Course 12 Synchronous transmission – multiplexing systems used in digital telephone networks

- **Disadvantages of the PDH transmission – multiplexing system – PDH:**
  - no unitary international standardization of the PDH transmission – multiplexing systems, several such standards coexisting in parallel: the American standard, the Japanese standard and the European standard;
  - low flexibility and high costs due to the asynchronous multiplexing;
  - limited management and maintenance facilities;
  - separate management and maintenance operations for each service;
  - difficulties related to the system state verification;
  - high sensitivity to faults;
  - difficulties related to provisioning supplementary transmission capabilities;
  - low flexibility network topology – are provided only point to point connections;
- The mentioned disadvantages are due to the fact that the network nodes are not synchronized and no appropriate supplementary transmission capabilities are provided for transmission of the management and maintenance information.

Advantages of the SDH transmission – multiplexing technique

- Multiplexing without positive or negative stuffing (in special cases it is possible to do multiplexing by stuffing – if the synchronization connection is interrupted).
- Reference clock standardized in the entire network.
- Direct access to individual channels – the multiplexing of tributaries is realized in such a way to allow access to the individual streams, without being necessary, the demultiplexing of the entire high speed bit stream. It is possible also flexible switching of the individual streams from one high speed channel on other channel.
- High rates for large bandwidth applications.
- Increased transport capacity for monitoring and network control. Changing the network configuration and provisioning supplementary transport capacities it is easier than in the case of PDH systems.
- Efficient and flexible monitoring of faults and alarms and the possibility of automatic correction of some problems.
- Integration of the previous plesiochronous multiplexing techniques.

Note: The mentioned facilities, related to network management and multiplexing / switching of elementary flows, are allowed by the use of some special management, monitoring and control channels with high bit rates (hundreds of kbps).

- In spite of universal standardization there are two synchronous transmission – multiplexing systems, namely: SDH (Synchronous Digital Hierarchy) and SONET (Synchronous Optical NETwork)
    - The SDH system is practically the European system and the SONET system is the American system;
    - The two systems use the same multiplexing algorithm, they have the same the control information and they have transport frames with similar dimensions and structure;
    - The basic transport frames are not identical (they have different dimensions) and the mapping of the plesiochronous tributaries is also different.
- The SDH/SONET transmission – multiplexing systems were designed initially for transmission of the PDH and PCM frames.
    - The structure of the SDH/SONET frames was chosen in such a way to allow the easy insertion of the PDH frames in the data structures characteristic to the synchronous systems.
    - The synchronization of the network nodes, the efficient multiplexing technique and network management allow the transmission of data flows generated by other types of sources, if appropriate mapping protocols are used.

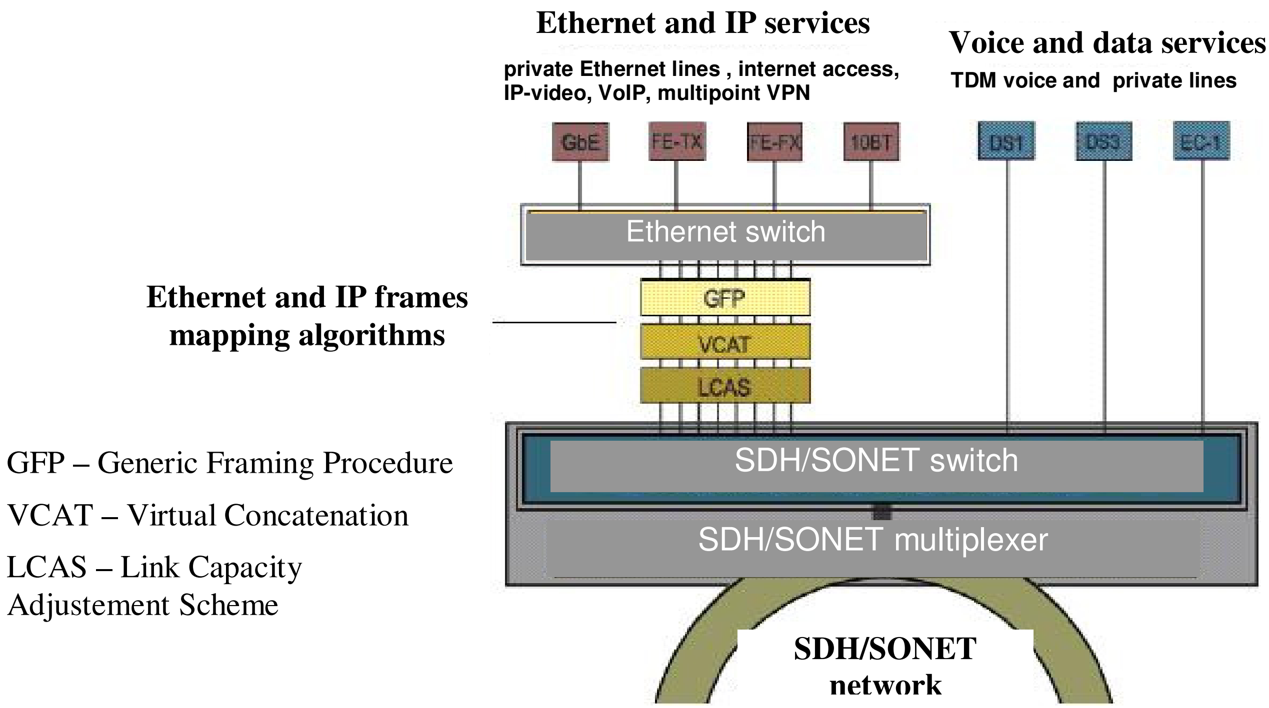

Fig. 1 Transmission of different type of data in SDH/SONET networks

SDH/SONET network topologies. Integration of the SDH/SONET networks in a global communication network

- There are 4 types of network topologies:
  - linear topology – used when the appropriate network topology is linear (ex. access networks in a high speed network) and when is not necessary a high protection to faults.
  - ring topology – used most often; ensures a high management flexibility and good protection to faults.
  - mesh topology – each node is connected with a number of other nodes – high management flexibility, high protection to faults but also high redundancy of the physical channels between nodes.
  - star topology – used to connect distant and less important nodes; ensures low protection to faults.

- The most used topologies in synchronous networks are the ring topologies, the network types with such topology being the following:
  - Network with one ring – each node can establish a connection with all other nodes and has access to a high speed network (long distance network); the nodes have access to all information available in the ring;
  - The fault protection of such a network is low;

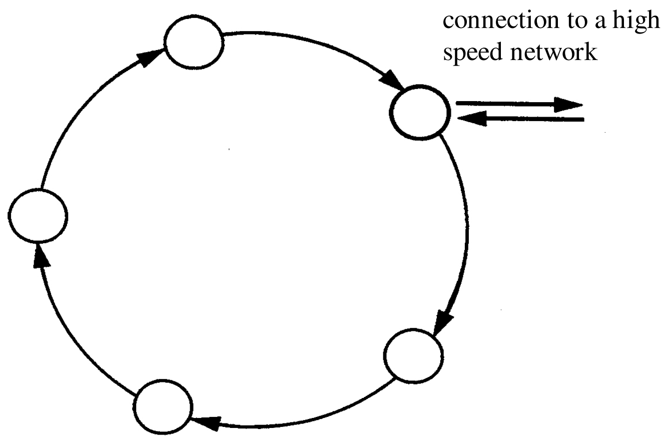

Fig. 2 Structure of a single ring synchronous SDH / SONET network

- Double ring network – are established two data transmission channels with opposite directions, the same information being transmitted in both directions; by setting up a second ring can be solved the problems of cable breaks;
  - each node transmits and receives the same information in/from two directions;
  - in the case of a cable break it is possible to switch on the other ring or even it is possible to close the ring in the affected nodes (self-healing rings);
  - the reliability of the network can be increased by interconnecting two double ring topologies in two points (see fig. 4).

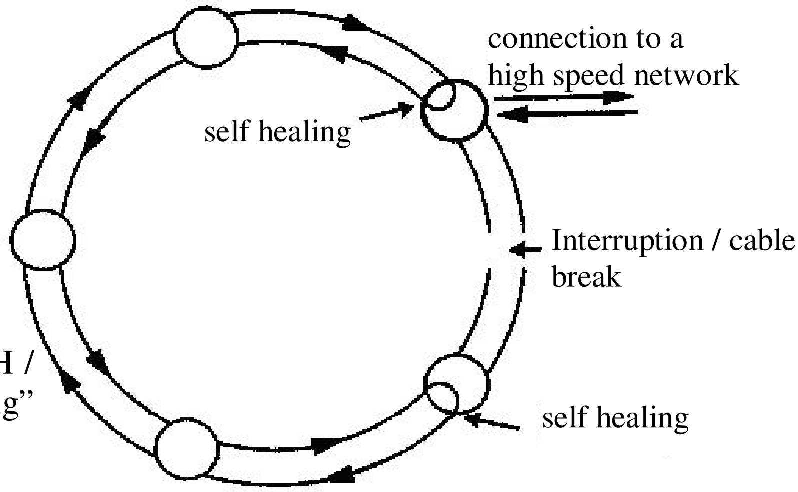

Fig. 3 Double ring synchronous SDH / SONET network with „self healing” capability

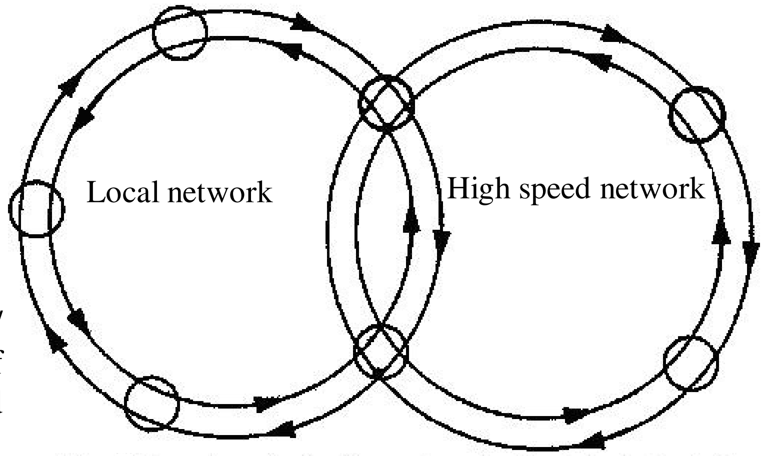

Fig. 4 Synchronous SDH / SONET network composed of two double rings interconnected in two points

o Four ring network, meaning two rings for transmission in one direction and two rings for transmission in the opposite direction; very good protection against faults, but high redundancy – see figure 5.

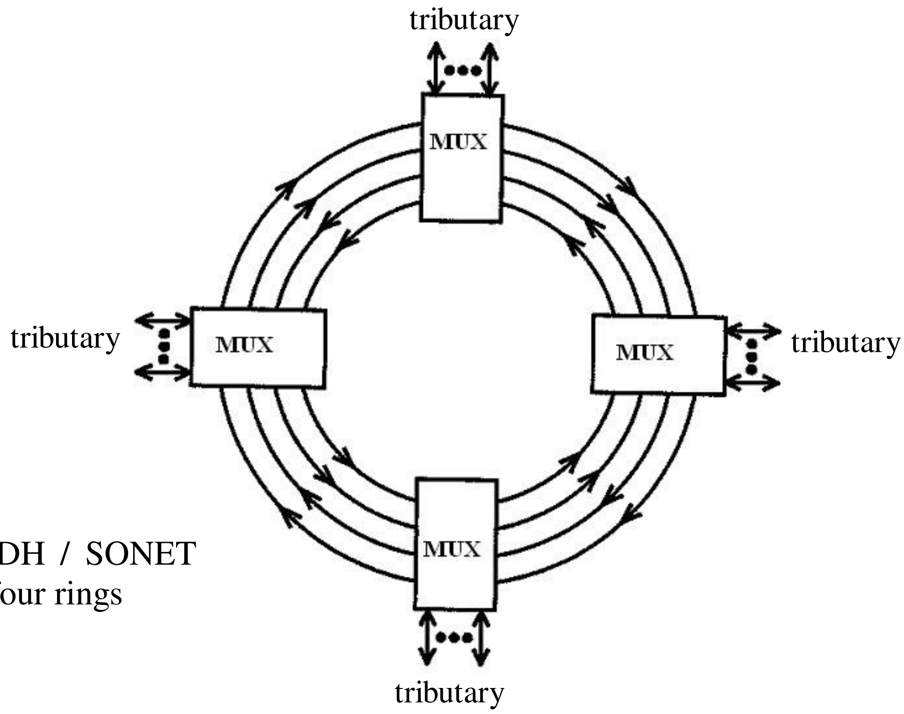

Fig. 5 Synchronous SDH / SONET network composed of four rings

- As examples are presented two data transmission network structures which include SDH/SONET networks
    - In fig. 6 is presented the possible structure of an international network which connect several national networks.
    - The national networks are OC-12 - SONET rings (equivalent with STM-4 – SDH – networks having a bit rate of 622Mbps); the international network is an OC-48 - SONET ring (equivalent with STM-16 – SDH – networks having a bit rate of 2488Mbps).

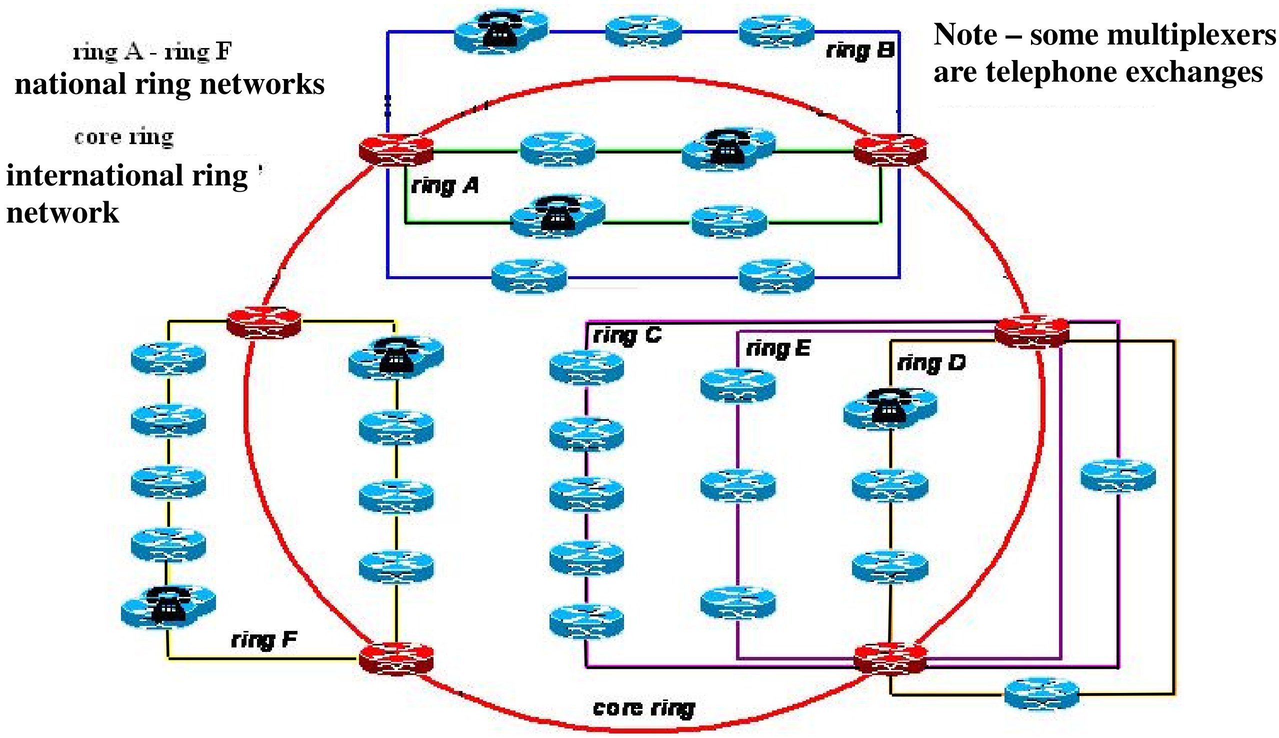

Fig.6 International SDH/SONET network which connect several national networks

- In fig. 7 is presented a possible scenario of SDH and SONET networks covering a large geographical area; these networks connect several digital transmission systems with different bit rates.
  - Can be noticed in this figure the PDH and SDH/SONET multiplexing hierarchies assigned to various digital sources and the high speed SDH/SONET multiplexing hierarchies interconnecting different digital transmission systems.
  - In the access network the bit rates are smaller or equal with that of an STM-1 frame (the basic frame of the SDH system), and the high speed (long distance) synchronous networks use STM-4, STM-16 or higher hierarchies (or equivalent SONET hierarchies).
  - In figure 7 can be noticed also the value of the bit rates assigned to different data sources and the PDH frames used to transport these data.

Note: STM-1 transport frame, basic SDH frame which has a total bit rate of 150Mbps, and STS-1 transport frame, basic frame of the SONET system which has a total bit rate of 50Mbps. Frame STM-0 is identical with frame STS-1; OC-X and STS-X frames are identical, OC-X frames are associated with optical carries and STS-X frames with electrical carriers.

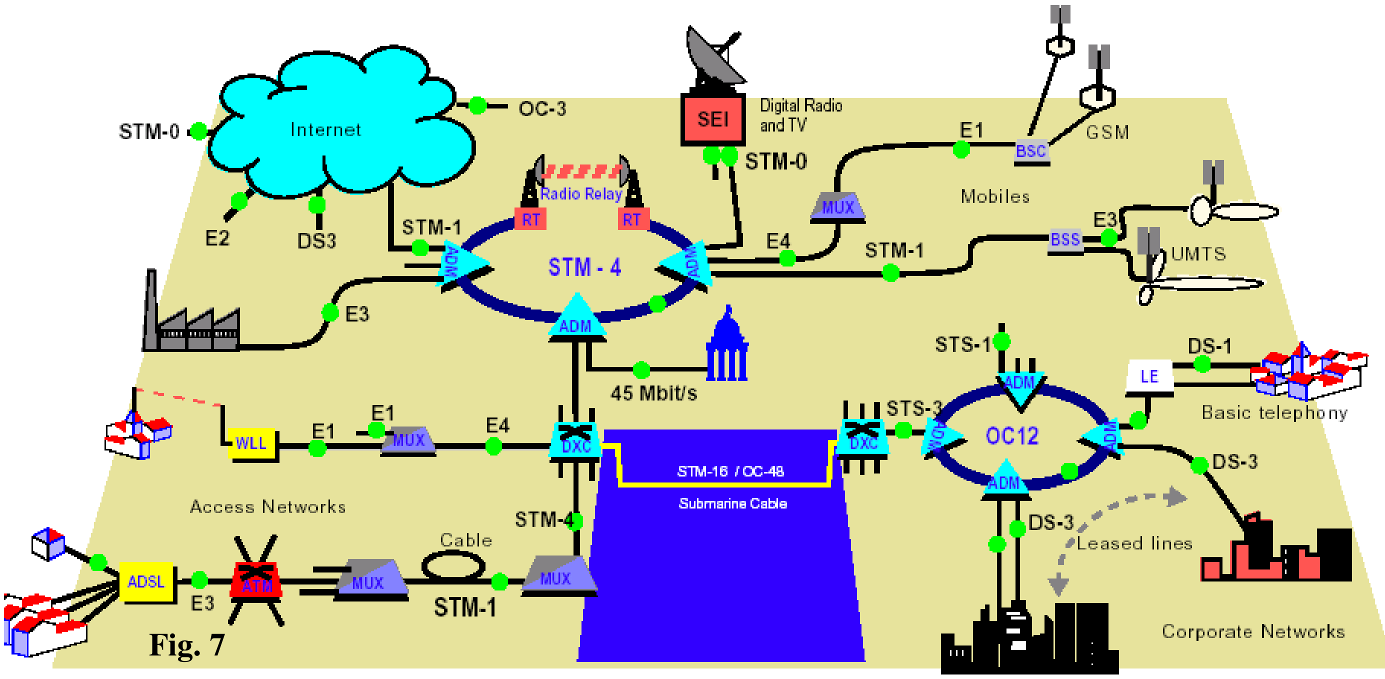

Fig. 7 Example of a digital transmission – multiplexing network including digital PDH, SDH and SONET networks

Types of multiplexers used in SDH/SONET systems

- No distinction is made between multiplexers and line terminating units; the multiplexing is not a simple bit interleaving as it is in the case of PDH systems;

  - beside the byte by byte interleaving it is ensured the monitoring of the signal, the transmission of the management information and provisioning of service channels.

- The multiplexers used in the synchronous SDH and SONET networks are more complex equipments than the multiplexers used in the PDH systems. The basic characteristics of these multiplexers are:
  - Provisioning of direct access to the multiplexed basic streams.
  - Multiplexing in the output stream of input streams with different bit rates and structures.
  - Increased flexibility for management of the transmission capacity.
  - More complex multiplexing technique than a simple bit or group of bits interleaving.
  - Some SDH/SONET multiplexers realize also switching operations, ensuring the transfer of some elementary streams between the multiplexed high bit rate streams.

- There are three types of SDH/SONET multiplexers, namely:
  - **Terminal multiplexer** – is the most simple type of multiplexer (see figure 8);
    - it is equipped with a synchronous line interface and plesiochronous/synchronous subscriber interfaces; the subscriber interfaces are located in the access module (AM);
    - on the line side the incoming STM-N or OC-N frame (higher order multiplex frame) is disassembled into elementary STM-1 or STS-1 frames which are distributed to the subscriber interfaces;
    - in the transmit direction the signals arrived from the subscriber interfaces are assembled into STM-1 or STS-1 frames which compose after that higher order STM-N or STS-N frames transmitted on the line;
    - on the subscriber side the signal "loops" can be switched; in doing this, the phase relation of the signals is maintained;

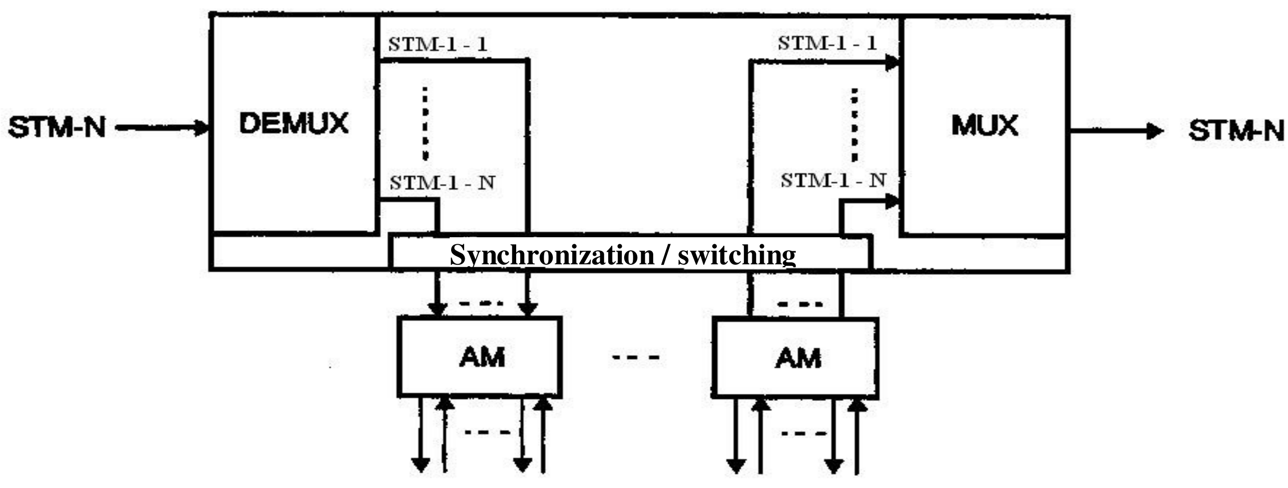

Fig. 8 Block schematic of a terminal SDH multiplexer

- **Add/Drop multiplexer** – are equipped with synchronous and asynchronous line interfaces and a special bus ((Add bus + Drop Bus) which allows the insertion and extraction of elementary PDH signals into / from the STM-N or OC-N frames.
    - Higher order STM-N or OC-N, signal is disassembled into elementary STM-1 or STS-1 frames.
    - The basic frames are applied to the signal extraction bus, the Drop-Bus, where the extraction of an elementary PDH signal takes place.
    - The subscriber signals which have to be transmitted are applied to the signal insertion bus, the Add-Bus, where they are assembled into appropriate data structures and then are inserted in basic STM-1 or STS-1 frames (see figure 9).
    - The multiplexing / demultiplexing process consists in the insertion or extraction of the tributary signals without being necessary the complete disassembling of the SDM/SONET multiplex signal.
    - The multiplexer includes a switching module of the input signals. When no signal insertion/extraction is performed the Add and Drop busses can be interconnected, being possible the switching between different subscriber interfaces.

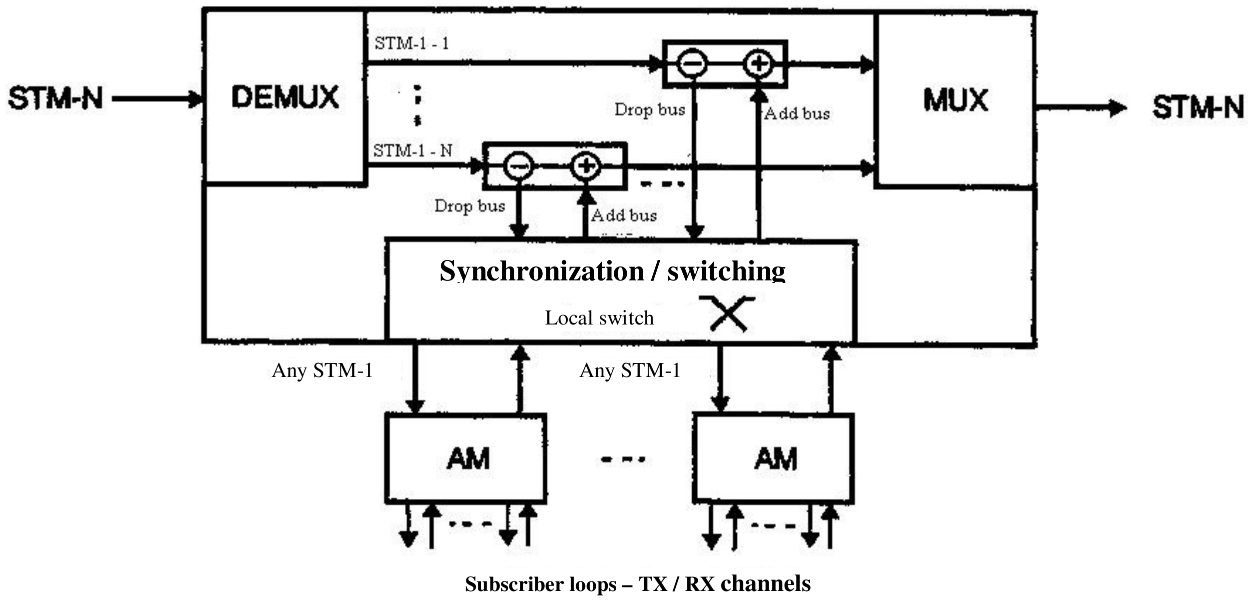

Fig. 9 Block schematic of an Add/Drop SDH multiplexer

- Cross-connect multiplexer – it is a switching matrix equipped with a (large) number of ports (interface modules) which can be line or subscriber interfaces;
    - digital signals received at a given input port can be connected through the switching matrix to the corresponding output port – furthermore the multiplexed signals of one input port can be disassembled into individual signals and sent to different output ports (see figure 10).
    - the incoming STM-N or OC-N signal is disassembled into individual STM-1 or STS-1 signals which are then routed to the input modules (IM).
    - the signals coming from the subscriber interfaces are assembled into STM-1 or STS-1 frames and are sent to the input modules.

- The input modules disassemble the STM-1 or STS-1 signals into independent basic units (containers) which are sent via the switching matrix to the corresponding output modules (OM) where the new STM-1 or STS-1 signals are assembled.
- An output multiplexer combines the individual STM-1 or STS-1 signals into one STM-N or OC-N signal.
- This structure allows the channel exchange between the input and output lines, between the input/output lines and subscriber lines and between the subscriber lines.

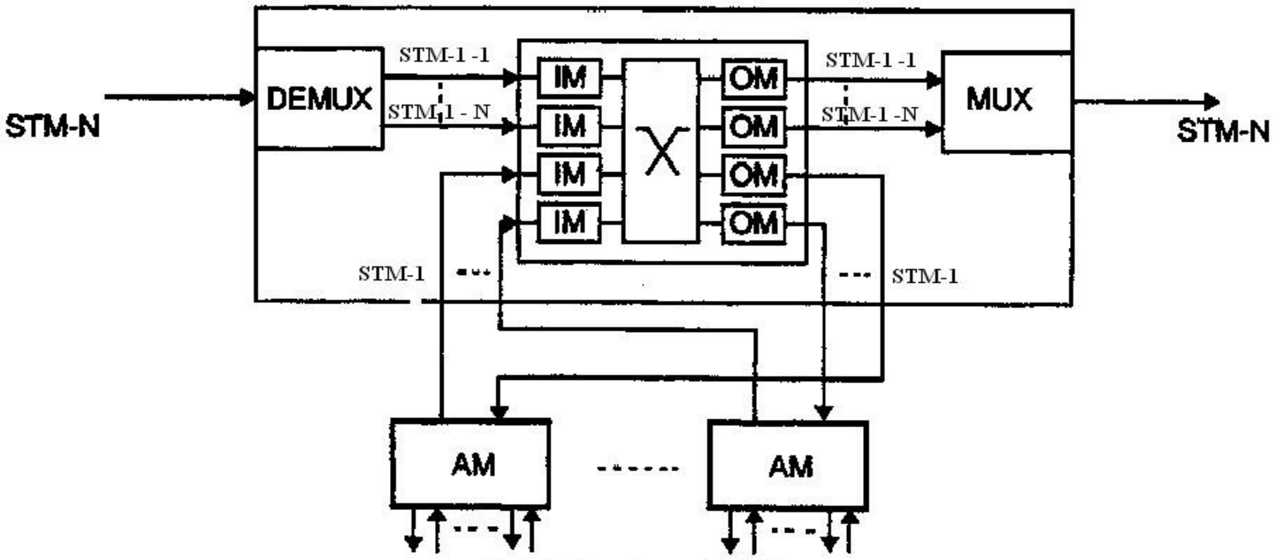

Fig. 10 Block schematic of a cross-connect SDH multiplexer

SDH regenerators

- In the case of PDH systems the regenerators have as tasks the regeneration of the signal, the check of the coding rule, the fault location and supplementary to ensure a service channel – the signal is transmitted transparently through regenerators;
- In the case of SDH networks the regenerators have several other tasks: the signal is descrambled and the structure of the STM-N frame is analyzed; the quality of the transmission is determined, the management information is evaluated and supplementary data and service channels are provided;

  - some headers of the frames are rebuild in each regenerator; fault location is performed by a management system using the information supplied by all the elements of the system, being not necessary special fault locating equipments.

Synchronization of the SDH/SONET networks

- In what concerns the synchronization of SDH/SONET network nodes, two major aspects are very important: which are the reference nodes (which generate the synchronization signal) and which is the synchronization network (how it is transmitted effectively the synchronization signal from the reference nodes to other nodes in the network).
- The synchronization network can be composed of:
  - a separate dedicate network where is transmitted an analog or digital signal used as timing reference – a separate network is necessary with inherent fault problems and is possible to have a phase difference between the data and the timing signal.

- the data transport network, an elementary channel being used for transmission of the timing signal (an elementary 1.544Mbps or 2.048Mbps channel or another elementary signal according to the bit rates of the transmitted PDH streams).

- Classification of the network nodes according to synchronization capabilities:

  - Primary Reference Clock (PRC, Stratum 1), with the following main characteristics:

– relative error $<10^{-11}$. Could be implemented using cesium clocks.

– free running, but may be correlated with CUT (Coordinated Universal Time).

– one per operator

  - Transit Synchronization Supply Unit (Transit SSU, Stratum 2), with the following main characteristics:

– relative error in holdover: $<10^{-9}$, could be implemented using rubidium clocks.

– stable enough for short periods of holdover operation (operation without synchronization reference from PRC).

  - Local Synchronization Supply Unit (Stratum 3), with the following main characteristics:

– relative error in holdover: $<2 * 10^{-8}$.

– implemented with temperature compensated crystals.

– reduced holdover capabilities.

– used in local switches.

  - SDH Equipment Clock (SEC) (Stratum 4), with the following main characteristics:

– relative error in holdover: $<10^{-8}$.

– relative error in free run: $4.6 * 10^{-6}$.

– used in local switches, digital channel banks and private exchanges

- Clock adjustment: based on clocks signals of the higher levels of the hierarchy (clock hierarchy) are generated correction signals of the local frequency; the frequency of the local clock floats around the frequency given by the PRC.

- In figure 11 is presented a possible structure of a simple synchronization network

- Theoretical limitations related to the structure of a synchronization network are the following:
  - The synchronization chain has to include no more than 10 SSU nodes and 60 SEC nodes;
  - Between two SSU nodes there are not allowed more than 20 SEC nodes;
  - These limitations are imposed by the stability of the node’s local clocks – this stability decreases as the number of nodes of the synchronization chain increases, due to the accumulation of synchronization errors on the synchronization chain.

Remark: do not confound the topology of the synchronization network with the topology of the data transport network; the topology of the synchronization network shows how is transmitted the clock reference from one node to other.

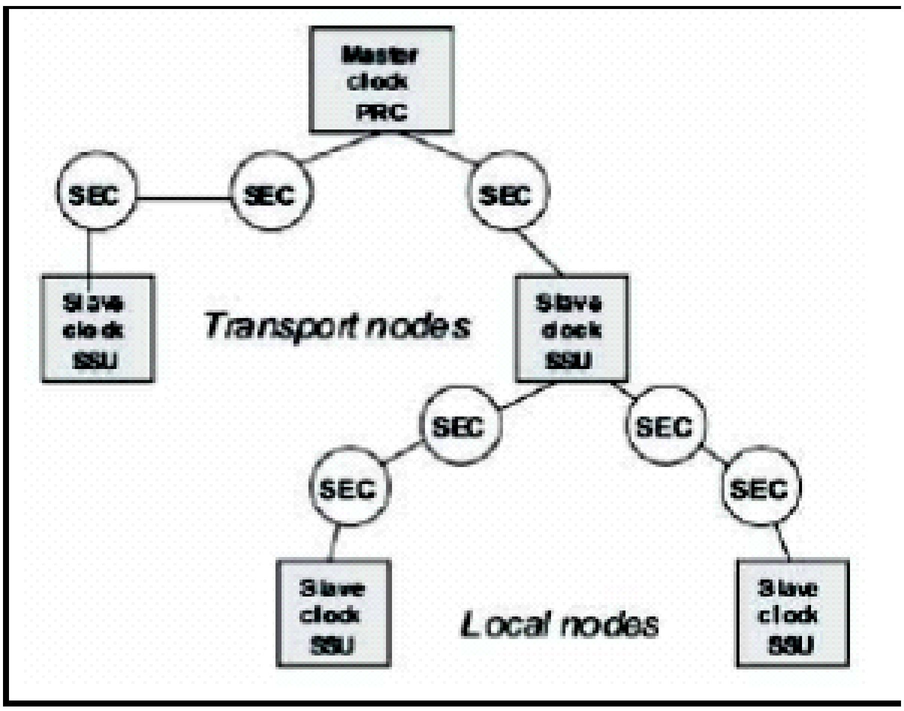

Fig. 11 Possible structure of a synchronization network

Principles of SDH/SONET multiplexing. Basic concepts

- The transmission of the SDH signals can be compared with the transport of containers on a conveyor belt;
  - The useful information („payload") is transported in containers of various sizes;
  - To transport the information, these containers need a label (header) which contains information on the container content, monitoring data, data evaluated at the receiver;
  - „the belt" used to transport the containers is divided up into several frames of identical size, frames in which are inserted the containers;
  - The position of the container relatively to the transport frame is arbitrary, that is a container does not have to start at the beginning of the frame and can extend over two adjacent frames.
  - The type of the data loaded in the container does not have any importance for the transport mechanism and the possible stuffing information can be regarded as a part of the payload ("useful data");
    - ♦ The containers have imposed dimensions, being necessary to load the entire structure before transporting them. Supplementary stuffing information is used if the payload can not fill completely the container.
  - The general structure of a container and the placement of this in the transport frame is presented in figure 12.

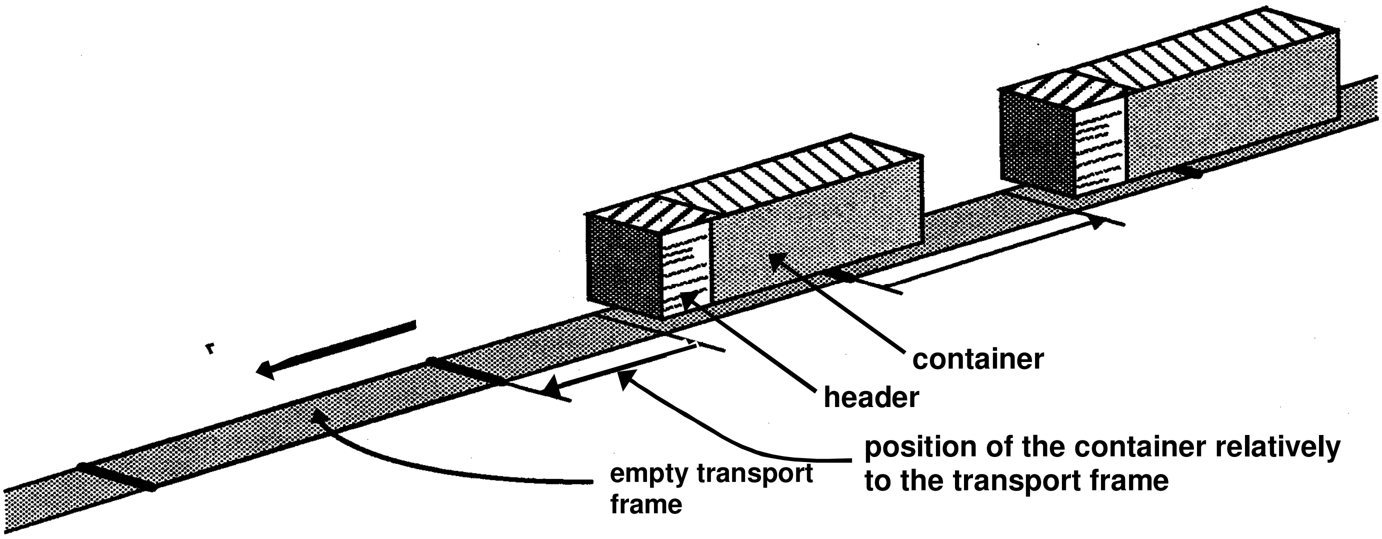

Fig. 12 General structure of a container and the placement of this on the transport frame

- o Before transmission several small containers can be combined to form a group of containers, packed into a larger container; each of this containers have a label which is evaluated at the receiver;
  - To each container is associated a position inside the group relatively to the beginning of the larger container.
  - If the payload is larger than the available container, several containers can be concatenated, forming a chain of containers;
    - As example can be mentioned a signal of 599,04Mbps rate (broadband ISDN) transported in 4 containers of 140Mbps maximum rate each;
    - the position of the container chain on the transport belt is defined by the position of the first container;
    - the transport frame must be dimensioned so that the size of the container chain does not exceed the size of the frame, but the container chain does not have to start at the beginning of the frame and can be distributed on two adjacent frames

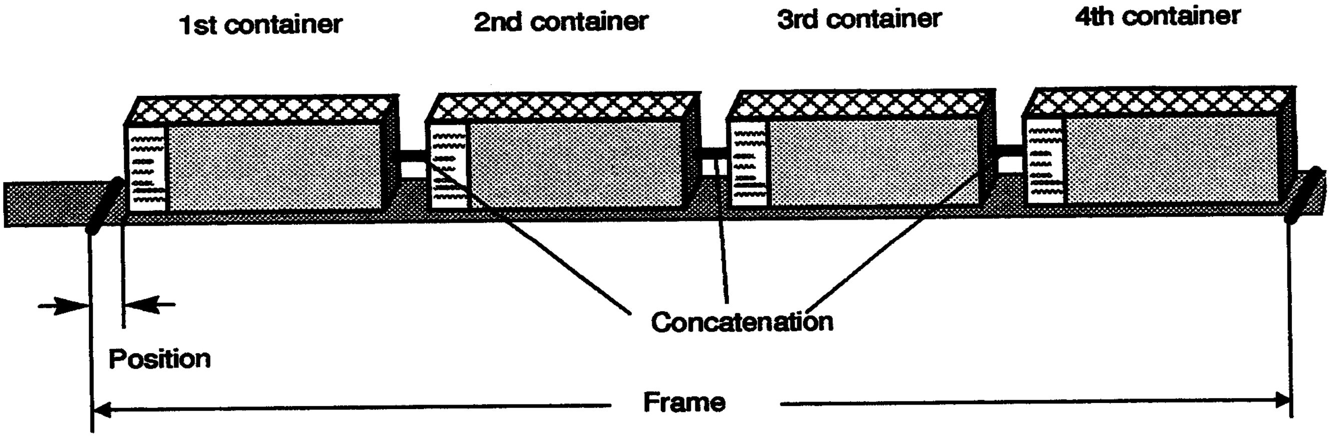

Fig. 13 Concatenation of several containers and insertion of the container block in the transport frame

- o The transport frame – represents the transmission medium (transport format) for the containers;

- it has a structure similar to that of a container, being composed of N columns and M rows;
- in order to meet the different capacity requirements, transport frames with different sizes have been defined – these subdivisions are referred to as hierarchy levels.

o SDH hierarchy levels: the transport frames of different hierarchy levels differ only by the number of columns – the number of columns increases with a factor of 4 from one level to other (see tab. 1).

SDH hierarchy level	No. of columns	No. of rows	Transport capacity (bit rate)
1	270	9	155,520Mbps
4	1080 (4*270)	9	622,080Mbps
16	4320 (16*270)	9	2488,320Mbps
64	17280 (64*270)	9	9953,280Mbps
256	69120 (256*270)	9	39830,12Mbps

Tab. 1 The SDH multiplexing hierarchy. The structure of the transport frames and the associated bit rates

o The structure of the transport frame of the first SDH hierarchy level is very important, the transport frames of higher levels being generated by multiplexing several primary frames. The structure of the transport frame of the first SDH level, frame called STM-1 ("Synchronous Transport Module") is presented in figure 14.

o This transport frame is practically a matrix type structure composed of 270 columns and 9 rows, the first 9 columns having special transport functions, and the remaining 261 columns being reserved for payload data;

  - The structure composed of the first 9 columns represents the "overhead" of the transport frame (SOH – Section Overhead), and it is placed at the beginning of the transport frame; it is independent of the payload and it is transmitted even if no payload data have to be transmitted; has also the role to identify the beginning of the transport frame.
  - The overhead is a minicontainer containing various information required for transmission and includes also a pointer (row no. 4) on 9 bytes which gives the position of the container inside the transport frame, relatively to the beginning of this.
    - Before a container is placed on the transport frame, the pointer value is computed and then the container is placed on the appropriate position on the frame;
  - The pointer permits also a dynamic adaptation of the container to the transport frame; the container can be moved in the transport frame in both directions by changing the offset value relatively to the beginning of the frame; if a cross-connection is realized, that is the container is taken from a "conveyor belt" and it is placed on other "conveyor belt", the new pointer is evaluated and the new position of the container is computed.
  - The transmission frequency of the STM-1 frames is 8kHz, the frame duration being 125μs.

- The transport capacity of the STM-1 is 270 columns*9 rows*8 bits*8000 frames/second =155.52Mbps out of which a capacity of 261 columns*9 rows*8 bits*8000 frames/second =150.336Mbps is allocated to payload data and the rest of 9 columns*9 rows*8 bits*8000 frames/second =5.184Mbps is allocated for “overhead”.

Remarks: the matrix type structure is assembled only in the information processing points, meaning multiplexers, switches, regenerators, the transmission being realized bit by bit. The transmission of the matrix bytes is realized line by line beginning with the upper left corner and inside a byte the first transmitted bit is the MSB.

❖ It is important to notice also the fact that the matrix type structure is assembled in regenerators, meaning that the regenerators has quality control and fault identification – signaling roles, being more than simple regenerators of the impulses transmitted on the line.

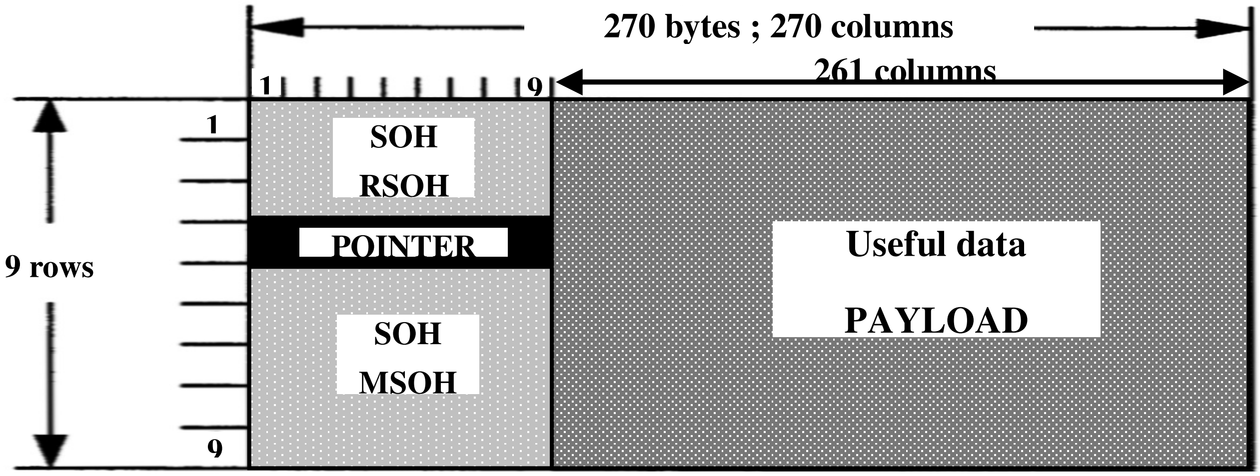

Fig. 14 Structure of STM-1 transport frame

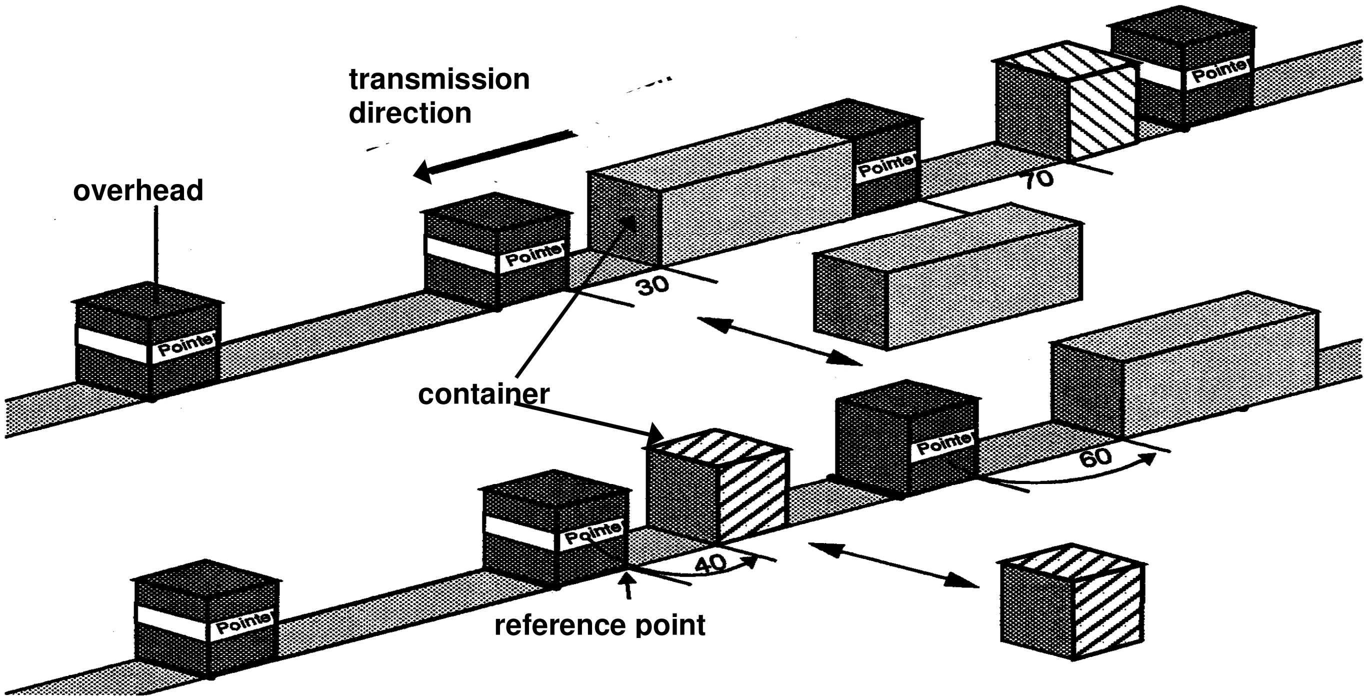

Fig. 15 Example of SDH pointer utilization for container positioning on the transport frame in the case of switching of data streams between different transport frames

- The SONET synchronous multiplexing system is intended especially (but not only) to the multiplexing of the PDH frames corresponding to the American plesiochronous multiplexing, fact which imposes a different structure of the basic transport frame called STS-1 („Synchronous Transport Signal”).
- Due to the need of universal standardization at high bit rates, the SONET frames are designed to be compatible with the SDH transport frames.
  - The STS-1 frame represents practically a third of the STM-1 transport frame, meaning the same number of rows but a number of columns three times smaller.
  - The structure of the basic STS-1 transport frame is given in figure 16, and in table 2 are presented the levels of the SONET multiplexing hierarchy and the equivalences with the SDH levels.

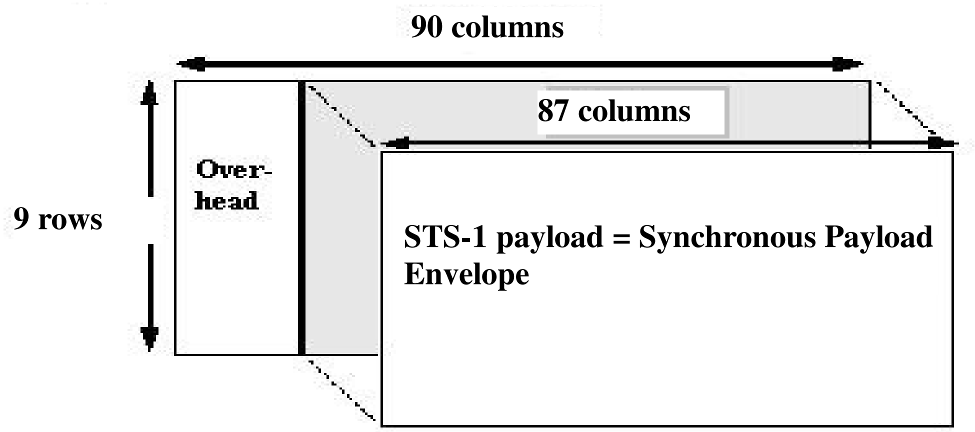

Fig. 16 Structure of the SONET STS-1 transport frame

SONET hierarchy levels	Structure (no. of columns)	Bit rate	SDH hierarchy levels
STS-1 (OC-1)	90	51,840Mbps	STM-0
STS-3 (OC-3)	270 (90*3)	155,520Mbps	STM-1
STS-12 (OC-12)	1080 (90*12)	622,080Mbps	STM-4
STS-48 (OC-48)	4320 (90*48)	2488,320Mbps	STM-16
STS-192 (OC-192)	17280 (90*192)	9953,280Mbps	STM-64
STS-768 (OC-768)	69120 (90*768)	39813,12Mbps	STM-256

Tab. 2 SONET multiplexing hierarchy. Structure of the transport frames, associated bit rates and the equivalence with the SDH multiplexing hierarchy.

Remark: the frame (level) STM-0 is not used usually !!! The terms STS and OC represent practically the same thing – STS refers to the electrical signal and OC refers to the optical signal.

- The superior order STM-N and STS-N transport frames are generated by interleaving individual STM-1 respectively STS-1 frames. The multiplexing is realized column by column for „payload” and pointer bytes.

- The SOH bytes are not multiplexed but they are generated separately for each STM-N or STS-N frame apart. The generation of a STM-4 frame from 4 STM-1 frames is illustrated in figure 17.

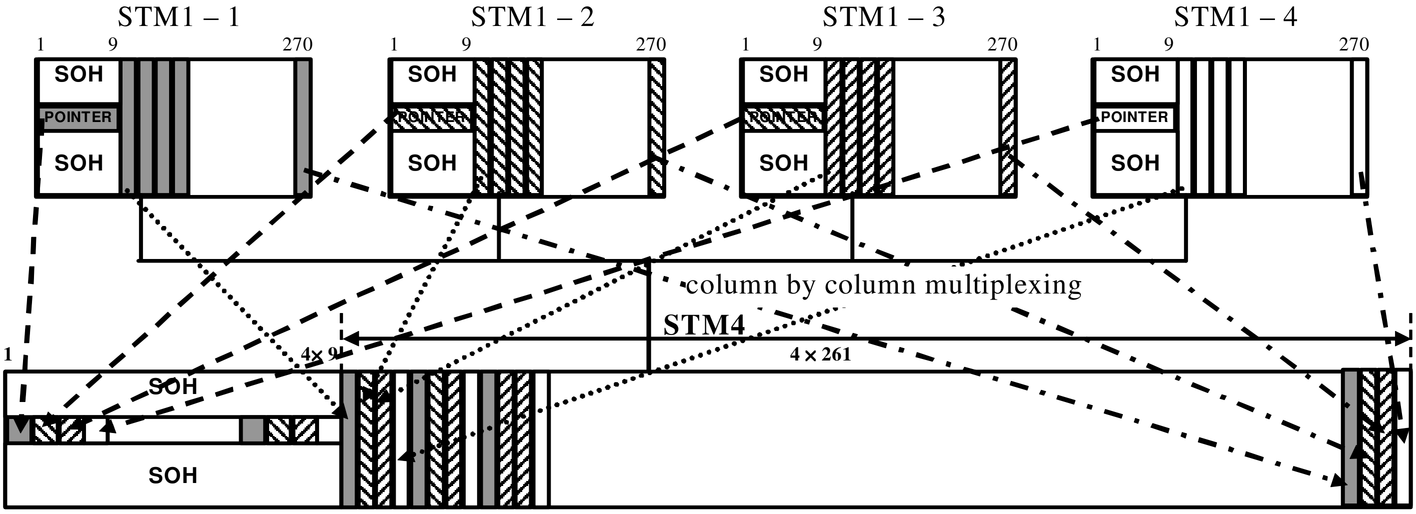

Fig. 17 Multiplexing of STM-1 transport frames into a STM-4 transport frame