IST Semester

Networks
- Part 1 -

CSMA/CA and IEEE 802.11

membre de UNIVERSITÉ DE LYON

Département Télécommunications
Services & Usages

INSA LYON

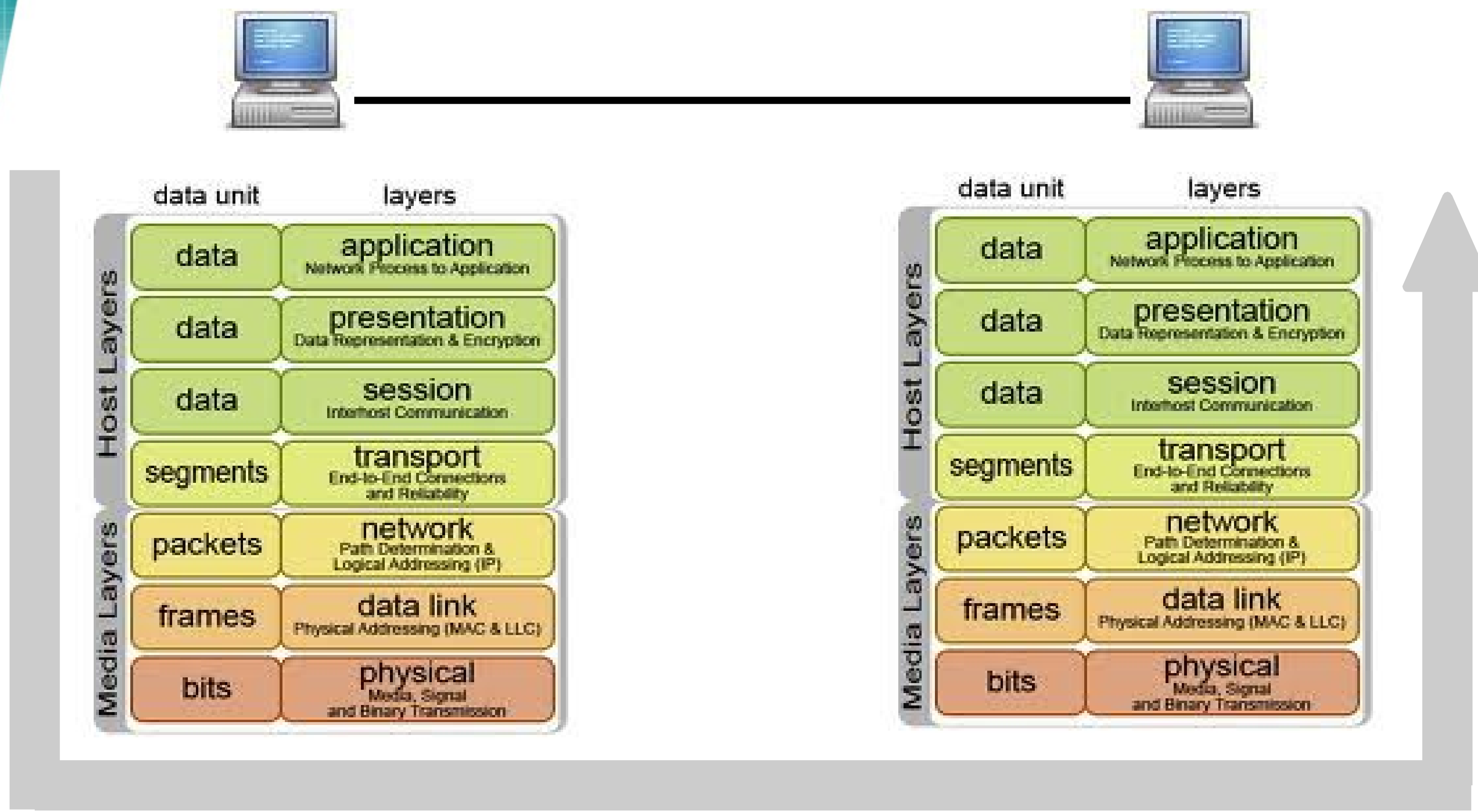
CSMA/CA and IEEE 802.11

- Speaker
  - Razvan Stanica
  - http://perso.citi.insa-lyon.fr/rstanica/IST-NET-WiFi.pdf
- Lab
  - CITI *[Centre of Innovation in Telecommunications and Integration of services]*
  - INRIA UrbaNet team
- Research
  - Mobile networking
  - Medium access control in wireless networks
  - Intelligent transportation systems

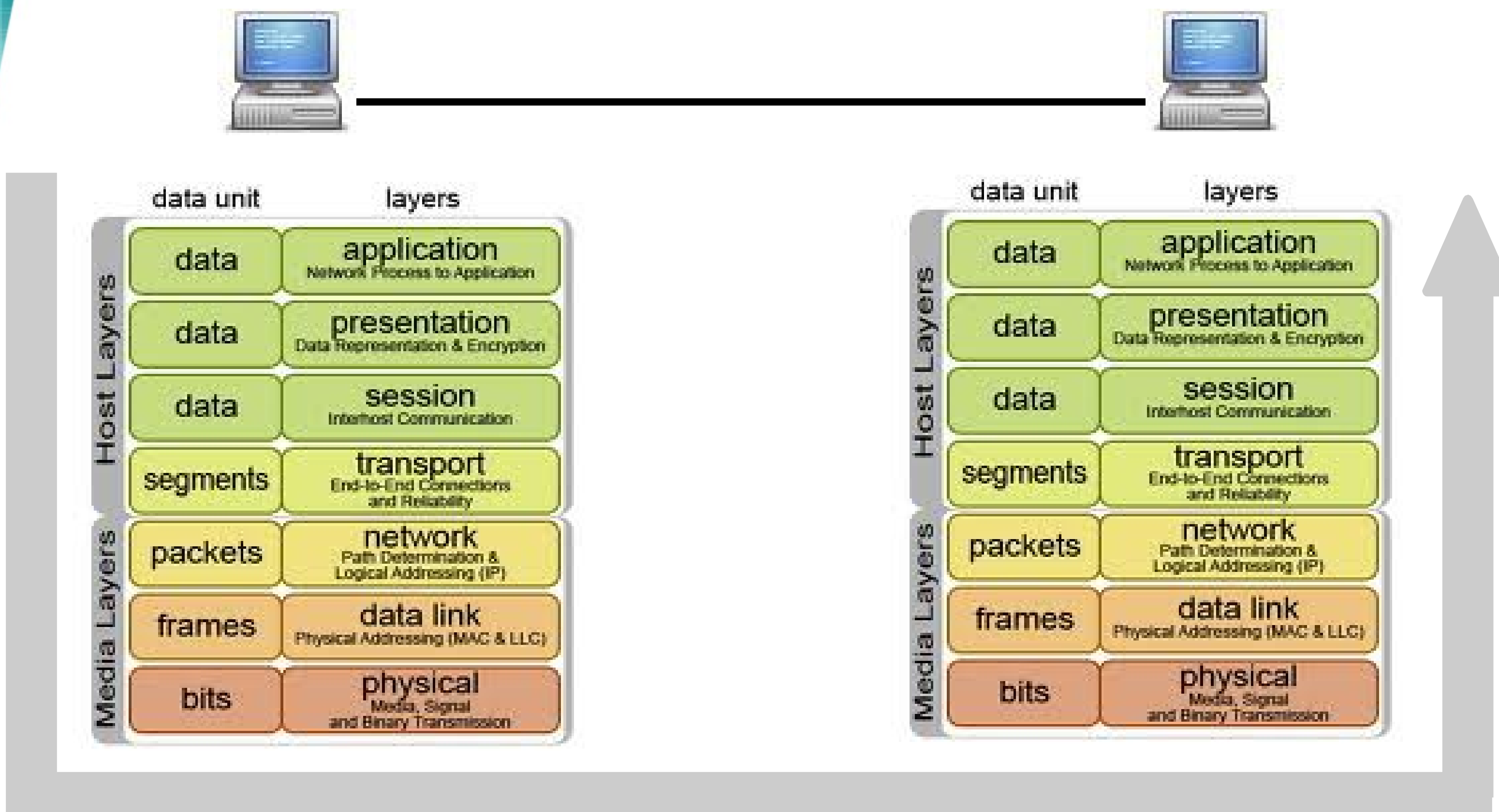
CSMA/CA and IEEE 802.11

- The plan for today
  - What makes wireless so special?
  - Carrier Sense Multiple Access with Collision Avoidance – Why? How?
  - What else is in IEEE 802.11?

Basic concepts: Networking



Basic concepts: Networking



<u>**Wireless simply means that there are no wires at the PHY layer**</u>

Basic concepts: PHY Layer

- Performed Services

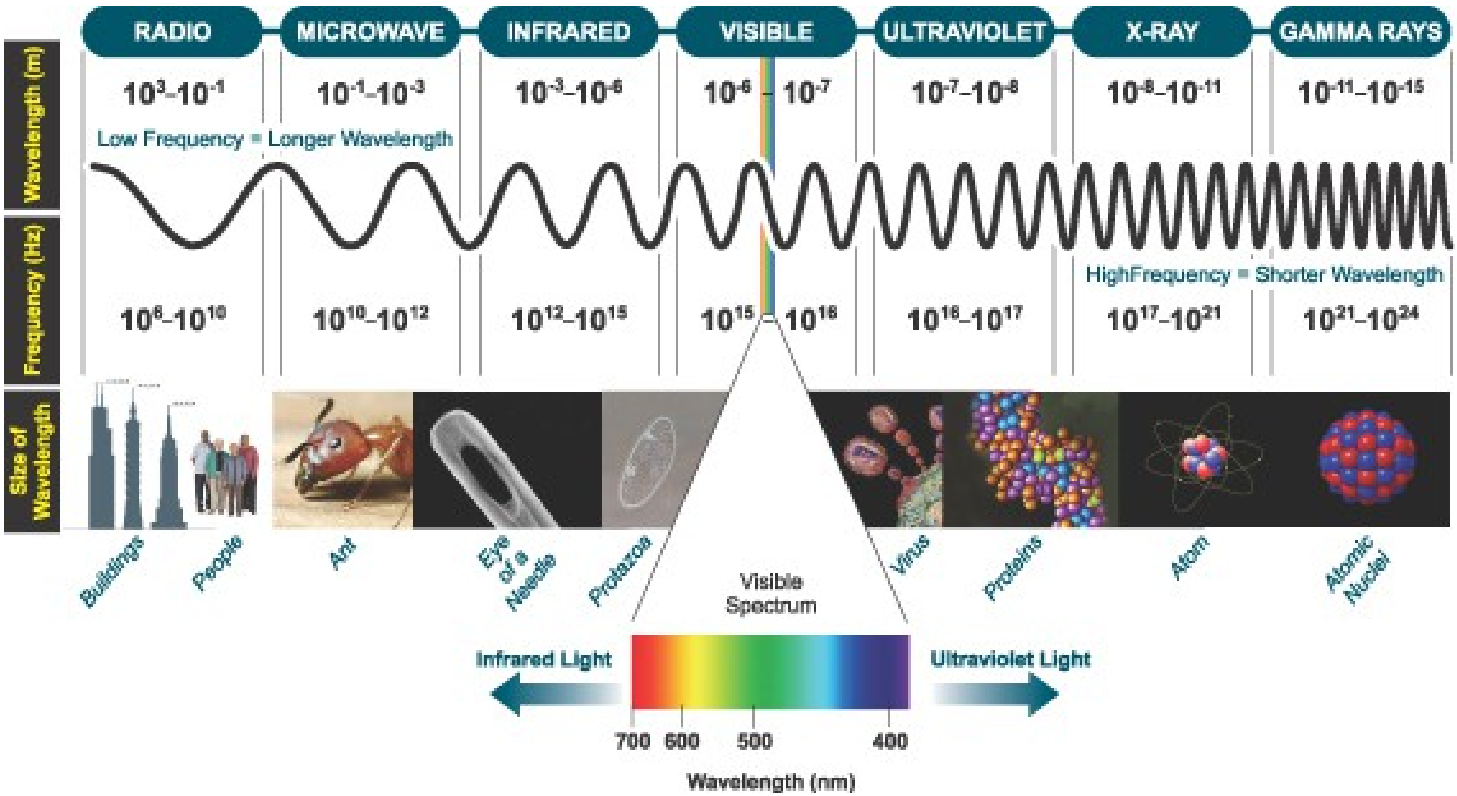


  - Standardized mechanical and electrical interfaces
  - Signal processing (equalization,training sequences)
  - Coding (channel, line)
  - Modulation (adding information to the EM wave)
  - Carrier sense, collision detection (when possible)

Basic concepts: Wireless

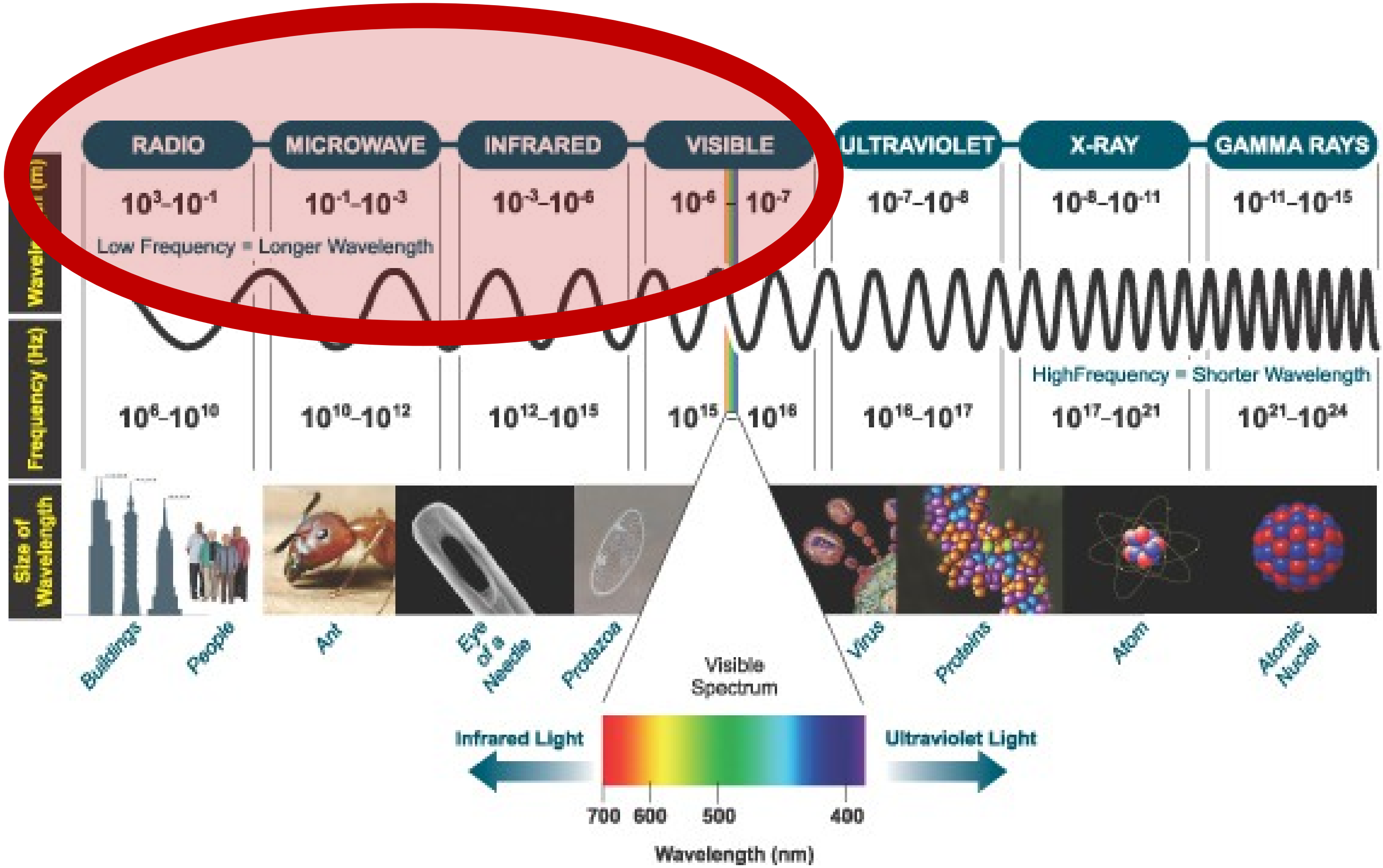
- EM frequency spectrum

$\lambda = c/f$



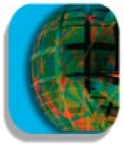
Basic concepts: Wireless

- Where wireless communication happens



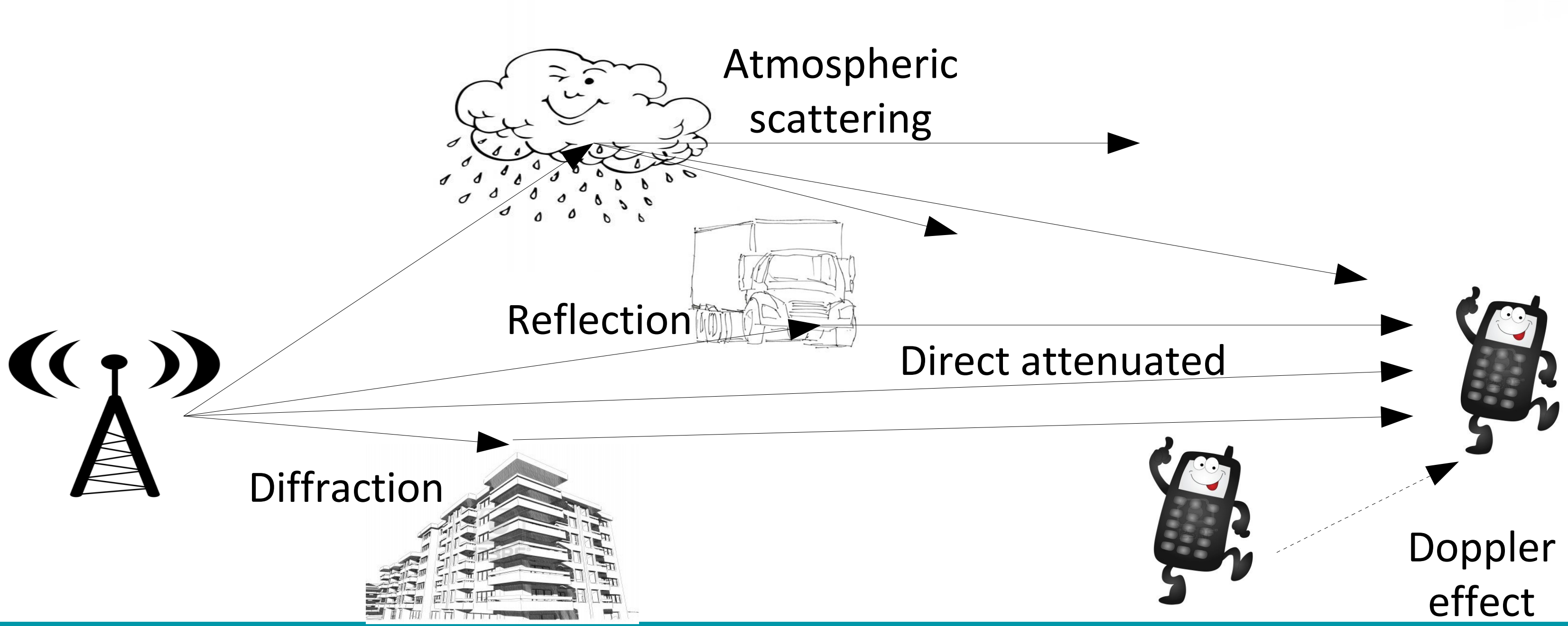
Basic concepts: Wireless Spectrum

Name	f	λλ	Usage
Low **F**requency	30 KHz	10 Km	Aeronautical & maritime navigation, metereology
Medium **F**requency	300 KHz	1 Km	AM radio
High **F**requency	3 MHz	100 m	Amateur radio (Morse code), marine, aviation, military
Very **H**igh **F**requency	30 MHz	10 m	FM radio
Ultra **H**igh **F**requency	300 MHz	1 m	Television, Cellular networks, WiFi
Super **H**igh **F**requency	3 GHz	10 cm	WiFi, Satellite transmission, Bluetooth, Wireless USB
Extremely **H**igh **F**requency	30 GHz	1 cm	Radar, Satellite sensing, Wireless HD, WiFi(?)
Infrared	300 GHz	1 mm	Lasers, LEDs, Free Space Optical Communication



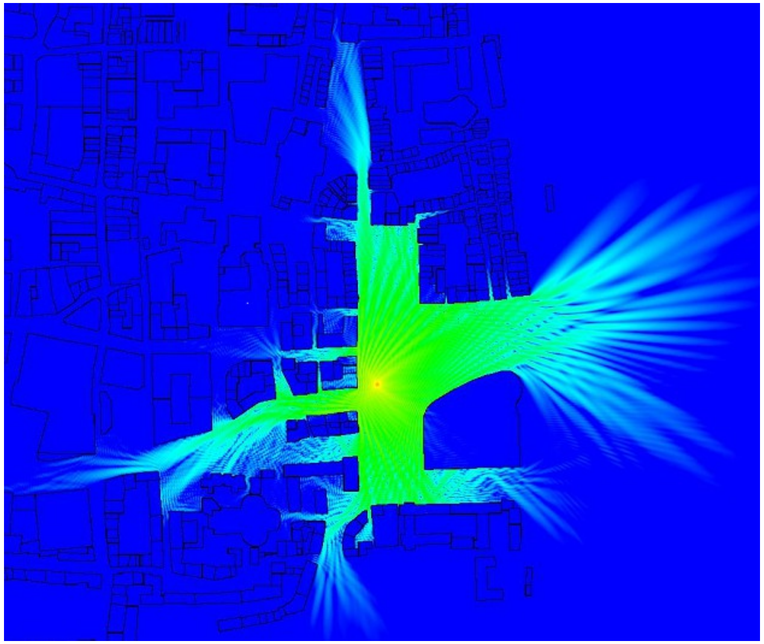
Basic concepts: Wireless Propagation

- Everything you know from EM physics
  - Free space attenuation $P_r \sim P_t \left(\frac{\lambda}{R}\right)^2$



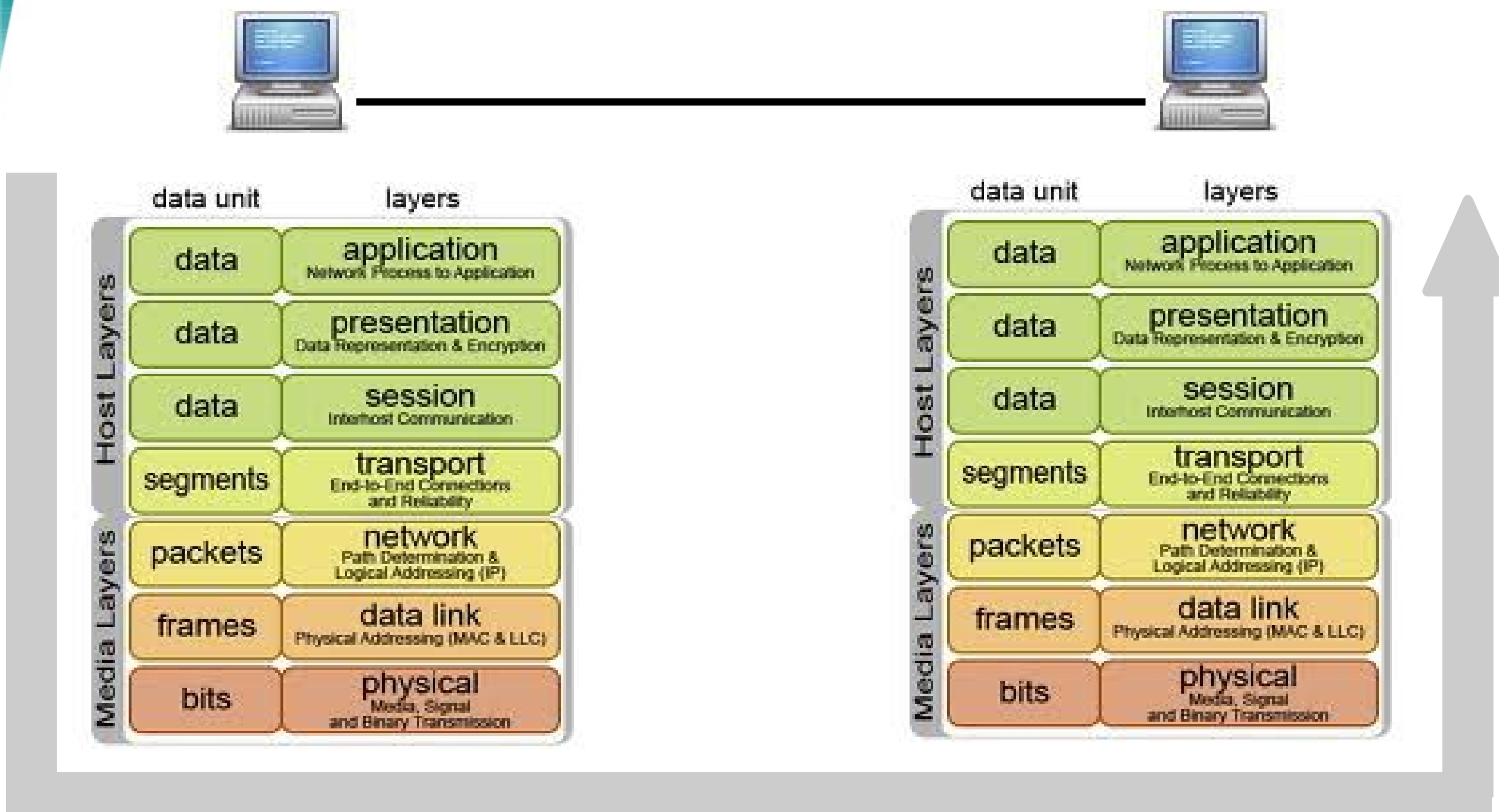
Basic concepts: Wireless Propagation

- As a result of the complex RF propagation, the **strength** of the received signal is highly irregular



[City of Koln, 100mW at 2.4GHz **]**

Basic concepts: MAC layer



The topic of this class is medium access control (a part of the data link layer)

Basic concepts: MAC layer

- Why do we need a course for a sub-layer?
  - The MAC protocol decides who transmits at a given time and space
  - The number of different protocols is impressive: TDMA, CDMA, OFDMA, Token Bus, Token Ring, Aloha, etc.
  - This class is focused on Carrier Sense Multiple Access (but not 100%)

CSMA:
The principle

- Listen before you talk

  - Every station senses the channel for a certain time before transmitting

  - If the channel is idle, transmission goes on

  - If the channel if busy, wait and:
    - send as soon as it becomes idle (1-persistent)
    - choose a random back-off and try again (non-persistent)
    - send with probability p when idle (p-persistent)

CSMA:
The flavours

- Two major branches of protocols
  - CSMA with Collision Detection (CSMA/CD). You saw it (this morning?) in Ethernet.
  - CSMA with Collision Avoidance (CSMA/CA). Used in WiFi and ZigBee.

CSMA/CD: A remainder

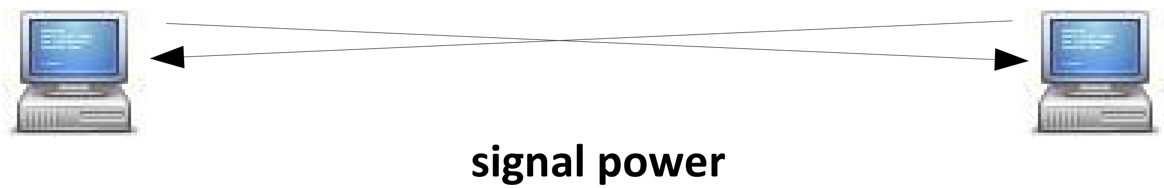
- How does it work?
  - It's CSMA, so we listen before we talk.
  - The CD part explains what happens when two stations start transmitting at the same time.
  - The collision detected procedure:
    - keep transmitting a jamming signal for one slot. This way everybody detects the collision.
    - check if you are allowed to retransmit (retransmission limit).
    - double the contention window and back-off.

b= rand(0,CW-1)

Cw_{min}= 1

CSMA/CD:
A remainder

- How does it work?



- Ethernet uses a wired PHY

- Small signal attenuation

- Collision is detected from the first slot (5.12 µs)

CSMA/CD:
A remainder

- How does it work?

Station A	i					
Station B	i					
Station C	i					

CSMA/CD:
A remainder

- How does it work?

Station A	i	x					
Station B	i	x					
Station C	i						

CSMA/CD:
A remainder

- How does it work?

Station A	i	x				
Station B	i	x				
Station C	i					

- 4 possibilities for the back-off:
  - b(A)=0, b(B)=0
  - b(A)=0, b(B)=1
  - b(A)=1, b(B)=0
  - b(A)=1, b(B)=1

CSMA/CD:
A remainder

- How does it work?

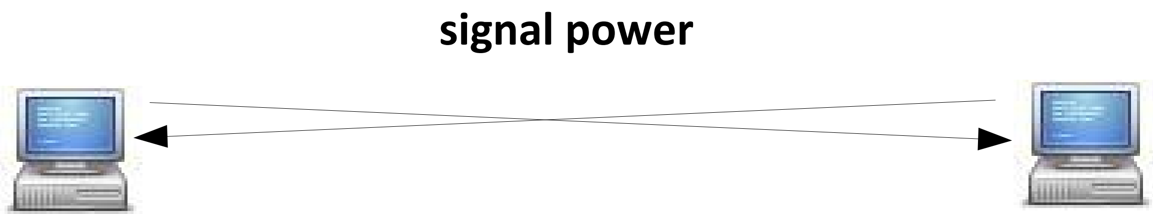
Station A	i	x	x			
Station B	i	x				
Station C	i					

- On Ethernet, a small back-off can solve collisions quickly with high probability

CSMA/CD: A remainder

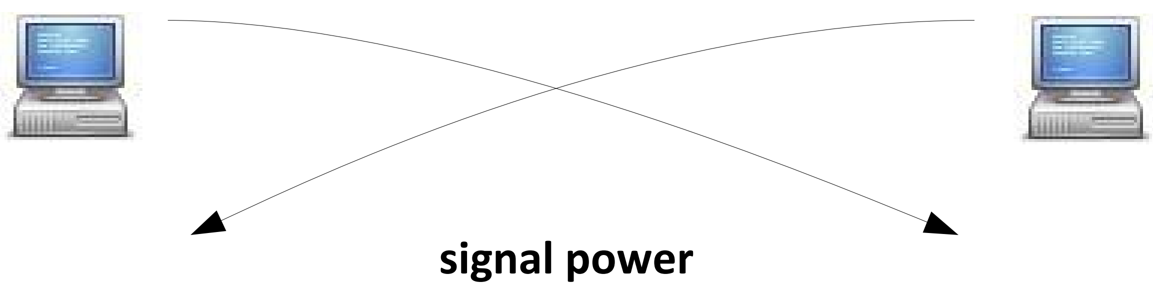
- Works great on Ethernet. Why not use it on WiFi?

  - Wired



  - Wireless – **no CD while transmitting!**

Signal attenuates much faster: The near-far effect

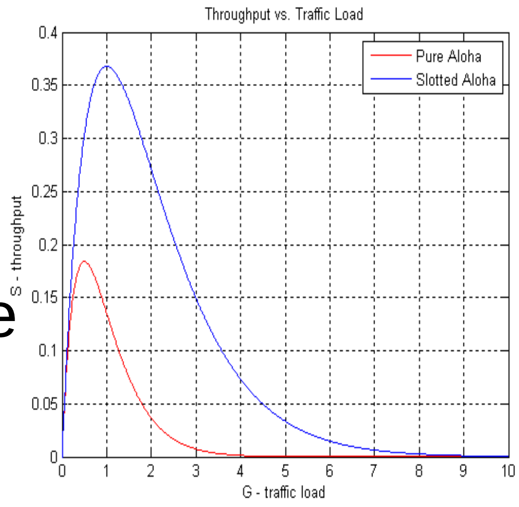


CSMA/CA: The origins

- Wireless needs something different

  - Aloha
    - AlohaNet: first wireless packet network ('70s)
    - no carrier sense, just transmit
    - no ACK message means back-off

  - Slotted Aloha
    - stations are synchronized
    - transmissions can only start at the beginning of a slot



CSMA/CA:
The origins

- Wireless needs something different
  - Aloha is not efficient – too many collisions as the load increases.
  - The idea of using missing ACKs to schedule retransmissions is valid (and used in CSMA/CA).
  - However, missing ACKs **are not collision detection.** They are just a mechanism for error control – Automatic Repeat reQuest (ARQ)

CSMA/CA:
The origins

- Wireless needs something different
  - CSMA/CA appears in the '80s, originally as a MAC protocol in the Apple LocalTalk network.
  - It becomes the basis of the IEEE 802.11 standard, a.k.a. WiFi.
  - It is the most successful wireless communications technology up to date.

CSMA/CA: The principles

- A station that wants to transmit
  - Listen the channel (carrier sense)
  - If channel is idle, transmit
  - If channel is busy, choose a random back-off
  - During back-off, time becomes slotted
  - If a slot is idle, decrement the back-off timer
  - If a slot is busy, freeze the back-off timer
  - When the timer reaches 0, transmit
  - If no ACK message is received, double the contention window and restart the procedure

b= rand(0,CW-1)

CW_{min}= 32

CSMA/CA: The principles

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$b = rand(0, CW-1)$

$CW_{min} = 32$

CSMA/CA:
The principles

- Why does it work?
  - The relatively high value for CW is essential.

Station A	i					
Station B	i					
Station C						

CSMA/CA: The principles

- Why does it work?

i= idle, t= transmission,
W= wait for ACK,
x= collision detected

  - The relatively high value for CW is essential.

Station A	i	t	t	t	t	t	w	w	x		
Station B	i	t	t	t	t	t	w	w	x		
Station C											

  - On Ethernet, a collision was detected in maximum 5.12 µs
  - On WiFi, a missing ACK (not necessarily a collision), is detected after several ms

CSMA/CA: The principles

- Why does it work?

i= idle, t= transmission,
w= wait for ACK,
x= collision detected

  - The relatively high value for CW is essential.

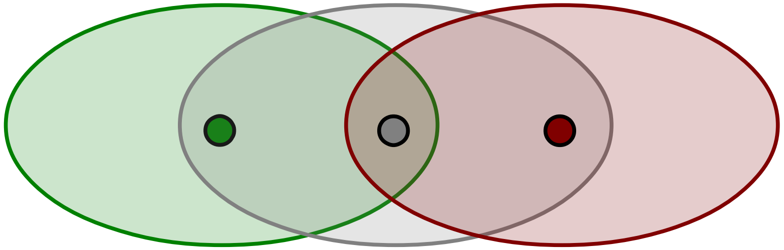
Station A	i	t	t	t	t	t	w	w	x		
Station B	i	t	t	t	t	t	w	w	x		
Station C											

- Using CW_{min}, on CSMA/CD we have a 50% probability for another collision.
- Using CW_{min}, on CSMA/CA we have a 3,125% probability for another collision.

CSMA/CA: The problems

- Great, this solves everything!
  - Not exactly: hidden terminals

and cannot
hear each other



Common scenarios

sends DATA to
wants to access the channel
but hears the DATA from
waits the end of DATA, then
senses the channel idle and transmits
► **collision** between **DATA** and **ACK**

sends DATA to
wants to access the channel
and senses it idle and transmits
► **collision** between **DATA** and **DATA**

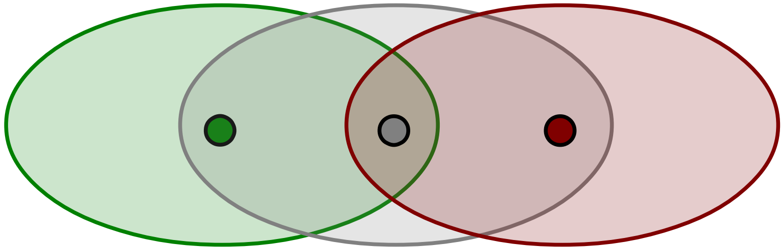
CSMA/CA:
The problems

- The RTS/CTS handshake
  - The collision probability between hidden nodes increases with the size of the messages
  - The idea: use two short control messages to reserve the medium: Request-to-Send (RTS) and Clear-to-Send (CTS)
  - RTS and CTS contain information about the duration of the following transmission (DATA+ACK)

CSMA/CA: The problems

- The RTS/CTS handshake

🟢 and 🔴 cannot hear each other



🟢 sends RTS to ⚪
⚪ sends CTS to 🟢
🔴 hears the CTS and considers the channel busy for the announced duration
🟢 sends DATA to ⚪
⚪ sends ACK to 🟢

The RTS/CTS handshake is also known as <u>virtual carrier sense</u>.

IEEE 802.11: The beginnings

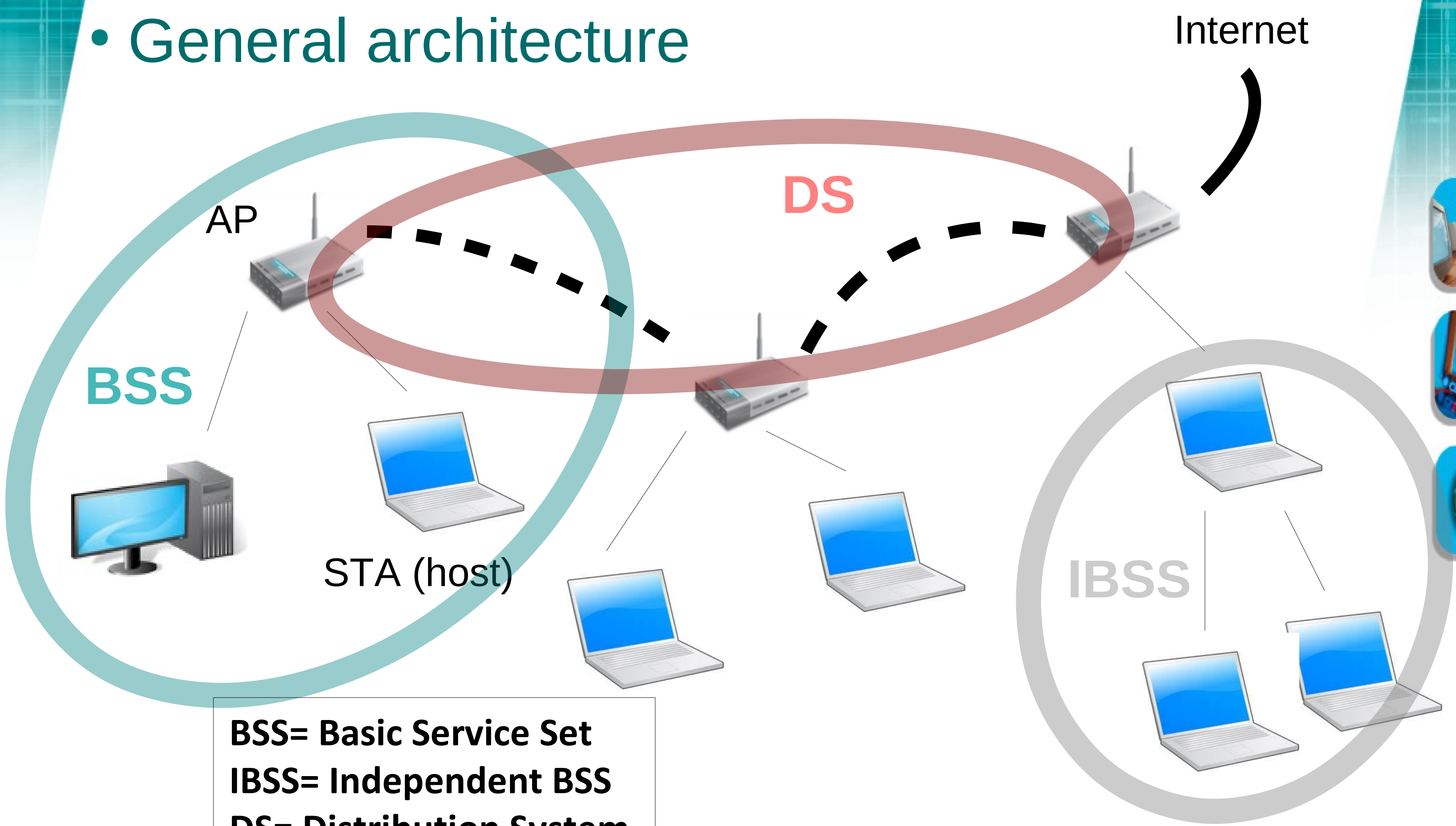
- In 1985, the US Federal Communications Commission (FCC) created the Industrial, Scientific and Medical band (ISM) for non-licensed applications (2,4GHz)
- In 1990 the IEEE establishes the 802.11 committee
- The IEEE 802.11 standard was finalized in 1997 and became the de-facto standard for WLAN

IEEE 802.11: Evolutions

- Higher data rate: 11 Mbps (b), 54 Mbps (g), 100+ Mbps (n) 500+ Mbps (ac)
- Use of different frequencies (a – 5GHz, ad – 60GHz)
- Use of multiple antennas (n, ac)
- Integrating Quality of Service (e)
- Dedicated environments: mesh (s), vehicular (p)
- Security enhancements (i)

IEEE 802.11: Introduction

- General architecture



BSS= Basic Service Set
IBSS= Independent BSS
DS= Distribution System

IEEE 802.11: Introduction

- BSS association
  - **Scanning** – STA looks for (chooses) an AP nearby
    - *Passive*: just wait for the periodic AP beacon
    - *Active*: probe APs for beacons
  - **Authentication** – STA proves to have access
    - *Open*: skip this phase
    - *Secure*: challenge by the AP, the STA needs to have a shared key to respond correctly
  - **Association** – STA enters the BSS
    - STA -> AP: association request
    - AP -> STA: association response
    - AP informs old AP via the DS in case of roaming

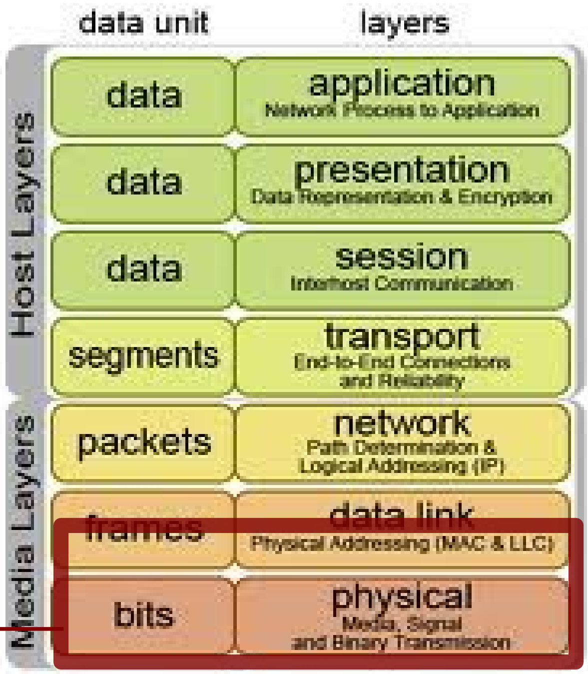
IEEE 802.11: Introduction

- 802.11 is not only about the MAC

- IEEE 802.11 defines protocols for the **PHY** and **MAC**

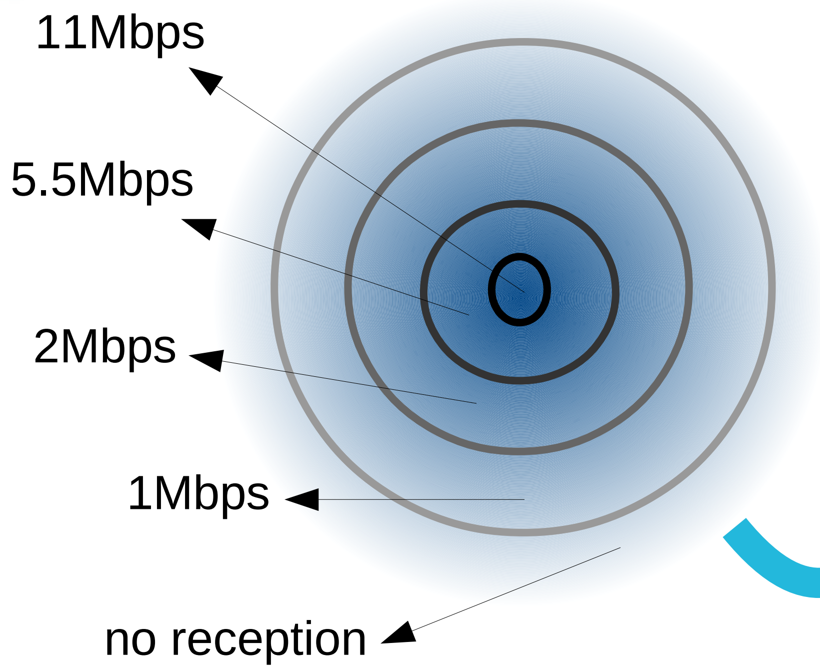
physical layer

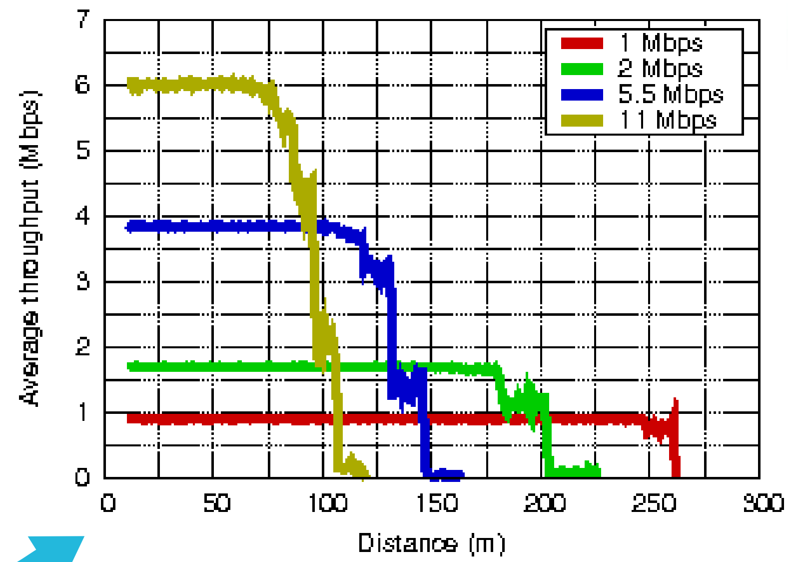
medium access control sub-layer



IEEE 802.11: PHY Basics

- Modulation – gives us the data rate
  - To decode a more complex modulation, we need a higher signal strength
  - Trade-off between data rate and transmission range





[ns-2 simulation, 802.11b]

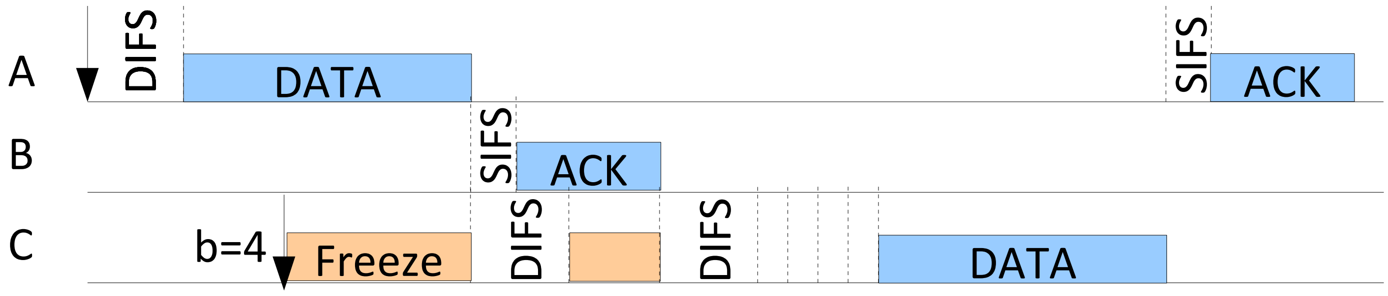
IEEE 802.11: DCF

- CSMA/CA implementation = Distributed Coordination Function (DCF)
  - four types of **InterFrame Space** (IFS)
    - Short InterFrame Space (**SIFS**)
      used to separate transmissions belonging to a same dialogue (before a CTS or an ACK)
    - Point coordination InterFrame Space (**PIFS**)
      for data in the contention-free period (see later), to preempt any contention-based traffic
    - Distributed InterFrame Space (**DIFS**)
      standard IFS, used to separate transmissions of different dialogues
    - Extended InterFrame Space (**EIFS**)
      used by a station that received an erroneous frame

  - SIFS < PIFS < DIFS < EIFS

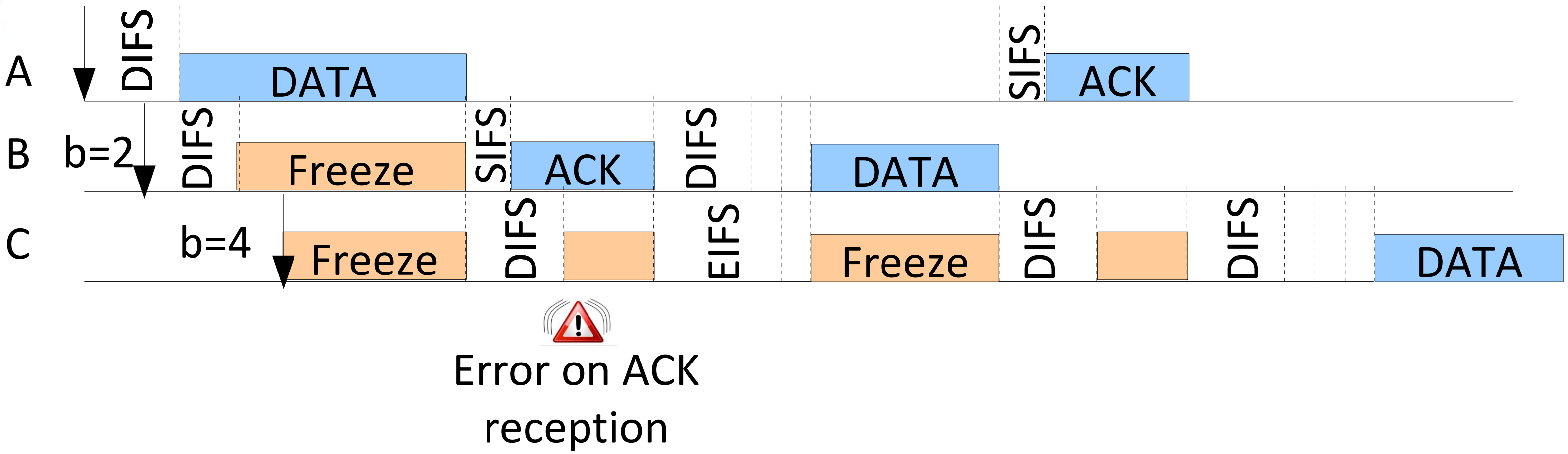
IEEE 802.11: DCF

- Scenarios



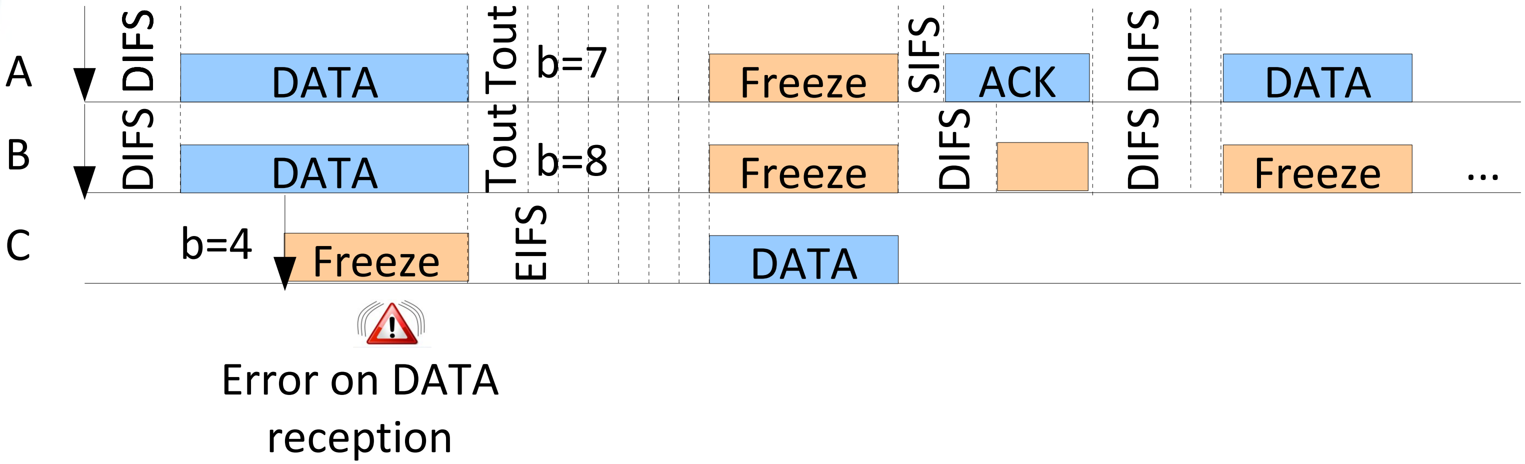
IEEE 802.11: DCF

- Scenarios



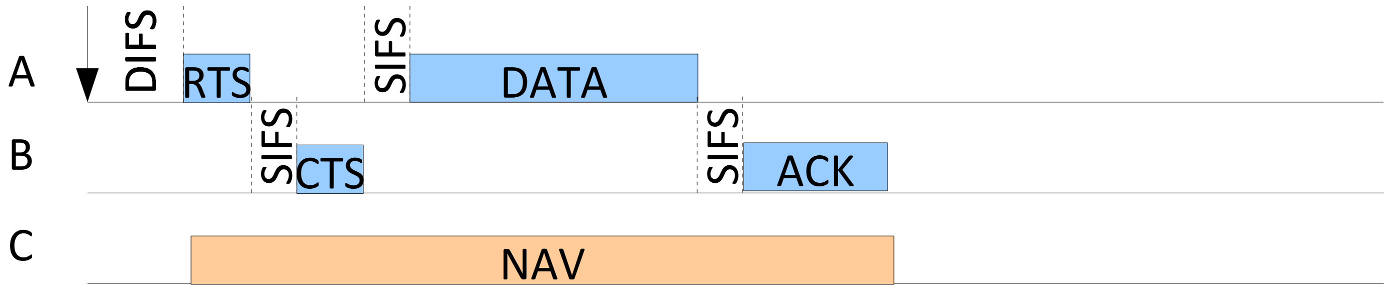
IEEE 802.11: DCF

- Scenarios



IEEE 802.11: DCF

- Scenarios



- NAV = Network Allocation Vector = Virtual Carrier Sense
- The RTS/CTS handshake is optional in IEEE 802.11

IEEE 802.11: DCF

Broadcast messages

- Broadcast= one transmitter, multiple receivers
- If all receivers transmit CTS or ACK after SIFS, collisions are unavoidable
- Broadcast messages are transmitted only once using the minimum CW, and their transmission is unreliable (no ACK)

IEEE 802.11: DCF

- Why do we still get collisions with Collision Avoidance?

  - CA mitigates collisions, but it does not eliminate them

  - The collision probability depends on
    - the number of contending stations
    - the size of the contention window

  - A higher CW reduces the collision probability, but increases the delay introduced by back-off

IEEE 802.11: DCF

- The DCF is:

  - A very strong MAC protocol in the context of a WLAN (an AP and 10-20 stations)

  - The most successful wireless technology in the world

  - The cheapest wireless technology on the market

IEEE 802.11: DCF

- But the DCF is too:
  - Only a MAC layer solution among others (cellular networks use CDMA or OFDMA)
  - A mediocre protocol when mobility is considered
  - An unusable technology under high node density

IEEE 802.11: DCF

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  - Only a MAC layer solution among others (cellular networks use CDMA or OFDMA)
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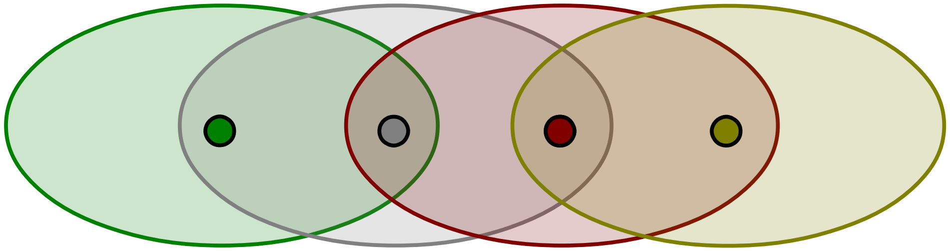
IEEE 802.11: DCF

An example – multi-hop networks

- **exposed** terminal – a tremendous reduction in throughput



sends RTS to

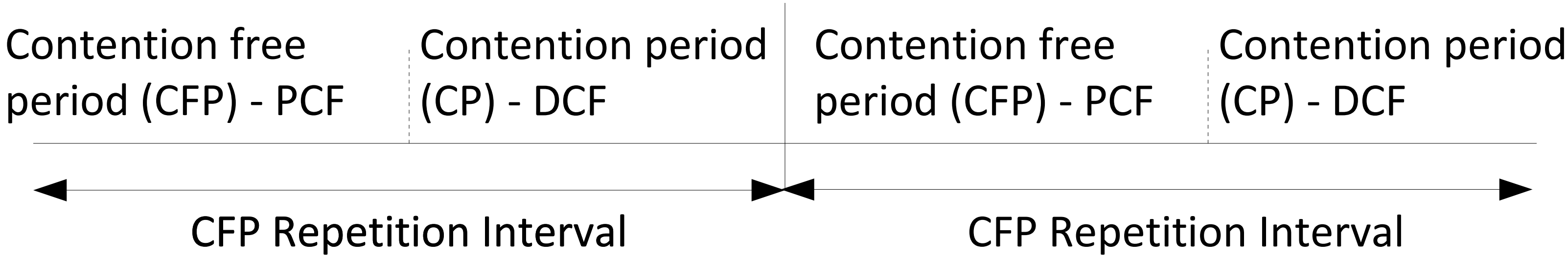
sends CTS to

receives RTS from and refrain from transmitting to

...but transmission from to would not cause a collision!

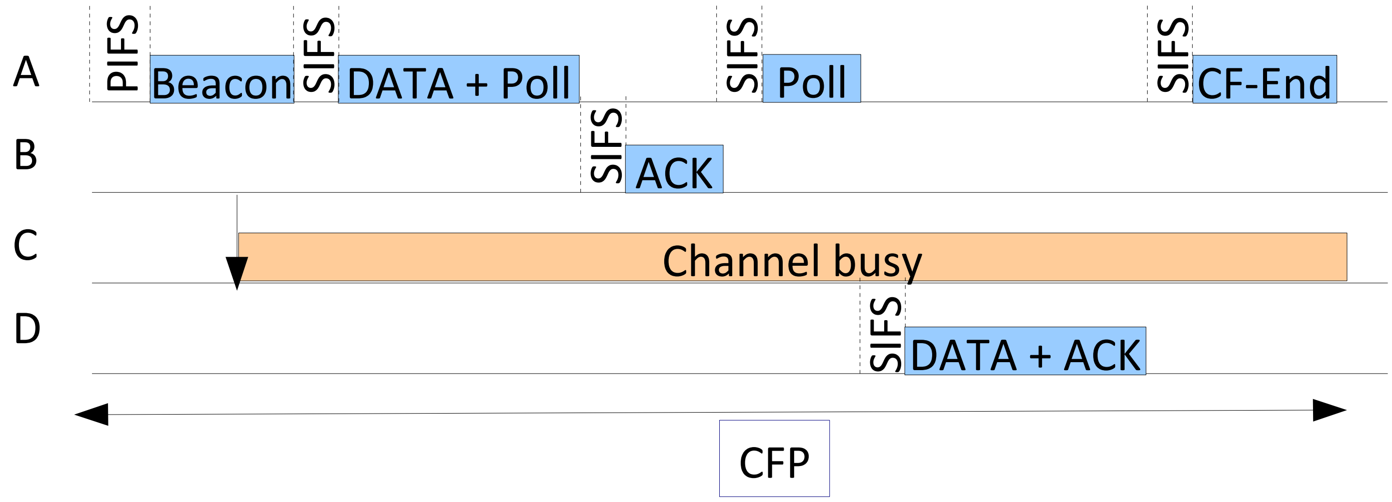
IEEE 802.11: PCF

- There is more than DCF in IEEE 802.11
  - Point Coordination Function (PCF)
  - Contention-Free frame transfer protocol
  - Based on polling made by the access point
  - Coexists with DCF



IEEE 802.11: PCF

- How does PCF work?



IEEE 802.11: Frame Format

- The 802.11 frame

Preamble	PLCP	MAC Data	CRC

- The MAC Data

Frame Control	Duration	Address1	Address2	Address3	Sequence Control	Address4	Frame Body	CRC

IEEE 802.11: Frame Format

- Why do we need 4 addresses?
  - The Frame Control field contains (among others) two bits named To DS and From DS
  - The value of To DS and From DS gives the meaning of the 4 addresses

To DS	From DS	Address1	Address2	Address3	Address4
0	0	Destination	Source	BSSID	N/A
0	1	Destination	BSSID	Source	N/A
1	0	BSSID	Source	Destination	N/A
1	1	Receiver	Transmitter	Destination	Source

CSMA/CA and IEEE 802.11

Bibliography

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- **S. Xu, T. Saadawi**, *“Does the IEEE 802.11 MAC protocol work well in multi-hop wireless ad hoc networks?”*, IEEE Communications Magazine, June 2001
- **A. Colvin**, *“CSMA with Collision Avoidance”*, Computer Communications, October 1983