ANALOG AND DIGITAL SWITCHING

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Contents

Summary

This chapter provides basic information about switching techniques and technologies used in telecommunication networks. Switching node architectures and their functions are described. Basic terminology is presented, and principles of switching elements and switching networks operation are described.

1. Introduction

Telecommunication networks are designed to convey information between users. This information is provided by the user through appropriate *terminal unit* (telephone set, personal computer, for example). When two users want to exchange information, their terminals are to be connected by a transmission system. When there are more than two users connected to the network who want to exchange information, transmission systems are to be provided between each pair of them. However, when the number of users grows, it becomes uneconomical or even infeasible to arrange a transmission system between each pair of users. When, for instance, a network contains six users, 15 transmission systems should be provided (see Figure 1). For N users, the number of required transmission systems is equal to $N(N-1)/2$. Moreover, apart from the terminal unit, each subscriber should have a device, which enables him/her to choose appropriate transmission system before he/she could communicate with another user. To reduce the number of transmission systems, switching nodes were introduced in telecommunication networks. Users are connected to a switching node by one transmission system, as it is shown in Figure 2. The *switching node* provides, on request, *a connecting path* between a pair of users. Depending on the way information is conveyed in a telecommunication network, this connecting path may be provided for the duration of a call (*circuit switching*), or only when information is really transmitted (*message switching* or *packet switching*).

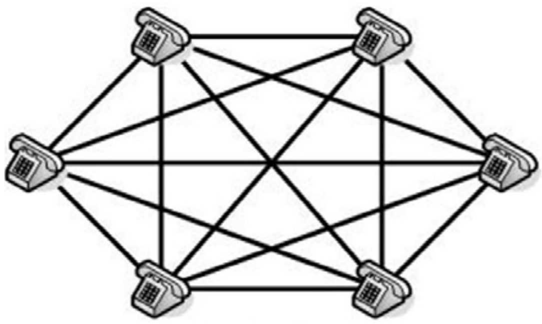

Figure 1: An example of a telecommunication network with six users

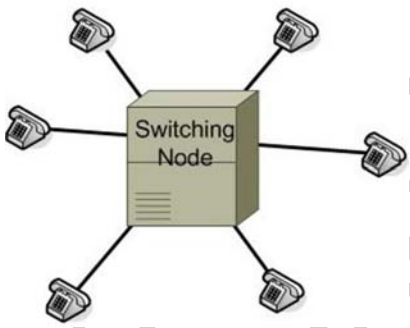

Figure 2: An example of a telecommunication network with six users and a switching node

Practical telecommunication networks contain many switching nodes, usually connected between themselves in the hierarchical order. There are many telecommunication networks, which uses different techniques and play different roles in transferring information between users. Switching nodes are called differently in different networks. For instance, in the telephone network, a switching node is called *a telephone exchange* or *a telephone office*. Another example is the Internet network, where a switching node is called *a router*.

2. Switching Node Architectures

The general architecture of a switching node is presented in Figure 3. It contains *N* input modules, *N* output modules, a switching fabric, a control unit, and a management unit. Each input link is connected to one input module. Functions realized in the input module depend on the transmission method used in the link. In general, it converts line signals to signals suitable for processing and transmitting in the switching node. It also synchronizes frames, extracts signaling information and passes it to the control unit, and prepares signals for transmission through the switching fabric. The switching fabric transfers input signals to requested output modules through connecting paths, which are set up for this purpose. At the output module, signals received from the switching fabric are prepared for further transmission through the output link. This includes framing, insertion of signaling information if required, and transcoding of signals to the line code and form appropriate for the output link. The control unit processes calls, sets up connecting paths through the switching fabric, processes signaling information, handles errors in call processing, and performs traffic routing and management functions. The management unit manages the configuration of the switching node, performs testing, billing and security management. Some other units, not shown in Figure 3, like main distribution frame and powering, are also parts of the switching node.

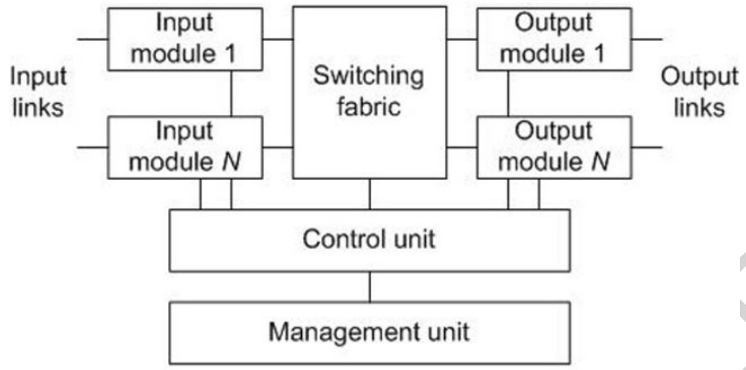

Figure 3: The general switching node architecture

In telephone exchanges, analog subscribers are connected through subscriber line interface circuits (SLIC). The respective circuit for digital (ISDN) subscribers is called a digital subscriber line interface circuit (DSLIC). These interface circuits are placed in local and remote units called concentrators (Figure 4). Concentrators are connected to the main exchange by means of the set of E1 links. These types of links are also used for connections with other exchanges. Currently, subscribers are more often connected to the remote subscribers' modules which are connected to a main exchange by means of access networks.

In ATM networks, switching nodes are called ATM switches. Input and output modules of an ATM switch are called input and output port controllers, respectively (see Figure 5). Input and output port controllers may be fabricated on one circuit board called a line interface card. An input line is connected to the physical interface which converts incoming bit stream from a line code to the binary code (optical to electronic conversion is also performed when an optical fiber is used), synchronizes bits and frames (when cells are transmitted in the frame, for instance SDH/SONET or E1), and process information in the header of the frame. Extracted cells are passed to the cell synchronization units, which delimits cells' boundaries, checks correctness of received cells, discards cells with errors in header and empty cells, and passes remaining cells to the cell processing unit. In the cell processing unit cells are prepared for transmission through the switching fabric. The destination output port for each cell is determined using routing information table and an internal header is added. Depending on the switch organization buffers may be also placed in the input module to overcome output contention problems. At the output port controller, cells from the switching fabric are passed to the cell processing unit, which removes internal header and inserts new header with the label assigned to the cell on the outgoing link. In HEC unit a header error check code is calculated and inserted in the respective field of the cell's header, and empty cells are generated if necessary. Then cells are put into frames (if framed transmission is used) and converted to the signal appropriate for transmission in the output link. Output buffers are also located at the port controller.

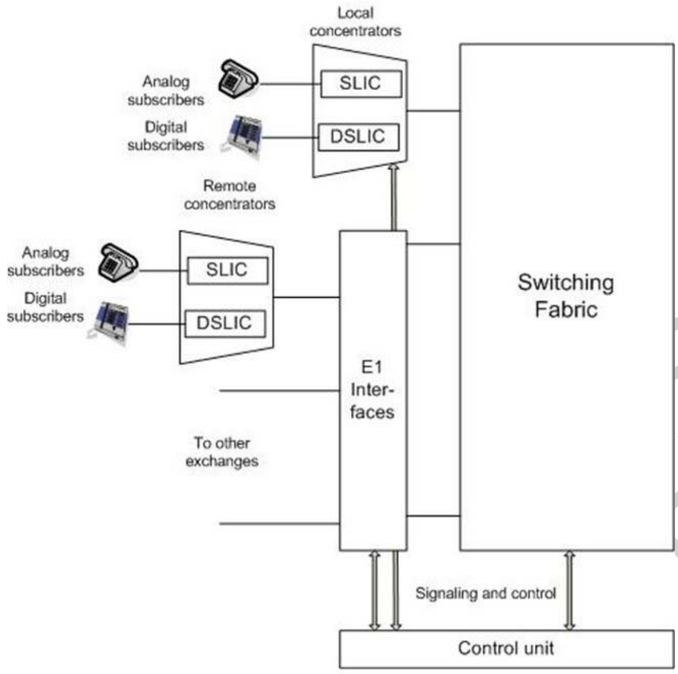

Figure 4: A digital telephone exchange

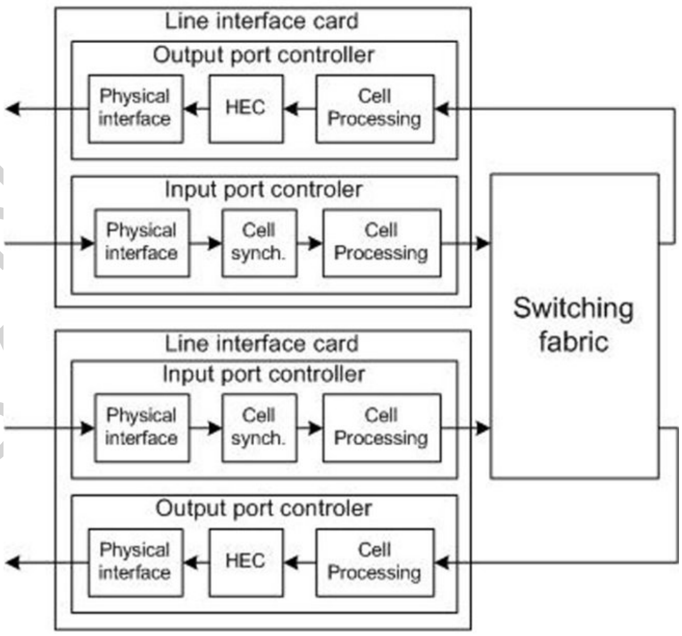

Figure 5: An ATM switch

IP routers can be categorized depending on their size into low-end routers, middle-size routers, and high-end routers. The first two classes perform switching functions in software. Line cards are connected to the central processing unit through a shared bus

(Figure 6a). Processing units can be also placed on line cards for packet forwarding, in order to reduce the central processing unit load. The capacity of the processing unit and central bus speed limits the capacity of such types of routers. In high-end routers of large capacity a switching fabric is used to switch packets between inputs and outputs. Ingress line card contains physical interface and packet processor (Figure 6b). The physical interface performs optical-to-electrical and serial to parallel conversions. It also synchronizes incoming bits, processes frame overhead, and delineates packets. Packets are then processed by the packet processor, which performs table lookup and packet classification. The packet processor also performs various control functions like traffic access control, buffer management, and packet scheduling. All these functions may be implemented in more than one unit. Most switching fabrics use synchronized packet switching, i.e., variable length input packets are segmented into fixed length packets for transferring through the switching fabric. This function is also realized in the packet processor. After switching, fixed length packets are again processed by packet processor at the egress line card. They are reassembled to original variable length packets, buffered and scheduled for transmission. At the physical interface packets are placed in appropriate frame (SDH/SONET), frame header is generated, and then the bit stream is converted from parallel to serial and from electrical to optical form. Fixed length packets are called cells, but they do not have the same length as ATM cells. The principle of switching is the same as for ATM switching.

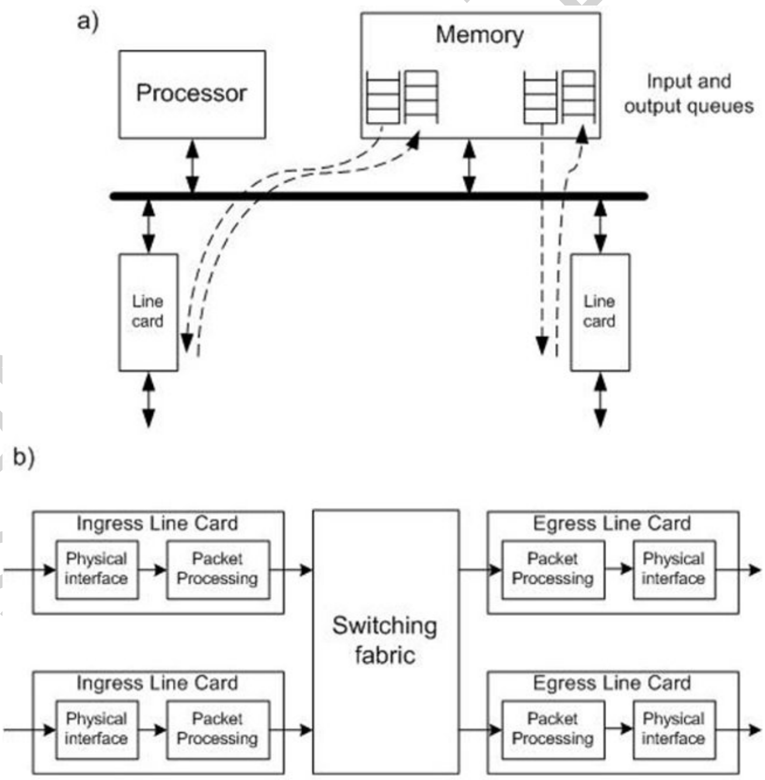

Figure 6: Routers with switching functions performed in software (a) and hardware (b)

Cross-connect systems are switching nodes used in transport networks. When a transport network is based on SDH/SONET systems and switching is made in electronic form, the switching nodes are called digital cross-connect systems (DXCs) and digital add/drop multiplexers (ADMs). The principle of switching in these systems is similar to TDM switching. Currently optical transmission is used in transport networks and DXCs are being replaced with optical cross-connect systems (OXCs) and optical ADMs (OADMs). The optical transport network provides connecting paths between users (telephone exchanges, IP routers). This connecting path is also called a lightpath, and it uses one optical channel (one wavelength) in an optical fiber. The optical transport network may use ring or mesh topology. OADMs are placed on the network edge, and provide access to the Optical Transport Network (OTN). OADMs are also useful in building simple optical networks with small numbers of nodes and wavelengths. An example of OTN is shown in Figure 7.

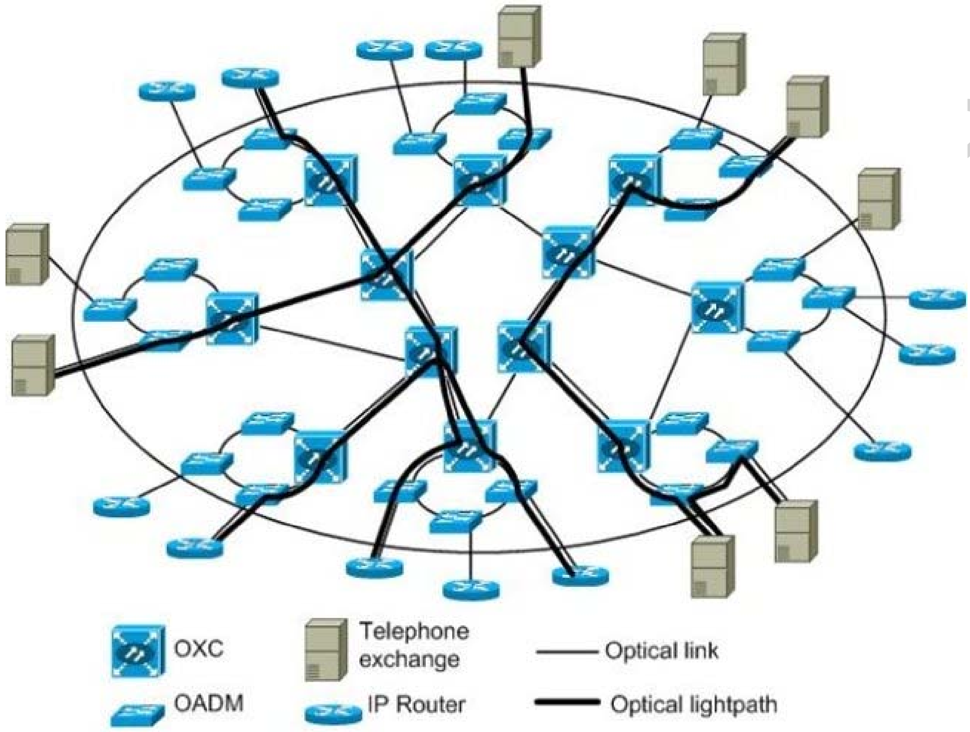

Figure 7. The Optical Transport Network

3. Switching Technologies and Techniques

In this Section the main switching technologies and techniques will be considered. The term "technology" refers to the physical implementation of switching, i.e. devices and physical phenomena used to switch signals between inputs and outputs. The term "technique" refers to a transfer mode used for conveying information. It describes a technique used in telecommunication networks for transmitting, multiplexing, and switching.

The first switching technology implemented in telecommunication networks was *manual switching*. It was used in both telegraph and telephone networks. The first telephone exchange was installed in 1878, only two years after A. G. Bell invented the telephone. Telephone connections were set up by an operator on a manual switchboard by plugging a patch cord into respective jacks (see Figure 8).

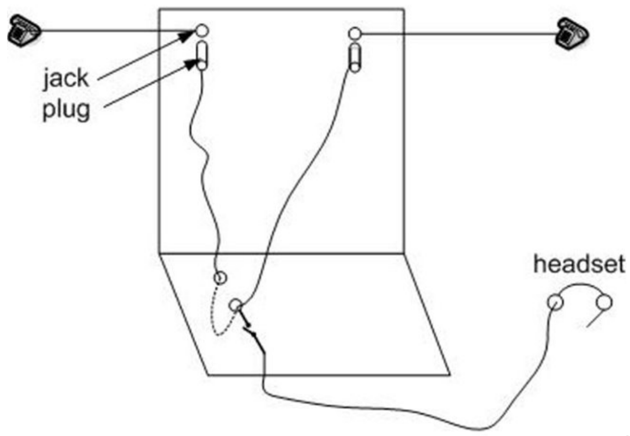

Figure 8: The manual switching office

Manual switching was replaced by *automatic switching* eleven years later. Automatic switching is used in the telephone network till today. It enables to set up connections between users without an operator assistance. At the beginning automatic switching offices used *electromechanical switching* technology. Two kinds of electromechanical switching systems were installed in the telephone network. The first one used *automatic telephone selector* invented by A. B. Strowger and patented in 1889. Later, in 1899, Keith and Erickson patented the Strowger selector, which was used for many years in telephone offices. Such systems are called *step-by-step switching systems* after the way selector operated. The basic principle of the Strowger selector is to connect any selector inlet to any of its 100 outlets. Outlets were placed in 10 arcs (one on top of another), 10 output in each arc. The output was selected by a double movement: first vertical motion to select one out of ten arcs, then rotating motion around the vertical axis to select one out of ten outlets in the arc. Such a selector is known as two-motion selector. A movement of the selector was controlled by digits dialed by a subscriber. First digit controls the vertical movement and the second digit controlled the horizontal movement. This selector is called *a final selector*. In the switching system with more than 100 subscribers, *group selectors* were placed before final selectors. For instance in a switch with 1000 subscribers one stage of group selectors is added (see Figure 9).

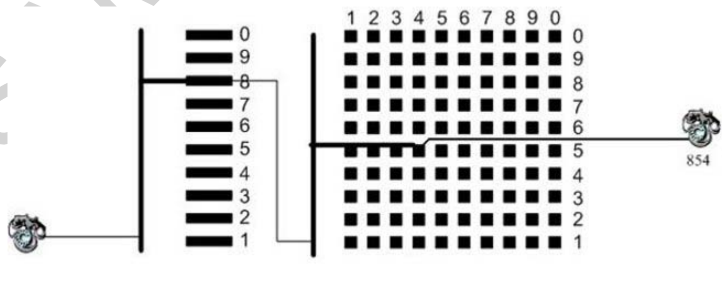

Figure 9: A step-by-step switching system of capacity 1000 subscribers. Calling subscriber sets up connections to subscriber 854

Each pulse from the first dialed digit causes the group selector to raise one level. While the dial was returning to its rest position, this selector automatically rotates around its vertical axis and stopped at the first outlet found free. Pulses from the next two digits controlled vertical and horizontal movements of the final selector. Electromechanical systems build of Strowger selectors used later registers and wired logic called translators. Dialed digits were recorded in the register and translated by the translator. Movements of selectors were then controlled by the register.

The other electromechanical system is called *a crossbar switching system*. The name comes from the new type of selector patented in 1919 by Betulander and Palmgren, and called *a crossbar switch*. The first such system was installed in 1938. The crossbar switch uses horizontal and vertical bars, also called selecting and hold bars, respectively. These bars were operated by electromagnets that receive their signals from control devices called markers. Selecting bars move in up and down directions, while hold bars rotate to make the contact (Figure 10).

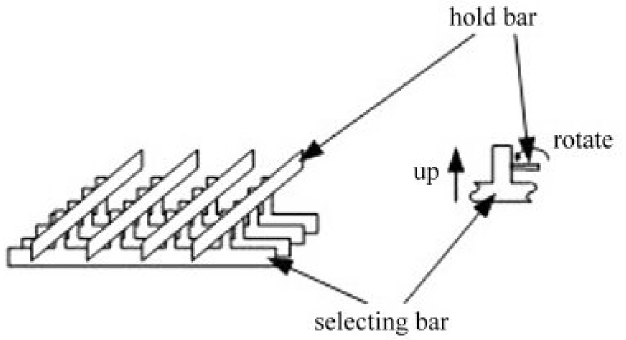

Figure 10: A crossbar switch

The beginning of electronic era influenced also the telecommunication industry. Binary devices in logic circuits, like gates and flip-flops, were used in different parts of switching systems for controlling and also for switching. First, *electronic switching systems* used reed relays to switch analog signals from inputs to outputs (they are also referred to as *semi-electronic switching systems*). The reed relay consists of contacts produced from ferrous metal reeds which are placed in a hermetically sealed glass envelope. This envelope is mounted inside a coil, and when an electric current is present in the coil, the contacts are closed and respective input and output pair is connected. An example of 4×4 switch is shown in Figure 11. Later, reed relays were replaced by analog gates.

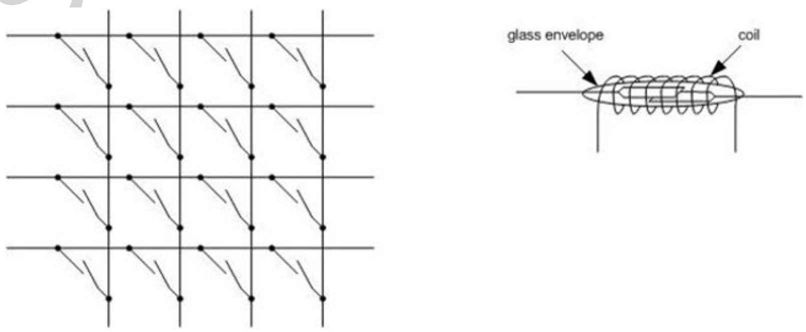

Figure 11: A reed relay and a 4×4 switching matrix

All systems described up to now in this Section switched analog signals from inputs to outputs. This type of switching is also referred to as *analog switching*.

Implementation of digital transmission of voice signals in PCM systems made analog switching inconvenient, since digital signals had to be converted into analog form for switching, and then they had to be back digitized for transmission to the next switching exchange. Integrated circuits and electronic memories enabled to move from analog switching to *digital switching*. The first digital switching system was installed in 1976. Digital switching allowed substantial growth on the size of electronic switching systems. This switching technology is currently used in switching systems, not only in telephone exchanges but also in packet switches (IP routers) and digital cross-connect systems used in transport networks based on SDH/SONET systems.

Current telecommunication networks employ optical transmission systems. These systems offer a huge transmission bandwidth unavailable for copper cables (40 or even 160 Gbps on one wavelength, with many wavelengths transmitted in one optical fiber). Electronic switching cannot be used at such high rates, so incoming signals have to be not only converted from optical to electrical form but also have to be demultiplexed to lower bit rates. Therefore, *optical switching*, called also *photonic switching*, which enables optical signals to be switched directly from inputs to outputs without conversion to electronic form are now introduced in telecommunication networks. Optical switching technology is used in optical cross-connect systems installed in emerging automated switched optical transport networks (AOTN). Optical technologies used in optical switching can be classified in two main categories: guided lightwave switching and free-space switching. They can be further divided depending on physical effects and phenomena used for the switching process. Examples of guided lightwave switching are electro-optic switching, accusto-optic switching, thermo-optic switching, switching based on optical amplifiers, or moving fibers switching. In the free-space switching light beams propagate in free space and optical effects, for instance reflection, are used to direct these light beams to appropriate output fibers. An optical crossbar switch built from micromirrors is shown in Figure 12, as an example.

There are four main switching techniques in telecommunication networks: *circuit switching*, *message switching*, *packet switching* and *ATM switching*.

In *circuit switching* a connection between two users (users' terminals) is established temporary on a request for their exclusive use throughout a call. This connection can be a physical communicating path (metallic wires, optical fibers, optical wavelength), or physical medium is assigned to a call for short periods (called *time slots*) at regular intervals. The former case is referred to *space-division switching*, the later – to *time-division switching*. Switching resources (connecting paths, time slots) are assigned to users on the call-by-call basis. Each call consists of three phases: connection set-up, call duration, and connection clear-down. In the first phase, control information, called *signaling*, is exchanged between switching nodes and users involved in a call, and respective connecting paths are reserved (or set-up) in switching nodes. In the next phase, the call is supervised by switching nodes to detect the end of a call. Finally, after a call is terminated by any user, respective resources are released in accordance with signaling information.

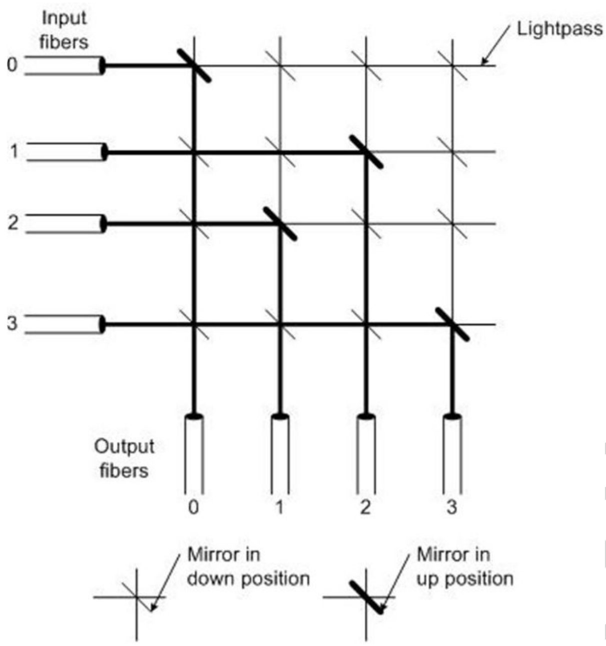

Figure 12: An optical switch with micromirrors as cross-points

Circuit switching provides a fixed bit rate for transmission. For instance, in E1 system this rate is 64 kbps (8 bits per frame, 8000 frames per second). *Multi-rate circuit switching* was proposed to overcome the inflexibility of this single bit rate when services with different bit rate requirements were introduced. In multi-rate circuit switching, called also *multi-channel* or *multi-slot switching*, one connection may occupy more than one time slot. This type of switching is used in N-ISDN (Narrowband Integrated Services Digital Networks) for example, for videotelephony.

Another inconvenience in circuit switching is that occupied channels cannot be used by other connections when no information is being sent by users. To use channels more efficiently, fast circuit switching has been proposed. In *fast circuit switching* information on the required bandwidth, destination, and label identifying the connection are assigned during the connection set-up phase, but channels are allocated dynamically only when information is being sent from the source to the destination. This approach, however, has not found practical implementation in the telecommunication network.

In *message switching* information is conveyed between users in a self-contained block called a message. A message is first received and stored in a switching node, and then it is forwarded to one or more users, or a next switching node (or nodes). Therefore, this type of switching is also called *store-and-forward switching*. A message contains a header with its destination address (or addresses), so no other control information is needed to transfer messages. Messages are sent on appropriate links one by one. A transmission link is occupied only for the time message is sent. Then it may be used by another message. Communicating terminals need not be available at the same time. A message sent by one terminal is stored in a switching node and sent to another terminal when it is available. Messages can be delivered at a different speed than at which they were sent, and can be also processed in the node for instance for code conversion. An example of message switching is telegram service used in telecommunication networks.

In *packet switching* networks users' data are transferred by structured sequences of bits called packets. Each packet, apart from user data, also contains additional information which is used inside the network for routing, error control, flow control, etc. This information is placed at the front of packets and is called a header (some additional bits, like error correcting codes, are located at the end of packets). Packets have a variable but limited length and may be transmitted at any time, provided that no other packet is transmitted in a transmission link. Similarly as in message switching, a transmission link is occupied only when a packet is transmitted. Packets wait for its transmission in a queue. When user information is longer than the maximum packet length, it is segmented into several packets. Packet switching networks may operate in two different modes: *the datagram mode* and *the virtual circuit mode*. In the datagram mode each packet is considered as independent message and is routed through the network separately. However, packets have limited length and may be lost in the network because of congestions (in message switching a message can be sent only when it can be accepted by a receiving side). In the *virtual circuit mode*, the logical connection is set up between two terminals before information is transferred. Each logical connection is identified by a number which is places in a header of each packet belonging to this connection. Packets of the same virtual connection follow the same route in the network. Signaling information is used to control virtual connections. An example of a packet switching network operating in virtual circuit mode is the telecommunication network based on ITU-T Recommendation X.25. The Internet is the packet switching network operating in datagram mode. Alternative solutions of packet switching networks are *frame relaying* and *frame switching* networks.

In *ATM switching* networks data are transferred in fixed length packets called *cells*. Cells are transmitted synchronously one after another, and a time for transmitting one cell is called a time slot. When no information is to be sent an empty cell is transmitted (this differentiate such networks from packet switching networks, where nothing was sent when there was no packets for transmission). However, transmitted cells are not structured into frames, like in time-division circuit switching. Users can insert data into any empty cell, so cells transmitted from a user may appear at any time when new cell (time slot) is started. Each cell contains a header with a label, which is used to direct a cell to a destination user. A label is assigned to a call at the connection set-up phase and is released after the call is terminated. When no information is to be sent when a connection is set up, empty cells are sent.

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Bibliography

Chao H.J., Lam C.H., and Oki E. (2001). *Broadband Packet Switching Technologies: A Practical Guide to ATM Switches and IP Routers*, 459 pp. John Wiley & Sons. [A classic book on broadband packet switching systems and fabrics, both electronic and photonic]

Chapuis R.J. (2003). *100 Years of Telephone Switching. Part 1: Manual and Electromechanical Switching (1878–1960's)*. 496 pp. IOS Press. [The book is about the history of core switching systems and signaling developed and used in public telecommunication networks]

Chapuis R.J., Joel A.E., Jr., (2003) . *100 Years of Telephone Switching. Part 2: Electronics, Computer and Telephone Switching(1960–1985).* 612 pp. IOS Press. [The book is about the history of core switching systems and signaling developed and used in public telecommunication networks]

GRINSEC (1983). *Electronic Switching*, 680 pp. North-Holand. [This book describes many aspects of electronic switching systems' design, production, and introduction in telephone networks]

Kabaciński W. (2005). *Nonblocking Electronic and Photonic Switching Fabrics*, 270 pp. Springer. [A survey of switching fabrics architectures and their combinatorial properties]

Redmill F.J. and Valdar A.R. (1990). *SPC Digital Telephone Exchanges*, 497 pp. Peter Peregrinus Ltd., London, United Kingdom. [This book describes many aspects of digital switching systems and their control aspects]

Thompson R.A. (2000). *Telephone Switching Systems*, 857 pp. Artech House. [The book describes many aspects of telephone switching system, form old electromechanical switching to modern photonic switching systems]

Biographical Sketch

Wojciech Kabaciński graduated in Telecommunications in 1983 (with honors) from Poznan University of Technology (PUT). In 1988 he received a Ph.D. degree (his thesis was awarded by the Ministry of National Education) and in 1999 he received the *Doctor Habilitus* degree, both form PUT. Since 1983 he has been employed at the Institute of Electronics and Telecommunications, PUT, where he currently is a full professor.

Prof. Kabaciński has published 5 books, over 100 papers in journals and conference proceedings in Polish and English mostly on switching systems, switching networks, and telecommunication networks. He also holds (as co-author) 10 patents (including 2 European patents and 1 USA patent) concerning expandable digital switching networks architectures. His main research interests include: digital switching systems, photonic switching networks and systems, switching network architectures. He conducted two projects founded by the Polish State Committee for Scientific Research (KBN) dealing with the new switching network architectures suitable for packet switching.

He acts as a reviewer for many international journals (*IEEE Transactions on Communications*, *IEEE Communications Magazine*, *IEEE Journal on Selected Areas in Communications*, *IEEE/ACM Transactions on Networking*, *Performance Evaluations*), served as the Guest Editors of Feature Topic in *IEEE Communications Magazine* concerning Clos switching networks, and was the member of technical program committees of a few international conferences and symposia including: IEEE International Conference on Communications (2002, 2004, 2006, 2007), IEEE Globecom (2003, 2004), International Conference on Telecommunications (2000, 2001, 2002, and 2003), Conference on Next Generation Internet Design and Engineering, NGI (2005, 2006, 2007).

Professor Kabaciński is the senior member of IEEE Communications Society and Association of Polish Electrical Engineers (SEP). He currently serves as a Chair of Communications Switching and Routing Technical Committee of Communications Society and as a chair of IEEE Chapter Communications – Poznań.