IEEE 802.11 – Wireless LAN

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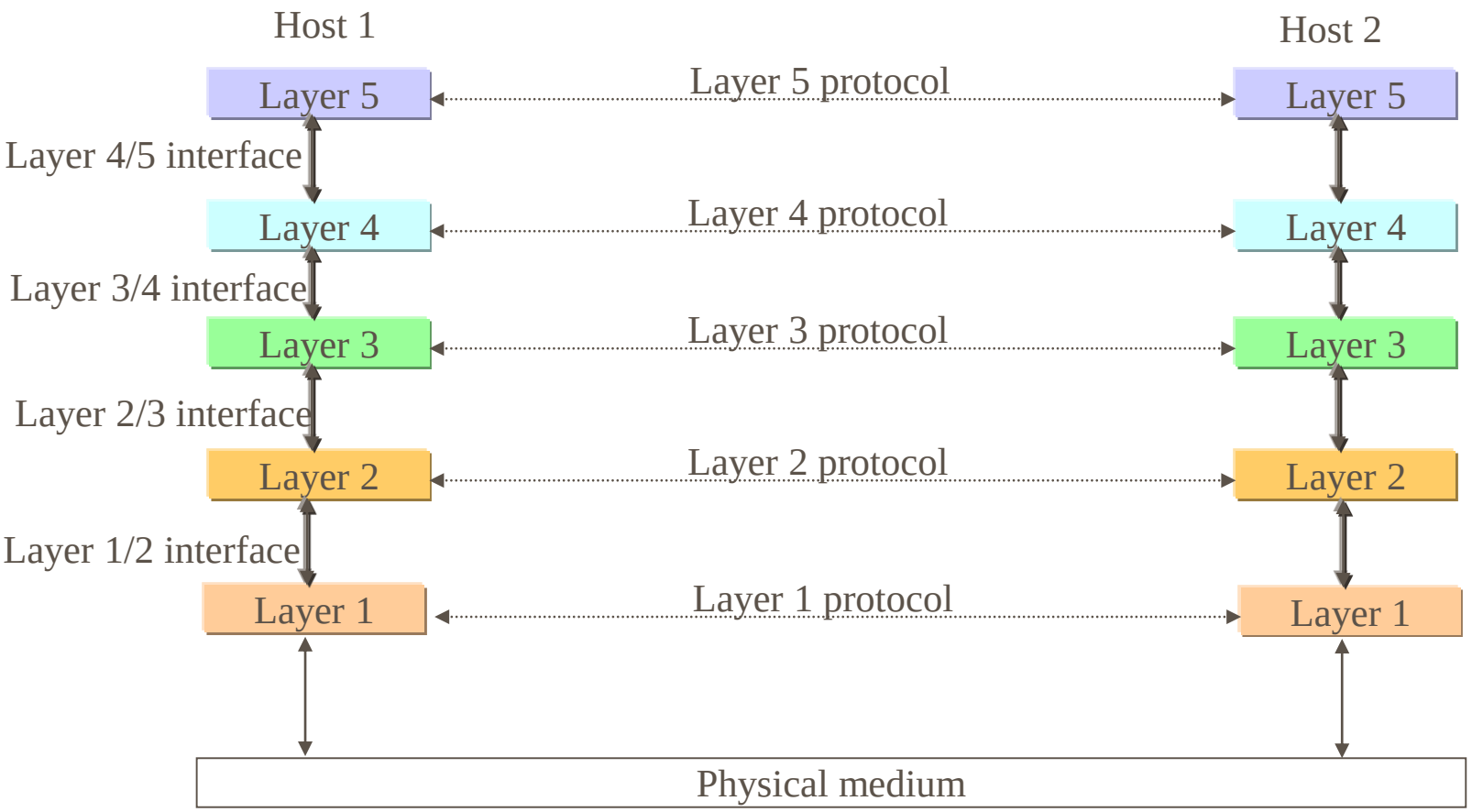
Layers, Protocol, and Interfaces



References

- IEEE 802.11 standards

Outline

- Introduction
- Physical Layer
- Medium Access Control (MAC)
- QoS Support – IEEE 802.11e

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Original 802.11 specification

- Done in 1997
  - 1Mbps and 2Mbps data rates
  - a set of fundamental signaling methods
  - services
- The most critical issue affecting WLAN demand has been the *limited* data rate.
  - **too *slow*** to support most general business requirements
  - slowed adoption of WLANs

真正可用的只有一半，因為會有 header / error message

- The goal is to achieve wireless **performance** and **throughput** comparable to wired Ethernet.

802.11 Standards

這個頻段是免費
unlicensed frequency band

- Until 802.11b --> Transmission is up to 11 Mbps. (2.4 GHz)
- 802.11g/a – 54 Mbps (5 GHz)

速度*距離 = 常數

- 802.11n – 600 Mbps (5 GHz), **MIMO (multiple-input multiple-output)** and **40 MHz** channels to the PHY (physical layer), and frame aggregation to the MAC layer.

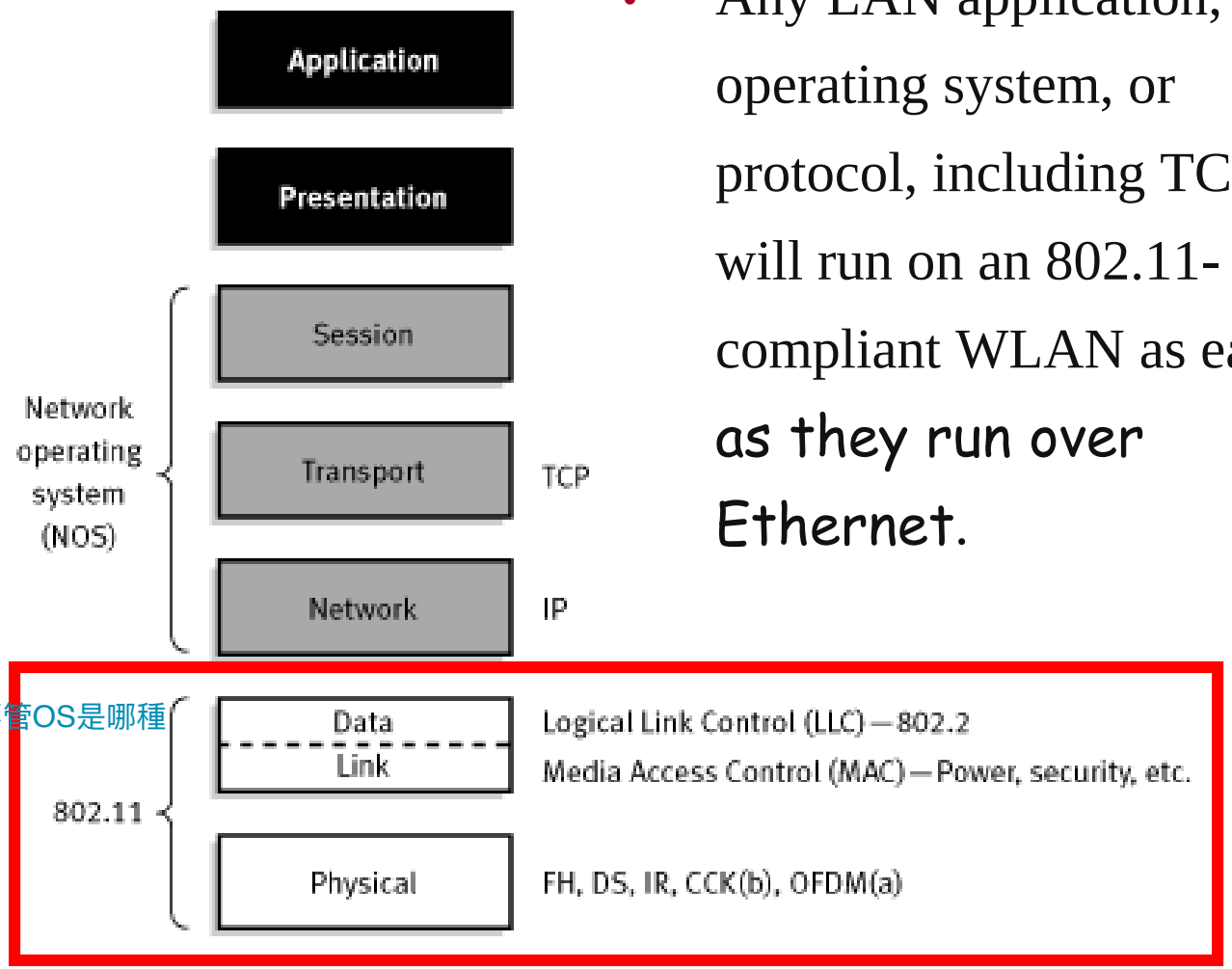
1.processor多

2.頻寬加寬

封包變長

- 802.11ac – up to 1Gbps (5 GHz) (up to **160 MHz** channel bandwidth, up to **8 MIMOs**, downlink multi-user MIMO (up to four clients), and high-density modulation (up to 256-QAM).
- 802.11ax – up to 9.6 Gbps; **6 GHz spectrum**

Protocol Layers



- Any LAN application, operating system, or protocol, including TCP/IP, will run on an 802.11-compliant WLAN as easily as they run over Ethernet.

Data蓋上Link，可以不管OS是哪種

Introduction

- The basic architecture, features, and services of 802.11b/g/a/n/ac/ax are defined by the *original* 802.11 standard.
- The 802.11b/g/a/n/ac/ax specification affects only the physical layer
  - adding higher data rates and
  - more robust connectivity

Two Types of 802.11 Equipment

- *A wireless station*
  - usually a computer or device (IoT, IIoT) equipped with a **802.11 NICs.**

IoT = Internet of Thing

IIoT = Intelligence Internet of Thing

- *An access point* (AP)
  - a bridge between the **wireless** and **wired** networks.

802.11 Operation Modes

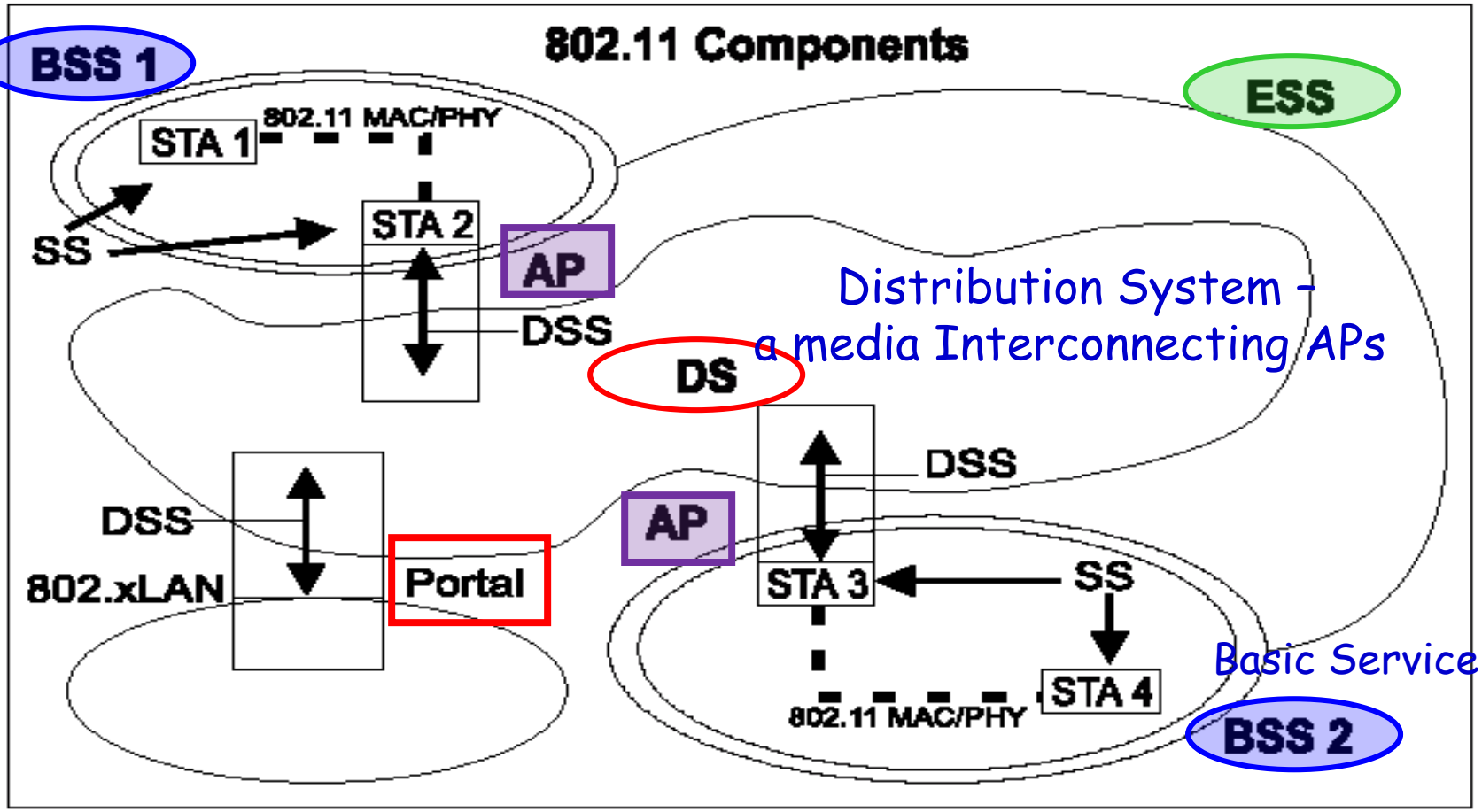
- Two network architectures are defined:
  - Infrastructure mode
  - Ad Hoc mode

Infrastructure Network

- Consists of at least *one access point* and *a set of wireless end stations*.
- Also called a Basic Service Set (BSS).
- An Extended Service Set (ESS)
  - A set of two or more BSSs forms a single subnetwork.
- The transmission of data from the *wireless* to the *wired medium* is via an Access Point.

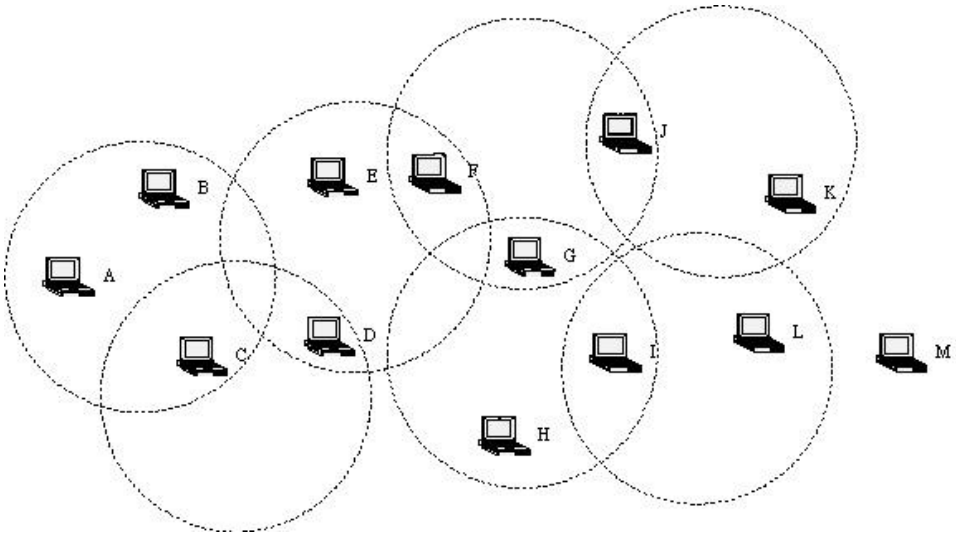
Components of the IEEE 802.11 Architecture

無線/有線相連，基本上還是依賴有限，頻寬才夠

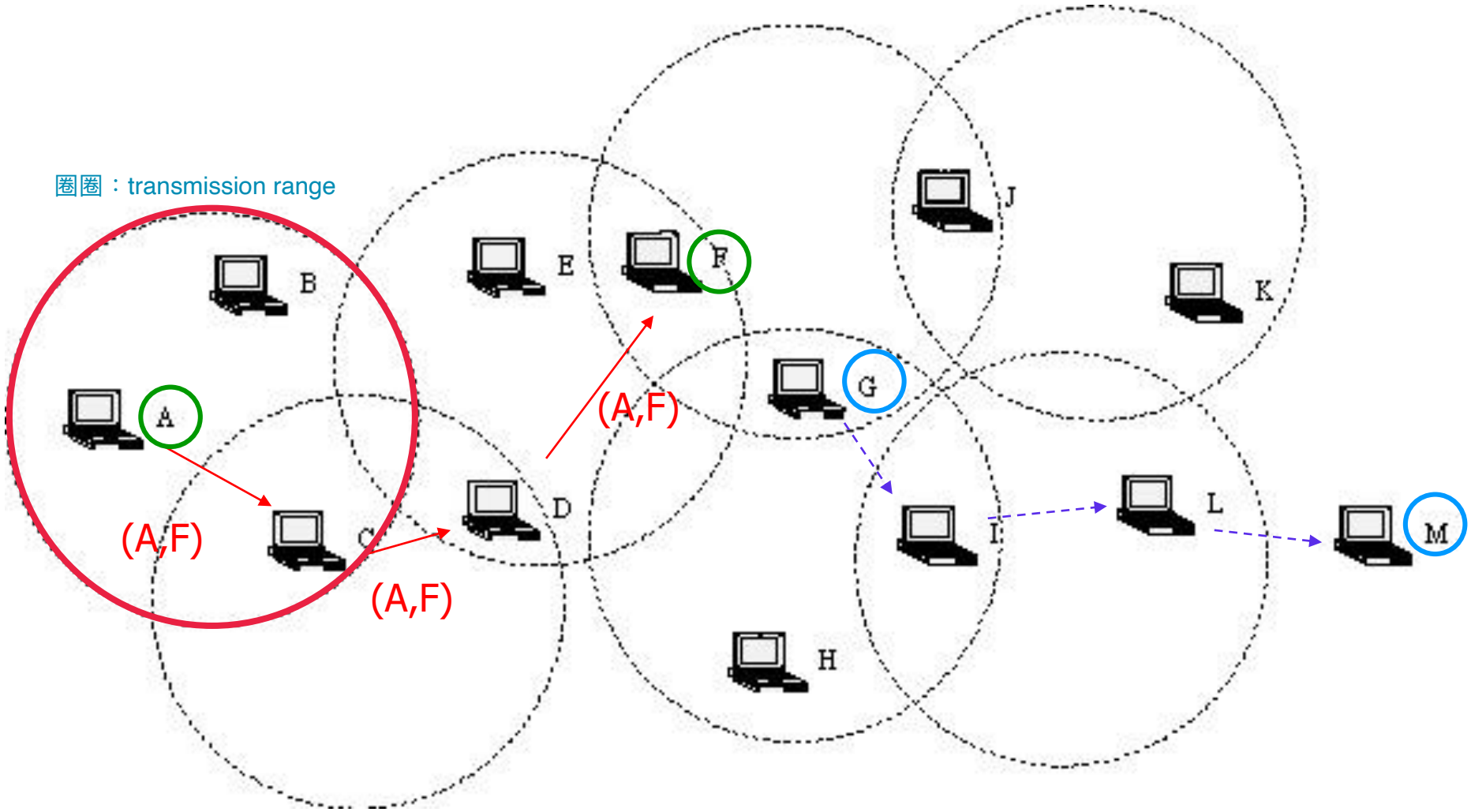


Ad hoc Wireless Networks

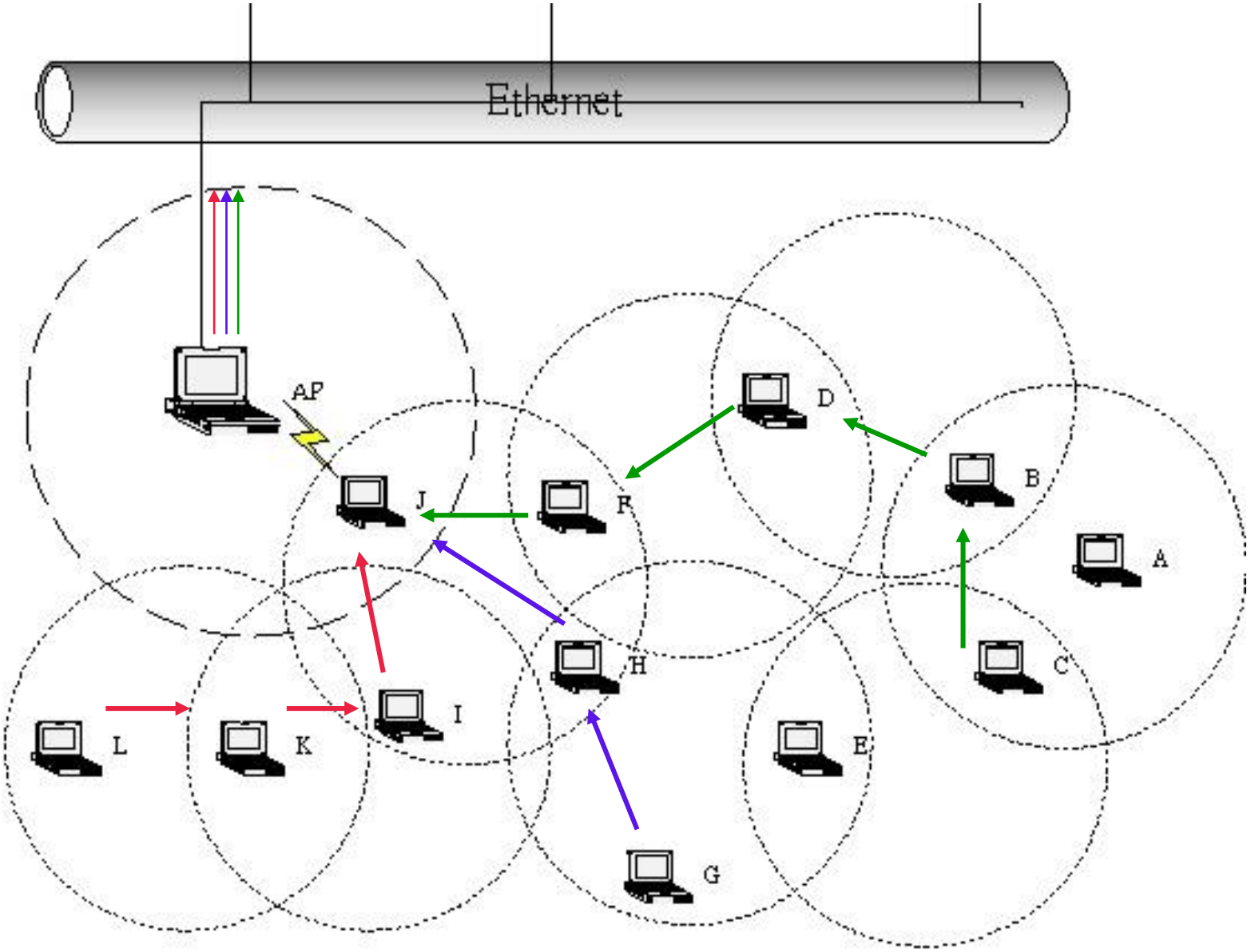
- A ***multi-hop***, ***adaptive***, and ***self-organizing*** wireless networks and ***pervasive*** (i.e., spreading everywhere) communications.
- **Fast deployable and self-organizing characteristics.**
- May have strong potential impact on
  - **on-the-road**
  - ***military and emergency***



Ad hoc Wireless Networks



Ad hoc Wireless Networks



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- Introduction
- Physical Layer
- Medium Access Control (MAC)
- QoS Support – IEEE 802.11e

The 802.11 Physical Layer

- Original 802.11 defines ***two*** spread-spectrum radio techniques and a diffuse infrared specification.
- **Wireless Frequency Range**
  - IEEE 802.11b /g - 2.4GHz to 2.4835GHz
  - IEEE 802.11a - 5.15GHz to 5.35GHz and 5.725GHz to 5.825GHz
- These frequency bands are recognized by **regulatory agencies**, e.g., FCC (USA), ETSI (Europe), MKK (Japan) and NCC (Taiwan) for **unlicensed radio operations.**
- **Sharing the space with low-power signals** from home electronics like cordless phones, microwaves, and garage-door openers – ***interference.***

802.11: two spread-spectrum radio techniques

- Defines data rates of 1Mbps and 2Mbps via radio waves.
- Frequency Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS)
  - Fundamentally different signaling mechanisms.
  - Do ***not*** interoperate with one another.

Frequency Hopping Technique (1/2)

- The 2.4 GHz band is divided into *75* one-MHz subchannels.
- The sender and receiver agree on a ***hopping pattern***, and **data is sent over a sequence of the subchannels**.
- *Each* conversation occurs over a *different* hopping pattern.
- The patterns are designed to minimize the chance of **two** senders using the **same** subchannel at the **same** time instant.

Frequency Hopping Technique (2/2)

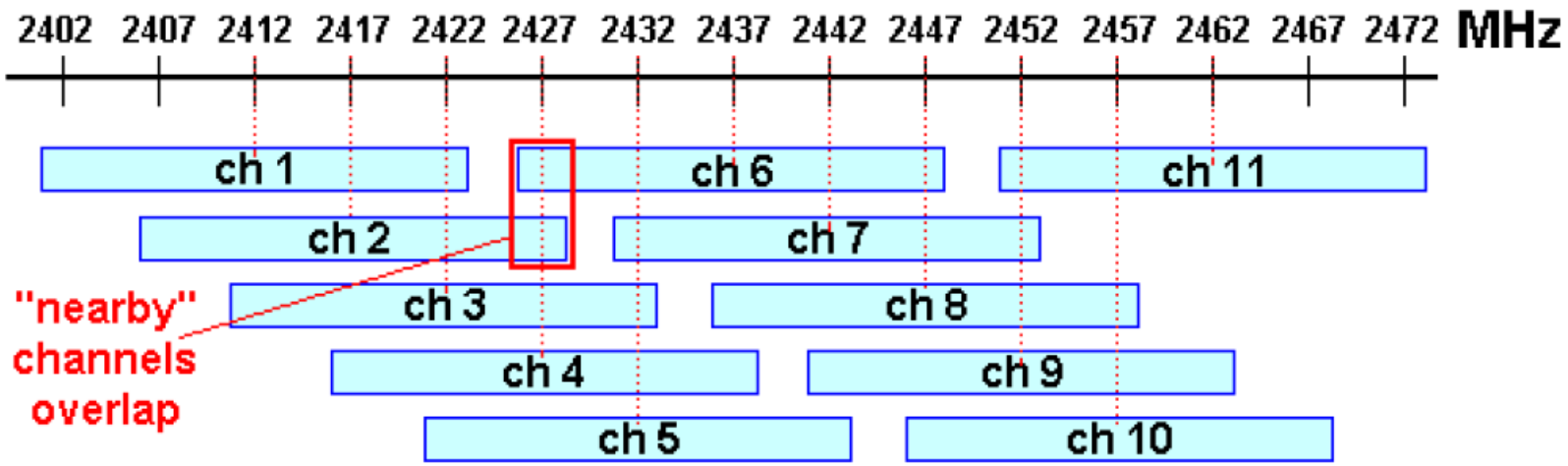
- Relatively simple radio design
- *Limited* to speeds of *no* higher than 2 Mbps
  - Mainly due to FCC regulations that **restrict subchannel bandwidth to 1MHz**
  - It spreads the usage across the entire 2.4 GHz band
  - It requires stations **hop often**, which leads to a high amount of ***hopping overhead***.

Direct Sequence Signaling Technique

- Divides the 2.4 GHz band into ***14*** **twenty-two MHz channels**
- Adjacent channels overlap one another *partially*, with ***3 of the 14*** **being completely non-overlapping**.
- Data is sent across *one* of these **22 MHz** channels without hopping to other channels.

802.11: 11 channels

Only 3 non-overlapping channels available for 802.11b/g (2.4 GHz)



Regulatory Domain	Allowed Channels
US (FCC) / Canada (IC)	1 to 11 (2.412-2.462 GHz)
Europe, excluding France & Spain (ETSI)	1 to 13 (2.412-2.472 GHz)
France	10 to 13 (2.457-2.472 GHz)
Spain	10 to 11 (2.457-2.462 GHz)
Japan (MKK)	14 (2.484 GHz)

Direct Sequence Signaling Technique – Chipping

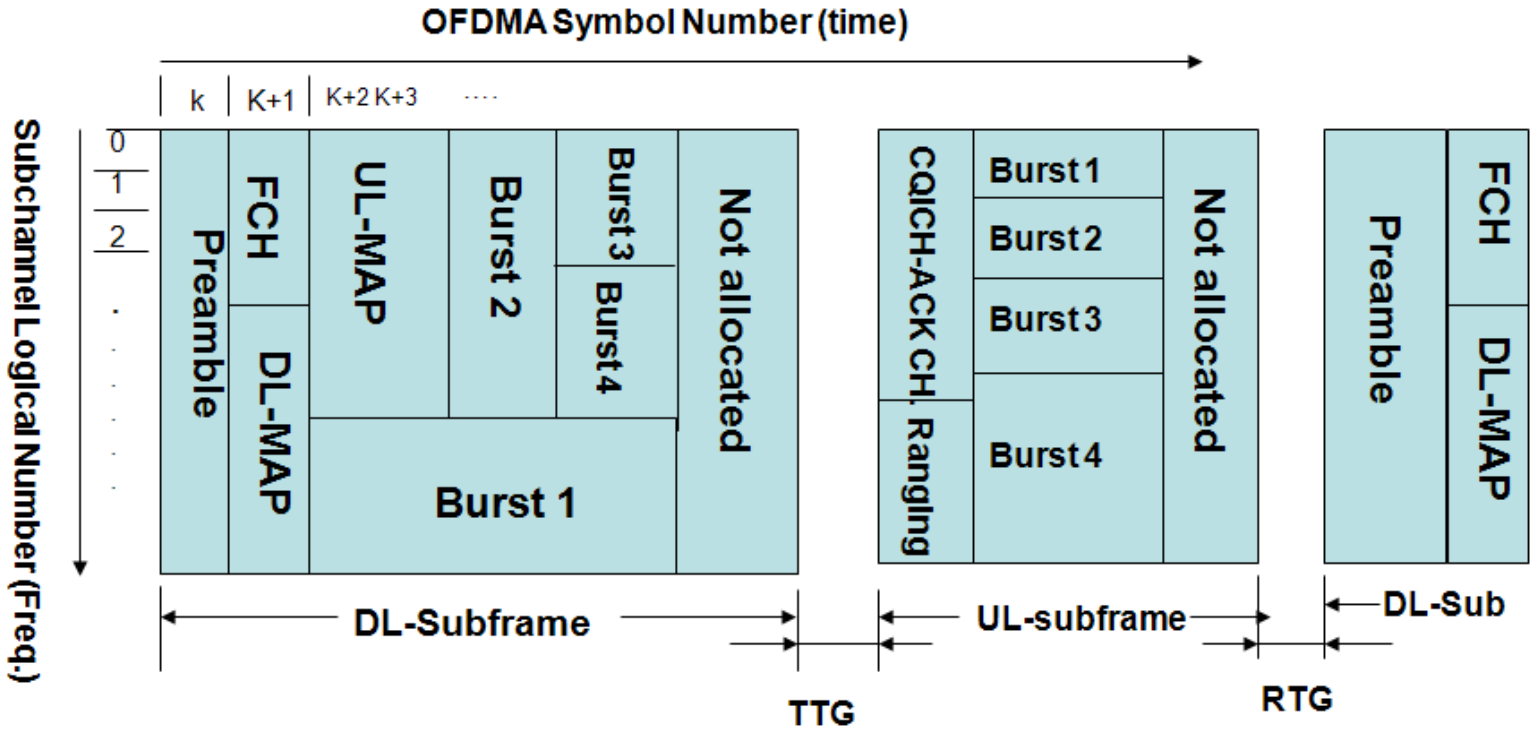
- "Chipping" - A technique used to *compensate for* ***noise*** on a given channel.
- **To *reduce* number of retransmission and noise**, each bit of user data is converted into a series of **redundant bit patterns called "chips."**
- The inherent redundancy of each chip combined with spreading the signal across the **22 MHz** channel provides for a form of *error checking* and *correction.*
- If part of the signal is damaged, it can still be recovered in many cases, minimizing the need for retransmissions.

IEEE 802.11 Wireless LAN: 802.11 b/g/a/n/ac/ax

- 802.11b
  - **2.4-5 GHz unlicensed** spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - **all** hosts use **same** chipping code
- 802.11a
  - **5-6 GHz** range
  - up to 54 Mbps
- 802.11g
  - 2.4-5 GHz range
  - up to 54 Mbps
- 802.11n: **multiple antennae**
  - 2.4-5 GHz range
  - up to **600 Mbps** (40MHz, **MIMO 4x150Mbps**)
  - improved network throughput (indoor 70m, outdoor 250m)

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

Orthogonal Frequency-Division Multiplexing (OFDM)



- A large number of closely-spaced *orthogonal sub-carriers* are used to carry data.
- The total data rates is maintained similar to conventional *single-carrier* modulation schemes in the same bandwidth.
- The data is divided into **several parallel** data streams or channels, one for each sub-carrier.
- Each sub-carrier is modulated with a conventional modulation scheme (e.g., QAM PSK) at a low symbol rate.

OFDM: advantages

- Compared to single-carrier schemes, it has the ability to cope with severe channel conditions, e.g.,
  - *attenuation*
  - *interference*
  - frequency-selective *fading* due to *multipath*

  without complex equalization filters.
- Channel equalization is simplified
  - OFDM may be viewed as using many slowly-modulated *narrowband* signals rather than one rapidly-modulated wideband signal.

802.11b - Dynamic Rate Shifting (1/2)

- The goal is to support very *noisy* environments as well as *extended range*.
- Data rates are ***automatically*** **adjusted** to compensate for the changing nature of the radio channel.
- When devices move **beyond** the optimal range for 11 Mbps operation, or **substantial interference** is present, 802.11b devices will transmit at *lower* speeds, falling back to 5.5, 2, and 1Mbps.

802.11b - Dynamic Rate Shifting (2/2)

- Likewise, if the device **moves back** within the range of a higher-speed transmission, the connection will **automatically speed up** again.
- Rate shifting is a physical-layer mechanism *transparent* to the user and the upper layers of the protocol stack.

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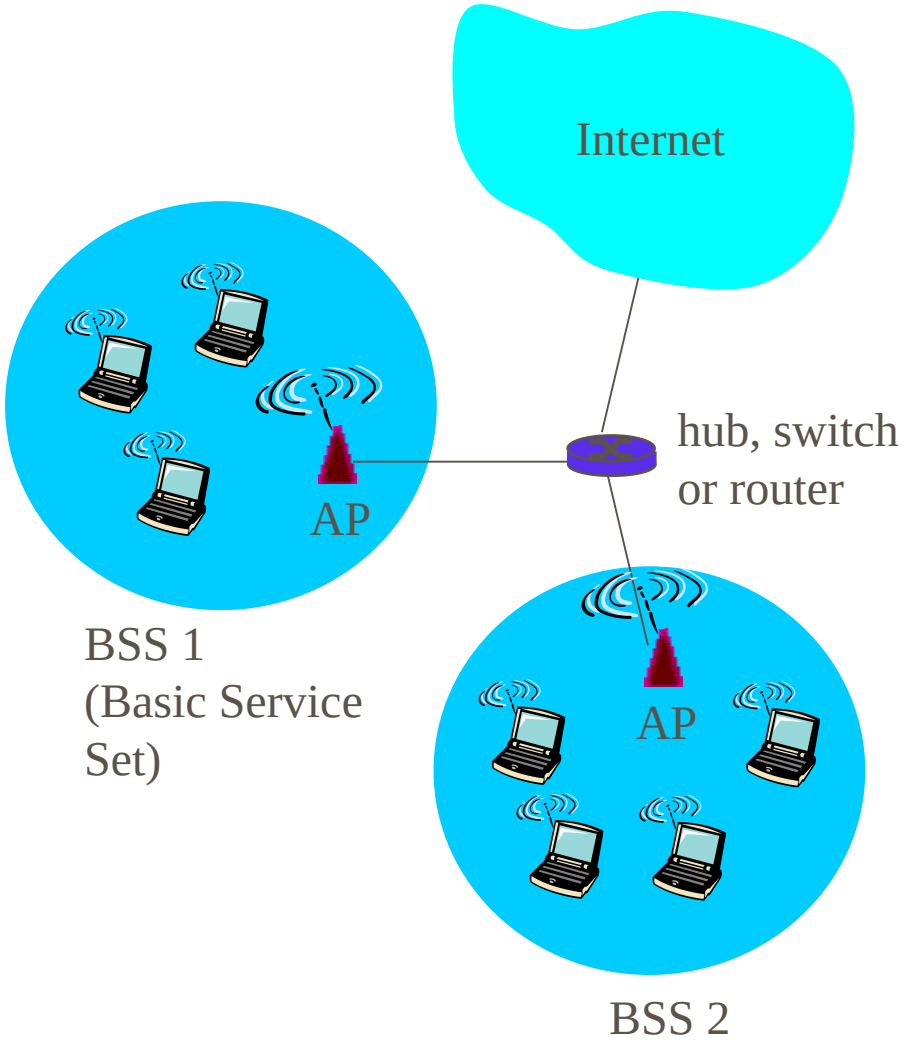
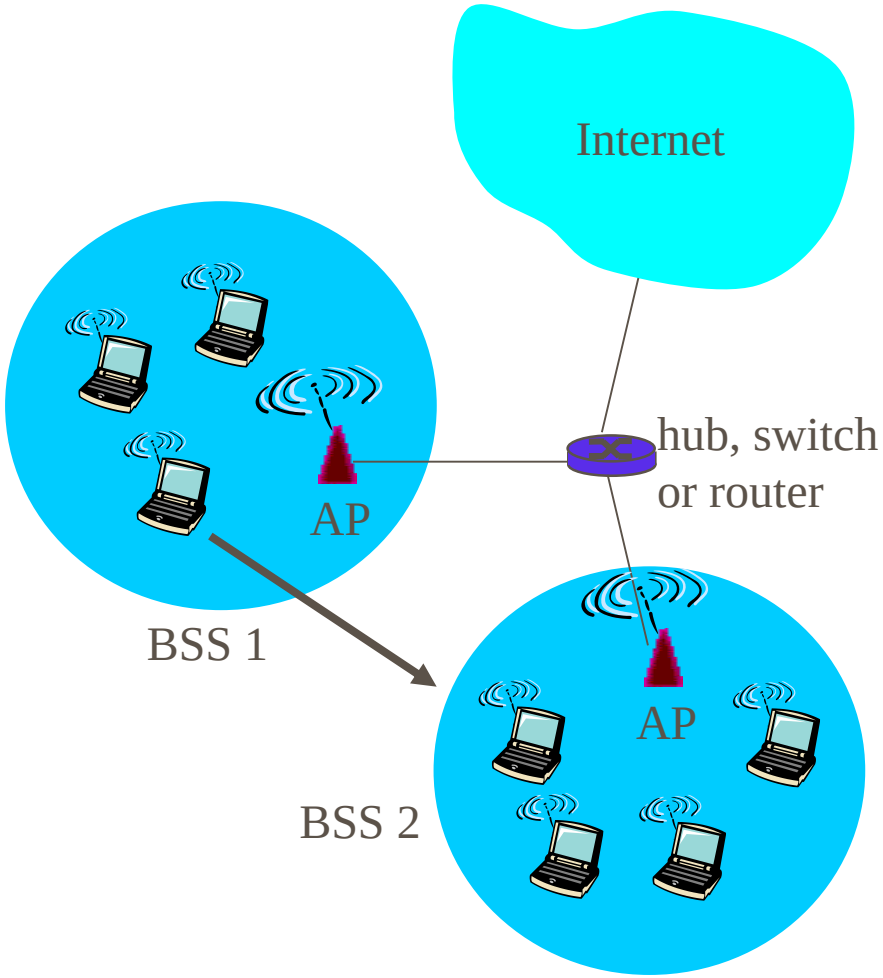
802.11 LAN: The MAC Layer Services (1/2)



- Association - the establishment of wireless links between wireless **clients** and **APs**.
- Data transfer - Wireless clients use a ***Carrier Sense Multiple Access with Collision Avoidance*** **(CSMA/CA)** algorithm as the ***media access*** **scheme**.

802.11 LAN: The MAC Layer Services (2/2)



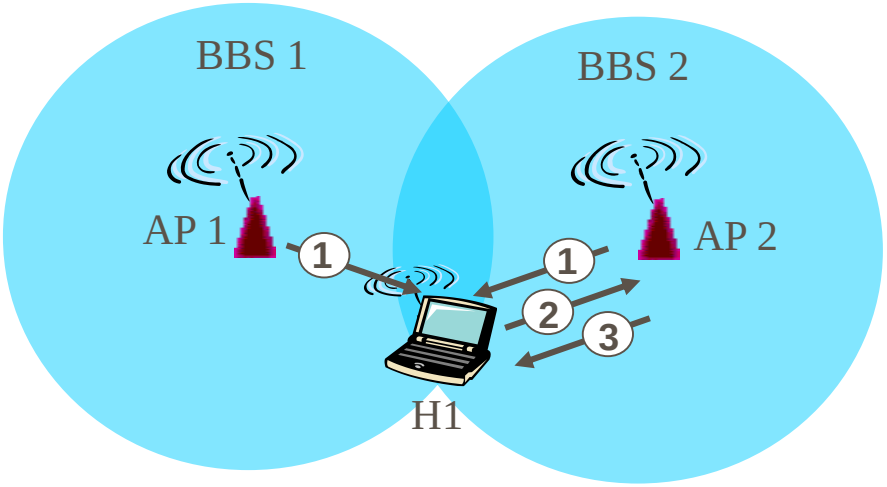
- Re-association - This takes place *in addition to* association when a wireless client **moves** from one BSS to another.
- Authentication - To prove a client identity

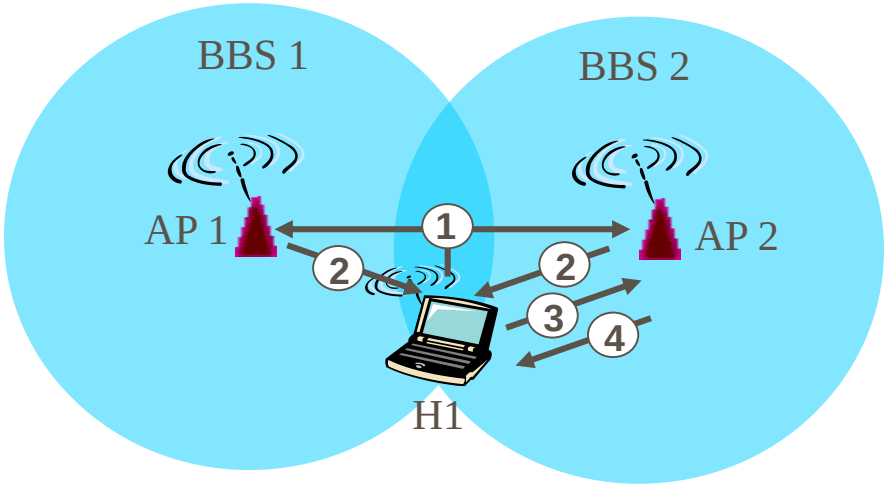
  (prove AP identity)

802.11: Channels, association

- 802.11b: 2.4GHz-2.485GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- host: must *associate* with an AP
  - **scans** channels, **listening** **for** ***beacon frames*** containing **AP's name (SSID) and MAC address**
  - **selects** AP to associate with
  - may perform **authentication**
  - typically runs DHCP to get IP address in AP's subnet

802.11: passive/active scanning





Passive Scanning (scan 11 channels):

(1) beacon frames (containing SSID and MAC address) sent from APs

(2) association Request frame sent: H1 to selected AP

(3) association Response frame sent: selected AP to H1

Active Scanning:

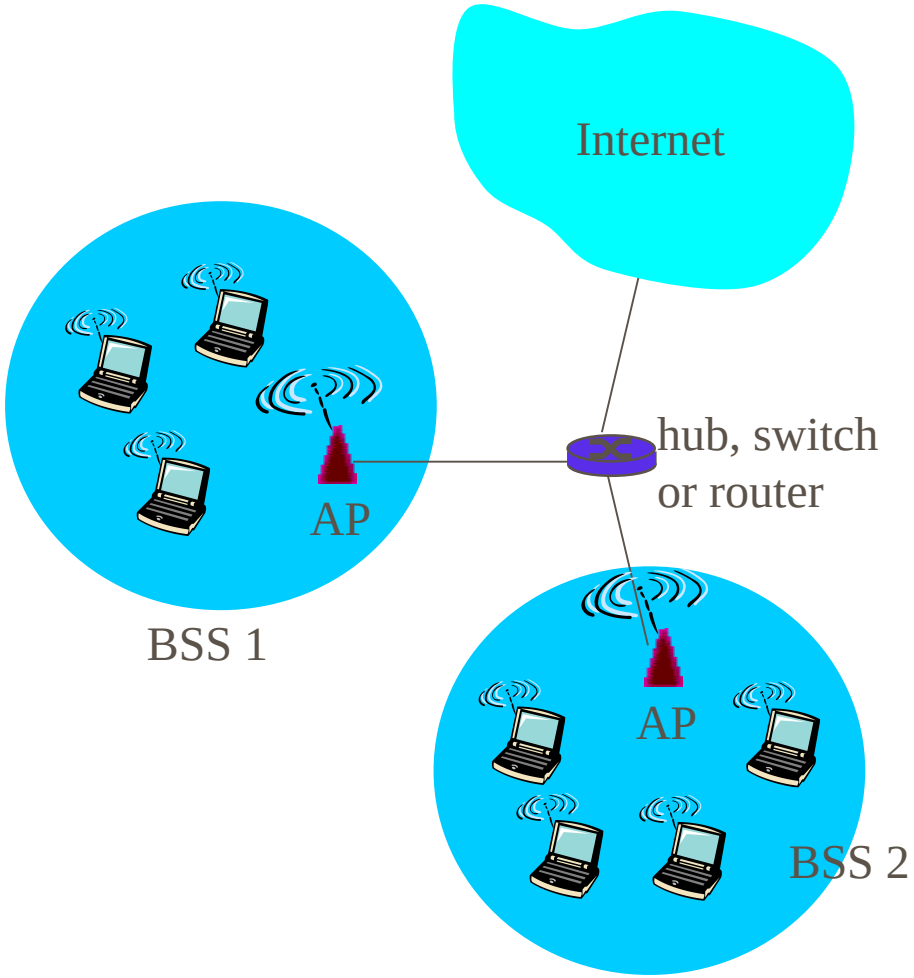
(1) Probe Request frame broadcast from H1

(2) Probes response frame sent from APs

(3) Association Request frame sent: H1 to selected AP

(4) Association Response frame sent: selected AP to H1

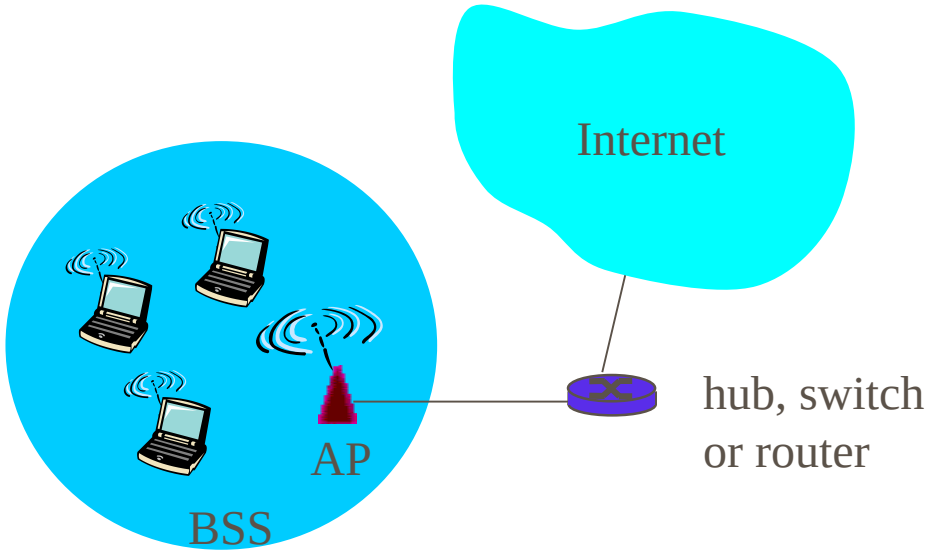
Extended Service Set (ESS)



- Two adjoining Basic Service Sets **form** an Extended Service Set (ESS) if they are defined by a *common ESSID*.
- If a common ESSID is defined, a wireless client can roam from one area to another.

WLAN Throughput …

- It is a *multi-access* network – medium access control scheme is needed.
- Depends on several factors, including
  - number of users
  - microcell range
  - Interference (come back later)



Carrier Sense Multiple Access with **Collision Avoidance** (CSMA/CA)

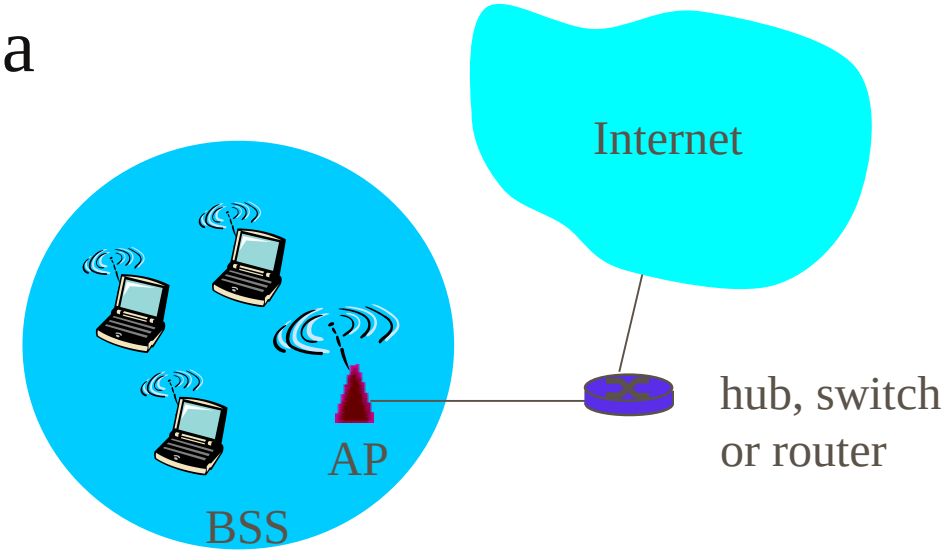
- Distributed Coordination Function (DCF)
- The fundamental access method of 802.11 MAC
- ***A random backoff time*** **following a busy medium condition.**
- Immediate positive acknowledgement.

InterFrame Space (IFS)

- IFS - A time interval that a STA must **wait** before transmitting a frame

Four IFSs are defined.

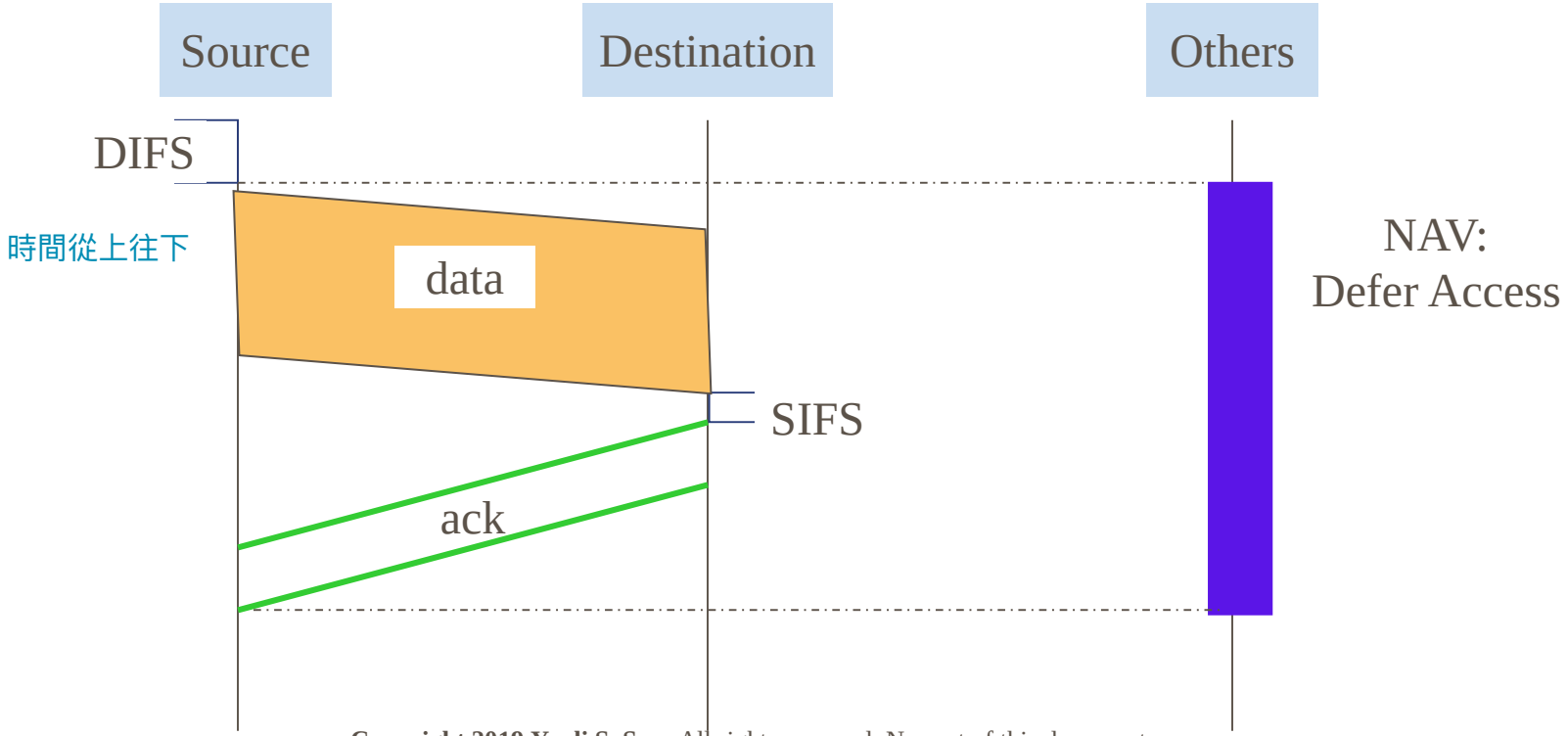
1) DIFS (DCF)
   - for frames sent in Contention Period (CP).
2) SIFS (short)
   - For **control** frames like ACK.
3) EIFS (Extended)
   - for frame **retransmission**.
4) PIFS (Point Coordination Function)
   - for frames sent in CFP of PCF.



- **SIFS < PIFS < DIFS < EIFS**
  - The shorter the IFS, the higher the priority to access WM.
- The IFS timing is independent of the STA bit rate.
- It is fixed for each PHY.

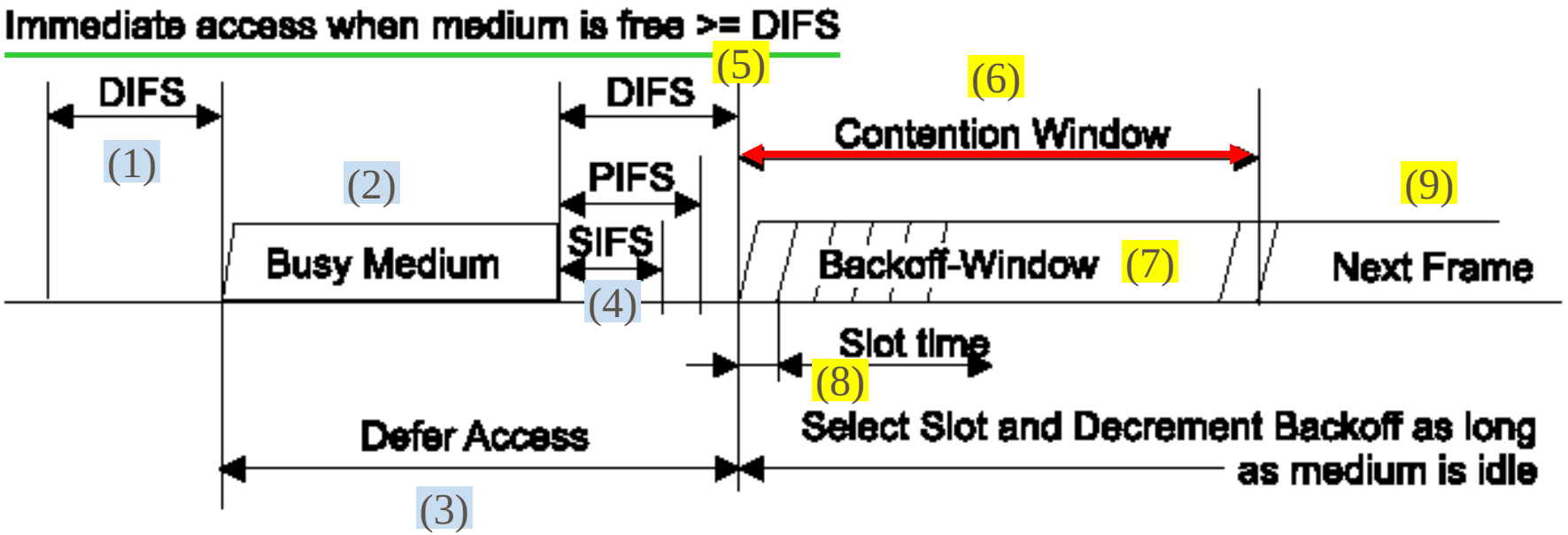
Data Transmission and MAC-level Acknowledgment

- Immediate Positive ACK frame for **error detection**
- **Retransmission** for **error recovery**



Four Interframe Spaces (IFSs)

- DIFS (DCF) : for frames sent in Contention Period (CP)
- SIFS (short) : for control frames like ACK
- EIFS (extended) : for frame retransmission



CSMA/CA Protocol

- Carrier sense
  - When a node has a packet to transmit, it first **listens** to ensure no other node is transmitting
- Collision avoidance
  - If the channel is *clear*, it chooses a random *"backoff factor".*
  - During periods if the channel is *clear*, the node *decrements* its backoff counter.
  - When the backoff counter reaches *zero*, the node *transmits* the packet.

➢ The random *Backoff factor is used to minimize the probability of collision.*

CSMA/CA Protocol (cont'd)

- Collision is unavoidable!
  - binary exponential backoff of CW **(Contention Window)** range
- In DCF, every STA computes its own backoff time。

Backoff time =INT(CW*Random())slot time***

  - **CW:** an integer between [CW_{min}, CW_{max}]
    - initial CW_{min} =7 and CW_{max}=255。
  - Random(): a number within 0 and 1.
  - INT(x): the largest integer <= x.

Why Collision Avoidance …

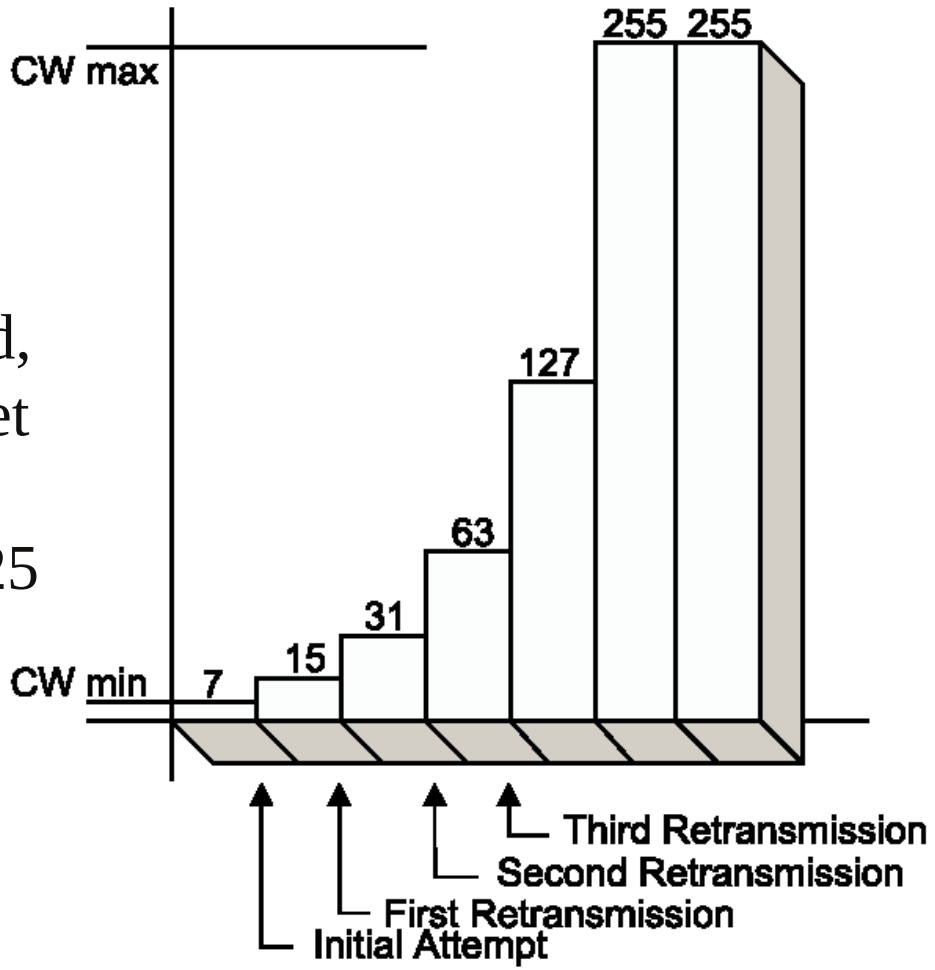
- Collision detection, as is employed in Ethernet, *cannot* be used for the radio frequency transmissions.
  - When a node is transmitting it ***cannot*** hear any other node in the system which may be transmitting.
  - Its own signal will drown out any others arriving at the node.
- Since the probability that two nodes will choose the same backoff factor is *small*, collisions between packets are *minimized*.

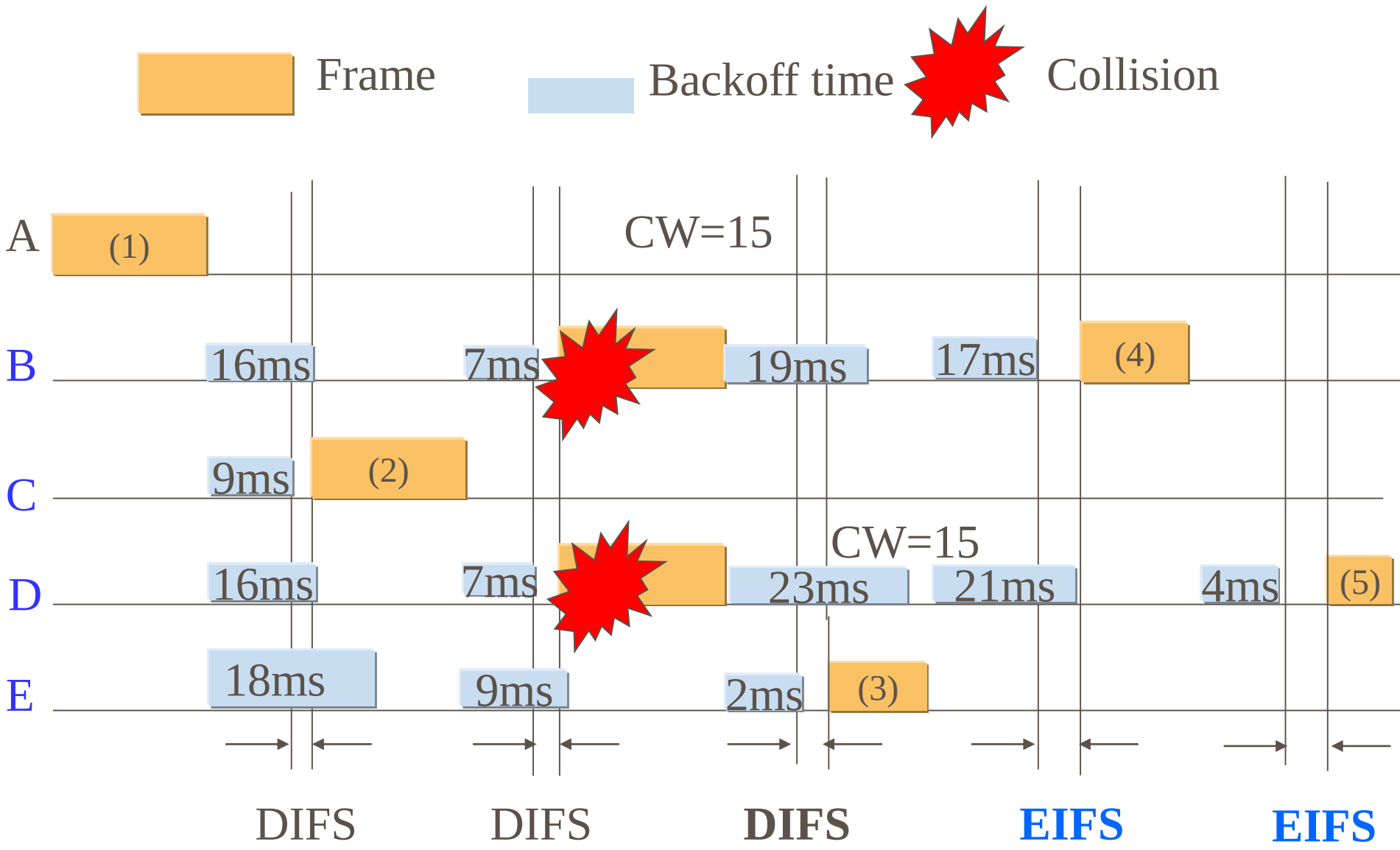
Collision and Retransmission

- When **two or more** STAs have zero backoff time, they will transmit frames at the same time, resulting in collision.
- All transmitting STAs will **not receive ACKs** from target receivers.
- After collision, each STA enters the **mode of frame retransmission** in which the value of IFS is set to EIFS.
- The CW value is **doubled**, upper bounded by CW_{max}.

Collision and Retransmission (cont'd)

- For a frame, if continuously collided, the value of CW is set as follows: 7,15,31,63,125,255,255,255,…



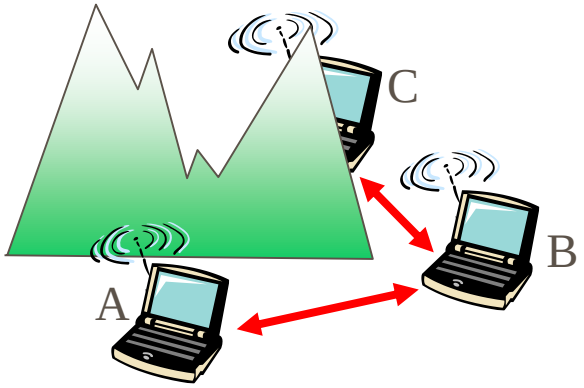


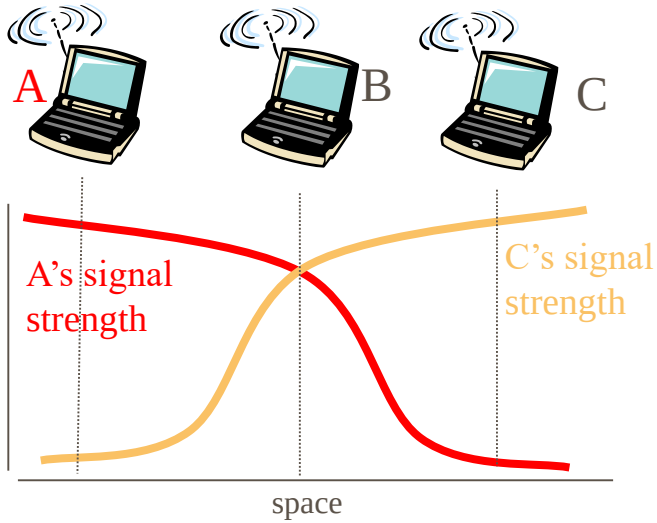
Backoff in CSMA/CA vs. in CSMA/CD

- IEEE802.11使用的backoff演算法與在IEEE802.3中所使用的backoff演算法基本上是相同的 (exponential backoff for retransmission)。
- 兩者最大不同的地方在於CSMA/CD中，是在STA發生collision後才啟動backoff演算法。而在CSMA/CA中，每個STA**在發生collision前就執行backoff演算法**。
- CSMA/CA中先執行backoff演算法最主要的目的就是要減少collision發生的機率，因為在wireless環境下collision的監測並不容易實行。解決collision所必須付出的成本遠比在wired情況下大，因此必須盡量減少collision發生。

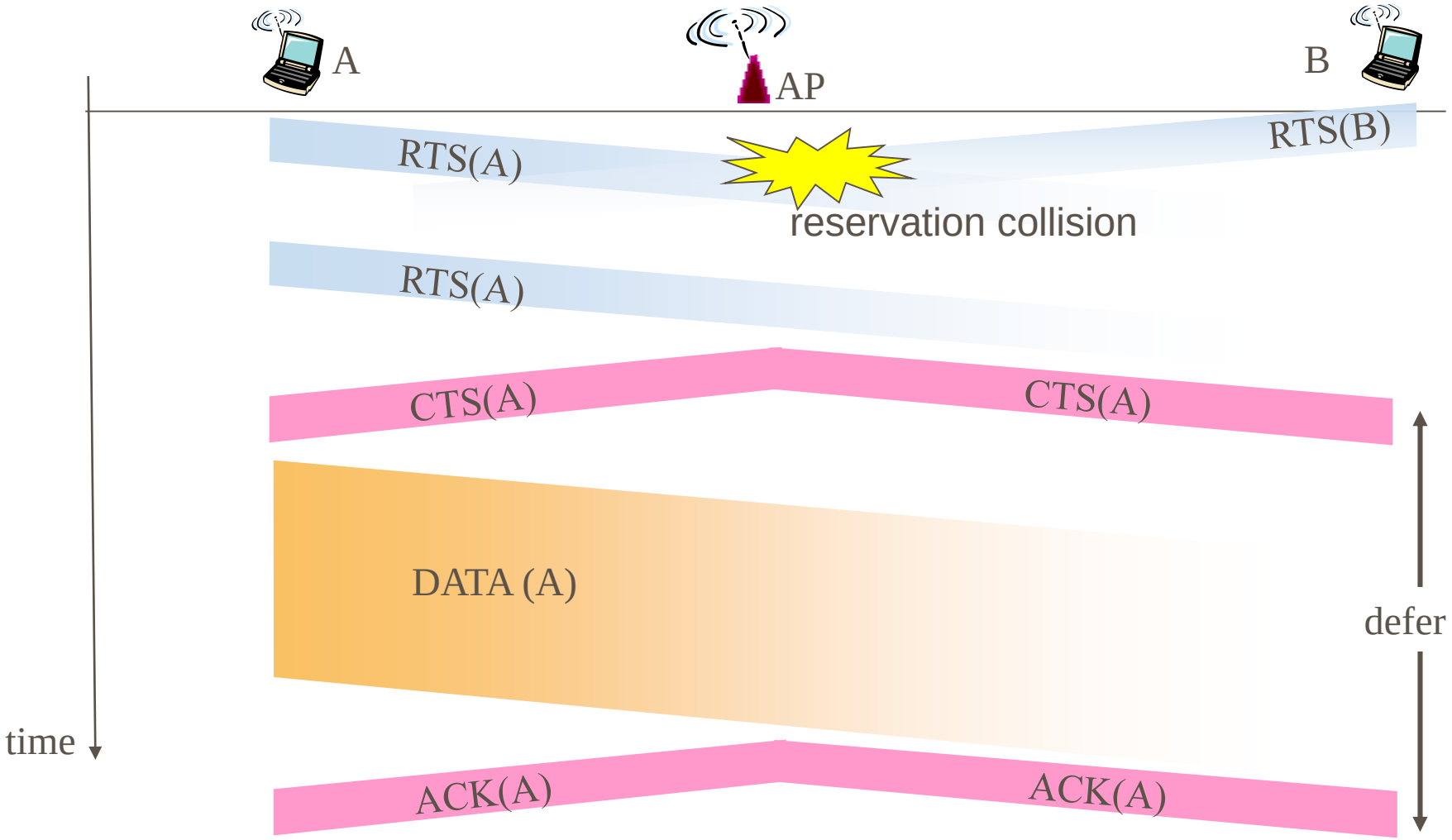
IEEE 802.11: multiple access

- CSMA – "sense before transmitting"
  - don't collide with ongoing transmission by other node
- *No* collision detection!
  - Wireless station is difficult to receive (sense) collisions when transmitting due to weak received signals (fading)
  - can't sense all collisions in any case: hidden terminal, fading

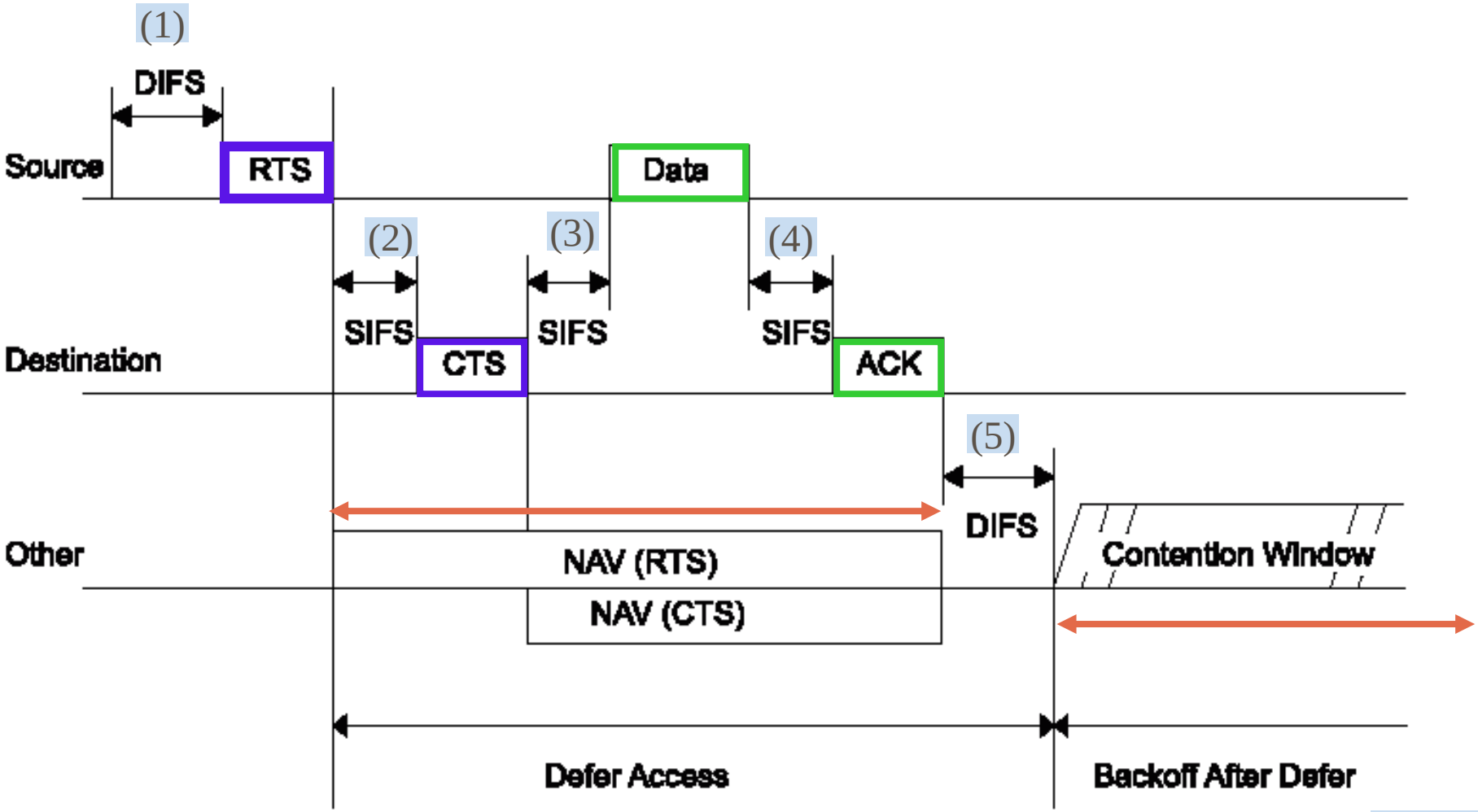




Collision Avoidance: RTS (Ready-to-Send) - CTS (Clear-to-Send) exchange



RTS/CTS in DCF (1/2)

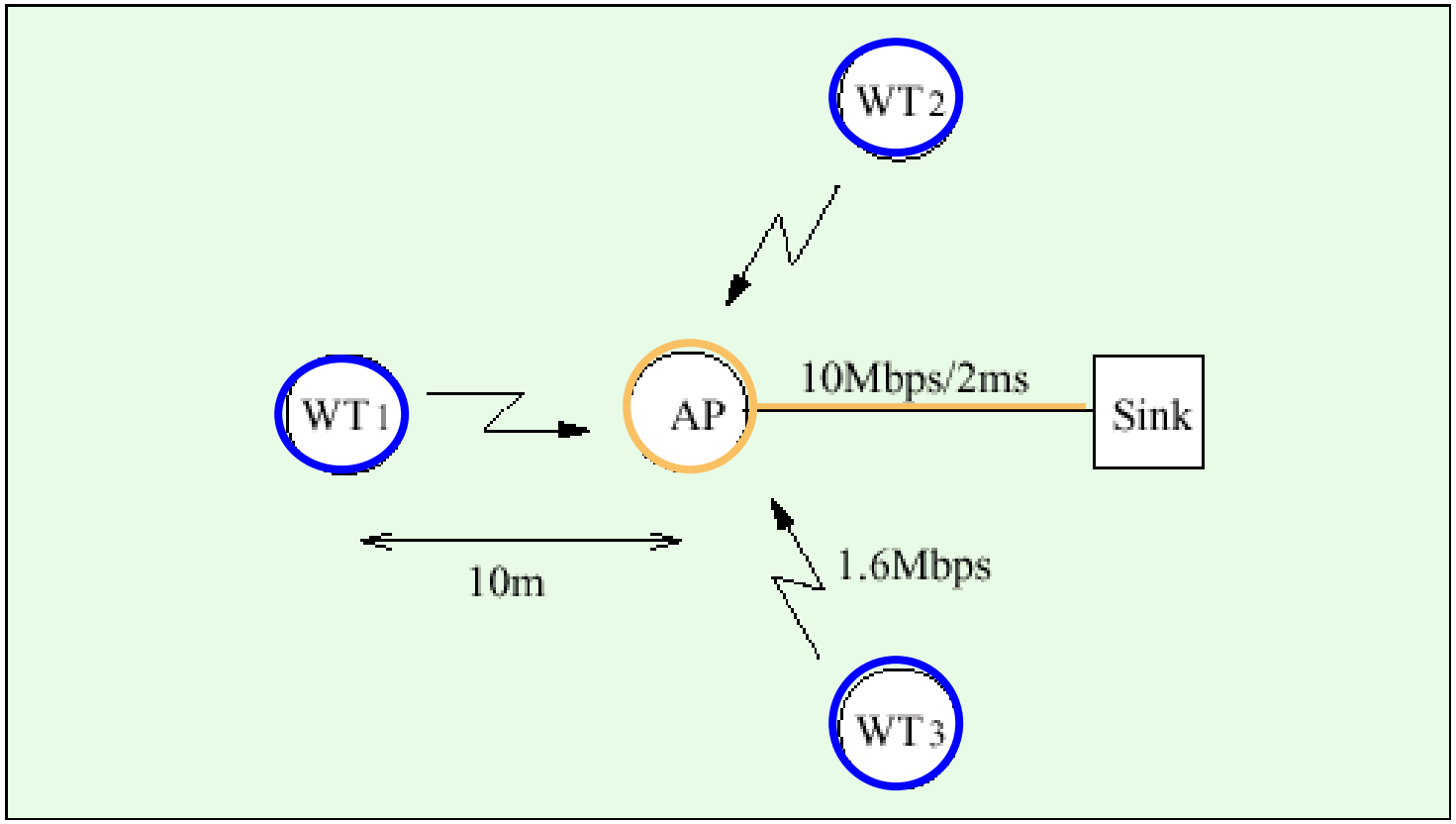


Back

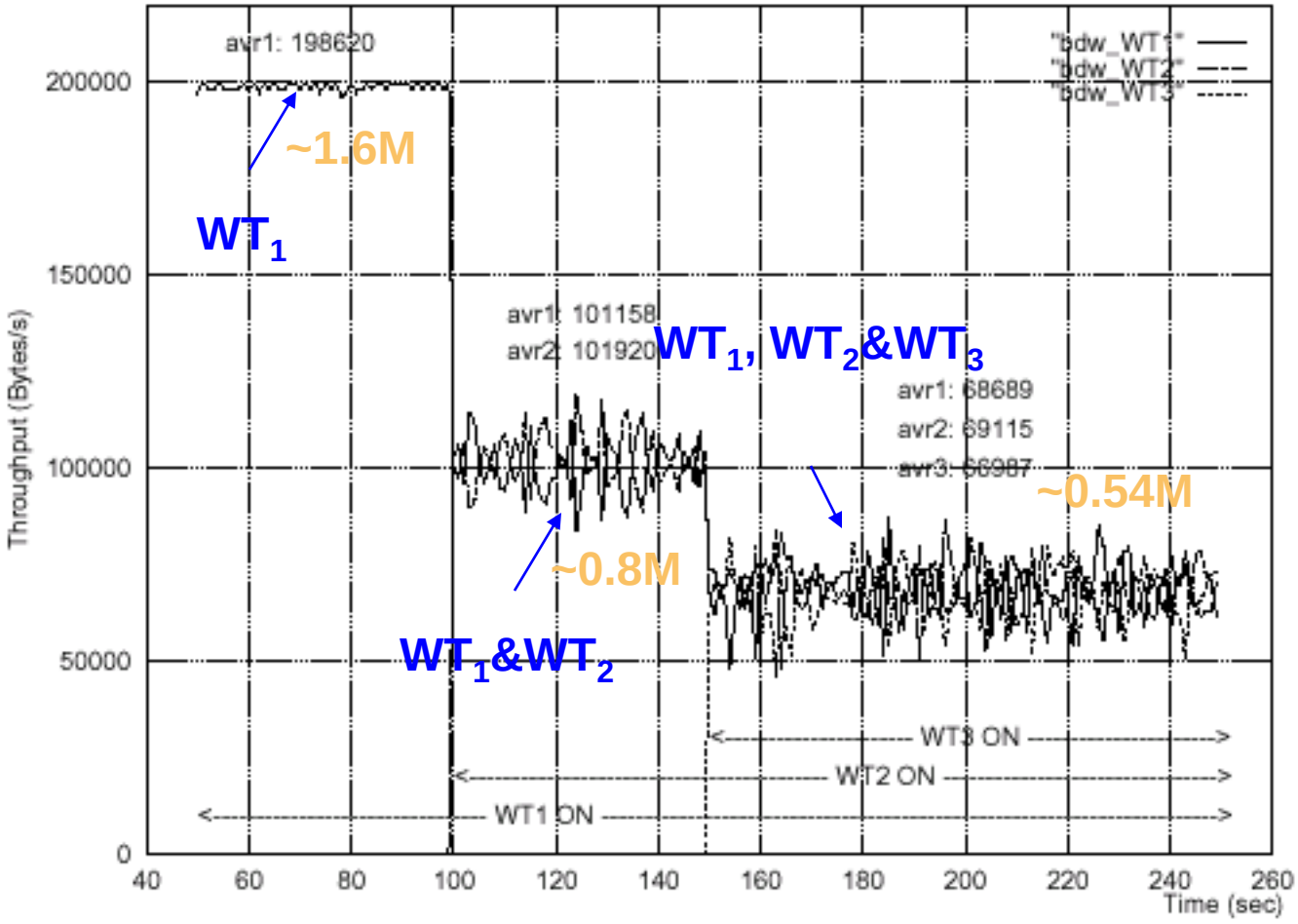
RTS/CTS in DCF (2/2)

- A STAs can be configured to use RTS/CTS either *always*, *never* or *only* **on frames longer than a specified length** (RTS_Threshold).

Simulation Topology



UDP flows using Legacy CSMA/CA



Discussion: WLAN Performance

- Standard CSMA/CA is a *probabilistic* method.
- When system load is low, CSMA/CA provides a simple, *fair* solution.
  - Performance instability – **large** throughput fluctuation; delay, jitter and drop rate – **unpredictable**, large variation.
- When system load is *high*, **collision overhead** will make the throughput low.

The end. ☺

802.11ay: millimeter-wave spectrum

- Large swaths of contiguous millimeter-wave spectrum are being opened in the U.S.
- Using some of these bands for new and interesting high data throughput applications.
- For example, 802.11ay for approximately 4 GHz, up to approximately 8 GHz.

8K: 7680×4320

- **8K Ultra High Definition (UHD)**, also known as **Full UHD**, **FUHD**, or **Full Ultra HD.**
- Horizontal and vertical resolution: total image dimensions of (7680×4320)
  - 2x2 times the 4K UHD;
  - 4x4 times the 1080p (Full HD);
  - six times the linear resolution of 720p.
- smooth gradients and high levels of sharpness that objects shown can appear even more realistic than in real world, referred to as hyperrealism.

Japan NTT DoCoMo and NEC: streaming live 8K live video over 5G

- Japanese telco NTT DoCoMo and compatriot conglomerate NEC.
- "8K ultra-high-definition live video featuring a steam locomotive train was transmitted from a 5G base station installed along a railroad to a 5G mobile station located inside a running SL train and put on an 8K display," NEC said on Friday about the test conducted in November.
- The test also streamed 4K content to passenger handsets, however with the lack of 5G handsets available, the content hit the passenger mobiles via Wi-Fi from a 5G station on the train.

Japan NTT DoCoMo and NEC: streaming live 8K live video over 5G

- The NEC base stations used supported 4.5GHz and 28GHz bands, with the test itself forming **part of a Japanese government project** to examine the **outdoor use of 5G systems** that have average data speeds of 4Gbps to 8 Gbps.

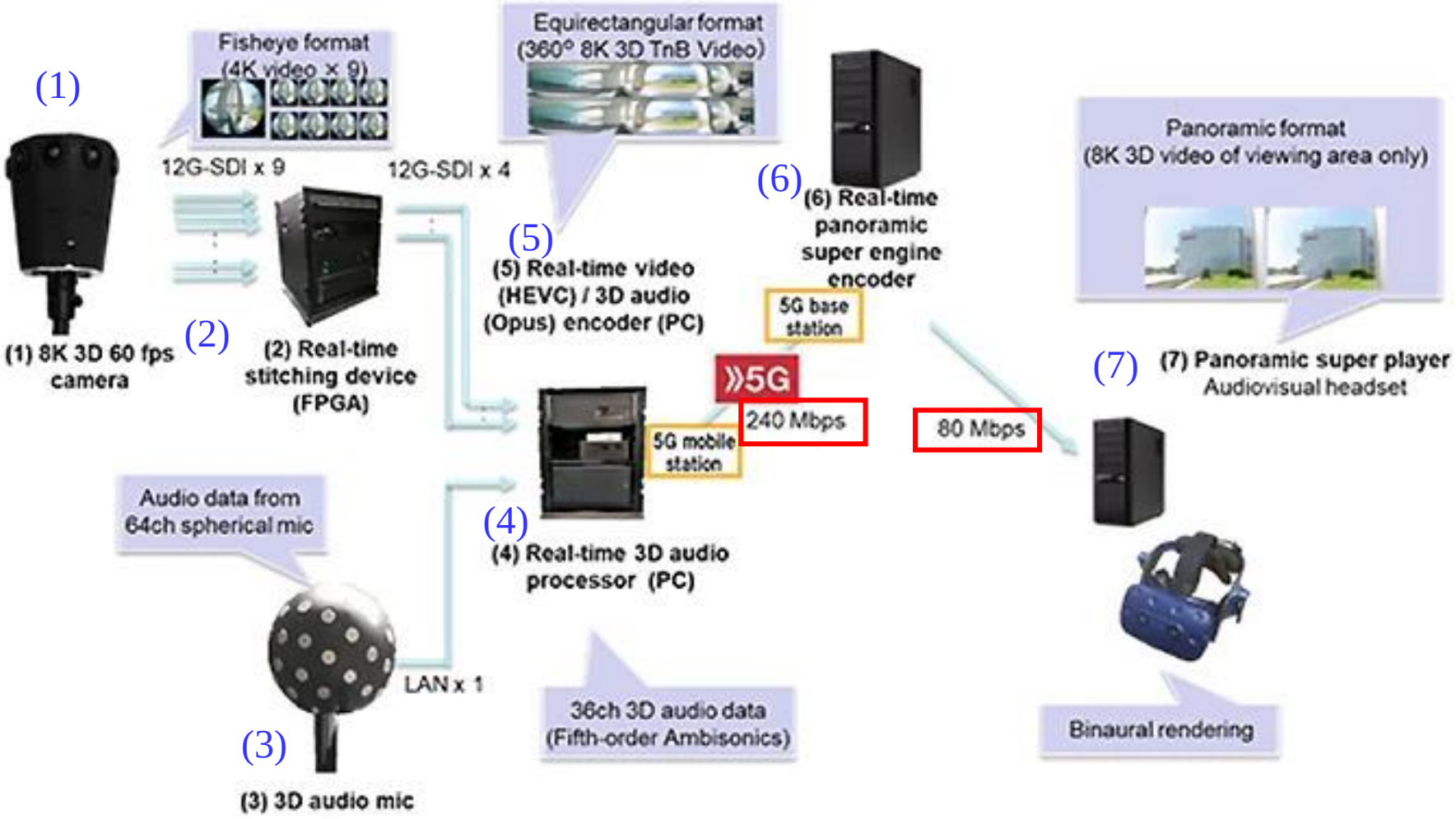
NTT Docomo creates first 5G-ready streaming system for 8K stereoscopic VR

- FEBRUARY 4, 2019
- first 8K 3D virtual reality system" for live 5G streaming at 60 frames per second (FPS).
- Designed to facilitate streaming of high-quality panoramic VR content from any location with a 5G network.
- The system consists of an 8K 3D camera with 360-degree video recording abilities, a Yamaha-developed spherical 3D microphone with 64 channels of audio recording, several computers, and a 5G base station.
- Docomo, Japanese TV station HTB, and NEC successfully tested the system yesterday at a rehearsal for the famous Sapporo Snow Festival in Hokkaido.
- In hopes that **VR headset wearers** will enjoy ultra high resolution, stereoscopic live videos that can be viewed from different angles.
- Processing and bandwidth demands are incredible, as the output from multiple camera lenses needs to be **instantly stitched together** multiple times each second and then streamed to a 5G network, along with perfectly synchronized 3D audio.

super-fast video stitcher

- Multiple computers turn the 3D camera's **nine** 4K video streams into **two** 360-degree 8K 3D videos *in real time*, then compress the videos for streaming over 5G.
- Another machine turns a 3D audio mic's 64 sound channels into 36 channels of 3D audio.
- The resulting stream includes panoramic 8K 3D video, plus stereo audio that changes based on the user's tracked head position.

Streaming System



12G-SDI

- **SDI:** Serial Digital Interface (SDI) is a family of digital video interfaces first standardized by SMPTE (Society of Motion Picture and Television Engineers) in 1989.
- **SDI has been the professional standard for AV interfaces since the 90s,**
- **with 4K and UHD become much more prevalent video formats for broadcasters (and requiring a massive four times the bandwidth of HD,** 12G is an SDI standard developed to support greater resolution, frame rates and colour fidelity. It provides **four** times the bandwidth of HD, carrying **12Gbps, making it ideal for the 4Kp60 format.**
- *from SD-SDI, HD-SDI (~1.5Gbps) to 3G-SDI, 6G-SDI, 12G-SDI (~12Gbps) and 24G-SDI*
- **SD-SDI:** The SD-SDI standard support the 270 Mb/s bit rate. for digital video transmission over coaxial cable (standard 75-ohm cable, the same type used in most home television (TV) installations.) The most common data speed is 270Mbps up to 540 Mbps.
- The SDI standard uses data words that are 8 or 10 bits in length. Signals are uncompressed and are self-synchronizing between the source (transmitter) and destination (receiver).

- Now that the streaming system is ready, the question is how 8K 3D VR content will actually be viewed by end users. Docomo describes its viewing device as a "panoramic super player audiovisual headset" and shows an image of an HTC Vive Pro, which is likely only being used to demonstrate the platform.

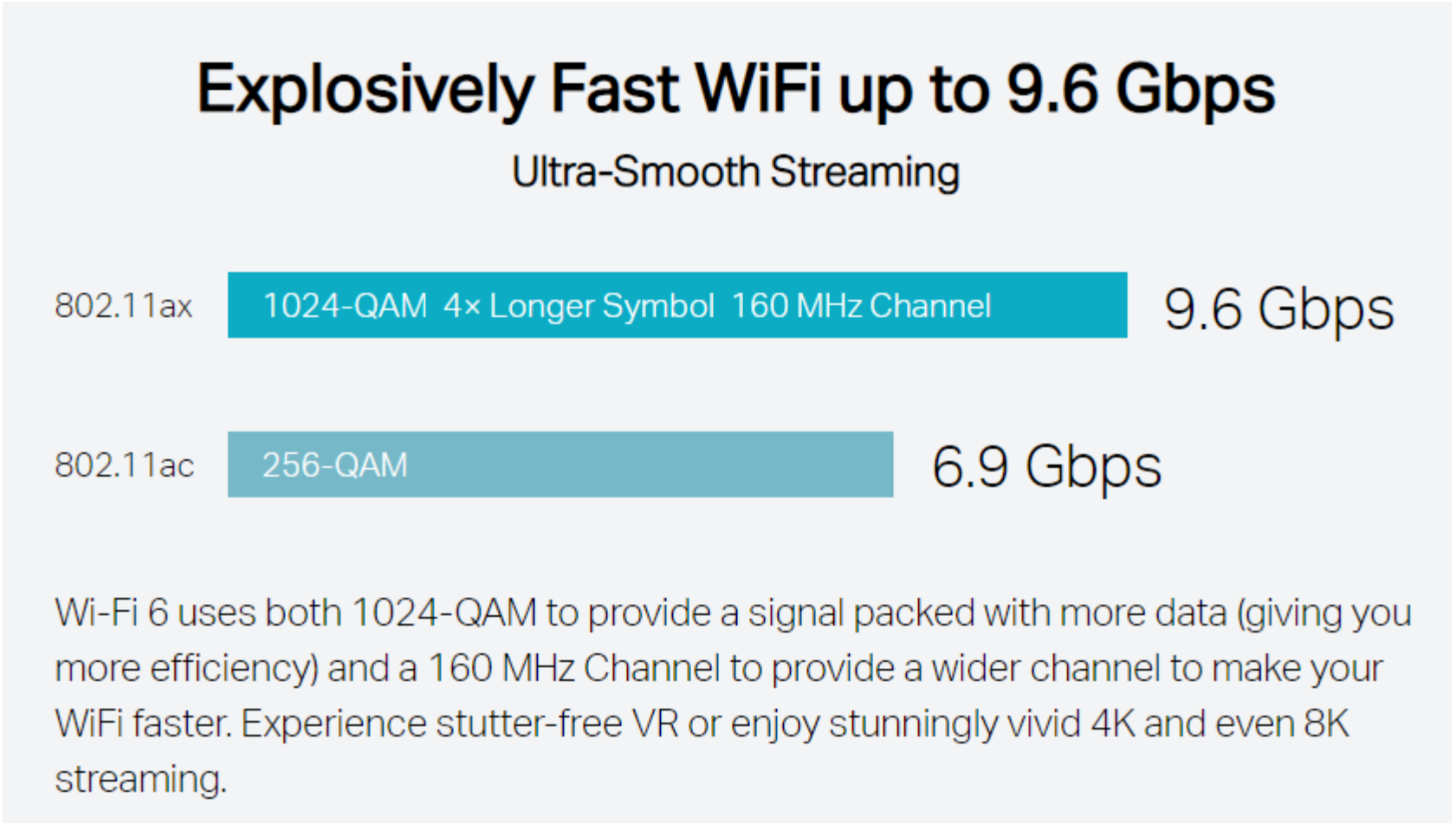
Fixed Wireless Access (FWA)

- It works primarily when **two fixed locations** are required to be connected directly.
- Traditionally, it is done by using leased lines or cables.
- FWA is cheaper alternative, specifically in densely populated areas.
- Usually, the fixed wireless broadcasting equipment is hoisted at building roofs on both the locations to ensure an obstruction free data transmission, in line of sight or is in a similar direction for better signal reception.
- Moreover, FWA can also be implemented in point-to-multipoint and multipoint-to-multipoint transmission modes.

Wi-Fi 6

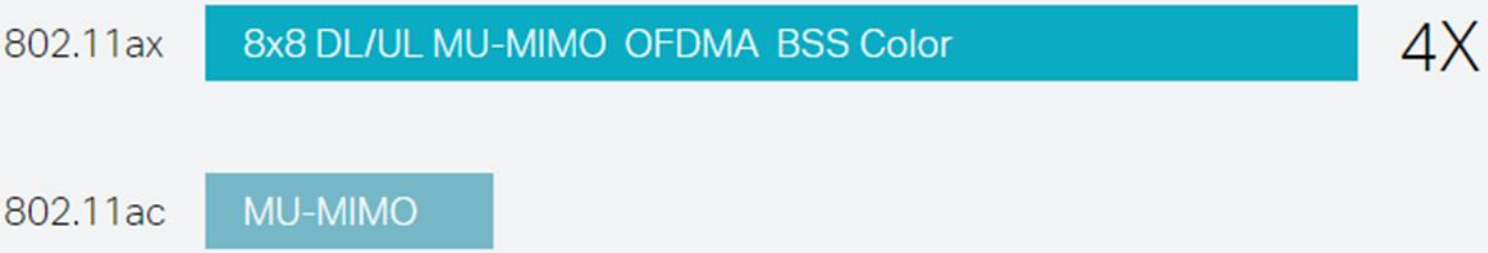
- also known as “AX **WiFi**" or "802.11ax **WiFi**”
- It builds and improves on the current 802.11ac standard.
- Wi-Fi 6
  - was originally built in response to the growing number of devices in the world.
  - is designed to improve *speed*, increase *efficiency* and reduce congestion in heavy bandwidth usage scenarios.
- If one owns a VR device, multiple smart home devices, or simply have a large number of devices in a household, then a Wi-Fi 6 router might just be the best WiFi router for you.

https://www.tp-link.com/us/wifi6/



4x More Capacity for More Devices

Ideal for Crowded Networks



Wi-Fi 6 uses 8x8 uplink/downlink, MU-MIMO, OFDMA, and BSS Color to provide up to 4x larger capacity and to handle more devices. Come home to a virtually flawless smart home experience or throw house parties with a network built to handle all your guests and their devices.

Wi-Fi Technology

- Wi-Fi technology turns 20 in 2019.
- It has proven to be successful beyond the wildest expectations.
- FCC considers allowing 1,200 MHz of spectrum in the 6 GHz band (5.925-7.125GHz) for unlicensed use, as well as similar work in the E.U., to free up enough spectrum to move Wi-Fi forward into a new era of high performance.

Why make 6GHz band compelling for unlicensed use?

- Visual Networking Index (VNI) forecasts that by 2022, Wi-Fi will carry 51% of global IP traffic, more than any other wired or wireless access technology.
- The total number of Wi-Fi hotspots (including home spots) is expected to reach 549 million by 2022.
- 70 MHz in the 2.4-GHz band; 500 MHz in the 5-GHz band