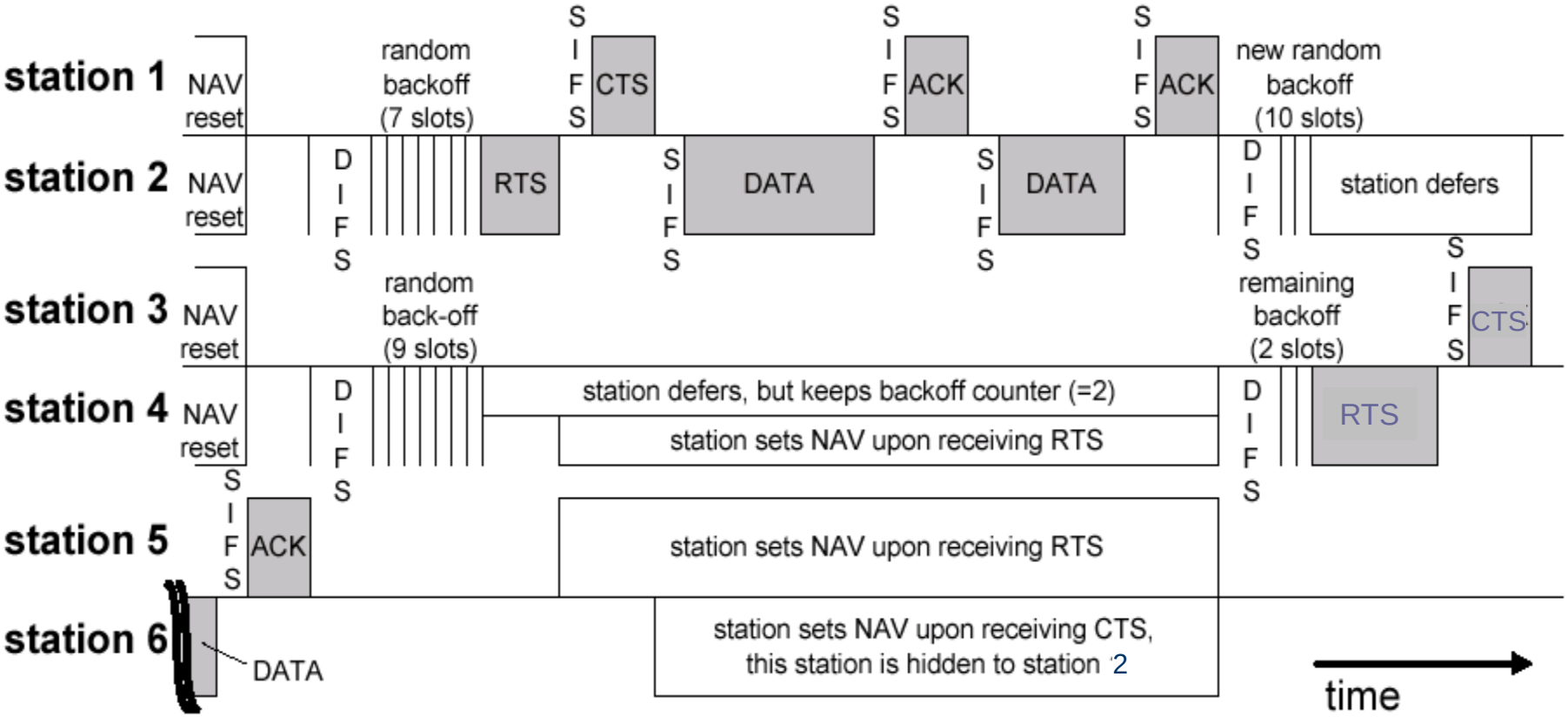
The IEEE 802.11 family of standards

continued

Example of DCF transmission



CW doubles after each collision

- Initial CW -> 3 (backoff 0-3)
- CW after Collision 1 → 7 (backoff 0-7)
- CW after Collision 2 → 15 (backoff 0-15)
- CW after Collision 3 → 31 (backoff 0-31)
- CW after Collision 4 → 63 (backoff 0-63)

How the Contention Window works

- Whenever a backoff occurs the backoff time is uniformly chosen in the range $[0, W-1]$
- After each unsuccessful transmission the backoff windows size is doubled, up to a maximum value
- Once the backoff window size reaches its maximum value it will stay at that value until it is reset
- The value of W will be reset after every successful transmission of a data or RTS packet, or when a retry counter reaches its limit

Exponential Backoff

- Initial value of CW is CWmin
- For each collision, double the contention window CW
- Maximum value of CW is CWmax
- After successful transmission set contention window to CWmin

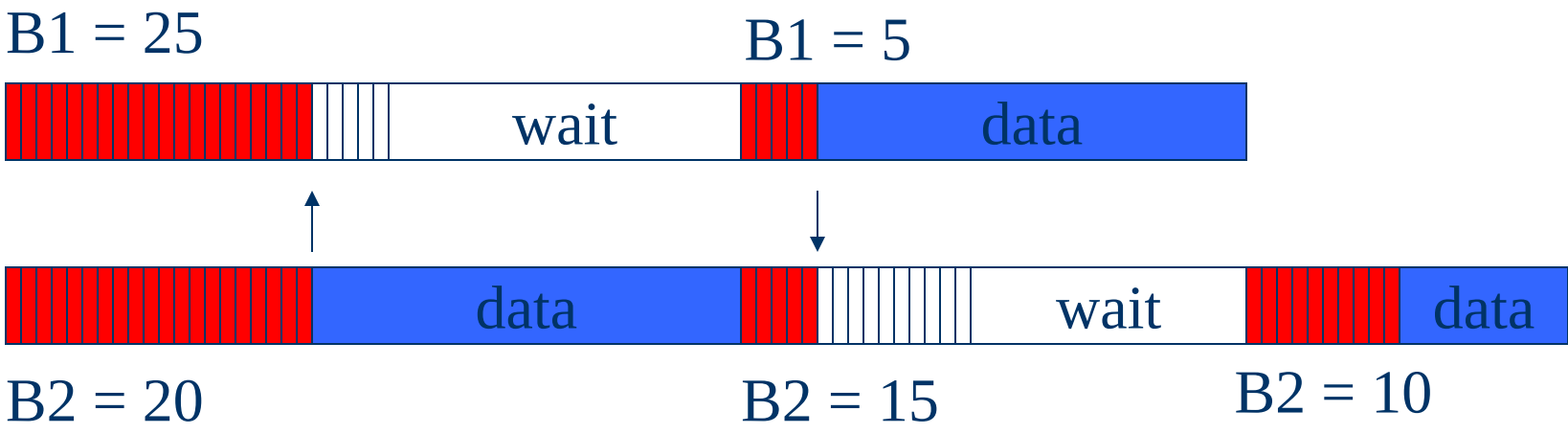
Collision Avoidance

- Collision avoidance mechanism: When transmitting a packet, choose a backoff interval in the range [0,cw]
  - cw is contention window

- Count down the backoff interval when medium is idle
- When backoff interval reaches 0, transmit

Collision Avoidance: Example

Timer decremented only in **RED periods**



cw = 31

B1 and B2 are backoff intervals at nodes 1 and 2

Disadvantages of DCF

- Unpredictable collision number
- Unpredictable delay of successful transmission
- Unpredictable throughput
- Uncontrolled selection of station to transmit

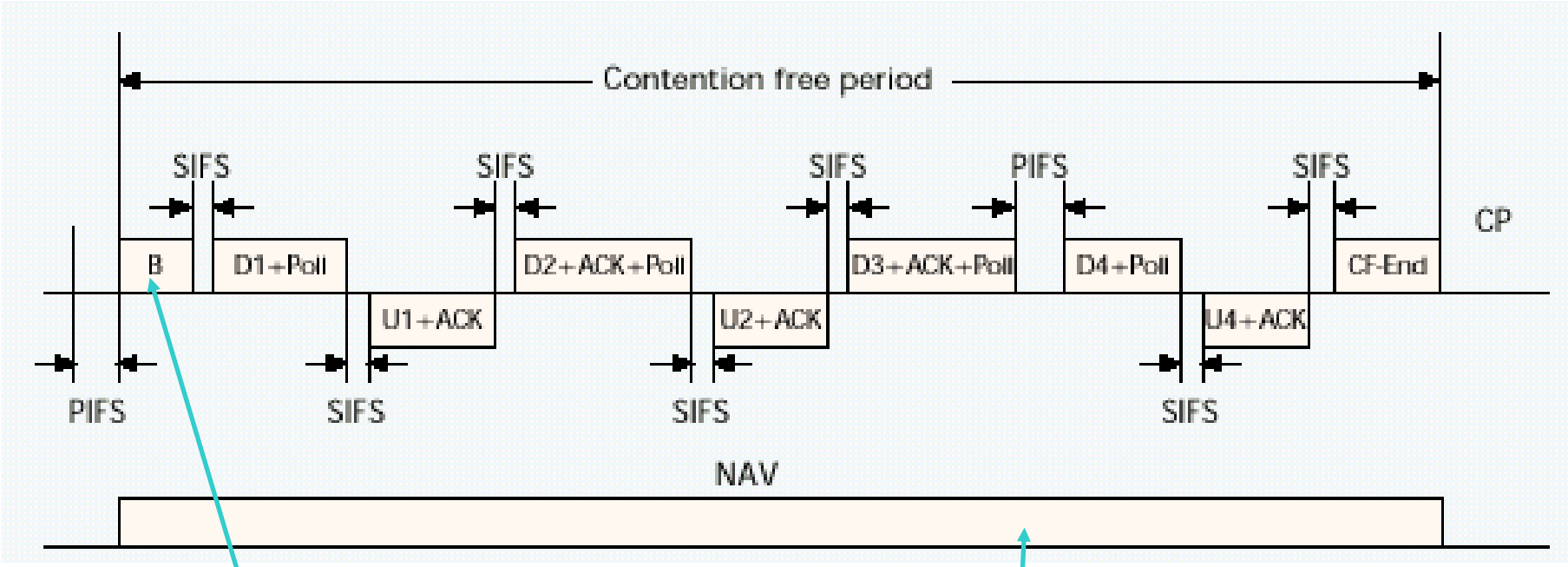
And one advantage:

- Low transmission delay and good performance for low traffic

Point Coordination Function (I)

- ✓ Activated by the AP whenever it decides to switch to contention-free period (e.g. when it observes large number of collisions)
- ✓ As a general rule, DCF for low traffic, PCF for high traffic
- ✓ In this mode the AP is referred to as Point Coordinator
- ✓ It has priority compared to DCF because it is activated for idle period PIFS<DIFS

Point Coordination Function (II)

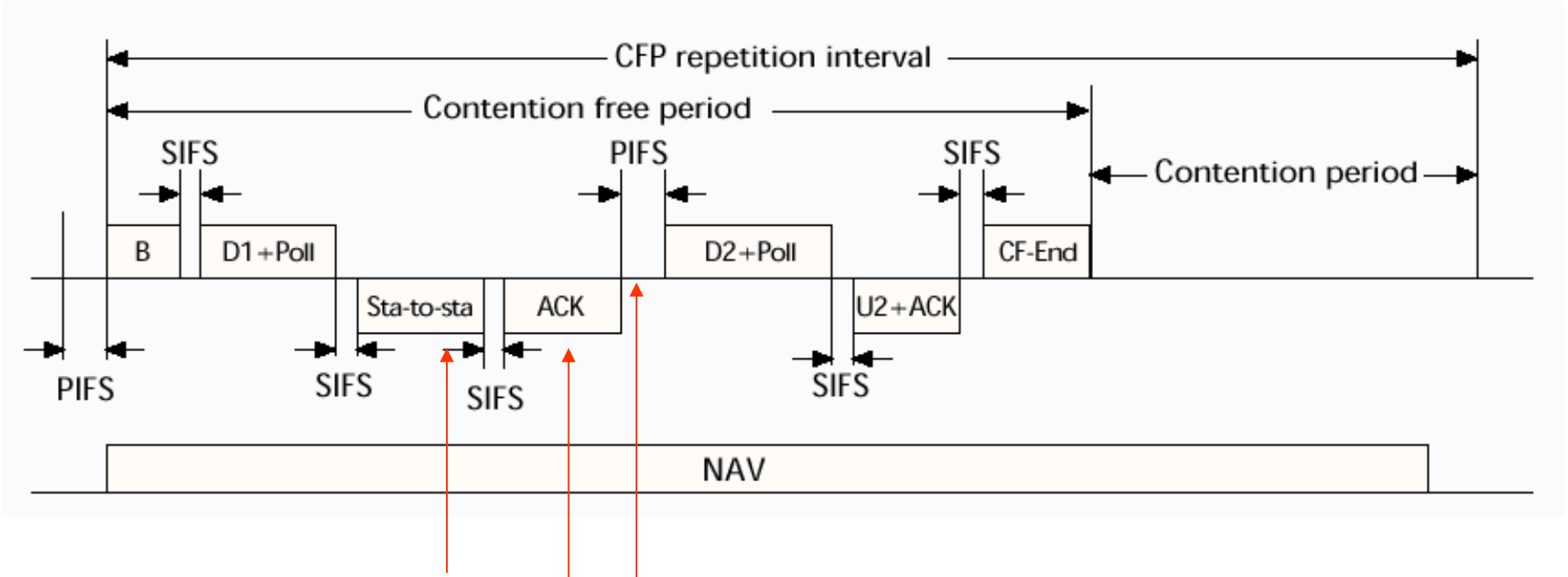


Synchronization beacon

Variable duration of
Contention Free Period

Point Coordination Function (III)

If a Station wants to transmit to another station during a CFP (contention-free period)



- When it is time to transmit, a STA chooses to transmit to aniother STA in the same BSS
- When the other STA receives data, replies with DCF Ack to the first STA
- AP waits for time equal to PIFS before continuing to the next STA (why?)

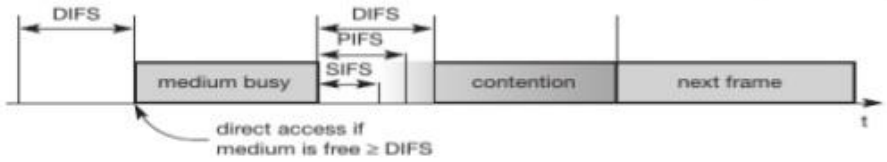
Main restrictions of PCF regarding QoS

- ✓ Terminals cannot send their requirements to AP
- ✓ AP has no way to interrupt an ongoing transmission to send the synchronization beacon* and pass to PCF mode
- ✓ Poll does not set the time the channel is given to a STA, which means that the STA can keep the channel for the maximum allowed time*

* Maximum packet (MPDU) allowed 4095 bytes = 32760 bits = 32,76 msec (for a 1Mbps channel)

Inter-Frame Spaces

Medium Access and Inter-frame Spacing



DIFS - 34 µsec
PIFS - 25 µsec
SIFS - 16 µsec

- **Short inter-frame spacing (SIFS)** – shortest waiting for medium access (highest priority) ex. Control msg.
- **PCF inter-frame spacing (PIFS)** – used for time bounded services.
- **DCF inter-frame spacing (DCF)** – longest waiting time and has the lowest priority for medium access.

[Contention – duration in which several nodes try to access the medium]

- Inter frame spacing required for MAC protocol traffic
  - SIFS = Short interframe space
  - PIFS = PCF interframe space
  - DIFS = DCF interframe space
- Back-off timer expressed in terms of number of time slots

IEEE 802.11e
Quality of Service in 802.11

Best Effort vs. QoS

- Best Effort:
  - You get a link to the Internet with at most B bits/sec.
  - If you don't like it, switch to another provider.
- Quality of Service (QoS)
  - We provide you some kind of guarantees for:
    - Bandwidth
    - Latency
    - Jitter
  - I.e., network is engineered to provide some Quality beyond "Not to exceed B bits/s"

Two Styles of QoS

- Worse-case
  - Provide bandwidth/delay/jitter guarantee to every packet
  - E.g., “hard real time”
- Average-case
  - Provide bandwidth/delay/jitter guarantee over many packets
  - Statistical in nature
  - E.g. “Soft real time”

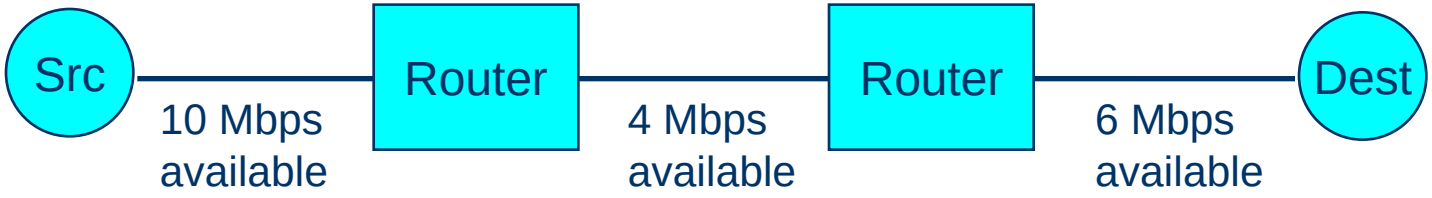
Worse-case : Guaranteed Services

- Service contract
  - Network to client: guarantee a deterministic upper bound on delay for each packet in a session
  - Client to network: the session does not send more than it specifies
- Algorithm support
  - Admission control based on worst-case analysis
  - Per flow classification/scheduling at routers

Average-case: Controlled Load Service

- Service contract:
  - Network to client: Average delay, jitter, bandwidth, e.g., makes network appear as an unloaded, best effort network with bandwidth and delay
  - Client to network: the session does not send more than it specifies **on the average**
- Algorithm Support
  - Admission control based on measurement of aggregates
  - Scheduling for aggregate possible

Resource Reservation: Example



Case 1: Source attempts to connect to destination, and attempts to reserve 4 Mbps for the connection

Result: Connection accepted. There is enough bandwidth available. Available link bandwidths updated.

Case 2: Source attempts to connect to destination, and attempts to reserve 5 Mbps for the connection

Result: Failure. There is not enough bandwidth available on one of the links.

Resource Reservation *(cont'd)*

- Once a connection is accepted, the host must use only the amount of resources reserved. It may not use more than that.
- What if the host is malicious and attempts to use more network resources than it reserved?

What QoS means

- Quality of Service – QoS: The «efficient» data transmission resulting «satisfactory» operation of a network application as it is perceived by the user
- What «satisfactory» operations means? Usually subjective and depends on the user preferences, and specific needs
- What «efficient» transmission means? Is the data transmission that satisfies specific quality of service parameters, extracted based on the «efficient» operation of a network application
- Typical QoS parameters:
    - mean end-to-end delay
    - maximum end-to-end delay
    - maximum delay jitter
    - mean packet error rate

Why Quality of Service (QoS)?

- Definition:
  QoS is the concept for specifying how “good” the offered services are.
- Concept:

- Quality of service is a concept based on the statement that not all applications need the same performance from the system/network over which they run.
- Thus, applications may indicate their specific requirements to the network, including cost, before they actually start transmitting data.

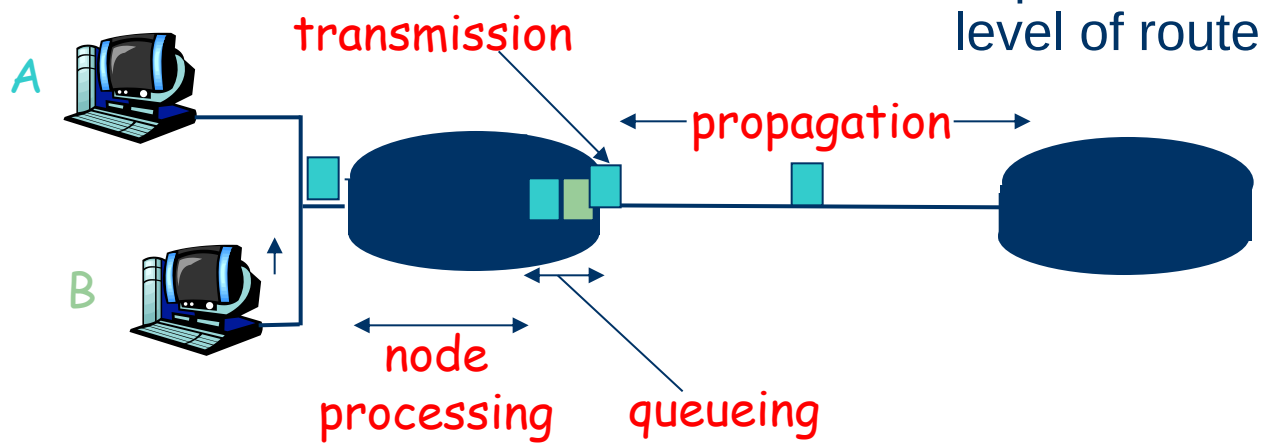
Major Parameters Defining QoS

- Throughput – the total amount of work completed during a specific time interval.
- Delay – the elapsed time from when a request is first submitted to when the desired result is produced.
- Jitter – the delays that occur during playback of a stream.
- Reliability – how errors are handled during transmission and processing of continuous media.

Delay in packet-switched networks (1)

Packets experience delay on end-to-end path

- four sources of delay at each hop:
  - node processing:
    - check bit errors
    - determine output link
  - queuing
    - time waiting at output link for transmission
    - depends on congestion level of router



Delay in packet-switched networks (2)

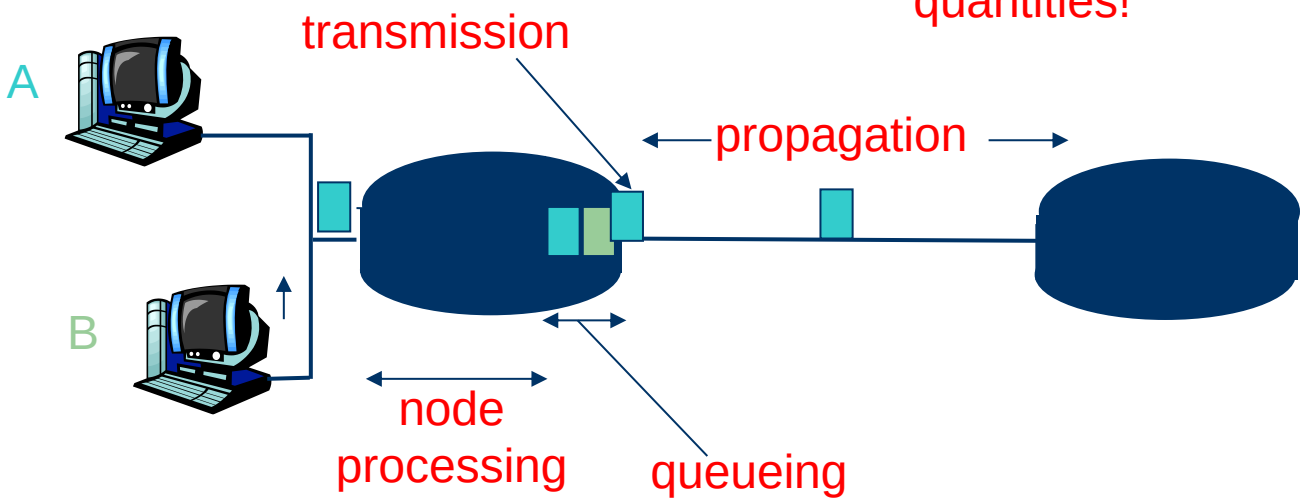
Transmission delay:

- R = link bandwidth (bps)
- L = packet length (bits)
- time to send bits into link = L/R

Propagation delay:

- d = length of physical link
- s = propagation speed in medium (~$2x10^8$ m/sec)
- propagation delay = d/s

Note: s and R are *very* different quantities!



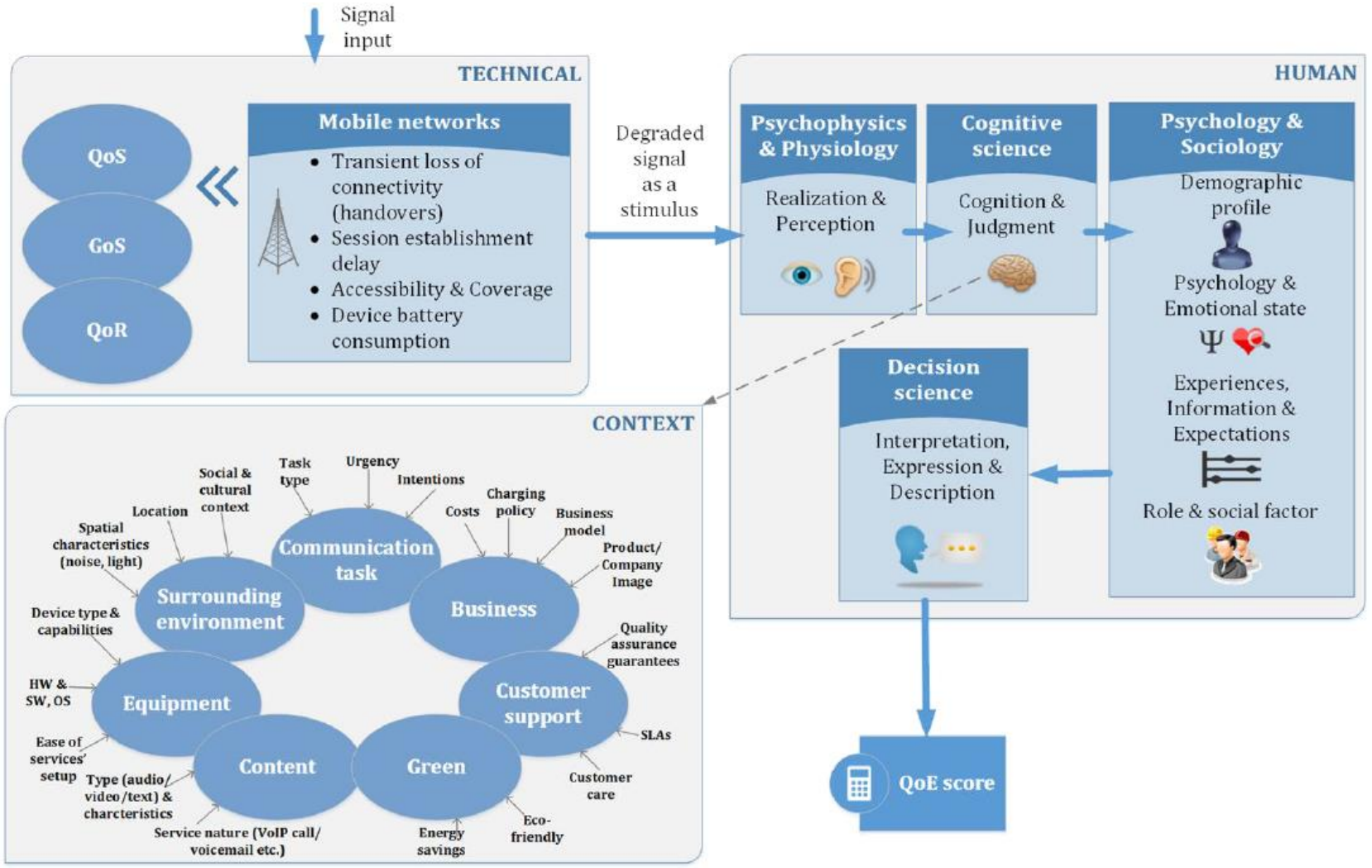
Communication QoS Parameters

- Average Throughput (bit rate, bandwidth)
- Burstiness (average to peak ratio)
- Maximum transit (delay)
  - Important for response time and RT perception
- Maximum Jitter (delay variance),
  - Important for synchronization
- Reliability
  - Acceptable bit error rate
  - Acceptable packet error rate

QoS guarantees

- Based on the type of traffic, and user needs and preferences, QoS parameters are extracted.
- Real-time applications (voice, video) have strict requirements for low mean and max delay (100-200 msec end-to-end), and looser requirements for mean packet error rate (e.g., 10^{-3}).
- Non-real-time applications (email, file transfer) have strict requirements for packet errors, but looser requirements for delay (e.g., a few seconds).
- The target for QoS parameters are shared per link.
- The main target of the layer 2 (Data-Link) protocols is to guarantee the target values of the QoS parameters per data flow.
- So the MAC protocol at 802.11 has to guarantee the target QoS values in the WiFi radio interface.

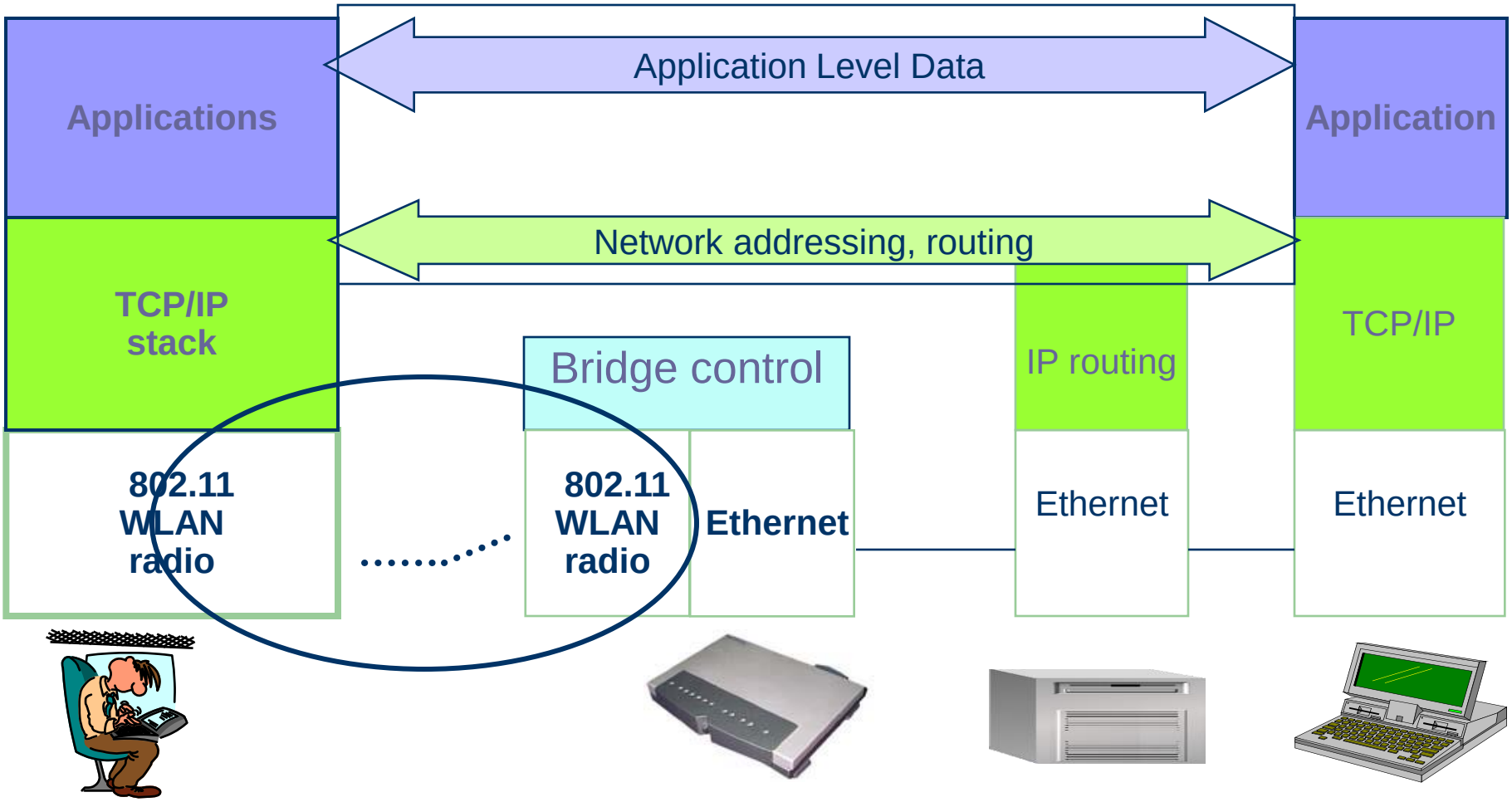
Quality of experience - QoE



Quality of experience - QoE

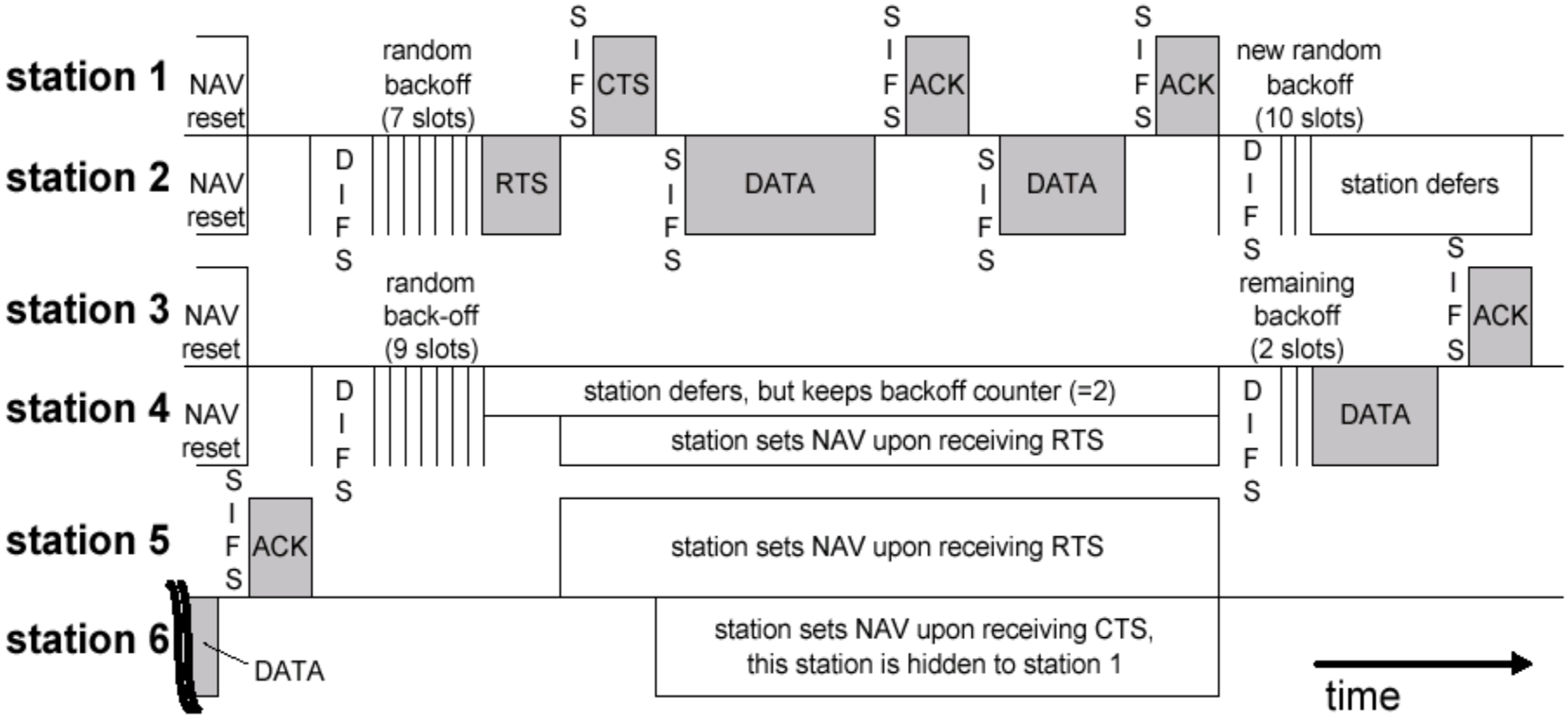
Aspect	Quality Influence Factors	
Mobile networks	Vertical and horizontal handovers Battery consumption Session establishment delay	Accessibility Coverage
Service	Call setup success ratio Blocking probability Call setup time	Call cut-off ratio Availability & Reliability
Transport / Network	Round trip / one-way delay Jitter Packet loss ratio Delay burstiness distribution	Loss burstiness distribution Bottleneck bandwidth Congestion period
Physical	SNR / SIR / SINR Bit rate BLER Outage probability Packet / Symbol / Bit Error Probability Outage capacity	Ergodic capacity / rate Throughput Diversity order / coding gain Area spectral efficiency Energy efficiency

Quality of experience - QoE



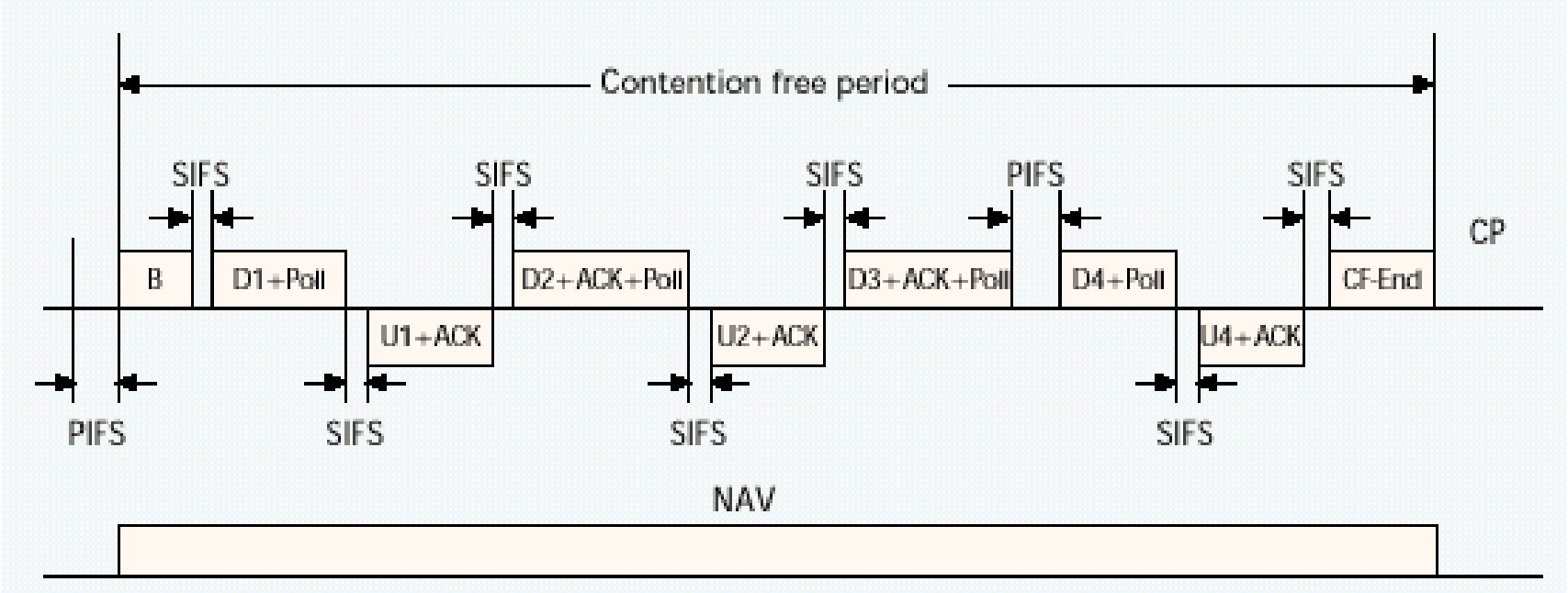
QoS restrictions in standard 802.11

• DCF is based on contention so it cannot differentiate traffic and provide guaranteed delays and packet losses



QoS restrictions in standard 802.11

- In PCF there is no knowledge of requirements per terminal to give the channel to the most demanding ones
- In PCF polling time is unspecified, giving the channel for unknown time



Extensions introduced by 802.11e

- AP is called Hybrid Coordinator (HC) implementing Hybrid Coordination Function (HCF) that includes two modes of operation:
- EDCA (Enhanced Distributed Coordination Access): Different traffic classes in DCF with different behavior and medium access probabilities
- HCCA (HCF Control Channel Access): Improving weaknesses of PCF (beacon transmission, controlled reservation time, queue size information)

EDCA
(Enhanced Distributed Coordination Access)

- CSMA/CA and Exponential Backoff
- Four Access Categories (ACs) within one station