

# 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 2802.11 Frame Format

**Anand Bhojan**

COM3-02-49, School of Computing

[banand@comp.nus.edu.sg](mailto:banand@comp.nus.edu.sg) ph: 651-67351

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   
 2 

 **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.

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

**Lots of work by TAs in background**



# Wireless LANs

**Introduction to Wireless Networks and WLAN**

IEEE 802.11 MAC Sublayer - CSMA/CA

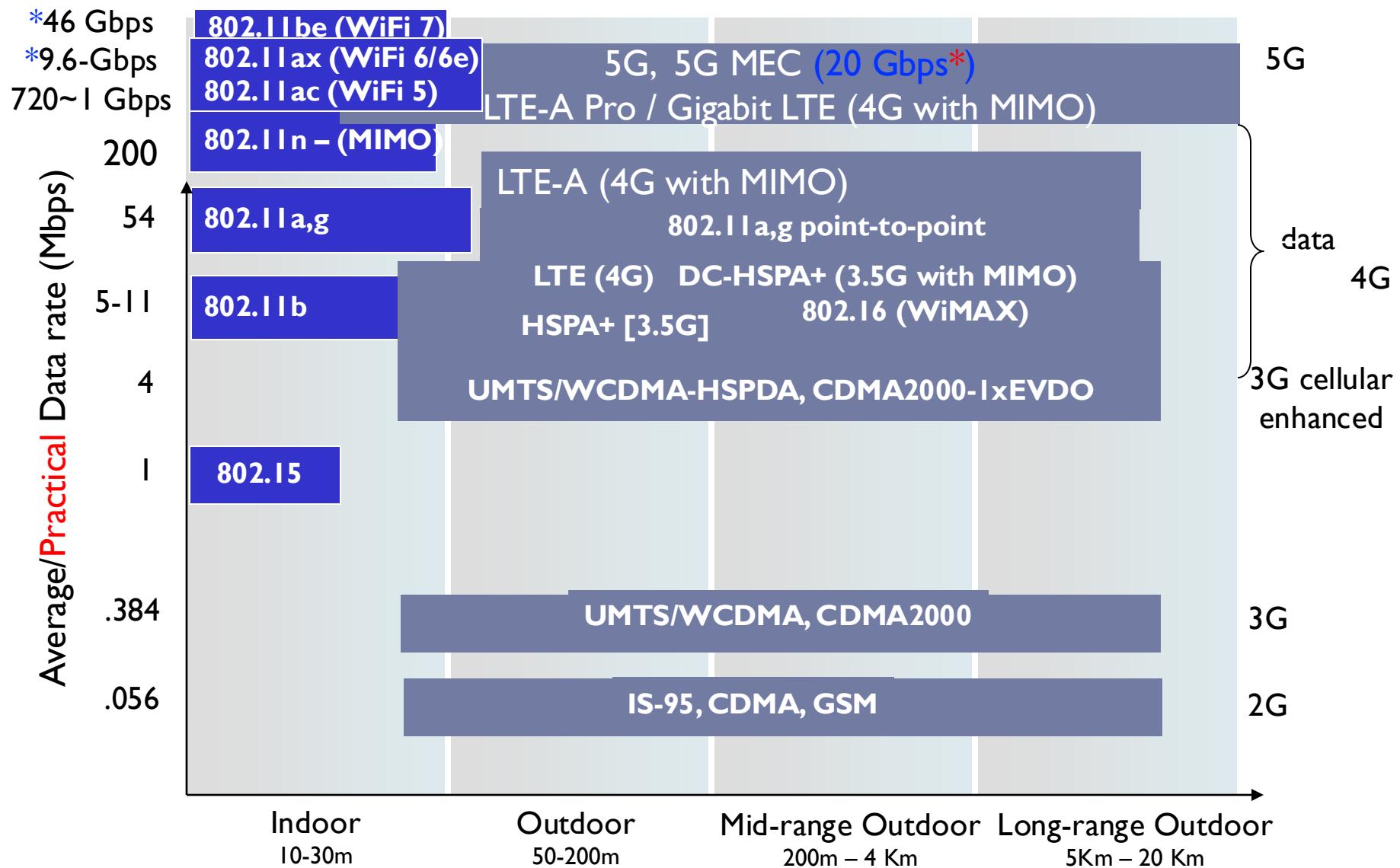
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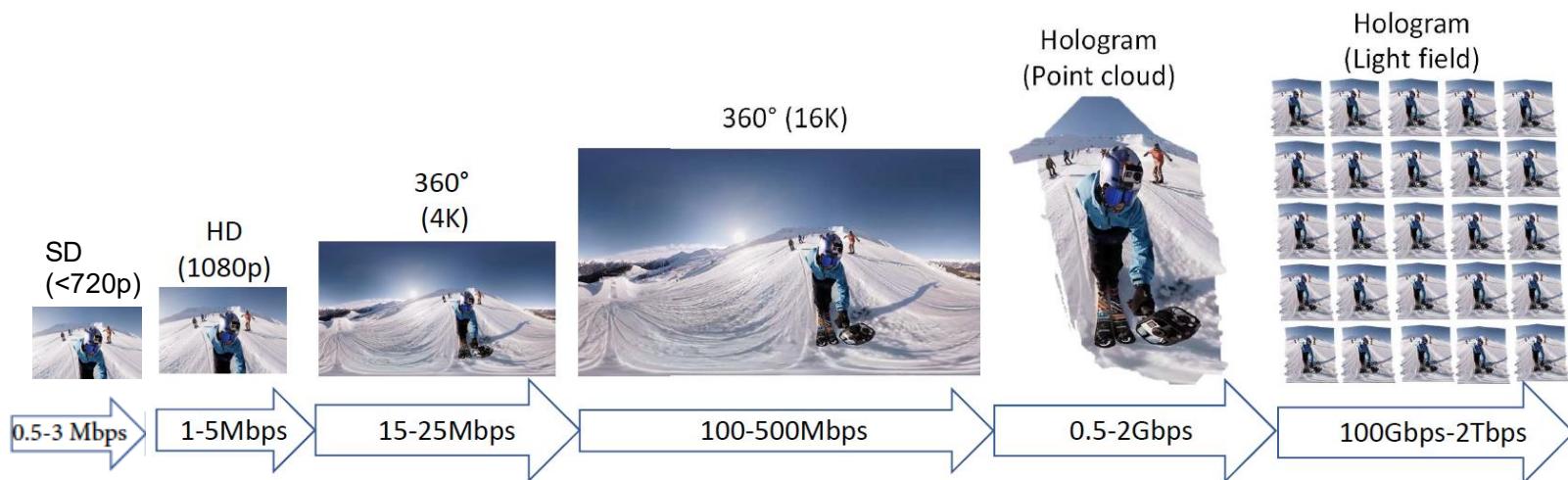
LAB:- Inspect IEEE 802.11 Frame Format

# 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



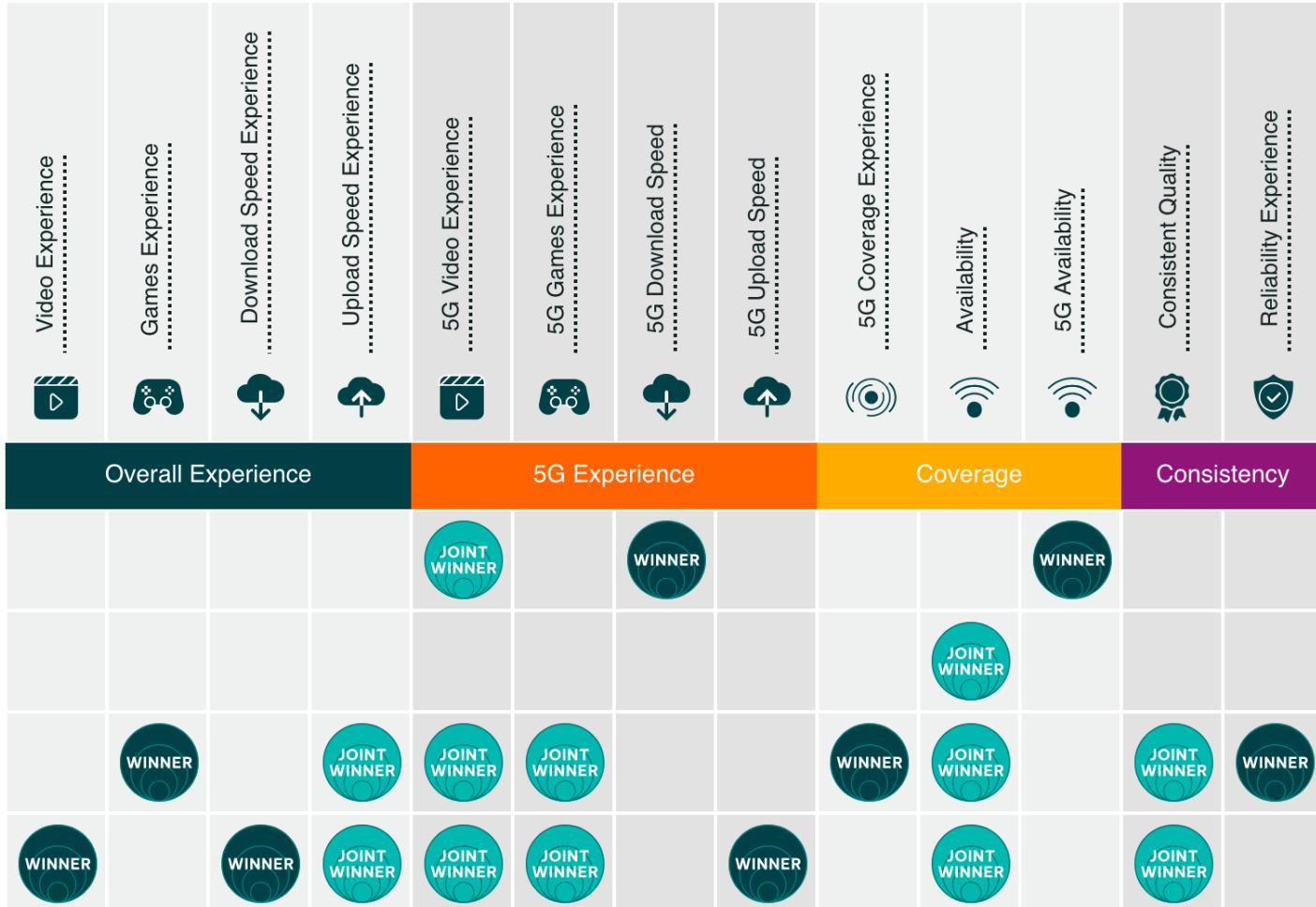
# Singapore 5G Mobile Network Scene – June 2025

## Mobile Experience Awards

JUNE 2025, SINGAPORE REPORT



OPEN SIGNAL

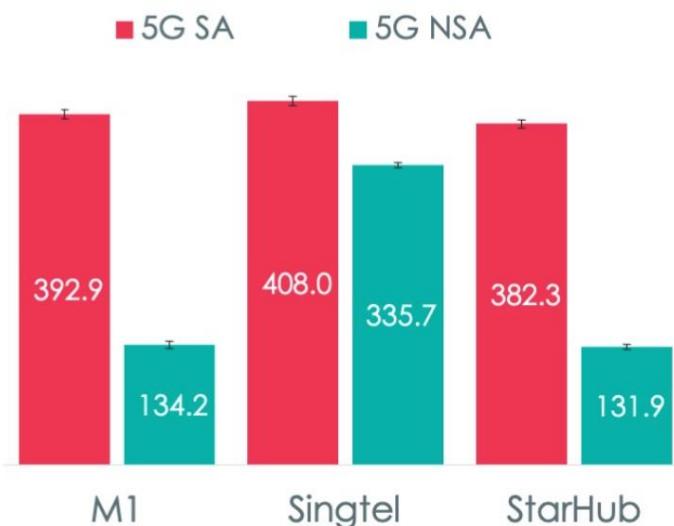


Mobile Network Experience Report | June 2025 | © Opensignal Limited

# 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 p s v aa ad ac ad af ah i? 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)

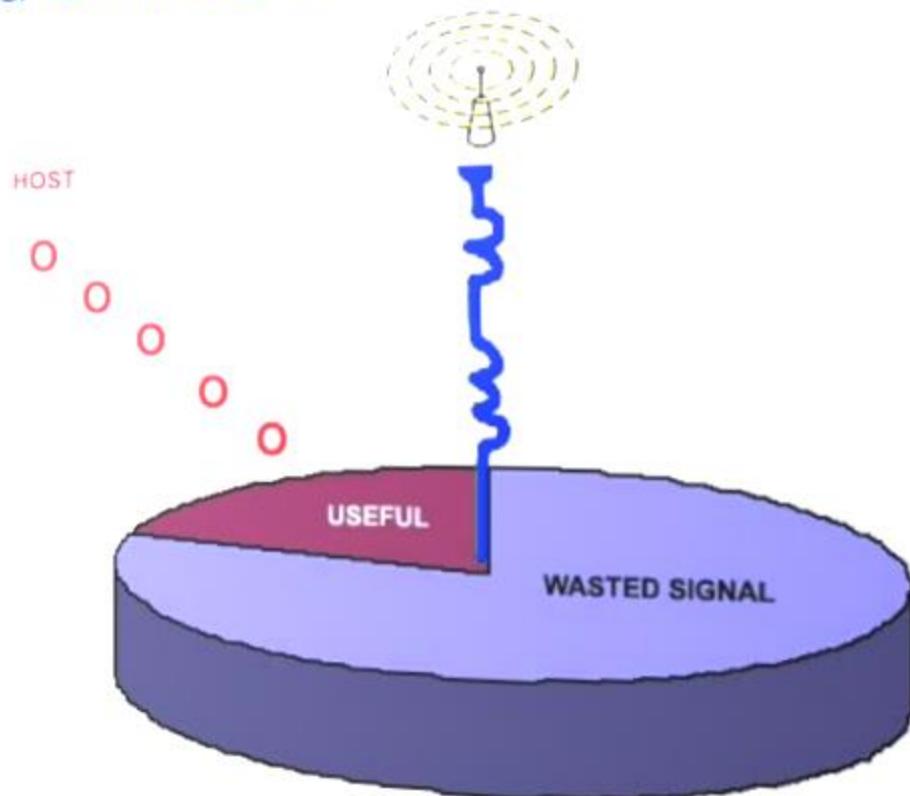


## 802.11ac (WiFi 5, 2014)

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



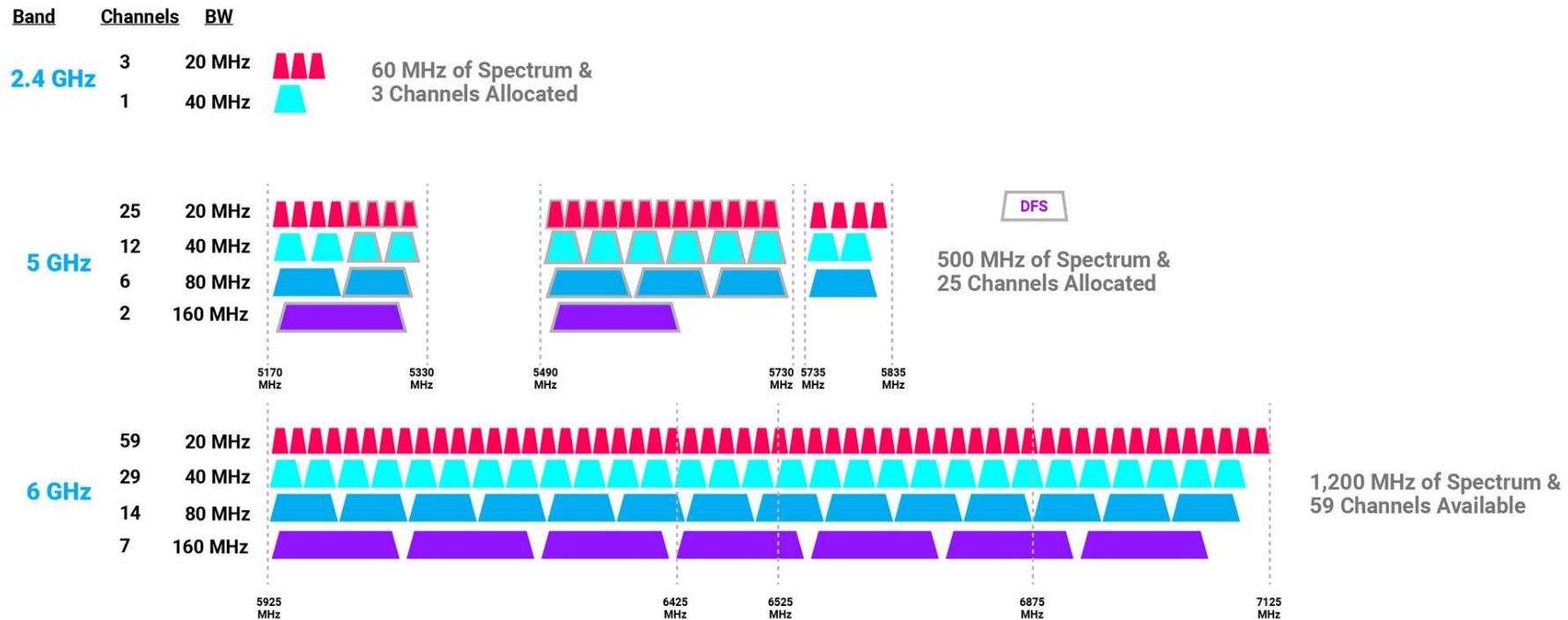
## Standard Omnidirectional Antenna



# 802.11 Standards – KEY TECHNOLOGIES

## (802.11ax-E) WiFi 6E

### Wi-Fi 6E



# 802.11 Standards – KEY TECHNOLOGIES

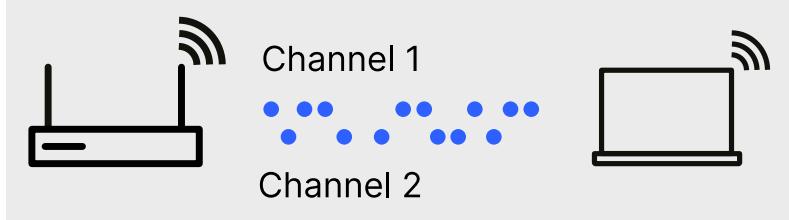
## (802.11be) WiFi 7 – MultiLink Operation (MLO)

### 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)

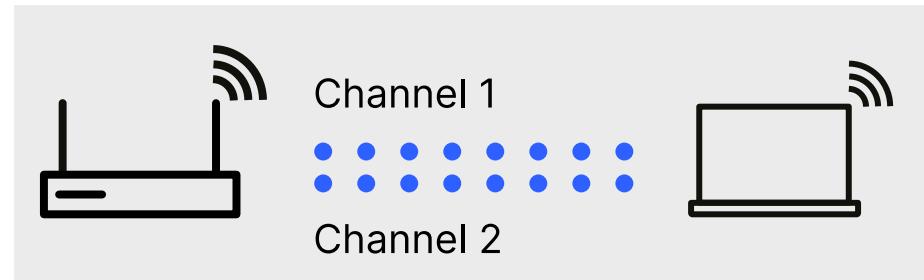


Client: Single Radio Module (with 2 fq bands. Eg. 2.4 GHz + 5 GHz, or 5 GHz + 6 GHz)

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

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

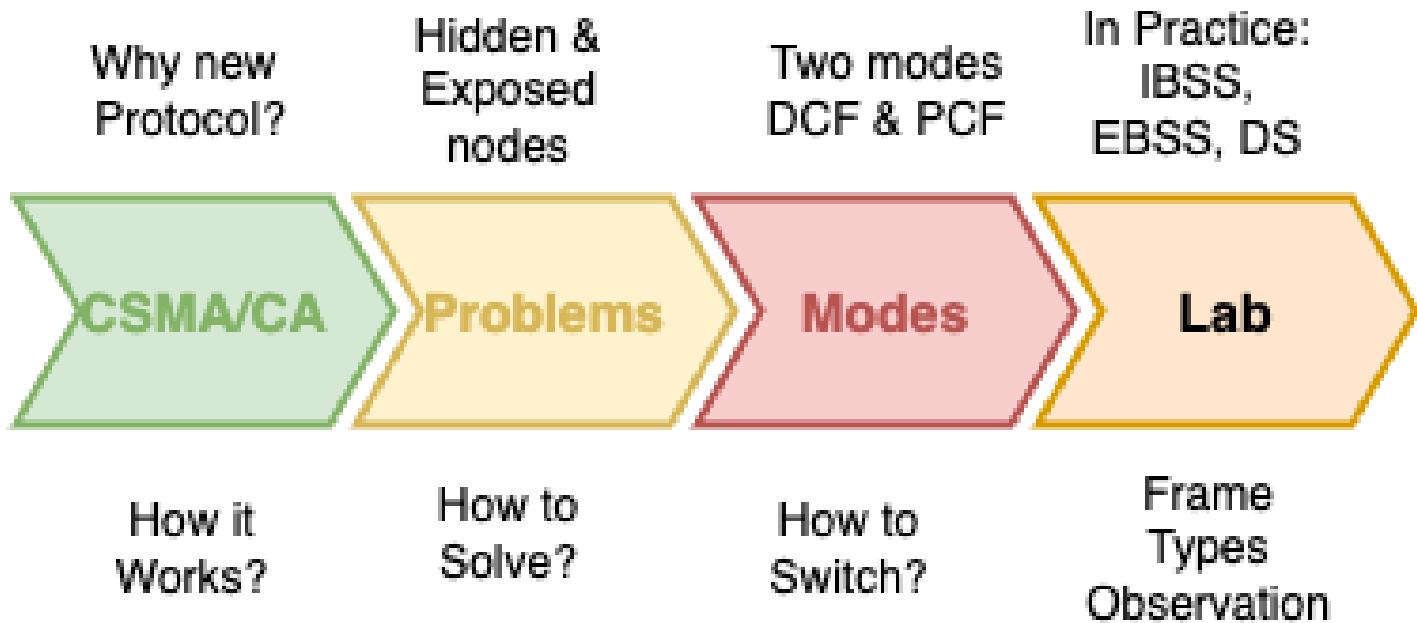
**Access point**  
(Concurrent dual radio)



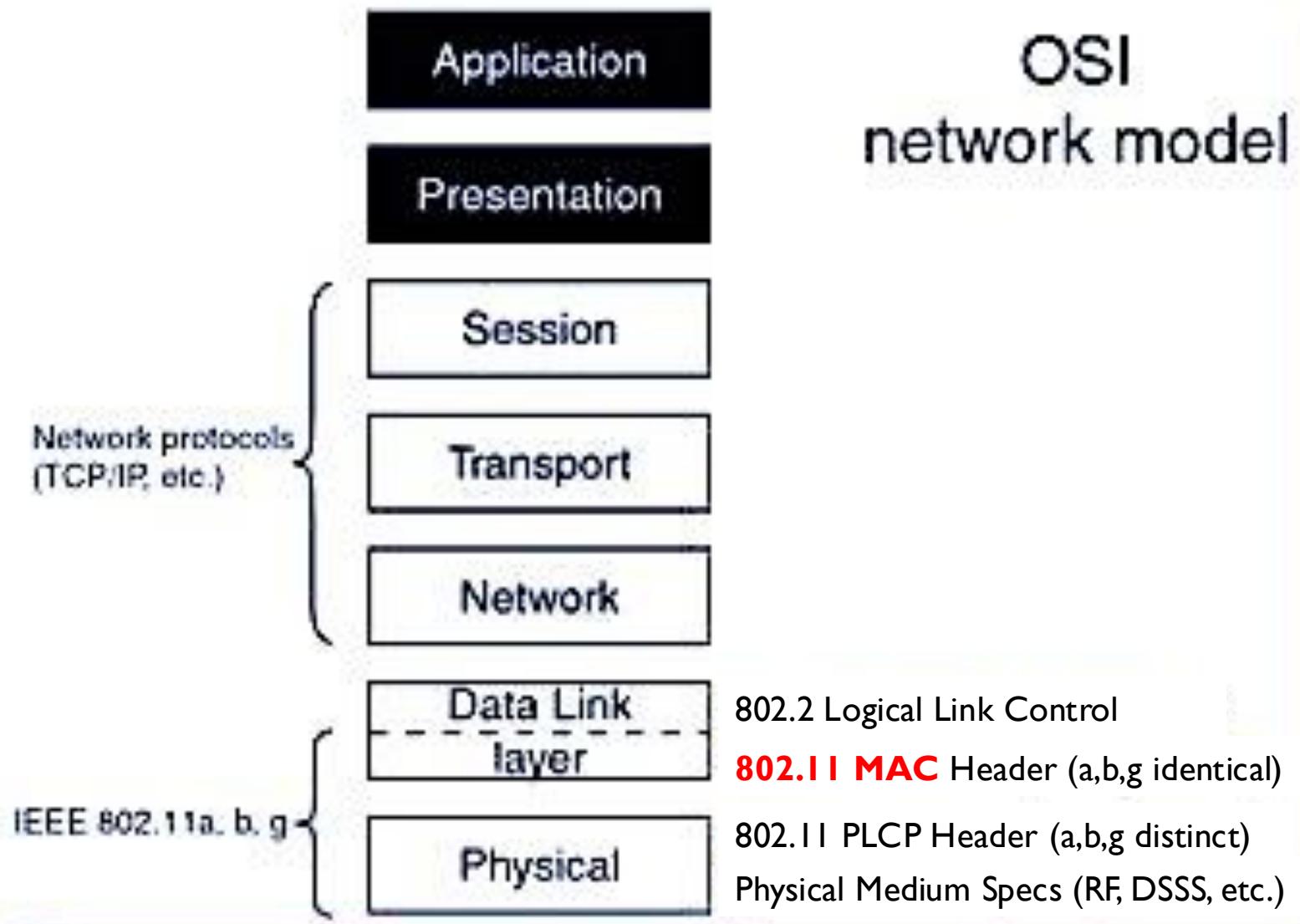
Client: Dual Radio Module (with 2 fq bands. Eg. 2.4 GHz + 5 GHz, or 5 GHz + 6 GHz)

Concurrent communication on two frequency bands.

# What we learn in this session...



# IEEE 802.11 Standards – For Your Reference





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<https://pollev.com/banand>

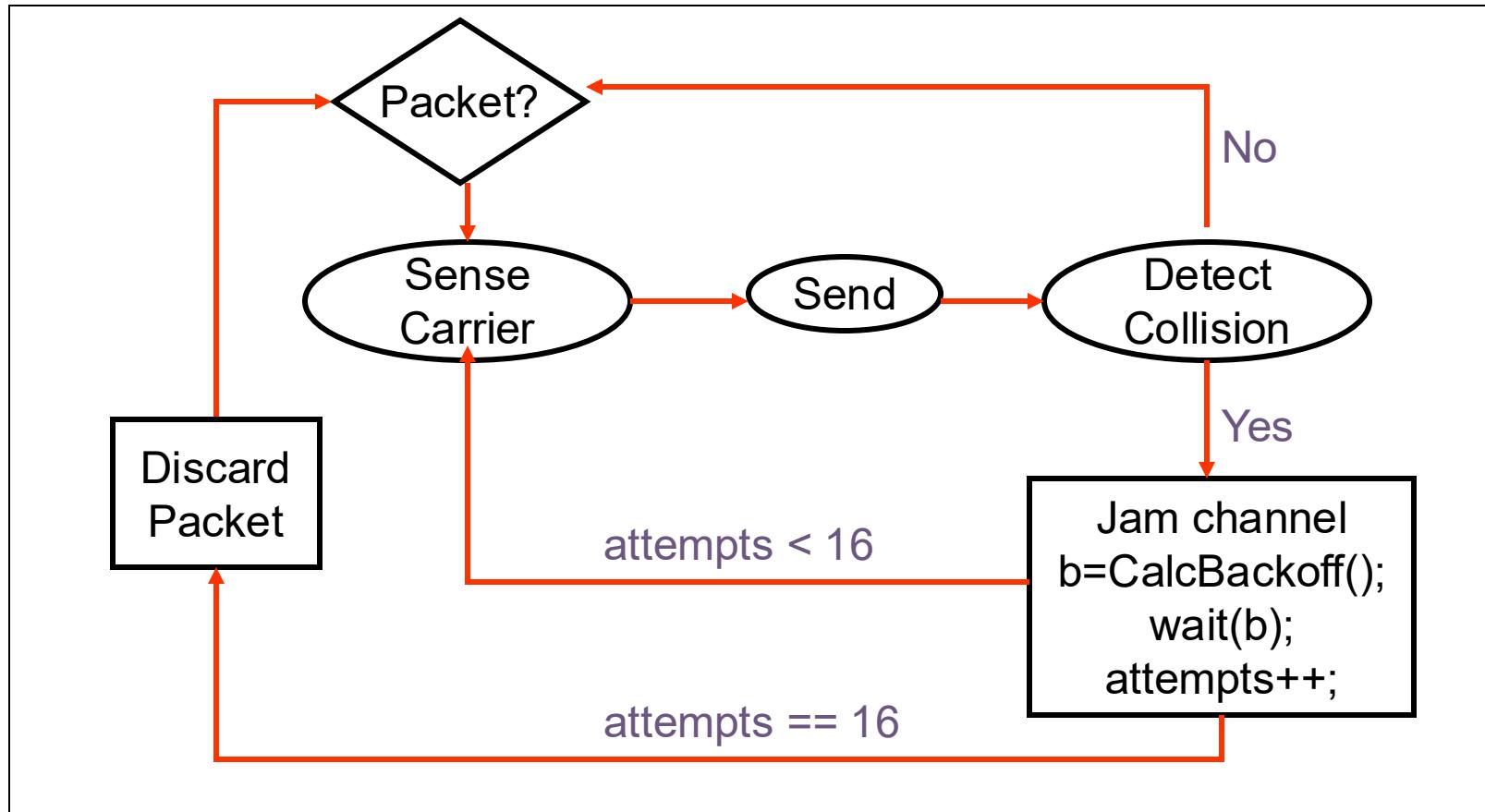
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Make sure you  
**LOGIN**  
using your  
NUSNET ID.



# 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!**

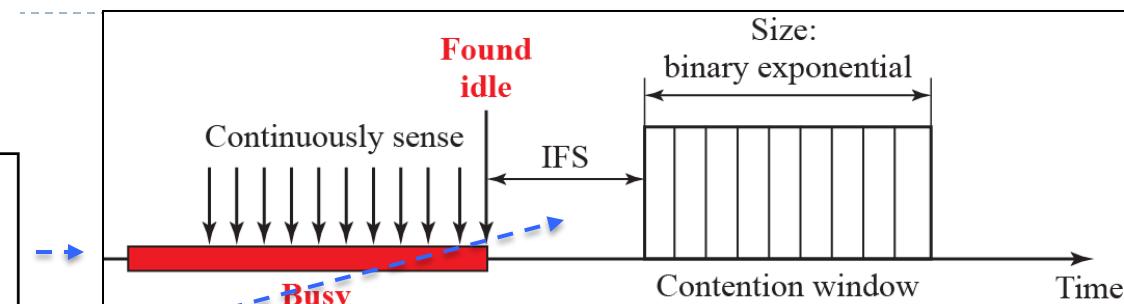
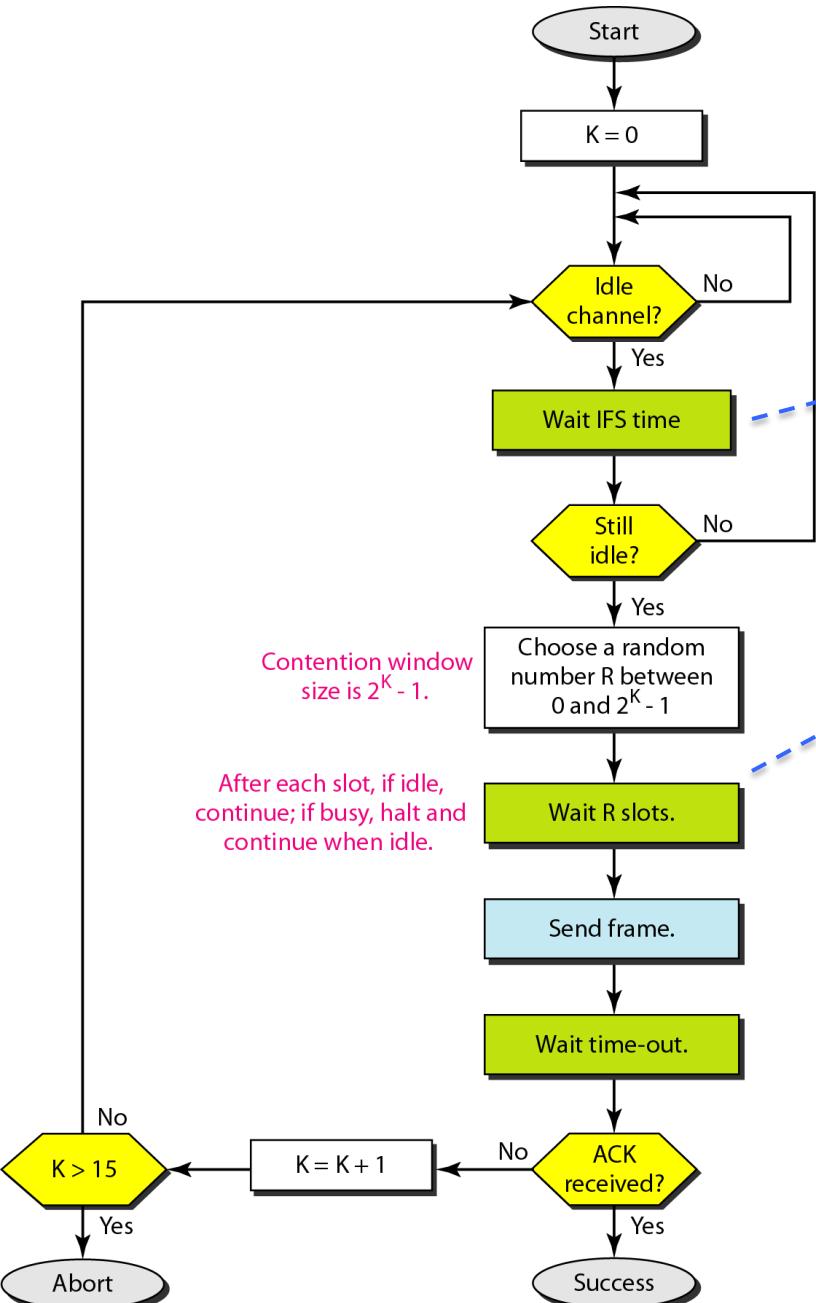
WLANS use “Collision Avoidance”

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



<https://pollev.com/banand>

# IEEE 802.11 MAC Layer Protocol (CSMA/CA)

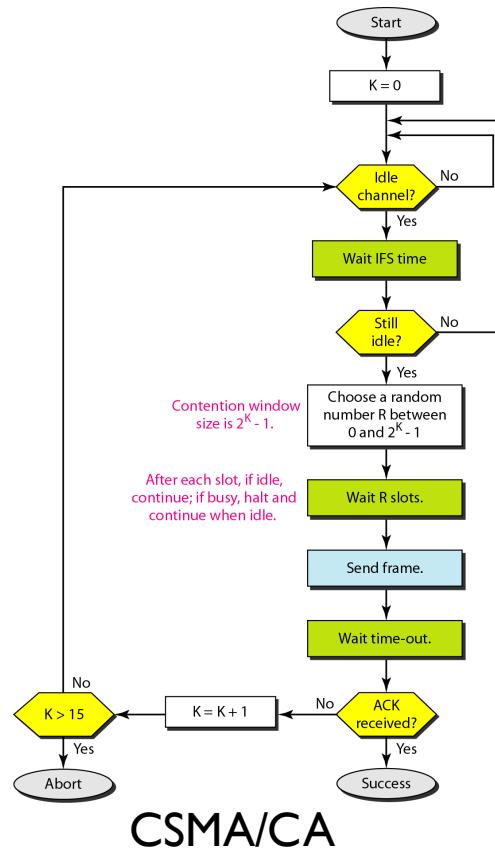
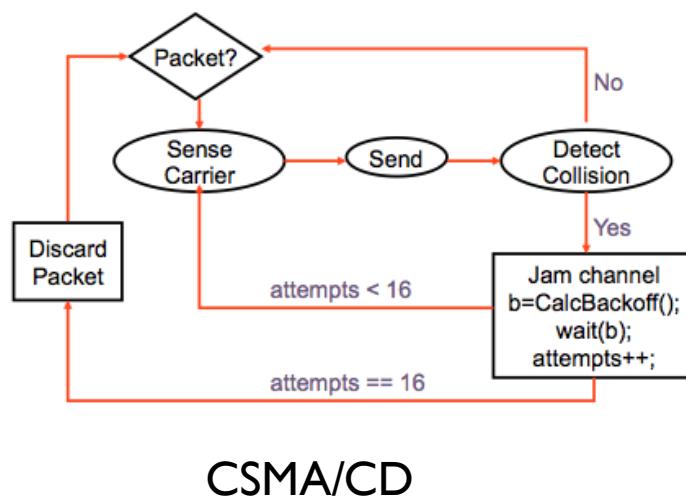


what is IFS?

- ▶ What is the purpose of IFS?
- ▶ What is the purpose of Contention Window?
- ▶ Then, is Collision Avoidance Achieved?

# Why Collision Avoidance?

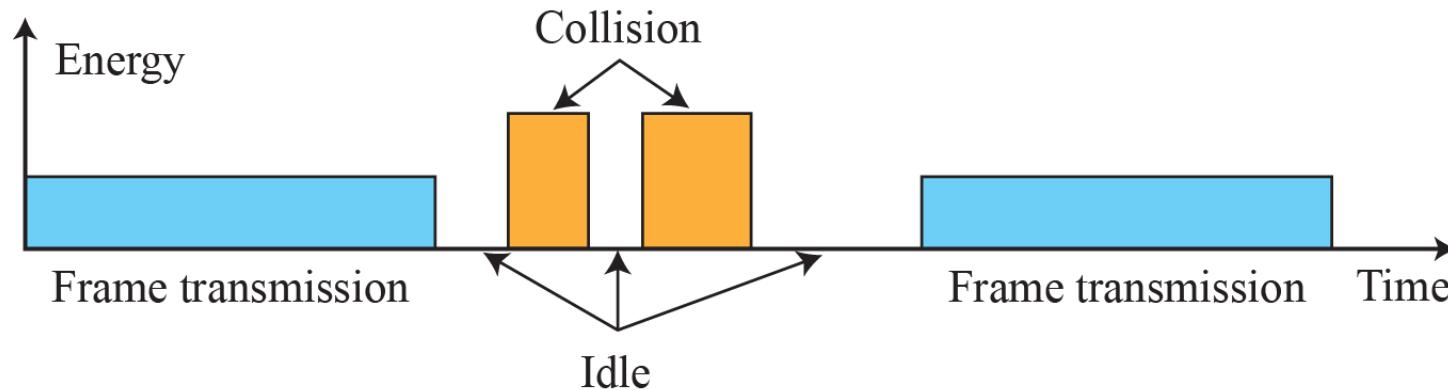
- ▶ CSMA/CA looks more inefficient (waiting times, ACKs, etc) than CSMA/CD. Then, why can't we use CSMA/CD for wireless?



# 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?



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**CSMA/CA - Hidden Node and Exposed Node Problems**

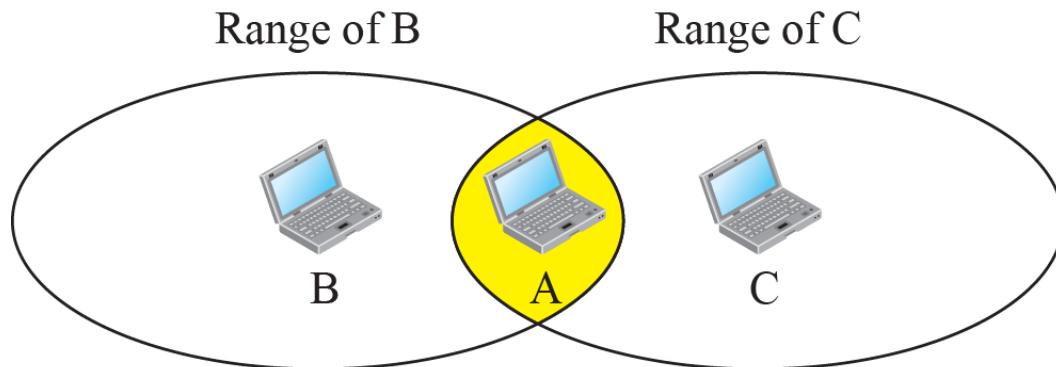
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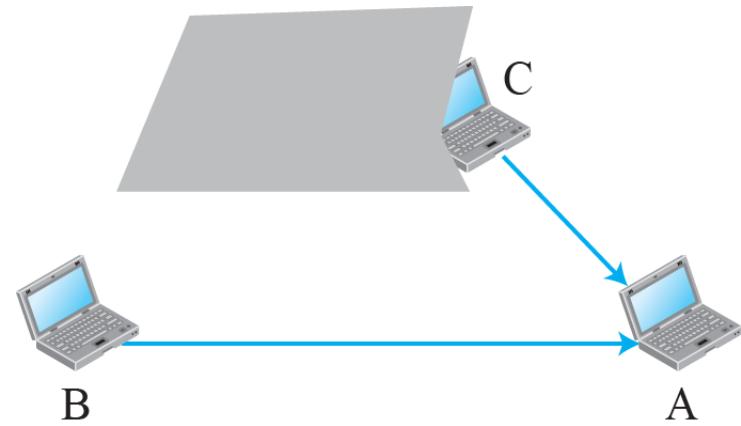
LAB:- Inspect IEEE 802.11 Frame Format

# 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.

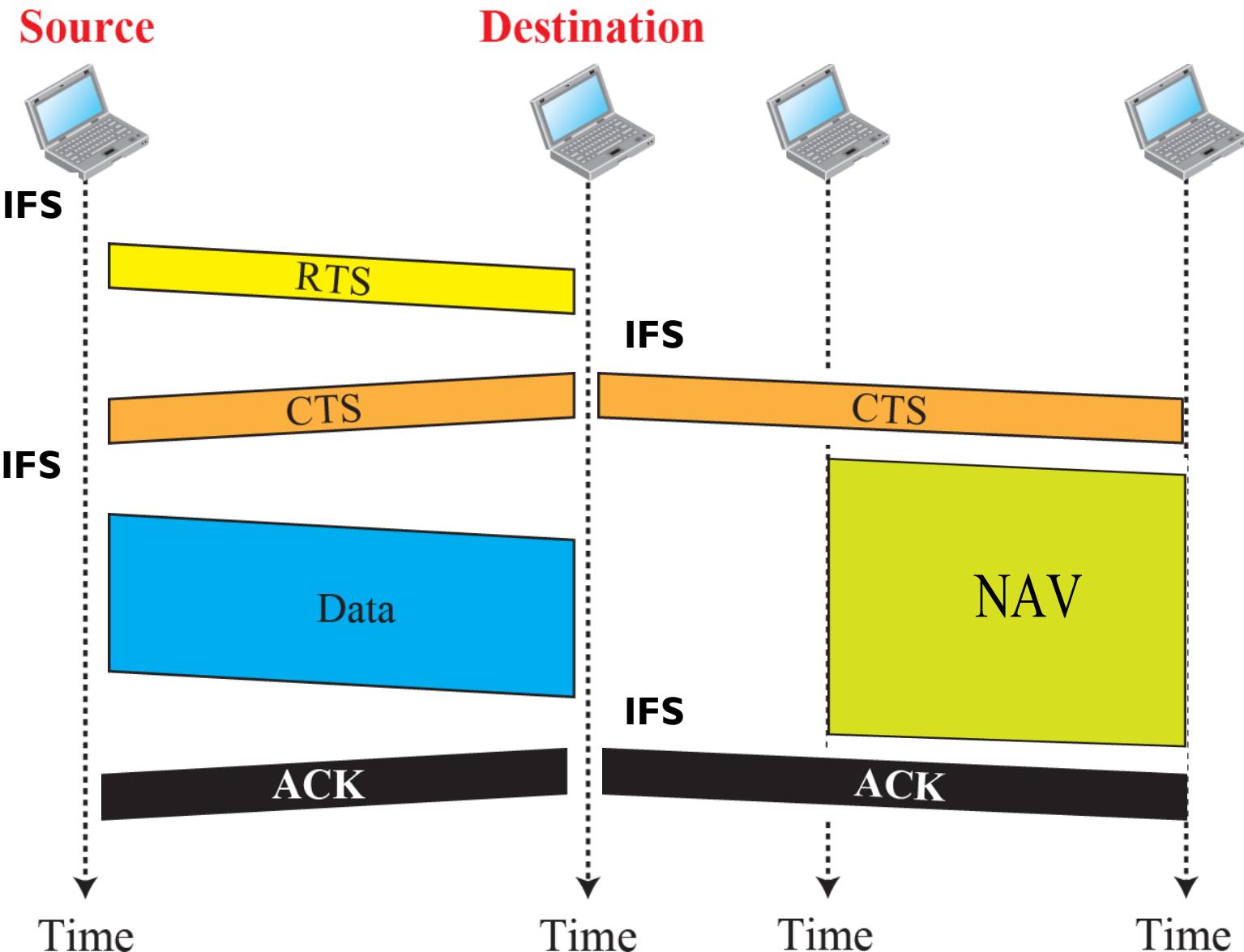


- b. Stations B and C are hidden from each other.

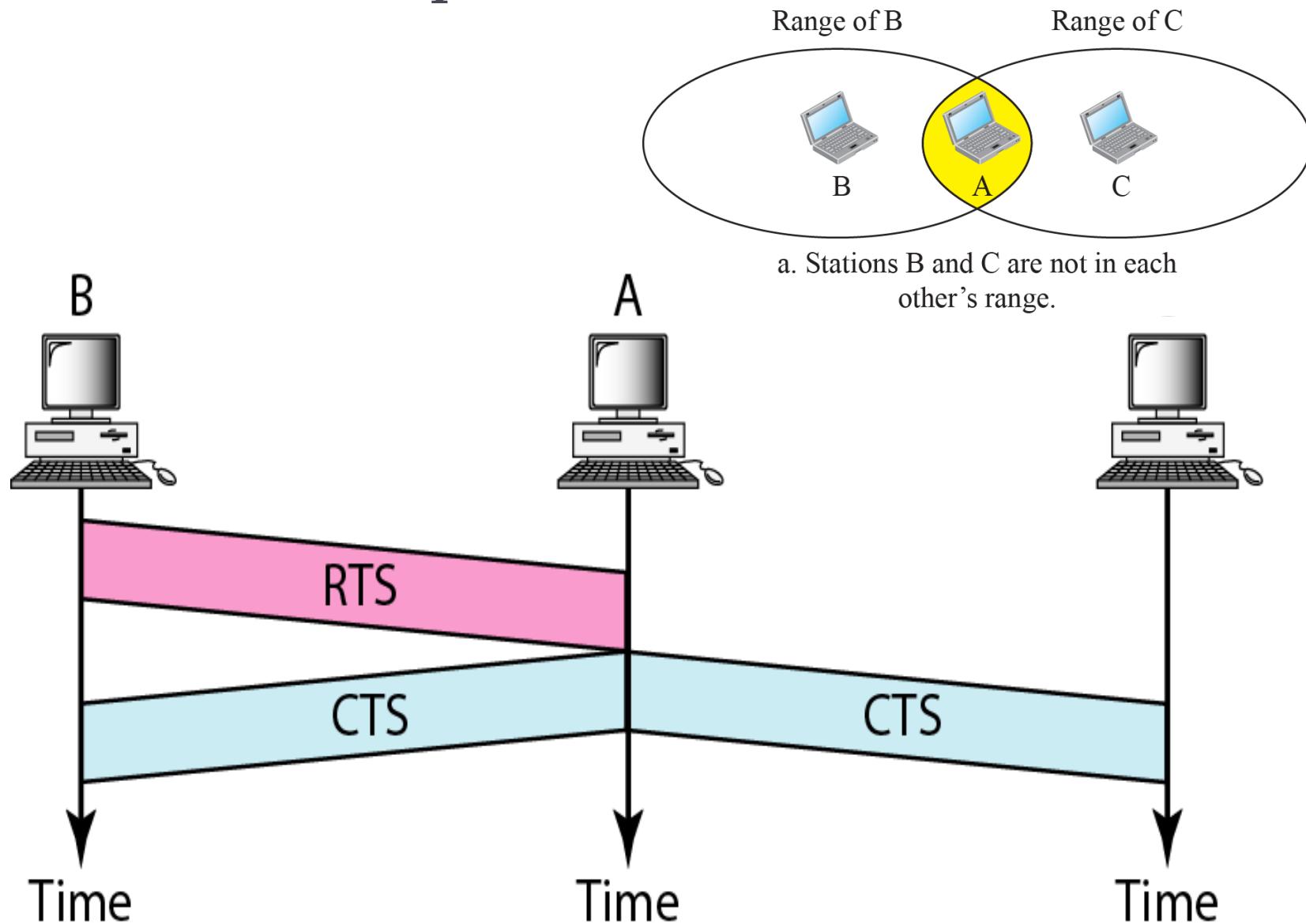
- ▶ So what?
  - ▶ Hidden nodes **reduce the capacity of the network** as they increase the possibility of collision

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

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



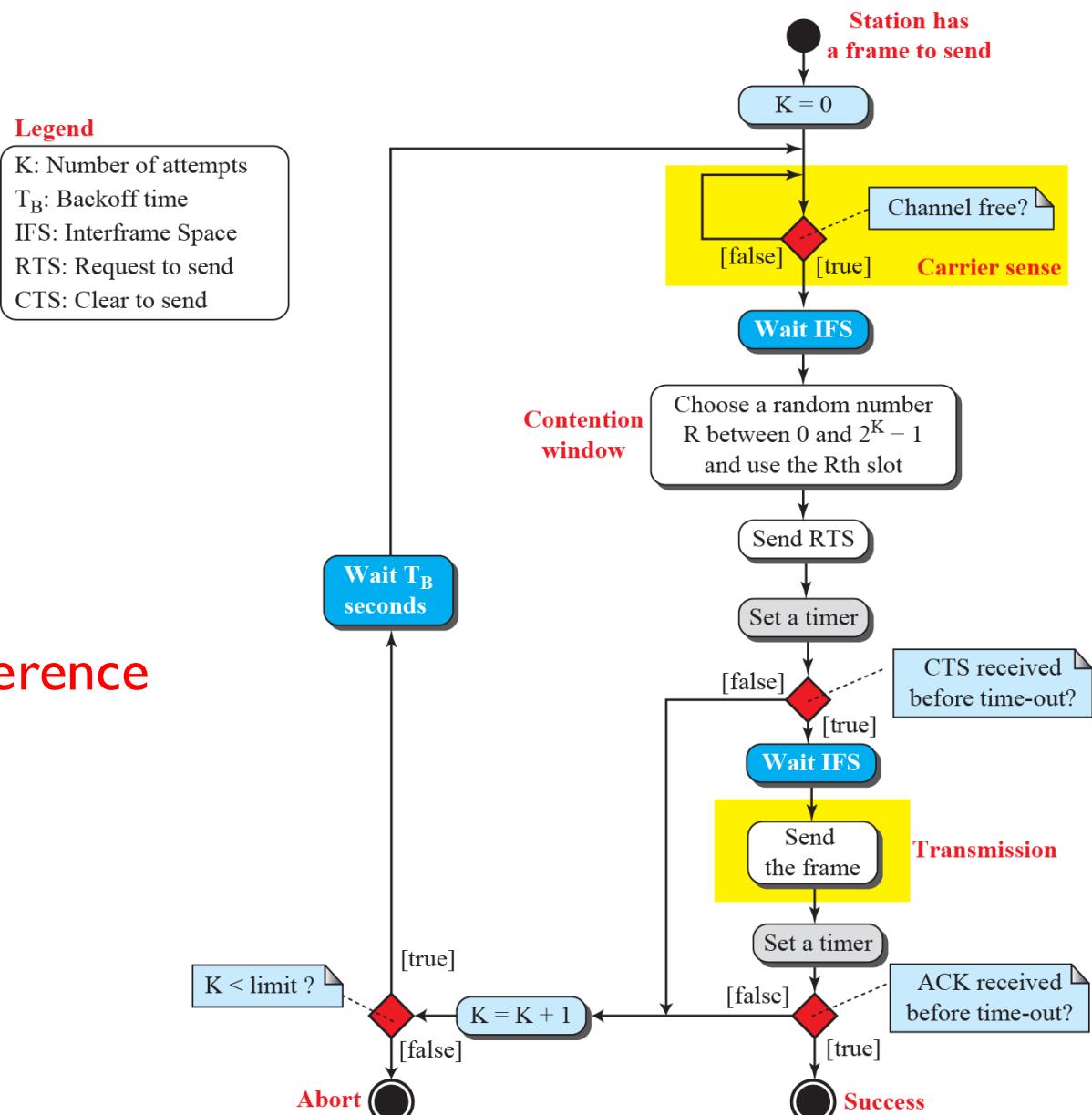
# Use of reservation scheme (CTS) prevents hidden station problem



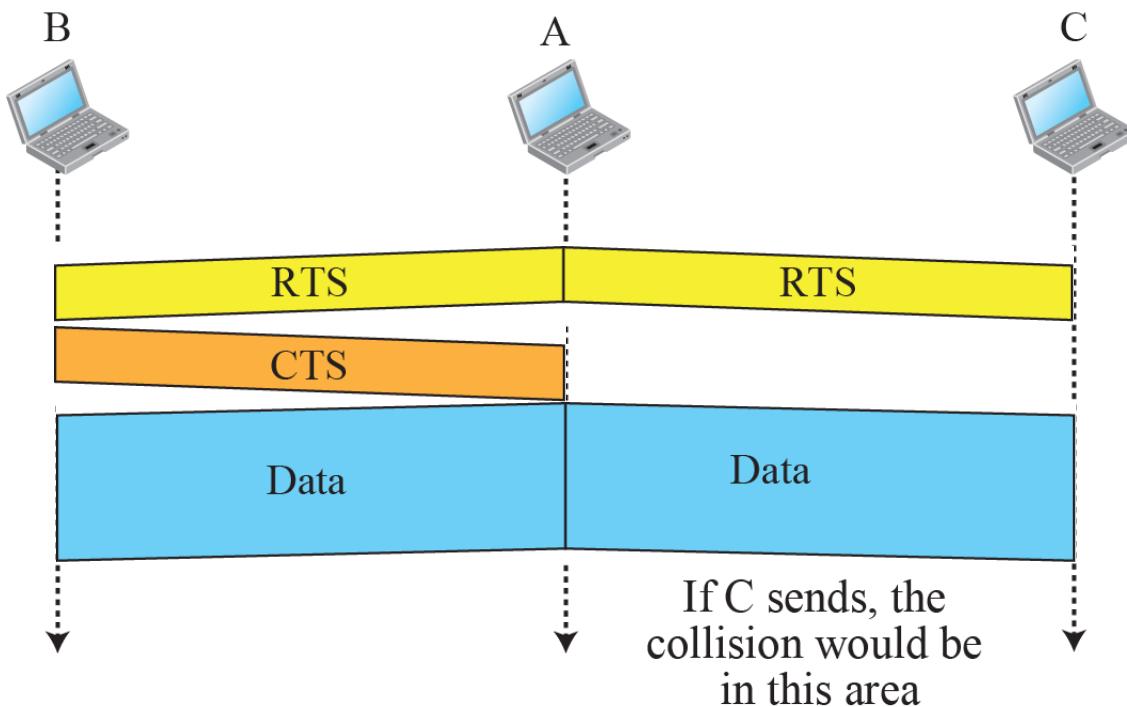
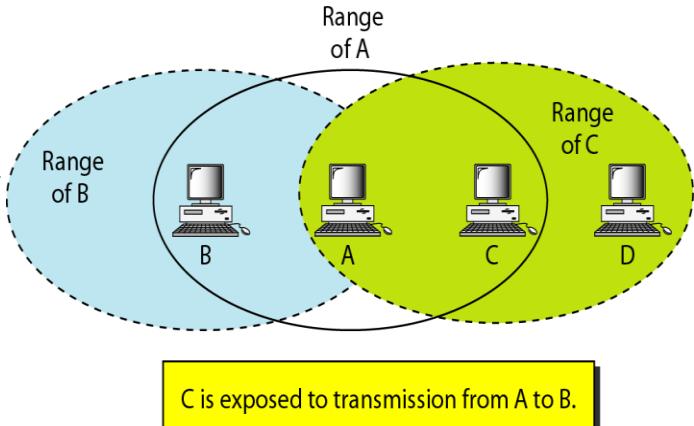
# IEEE 802.11 MAC Layer (CSMA/CA – RTS/CTS)

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

Updated Flowchart  
– For Your Reference



# CSMA/CA Suffers from - Exposed node Problem



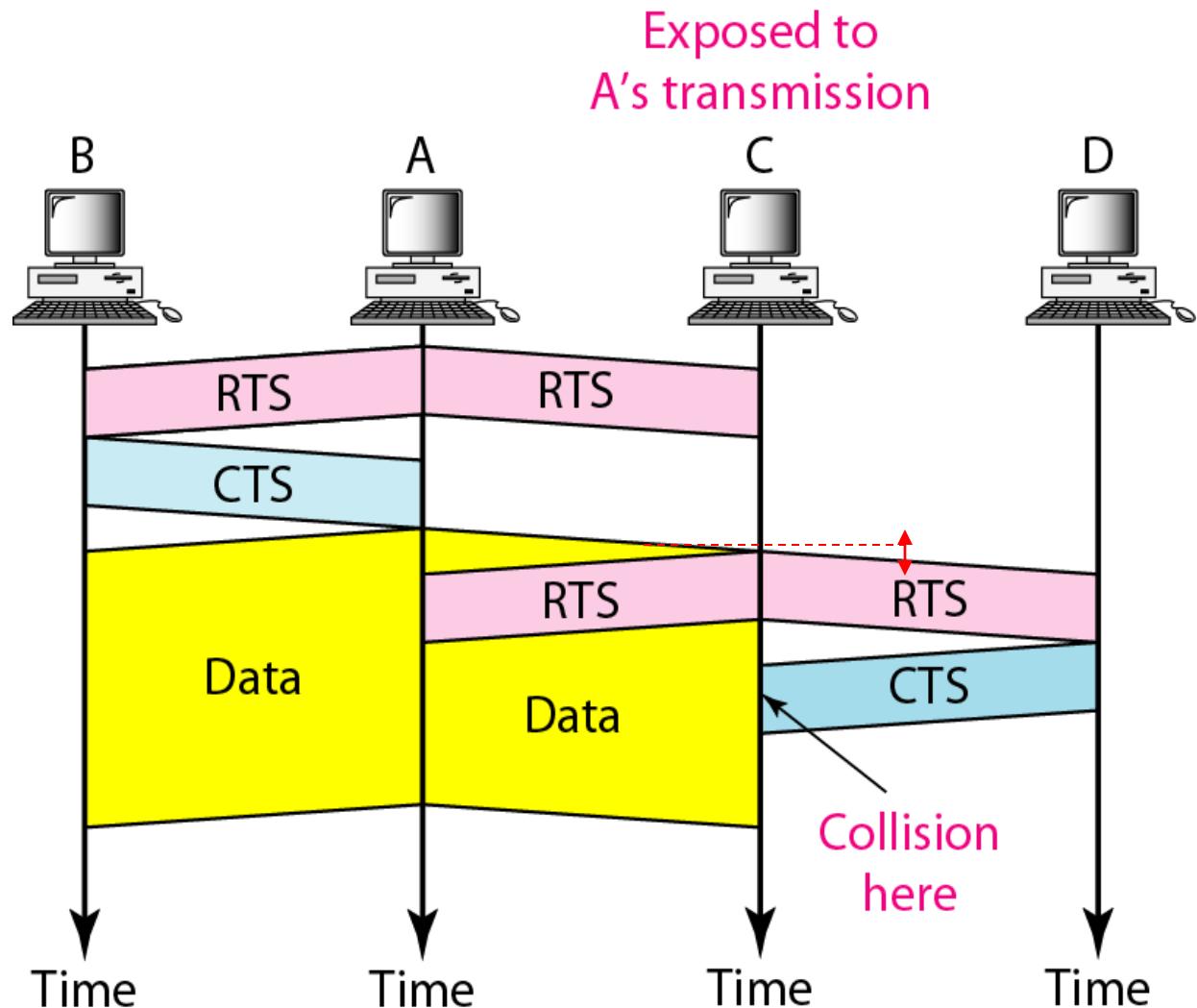
C can send to D because this area is free, but C erroneously refrains from sending because of received RTS.

**C is too conservative and wastes the capacity of the channel**

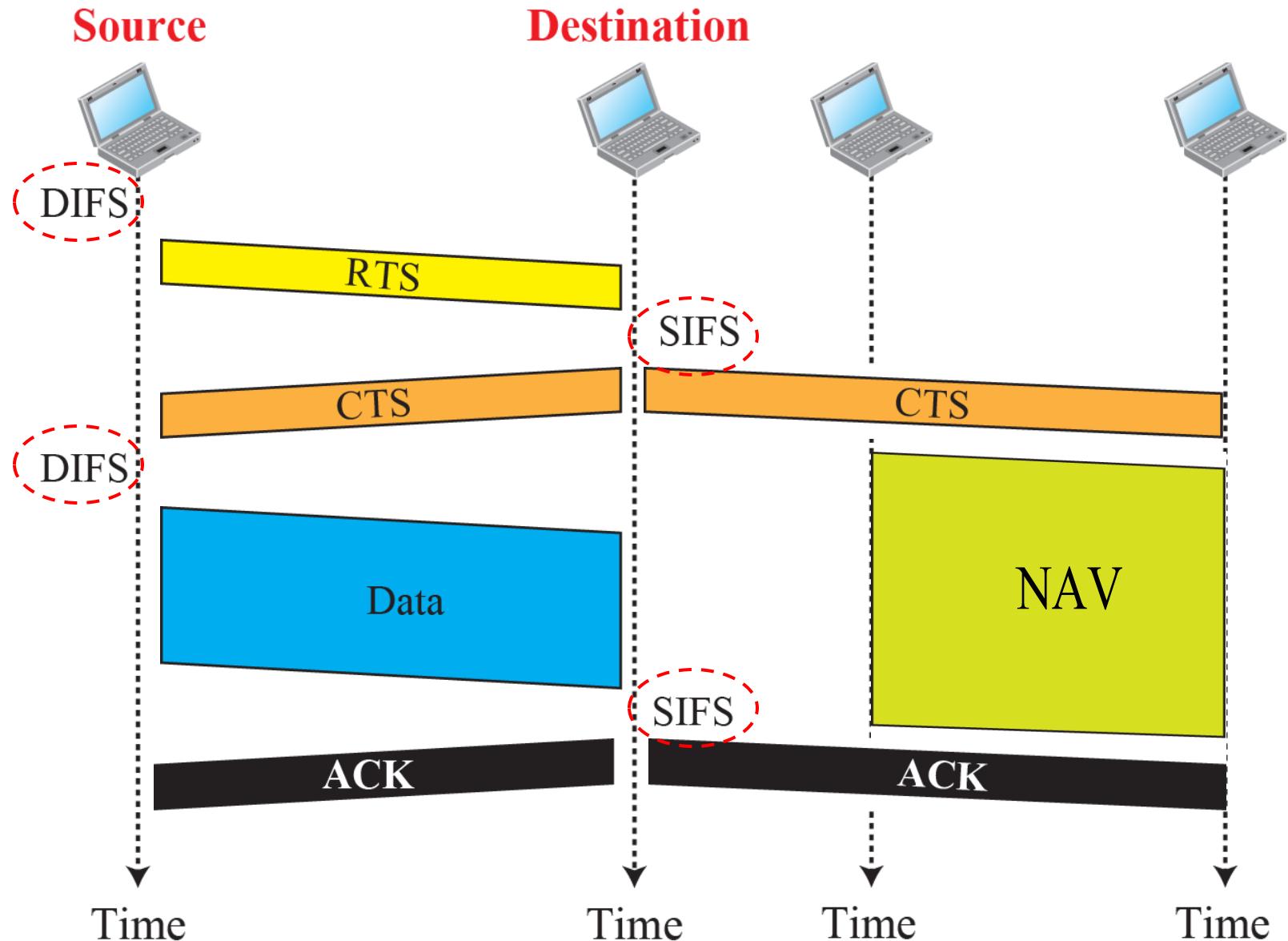
**Q:** What if C sending an RTS immediately after Timeout for CTS from B and No Data in Channel?

# 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



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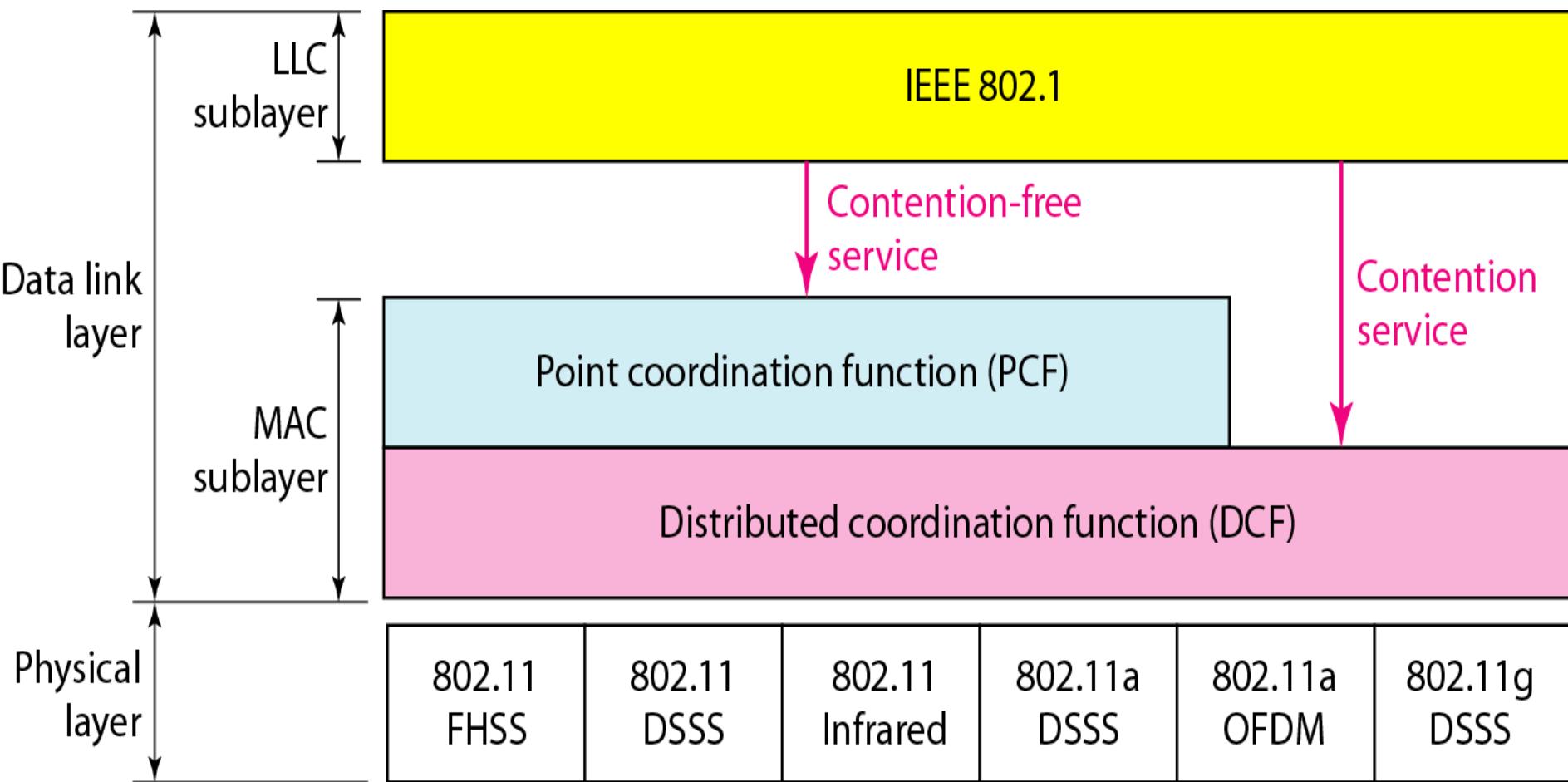
LAB:- Inspect IEEE 802.11 Frame Format

# 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

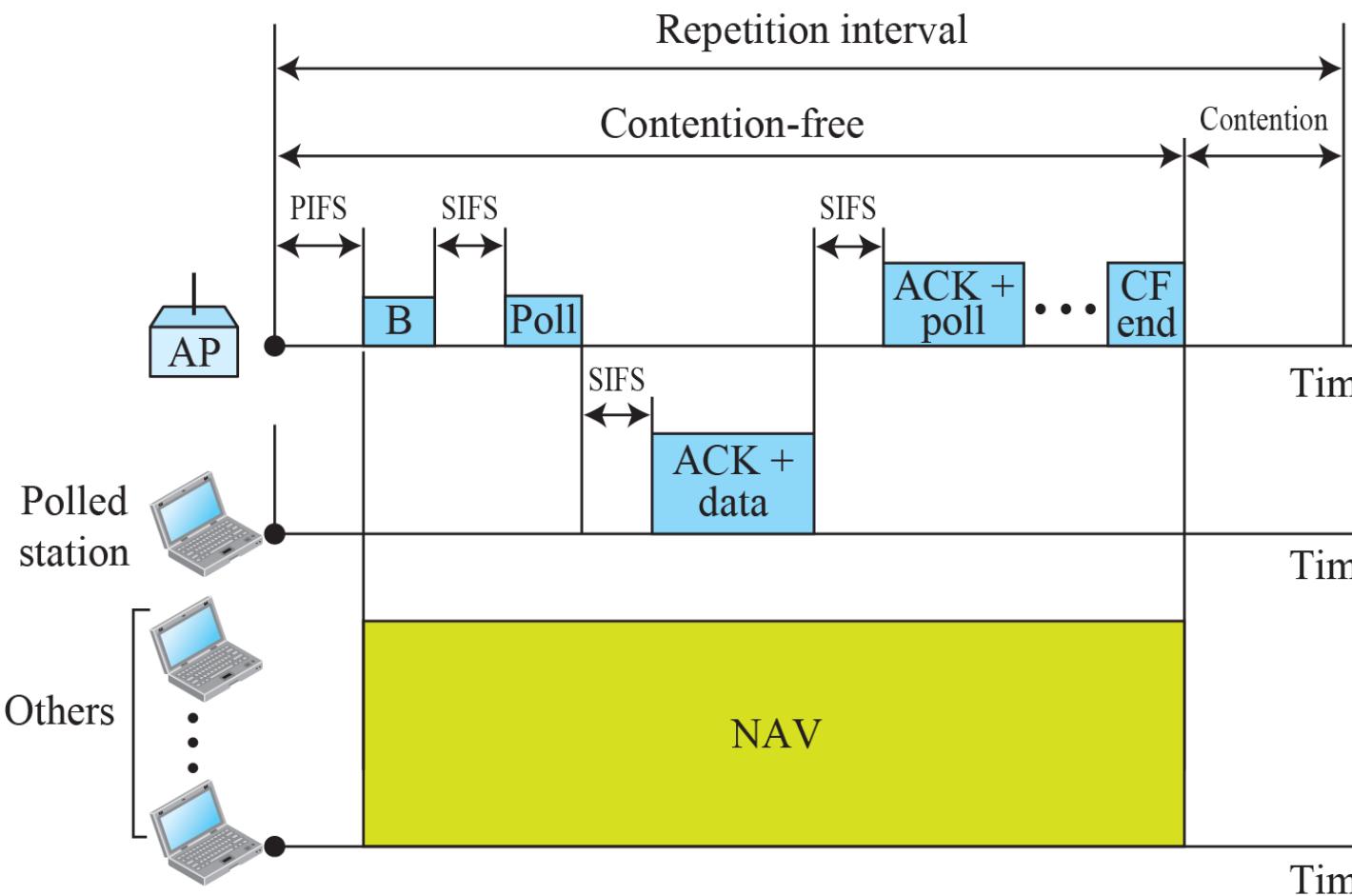
- ▶ PCF provides a **centralized, contention free polling access** method. **Point Coordinator (PC)** module at AP performs polling.
  - ▶ Stations request that AP **register** them on polling list
  - ▶ AP regularly **polls stations** on polling list and **delivers traffic**
- ▶ But, How does AP gets 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



## Legend

- B: Beacon frame
- CF: Contention-free
- AP: Access point
- NAV: No carrier sensing

# 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:

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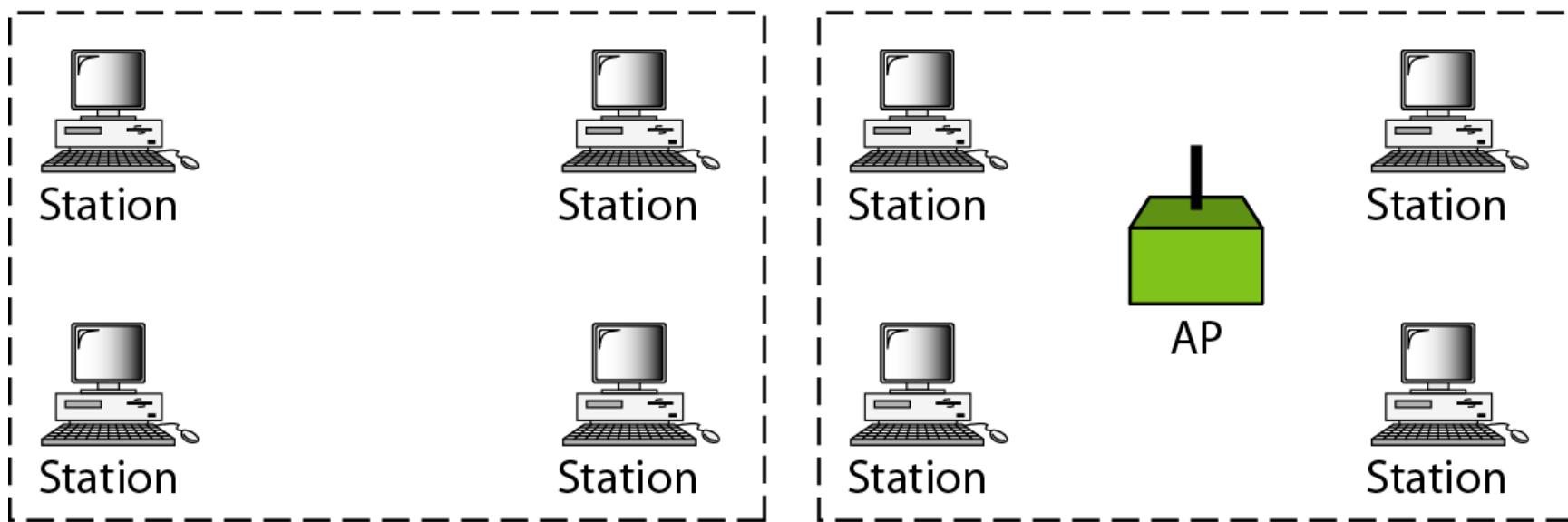
LAB:- Inspect IEEE 802.11 Frame Format

# 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



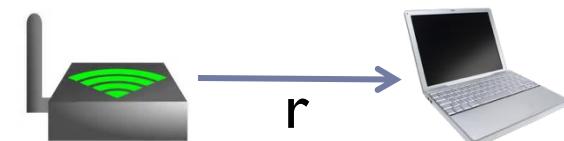
Ad hoc network (BSS without an AP)  
(aka: IBSS – Independent Basic Service Set)

Infrastructure (BSS with an AP)

# IEEE 802.11 - Extended Service Set (ESS)

## Extended Service Set (ESS):

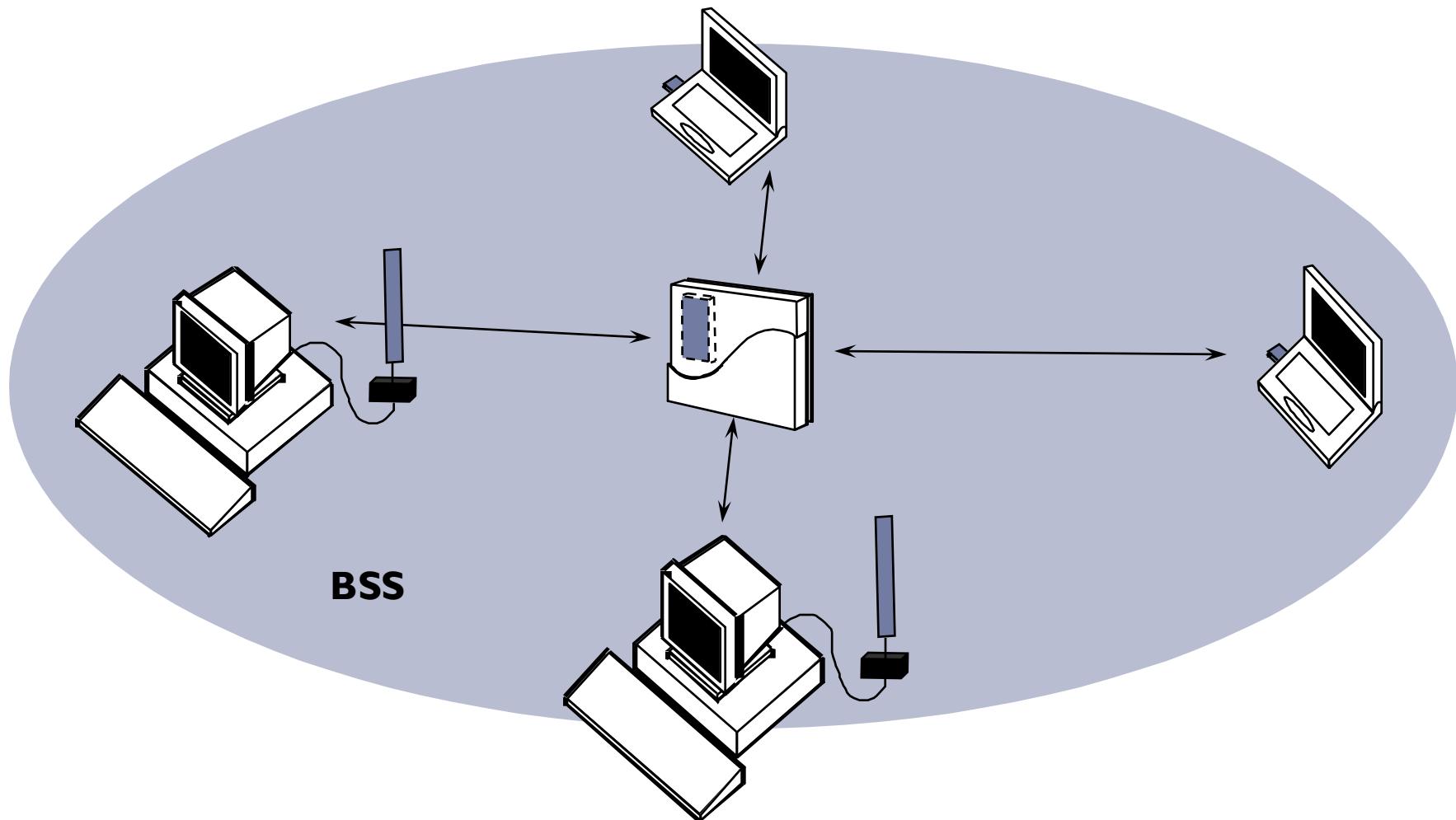
- ▶ A set of **one or more Basic Service Sets interconnected by a Distribution System (DS)**
  - ▶ But, why not a single big BSS?
- ▶ Traffic always flows via Access-Point
- ▶ Diameter of the cell is double the coverage distance between two wireless stations



## Distribution System (DS):

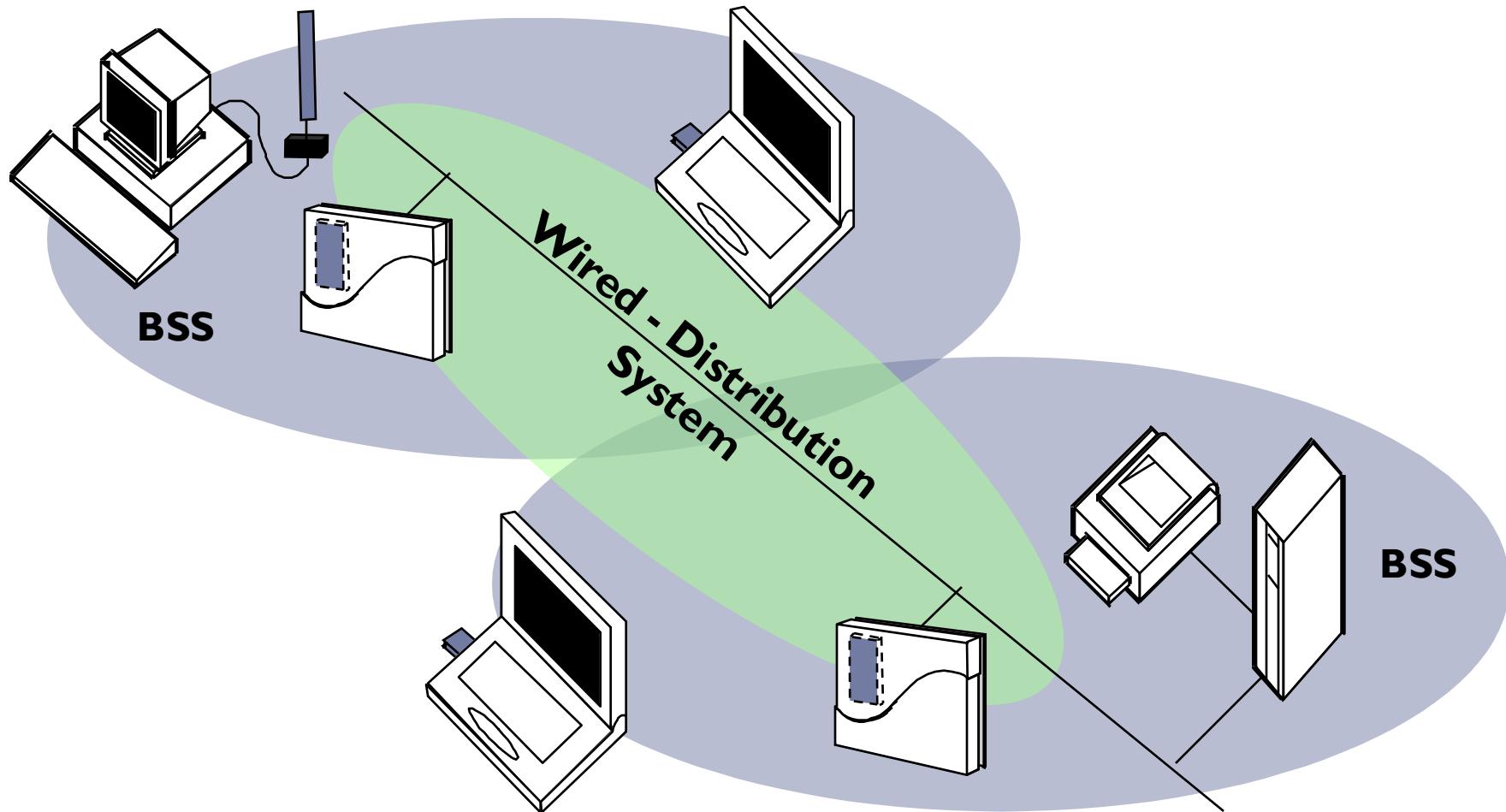
- ▶ A system to interconnect a set of Basic Service Sets
  - ▶ Integrated (Single AP), Wired, Wireless

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

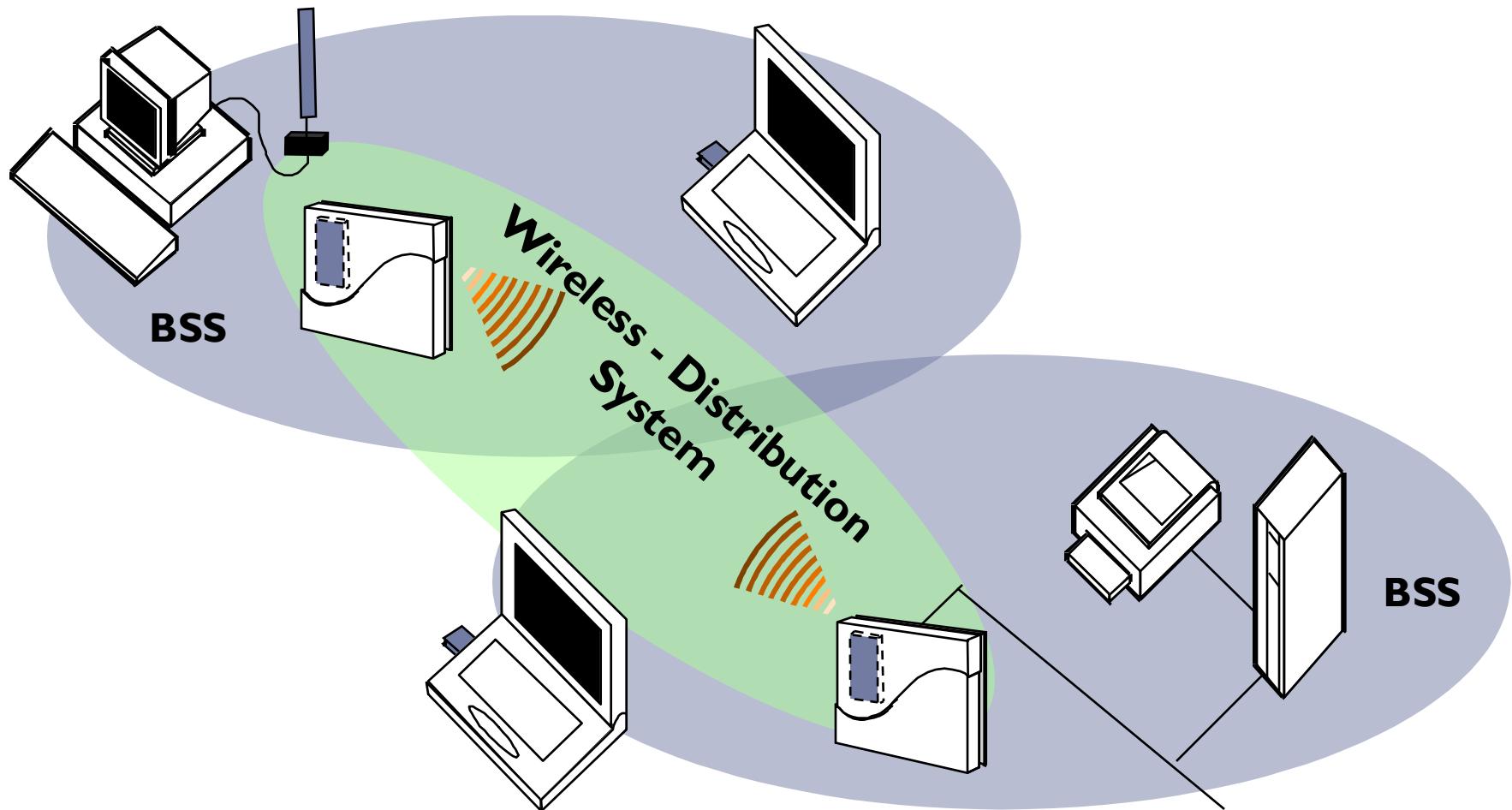


# Extended Service Set (ESS)

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



# Extended Service Set (ESS) BSS's and **wireless** Distribution System (DS)



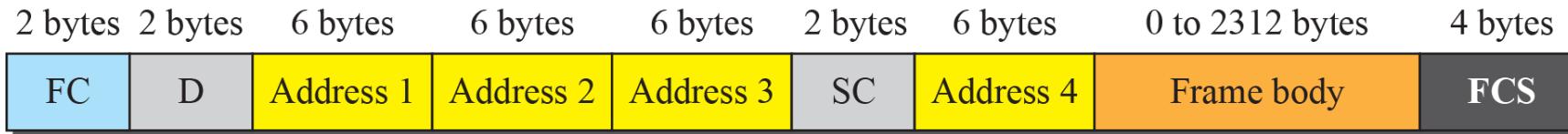
## Service Set Identifier (SSID) or Extended SSID (ESSID):

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

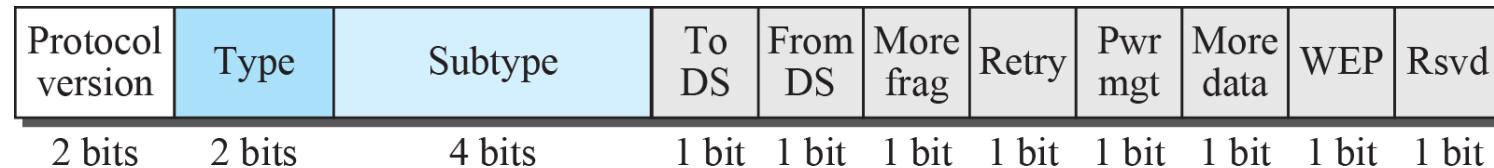
## Basic Service Set Identifier (BSSID)

- ▶ “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



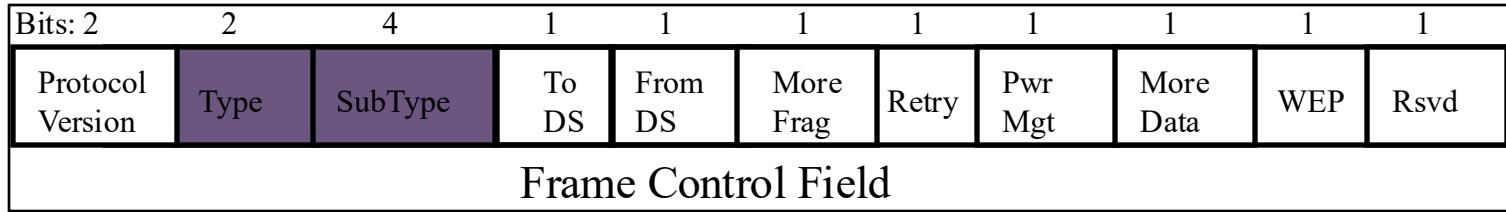
D- Duration of the transmission  
SC – Sequence Control



**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 | <b>Management Frame</b> |  |
|           | Beacon                  | (Re)Association                                |
|           | Probe                   | (De)Authentication                             |
|           | Power Management        |  |
| ▶ Type=01 | <b>Control Frame</b>    |  |
|           | RTS/CTS & ACK           |  |
| ▶ Type=10 | <b>Data Frame</b>       |  |
|           |                         | <b>Q: Purpose of beacons?</b>                  |
|           |                         | <b>Q: When Re-Association is done and how?</b> |

# Why four addresses?

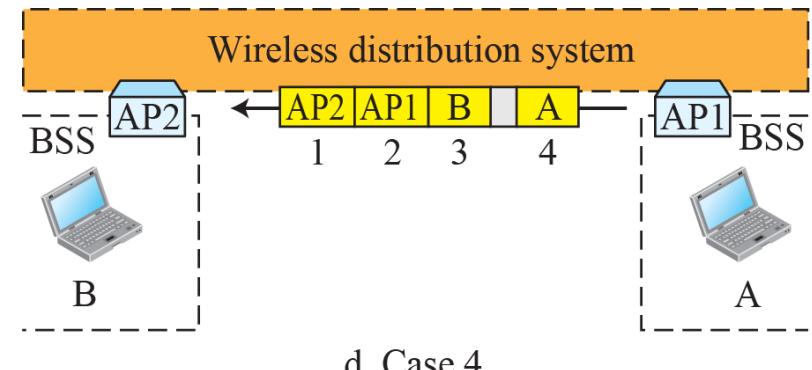
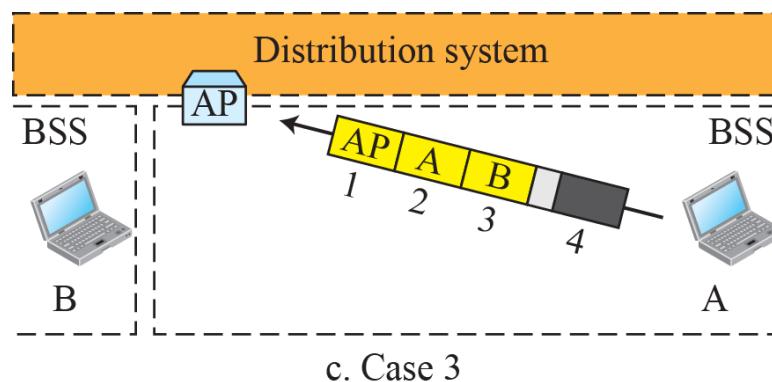
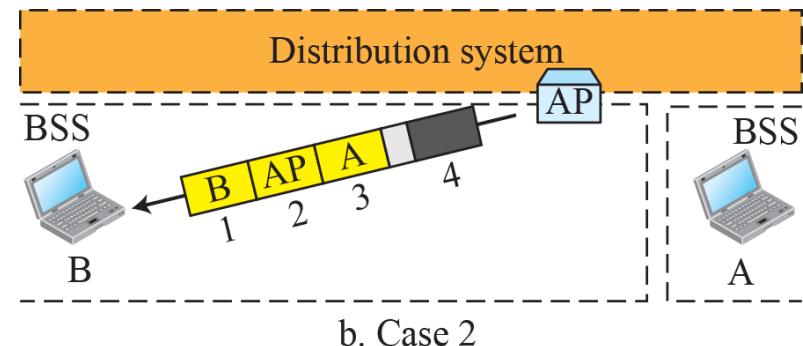
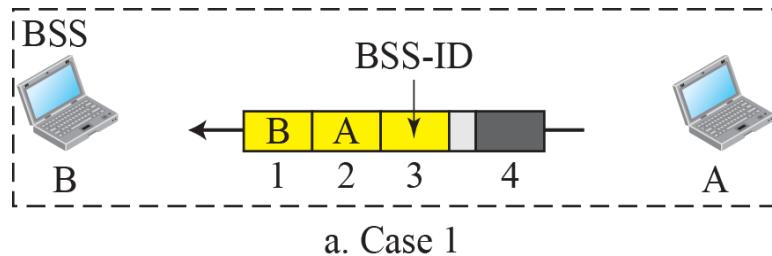


D- Duration of the transmission  
SC – Sequence Control

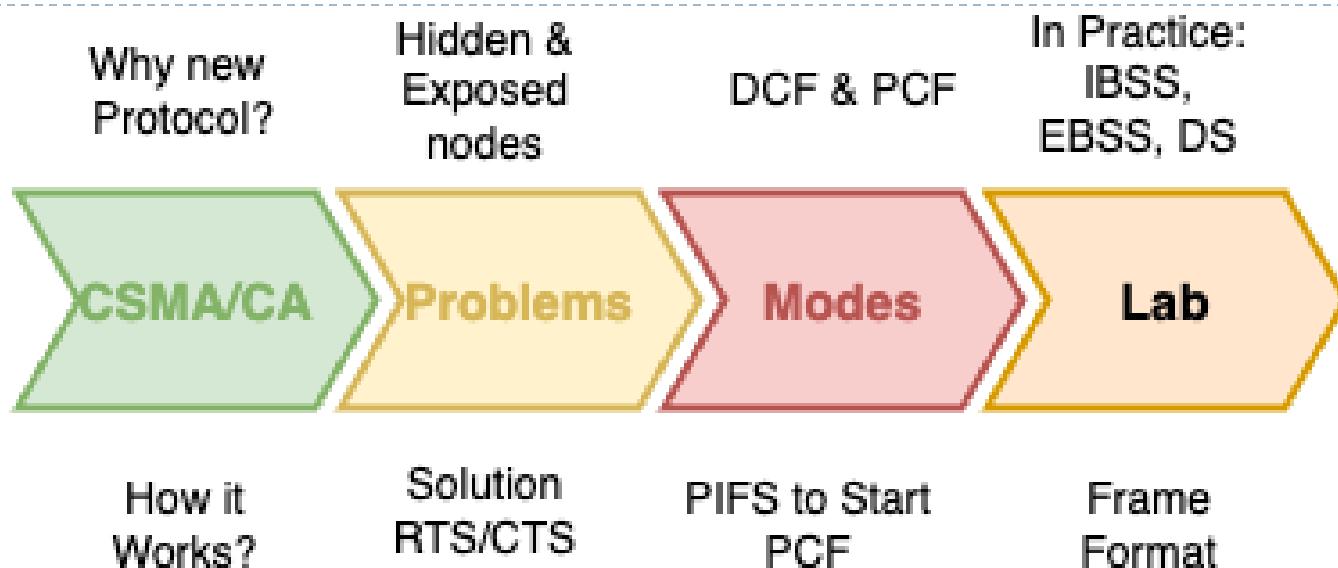
Protocol version	Type	Subtype	To DS	From DS	More frag	Retry	Pwr mgt	More data	WEP	Rsvd
2 bits	2 bits	4 bits	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit

To DS	From DS	Address 1	Address 2	Address 3	Address 4
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



# 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

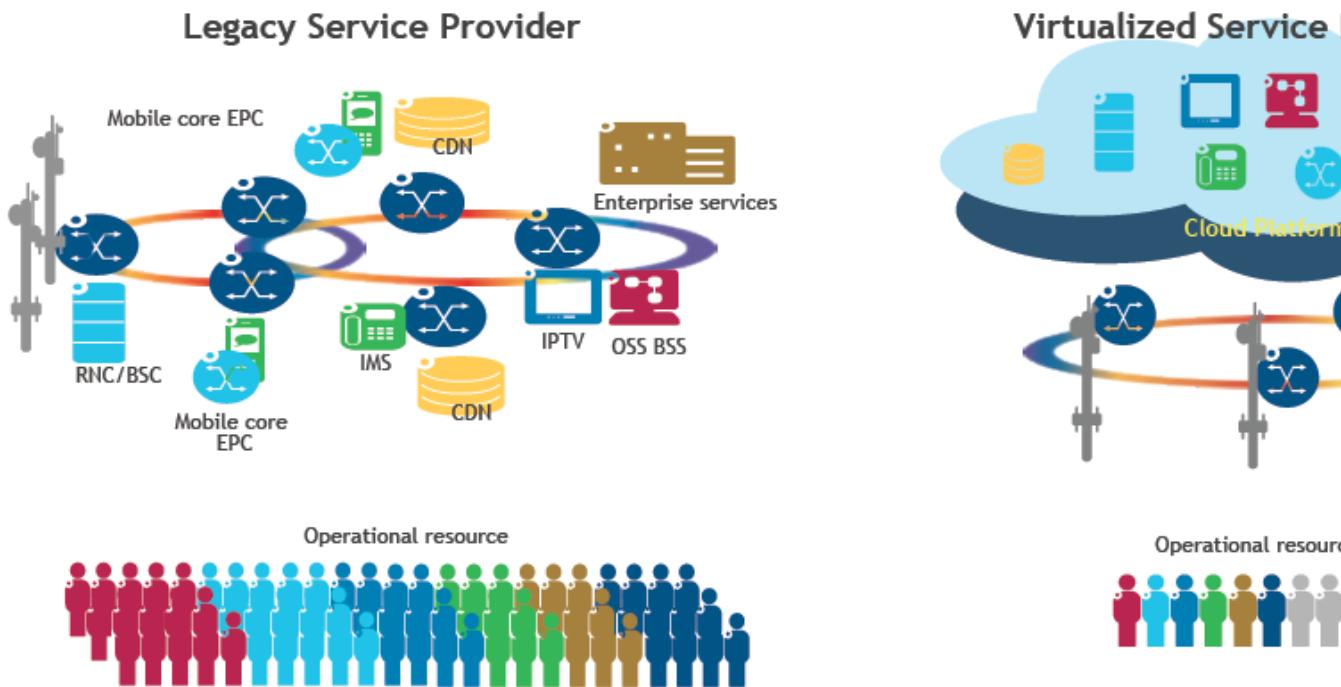
For Your Reference

- ▶ 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

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

