Wireless networks

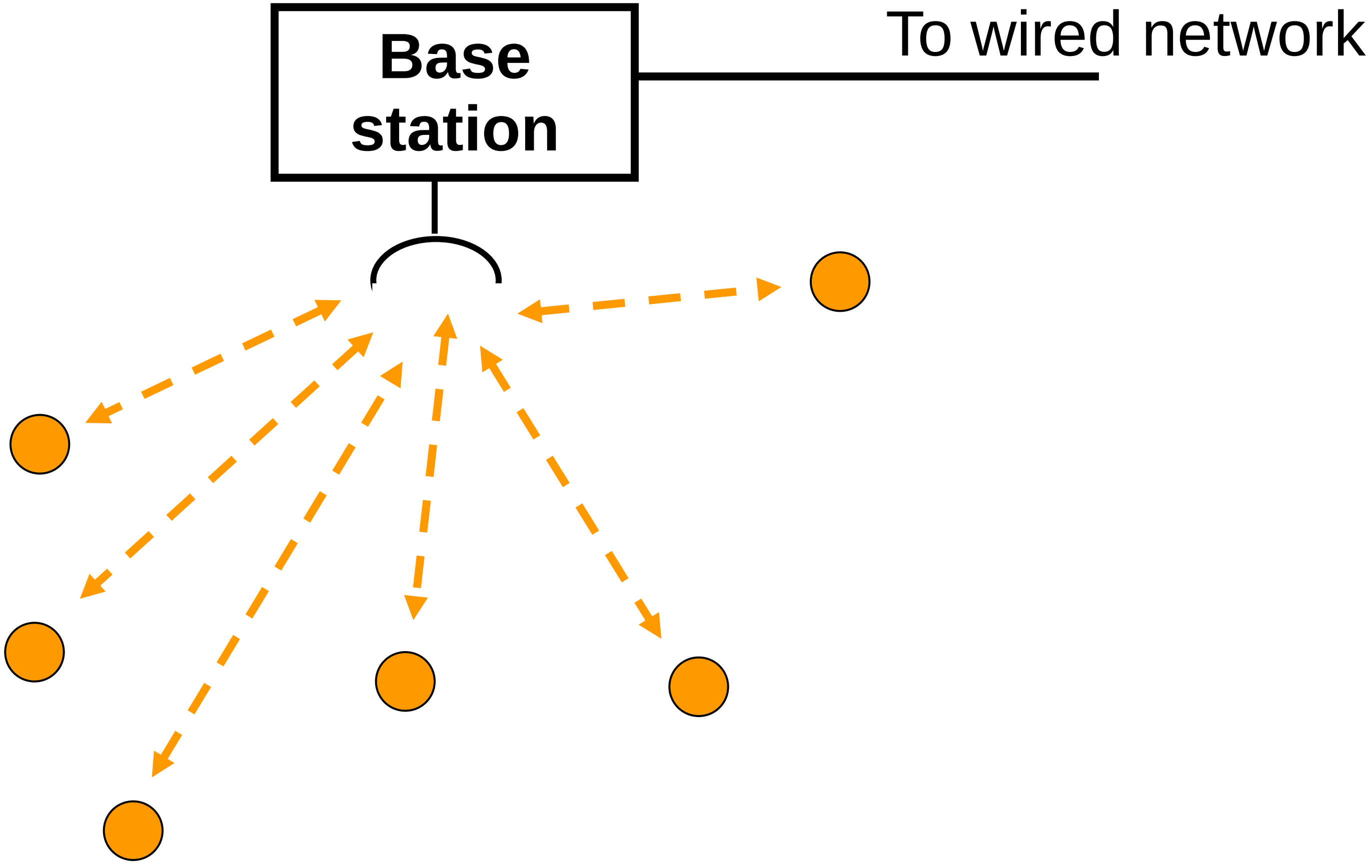
Overview

- Wireless networks basics
- IEEE 802.11 (Wi-Fi) a/b/g/n
- ad Hoc MAC protocols
- ad Hoc routing DSR AODV

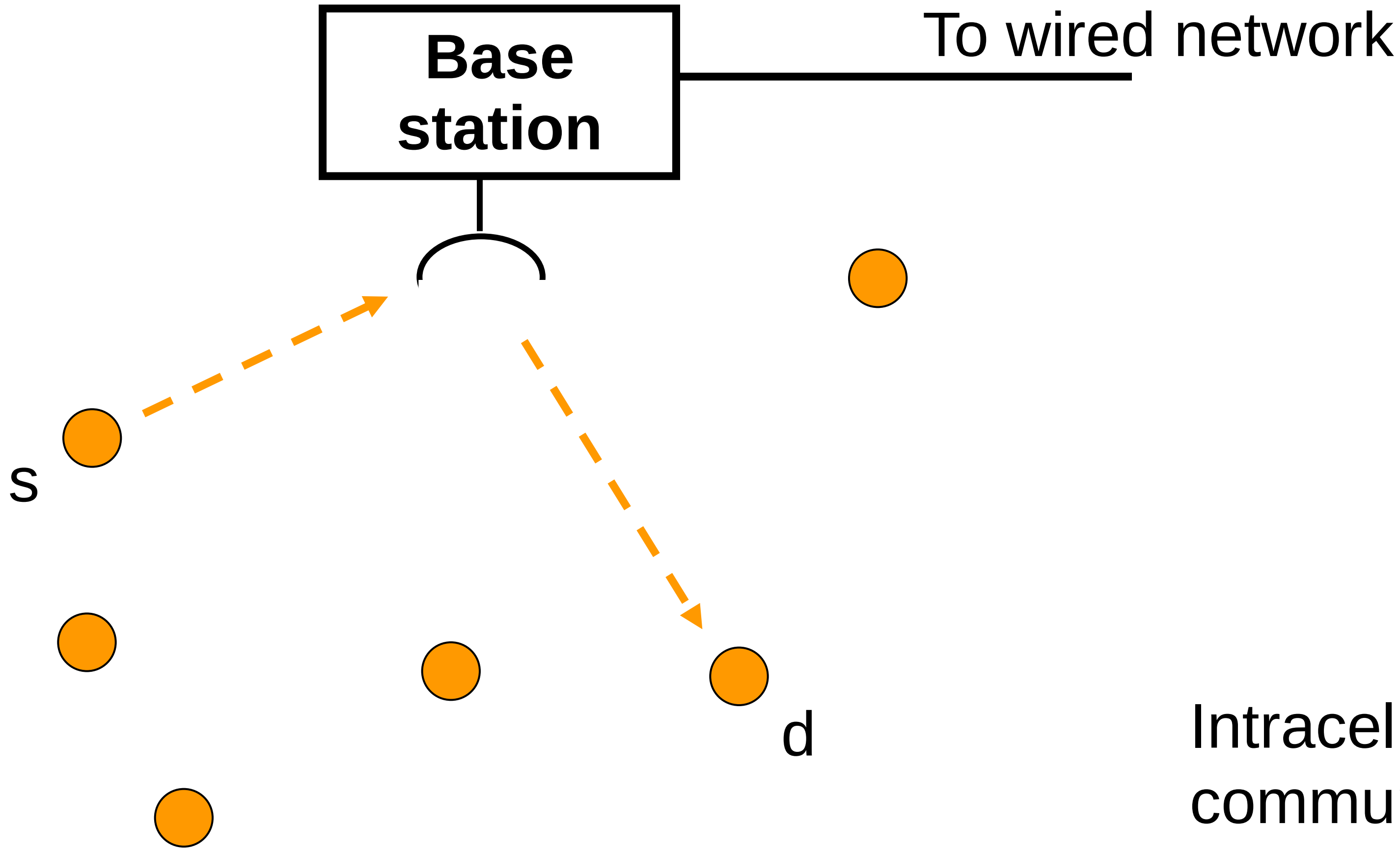
Wireless Networks

- Autonomous systems of mobile hosts connected by wireless links
- Nodes are autonomous and independent
  - mobile, battery powered
  - communicate mainly via radio frequncies
- Two modes of operations
  - *wireless networking with a base station*:
    - wired **access points**
  - *ad hoc networking*:
    - no centralized coordinators

Wireless networking with a BS

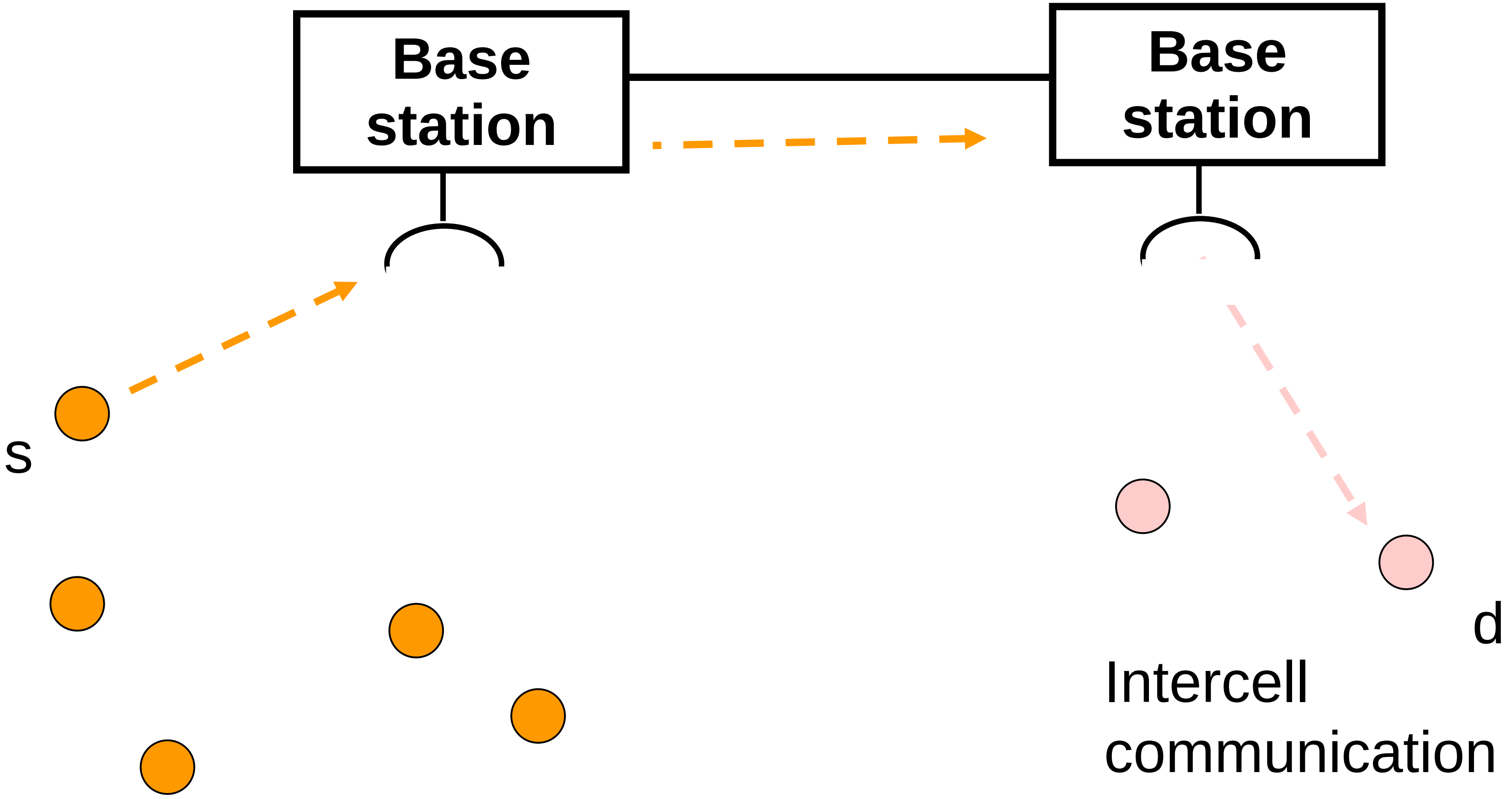


Wireless networking with a BS (2)

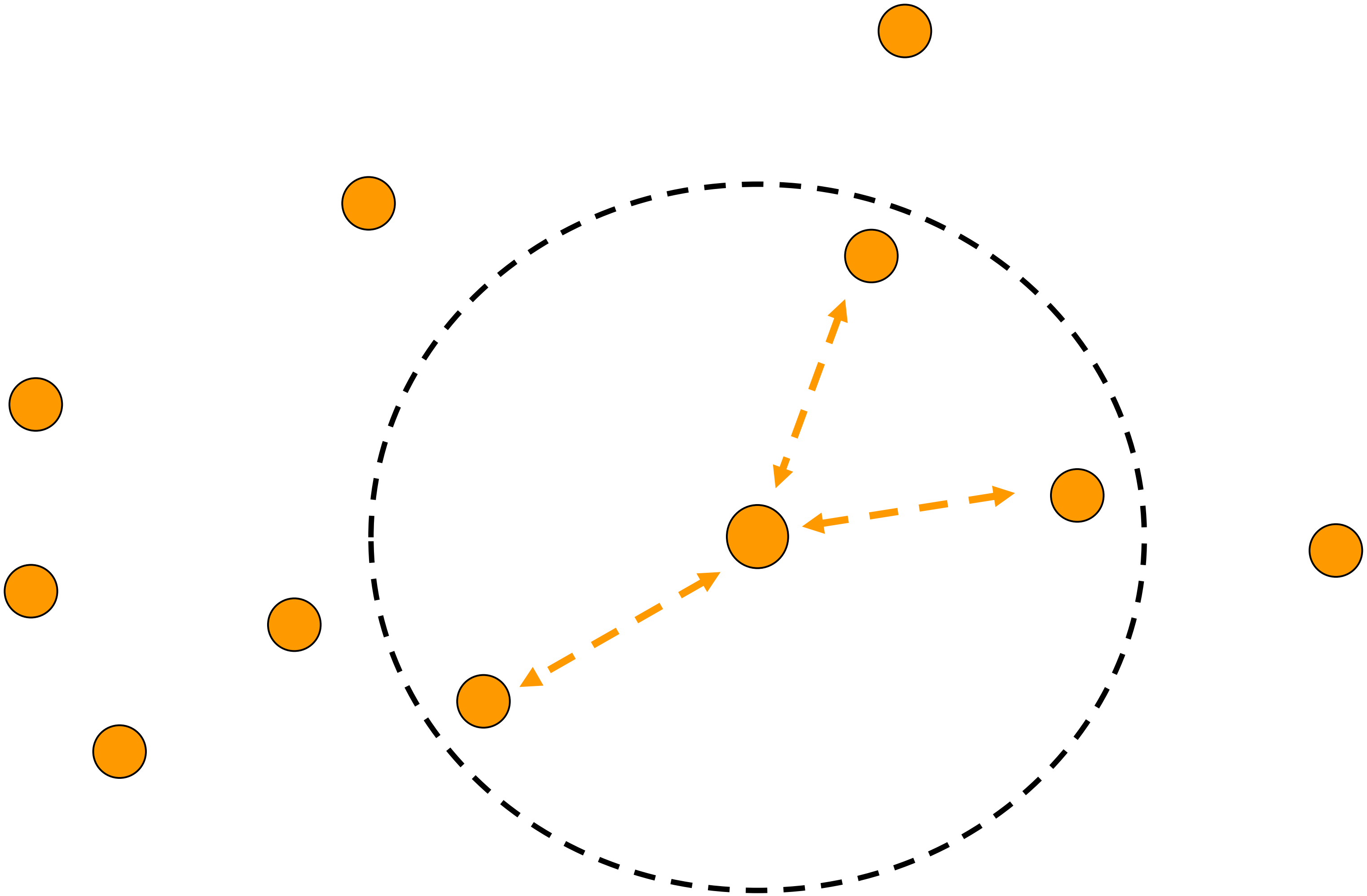


Intracell communication

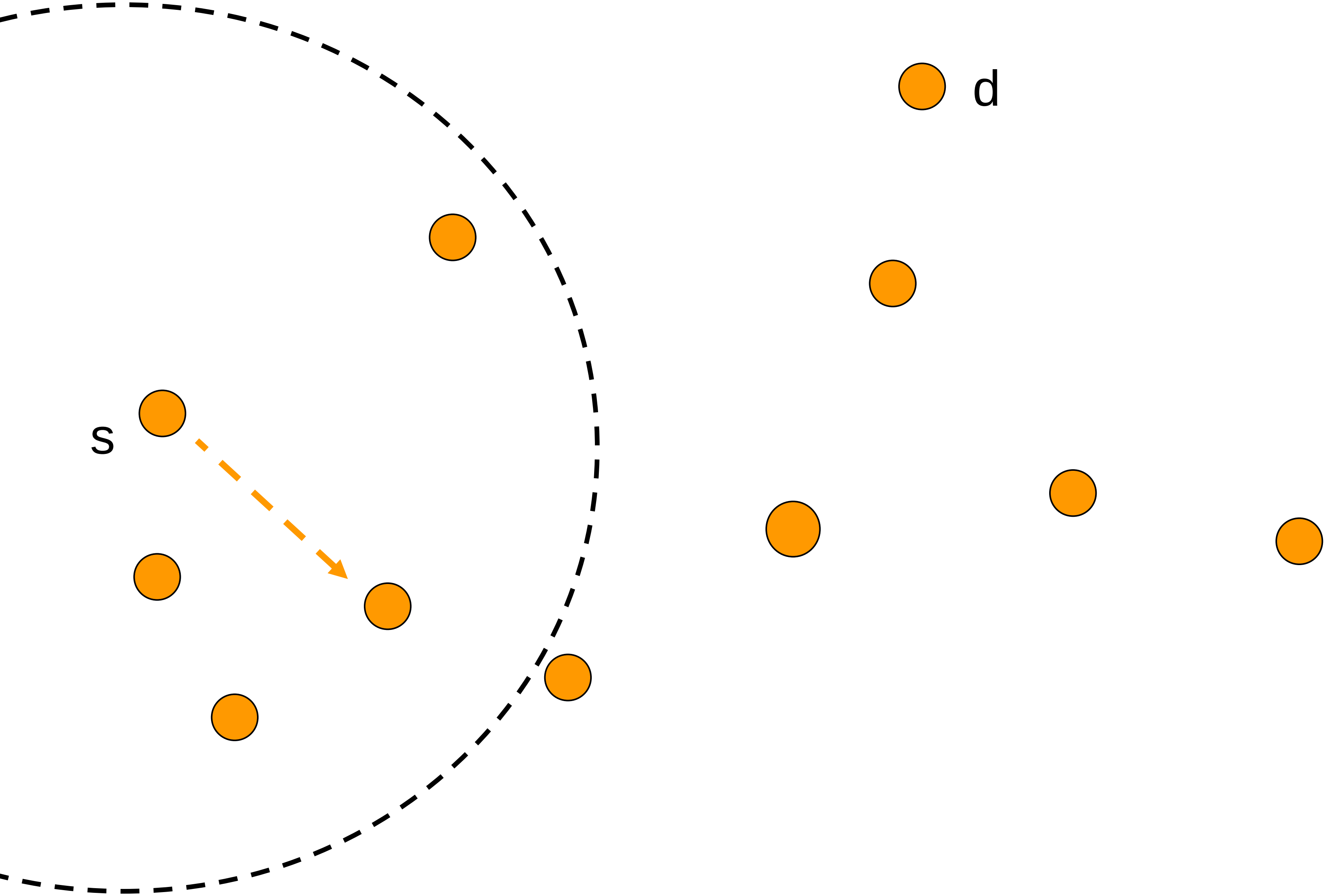
Wireless networking with a BS (3)



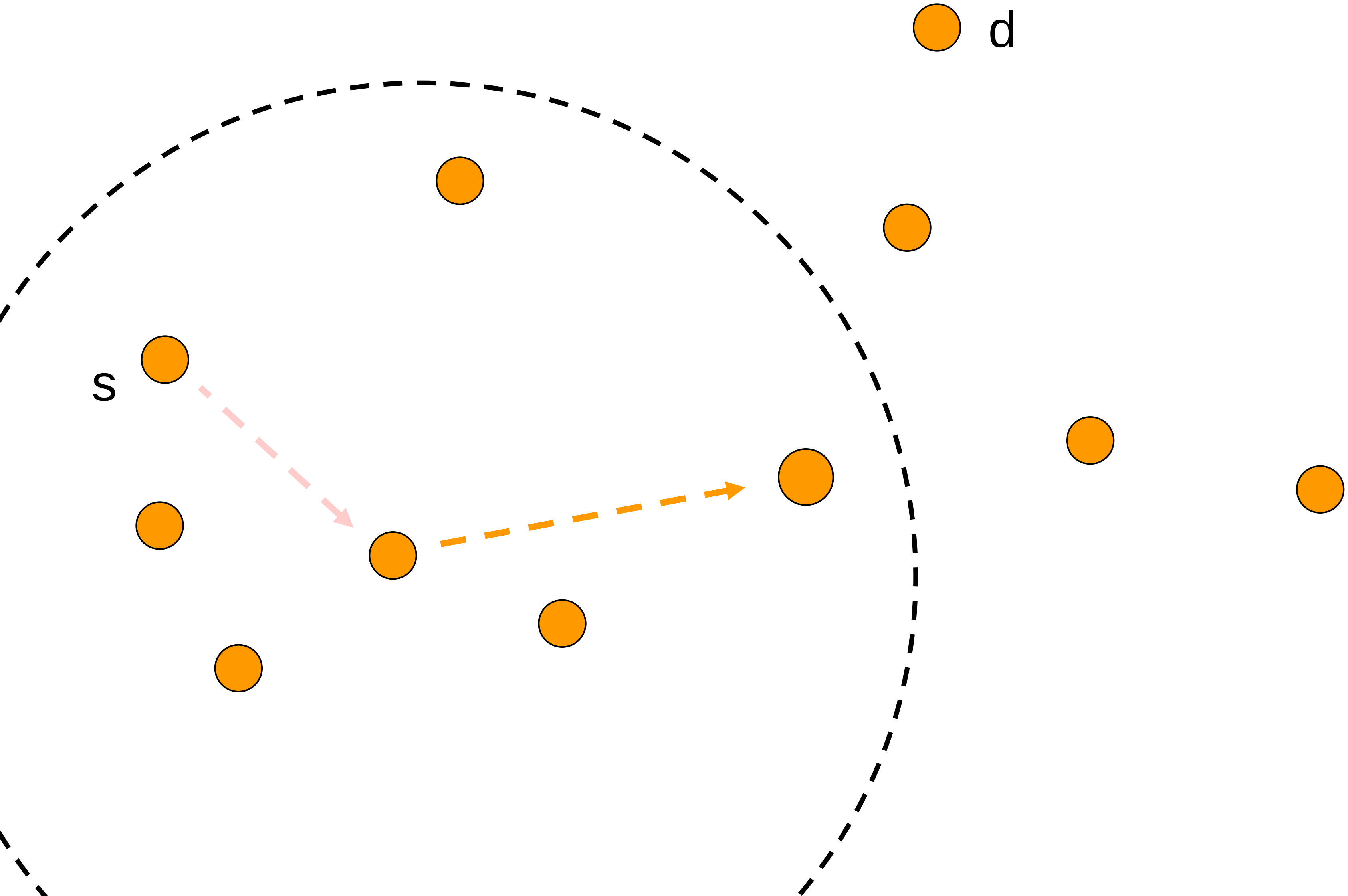
Ad hoc networking



Ad hoc networking (2)

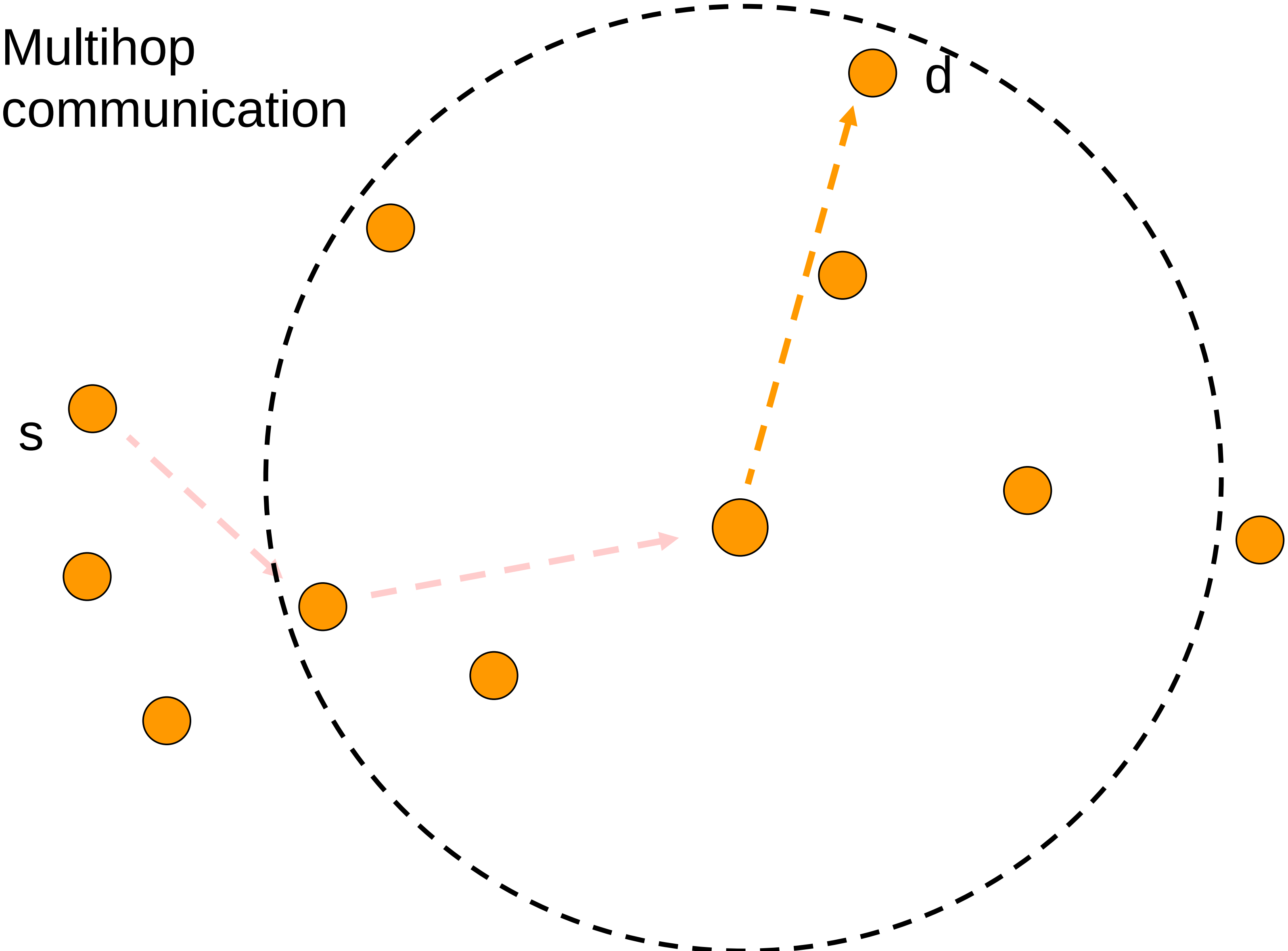


Ad hoc networking (3)



Ad hoc networking (4)

Multihop
communication



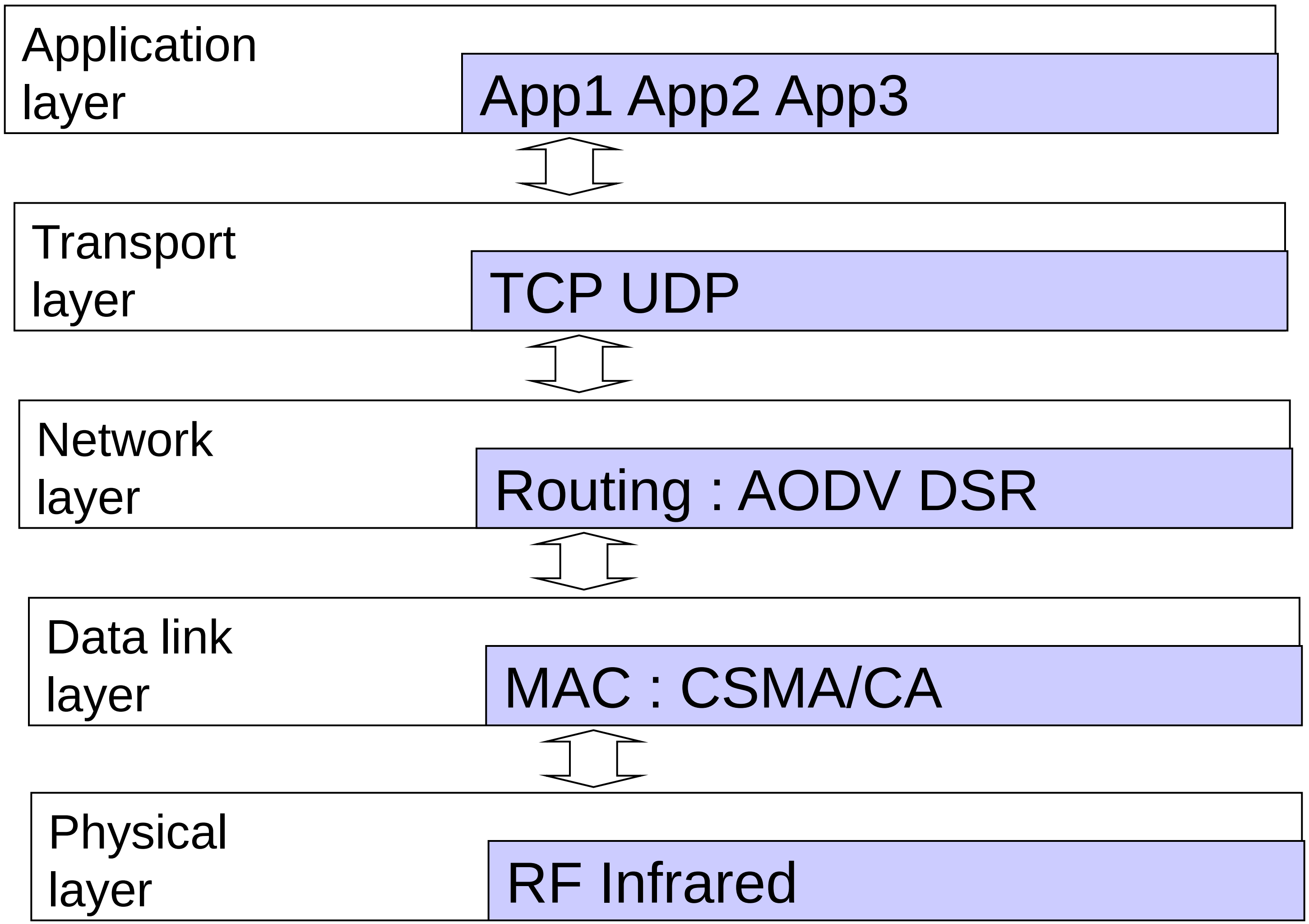
Wireless networks: challanges

- Limited knowledge
  - a terminal cannot head all the others
  - multipath fading effects
- Mobility/Failure of terminals
  - terminals move in the range of different BS
  - terminals move away from each other
- Limited terminals
  - battery life, memory, processing and transmission range
- Privacy
  - eavesdropping of ongoing communications

Wireless networks: some problems

- Access to a shared wireless channel
  - CSMA/CD cannot be used
  - hidden-exposed terminal problem
- Hand-off
  - moving a terminal into the range of a different BS
- Routing
  - deciding a path from source to destination in multi hop networks
  - dealing with arbitrary changes in neighborhood

Wireless networks: protocol stack



Wired networks MAC protocols

- Basic assumptions:
  - a single channel is available for all communications
  - all stations can transmit on it and receive from it
  - if frames are send simultaneously on the channel the resulting segnal is garbles (a **collision**)
  - all stations can detect collisions

- Different protocols
  - ALOHA, slotted ALOHA, CSMA, CSMA/CD

CSMA/CD

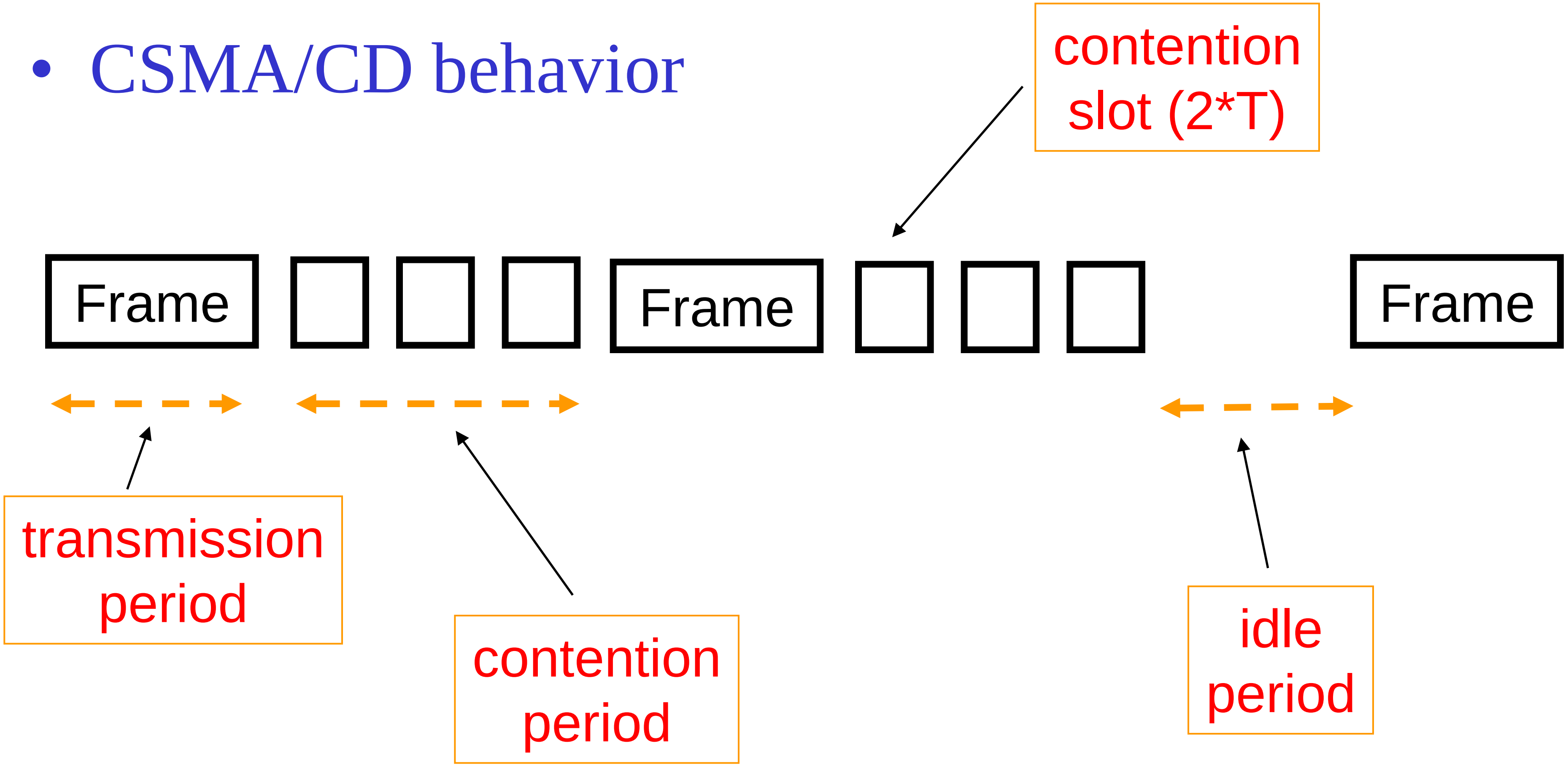
- Carries Sense Multiple Accesses with *Collision Detection*
- Basic idea of CSMA:
  - When a station has a frame to send listens to the channel to see if anyone else is transmitting
  - *if the channel is busy*, the station waits until it becomes idle
  - when channel is idle, the station transmits the frame
  - if a collision occurs the station waits a random amount of time and repeats the procedure.

CSMA/CD (2)

- CSMA with *Collision Detection*
  - a station aborts its transmission as soon as it detects a collision
    - if two stations sense the channel idle simultaneously and start transmitting, they quickly abort the frame as soon as collision is detected
  - it is widely used on LANs in MAC sub-layer
  - IEEE 802.3 Ethernet

CSMA/CD (3)

- CSMA/CD behavior



Binary Exponential Backoff

- Used in IEEE 802.3
- Time after a collision is divided in contention slots
  - length of a contention slot is equal to worst case round propagation time (2T if T is the time to reach the most distant stations)
- After the first collision
  - each station waits 0 or 1 slot before trying again

Binary Exponential Backoff (2)

- After collision *i*
  - chooses *x* at random in 0, 1, 2, …,2^i-1
  - skips *x* slots before retrying

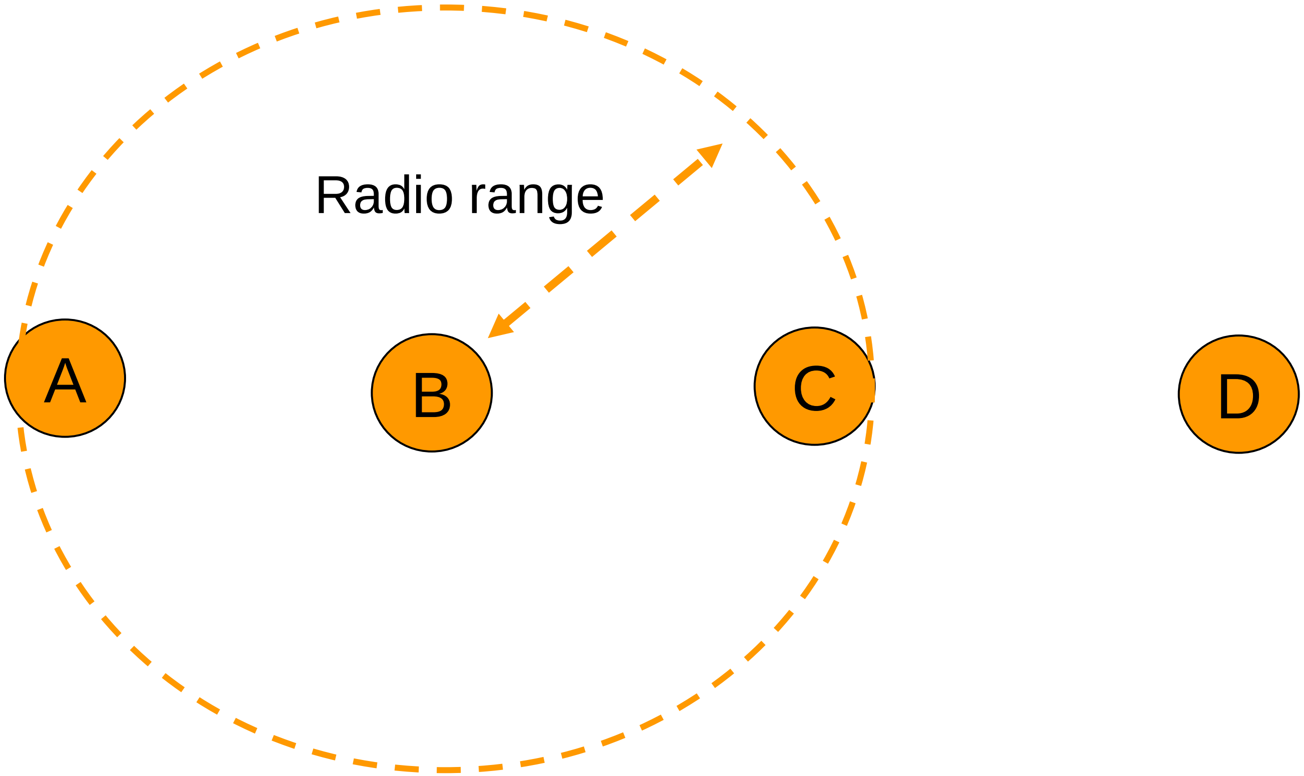
- After 10 collisions:
  - the randomization interval is frozen at 0..1023

- After 16 collisions
  - failure is reported back to upper levels

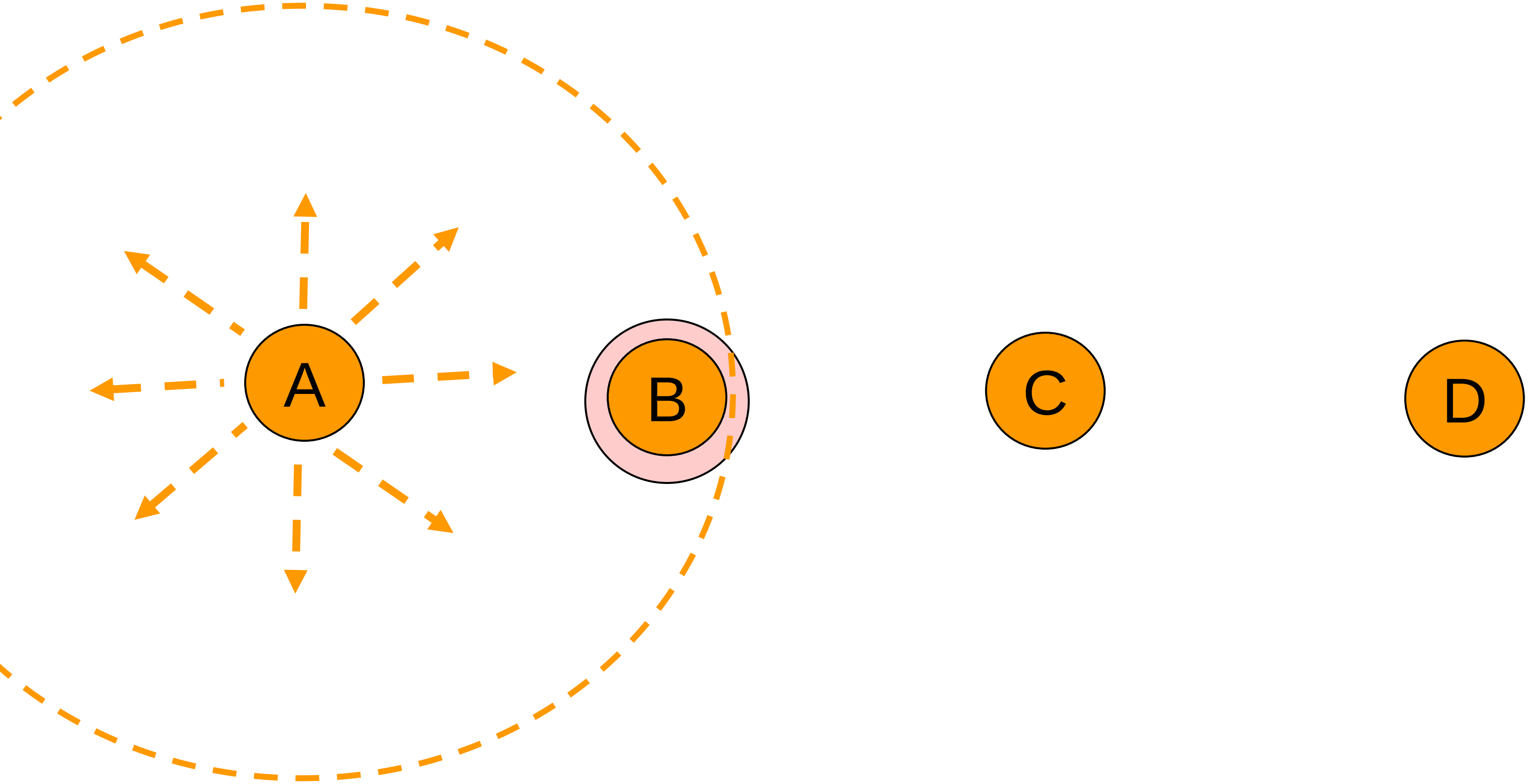
Wireless networks: MAC

- Hidden terminal problem
  - what matters is interference at the receiver *not* at the sender

The hidden terminal problem

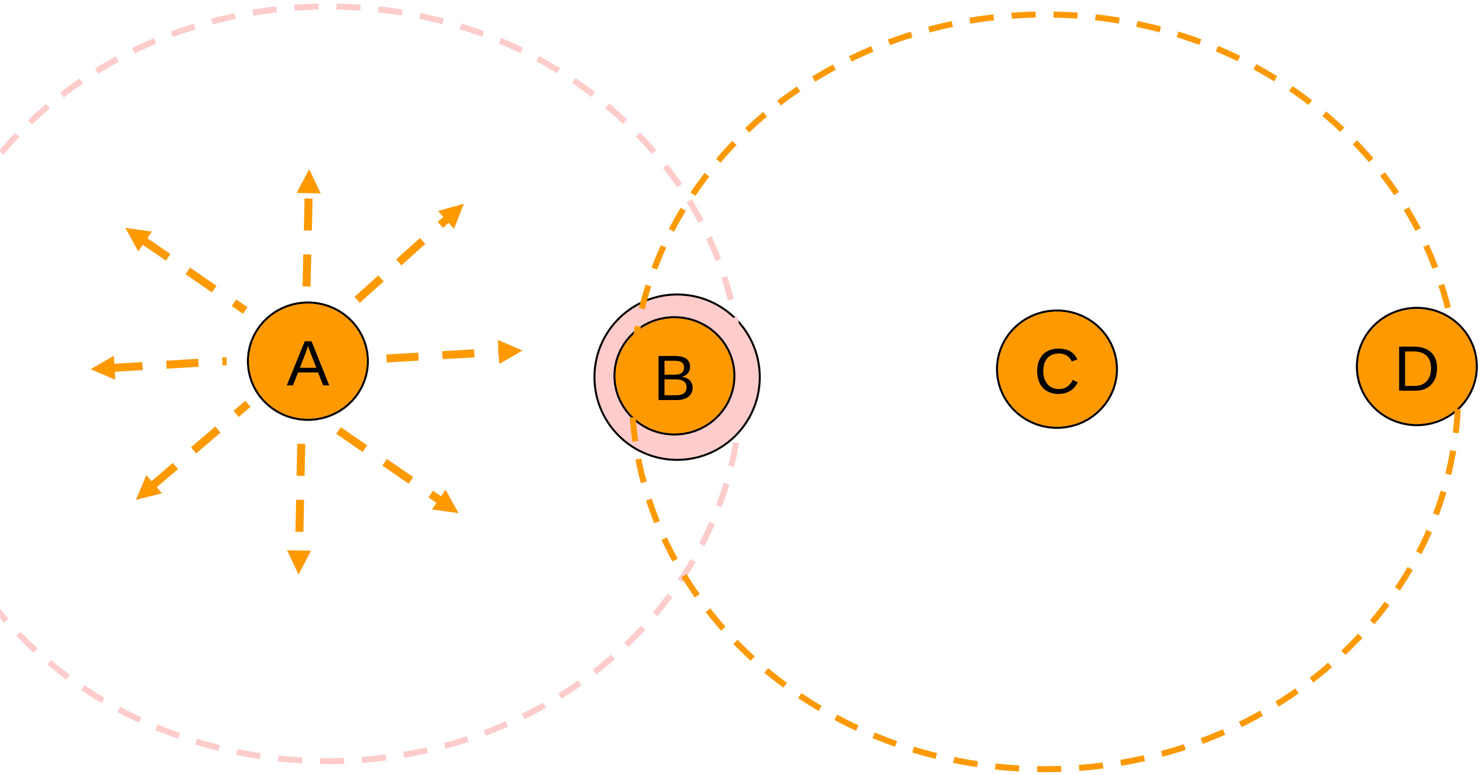


The hidden terminal problem (2)



A is sending to B

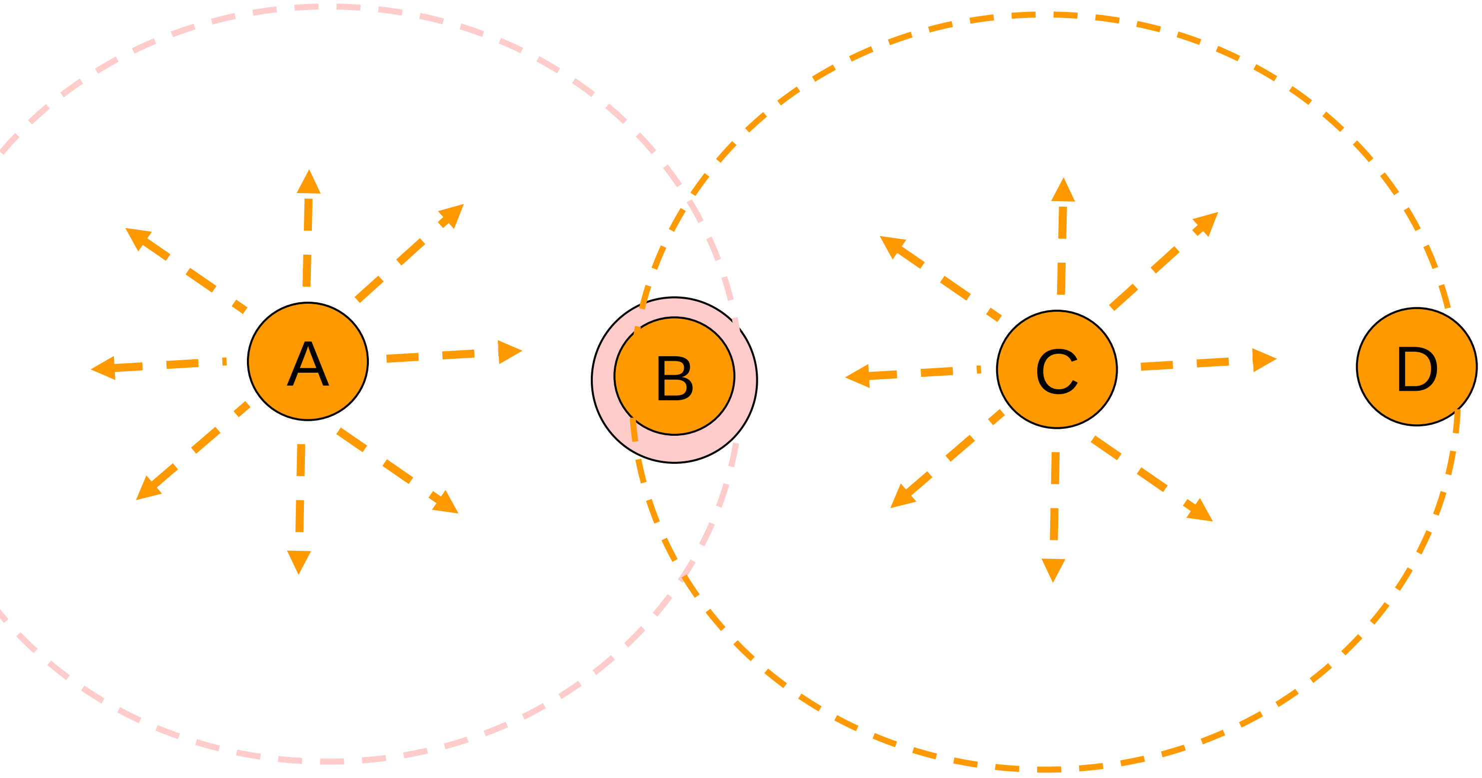
Hidden terminal problem (3)



A is sending to B

C senses the medium: it will NOT hear A, out of range

Hidden terminal problem (4)



A is sending to B

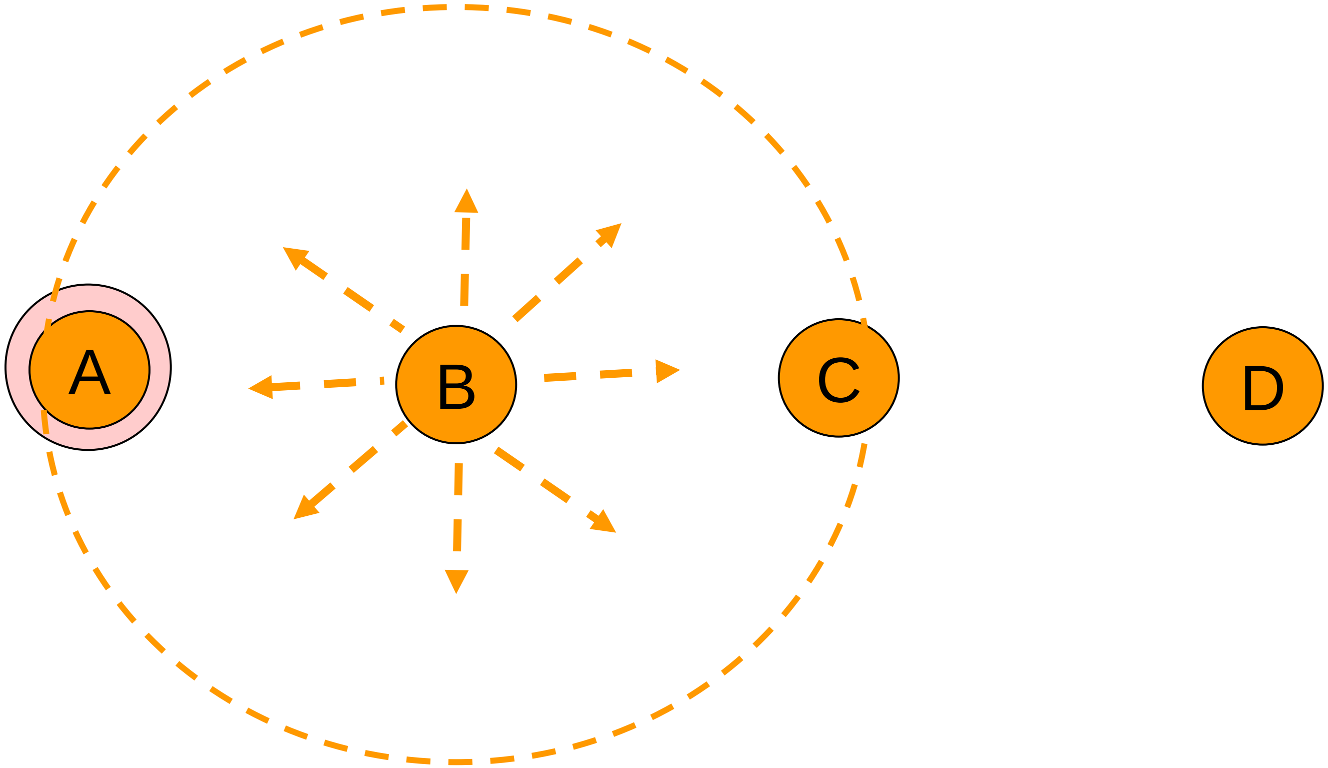
C senses the medium: it will NOT hear A, out of range

C starts to sent to B -- COLLISION OCCURS at B

Wireless networks: MAC

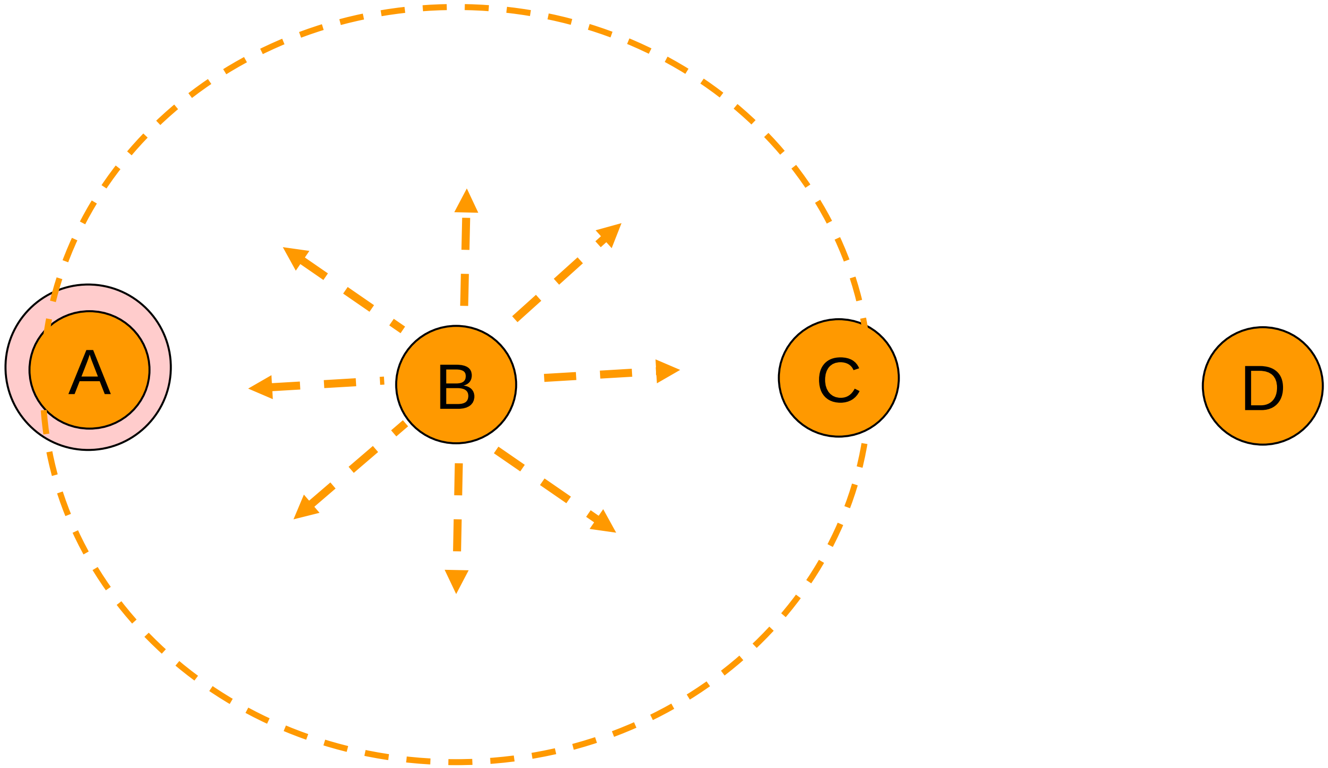
- Hidden terminal problem
  - what matters is interference at the receiver *not* at the sender
  - in the example: C is not able to detect a potential competitor because it is out of range and collision happens at B (the receiver)
- Exposed terminal problem
  - a station can hear a transmission and be able to transmit without interfere with it

The exposed terminal problem



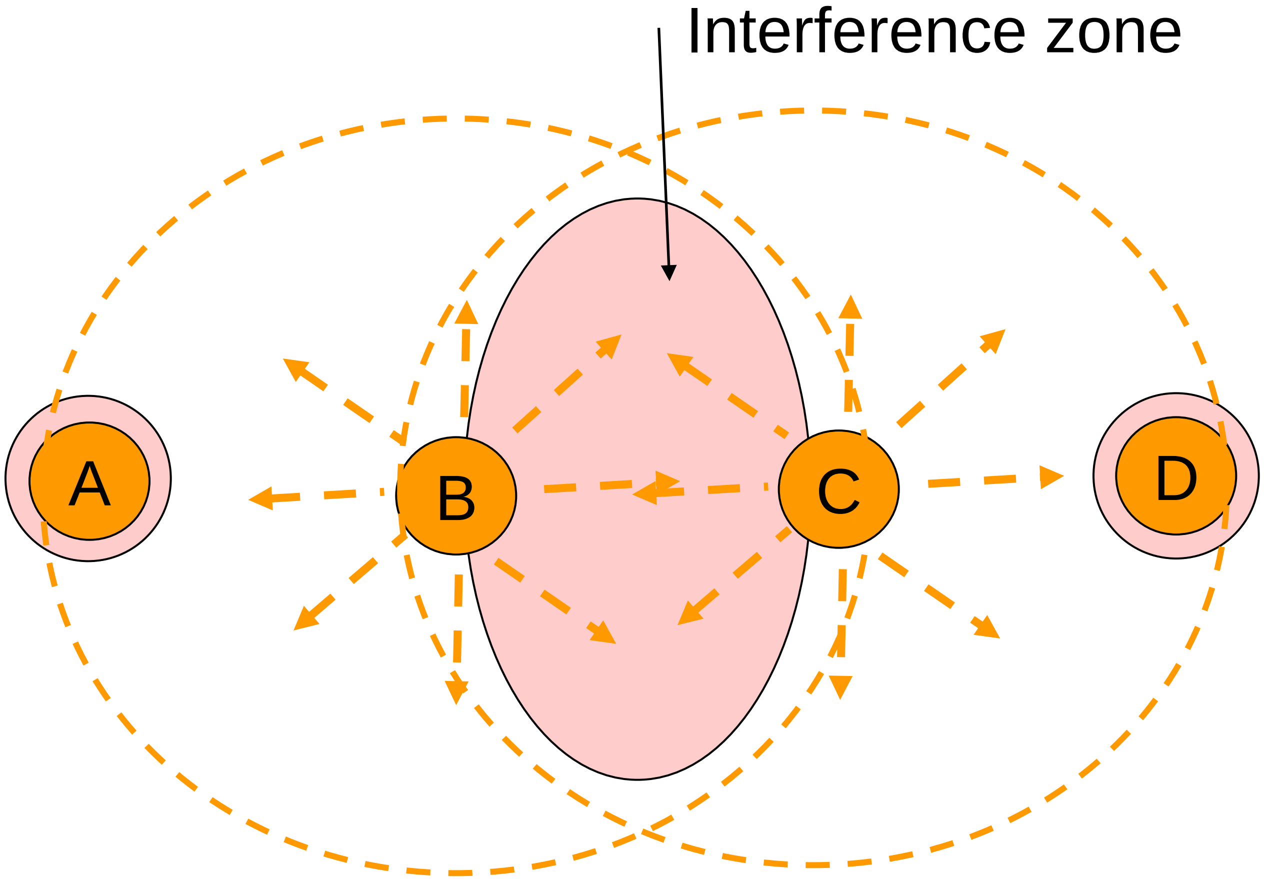
1. B is transmitting to A, C wants to transmit to D

The exposed terminal problem (2)



1. B is transmitting to A, C wants to transmit to D
2. C senses the medium,
   hears B and concludes: **cannot transmit** to D

The exposed terminal problem (3)



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.

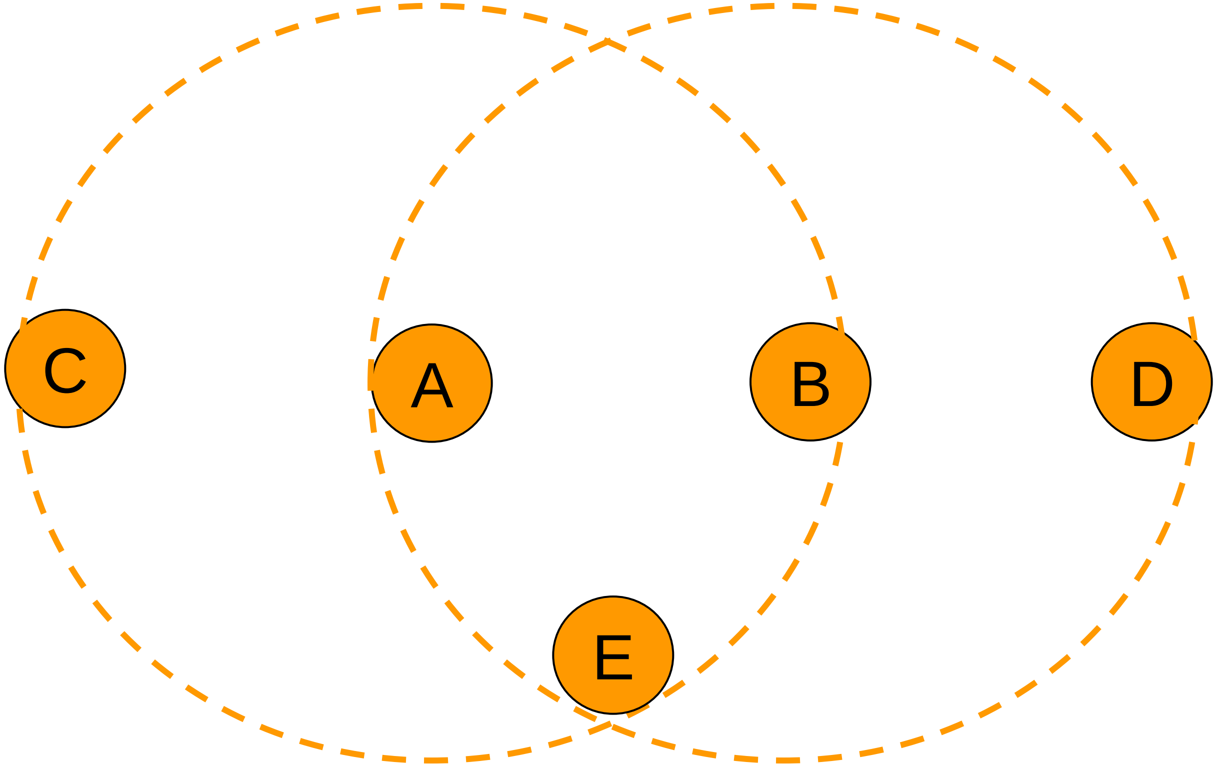
Wireless networks: MAC (2)

- what matters is interference at the receiver *not* at the sender
  - this cannot be established *sensing the carrier at the sender*
- Multiple transmissions can occur simultaneously if destinations are out of range of each other
  - a station can hear a transmission and be able to transmit without interfere with it
- Need different MAC protocols from wired LANs

The MACA protocol

- Multiple Accesses with Collision Avoidance
- Basic idea:
  - stimulate the receiver into transmitting a short frame
  - then transmitting a (long) data frame
  - stations hearing the short frame refrain from transmitting during the transmission of the subsequent data frame

The MACA protocol

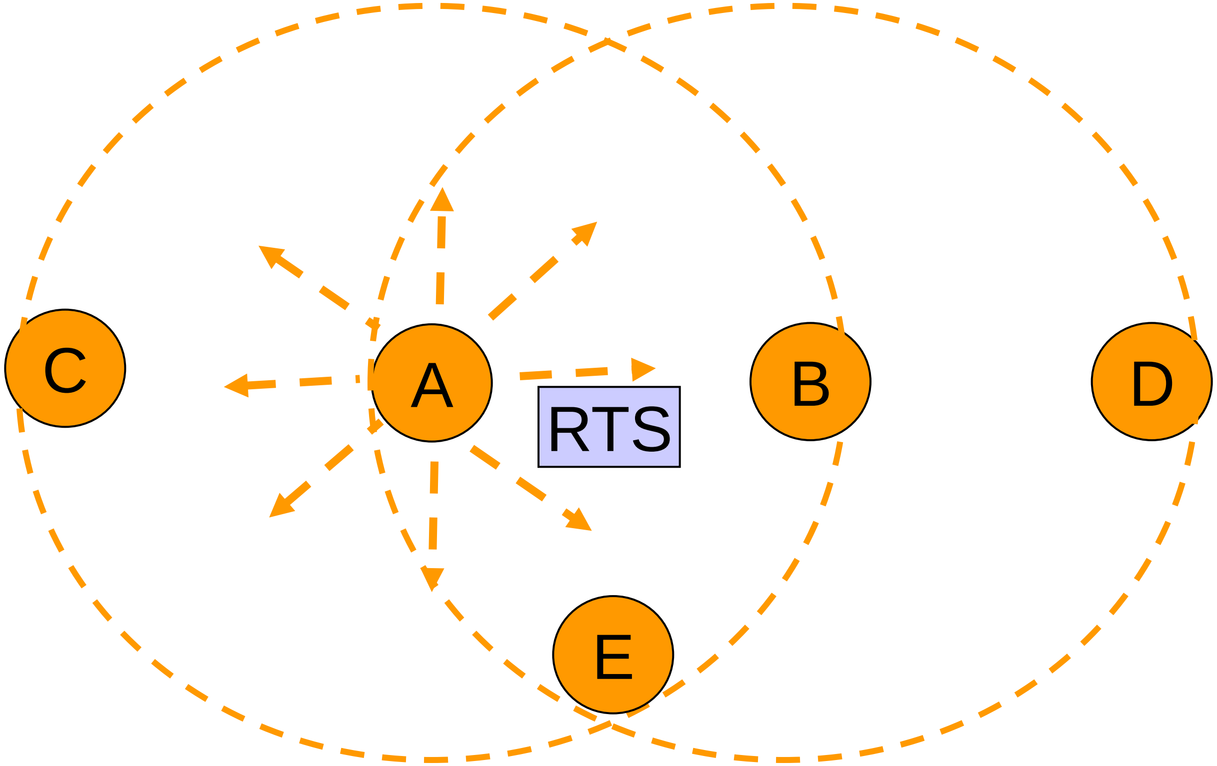


C is within range of A but *not within range of B and D*

D is within range of B but *not within range of A and C*

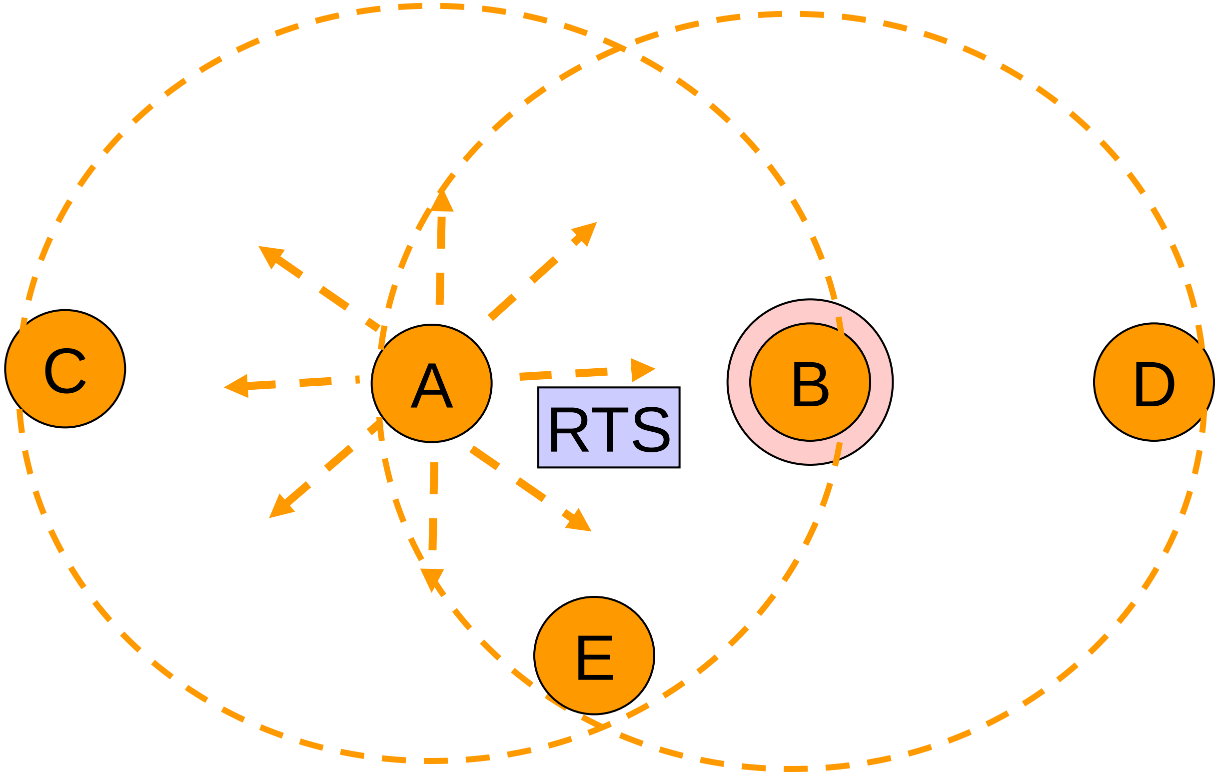
E is within range of both A and B

The MACA protocol (2)



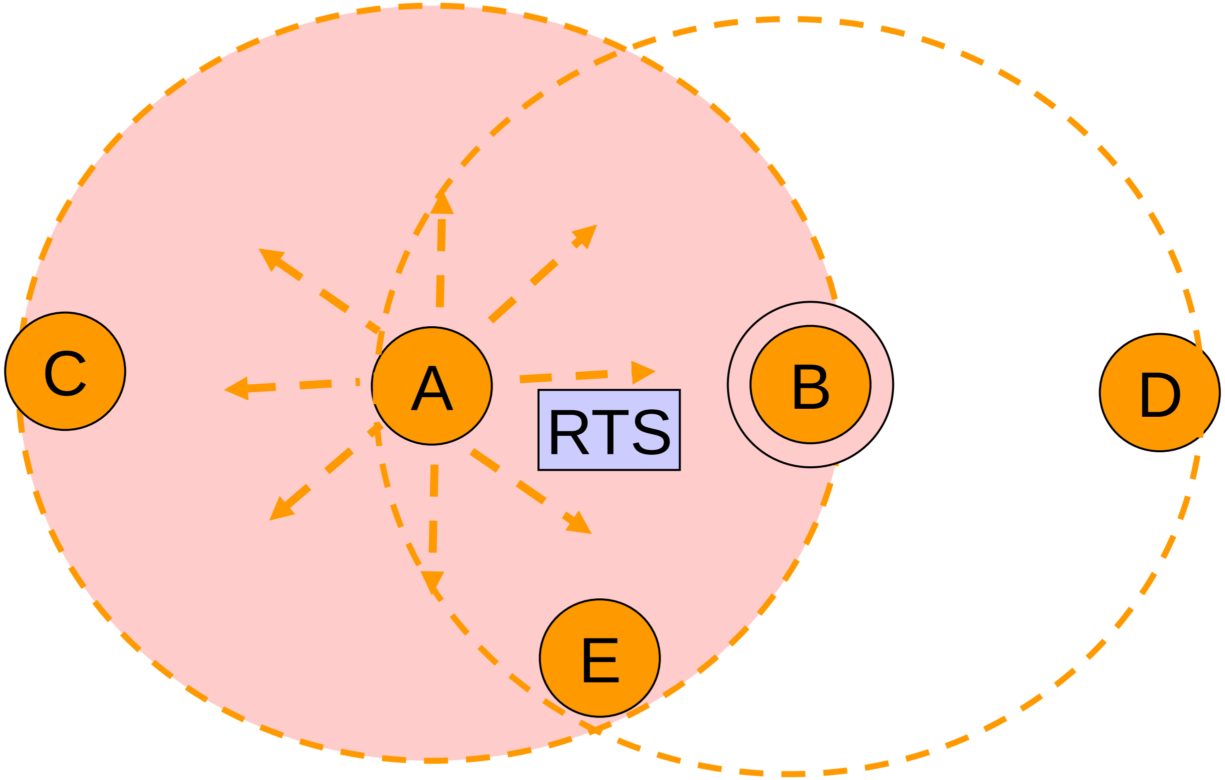
1. A wants to transmit to B, sends a Request To Send to B

The MACA protocol (2)



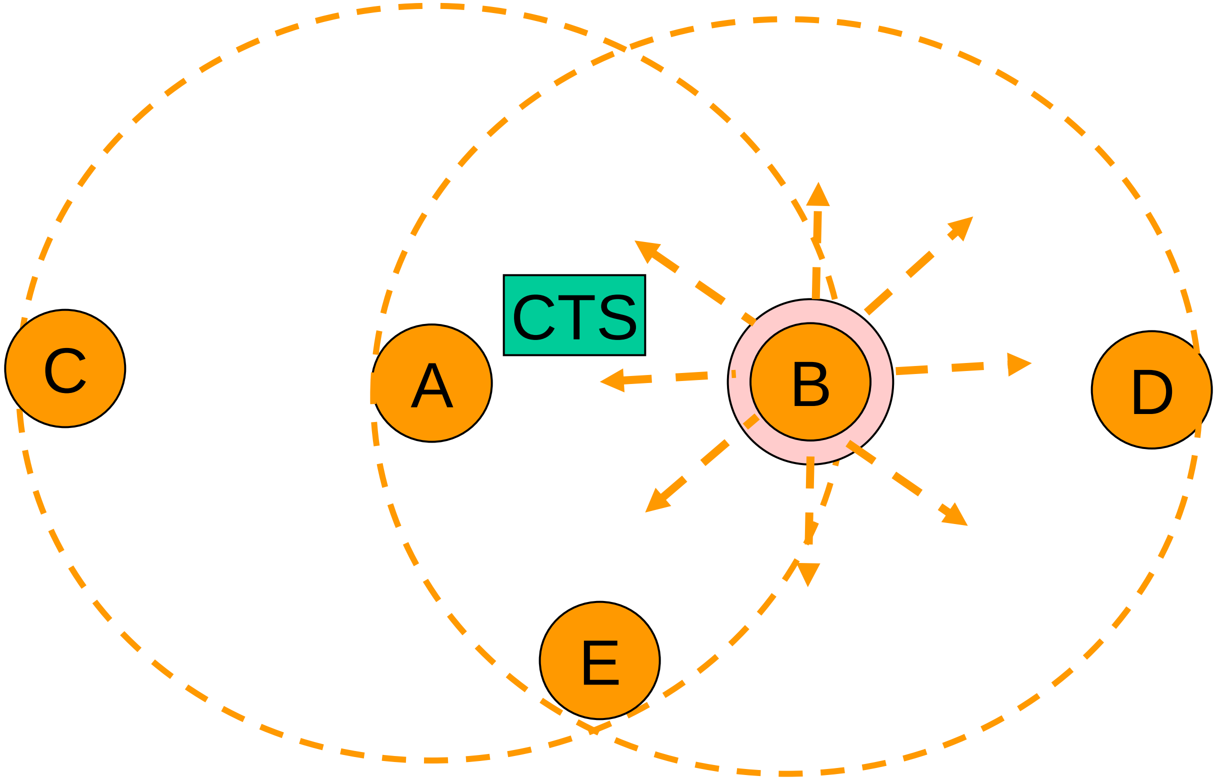
1. A wants to transmit to B, sends a <u>Request To Send</u> to B
   RTS is a short frame including the length of the data frame that will eventually follow

The MACA protocol (3)



1. A wants to transmit to B, sends an RTS to B

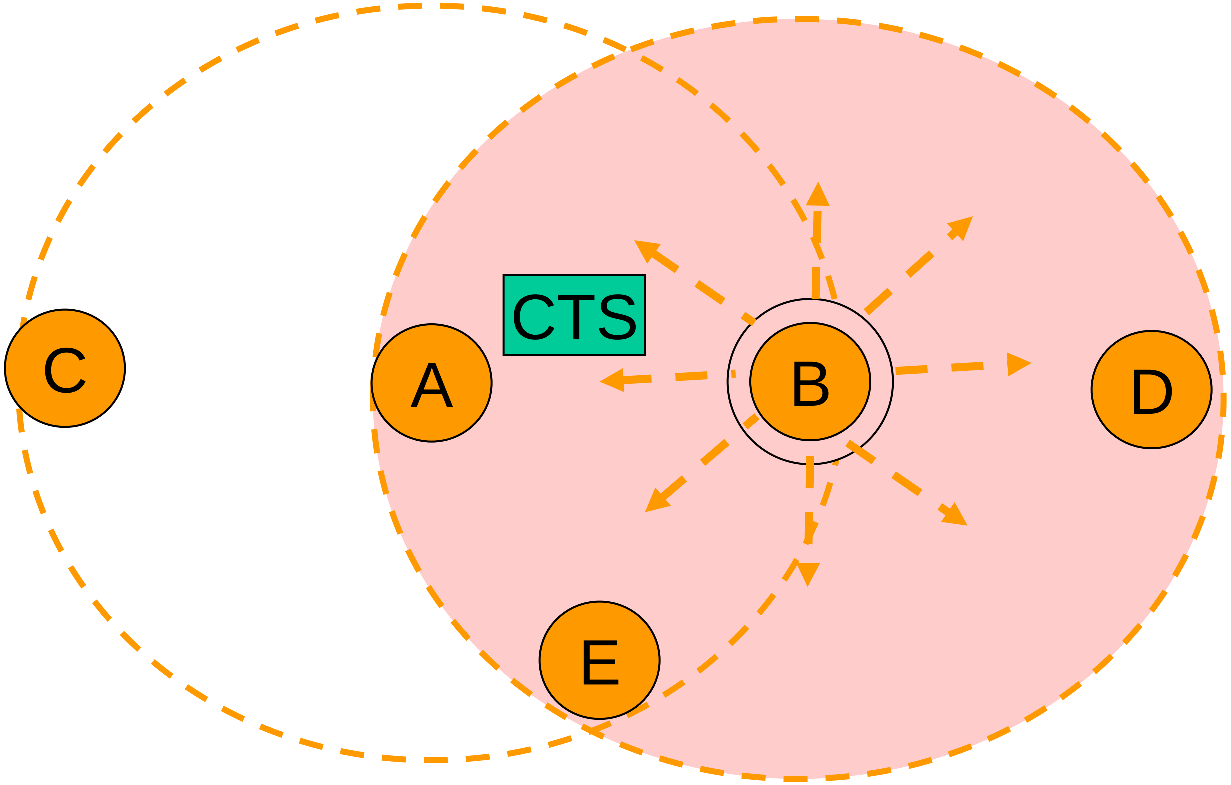
The MACA protocol (4)



1. A wants to transmit to B, sends an RTS to B
2. If B wants to receive the message replies with a Clear To Send

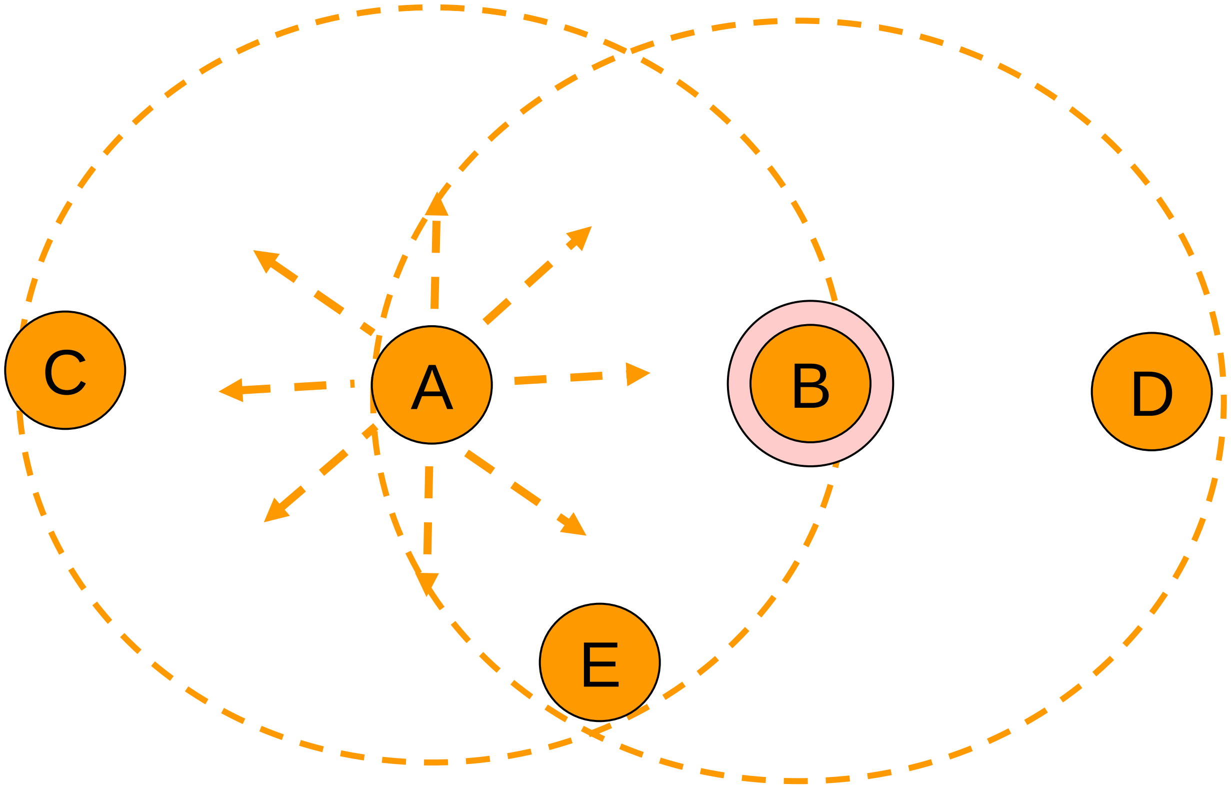
CTS is a short frame with data length copied from RTS

The MACA protocol (5)



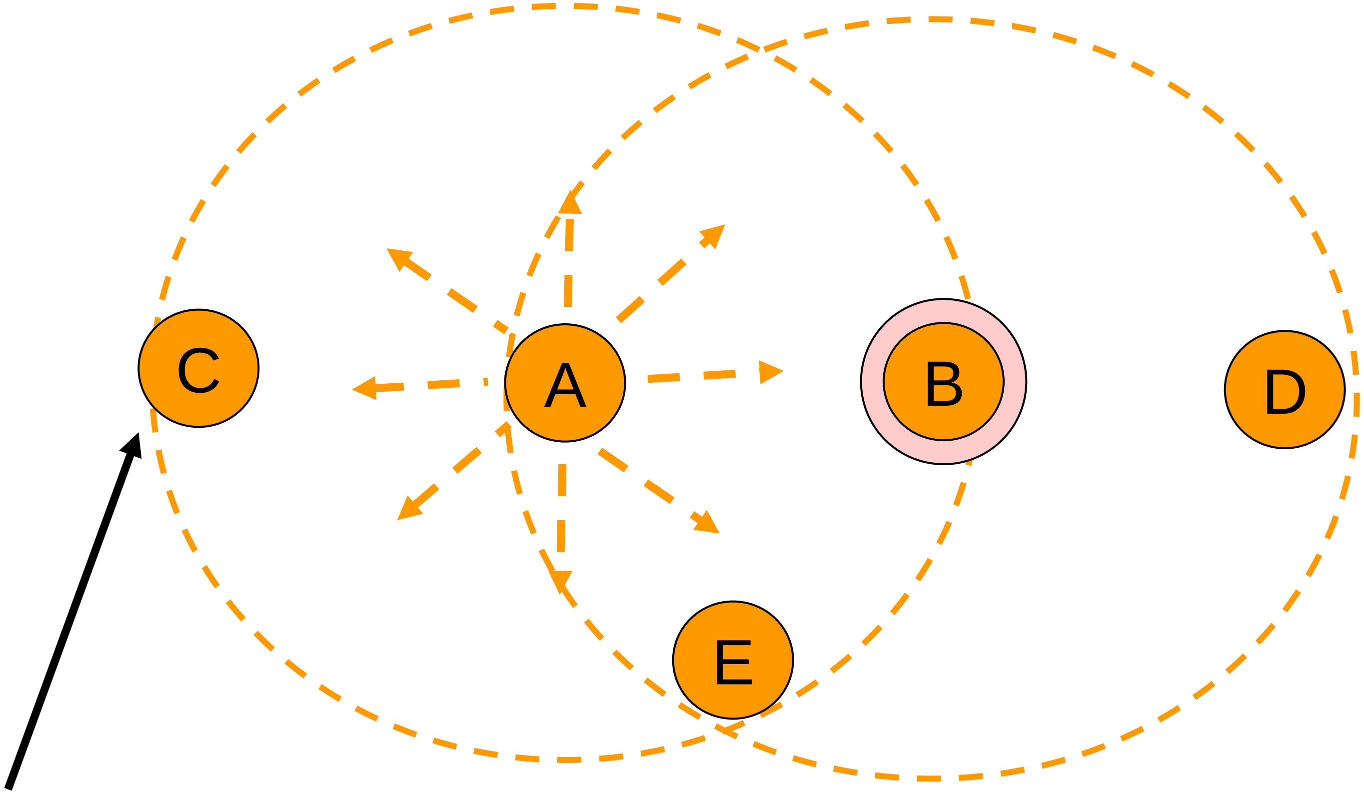
1. A wants to transmit to B, sends an RTS to B
2. If B wants to receive the message replies with a CTS

The MACA protocol (6)



1. A wants to transmit to B, sends an RTS to B
2. If B wants to receive the message replies with a CTS
3. Upon receipt of the CTS frame, A transmits the data frame

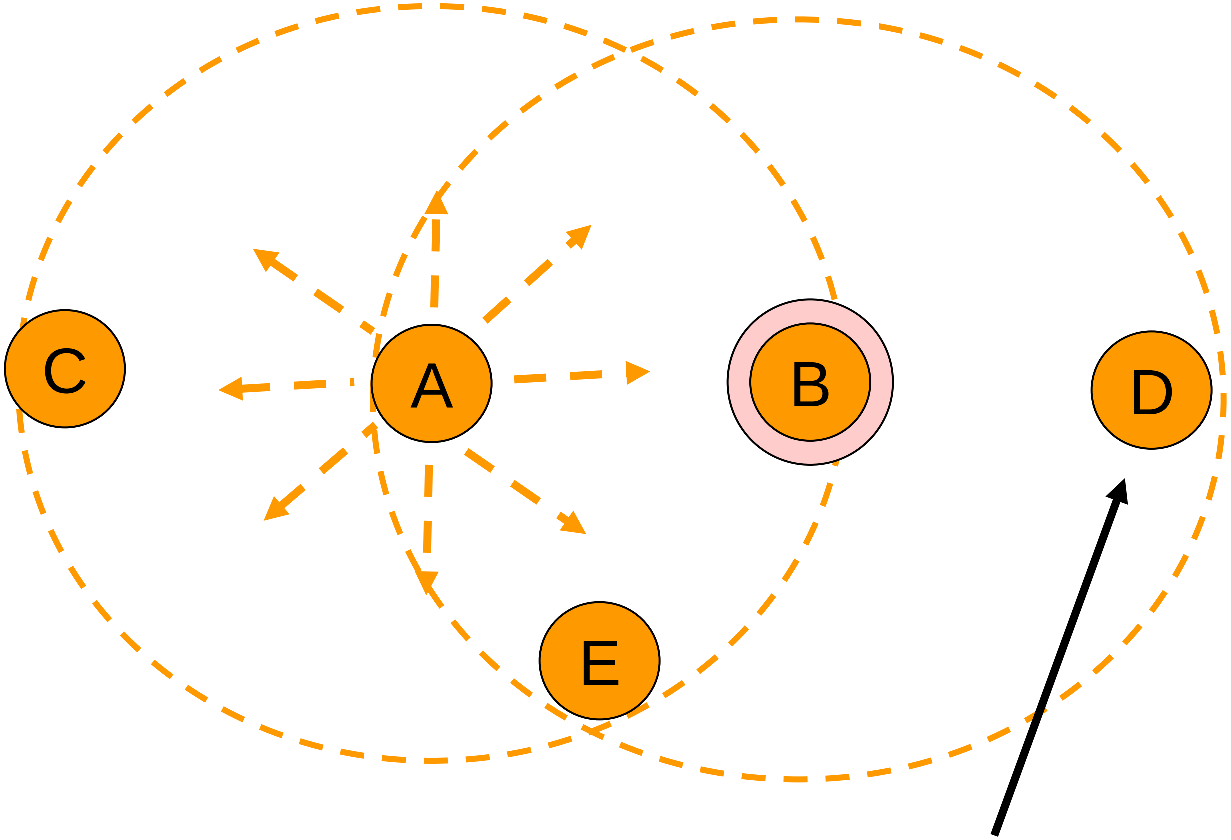
The MACA protocol (7)



C hears RTS, but not CTS

it is free to transmit after A has received the CTS from B

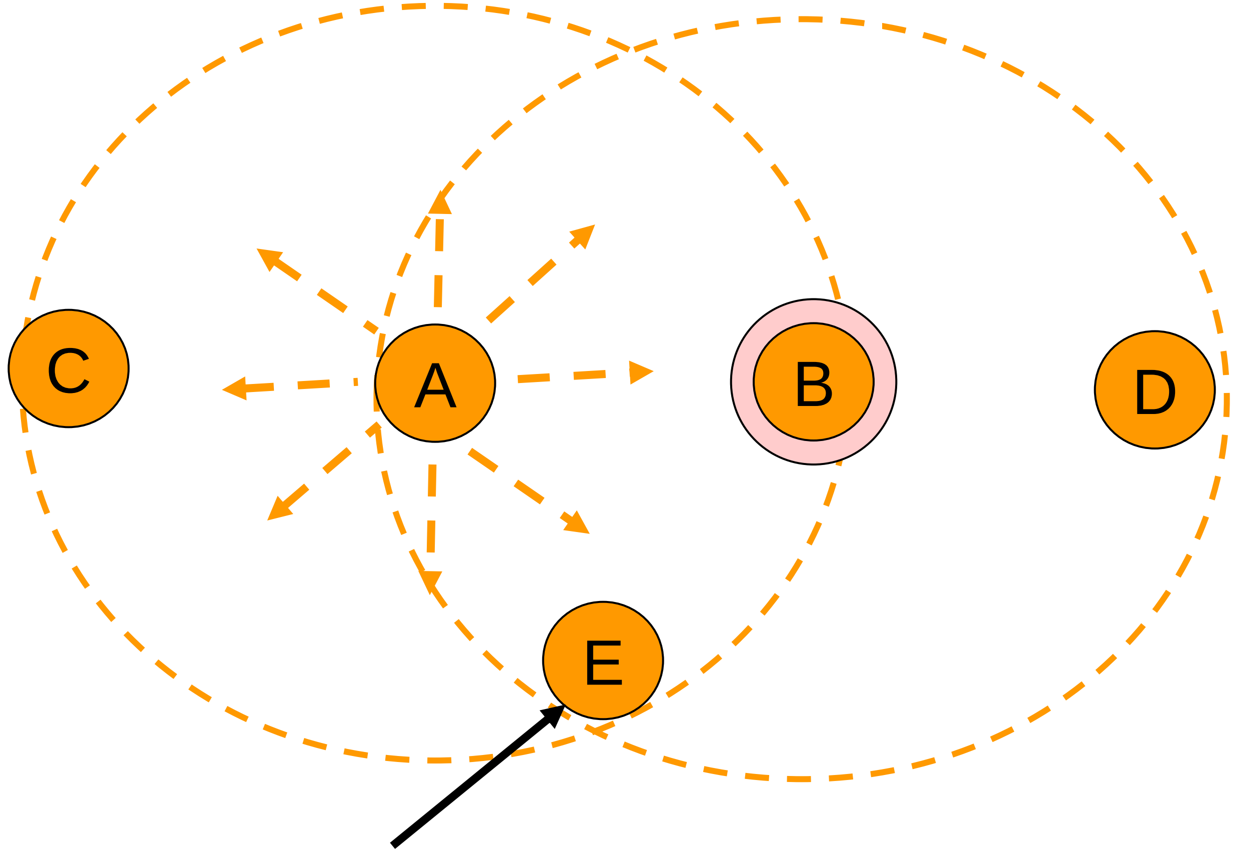
The MACA protocol (8)



D hears CTS, but not RTS

it should stay silent until data frame transmission completes

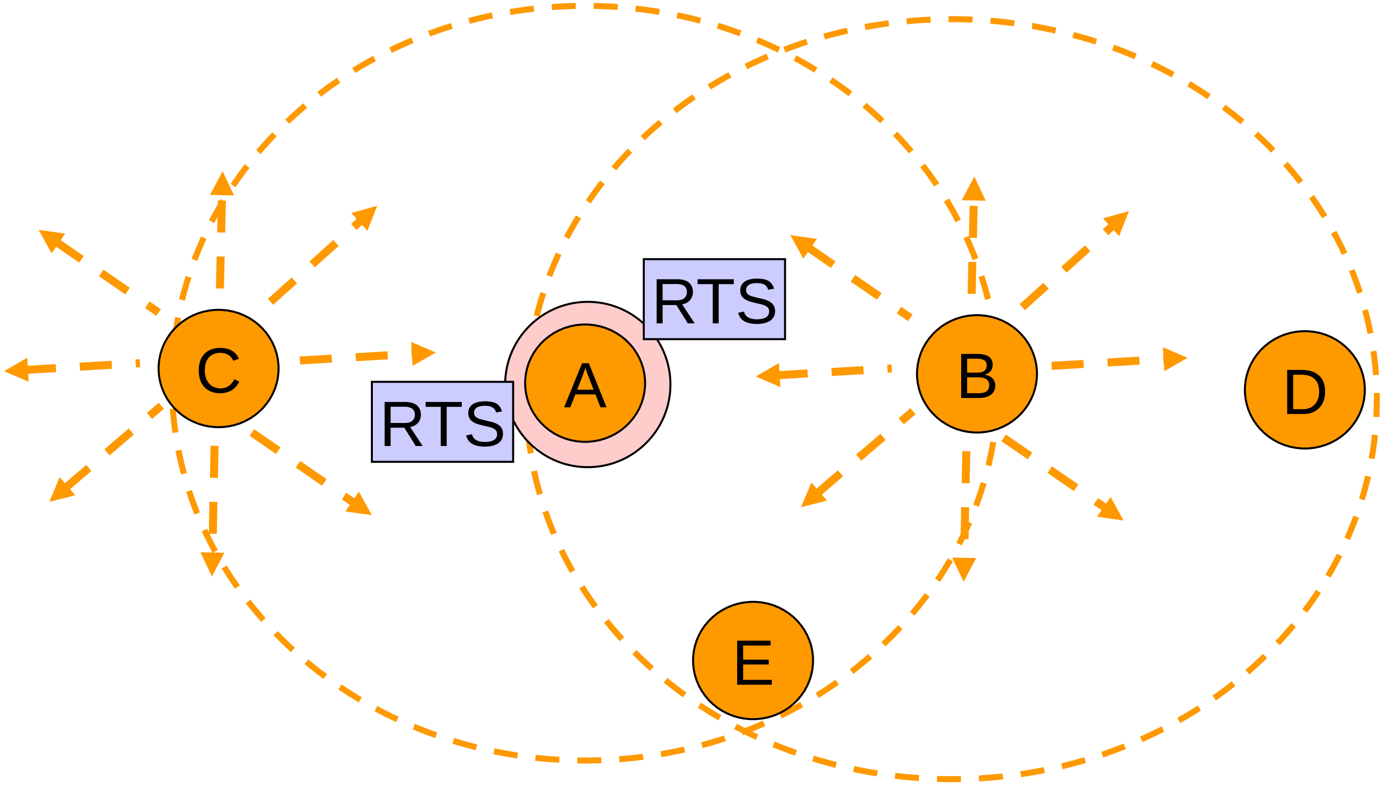
The MACA protocol (9)



D hears CTS and RTS

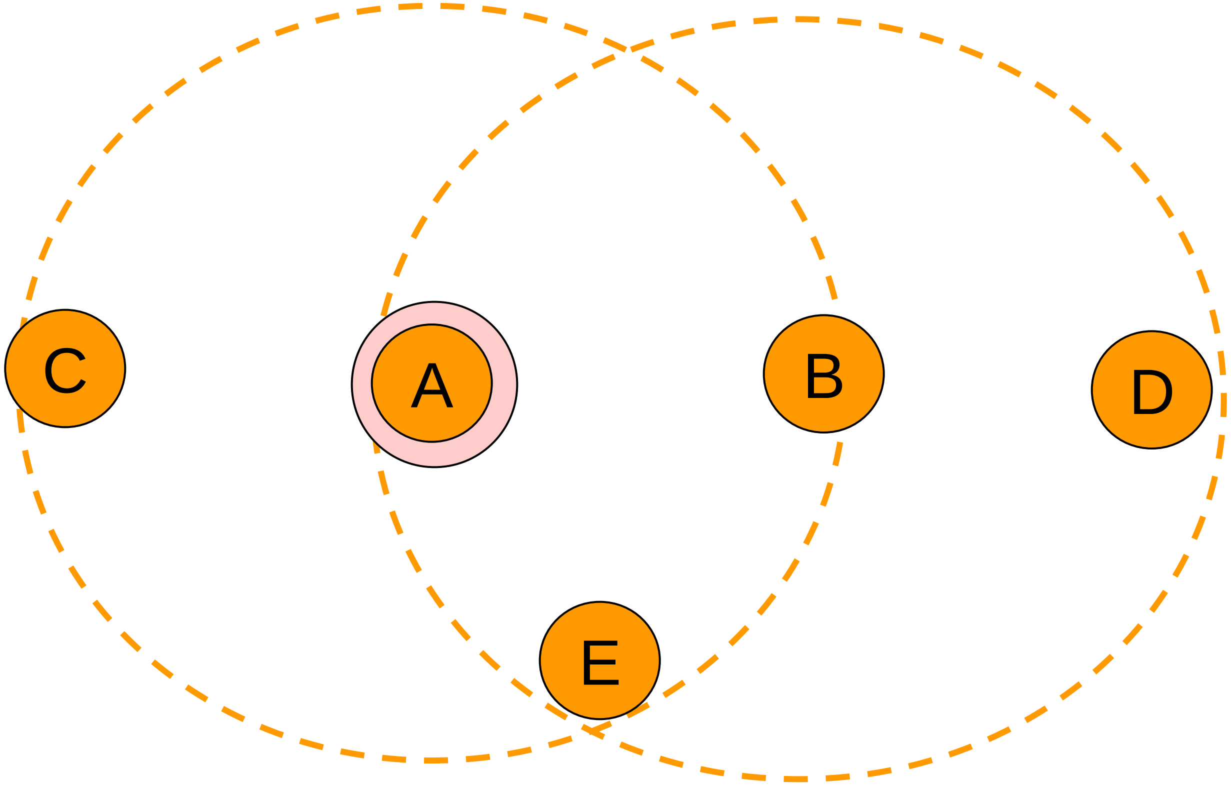
it should stay silent until data frame transmission completes

The MACA protocol: collisions



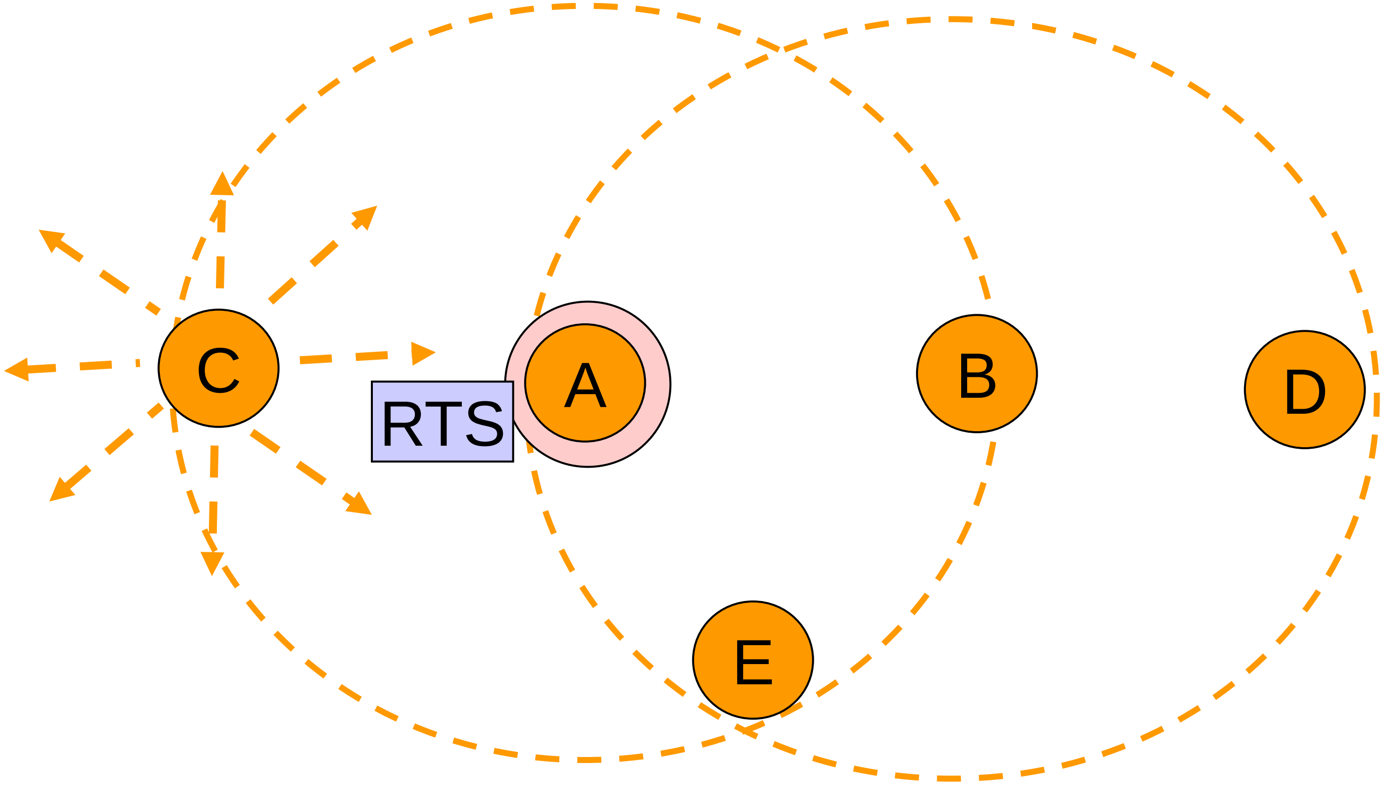
C and B send RTS simultaneously to A

The MACA protocol: collisions (2)



C and B send RTS simultaneously to A
The two messages collide
No CTS is generated

The MACA protocol: collisions (3)



C and B use *Binary Exponential Backoff* (same as Ethernet) to retry RTS

MACAW: MACA for Wireless

- 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 doing so 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

- IEEE 802.11 (Legacy mode)
  - First released in 1997 and clarified in 1999
  - rarely used today
  - 1-2 Mbps data rate implemented via
    - infrared (IR) signals,
    - radio frequencies in the 2.4GHz band (ISM -- Industrial Scientific Medical Frequency band)
  - many degrees of freedom: interoperability was challenging among different products
  - rapidly supplemented (and popularized) by 802.11b
  - most used today 802.11a/b/g emerging 802.11n

IEEE 802.11 family (2)

- IEEE 802.11b
  - Released 1999
  - Operating frequency: 2.4GHz band (ISM band)
    - potential interference with other appliances : cordless telephones, microwave ovens etc
  - Throughput (typ): 4.3 Mbps
  - Data rate (max): 11 Mbps
  - Modulation technique: DSSS

IEEE 802.11 family (3)

- IEEE 802.11a
  - Released 1999
  - Operating frequency: 5 GHz band (Unlicensed National Information Infrastructure U-NII band)
  - Throughput (typ): 23 Mbps
  - Data rate (max): 54 Mbps
  - Modulation technique: OFDM

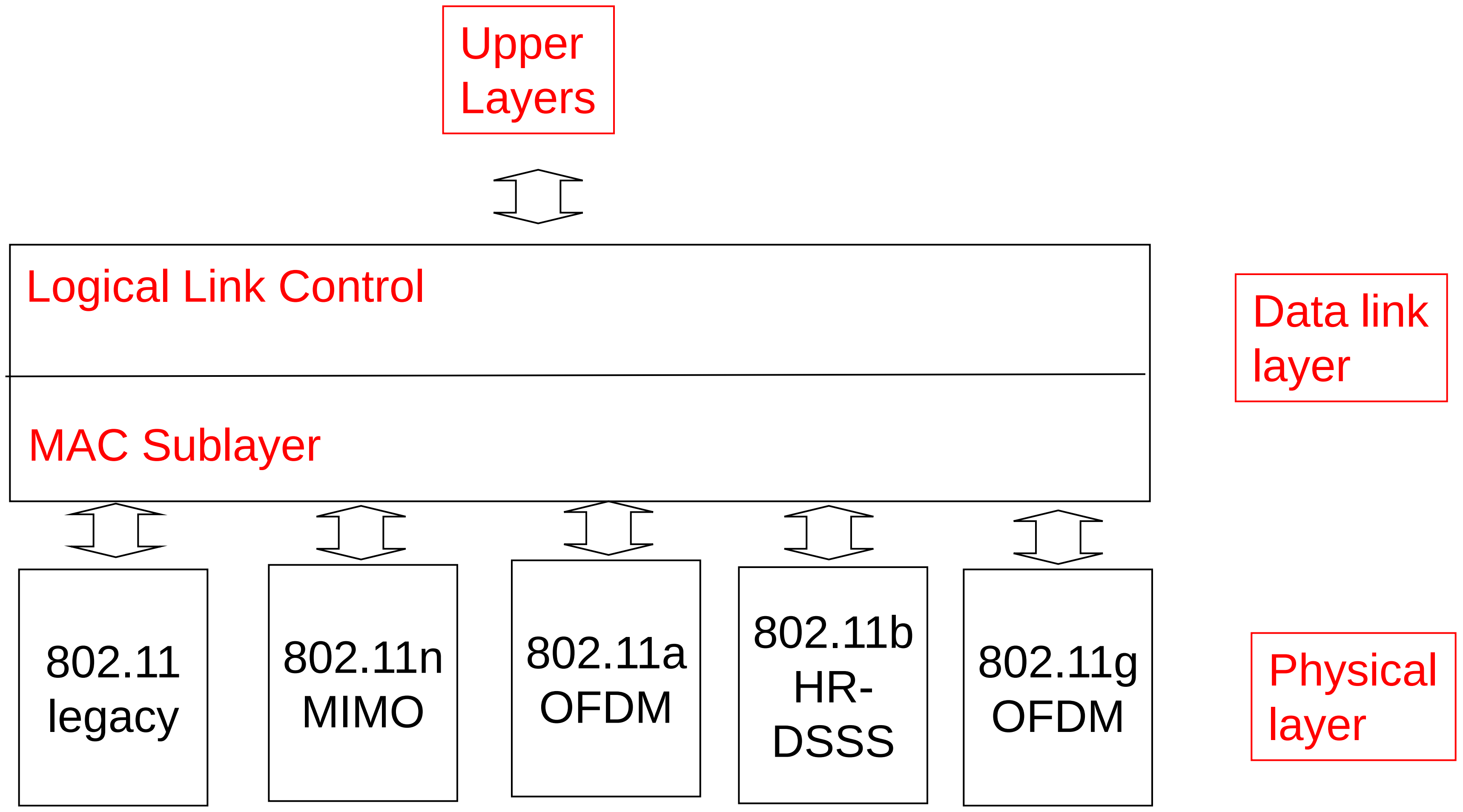
IEEE 802.11 family (4)

- IEEE 802.11g
  - Released 2003
  - Operating frequency: 2.4GHz band (ISM band)
  - Throughput (typ): 19 Mbps
  - Data rate (max): 54 Mbps
  - Modulation technique: OFDM

IEEE 802.11 family (5)

- IEEE 802.11n
  - To be released 2009
  - Operating frequency: 2.4GHz band and 5GHz band
  - Throughput (typ): 74 Mbps
  - Data rate (max): 248 Mbps
  - Modulation technique: MIMO using multiple antennas

IEEE 802.11: protocol stack



IEEE 802.11: Architecture

- A group of stations operating under a given coordination function
  - may use or not a base station (Access Point)
  - is using APs a station communicates with another channeling all the traffic through a centralized AP
  - AP can provide connectivity with other APs and other groups of stations via fixed infrastructure

IEEE 802.11: Architecture (2)

- Supports ad hoc networks

  the IEEE 802.11 view

  a group of stations that are under the direct control of a single coordination function without the aid of an infrastructure network

  – a station can communicate directly with another without channeling all the traffic through AP

The physical layer

- All techniques make it possible to deliver a MAC frame from one station to another
- Technology used and speed differ
- We give a short list of keyword

The physical layer: IR

- Features:
  - Diffused transmission at 0.85-0.95 microns
  - Two speeds: 1Mbps 2Mbps
  - encoding *gray code*
    - at 1Mbps : 4 bits on 16 bits containing fifteen 0s and a single 1
    - at 2Mbps : 2 bits on 4 bits 0001,0010,0100, 1000
  - cannot penetrate walls, swamped by sun
  - not very popular

The physical layer: FHSS

- Frequency Hopping Spread Spectrum
  - 79 channels, 1MHz wide each starting at the low end of the 2.4 GHz
  - bandwidth: 1MBps
  - Frequency hopping
    - pseudo-random generator drives hopping
    - same seed on all stations, synchronization
    - dwell time (time spent in each frequency) less than 400msec
    - makes eavesdropping harder
    - solves multipath fading over long distances

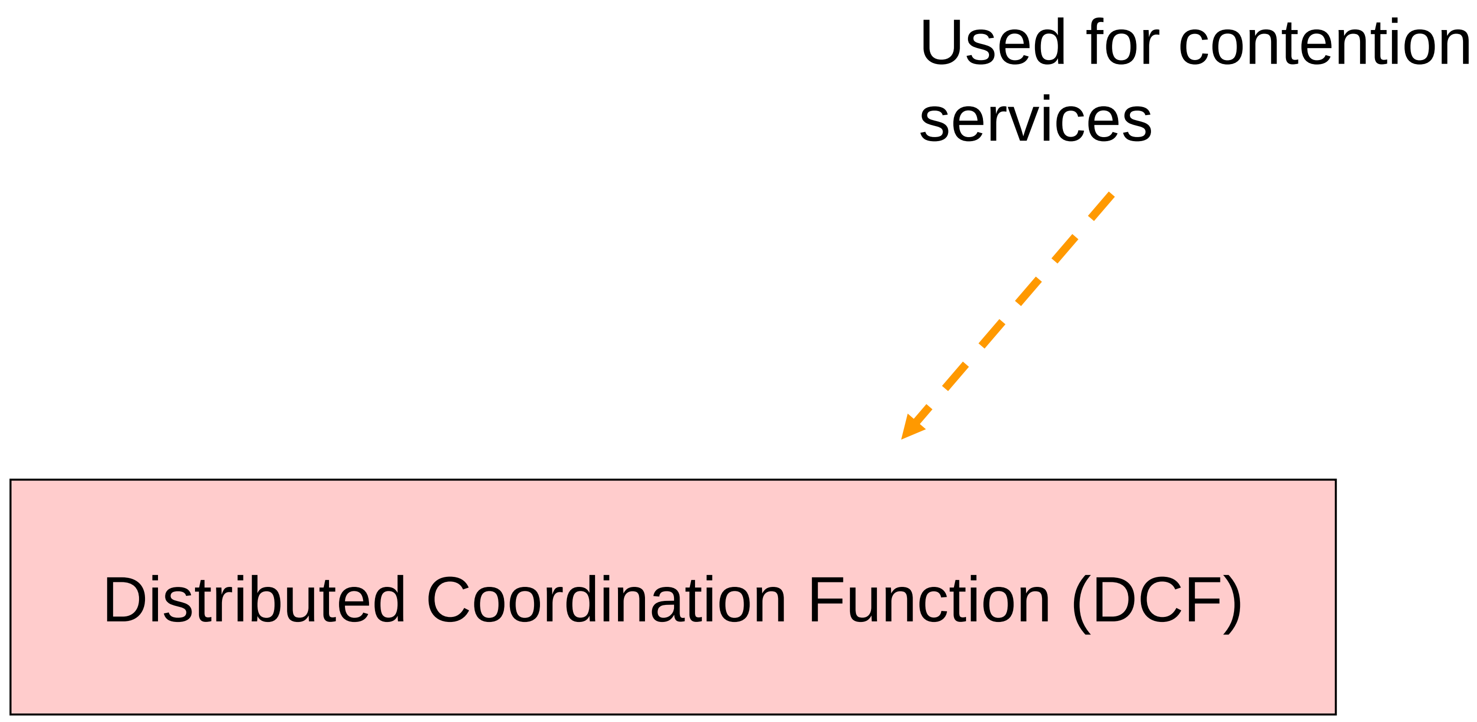
The physical layer: DSSS

- Discrete Sequence Spread Spectrum
  - bandwidth: 1-2MBps
  - ?????

IEEE 802.11:MAC Sublayer

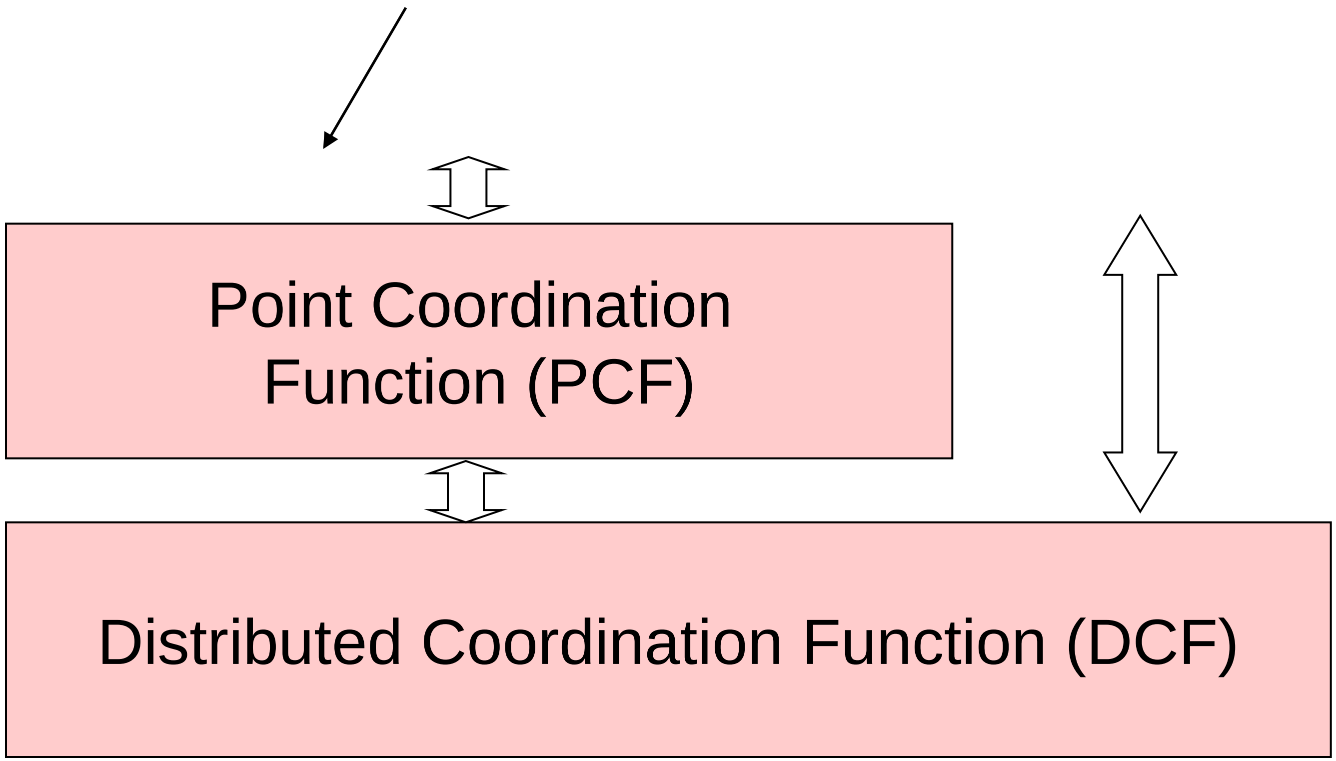
- Two modes of operations:
  - DCF : Distributed Coordination Function
    - completely decentralized
    - thought for best effort asynchronous traffic
  - PCF : Point Coordination Function
    - uses base station to control all activity in its cell
    - thought for delay-sensitive traffic
    - BS polls stations to ask for transmissions
    - based on DCF
- DCF <u>must</u> be implemented by all stations
- DCF and PCF can be active at the same time in the same cell

IEEE 208.11 MAC architecture



IEEE 208.11 MAC architecture (2)

Used for contention free services and based on DCF



IEEE 802.1: DCF

- Must be implemented by all stations
- Completely decentralized
- Best effort asynchronous traffic
- Stations must contend for the channel for each frame
  - using CSMA/CA

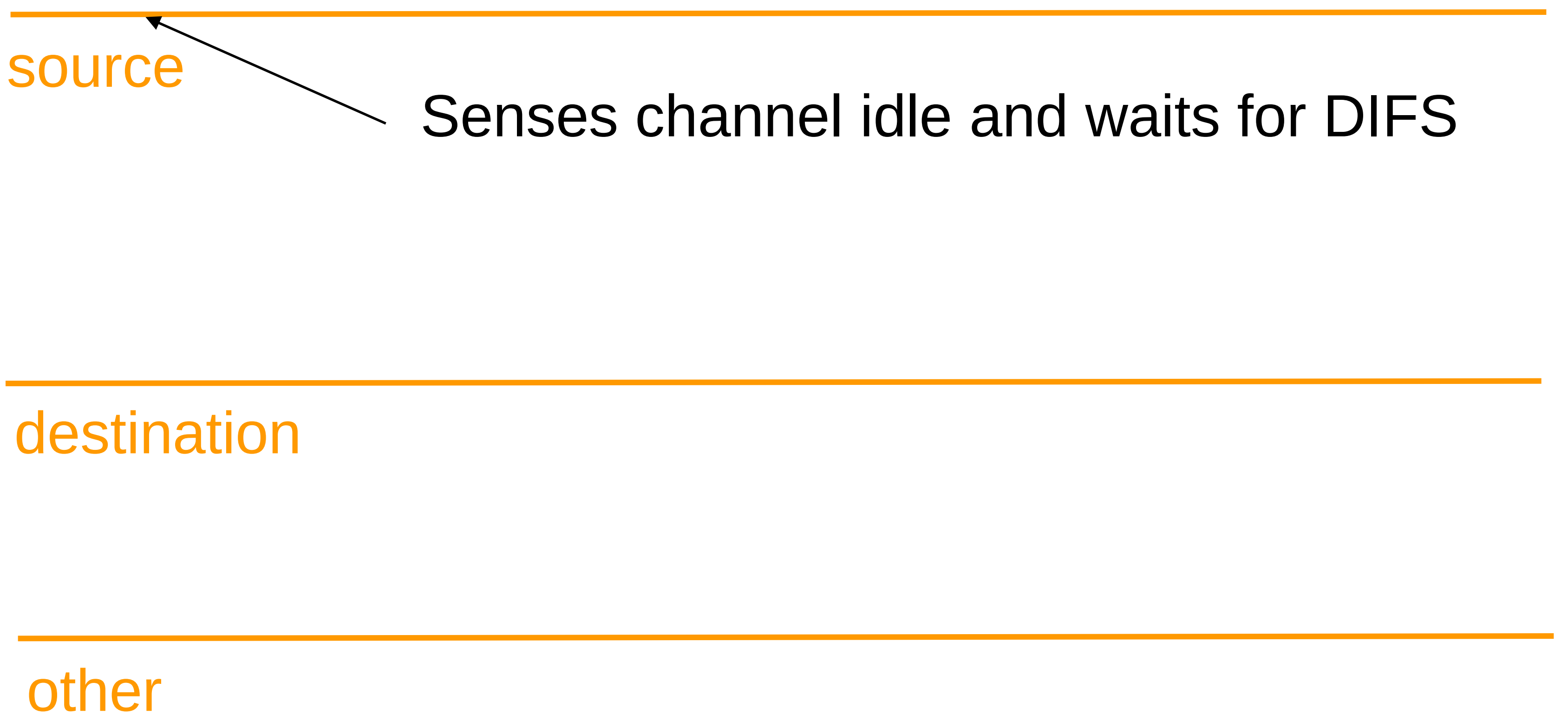
IEEE 802.1: DCF (2)

- Carrier sensing is performed at two levels:
  - *physical CS*
    - detects the presence of other IEEE 802.11 WLAN users by analyzing all the detected packets
    - detects any activity in the channel due to other sources
  - *virtual CS*
    - performed sending duration information in the header of an RTS, CTS and data frame
    - duration information is used to adjust station's NAV (network allocation vector) that indicates channel busy and the time that must elapse before sampling again the channel for idle status
  - A channel is marked busy if either the physical or the virtual CS indicate busy

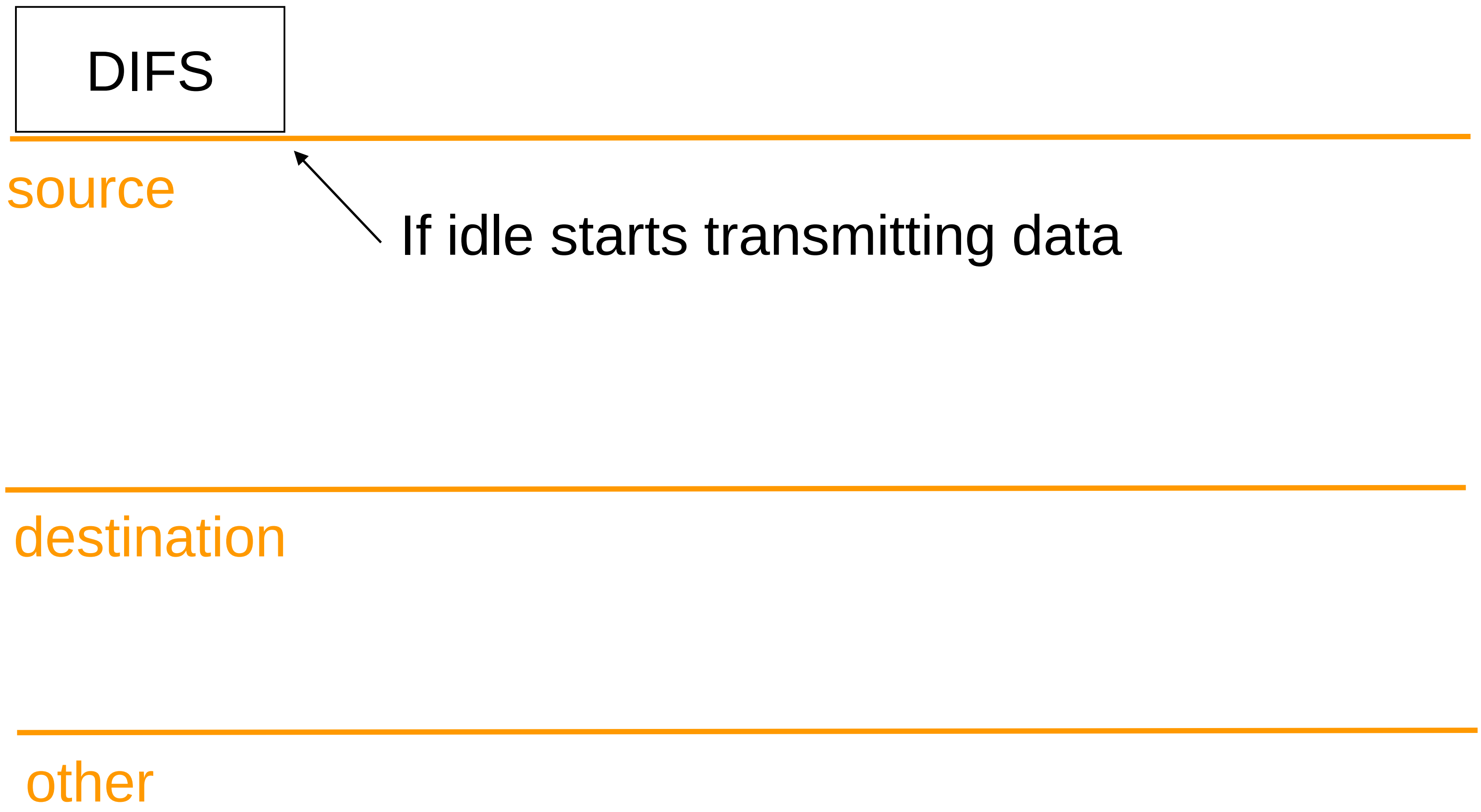
IEEE 802.1: DCF (3)

- Priority access to the medium is controlled through the use of interframe space (IFS) time intervals
  - IFS: mandatory periods of idle time on the transmission medium
- Three IFS specified by the standard:
  - short IFS (SIFS)
  - point coordination function IFS (PIFS)
  - DCF-IFS (DIFS)
  - SIFS < PIFS < DIFS
  - stations only required to wait a SIFS have the highest priority

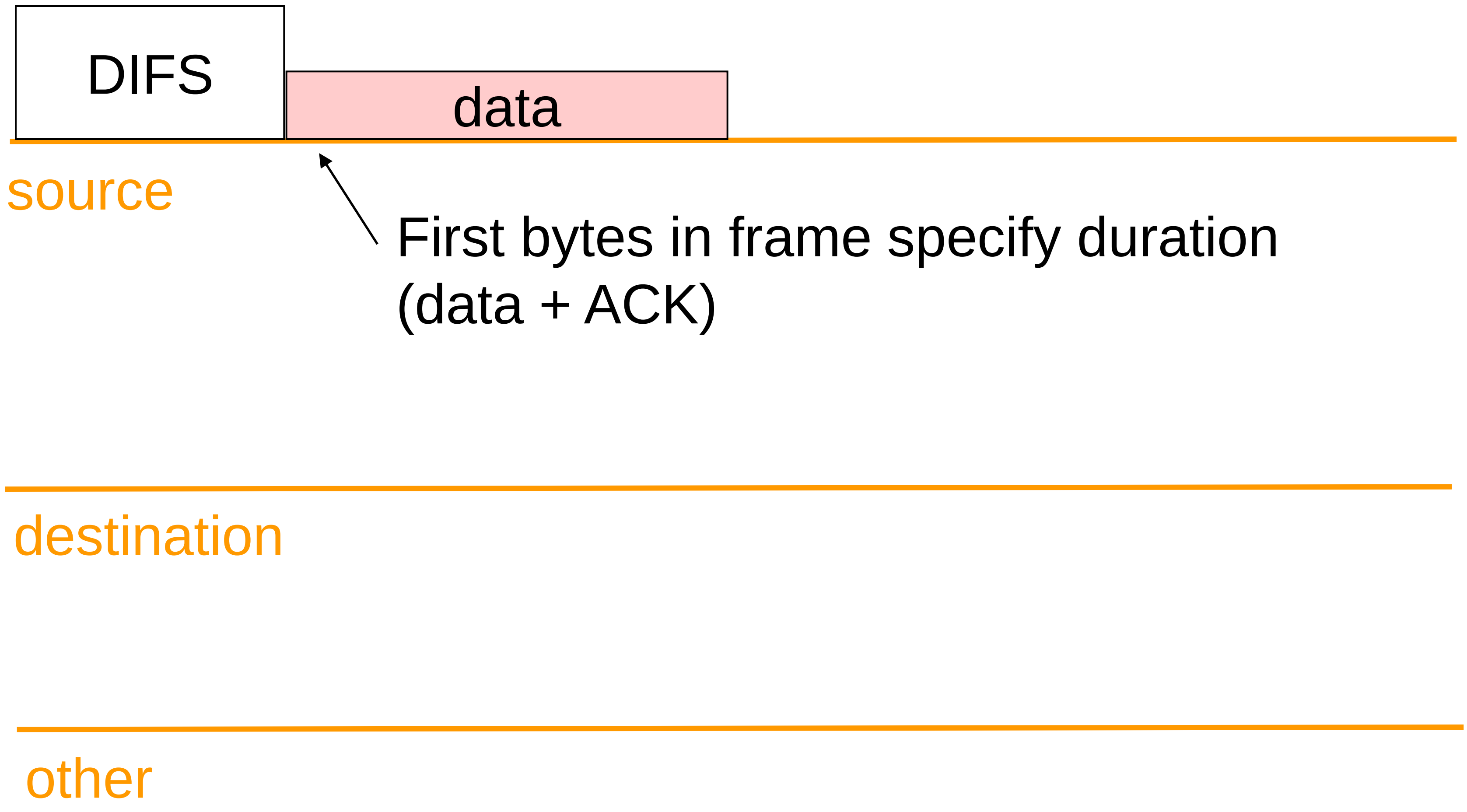
DCF basic access method



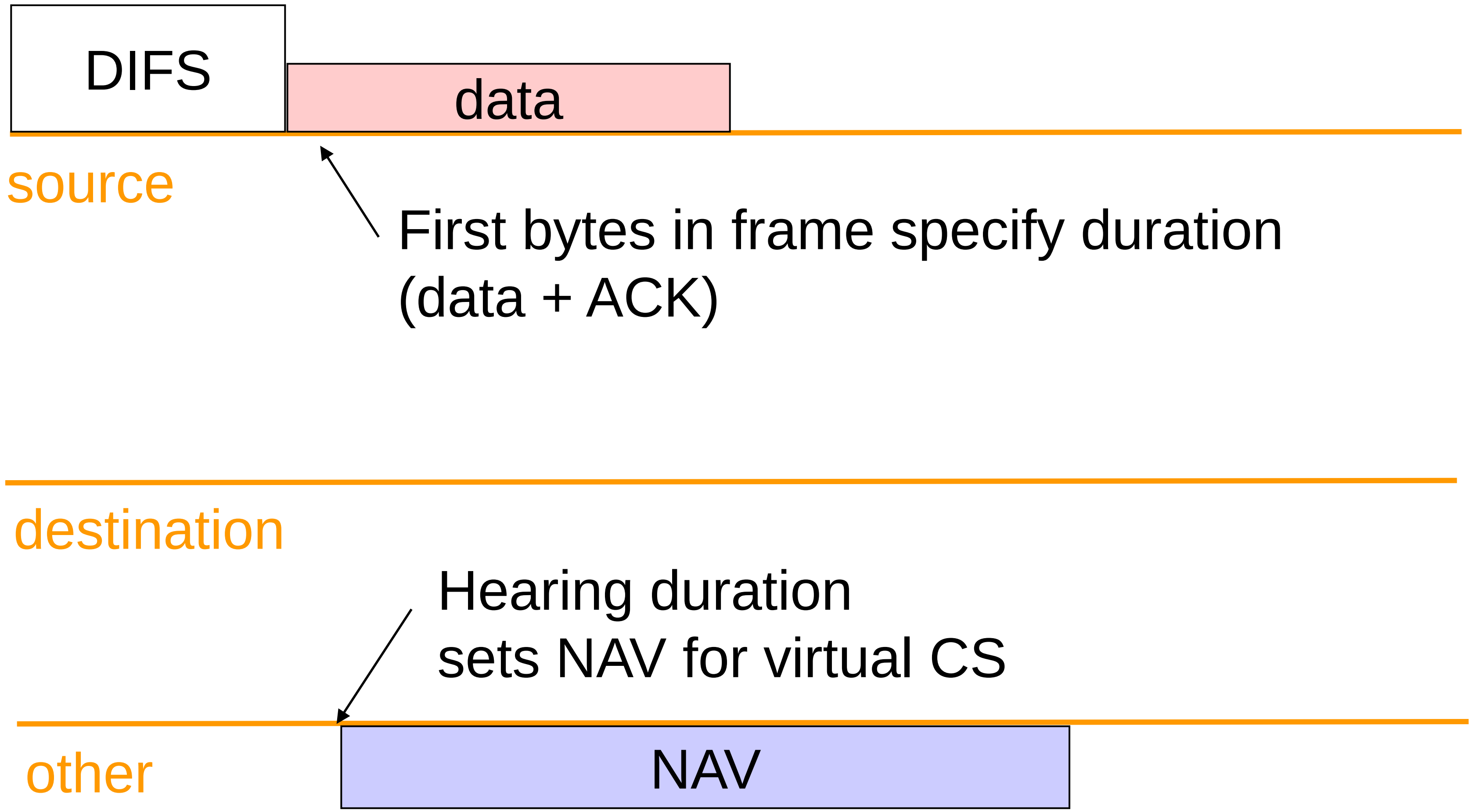
DCF basic access method (2)



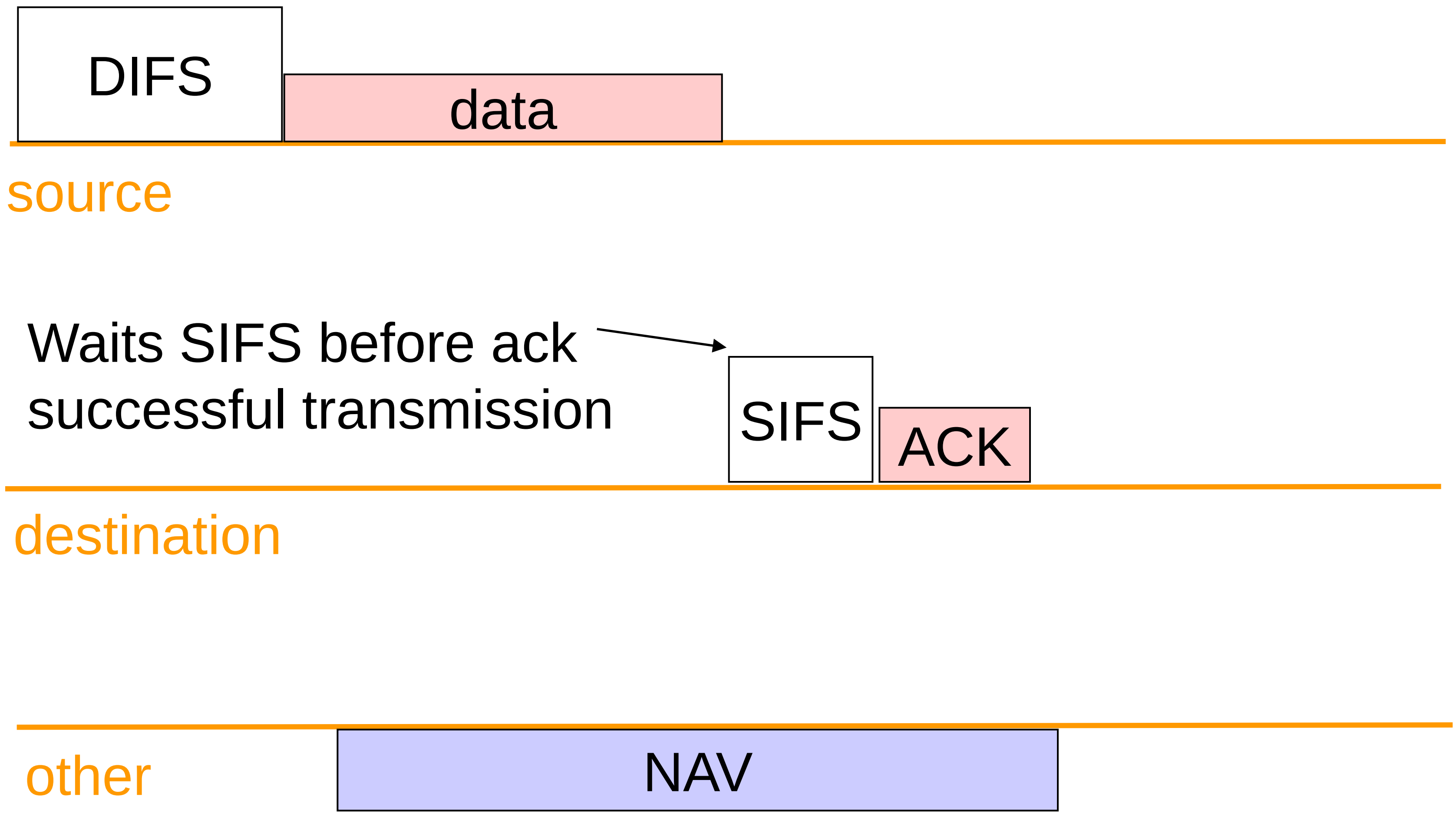
DCF basic access method (3)



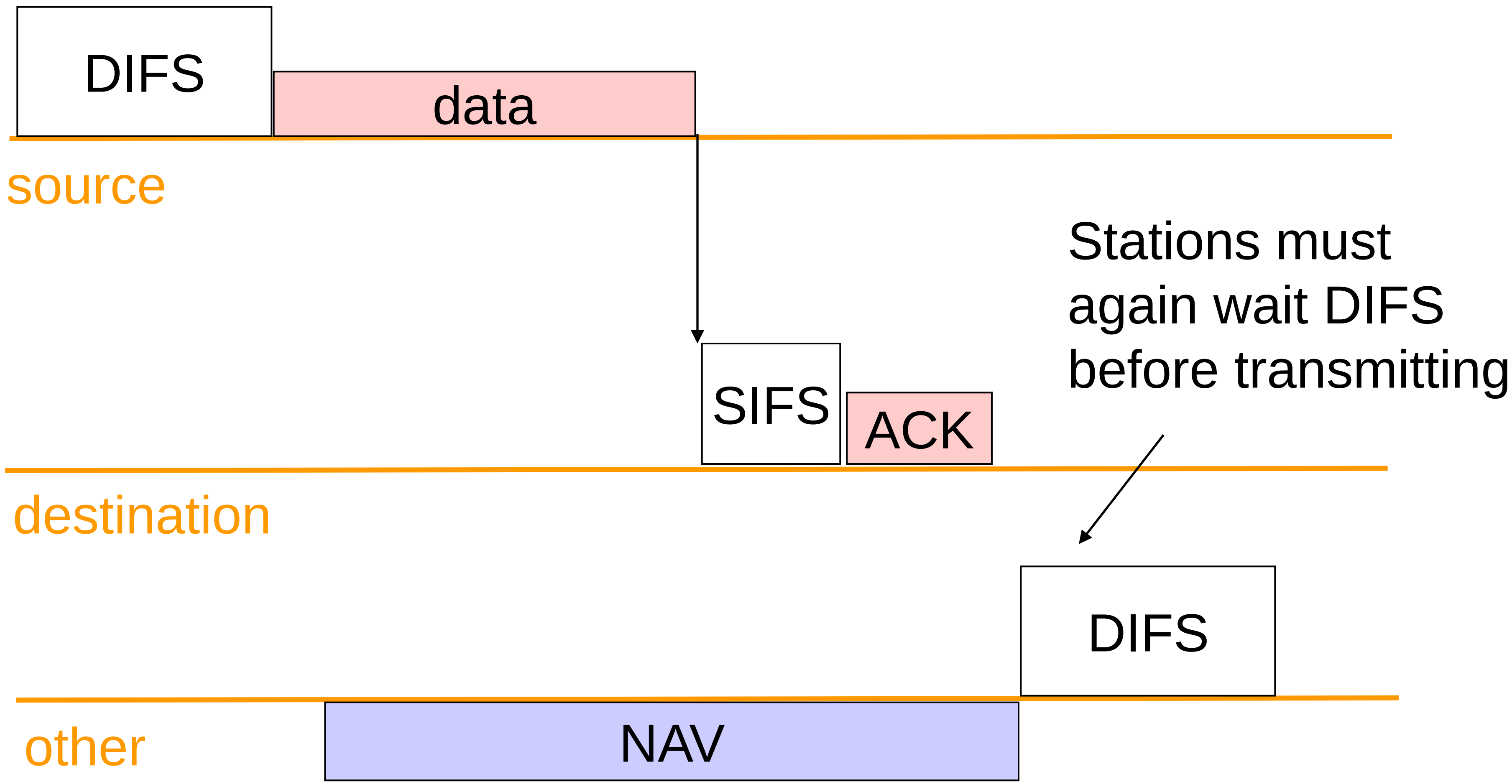
DCF basic access method (3)



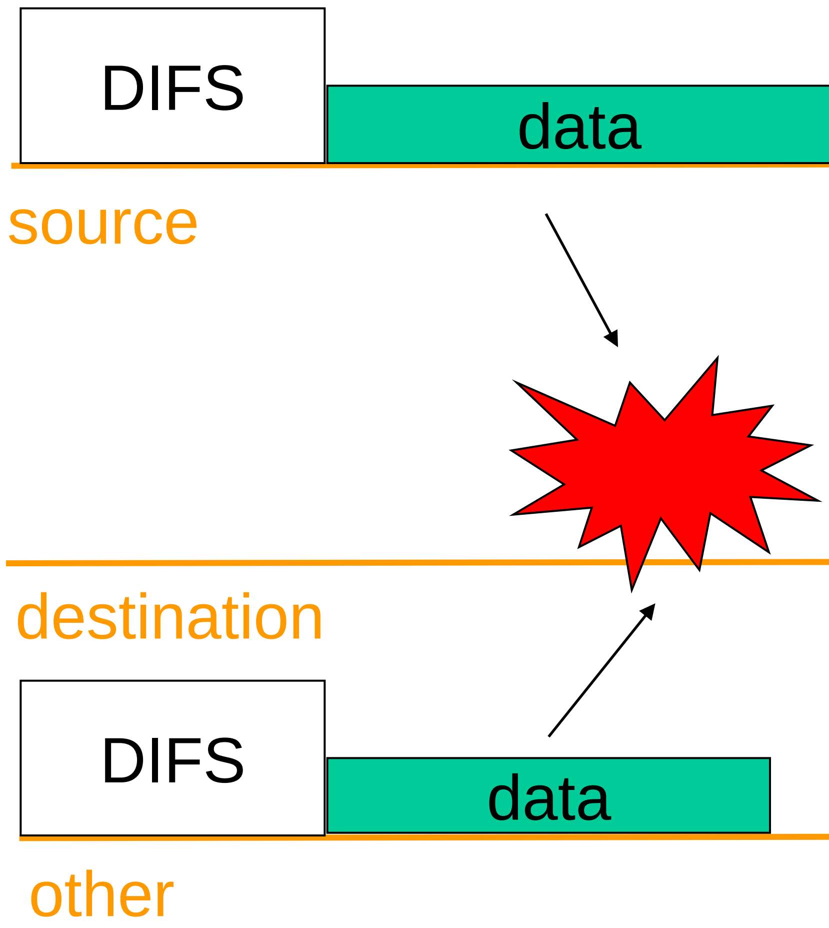
DCF basic access method (4)



DCF basic access method (5)



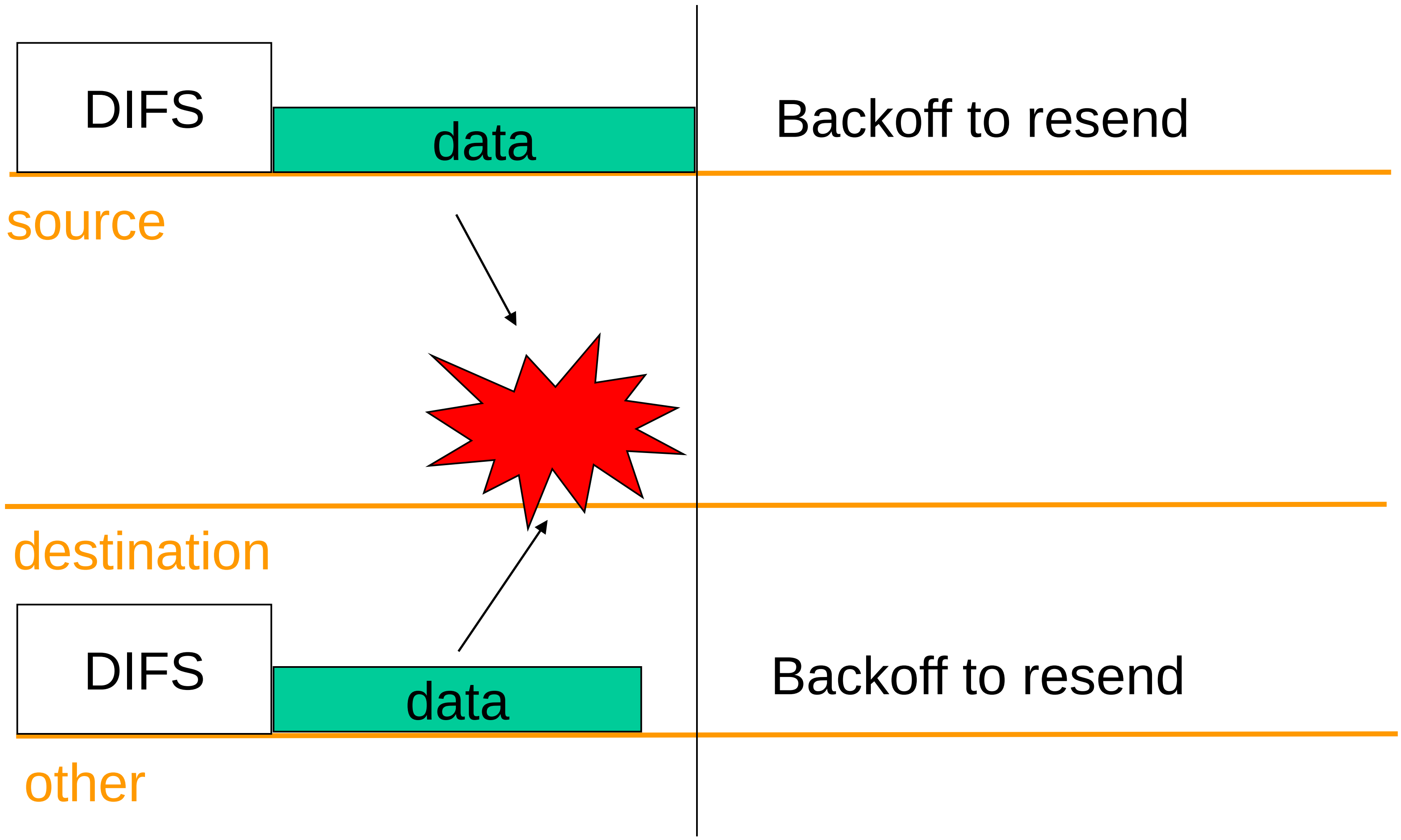
DCF basic access method: collision



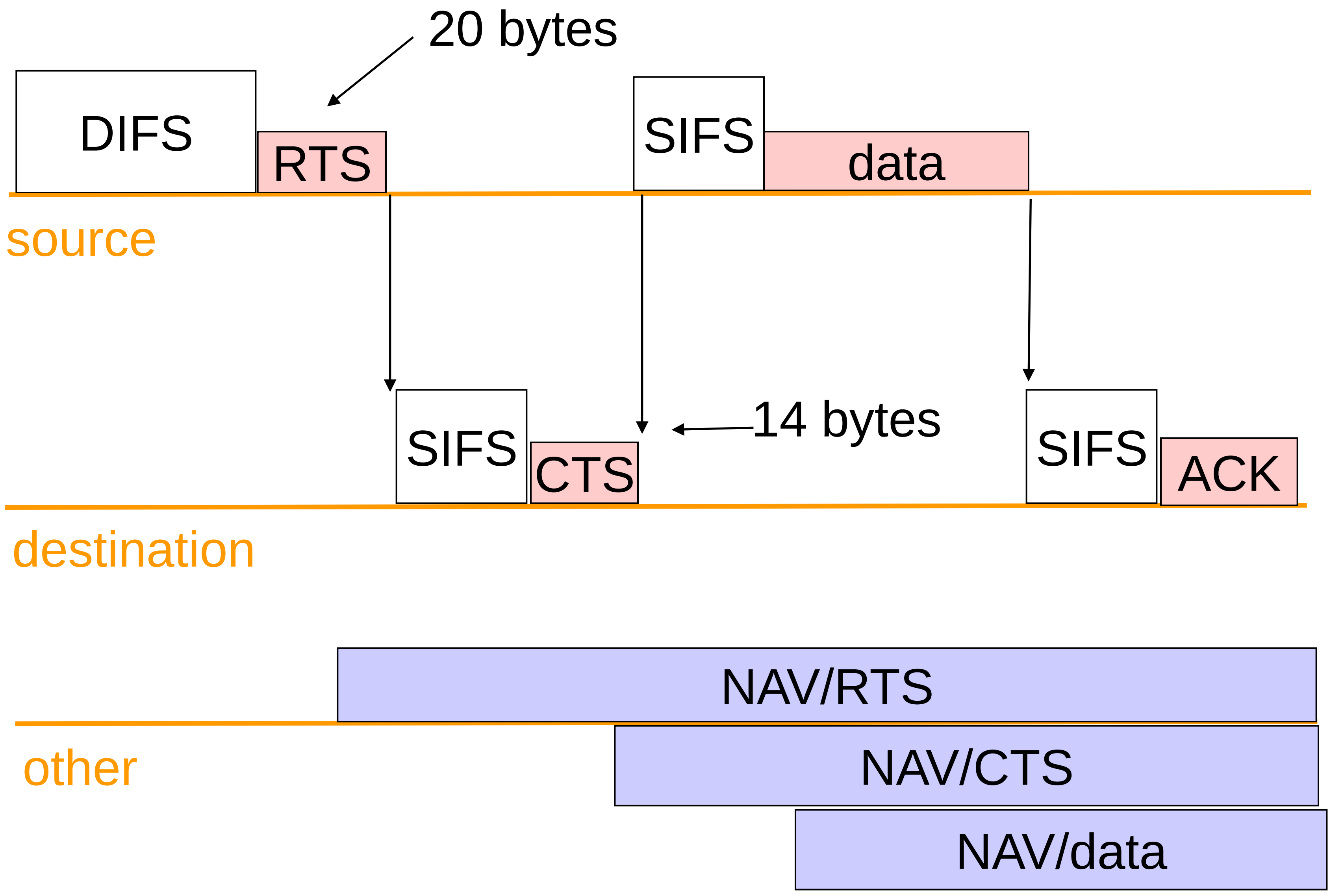
When collision occurs stations continue to transmit the entire frame

Band wasted for large data frames

DCF basic access method: collision (2)



DCF RTS/CTS


20 bytes
DIFS
RTS
SIFS
data
source
SIFS
CTS
14 bytes
SIFS
ACK
destination
NAV/RTS
other
NAV/CTS
NAV/data

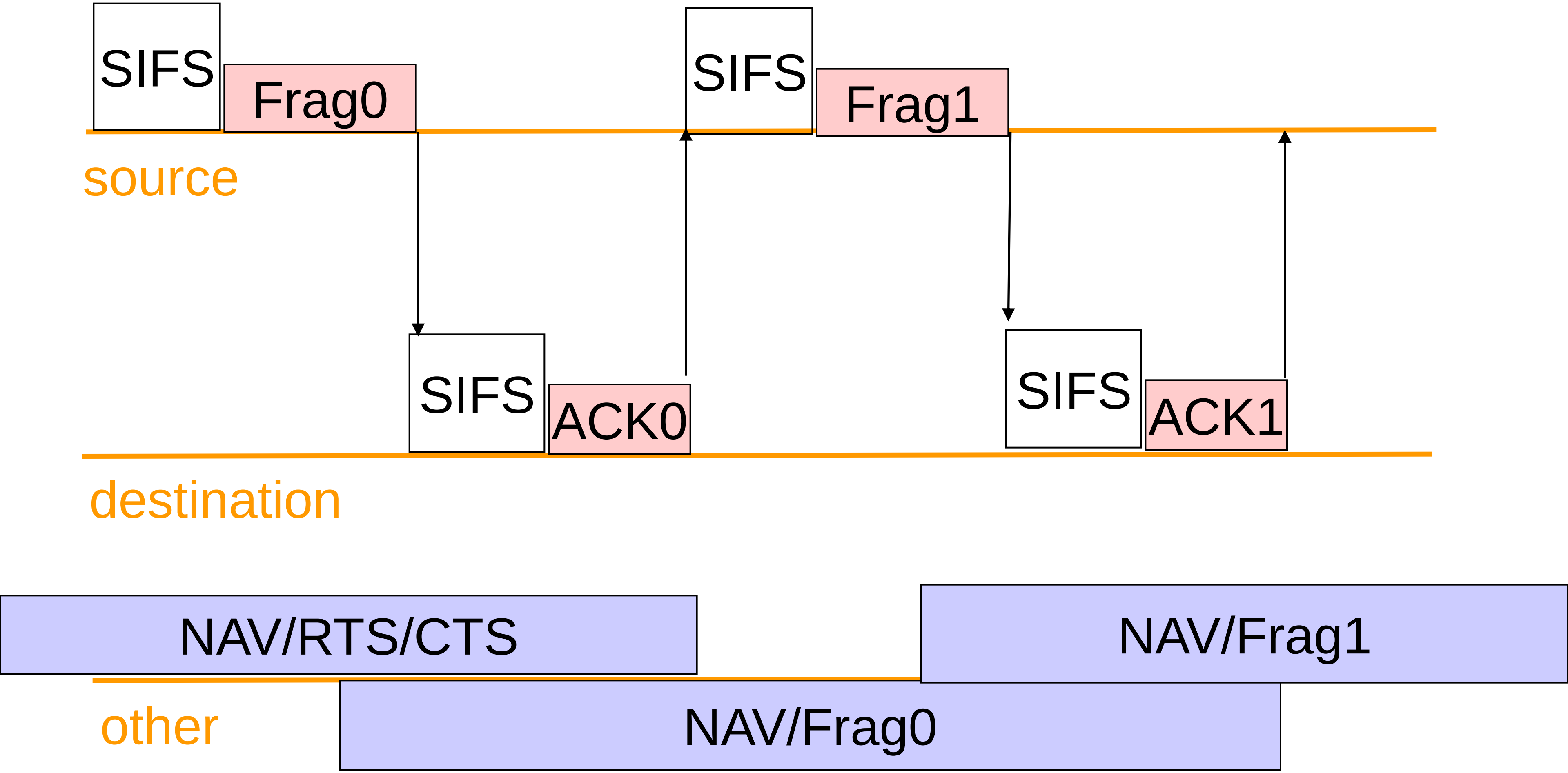
DCF: RTS/CTS

- Three choices:
  - never use RTS/CTS: lightly loaded medium
  - use RTS/CTS for long messages: when length exceeds **`RTS_Threshold`**
  - always use RTS/CTS

DCF: Fragmentation

- Fragmentation of large data frames may improve reliability:
  - performed only if data is larger than Fragmentation_Theshold (size of each fragment except last)
  - all fragments are sent in sequence
  - channel is not released until the complete data has been transmitted or the source station fails to receive an acknowledgement for the transmitted fragment

DCF Fragmentation (2)



DCF: Fragmentation (3)

- When an ACK is not received in time, the source station re-contends the channel
- after getting the channel again it starts from the last unacknowledged fragment

- if RTS/CTS is used the duration in RTS/CTS account only for the transmission of the first fragment

- the subsequent duration information are extracted in the duration information of each fragment

More on random backoff

- Time is slotted
  - slots of **`Slot_time`** different for each PHY layer used
- To get a channel after a collision
  - a station senses the channel if the channel is not busy it waits until the channel is idle for a DIFS period
  - after DIFS idle it computes a random backoff time
    - randomly chooses a number *x* of slots to be waited (init. 0--7)
    - decrements *x* until channel becomes busy or *x* reaches 0
      - if x==0, the station sends the frame
      - if x>0 and channel becomes busy the station freezes the timer, and starts to decrement it after it becomes idle again for DIFS

More on random backoff (2)

- To get a channel after a collision (contd.)
  - if two stations reach 0 at the same time a new collision occurs
  - after the *i* collisions, *x* is chosen in range

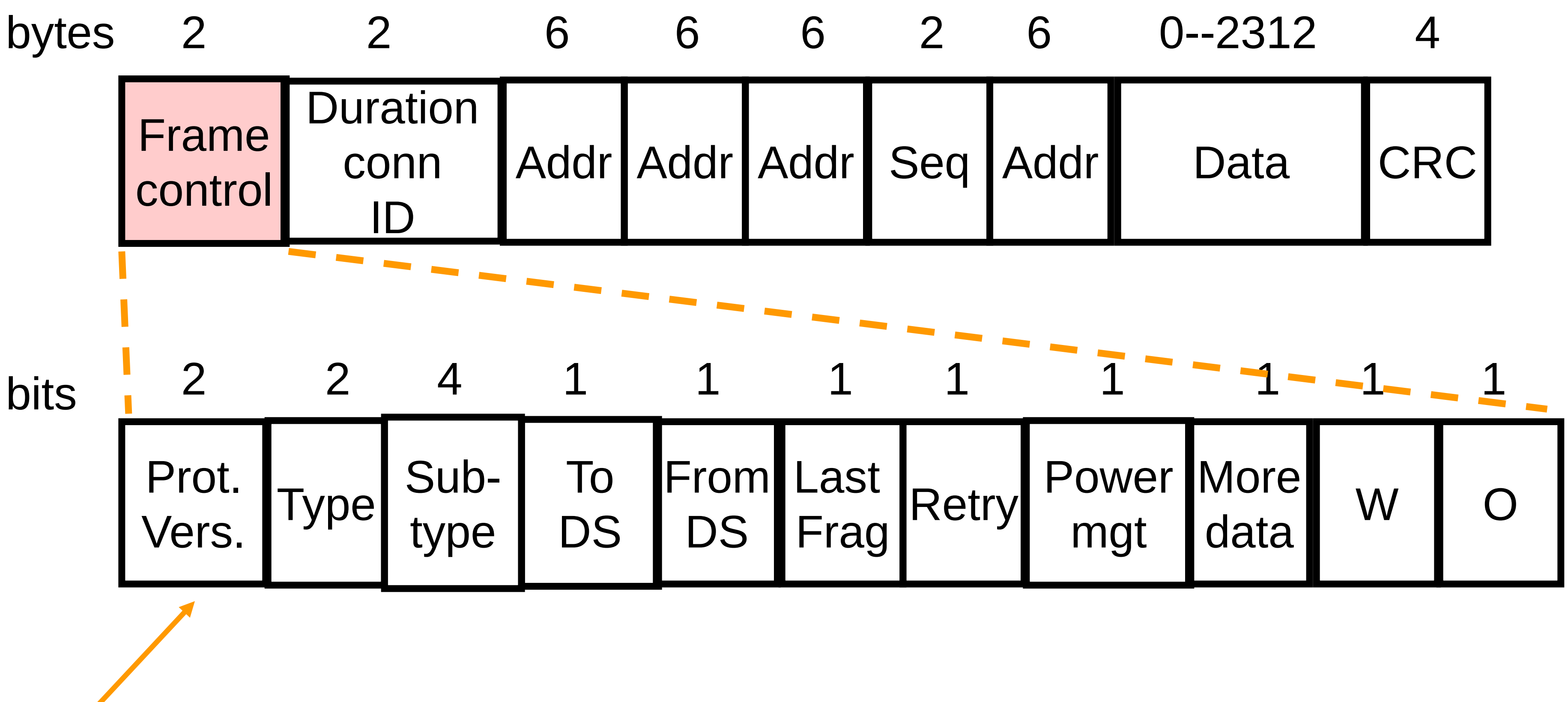
$$0 \ldots \lfloor 2^{(2+i)} * ranf() \rfloor$$

    where *ranf()* is a uniform random var. in (0,1)
  - The idle period after a DIFS idle period is called *contention window* (CW)

IEEE 802.11: Frames

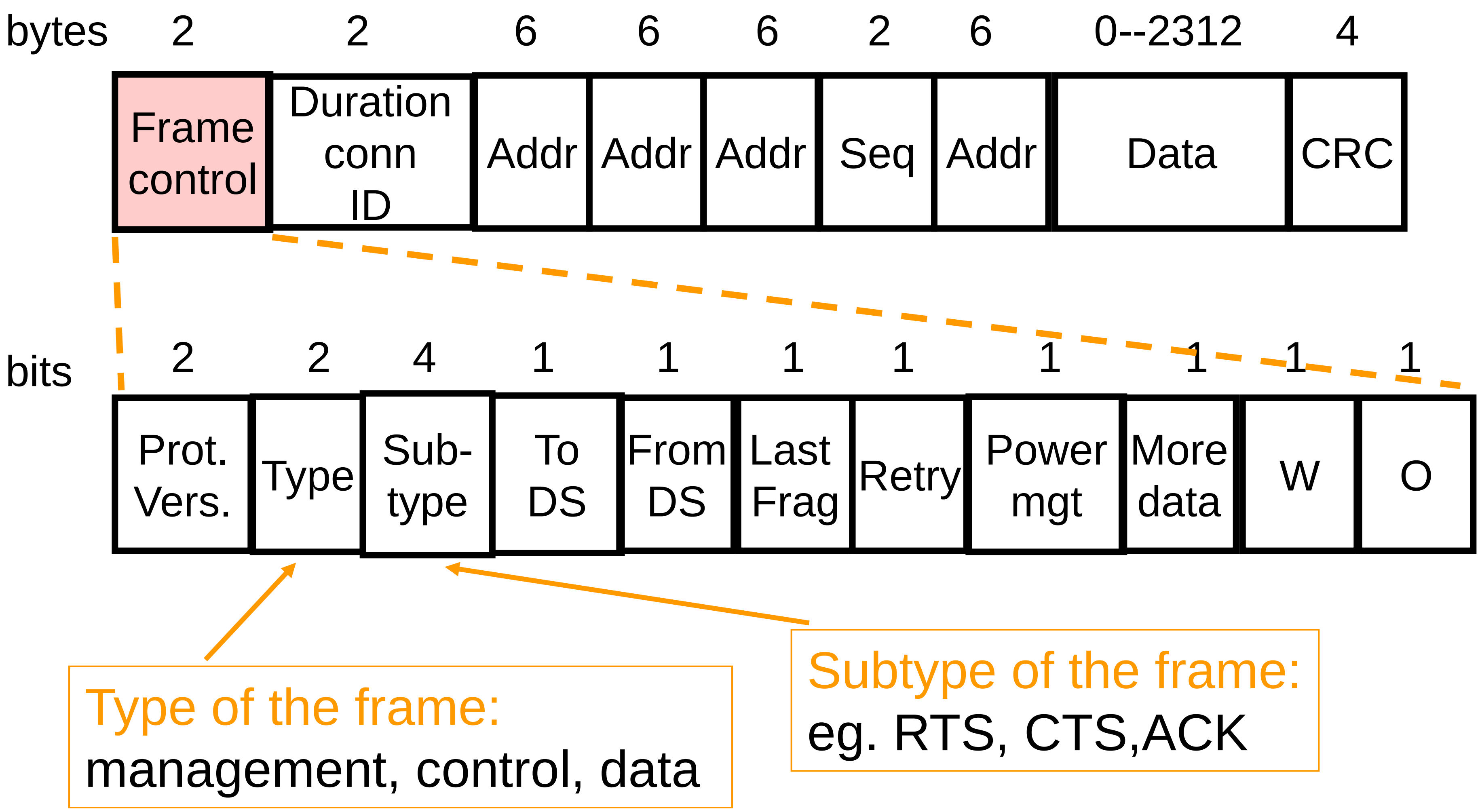
- Three types of frames:
  - management: station association/disassociation with the AP, synchronization, authentication
  - control: handshaking and acknowledgement
  - data: data transmission, can be combined with polling and ACK in PCF

IEEE 802.11: Frame format



Version: more than one protocol can coexist in the same cell

IEEE 802.11: Frame format (2)



IEEE 802.11: Frame format (3)

bytes	2	2	6	6	6	2	6	0--2312	4
	Frame control	Duration conn ID	Addr	Addr	Addr	Seq	Addr	Data	CRC

bits	2	2	4	1	1	1	1	1	1	1	1
	Prot. Vers.	Type	Sub-type	To DS	From DS	Last Frag	Retry	Power mgt	More data	W	O

Is the frame going **to** or coming **from** the intercell distribution system?

eg. To/From Ethernet interconnecting AS

IEEE 802.11: Frame format (4)

bytes	2	2	6	6	6	2	6	0--2312	4
	Frame control	Duration conn ID	Addr	Addr	Addr	Seq	Addr	Data	CRC

bits	2	2	4	1	1	1	1	1	1	1	1
	Prot. Vers.	Type	Sub-type	To DS	From DS	More Frag	Retry	Power mgt	More data	W	O

More fragments will follow?

Marks retransmission of a frame sent earlier

IEEE 802.11: Frame format (5)

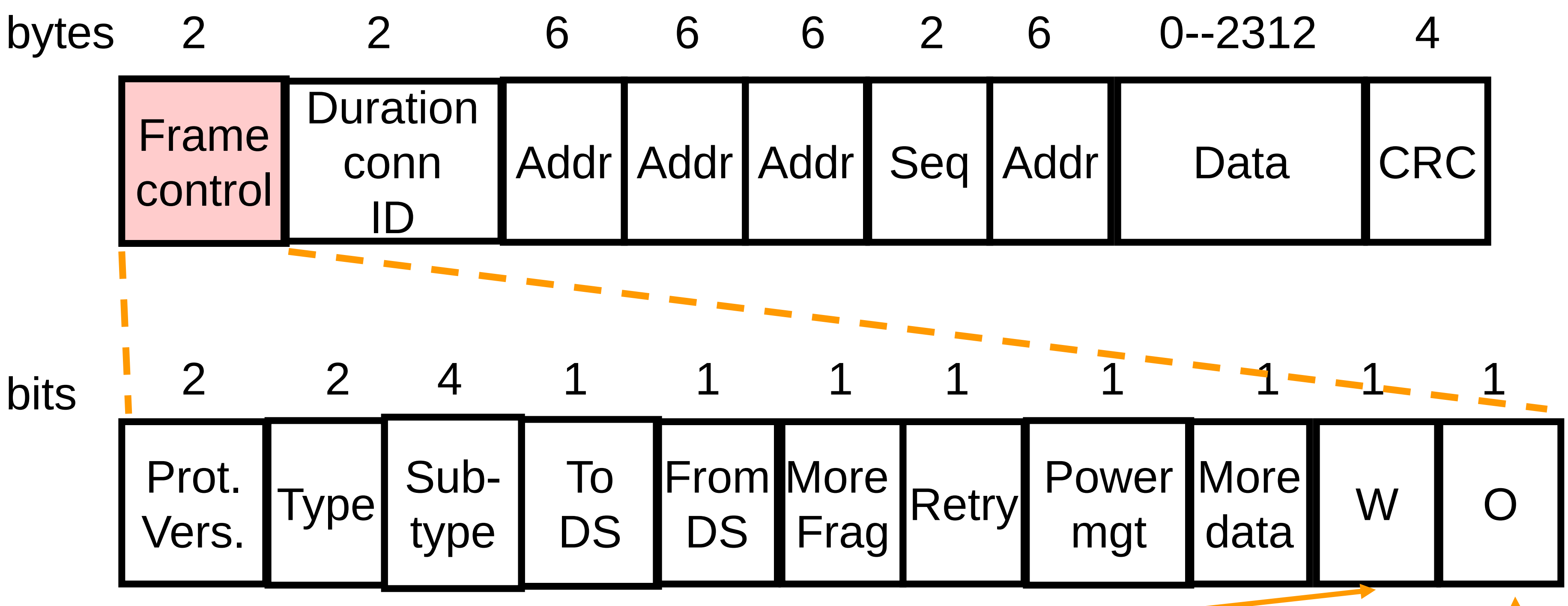
bytes	2	2	6	6	6	2	6	0--2312	4
	Frame control	Duration conn ID	Addr	Addr	Addr	Seq	Addr	Data	CRC

bits	2	2	4	1	1	1	1	1	1	1	1
	Prot. Vers.	Type	Sub-type	To DS	From DS	More Frag	Retry	Power mgt	More data	W	O

Power mgt: Used to put the receiver into sleep or take out from sleep

More data: Sender has additional frames for the receiver

IEEE 802.11: Frame format (6)



Has the frame been encripted using WEP?

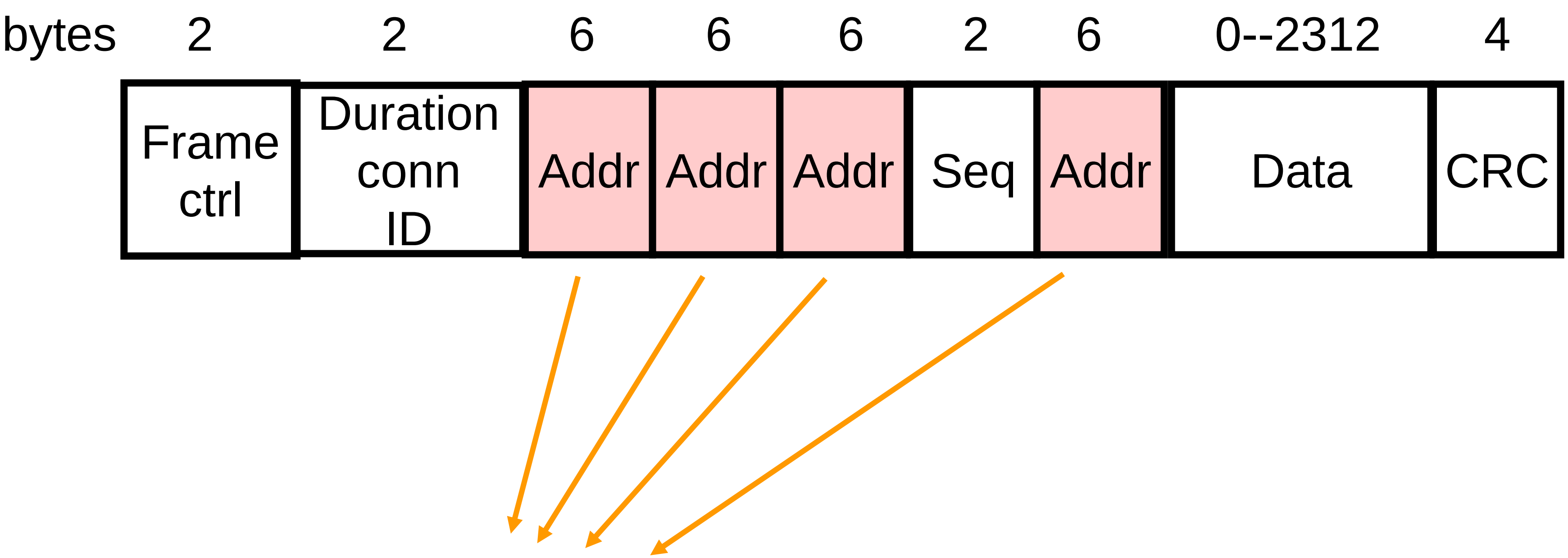
Order: a sequence of frames with this bit on must be processed in order

IEEE 802.11: Frame format (7)

bytes	2	2	6	6	6	2	6	0--2312	4
	Frame control	Duration conn ID	Addr	Addr	Addr	Seq	Addr	Data	CRC

Time (microsecs): how long the frame/fragment and its acknowledgement will occupy the channel

IEEE 802.11: Frame format (8)



Standard IEEE 48-bit MAC addresses:
source, destination, source and destionation AP for inter-cell traffic

IEEE 802.11: Frame format (9)

bytes	2	2	6	6	6	2	6	0--2312	4
	Frame ctrl	Duration conn ID	Addr	Addr	Addr	Seq	Addr	Data	CRC

Sequence: allows fragments
to be numbered. 12 bits identify the frame
and 4 identify fragments

IEEE 802.11: Frame format (10)

bytes	2	2	6	6	6	2	6	0--2312	4
	Frame ctrl	Duration conn ID	Addr	Addr	Addr	Seq	Addr	Data	CRC

Payload + (optional) bytes *encription/decription for WEP (Wired Equivalent Privacy) protocol*

IEEE 802.11: Frame format (11)

bytes	2	2	6	6	6	2	6	0--2312	4
	Frame ctrl	Duration conn ID	Addr	Addr	Addr	Seq	Addr	Data	CRC

Cyclic Redundancy Check:
32 bit hash code of the data
for transmission error detection
(NOT recovery)

IEEE 802.11: PCF

- Optional capability:
  - connection oriented
  - provides contention-free frame transfer
  - acts under the control of the point coordinator (PC) that performs polling and enables stations to transmit without contending for the channel
  - the method by which polling tables are maintained and polling sequence is determined is left to the implementor
  - it is required to coexist with DCS

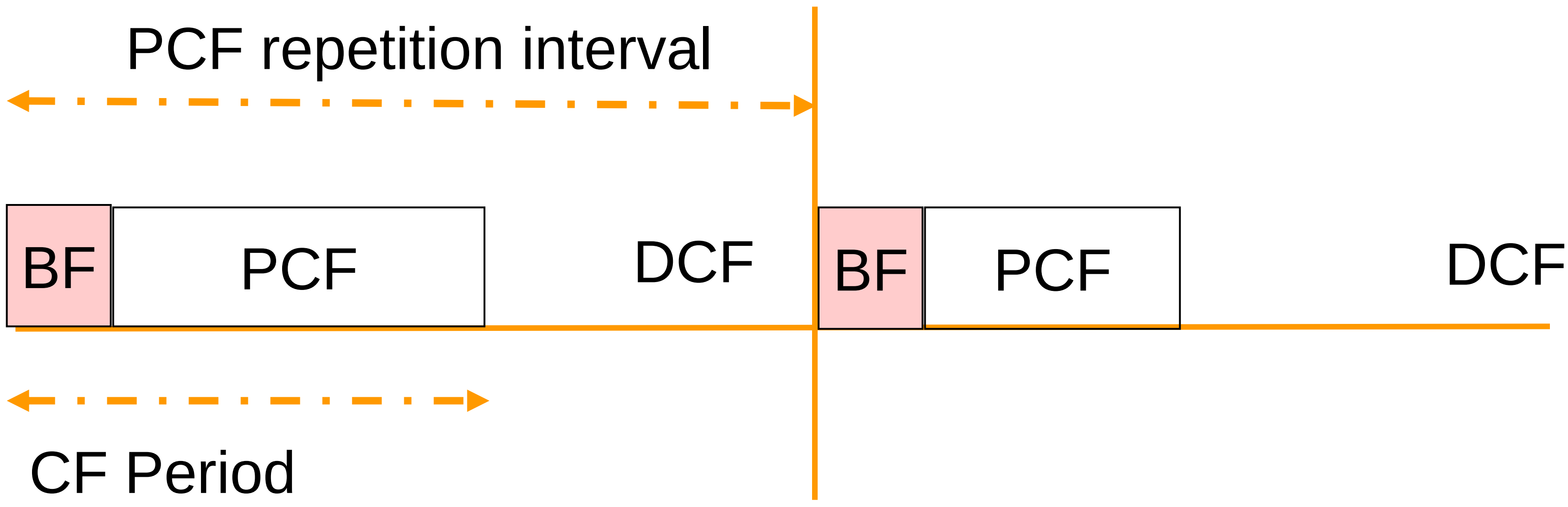
IEEE 802.11: PCF (2)

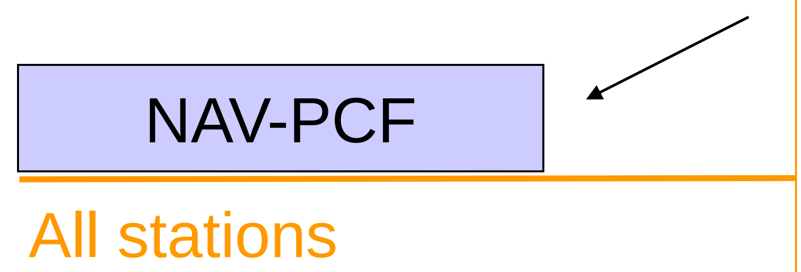
- Starting contention-free period
  - AP sends a Beacon Frame (BF)
  - stations synchronize using BF
- PCF occurs periodically
  - **`CFP_rate`** specifies the repetition interval
  - in each repetition interval a portion of the time is allotted for contention-free traffic and the remaining for contention based traffic
  - **`CFP_rate`** corresponds to an integral number of BF

IEEE 802.11: PCF (3)

- Length of PCF period
  - CFP_Max_Duration determines the maximum size of a contention free period
  - AP decides the actual length, can be smaller if PCF traffic is light or DCF traffic is heavy

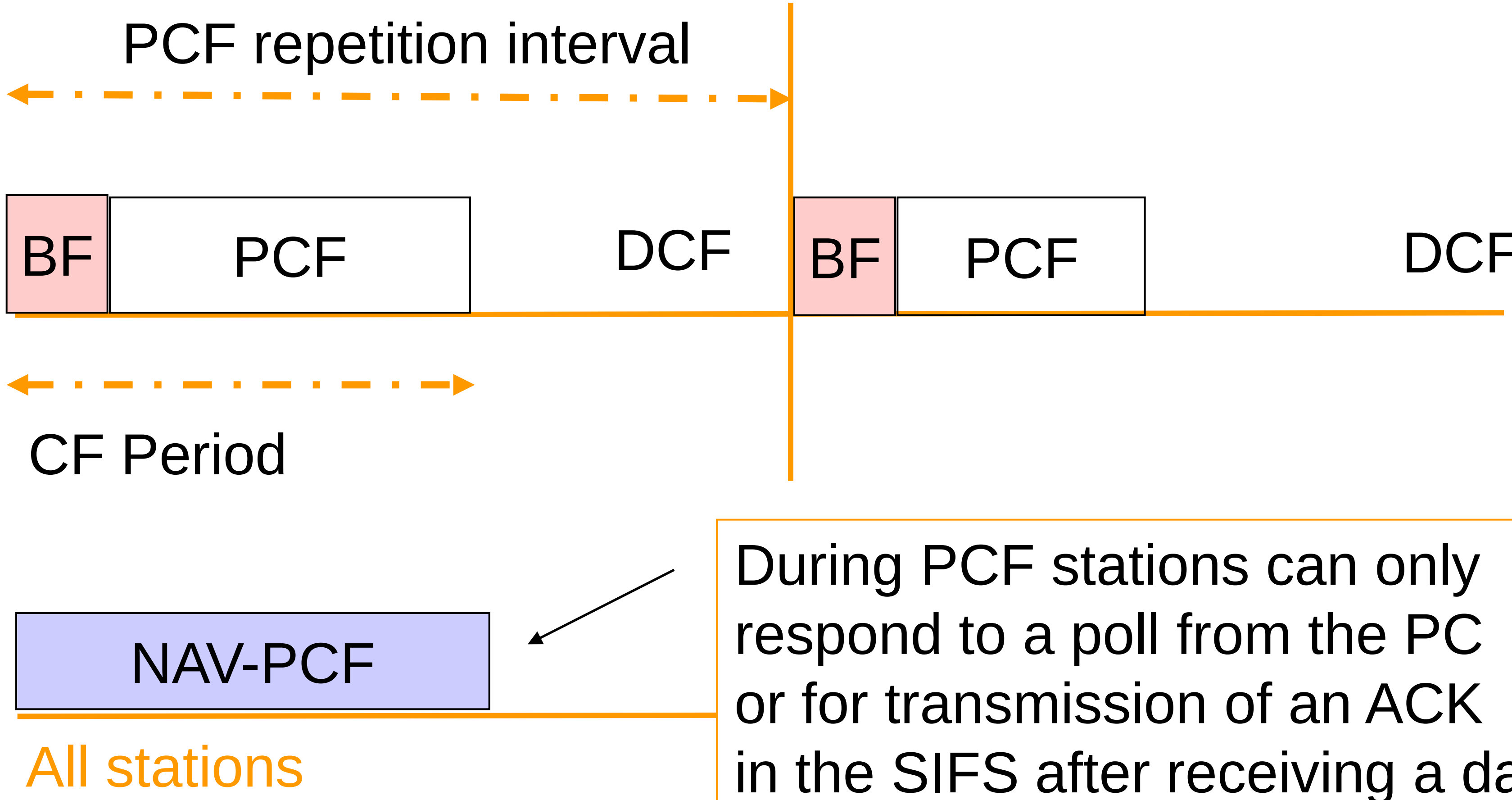
Coexistence of PCF and DCF





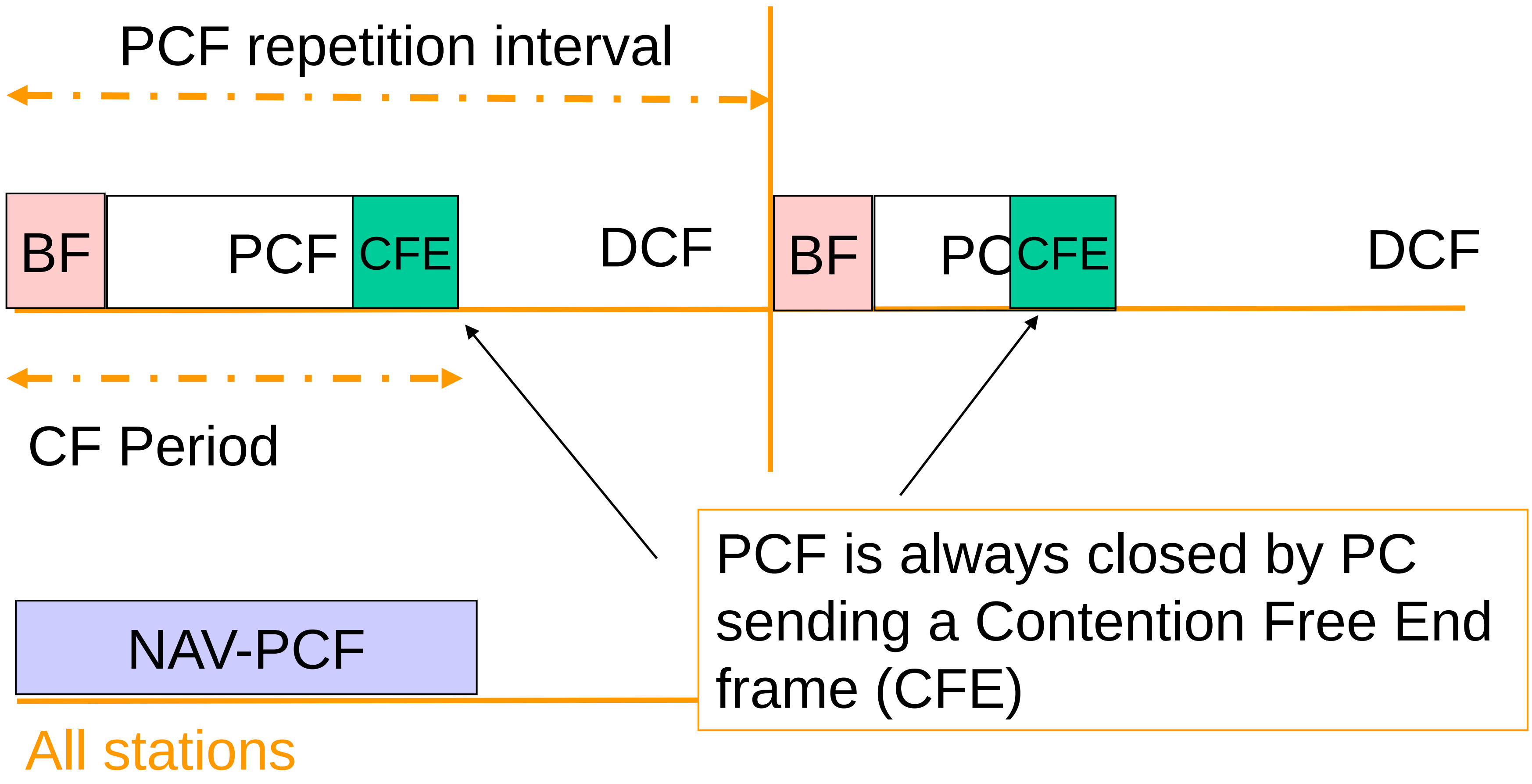
At the beginning of each period all stations update their NAV to the maximum length of PCF (CFP_max_duration)

Coexistence of PCF and DCF (2)

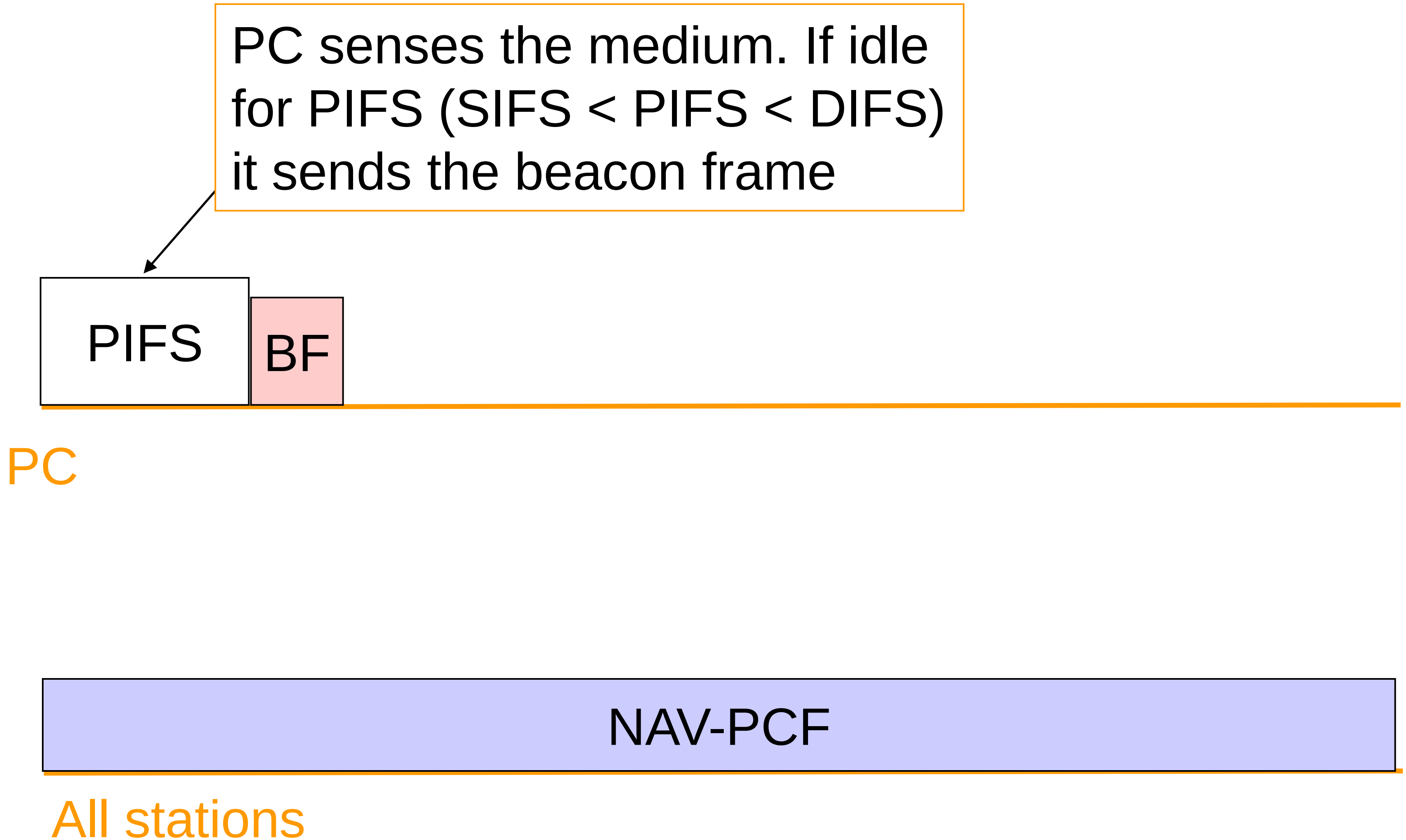


During PCF stations can only respond to a poll from the PC or for transmission of an ACK in the SIFS after receiving a data frame

Coexistence of PCF and DCF (3)

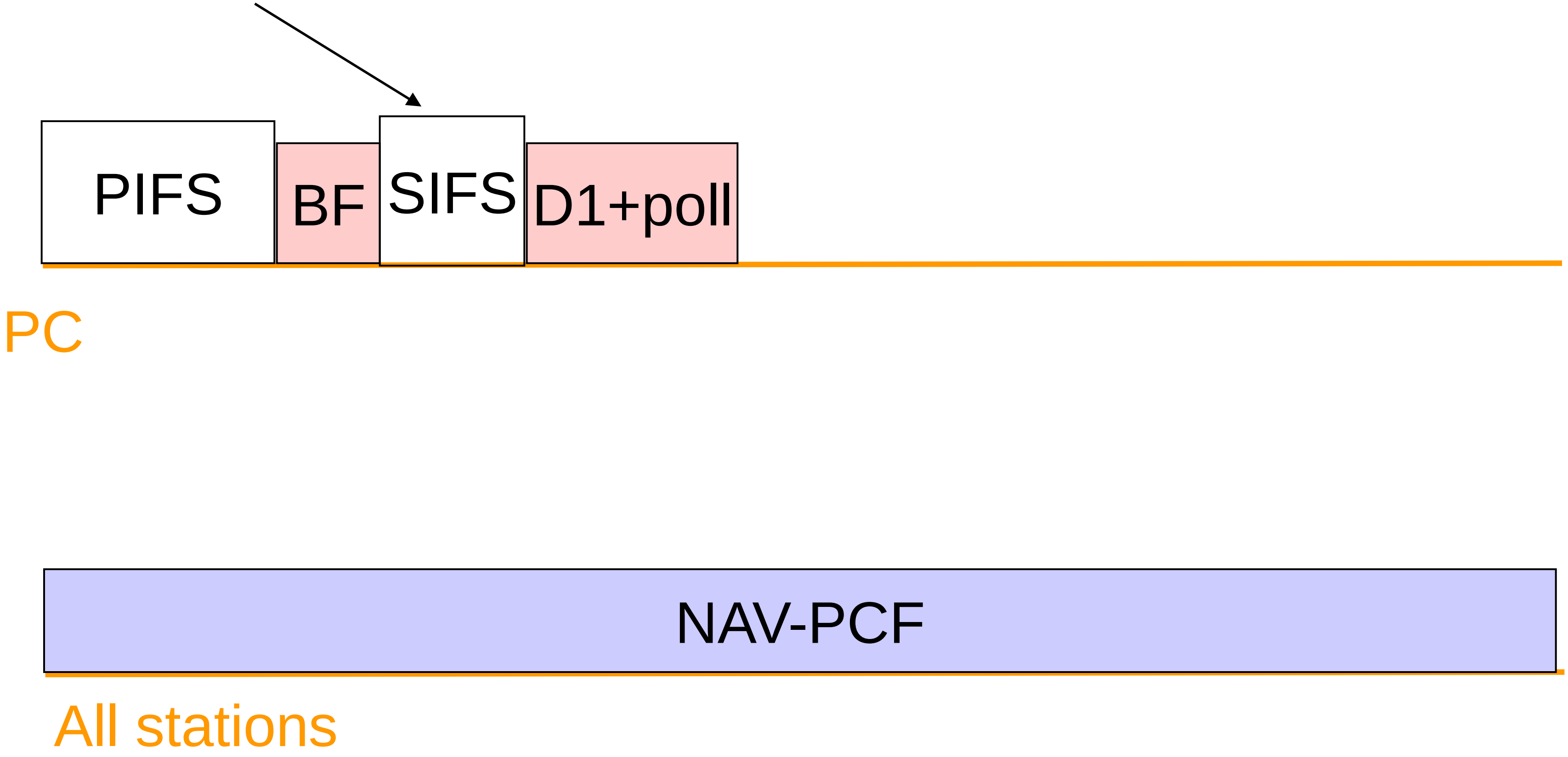


Running PCF

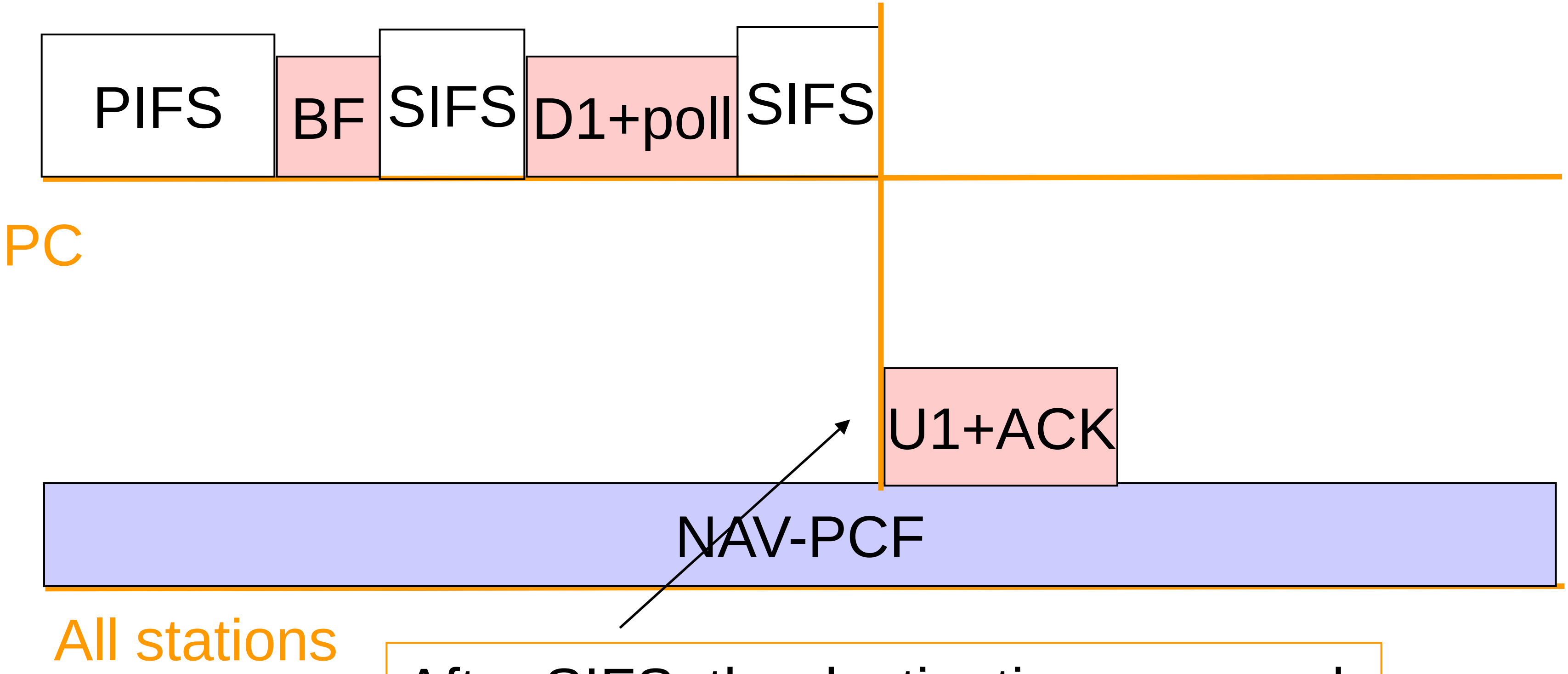

PC senses the medium. If idle for PIFS (SIFS < PIFS < DIFS) it sends the beacon frame
PIFS
BF
PC
NAV-PCF
All stations

Running PCF (2)

Then waits for SIFS and sends a data and/or CF-poll frame



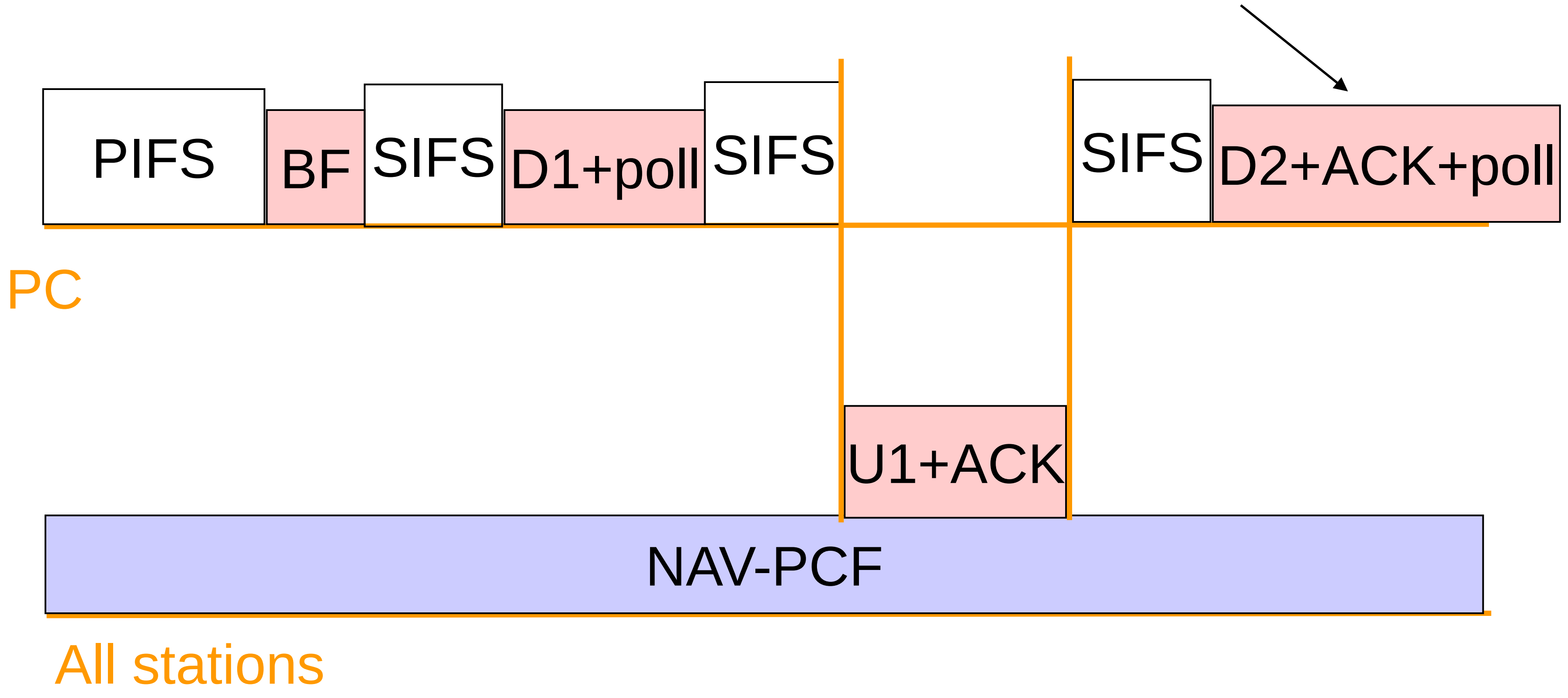
Running PCF (3)



After SIFS, the destination can send a CF-ACK or data+CF-ACK frame

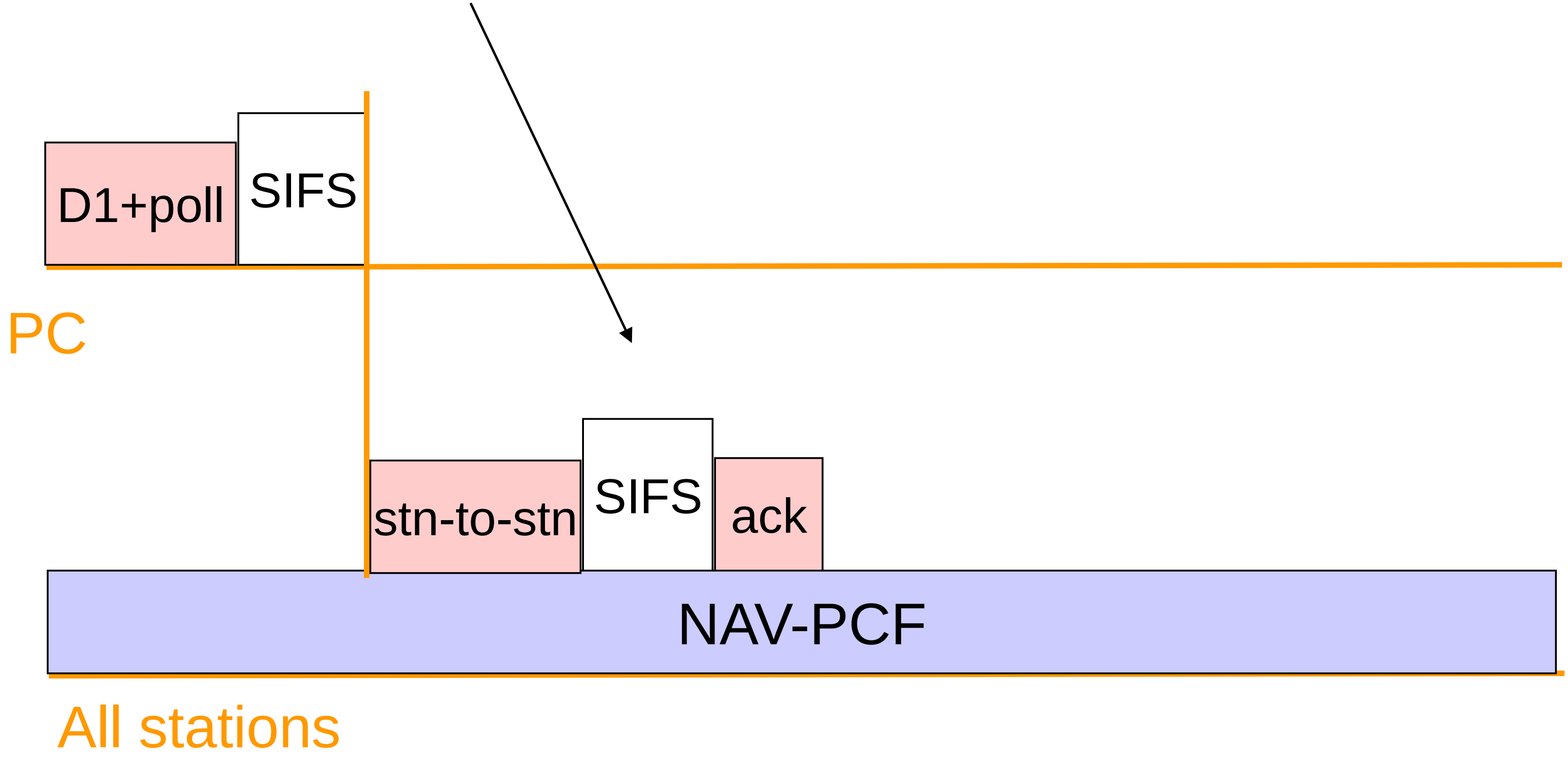
Running PCF (4)

After SIFS, the PC can send
a CF-ACK or data or CF-poll frame



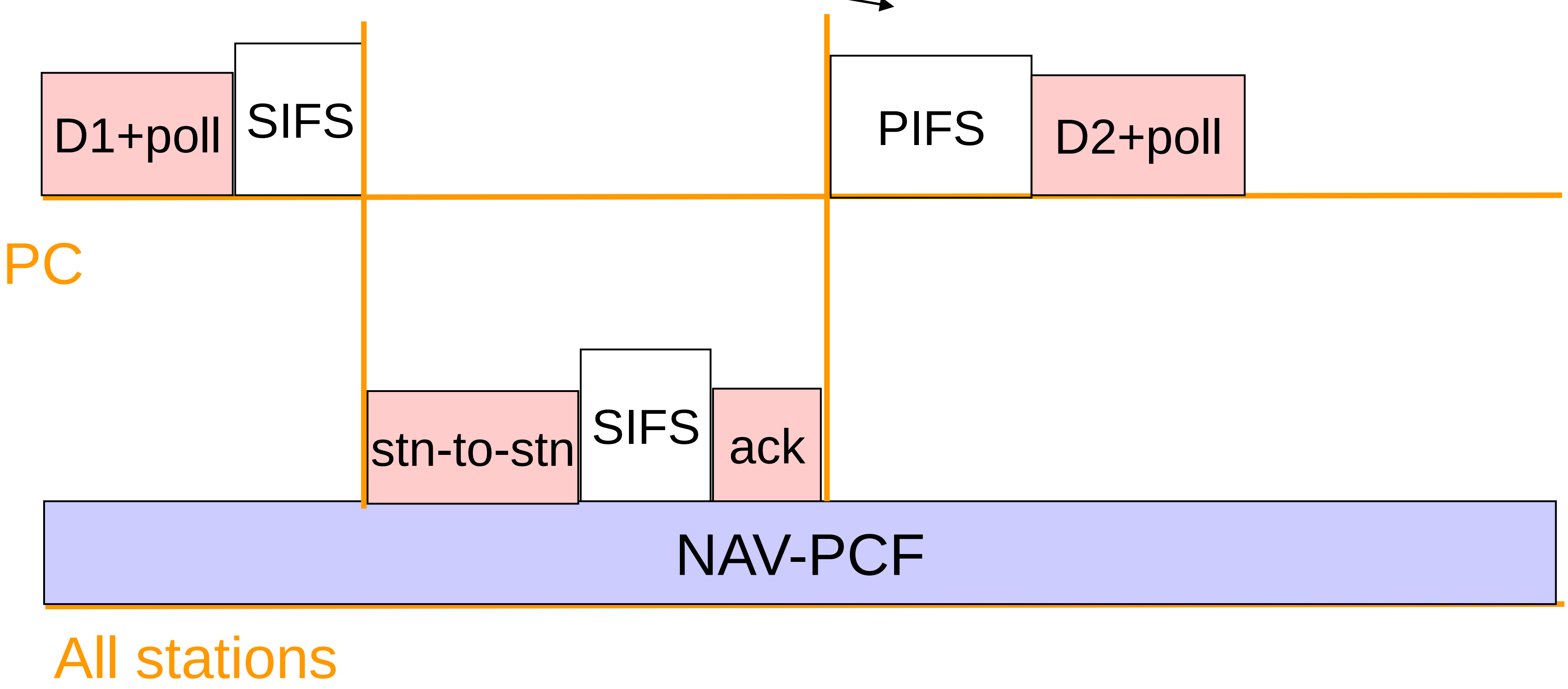
Running PCF (5)

When polled a station can send data directly to another station



Running PCF (6)

PC waits PIFS following and ACK frame to be sure transmission is finished before polling again



Running PCF (7)

- With this model
  - PC can decide to send to a non-PCF aware station (one that only has DCF)
    - interaction works well as this station will respond with and ACK
  - messages can be fragmented as in DCF