Real-Time Networks
Layers and impact on QoS

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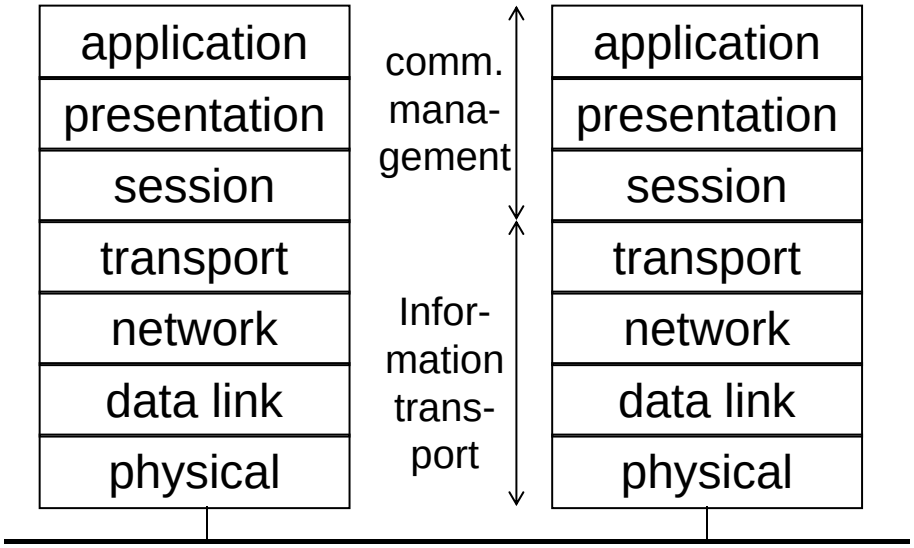
Outline

- ISO Open Systems Interconnection (OSI) model
- Physical layer impact
- Data link layer impact
  - Medium access control
  - Logical link control
- Network and transport layers impact
- Application layer impact
  - Interaction models

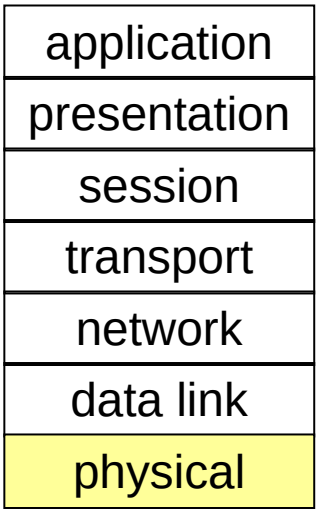
ISO OSI Model

- ISO: International Standards Organization
- OSI: Open System Inteconnection



Physical Layer

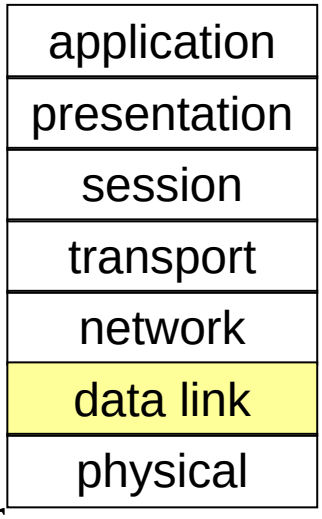
- Transport of bits
- Characteristics
  - Mechanical
  - Electrical (voltages, currents, impedance, baud rate, modulation, bit encoding, synchronisation, etc.)
  - Functional (topology, repeaters, etc.)



Data Link Layer

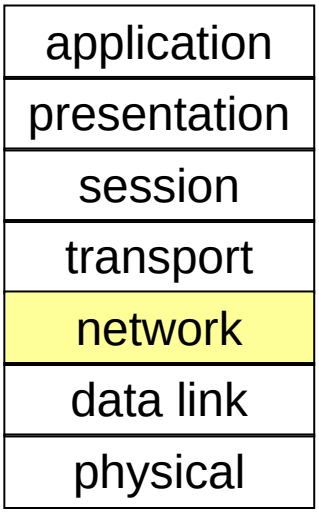
- Groups bits in frames
- Frame synchronization
- Detection (correction) of errors
- Flow control
- Management of access to medium

- Is often dependent on the physical layer



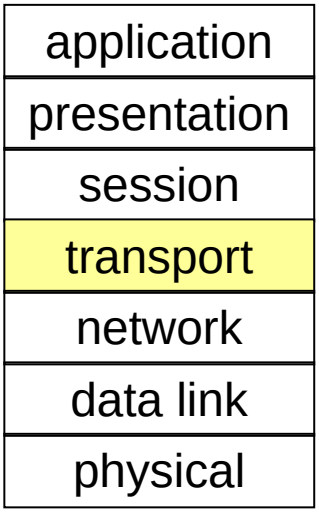
Network layer

- Routing of packets across links
- Flow congestion / control
- Gives a unique address over the network



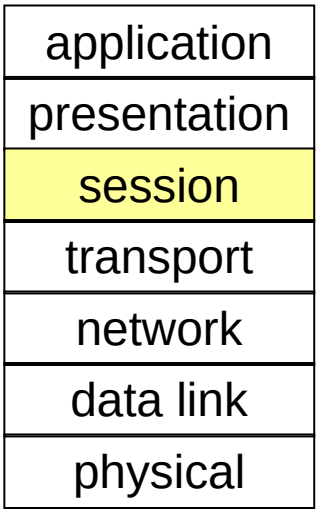
Transport layer

- End to end reliable and transparent transport of information on a network
  - Checking and correcting errors
  - Flow regulation
- Establishment (release) of virtual circuits
- Multiplexing of virtual circuits



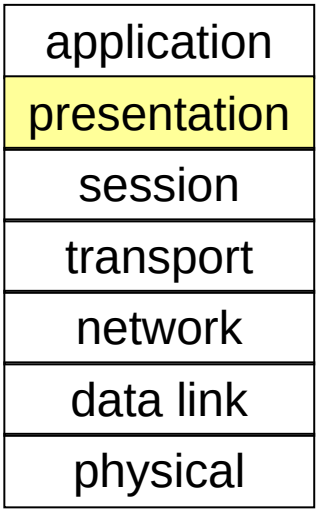
Session layer

- Management of dialog
  - Definition of synchronization points
  - Return to known state



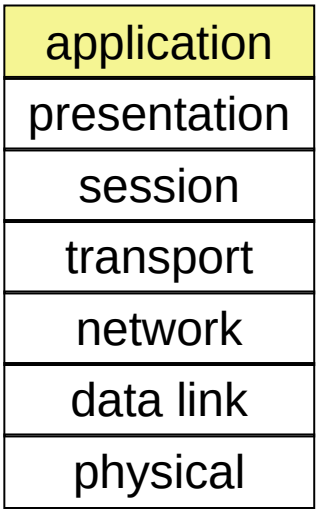
Presentation layer

- Format conversion
  - To and from transfer syntax
- Ciphering
- Data compression



Application layer

- The only one visible to the application
- Add semantics to the information transfers
  - Defines concepts
  - Provides services
- Ex. FTP, SNMP, HTTP



Interconnections

- Repeaters
  - physical layer
- Bridges
  - data link layer
- Routers
  - network layer
- Gateways
  - application layer

See [Perlman, 2000]

Repeaters

- Used when the protocols on all layers are identical on both sides
- Connect two data circuits
- Expand the distance covered by (or the number of devices connected to) a data link whether wireless or wired.
- Regenerate the signals received on one side and transmit them on the other side and vice-versa.
- On some occasions, may also be used to interconnect a wireless cell to a wired link
  - Word repeaters
- Ethernet hubs are an example of repeaters.

Bridges

- Interconnect subnetworks using the same layer protocols above the data link layer
- Interconnect data links
- Both sides must also use compatible addressing information
- Examples:
  - IEEE 802.11 base stations interconnect an Ethernet based link and a wireless cell.
  - an Ethernet switch is used to interconnect two or more Ethernet links.

Routers

- Operate at the network layer level
- Their task is to find a route to convey a message from a source to a destination
  - Exchange information between themselves in order to find such a route
  - Can thus find an optimum path between two nodes
    - whereas bridges only use a subset of the available topology.
- Difference with bridges
  - Bridges are transparent, routers are not
  - Routers modify the packets they forward in particular their address fields

Gateways

- Used when the protocols at the application layer are different on both sides
- Translate the messages from one protocol to the other one.
- Examples:
  - Connecting a Profibus or a CAN Open network to the Internet using HTTP over TCP/IP, requires a gateway because the protocols are different at all layers.
- Sometimes called “proxies”

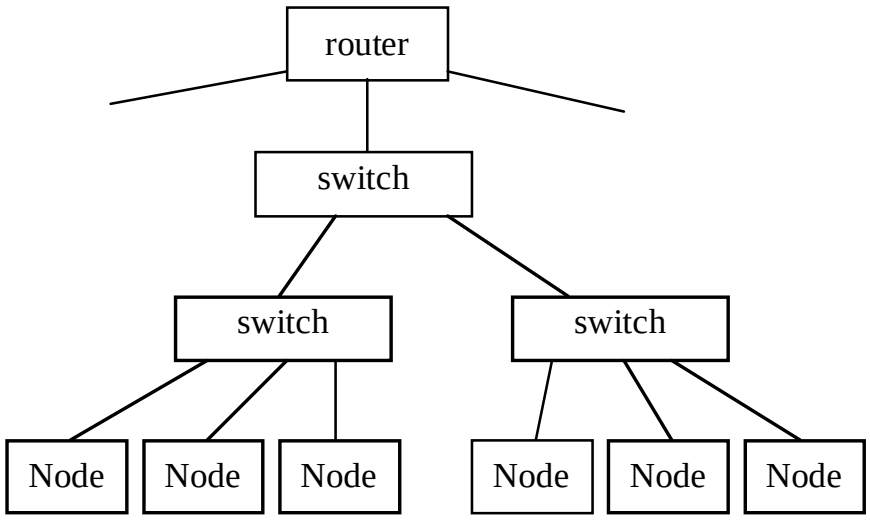
Impact of layers on QoS

- Observable properties of the network
  - Transfer delay bounds
  - Transfer delay variations (jitter)
  - Throughput
- All layers have an impact but some more than others

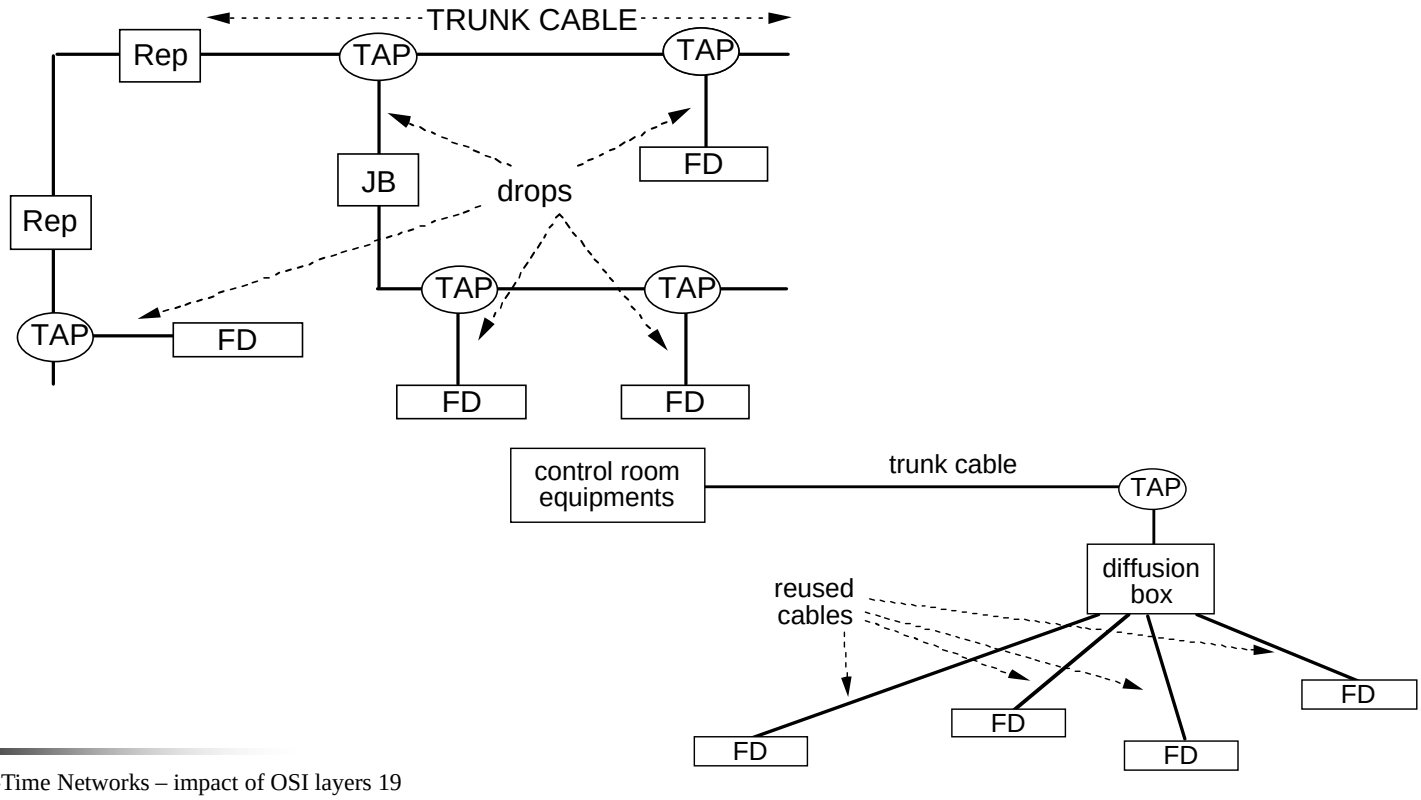
Physical layer

- Topology and physical limitations
  - How many nodes may be reached in one hop ?
- Bit rate (not Baud rate)
- Signal to noise ratio
  - Bit error rate
- Resilience to interferences
  - Bit error rate
  - Bursts of errors on bits

Topologies in offices



Topologies in factories



Medium Access Control

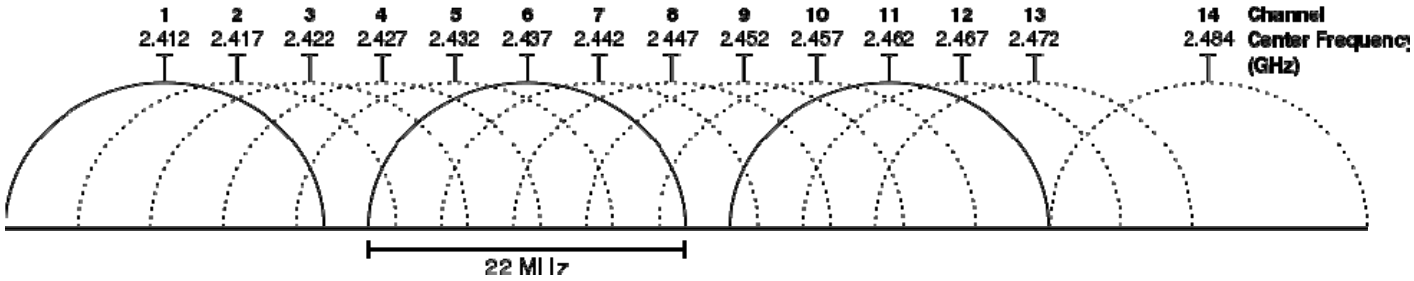
- Access mechanism
  - May be influenced by priorities
- Error detection scheme
  - Performance of error detection
- Error correction scheme
  - Automatic Repeat reQuest (stop and wait, selective repeat, Go back N)
  - FEC
  - Hybrid FEC-ARQ
- Packet delimitation
  - Packet error rate

Access mechanism

- How to isolate the emissions from different sources
- 3 basic choices
  - Use different frequency bands
    - Frequency Division Multiple Access (FDMA)
  - Emit at different instants
    - Time Division Multiple Access (TDMA)
  - Use a combination of both
    - Code Division Multiple Access (CDMA)
      - CDMA is also used to spread the spectrum of emission

FDMA

- Different transmitters use different channels
  - There is often some overlap between adjacent channels
    - Example: 802.11 (14 channels, but no more than 4 at any given place)



- Hardly used in wired LANs
- Hopping used in some WLANs to mitigate interferences (for instance DECT, wirelessHART)

TDMA

- All nodes use the same frequency but at different instants
- Some temporal synchronisation is thus required
- Advantages
  - The bandwidth can be adapted according to the emitter
  - It is possible to power off the emitter in absence of emission
- Drawbacks
  - Additional load due to synchronisation
  - More problems (than with CDMA) with multiple paths

CDMA

- Separation in time and frequency
- Two principles
  - Direct sequence: each bit is converted into a sequence of chips
  - Frequency hopping: each transmission is performed at a different carrier frequency (used in Bluetooth, Wireless HART and ISA100.11a)
- Advantages
  - Difficult to spy, rather insensitive to perturbations, no need for synchronisation, cells may use the same frequency band
- Drawbacks
  - Complex, requires control of emission power, requires a large frequency band

FDD and TDD

- 2 ways to handle full duplex operations
  - FDD (Frequency Division Duplexing)
    - Each direction uses a different band
  - TDD (Time Division Duplexing)
    - Both directions use the same band but at different instants

TDMA

- Predetermined
  - Each node has one (or more) slots in time
  - Usually called “TDMA” or “pure TDMA”
- Centralised access control
  - Polling, probing
- Decentralised techniques
- Reservation

Centralised access

- One master station / N slave stations
  - A slave station may only transmit as a response to the master station
- Advantages
  - Simple, the master is the unique point of coordination
  - Easy to adapt polling to slaves needs
  - Worst case polling time can be calculated
    - Good point for real-time applications
- Drawbacks
  - The master is a hot point for reliability
  - The master is used in each transfer -> additional delays
  - Not very efficient when few slaves are active (or numerous slaves)
    - Can be improved by probing

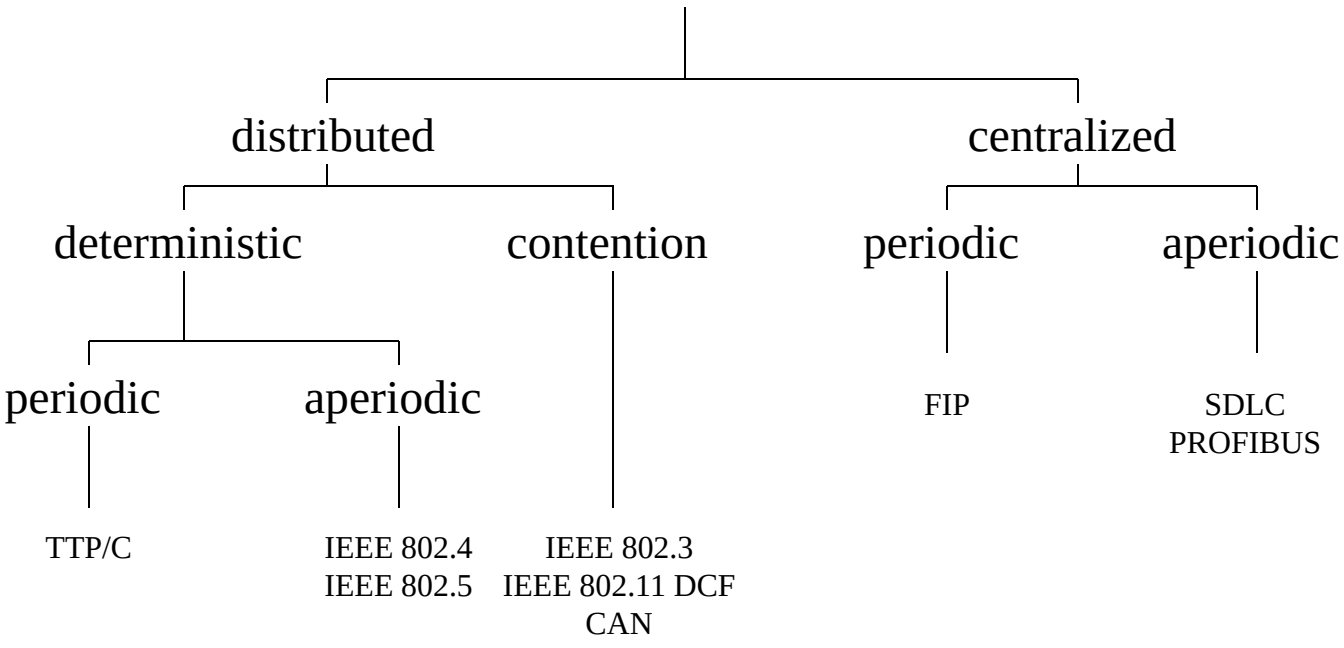
Distributed access

- Appealing as compared to centralized techniques
  - More reliable
  - Access delays often shorter
  - Better use of the bandwidth
  - No need for planning (i.e. in case of multiple wireless cells)
- drawbacks
  - Often more complex
  - Not always easy to predict temporal properties

Distributed access techniques

- Static (predetermined)
- Distributed probing
- ALOHA
- Carrier Sense Multiple Access (CSMA)
- Ethernet
- CSMA/CA
- Token bus
- Token ring

Classification of some solutions



Reservation

- When a node wants to transmit (for a long period)
  - Gets access and signals its request
  - Request is granted and resources are allocated
    - Resources may be slots or medium for a given duration
  - When the node no longer needs the resources, it releases them (may be automatic)
- There is no conflict on the resource use
- There might conflicts in the requests

- Widely used technique (cellular phones, 802.11, …)
- Interesting from the QoS perspective

Logical Link Control

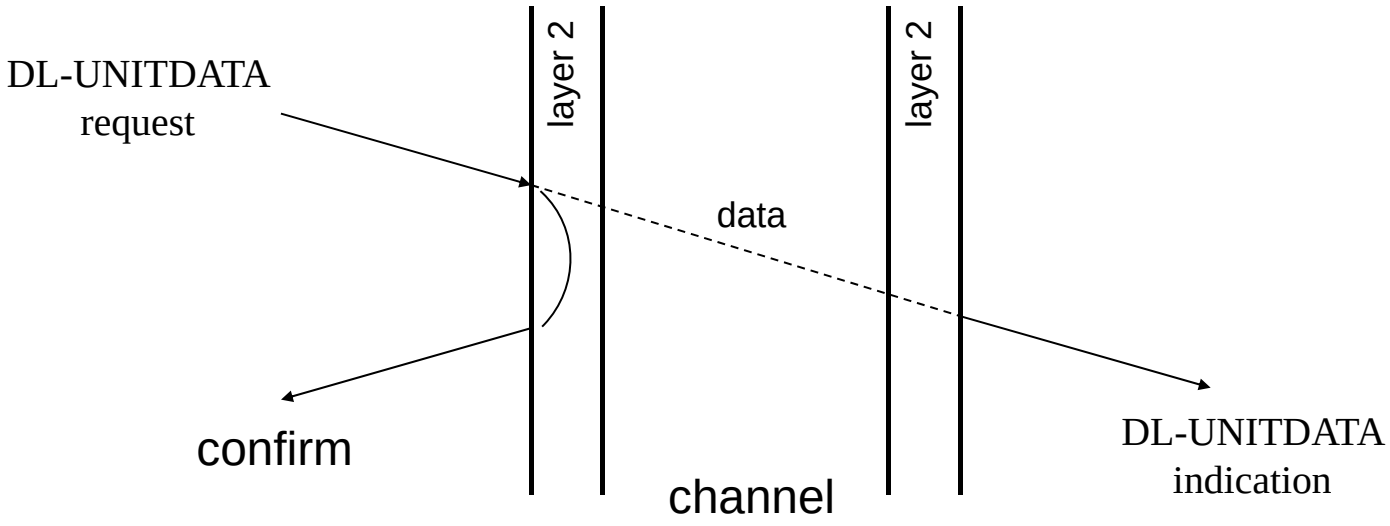
- Connectionless services
  - QoS: priority
  - SDN (Send Data with No ack)
    - Unacknowledged connectionless-mode data transfer
      - DL-UNITDATA request - DL-UNITDATA indication
  - SDA (Send Data with Ack)
    - Acknowledged connectionless-mode data unit transmission service
      - DL-DATA-ACK request, DL-DATA-ACK indication, DL-DATA-ACK-STATUS indication
  - RDR (Request Data with Reply) or SDR (Send Data with Reply)
    - Acknowledged connectionless-mode data unit exchange service
      - DL-REPLY request - DL-REPLY indication - DL-REPLY-STATUS indication
      - DL-REPLY-UPDATE request DL-REPLY-UPDATE-STATUS indication

Logical Link Control (2)

- Connection oriented service
  - QoS: priority
  - Connection establishment
    - DL-CONNECT request - DL-CONNECT indication - DL-CONNECT response - DL-CONNECT confirm
  - Data transfer
    - DL-DATA request -- DL-DATA indication
  - Termination
    - DL-DISCONNECT request -- DL-DISCONNECT indication
  - Reset
    - DL-RESET request -- DL-RESET indication -- DL-RESET response -- DL-RESET confirm
  - Flow control
    - DL-CONNECTION-FLOWCONTROL request - DL-CONNECTION-FLOWCONTROL indication (parameter: amount of data allowed)

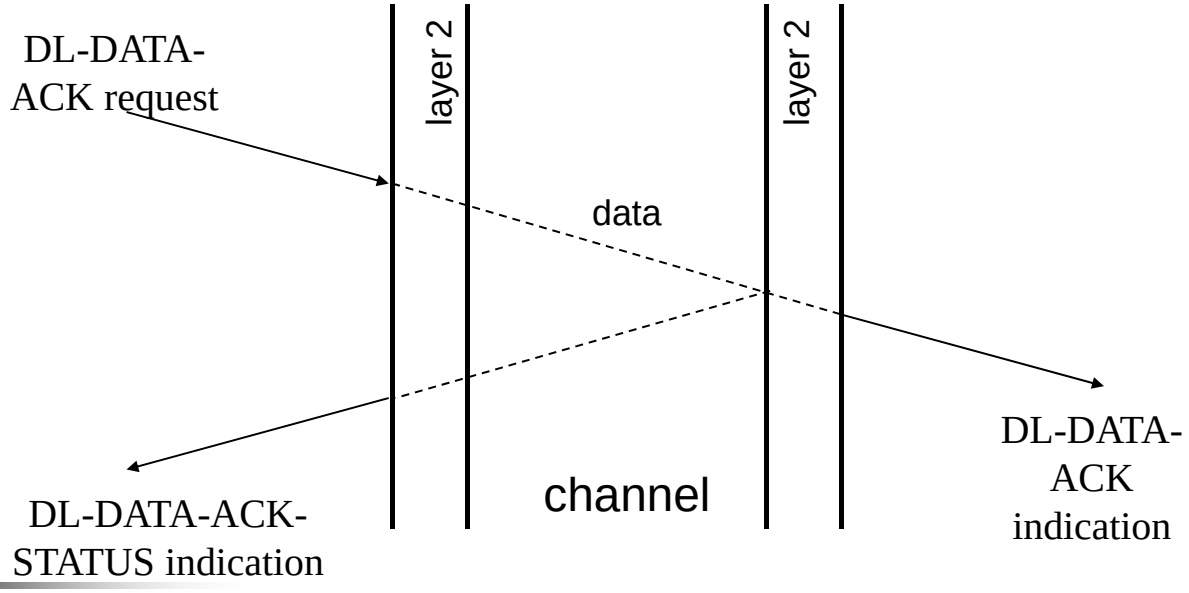
Send Data No acknowledge (SDN)

- No temporal problem (except access control)
- Possible response is separated (adds time)
- May be used to synchronise (multicast or broadcast)



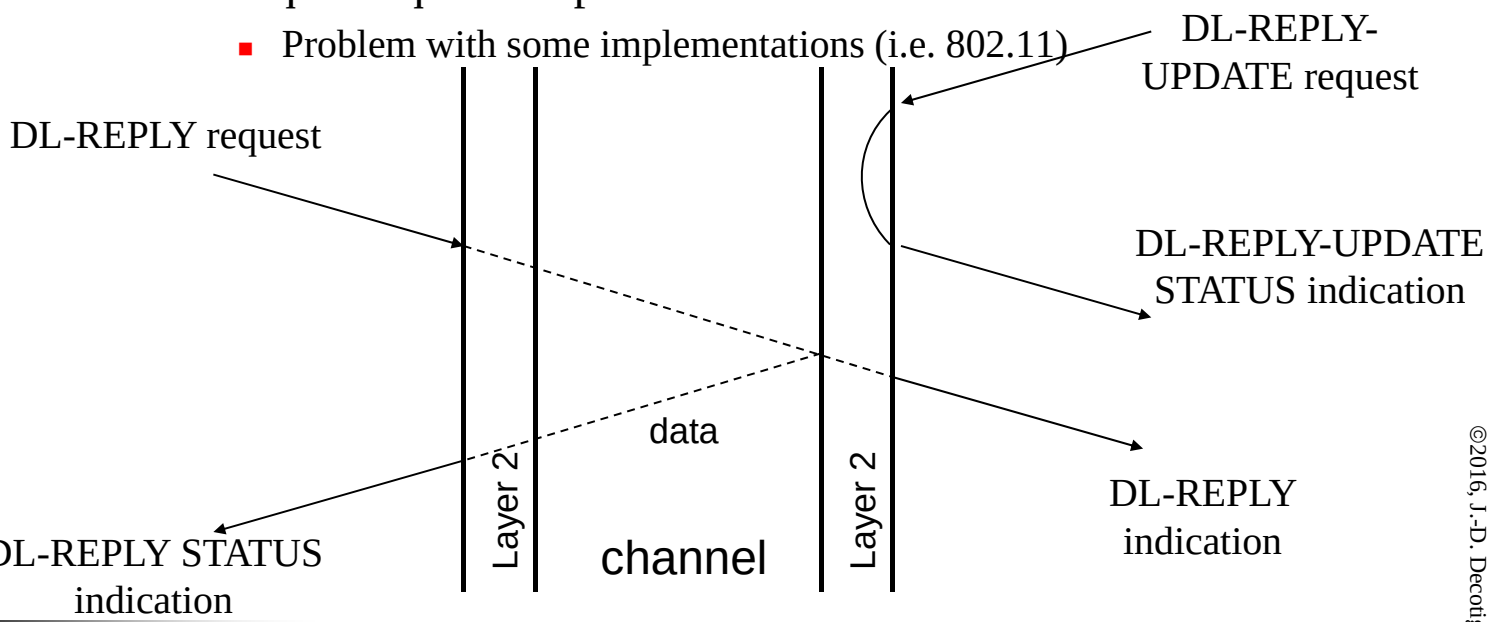
Send Data with Ack. (SDA)

- No temporal problem (except access control)
- Possible response is separated (adds time)



Request Data with Response (RDR)

- Good to decouple requester from provider applications
- Requires quick response
  - Problem with some implementations (i.e. 802.11)



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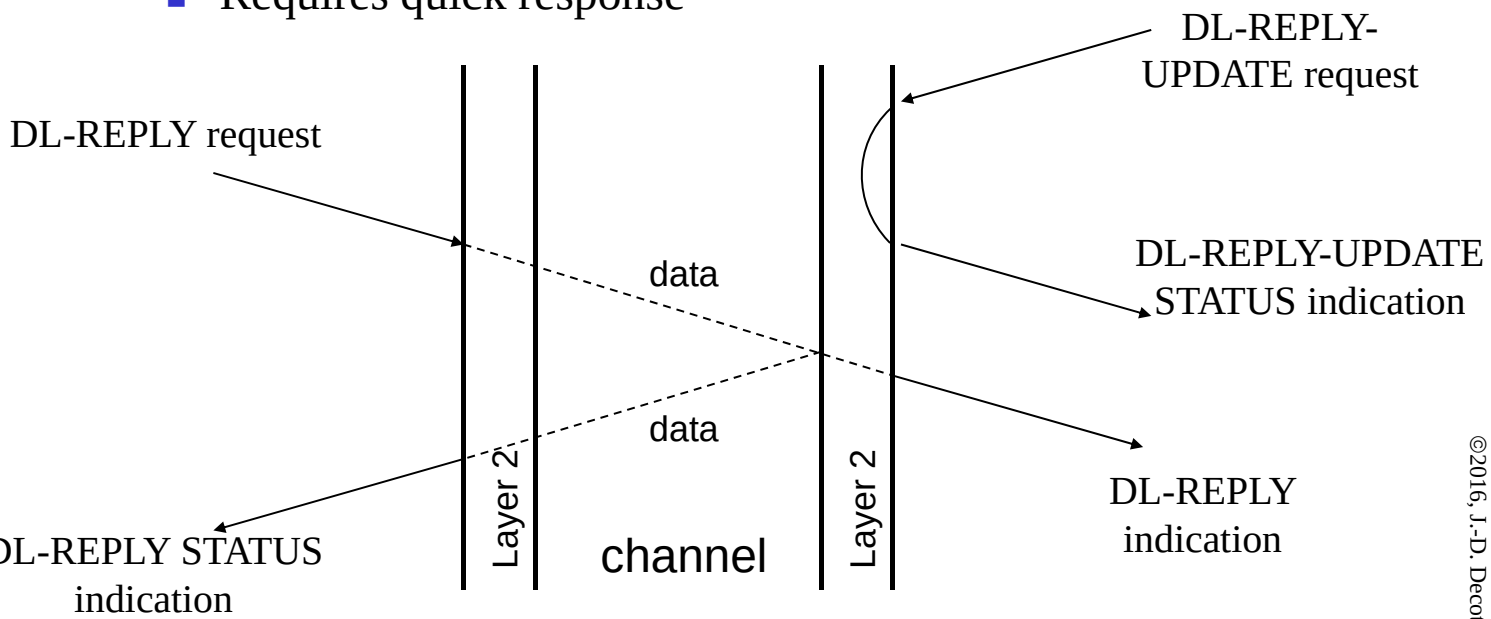

Network Layer

- QoS negotiation and admission control
- Resource reservation
- Packet buffering and scheduling
- Resource management
- Routing table management
  - See [Pragyansmita]
- Metrics
  - Bandwidth, delay, delay variation (jitter)

Network Layer (2)

- Enabling QoS routing of data
  - Consider various metrics to select the best route
  - Provide a fair bandwidth to non QoS flows
  - Graceful performance degradation
- Approaches
  - Statefull: manage per flow state & perform per flow operations
    - Intserv + RSVP
  - Stateless:
    - DiffServ (different behavior between core and edge routers)

Transport Layer

- Connection establishment and release
- Flow control mechanisms
- Error control mechanisms

ISO transport layer QoS parameters

- Connection establishment delay: max. acceptable time between a transport connection being requested and its confirmation being received by the user
- Connection establishment failure probability: probability that a connection cannot be established within the max. delay Connection release delay: max. acceptable delay between a user initiating release of a connection and actual release at peer user
- Throughput: number of bytes of user data sent per unit of time
- Transit delay: elapsed time between submission and delivery
- Residual error rate: ratio of incorrect, lost and duplicate TSDUs to the total number sent
- Transfer failure probability: ratio of total transfer failures to total transfer samples during a given window

ISO transport layer QoS parameters

- Connection Release Failure Probability: fraction of connection release attempts that did not complete within the connection release delay interval (as agreed)
- Protection: used by the user sender to specify interest in having the transport protocol provide protection against unauthorized third parties reading or modifying the transmitted data.
- Priority: used to specify the relative importance of transport connections. In case of congestions or the need to recover resources, lower-priority connections are degraded or terminated before higher-priority ones.
- Resilience: probability that the transport protocol will spontaneously terminate a connection due to internal or network problems [Iren 99]

Session and Presentation Layers

- Session layer
  - Check points
    - Frequency of check pointing impact time lost for recovery
- Presentation layer
  - Compression
  - Transfer syntax compactness

Application Layer

- Interaction model [Thomesse 93]
  - Client-server
    - Need to wait until server responds
  - Publish-subscribe
    - Temporal decoupling between the publisher and the user
  - Producer-consumer

References

- R. Perlman, “Interconnections – bridges and routers”, 2nd edition, Addison Wesley, Reading, 2000
- S. Iren et al., “The transport layer: tutorial and survey”, ACM Computing Surveys, vol. 31, no. 4, pp. 360-404., Dec. 1999.
- J.-P. Thomesse, “Time and industrial local area networks”, in Proc. of 7th COMPEURO'93, Paris-Evry, France, May 24-27, 1993, pp. 365-374.
- ISO/IEC 7498:1: 1996. Information Processing Systems - Open systems interconnection - Basic reference model : the Basic model
- ISO/IEC 8802.2: 1998. Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements. Part 2: Logical link control

References (2)

- Pragyansmita Paul and S.V.Raghavan, “survey on QoS Routing”, 15th International Conference on Computer Communications, August 12-14, 2002, Mumbai.
- M. El-Gendy, A. Bose, K. Shin, “Evolution of the Internet QoS and Support for Soft Real-Time Applications”, proc. of the IEEE, vol. 91 (7), July 2003, pp. 1086-1104.
- ISO/IEC 15802-3: 1998, ANSI/IEEE Std 802.1D, 1998 , Information technology - telecommunications and information exchange between systems – local and metropolitan area networks - common specifications. Part 3: Media Access Control (MAC) bridges, 10 Dec. 1998