MOBILE COMPUTING - INTRODUCTION

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AP/CSE

LEARNING OBJECTIVES

- To understand the basic concepts of mobile computing

WHAT IS MOBILE COMPUTING?

- Mobile Computing (Ubiquitous Computing / Nomadic Computing) is described as the ability to compute remotely while on the move.
- Fast and new emerging technology.
- People can access information from anywhere and anytime.
- Mobile Computing (2 distinct concepts)
  - Mobile Communication
    - The capability to change the location while communicating to invoke computing services at some remote computers.
  - Mobile Computing
    - The capability to automatically carry out certain processing related service invocations on a remote computer
- Provides flexibility to the user

MOBILE COMPUTING VS WIRELESS NETWORKING

- MC and WN are not same.
- Mobile Computing
  - Computing environment is mobile → sender or receiver is on the move while transmitting or receiving information.
  - Accessing Information and remote computational services on the move.
- Wireless Networks
  - Basic communication infrastructure necessary to make mobile computing possible.
- Therefore mobile computing is based on wireless networks

MOBILE COMMUNICATION

- Two aspects of mobility:
  - user mobility: users communicate (wireless) "anytime, anywhere, with anyone"
  - device portability: devices can be connected anytime, anywhere to the network

•Wireless vs. mobile Examples

Wireless	Mobile	Examples
✗	✗	desktop computer or a wired printer
✗	✓	a laptop computer or a tablet connected to a wired network
✓	✗	wireless router or a Wi-Fi printer
✓	✓	Smartphone, Tablet, Smart watch

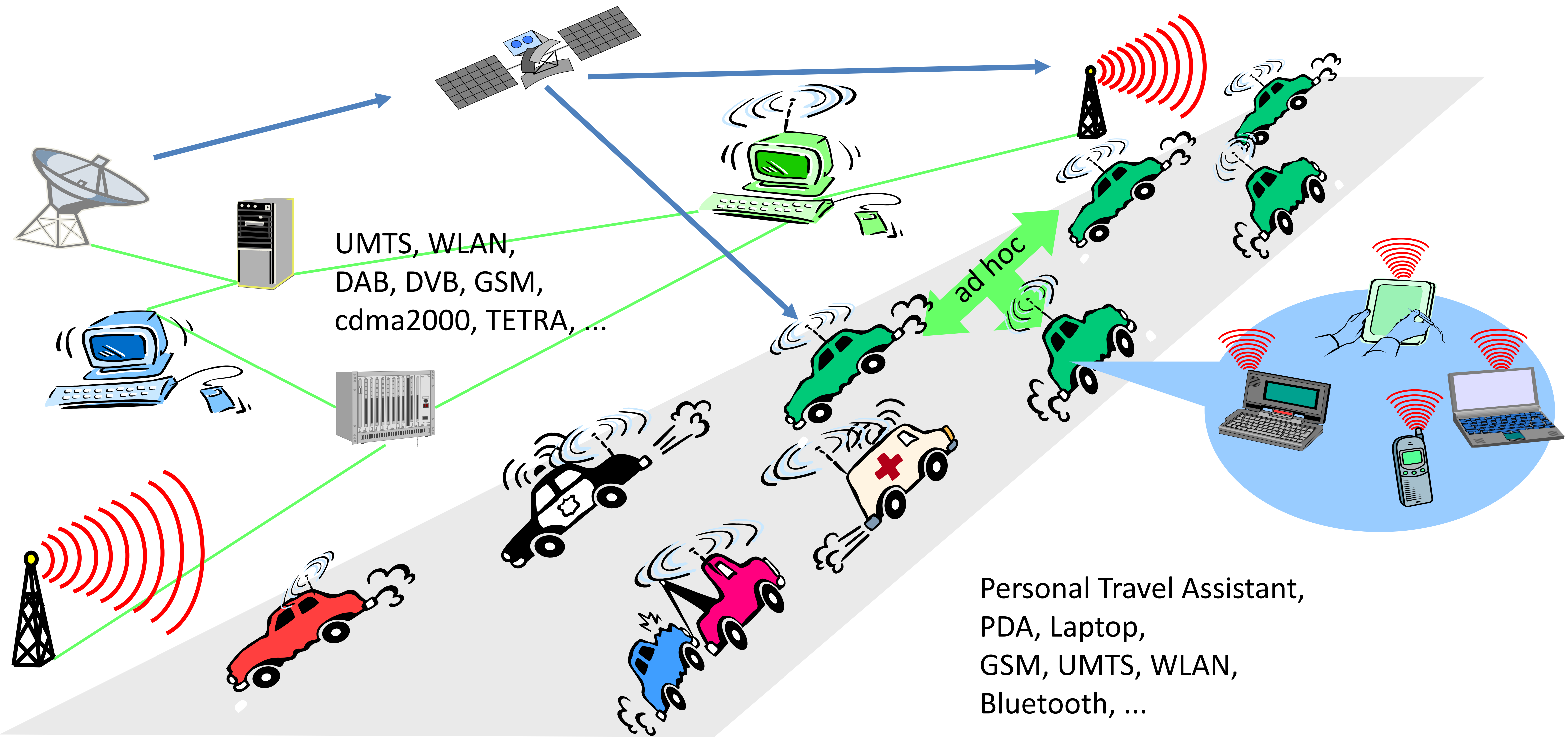
•The demand for mobile communication creates the need for integration of wireless networks into existing fixed networks:

- local area networks: standardization of IEEE 802.11 (**IEEE 802.11be -** Wi-Fi 7- Extremely High Throughput)
- Internet: Mobile IP extension of the internet protocol IP (IPv6, **IPv6 over LTE,** IPv6 over 5G)
- wide area networks: e.g., internetworking of GSM and ISDN, VoIP over WLAN and POTS

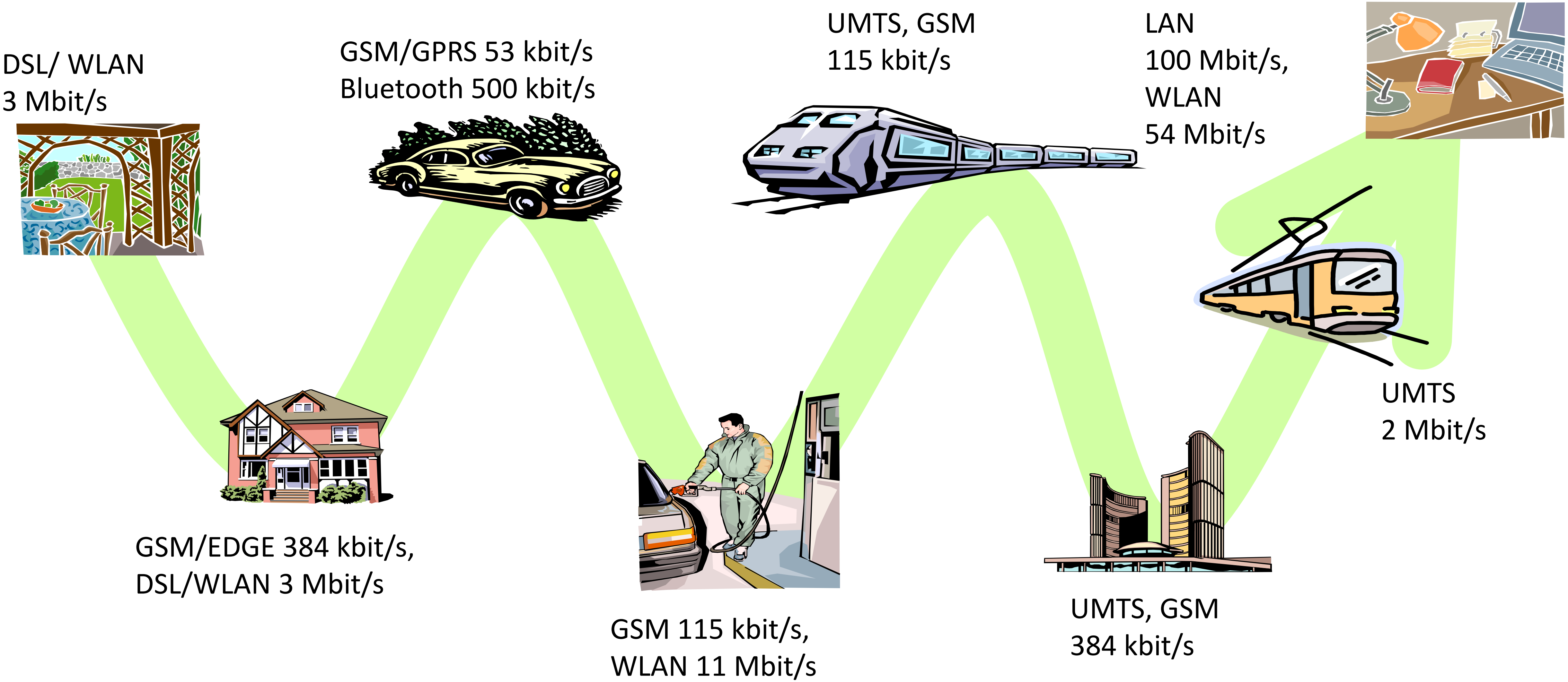
APPLICATIONS I

- Vehicles
  - transmission of news, road condition, weather, music via DAB/DVB-T
  - personal communication using GSM/UMTS/LTE
  - position via GPS
  - local ad-hoc network with vehicles close-by to prevent accidents, guidance system, redundancy
  - vehicle data (e.g., from busses, high-speed trains) can be transmitted in advance for maintenance
- Emergencies
  - early transmission of patient data to the hospital, current status, first diagnosis
  - replacement of a fixed infrastructure in case of earthquakes, hurricanes, fire etc.
  - crisis, war, ...

TYPICAL APPLICATION: ROAD TRAFFIC



MOBILE AND WIRELESS SERVICES – ALWAYS BEST CONNECTED



APPLICATIONS II

- Traveling salesmen
  - direct access to customer files stored in a central location
  - consistent databases for all agents
  - mobile office
- Replacement of fixed networks
  - remote sensors, e.g., weather, earth activities
  - flexibility for trade shows
  - LANs in historic buildings
- Entertainment, education, ...
  - outdoor Internet access
  - intelligent travel guide with up-to-date location dependent information
  - ad-hoc networks for multi user games

LOCATION DEPENDENT SERVICES

- Location aware services
  - what services, e.g., printer, fax, phone, server etc. exist in the local environment
- Follow-on services
  - automatic call-forwarding, transmission of the actual workspace to the current location
- Information services
  - “push”: e.g., current special offers in the supermarket
  - “pull”: e.g., where is the Black Forrest Cheese Cake?
- Support services
  - caches, intermediate results, state information etc. “follow” the mobile device through the fixed network
- Privacy
  - who should gain knowledge about the location

SUMMARY

- Mobile Computing
- Wireless Networks vs Mobile computing
- Applications of Mobile Computing

TEST YOUR KNOWLEDGE

How does SHAREit or SHARE Karo app work???

REFERENCES

- Jochen H Schiller, “Mobile Communications”, Pearson Education, New Delhi, 2nd Edition,2007

MAC PROTOCOLS

Dr. A. Beulah

AP/CSE

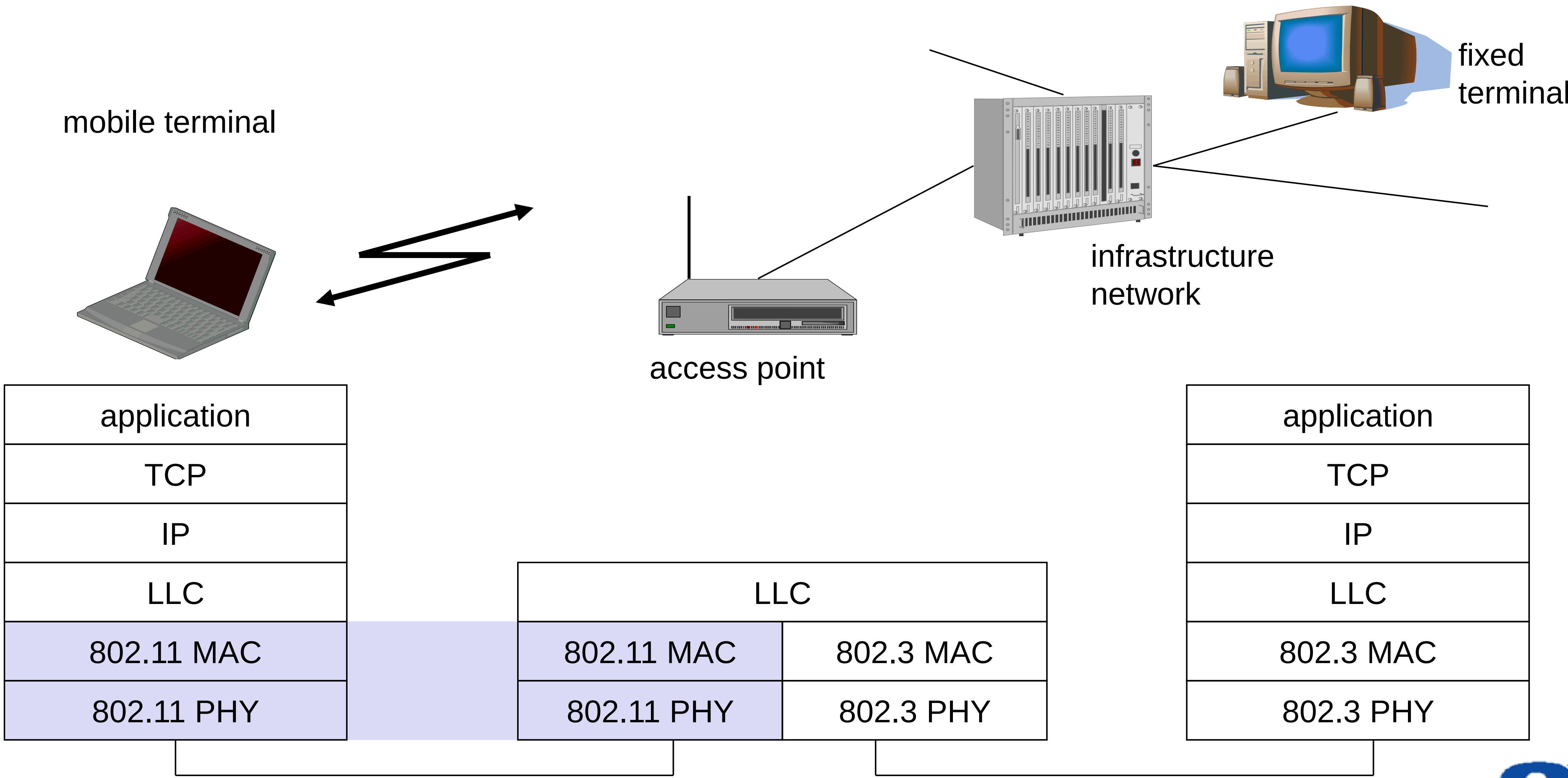
LEARNING OBJECTIVES

- To understand the about MAC protocols.

PURPOSE OF MAC PROTOCOLS

- The MAC sublayer provides
  - Addressing
  - channel access when multiple stations contend for the medium.
- Size of MAC Address??
- Mobile device MAC Address size???

PURPOSE OF MAC PROTOCOLS



PROPERTIES – MAC PROTOCOLS

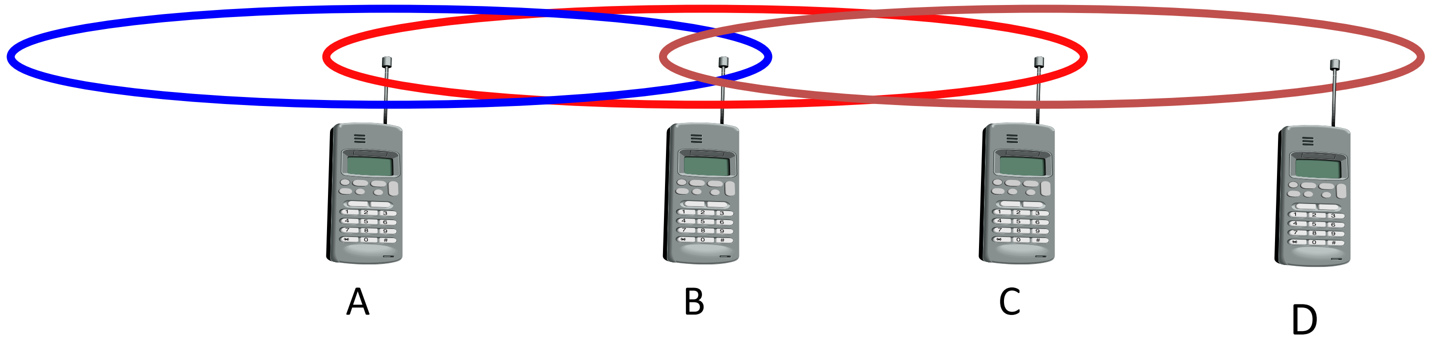
- Should implement some rules to enforce discipline when multiple nodes contend for a shared channel.
- Maximize the utilization of the channel.
- Fair Channel allocation
  - No discrimination for any node.
- Support different types of traffic with maximum and average bit rates.
- Robust incase of equipment failure and changing network conditions
- IEEE 802.11 (WLAN) – wifi hotspots.
- MANET- MACA

MOTIVATION FOR A SPECIALIZED MAC

- Difficult to implement a collision detection scheme, as collisions are hard to detect by the nodes.
- The main issues need to be addressed while designing a MAC protocol for ad hoc networks:
  - **Hidden and exposed terminal problems**:
  - Distributed Nature/Lack of Central Coordination
  - Mobility of Nodes: Nodes are mobile most of the time.

HIDDEN AND EXPOSED TERMINAL

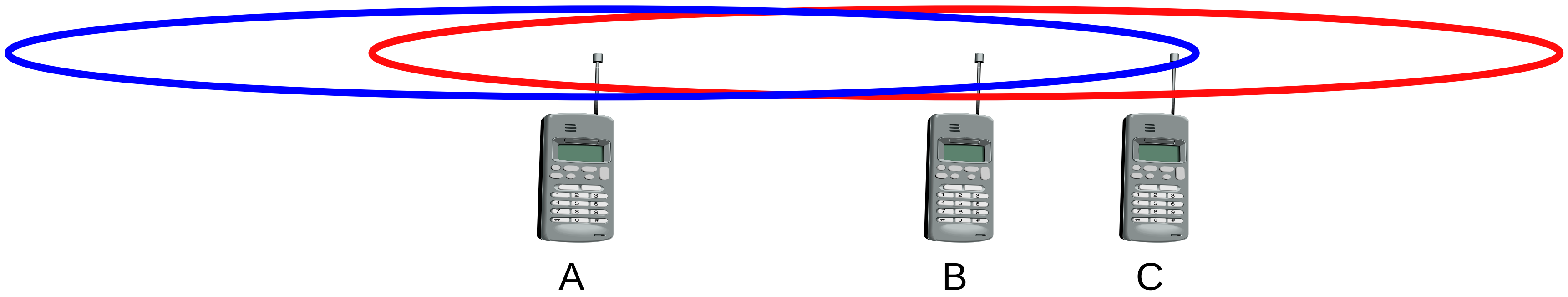
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a “free” medium
  - collision at B, A cannot receive the collision
  - A is “hidden” for C



- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, C senses the medium in use
  - but A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B

NEAR AND FAR TERMINALS

- Terminals A and B send, C receives
  - signal strength decreases proportional to the square of the distance
  - the signal of terminal B therefore drowns out A's signal
  - C cannot receive A



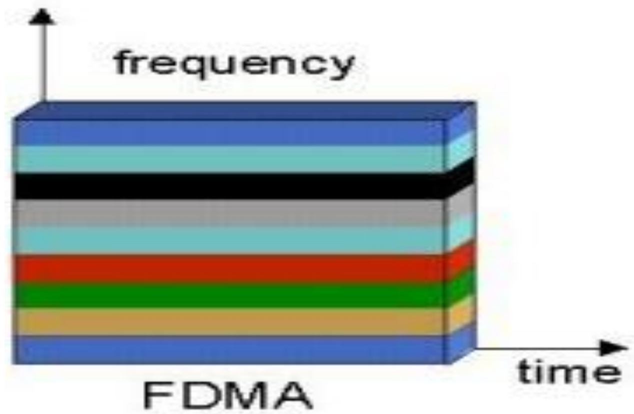
- If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer
- Also severe problem for CDMA-networks - precise power control needed!

ACCESS METHODS SDMA/FDMA/TDMA

- SDMA (Space Division Multiple Access)
  - segment space into sectors, use directed antennas
  - cell structure
- FDMA (Frequency Division Multiple Access)
  - assign a certain frequency to a transmission channel between a sender and a receiver
  - permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
- TDMA (Time Division Multiple Access)
  - assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time
- Code Division Multiple Access(CDMA)

FDMA

- Frequency division multiple access (FDMA) comprises all algorithms allocating frequencies to transmission channels according to the frequency division multiplexing (FDM)
- The existing bandwidth is divided into sub bands / channels



FDMA

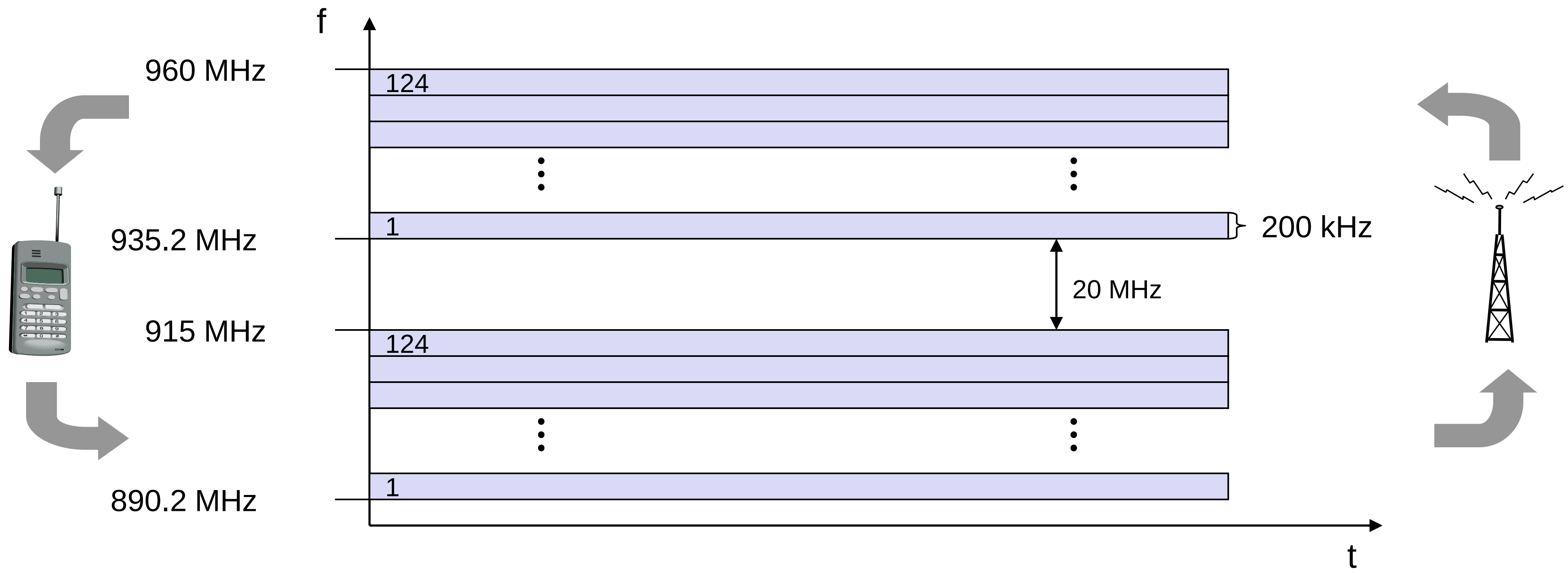
- Pure FDMA
  - Channels can be assigned to the same frequency at all times
- FDMA combined with TDMA
  - Channels can change frequencies according to a certain pattern
- For full duplex communication each user is allocated 2 unique frequency for transmitting and receiving signals during the call
  - Forward Link (Mobile to BS)
  - Reverse Channel (BS to Mobile)
- No other user can be allocated with same frequency to make a call.

FDMA

Frequency division duplex (FDD)

- The two directions, mobile station to base station and vice versa are separated using different frequencies.
- This scheme is called as frequency division duplex (FDD)
- Again, both partners have to know the frequencies in advance ; they cannot just listen into the medium.
- The two frequencies are also known as uplink and downlink

FDMA



FDMA

Uplink Frequency (For Transmission)

- From mobile station to base station or from ground control to satellite
- All uplinks use the band between 890.2 and 915

Downlink Frequency (Receiving information)

- From base station to mobile station or from satellite to ground control
- All downlinks use 935.2 to 960 MHz

FDMA

Allocation of uplink and downlink Frequency

- According to FDMA, the base station, allocates a certain frequency for up and downlink to establish a with a mobile phone
- Up and downlink have a fixed relation
- If the uplink frequency is $f_u = 890$ MHz + $n \cdot 0.2$ MHz, the downlink frequency is $f_d = f_u + 45$ MHz, i.e., $f_d = 935$ MHz + $n \cdot 0.2$ MHz for a certain channel n.
- The base station selects the channel. Each channel (uplink and downlink) has a bandwidth of 200 kHz
- This illustrates the use of FDM for multiple access (124 channels per direction are available at 900 MHz) and duplex according to a predetermined scheme.

FDMA

- 3rd channel uplink and downlink frequency

- $f_u = 890 \text{ MHz} + n*0.2 \text{ MHz}$

  $= 890 \text{ MHz} + 3*0.2 \text{ MHz}$

  $= 890.6 \text{ MHz}$

- $f_d = f_u + 45 \text{ MHz}$

  $= 890.6 \text{ MHz} + 45 \text{ MHz}$

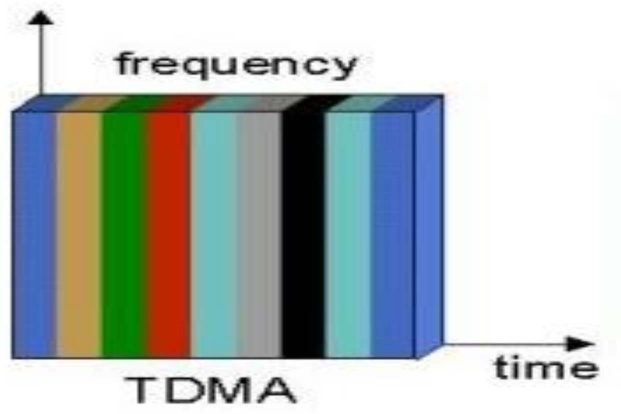
  $= 935.6 \text{ MHz}$

FDMA

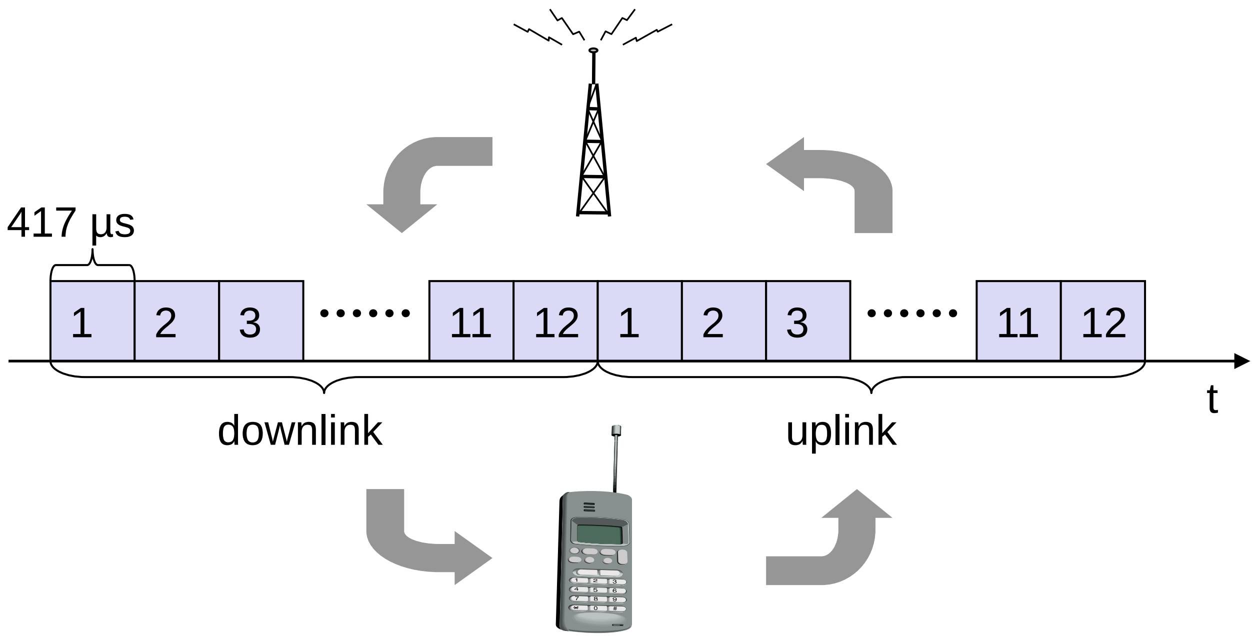
- Drawback
  - When allocated user paused between transmission –unused transmission
  - No user is allocated, the band goes idle.
  - Does not achieve high channel utilization

TDMA

- Time division multiple access (TDMA) allocate certain time slots for communication, i.e., controlling TDM.
- The timeline is divided into fixed time slots.
- Time slots are allocated in round robin manner.



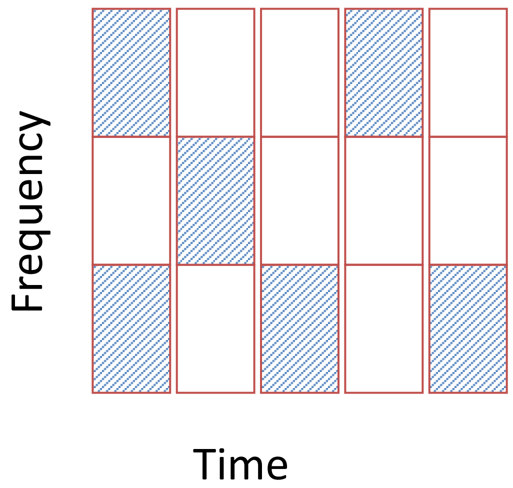
<u>Time Division Duplex (TDD)</u>



TDMA

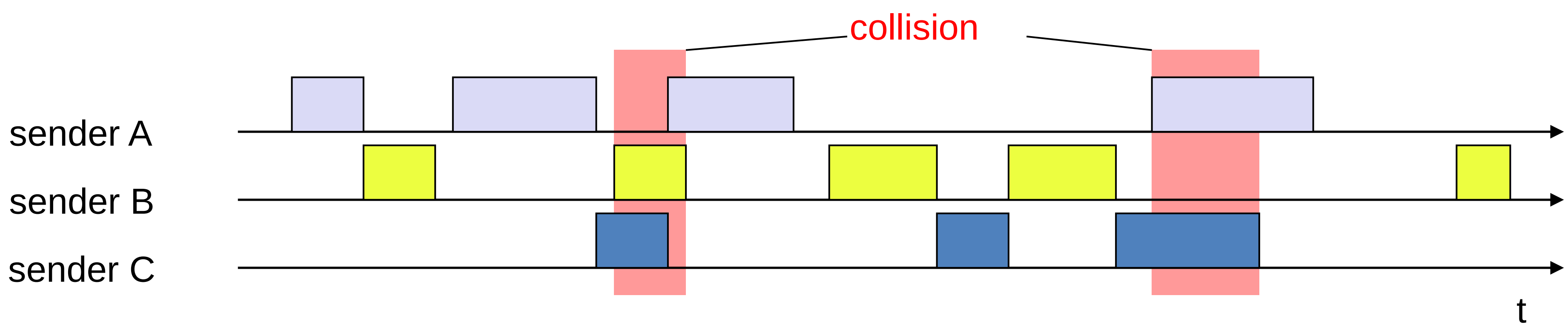
- Only one frequency is used.
- Each partner must be able to access the medium for a time slot at the right moment.
- The base station uses 12 slots for downlink and the mobile uses other 12 slots for uplink.
- Up to 12 different mobile stations can use the same frequency.
- Every 10ms = 417µs*24 a mobile station can access the medium.
- Very inefficient for bursty data
- Unused Time slots go idle , leading to low channel Utilization

HYBRID FDMA/TDMA



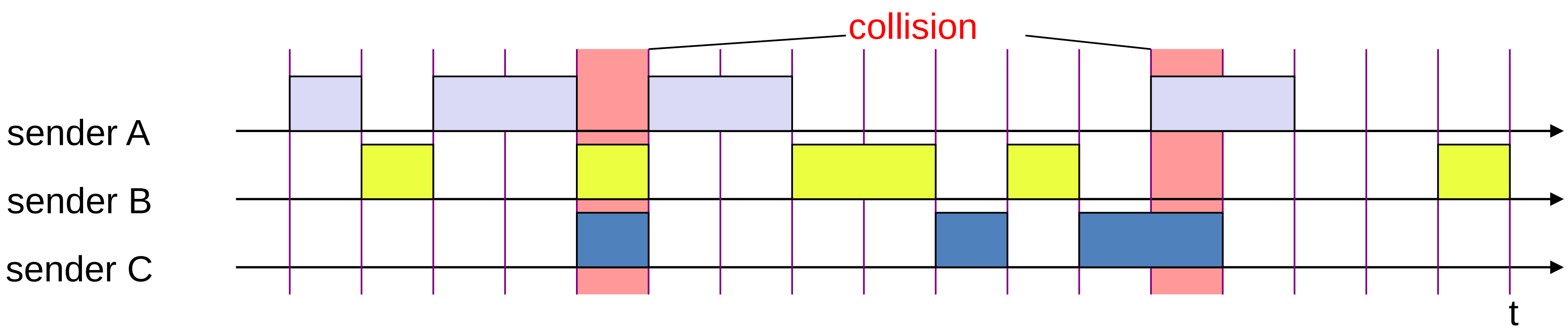
ALOHA

- Mechanism
  - random, distributed (no central arbiter), time-multiplex
- Free for all
- Any station has a frame to transmit, it transmits.
- Collision occurs when more than one station transmits.



SLOTTED ALOHA

- Mechanism
  - Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
- Slot size is equal.
- Therefore fixed time for frame transmission.
- Beacon signal – to notify start of time slot
- If a station is ready with a frame, it waits until start of next transmission time.
- Collision occurs at time slots.



CSMA

- Carrier Sense Multiple Access.
- Before transmitting the data listens the medium
- If medium is idle then transmit else wait and try again.
- How to identify collision occurs?
- 2 stations senses and transmit at time t.
- No ack for some amount of time.
- Assume collision and retransmit.

CSMA/CD

- CSMA wastes bandwidth
- Some mechanism is needed to detect collision
- Listen the medium continuously when the medium is transmitting
  - If idle transmit
  - If collision stop transmission
    - Then transmit jamming signal.
  - Wait a random time and then try to transmit again. (exponential backoff algorithm)
- Improves performance by terminating transmission ie avoiding collision

EXPONENTIAL BACKOFF ALG.

- The retransmission is delayed by an amount of time derived from the slot time and the number of attempts to retransmit.
- After *c* collisions, a random number of slot times between 0 and $2^c - 1$ is chosen.
- For the first collision, each sender will wait 0 or 1 slot times.
- After the second collision, the senders will wait anywhere from 0 to 3 slot times inclusive.

EXPONENTIAL BACKOFF ALG.

- After the third collision, the senders will wait anywhere from 0 to 7 slot times (inclusive), and so forth.
- As the number of retransmission attempts increases, the number of possibilities for delay increases exponentially.
- The 'truncated' simply means that after a certain number of increases, the exponentiation stops; i.e. the retransmission timeout reaches a ceiling, and thereafter does not increase any further.
- For example, if the ceiling is set at $i = 10$ then the maximum delay is 1023 slot times.

CSMA/CD

- In wireless network CSMA/CD does not work well.
- Carrier sense → NAV (Network Allocation Vector)
  - Virtual carrier-sensing mechanism used with wireless network protocols such as IEEE 802.11
  - The MAC layer frame headers contain a *duration* field that specifies the transmission time required for the frame, in which time the medium will be busy.
  - The other stations listening on the wireless medium read the *Duration* field and set their NAV, which is an indicator for a station on how long it must defer from accessing the medium
  - The NAV may be thought of as a counter, which counts down to zero at a uniform rate
  - Counter → 0 → Medium is idle
  - Counter → non zero → Medium is busy

CSMA/CD

- Wired network → Collision Detection is simple.
  - No voltage → Medium idle
  - Current flows → some station is transmitting
  - Voltage for each bit → 18-20 mA
  - When collision each bit is > 24mA
- Wireless network → very difficult.
  - When the signal is weak, it can easily be masked by noise.
  - The destination notices this while performing checksum.
  - Leads to retransmission, wastage of bandwidth.
  - Therefore collision detection does not work well with wireless networks

CSMA/CA

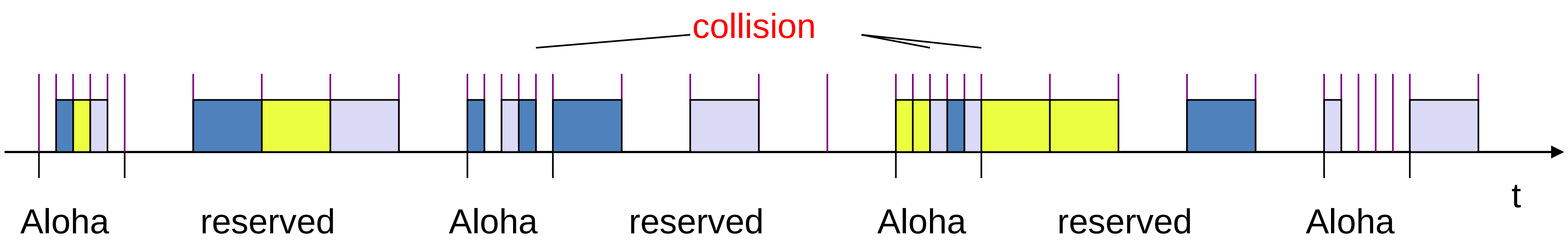
- A node wishing to transmit data has to first listen to the channel for a predetermined amount of time to determine whether or not another node is transmitting on the channel within the wireless range.
- If the channel is sensed "idle," then the node is permitted to begin the transmission process.
- If the channel is sensed as "busy," the node defers its transmission for a random period of time.
- Collision avoidance is used to improve CSMA performance by not allowing wireless transmission of a node if another node is transmitting, thus reducing the probability of collision due to the use of a random waiting time.

DAMA - DEMAND ASSIGNED MULTIPLE ACCESS

- Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrival and packet length)
- Reservation can increase efficiency to 80%
  - a sender *reserves* a future time-slot
  - sending within this reserved time-slot is possible without collision
  - reservation also causes higher delays
  - typical scheme for satellite links
- Examples for reservation algorithms:
  - *Explicit Reservation according to Roberts (Reservation-ALOHA)*
  - *Implicit Reservation (PRMA)*
  - *Reservation-TDMA*

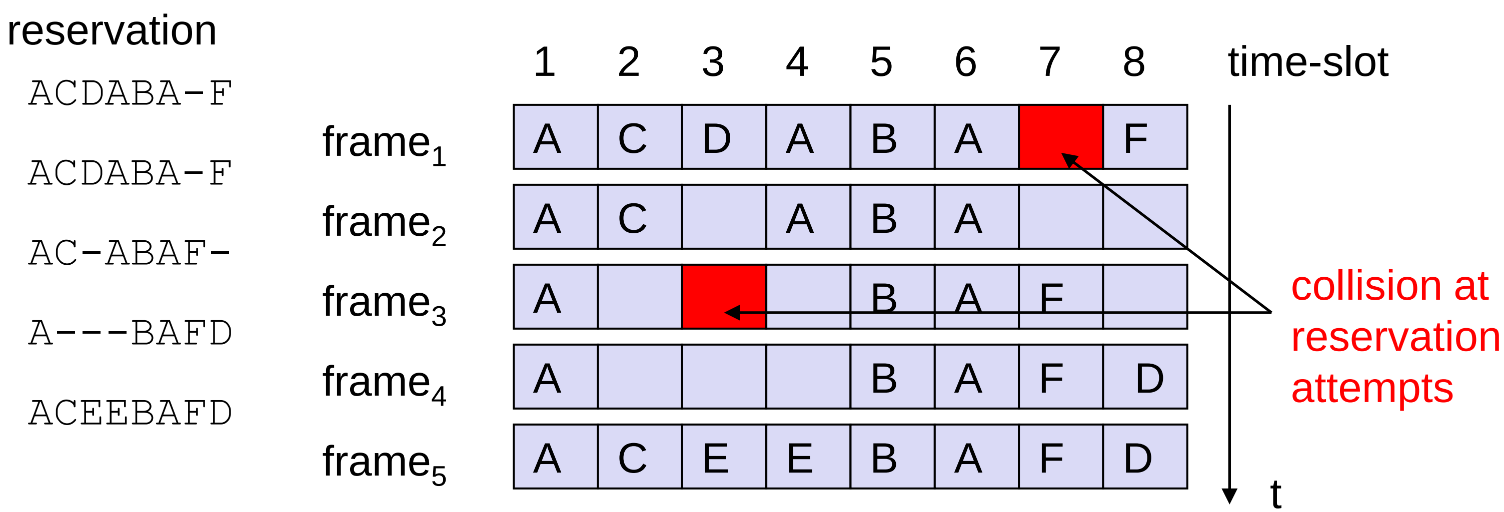
ACCESS METHOD DAMA: EXPLICIT RESERVATION

- Explicit Reservation (Reservation Aloha)(satellite transmission)
  - two modes:
    - ALOHA mode for reservation:
      competition for small reservation slots, collisions possible
    - reserved mode for data transmission within successful reserved slots (no collisions possible)
  - it is important for all stations to keep the reservation list consistent at any point in time and, therefore, all stations have to synchronize from time to time



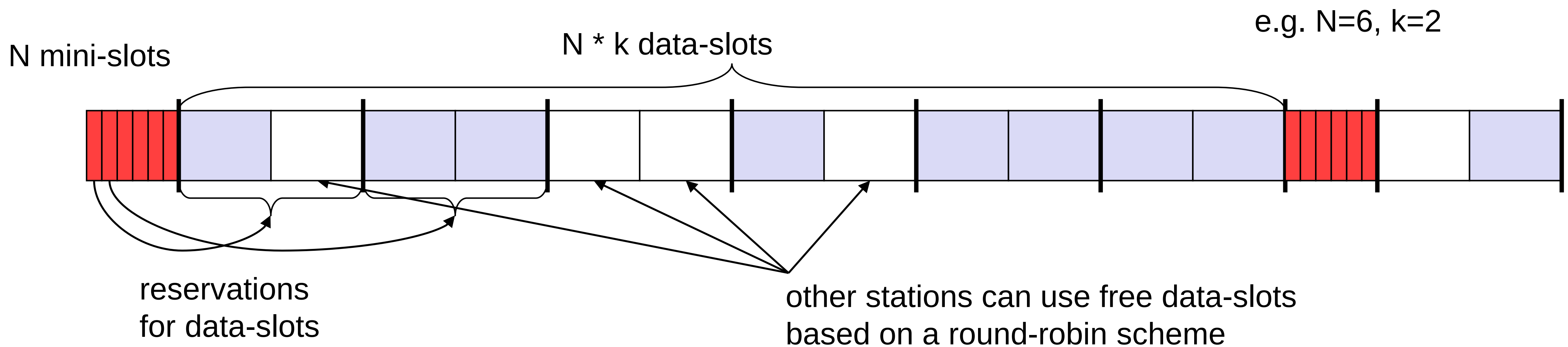
ACCESS METHOD DAMA: PRMA

- Implicit reservation (PRMA - Packet Reservation MA):
  - a certain number of slots form a frame, frames are repeated
  - stations compete for empty slots according to the slotted aloha principle
  - once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send
  - competition for this slots starts again as soon as the slot was empty in the last frame



ACCESS METHOD DAMA: RESERVATION-TDMA

- Reservation Time Division Multiple Access
  - every frame consists of N mini-slots and x data-slots
  - every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k).
  - other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)

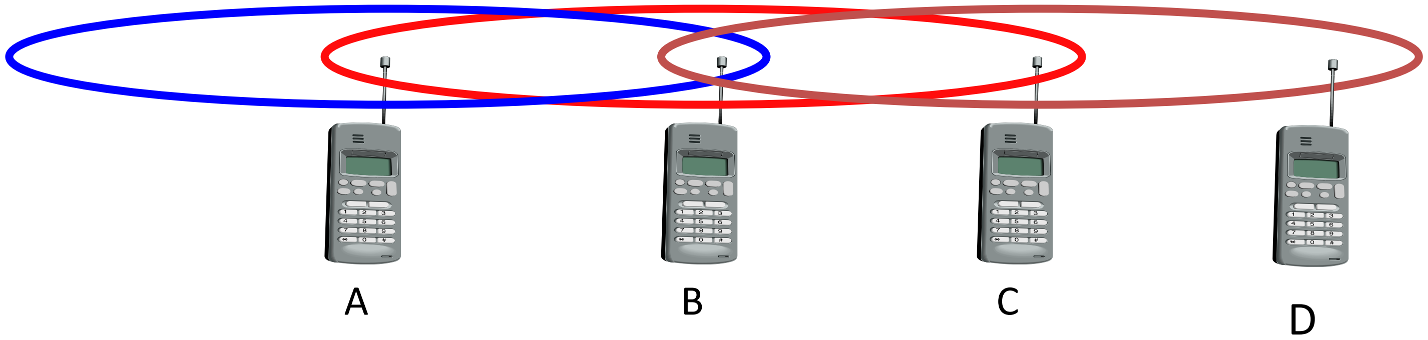


MULTIPLE ACCESS WITH COLLISION AVOIDANCE

- This is done by RTS/CTS
- RTS (request to send):
  - A sender request the right to send from a receiver with a short RTS packet before it sends a data packet
- CTS (clear to send):
  - The receiver grants the right to send as soon as it is ready to receive

HIDDEN AND EXPOSED TERMINAL

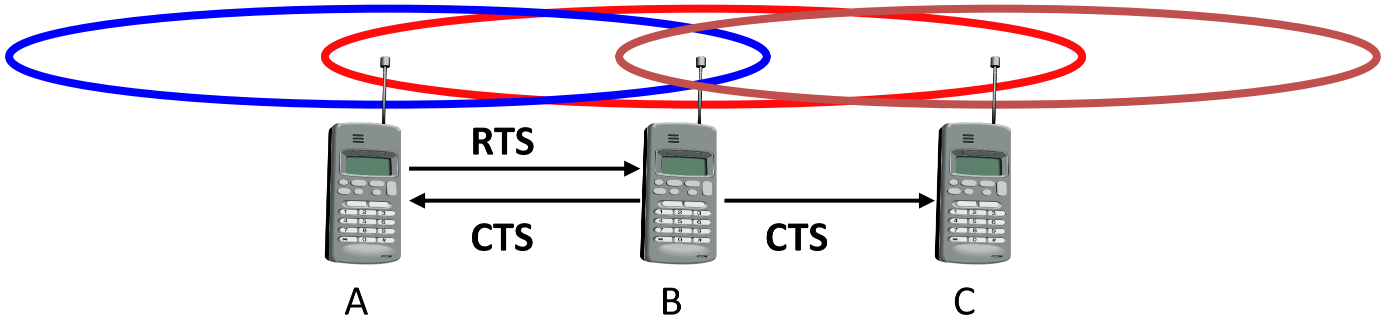
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a “free” medium
  - collision at B, A cannot receive the collision
  - A is “hidden” for C



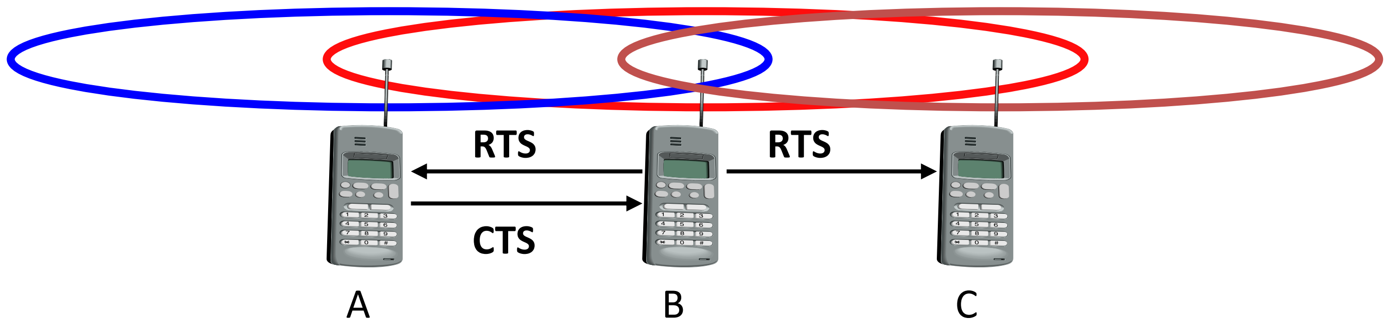
- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, C senses the medium in use
  - but A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B

MULTIPLE ACCESS WITH COLLISION AVOIDANC

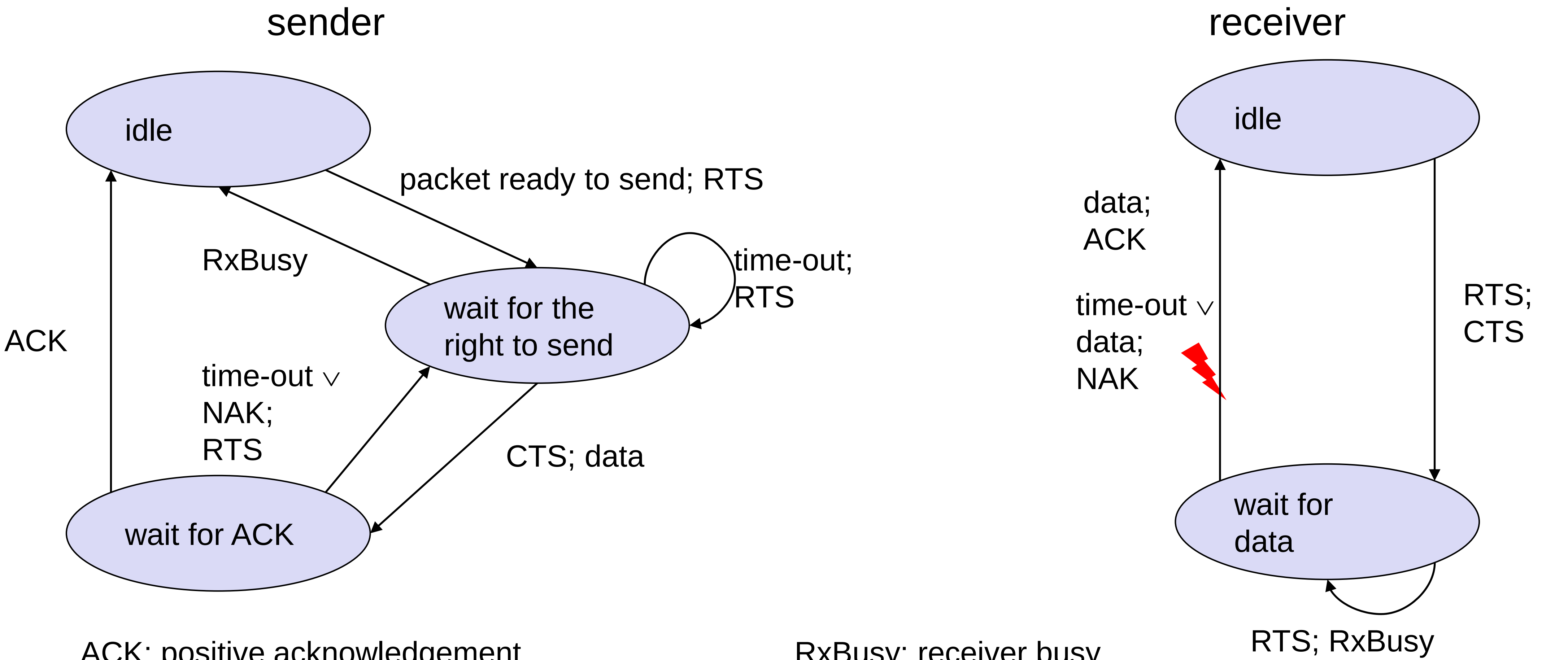
- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B



- MACA avoids the problem of exposed terminals
  - B wants to send to A, C to another terminal
  - now C does not have to wait for it cannot receive CTS from A



MACA – STATE DIAGRAM



ACK: positive acknowledgement
NAK: negative acknowledgement

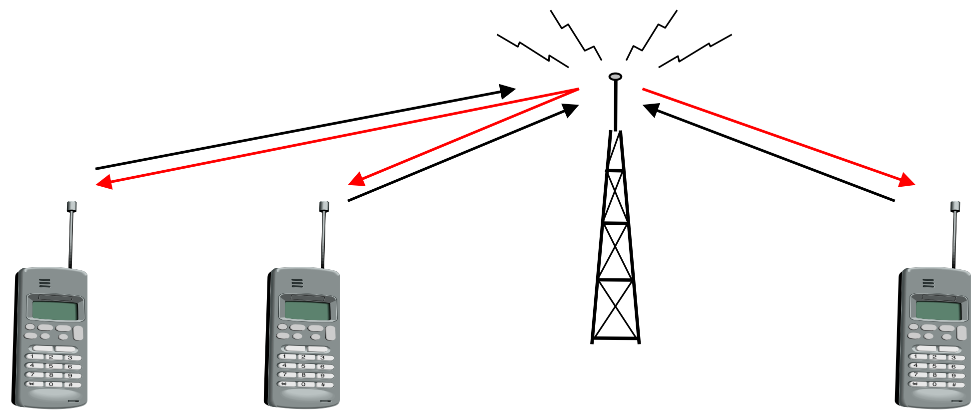
RxBusy: receiver busy

POLLING MECHANISMS

- If one terminal can be heard by all others, this “central” terminal (a.k.a. base station) can poll all other terminals according to a certain scheme
  - now all schemes known from fixed networks can be used (typical mainframe - terminal scenario)
- Example: Randomly Addressed Polling
  - base station signals readiness to all mobile terminals
  - terminals ready to send can now transmit a random number without collision with the help of CDMA or FDMA (the random number can be seen as dynamic address)
  - the base station now chooses one address for polling from the list of all random numbers (collision if two terminals choose the same address)
  - the base station acknowledges correct packets and continues polling the next terminal
  - this cycle starts again after polling all terminals of the list

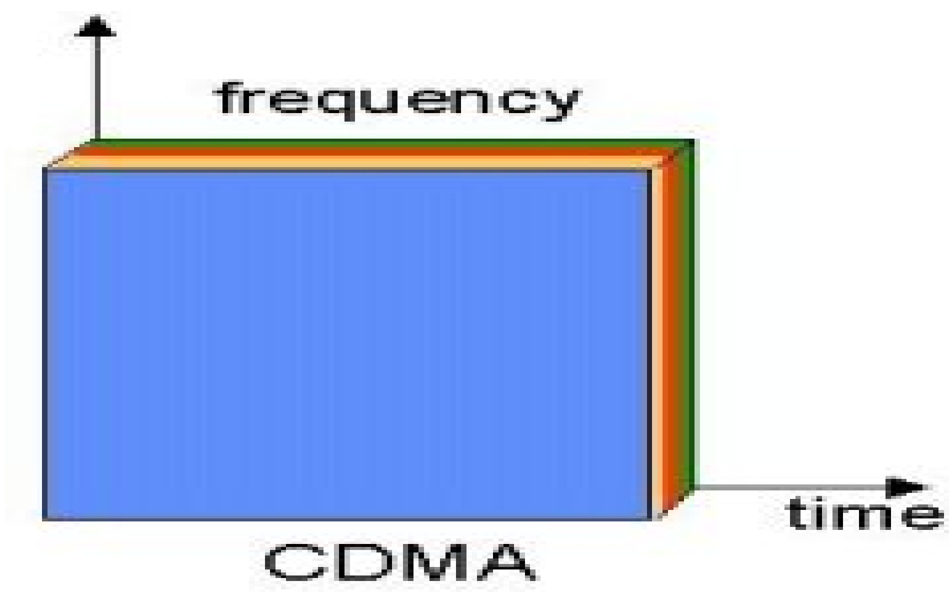
ISMA (INHIBIT SENSE MULTIPLE ACCESS)

- Current state of the medium is signaled via a "busy tone"
  - the base station signals on the downlink (base station to terminals) if the medium is free or not
  - terminals must not send if the medium is busy
  - terminals can access the medium as soon as the busy tone stops
  - the base station signals collisions and successful transmissions via the busy tone and acknowledgements, respectively (media access is not coordinated within this approach)
  - mechanism used, e.g., for CDPD (USA, integrated into AMPS)



CDMA

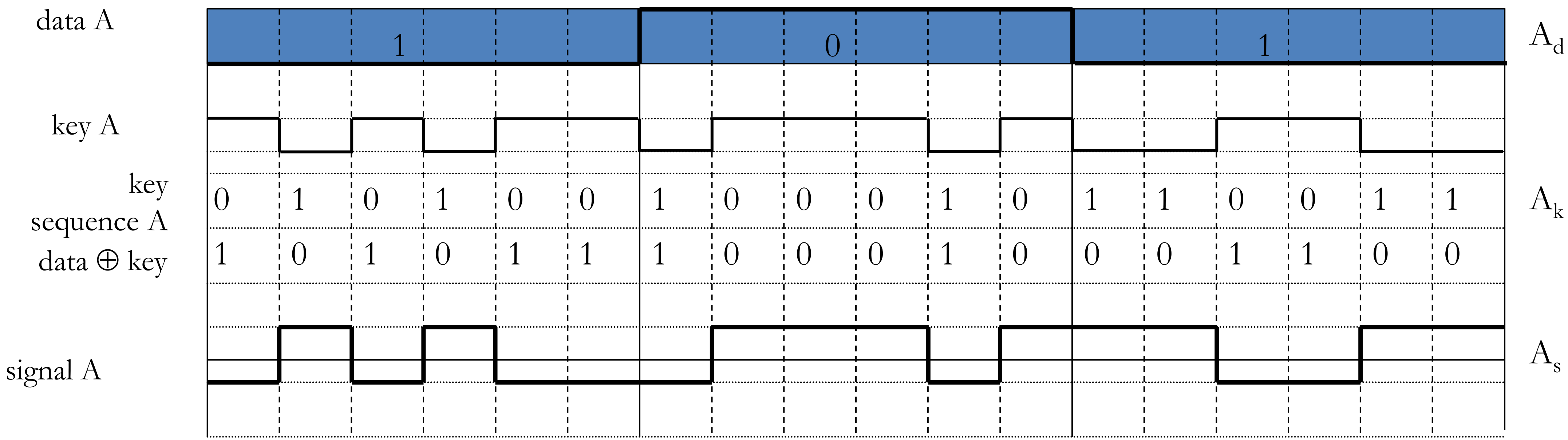
- All terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel
- Each sender has a unique random number, the sender XORs the signal with this random number
- The receiver can "tune" into this signal if it knows the pseudo random number, tuning is done via a correlation function



CDMA

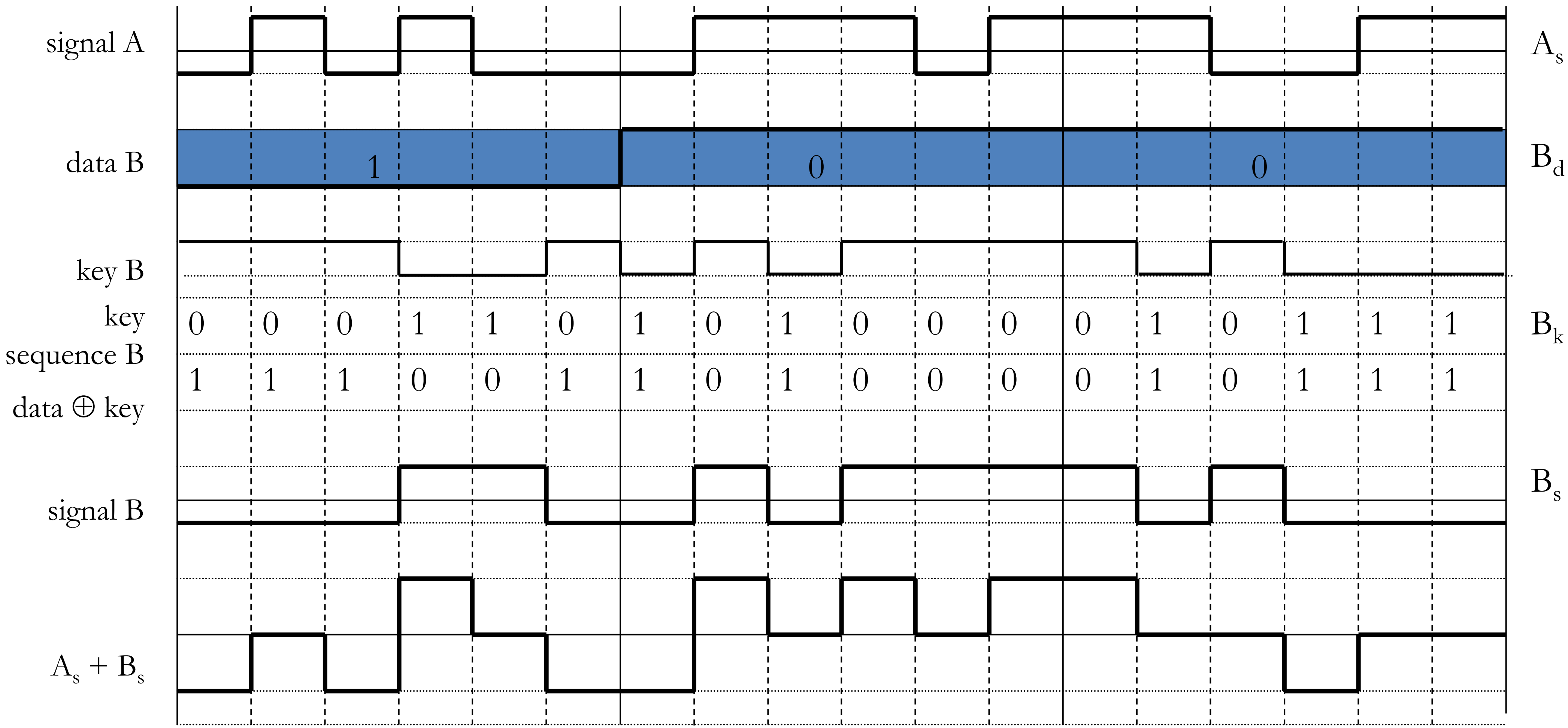
- Sender A
  - sends $A_d = 1$, key $A_k = 010011$ (assign: "0"= -1, "1"= +1)
  - sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
  - sends $B_d = 0$, key $B_k = 110101$ (assign: "0"= -1, "1"= +1)
  - sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose in space
  - interference neglected (noise etc.)
  - $A_s + B_s = (-2, 0, 0, -2, +2, 0)$
- Receiver wants to receive signal from sender A
  - apply key A_k bitwise (inner product)
    - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
    - result greater than 0, therefore, original bit was "1"
  - receiving B
    - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. "0"

CDMA

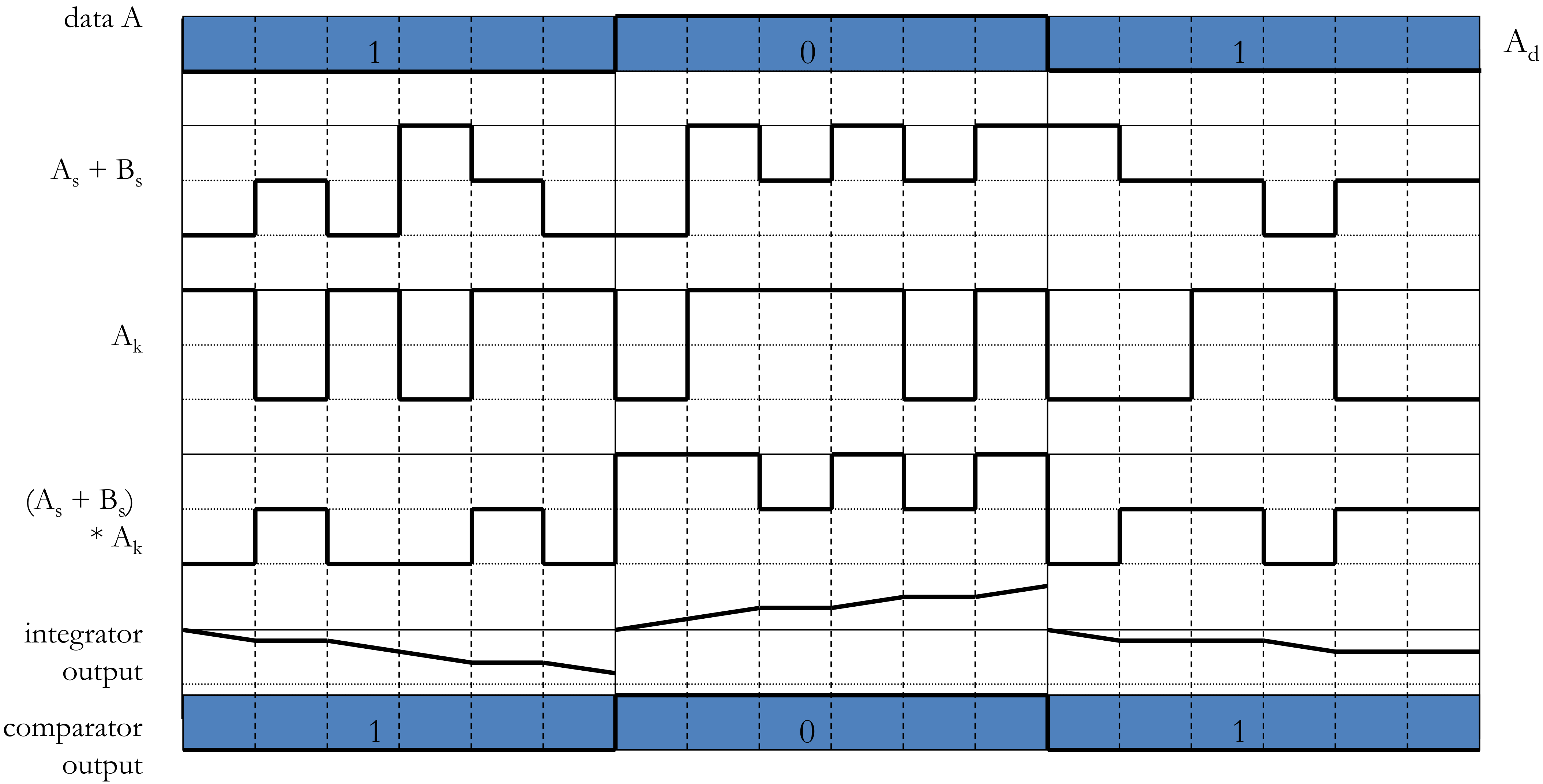


Real systems use much longer keys resulting in a larger distance between single code words in code space.

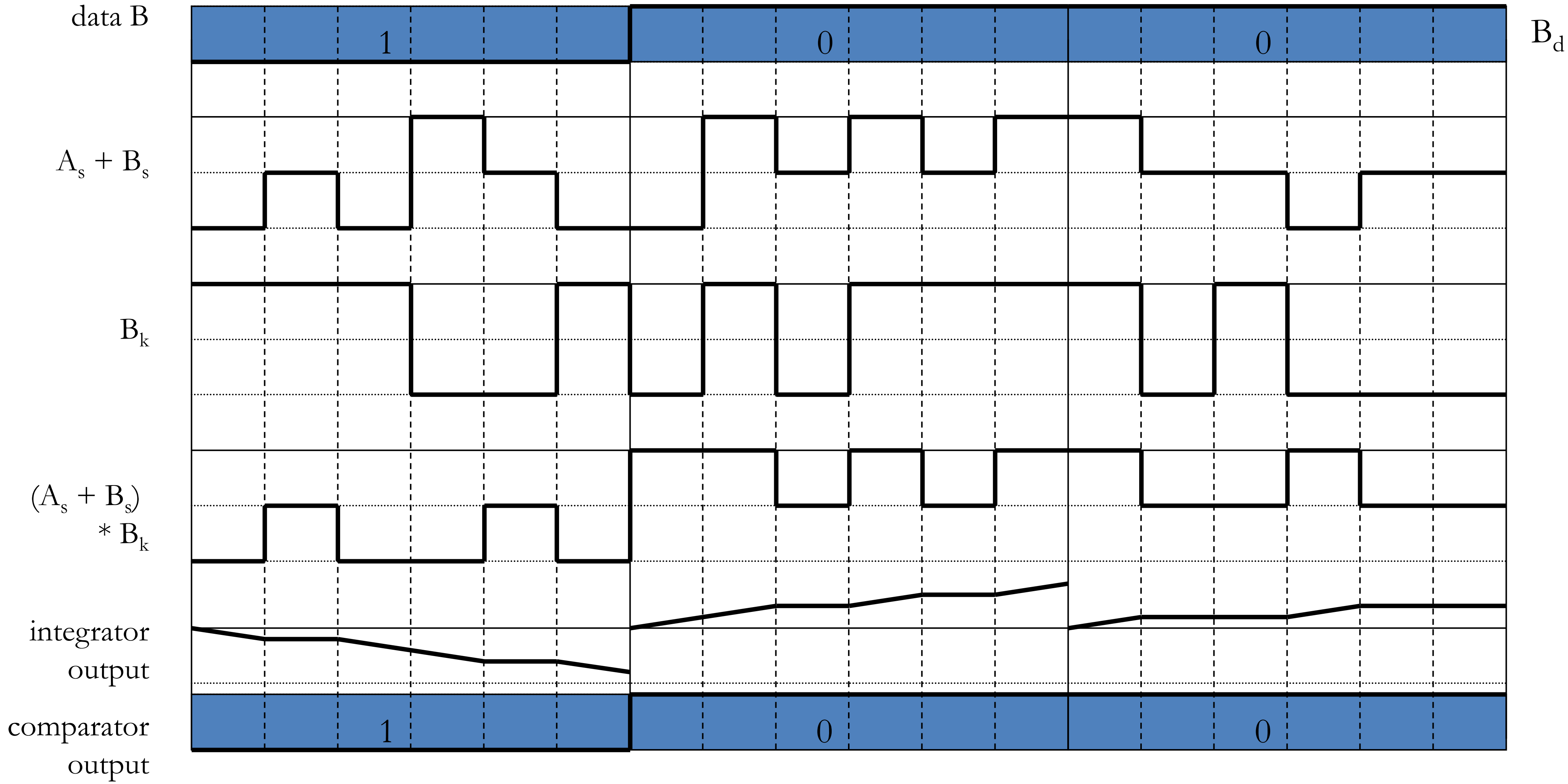
CDMA


signal A
data B
1
0
0
key B
key sequence B
0 0 0 1 1 0 1 0 1 0 0 0 0 1 0 1 1 1
1 1 1 0 0 1 1 0 1 0 0 0 0 1 0 1 1 1
data ⊕ key
signal B
$A_s + B_s$
A_s
B_d
B_k
B_s

CDMA


data A
1
0
1
A_d
$A_s + B_s$
A_k
$(A_s + B_s)$
$* A_k$
integrator
output
comparator
output
1
0
1

CDMA



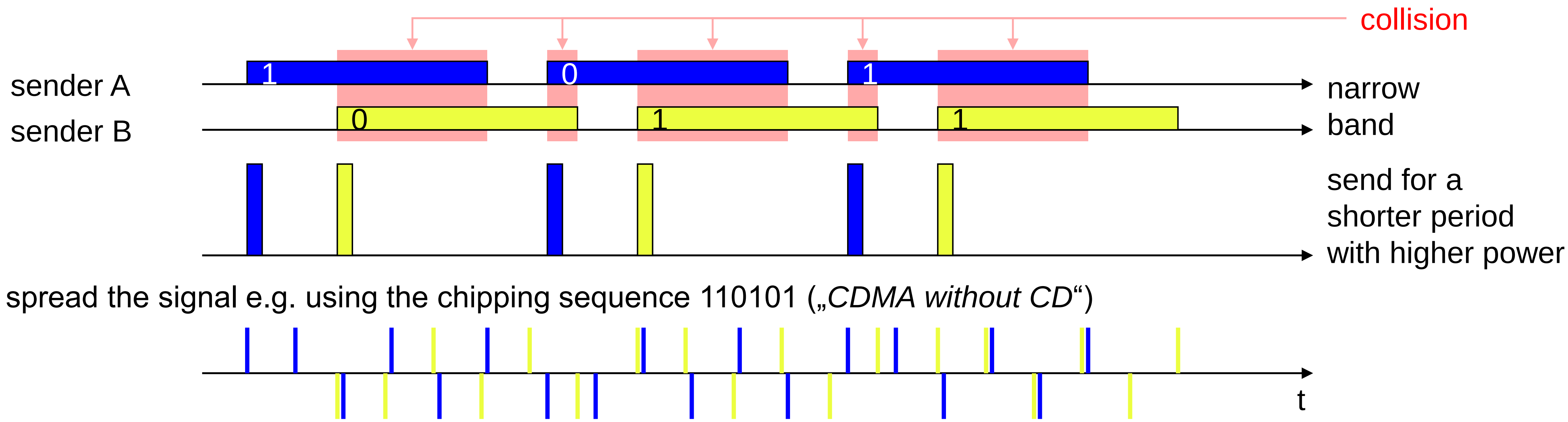
data B
1
0
0
B_d
$A_s + B_s$
B_k
$(A_s + B_s)$
$* B_k$
integrator
output
comparator
output
1
0
0

CDMA

- Disadvantages:
  - Higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
  - All signals should have the same strength at a receiver
- Advantages:
  - All terminals can use the same frequency, no planning needed
  - Huge code space (e.g. 2^{32}) compared to frequency space
  - Interferences (e.g. white noise) is not coded
  - Forward error correction and encryption can be easily integrated

SAMA - SPREAD ALOHA MULTIPLE ACCESS

- Aloha has only a very low efficiency, CDMA needs complex receivers to be able to receive different senders with individual codes at the same time
- Idea: use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha



Problem: find a chipping sequence with good characteristics

COMPARISON SDMA/TDMA/FDMA/CDMA

Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time-slots, demand driven or fixed patterns	segment the frequency band into disjoint sub-bands	spread the spectrum using orthogonal codes
Terminals	only one terminal can be active in one cell/one sector	all terminals are active for short periods of time on the same frequency	every terminal has its own frequency, uninterrupted	all terminals can be active at the same place at the same moment, uninterrupted
Signal separation	cell structure, directed antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantages	very simple, increases capacity per km²	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantages	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers, needs more complicated power control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA

SUMMARY

- MAC Protocols
  - Properties, Issues
  - Different Categories of MAC

TEST YOUR KNOWLEDGE

- Switches are capable of reading the MAC address field from each frame that comes to them. So we can say they work on the ____________ layer from the TCP/IP model.
  - Physical
  - Network
  - Data Link

- In IEEE 802.11, a ___ is made of stationary or mobile wireless stations and an optional central base station, known as the access point (AP)
  - ESS
  - BSS
  - CSS

TEST YOUR KNOWLEDGE

- Recall the problem of hidden and exposed terminals. What happens in the case of such terminals if Aloha, slotted Aloha, reservation Aloha, or MACA is used?

- Who performs the MAC algorithm for SDMA? What could be possible roles of mobile stations, base stations, and planning from the network provider?

TEST YOUR KNOWLEDGE

- A BSS without an AP is called an __________.
  - an ad hoc architecture
  - an infrastructure network

- communication between two stations in two different BSSs usually occurs via two _________.
  - BSSs
  - ESSs
  - APs

TEST YOUR KNOWLEDGE

- When a frame is going from one station to another in the same BSS without passing through the distribution system, the address flag is _____
  - 00
  - 01
  - 10
- When a frame is going from a station to an AP, the address flag is _____.
  - 01
  - 10
  - 11

REFERENCES

- Jochen H. Schller, “Mobile Communications”, Second Edition, Pearson Education, New Delhi, 2007.
- Behrouz A. Forouzan, “Data communication and Networking”, Fourth Edition,Tata McGraw – Hill, 2011.

WIRELESS LAN

Dr. A. Beulah

AP/CSE

LEARNING OBJECTIVES

- To understand the about wireless LAN protocols.

MOBILE COMMUNICATION TECHNOLOGY ACCORDING TO IEEE (EXAMPLES)

Local wireless networks
WLAN 802.11

WiFi

802.11a → 802.11h
802.11i/e/…/n/…/z/aa/..an
802.11b → 802.11g

Personal wireless nw
WPAN 802.15

ZigBee

802.15.4 → 802.15.4a/b/c/d/e/f/g
802.15.5, .6 (WBAN)
802.15.3 → 802.15.3b/c
802.15.2
802.15.1

Bluetooth

Wireless distribution networks
WMAN 802.16 (Broadband Wireless Access)

WiMAX

+ Mobility

[802.20 (Mobile Broadband Wireless Access)]
802.16e (addition to .16 for mobile devices)

Wireless WANs (**WWAN**)
Cellular Networks: GSM(2G), GPRS(2.5G), UMTS(3G), LTE (4G)
Satellite Networks: Iridium, Globalstar

CHARACTERISTICS OF WIRELESS LANS

- Advantages
  - Very flexible within the reception area (Radio wave can penetrate walls, sender and receiver can be placed anywhere)
  - Ad-hoc networks without previous planning possible
  - (almost) no wiring difficulties (e.g. historic buildings). Current networking technology can be introduced without being visible.
  - Wireless networks can survive disasters like, e.g., earthquakes, fire or users pulling a plug.
  - Cost effective: No network sockets. Adding additional users does not require any infrastructure change.

CHARACTERISTICS OF WIRELESS LANS

- Disadvantages
  - Typically very low bandwidth compared to wired networks (1-10 Mbit/s) due to shared medium
    - IEEE 802.11ac theoretical speed 1.7Gbps ; real-time speed 1Gbps
    - But, Ethernet theoretical speed 100Gbps
  - products have to follow many national restrictions if working wireless, it takes a vary long time to establish global solutions like, e.g., IMT-2000
  - Using radio waves might interference with other high tech equipment ex: hospitals.
  - The open radio interference makes eavesdropping much easier in WLANs than in wired network.

DESIGN GOALS FOR WIRELESS LANS

- Global, seamless operation
- Low power for battery use
- No special permissions or licenses needed to use the LAN
- Robust transmission technology
- Simplified spontaneous cooperation at meetings
- Easy to use for everyone, simple management
- Protection of investment in wired networks
- Security (no one should be able to read my data), Privacy (no one should be able to collect user profiles), Safety (low radiation)
- Transparency concerning applications and higher layer protocols, but also location awareness if necessary

TYPES OF TRANSMISSION

- Infra Red
- Radio wave

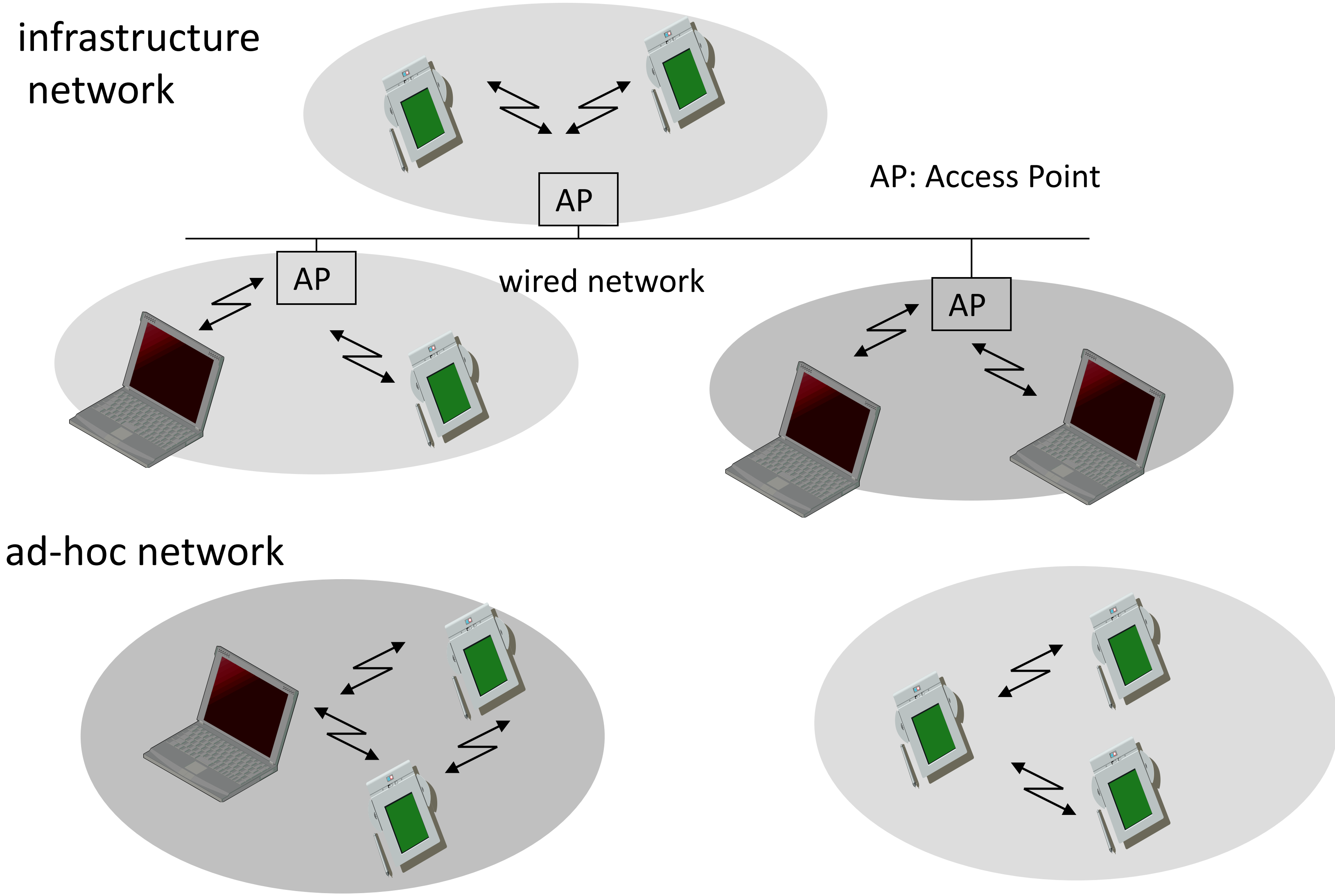
INFRA RED

- Infra Red transmits between 700 nm – 1 mm wavelength
- Diffuse light reflected at walls, furniture etc. or directed light if line of sight(LOS) exists.
- Sender → Laser diodes, Receiver → Photodiodes
- Advantages
  - Simple, cheap
  - No licenses needed
- Disadvantages
  - Interference by sunlight, heat sources etc.
  - Many things shield or absorb IR light
  - Low bandwidth
- Example
  - available in many mobile devices (IR Blaster)

RADIO WAVE

- Typically using the license free ISM band at 2.4 GHz or 5.7GHz
- Advantages
  - Experience from wireless WAN and mobile phones can be used
  - Coverage of larger areas
- Disadvantages
  - Very limited license free frequency bands
  - Interference with other electrical devices
- Example
  - Laptops, Mobile phones

COMPARISON: INFRASTRUCTURE VS. AD-HOC NETWORKS



INFRASTRUCTURE NETWORKS

- The access point does medium access, and also acts as a bridge to other wireless or wired networks.
- Many Network functionalities are done within the access point, but the wireless clients does only data transmission.
- Collisions may occur if medium access of the wireless nodes and the access point is not coordinated.
- Cannot be used for disaster relief in cases where no infrastructure is left

AD-HOC NETWORKS

- Nodes within an ad-hoc network can only communicate if they can reach each other physically, i.e., if they are within each other's radio range or if other nodes can forward the message.
  - Quick replacements of infrastructure or communication scenarios far away from any infrastructure

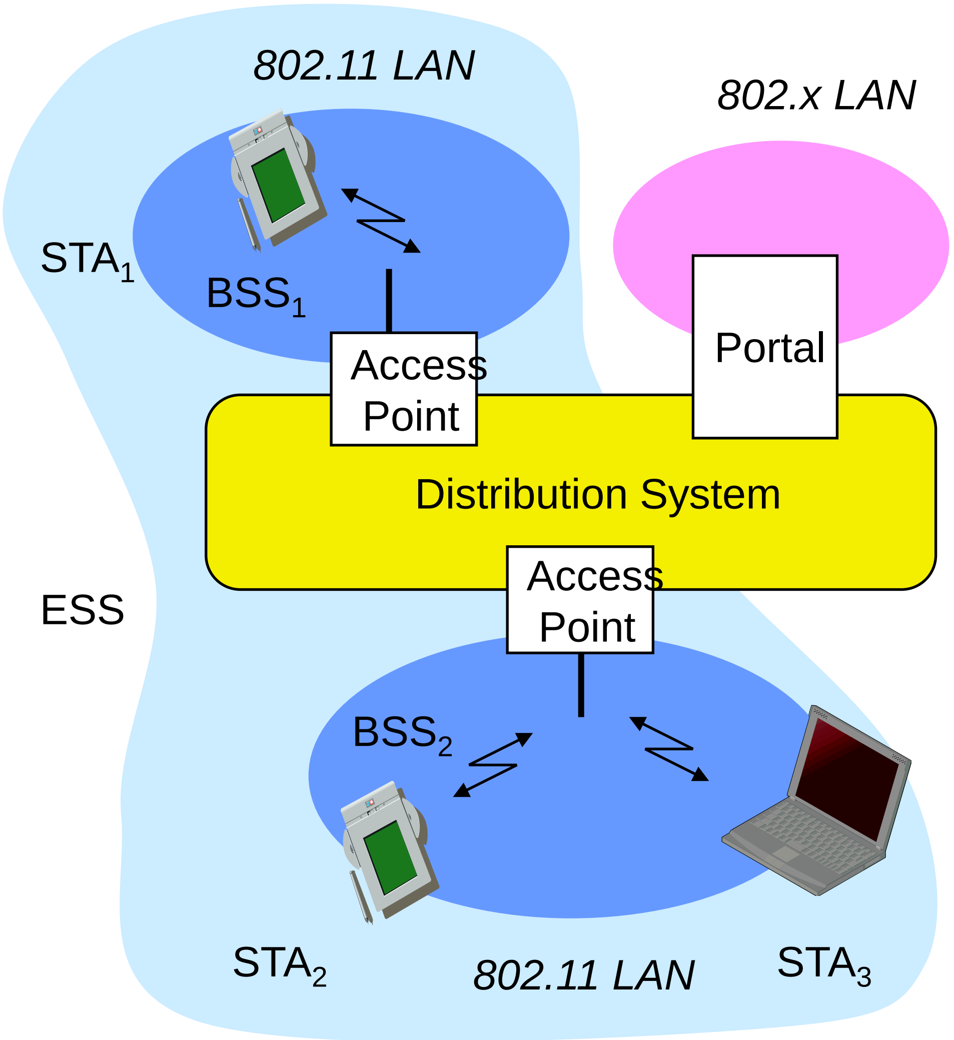
IEEE 802.11

STANDARDS

- LAN standards → 802.x
- 802.11 → Wireless LAN
- The MAC layer should be able to operate with multiple physical layers, each of which exhibits a different medium sense and transmission characteristic.

IEEE Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ax
Year Released	1999	1999	2003	2009	2014	2019
Frequency	5Ghz	2.4GHz	2.4GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz
Maximum Data Rate	54Mbps	11Mbps	54Mbps	600Mbps	1.3Gbps	10-12Gbps

802.11 - ARCHITECTURE OF AN INFRASTRUCTURE NETWORK

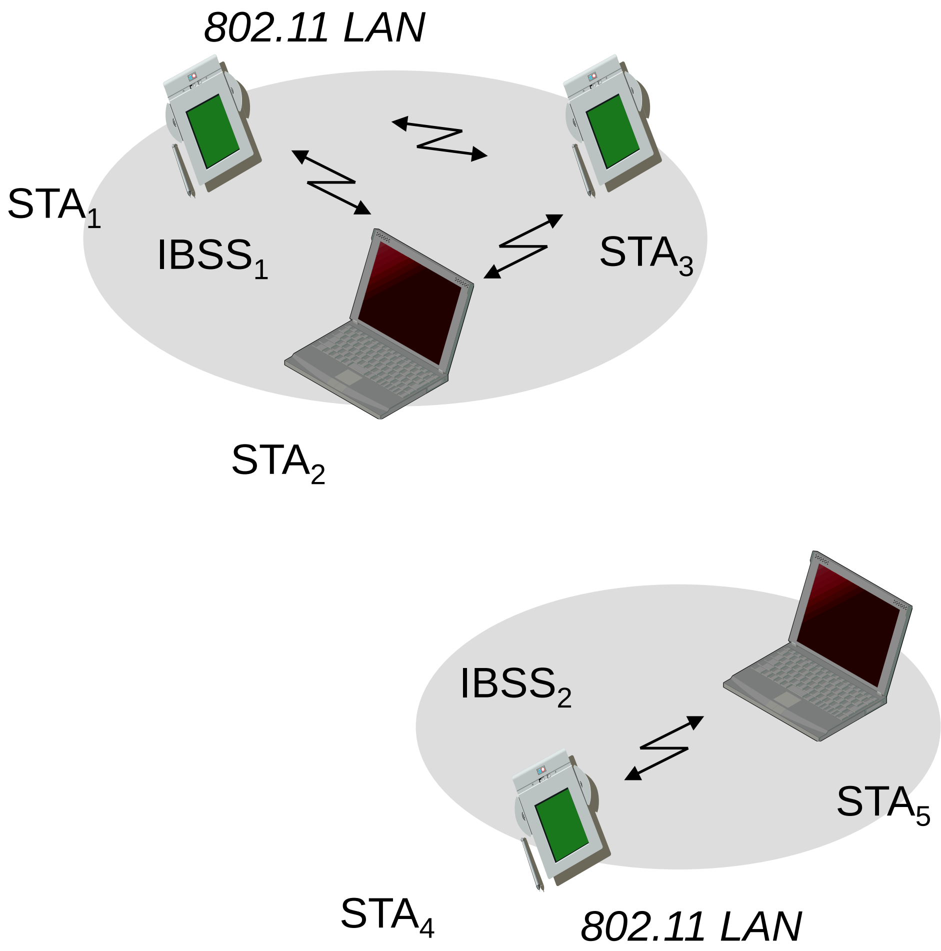


- Station (STA)
  - terminal with access mechanisms to the wireless medium and radio contact to the access point
- Basic Service Set (BSS)
  - group of stations using the same radio frequency
- Access Point
  - station integrated into the wireless LAN and the distribution system
- Portal
  - bridge to other (wired) networks
- Distribution System
  - interconnection network to form one logical network (EES: Extended Service Set) based on several BSS

WORKING PRINCIPLE

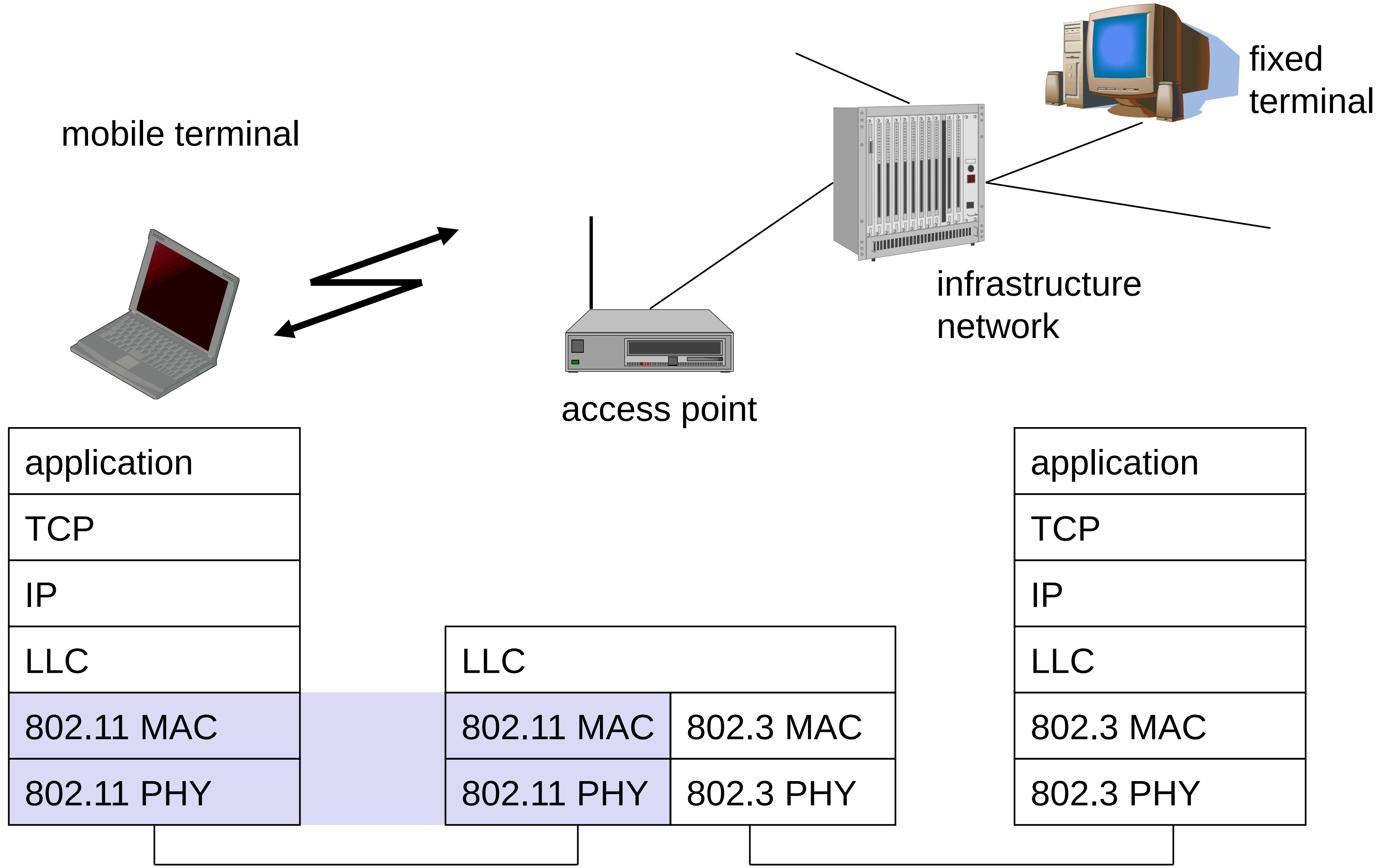
- Stations select an AP and communicate through it.
- The APs support
  - roaming
  - synchronization within a BSS
  - power management
  - media access.
- The distribution system handles data transfer between the different APs.

802.11 - ARCHITECTURE OF AN AD-HOC NETWORK



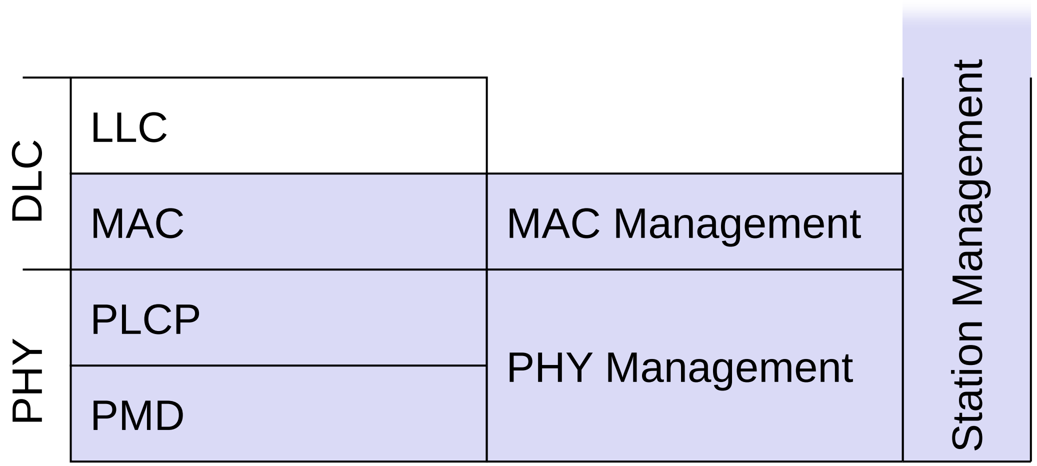
- Direct communication within a limited range
  - Station (STA):
    terminal with access mechanisms to the wireless medium
  - Independent Basic Service Set (IBSS):
    group of stations using the same radio frequency

IEEE STANDARD 802.11



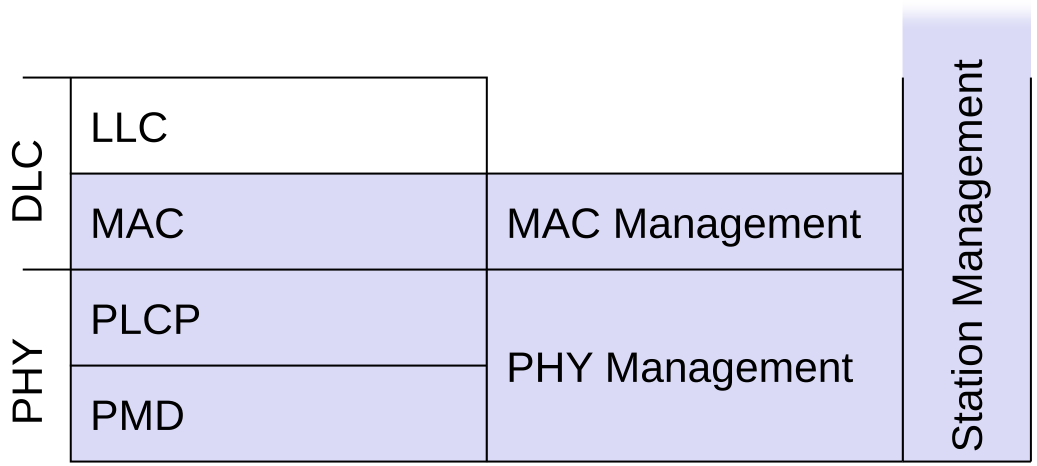
802.11 - LAYERS AND FUNCTIONS

- The IEEE 802.11 standard only covers the physical layer **PHY and medium** access layer **MAC like the other 802.x LANs do.**
- **The physical layer is subdivided** into the **Physical layer convergence protocol (PLCP) and the Physical medium dependent sublayer PMD.**
- The basic tasks of the MAC layer comprise medium access, fragmentation of user data, and encryption.



802.11 - LAYERS AND FUNCTIONS

- MAC
  - access mechanisms, fragmentation, encryption
- MAC Management
  - synchronization, roaming, Management Information Base (MIB), power management
- PLCP Physical Layer Convergence Protocol
  - clear channel assessment (CCA) signal (carrier sense)
- PMD Physical Medium Dependent
  - modulation, coding
- PHY Management
  - channel selection, MIB
- Station Management
  - coordination of all management functions



802.11 - PHYSICAL LAYER

- 3 versions: 2 radio (typ. 2.4 GHz), 1 IR
- All PHY variants include the provision of the **Clear Channel Assessment signal (CCA).**
- This is needed for the MAC mechanisms controlling medium access and indicates if the medium is currently idle.
- The transmission technology determines exactly how this signal is obtained.
- The PHY layer offers a Service Access Point (SAP) with 1 or 2 Mbit/s transfer rate to the MAC layer (basic version of the standard).

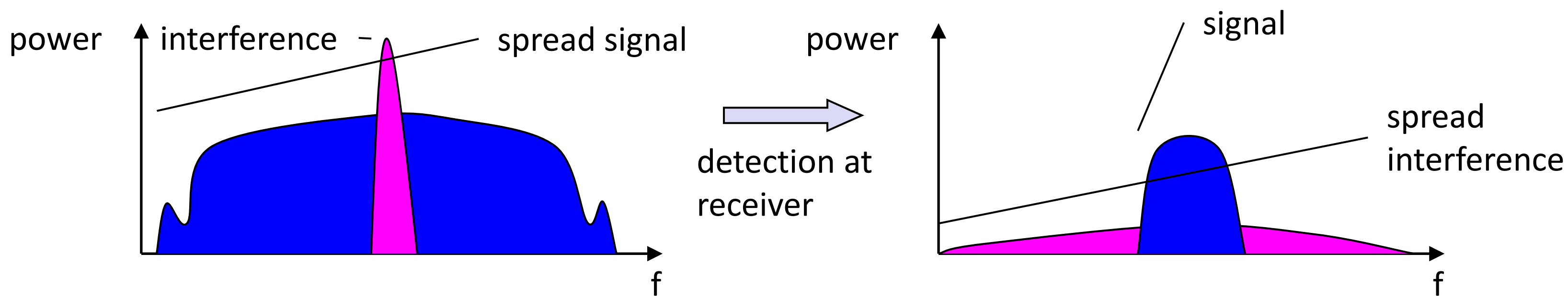
802.11 - PHYSICAL LAYER

- 3 versions: 2 radio (typ. 2.4 GHz), 1 IR
- FHSS (Frequency Hopping Spread Spectrum)
- DSSS (Direct Sequence Spread Spectrum)
- Infrared

802.11 - PHYSICAL LAYER

Spread spectrum technology

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal into a broad band signal using a special code
  - protection against narrow band interference

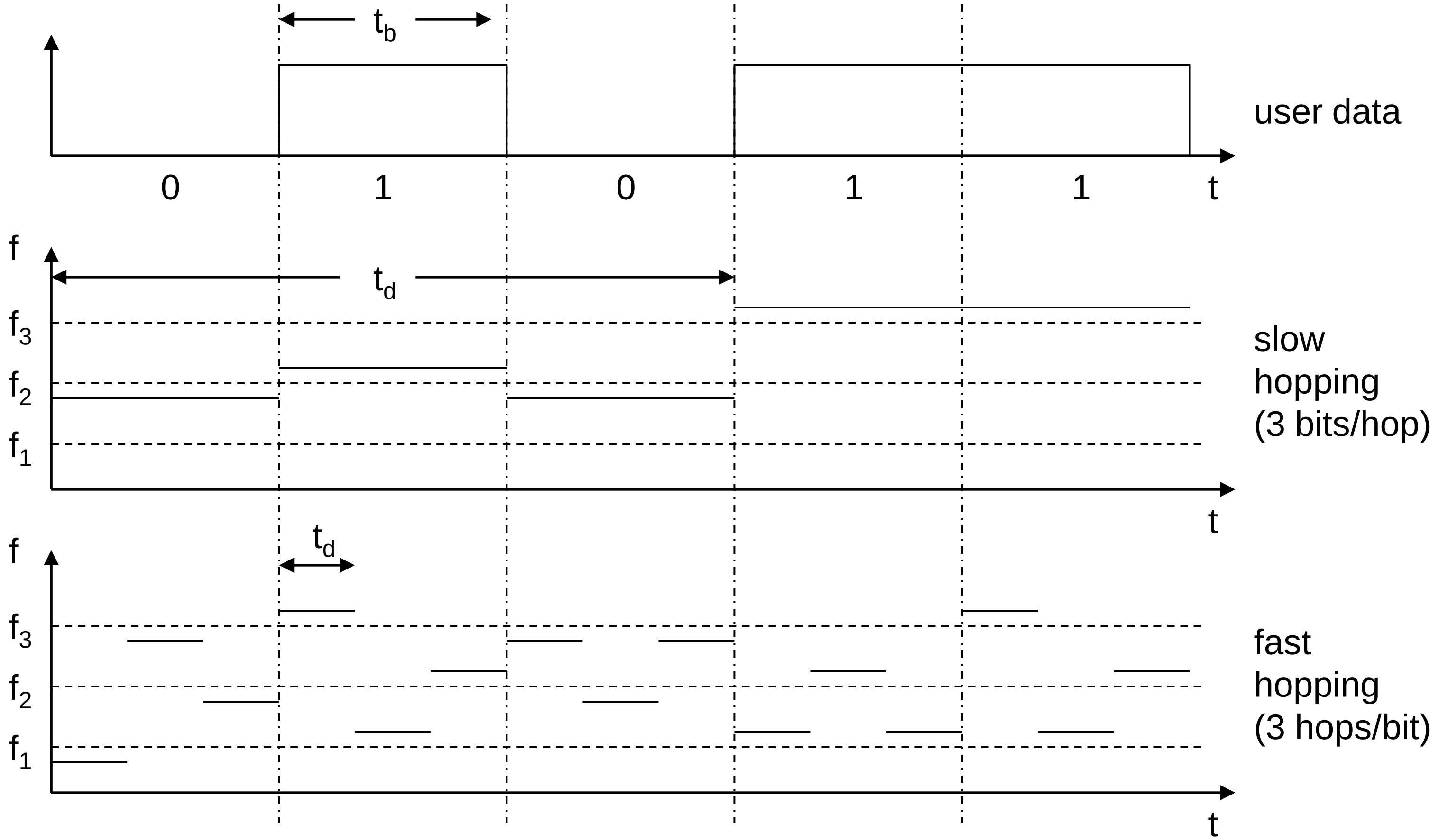


- Side effects:
  - coexistence of several signals without dynamic coordination
  - tap-proof
- Alternatives: Direct Sequence, Frequency Hopping

802.11 - PHYSICAL LAYER

- FHSS (Frequency Hopping Spread Spectrum)
  - spreading, despreading, signal strength, typ. 1 Mbit/s
  - min. 2.5 frequency hops/s (USA), two-level GFSK modulation
- Two versions
  - Fast Hopping:
    several frequencies per user bit
  - Slow Hopping:
    several user bits per frequency

802.11 - PHYSICAL LAYER

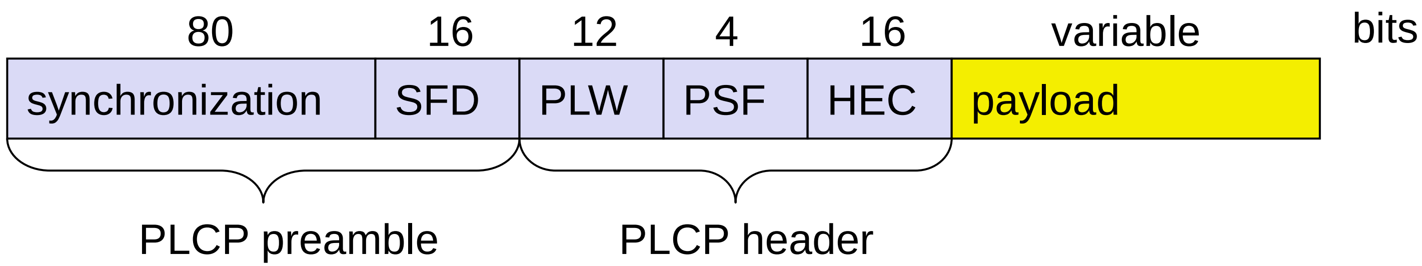


t_b: bit period t_d: dwell time

802.11 - PHYSICAL LAYER

FHSS PHY packet format

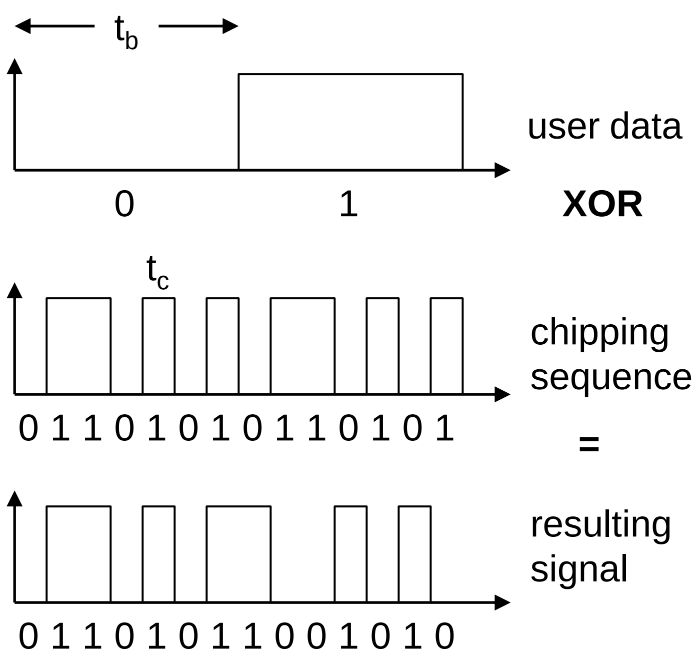
- Synchronization
  - synch with 010101... pattern
- SFD (Start Frame Delimiter)
  - 0000110010111101 start pattern
- PLW (PLCP_PDU Length Word)
  - length of payload incl. 32 bit CRC of payload, PLW < 4096
- PSF (PLCP Signaling Field)
  - data of payload (1 or 2 Mbit/s)
- HEC (Header Error Check)
  - CRC with $x^{16}+x^{12}+x^5+1$



802.11 - PHYSICAL LAYER

- DSSS (Direct Sequence Spread Spectrum)
  - DBPSK modulation for 1 Mbit/s (Differential Binary Phase Shift Keying), DQPSK for 2 Mbit/s (Differential Quadrature PSK)
  - preamble and header of a frame is always transmitted with 1 Mbit/s, rest of transmission 1 or 2 Mbit/s
  - chipping sequence: +1, -1, +1, +1, -1, +1, +1, +1, -1, -1, -1

    (Barker code)
  - max. radiated power 1 W (USA), 100 mW (EU), min. 1mW

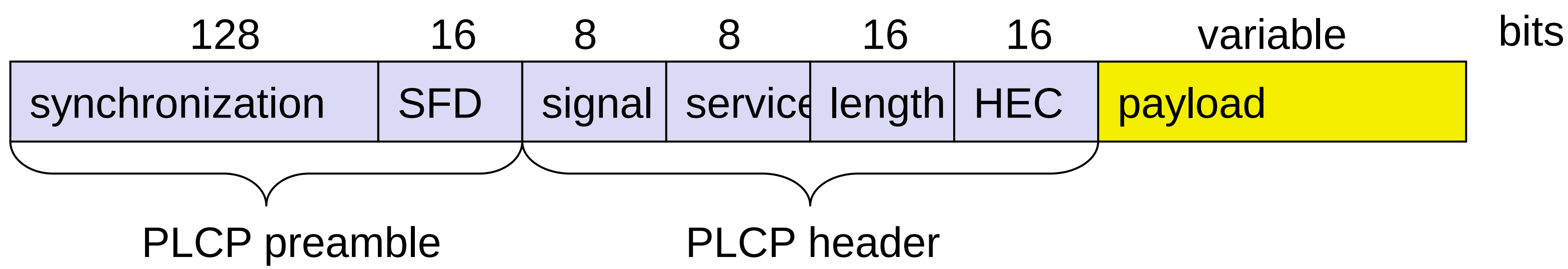


t_b: bit period
t_c: chip period

802.11 - PHYSICAL LAYER

DSSS PHY packet format

- Synchronization
  - synch., gain setting, energy detection, frequency offset compensation
- SFD (Start Frame Delimiter)
  - 1111001110100000
- Signal
  - data rate of the payload (0A: 1 Mbit/s DBPSK; 14: 2 Mbit/s DQPSK)
- Service
  - future use, 00: 802.11 compliant
- Length
  - length of the payload
- HEC (Header Error Check)
  - protection of signal, service and length, $x^{16}+x^{12}+x^5+1$



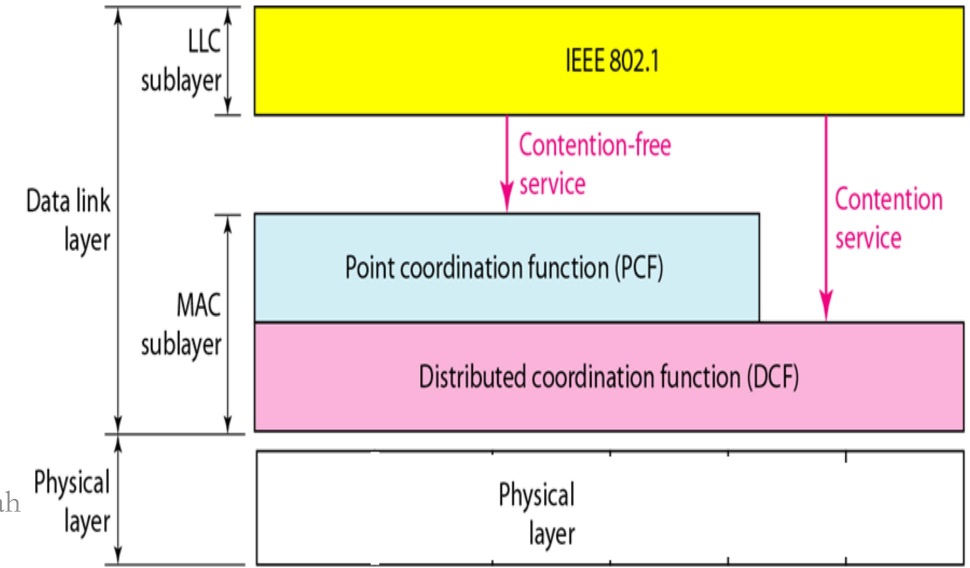
802.11 - PHYSICAL LAYER

Infrared

- The PHY layer, which is based on infra red (IR) transmission, uses near visible light at 850–950 nm.
- The maximum range is about 10 m if no sunlight or heat sources interfere with the transmission.
- Typically, such a network will only work in buildings, e.g., classrooms, meeting rooms etc.
- Frequency reuse is very simple – a wall is more than enough to shield one IR based IEEE 802.11 network from another.

802.11 - MAC LAYER

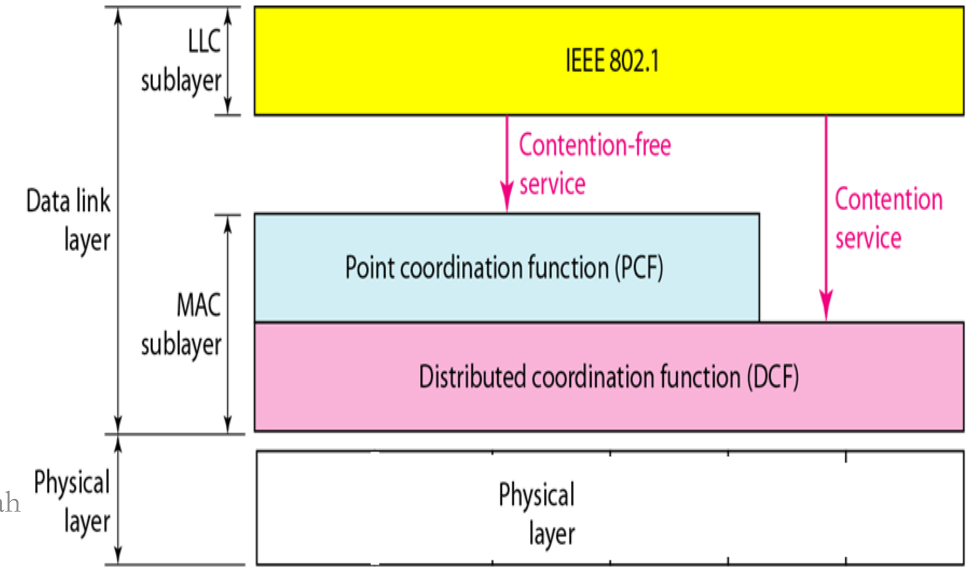
- 3 basic access mechanisms for IEEE 802.11:
  1. The mandatory basic method based on a version of CSMA/CA
  2. An optional method avoiding the hidden terminal problem
  3. A contention- free polling method for time-bounded service.
- The first two methods are also summarized as **distributed coordination function (DCF), the third** method is called **point coordination function (PCF).**



802.11 - MAC LAYER

- **DCF** only offers asynchronous service, while **PCF** offers both asynchronous and time-bounded service but needs an access point to control medium access and to avoid contention.
- The MAC mechanisms are also called **distributed foundation wireless medium access control (DFWMAC).**
- For all access methods, there are several parameters for controlling the waiting time before

  medium access are important.



802.11 - MAC LAYER

- Traffic services
  - Asynchronous Data Service (mandatory)
    - exchange of data packets based on “best-effort”
    - support of broadcast and multicast
  - Time-Bounded Service (optional)
    - implemented using PCF (Point Coordination Function)
- Access methods
  - DFWMAC-DCF CSMA/CA (mandatory)
    - collision avoidance via randomized “back-off“ mechanism
    - minimum distance between consecutive packets
    - ACK packet for acknowledgements (not for broadcasts)
  - DFWMAC-DCF w/ RTS/CTS (optional)
    - Distributed Foundation Wireless MAC
    - avoids hidden terminal problem
  - DFWMAC- PCF (optional)
    - access point polls terminals according to a list

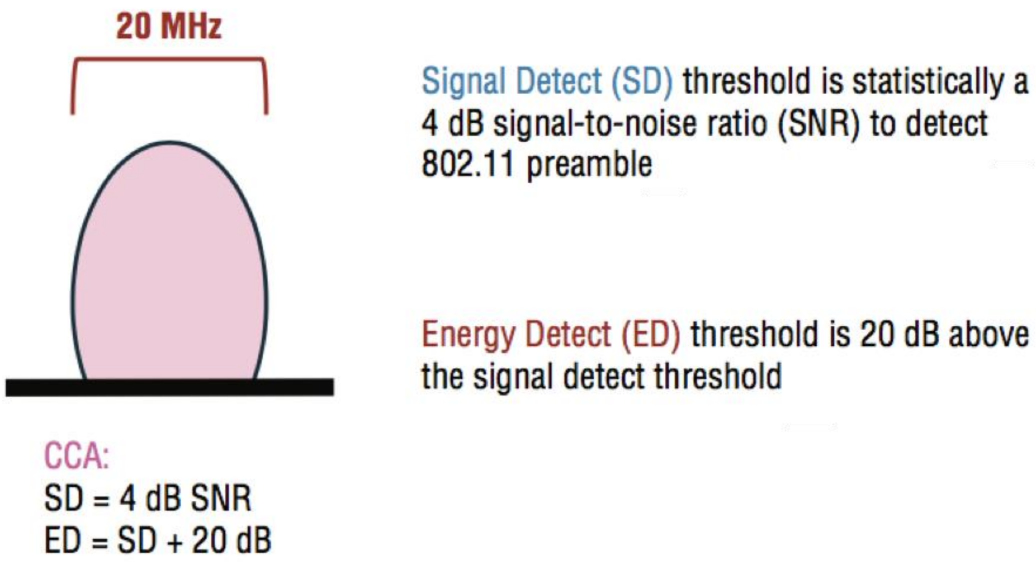
802.11 - MAC LAYER

DCF and CSMA/CA

- Wi-Fi standards (IEEE 802.11) use DCF technique that employs CSMA/CA networking
- Role of DCF and CSMA/CA
  - Used to avoid communication failure due to packet collision
  - Required because the unlicensed ISM band is used
- Carrier Sense
  - To avoid communication failure (due to packets colliding), each node listens to the shared medium (ie 2.4 and 5GHz wireless channel) to detect whether another node is communicating or not.

802.11 - MAC LAYER

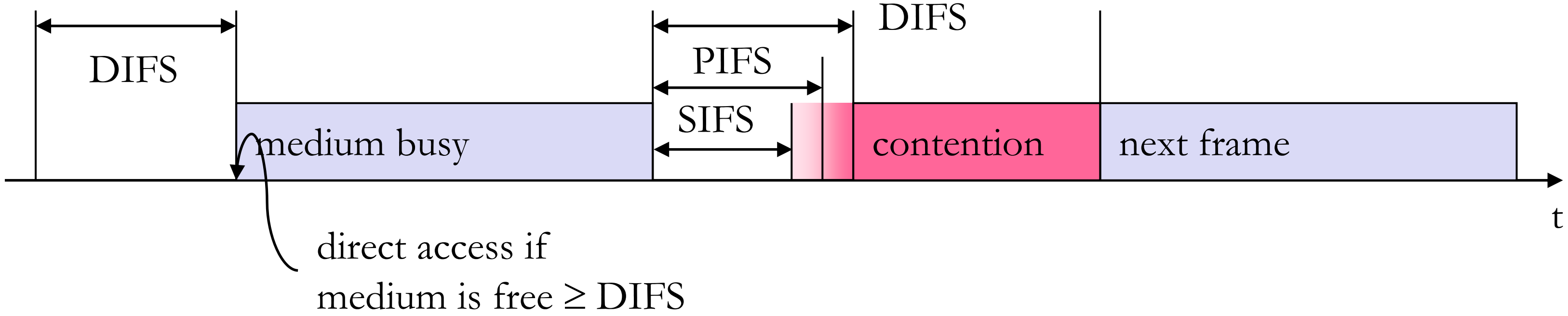
- Carrier sense is done base on CCA, Clear Channel Assessment



802.11 - MAC LAYER

- Collision Avoidance
  - If another node's communication is detected, other nodes will not transmit for a specific period of time (NAV period)
- NAV (Network Allocation Vector)
  - Period of time to wait for another node to complete packet communications.
- IFS (Inter Frame Spacing) Priority
  - Control priority using inter-frame space duration

802.11 - MAC LAYER

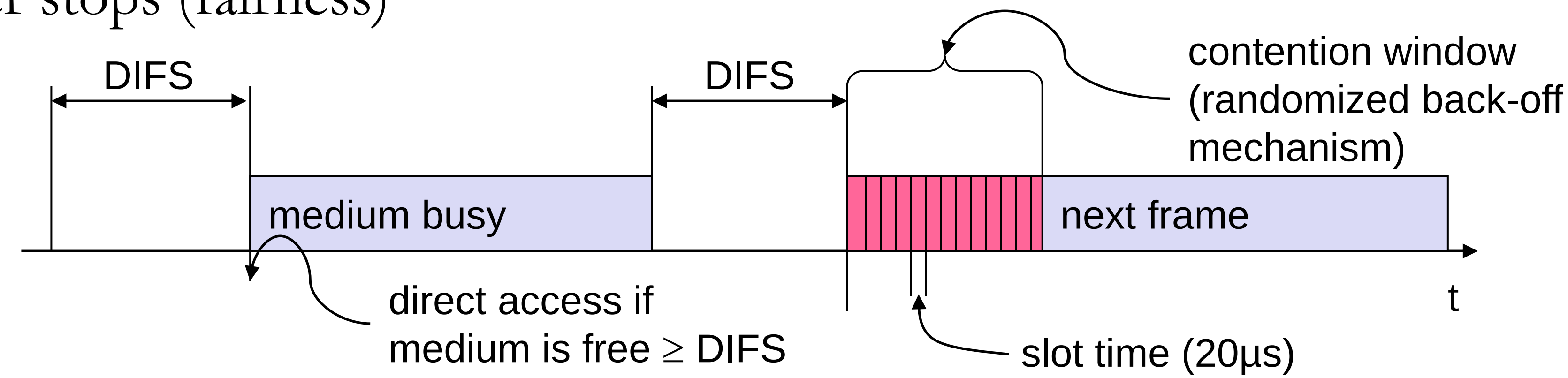


- SIFS (Short Inter Frame Spacing)
  - Short Waiting Time
  - Highest priority, for ACK, CTS, polling response
  - DSSS →10 µs FHSS →28 µs
- PIFS (Point Coordination Function IFS)
  - Waiting Time between DIFS and SIFS
  - Medium priority, for time-bounded service using PCF
  - PIFS = SIFS +Slot Time
- DIFS (DCF, Distributed Coordination Function IFS)
  - Denotes long waiting Time.
  - lowest priority, for asynchronous data service
  - DIFS = SIFS +2 x Slot Time

802.11 - MAC LAYER

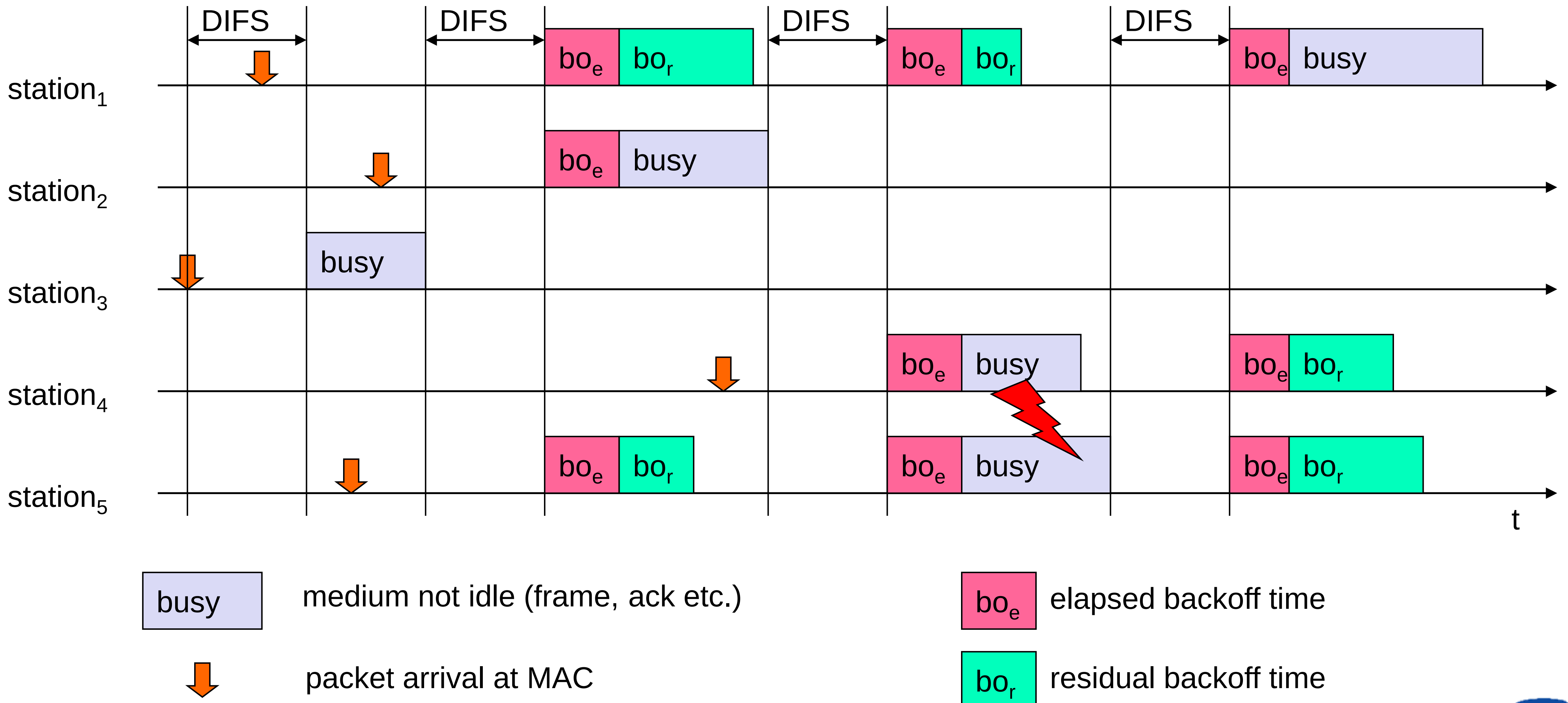
Basic DFWMAC-DCF using CSMA/CA

- Station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- If the medium is free for the duration of an Inter-Frame Space (IFS), the station can start sending (IFS depends on service type)
- If the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
- If another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)



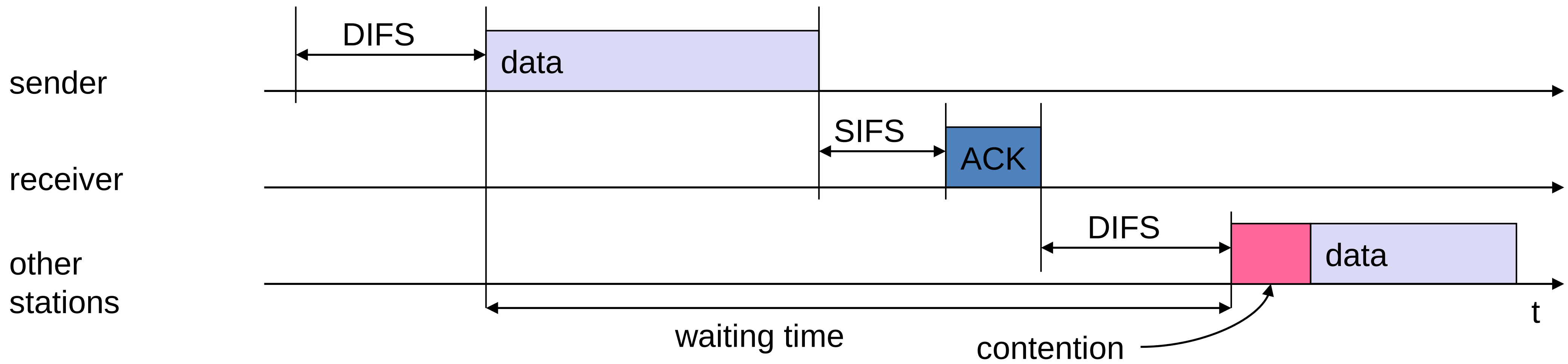
802.11 - MAC LAYER

- 802.11 - competing stations - simple version



802.11 - MAC LAYER

- Sending unicast packets
  - station has to wait for DIFS before sending data
  - receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
  - automatic retransmission of data packets in case of transmission errors

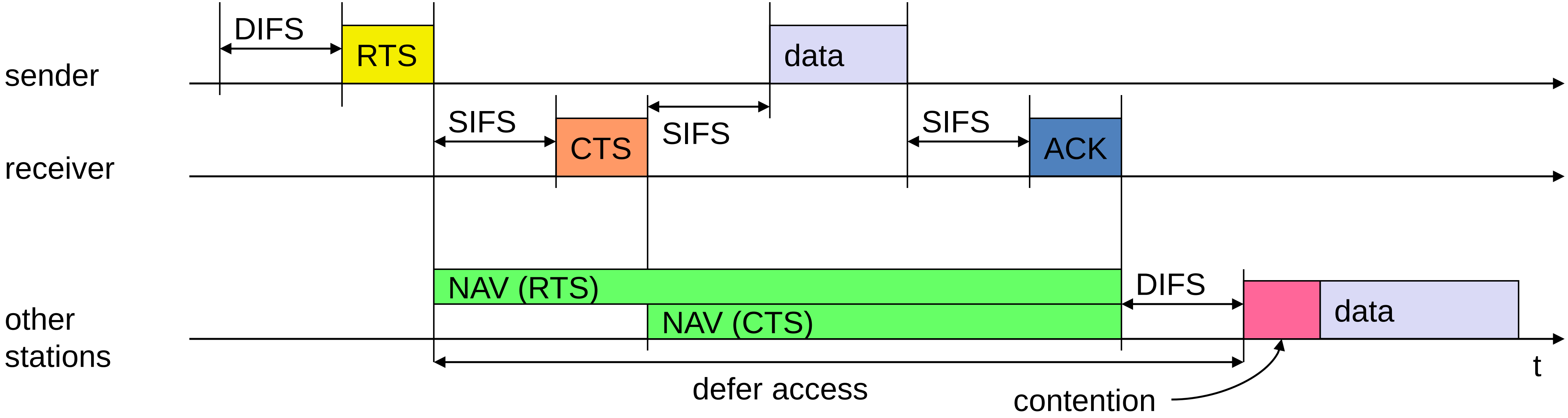


802.11 - MAC LAYER

DFWMAC-DCF with RTS/CTS extension

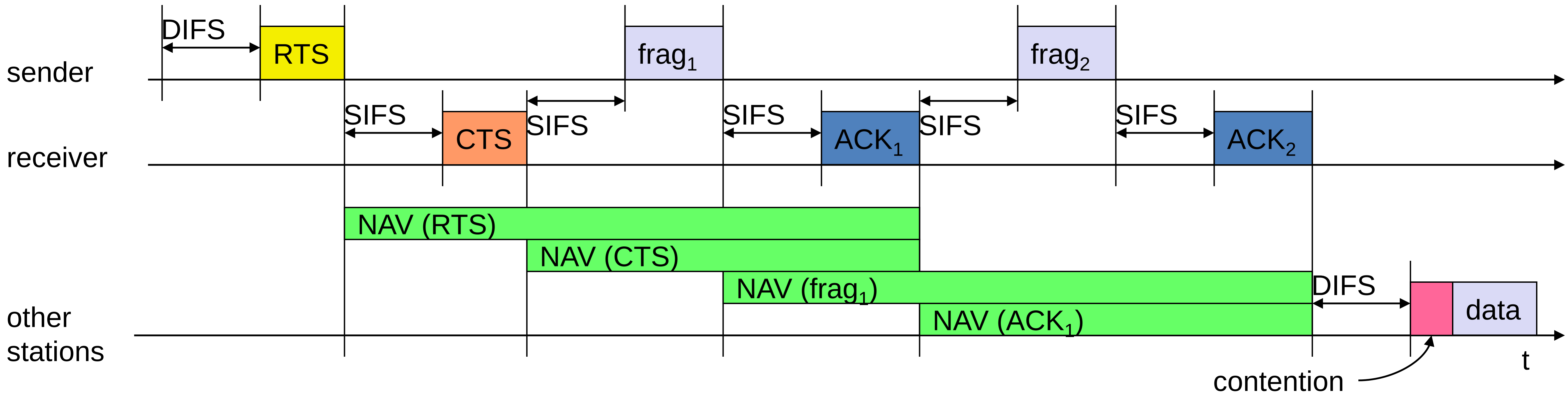
- Station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
- Acknowledgement via CTS after SIFS by receiver (if ready to receive)
- Sender can now send data at once, acknowledgement via ACK
- Other stations store medium reservations distributed via RTS and CTS

802.11 - MAC LAYER



802.11 - MAC LAYER

Fragmentation

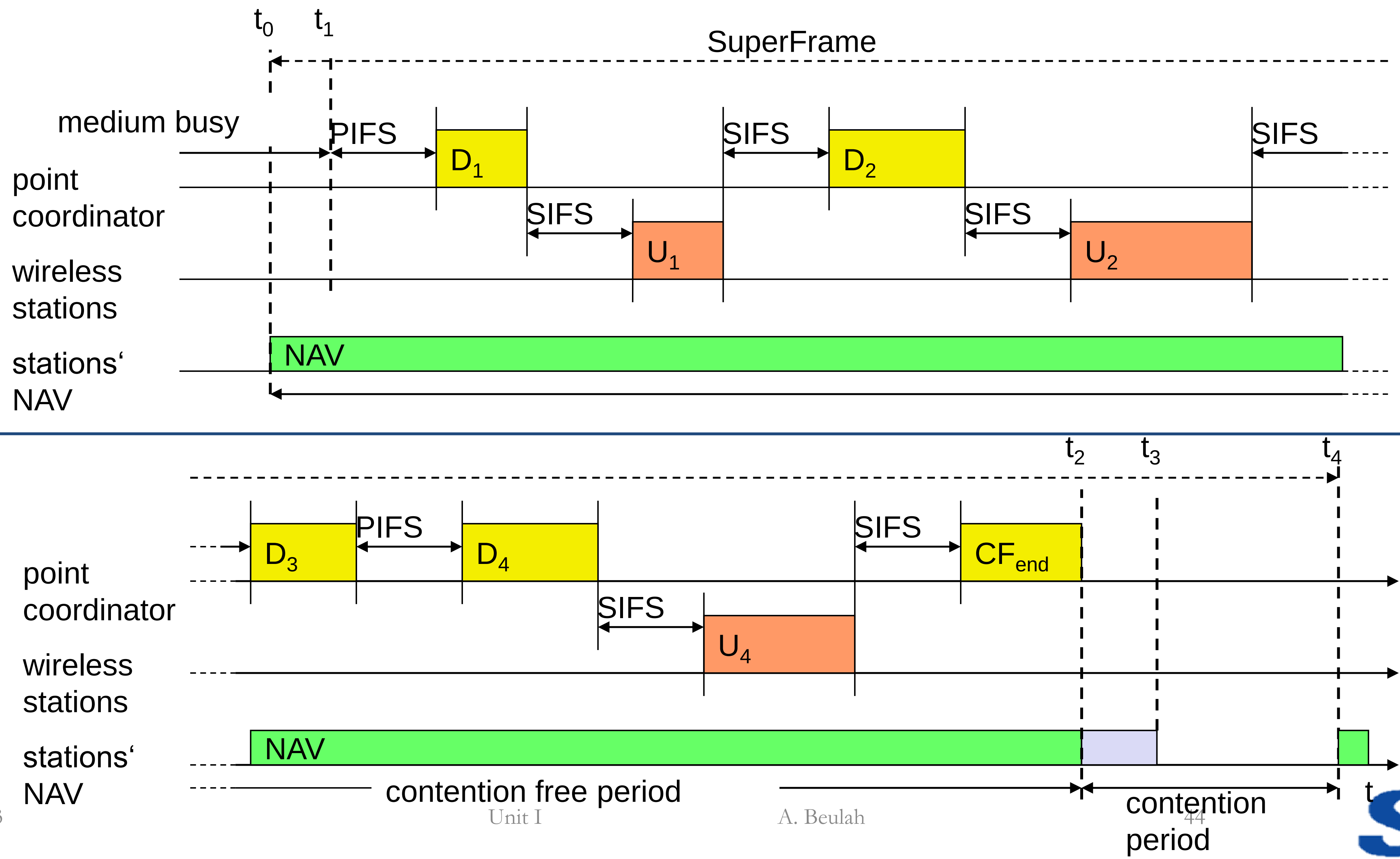


802.11 - MAC LAYER

DFWMAC-PCF with polling

- Using PCF requires an access point that controls medium access and polls the single nodes.
- Adhoc networks cannot use this function so, provide no QoS but best effort in IEEE 802.11 WLANs.
- The point coordinator in the access point splits the access time into superframe periods.
- A superframe comprises a contention-free period and a contention period.
- The contention period can be used for the two access mechanisms presented above.

802.11 - MAC LAYER



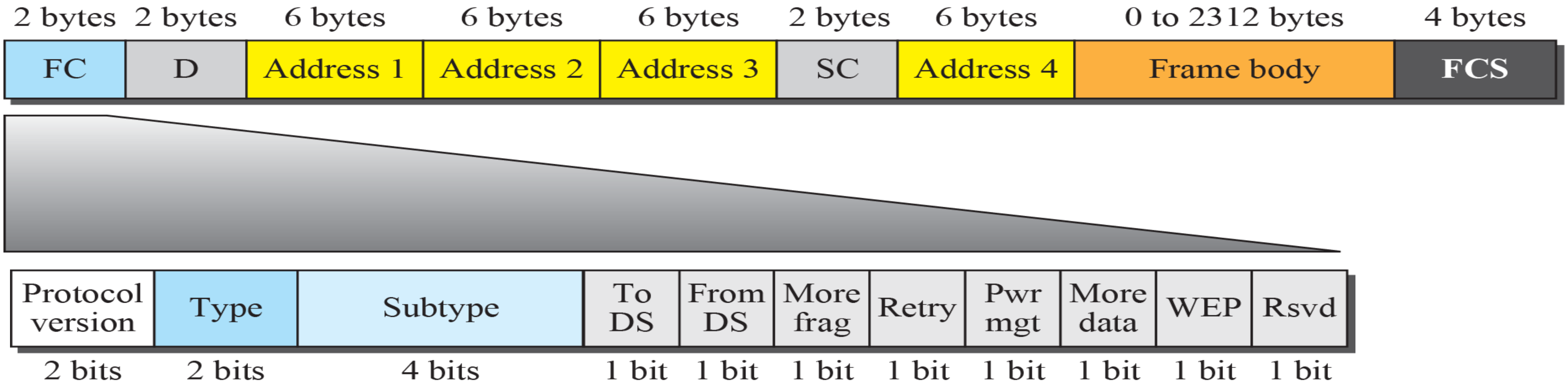
802.11 - MAC LAYER

802.11 - Frame format

- Types
  - control frames, management frames, data frames
- Sequence numbers
  - important against duplicated frames due to lost ACKs
- Addresses
  - receiver, transmitter (physical), BSS identifier, sender (logical)
- Miscellaneous
  - sending time, checksum, frame control, data

802.11 - MAC LAYER

- Frame format



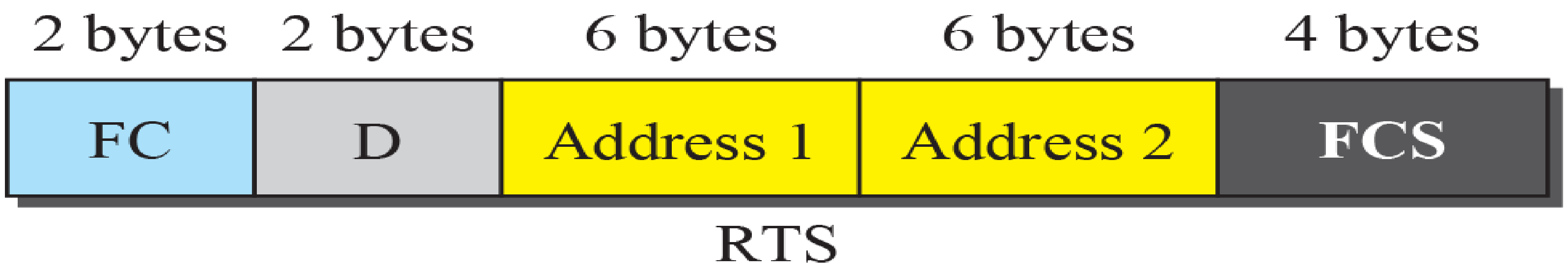
802.11 - MAC LAYER

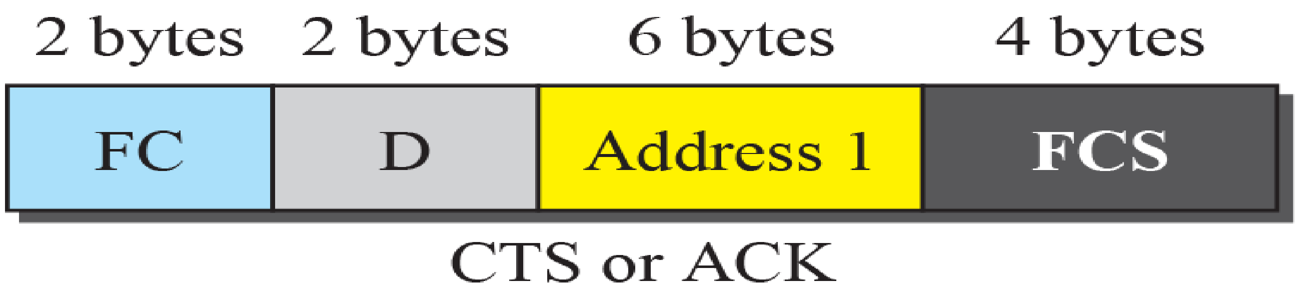
Field	*Explanation*
Version	Current version is 0
Type	Type of information: management (00), control (01), or data (10)
Subtype	Subtype of each type (see Table 6.2)
To DS	Defined later
From DS	Defined later
More flag	When set to 1, means more fragments
Retry	When set to 1, means retransmitted frame
Pwr mgt	When set to 1, means station is in power management mode
More data	When set to 1, means station has more data to send
WEP	Wired equivalent privacy (encryption implemented)
Rsvd	Reserved

Subtype	*Meaning*
1011	Request to send (RTS)
1100	Clear to send (CTS)
1101	Acknowledgment (ACK)

802.11 - MAC LAYER

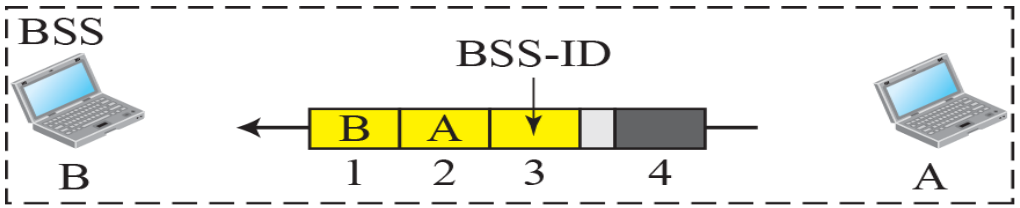
- Control Frames



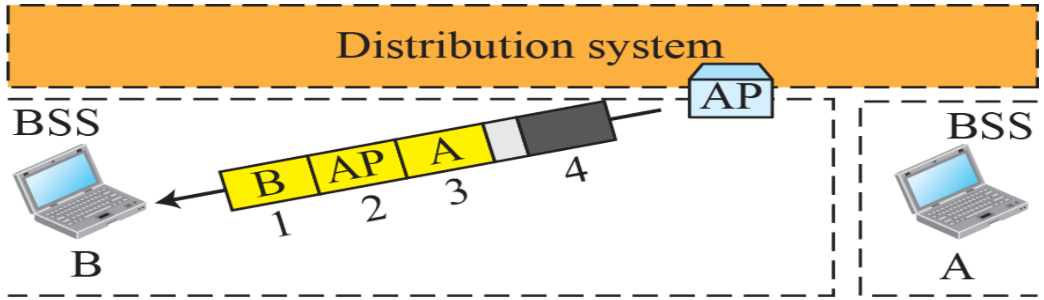


802.11 - MAC LAYER

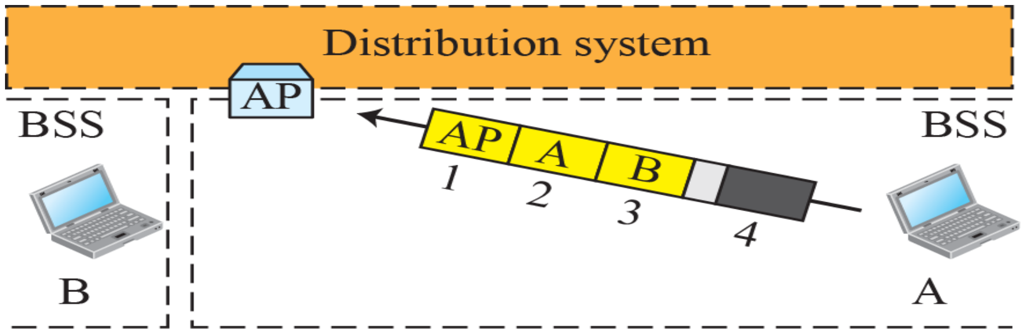
- Addressing mechanism



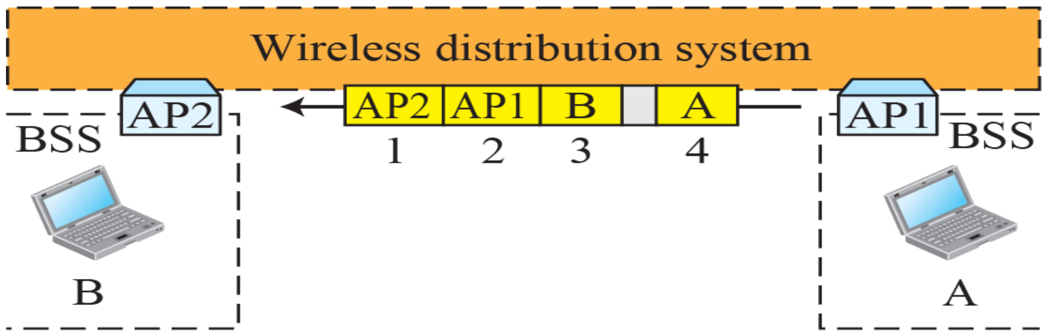
a. Case 1



b. Case 2



c. Case 3



d. Case 4

802.11 - MAC LAYER

- Addressing mechanism

scenario	to DS	from DS	address 1	address 2	address 3	address 4
ad-hoc network	0	0	DA	SA	BSSID	-
infrastructure network, from AP	0	1	DA	BSSID	SA	-
infrastructure network, to AP	1	0	BSSID	SA	DA	-
infrastructure network, within DS	1	1	RA	TA	DA	SA

DS: Distribution System
AP: Access Point
DA: Destination Address
SA: Source Address
BSSID: Basic Service Set Identifier
RA: Receiver Address
TA: Transmitter Address

802.11 - MAC LAYER

802.11 - MAC management

- Synchronization
  - try to find a LAN, try to stay within a LAN
  - timer etc.
- Power management
  - sleep-mode without missing a message
  - periodic sleep, frame buffering, traffic measurements
- Association/Reassociation
  - integration into a LAN
  - roaming, i.e. change networks by changing access points
  - scanning, i.e. active search for a network
- MIB - Management Information Base
  - managing, read, write

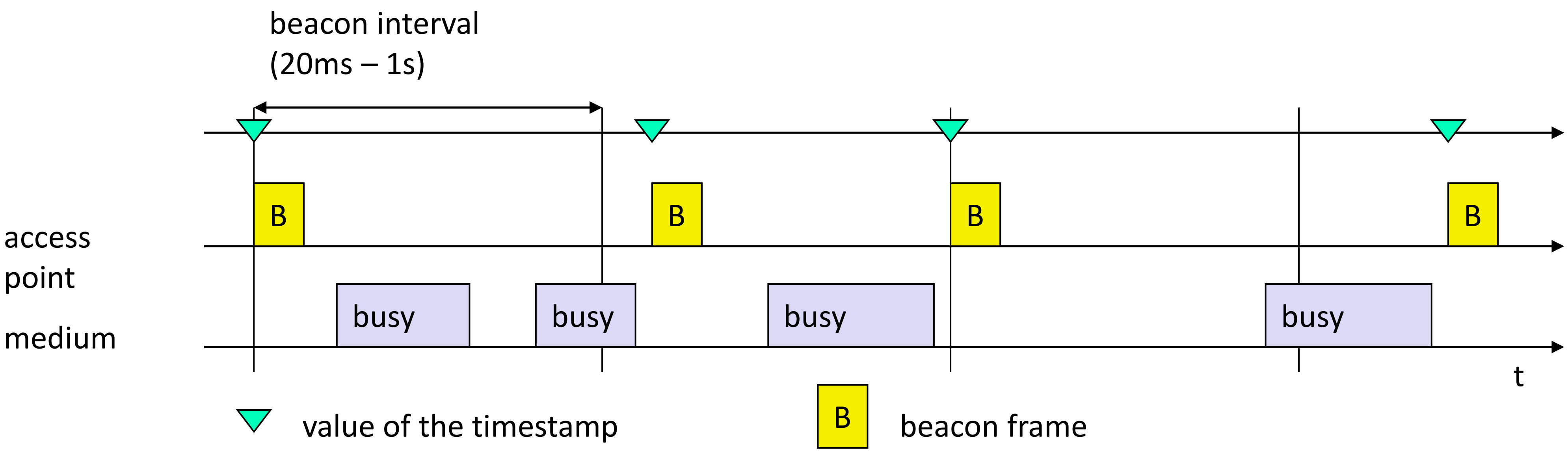
802.11 - MAC LAYER

Synchronization

- Timing synchronization function (TSF)
- Used for power management
- Beacons sent at well known intervals
- All station timers in BSS are synchronized

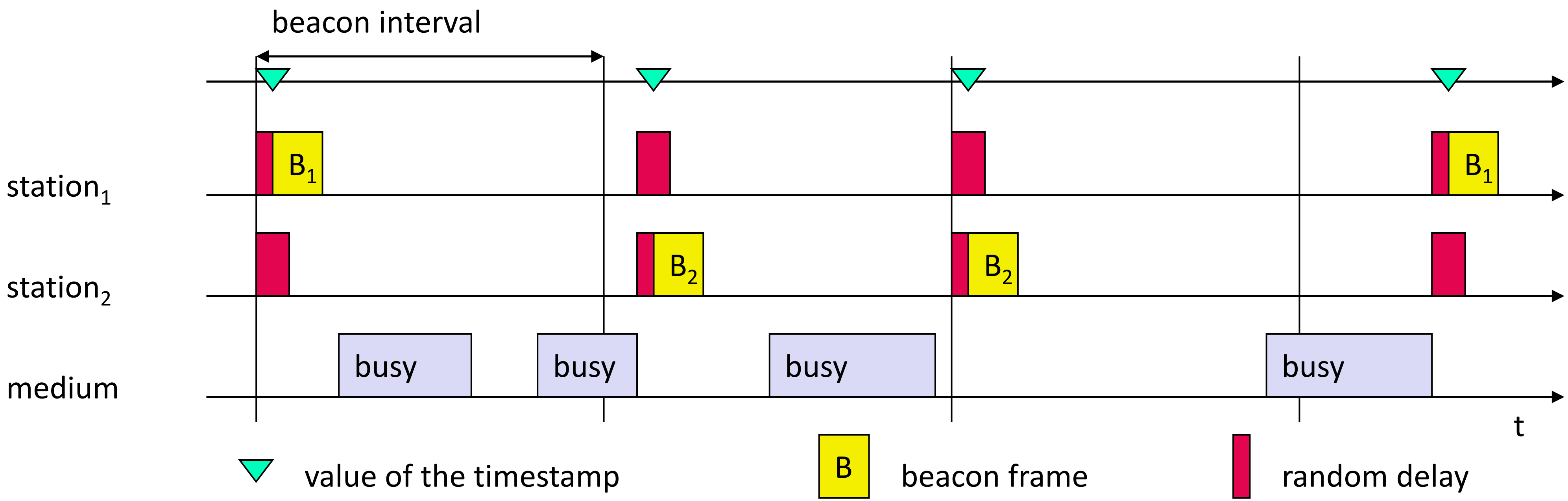
802.11 - MAC LAYER

- **Synchronization using a Beacon (infrastructure)**



802.11 - MAC LAYER

- **Synchronization using a Beacon (ad-hoc)**



802.11 - MAC LAYER

Power management

- Idea: switch the transceiver off if not needed
- States of a station: sleep and awake
- Timing Synchronization Function (TSF)
  - stations wake up at the same time
- Infrastructure
  - Traffic Indication Map (TIM)
    - list of unicast receivers transmitted by AP
  - Delivery Traffic Indication Map (DTIM)
    - list of broadcast/multicast receivers transmitted by AP
- Ad-hoc
  - Ad-hoc Traffic Indication Map (ATIM)
    - announcement of receivers by stations buffering frames
    - more complicated - no central AP
    - collision of ATIMs possible (scalability?)
- APSD (Automatic Power Save Delivery)
  - new method in 802.11e replacing above schemes

802.11 - MAC LAYER

Power management approach

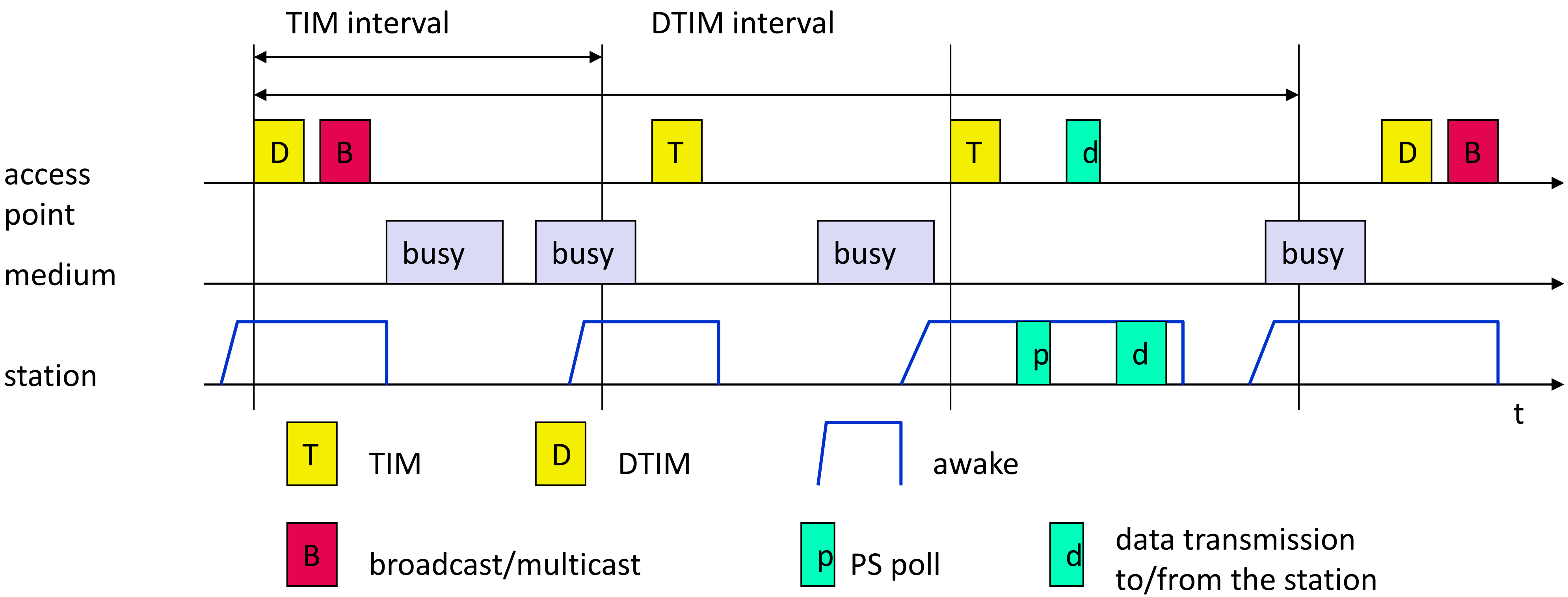
- Allow idle stations to go to sleep

  - station's power save mode stored in AP

- APs buffer packets for sleeping stations- AP announces which stations have frames buffered - traffic indication map (TIM) sent with every beacon
- Power saving stations wake up periodically

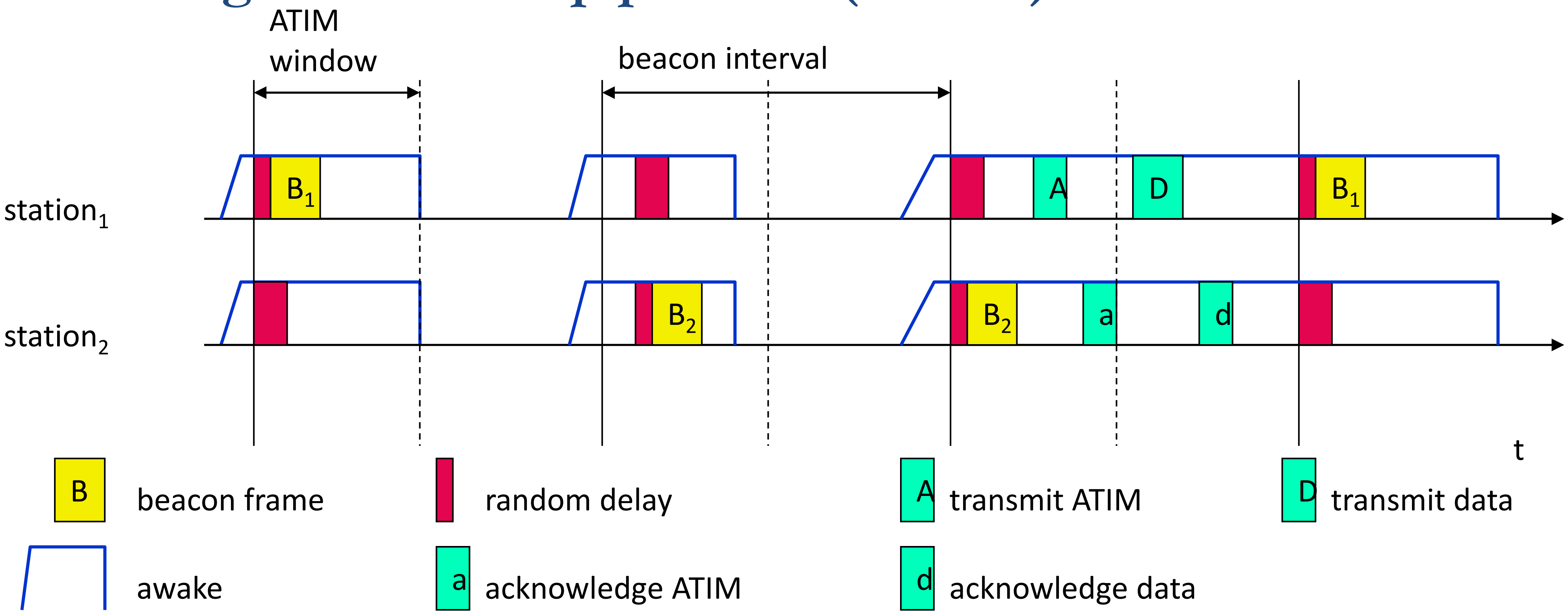
802.11 - MAC LAYER

- **Power saving with wake-up patterns (infrastructure)**



802.11 - MAC LAYER

- **Power saving with wake-up patterns (ad-hoc)**



802.11 - MAC LAYER

802.11 – Roaming

- No or bad connection? Then perform:
- Scanning
  - scan the environment, i.e., listen into the medium for beacon signals or send probes into the medium and wait for an answer
- Reassociation Request
  - station sends a request to one or several AP(s)
- Reassociation Response
  - success: AP has answered, station can now participate
  - failure: continue scanning
- AP accepts Reassociation Request
  - signal the new station to the distribution system
  - the distribution system updates its data base (i.e., location information)
  - typically, the distribution system now informs the old AP so it can release resources
- Fast roaming – 802.11r
  - e.g. for vehicle-to-roadside networks

802.11 - MAC LAYER

- Mobile stations may move - beyond the coverage area of their AP
  - but within range of another AP
- Re association allows station to continue operation.

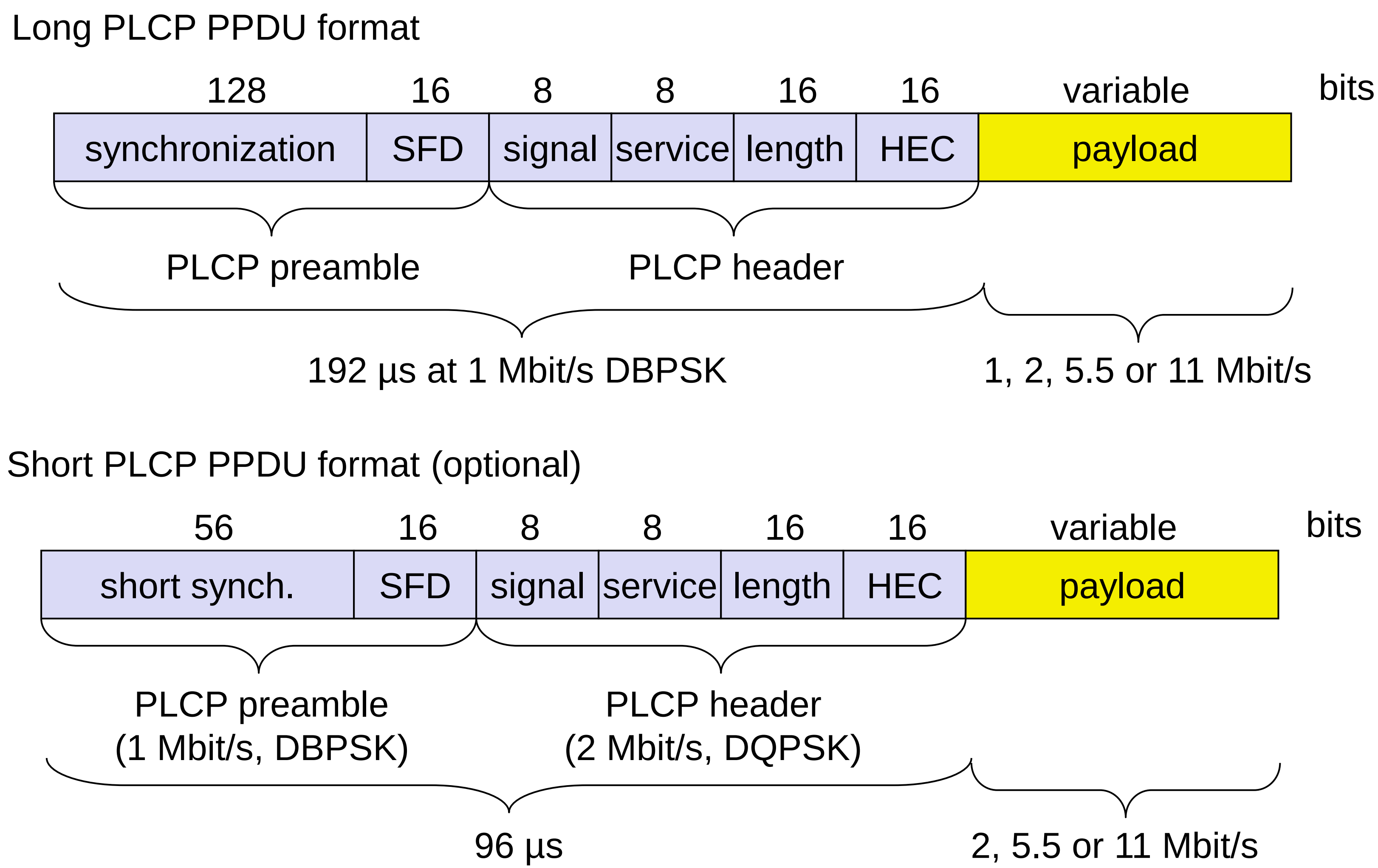
802.11 - MAC LAYER

- **802.11b**

- Data rate
  - 1, 2, 5.5, 11 Mbit/s, depending on SNR
  - User data rate max. approx. 6 Mbit/s
- Transmission range
  - 300m outdoor, 30m indoor
  - Max. data rate ~10m indoor
- Frequency
  - DSSS, 2.4 GHz ISM-band
- Security
  - Limited, WEP insecure, SSID
- Availability
  - Many products, many vendors
- Connection set-up time
  - Connectionless/always on
- Quality of Service
  - Typ. Best effort, no guarantees (unless polling is used, limited support in products)
- Manageability
  - Limited (no automated key distribution, sym. Encryption)
- Special Advantages/Disadvantages
  - Advantage: many installed systems, lot of experience, available worldwide, free ISM-band, many vendors, integrated in laptops, simple system
  - Disadvantage: heavy interference on ISM-band, no service guarantees, slow relative speed only

802.11 - MAC LAYER

- **IEEE 802.11b**
- **PHY frame formats**



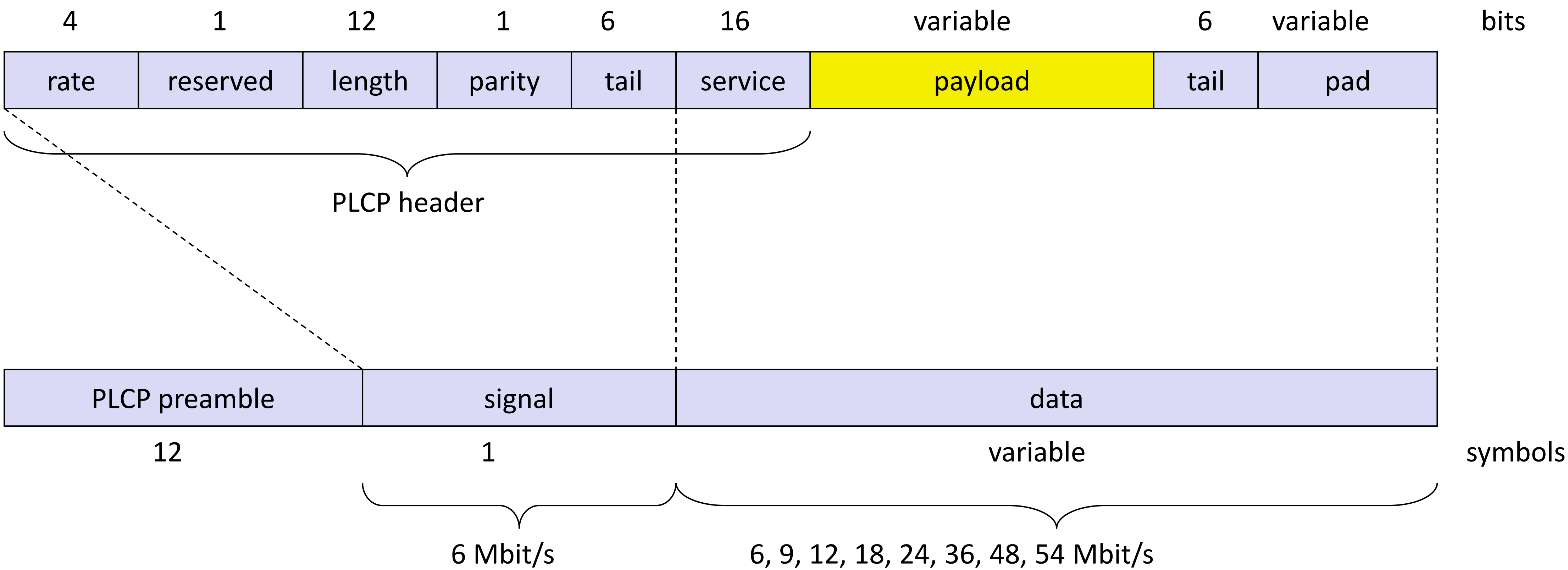
802.11 - MAC LAYER

- **802.11a**

- Data rate
  - 6, 9, 12, 18, 24, 36, 48, 54 Mbit/s, depending on SNR
  - User throughput (1500 byte packets): 5.3 (6), 18 (24), 24 (36), 32 (54)
  - 6, 12, 24 Mbit/s mandatory
- Transmission range
  - 100m outdoor, 10m indoor
    - E.g., 54 Mbit/s up to 5 m, 48 up to 12 m, 36 up to 25 m, 24 up to 30m, 18 up to 40 m, 12 up to 60 m
- Frequency
  - Free 5.15-5.25, 5.25-5.35, 5.725-5.825 GHz ISM-band
- Security
  - Limited, WEP insecure, SSID
- Availability
  - Some products, some vendors
- Connection set-up time
  - Connectionless/always on
- Quality of Service
  - Typ. best effort, no guarantees (same as all 802.11 products)
- Manageability
  - Limited (no automated key distribution, sym. Encryption)
- Special Advantages/Disadvantages
  - Advantage: fits into 802.x standards, free ISM-band, available, simple system, uses less crowded 5 GHz band
  - Disadvantage: stronger shading due to higher frequency, no QoS

802.11 - MAC LAYER

- **IEEE 802.11a**
- **PHY frame formats**



SUMMARY

- MAC Protocols
  - Properties, Issues
  - Different Categories of MAC

TEST YOUR KNOWLEDGE

- Switches are capable of reading the MAC address field from each frame that comes to them. So we can say they work on the ____________ layer from the TCP/IP model.
  - Physical
  - Network
  - Data Link

- In IEEE 802.11, a ___ is made of stationary or mobile wireless stations and an optional central base station, known as the access point (AP)
  - ESS
  - BSS
  - CSS

TEST YOUR KNOWLEDGE

- A BSS without an AP is called an __________.
  - an ad hoc architecture
  - an infrastructure network

- communication between two stations in two different BSSs usually occurs via two _________.
  - BSSs
  - ESSs
  - APs

TEST YOUR KNOWLEDGE

- When a frame is going from one station to another in the same BSS without passing through the distribution system, the address flag is _____
  - 00
  - 01
  - 10
- When a frame is going from a station to an AP, the address flag is _____.
  - 01
  - 10
  - 11

REFERENCES

- Jochen H. Schller, “Mobile Communications”, Second Edition, Pearson Education, New Delhi, 2007.
- Behrouz A. Forouzan, “Data communication and Networking”, Fourth Edition,Tata McGraw – Hill, 2011.