ROYAL INSTITUTE
OF TECHNOLOGY

Communication Networks

Nicholas Honeth <nicholash@ics.kth.se>

ROYAL INSTITUTE OF TECHNOLOGY

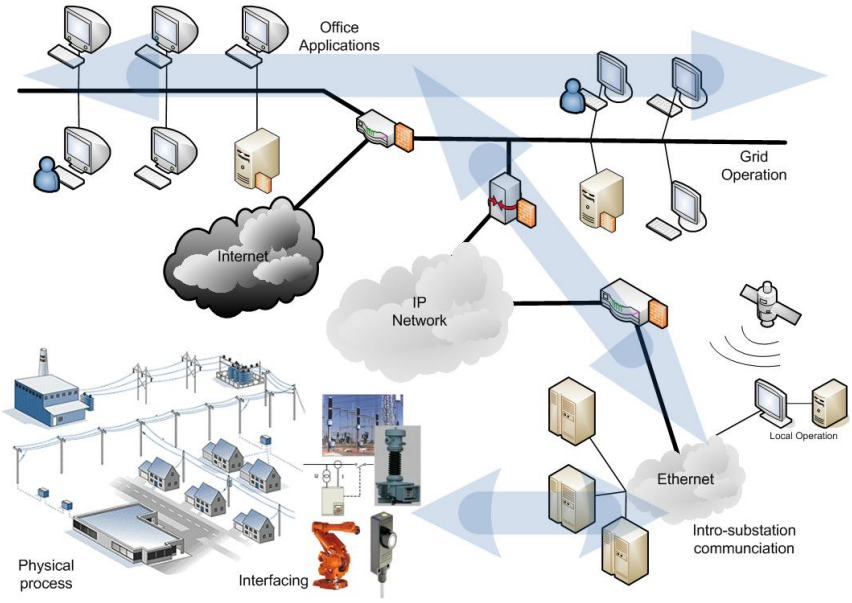
Contents of the series

- Lecture 10
  - Recap of the networks we've seen so far
  - OSI model
  - Circuit and packet switching
  - Physical media
- Lecture 11
  - Topologies
  - Media access techniques
  - Addressing and routing
  - Protocols in power systems applications
  - Delay, loss and throughput

ROYAL INSTITUTE OF TECHNOLOGY

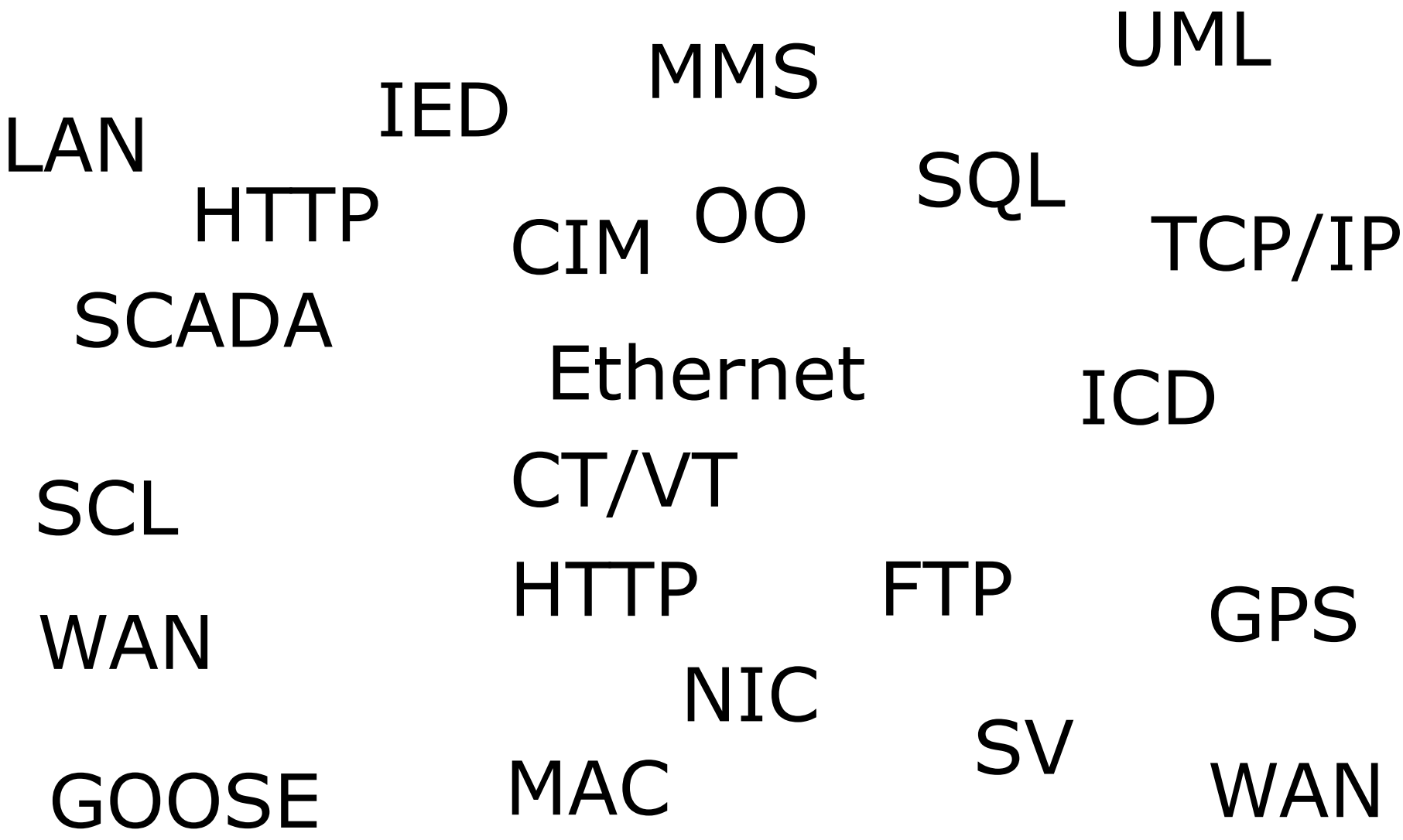
Contents of lecture 11

- Recap of the last lecture
- Topologies
- Media access techniques
- Protocols in power systems applications
- Delay, loss and throughput



ROYAL INSTITUTE OF TECHNOLOGY

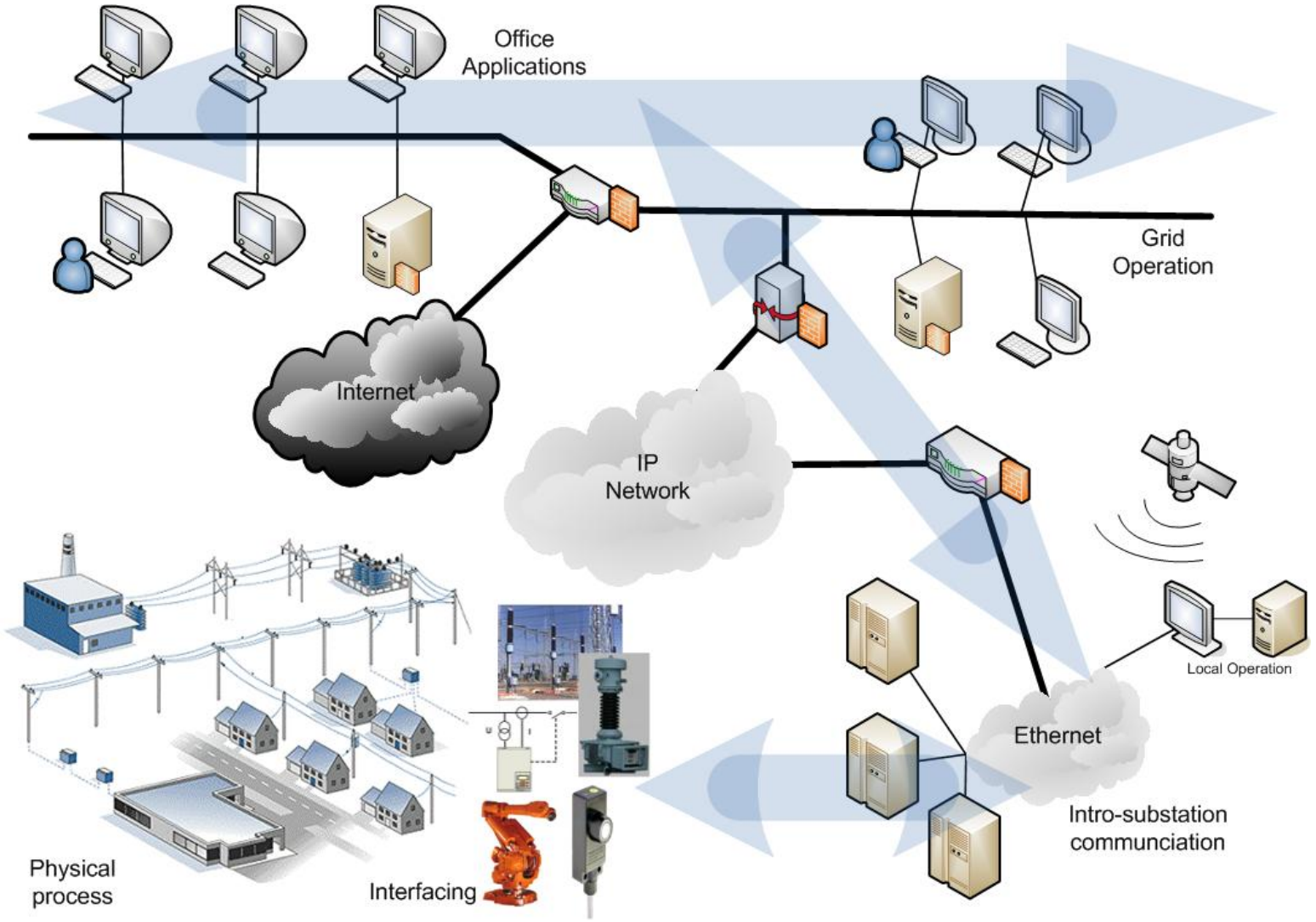
Some terms and acronyms…



ROYAL INSTITUTE OF TECHNOLOGY

Recap

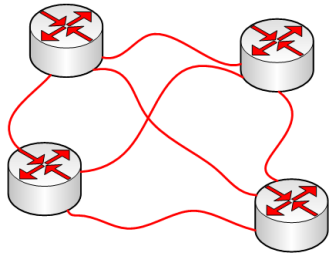
Computers and Networks in Power Systems

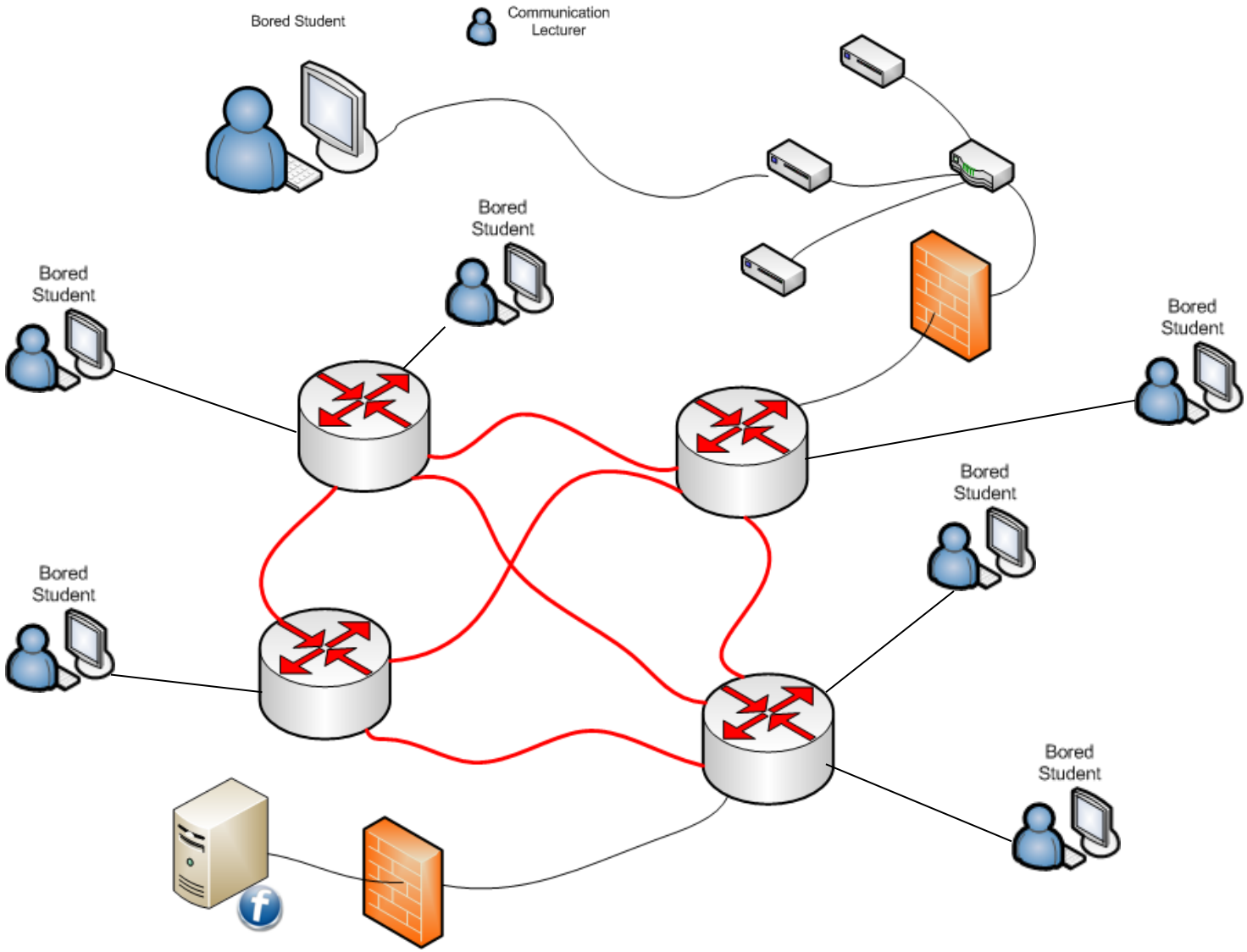


ROYAL INSTITUTE OF TECHNOLOGY

Recap

Protocol basics

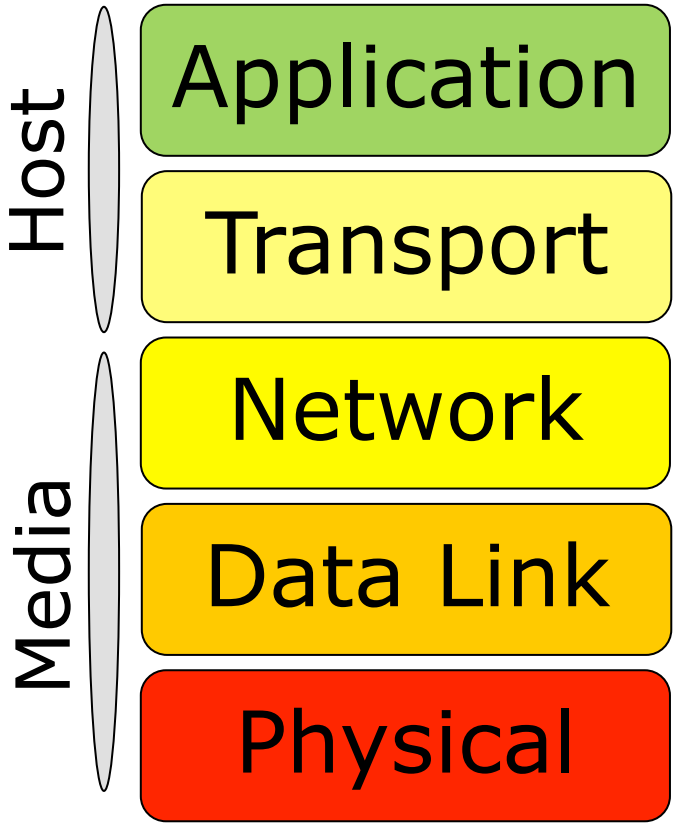




ROYAL INSTITUTE OF TECHNOLOGY

Recap

The OSI model

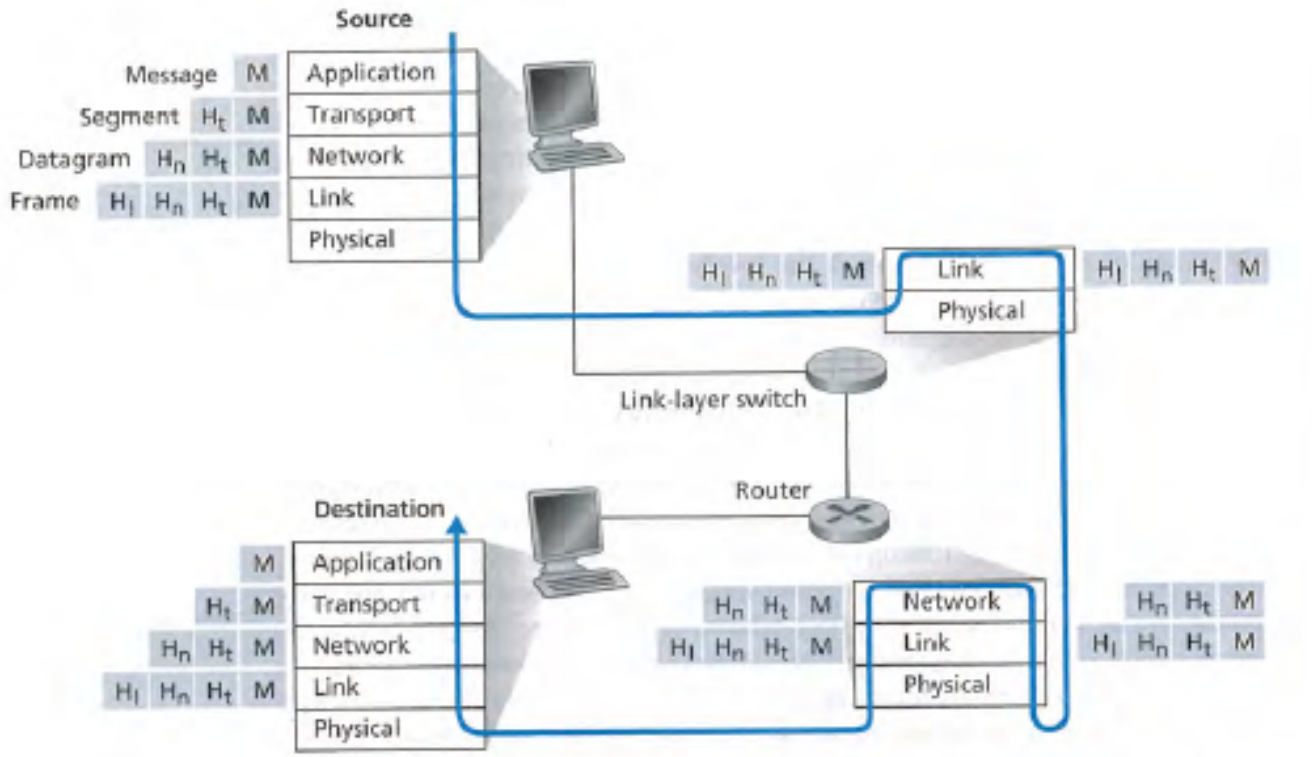


ROYAL INSTITUTE OF TECHNOLOGY

Recap

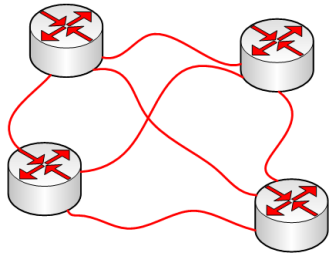
Transition between layers

Application
Transport
Network
Data Link
Physical

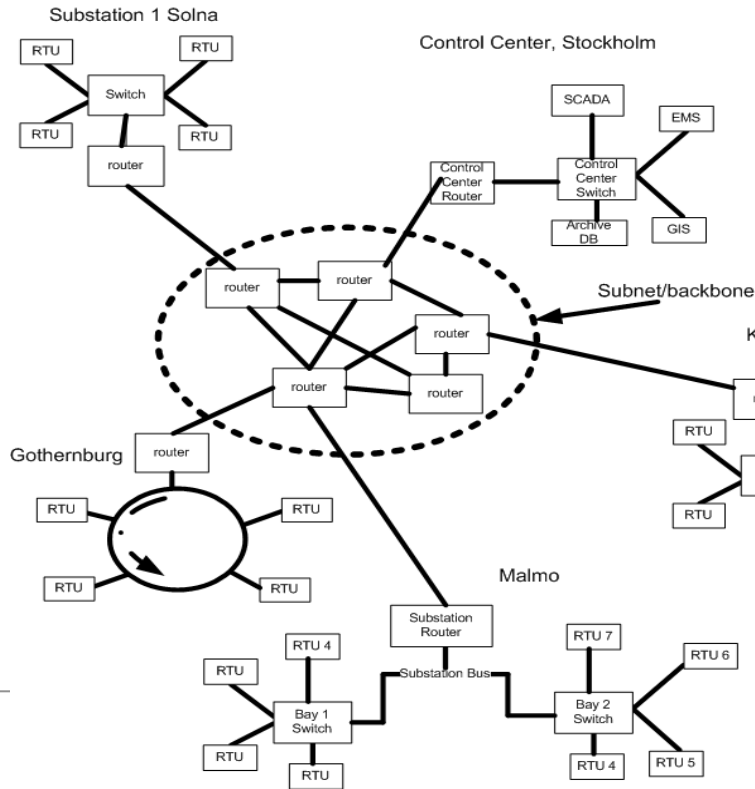


ROYAL INSTITUTE OF TECHNOLOGY

Network topology



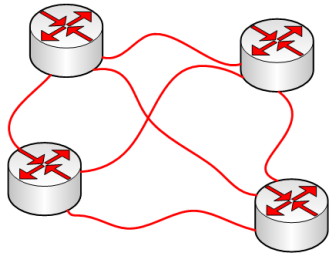
- Common topologies
  - Point-to-point
  - Bus
  - Star
  - Ring
  - Mesh
- Mixed topologies
- Physical and logical topologies
- Duplex



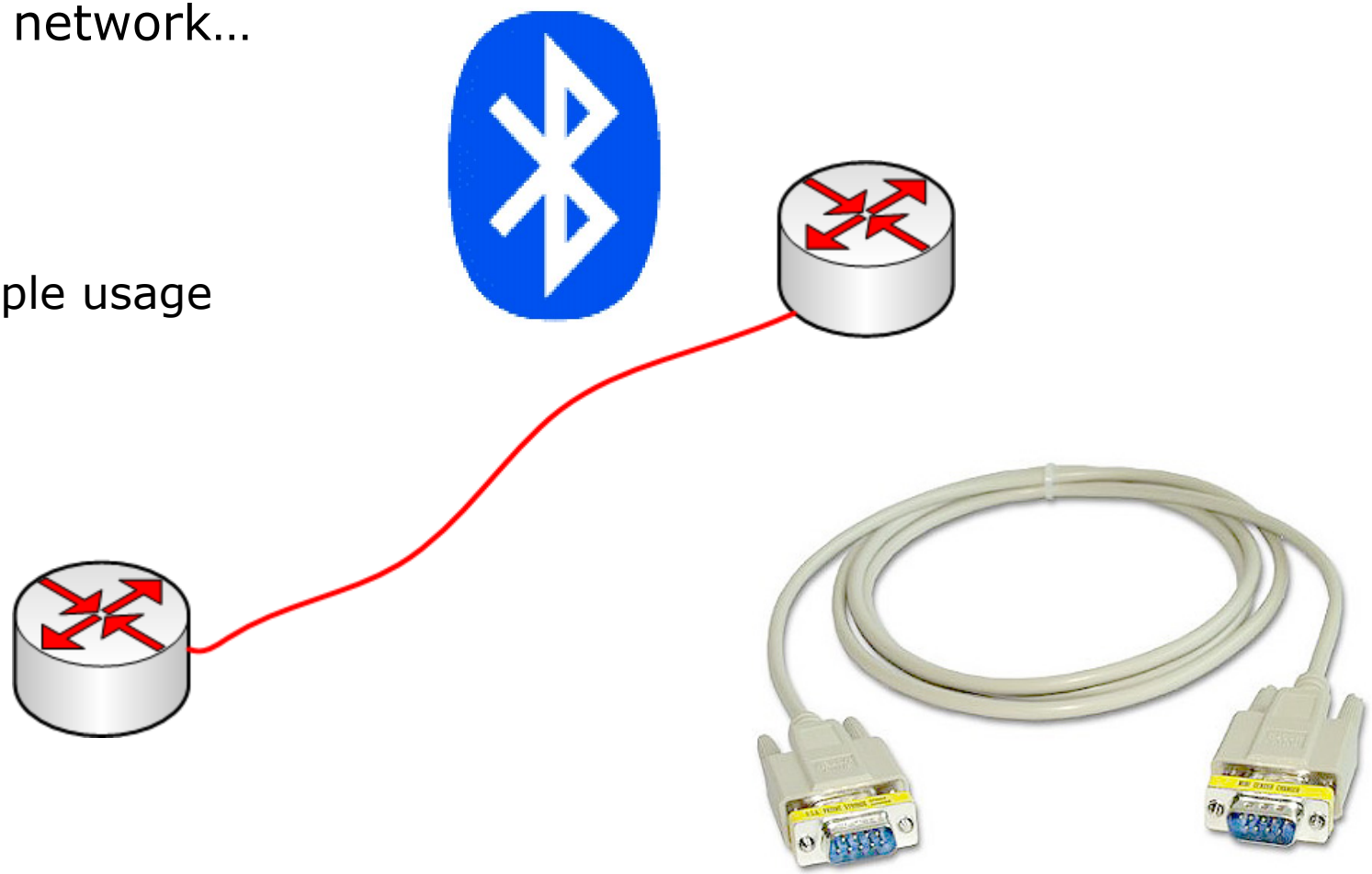
ROYAL INSTITUTE OF TECHNOLOGY

Topology

Point-to-point



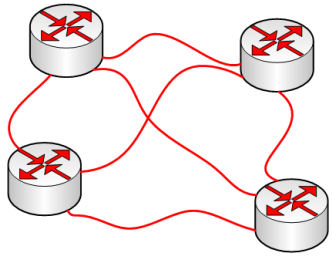
- Simplest type of network…
- Examples
  - ”Null modem”
  - Bluetooth – simple usage



ROYAL INSTITUTE OF TECHNOLOGY

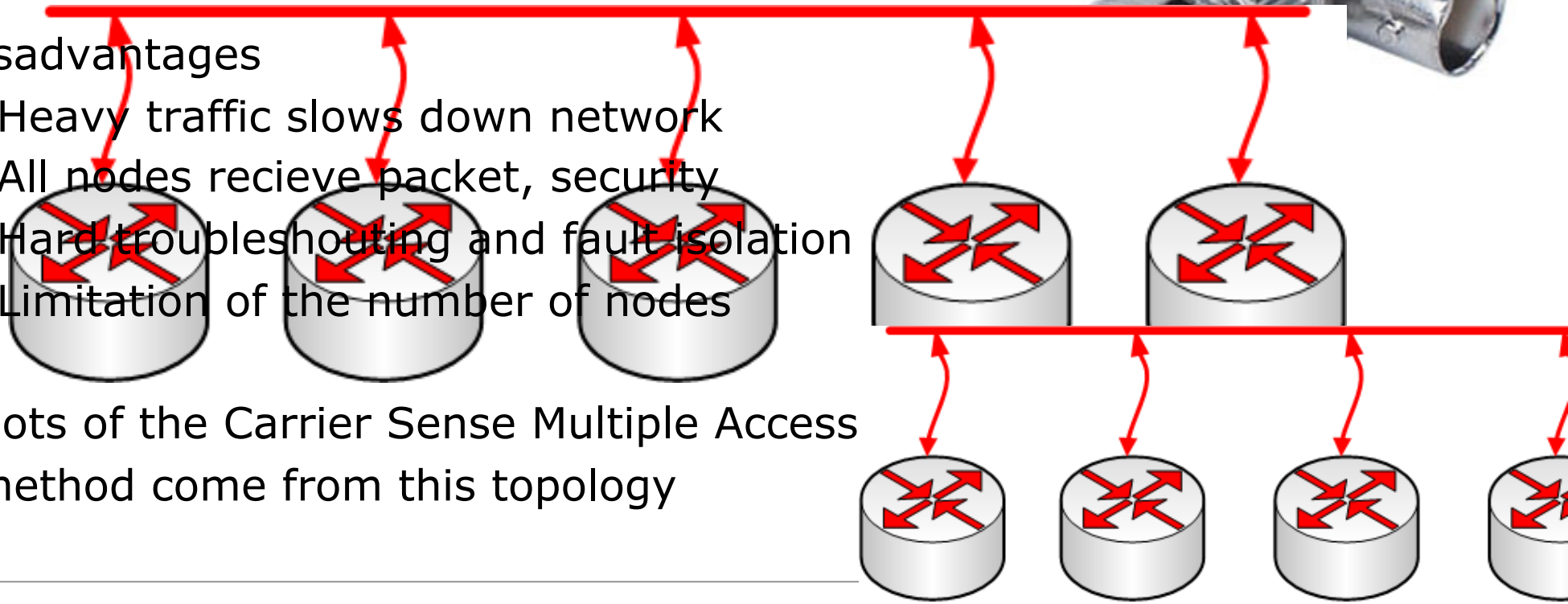
Topology

Bus



- Advantages
  - Bus not dependent on a single machine
  - High flexibility in configuration, easy to add and remove
  - Direct node to node communincation

- Disadvantages
  - Heavy traffic slows down network
  - All nodes recieve packet, security
  - Hard troubleshouting and fault isolation
  - Limitation of the number of nodes

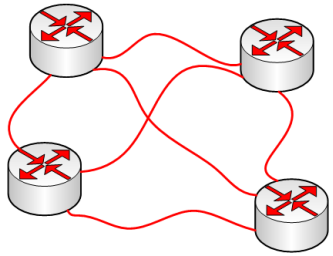


- Roots of the Carrier Sense Multiple Access method come from this topology

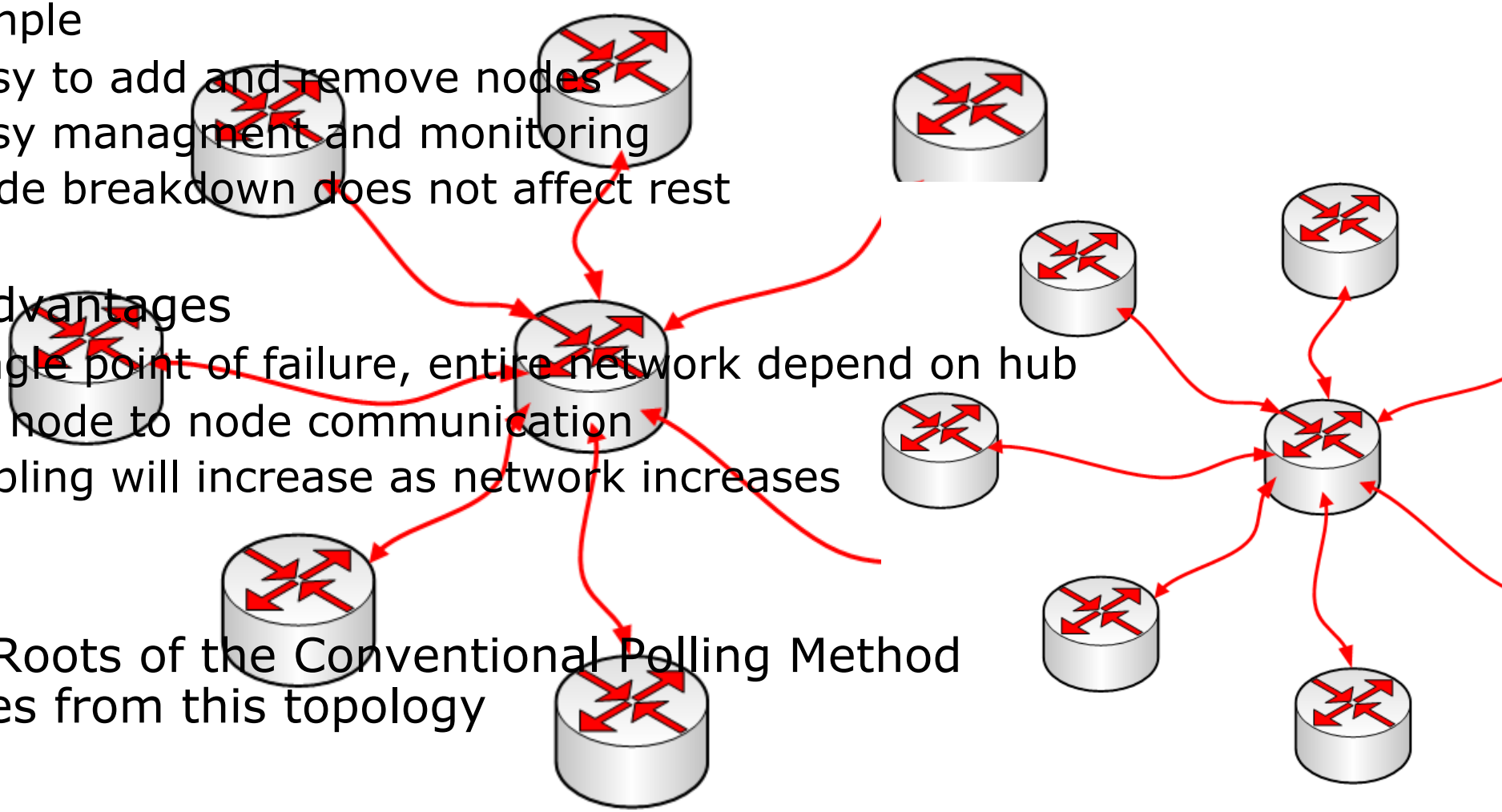
ROYAL INSTITUTE OF TECHNOLOGY

Topology

Star



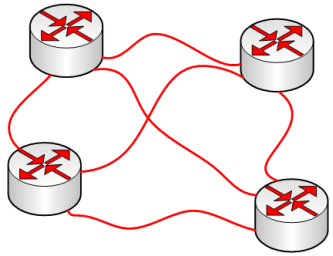
- Advantages
  - Simple
  - Easy to add and remove nodes
  - Easy managment and monitoring
  - Node breakdown does not affect rest
- Disadvantages
  - Single point of failure, entire network depend on hub
  - No node to node communication
  - Cabling will increase as network increases
- The Roots of the Conventional Polling Method comes from this topology



ROYAL INSTITUTE OF TECHNOLOGY

Topology

Ring

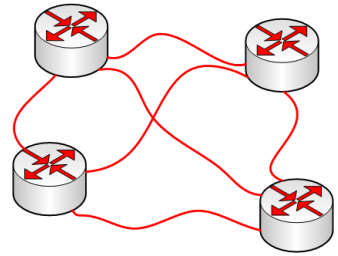


- Advantages
  - Generally All computer have equal access to the network
  - Node to node communication
  - Performance remains even with increase of load
- Disadvantages
  - Single node failure impacts network
  - Sometimes hard to isolate faults
  - Adding removing nodes disrupts network
- Related to the Token Media Access Method

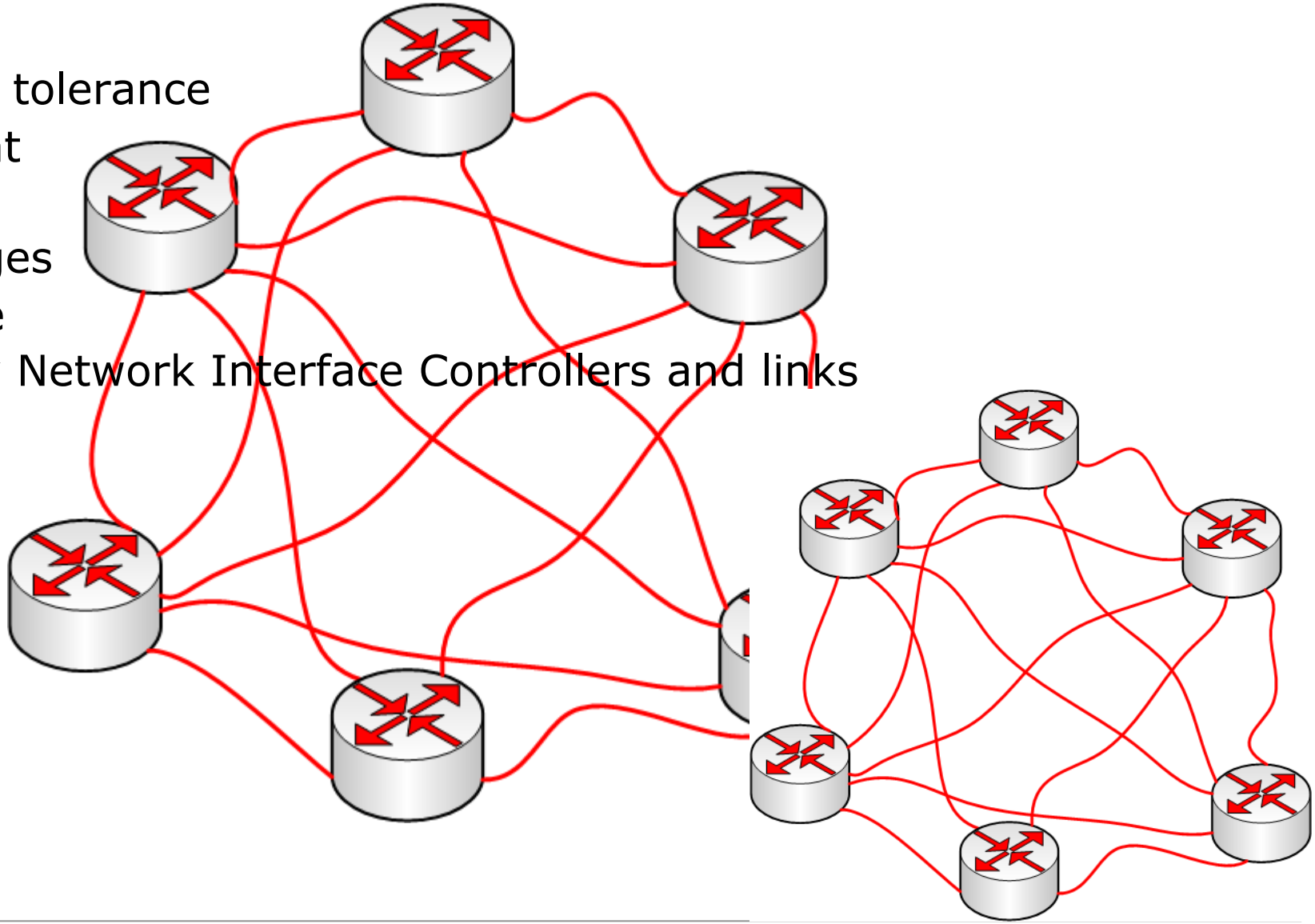
ROYAL INSTITUTE OF TECHNOLOGY

Topology

Mesh

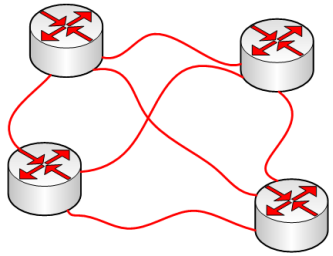


- Advantages
  - High fault tolerance
  - Redundant
- Disadvantages
  - Expensive
  - Too many Network Interface Controllers and links



Topology

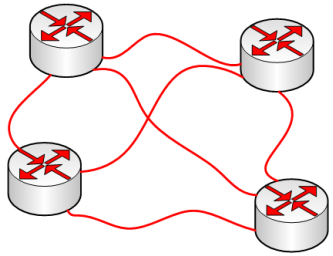
Mesh



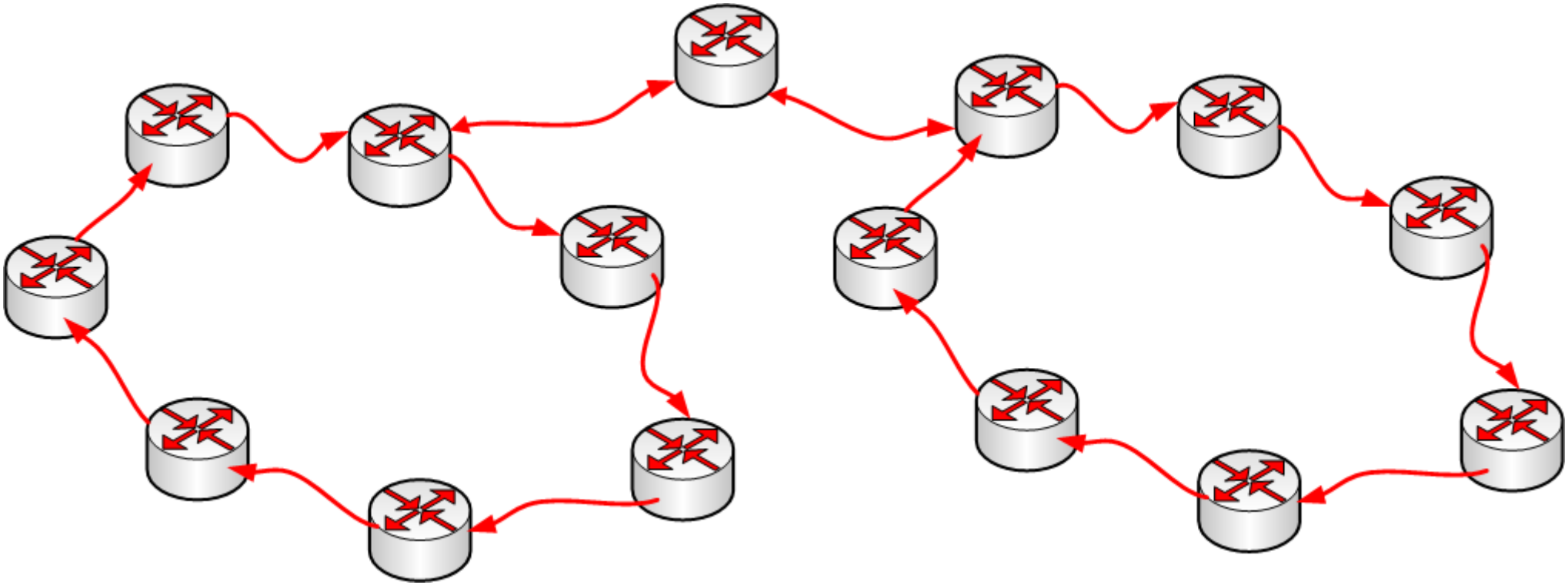
ROYAL INSTITUTE OF TECHNOLOGY

Topology

Mixed topologies – Star Ring



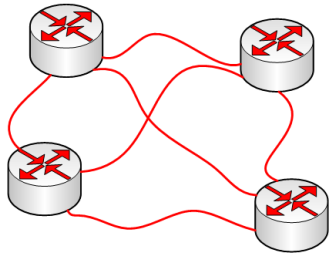
Star, Ring and Bus, are basic topologies, and can be combined e.g Star Ring or star star Bus topologies

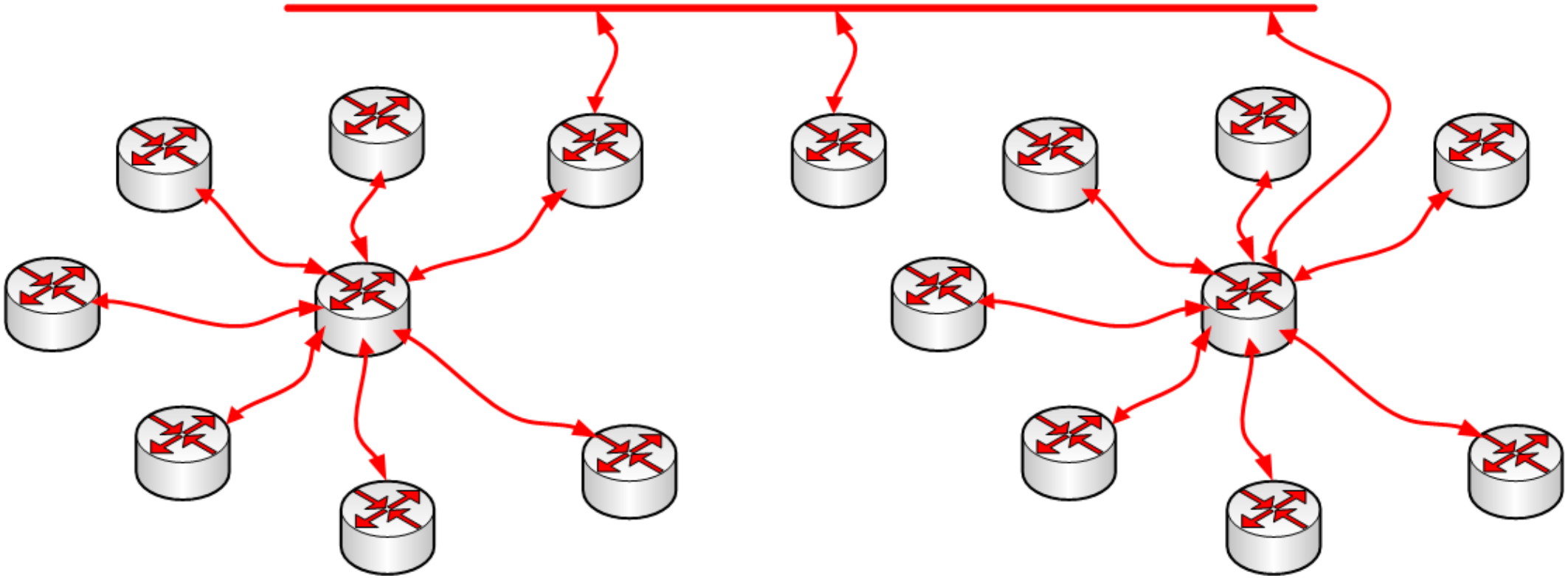


ROYAL INSTITUTE OF TECHNOLOGY

Topology

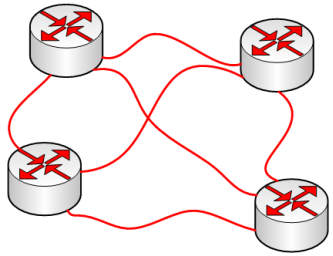
Mixed topologies – Star Bus



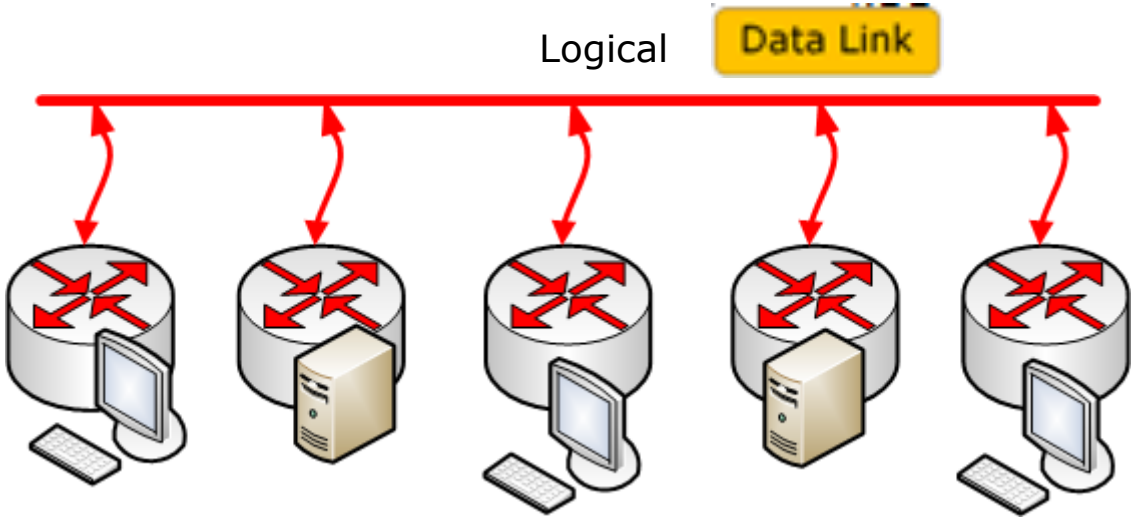


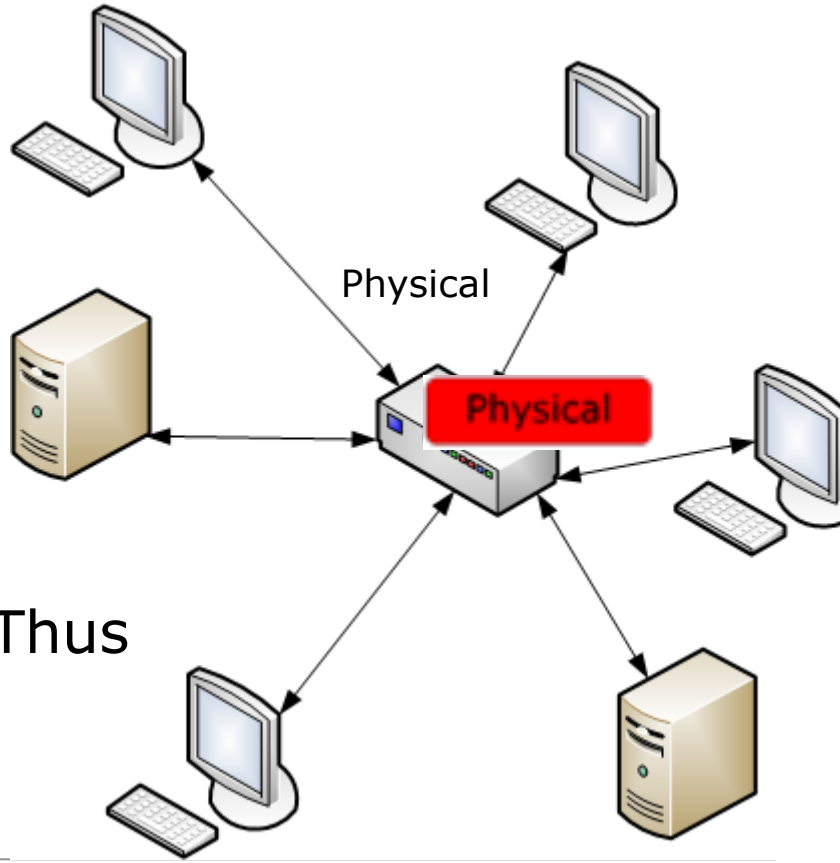
Topology

Physical and logical topologies



- Example: Ethernet traditionaly was based on bus topology but with the use of a hub it is phyiscally a star



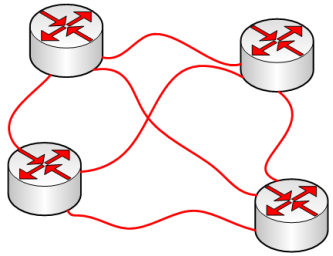


- Hub retransmits the signal to all ports. Thus effectively making it bus network.

ROYAL INSTITUTE OF TECHNOLOGY

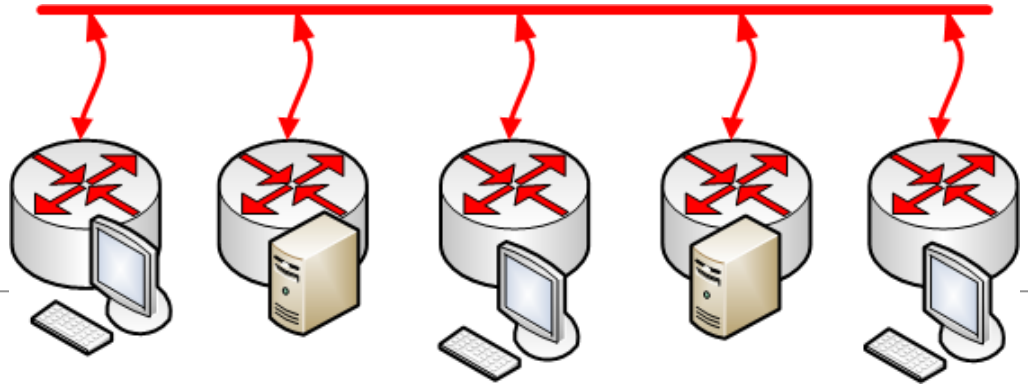
Topology

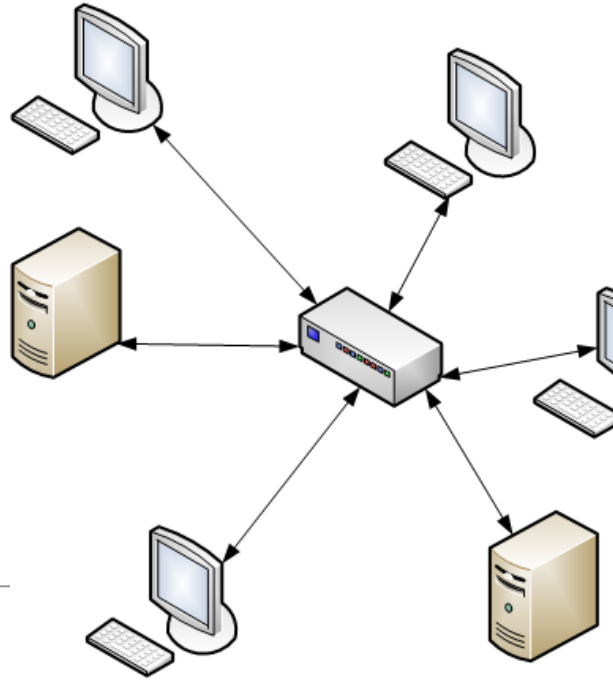
Physical and logical topologies



- Topologies determine the characteristics of the network, for example:
  - Layout of the network and wiring
  - Number of Nodes and size of the network
  - Message Reliability

- In modern networking the physical topology no longer limits the media access method used.

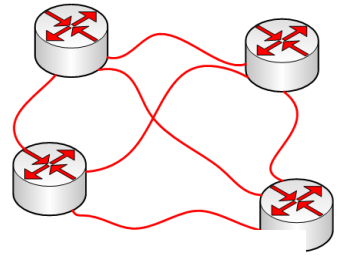


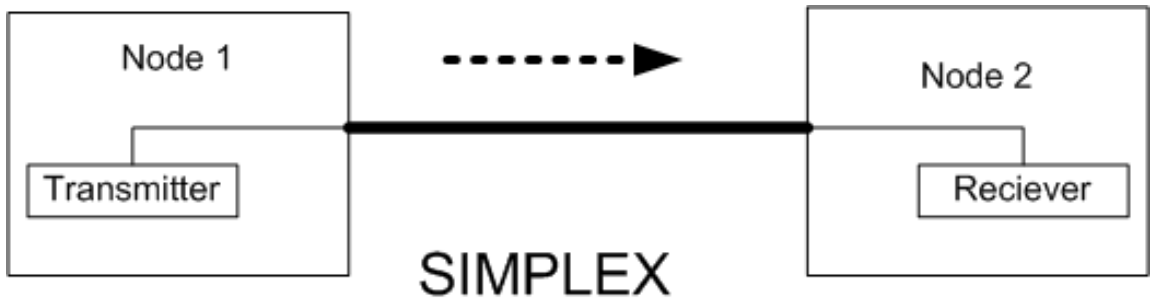


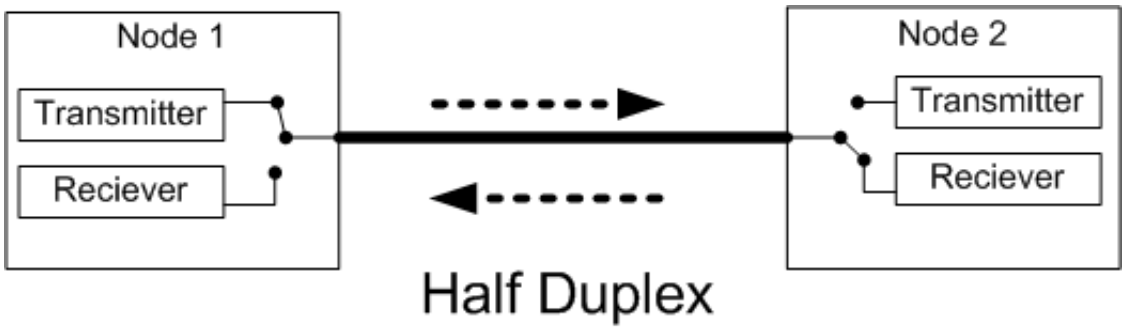
ROYAL INSTITUTE OF TECHNOLOGY

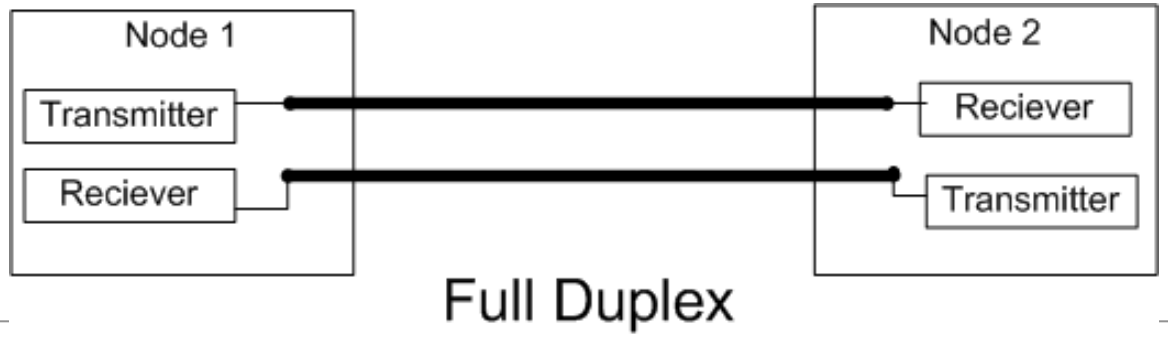
Topology

Duplex





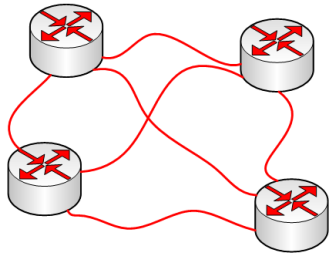


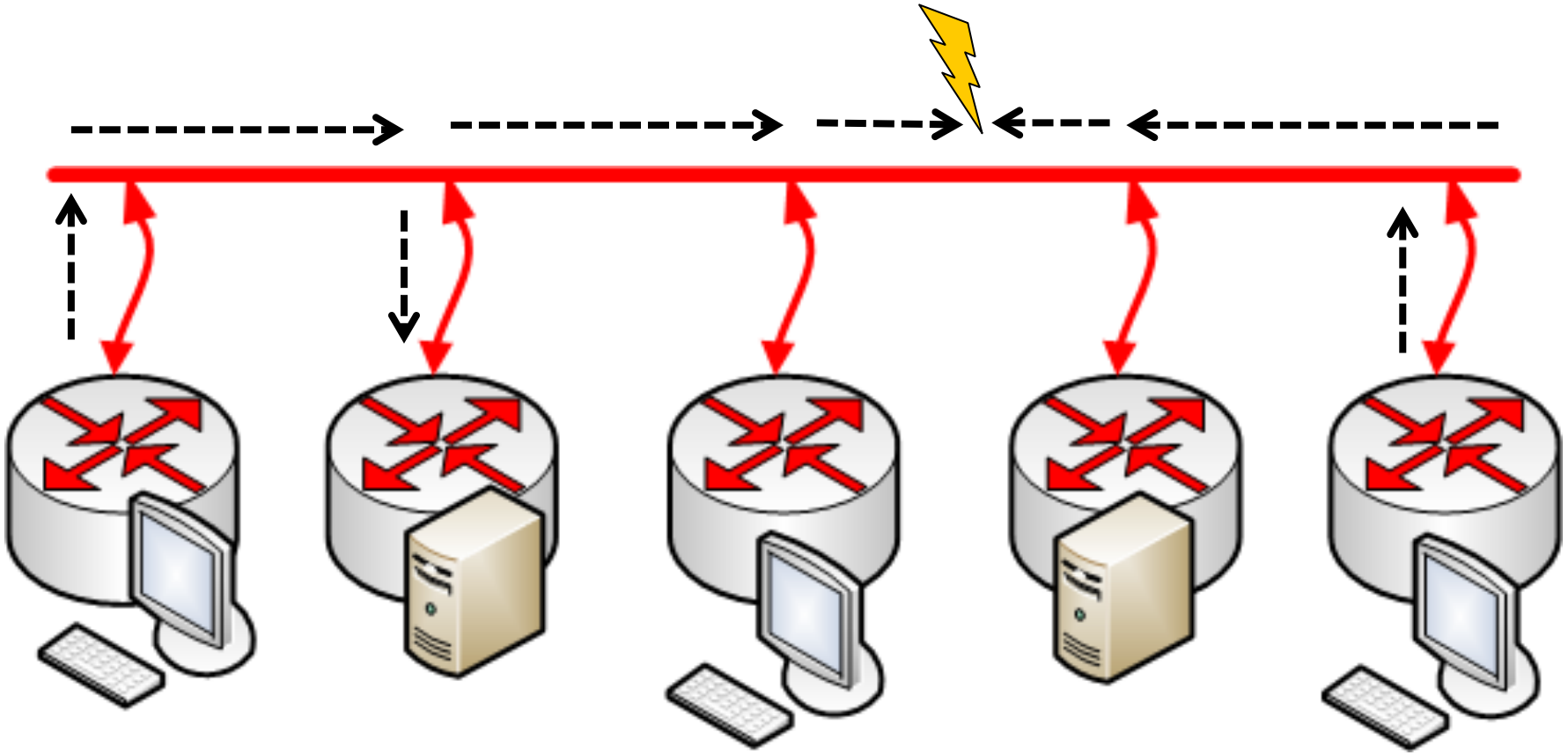


ROYAL INSTITUTE OF TECHNOLOGY

Media Access Control

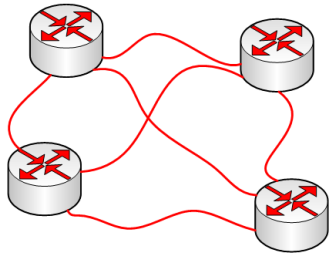
Carrier-sense multiple access (CSMA) / Collision Detection (CD)

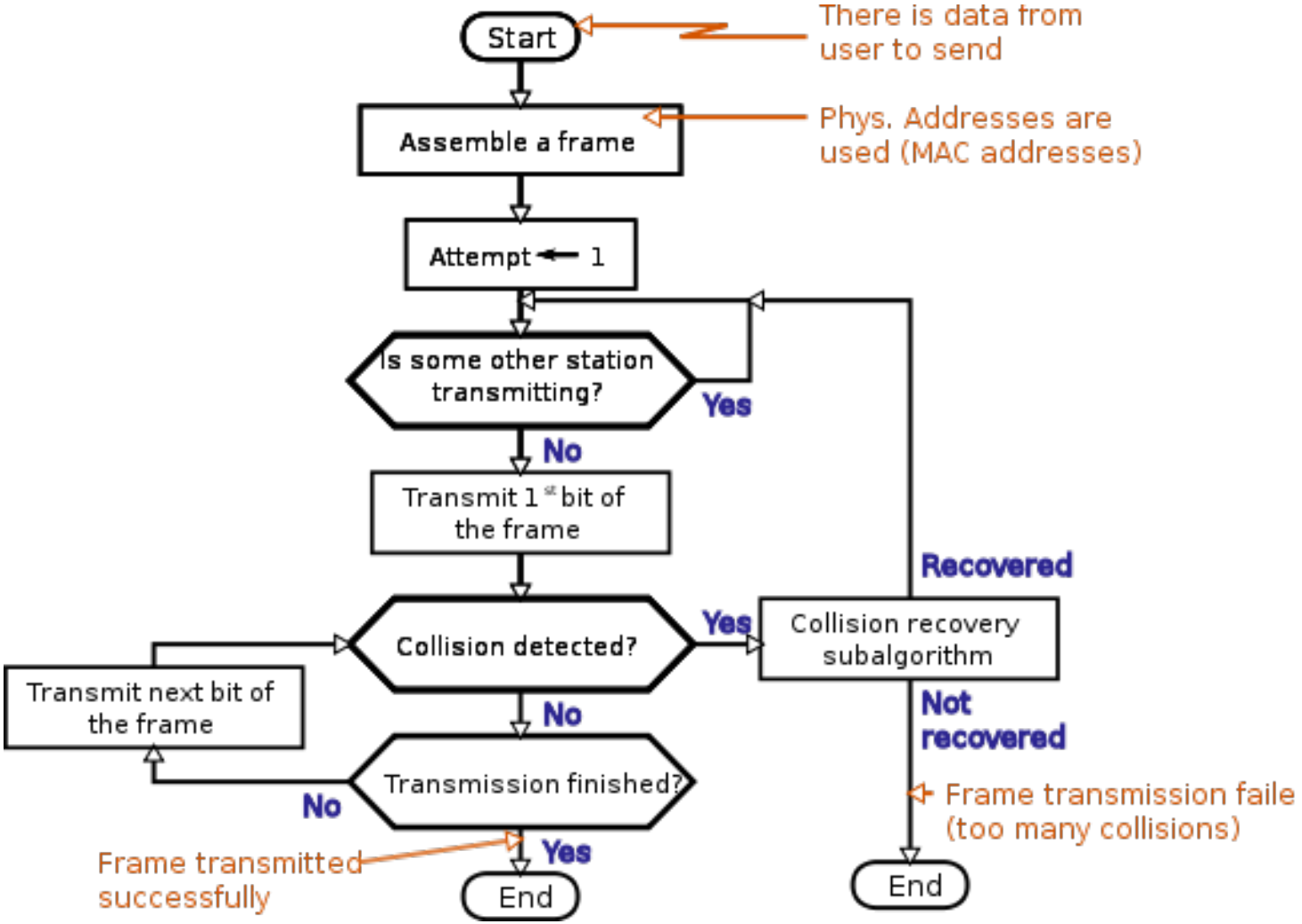


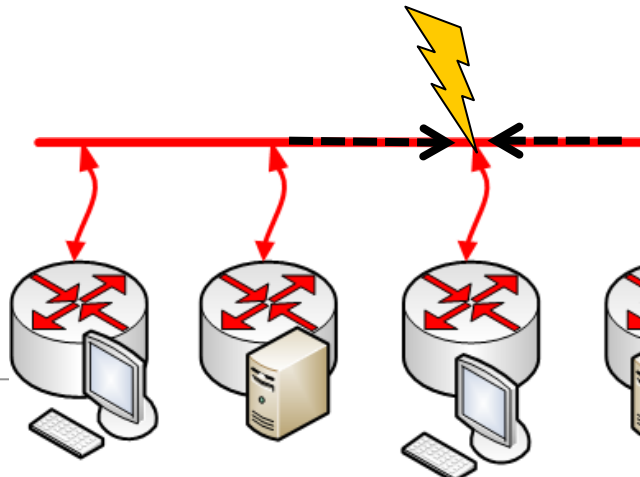


Media Access Control

Carrier-sense multiple access (CSMA) / Collision Detection (CD)

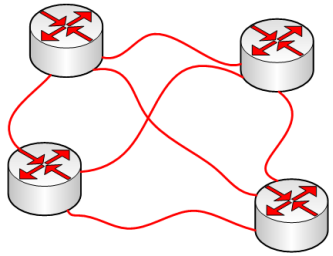


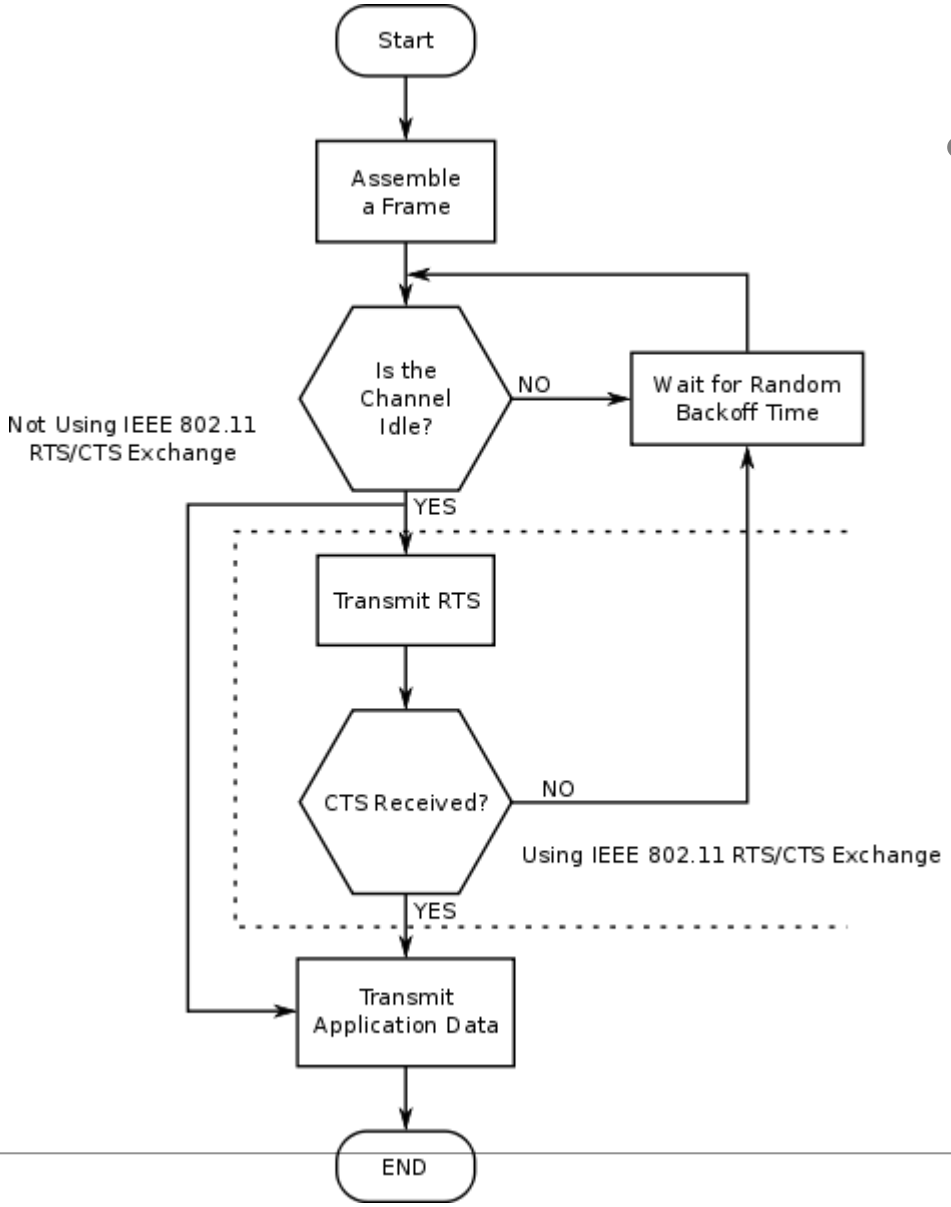




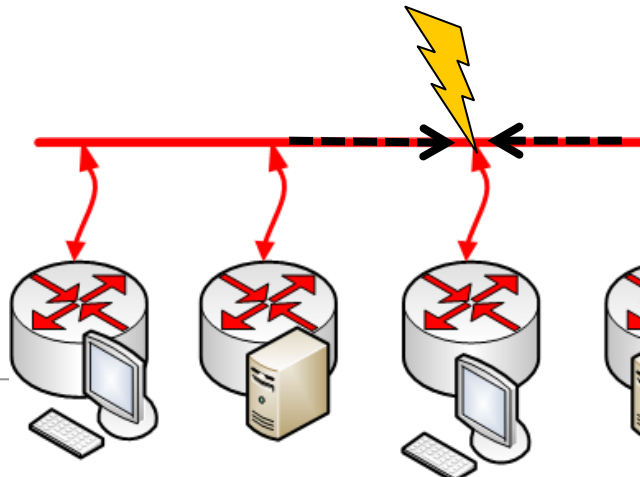
Media Access Control

Carrier-sense mutliple access (CSMA) / **Collision Avoidance (CA)**



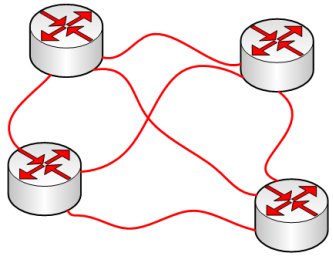


- Used in
  - IEEE 802.11
  - IEEE 802.15



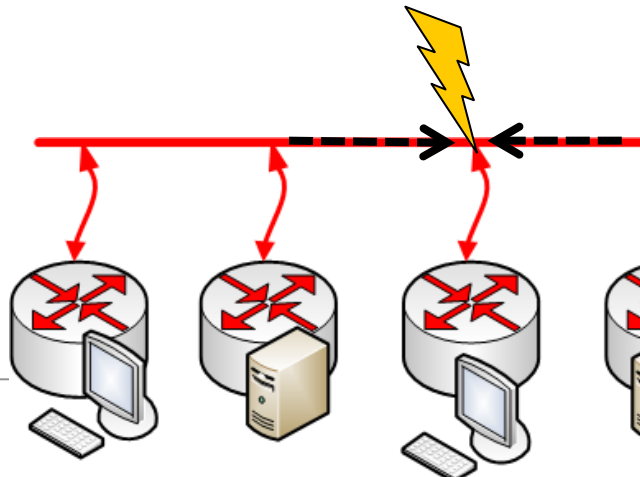
Media Access Control

Carrier-sense mutliple access (CSMA) / Collision Detection (CD)



- Advantages
  - Peer to Peer Communication
  - Efficient under light and heavy loads
  - Variations in data transfer requirements handled
  - Urgent request can be handled instantly
  - No centralized bus controller is required

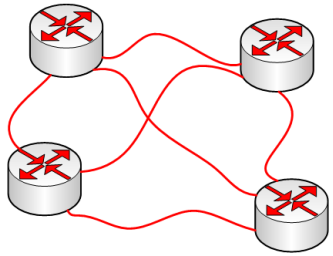
- Disadvantages
  - Communication failure to a specific device will only response requested and none given
  - Network configuration is complex
  - Non deterministic response times
  - Data collision is inherent
  - Medium capture effect

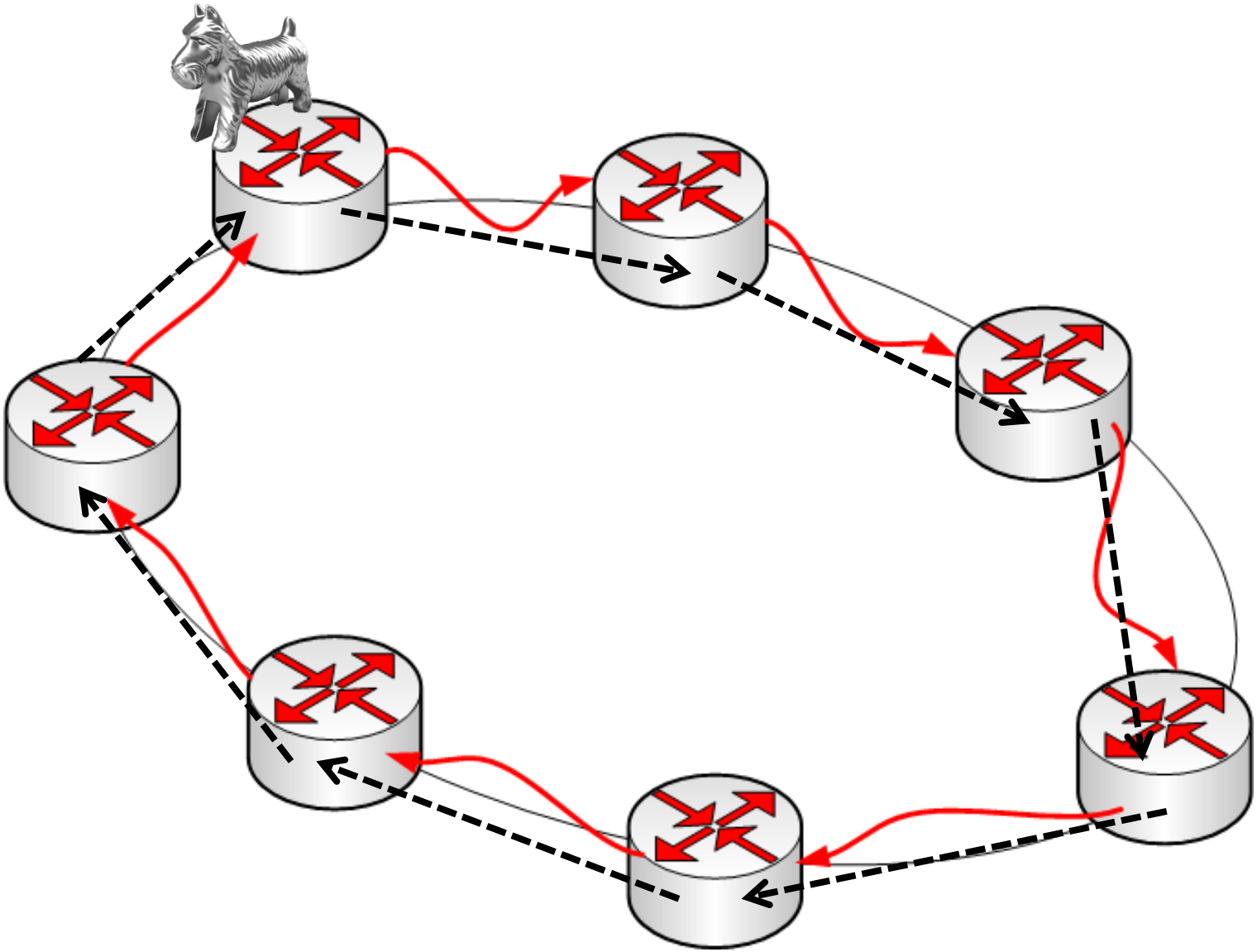


ROYAL INSTITUTE OF TECHNOLOGY

Media Access Control

Token Passing – Token Ring

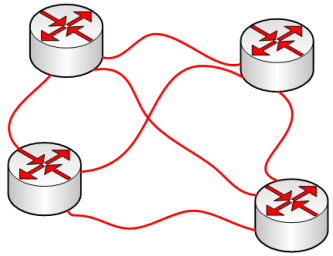




ROYAL INSTITUTE OF TECHNOLOGY

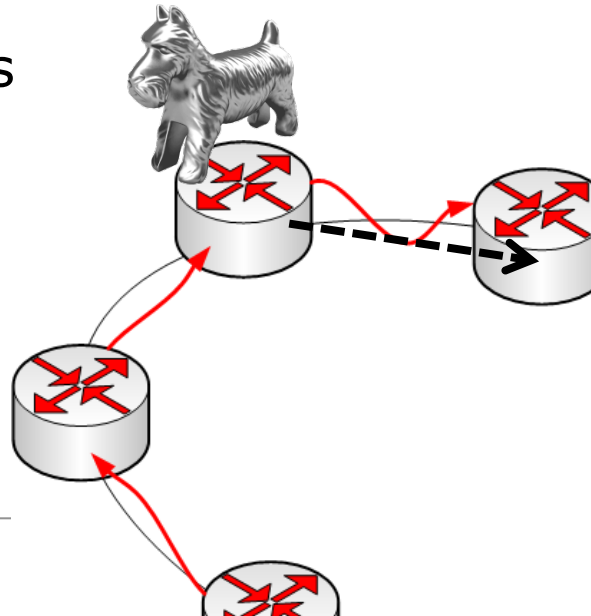
Media Access Control

Token Passing – Token Ring



- Advantages
  - No Data Collisions
  - Peer to peer communication
  - Efficient under lightly loaded systems
  - Variations in data transfer requirements can be handled by the system

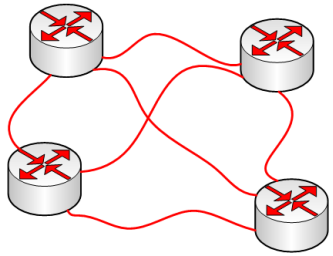
- Disadvantages
  - Hard to detect communication or node failure
  - Network still dependent on central communications controller
  - Semi deterministic response times obtained
  - Unnecessary waiting times still inherent



ROYAL INSTITUTE OF TECHNOLOGY

Media Access Control

Other types



- Mainly for wireless networks:
  - Slotted ALOHA
  - Dynamic TDMA
  - CDMA
  - OFDMA

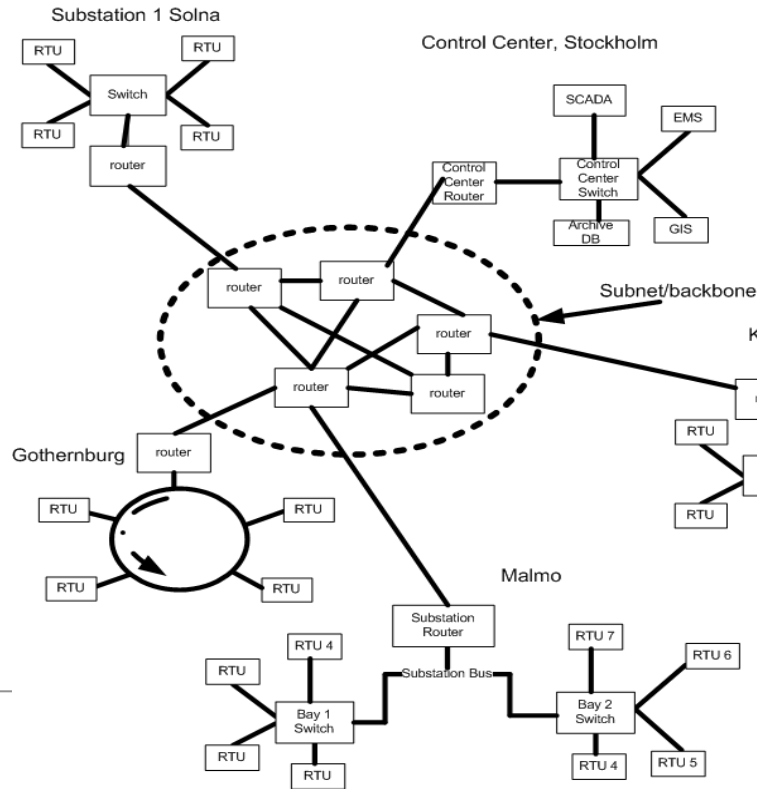
- Not so relevant for our overview, but good to recognise.

ROYAL INSTITUTE OF TECHNOLOGY

Routing and Addressing

Application
Transport
Network
Data Link
Physical

- Network layer
  - IP addresses
  - Broadcast and multicast
  - Routing tables
- Data link layer
  - MAC addresses
  - ARP
  - Switching

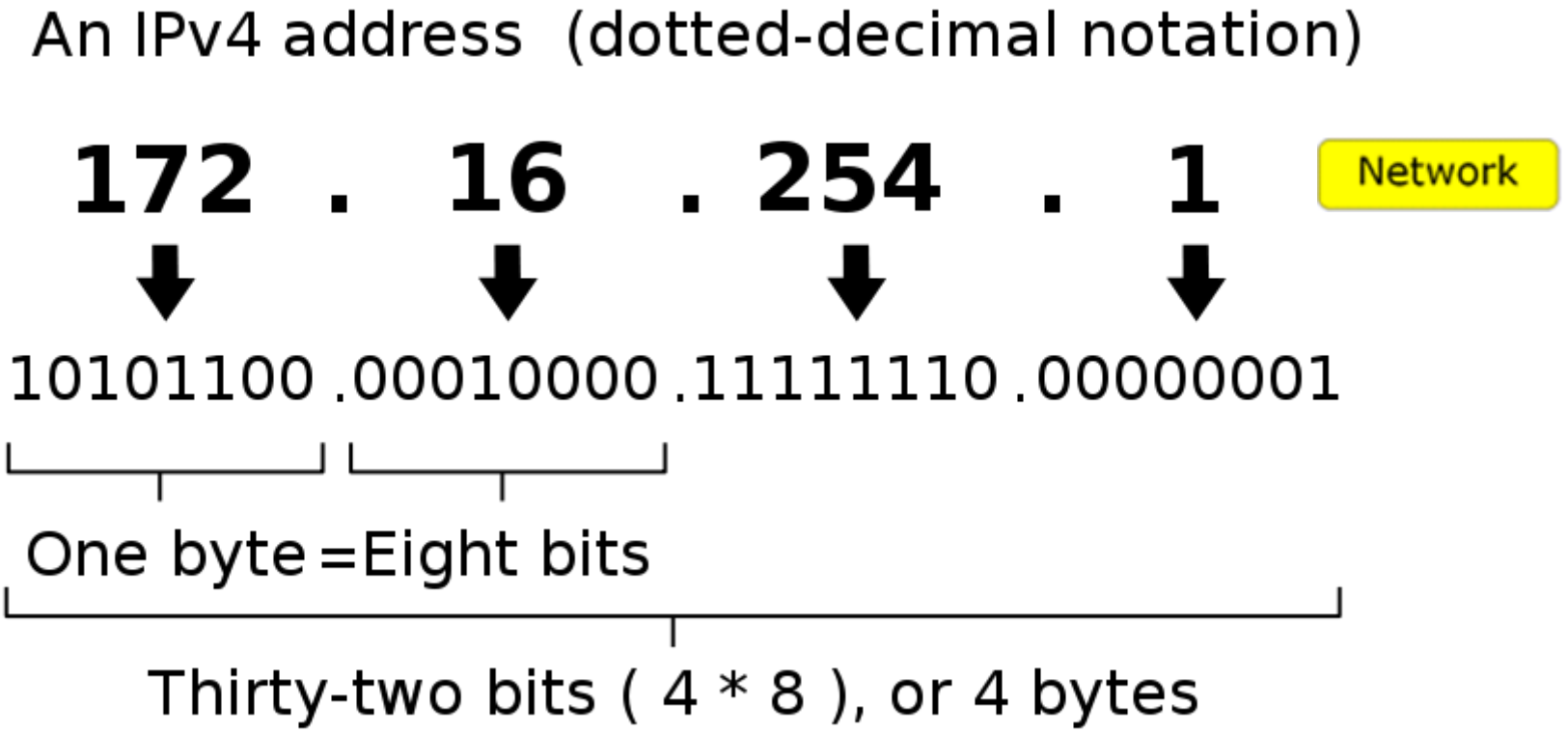


ROYAL INSTITUTE OF TECHNOLOGY

Routing and Addressing

Network layer – IP addresses

Application
Transport
Network
Data Link
Physical



- 32 bits are able to address only 4 294 967 296 unique nodes

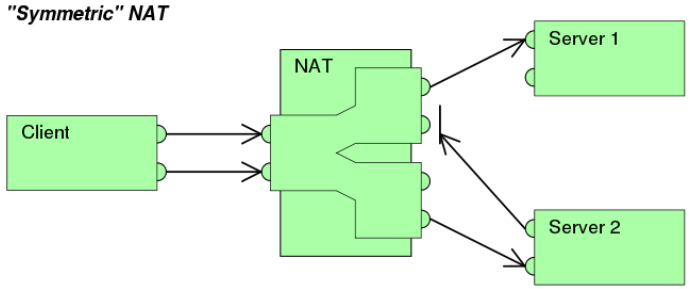
ROYAL INSTITUTE OF TECHNOLOGY

Routing and Addressing

Network layer – IP addresses

- Address assignment:
  - Manual static assignment
  - Dynamic Host Configuration Protocol (DHCP)

- Private networks can be separated from the internet using Name Address Translation (NAT)
  - Only one external IP address needed
  - Translation using a table of **port numbers**



- IPv6 addresses aim to mitigate the address exhaustion problem by using 128-bit addresses

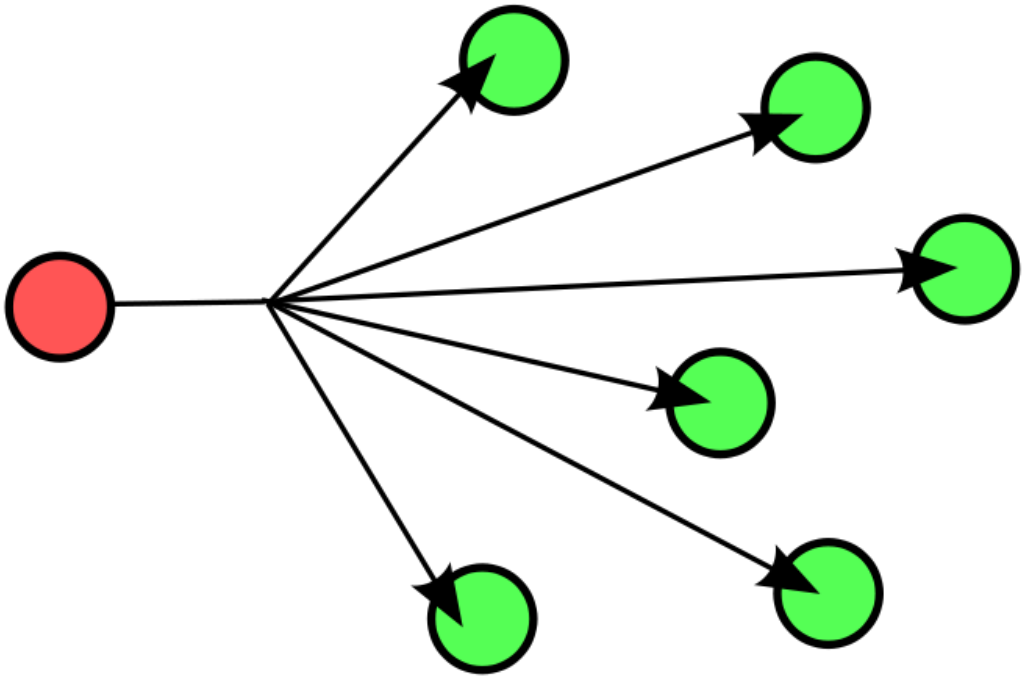
ROYAL INSTITUTE OF TECHNOLOGY

Routing and Addressing

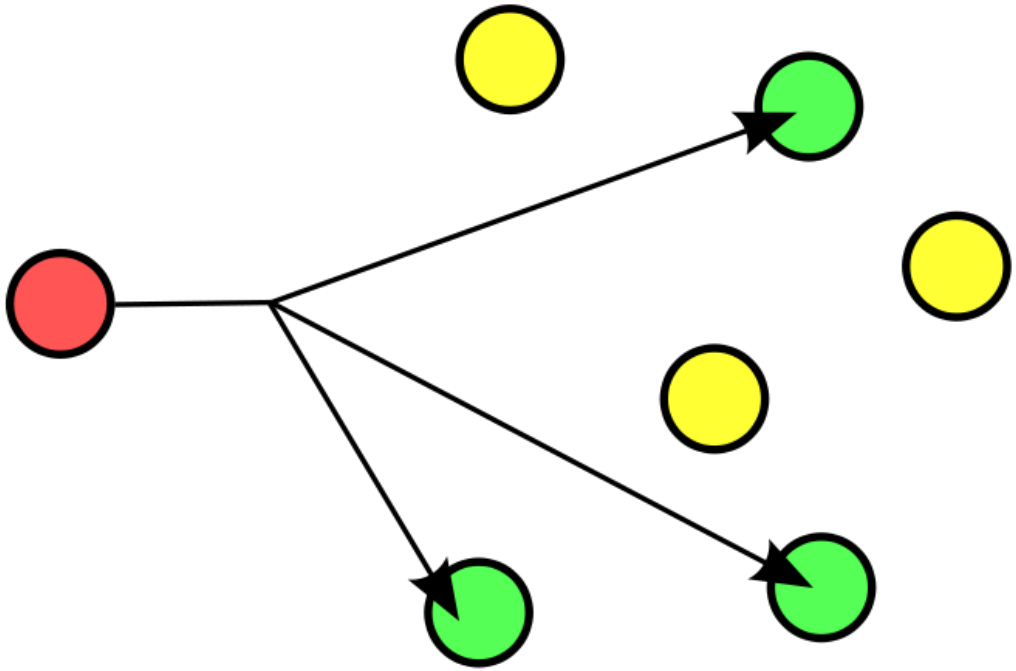
Network layer – Broadcast and multicast

Application
Transport
Network
Data Link
Physical

Broadcast



Multicast



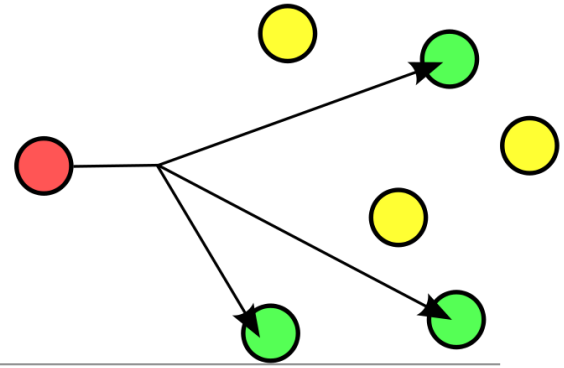
ROYAL INSTITUTE OF TECHNOLOGY

Routing and Addressing

Network layer – Broadcast and multicast

Application
Transport
Network
Data Link
Physical

- Broadcast
  - Just send to everyone
  - Broadcast address -> (255.255.255.255)
- Multicast
  - IP multicast group address
    - Receivers inform the network infrastructure that they are interested
      - Internet Group Management Protocol (IGMP)
  - Multicast distribution tree
    - Receiver-driven tree creation
- Really useful for ex. live TV broadcast over IP
  - Phasor data in the ”smart grid”?



ROYAL INSTITUTE OF TECHNOLOGY

Routing and Addressing

Network layer – Routing table

Application
Transport
Network
Data Link
Physical

- Table maintained on network-layer devices;
  - Hosts
  - Routers

Host id	Cost	Next hop
.....	.....	.....
.....	.....	.....

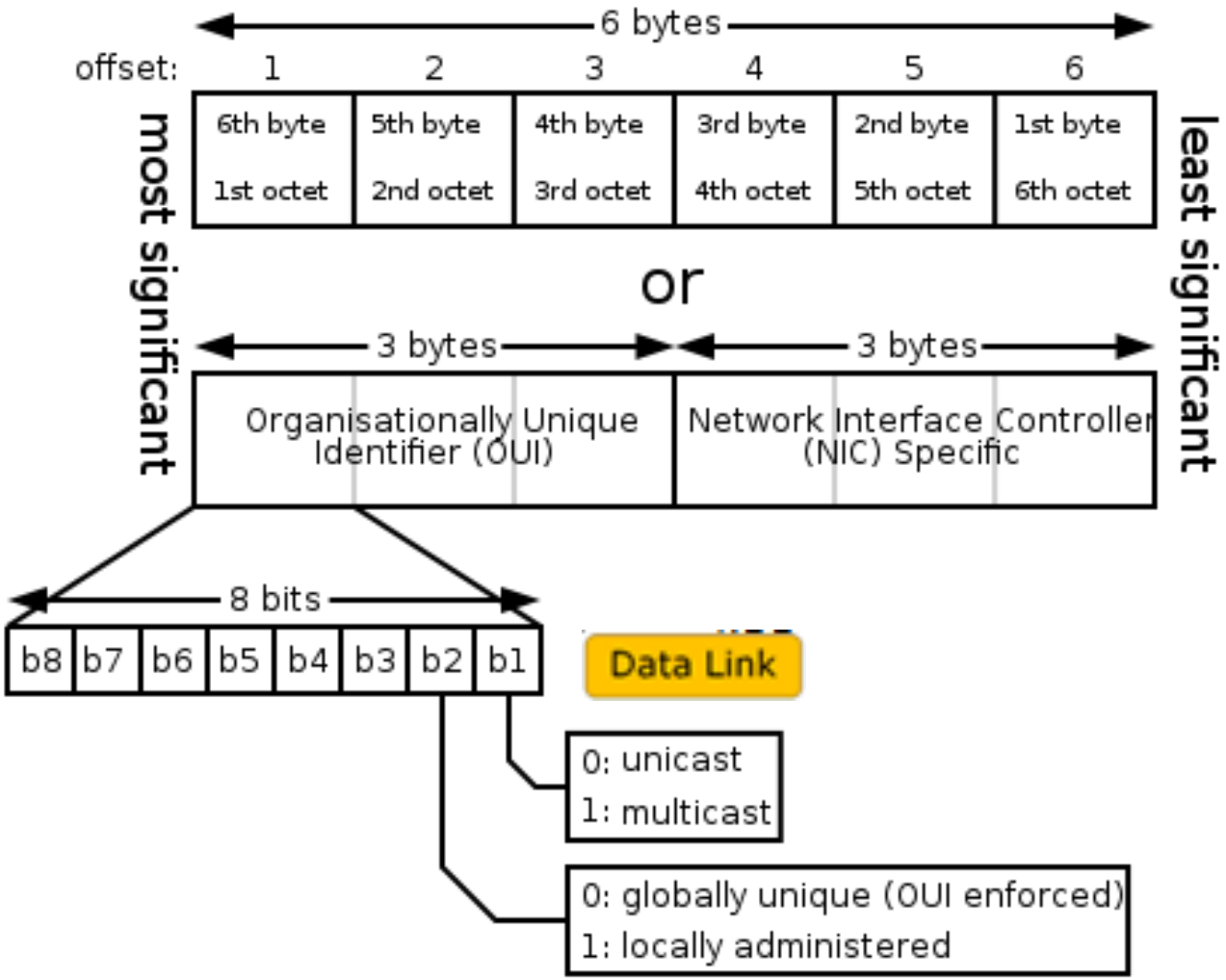
- Three main fields:
  - Host id – destination network ID (IP address/range)
  - Cost – or metric of the path
  - Next-hop – the specific address of the device to forward to

ROYAL INSTITUTE OF TECHNOLOGY

Routing and Addressing

Data link layer – MAC addresses

Application
Transport
Network
Data Link
Physical



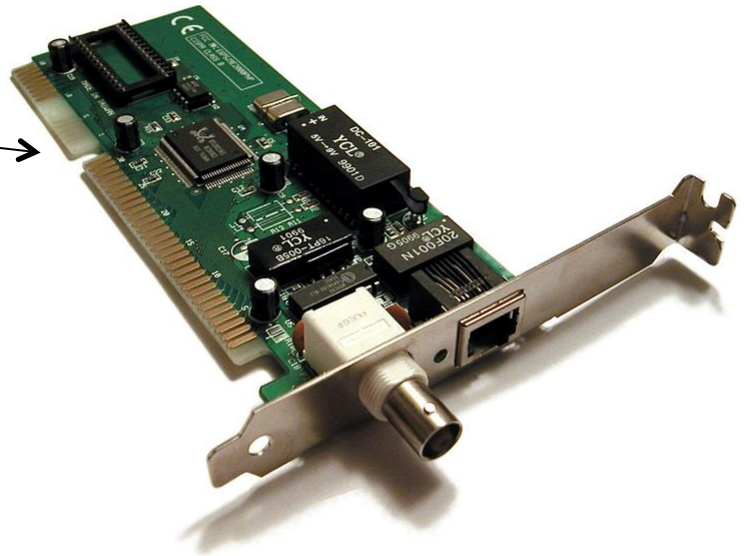
ROYAL INSTITUTE OF TECHNOLOGY

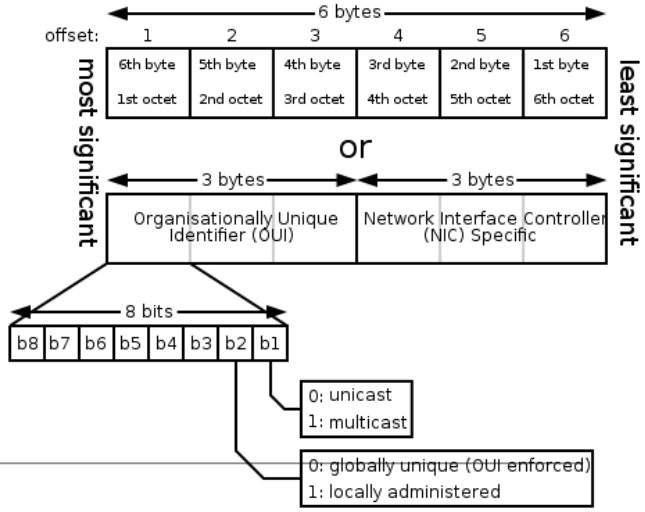
Routing and Addressing

Data link layer – MAC addresses

Application
Transport
Network
Data Link
Physical

- Burned into H/W of NIC
- Can be "spoofed"
- Used in:
  - Ethernet
  - 802.11 wireless networks
  - Bluetooth
  - IEEE 802.5 token ring
  - most other IEEE 802 networks
  - Fiber Distributed Data Interface (FDDI)
  - ATM
  - The ITU-T G.hn standard – home power line





ROYAL INSTITUTE OF TECHNOLOGY

Routing and Addressing

Data link layer – Address Resolution Protocol

Application
Transport
Network
Data Link
Physical

- ARP links IP address to MAC address
- Replaced by Neighbour Discovery Protocol (NDP) in IPv6
- Ubiquitous among IPv4 devices
- Vulnerable to local attack
  - ARP poisoning

Internet Protocol (IPv4) over Ethernet ARP packet		
bit offset	0 – 7	8 – 15
0	Hardware type (HTYPE)	
16	Protocol type (PTYPE)	
32	Hardware address length (HLEN)	Protocol address length (PLEN)
48	Operation (OPER)	
64	Sender hardware address (SHA) (first 16 bits)	
80	(next 16 bits)	
96	(last 16 bits)	
112	Sender protocol address (SPA) (first 16 bits)	
128	(last 16 bits)	
144	Target hardware address (THA) (first 16 bits)	
160	(next 16 bits)	
176	(last 16 bits)	
192	Target protocol address (TPA) (first 16 bits)	
208	(last 16 bits)	

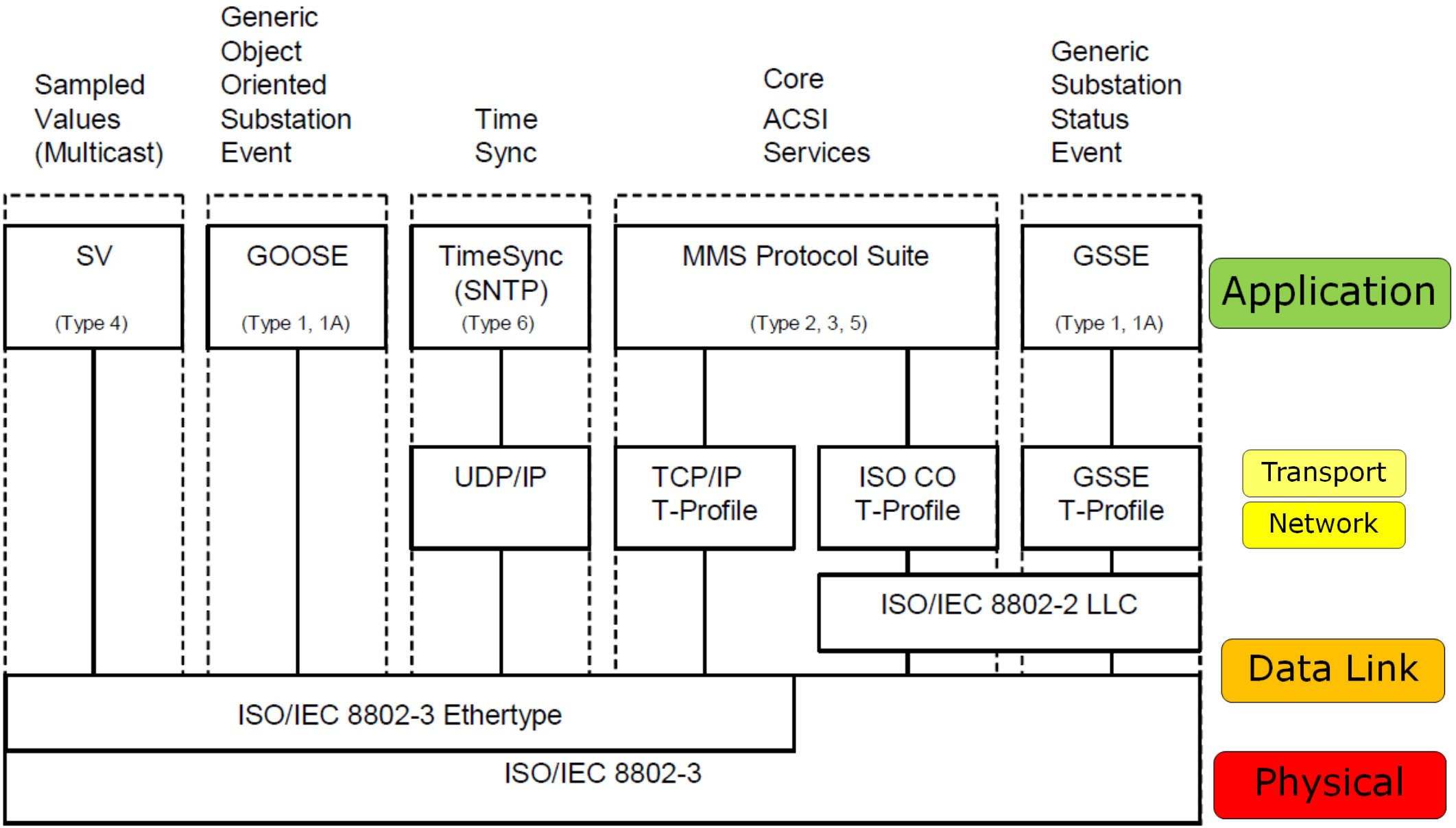
ROYAL INSTITUTE OF TECHNOLOGY

Protocols used in power systems

- IEC 61850
  - GOOSE
  - SV
  - MMS
- IEC 60870-5-10x
- Modbus
- DNP3
- ICCP

Protocols used in power systems

IEC 61850-8-1



Protocols used in power systems

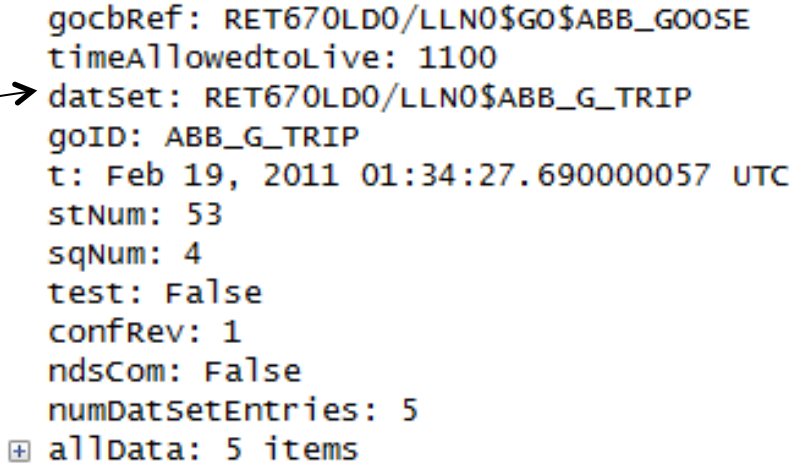
GOOSE

- Generic Object Oriented Substation Event

  - Specified in IEC 61850-8-1

  - Status and values
  - Grouped into dataset

  - Transmitted within a time of 4ms



ROYAL INSTITUTE OF TECHNOLOGY

Protocols used in power systems

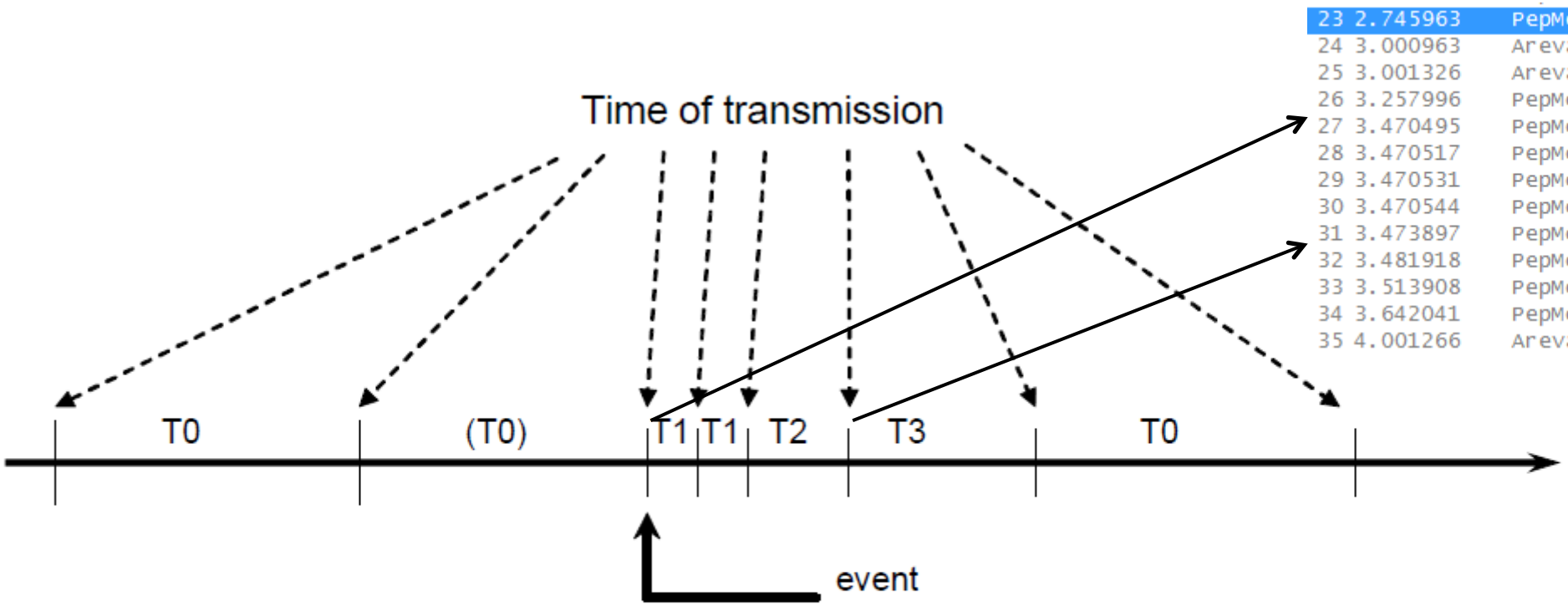
GOOSE

IEC 61850-7-2 parameter	Parameter name
Argument	Argument
	Destination address
DatSet	datSet
GoID[a)]	goID
GoCBRef	gocbRef
T	t
StNum	stNum
SqNum	sqNum
timeAllowedtoLive	timeAllowedtoLive
Test	test
ConfRev	confRev
NdsCom	ndsCom
GOOSEData	numDatSetEnries
	allData
	timeAllowedToLive

```
gocbRef: RET670LD0/LLN0$GO$ABB_GOOSE
timeAllowedtoLive: 1100
datSet: RET670LD0/LLN0$ABB_G_TRIP
goID: ABB_G_TRIP
t: Feb 19, 2011 01:34:27.690000057 UTC
stNum: 53
sqNum: 4
test: False
confRev: 1
ndsCom: False
numDatSetEntries: 5
allData: 5 items
```

Protocols used in power systems

GOOSE – retransmission strategy



T0	retransmission in stable conditions (no event for a long time).
(T0)	retransmission in stable conditions may be shortened by an event.
T1	shortest retransmission time after the event.
T2, T3	retransmission times until achieving the stable conditions time.

Protocols used in power systems

MMS

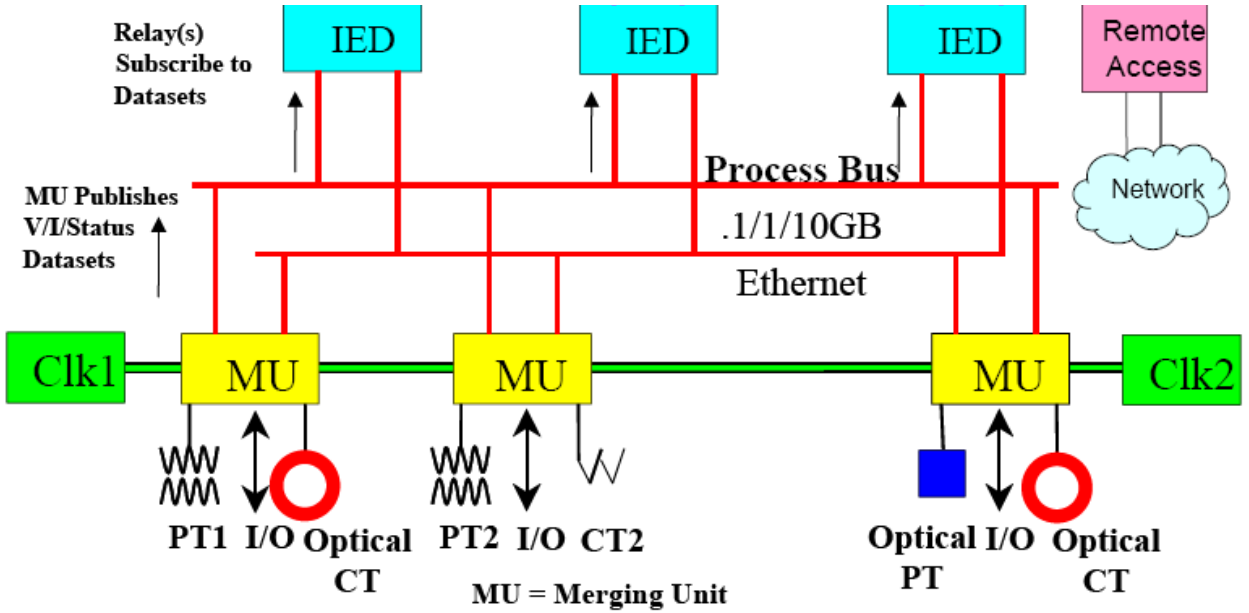
- Open standard
- Transferring real-time process data
- Provides standard messages
- Encoding rules

Application	Association Control Service Element (ACSE)- ISO 8649/8650
Presentation	Connection Oriented Presentation - ISO 8822/8823 Abstract Syntax Notation (ASN)- ISO 8824/8825
Session	Connection Oriented Session - ISO 8326/8327
Transport	ISO transport over TCP - RFC 1006 Transmission Control Protocol (TCP) - RFC 793
Network	Internet Control Message Protocol (ICMP) - RFC 792 Internet Protocol (IP)- RFC 791 Address Resolution Protocol (ARP)- RFC 826
Link	IP datagrams over Ethernet - RFC 894 MAC - ISO 8802-3 [Ethernet]
Physical	Ethernet

Protocols used in power systems

IEC 61850-9-2 Sampled Values (SV)

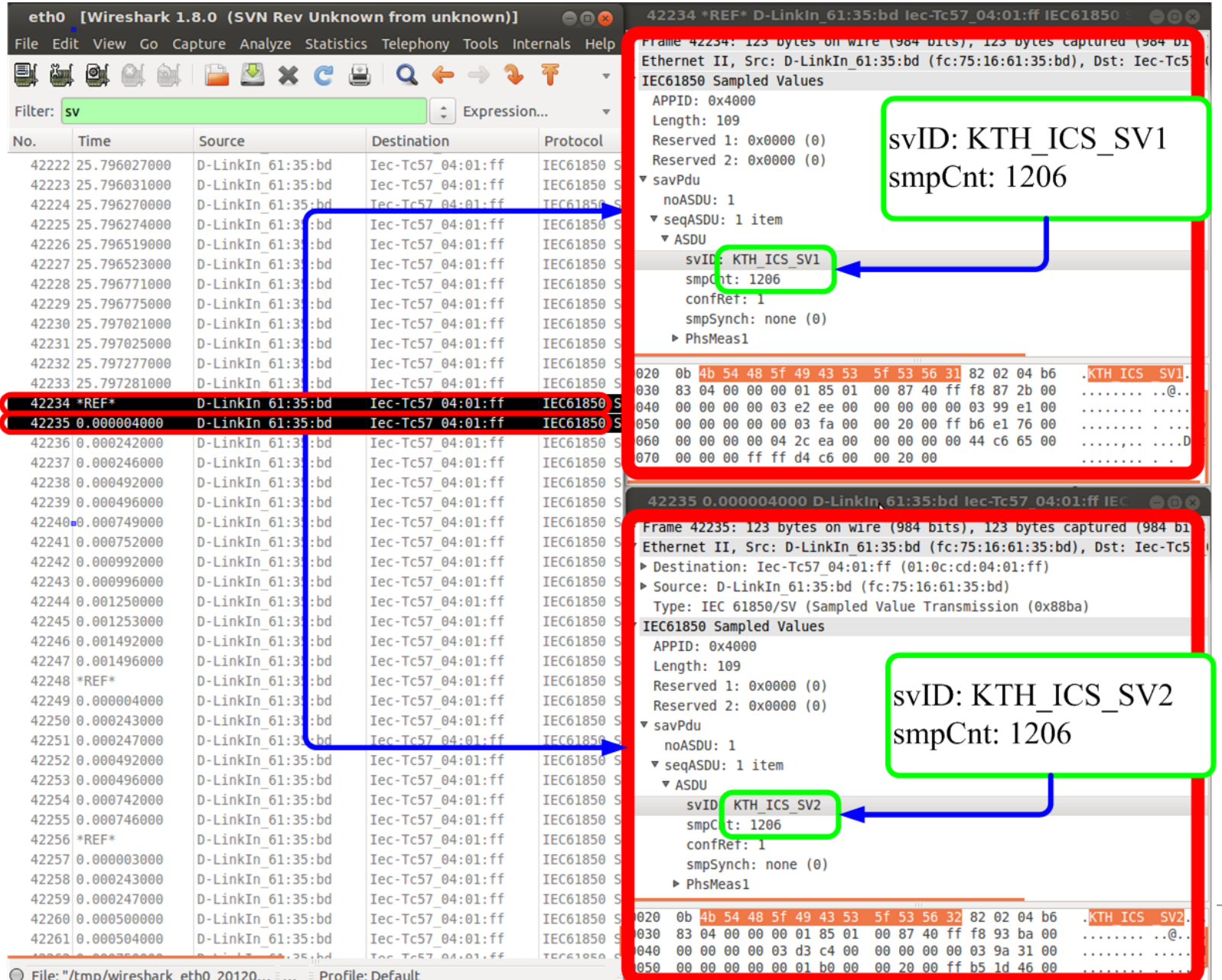
- Used on the process bus
- Transmits 3-phase CT/VT measurements
- Sampling rate of 4kHz
- Need time synchronization



ROYAL INSTITUTE OF TECHNOLOGY

Protocols used in power systems

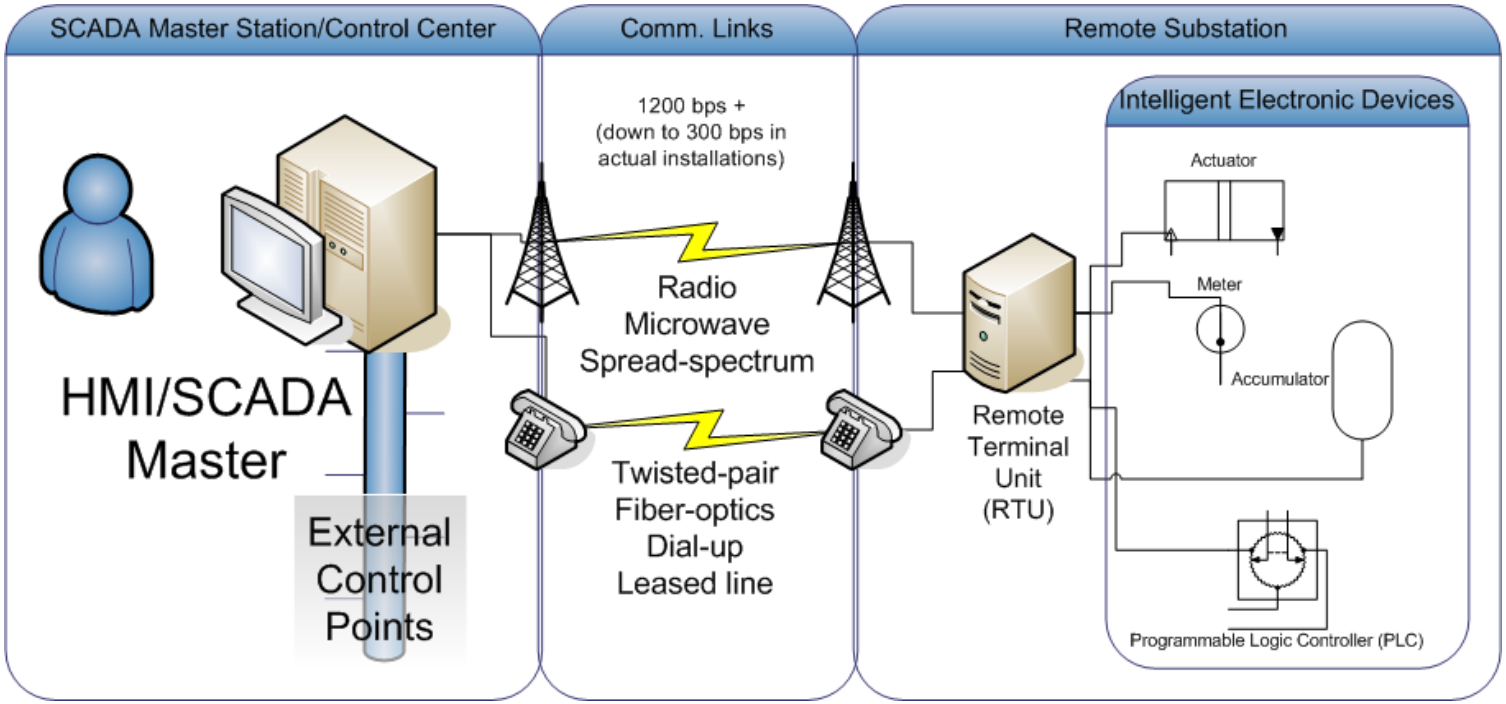
IEC 61850-9-2 Sampled Values (SV)



Protocols used in power systems

IEC 60870-5-10x

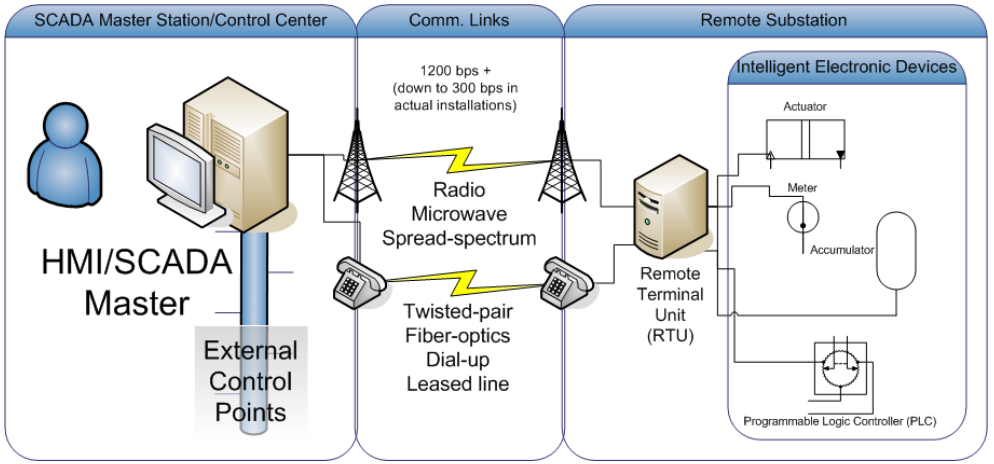
- A suite of “RTU protocols”…



Protocols used in power systems

IEC 60870-5-10x

- Standard by TC57 (same as IEC 61850)



  - Specifically for power systems
    - Monitoring
    - Control
    - Teleprotection

  - A few difference flavors exist:
    - 101 – Serial RTU protocol
    - 103 – interoperability between protection/substation devices
    - 104 – Variant of 101 carried over TCP/IP

  - Still very commonly used.

ROYAL INSTITUTE OF TECHNOLOGY

Protocols used in power systems

IEC 60870-5-10x

IEC 101 Frame Format, Variable length		
Data unit	**Name**	**Function**
Start Frame	Start Character	*Indicates start of Frame*
	Length Field (*2)	*Total length of Frame*
	Start Character (repeat)	*Repeat provided for reliability*
	Control Field	*Indicates control functions like message direction*
	Link Address (*0,1 or 2*)	*Normally used as the device / station address*
Data Unit Identifier	Type Identifier	*Defines the data type which contains specific format of information objects*
	Variable Structure Qualifier	*Indicates whether type contains multiple information objects or not*
	COT (*1 or 2*)	*Indicates causes of data transmissions like spontaneous or cyclic*
	ASDU Address (*1 or 2*)	*Denotes separate segments and its address inside a device*
Information Object	Information Object Address (*1 or 2 or 3*)	*Provides address of the information object element*
	Information Elements (n)	*Contains details of the information element depending on the type*
Information Object-2	-----	
-----	-----	
Information Object-m		
Stop Frame	Checksum	*Used for Error checks*
	Stop Char	*Indicates end of a frame*

Protocols used in power systems

Modbus

- Master/slave RTU protocol mainly for PLC interfacing

  - Address up to 240 devices
  - *Coils* and *contacts* – old names for status and command points

  - Many versions (“flavours”)
    - Serial RTU, ACSII
    - TCP/IP
    - UDP

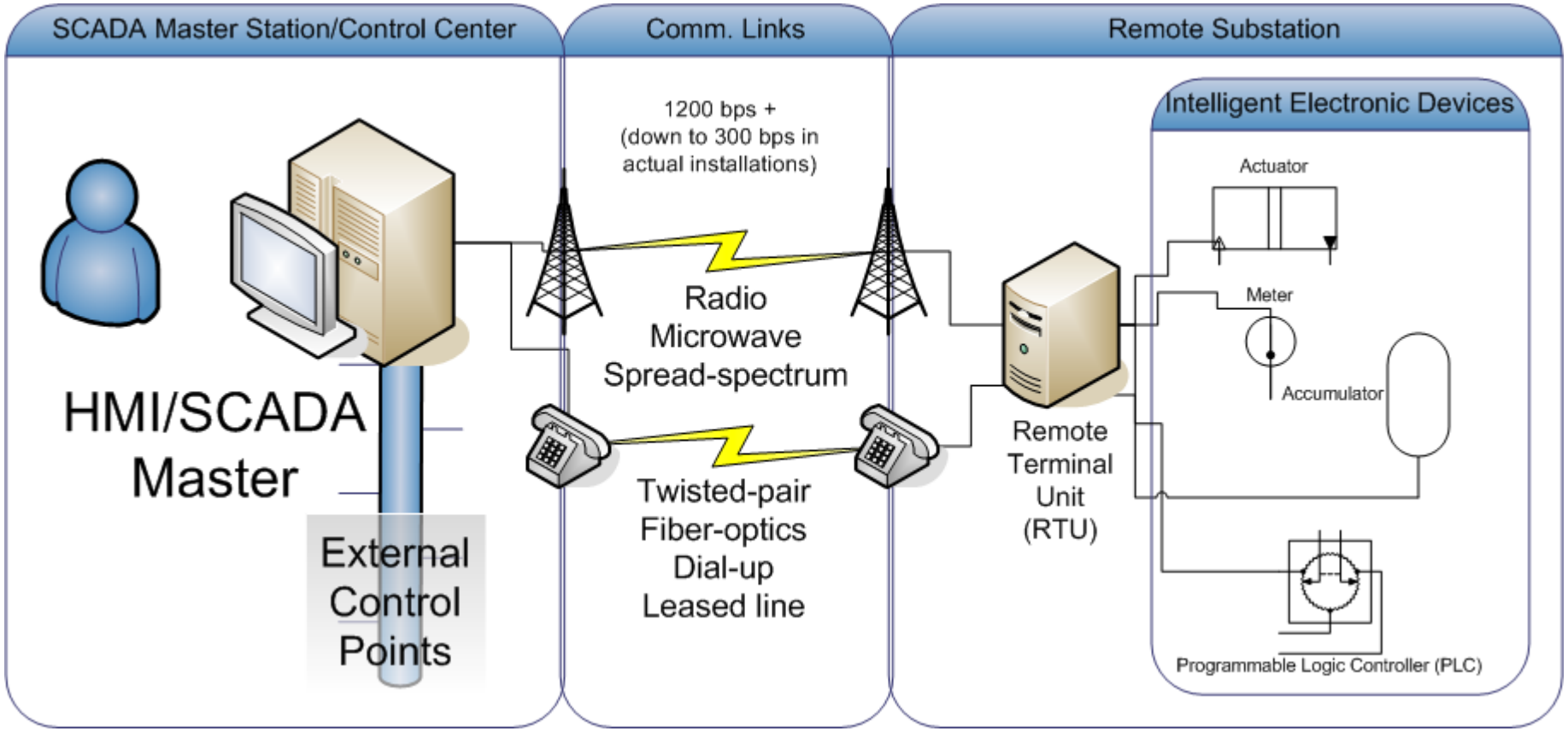
Modbus TCP Frame Format		
Name	**Length**	**Function**
Transaction Identifier	2 bytes	*For synchronization between messages of server & client*
Protocol Identifier	2 bytes	*Zero for MODBUS/TCP*
Length Field	2 bytes	*Number of remaining bytes in this frame*
Unit Identifier	1 byte	*Slave Address (255 if not used)*
Function code	1 byte	*Function codes as in other variants*
Data bytes	n bytes	*Data as response or commands*

Modbus RTU Frame Format		
Name	**Length**	**Function**
Start	3.5c idle	*at least 3-1/2 character times of silence (MARK condition)*
Address	8 bits	*Station Address*
Function	8 bits	*Indicates the function codes like read coils / inputs*
Data	n * 8 bits	*Data + length will be filled depending on the message type*
CRC Check	16 bits	*Error checks*
End	3.5c idle	*at least 3-1/2 character times of silence between frames*

Protocols used in power systems

DNP3

Also an ”RTU protocol”…



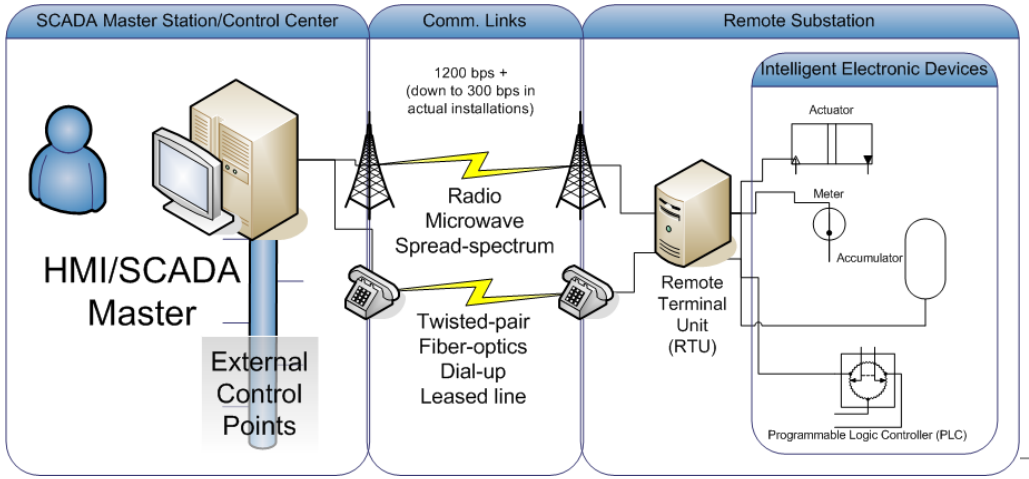
Protocols used in power systems

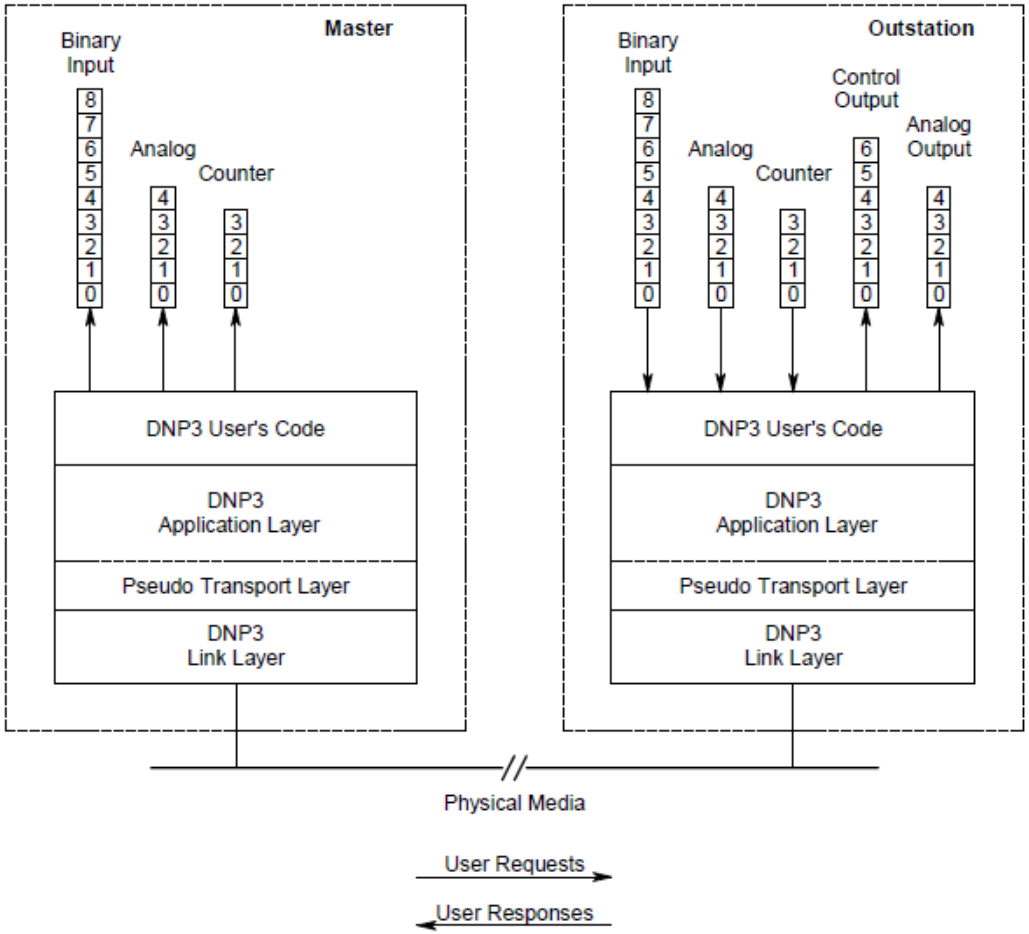
DNP3

- Distributed Network Protocol
  - SCADA master
  - Remote Terminal Units (RTU)
  - Intelligent Electronic Devices (IED)

  - Mainly for SCADA->RTU/IED

  - Polling and spontaneous access

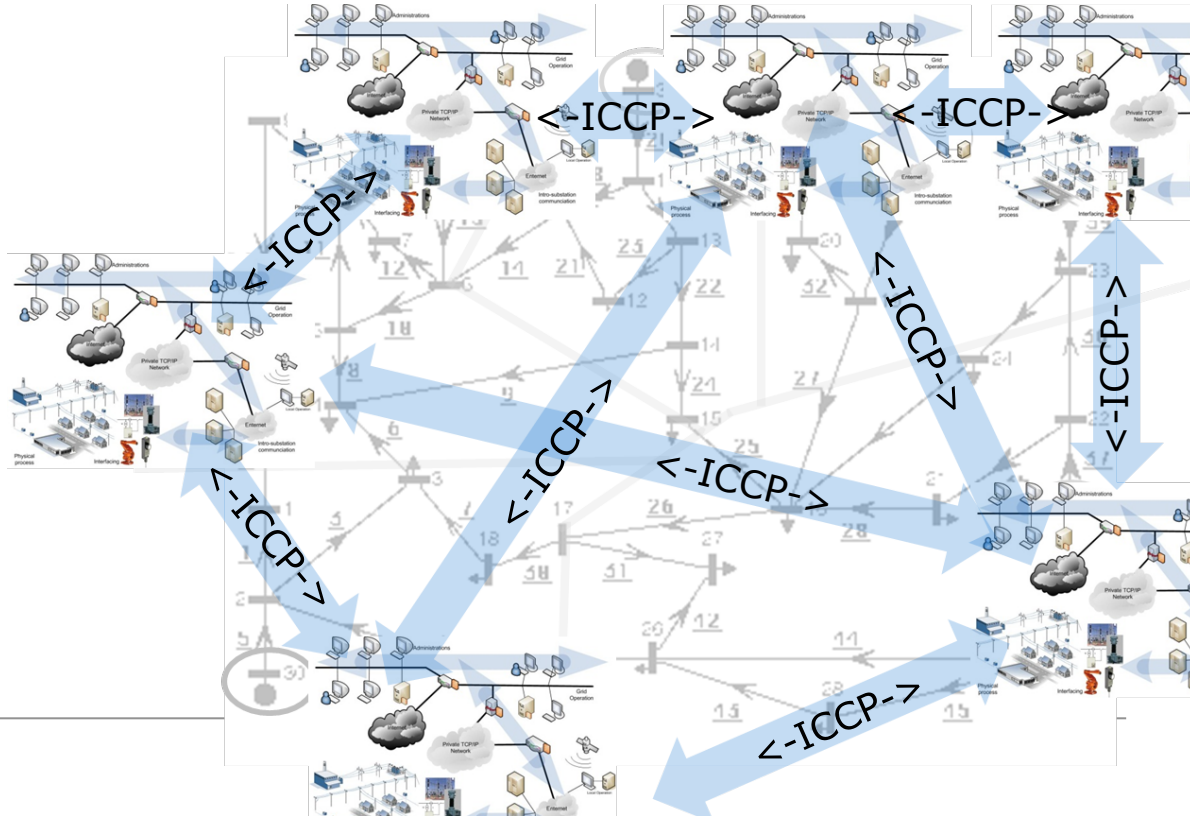




Protocols used in power systems

ICCP

- Inter-Control Center Communications Protocol (IEC 60870-6/TASE.2)
  - Communication between SCADA systems
  - Client/server model
  - Carried over TCP/IP
  - No authentication or encryption



Protocols used in power systems

ICCP - Functionality

- Functions such as:

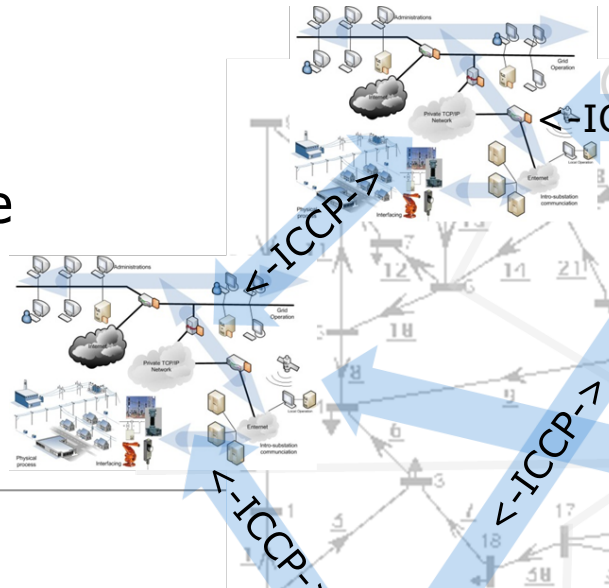
  - Periodic System Data
    - Status points, analogue points, quality flags, time stamp, counters, protection events

  - Device Control
    - on/off, trip/close, raise/lower etc and digital setpoints.

  - Program Control
    - Allows an ICCP client to remote control programs executing on an ICCP server.

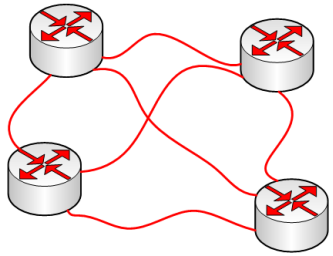
  - Scheduling, accounting, outage and plant information

  - Historical time series data between a start and end date

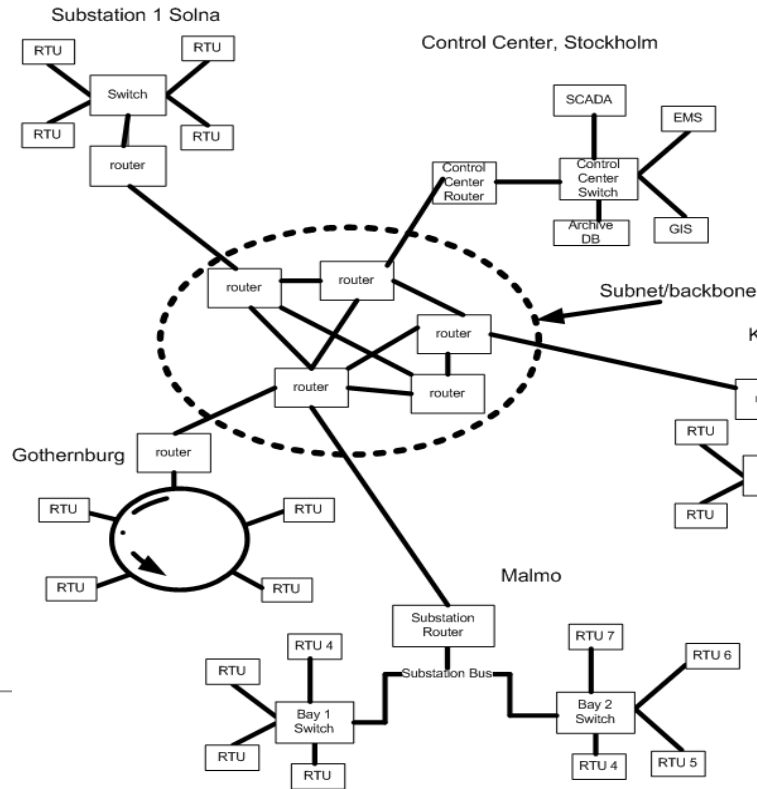


ROYAL INSTITUTE OF TECHNOLOGY

Delay, loss and throughput



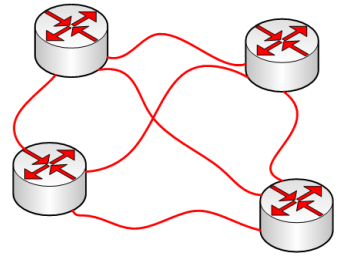
- Delay
- Loss
- Throughput



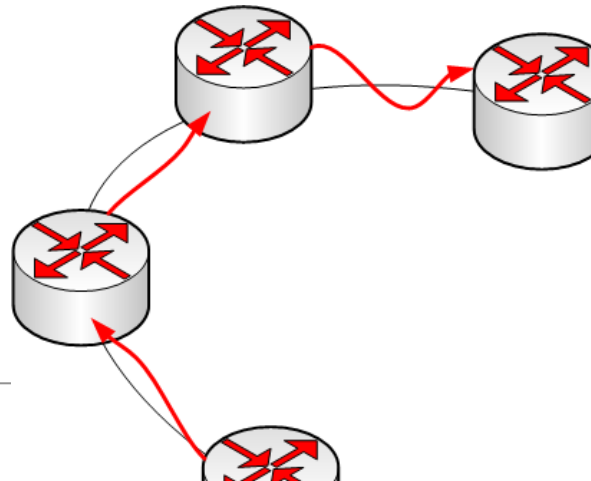
ROYAL INSTITUTE OF TECHNOLOGY

Delay, loss and throughput

Delay

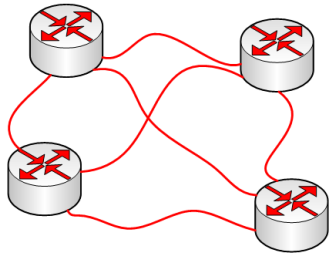


- Composed of:
  - Processing delay
    - Time taken for a router to process packet header
  - Queuing delay
    - Time that the packet waits in the queue
  - Transmission delay
    - Time taken to push the packet bits onto the link
  - Propagation delay
    - Time taken for signal to reach it’s destination

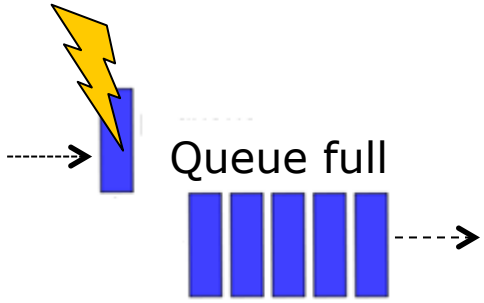


Delay, loss and throughput

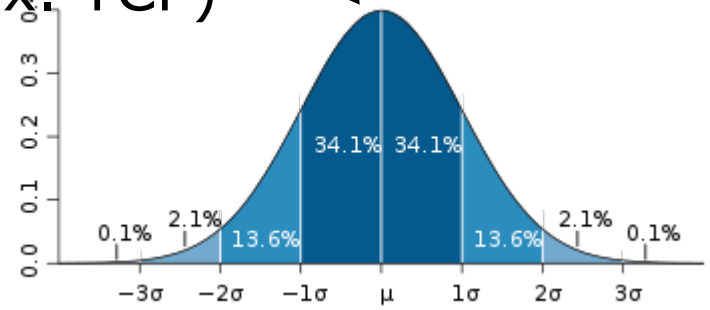
Loss



- Occurs when packets fail to reach their destination
- Router with full queue will drop packets



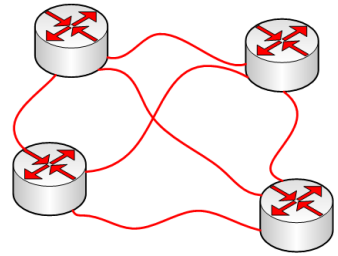
- Corruption of packet data
  - Bad signal-to-noise ratio
- Causes undesirable “jitter” in Real-Time applications
- Recovery often by higher-layer protocols (ex. TCP)



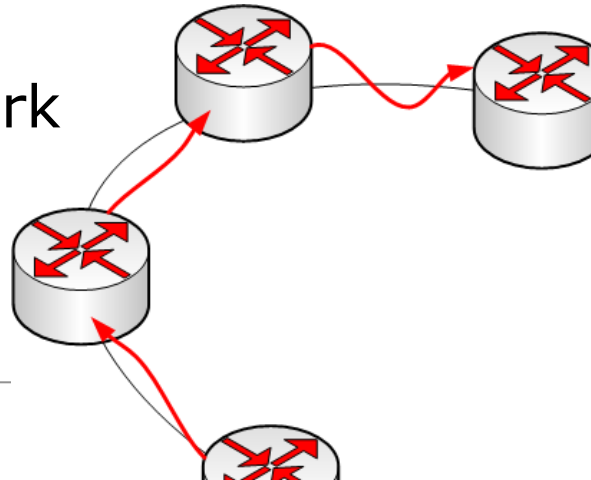
ROYAL INSTITUTE OF TECHNOLOGY

Delay, loss and throughput

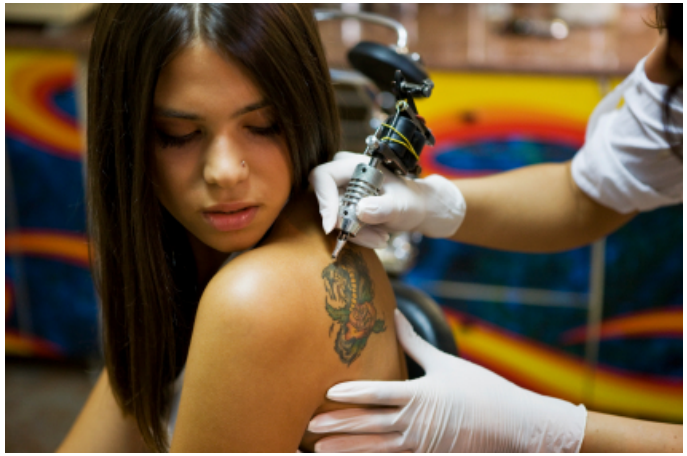
Throughput



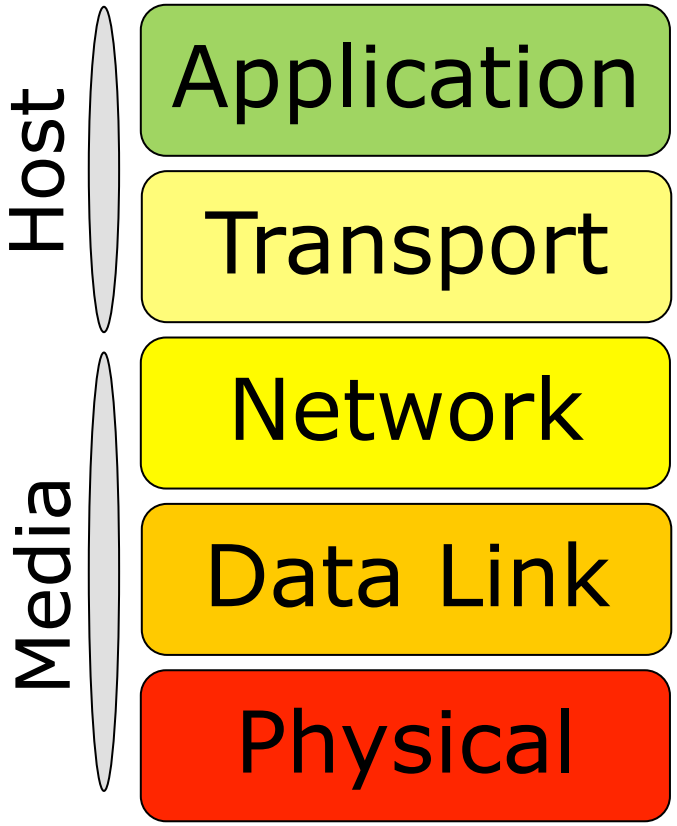
- Measured in bits-per-second (bps)
  - *not* Bytes (8-bits)
- Instantaneous
  - At any instant in time
- Average
  - Over a period of time
- Need to identify the bottleneck link in the network

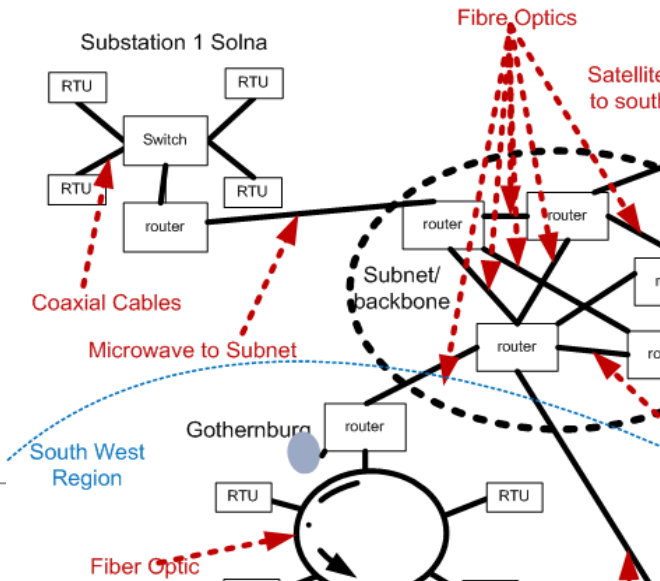


Conclusions



Thinking of getting a tattoo?



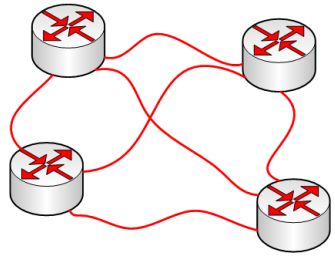


The OSI model will always be fashionable!

ROYAL INSTITUTE OF TECHNOLOGY

Communication Networks

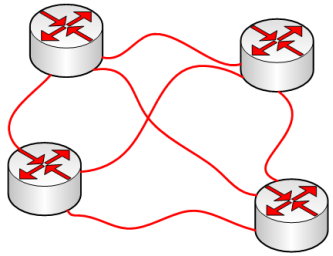
Conclusion



- A language to categorise and understand the many protocols, media and devices that exits
  - The OSI model
- Looked at the architectures, protocols and network infrastructure used in power systems control (SCADA & SAS)
- Routing and switching in more detail
- Protocols used in power systems applications
- Brief discussion of metrics on networks

ROYAL INSTITUTE OF TECHNOLOGY

What's next..



- **Wide Area Communication & SCADA**
- **Cybersecurity**