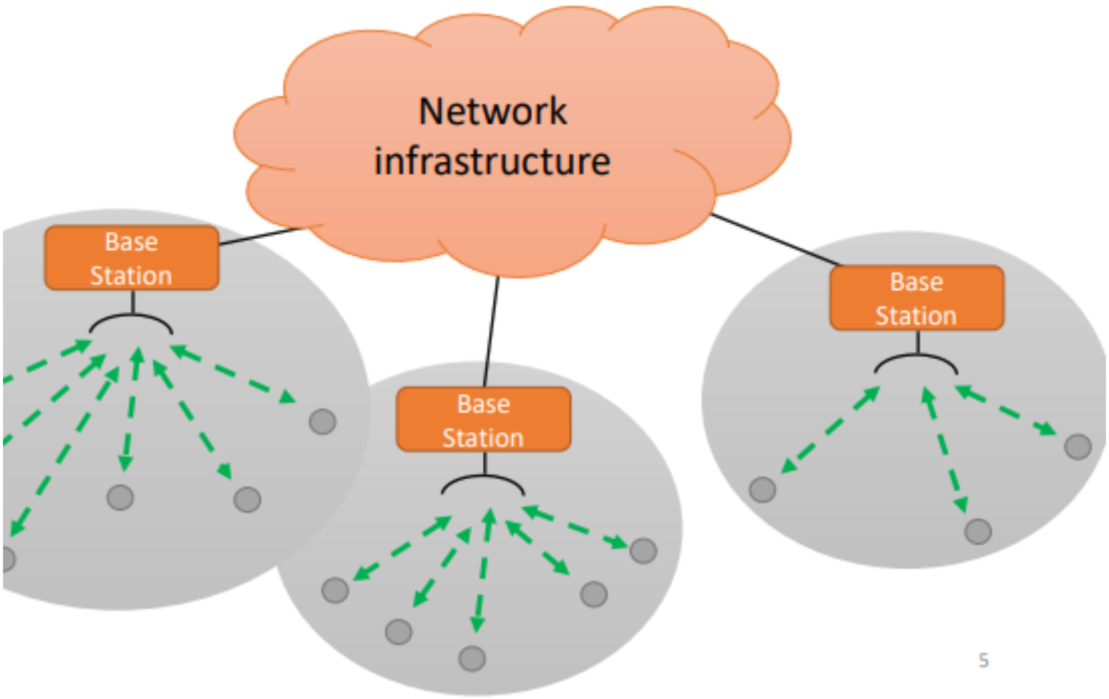
B 01 - Wireless Networks

Why wireless networks?

- need cables in computer to
  - communicate: strasfer data between nodes
  - provide power: between devices
- Cyber-physical systems embed computers in physical objects
  - they're everywere: free placement, mobility, exposed to the wild → go wireless (can't wire everything)
  - hence: wireless to replace cable in communications and batteries to replace cables in power supply

Wireless networks

- network of **hosts** connected by **wireless links**
  - **hosts**: end-system devices that runs apps
    - mobile (often, but not necessary)
    - battery-powered (typycally)
- 2 modes of operaiotions
  1. **infrastructure**: BS(base stations) || wired access points
  2. **ad hoc networking**: no centralised coordinatiors (that coordinate shared medium), links connected wired
- **elements of wireless network**



  -
  - **wireless hosts**:

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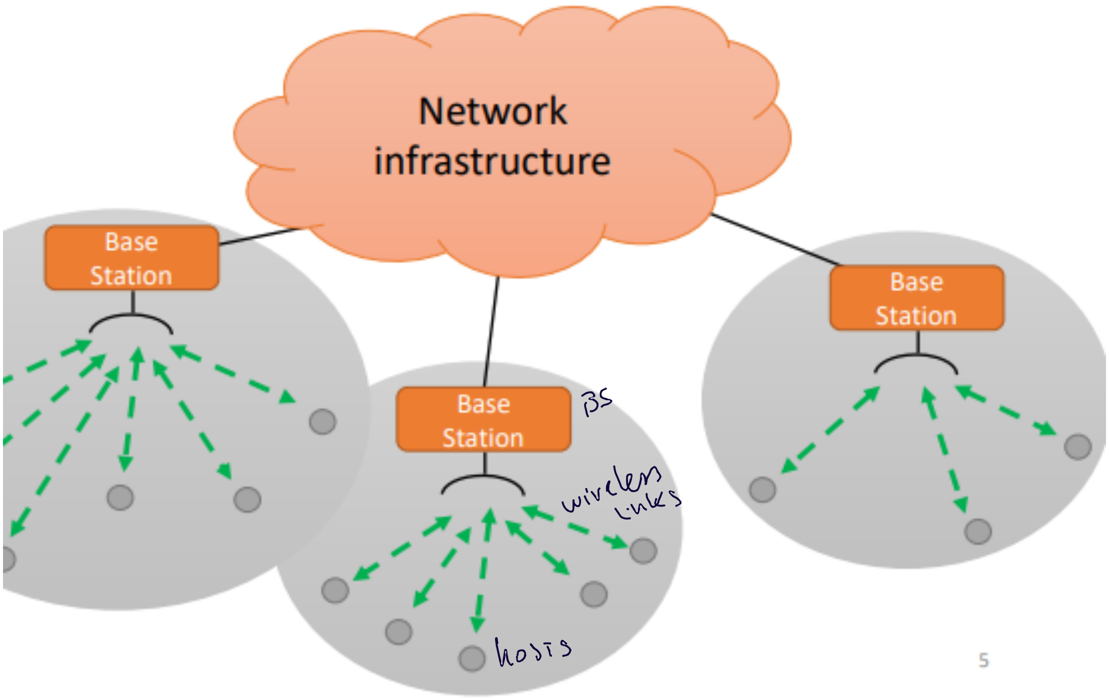


  - ---
  - **wireless hosts:**

    - run applicatins
    - stationary (fixed location), wireless not always mean mobility || mobile
    - devices want to communicate to internet → traverse internet
    - are connected wireless to BS
- **base stations**:
    - cover geographic areas
    - all communications to devices travese BS
    - manage resource of phisical medium
    - connected to a wired network
    - *relay*: responsible to send packets between wired ntwrk and wireless hosts (in its area)
    - e.g.:acess points(in wi-fi)/cell towers (in mobile phone)...
    - problem to solve for acess POINT: ~~points:~~ new accesses, coordinatin medium, oving devices
- **wireless links**:
    - connect mobile to base stations
    - *Multiple Aceess Protocol* to coordinates *link access*
    - various *data rates*, *trasmission range*
- **infrastructure mode** (network infrastructure):
    - BS connects mobiles into wired network
    - problem: nodes can move between BSs → exchainging **control message**: connection doesn't terminate → **change of responibility**
        - devices can move between BS of different/same **providers**:
            - they provide authentication, billing
- **intracell communication**: two hosts (end devices) communicates inside the same BS's area
- **intercell communication**: two hosts communicates through differente BS's areas

wireless network taxonomity

	Single hop	Multiple hops
infrastructure (e.g., APs)	host connects to base station (WiFi, WiMAX, cellular 3G,4G,5G) which connects to larger Internet	host may have to relay through several wireless nodes to connect to larger Internet: MESH networks
no infrastructure	no base station, not necessarily connection to larger Internet (e.g. Bluetooth)	no base station, no connection to larger Internet. May have to relay on other nodes to reach a given wireless node (ZigBee, ad hoc, VANET)

Wireless links (chatateristics) vs wired links

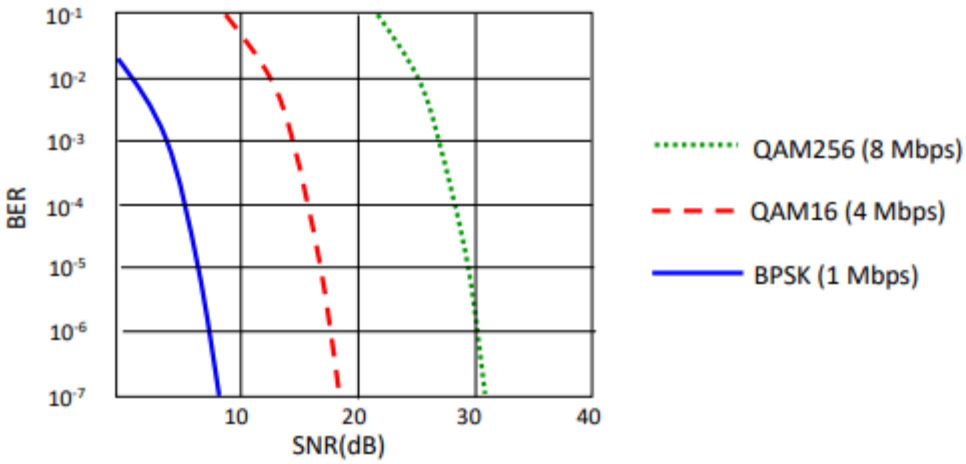
- electromagnetic waves in the air (tonight, oh lord, I can feel it comin' in the air tonigh, Phil Collins)
- 1) **decresed signal strenght:**
  - problem
  - signal decreases with lenght
  - radio signal attenuates as it propagates thru matter
    - obstacols can block electromagnetic waves
- 2) **interference with other sources**:
  - standardized wireless network frequency shared by other devices (e.g.: 2,4Ghz)
  - microwaves ownes, mobile phones, engince, appliances may *interference as well
  - receivers detect the sum of signal in the environment
- 3) **multipath propagation***:
  - radio signal (electro waves)reflect on objects or ground, arriving at destination at different times

Wireless tools

- **SNR**: signal to noise ratio → evaluate *quality of the signal*
  - SNR = (*signal power/noise power)*
    - id est(meaningful input/meaningless or unwanted input(power of background noise)) such that 0 < SNR < +infinty, (watt or dBm)
    - SRN in dB (10th part of bel (B symbol): 10 dB=1B, logaritmic unit ratio over two homogeneous quantities) = 20 * log(signal/noise)
  - larger is SNR → easier is to esxtract signal form noise (cool thing)
- **BER**: Bit Error Rate: probability taht a trasmitted bit is received in error at the reciver

- **SNR** vs **BER tradeoff**: how implicit is information in electro waves
  - given a phisical layer: increase power → increase SNR(quality of the signal) → decrease BER (send bits → electro waves to the medium)
    → SPEAK LOUDER & CLEAR
- **given SNR**: choose a physucal layer that meets BER requirement, **giving highest throughput**
- **SNR** may chainge with *mobility*:
  - dynamically adapt physical layer (modulation tecnique)

amount of errors you have



- also *signal attenuation* or *obstacles* **limit transmission range**

Wireless network challenges

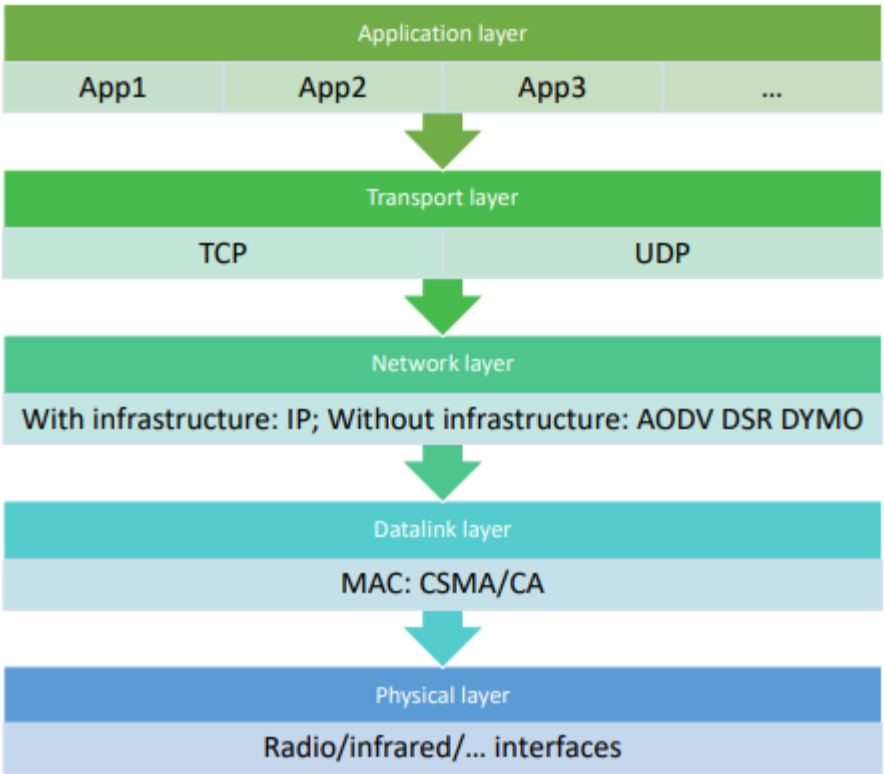
1. **Limited knoweledge**:
   - a node detect a situation, but not all communications
   - a terminal cannot hear all the other
   - => hidden/exposed terminal problem
2. **Mobility/failure of terminals**:
   - terminals move (join/exit) in the range of different BS
   - terminals move away from each other
3. **Limited terminals**:
   - battery life, memory, processing, trasmission range
4. **Privacy**:
   - eavesdropping of ongoin communications
     → INTERCETTAZIONI

Wireless network required mechanism

1. **Access** to a shared wireless channel
   - CSMA/CD (Carrier Sense Multiple Accesses with Collision Detection) multi access protocol CANNOT be used.
2. **Hand-off** ("goin' away")(network with infrastructure):
   - moving terminal into range of different BS
3. **Routing** (multi-hop ad hoc networks)
   - finding a path form **source** to **destination** in multi-hops networks

    - deling with arbitrary changes in neighborhood

Wireless networks protocol stack

- | bits | frames | packets | segments | data |
- 

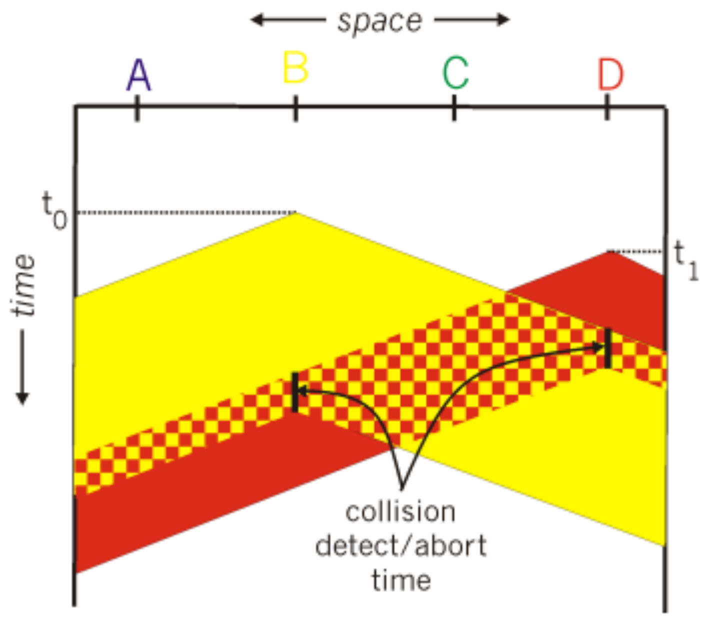
  L5: Data
  L4: segments
  L3: packets
  L2: Frame
  L1: bits

Recap: MAC protocol for wired networks

- a single channel availble for **all** the communications
- **all** stations can transmit and send on the channel
- if frames are sent simoultanesly on the channel
    - → resulting signal is **garbled** (**a collision occurs***)
- CSMA, CSMA/CD, ALHOA, slotted ALOHA

CSMA

- Carrier Sense Multiple Accesses
- when a station has a frame to send → listen to the channel to see if anyone else is trasmitting
- if channel is busy → station waits untill it becomes idle
- when channel il idle → station stransmits the frame
- if a collision occurs → station waits a random amount of time and repeats
-



CSMA/CD

- a station aborts its trasmission as soon as it detects a collision
  - if two stations sense channel idle at the same time and start transmitting
    - → stations quickly abort the frame as soon as collision is detected
- wudely used in LANs in MAC sub-layer
- IEEE 802.3
- **T** is the time required to reach the farthest station
- it takes minimum RTT (# time between sending/reciving the signal) (2 * T) to detect collision

Binary Exponential Backoff

- defines time that station has to wait for trasmitting again a frame
- algorithm:
- time after a collision is divided in **contention slots**:
  - lenght of a contention slot is equal to the worst case round propagation time (2T if T time to reach farthest station)
- after 1st collision:
  - each station waits 0 or 1 slot before trying again (success or collision)
- after collision **i**:
  - choose x at random in (0, 2^**i** -1) → exp:more collision, more time, may increase exponentially
- after 10 collisions:
  - choose x at random in a frozen interva (0..1023)
- after 16 collisions:
  - failure is reported back to upper levels

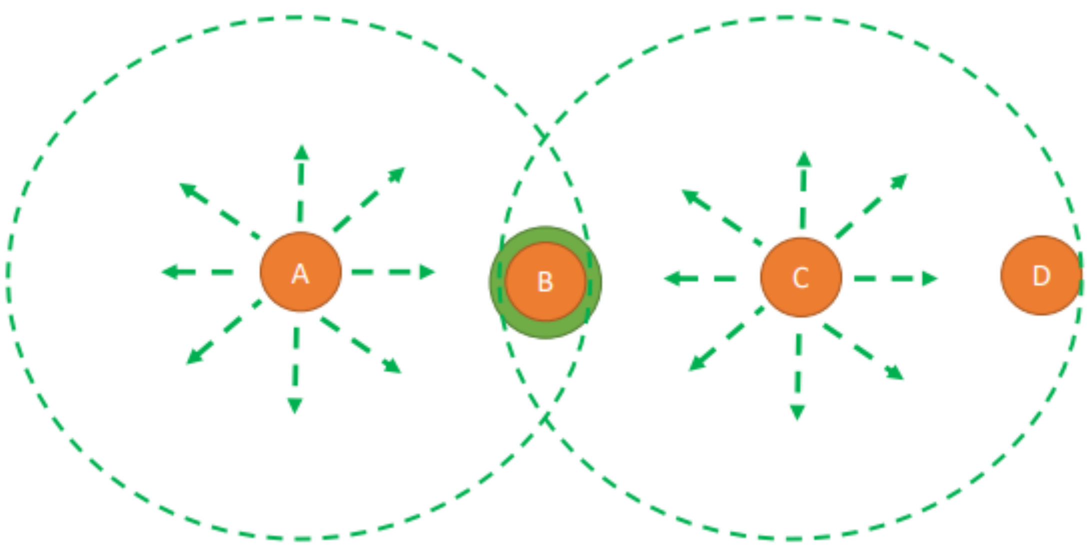
Why MAC doesn't work on wireless

- station transmit and send if there is another communication in channel → multiple antennas

CSMA/CD detects interference while trasmitting!	in wired networks it's OK, but not in wireless!
Hidden terminal problem	what matters is **interference at the receiver** *not* at the sender
Exposed terminal problem	what matters is **interference at the receiver** *not* at the sender

Hidden terminal problem

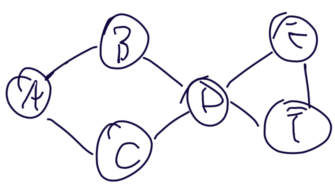
- two or more stations which are out of the range of each other transmit simultaneously to a comme recipient



- A is sending to B
  C senses the medium: it will NOT hear A, out of range
  C transmits to anybody (either B or to D) : **COLLISION at B!**

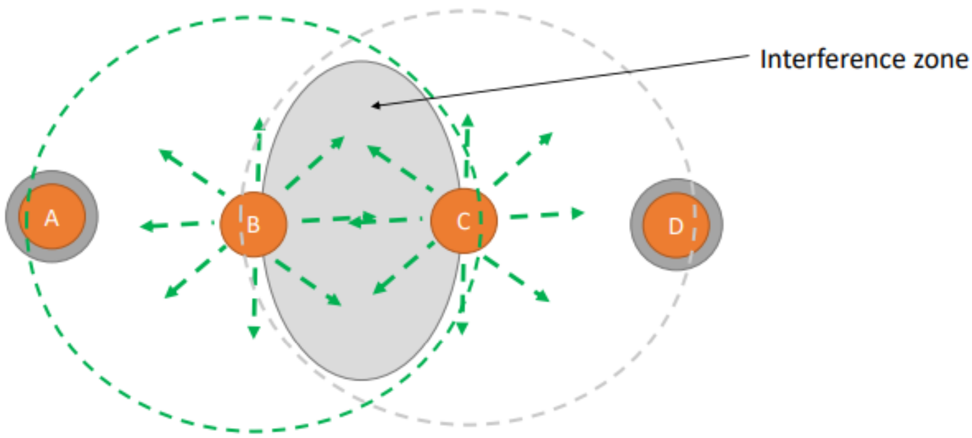
will not sense anything when T, destroy comm.

1) Hidden Terminal $E \xrightarrow{T} D$: can interfere: B C, F ⇒ F also in range of F (sense channel)
2) " " $D \xrightarrow{T} C$: A doesn't receive nothing from D ⇒ hidden ⇒ no hidden
3) Exposed " $D \xrightarrow{T} B$: C E F will not make interfere with B, but sense channel as busy
4) " " $B \xrightarrow{TR} A$: D



Hidden terminal problem	C is not able to detect a potential competitor because it is out of range: a collision happens at B (the receiver) For the same reason A does not detect the collision C is **hidden** with respect to the communication from A to B

Exposed terminal problem

- a trasmitting station is prevent from sending frames due to interference with another transmitting station
- 

  1. B is transmitting to A, C wants to transmit to D
  2. C senses the medium, concludes: **cannot transmit** to D
  3. The two transmissions can actually happen in parallel.
-
Exposed terminal problem	C hears a transmission C does not send to D although its transmission would be OK C is **exposed** with respect to the communication from B to A
- so:

What matters is **interference at the receiver** not at the sender

- this cannot be checked by sensing the carrier at the sender

→

Multiple transmissions can occur simultaneously if destinations are out of range of each other

- a station may hear a transmission and be able to transmit without interfere with it

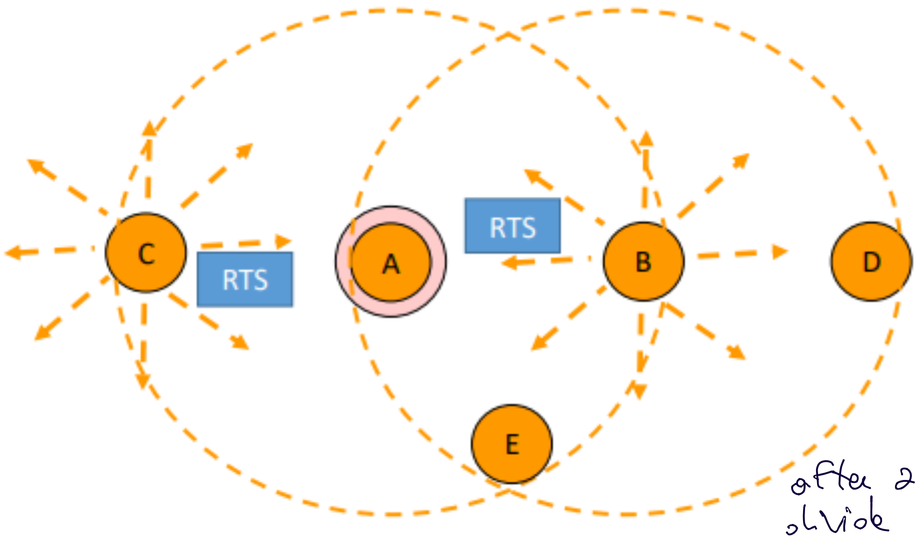
→

Need sensibly different MAC protocols from wired LANs

MACA protocol $\boxed{\text{CSMA/CA}}$

- Multiple Accesses with Collision Avoidance:
  - stimulate the receiver into trasmittig to it a short frame first by sender
    - RTS: Request To Send, includes length of the longer frame
  - if the station receiver wants to recive the message, replies with another frame
    - CTS: Clear To Send short frame with data lenght copied from RTS frame
  - then transmit a (long data frame)
  - stations hearing the short frame **refrain from transmitting** during the transmission of the subsequent data frame
- collision:

time to reach farthest station T



C and B send RTS simultaneously to A

-
  - the two messages collinde: **no CTS generated**
  - C and B uses ***Binary exponential backoff*** (same as ethernet) to retry RTS

after a collision, divide time in contention slots = 2T
- after 1st collision wait 0,1 contention slots
- after collision i: pick rand # : (0, 2^i-1)
- after collision 10 (0, 1023)

- after collisions → report error to the upper layers

MACAW: MACA for Wireless network

Fine tunes MACA to improve performance:

- introduces an ***ACK frame*** to acknowledge a successful data frame
- added ***Carrier Sensing*** to keep a station from transmitting RTS when a nearby station is also transmitting an RTS to the same destination
- exponential backoff is run for each separate pair source/destination and not for the single station
- mechanisms to exchange information among stations and recognize temporary congestion problems
- CSMA/CA used in IEEE 802.11 is based on MACAW

IEEE 802.11

FAMILY OF STANDARDS

- IEEE 802.11 (Legacy mode, 1st version)
  - relased in '97, clarified in '99
  - rarely used today → evolving in a/b/g/n (theese most used today)
  - **data rate**: started with 1.2 Mbps *data rate* implemented via:
    - infrared signals (IR)
  - **radio frequencies** in the 2.4 Ghz band (Industral Scientific Medical Freq.)
  - many **degrees** of freedom:
  - **interoperability** among different productos was challenging
  - became popular with version 802.11b
- IEEE 802.11**a**
  - '99
  - **operating (radio) frequency**: 5 Ghz band
  - **throughput**(typ): 23 Mbps
  - **data rate**(max): 54 Mbps
    - - lot of difference, exploit max transmission capacity of technologies
- IEEE 802.11.**b**
  - '99
  - **operating (radio) frequency**: 2,4 Ghz band (ISM band)

        - problem: in some environments (domestic) interference (microwave owens, cordless tel)
    - **throughput** (typ): 4.3 Mbps (<A)
    - **data rate** (max): 11 Mbps

- IEEE 802.11**g**

    - 2003
    - **operating (radio) frequency**: 2,4 Ghz band (SM)
    - **throughput**(typ): 19 Mbps and more (>B)
    - **data rate**(max): 54 Mbps

- IEEE 802.11**n**

    - 2009
    - **operating (radio) frequency**: 2,4 Ghz and 5 Ghz band
    - **throughput**(typ): 74 Mbps and more (>G)
    - **data rate**(max): 248 Mbps
    - supports MIMO tecnhologies:
        - a node can use multiple antennas at the transmitter/reciver

- Wi-Fi 5 - IEEE 802.11**ac**

    - 2013
    - **operating (radio) frequency**: 2,4 Ghz and 5 Ghz band
    - **data rate** (max):
        - at **5 Ghz**: 1.3 Gbps
        - at **2.4 Ghz**: 450 Gbps

- Wi-Fi 6 IEEE 802.11**ax**

    - 2019
    - **data rate**: reaches up 10 Gbps
    - improvements
        - power consumption and security
        -

- IEEE 802.11 Wireless LAN

IEEE 802.11 standard	Year	Max data rate	Range	Frequency
802.11b	1999	11 Mbps	30 m	2.4 Ghz
802.11g	2003	54 Mbps	30m	2.4 Ghz
802.11n (WiFi 4)	2009	600	70m	2.4, 5 Ghz
802.11ac (WiFi 5)	2013	3.47Gpbs	70m	5 Ghz
802.11ax (WiFi 6)	2020 (exp.)	14 Gbps	70m	2.4, 5 Ghz
802.11af	2014	35 – 560 Mbps	1 Km	unused TV bands (54-790 MHz)
802.11ah	2017	347Mbps	1 Km	900 Mhz

- all use CSMA/CA for multiple access, and have base-station and ad-hoc network versions

- 802.11 **af-ah**:
  - sendind data for measurement
  - **low frequency** → **higher range** (higher coverage)
    - cool for IoT: sensor in fields need coverage

- 802.11 stack
  - all theese protocols are at L2 (phiscal, frame shit)
    - differen releases → different implementations
    - MAC and logically controls
    -

NETWORK

MAC: CSMA/CA DATA LINK

802.11 Architecture

802.11 family PHYSICAL

- a group of stations (AP) has **coordination funcition**
  - to transmit data send/rec
- 1) AC can be used in between nodes/other AC (link)/group of stations via fixed infrastructure

→ can used: 1) infrastructure wireless net 2) No infra wireless net

  - if using AP, a station communicates with another
    - challenging all traffic thru a centralised AP
- may or not use a BS
- 2) supports **ad hoc** network (no infrastructure):
  - a group of stations that are under the direct control of a single channel coordination function, without the aid of an infrastructure network
  - no centralised role of AP
  - distributed aming nodes belong ad hoc network

MAC SUBLAYER of 802.11

•) 2 Modes of operations

1) DCF: Distributed Coordination Function => MUST BE PRESENT in ALL the DEVICES

- all stations have to run CSMA/CA to see if they can access the channel:
  - sense channell
  - if free → send RTS
  - if receive CTS => start transmit

  } all stations

2) PCF: Point Coordination Function => OPTIONAL, IMPLEMENT PCF ABOVE DCF

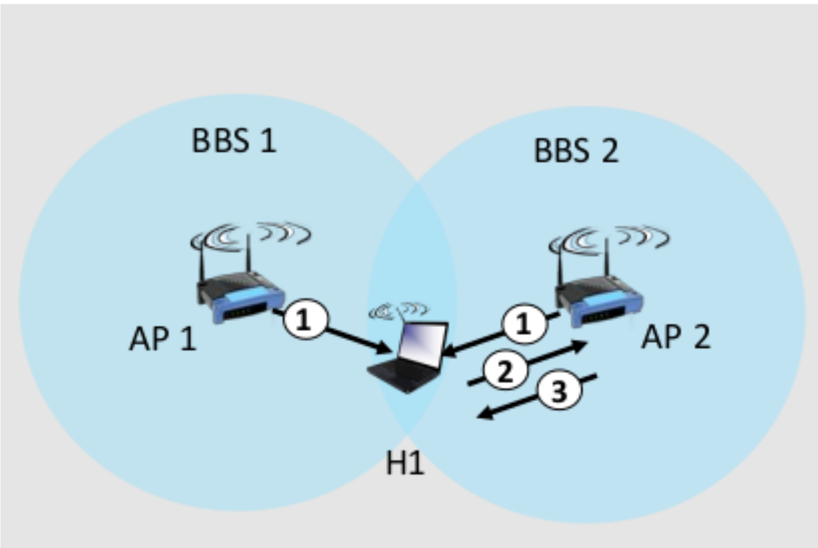
- MAC is coordinated by access point:

=> AP may reserve part of the time and tell to other stations that that time slot is reserved to let 1 station to transmit

- used in video streaming TRANSMISSION this will not carrier sense & send RTS ← CTS

- a station can communicate directly with another without channelling all trafic thu AP
- spectrum diveded into channels at different frequencies
  - → range of frequency divided in # of channels (usually 11)
  - → AP admin choose frequency for AP
  - → AP communicate thru channel using that frequency with the device
  - interference possible: channal can be the same as that choose by neighboring AP
- a node join to a network must associate with AP
  - scans channels
  - listen for beacon frames
    - containing SSID(net name) && (BSSID) MAC of the AP
    - host selects AP to associate with
    - they can perform auth
    - typically they run DHCP to get IO address in P's subnet

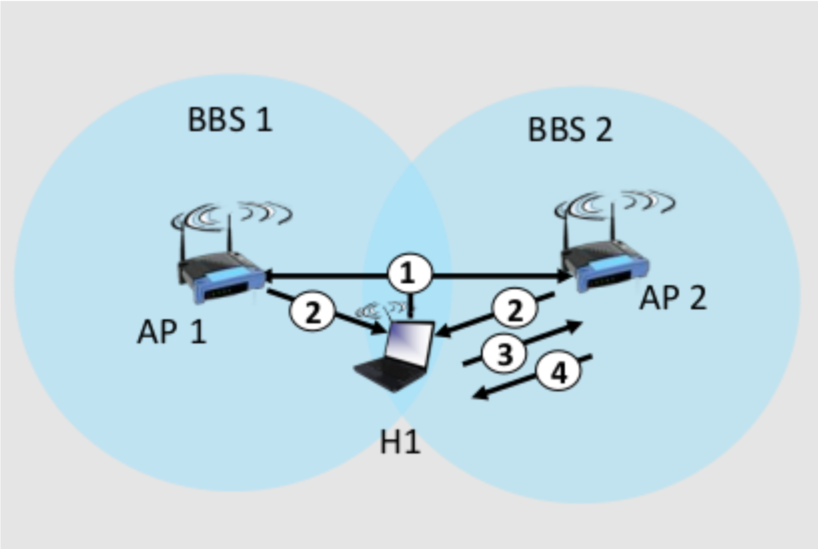
Scanning

- host want to join the network
  - must discober infos abot AC to join to the network
- **passive scanning**
  - 

    1. beacon frames sent from APs
       - AC periodically sends beacon frames
    2. association **request** frame sent:
       - H1 to select AC (based on BSSID)
       - choosing the AP according higher signal strength (depends on vendor implementation really)

3. association **response** frame sent from AP to H1

- **active scanning**

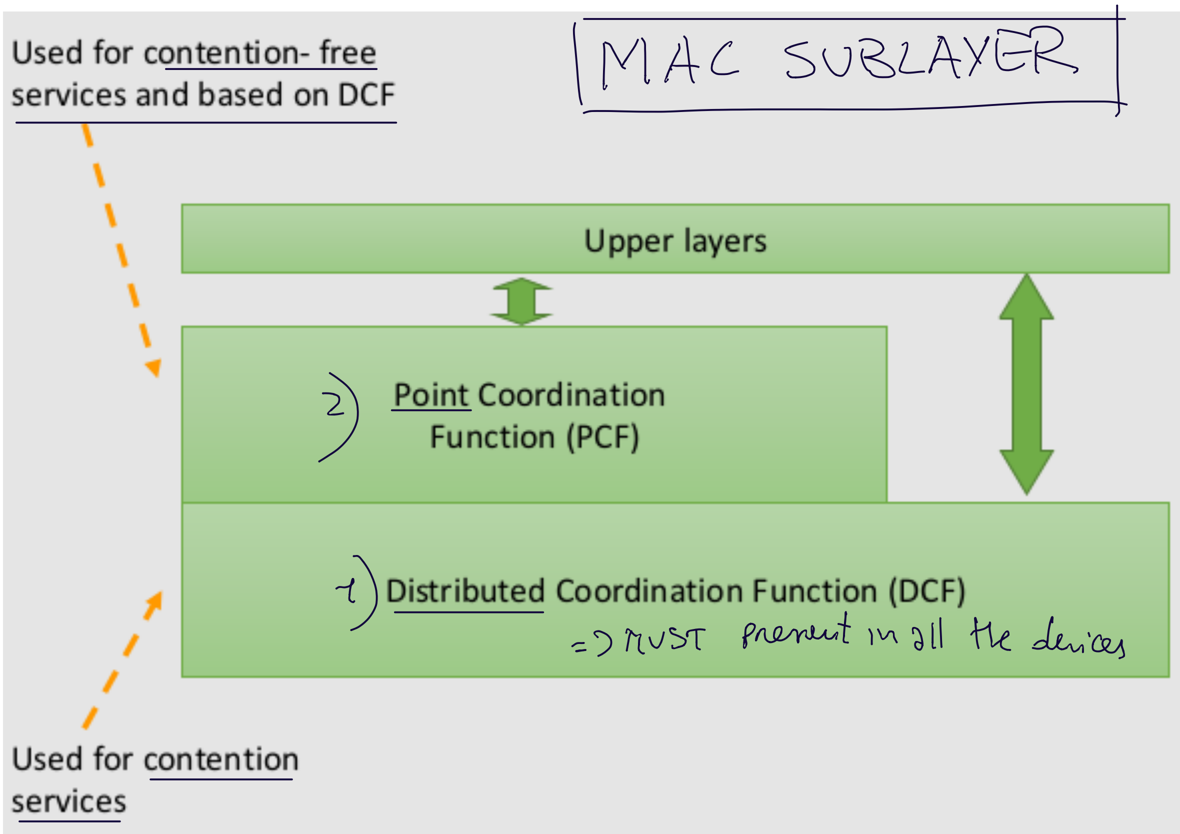
- 

  - a node arrives in network → send beacon → want the reply to an AP

  1. Probe **request** frame broadcast from H1
  2. probe **response** frames sent from APs
  3. **association request** frame sent:
     - H1 to selected AP
  4. **Association response** frame sent:
     1. from selected AP to H1

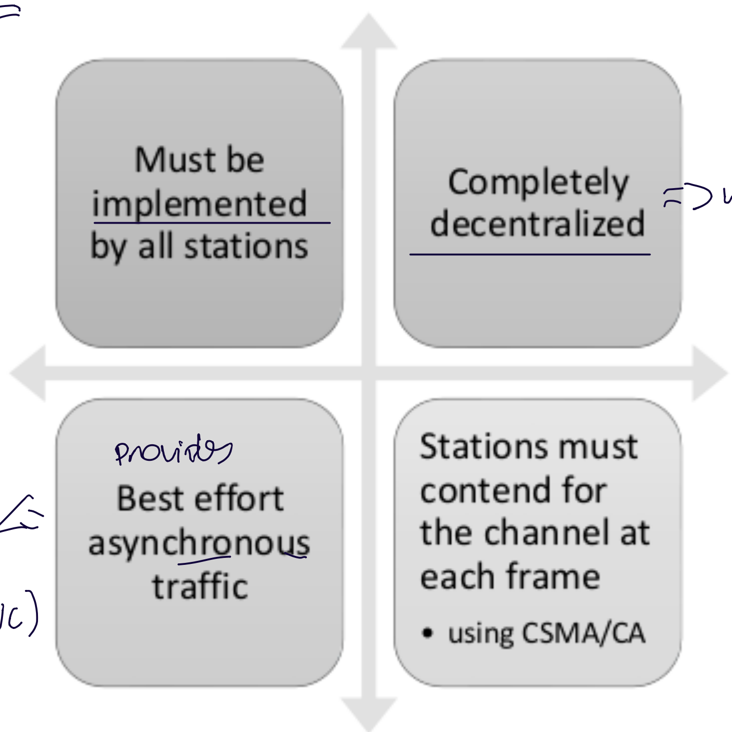
  - *association request* and *association response* nedeed cuz can have multiple AP, but not aware if AP resplies

MAC Sublayer



- **DCF**: Distributed Coordination Function, here implements MACA → distributed access to shared medium
  - completey decentred
  - thought for best effort asynchronous traffic
  - **must be implemented by all stations**

DCF



=> no central point that tells to BS when talk

traffic async
⇓
can transmit when you want (NO TIME SYNC)

best, effort
⇓
you don't know if you will be able to transmit

send RTS as will not have back a CTS

CS & CA

- Carrier sensing is performed at two levels:
  - *phisical CS*: Carrier Sense implemented in Phisical: sense the channel before transmitting
    - informal: before trasmission if another station is transmitting → detect incoming signal → if channel is free → transmit
    - formal:
      - checking the frequency to determine wheteher the medium is in use or not
      - phisical carrier sense to detect incoming signal
      - detects any activity in the channel due to other sources
  - *virtual CS*: : if you receive a CTS => you set up virtual carrier sense (as if channel is busy for you)
    - performed sending duration information in the headr of an RTS, CTS and data frame
    - keep channel virtually bused up to the end of frame transmission
    - a channel is marked busy if either the physical or the virtual CS indicate busy
  - a channel is marked busy if either the physical or the virtual CS indicate busy
- always about coordinatin function: to make things work
  - priority access to the medium is controlle thru the use of **interframe space** (IFS) time interval: min time need to wait to send new frame (time between 2 frames) ↳ when transmit a frame, before transmit a new frame
    - formal IFS: mandatory periods of idle time on the transmission medium => wait a fixed time interval ↓ fixed ↓ don't want overlapping
  - Three IFS specified by stamdard (always talking about IEEE 802.11)
    1. Short IFS (SIFS)
    2. Point Coordination Function IFS (PIFS)
    3. Distributed Coordination Function (DIFS)
    - SIFS < PIFS < DIFS
    - stations only require to wait SIFS have the higher priority:
      - node with highet priority wait less the others with smaller one
- PCF: Point Coordination Function: access medium between nodes to organise communication service
  - contention free
  - uses BS to control all activity in its cell
  - though for delay-sensitive traffic
  - AP pools station for transmissions
  - based on DCF

IFS also to give priority

- Trans 1 frame
- Trans the 2nd

⇓

wait time before transmit
=> if you want to give priority to another STATION, other station will wait a smaller time interval
=> will transmit first
=> PCF

- **DCF || PCF can be active at same time in same cell**

- MANCA ULTIMA SLIDE