# Computer Network

## Wireless Network

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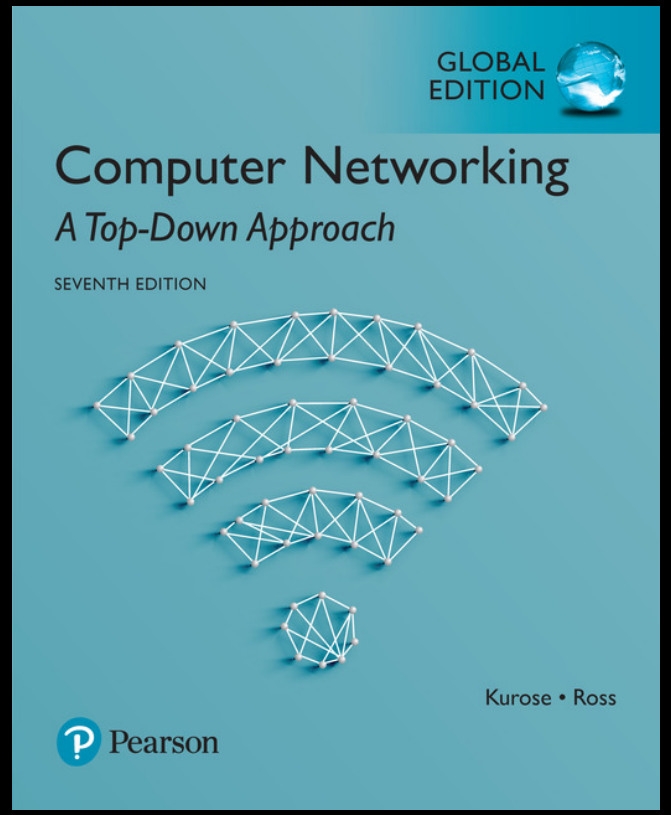
# Textbook




## Computer Networking

*A Top–Down Approach*

7th edition

Jim Kurose, Keith Ross

Pearson

April 2016

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Computer Network introduction

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Computer Network introduction

# 01. Wireless Network

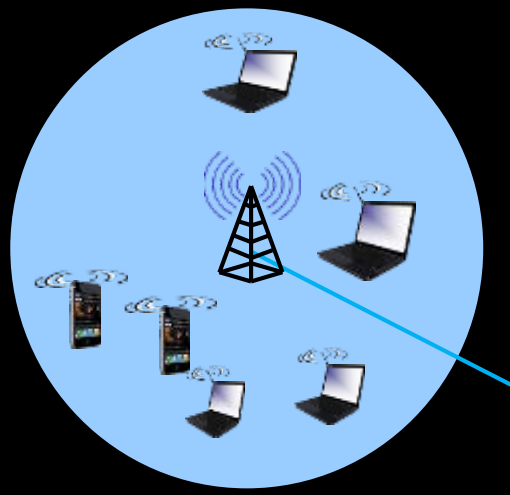
# Background

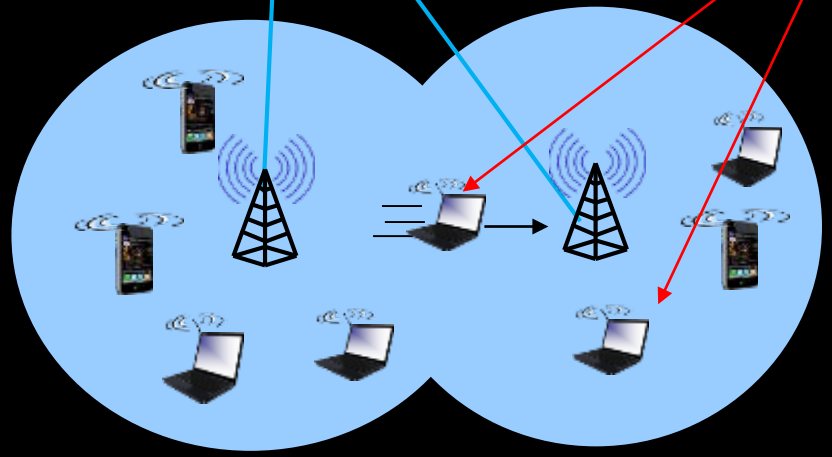
- The number of wireless Internet-connected devices is gradually exceeding the number of wired Internet-connected devices
  - laptops, Internet-enabled phones promise anytime untethered Internet access

- Two important (but different) challenges
  - wireless: communication over wireless link
  - mobility: handling the mobile user who changes point of attachment to network


출처 –
https://www.google.co.kr/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwjNneTKyM3cAhUFU7wKHUz_C_AQjRx6BAgBEAU&url=https%3A%2F%2Fseanb.co.uk%2F2017%2F04%2Ftalking-to-smart-home-devices%2F&psig=AOvVaw2bOQ_WtWn2UFJn8ihg5wSS&ust=1533271376426504

# Wireless Network Elements: Hosts



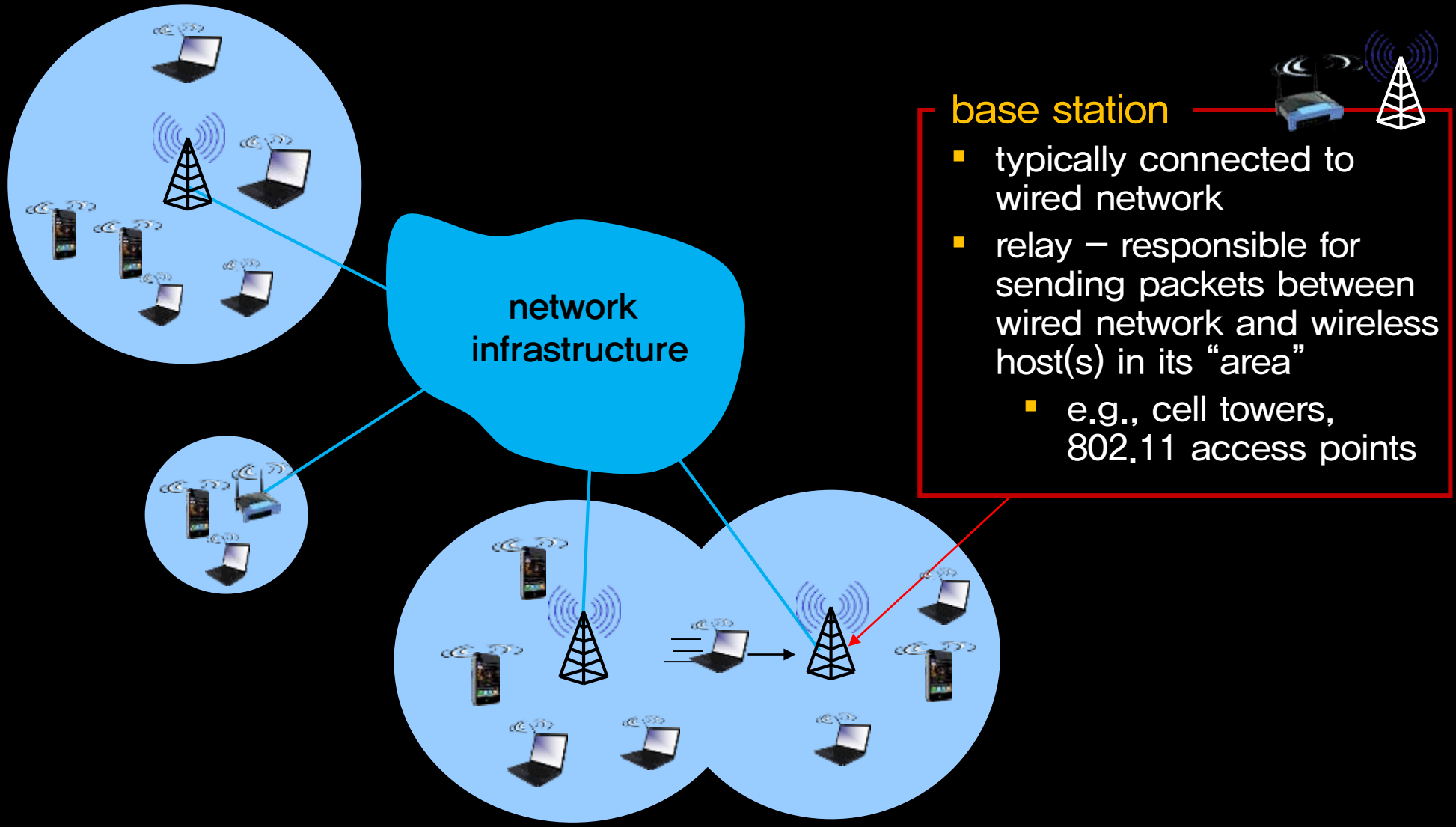


network infrastructure

wireless hosts

- laptop, smartphone
- run applications
- may be stationary (non-mobile) or mobile
  - wireless does *not* always mean mobility

# Wireless Network Elements: Base Station

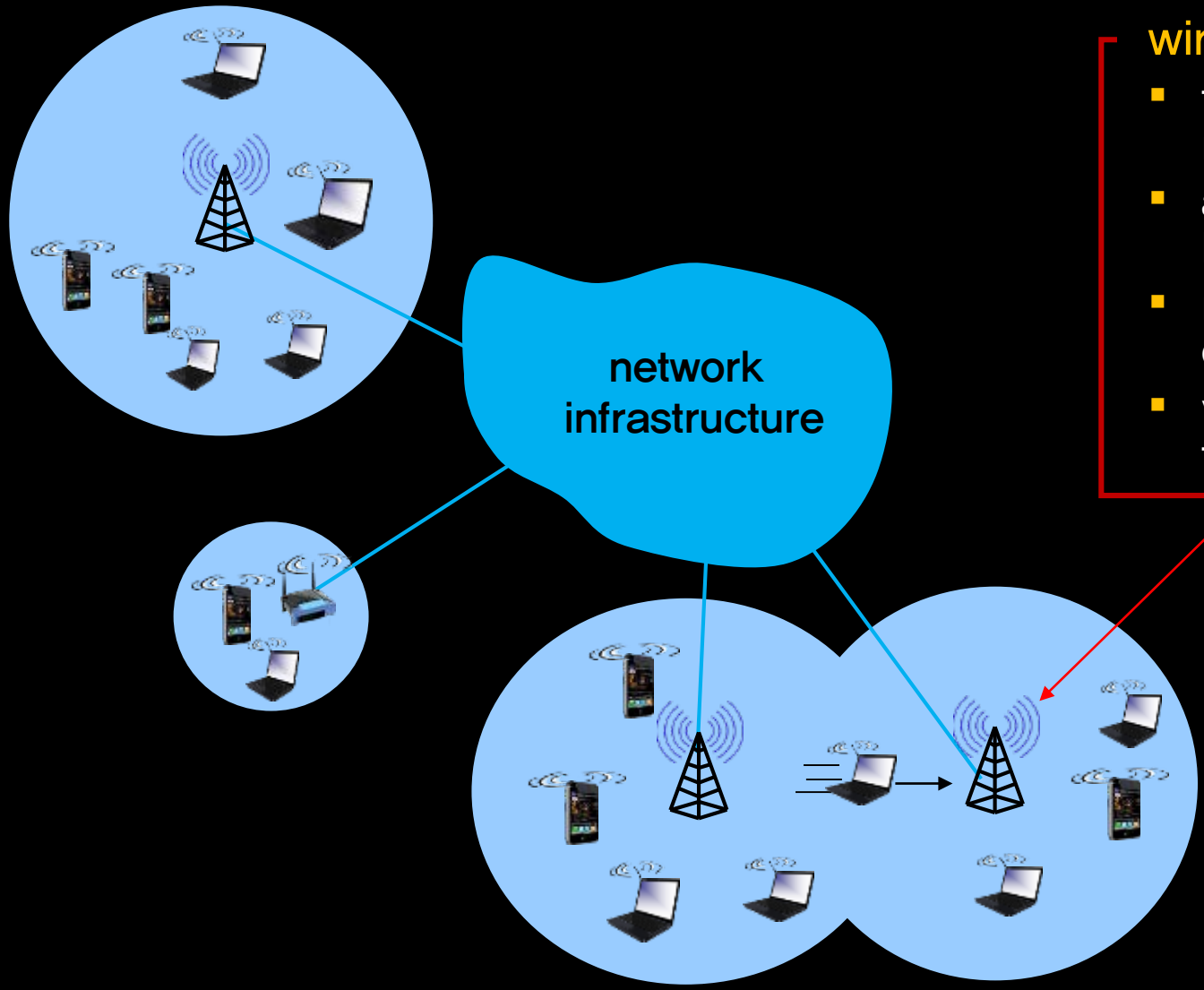





**base station**

- typically connected to wired network
- relay – responsible for sending packets between wired network and wireless host(s) in its "area"
  - e.g., cell towers, 802.11 access points

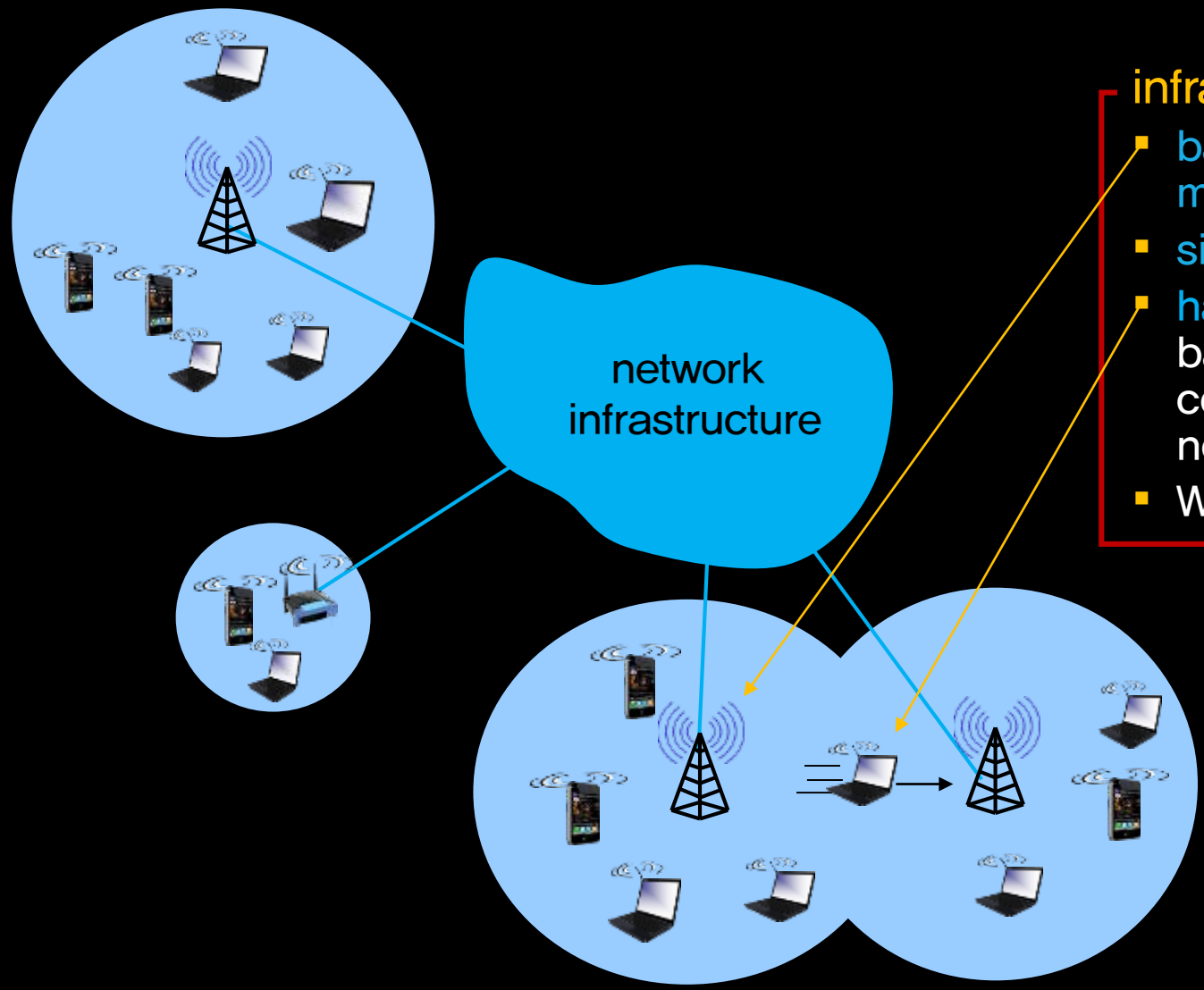
# Wireless Network Elements: Link




**wireless link**

- typically used to connect mobile(s) to base station
- also used as backbone link
- multiple access protocol coordinates link access
- various data rates, transmission distance

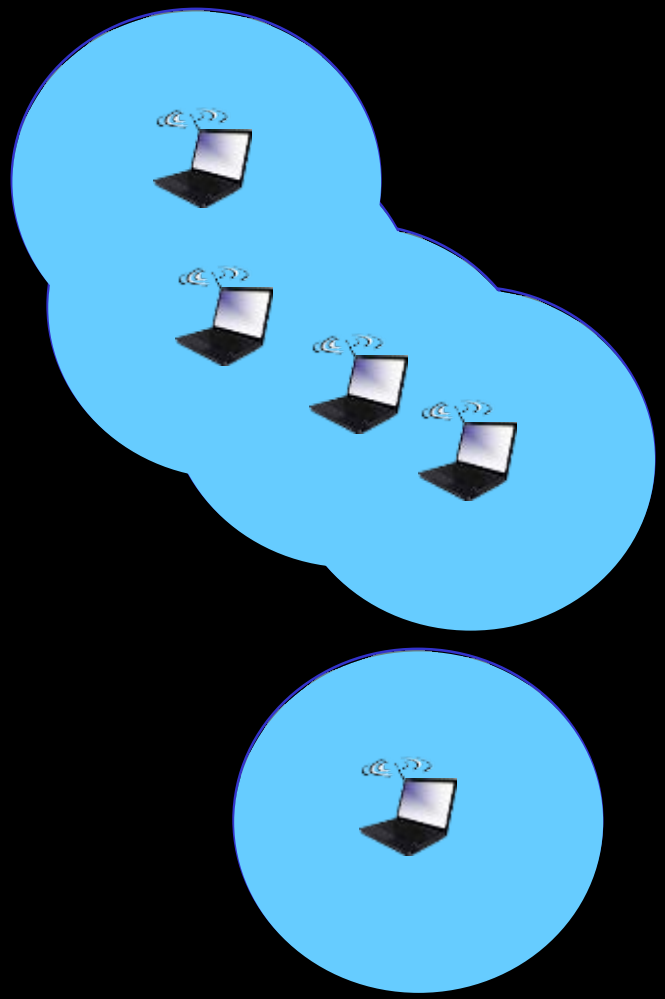
# Network Topology: Infrastructure Mode




**infrastructure mode**

- base station connects mobiles into wired network
- single hop communication
- handoff: mobile changes base station providing connection into wired network
- Wi–Fi, cellular, WiMAX, etc.

# Network Topology: Ad-Hoc Mode



**ad hoc mode**

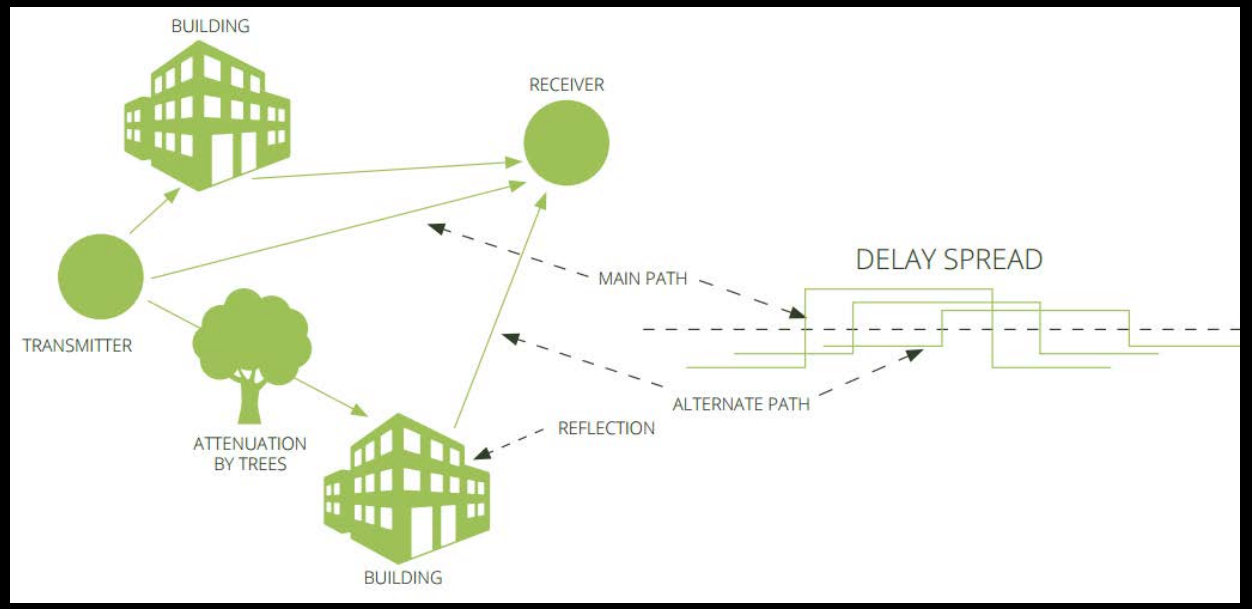
- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves
- multi-hop communication
- Wi-Fi Direct, Bluetooth, etc.

# Wireless Link Characteristics (1/2)

Important differences from wired link:

- Decreased signal strength: radio signal attenuates as it propagates through matter (path loss)
- Interference from other sources: standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices interfere as well
- Multipath propagation: radio signal reflects off objects ground, arriving at destination at slightly different times

*… make communication across wireless link much more "difficult"*

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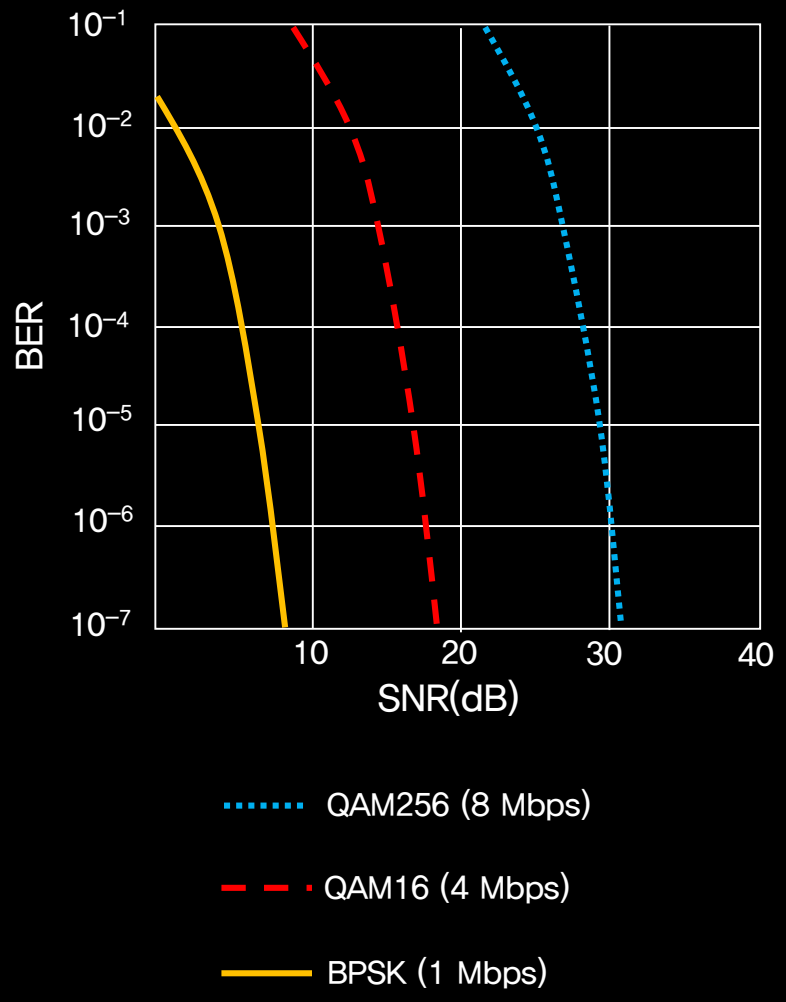
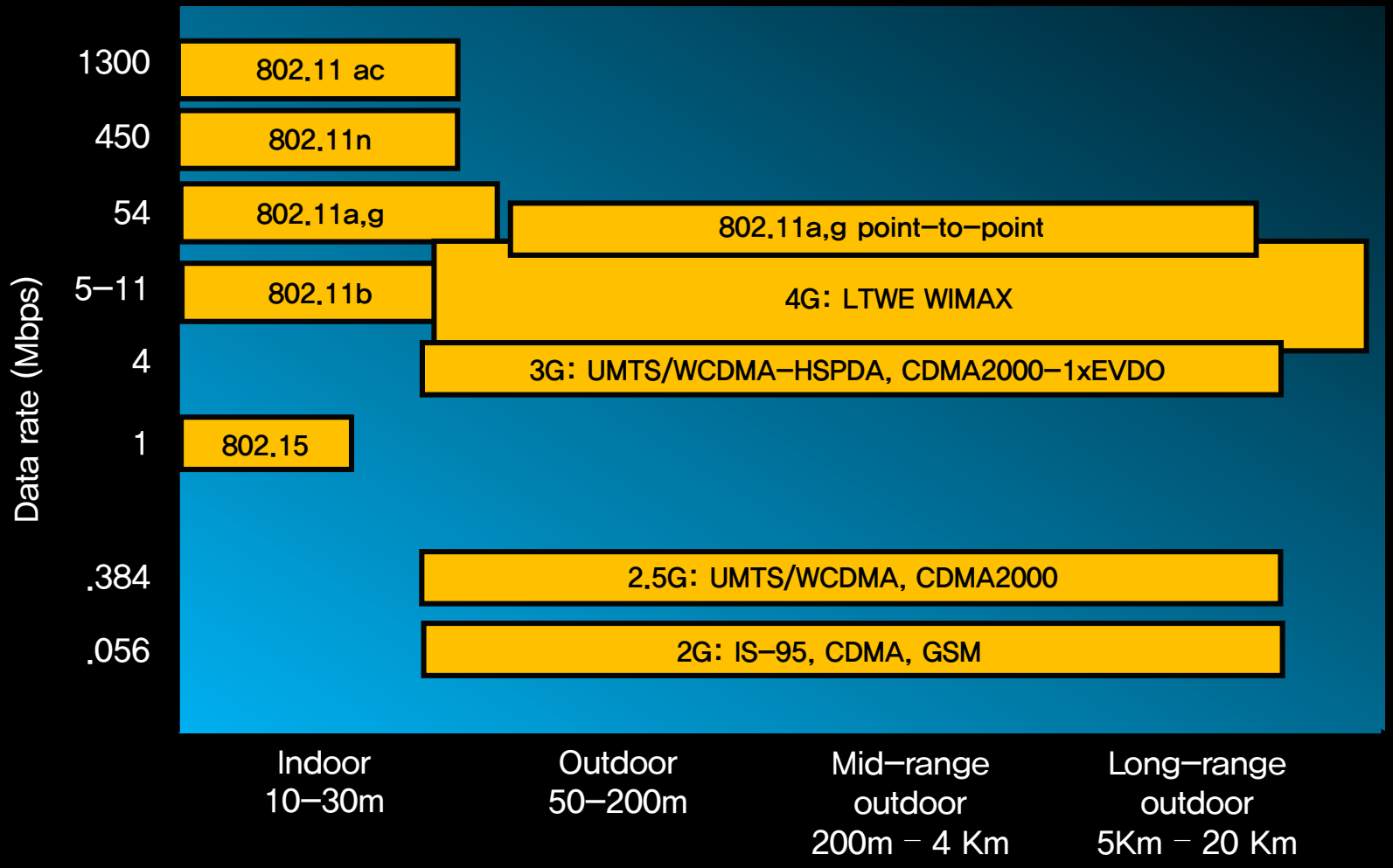
# Wireless Link Characteristics (2/2)

- SNR (Signal-to-Noise Ratio)
  - larger SNR – easier to extract signal from noise
- SNR vs BER (Bit-Error Rate) tradeoff
  - given physical layer: increase power -> increase SNR->decrease BER
  - given SNR: choose physical layer that meets BER requirement, giving highest throughput
  - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)



# 02. 802.11 Wireless LAN (Wi-Fi)

# Comparison of Wireless Technologies



# IEEE 802.11 Family

**802.11b** (released in 1999)

- 2.4 GHz unlicensed spectrum
- up to 11 Mbps

**802.11a** (released in 1999)

- 5 GHz unlicensed spectrum
- up to 54 Mbps

**802.11g** (released in 2003)

- 2.4 GHz range
- up to 54 Mbps

**802.11n** (released in 2009)

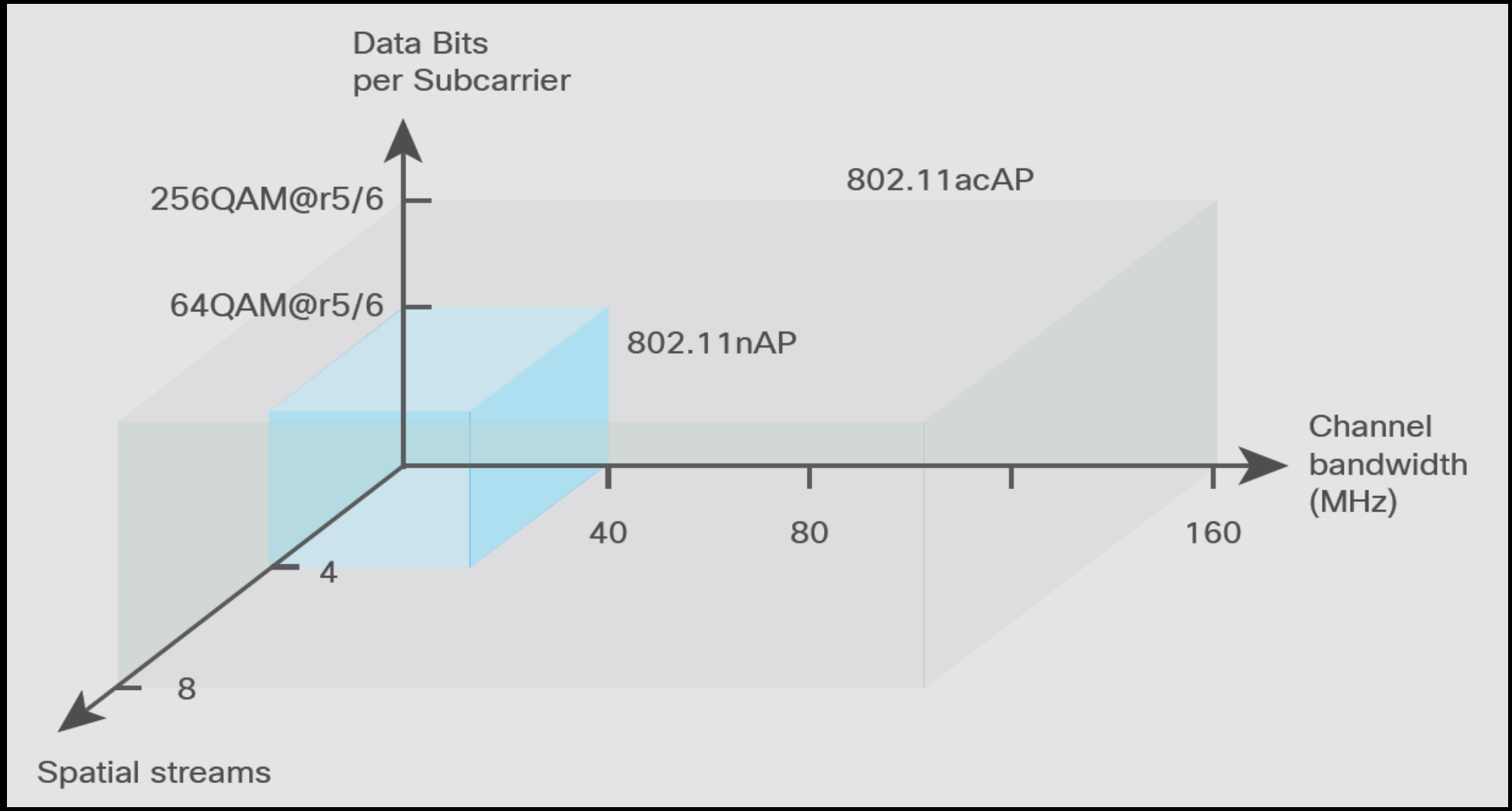
- 2.4 or 5 GHz range
- up to 450 Mbps (SU-MIMO)

**802.11ac** (released in 2014, 2016)

- 5 GHz range
- up to 866.7 Mbps (SU-MIMO), 1.73 Gbps (MU-MIMO)

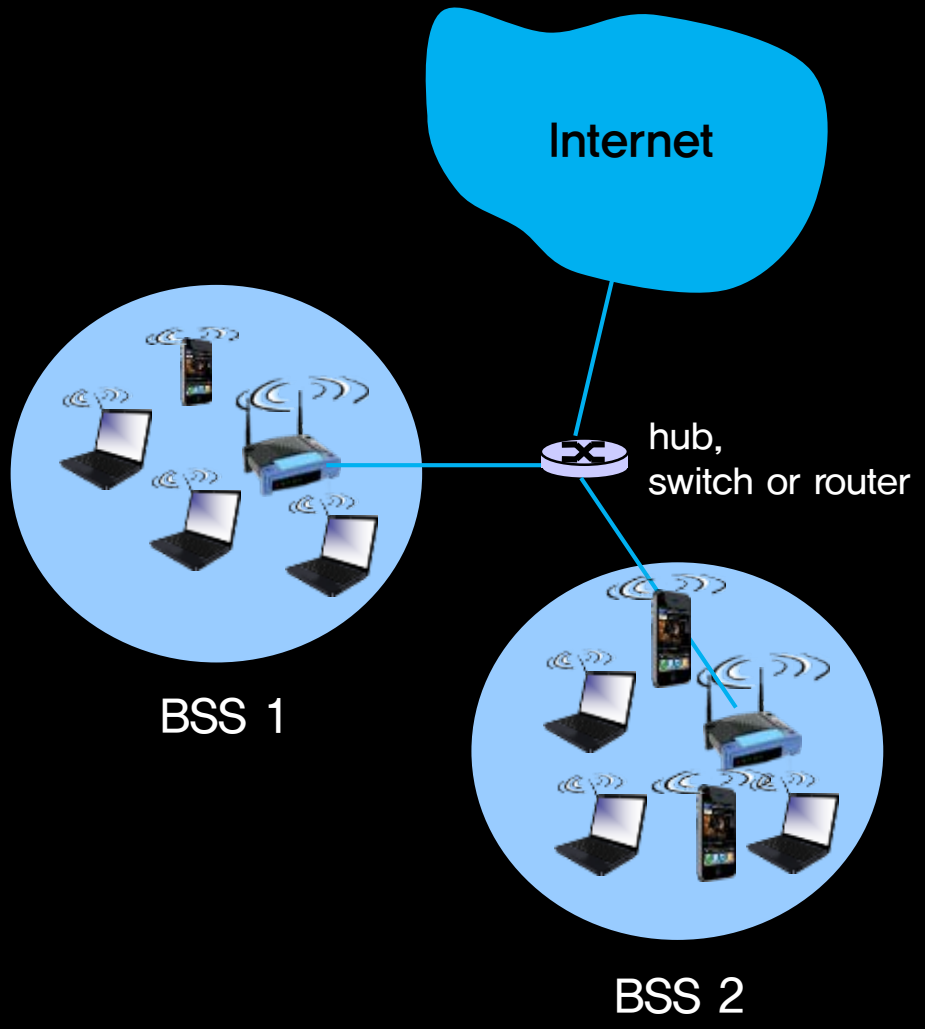
- *All have base-station and ad-hoc network versions*
- *All use CSMA/CA for multiple access*

# How 802.11ac accelerates 802.11n




출처 – https://www.cisco.com/c/dam/en/us/products/collateral/wireless/aironet-3600-series/white-paper-c11-713103.pdf

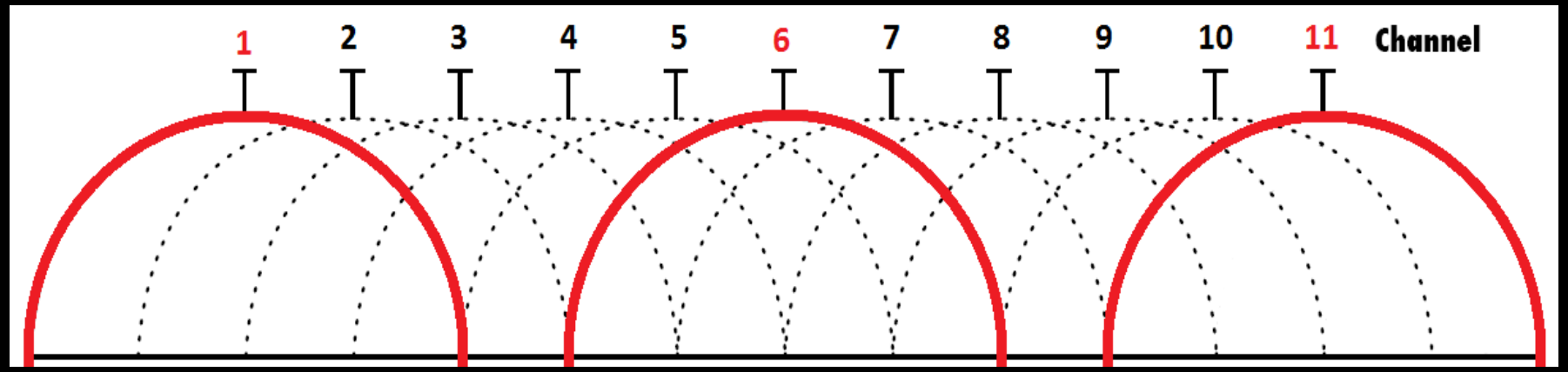
# 802.11 LAN Architecture




- Basic Service Set (BSS) (aka “cell”) in infrastructure mode
- Wireless host communicates with base station
  - base station = access point (AP)

# 802.11 Channels

- 802.11b
  - 2.4GHz–2.485GHz spectrum divided into 11 channels at different frequencies
  - Administrator chooses frequency for AP
  - interference possible: channel can be overlapped with that chosen by neighboring AP

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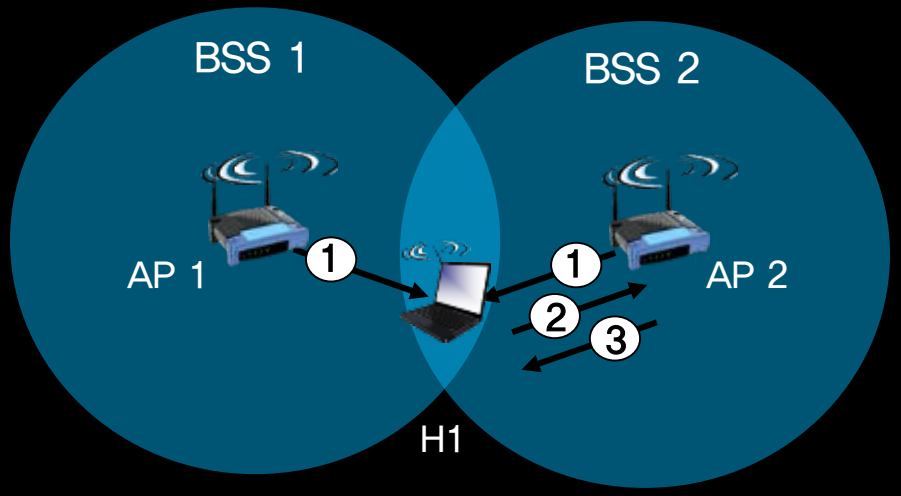
# AP Association

- Host must associate with an AP
  - ① scans channels, listening for beacon frames containing AP's name (SSID) and MAC address
  - ② selects AP to associate with and sends association Request
    - may perform authentication
  - ③ receives association Response from the selected AP
  - ④ will typically run DHCP to get IP address in AP's subnet



# 802.11 Frame: Addressing

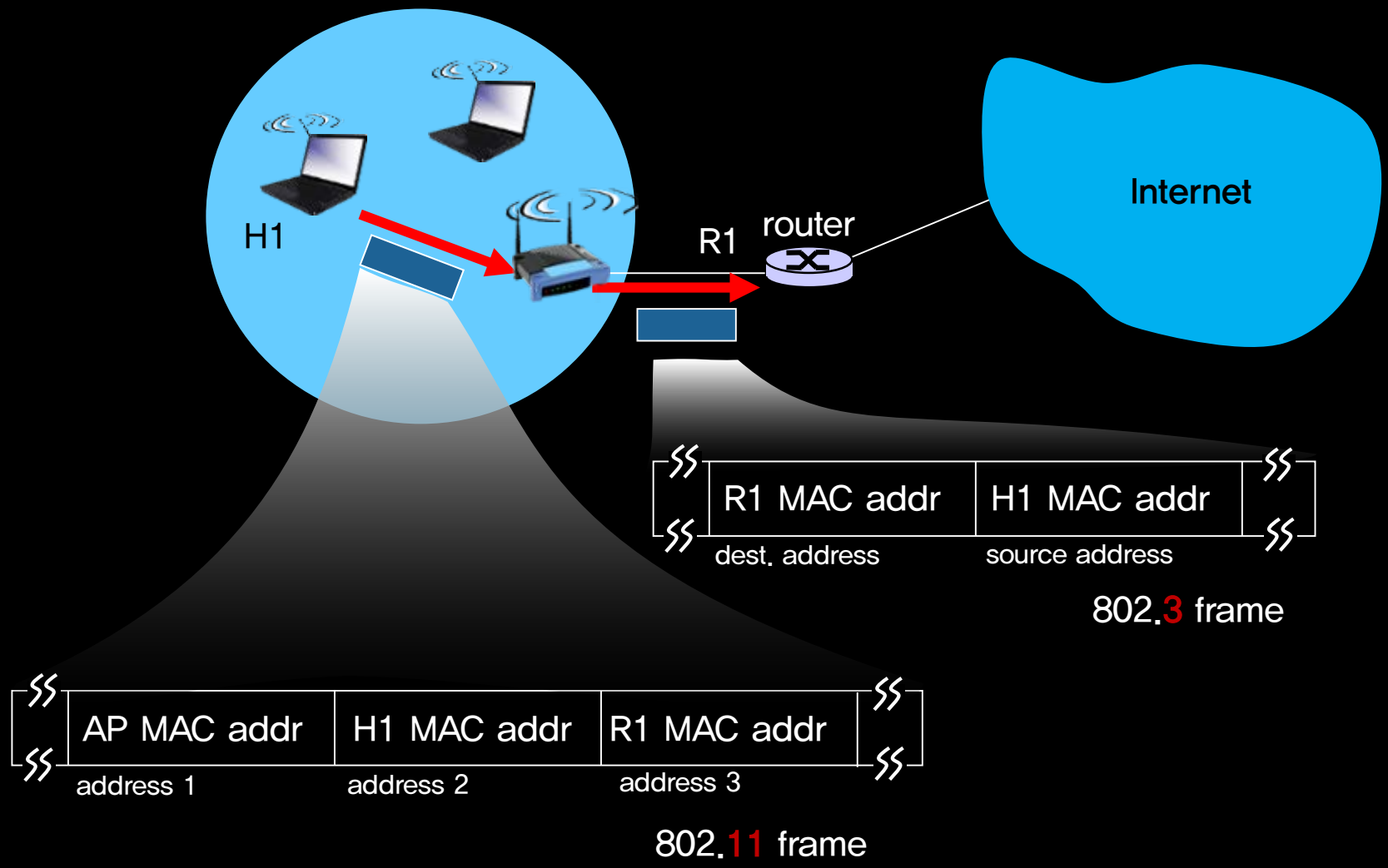

Address 1: MAC address of wireless host or AP to receive this frame

Address 2: MAC address of wireless host or AP transmitting this frame

Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

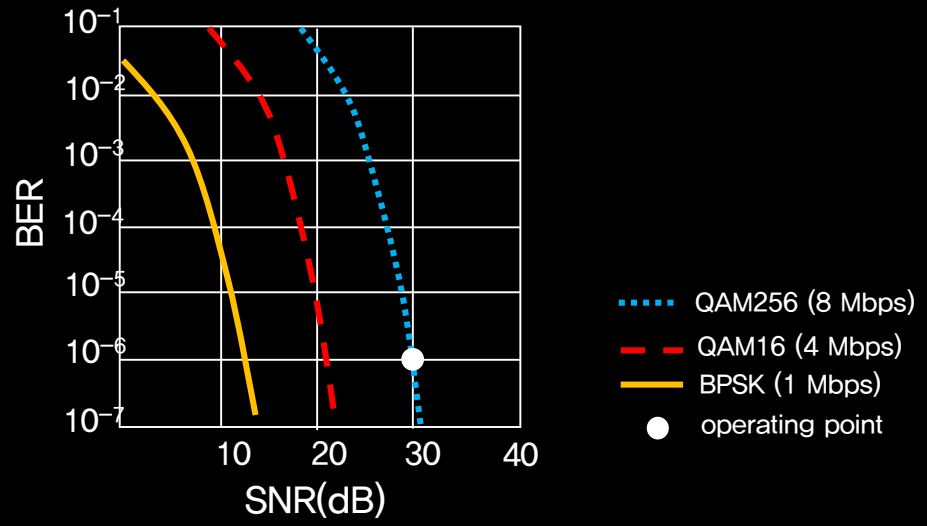
# 802.11 Frame: Addressing



# 802.11 Rate Adaptation

- "802.11g supports various data rates: 6, 9, 12, 18, 24, 36, 48 and 54 Mbps."

- Base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies




1. SNR decreases, BER increase as node moves away from base station
2. When BER becomes too high, switch to lower transmission rate but with lower BER

# 03. CSMA/CA

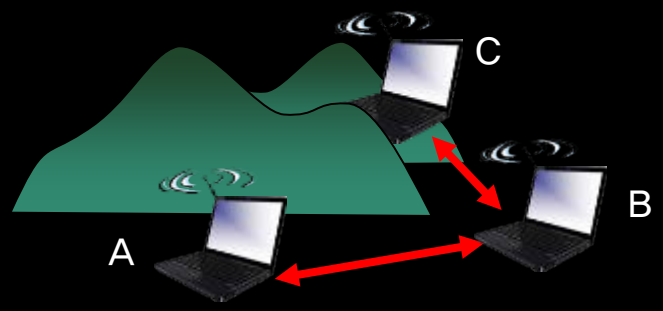
# CSMA in Wireless

- CSMA, CSMA/CD
  - sense before transmission
  - retransmit in case of collision

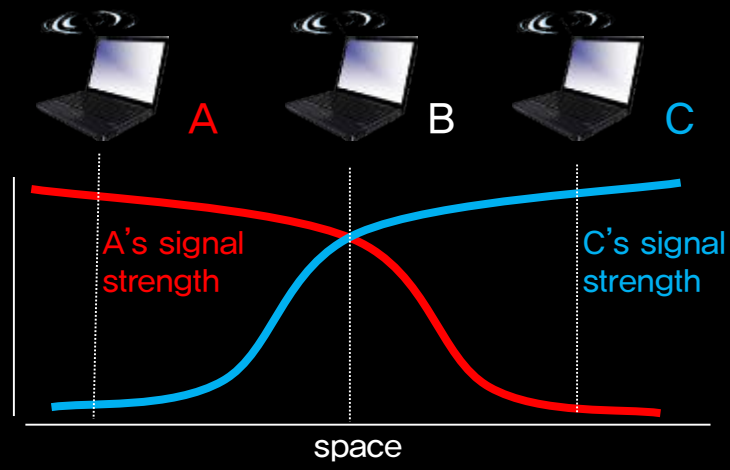
*But, if sending node cannot listen?*

*But, if sending node cannot detect collision?*

## Case 1: Obstacle




## Case 2: Attenuation



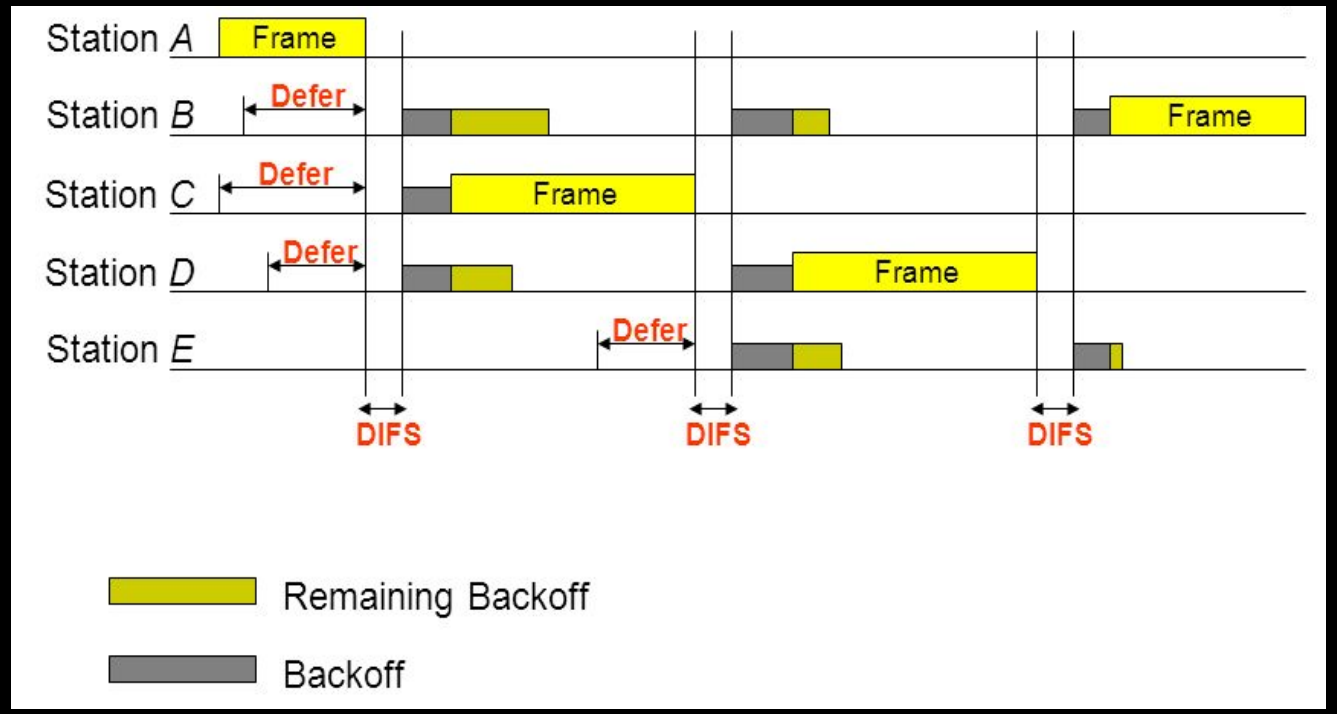

***Hidden terminal problem***

- B, A hear each other
- B, C hear each other
- A, C cannot hear each other means A, C unaware of their interference at B

- CSMA/CA (Collision Avoidance)

**802.11 sender**

1. If sense channel idle for DIFS
   then transmit entire frame (no CD)
2. If sense channel busy then
   - start random backoff time
   - timer counts down
     while channel is idle
   - transmit when timer expires

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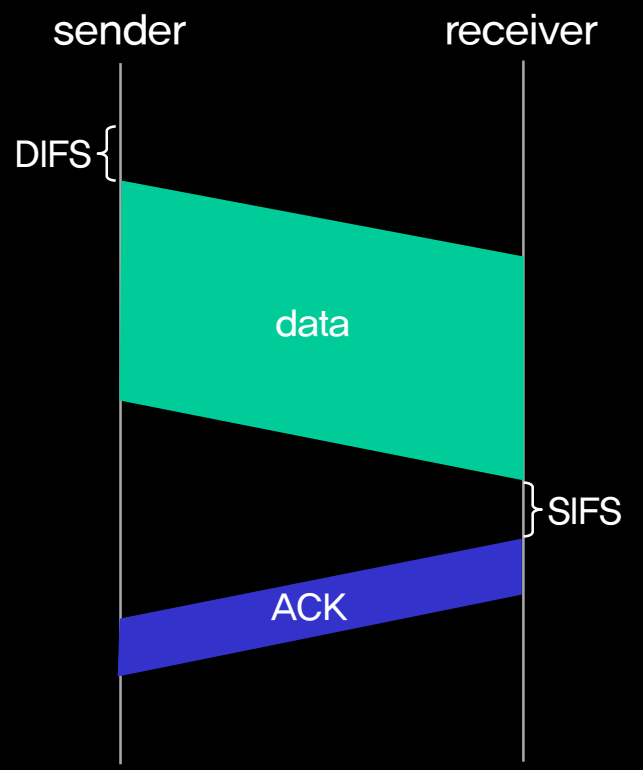
# 802.11 DCF (Distributed Coordination Function)

## 802.11 receiver

- If frame received OK, return ACK after SIFS (ACK needed due to hidden terminal problem)

## 802.11 sender (cont'd)

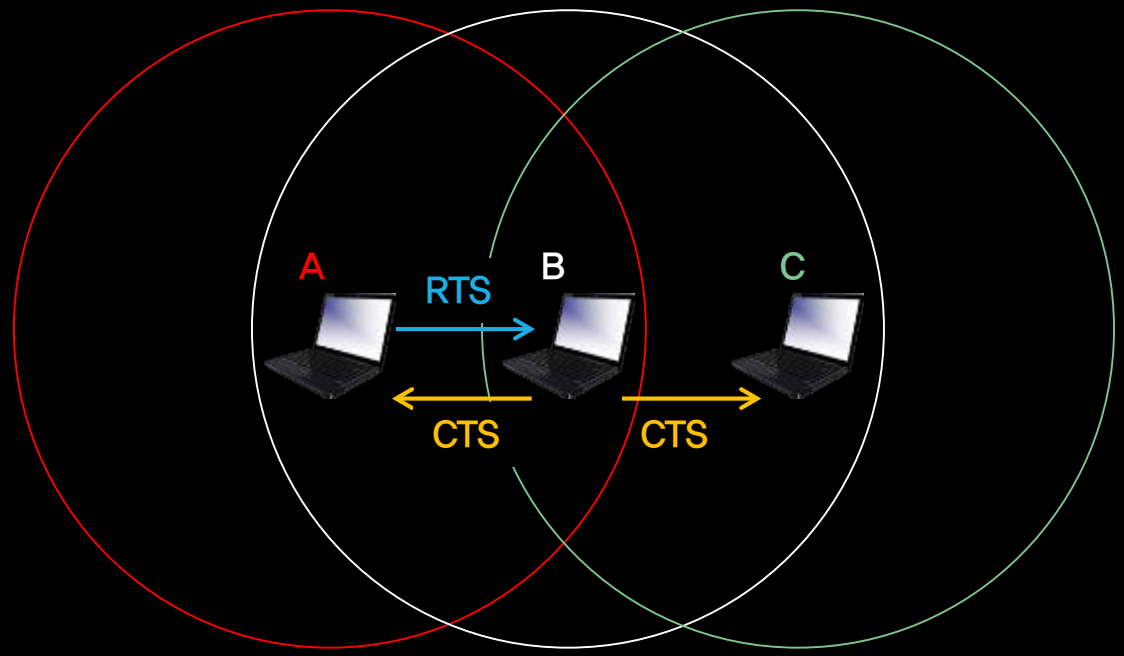
- If sender receives no ACK, it increases random backoff interval, repeat 2




* DIFS (Distributed Inter-Frame Space)
〉SIFS (Short Inter-Frame Space)

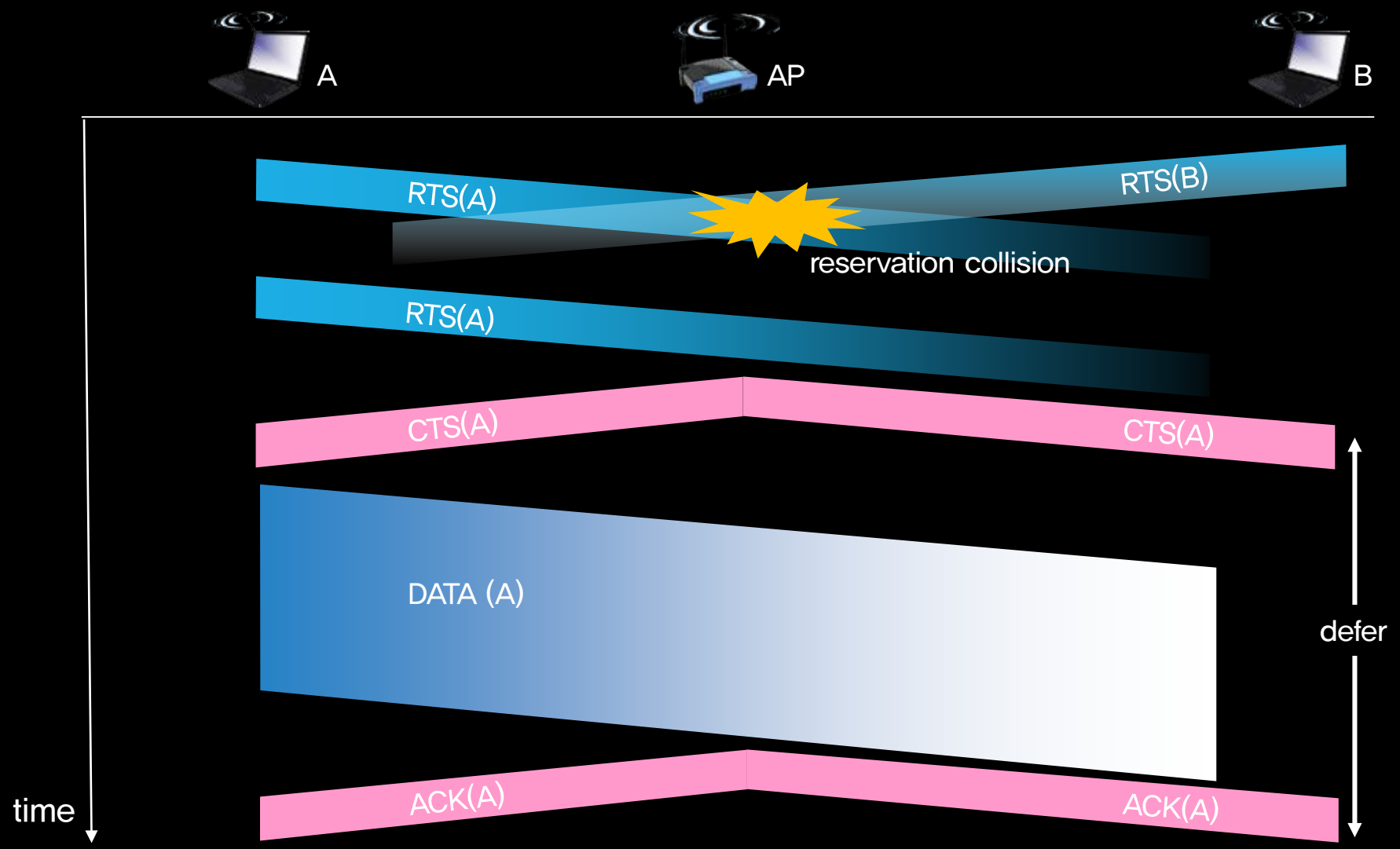
# Resolution to Hidden Terminal Problem

- Idea: allow sender to "reserve" channel, avoiding collisions of long data frames
- Sender first transmits small request–to–send (RTS) packets to BS using CSMA
- RTSs may still collide with each other (but they're short)
- BS broadcasts clear–to–send CTS in response to RTS
- CTS heard by all nodes
  - other stations defer transmissions

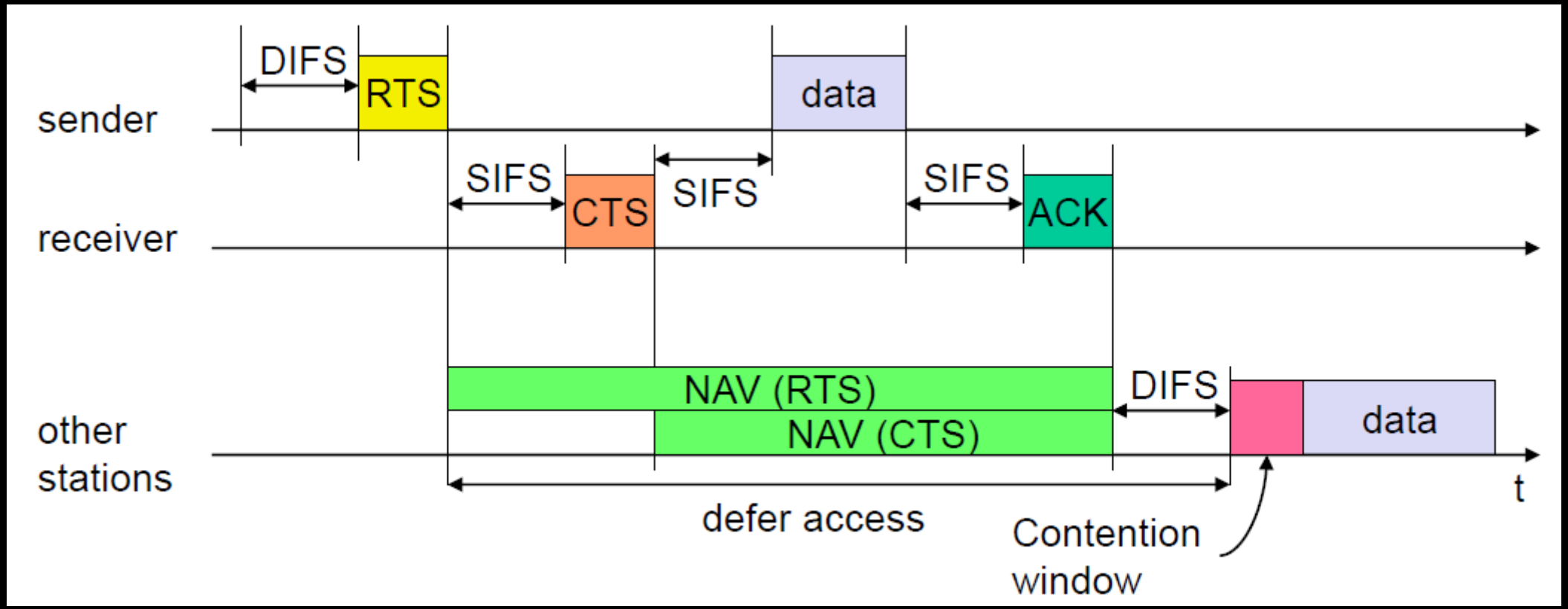



Avoid data frame collisions completely using small reservation packets!

# RTS–CTS–DATA–ACK



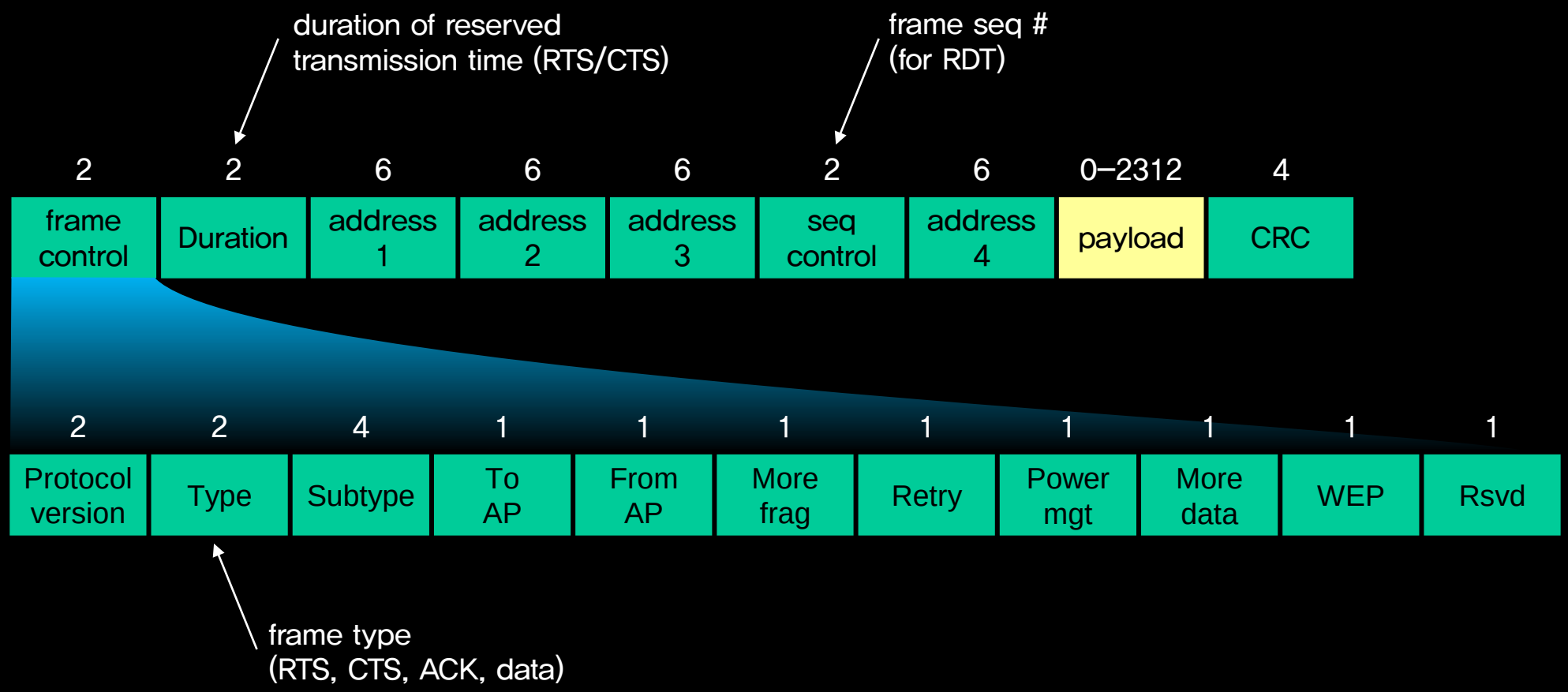
# 802.11 DCF Time Diagram




출처 – https://www.iith.ac.in/~tbr/teaching/docs/Schiller-802.11.pdf

* NAV (Network Allocation Vector)

# 802.11 Frame (more)



# 04. Li-Fi

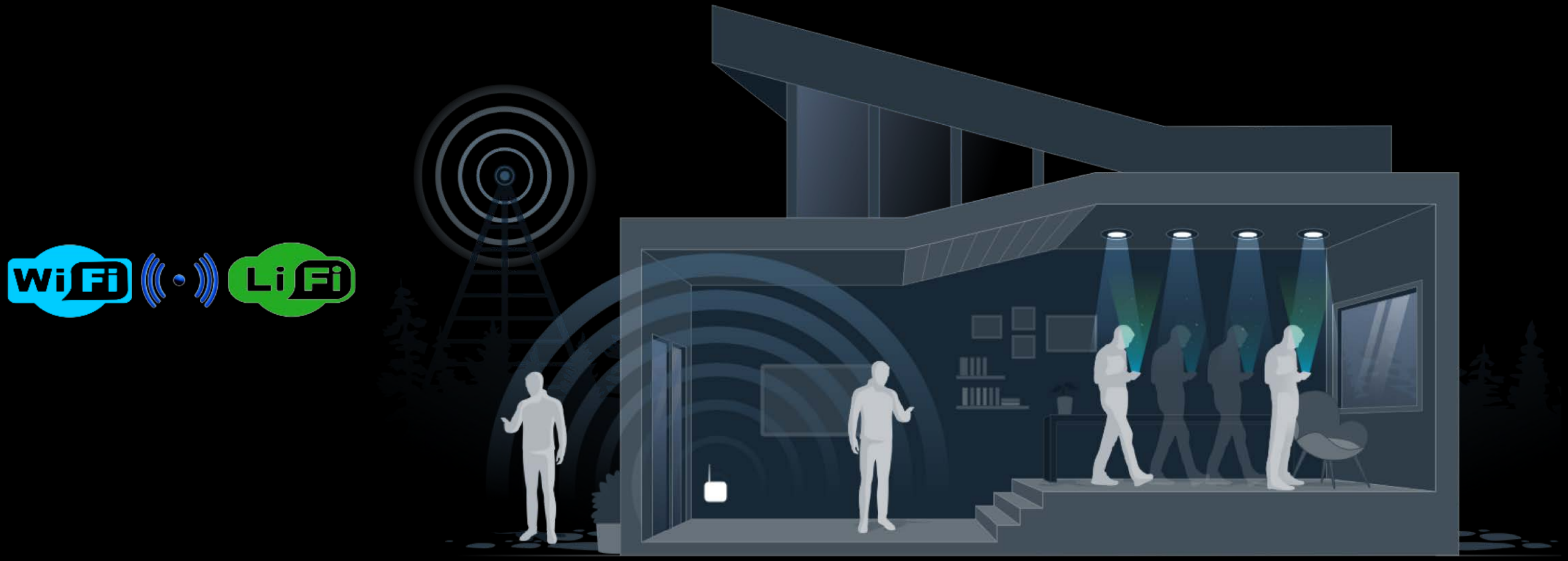
# Li-Fi (Light Fidelity)

- Visible Light Communication (VLC)
- Mergence of lighting and data communications in applications such as
  - modulated area lighting
  - signboards
  - streetlights
  - vehicle safety lighting
  - traffic signals


출처 –
https://www.google.co.kr/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwj1jMih8NLcAhUJ6bwKHf4pCekQjRx6BAgBEAU&url=https%3A%2F%2Fdarkwebnews.com%2Ftechnology%2Flifi-vs-wifi%2F&psig=AOvVaw2u8ksUZEITuPEXUITf0M1H&ust=1533453113545761

# Seamless Connectivity

- Comprises of multiple light bulbs that form a wireless network

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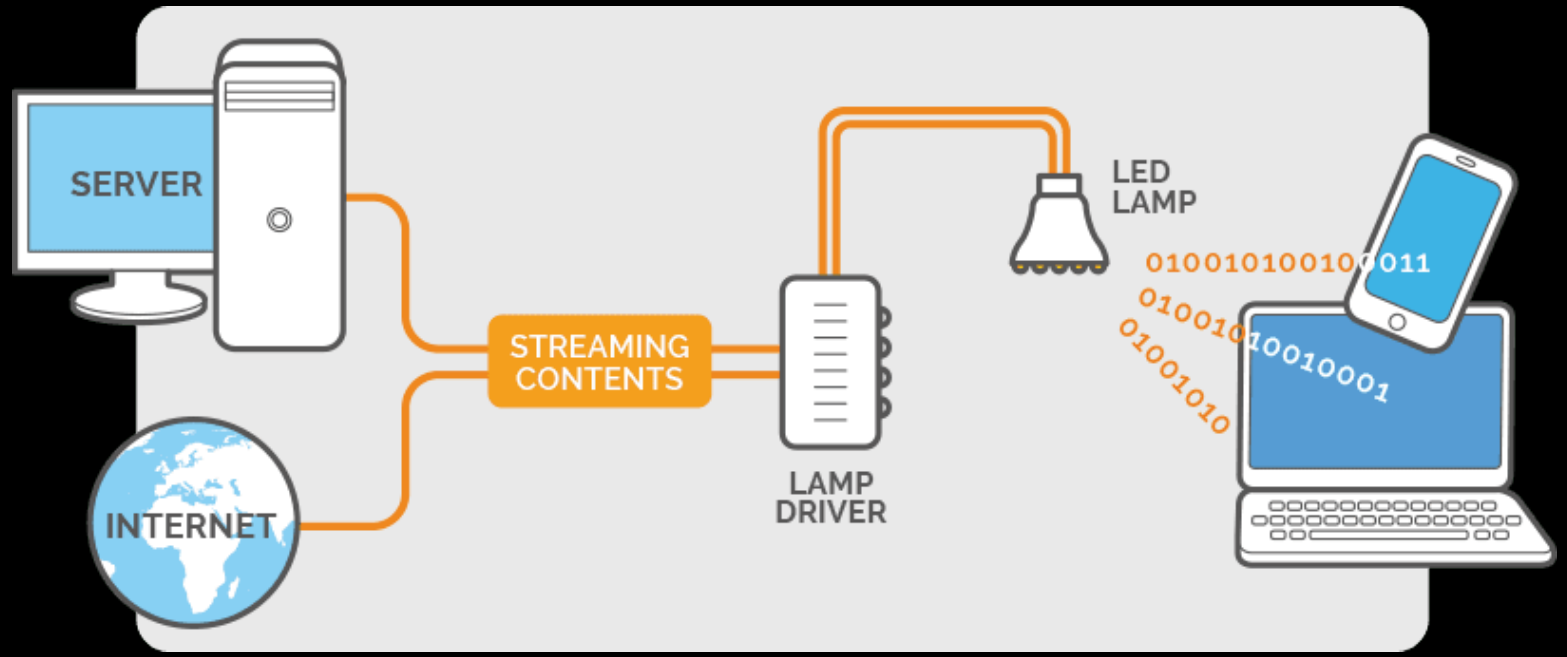
# How Li-Fi Works

- LED light bulb
- Photo-detector to receive light signal
- Infra-red transmitter to upload information

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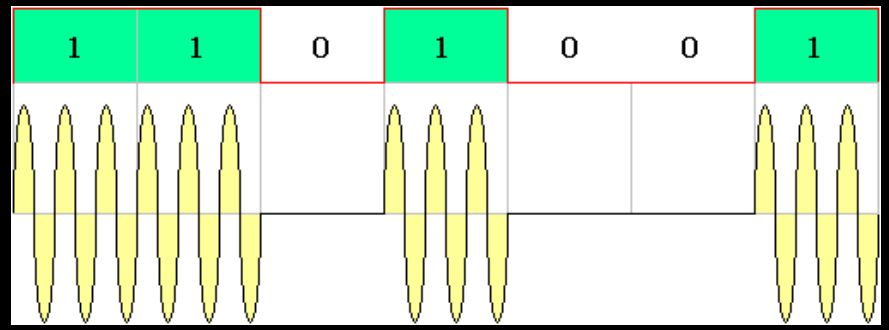
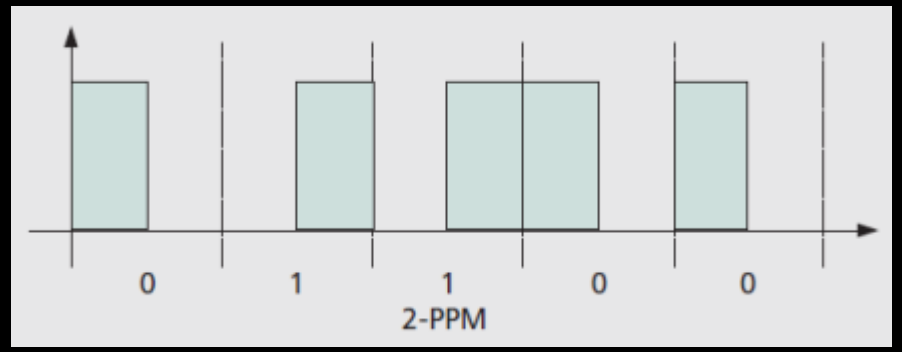
# Li-Fi Modulation (1/2)

- On-off keying (OOK)
  - simplest modulation
  - LEDs turned on or off according to data bits

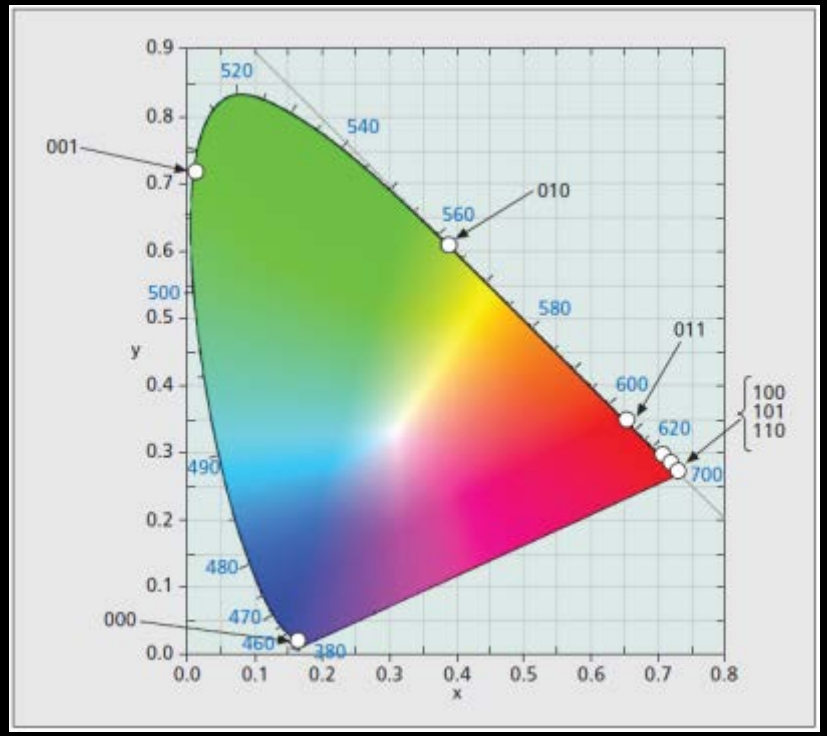



- Variable pulse position modulation (VPPM)
  - PPM + variable pulse width (duty cycle)
  - duty cycle change in response to the requested dimming level



# Li-Fi Modulation (2/2)

- Color shift keying (CSK)
  - similar to FSK in that the bit patterns are encoded to color (wavelength) combinations
  - e.g., for 4-CSK the light source is wavelength keyed such that one of four possible colors is transmitted per bit pair combination

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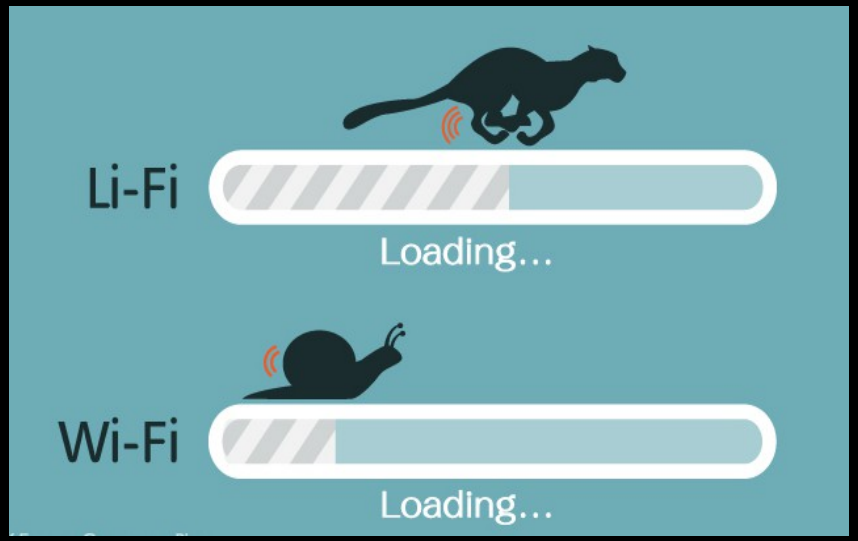
# Potentials and Limitations

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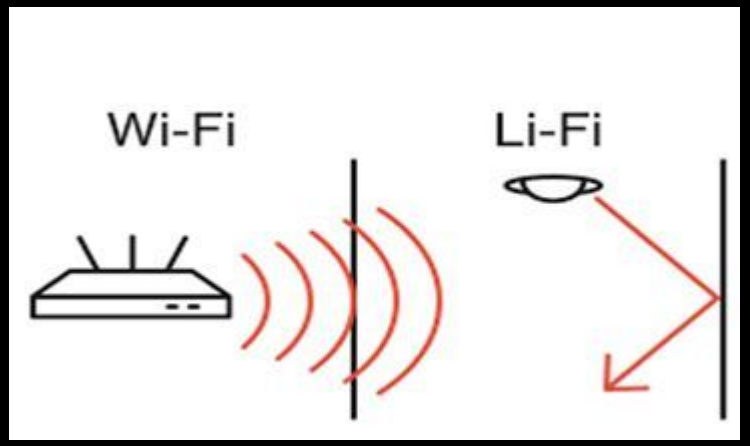
- High data rate: in theory, 100 times faster than Wi-Fi
- More secure than electronic signal
  - hard to eavesdrop

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- No penetration
- Short-range
- Difficult to use in outdoors with strong light

# Application: Li-Fi on Board


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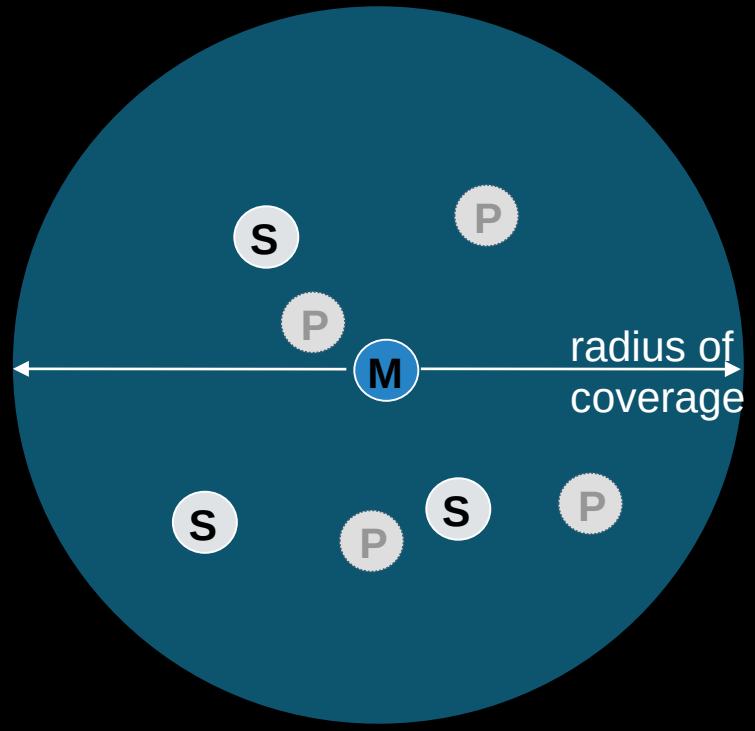
https://www.google.co.kr/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwj5m5_V79LcAhWJvrwKHWNFDtUQjRx6BAgBEAU&url=http%3A%2F%2Fwww.nextlifi.com%2Fli-fi-media-hub%2F&psig=AOvVaw2u8ksUZEITuPEXUITf0M1H&ust=1533453113545761

# 05. Bluetooth Classic & Smart

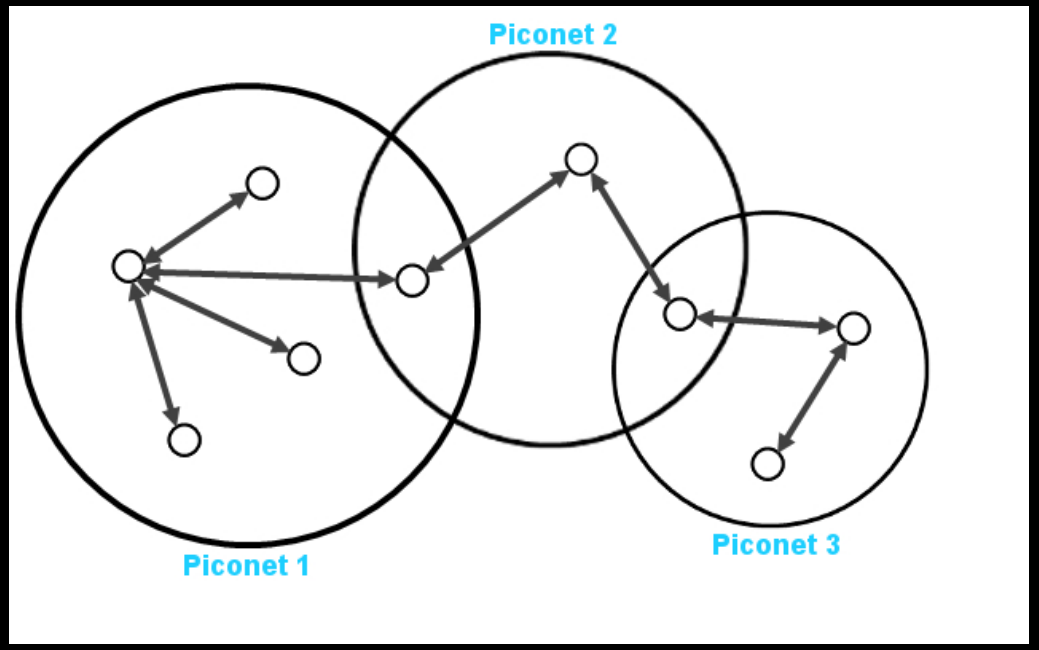
# IEEE 802.15.1: Bluetooth

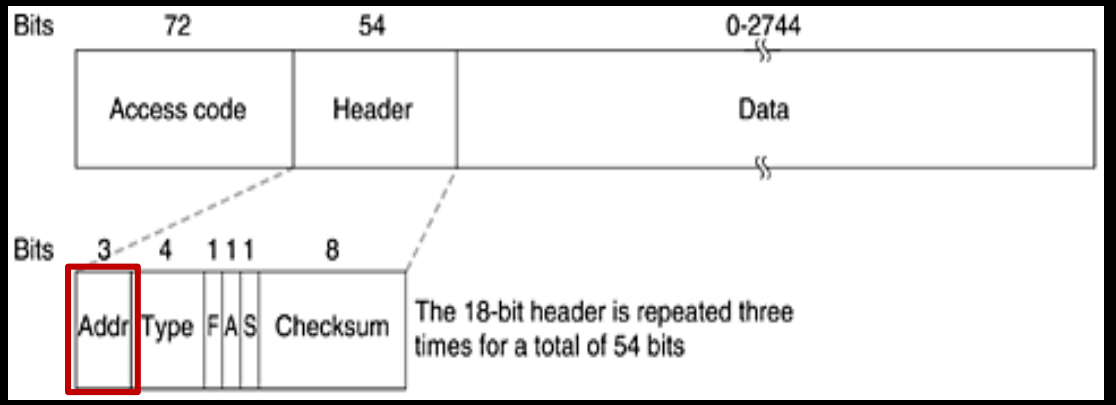
- IEEE 802.15: Wireless Personal Area Network (WPAN)
  - less than 10 m diameter
  - replacement for cables (mouse, keyboard, headphones)
- Bluetooth (developed by Ericsson in 1994)
  - Ad hoc: no infrastructure
  - Master/slaves:
    - slaves request permission to send (to master)
    - master grants requests
  - 2.4–2.5 GHz radio band
  - up to 721 kbps



# Bluetooth Classic

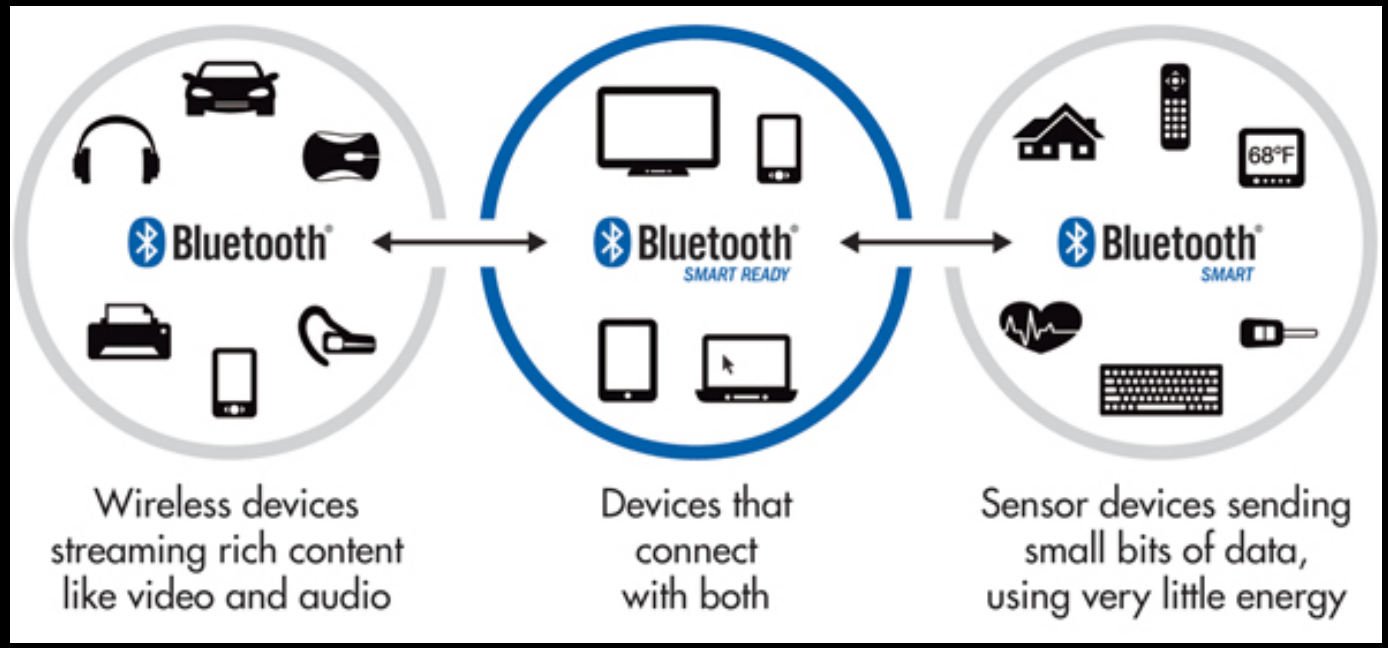
- Battery drain: all slaves listen for incoming connections, so need to be on constant standby
- Maximally 7 slaves can be connected to master



# Bluetooth 4.0: Bluetooth Smart (BLE)

- Bluetooth Smart: incompatible with the Classic version
- Bluetooth Smart Ready: supporting the both

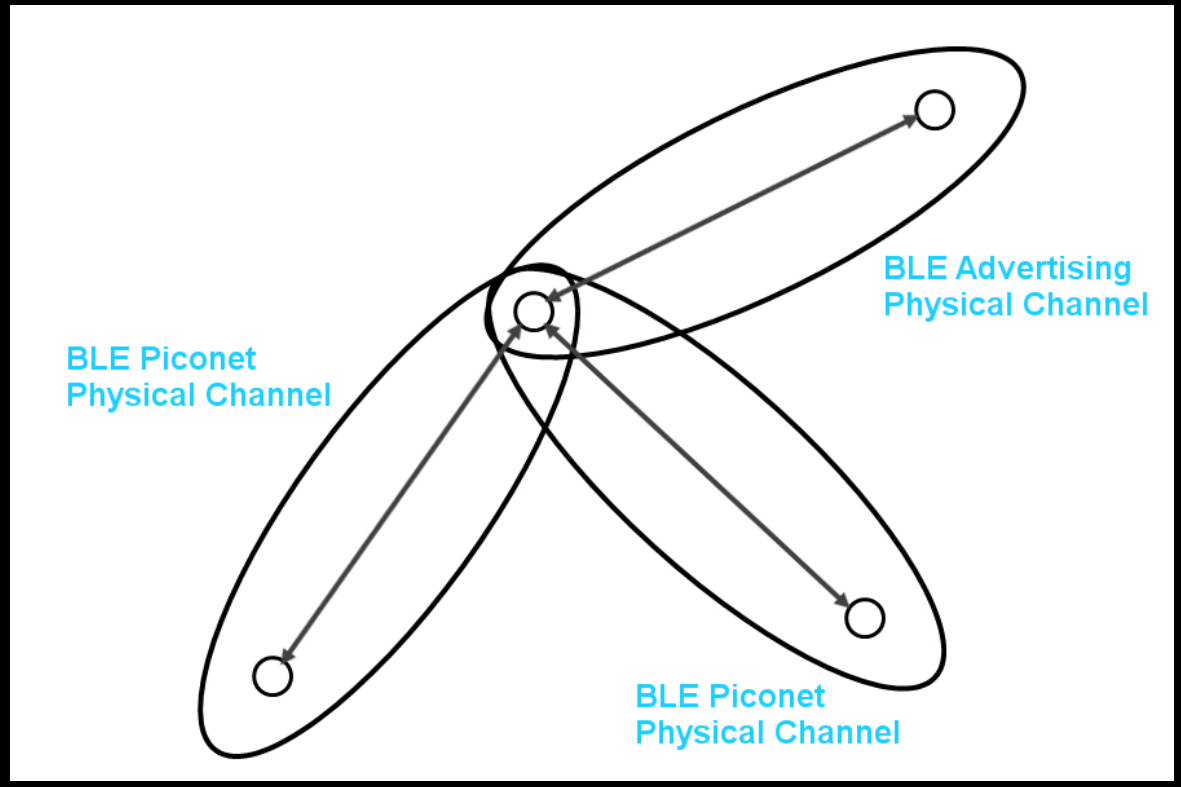




출처 –
https://www.google.co.kr/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwiYiJPniNPcAhULVbwKHalUA6cQjRx6BAgBEAU&url=https%3A%2F%2Fwww.digikey.com%2Fen%2Farticles%2Ftechzone%2F2016%2Fjul%2Fbluetooth-low-energy-design-101-from-chipsets-to-protocol-stacks-to-modules&psig=AOvVaw0KeFeB_kG-nkTlGeQkTGFc&ust=1533460774540952

# BLE Topology

- The slaves each communicate on a separate physical channel with the master

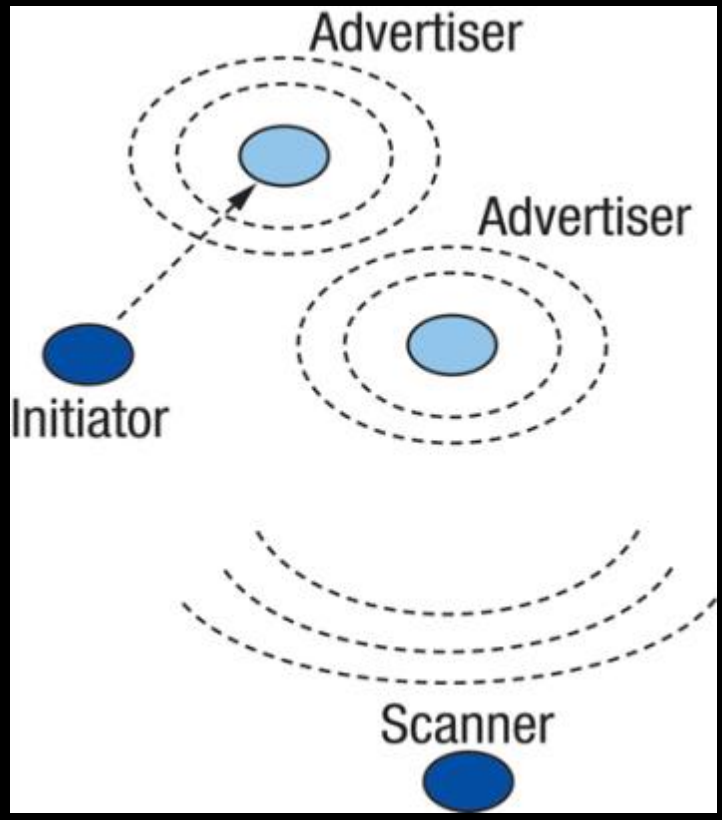


# BLE Connection

- Connection phases

① a BLE slave invites connection by advertising itself, thus in total control of when to consume power

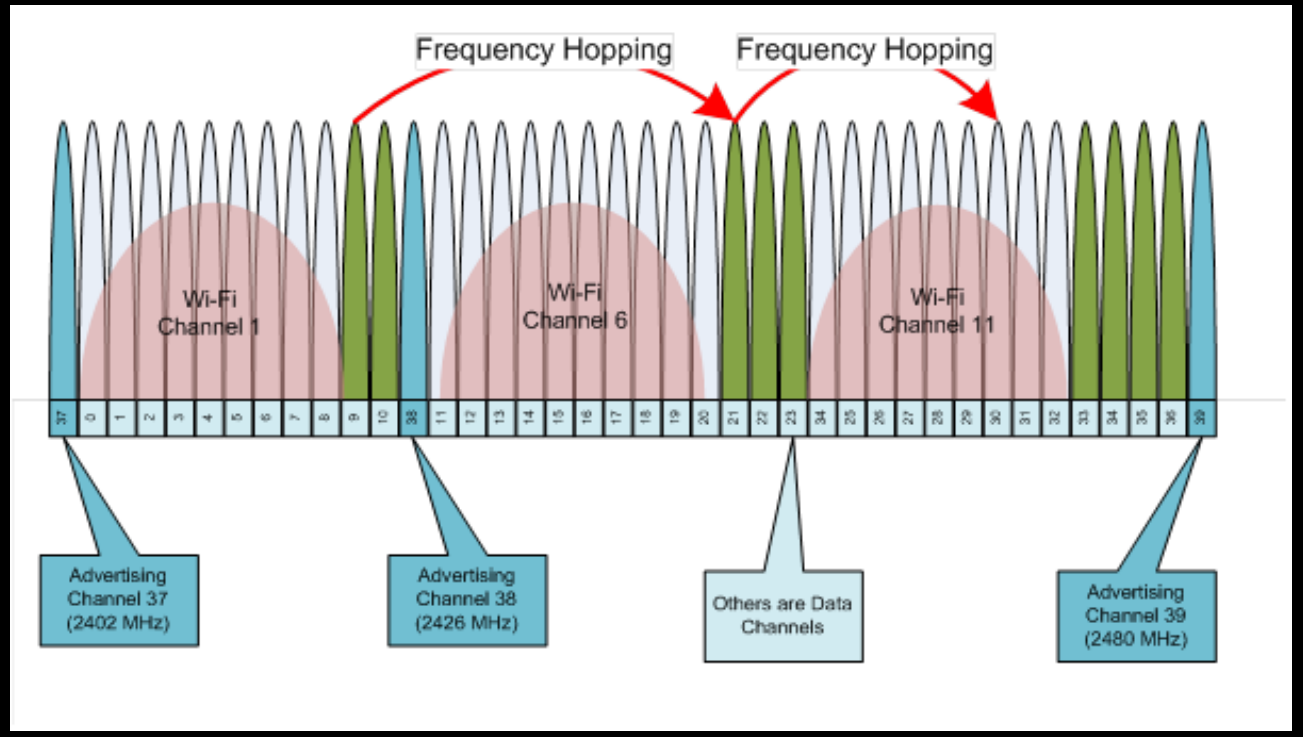
② a master, which has less power–constraint, scans the advertising and initiates connections on the back of an advertisement packet




An advertiser periodically sends and will always act as a slave when it is connecting. A scanner is waiting for an advertisement and is always a master when connecting.

# BLE Channel

- Channel usage
  - Classic: 79 1-MHz channels
  - Smart: 40 2-MHz channels (3 for advertising + 37 for data)




출처 –
https://www.google.com/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwj94dXE1dPcAhXli7wKHaVwB2IQjRx6BAgBEAU&url=https%3A%2F%2Fhackaday.com%2F2013%2F08%2F29%2Fprimer-on-bluetooth-low-energy%2F&psig=AOvVaw0bCsdjGAf1Xlfs8S9zQShH&ust=1533481402213070

# Classic vs. BLE

| Tech. Specification | Classic | Bluetooth Smart |
|---|---|---|
| Application throughput | 0.7~2.1 Mbps | 0.27 Mbps |
| Active slaves | 7 | Not defined |
| Latency (from a non-connected state) | Typically 100 ms | 6 ms |
| Power consumption | 1 W as the reference | 0.01~0.5 W |

# 06. B5 (Bluetooth 5)

# B5 Compared with BLE

- Released in Dec. 2016
- Features


| ADVANTAGES | FEATURES | END USER EXAMPLES |
|---|---|---|
| Robust, reliable connections indoors and outdoors | 4×Range | Whole house/building coverage/outdoor e.g. Nordic Semi tests drone connectivity to 750m outdoor range! |
| Faster data transfer, reduced TX / RX time | 2×Speed | Lower latency, increased performance & faster data transfer for critical data e.g. swifter FW updates, download of logged sensor data |
| More data capacity in Connectionless Services | 8×Increase broadcast message capacity | Beacons & location/tracking services can be improved for greater data & information e.g. enhanced user experiences in facility tours |

# Usefulness of B5

- The range can be tuned (up to 4x longer than BLE) for a variety of environments and applications
  - e.g., whole-home and building coverage, drone, etc.
  - the flexibility for a developer to make the best choice for their implementation
- The increasing broadcast message capacity (up to 8x greater than BLE) provides the basis for creating next-generation beacons, allowing much richer, multi-faceted sets of contextual data to be broadcast
  - e.g, a vending machine or refrigerator broadcasting its location ID, temperature, stock level, battery level, number of times the door has been opened, and other maintenance indicators all at once

# Physical Layer in B5 Protocol Stack

- Choice out of three PHYs

## LE 1M

- PHY in BLE
- Mandatory
- GFSK
- Symbol rate of 1Ms/s

Backward compatibility

## LE 2M

- GFSK
- Double symbol rate (2Ms/s)
- Double frequency deviation (370 kHz) to mitigate inter–symbol interference

2x Speed

## LE Coded

- Forward Error Correction (FEC)
- Convolutional encoding + Pattern mapper
- Tradeoff between robustness and overall data rate

4x Range

# More on LE Coded PHY

- Two stages for the bit stream process: FEC and Patten mapper

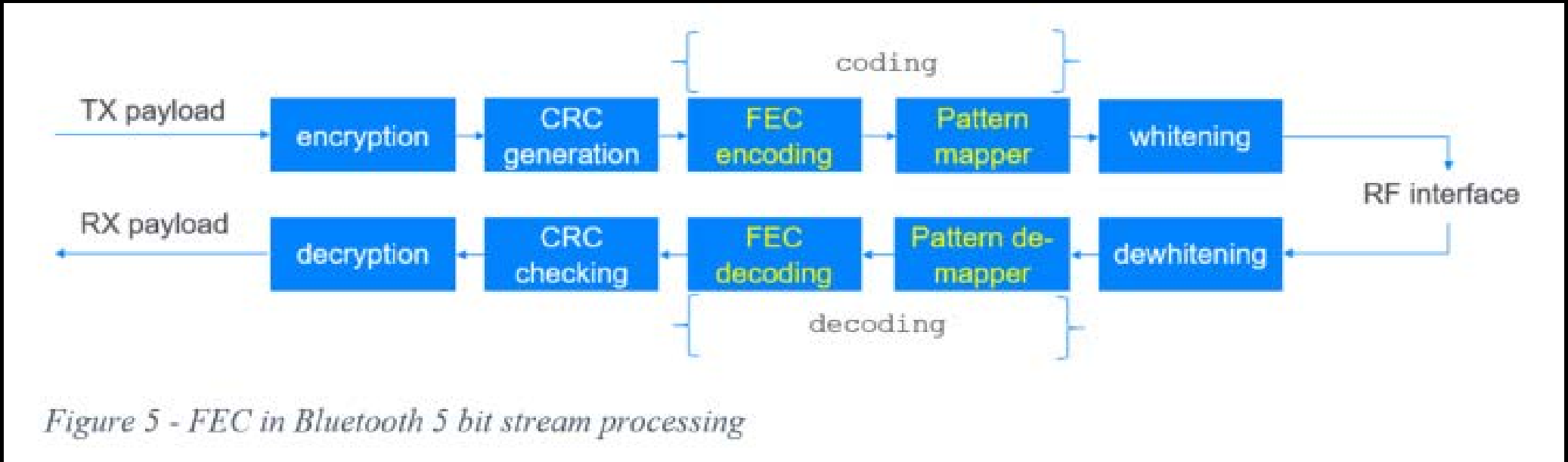



*Figure 5 - FEC in Bluetooth 5 bit stream processing*

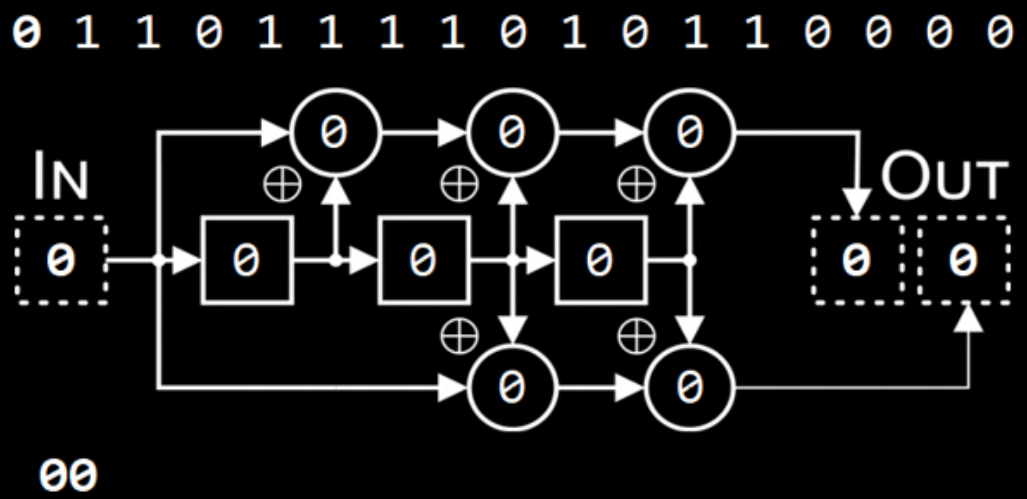
출처 – https://www.bluetooth.com/bluetooth-technology/bluetooth5/bluetooth5-paper

# More on LE Coded PHY

- FEC encoding: a convolutional encoder
  - 2 bits **generated** for every input bit by the polynomial:

$$G_0(x) = 1 + x + x^2 + x^3$$

$$G_1(x) = 1 + x^2 + x^3$$




출처 –
https://www.google.co.kr/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwj00vn2_8PcAhVZdt4KHZ-zBi0QjRx6BAgBEAU&url=https%3A%2F%2Fwww.allaboutcircuits.com%2Ftechnical-articles%2Flong-distance-bluetooth-low-energy-bit-data-paths%2F&psig=AOvVaw3qt9fHsf0wYnv64eEbFg5Q&ust=1532942653586251

# More on LE Coded PHY

- Pattern mapper
  - converts each bit from the convolutional FEC encoder into P symbols
  - P depending on coding schemes
    - S=2: P=1
    - S=8: P=4

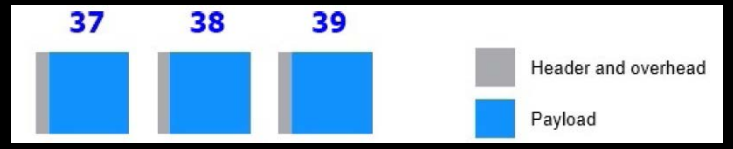
| Input (from FEC Encoder) | Output with S=2 | Output with S=8 |
|---|---|---|
| 0 | 0 | 0011 |
| 1 | 1 | 1100 |

# Comparison of Three PHYs

| | LE 1M | LE Coded S=2 | LE Coded S=8 | LE 2M |
|---|---|---|---|---|
| Symbol Rate | 1 Ms/s | 1 Ms/s | 1 Ms/s | 2 Ms/s |
| Data Rate | 1 Ms/s | 500 Kbit/s | 125 Kbit/s | 2 Mbit/s |
| Error Detection | CRC | CRC | CRC | CRC |
| Error Correction | NONE | FEC | FEC | NONE |
| Range Multiplier (approx.) | 1 | 2 | 4 | 0.8 |
| Bluetooth 5 Requirement | Mandatory | Optional | Optional | Optional |

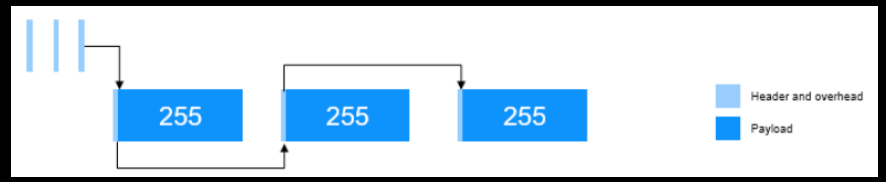
# Advertising Extensions

- Advertising packets in Bluetooth 4
  - Payload size limited to 31 octets long
  - Transmitted only up to three dedicated channels




- Advertising extensions in Bluetooth 5
  - Payload size up to 255 octets long
  - Offloading possible to 37 broadcasting channels


  - Advertising packet chaining




출처 – https://www.bluetooth.com/bluetooth-technology/bluetooth5/bluetooth5-paper

# Summary

# Summary (1/2)

**01** Wireless Network

- wireless network elements
- wireless link characteristics

**02** 802.11 Wireless LAN (Wi-Fi)

- 802.11 family
- 802.11 frame structure and rate adaptation capability

**03** CSMA/CA

- 802.11 DCF for collision avoidance
- RTS/CTS for hidden terminal problem

**04** Li-Fi

- visible light communication
- shorter range and faster than Wi-Fi

# Summary (2/2)

05

**Bluetooth Classic & Smart**

- wireless personal area network (WPAN)
- Smart – Bluetooth Low Energy (BLE)

06

**B5 (Bluetooth 5)**

- 4x range, 2x speed, 8x broadcast message capacity
- choice out of three PHYs