Computer Networks

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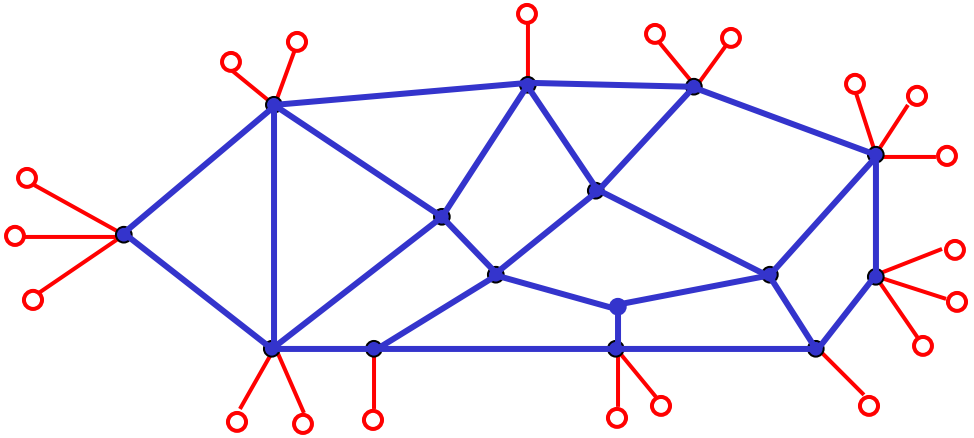
Basic Network Concepts

- A computer network is a set of nodes connected by communication links.
- Nodes may be:
  - **End systems**, on which applications can run
  - **Communication nodes**, which just pass data



Types of Computer Network

- Computer networks are often classified into:
  - **Local Area Networks (LAN):** Size up to a few kilometers, typically covering a building, company or institution.
  - **Wide Area Networks (WAN):** Large geographical coverage, perhaps world-wide.
  - **Metropolitan Area Networks (MAN):** Covering a town or other relatively large area.
- Classification is partly:
  - ***Historical:*** Before liberalisation of telecommunication services, only tele-monopolies could set up large networks.
  - ***Technological:*** Small networks can use cheaper technology to give high-speed access.

Concepts of Layering

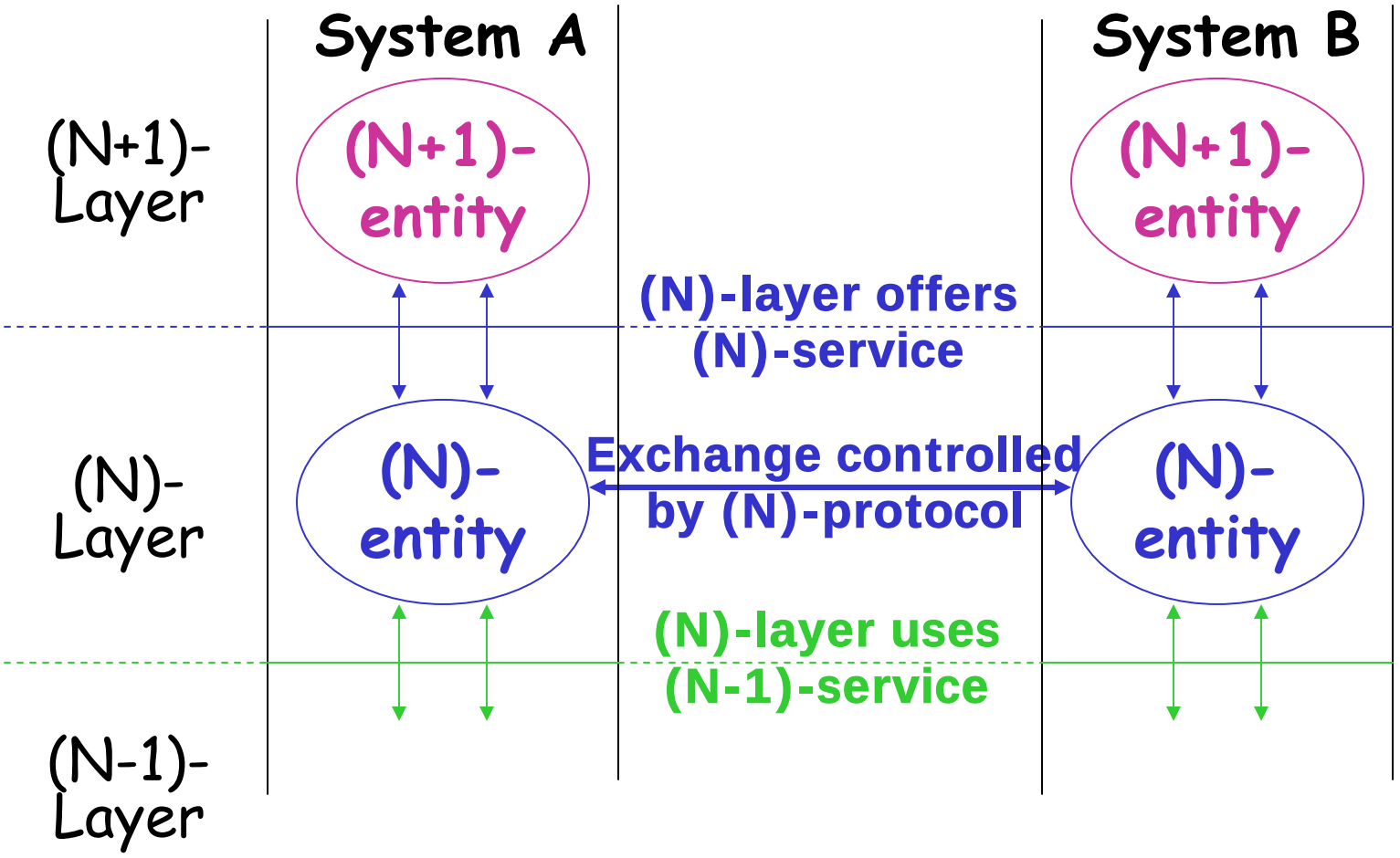
Layer **N** offers a **service** (a set of facilities) to its "users" in the layer above, layer **(N+1)**.

The service offered by layer **N** builds on the facilities offered by the layer below, layer **(N-1)**.

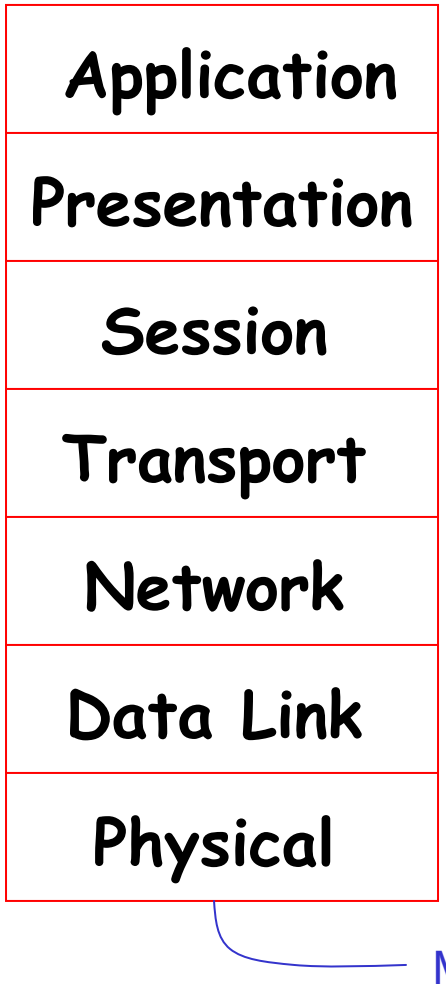
Added value offered by layer **N** is achieved by exchange of messages following a set of rules characteristic for that layer: the **(N)-protocol**. Example:

- Layer **(N-1)** offers an insecure service where data may be overheard by intruders.
- **(N)-protocol** specifies that messages sent via the **(N-1)-service** must be encrypted using secret key encryption.
- Layer **N** offers a secure, confidential service.

Layered Architectures (2)



OSI Reference Model



Direct support to application processes (File transfer, e-mail, transactions,...)

Transformation to suitable syntactic form (Character sets, data structures,...)

Organisation of dialogues (Synchronisation points, token control)

End-to-end transfer of data (End-to-end error, sequence & flow control)

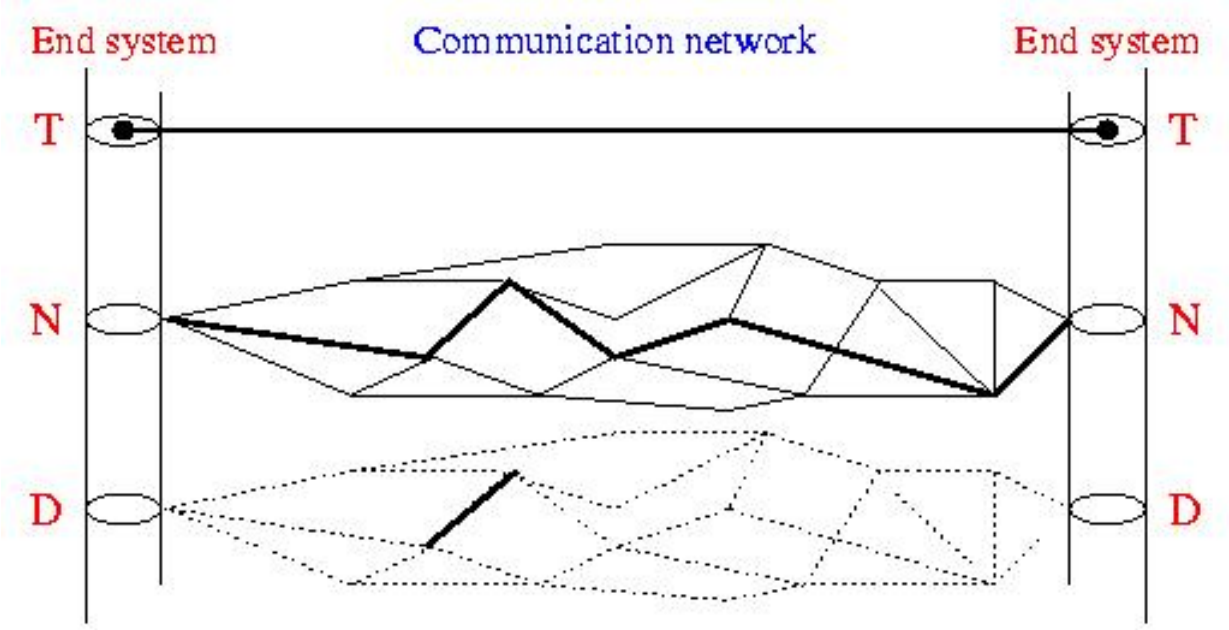
Transfer of data between arbitrary systems (Routing, multiple subnets, flow control)

Transfer of data between directly connected systems (Error, sequence & flow control)

Signalling on physical medium

OSI Lower Layers

- **Data Link:** transfers data between directly connected systems (via direct cable or shared medium)
- **Network:** permits data transfer to arbitrary systems ("nodes").
- **Transport:** provides illusion of direct end-to-end connection between processes in arbitrary systems.



Internet Layered Architecture

- A simplified model, with OSI Upper Layers reduced to a single layer:

Application	Direct support to application processes
Transport	End-to-end transfer of data
Network	Transfer of data between arbitrary systems
Data Link	Transfer of data between directly connected systems
Physical	Signalling on physical medium

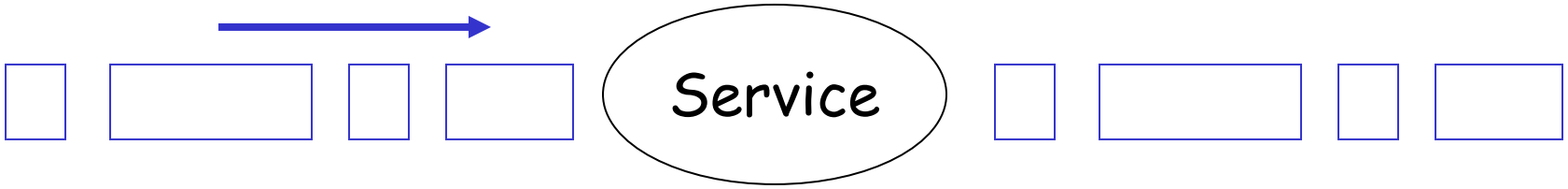
Services and Protocols

Services

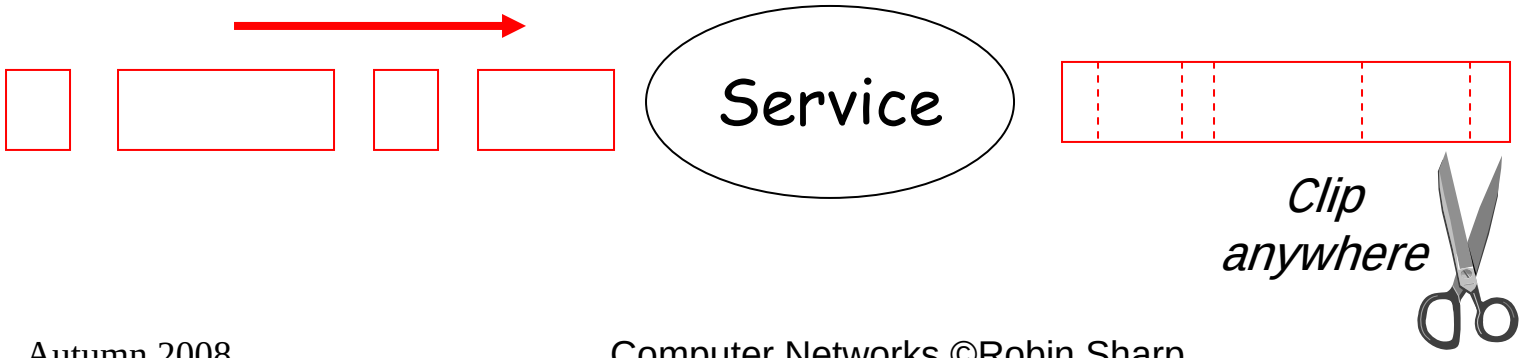
- Service describes what facilities are offered by a layer viewed as a "**black box**", for example:
  - Sequence preservation
  - Data unit synchronisation
  - Freedom from error
  - Connection-orientation
  - N-peer operation
  - Simplex/duplex/multiplex operation
  - Expedited data
  - Security
- Service does *not* tell us how these features are achieved.

Data unit synchronisation

- Are the “data units” received by the receiver(s) the same size as those sent by the sender?
  - Message(/block-) oriented services:



  - Stream-oriented services:



Errors in communication

- Three basic error types:
  - **Message loss:** Receiver fails to receive a message sent by the sender.
  - **Message corruption:** Receiver receives a message different from the one sent by the sender.
  - **Spurious message:** Receiver receives a message not sent by the (apparent) sender.
- Measures of error rate:
  - **Bit Error Rate (BER):** Fraction of received bits in error.
  - **Residual Error Rate (RER):** Fraction of erroneous blocks.

$$RER = \frac{N_l + N_c + N_u}{N_s + N_u}$$

N_s= Blocks sent
N_c= Corrupt blocks
N_l = Lost blocks
N_u= Spurious blocks

Connection-mode services

- Users have to establish a *logical channel* between one another before they can exchange actual data.
- Simple example: Telephone service.
- Advantages:
  - Administrative info. such as full address of destination, security parameters etc etc only needs to be exchanged when connection is being set up.
  - Gives a “context” for the subsequent exchange of messages, making it possible to keep track of lost or misordered messages during a conversation.
- Disadvantages:
  - Inefficient if only a small amount of data to be exchanged.

Connectionless-mode services

- *No connection* set up before exchange of data.
- Each message is sent *independently* of the others.
- Simple example: Postal service.
- Advantages:
  - Less administration if small amount of data.
  - May be faster: No need to wait for delivery of predecessors.
- Disadvantages:
  - All administrative info. has to be carried round in all messages, as the service has no memory of previous messages (*stateless* service).
  - No guarantee of delivery in right order.
  - No guarantee of delivery at all *("send-and-pray").*

N-peer operation

- Point-to-point service:

  Offers point-to-point communication between two parties.

  Simple case: Two parties with equal status (Two-peer service).

- Multi-peer service:

  Several users can communicate with one another at one time.

  Often classified into:

  - **Broadcast service:** All available users of service receive a message sent by one of them.
  - **Multicast service:** A selected subset of users receive a message sent by one of them.
  - **Inverse broadcast:** A single receiver can receive simultaneously from all the other service users.

N-plex services

- Simplex service: Transfers messages in one direction only through logical or physical channel.
- Duplex service: Messages can pass between two parties in both directions.
  - Half-duplex: Only one direction at a time.
  - Full duplex: Both directions at once.
- Multiplex service: Many users can use the logical or physical channel, via some sharing mechanism. E.g.:
  - Frequency-division multiplexing: Use different frequencies (radio, TV, optical,...)
  - Time-division multiplexing: Share the available time between the users.

Security

Typical aims of a secure service are to ensure:

- **Confidentiality:** Protection of information in transit from being picked up by unauthorised parties.
- **Integrity:** Protection of information in transit from being modified by alteration, deletion, replaying or insertion of new messages.
- **Authentication:** Correct identification of the origin of a message or electronic document.
- **Non-repudiation:** Protection against the sender or receiver denying that a message was transferred between them.
- **Availability:** Protection against service being denied to authorised users.

Quality of Service (QoS)

- Summarises quantitative properties of a service:
  - Throughput (bits/unit time)
  - Delay (for connection setup, transfer, connection release)
  - Reliability (in connection setup, transfer, connection release)
  - Resilience (probability of unrequested disconnection)
  - Error rate (BER, RER)
  - Protection against intruders (passive, active,...)
  - Priority (in delivery, in maintaining service quality)
- Parameters often given in terms of:
  - Target value (mean or median).
  - Permissible spread (max/min interval, variance,...).
  - (Possibly) a list of acceptable discrete values.

Protocols

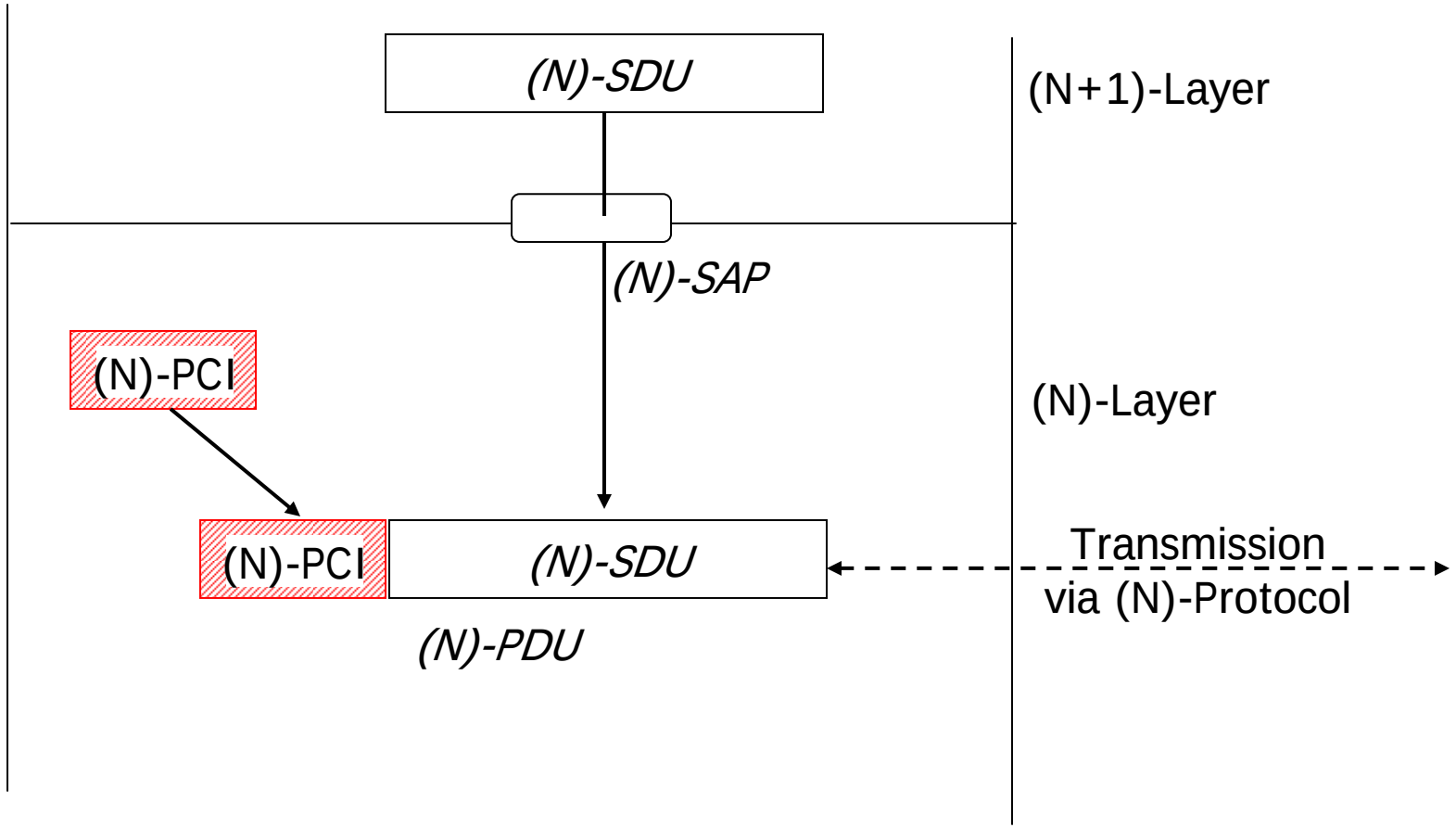
- Specify rules for how to provide the desired service:
  - **Rules of procedure:** Which messages to exchange in response to events occurring at the interface to the layer or internally (e.g. timeout).
  - **Message formats:** Format and encoding of messages to be transferred between the parties involved.
- OSI notation:
  - **Service Data Unit (SDU):** A message supplied by a user of a service.
  - **Protocol Data Unit (PDU):** A message exchanged between two or more parties as part of a protocol.
  - An initial is often used to indicate the relevant OSI layer. E.g. NPDU: A PDU exchanged in the Network layer.

Protocol Control Information (PCI)

- Information used to control the exchange of PDUs according to the rules of the protocol, such as:
  - Identification of source and destination of PDU.
  - Sequence numbers used to detect lost or misordered PDUs.
  - Checksums used to detect corrupted PDUs.
  - Timestamps used to detect outdated PDUs.
  - Security-related information.
- An administrative PDU (e.g. acknowledgement for receipt of data) may consist just of PCI.
- In a Data PDU, PCI is added as a header and/or trailer to (part of) an SDU supplied by the user.

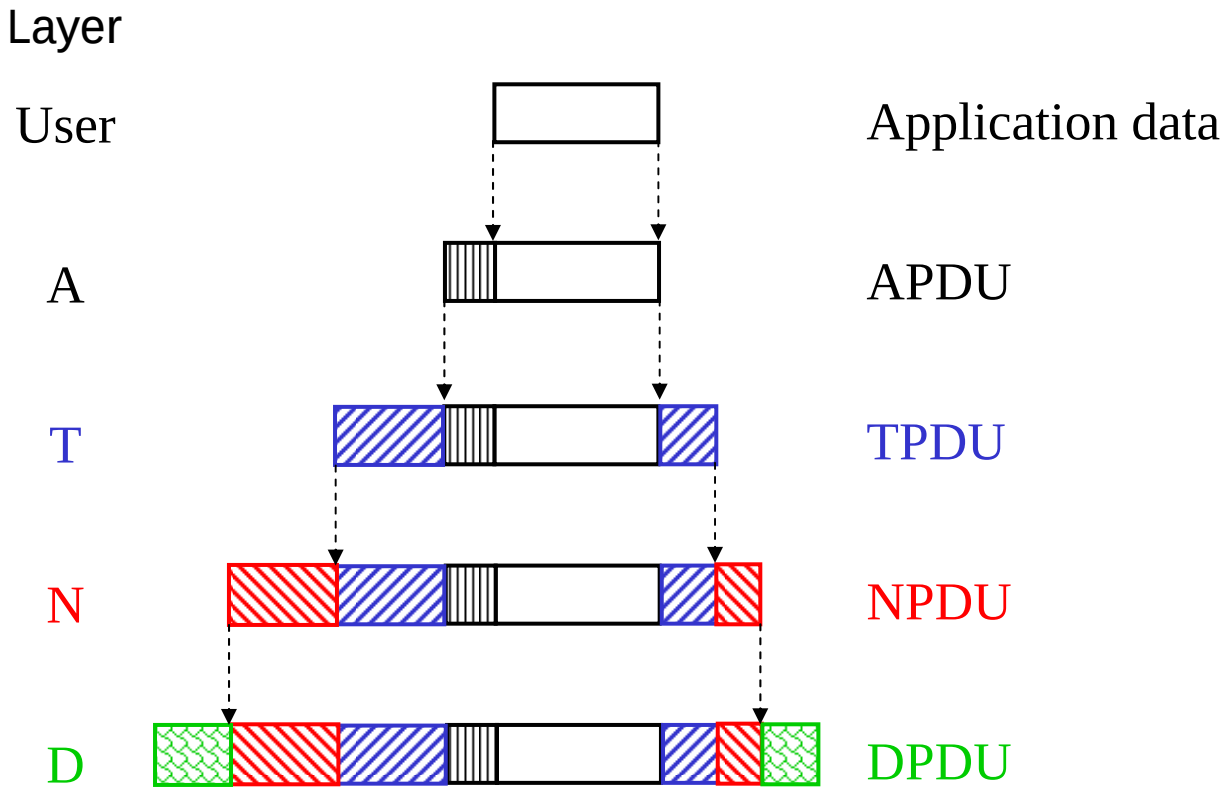
PCI in a PDU

- Simple example: PCI in header, data from whole SDU.



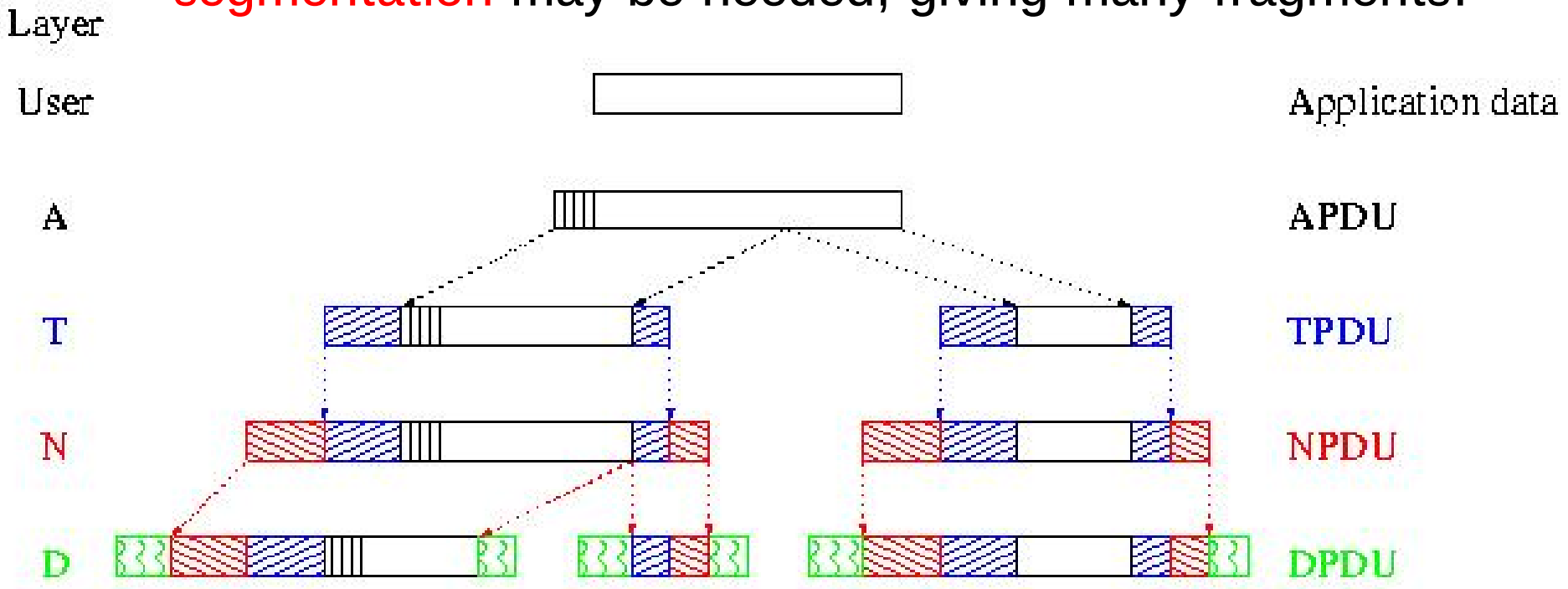
Embedding of layered PDUs

- In a layered architecture, PCI will be added in each layer. Simple case:



Segmented embedded PDUs

- When PDUs get larger than a given layer permits, segmentation may be needed, giving many fragments:

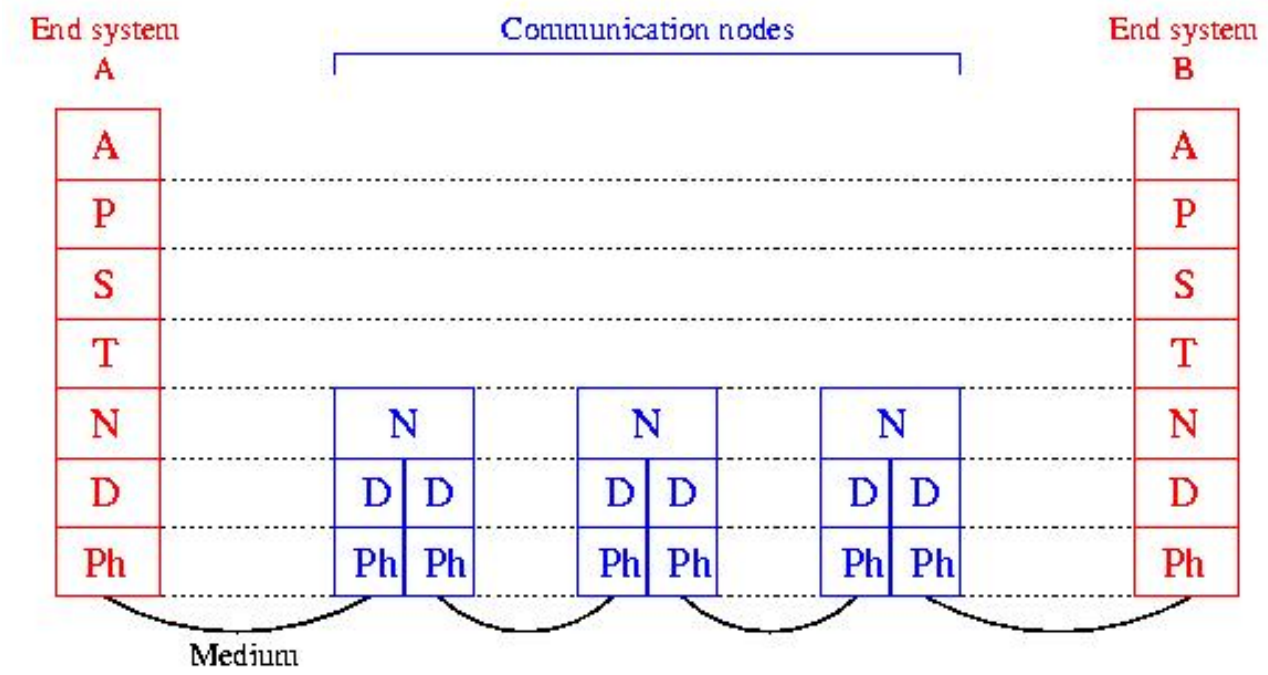


- Effective data rate may drop due to sudden jumps in amount of PCI.

Network Technology

Communication nodes

- Communication nodes typically implement OSI layers up to and including the Network layer:



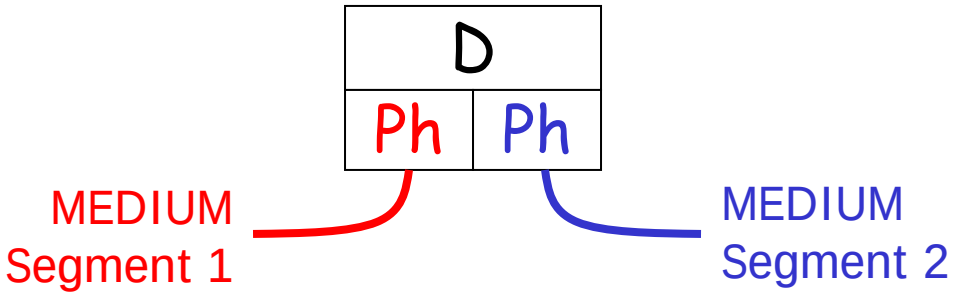
- Comm. nodes are responsible for accepting PDUs on incoming link, routing to an outgoing link and transmitting on outgoing link.

Routers

- Implement layers up to (at least) Network layer.
- Can choose a suitable route for sending an incoming PDU on to its destination.
- May be able to filter off irrelevant or unsuitable traffic, for example:
  - Traffic which has taken too long time to cross the network.
  - Traffic from known unreliable sources.
  - Traffic on incoming links not “matching” the claimed source address.
  - Traffic to destinations or applications which do not want it.
  - Traffic which misuses the protocols in some way.

Bridges

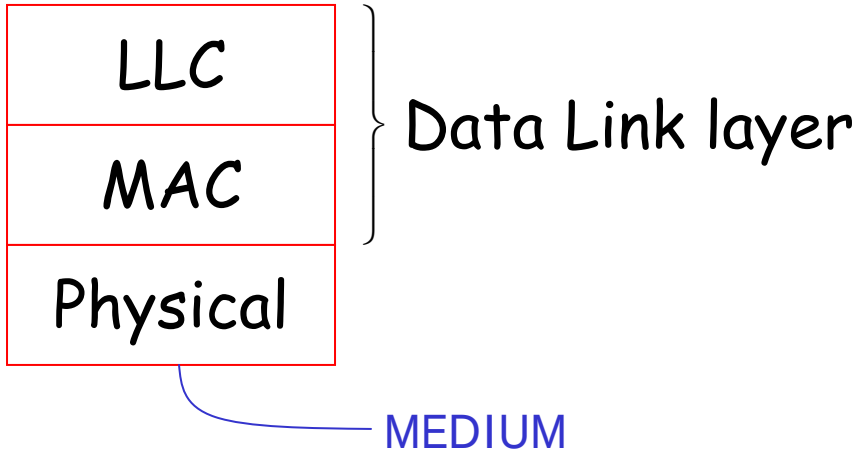
- Implement layers up to Data Link layer.
- Are used to connect segments within a given network.



- Typical functions:
  - **Adaptation** between different conventions used for signalling in Physical layer in different segments.
  - **Filtering** to remove traffic which does not need to cross the bridge to reach destination. (Note: not really routing!)

LAN Technologies

- Differ from WAN technologies especially in the Data Link and Physical layers.
- Data Link layer divided into two sub-layers:
  - Technology-dependent **Medium Access Control** sub-layer.
  - Technology-independent **Logical Link Control** sub-layer, which can be based on various different MAC sub-layers.

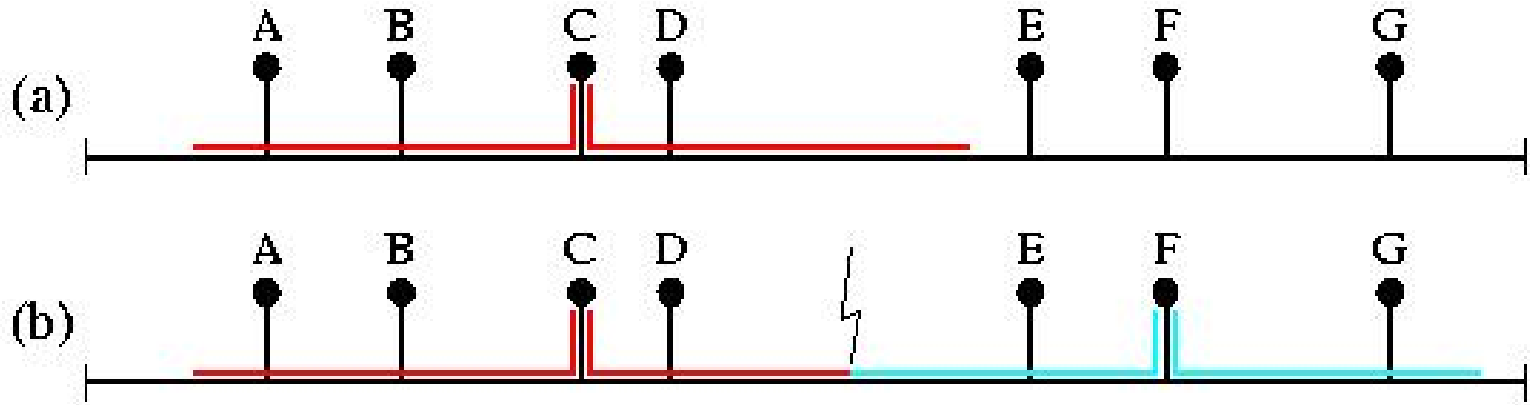


IEEE / ISO LAN MAC Standards

IEEE	ISO	Technology
802.3	8802-3	CSMA/CD (“Ethernet”)
802.4	8802-4	Token Bus
802.5	8802-5	Token Ring
802.6	8802-6	Distributed Queue Dual Bus (DQDB)
802.9	8802-9	Integrated Services (IS) LAN
802.11	8802-11	Wireless LAN
802.12	8802-12	Demand-priority Access
802.15	8802-15	Wireless Personal Area Networks (WPAN)
802.16	8802-16	Fixed Broadband Wireless Access (FBWA)

Contention protocols

- Simple principle for controlling access to medium: Senders compete for access. If medium is free, transmission is OK.
- Typically used on broadcast media (bus, cable, wireless).
- Basic feature of broadcast medium: Signals spread out from sender in all directions.



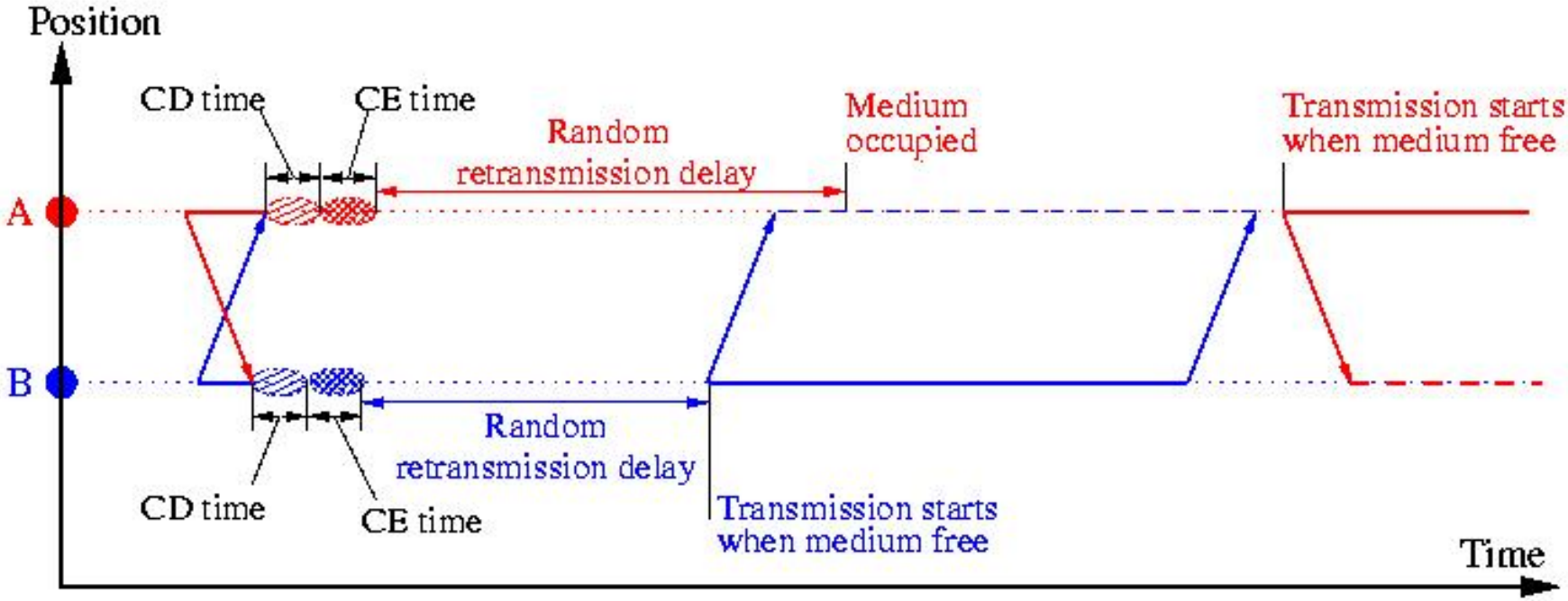
- If several systems send at same time, signals "collide" and messages gets lost.

CSMA/CD

- **Unrestricted contention**, where systems just try to send when they want to, is inefficient: Many collisions ($\Rightarrow$ many retransmissions) occur as traffic intensity rises.
- **CSMA/CD** uses two rules to increase efficiency:
  - **C**arrier **S**ense **M**ultiple **A**ccess: Listen before sending. If medium is occupied, wait a random time before trying again.
  - **C**ollision **D**etect: Listen while sending. If another system is sending at same time, stop transmitting and try again later.
- In IEEE/ISO standardised CSMA/CD, the random waiting time is doubled (on average...) on each retry (Binary Exponential Backoff). This ensures stability as traffic intensity rises.

CSMA/CD (2)

Operation of CSMA/CD when collision occurs:



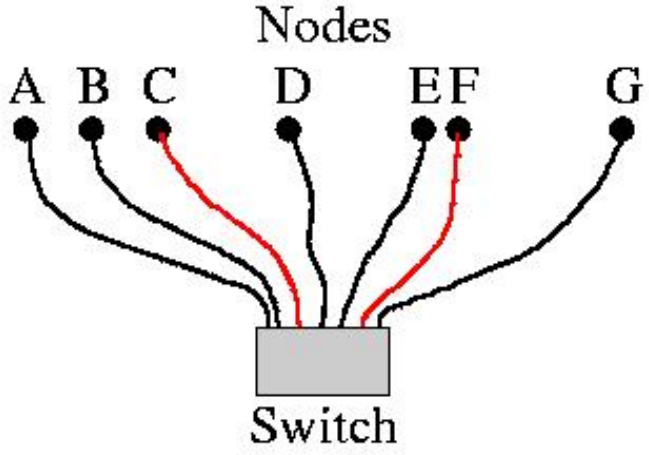
- Collision occurs if several senders find medium free at same time.
- After detection of collision, all systems are informed (CE), and the senders wait a random time before trying again.

CSMA/CD (3)

- For collisions to be detected, transmission of a PDU must last (significantly) longer than the time required for signals to reach the most distant systems. So:
  - **Min. PDU length** (depending on data rate)
  - **Max. physical extent** of medium
- CSMA/CD standards cover several technologies, media and data rates. Important examples:
  - 10 Mbit/s thick coaxial cable (**classic Ethernet**).
  - 10 Mbit/s thin coaxial cable (**thinwire Ethernet**).
  - 10 Mbit/s unshielded twisted pair, UTP-5.
  - 100 Mbit/s unshielded twisted pair, UTP-5 (**fast Ethernet**).
  - 1000 Mbit/s coaxial cable (**gigabit Ethernet**).

Switched Ethernet

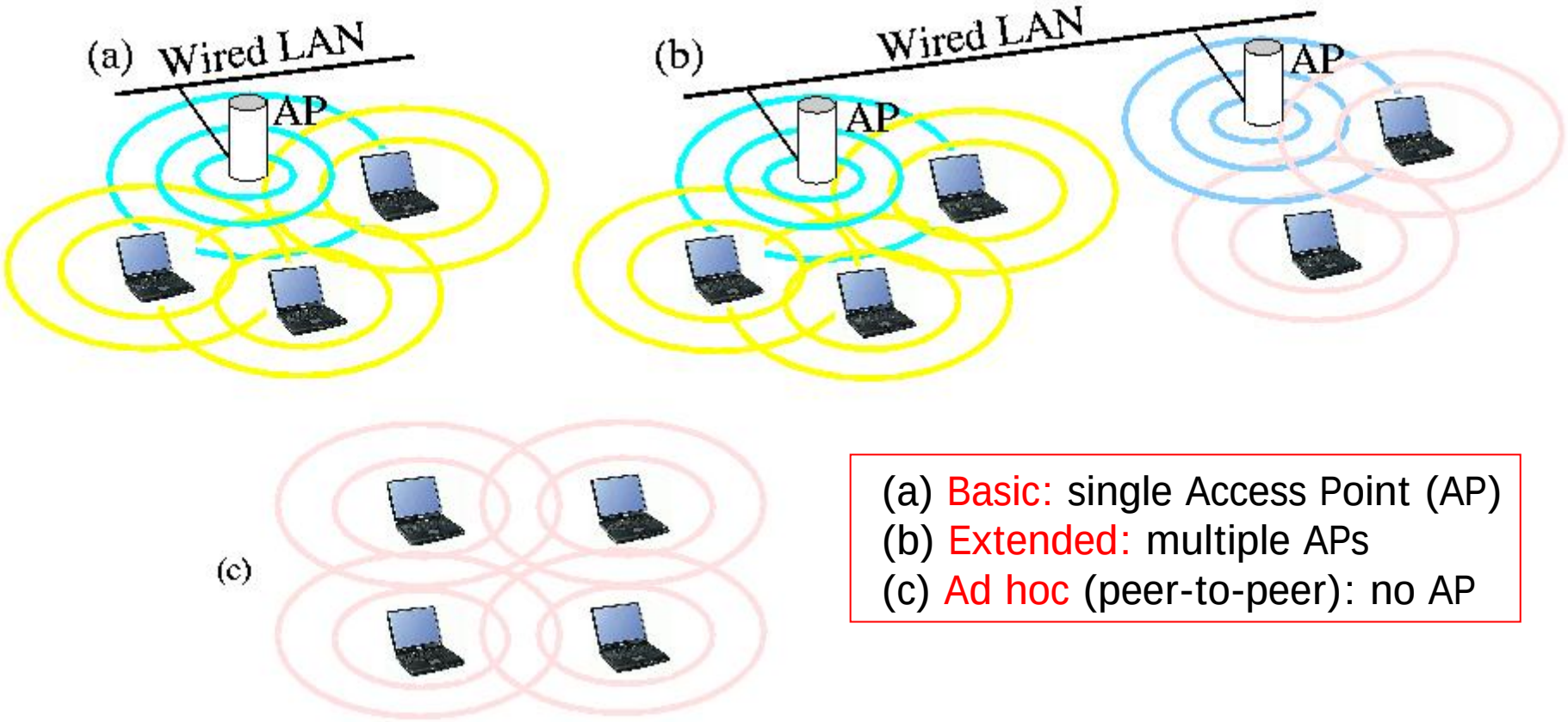
- An alternative to cable-based Ethernet, in which path between sender and receiver is set up dynamically in a switch:



- If path can be set up, full bandwidth of medium is available between the two nodes.
- Contention only for simultaneous transmissions to same destination.

Wireless LAN

- Important new technology, allowing mobility.
- Three basic setups:



(a) Basic: single Access Point (AP)
(b) Extended: multiple APs
(c) Ad hoc (peer-to-peer): no AP

Wireless LAN (2)

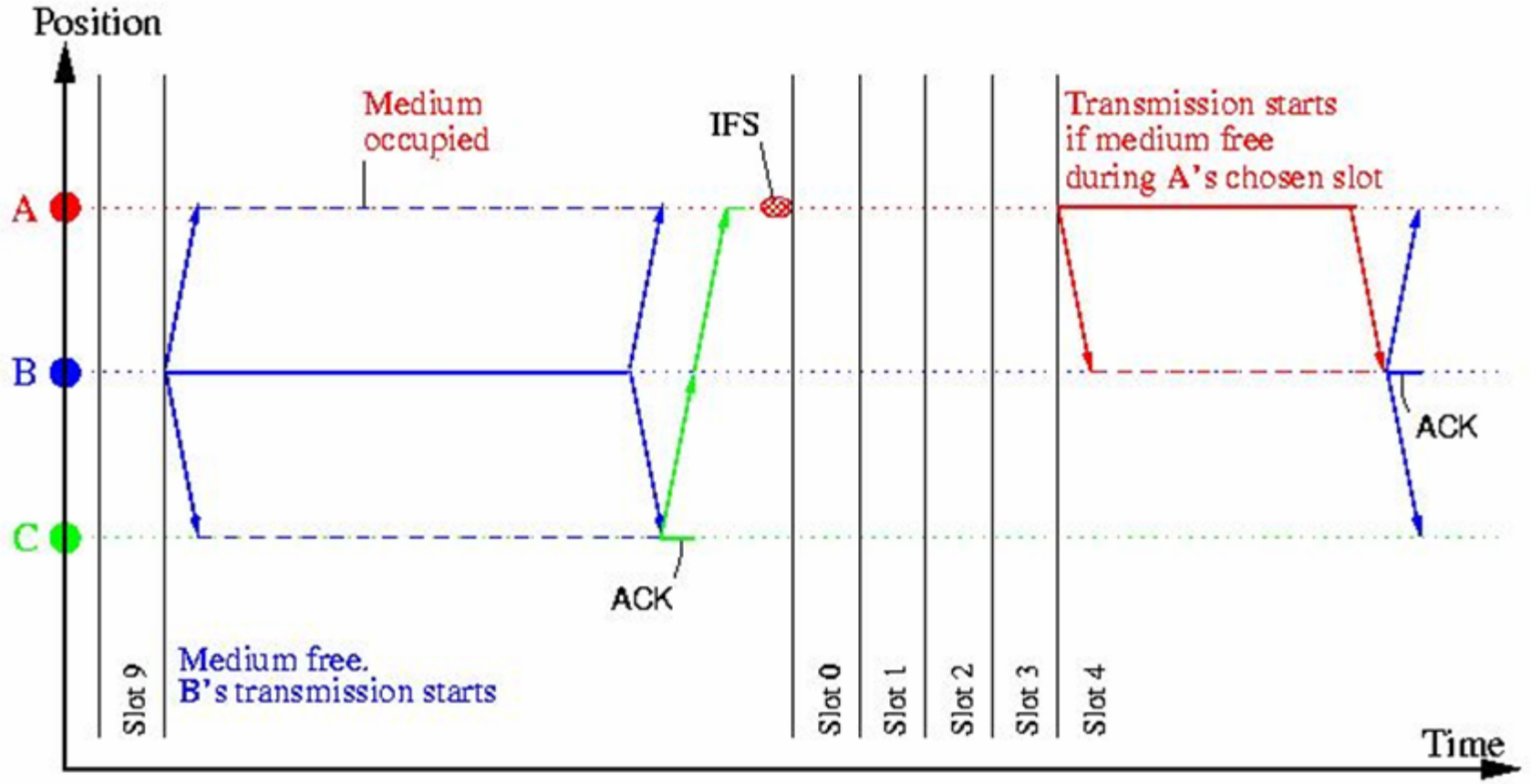
- A large number of standardised technologies, all part of IEEE 802.11 standard:

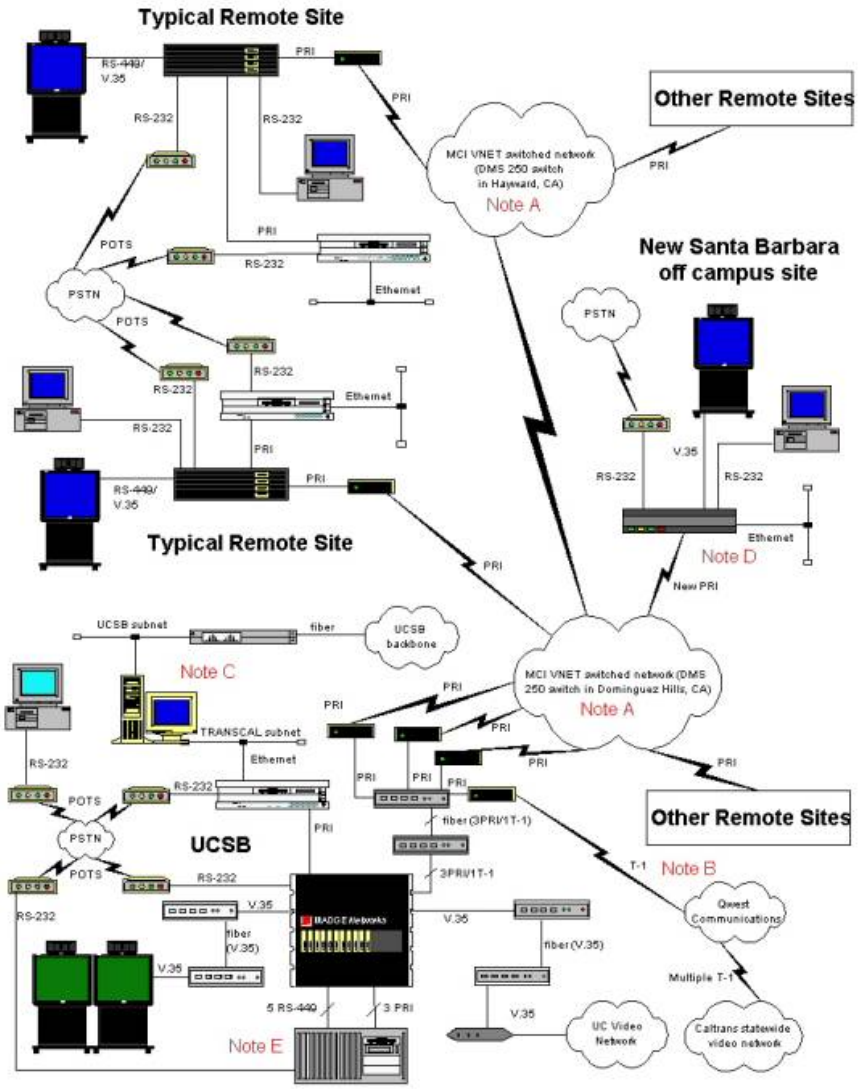
Standard	Physical Layer Technology
802.11	2.4 GHz radio band, 1 or 2Mbit/s data rate
802.11a	5 GHz radio band, up to 54 Mbit/s
802.11b	2.4 GHz radio band, 1, 2, 5.5 or 11 Mbit/s
802.11g	2.4 GHz radio band, 22 or 54 Mbit/s
802.11h	Spectrum management to use 5GHz band in Europe.

- 802.11e describes enhancements to give **QoS**.
- 802.11i describes enhancements to give improved **security**.

CSMA/CA Wireless MAC Protocol

- A contention protocol based on ***CSMA*** together with:
  - ***C***ollision ***A***voidance via reservation slots.
  - ***ACK***nowledgments to check that contention really didn't occur.





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