Communication Networks I

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1 Network Architecture

1.1 Network Topologies

1.1.1 Meshed Network

- fully meshed network of N nodes (verticals)
- $\frac{N\cdot(N-1)}{2}$ arcs or links (edges)
- shortest possible connections
- uneconomic for large N because of
  - high number of arcs
  - low usage of channels (for low traffic volume)
- applied typically in higher network levels

1.1.2 Star-Network

- introduction of a central node (transit node, transit switch center)
- basic mechanism to introduce hierarchical network structures
- N links
- two links for interconnection of two nodes
- applied for construction of hierarchical network structures (lower network levels); also applied in cellular mobile networks (access of mobile to base stations)

1.1.3 Bus Network

- common bus as a broadcast transmission system with passive coupling of nodes (terminals, servers) to the bus
- media access control, e.g. by carrier-sensing
- application: LAN

1.1.4 Ring Network

- common ring-type bus as a broadband transmission system with active coupling of nodes to the ring bus
- media access control either by reservation of time slots (time channels) in synchronous TDM or by token passing in packet mode
- restoration methods necessary in case of ring interrupt (e.g.: dual ring system with "self-healing" respration)
- application: LAN, WAN

1.1.5 Dual Bus

- pair of uni-directional buses
- synchronous time slot structure generated by head end station
- isochronous or asynchronous transfer modes
- allocation of slots/channels by reservation
- application: DQDB (distributed queue, dual bus) MAN

1.1.6 Folded Bus

- one bus with an outbound and an inbound segment (folded bus)
- each station connected to the outbound bus (receiving and transmitting) and the inbound bus (only receiving)
- central reservation by headed station or direct access to idle marked slots

1.2 Transmission and Multiplexing

1.2.1 Channel Multiplexing

In this multiplexing principle to each connection a transmission channel is associated for exclusive usage. This channel is characterized by a fixed bandwidth or bit rate. The multiplex link carries multiple channels (”channel multiplex”).
The implementation of the channel multiplex principle rests on various principles depending on the way how the common bandwidth/bit rate of the multiplex link is shared:

- Space Division Multiplex (SDM)
  - spacial devision of channels
  - channels may be realized as two-wire or four-wire lines
  - channel group (bundle) is related to grouping where all channels of that group are treated equally
  - bundle needs not necessarily be identical with a cable
- Frequency Division Multiplex (FDM)
  - in FDM, each channel is associated with an own (private) frequency band
  - frequency shift by single side band amplitude modulation
  - multiplexing by interleaving of frequency channels using carrier frequency systems
  - application of frequency shift group wise and hierarchically
  - n frequency channels with fixed bandwidth
- Synchronous Time Division Multiplex (STDM)
  - sampling theorem for band-limited signals → PAM signal representation

B	...	bandwidth of the signal
$2B$	...	sampling frequency
$T_R = \frac{1}{2B}$	...	sampling period
  - digitalization (coding) by A/D conversion
  - time interleaving
- Wavelength Division Multiplex (WDM)
  - each channel is formed by use of a different optical carrier frequency or wavelength λ_i (similar to FDM)
  - realized by laser modulation at different wavelength
  - electro-optical conversion of signals for each channel
  - superposition of optical signals of different channels on one fiber
- Code Division Multiplex
  - each channel uses a different code sequence (mutual orthogonal codewords) for modulation
  - multiplexing by superposition of the products of the signals with the codewords

1.2.2 Block Multiplexing (Address Multiplexing, Statistical Multiplexing)

Channel multiplexing normally allows only multiplexing of signals (channels) with constant bandwidth or bit rate. Contrary to channel multiplexing, block multiplexing allows multiplexing of data streams with variable bit rates. For this, the original data stream is packaged in blocks of constant or variable length; each block is extended by a ”header” which contains control information such as addresses, connection id´s, sequence number and further protocol related information necessary to conduct the block through the network and to identify the block to which connection or destination it may belong to. Blocks with constant (small) length are called ”cells”. Longer blocks with variable length are called ”packages” or ”massages”.
Blocks may be transported through the network independently (”connectionless”) or they may belong to a virtual connection (”connection oriented”). Blocks of different connections/applications are multiplexed according to the **Asynchronous Time Division Multiplex (ATDM)** principle. ATDM allows for connectionless and connection orientated transport. Blocks are switched according to the control information within the header field.

- ATDM with variable Bit rate (Packet/Frame Multiplex)
  - blocks with variable bit rate are terminated by special delimiter fields

Flag	Header	Data	Trailer	Flag

Delimiter (Flag): Binary combination for detection of begin and end of a block. Flags may not occur within the block; this is usually achieved by a bit stuffing method ("zero bit insertion")

Control (Header): Control information for switching, routing, sequence integrity etc. (address fields, connection id, sequence number(s), protocol instructions, ...)

Data: User data (with respect to this layer of consideration)

Control (Trailer): Frame checking sequence; sometimes additionally some special control information (such as "frame copied", ...)

  - time interleaving of various blocks follows "statistical multiplexing"; blocks are buffered and inserted in order of their arrival

- ATDM with constant Block length (Cell Multiplex)
  - cells can be multiplexed by
    - cell-based multiplexing
    - frame-based multiplexing
  - cells are built up similarly as packets

Header	Data

  - normally connection orientated transfered

1.2.3 Transfer Modes

- Synchronous Transfer Mode (STM)
  - multiplexing of (physical) channels according to the STDM principle
  - constant bit rate of all traffic flows
  - high quality of service due to channel reservation and fixed delay
  - integration of traffics (services) with identical bit rate (e.g. 64 kbit/s in ISDN) or classes with different bit rates (e.g. 64, 384, 1920 kbit/s)
- Packet Transfer Mode (PTM)
  - multiplexing of (virtual) channels according to the ATDM principle
  - variable bit rates, bursty traffic streams
  - heavy protocol overhead in lower layers (data link, network layer)
  - packet switching with variable packet length
  - good throughput, but bad real-time behavior
  - integration of traffics (services) with rather different intensities
- Asynchronous Transfer Mode (ATM)
  - multiplexing of (virtual) channels according to the ATDM principle
  - variable bit rates, bursty traffic streams
  - low protocol overhead in lower layers ("lightweight protocols")
  - flow control and error recovery only end-to-end
  - quality of service guaranteed by traffic control algorithms
  - integration of a wide spectrum of different types of traffics and services

1.2.4 Connection Concepts

A connection is a temporary, semi-permanent or a permanent communication relation between several entities of a communication network. Typically, to each connection some physical or logical resources are associated which support the information transfer between theses entities, either by exclusive reservation of these resources for the connection, or at least by sharing of the associated resources among a controlled group of connections. A connection can be accessed through a well-defined connection endpoint (CE). Connections are either uni- or bi-directional , depending on the information flow.

- Connection Oriented Communication
  - Physical Connection
  - Virtual Connection
- Connectionless Communication

1.2.5 Connection Attributes

Attribute	Value
Switching Principle	- Circuit Switching (CS) - Fast Circuit Switching (FCS) - Multi Channel Circuit Switching (MCCS) - Packet Switching (PS) - Fast Packet Switching (FPS) - Cell Switching (ATM)
Transmission of User Information	- Analog - Digital transparent (Bit sequence integrity) - Digital nontransparent (Redundancy reduction) - Continuous (Stream like) - Discontinuous (Packet like)
Transmission Rate	- Constant Bit rate (CBR) - Variable Bit rate (VBR) - Packet rate, Cell rate
Connection Establishment	- Permanent Connection - Semi-permanent Connection - Switched Connection
Connection Configuration	- Point-to-Point Connection - Point-to-Multi-point Connection (Multicast, Broadcast) - Multi-point Connection (Conference)

1.2.6 Addressing

- ISDN-Addressing (CCITT Recommendation E.160)

CC	NDC	SN	SA

CC ... Country Code
NDC ... National Destination Code
SN ... Subscriber Number
SA ... Sub address

- MAC Addressing

I/G	U/L	OUI	SA

I/G ... Individual/Group
U/L ... Universal/Local
OUI ... Organization ID
SA ... Sub address

1.2.7 Switching

Switching defines the establishment of connections (in case of connection-orientated communication) and the transport of information between any pair (or group) of terminals or request of users.
Two basic types are distinguished:

- Circuit Switching (CS)
  - basically connection-orientated
  - provides an physical end-to-end connection for exclusive use
  - realization by
    * Space Division Multiplex (SDM)
    * Time Division Multiplex (STDM)
    * Multi-Channel Circuit Multiplex (MCCS)
    * Fast Circuit Switching (FCS)
- Store-and-Forward Switching
  - based on transport of data units
  - dynamic sharing of transmission resources
  - higher usage of recourses may be possible on the expense of a variable transport delay

- realization by
  - Massage Switching
  - Packet Switching (PS)
  - Fast Packet Switching (FPS)

- Hybrid Switching
  - combines CS and PS

1.2.8 Routing

- Fixed Routing
  - pre-fixed path between origin and destination
  - routing table contains minimum information on the network structure within each node
  - neighbor nodes are defined by path selection algorithm (e.g. shortest path algorithm)
  - application in CS and PS networks
  - change of routing tables by network management functions
    - when network is extended
    - when a link brakes down
    - periodically to adapt to typical load changes
- Alternating Routing
  - path selection algorithm takes into account not only the network structure but also the load
  - overflow situation from first choice to second choice route in case of
    - link blocking (CS)
    - buffer blocking (PS)
  - sequence of overflow routes are defined on the basis of economic criteria
- Adaptive Routing
  - path finding algorithm adapts on the actual load situation
  - each node has to have information about the actual load
  - versions of adaptation
    - routing along the shortest queues
    - routing according to load sharing criteria
    - routing according to cost estimation
    - routing according to delay estimation
- Dynamic Routing
  - time dependent routing scheme
  - state dependent routing scheme
  - hierarchical routing
  - dynamic non hierarchical routing
  - crack back routing

1.3 System and Network Architecture

1.3.1 The ISO/OSI Reference Model

- Physical Layer (Ph)
  - activation/deactivation of transmission link
  - definition of all transmission properties (electrical, mechanical, functional and procedural)
  - transmission of individual bit streams or blocks of bits

- Data Link Layer (DL), Logical Link Layer (LL)
  - establishment/release of DL-connections (if connection-orientated)
  - transmission of Layer 2 protocol data units
  - integrity of data
    * sequence
    * data flow
    * error detection/correction
    * acknowledgement
- Network Layer (N)
  - definition of a unified address/numbering scheme
  - routing of network connections (CS) or Layer 3 PDUs (PS datagrams) from origin to destination
  - establishment/release of network connections
- Transmission Layer
  - establishment/release of transport connections
  - multiplexing/demultiplexing of T-connections on N-connection
  - address resolution (mapping of addresses)
  - integrity of data exchange end-to-end
  - enhancement of network layer deficiencies by choice of transport layer classes of service
- Session (S)
  - establishment/release of session connections
  - control of information exchange
  - definition of transmission mode
  - dialog synchronization
- Presentation (P)
  - establishment/release of presentation connections
  - transformation of data with respect to
    * code
    * format
    * syntax
  - data encryption
- Application (A)
  - establishment/release of presentation connections
  - support of application specific functions

2 Circuit Switching

2.1 Space Devision Multiplex

2.1.1 Non-Blocking Multi-Stage Switching Arrays

External Blocking occurs, if a connection cannot be switched from an idle incoming circuit to an outgoing circuit due to the fact that all outgoing circuits are busy.

Internal Blocking occurs, if a connection cannot be switched from an idle incoming circuit to an outgoing circuit due to the fact that no internal path is available to the outgoing circuit.

Non-Blocking Condition (Clos):

$$\boxed{k_1 = i_3 = g_2 = i_1 + k_3 - 1} \tag{1}$$

Optimization of Crosspoint

$$\boxed{n_{\min} = \sqrt{\tfrac{n_1 \cdot n_2}{n_1 + n_2}}} \tag{2}$$

for $n_1 = n_2 = n$:

$$\boxed{n_{\min} = \sqrt{\tfrac{n}{2}}} \tag{3}$$

$$\boxed{C_{\min} = 2 \cdot (n_1 + n_2) \cdot (2n_{\min} - 1)} \tag{4}$$

2.1.2 Combined Space/Time Switching Arrays

Time-Space-Time Switching Array

$$\boxed{m \geq 2n - 1} \tag{5}$$

Space-Time-Space Array

$$\boxed{k \geq i_1 + i_2 - 1} \tag{6}$$