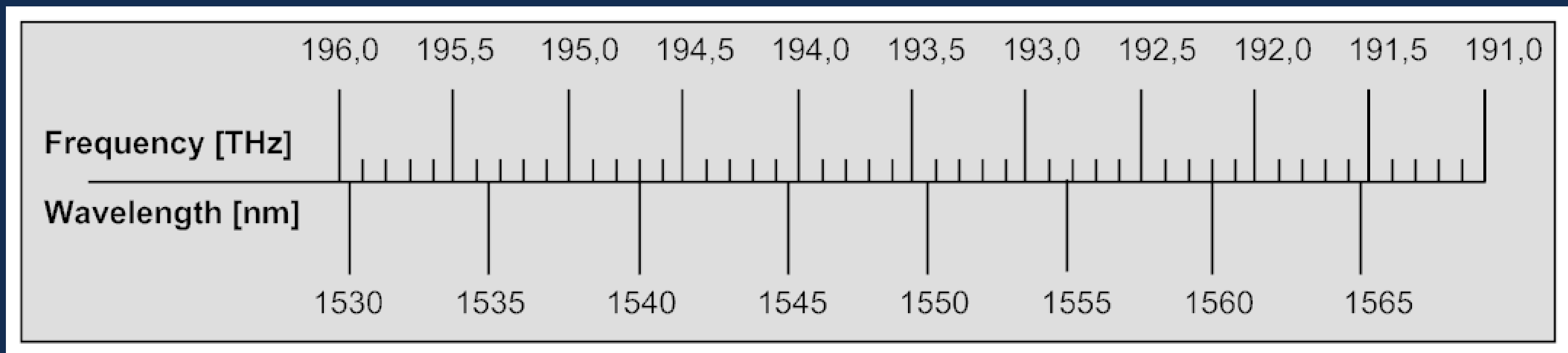
- Frequency grid (i.e. set of frequencies separated from each other by a specific value) with frequency spacing between adjacent channels of 100 GHz ($\Delta\lambda$ = 0.8 nm), according to which 41 wavelengths ranging from 1 528.77 nm (196.1 THz) to 1 560.61 nm (192.1 THz) are used.

- Frequency grid with a spacing of 50 GHz ($\Delta\lambda$ = 0.4 nm), allowing transmission of 81 wavelengths in the same range.

Note: $c = \lambda \cdot f$ where c is the speed of light in vacuum.

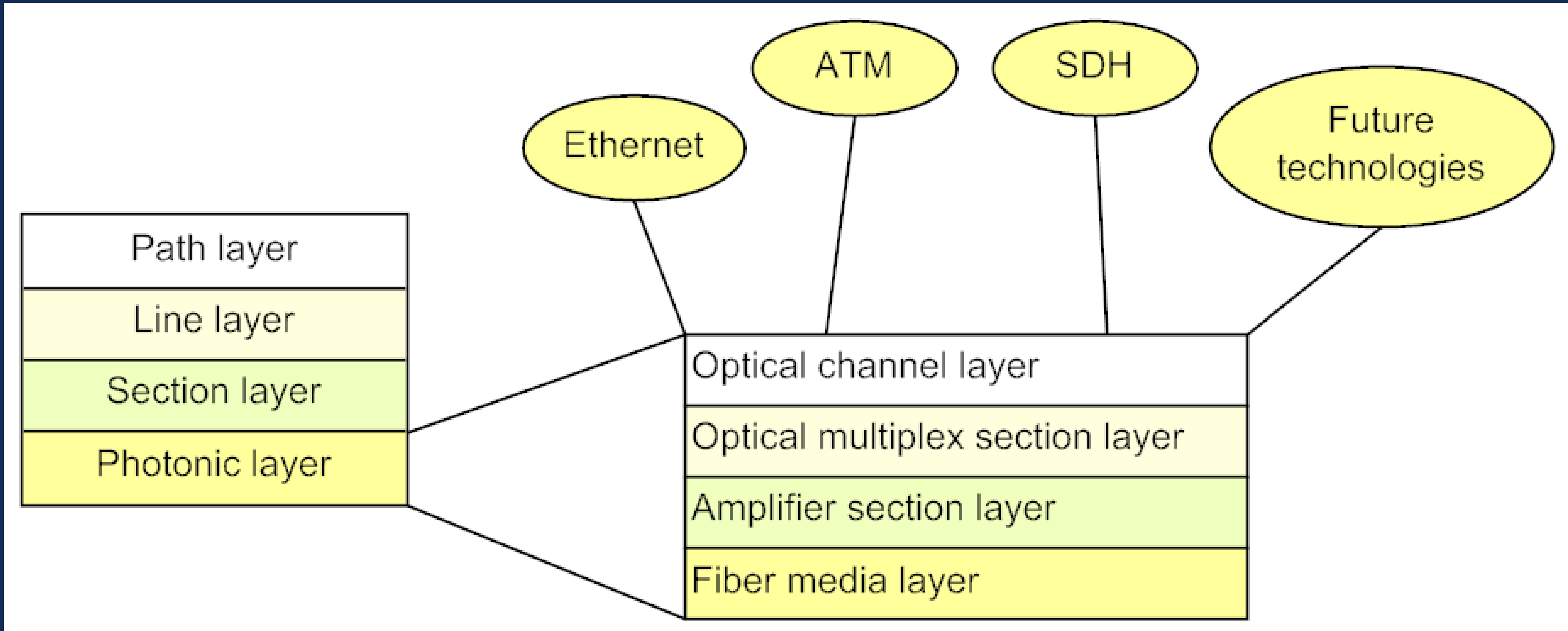
- Some companies also manufacture equipment known as high-dense WDM, capable of operating with the frequency step of 25 GHz thereby 161 wavelengths can be used.





Optical wavelengths used in DWDM

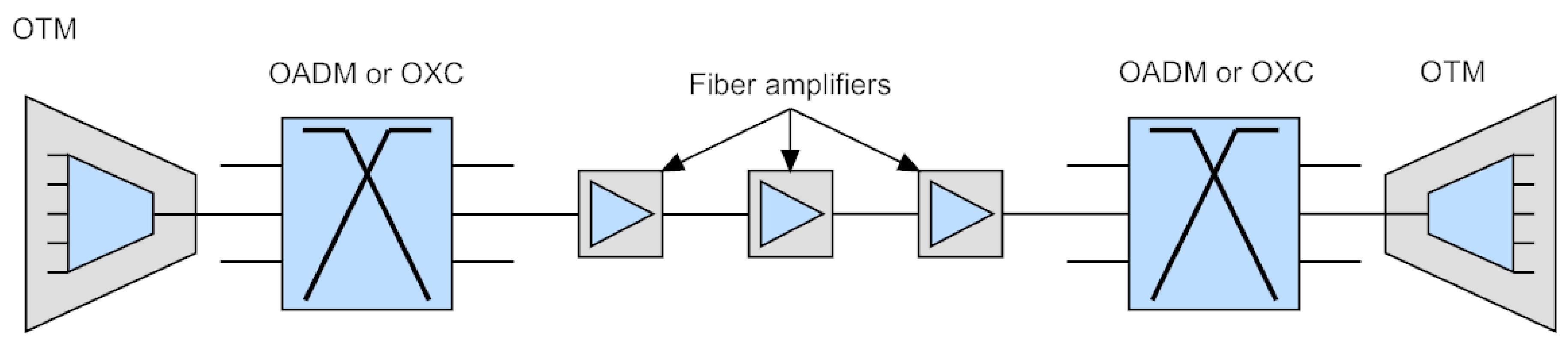
DWDM Protocol Stack



Comparison of SDH and DWDM protocol stacks

Equipment Types

- Fiber (optical) amplifier
- Optical terminal multiplexer (OTM)
- Optical add/drop multiplexer (OADM)
- Optical cross-connector (OXC)

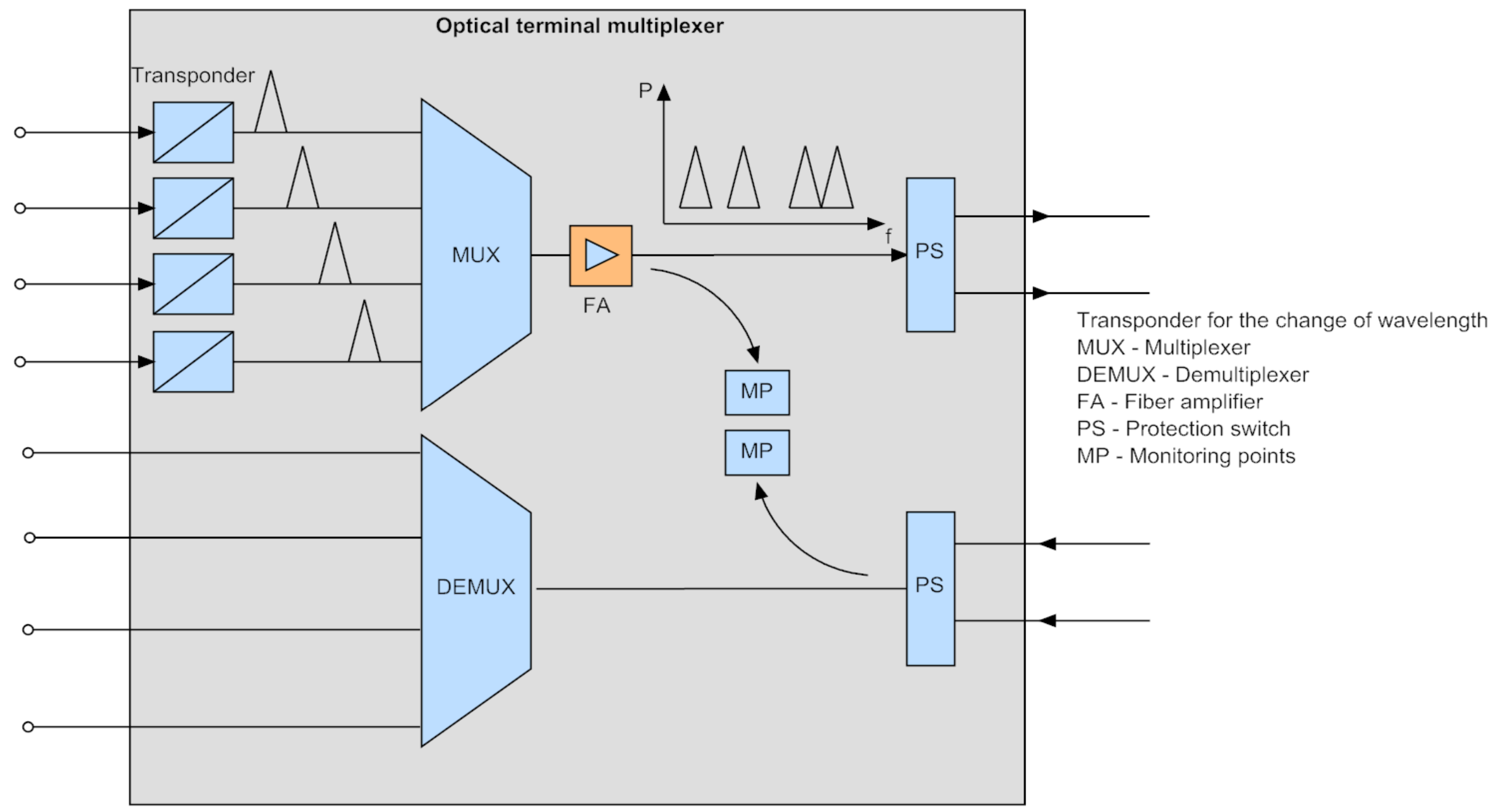


Equipment types in DWDM network

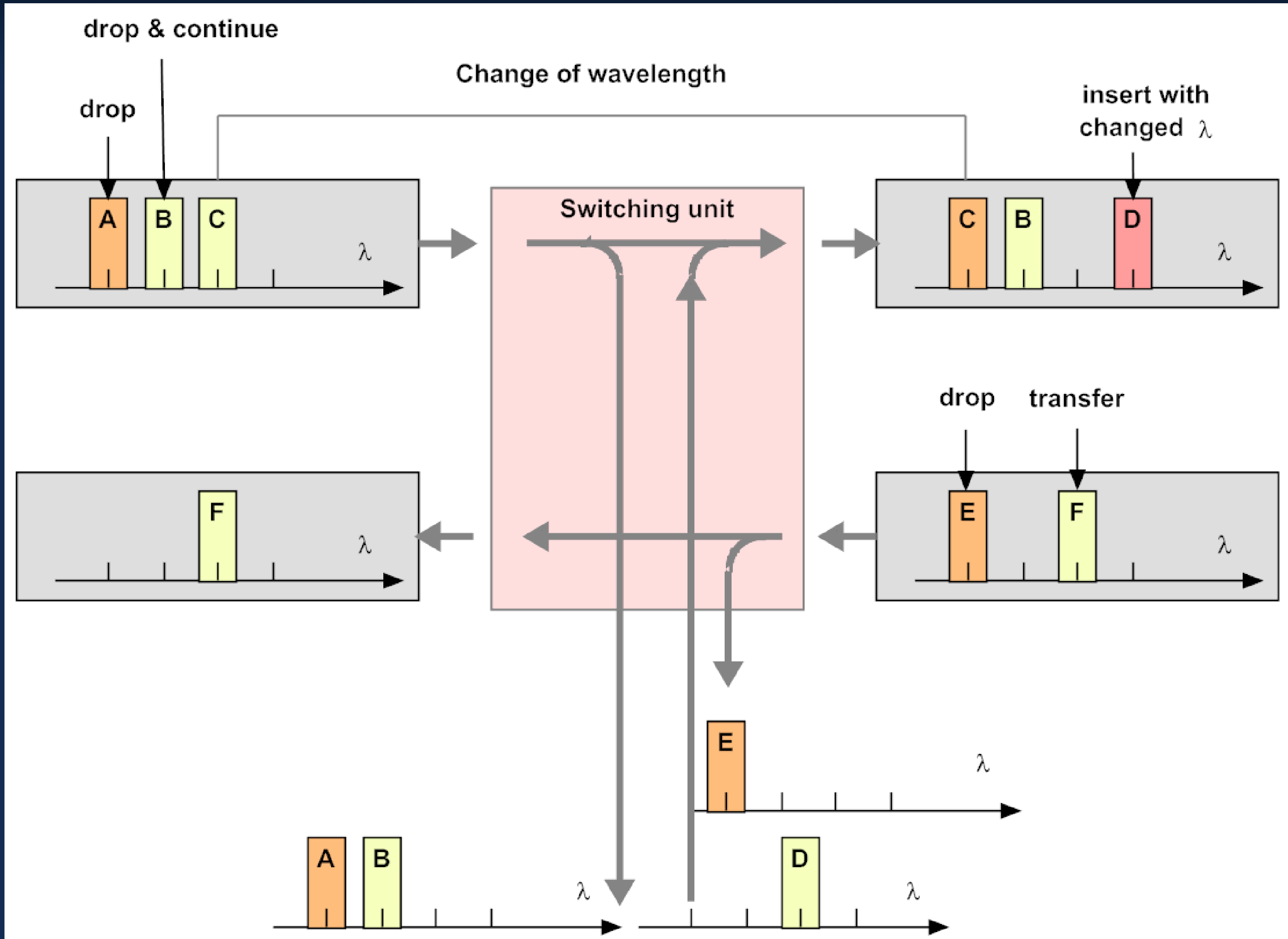
Fiber amplifiers

- Fiber amplifiers directly amplify the light signals, thus eliminating the necessity of intermediate conversion of these signals into electric form, as it is done by the regenerators used in SDH networks.
- The length of the section between two optical amplifying units can reach 150 km or more, which ensures the economic efficiency of the DWDM backbones, where the length of a multiplex section is 600 – 3 000 km provided that from 1 to 7 intermediate optical amplifiers are used. The limitation of the length of a multiplex section is the fact that although the optical amplifier can restore the signal power, it does not fully compensate the effect of chromatic dispersion. Because of this it is necessary to install DWDM multiplexers between the amplification sections for building long distance backbones. These DWDM multiplexers regenerate the signal by transforming it to electric form and then back to optic.

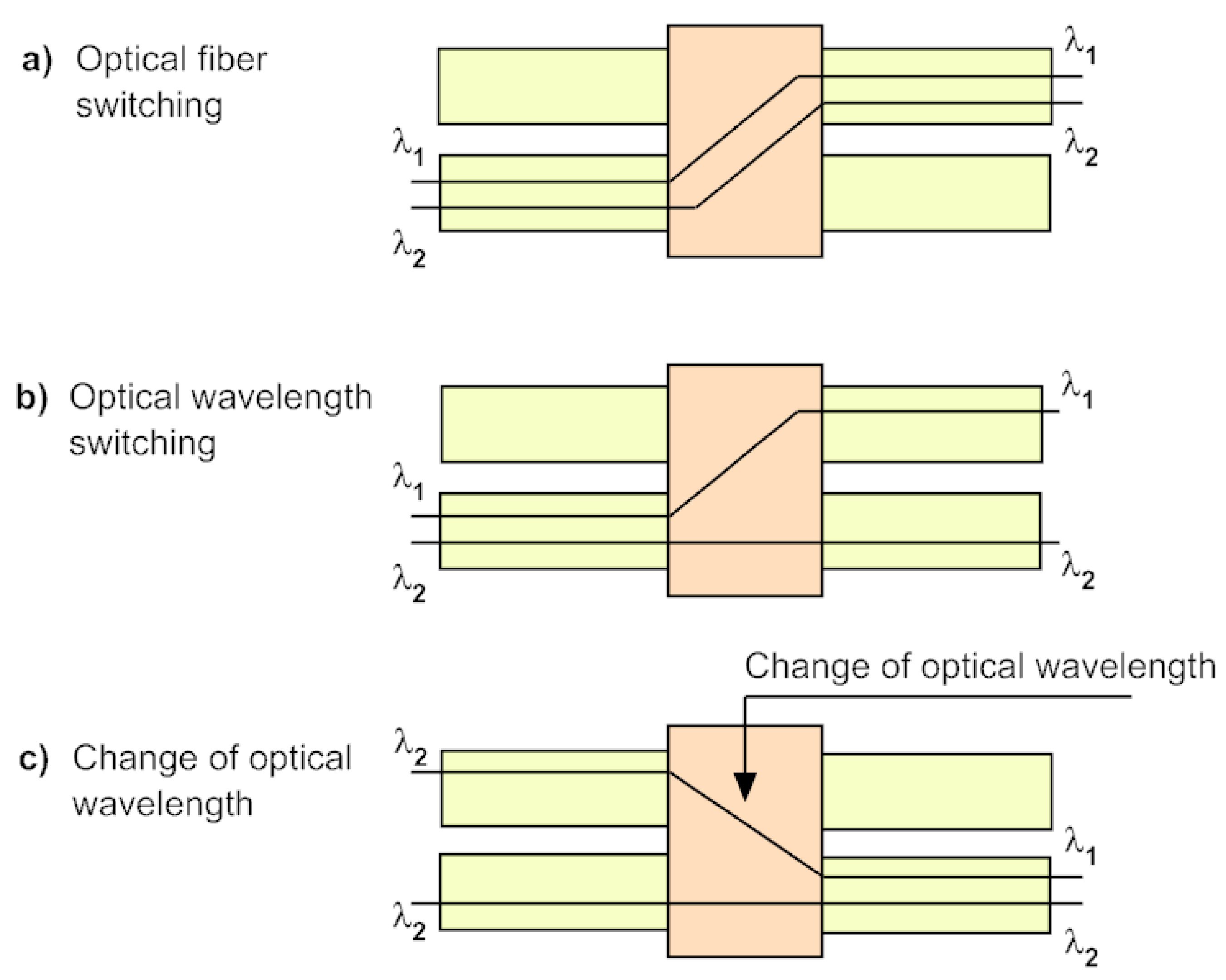
Optical terminal multiplexer (OTM)



Optical add/drop multiplexer (OADM)



Optical cross-connector (OXC)



Three main functions of OXC

Topologies of DWDM Networks

- Point-to-point chain - optical terminal multiplexers and optical add/drop multiplexers are used .
- Ring – reliable because of reserve paths, optical add/drop multiplexers are used.
- Mesh – optical cross-connectors are used.

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