Karlsruher Institut für Technologie

Institut für Technik der Informationsverarbeitung

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Communication Systems and Protocols

Session 12: Networks

Clicker Session: Recapitulation

- https://arsnova.eu/mobile/#id/33969518

Recapitulation

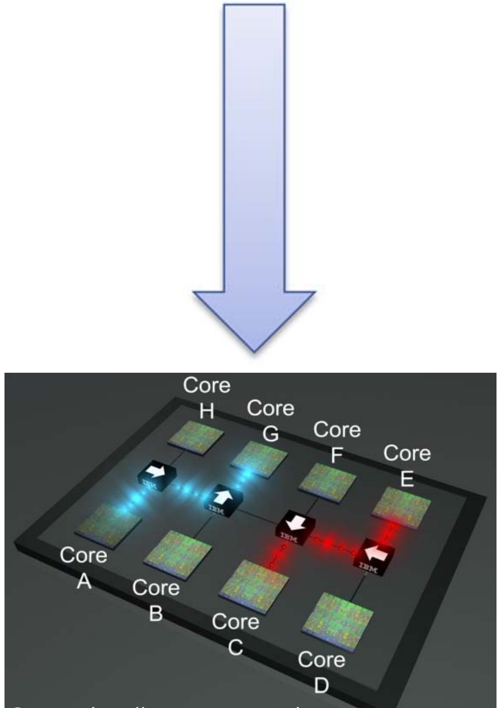
- Networks
  - Basic elements
  - Routing
  - Routing algorithms

Classification

Classification of networks by coverage area

- **WAN** (Wide Area Network)
  - spans over large geographical areas
  - carries aggregated global network traffic.
- **MAN** (Metropolitan Area Network)
  - Coverage up to 60 km
  - serves as access point to the global WAN
- **LAN** (Local Area Network)
  - Coverage up to 900 m
  - typically privately owned smaller networks
- **PAN** (Personal Area Network)
  - Coverage of ~10 m
  - network of personal items
- **NoC** (Network on Chip)
  - Coverage on chip (some millimeters)
  - connect computational units on a single chip

Source: http://www.techstagram.com



Source: http://www.cse.psu.edu

NoC vs LAN

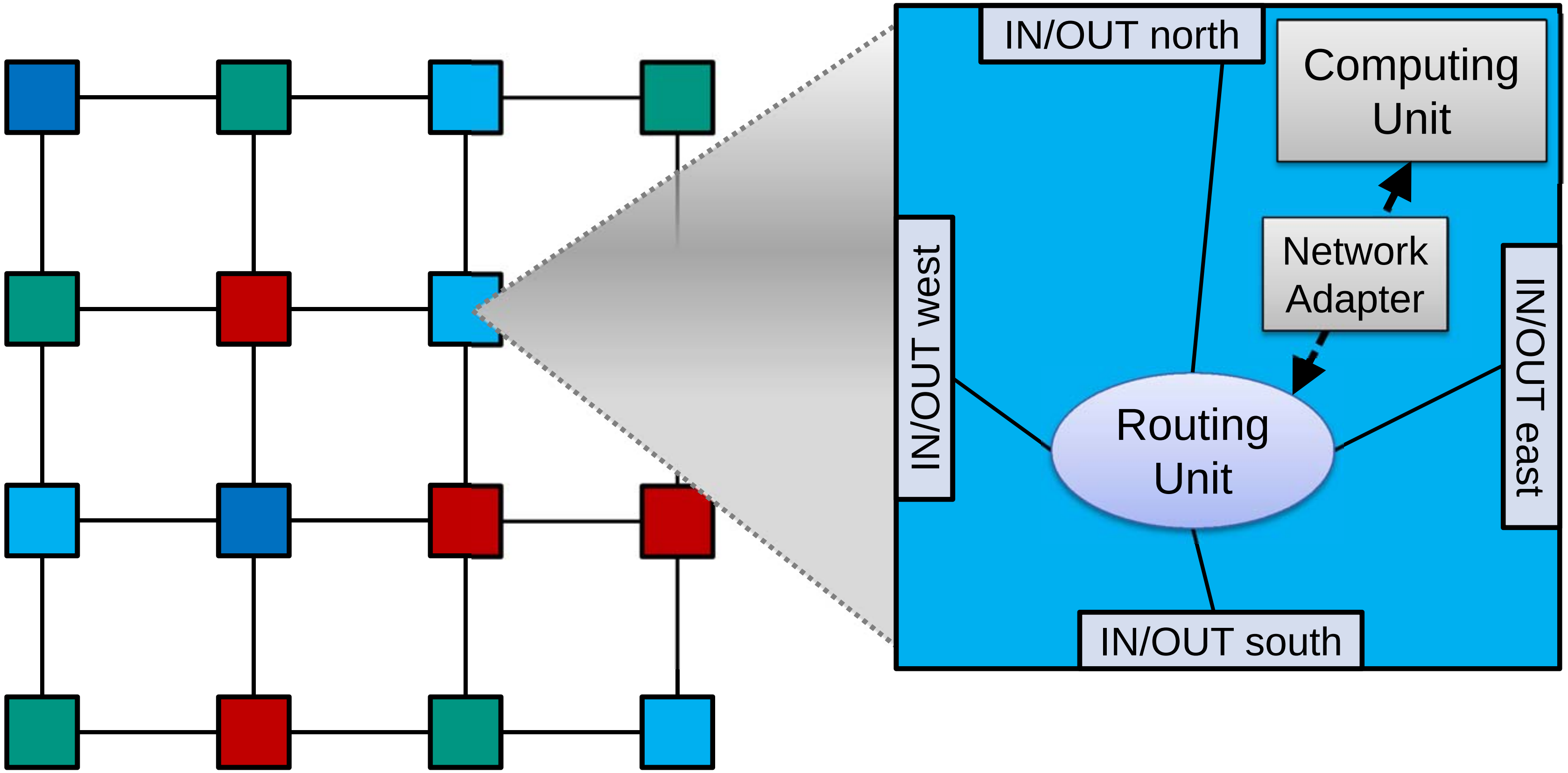
- Local Area Networks (LAN)
  - high computation power (PC)
  - wide coverage area
  - varying topology
  - very large number of connected nodes

- Network-on-Chip (NoC)
  - coverage area limited to the chip
  - topology usually fixed
  - number of nodes limited by chip size
  - High performance
  - Simple routers, low complexity

- But basic network and routing mechanics are similar for both types of networks.

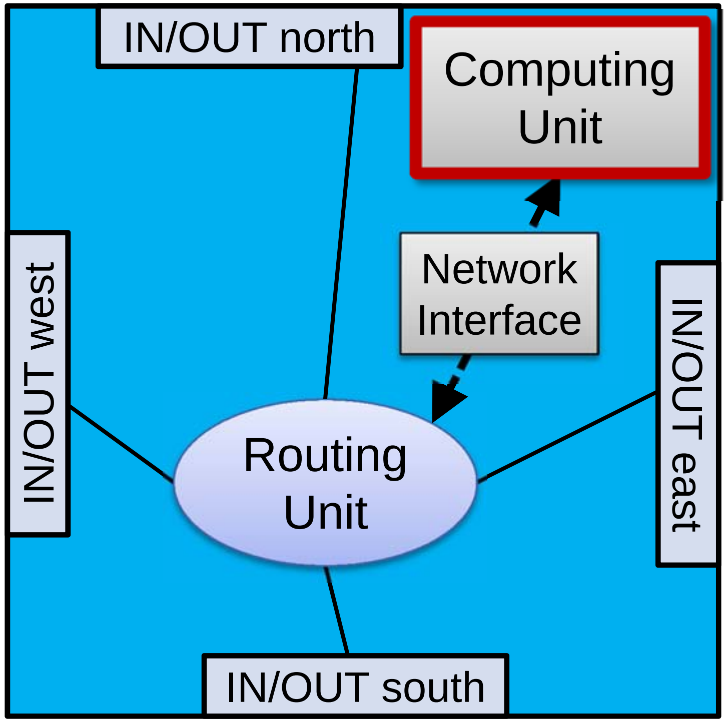
Networks & Nodes

Network Nodes – Basic Setup



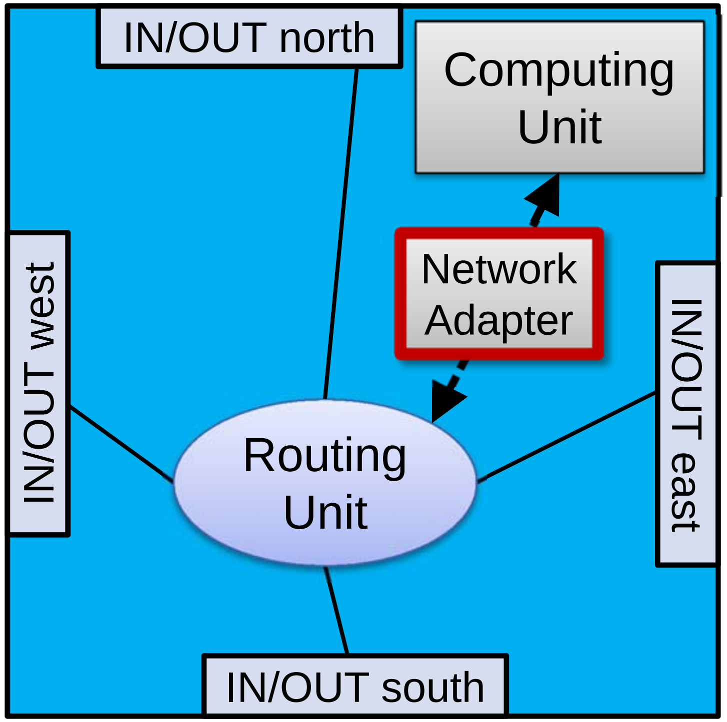
Computing Unit

- Computational Entity
  - Processor/Microprocessor
  - Memory
  - Infrastructure
  - I/O
- Runs an application or part of an application
- Is producing and consuming data
- Is connected to the network via the network interface



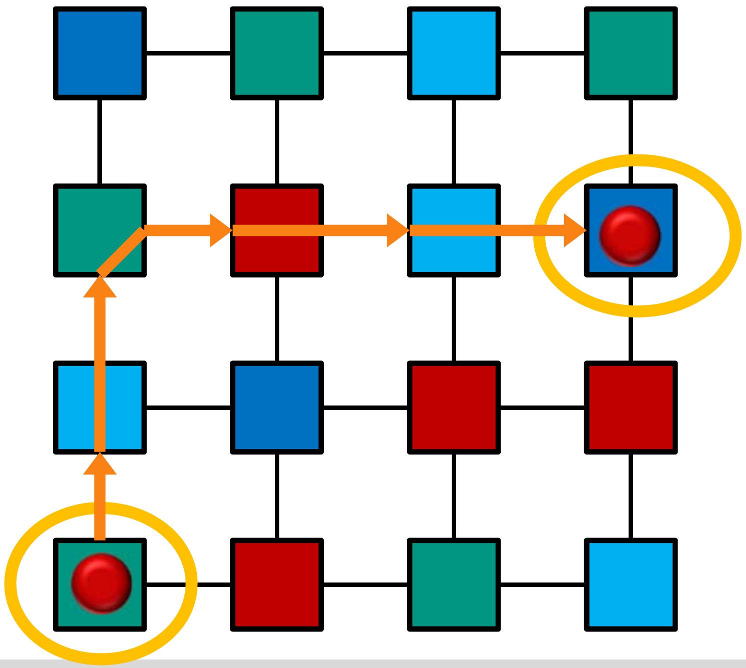
Network Adapter / Network Interface

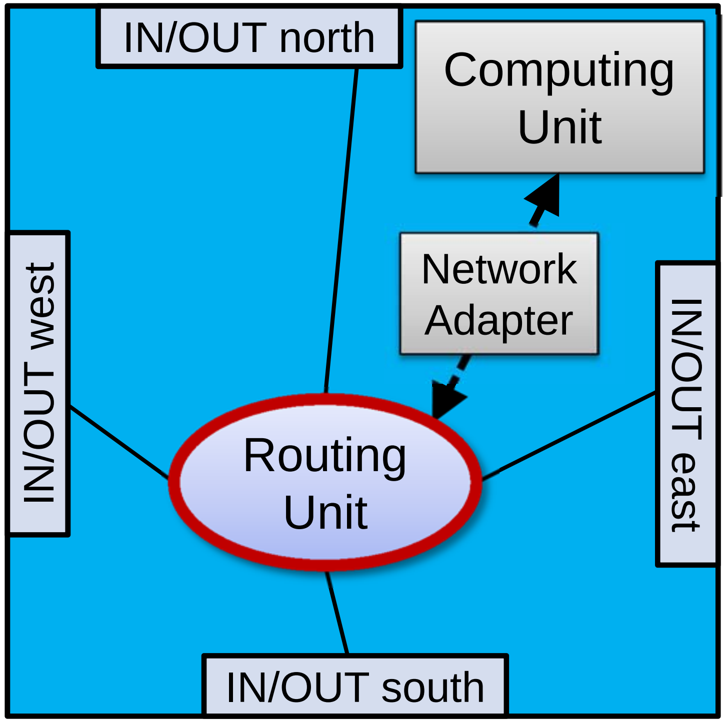
- Mediator between Computing Unit and Network
  - Packetizing of data
  - Framing
  - Flow Control
  - Error Correction
  - …



Routing Unit

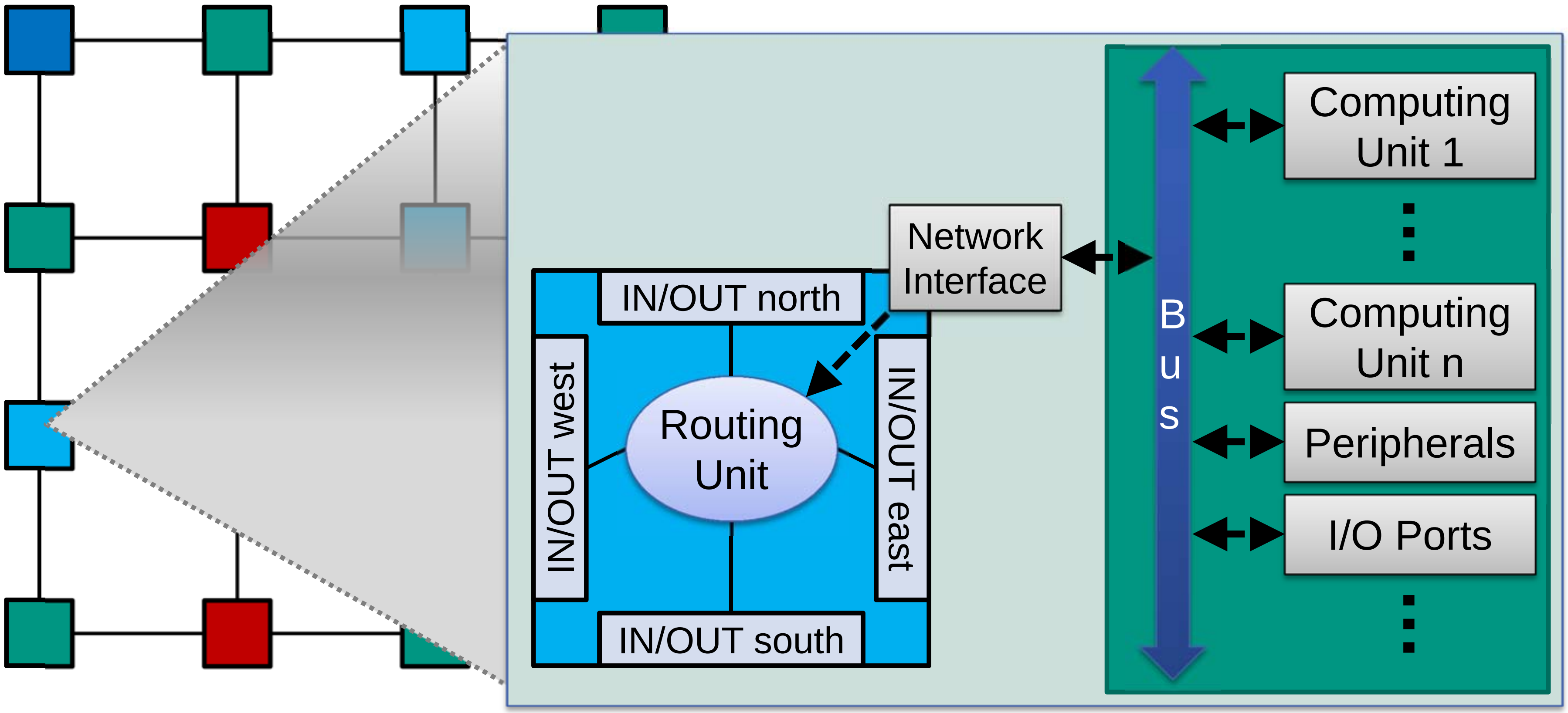
- Switches Paths
- Embedded intelligence that decides on the direction of the data (routing alorithm)
- Refresh signal
- Additional functionality possible (local storage, Error Correction, …)



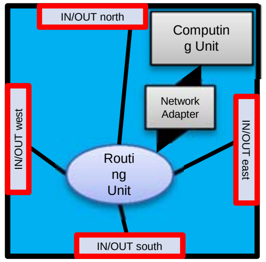


Network Nodes – Extended Setup

- A network node can contain:
  - multiple Computing Units
  - Peripherals (such as memory)
  - Input/Output Ports
  - …

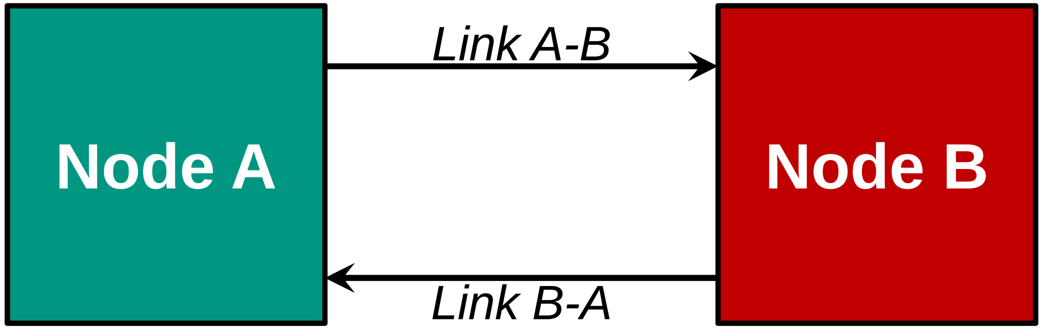


Network Link



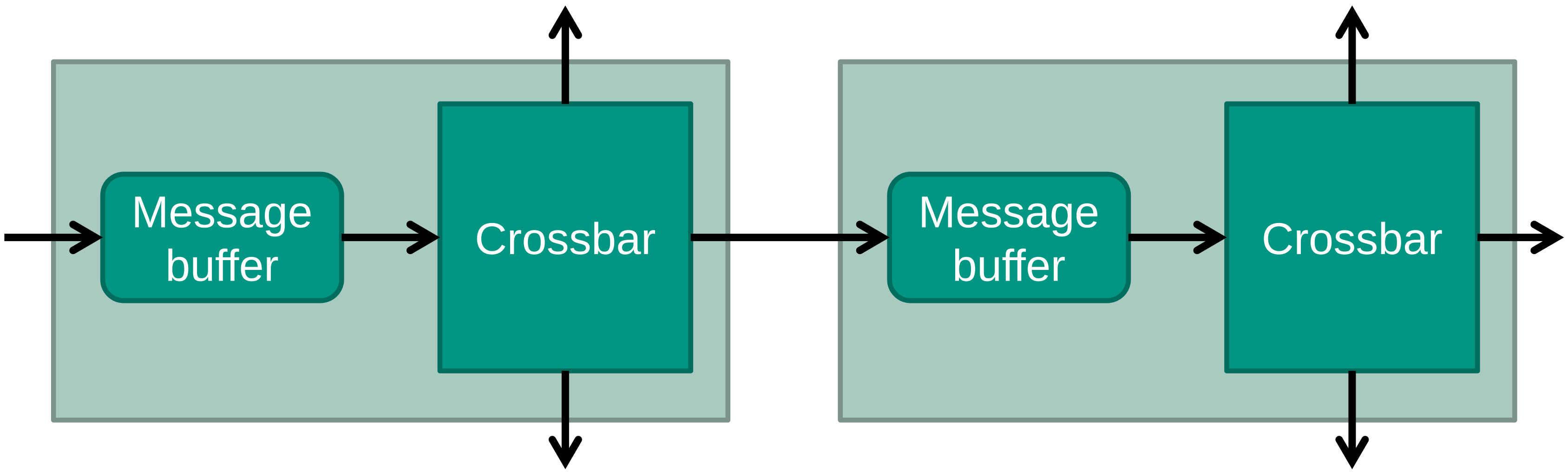
- Physical communication channel between neighboring nodes
- Unidirectional
- Link has fixed data width
- Multiple links between two nodes can exist (in either direction)
  - concurrent transmissions

  or
  - aggregation to achieve higher throughput/bandwidth



Network link for packet switching

- For circuit switching, data can be directly forwarded from one node to next node
- For packet switching, messages have to be stored if next node is not ready to take data → message buffers required
  - Message is stored in buffer until next node is ready for reception
  - Multiple messages can be stored in buffer

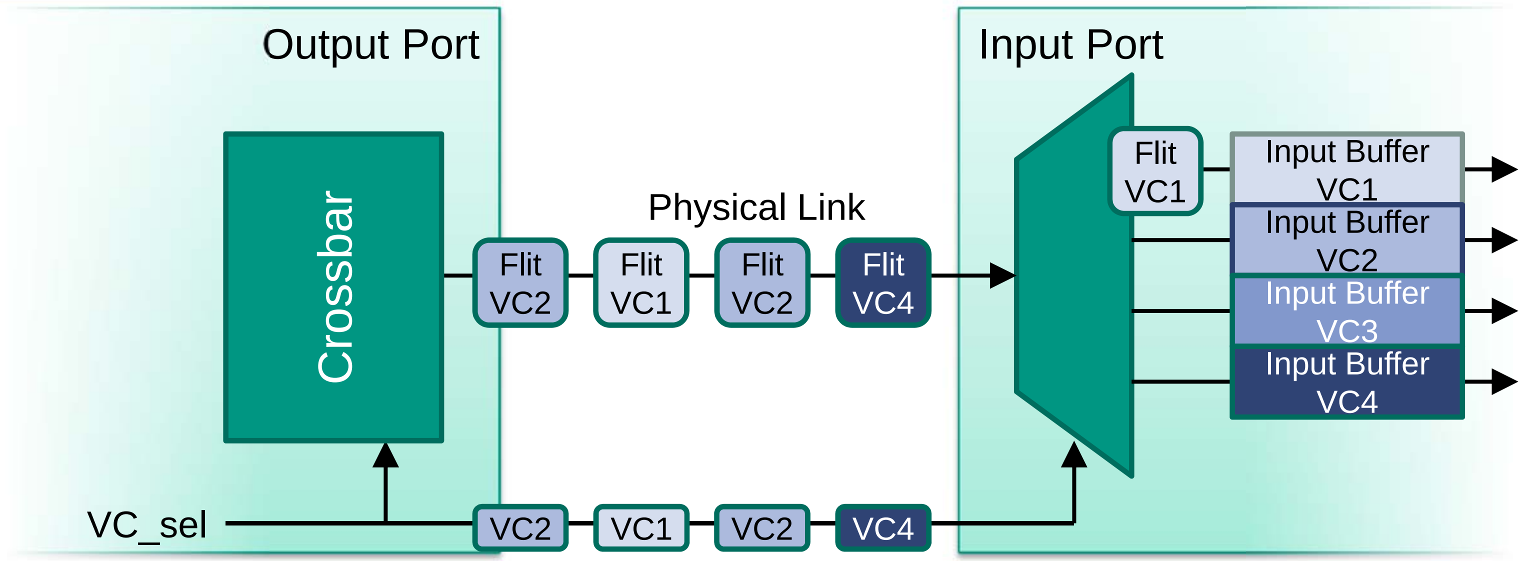


Motivation for virtual channels

- In larger networks, messages might have to wait for other messages to be transported
  - Link is blocked for circuit switching
  - Message buffer is blocked for packet switching
- Bad link utilization

- Solution: Share physical link between multiple communications

Virtual Channels (VC)



- Time Multiplexing of physical link
- Independent data transmissions on independent virtual channels (VC)
- Internal storage (buffers) in routers/tiles required
- Each node can take independent routing decisions (priorities, buffer levels)
- additional control logic within the routers/node as well as additional control information between nodes

Arbitration - Shedulling

- Network nodes have multiple shared components
  - Routing unit, if packet arrive at different ports and have to leave at same output port
  - Buffers
  - Output ports

  - Arbitration is required → Scheduling
    - Time Division Multiple Access (TDMA)
      - Fixed Slots for every packet

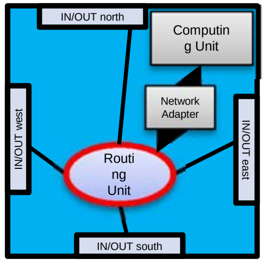
    - Round Robin (RR)
      - Fixed order (if no access required, slot can be taken by next request

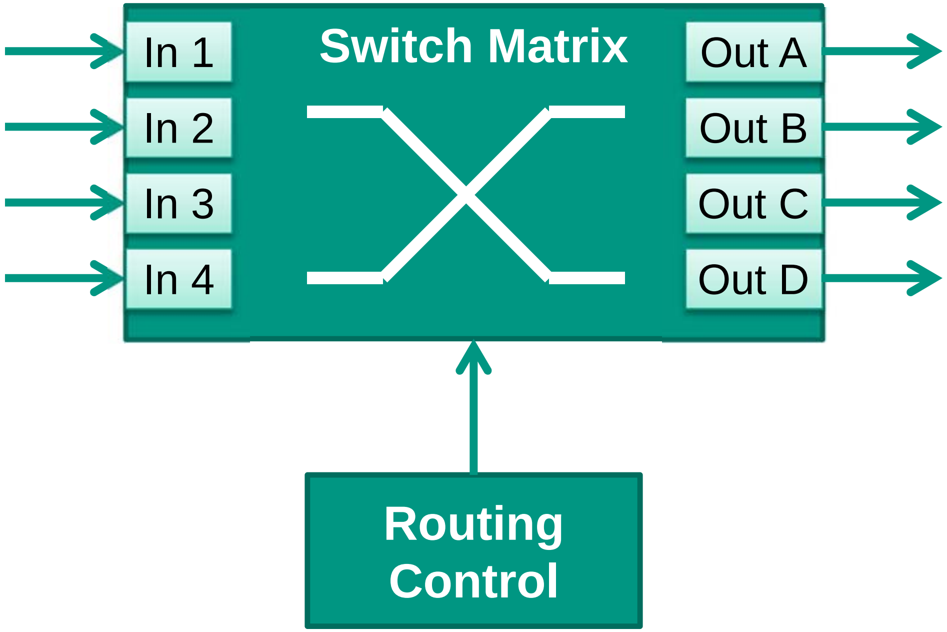
    - Priority
      - Assign priorities to messages

Detailed discussion of scheduling see lecture Systems and Software Engineering (Prof. Sax)

Minimal Components of a Routing Unit

- Switch matrix
  - connects one input to one output
  - multiple connections at the same time can exist



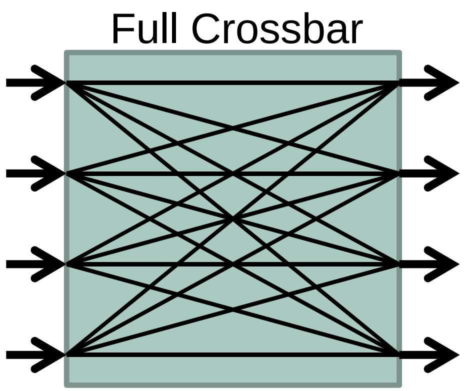


- Routing Control
  - evaluates data address
  - implements routing connections according to routing protocol
  - determines what input is connected to what output

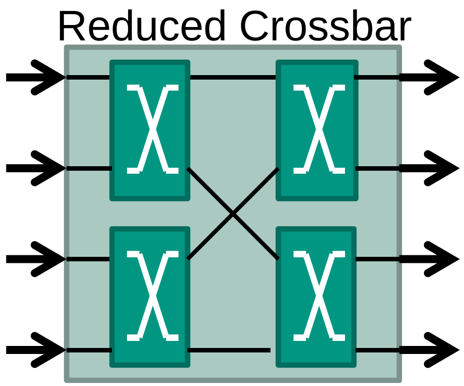
Switching matrix

- Switching matrixes are used to electrically connect inputs with outputs

- Full Crossbar
  - Any input can be connected to every output
  - No limitations for routing
  - Expensive in terms of hardware resources



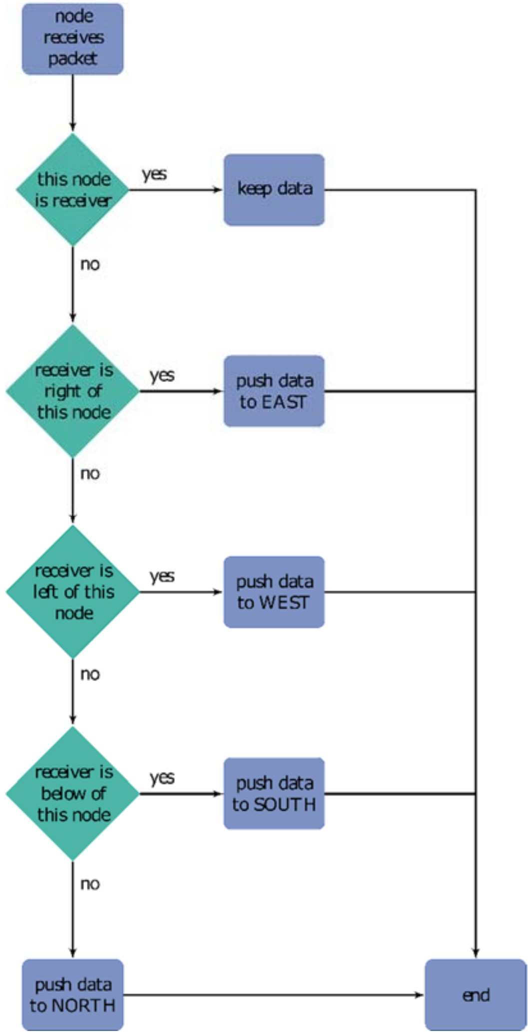
- Reduced Crossbar
  - Number of concurred connections is limited
  - Fewer resources required
  - Routing algorithm has to take care of individual characteristics of matrix



Example for Routing Control – Online Routing

- Routing decision is calculated inside routing unit
  - Decision depends on local information
  - Computation inside routing unit required

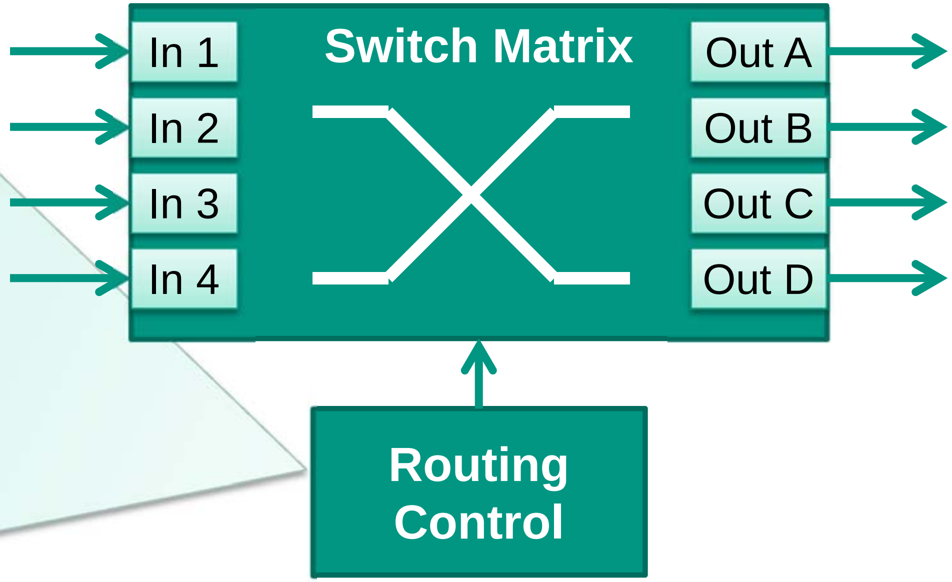
- XY-Routing algorithm
  - No internal storage needed
  - Simple algorithm



Example for Routing Control – Routing Table

- One row per destination address
- Content stores output port for a given destination
- Table can be static or dynamic
  - Example algorithm: Dijkstra

Destination Address	Output
0x0001	Out C
0x0002	Out C
0x0003	Out A
0x0004	Out D
⋮	⋮
0xFFFE	Out B
0xFFFF	Out C



Predetermined vs. Online Routing

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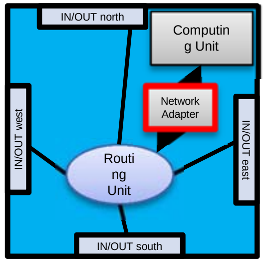
- Trade-Offs are necessary
  - Memory Size and Latency
  - Computations external/internal
  - Overhead data transfers/routing entries
  - … etc. …

Destination Address	Output
0x0001	Out C
0x0002	Out C
0x0003	Out A
0x0004	Out D
⋮	⋮
0xFFFE	Out B
0xFFFF	Out C

```
vector < int > SCNoCRouter::routingXY(const SCNoCCoord & current, const SCNoCCoord & destination)
{
   vector < int >ports;

   if ((flit.dst_id == local_id) && (G_ROUTING_TYPE != 5))

ports.push_back(PORT_LOCAL);
// keep data
   else if (destination.x > current.x)
         ports.push_back(PORT_EAST);

   else if (destination.x < current.x)
          ports.push_back(PORT_WEST);

   else if (destination.y > current.y)
         ports.push_back(PORT_SOUTH);

   else  ports.push_back(PORT_NORTH);

   return ports;
}
```

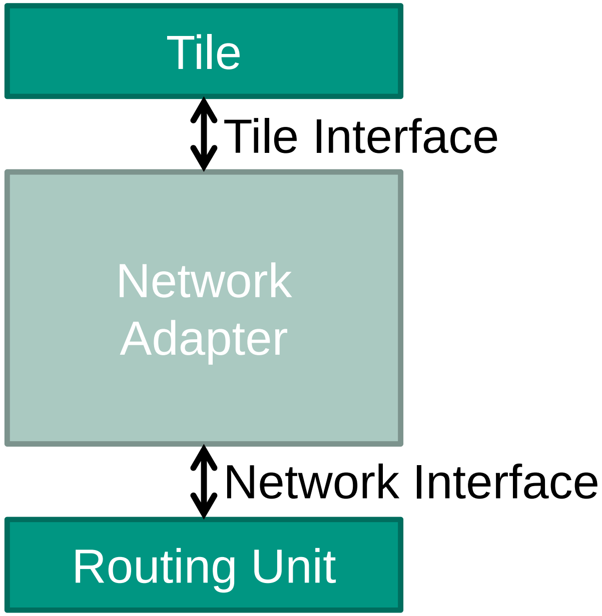
Network Adapter / Network Interface



- Used to attach system components to the network

- Can act as a wrapper to hide the network specific behavior from the attached tile → Protocol conversion

- Responsible for:
  - Packetization of data
  - Error Handling
  - Flow control
  - Generation of routing information
  - Network management



OSI Model, TCP/IP, Ethernet

Overview

- Communication Models (OSI-Layer Model)

- Local Area Networks (LANs)
  - Requirements
  - Net configuration
  - Couplers
  - Example: Token-Ring
  - Example : Ethernet
  - TCP/IP

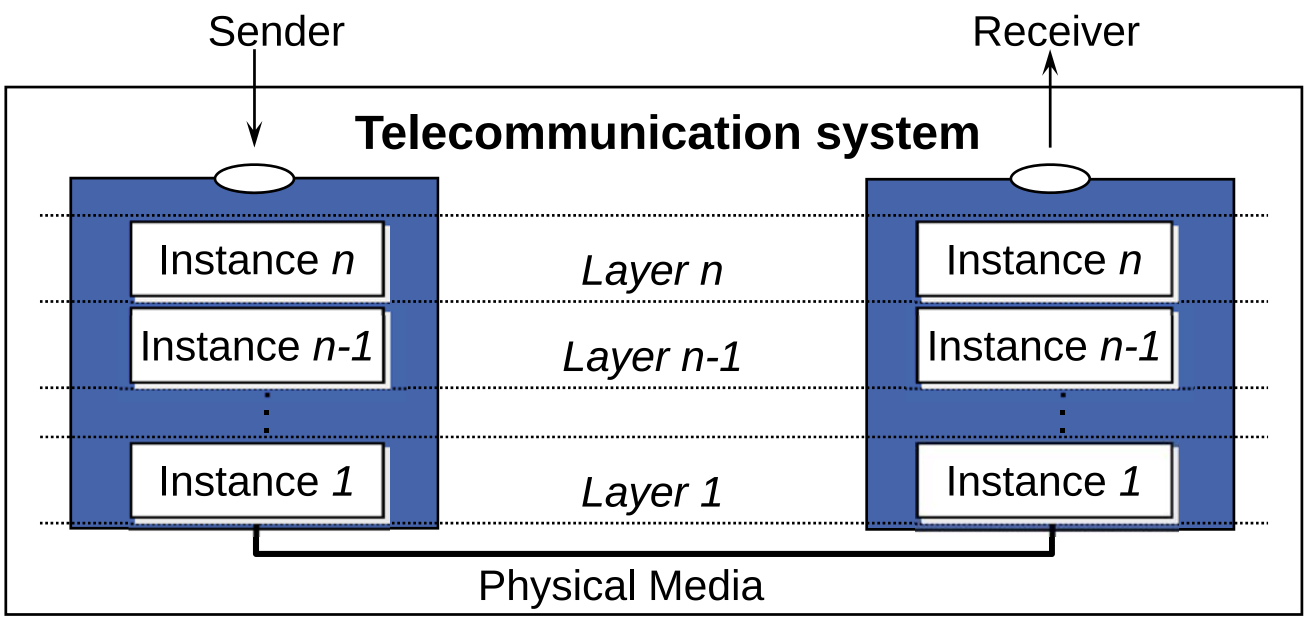
For more in-depth information visit the lecture „Telematik“ (Prof. Dr. Martina Zitterbart)

History of Communication Models

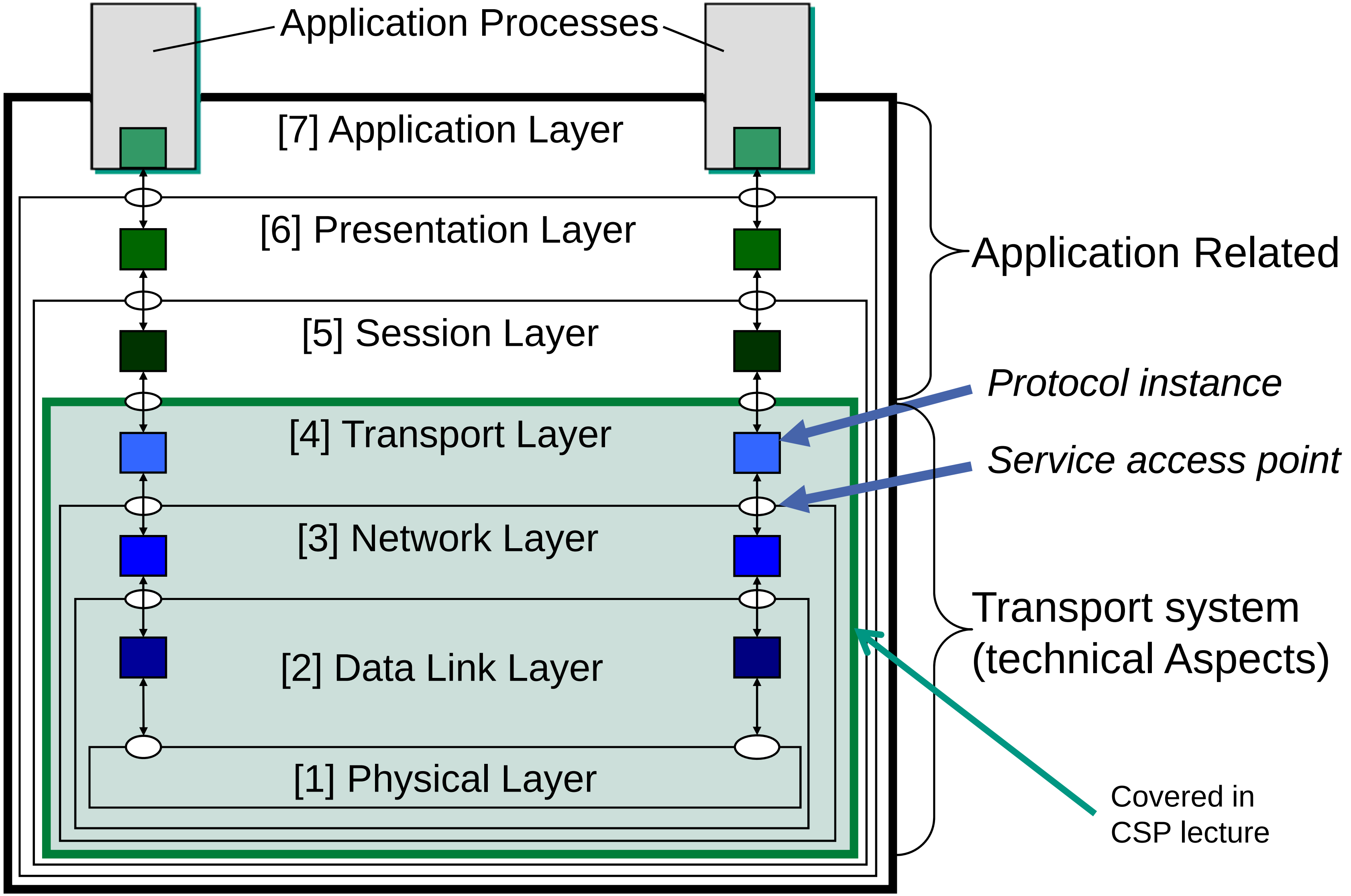
- First computer networks were vendor specific and closed networks
  - Today: mainly open networks
- Most important Wide Area Network (WAN):
  - 1969: ARPA-Net (Advanced Research Projects Agency)
  - Successor: Internet
- Computer communication requires mutual understanding of how the communication is supposed to function
  - Protocols
- All current communication architectures: Layer models
  - OSI-Reference Model, TCP/IP-Protocols
  - Every layer implements certain functions
  - Independency of layers due to standardized interfaces
  - Dedicated mapping of functionalities and services to certain layers.
- Most important reference model for computer communication published by ISO 1984 following the preliminary work of CCITT
  - OSI-7-layer model (Basic Reference Model for Open Systems Interconnection)
    - ISO 7498-Standard, later adapted by CCITT as X.200-standard)

Open Systems Interconnection (OSI) model

- Why a layered model?
  - Segmentation into manageable parts
  - Modular setup
  - Each layer provides a service to the layer above
  - The service is provided according to a specified protocol and under cooperation of the layer instances.
- Elaborate concept, therefore layers are sometimes clustered



Logic Architecture: OSI Reference Model



Layer Description

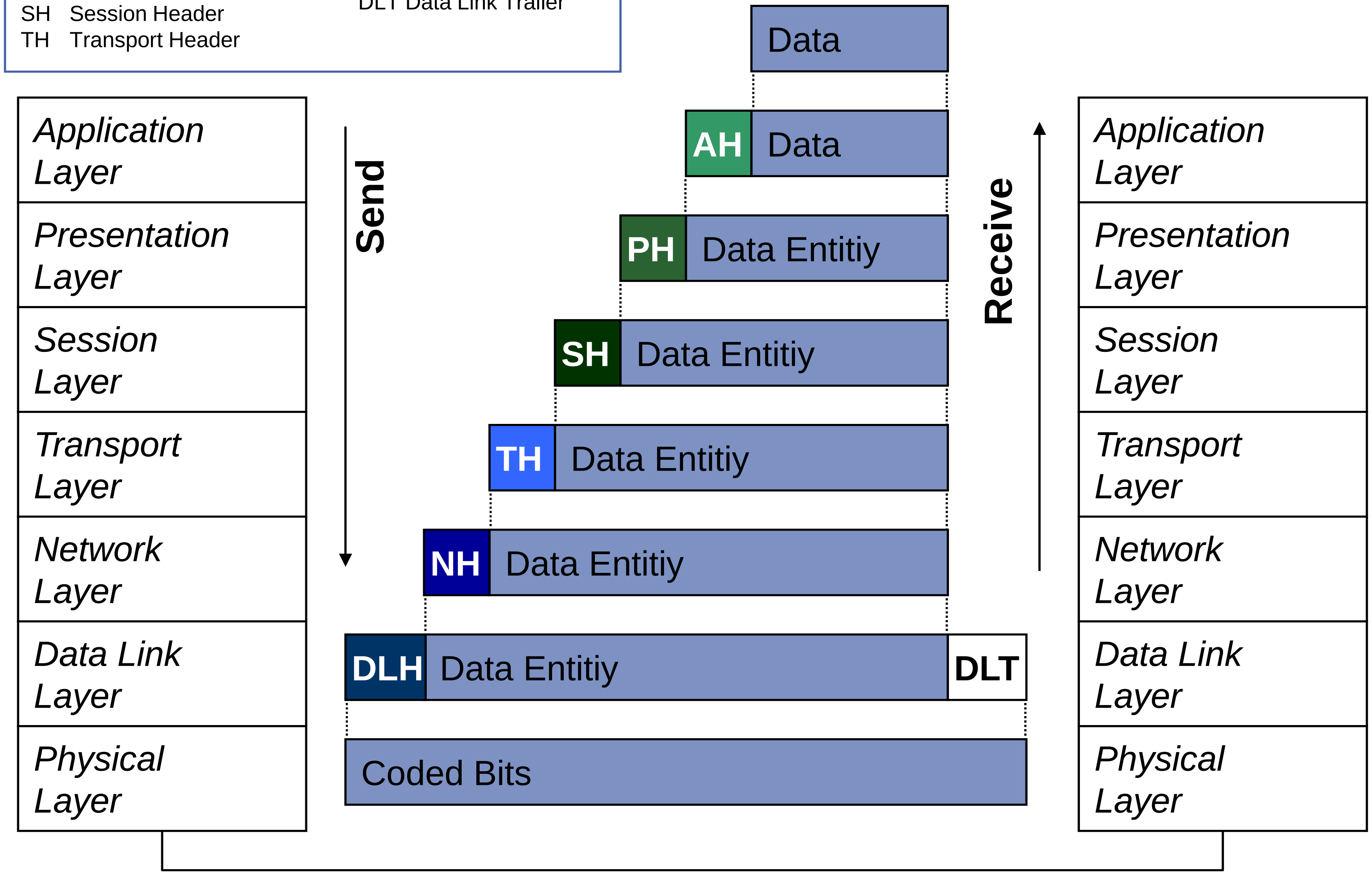
- Physical Layer, Layer 1:
  - Methods and schemes to transmit bit sequences
  - Defines the transmission medium (electrical and mechanical properties)
  - Line Coding
- Data Link Layer, Layer 2:
  - defines formats of data packets
  - defines error detection/correction schemes on logical level
- Network Layer, Layer 3:
  - Addressing of nodes
  - Routing and path finding
  - Flow Control
- Transport Layer, Layer 4:
  - Establish logic connections between nodes (channels)
  - provides stable channels

Layer Description

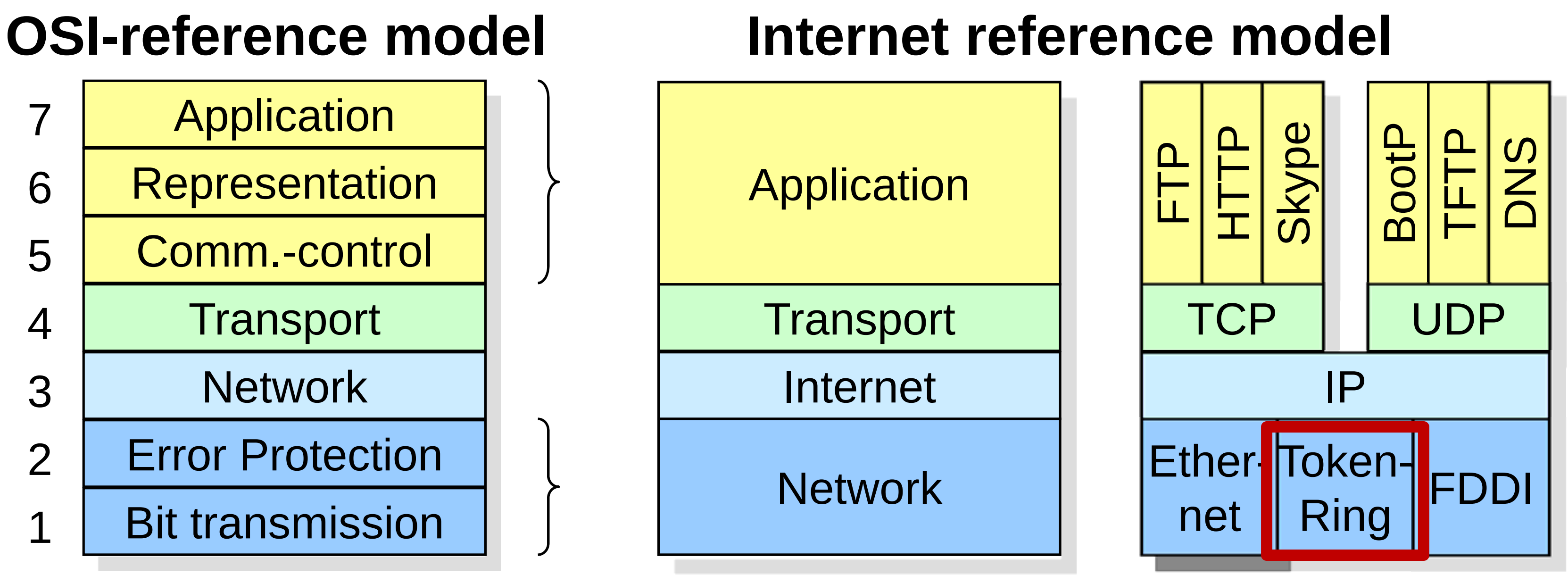
- Session Layer, Layer 5:
  - Control of Connections/Sessions between two communication partners:
    - Permissions
    - Structure of transmission
    - Opening, management, and closing of connection/session
- Presentation Layer, Layer 6:
  - Defines structure of application data including formatting, encryption, data representation, …
- Application Layer, Layer 7 :
  - Provides functions for an application such as:
    - eMail
    - FTP
    - …
  - Data Input and Output is done on this layer

Data Encapsulation

AH Application Header
PH Presentation Header
SH Session Header
TH Transport Header
NH Network Header
DLH Data Link Header
DLT Data Link Trailer



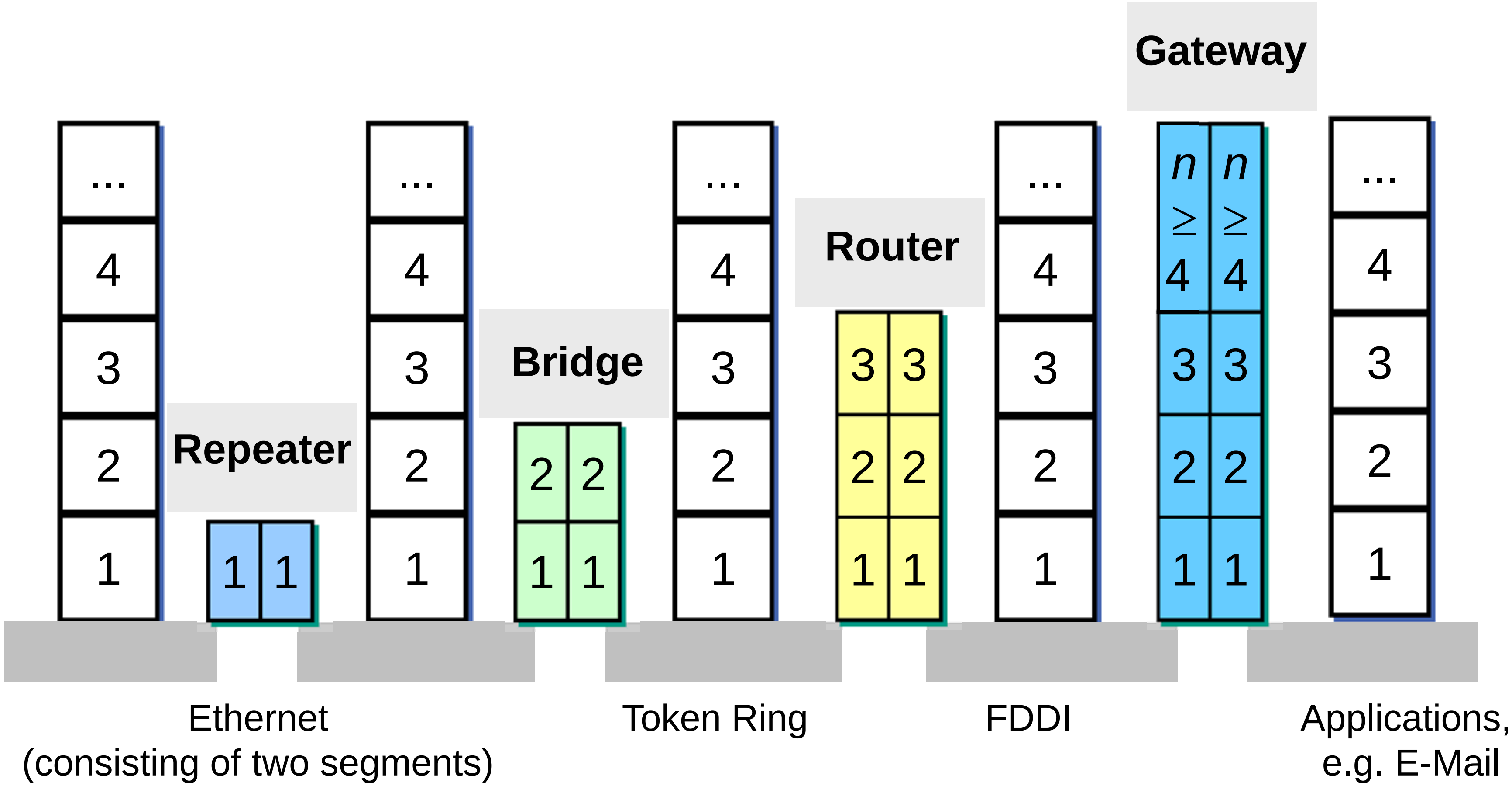
OSI Model in the real world: The Internet



- Main Differences
  - In the internet-reference model, tasks of OSI-layers 5 und 6 are moved completely into the application layer
  - OSI-layers 1 and 2 are combined to a single layer
  - TCP/IP supports two transport protocols: TCP (connection-orientated) and UDP (connection less)

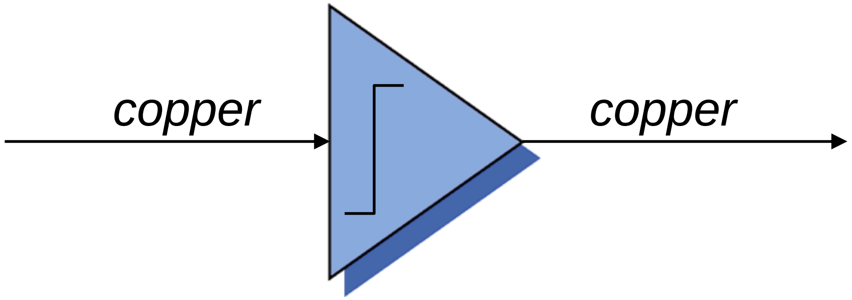
Network Coupling

Coupling of Networks– Internetworking

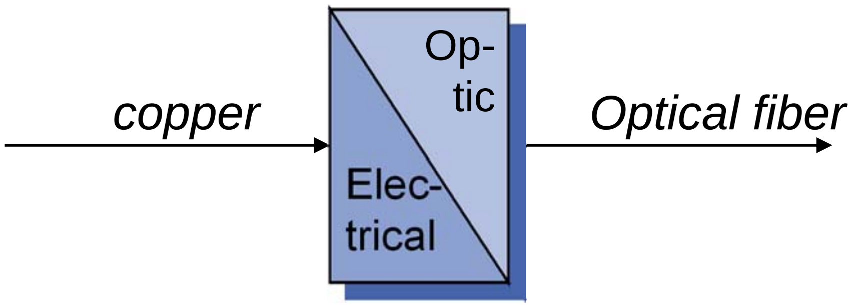


Repeater

- Coupling of physical media using signal regeneration / -amplification
  - No storage of intermediate data (buffering)
  - No packet processing
  - Media can differ, but protocol on layer 2 has to be equal



Electrical Repeater (Amplifier)



Electro-optical Repeater

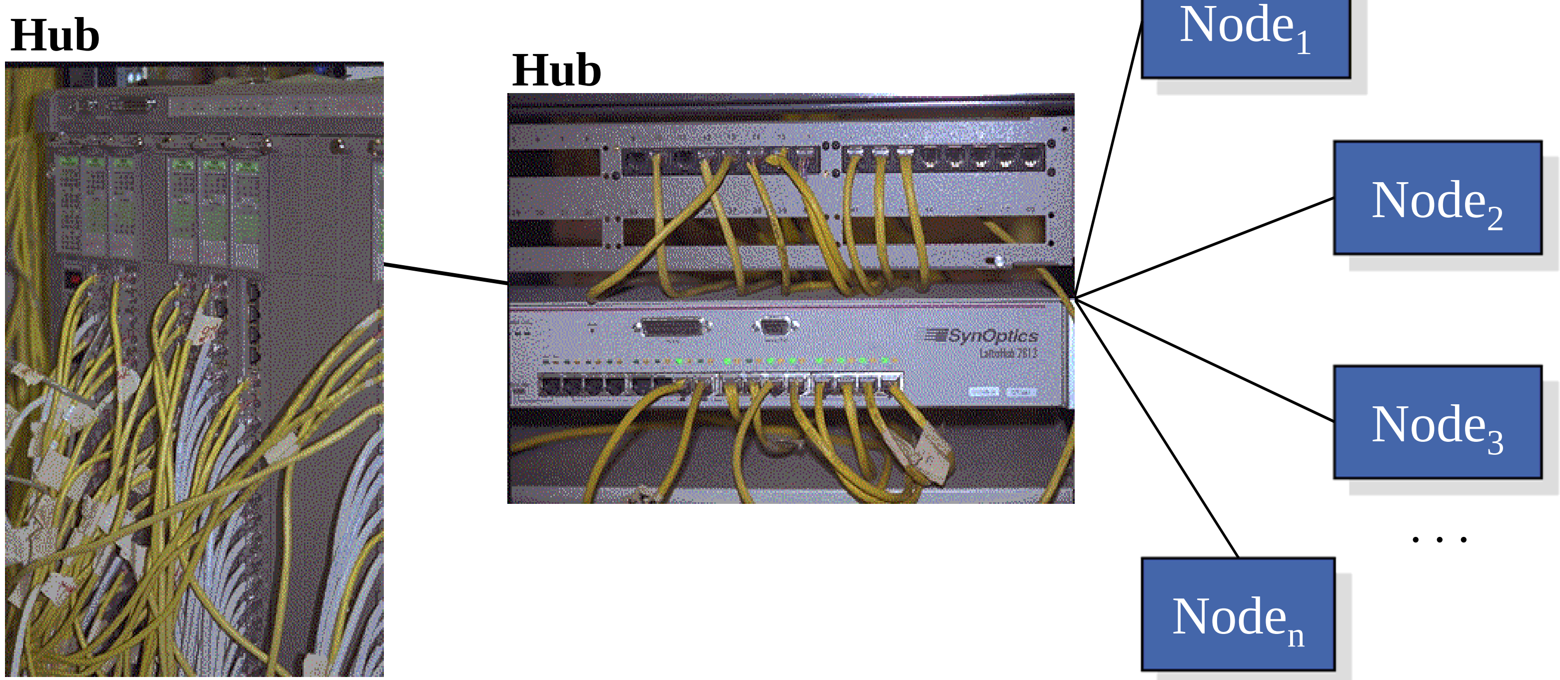
Repeater – Characteristics

- Network coupling on layer 1
- Field of application
  - Coupling of local networks to increase physical length of network segment
  - Generation of multiple outgoing signals in branching points
  - Change of transmission media

+ Simple, cheap technology
+ No performance penalties because of data processing
+ Very long communication links can be realized (e.g. transoceanic cables)
− No intelligence; all data is passed on
− No increase in network capacity because of partitioning

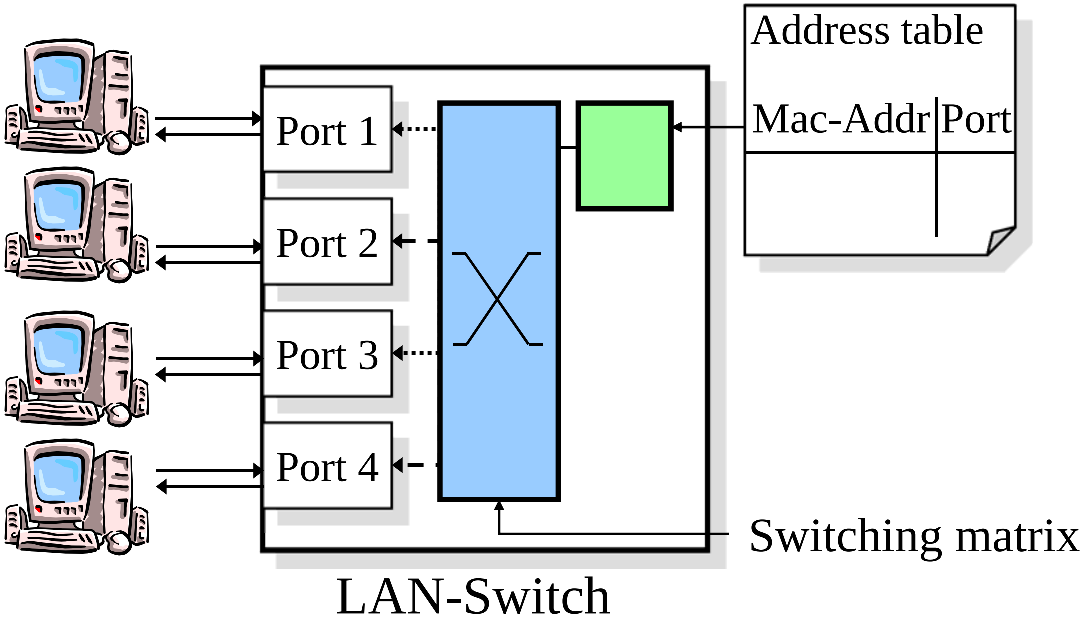
Hubs

- Nodes are connect to a hub using star topology
- Hubs provide similar functionality as repeaters (layer 1)
- Hubs can be cascaded
- Packets are forwarded to all connected nodes
  - ⇨ Data throughput of the whole network is not increased (compared to switch)



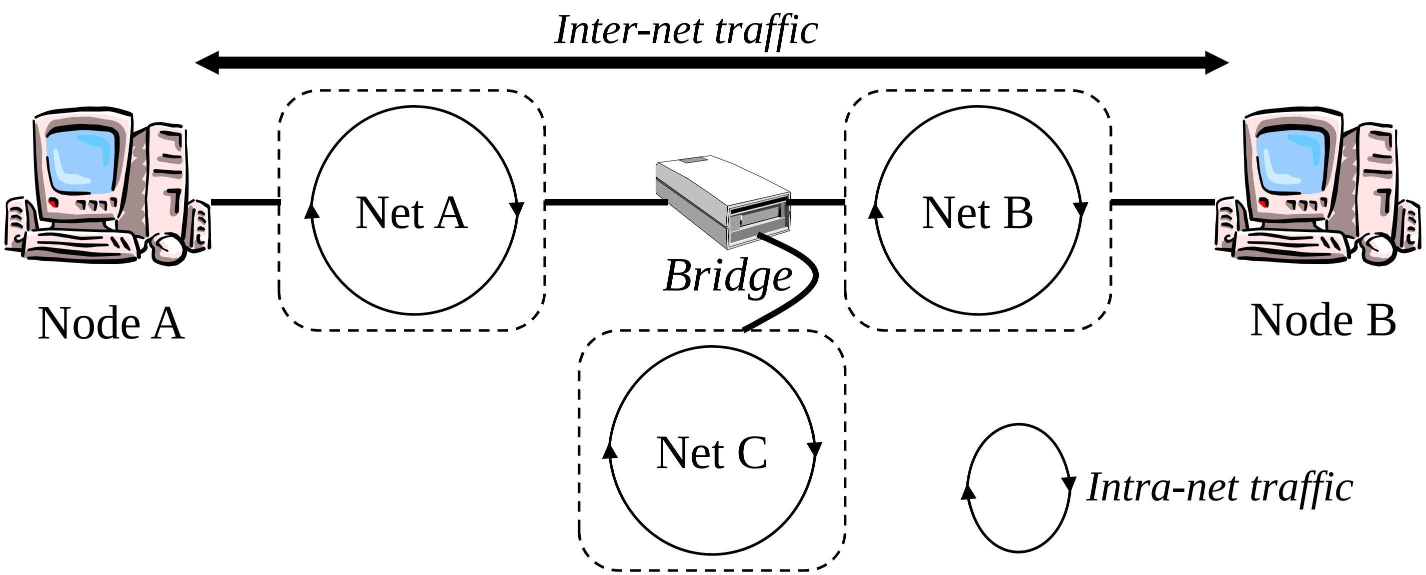
Switched LANs

- Star topology with one central component = *Switch*
- Every connected node can use the full network bandwidth
- Usually separation of sending and receiving direction (full duplex transmission)
- Parallel processing/forwarding of multiple incoming data packets
- Input and output are connected using an address table



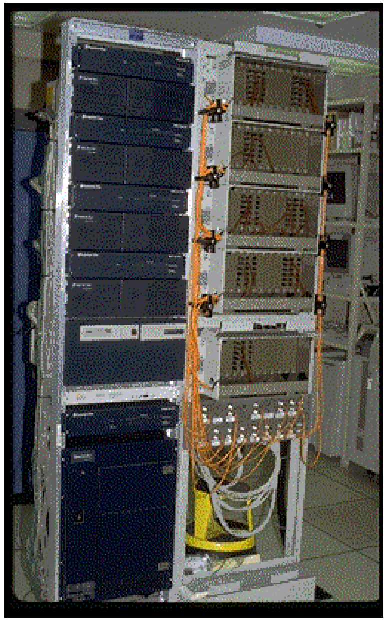
Bridge

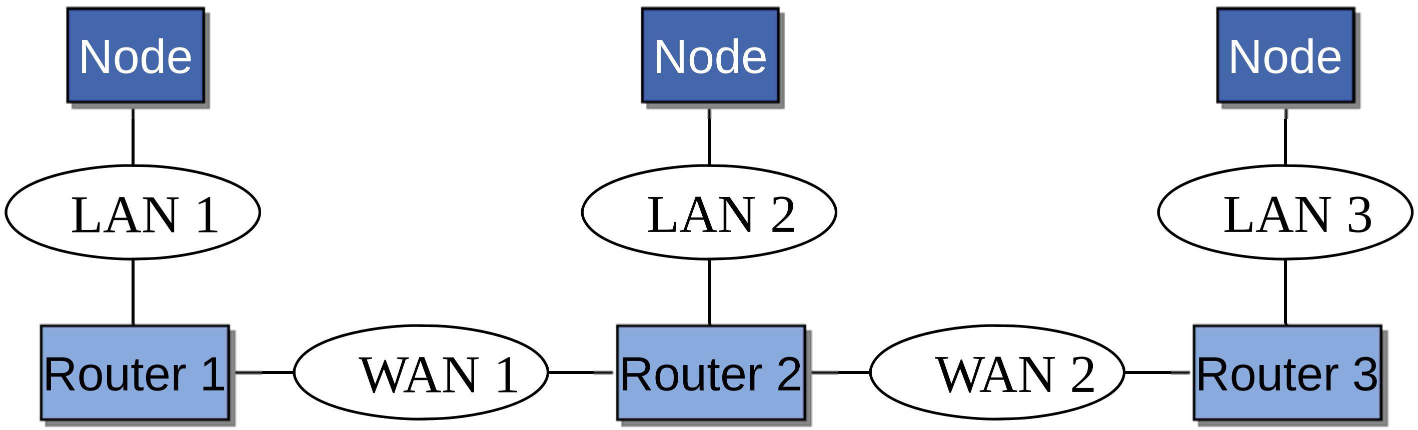
- Coupling of networks on layer 2
  - Networks of same type (e.g.. 802.x with 802.x) (non-translating)
  - Networks of different type (e.g. 802.x with 802.y ($x^{1}y$)) (translating)
- Functions:
  - Separation of intra-net traffic from inter-net traffic (filter functionality)
  - Increase of network capacity of large networks through partitioning (each partition with full number of nodes/network length)
  - Realization of simple routing functionality (routing on layer 2)



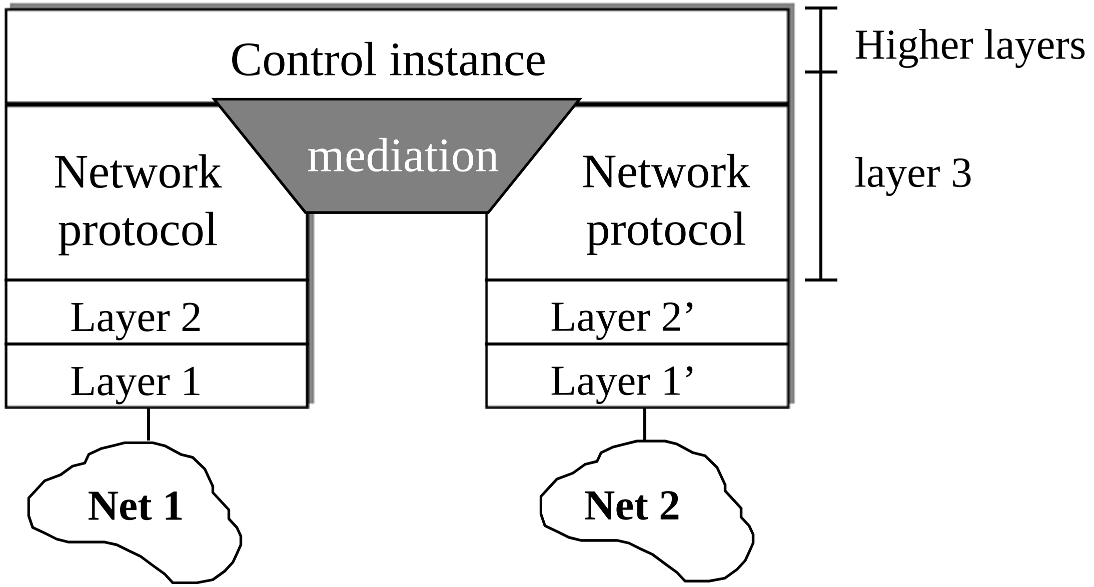
Router

- Network coupling on layer 3
- Functions:
  - Communication between distant node over one or more WANs
  - Routing using global unique and preferable hierarchical network addresses (e.g. IP address, ISO address)
  - Segmentation/reassembling of layer 3 packets to adapt to differing maximum packet sizes in layer 2
  - Security measures to control network access based on network address (“Firewall”)
  - Automatic limit of layer 2 broadcasts





Architecture of a router

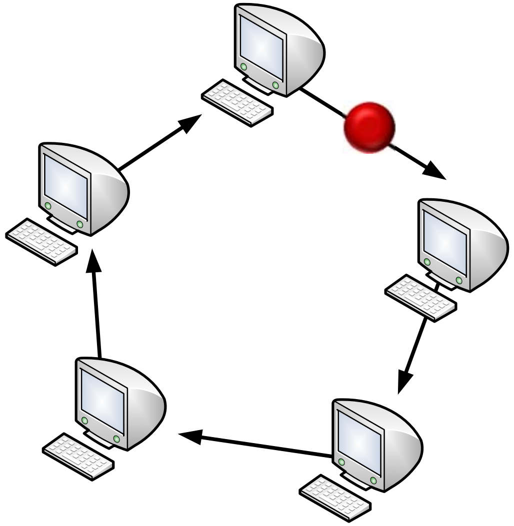


- Main characteristics:
  - Each network has its own layer 1 and layer 2 instances
  - Generally the network protocol is the same for all networks (e.g. IP-Router)
  - Choice of path is done based on unique network addresses
  - Mediation component connects the two network protocol instances, realizing the forwarding functionality
  - Control instance may implement routing protocols, protocols for error monitoring and management protocols

Examples for Networks

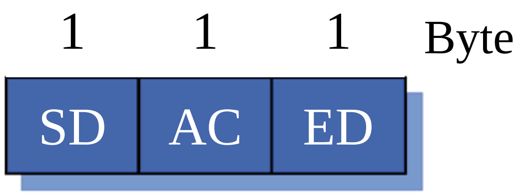
Token Ring (IEEE 802.5)

- Media Access control provided by a small data frame (token) that is circulating
  - cycling right to send (Token)
- A station having received the Free-Token can transmit data
- Data that has been send will return to the sending station due to the ring structure
  - Station takes data off the bus
  - Afterwards station passes the token to its successor
- Extensive token management is needed

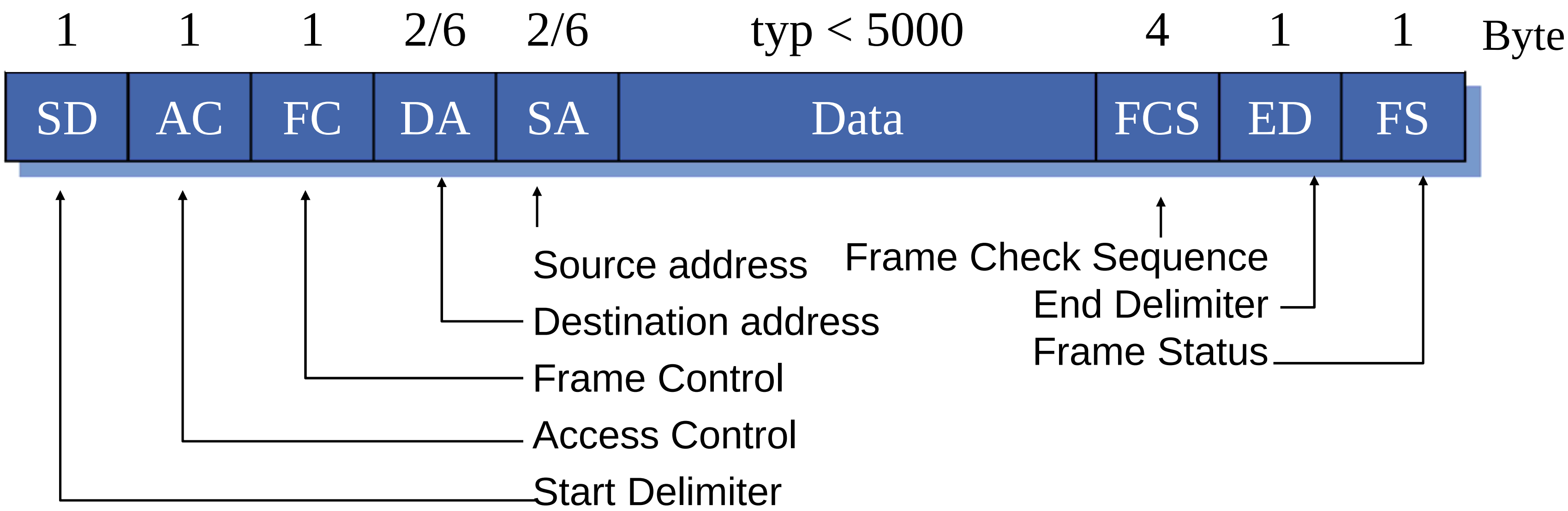


Packet Format of Token-Ring

Token Format:



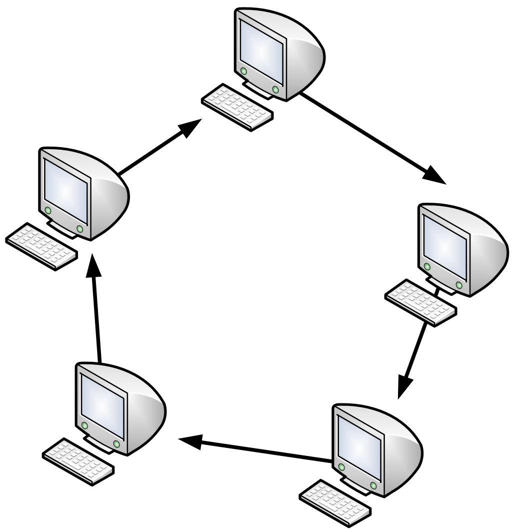
Data Frame Format:



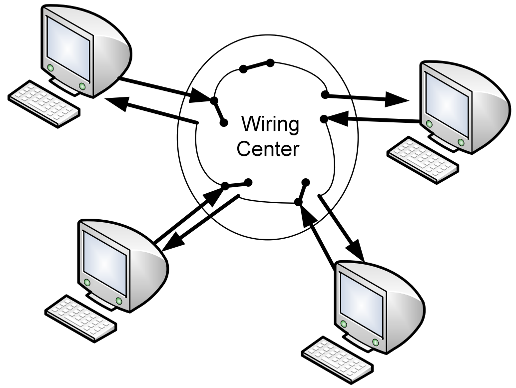
Token Ring Topologies

Two Topologies are implemented:

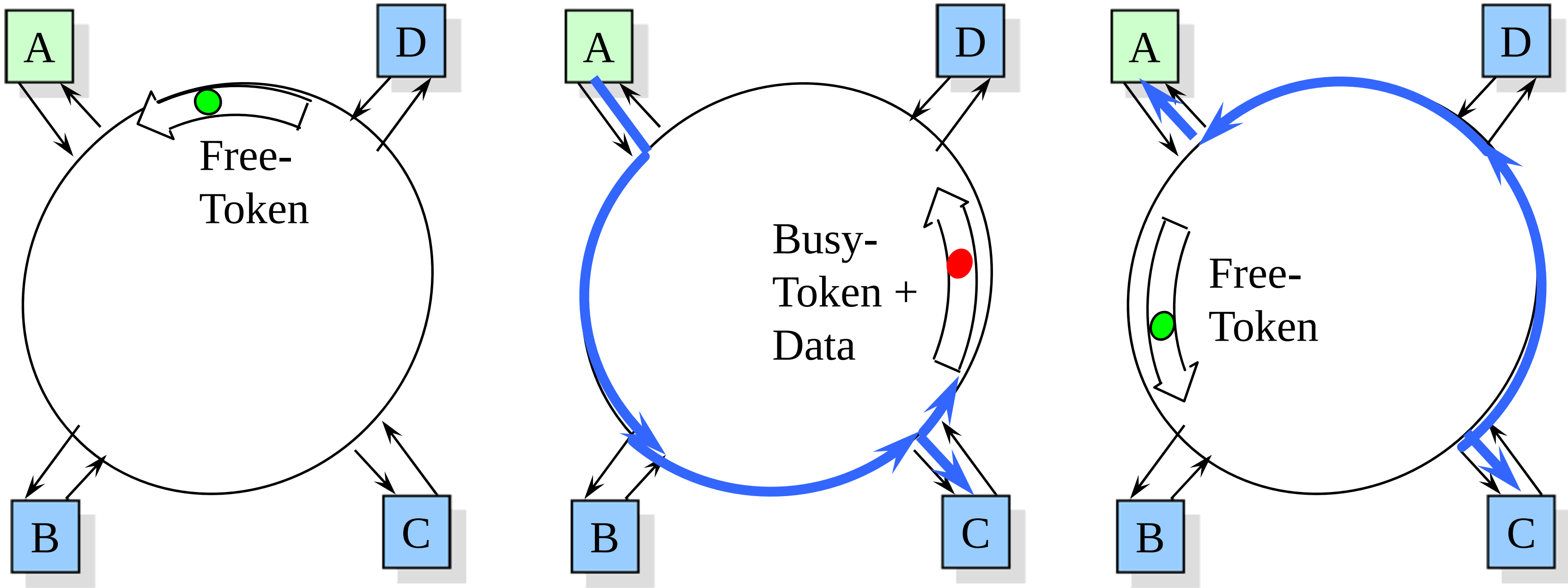
- Ring Topology
  - Token is passed from one node to the other
  - guaranteed fairness of medium access
  - control of token circulation time possible
  - access priorities possible



- Star Topology
  - Reduce risk of faults
  - Introduction of Wiring center as star node (physical structure is still a ring)
  - Nodes access network in “Star fashion” over the wiring center)
  - Nodes can be decoupled within the wiring center in case of a faulty connection or node



Example of a Token-Ring



- Free-Token is circulating
- A has data to send

- A has taken over the Token
- A sends data to C
- C copies data

- C copies and asserts acknowledge bits
- A deletes data
- Token is freed by A

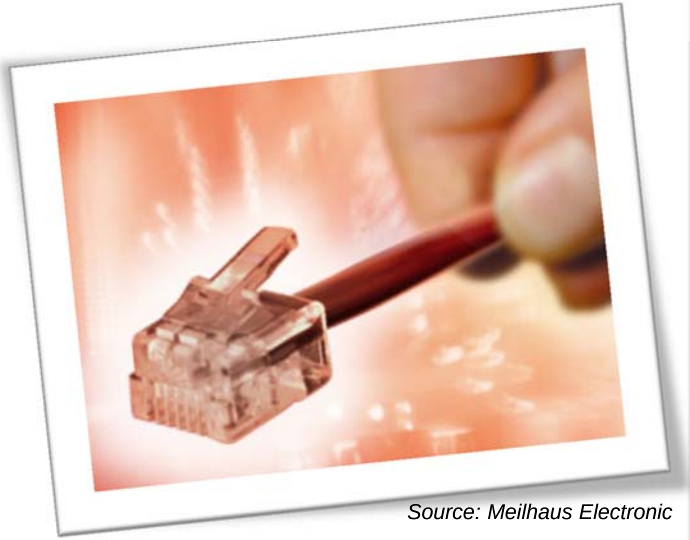
Ethernet

- Physical Layer, developed 1970‘s by Xerox
- Twisted Pair Wiring

- Dominant LAN technology due to
  - Easy to understand, implement, manage, and maintain
  - Allows low cost network implementations
  - Highly flexible topology for network installation
  - manufacturer independent interoperability of network components is guaranteed

- Uses CSMA/CD protocol for error detection

Source: Pantel

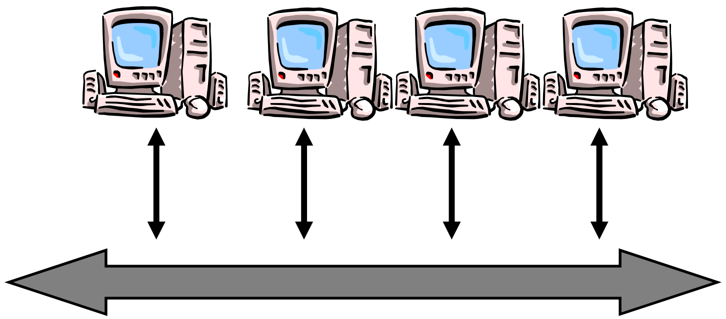


Source: Meilhaus Electronic

CSMA/CD (Ethernet)

- Topology
  - all stations are coupled over a common bus
  - every station can send at any point in time
  - ⇨ Collision of multiple transmissions destroys data!

- Arbitration Scheme:
  Carrier Sense Multiple Access with Collision Detection (CSMA/CD).
  - prior to sending: check medium
    (Listen Before Talk)
  - if medium free: start to send
  - while sending: check data on bus
    (Listen While Talk)
  - upon detection of a collision: abort send process and notify all connected stations



Packet format CSMA/CD according to IEEE 802.3

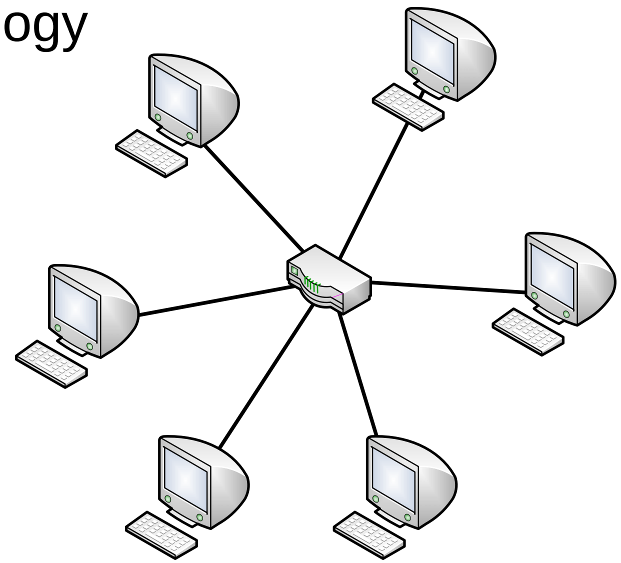
Preamble	SD	Destination Address	Source Address	Length	Data	PAD	FCS

PR =	Preamble for Synchronization [56 bit]
SD =	*Start-of-frame Delimiter* shows beginning of a block (10101011) (AB_H) [8 bit]
DA =	*Destination Address* [16/48 bit]
SA =	*Source Address* [16/48 bit]
Length =	Number of octettes within data field [16 bit]
Data =	Data field [0 - 1.500 byte]
PAD =	*Padding*, to append short data fields to reach necessary length of a data field (Collision detection) [0 - 368 bit]
FCS =	*Frame Check Sequence*, Polynomial division via CRC32 polynomial for error detection [32 bit]

Important: Some implementations of CSMA/CD (e.g. Ethernet 1.0, Ethernet 2.0 or IEEE 802.3) use some fields with slightly different meaning!

Fast Ethernet (IEEE 802.3u)

- Star topology



- Transmission capability 100 Mbit/s

Description	Cable	Segment Length	Advantages
100Base-T4	Four twisted pairs	100m (max.)	common cables
100Base-TX	Two twisted pairs	100m (max.)	full duplex at 100 Mbit/s
100Base-F	optic fibers	800m (max.)	full duplex, long distance

Gigabit Ethernet (IEEE 802.3z)

- Star topology
- Special coding necessary
- Transmission capability of 1,000 Mbit/s
- Unshielded twin wires are allowed
- Full duplex (all wires are used to send)
- Echo cancellation to subtract a node's own signal from the sum signal

Description	Cable	Segment Length
1000Base-T	4 unshielded twisted pairs (UTP-5)	100m
1000Base-CX	2 unshielded twisted pairs	25 m
1000Base-SX	Multimode-optical fibers	2 – 550 m
1000Base-LX	Multi-/Mono-mode-optical fiber	2 – 5,500 m

Comparison of CSMA/CD and Token Ring

CSMA/CD

Advantages

- simple protocol
- Installation during runtime is possible
- passive cable
- low latency with small load

Disadvantages

- no priorities
- non-deterministic, therefore no real-time capability
- limited cable lengths
- low efficiency due to many collisions, problematic with high loads

Token Ring

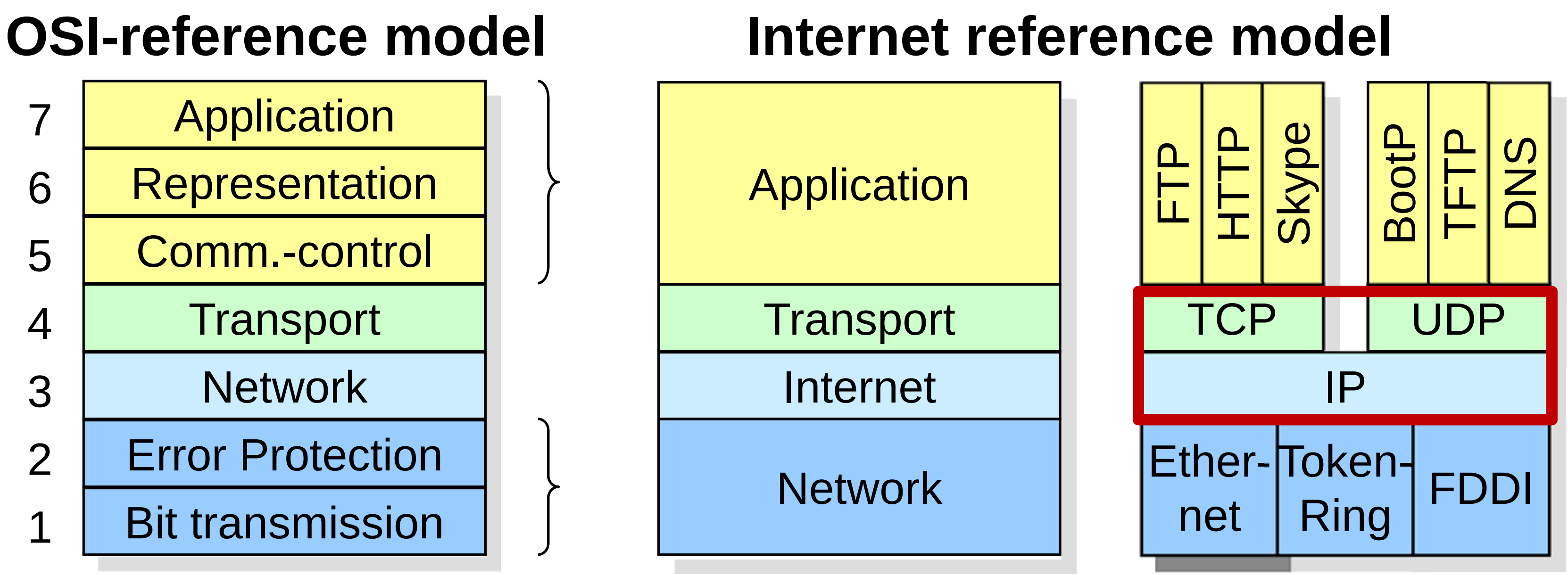
Advantages

- very good throughput and high efficiency under high loads
- automatic detection and elimination of cable breaks through wiring centers.
- Prioritization possible short frames possible
- real-time capability

Disadvantages

- centralized monitor for ring monitoring
- unnecessary latency under low loads
- erroneous monitor can affect complete ring

OSI Model in the Real World: The Internet



TCP/IP

- Protocol suite comprising
  - Transmission Control Protocol (TCP)
  - Internet Protocol (IP)
  - Other related protocols: User Datagram Protocol (UDP), Address Resolution Protocol (ARP), etc. …