

# CS3103 Computer Networks Practice

## Wireless LANs

Introduction to Wireless Networks and WLAN  
IEEE 802.11 MAC Sublayer - CSMA/CA  
CSMA/CA - Hidden Node and Exposed Node Problems  
IEEE 802.11 MAC Sublayer Modes – DCF and PCF  
LAB:- Building IEEE 802.11 Networks (BSS, ESS)  
LAB:- Inspect IEEE 802.11 Frame Format

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Contents



# Recap – from Assignment 2

- ▶ Why HTTP/3 connection to <https://http3.is/> or <https://cloudflare-quic.com/> fail from SoC network?

 bitxer Try <https://cloudflare-quic.com/> 




**bitxer** 11/09/2024 19:13

This is more reliable for me

 @bitxer This is more reliable for me



**juju** 11/09/2024 19:16

i refreshed until i got rate limited 



**bitxer** 11/09/2024 19:18

I cant think of anything else you can try


See if anyone else have sth else to suggest



**juju** 11/09/2024 19:20

tried on edge and it don't work either i'm cooked :l



 juju Dear cultured fellows, anybody's browser just refuses to allow http3 for Assignment 2 Q4? I'...

**juju** 12/09/2024 01:59

update: it works! on my home network that is... no idea why the browsers refused to use HTTP3 when I was on SoC network :l

# Recap – Lab Exercise

## Common Issues:

- Switches/Routers need restart due to SW (IOS) glitches
- Configuration from Previous Week's Lab setting are not erased (even after Erase-startup, Reload)
- Configuration from Previous Session are not Reset

**“In school you know the problem and you know the solution. In the ‘real world’ you rarely know the solution, and often don't even know the real problem”**

*Network engineers need to be self-reliant, methodical, and skilled in troubleshooting and debugging.*

We encountered some switchports (G0/1, Gi0/2, Gi0/9) are missing at the start of the lab session 1 and 2 after the switch has del vlan.dat, erase start-up and reload. We asked the students to 'switch OFF and ON the power switch (labelled: switch and router) of the switch and router at the start of lab session'. Seems like lab session 3 has no similar problem.

Lots of work by TAs in background

So please ask CS3103 students to do the above for lab sessions on Thurs (12 Sep) and Friday (13 Sep) and monitor. Thank you.



# Wireless LANs

**Introduction to Wireless Networks and WLAN**

IEEE 802.11 MAC Sublayer - CSMA/CA

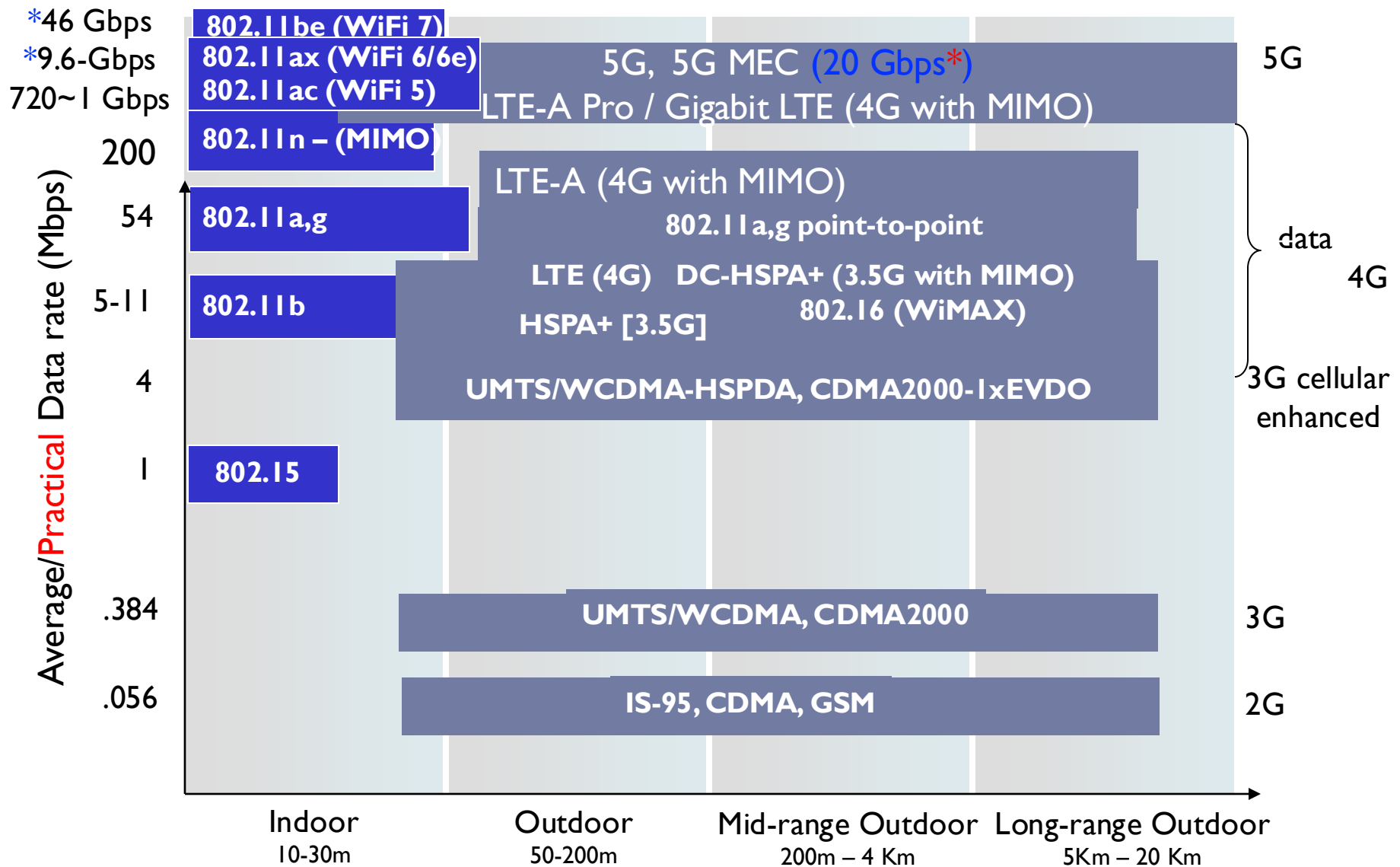
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# Characteristics of wireless link standards



# Why more bandwidth?

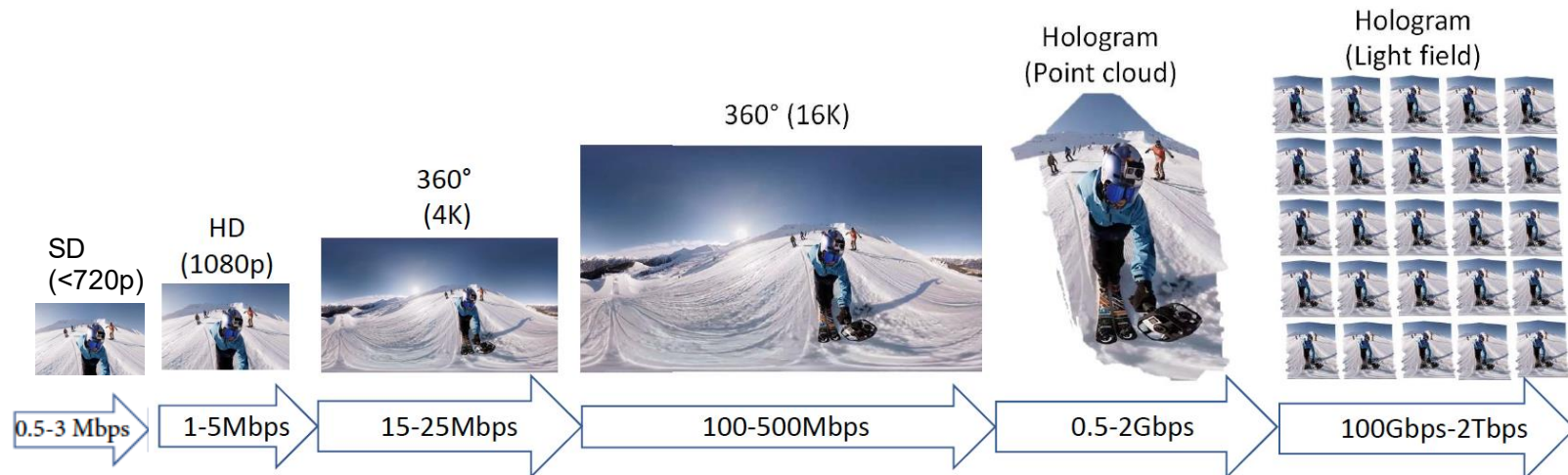
- ▶ Full HD Video ~ 5 Mbps

802.11ag – 54 Mbps

- ▶ 4K Video ~25 Mbps

- ▶ People always need more! Expectation grows!

- ▶ Leads to Application Demand => Infrastructure Demand








































# Singapore 5G Mobile Network Scene – June 2025

## Mobile Experience Awards

JUNE 2025, SINGAPORE REPORT



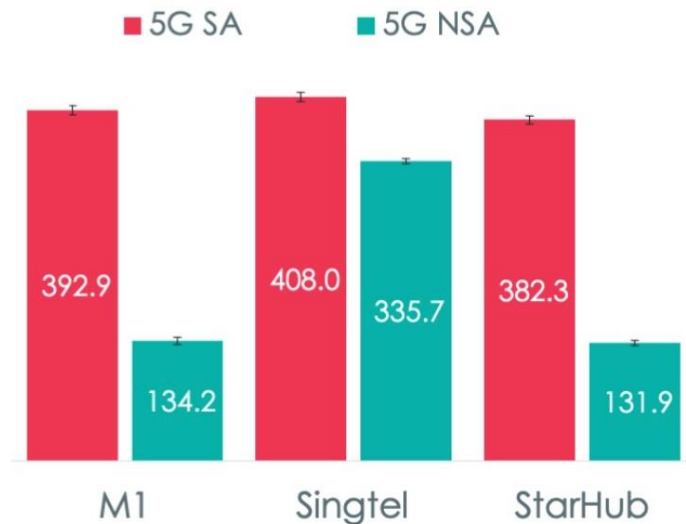
GENERAL	 Video Experience .....	 Games Experience .....	 Download Speed Experience .....	 Upload Speed Experience .....	 5G Video Experience .....	 5G Games Experience .....	 5G Download Speed .....	 5G Upload Speed .....	 5G Coverage Experience .....	 Availability .....	 5G Availability .....	 Consistent Quality .....	 Reliability Experience .....
	Overall Experience				5G Experience				Coverage			Consistency	
M1 													
SIMBA 													
Singtel 													
StarHub 													

Mobile Network Experience Report | June 2025 | © Opensignal Limited

# Singapore 5G Mobile Network Scene

Our users in Singapore generally enjoy improved mobile network experience on 5G Standalone compared to 5G Non Standalone

5G Download Speed (Mbps)



5G Consistent Quality (% of tests)



Data collection period: Feb 1 – May 1, 2025 | © Opensignal Limited

# IEEE 802.11 Standards

- ▶ IEEE has defined the specifications for a wireless LAN, called IEEE 802.11, which **covers the physical and data link layers (esp MAC)**.
- ▶ ISM Bands: 902-928 MHz, 2.4-4.835 GHz, 5.725-5.850 GHz
- ▶ 802.11b (WiFi 1, 1999)
  - ▶ 2.4 GHz range
  - ▶ up to 11 Mbps
  - ▶ DSSS scheme
- ▶ 802.11a (WiFi 2, 1999)
  - ▶ 5 GHz range
  - ▶ up to 54 Mbps
  - ▶ OFDM scheme
- ▶ 802.11g (WiFi 3, 2003)
  - 2.4 GHz range support both bands
  - up to 54 Mbps
  - OFDM, DSSS scheme
  - backward compatible with 802.11b
- ▶ 802.11n: multiple antenna (MIMO) (WiFi 4, 2009)
  - 2.4 or 5 GHz range
  - up to 600 Mbps (240 Mbps Practical)
  - OFDM scheme

What are 802.11 protocols? What is WEP? What is WPA2?

What is WiGig (Gigabit Alliance)? What is WAVE?

# IEEE 802.11 Standards

- ▶ IEEE has defined the specifications for a wireless LAN, called IEEE 802.11, which **covers the physical and data link layers (esp MAC)**.
- ▶ ISM Bands: 902-928 MHz, 2.4-4.835 GHz, 5.725-5.850 GHz
- ▶ 802.11ac (WiFi 5, 2013)
  - ▶ 2.4 GHz & 5 GHz range
  - ▶ Channel 160 MHz
  - ▶ up to 6.9 Gbps
  - ▶ OFDM scheme, **4x4 MIMO**
- ▶ 802.11ax (WiFi 6 2019)
  - ▶ 2.4 GHz & 5 GHz range
  - ▶ **WiFi 6e**: 6 GHz range
  - ▶ Channel 160 MHz
  - ▶ OFDMA
  - ▶ up to 9.6 Gbps, **8x8 MIMO**
- ▶ **802.11be** (WiFi 7, 2024)
  - 2.4 GHz & 5 GHz & 6 GHz range
  - up to 46 Gbps
  - **Channel 320 MHz**
  - OFDMA (extended) scheme
  - **16x16 MIMO**

# IEEE 802.11 Standards – KEY TECHNOLOGIES

## 802.11n

- 2.4 or 5 GHz range
- up to 600 Mbps (240 Mbps Practical peak)
- 4 Antennas @ 100 Mbps each

What happens when the devices do not have multiple antennas? (eg. Smartphones)

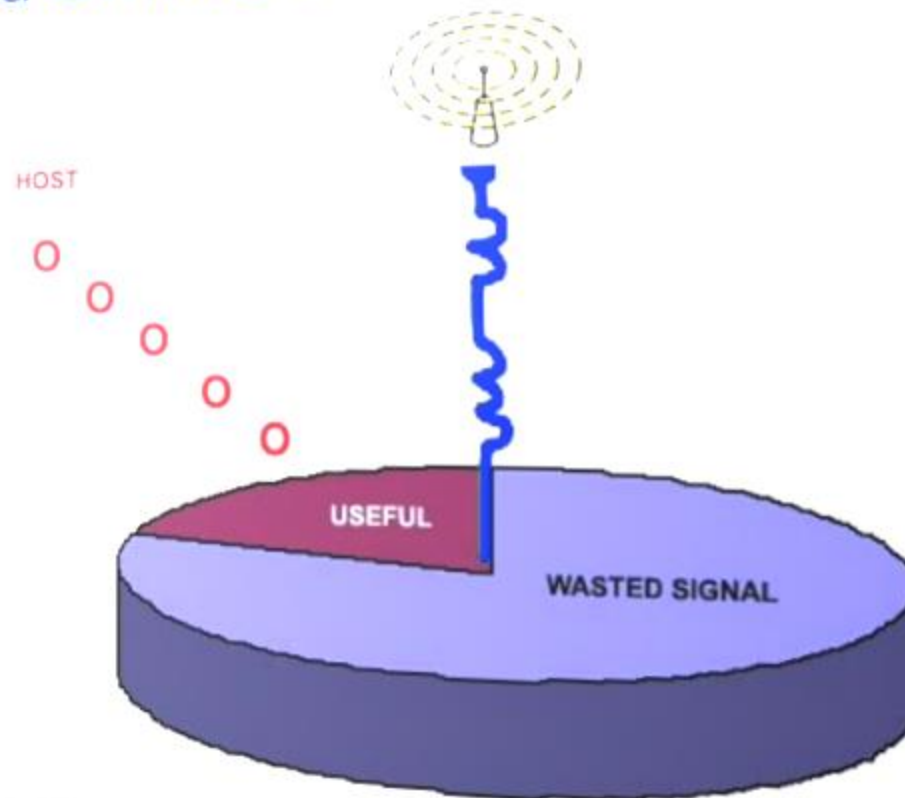


## 802.11ac (WiFi 5, 2014)

- 5 GHz range
- up to 1300 Mbps (720 Mbps Practical peak)
- 8 Antennas @ 400 Mbps each
- 5 GHz means short range?
- **Beamforming / 'smartsignal'**



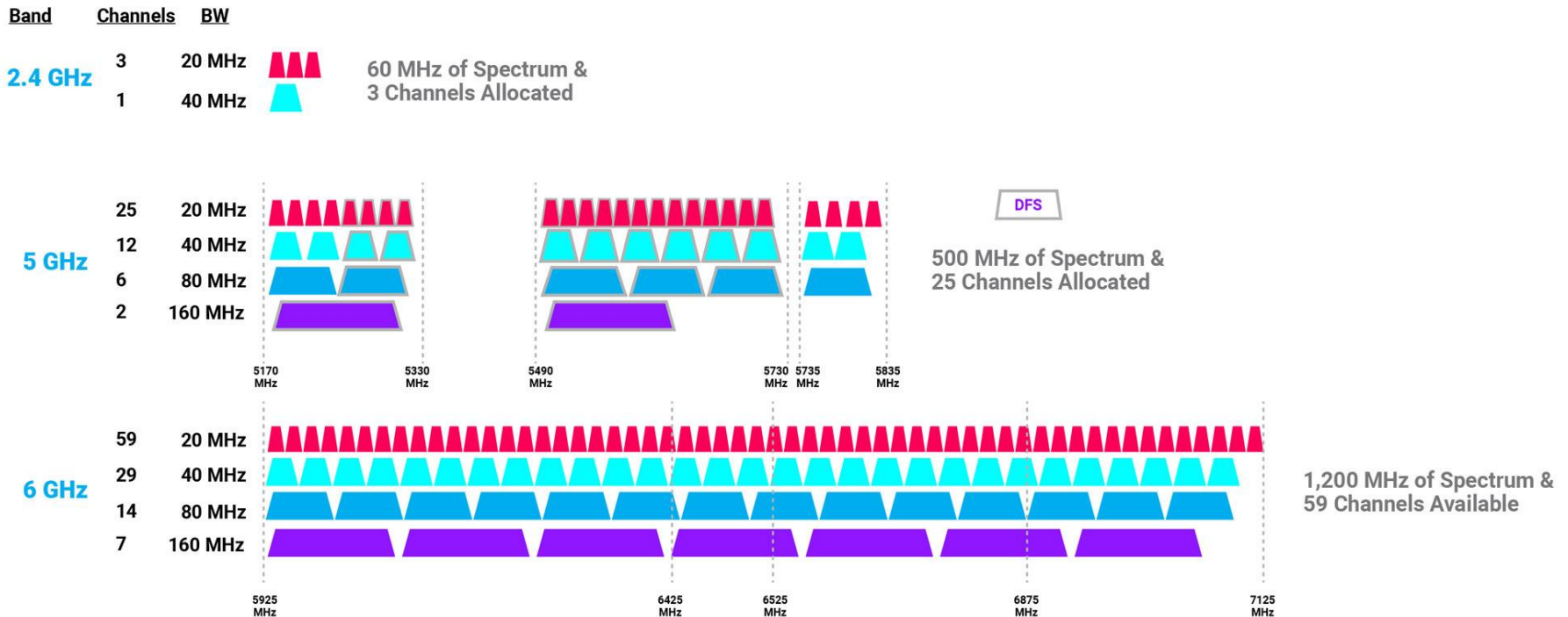
# Standard Omnidirectional Antenna



# 802.11 Standards – KEY TECHNOLOGIES

## (802.11ax-E) WiFi 6E

### Wi-Fi 6E



# 802.11 Standards – KEY TECHNOLOGIES

## (802.11be) WiFi 7– MultiLink Operation (MLO)

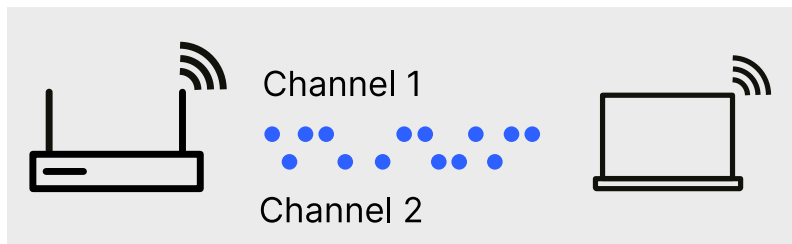
### Reliable parallel radio with **multi-link operation (MLO)**

Wi-Fi 7 makes it possible for access points and wireless clients to be **connected simultaneously on two frequency bands** for the first time. This has different advantages depending on the Wi-Fi client and the number of radio modules available.

#### Enhanced Multi-Link Single-Radio (eMLSR)

**Access point**  
(Concurrent dual radio)

**Client**  
(Single 2x2 radio)



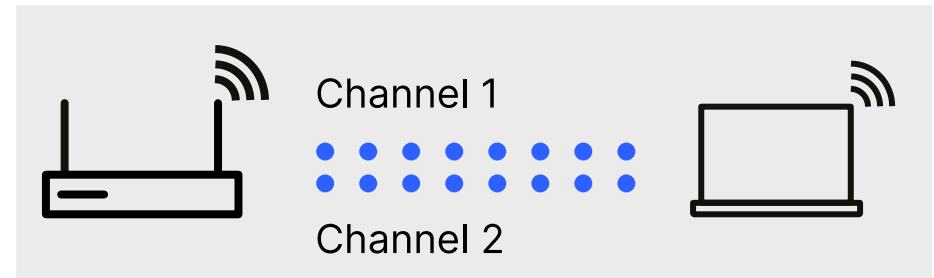
Client: Single Radio Module (with 2 fq bands. Eg. 2.4 GHz + 5 GHz, or 5 GHz + 6 GHz)

Choose the best frequency band/channel to send, switches automatically.

#### Multi-Link Multi-Radio (MLMR)

**Access point**  
(Concurrent dual radio)

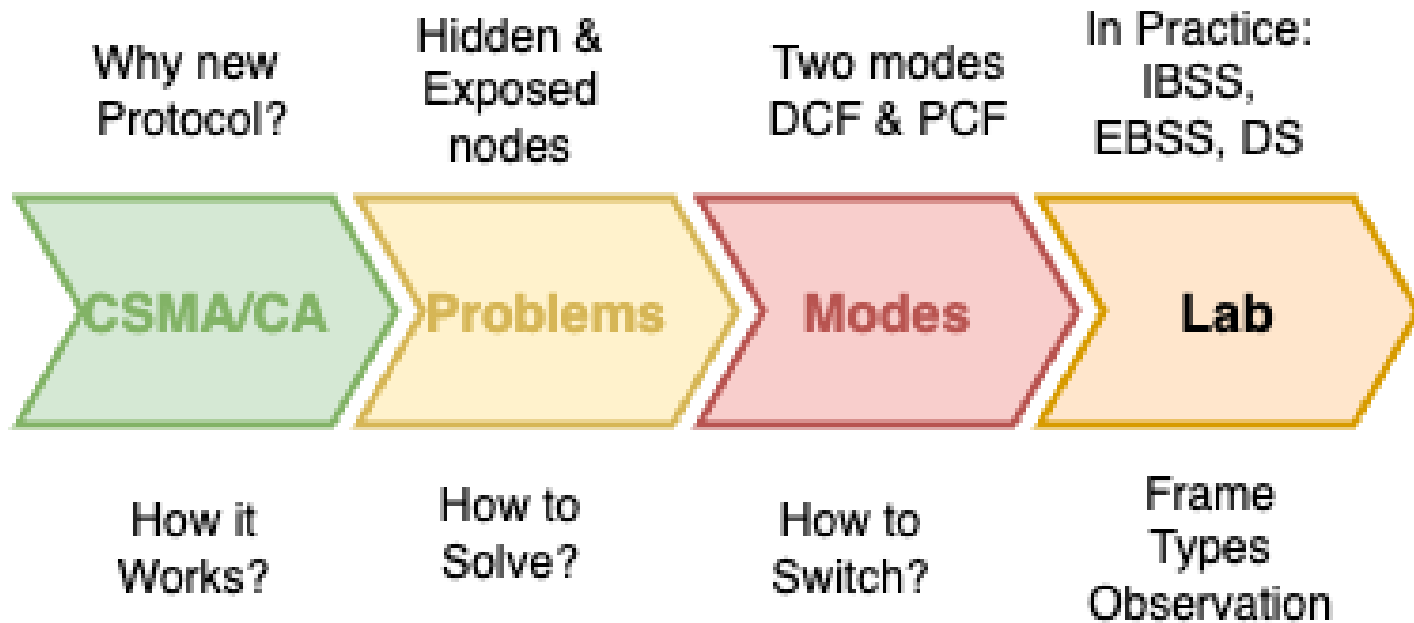
**Client**  
(Concurrent dual radio)



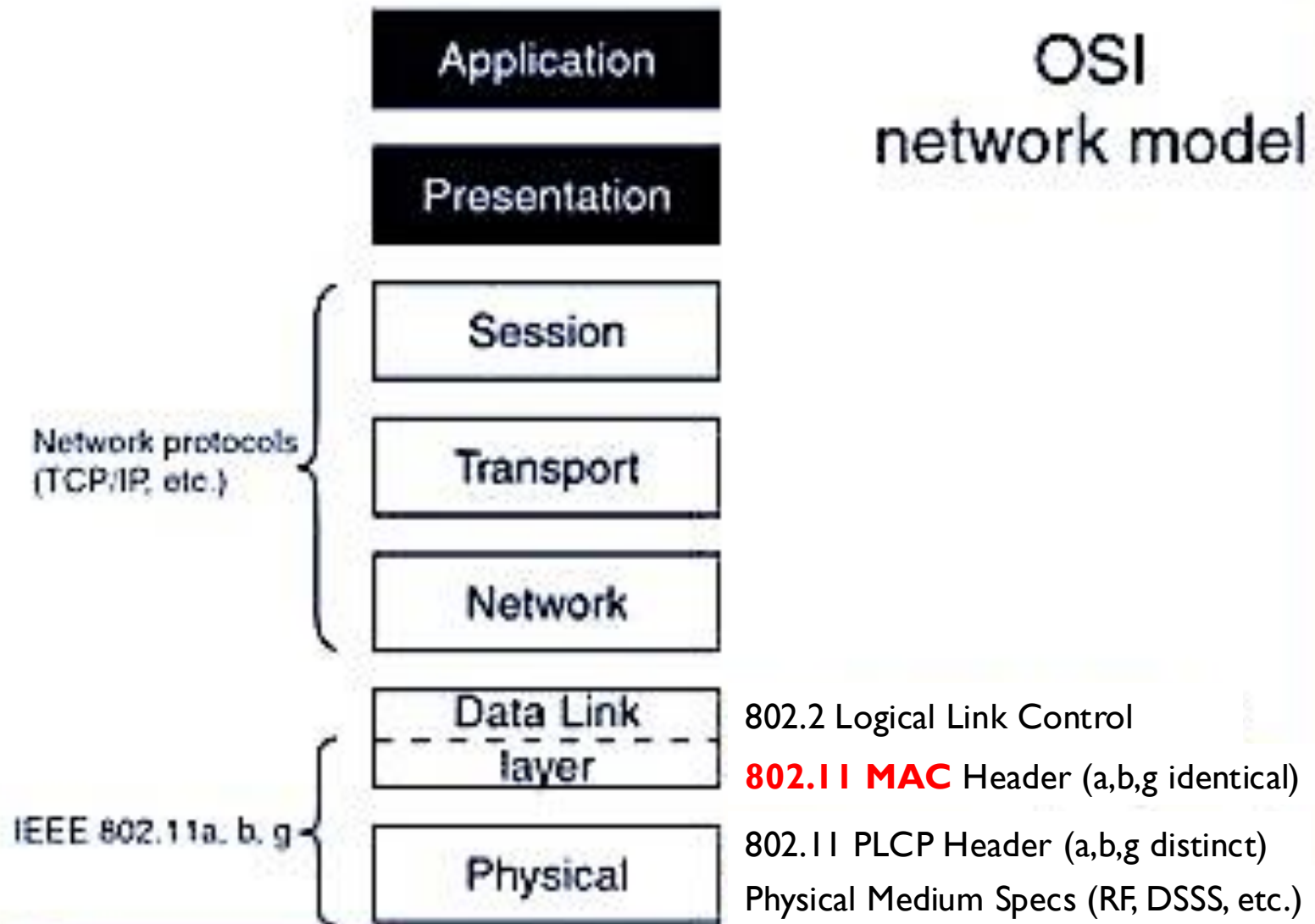
Client: Dual Radio Module (with 2 fq bands. Eg. 2.4 GHz + 5 GHz, or 5 GHz + 6 GHz)

Concurrent communication on two frequency bands.

# What we learn in this session...



# IEEE 802.11 Standards – For Your Reference





# Wireless LANs

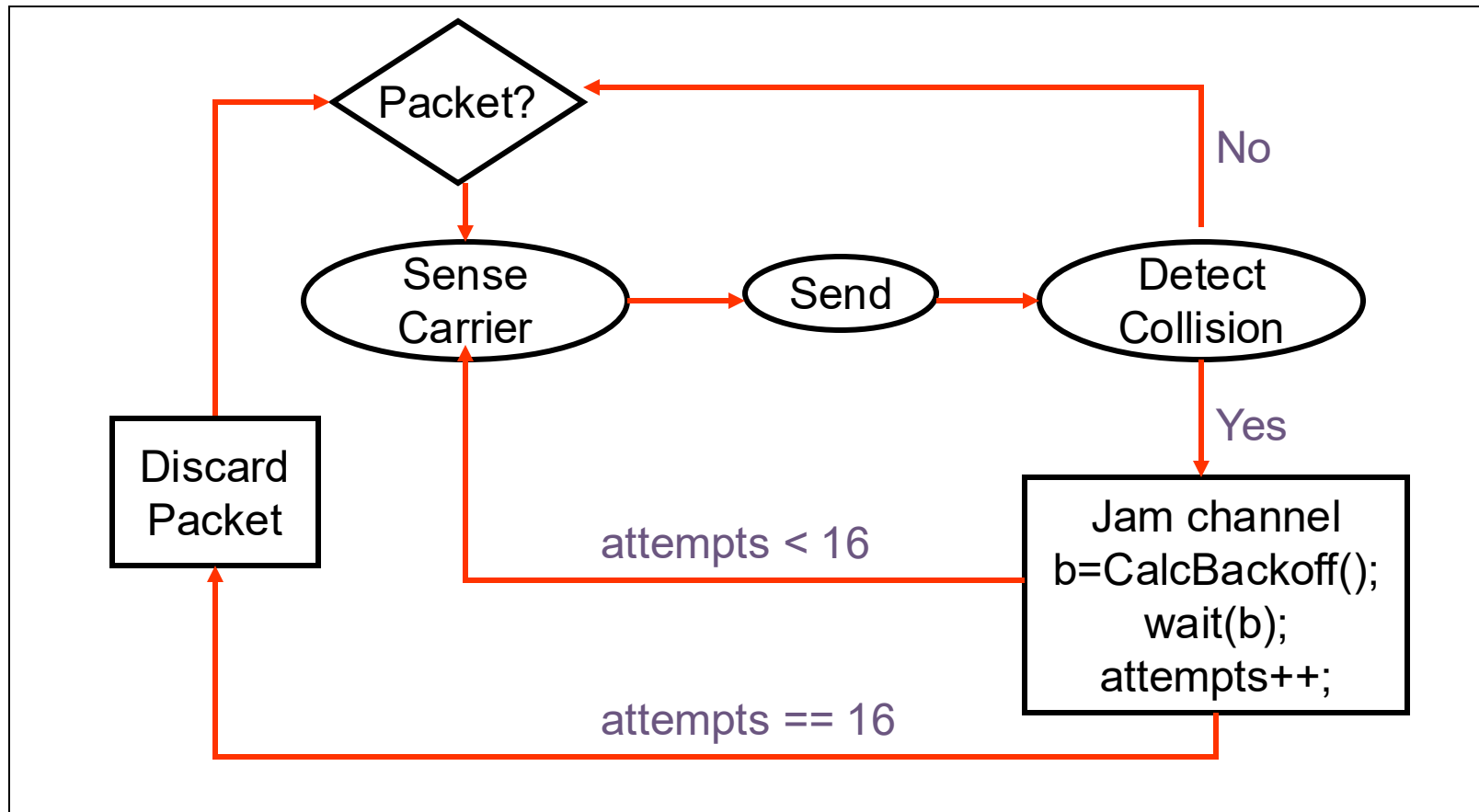
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Make sure you  
**LOGIN**  
using your  
**NUSNET ID.**



# Recall Ethernet MAC Layer! - CSMA/CD

“Listen While You Talk”



Q: Why there is **no** ACK? Is error-free delivery is guaranteed by the protocol?

# How is collision Detected in CSMA/CD?



**Any one can speak, leads to collision,  
then collision is resolved automatically!**

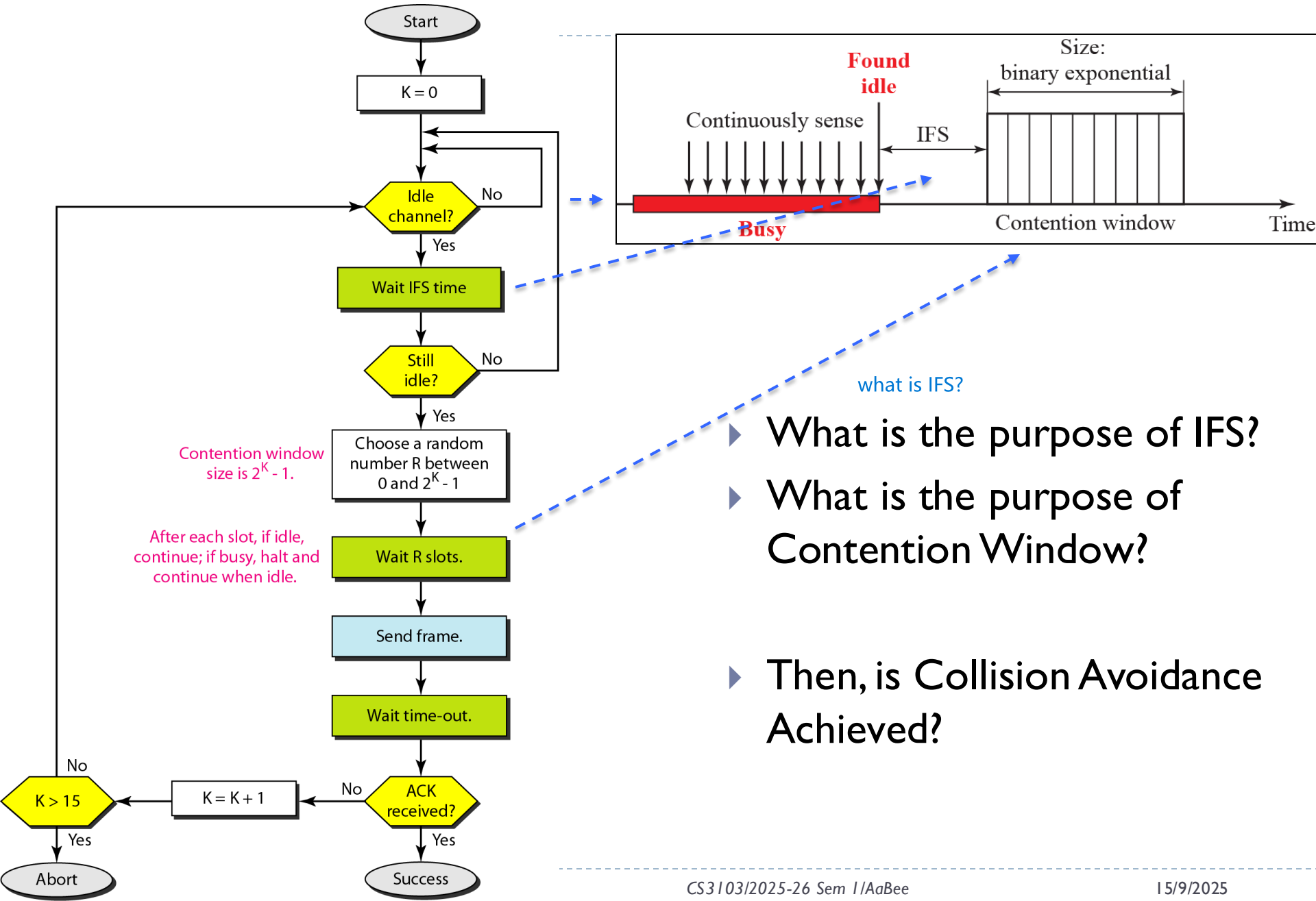
## WLANs use “Collision Avoidance”

What are the strategies to Avoid Collision in a Group Discussion environment?



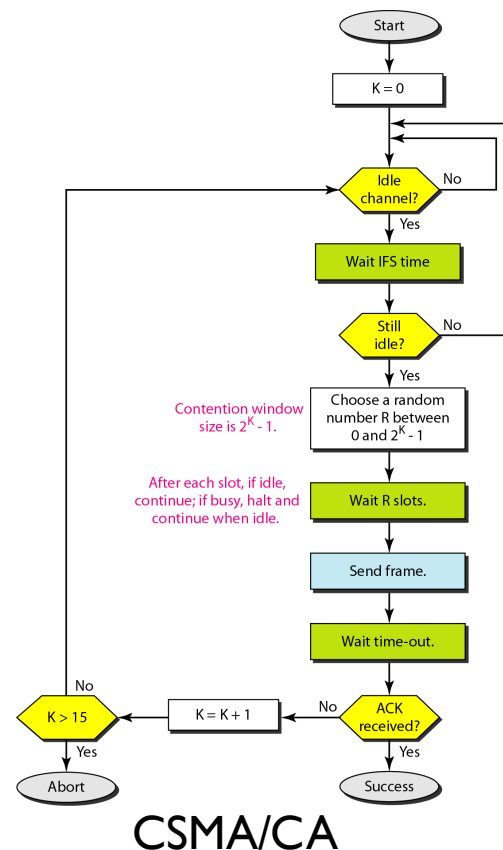
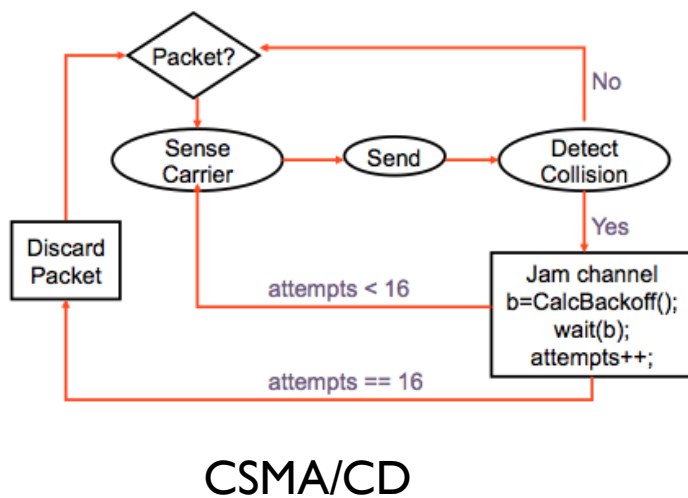
<https://pollev.com/banand>

# IEEE 802.11 MAC Layer Protocol (CSMA/CA)



# Why Collision Avoidance?

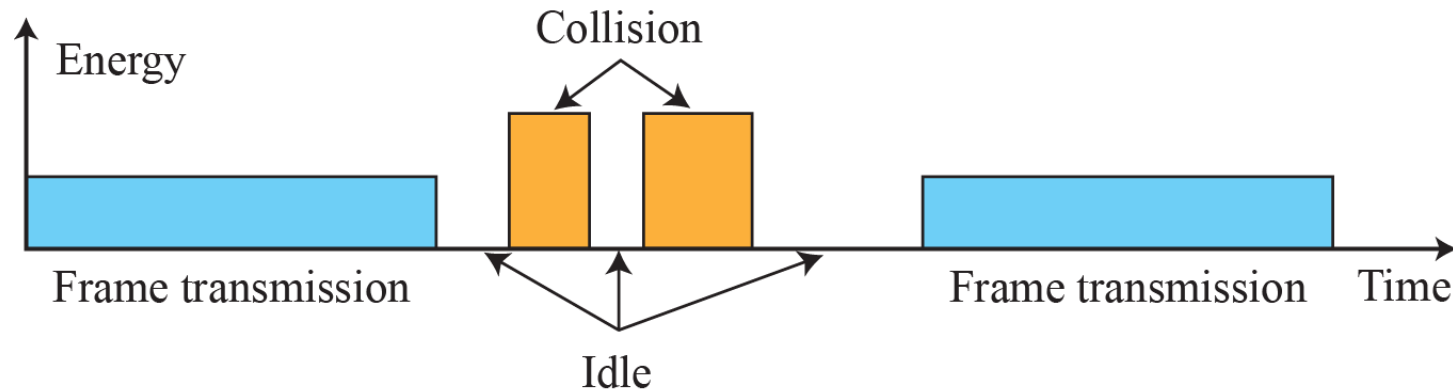
- ▶ CSMA/CA looks more inefficient (waiting times, ACKs, etc) than CSMA/CD. **Then, why can't we use CSMA/CD for wireless?**



# Collision Detection is Hard in Wireless Networks

## Requirements for Collision Detection

- Energy level during transmission, idleness, or collision



Any other requirement...

What is the key property of transmitter/receiver hardware system to detect collision?

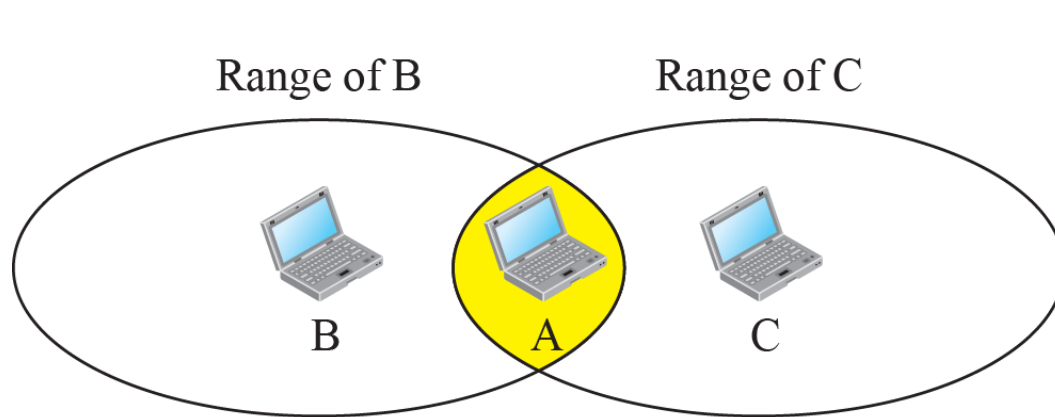


# Wireless LANs

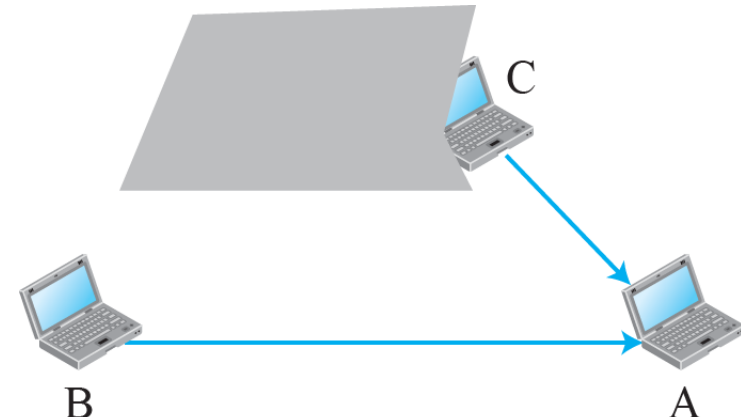
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# CSMA/CA Suffers from - Hidden node problem

- ▶ Stations B and C are hidden from each other wrt A
- ▶ B's transmission to A may overlap with C's transmission to A
- ▶ **Eg.:** What happens while B is transmitting to A, C senses the carrier to start transmission?



a. Stations B and C are not in each other's range.

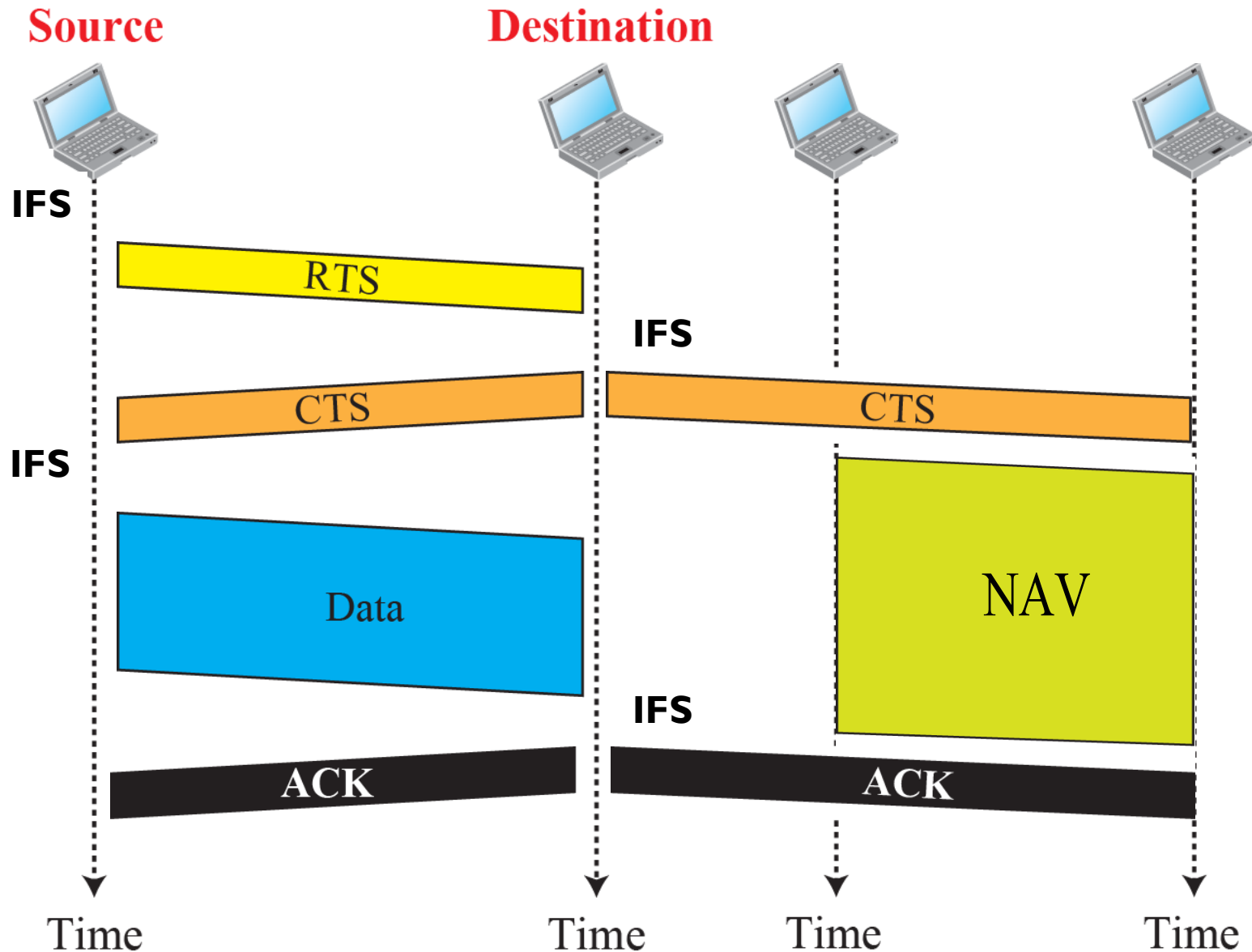


b. Stations B and C are hidden from each other.

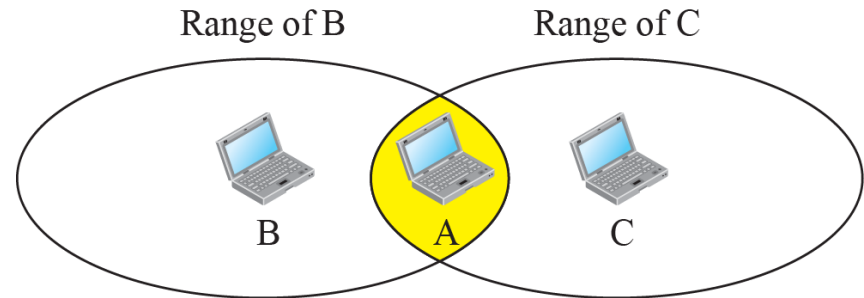
- ▶ So what?
  - ▶ Hidden nodes **reduce the capacity of the network** as they increase the possibility of collision

# IEEE 802.11 MAC Layer (CSMA/CA – RTS/CTS)

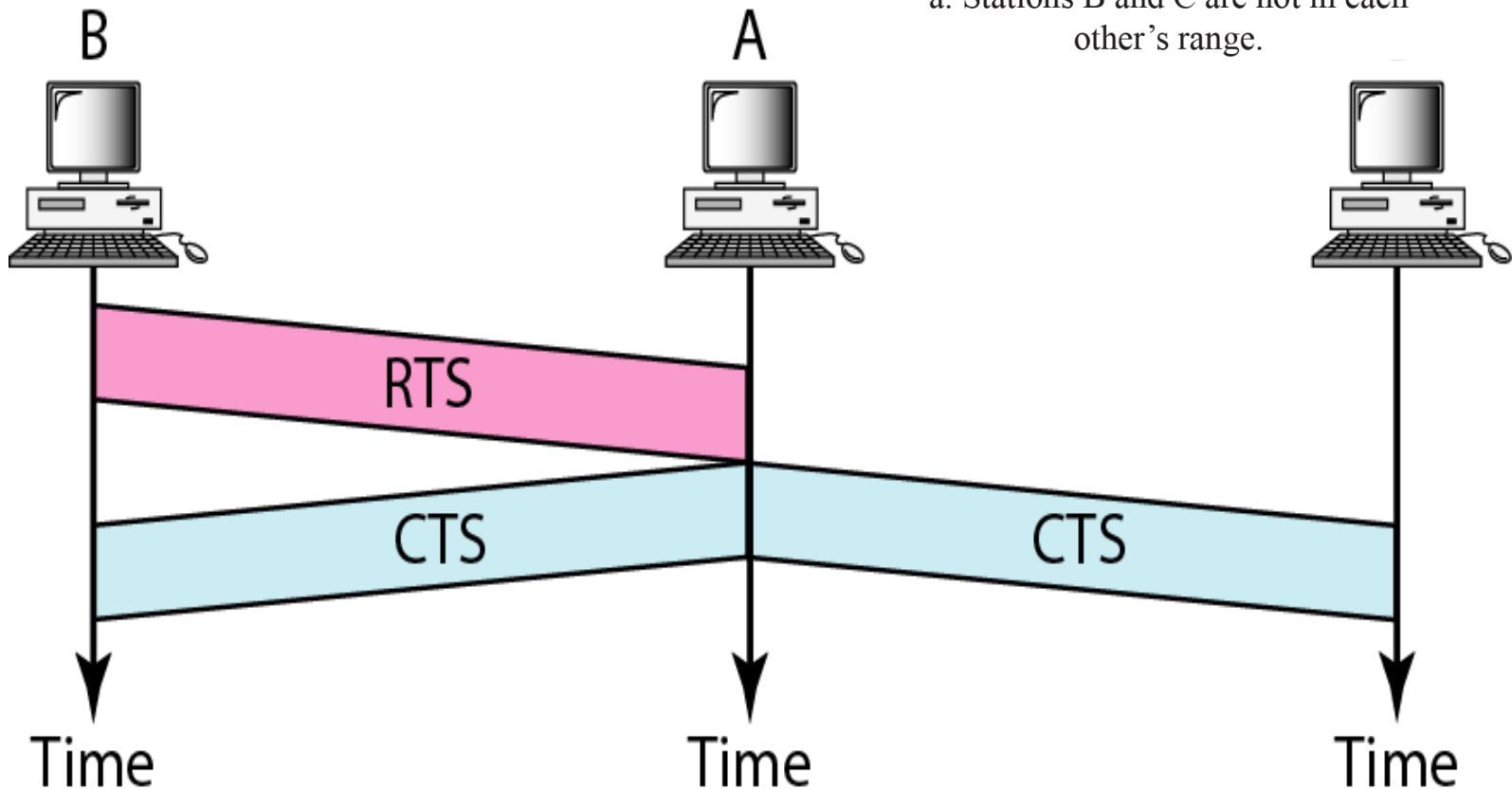
Reservation scheme (RTS/CTS) to solve “*Hidden Node problem*”



# Use of reservation scheme (CTS) prevents hidden station problem



a. Stations B and C are not in each other's range.



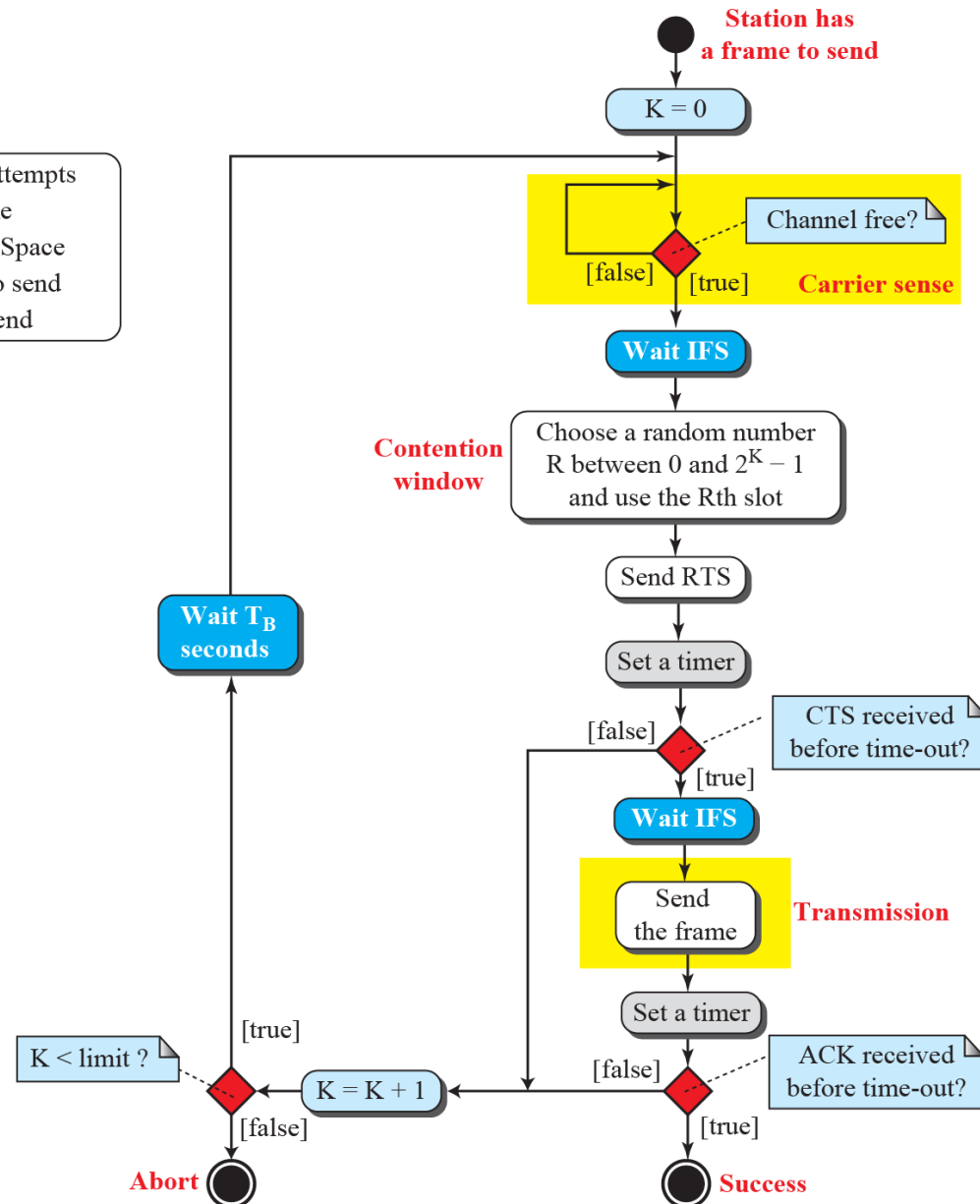
# IEEE 802.11 MAC Layer (CSMA/CA – RTS/CTS)

- Nifty (but optional) reservation scheme (RTS/CTS) to solve “Hidden Node problem”

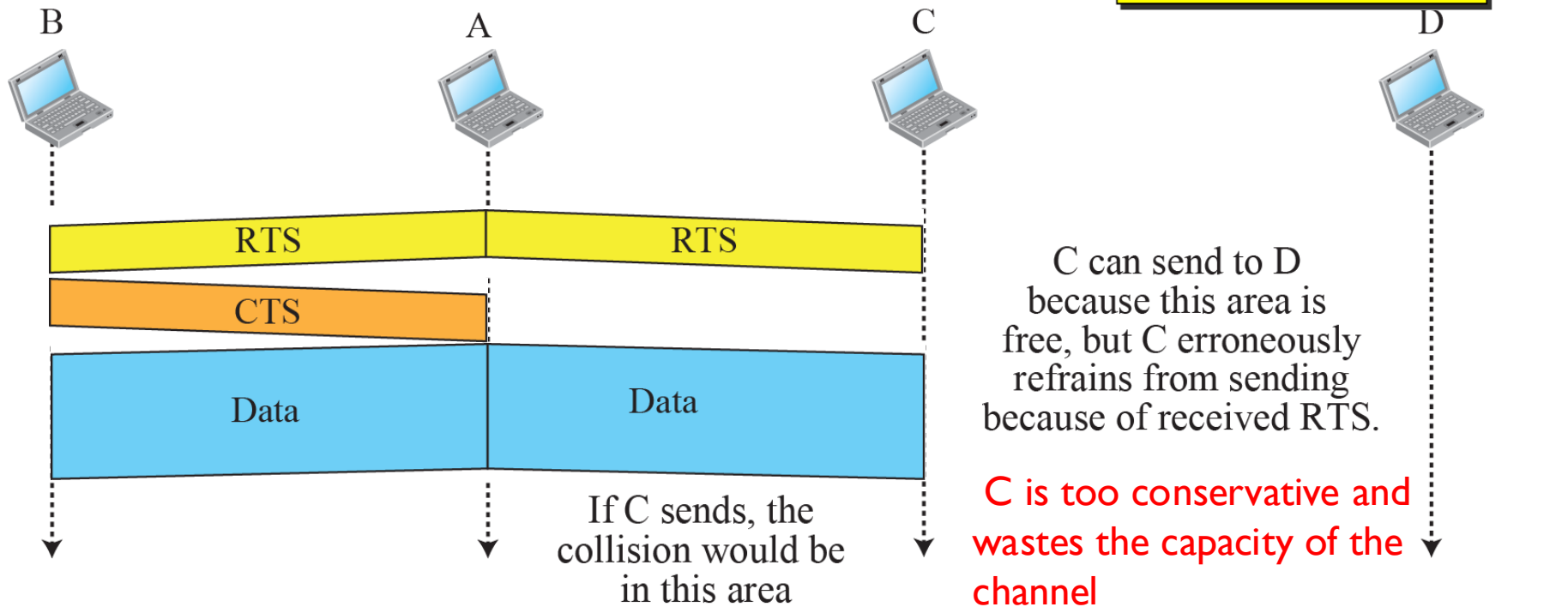
Updated Flowchart  
– For Your Reference

## Legend

K: Number of attempts  
 $T_B$ : Backoff time  
IFS: Interframe Space  
RTS: Request to send  
CTS: Clear to send



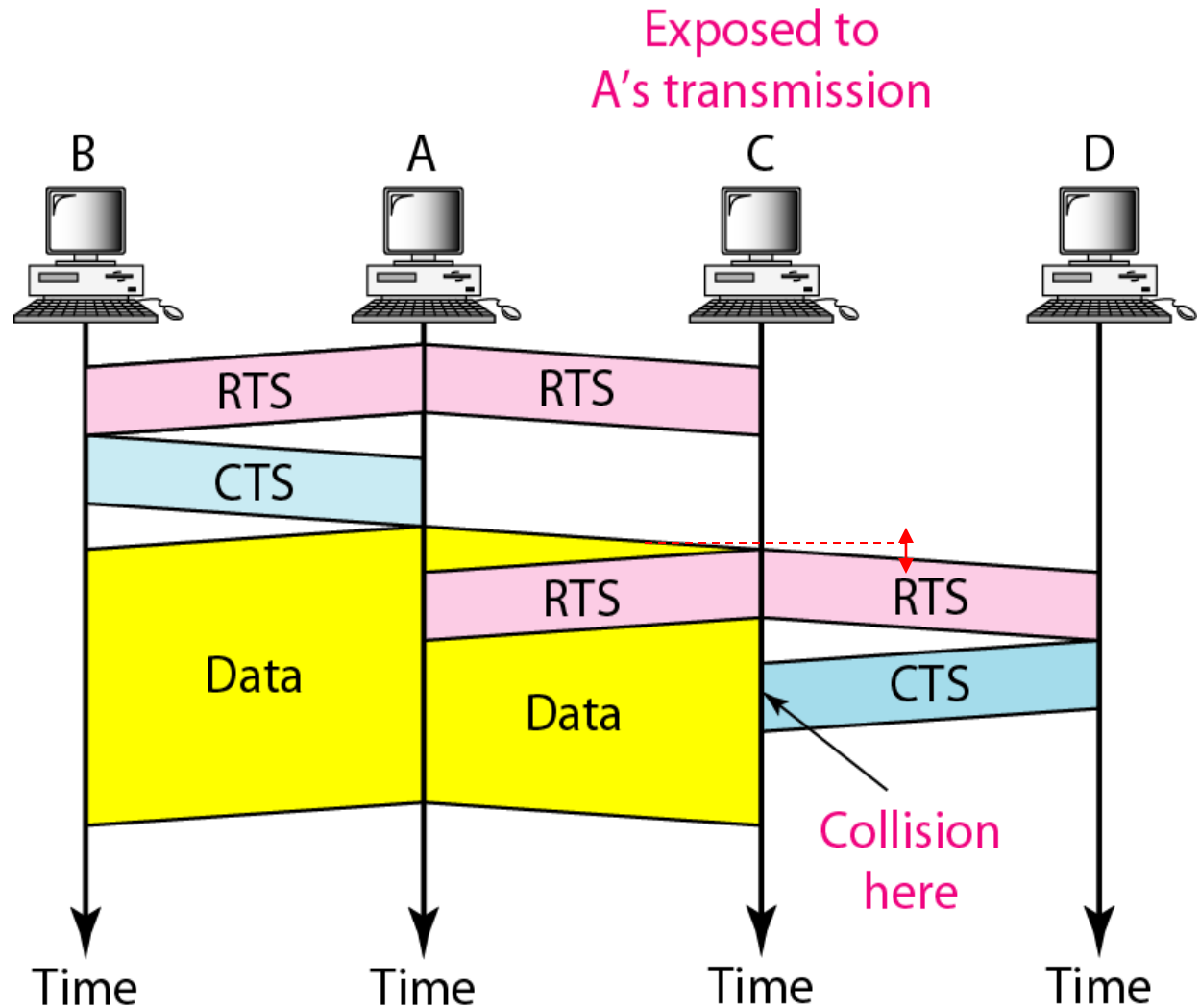
# CSMA/CA Suffers from - Exposed node Problem



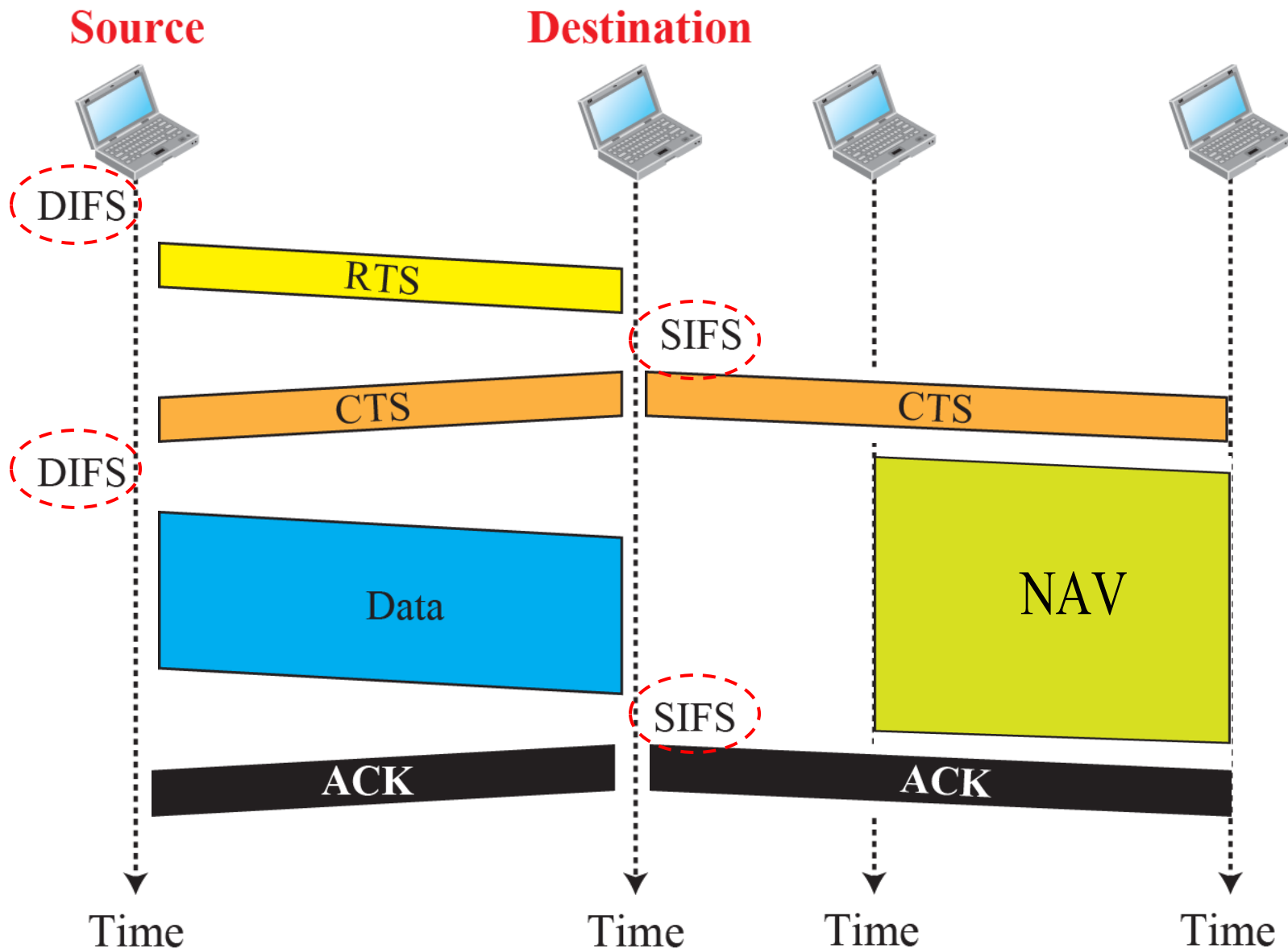
**Q:** What if C sending an RTS immediately after Timeout for CTS from B and No Data in Channel?

# RTS/CTS do not solve Exposed node Problem

- ▶ C hears RTS from A but not CTS from B.
- ▶ After a timeout period, it sends RTS to D
- ▶ A is in sending state and not receiving
- ▶ D responds with CTS
- ▶ Now C cannot hear D's CTS because of collision.
- ▶ C has to wait until A completes transmission



# InterframeSpace (IFS) Types



# InterframeSpace (IFS) Values

---

- ▶ **Distributed coordination function IFS (DIFS)**
  - ▶ **Longest IFS**
  - ▶ Used as minimum delay of asynchronous frames contending for access
- ▶ **Short IFS (SIFS)**
  - ▶ **Shortest IFS**
  - ▶ Used for immediate response actions. (priority is given for response messages over another new message from other stations)
- ▶ **Point coordination function IFS (PIFS) --- Discussed Next....**
  - ▶ **Mid-length IFS**
  - ▶ Used by centralized controller in PCF scheme when using polls

# IFS Usage

---

## ▶ DIFS

- ▶ Used for all ordinary asynchronous traffic

## ▶ SIFS

- ▶ Clear to send (CTS)
- ▶ Acknowledgment (ACK)
- ▶ Poll response

## ▶ PIFS --- *Discussed Next....*

- ▶ Used by centralized controller in issuing polls
- ▶ **Takes precedence** over normal contention traffic



# Wireless LANs

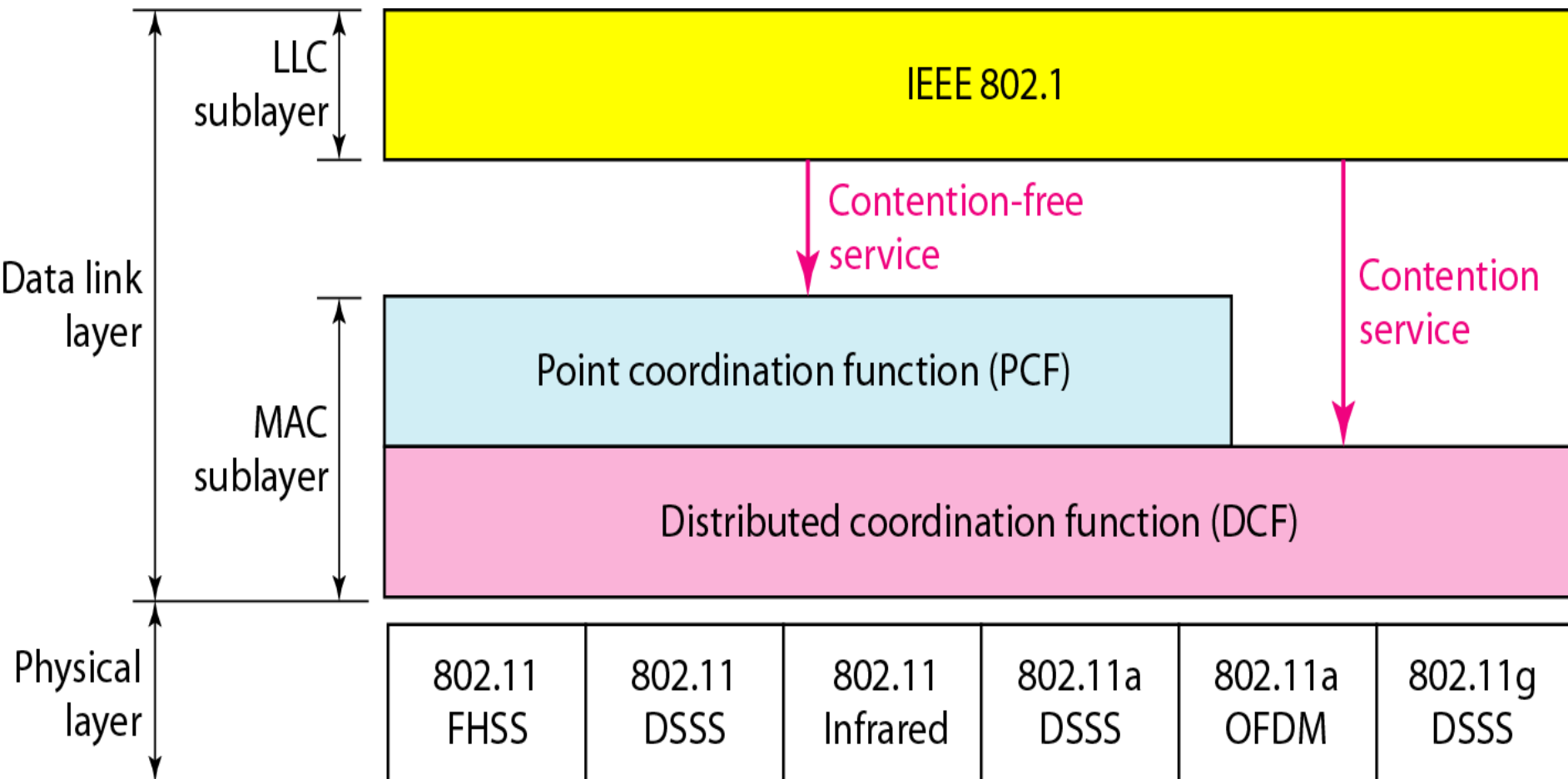
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# IEEE 802.11 MAC Sublayer - Modes

- ▶ Two modes of MAC layer protocols are defined (DCF & PCF)
- ▶ **Distributed Coordination Function (DCF)**  
Contention service - (what we have discussed so far)
- ▶ **Point Coordination Function (PCF) Polling Service.**
  - ▶ **Optional** access method for infrastructure network.
  - ▶ Used for time sensitive transmissions.

# MAC layers in IEEE 802.11 standard

- ▶ PCF is Implemented on **top of DCF**.



# PCF mode

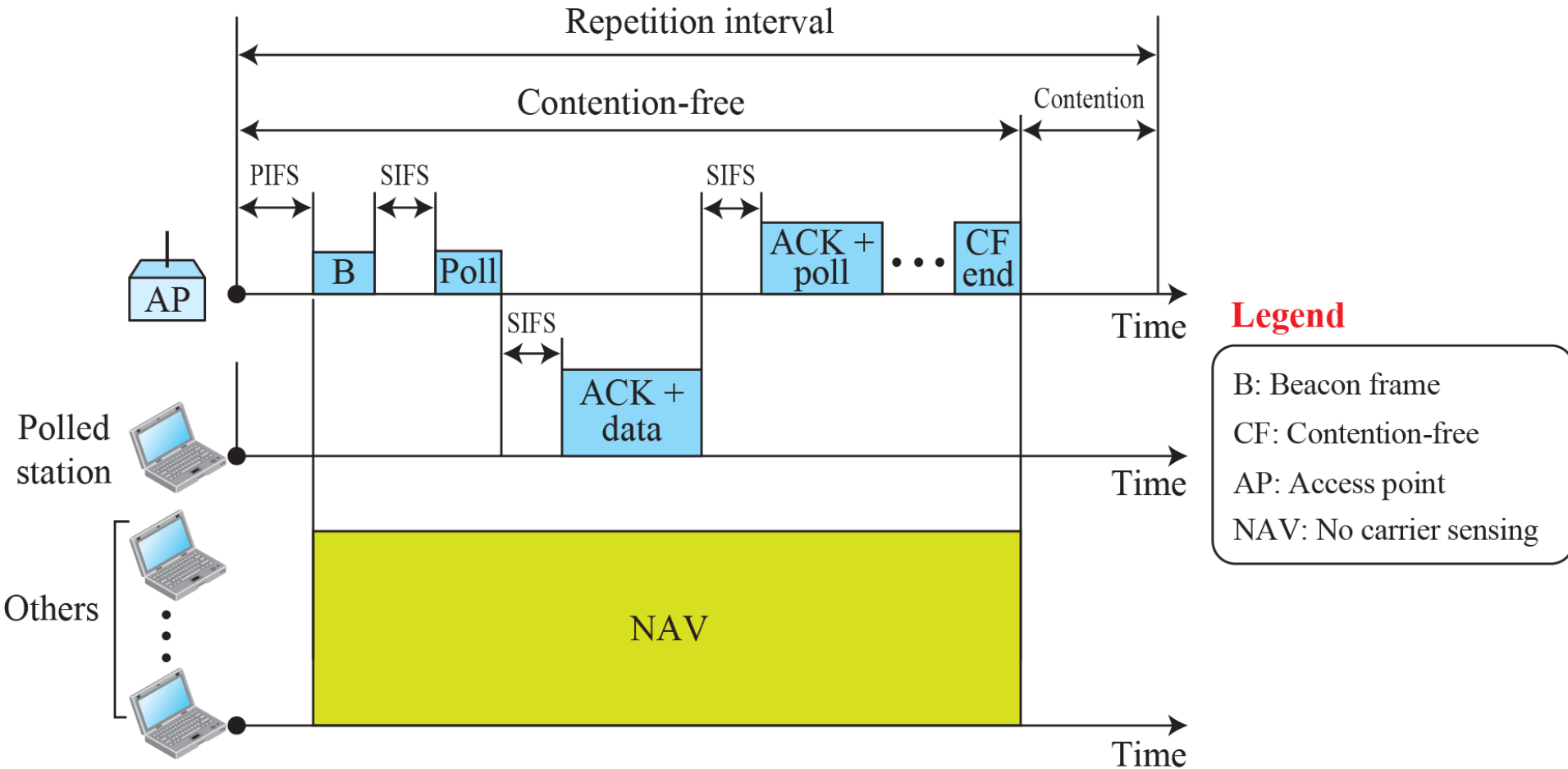
- ▶ PCF provides a **centralized, contention free polling access** method. **Point Coordinator (PC)** module at AP performs polling.
  - ▶ Stations request that AP **register** them on polling list
  - ▶ AP regularly **polls stations** on polling list and **delivers traffic**
- ▶ But, How does AP gets access to media?
  - ▶ Eg. 10 nodes are registered for Polling and refrain from contention, and
  - ▶ 4 nodes are not registered and operate in DCF mode. Hence, AP will be contenting with these 4 nodes.
  - ▶ To start PCF mode, the AP should first get control over the channel

# PCF mode

---

- ▶ **Simple Idea:** Another IFS value is introduced PIFS. PIFS is shorter than DIFS. AP uses PIFS to gain access to media.
  - ▶ So, How PIFS helps AP to get access to media?
- ▶ What will happen if AP always uses PIFS?

# Solution: AP uses repetition interval



# Research and Debate <Active Learning>

- ▶ Q: CSMA/CD is not necessary with modern switches which support full duplex dedicated connections. Nodes can transmit anytime as the Carrier is dedicated. Similarly, the changes/improvements in wireless LAN such as, multiple antenna mobile WiFi devices, will eliminate the need for CSMA and/or CA in future. Do you agree? Why?

Why is it important ?

This will lead to multiple good PhD topics &  
Business opportunities!

So, Participate & Learn!



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**802.11 in Practice:**

LAB:- Building IEEE 802.11 Networks (BSS, ESS)

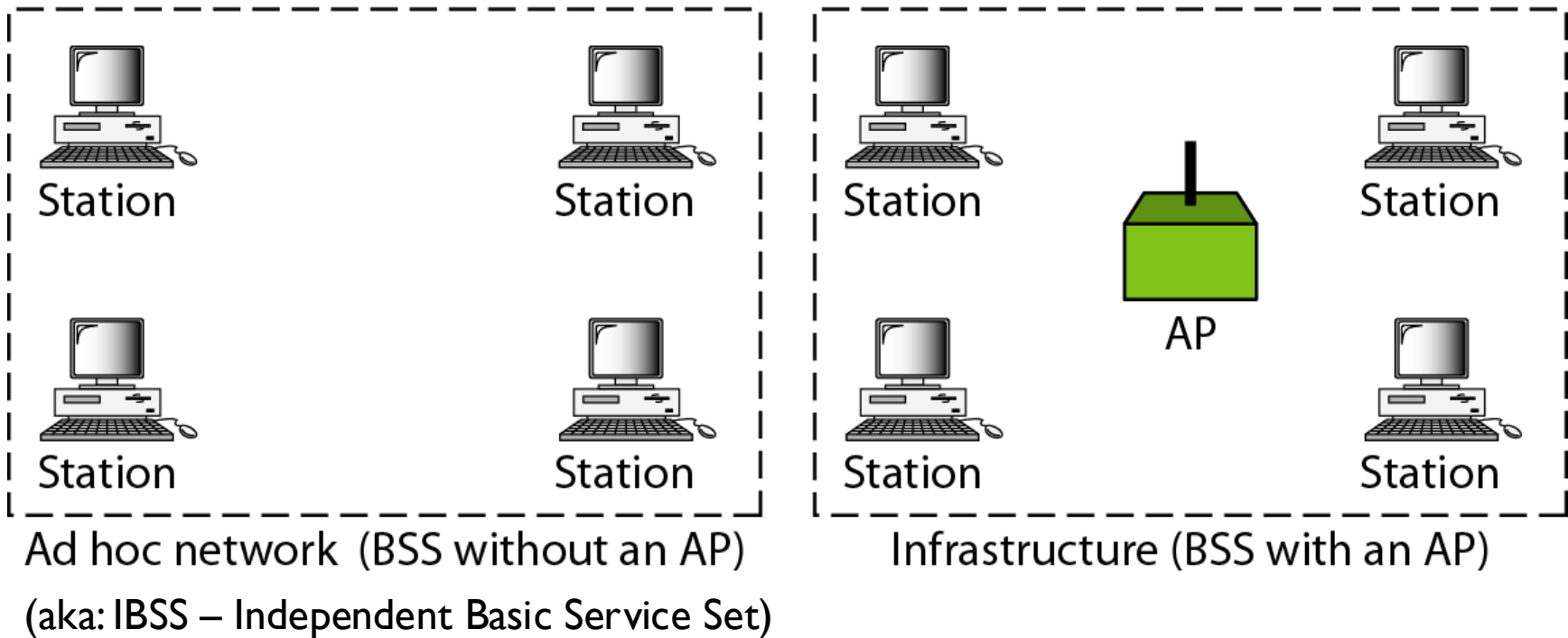
LAB:- Inspect IEEE 802.11 Frame Format

# IEEE 802.11- Basic Service Set (BSS) or Cell

**BSS:** A set of stations controlled by a single “Coordination Function” (=the logical function that determines when a station can transmit or receive)

**BSS:** Basic service set <or> **Cell** – Building Block of WLAN

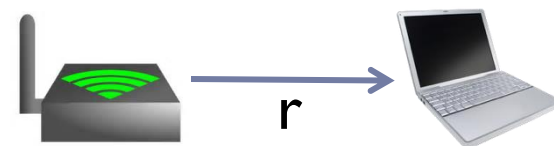
**AP:** Access point



# IEEE 802.11 - Extended Service Set (ESS)

## Extended Service Set (ESS):

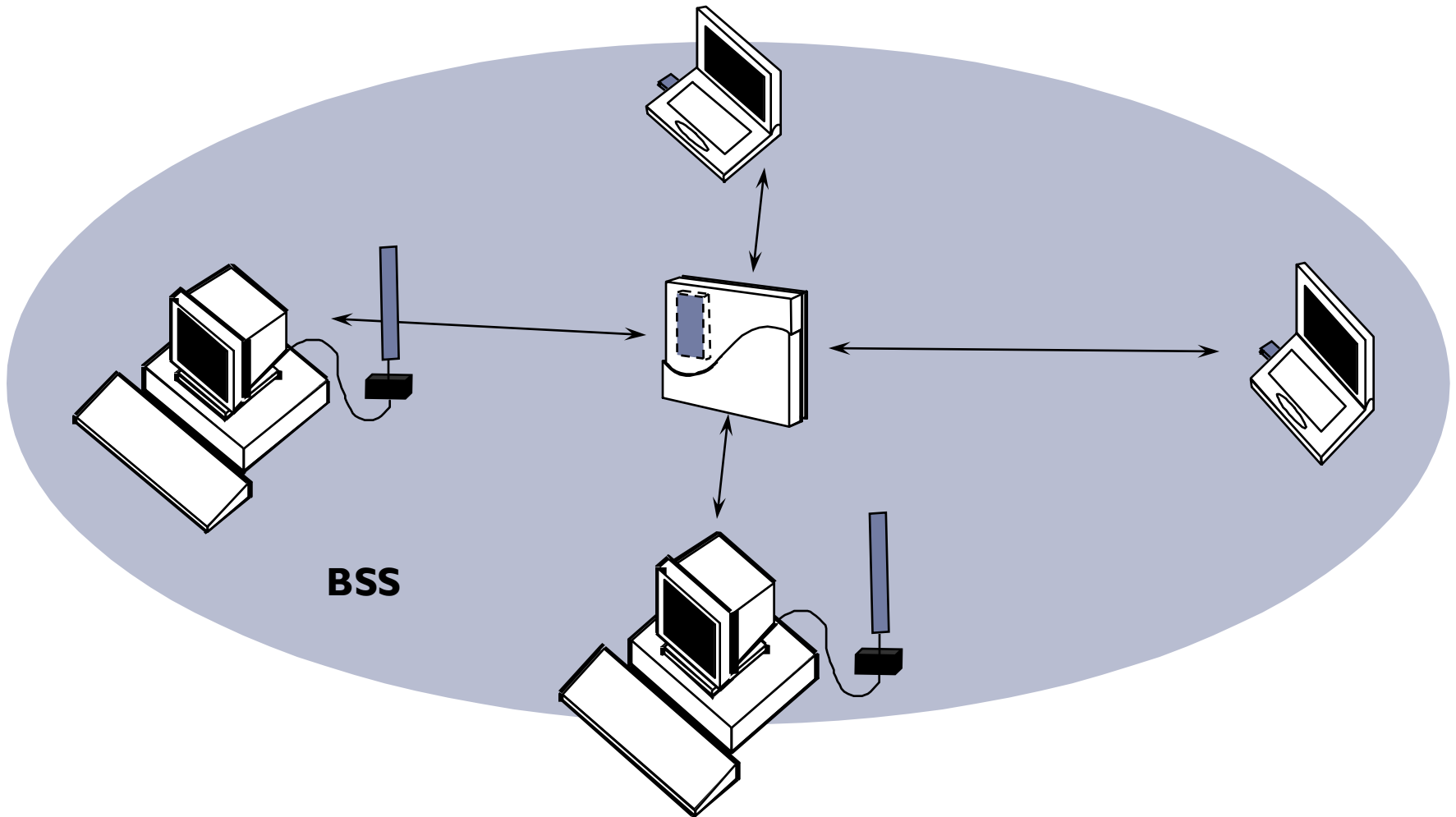
- ▶ A set of **one or more Basic Service Sets interconnected by a Distribution System (DS)**
  - ▶ But, why not a single big BSS?
- ▶ Traffic always flows via Access-Point
- ▶ Diameter of the cell is double the coverage distance between two wireless stations



## Distribution System (DS):

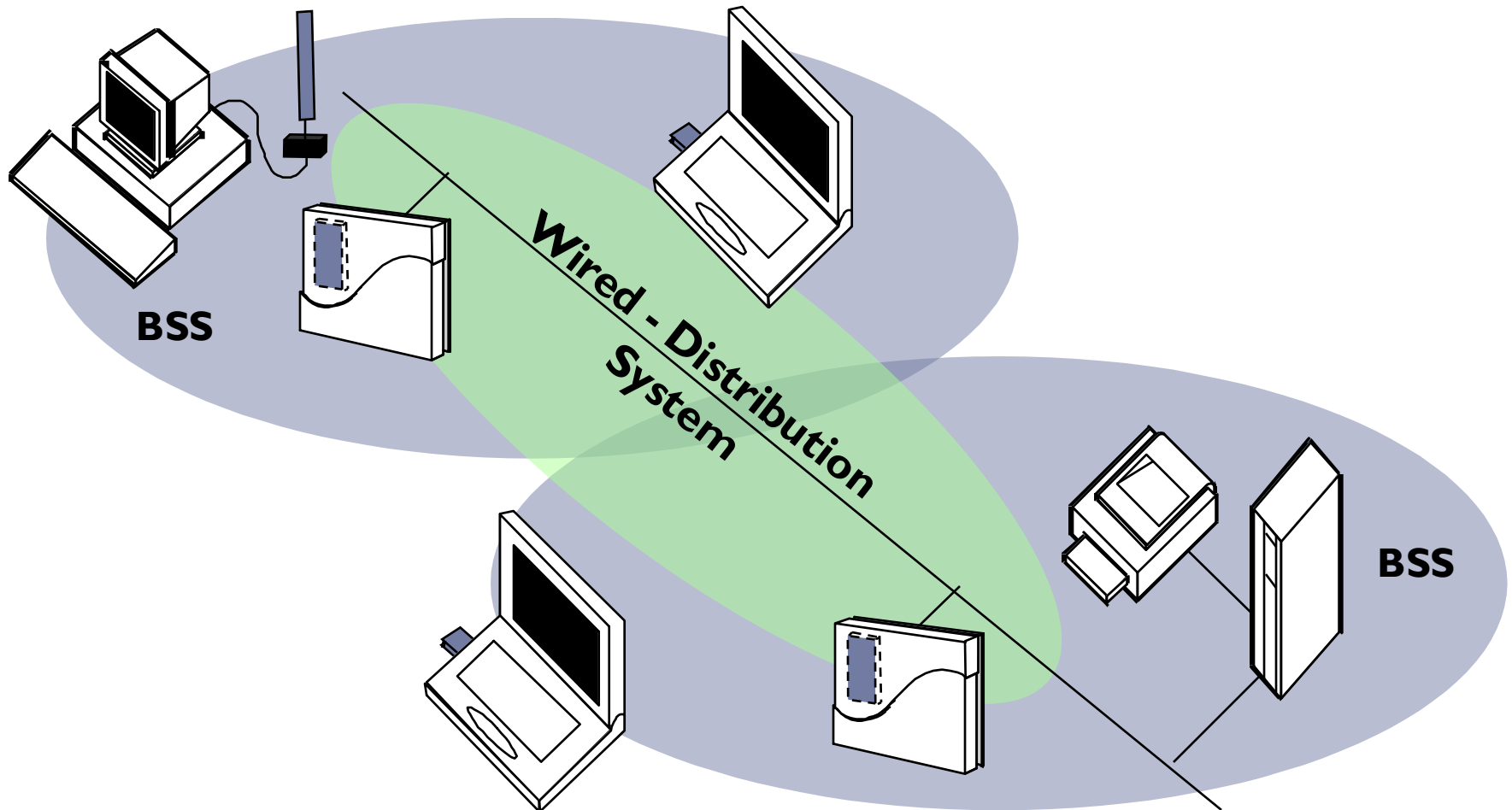
- ▶ A system to interconnect a set of Basic Service Sets
  - ▶ Integrated (Single AP),    Wired,    Wireless

Extended Service Set (ESS) can be a single BSS (with **integrated DS**)



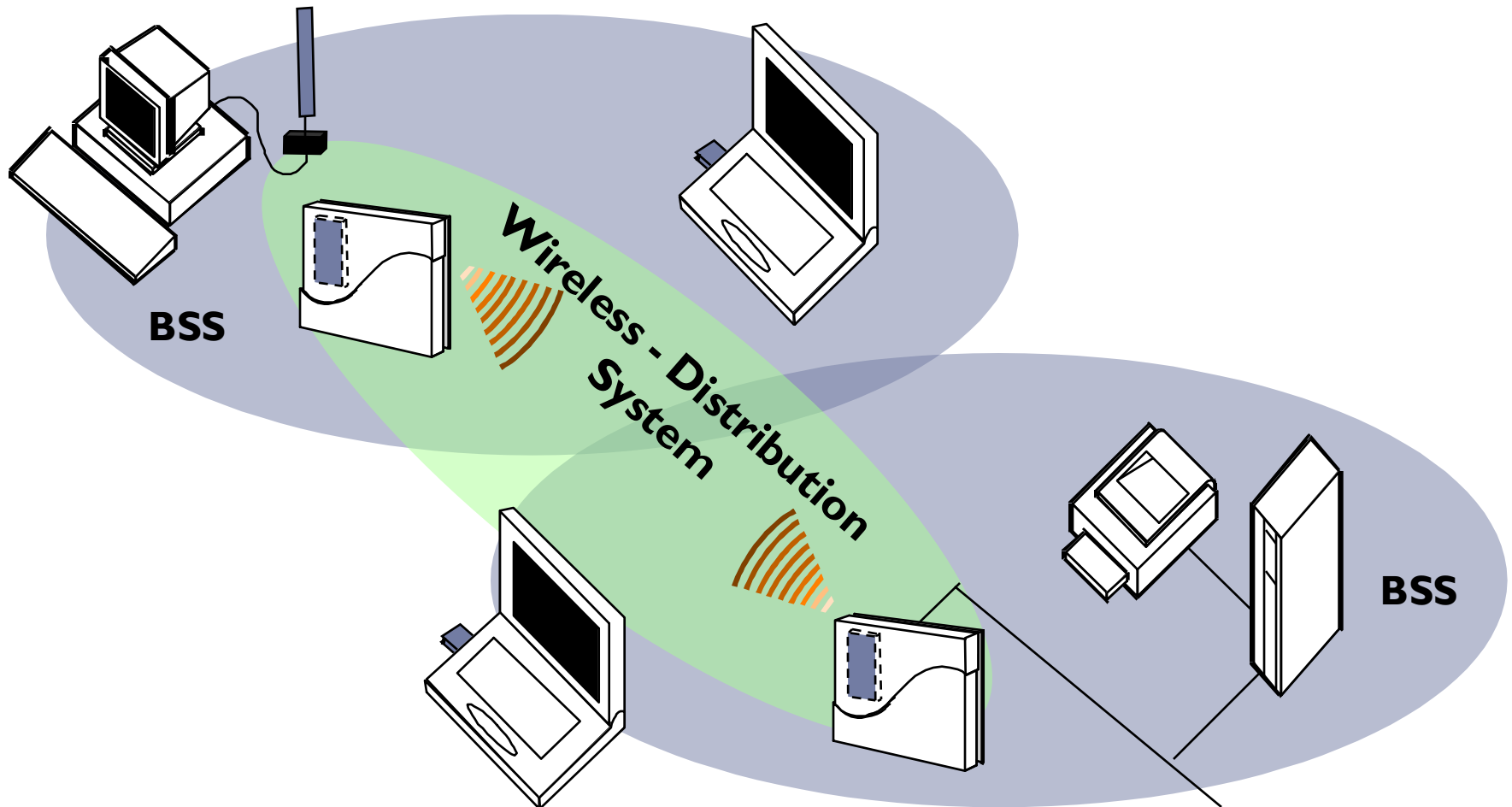
# Extended Service Set (ESS)

BSS's with **wired** Distribution System (DS)



# Extended Service Set (ESS)

## BSS's and **wireless** Distribution System (DS)



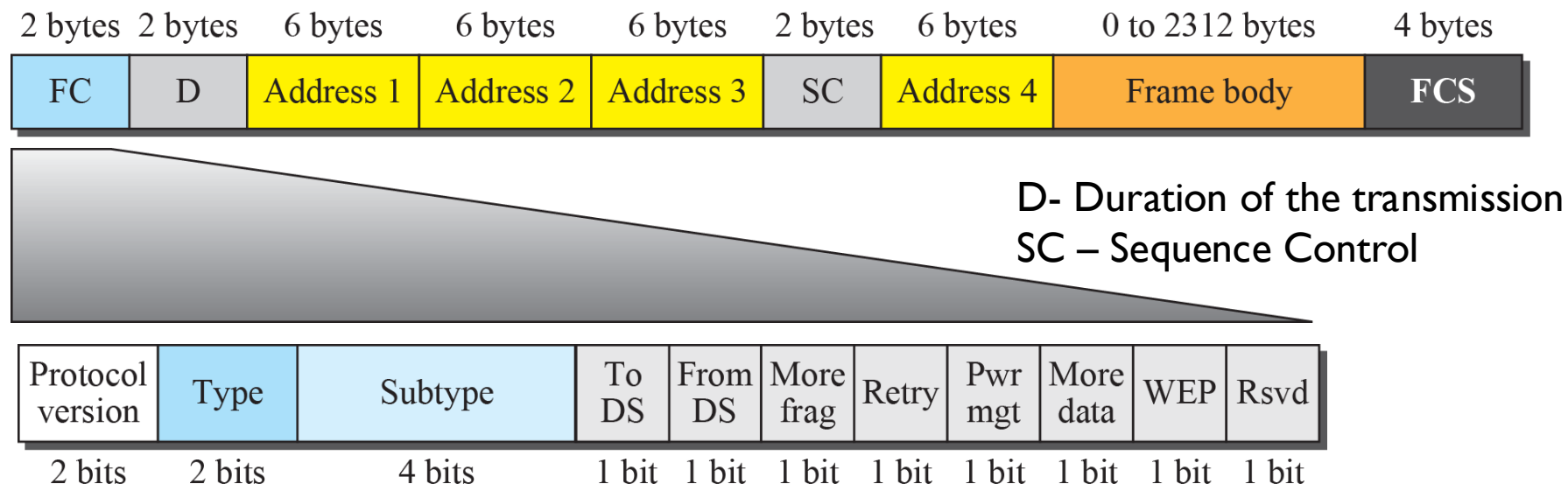
## Service Set Identifier (SSID) or Extended SSID (ESSID):

- ▶ “Network name”
- ▶ 32 octets long
- ▶ One network (ESS or IBSS) has one SSID

## Basic Service Set Identifier (BSSID)

- ▶ “cell identifier” [BSS identifier]
- ▶ 6 octets long (MAC address format)
- ▶ One BSS has one BSSID
- ▶ Value of **BSSID** is the same as the **MAC** address of the radio in the **Access-Point**
- ▶ **In an IBSS**, the BSSID is a locally administered MAC address generated from a **48-bit random number**.

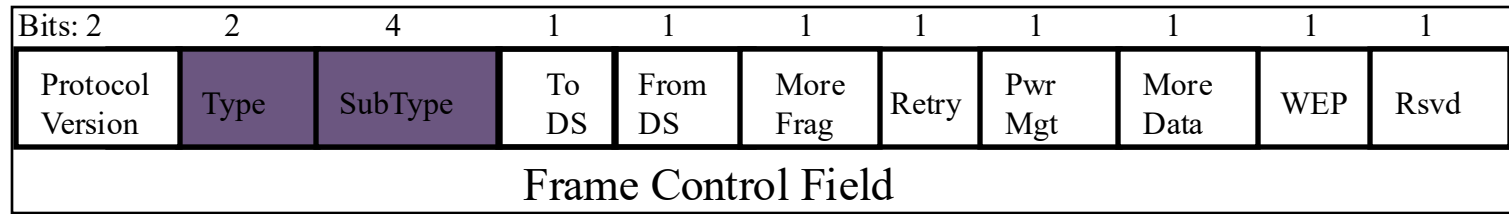
# IEEE 802.11 - Frame Formats



MAC Header format differs according to Type:

- ▶ Control Frames (several fields are omitted)
- ▶ Management Frames
- ▶ Data Frames

# Type field descriptions



Type and subtype identify the function of the frame:

► Type=00      Management Frame

Beacon

(Re)Association

Probe

(De)Authentication

Power Management

► Type=01      Control Frame

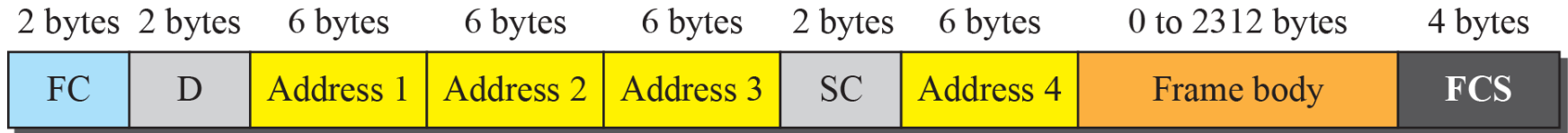
RTS/CTS & ACK

► Type=10      Data Frame

Q: Purpose of beacons?

Q: When Re-Association is done and how?

# Why four addresses?

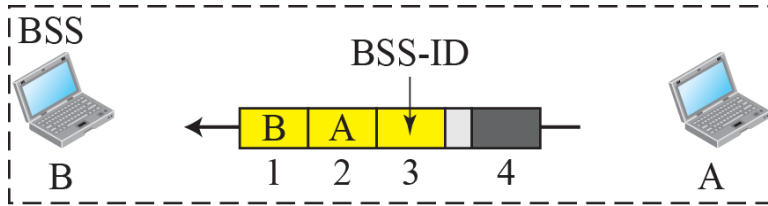


D- Duration of the transmission  
SC – Sequence Control

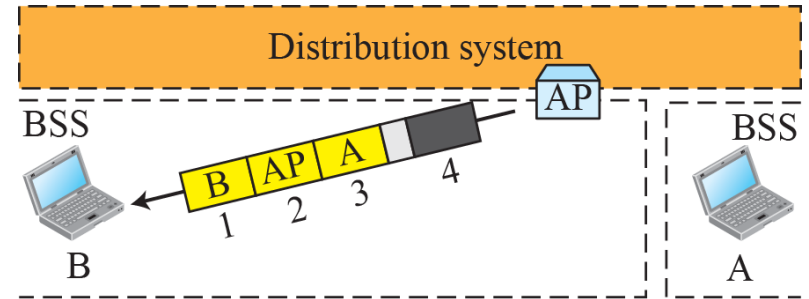
Protocol version	Type	Subtype	To DS	From DS	More frag	Retry	Pwr mgt	More data	WEP	Rsvd
2 bits	2 bits	4 bits	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit

<i>To DS</i>	<i>From DS</i>	<i>Address 1</i>	<i>Address 2</i>	<i>Address 3</i>	<i>Address 4</i>
0	0	Destination	Source	BSS ID	N/A
0	1	Destination	Sending AP	Source	N/A
1	0	Receiving AP	Source	Destination	N/A
1	1	Receiving AP	Sending AP	Destination	Source

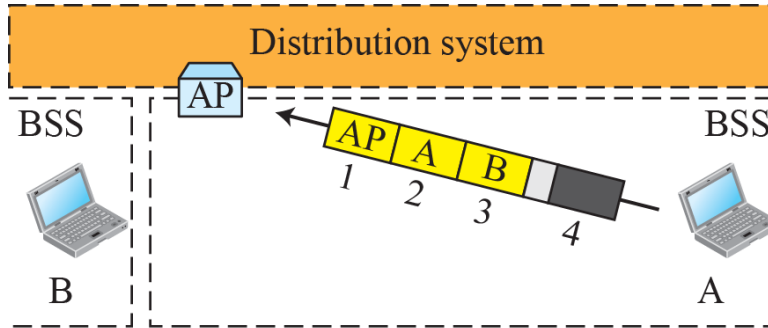
# Address Usage: Examples



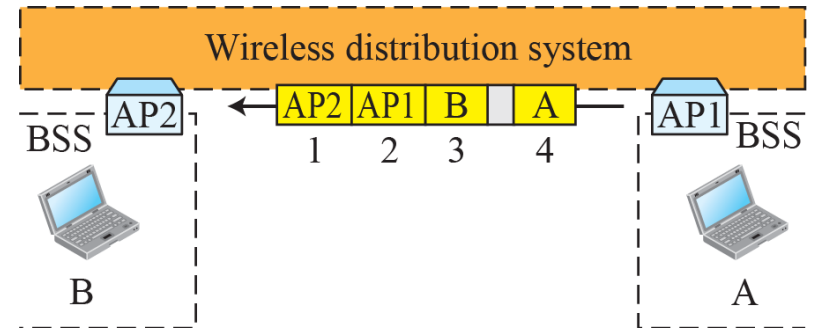
a. Case 1



b. Case 2

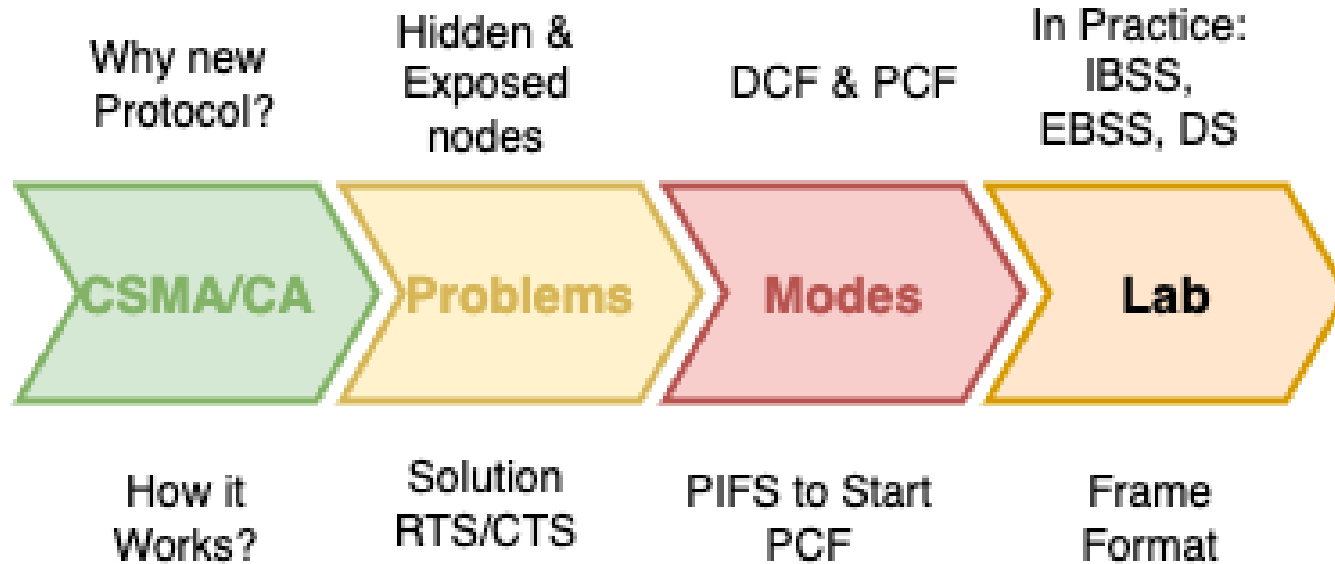


c. Case 3



d. Case 4

# Summary – Key Takeaways



## Questions to Ponder:

1. How a node associates with a AP?
2. How to handle mobility?
  - System must be able to switch between cells “on fly” – handover or handoff
3. What are WEP, WPA2 and WPA3?

# Key Challenges – for the pleasure of research and active learning

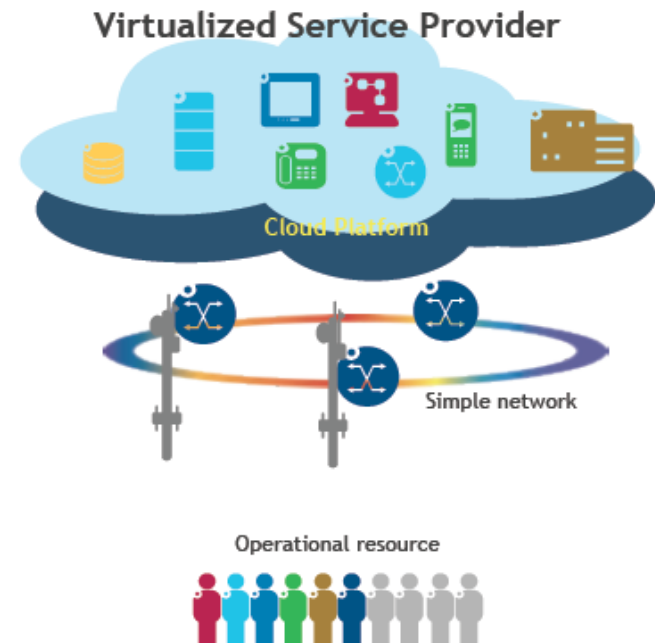
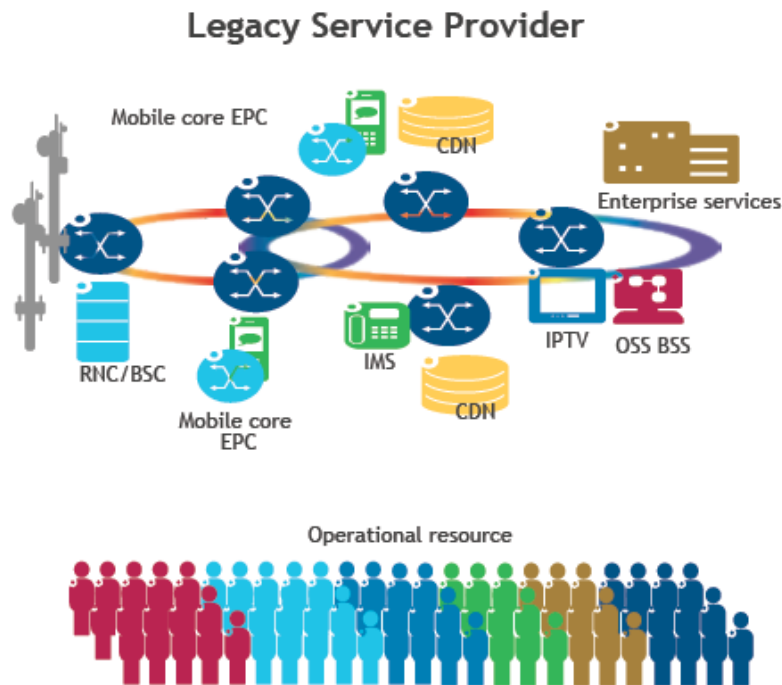
**For Your Reference**

- ▶ **Most common and still more works are required ...**
  - ▶ Efficient use of Wireless Channel Capacity and Fast Access
  - ▶ Mobility (Now users expect mobility among different access networks as they are surrounded by multiple wireless access networks to connect to Internet)
    - ▶ switch from one network to another (different authentication, addressing, customer's profile, routing, charging, ...)
  - ▶ Inability of cellular networks to deal with short bursts of data
    - ▶ Short bursts of data from web access, IoT, M2M devices
      - Check 5G Networks
  - ▶ High BW & Low Latency requirement of VR/AR.  
[60 GHz WiFi?]

# Key Challenges – pleasure of research...

## NETWORK FUNCTION VIRTUALIZATION MOVING NETWORK FUNCTIONALITY TO THE CLOUD

**For Your Reference**



I want a network which is elastic, that scales with my business, software definable and on-demand

- John Donovan – COO AT&T

# Reminders: Next Two Weeks

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- ▶ Tomorrow: DNS Lab
- ▶ Assignment 3 Due: A- End of this week and B- after term break
  - ▶ It looks simple, but challenging start early

**THANKS!**

# Attendance

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<https://inetapps.nus.edu.sg/ctr/>

