EE 597: Wireless Networks (Spring 12)

Intro to Cellular and WiFi Networks

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Acknowledgement

These slides were prepared by Dr. Kyuho Son, kyuhoson@usc.edu, visiting scholar at USC.

History of Cellular Technology

1G

Analog
AMPS

2G

Digital / PCS
GSM, CDMA (IS-95)

3G

WCDMA
CDMA2000

4G

OFDM
& MIMO

1G

- **First generation cellular systems**
  - Analog cellphone standards
  - Introduced in the 80's and continued until being replaced by 2G digital cellphone standards
  - Used FDMA with 30kHz FM-modulated voice channels
- **1G standards**
  - AMPS (Advanced Mobile Phone System) in the United States
  - NMT (Nordic Mobile Telephone) in Nordic countries, Eastern Europe and Russia
- **Speed**
  - Average between 4,800 to 9,600 bps (bits per second)

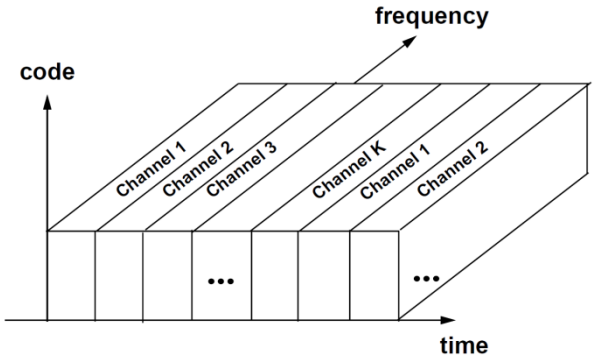
2G

- **Second generation cellular systems**
  - Digital cellphone standards
  - Mainly for digital voice, but SMS (short message service) is also available
- **Two types of 2G standards**
  - TDMA-based
    - GSM (Global System for Mobile Communication) originally from Europe but used worldwide
    - IS-136 aka D-AMPS (simply referred as TDMA) in the US
  - CDMA-based
    - IS-95 aka cdmaOne (simply referred as CDMA) in the US and parts of Asia
    - PDC (Personal Digital Cellular) used exclusively in Japan
- **Speed**
  - Up to 144 Kbps (2.5G in EDGE)

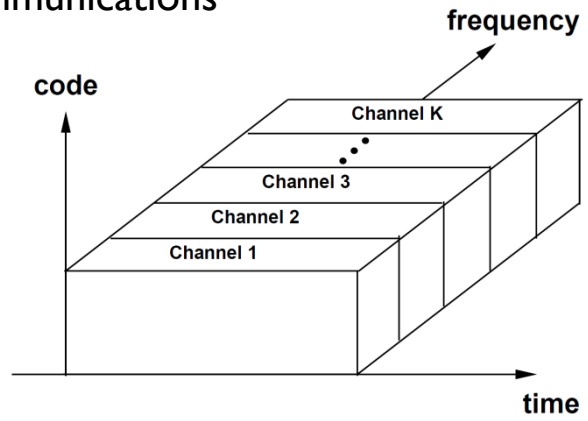
Types of Multiple Access

- **Multiple access**
  - The way of combining multiple data streams into one signal over a shared medium

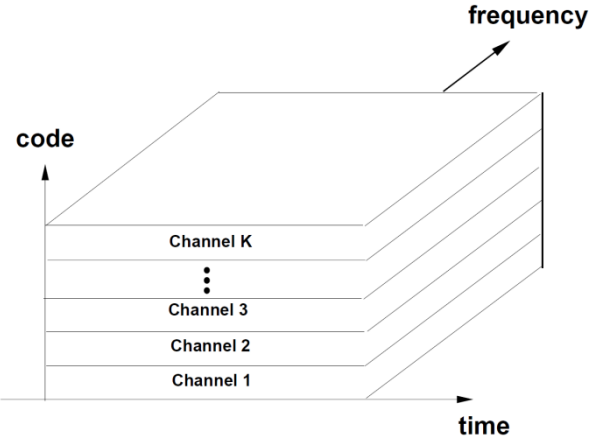
Source: A. Goldsmith, Wireless Communications



Time Division Multiple Access (TDMA)



Frequency Division Multiple Access (FDMA)



Code Division Multiple Access (CDMA)

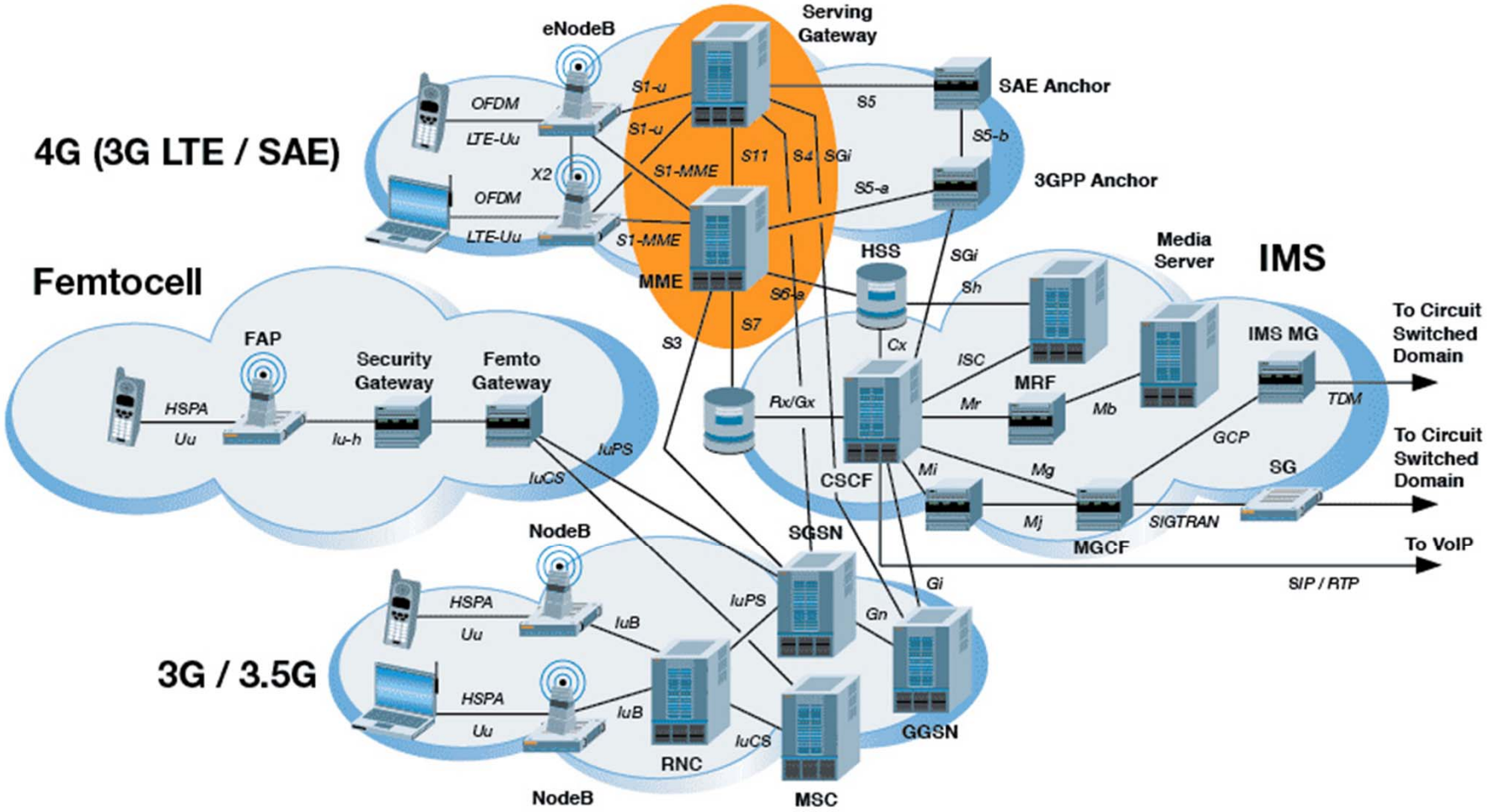
3G

- **Third generation cellular systems**
  - Provide the ability to transfer both voice and data (such as downloading information, exchanging email, and instant messaging)
  - Broadband (5MHz)
  - Global roaming
- **3G standards**
  - CDMA2000
  - WCDMA (Wideband CDMA)
  - TD-SCDNA (Time Division Synchronous CDMA)
- **Speed**
  - 384Kbps (moving) & 2Mbps (stationary)

4G

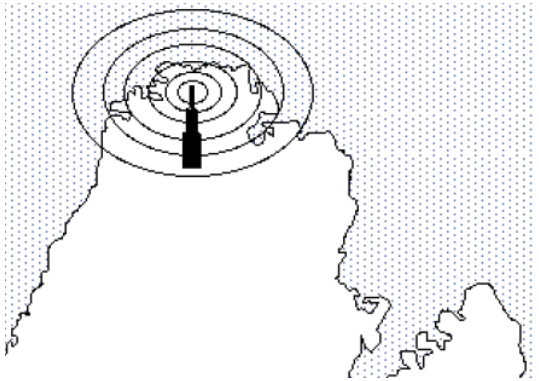
- **Fourth generation cellular systems**
  - Data-focused standards
- **Speed**
  - Much higher data rates (50-100 Mbps)
- **Key technologies for high spectral efficiency in 4G**
  - OFDM (Orthogonal Frequency-Division Multiplexing) / OFDMA
  - MIMO (Multiple-Input and Multiple-Output)
- **Two competing standards:**
  - 3GPP LTE (Long Term Evolution)
  - WiMax (Worldwide Interoperability for Microwave Access)

Network Architecture



Cellular Concept

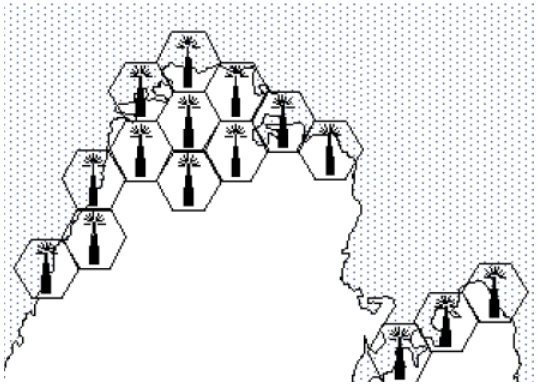
- **Early mobile radio system**
  - Similar to television broadcasting



  - One very powerful transmitter located at a tall tower
    - Large area coverage but difficult to spatially reuse the same frequencies throughout the system due to significant interference
    - In 1970, Bell had a mobile system in NYC with a single high power transmitter, it could only support 12 simultaneous calls. (limited capacity!)

Cellular Concept

- **The concept of cells**
  - Developed by Bell Labs 1960's-70's

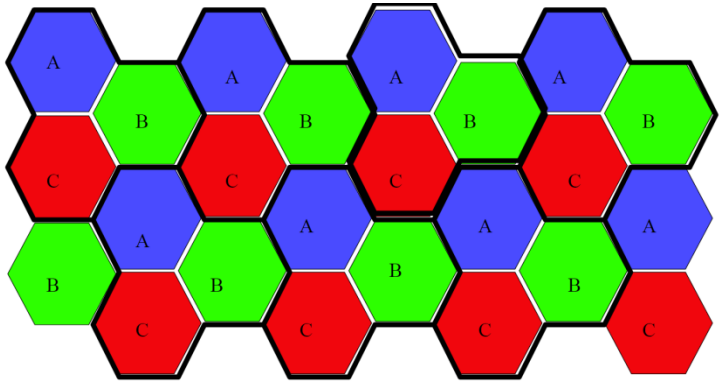


  - Instead of using one powerful transmitter, many low-power transmitters are placed throughout a coverage area
  - Fixed number of channels can be reused over and over again
    - e.g.) If we divide a metropolitan region into 10 different cells with low-power transmitters, then simultaneous conversations can be theoretically increased up to 10 times.

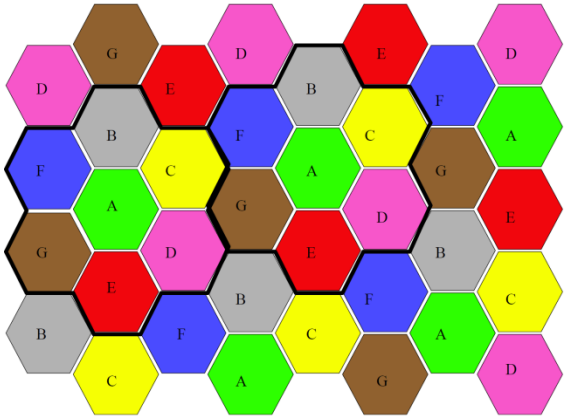
Frequency Reuse

- **The concept of frequency reuse**
  - Intelligent allocation and reuse of channels throughout different coverage areas which are separated from one another by sufficient distances so that co-channel interference is not unacceptable

Reuse-3 system (i=j=1)



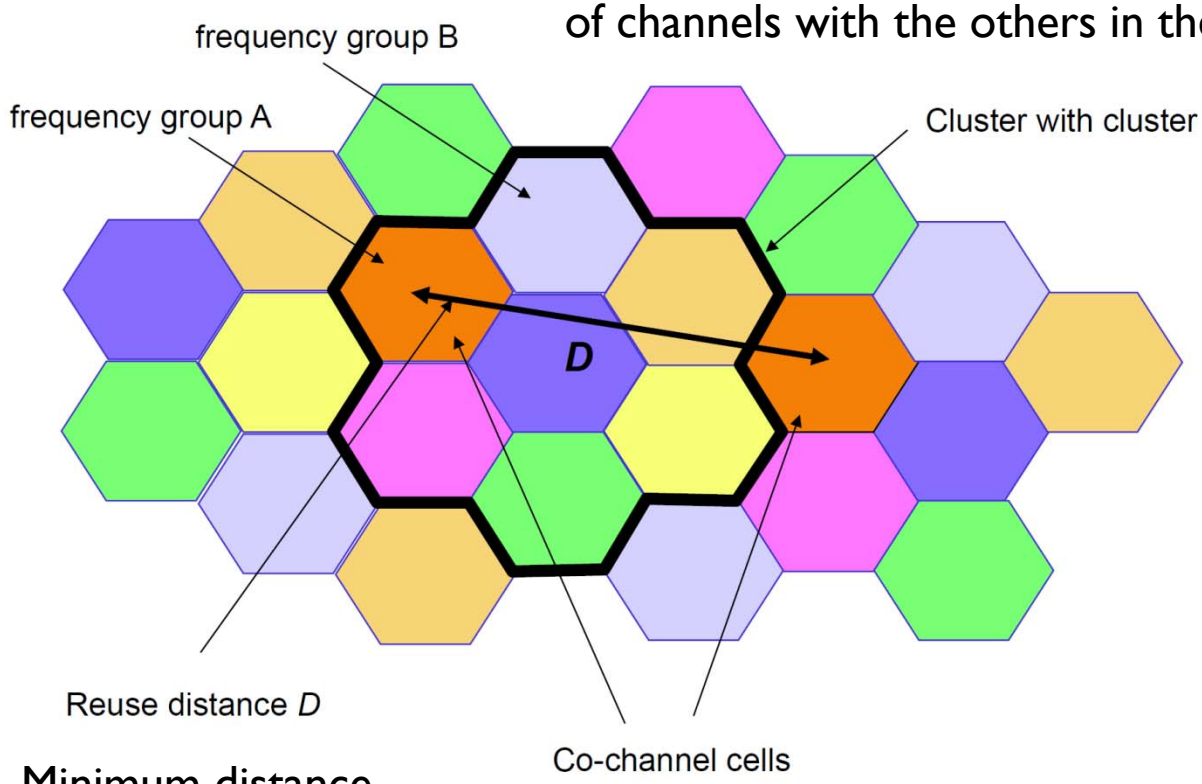
Reuse-7 system (i=2, j=1)



  - In hexagonal networks, only reuse-N system is possible.
    - $N = i^2 + ij + j^2$, where i and j are integers.
    - e.g.) N=1, 3, 4, 7, 9, …

Frequency Reuse

Cluster: Each cell uses totally the different set of channels with the others in the same cluster



Reuse distance: Minimum distance between two cells using same channel for satisfactory signal quality

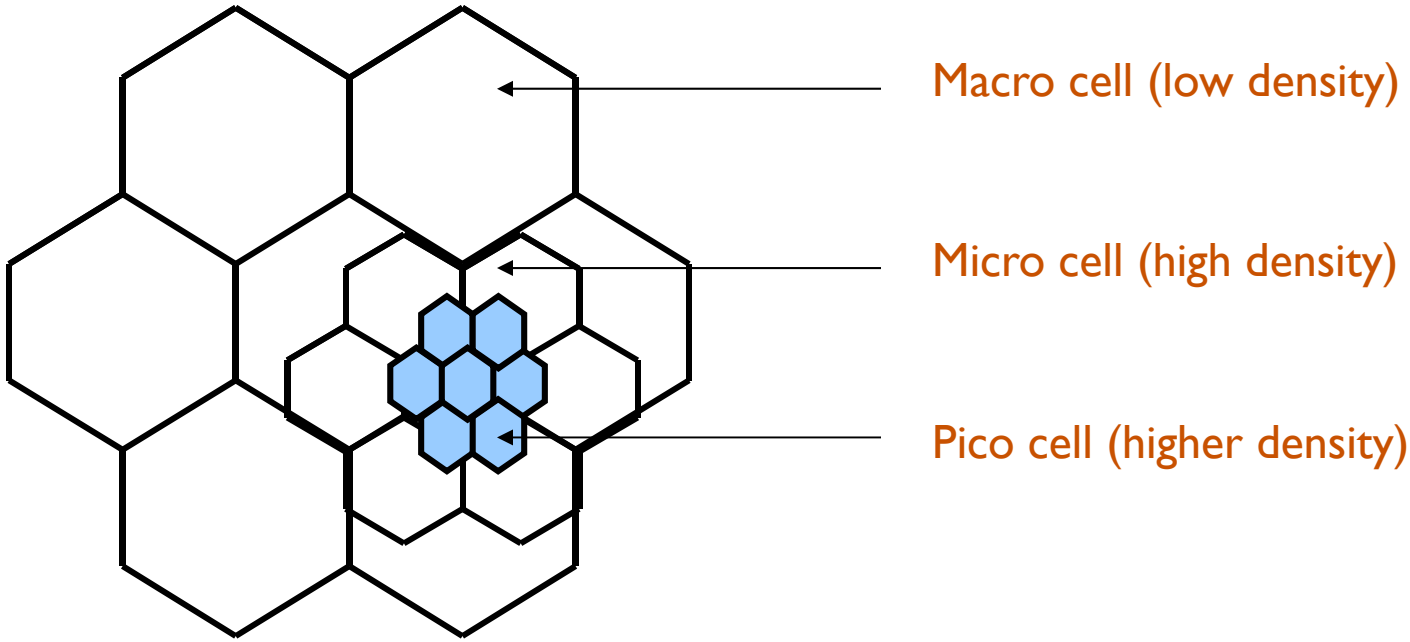
Co-channel interference: Interference caused by transmissions of co-channel cells

Increasing Spectral Efficiency

- **Demands for service keeps increasing**
- **Techniques to improve the capacity of cellular systems**
  - Cell splitting
  - Sectorization
  - Fractional frequency reuse

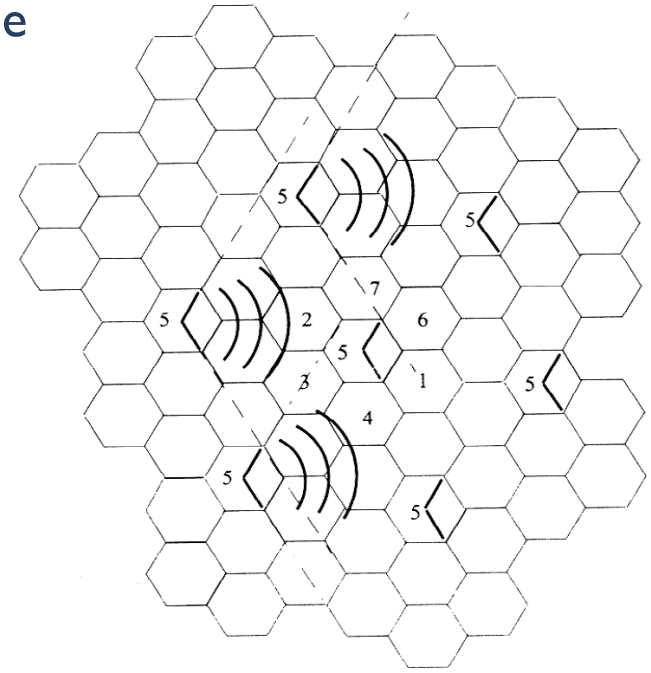
Cell Splitting

- **Cell splitting**
  - Subdividing a congested cell into smaller cells (reducing cell radius and keeping the D/R ratio unchanged) with a corresponding reduction in transmit power and antenna height
  - Can increase capacity by increasing the number of BSs



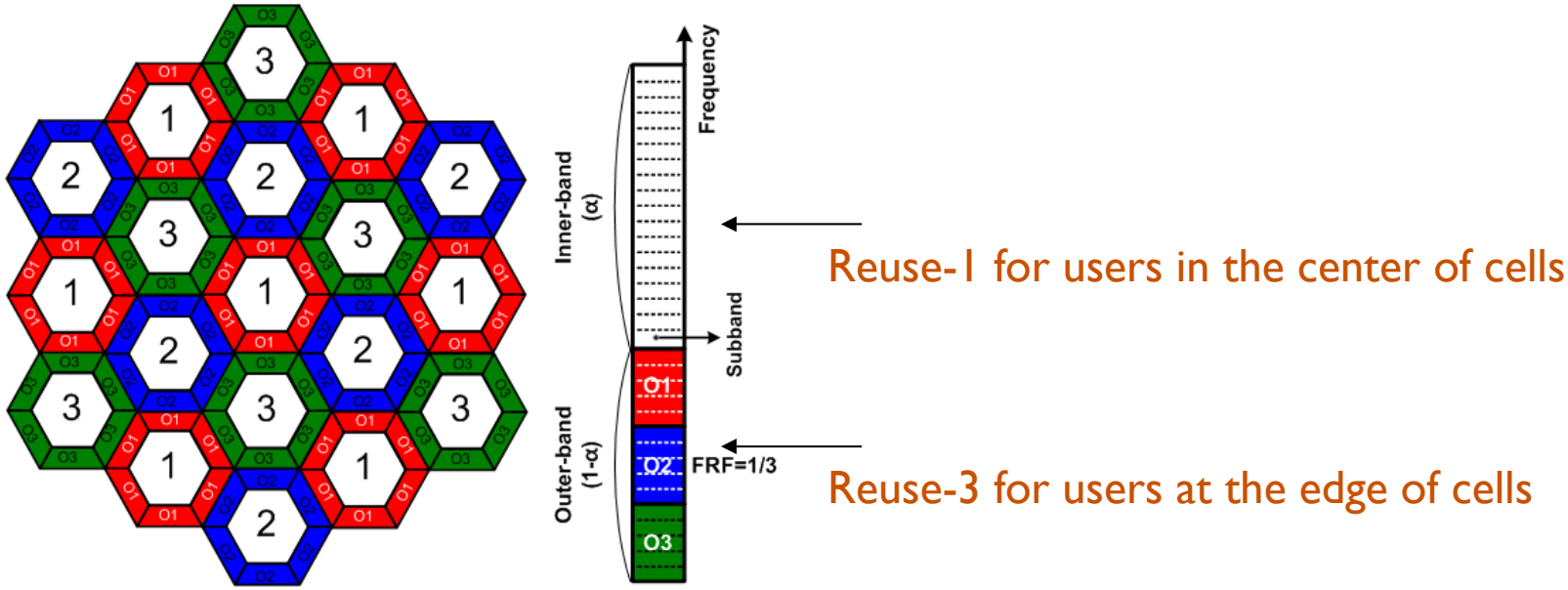
Sectorization

- **Sectorization**
  - Cells are divided into a number of wedge-shaped sectors using directional antennas
  - Can improve capacity by reducing co-channel interference
  - e.g.) 3 sector ➔ 1/3 co-channel interference



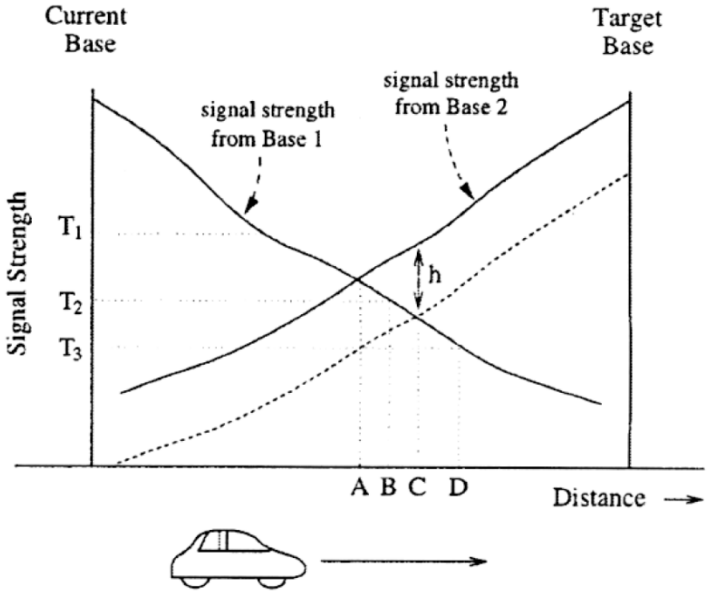
Fractional Frequency Reuse

- **Fractional frequency reuse (FFR)**
  - Allow users in different conditions to enjoy different reuse factors rather than determining the reuse distance by the worst-case user
  - Can increase capacity by increasing the number of channels available in each cell



Handoff (or Handover)

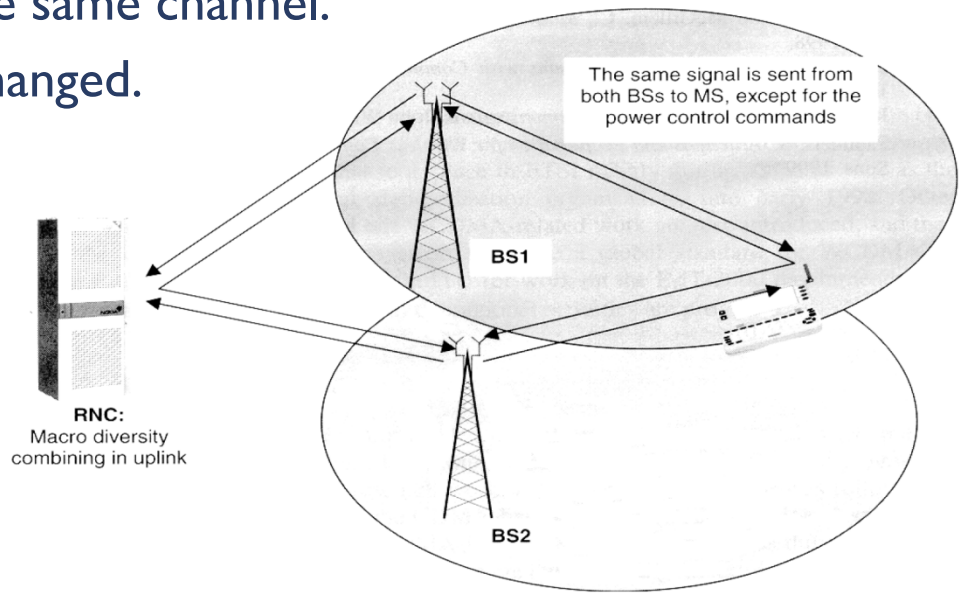
- **Reason for handoff**
  - Moving out of coverage
  - Load balancing



- **Handoff decision**
  - Relative signal strength (S1 < S2)
  - Threshold (S1 < threshold)
  - Hysteresis and dwell time to avoid ping-pong effects

Handoff

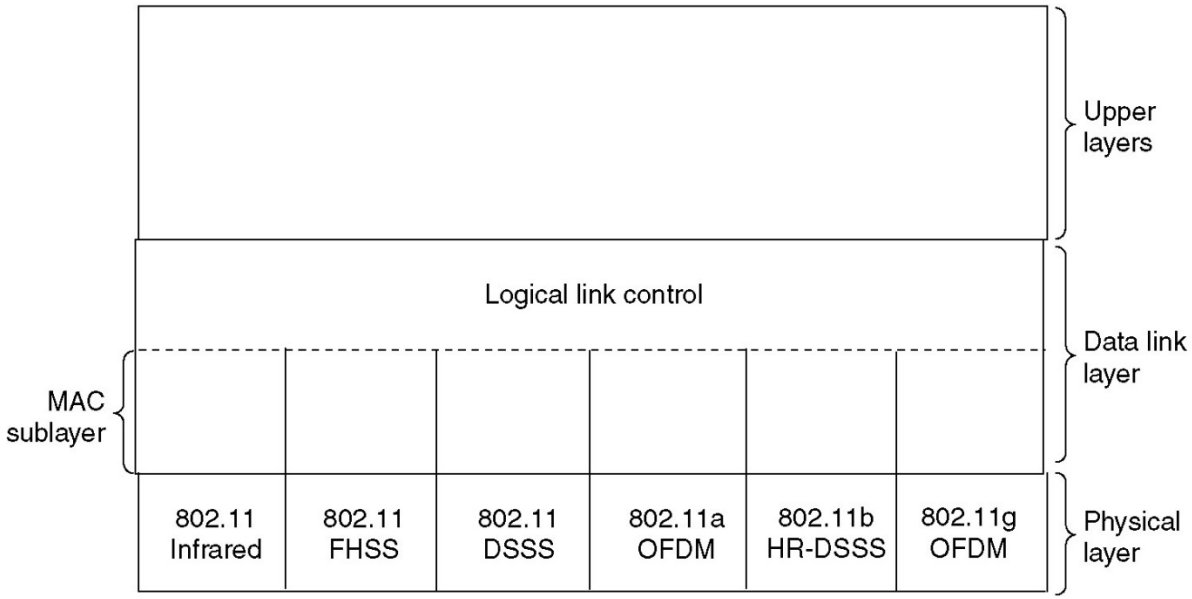
- **Hard handoff**
  - If adjacent cells do not have the same frequency, then channel and BS must change.
  - Break-before-make
- **Soft handoff**
  - In IS-95 CDMA, all cells use the same channel.
  - Only serving BS needs to be changed.
  - Make-before-break
  - Rake receiver



IEEE 802.11 Wireless LAN Overview

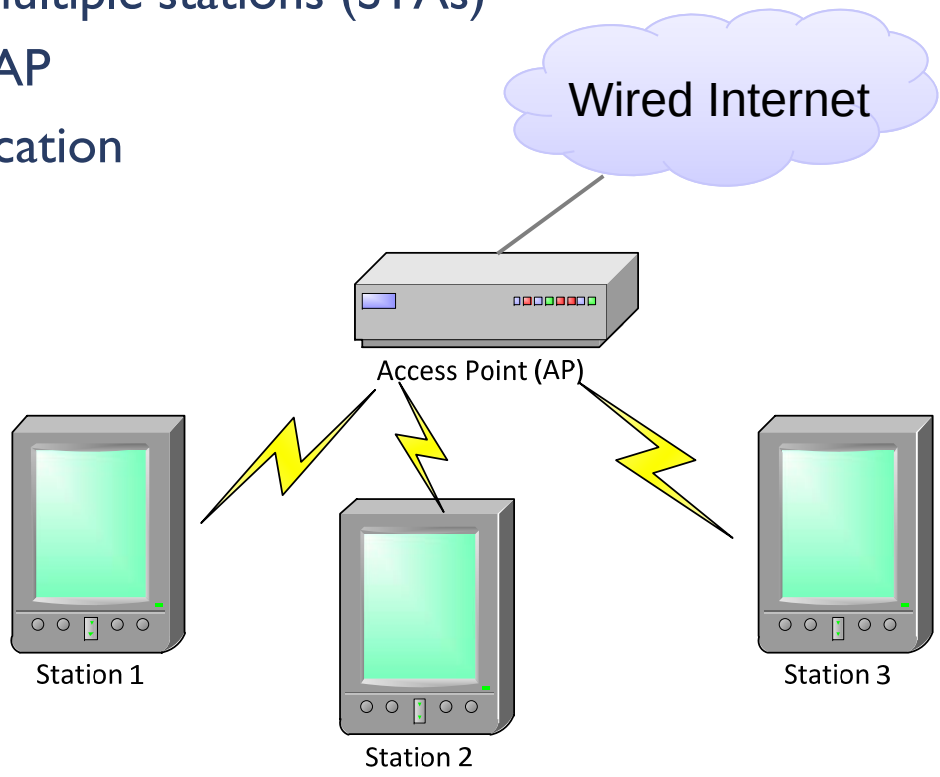
Overview – 802.11 Wireless LAN (WLAN)

- **Wireless Ethernet with compatible speed**
- **Supports up to 11 and/or 54 Mbps within >100 m range**
- **Operates at unlicensed ISM (Industrial, Scientific and Medical) bands at 2.4GHz (802.11 b/g) / 5GHz (802.11 a)**
- **Common MAC supports multiple PHYs (DSSS / FHSS / Infrared / OFDM)**



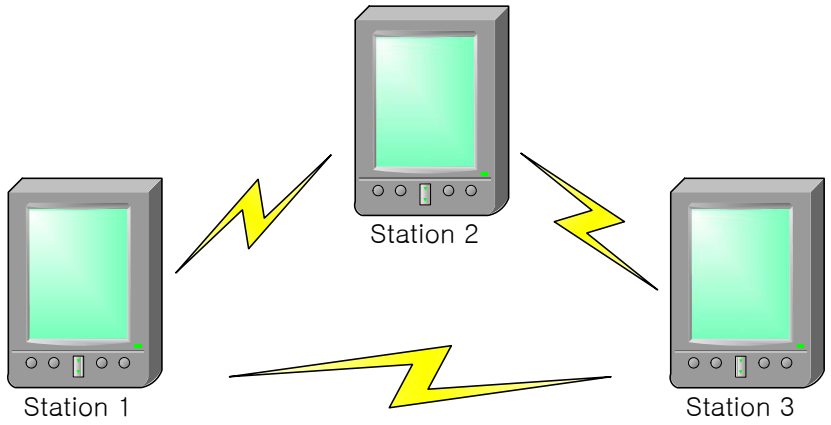
Two Configuration Modes 1/2

- **1. Infrastructure mode**
  - Infrastructure Basic Service Set (BSS)
  - An access point (AP) and multiple stations (STAs)
  - Every transmission is with AP
  - No peer-to-peer communication



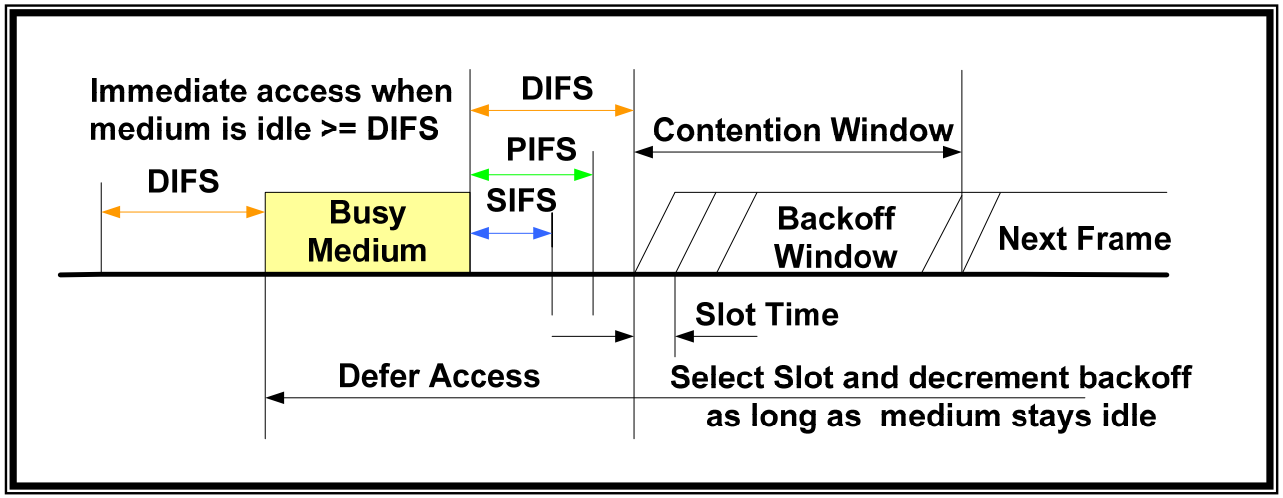
Two Configuration Modes 2/2

- **2. Independent mode (or Ad-hoc mode)**
  - Independent Basic Service Set → IBSS
  - Multiple stations and no access point (AP): ad-hoc network
  - Peer-to-peer communication only



Two Coordination Functions

- **Mandatory Distributed Coordination Function (DCF)**
  - For distributed contention-based channel access
  - CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance)



- **Optional Point Coordination Function (PCF)**
  - For centralized contention-free channel access

IEEE 802.11 Standards

802.11a	5 GHz, up to 54 Mbps
802.11b	2.4 GHz, up to 11 Mbps
802.11d	Enables 802.11 to work in various countries where it can't today
802.11e	QoS Enhancement
802.11f	Adds Access Point Interoperability
802.11g	2.4 GHz, up to 54 Mbps, compatible with 802.11b
802.11h	Resolves interference issues
802.11i	Security Enhancement
802.11j	Japanese regulatory extensions
802.11k	Radio resource measurement
802.11m	Enhanced maintenance features, improvements, and amendments
802.11n	Next generation of 802.11 with throughput in excess of 100Mbps
802.11r	Enhancements for fast roaming of WLAN units
802.11s	Wireless mesh networks

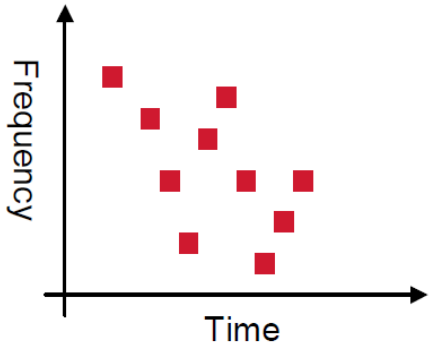
IEEE 802.11 Physical Layer

IEEE 802.11 Physical Layer

- **Many physical layer standards**
  - 1997: 802.11 infrared, FHSS, DSSS
  - 1999: 802.11a OFDM and 802.11b HR-DSSS
  - 2001: 802.11g OFDM

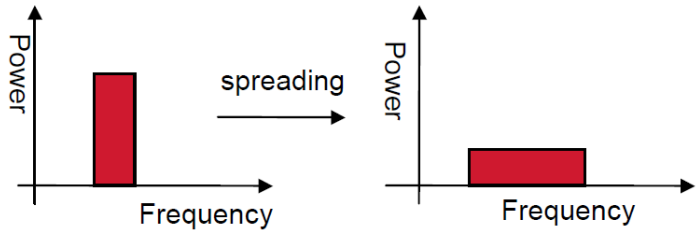
IEEE 802.11 Physical Layer

- **802.11 Infrared**
  - Two capacities 1 Mbps or 2 Mbps.
  - Range is 10 to 20 meters and cannot penetrate walls.
  - Does not work outdoors.
- **802.11 FHSS (Frequency Hopping Spread Spectrum)**
  - The main issue was multipath fading.
  - 79 non-overlapping channels, each 1 Mhz wide at low end of 2.4 GHz ISM band.
  - Dwell time: min. time on channel before hopping (400msec).

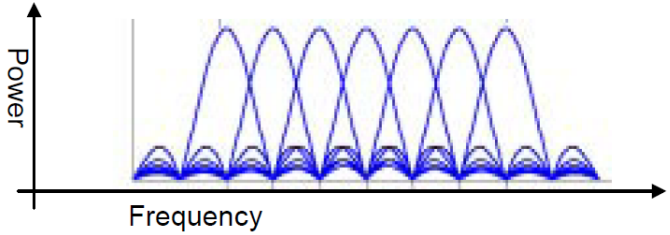


IEEE 802.11 Physical Layer

- **802.11 DSSS (Direct Sequence Spread Spectrum)**
  - Spreads signal over entire spectrum using pseudo-random sequence (similar to CDMA).
  - 1 or 2 Mbps.



- **802.11a OFDM (Orthogonal Frequency Divisional Multiplexing)**



  - Compatible with European HiperLan2.
  - 54Mbps in wider 5.5 GHz band → transmission range is limited.
  - Uses 52 FDM channels (48 for data; 4 for synchronization).
  - Encoding is complex (PSM up to 18 Mbps and QAM above this capacity).

IEEE 802.11 Physical Layer

- **802.11b HR-DSSS (High Rate Direct Sequence Spread Spectrum)**
  - 11a and 11b shows a split in the standards committee.
  - 11b approved just before 11a and hit the market.
  - Up to 11 Mbps in 2.4 GHz band.
  - Range is 7 times larger than 11a.
  - 802.11b and 802.11a are incompatible!
  - Note in this bandwidth all these protocols have to deal with interference from microwave ovens, cordless phones, garage door openers, Bluetooth, Zigbee.

IEEE 802.11 Physical Layer

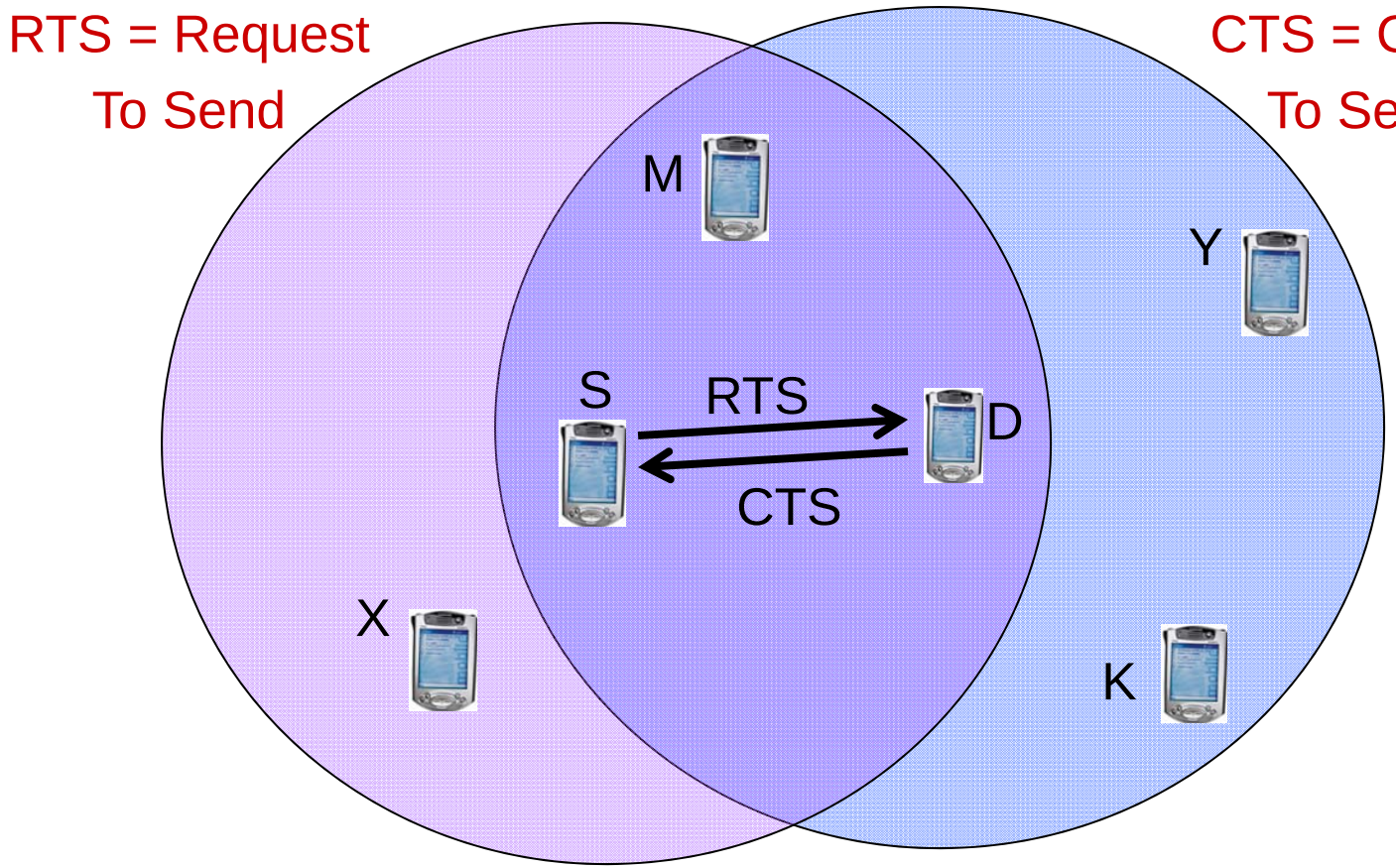
- **802.11g OFDM (Orthogonal Frequency Division Multiplexing)**
  - An attempt to combine the advantage of both 802.11a and 802.11b.
  - Supports speed up to 54 Mbps.
  - Uses 2.4 GHz frequency for greater range.
  - Is backward compatible with 802.11b.

IEEE 802.11 Medium Access Control Layer

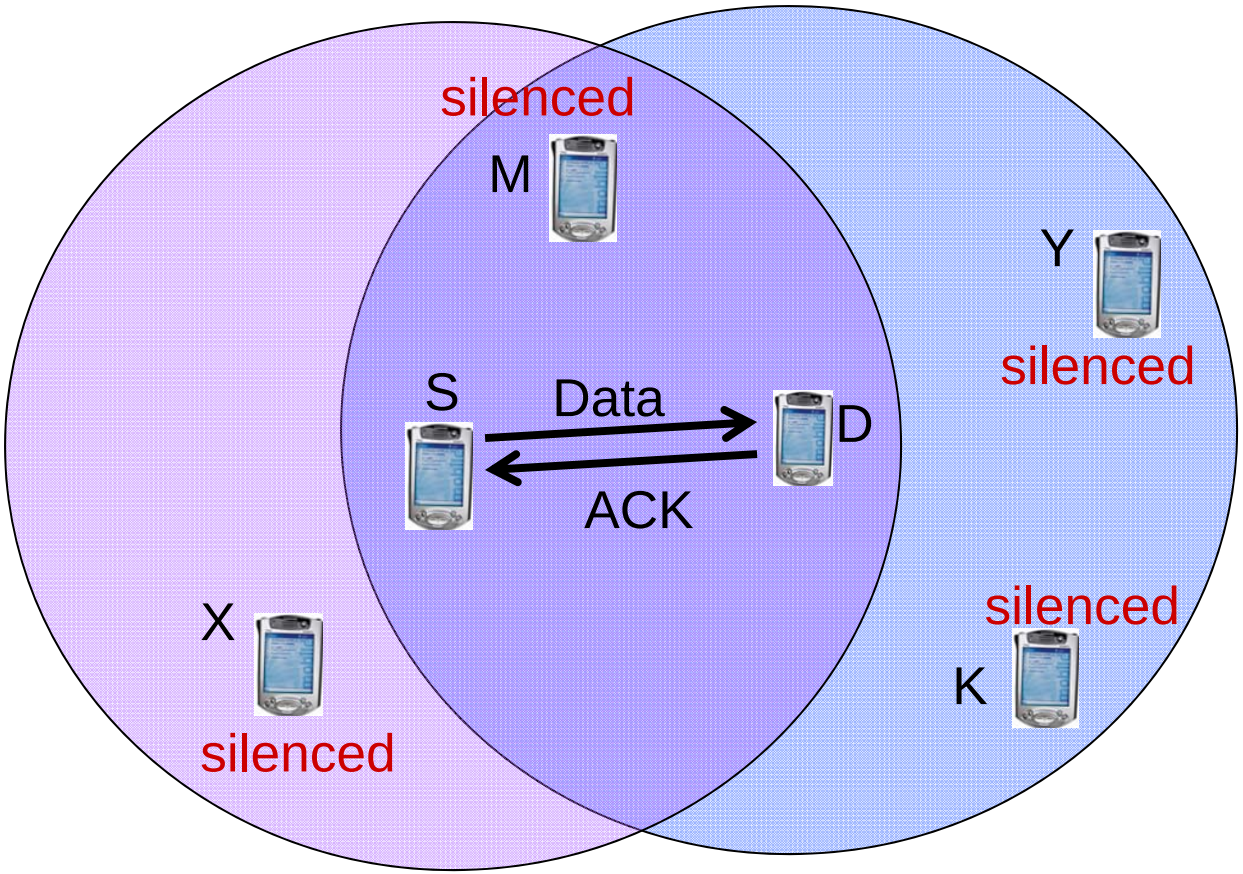
IEEE 802.11 MAC Layer
: DCF

- **Mandatory Distributed Coordination Function (DCF)**
  - Use CSMA/CA (CSMA with Collision Avoidance)
  - Robust for interference
    - Explicit acknowledgment, e.g., ACK or NACK message
    - Only CSMA/CA for broadcast frames
  - Optional Request To Send (RTS) / Clear To Send (CTS)
    - To alleviate hidden node problems
    - RTS/CTS provide a virtual carrier-sensing (duration of immediate dialog)

Request To Send (RTS) / Clear To Send (CTS)



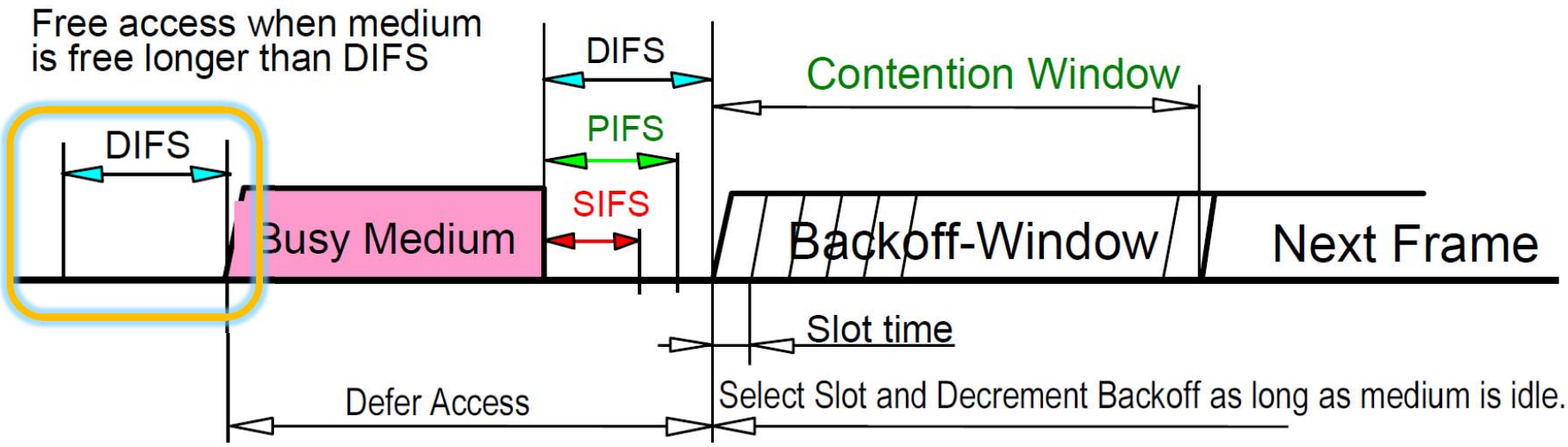
Request To Send (RTS) / Clear To Send (CTS)



IEEE 802.11 MAC Layer
: DCF

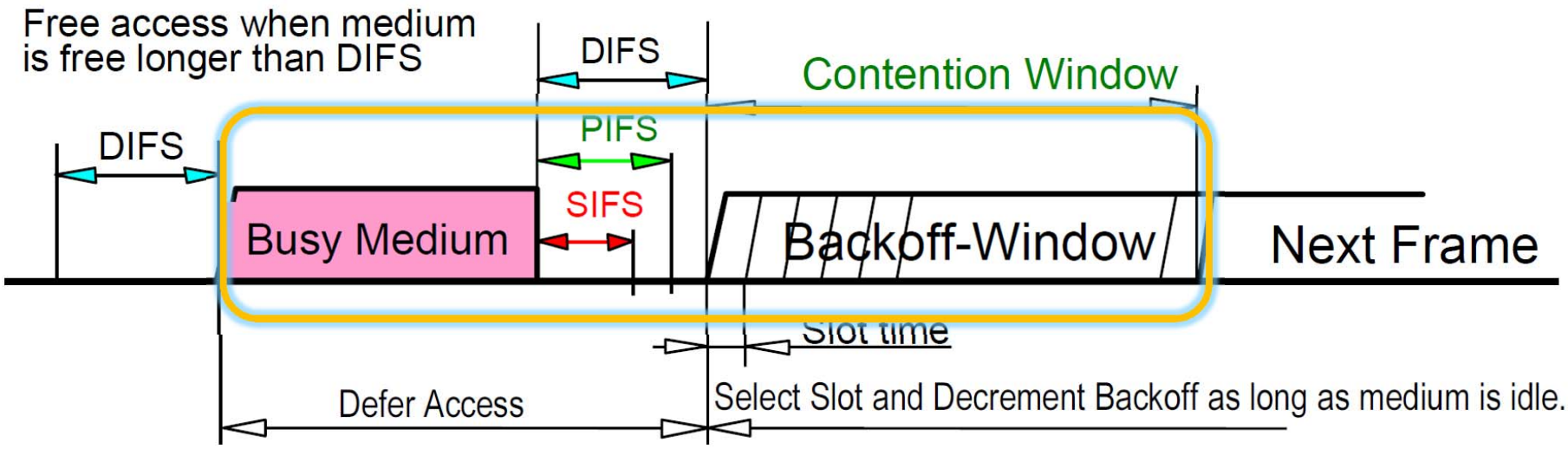
- **Carrier-sensing mechanisms**
  - Physical carrier-sense
    - Truly proves the channel
    - Provided by PHY, and depends on PHY
    - Clear Channel Assessment (CCA) by PHY
  - Virtual carrier-sense
    - Assume that the channel is busy (irrespective of CCA!) during the time indicated by the duration field in data frame or in RTS/CTS messages
    - Adjusts their NAV (Network Allocation Vector) accordingly.

DCF Operation



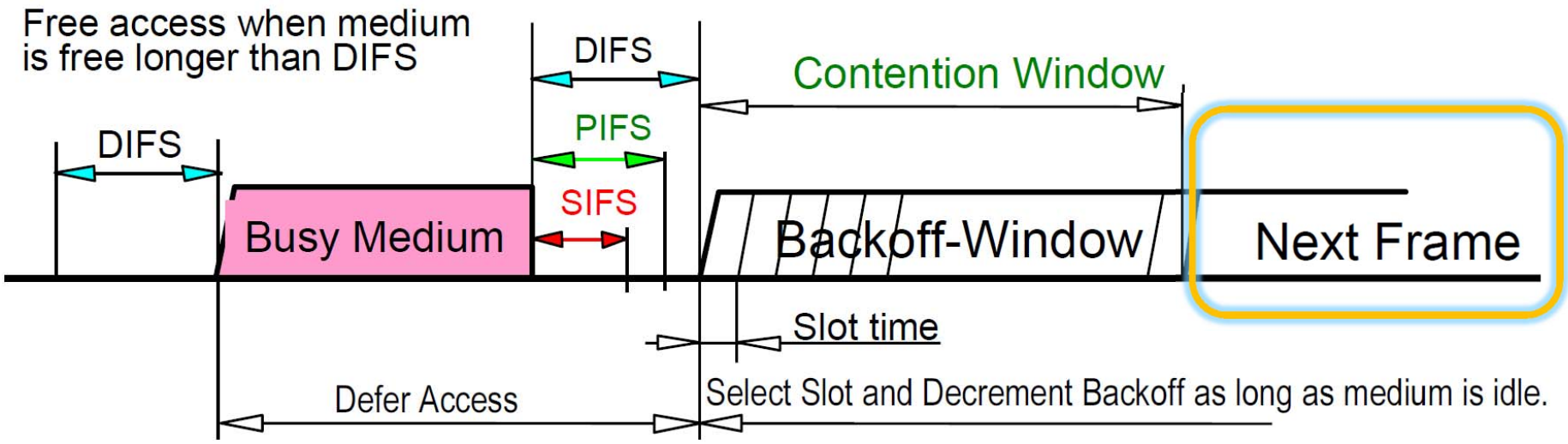
- 1. when the MAC layer receives a request to transmit a data, it checks the medium status based on the physical and virtual carrier sense mechanisms.
- 2. if the medium is not in use for an interval of DIFS, the MAC may begin transmission

DCF Operation (Cont'd)



- 3. if the medium is in use during the DIFS interval, the MAC will randomly choose a backoff value in the range of [0,CW].
- 4. if the medium is detected to be idle for one slot time, the MAC decrements the backoff value each time.

DCF Operation (Cont'd)



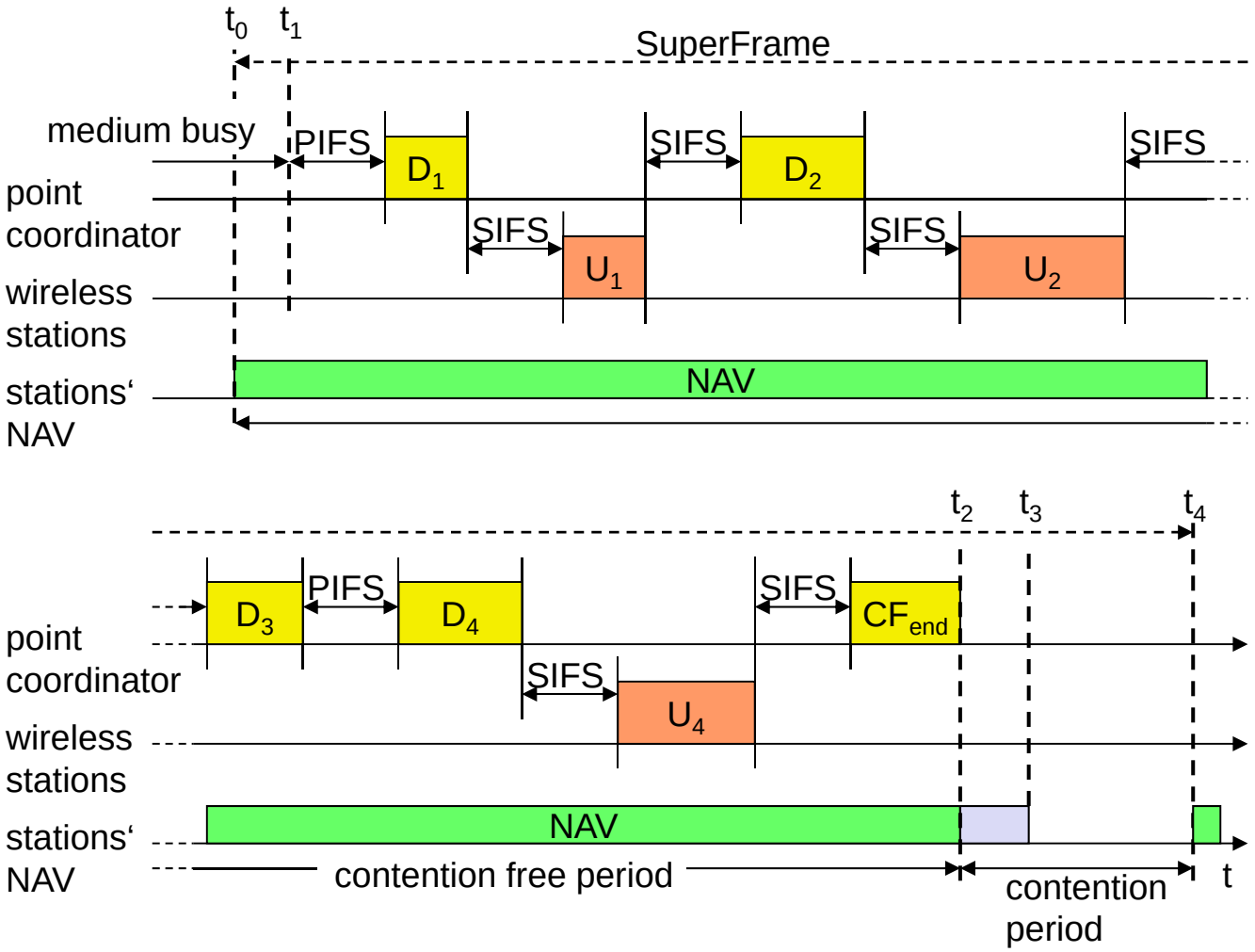
- 5. when the backoff value reaches 0, it begin a transmission.
- 6. if a collision happens, then the contention window (CW) is doubled for congestion avoidance and a new backoff interval is selected.
- 7. when a node successfully completes a data transfer, it restores CW to CWmin.

IEEE 802.11 MAC Layer
: PCF

- **Optional Point Coordination Function (PCF)**
  - A centralized collision-free MAC
  - The AP periodically polls other stations through beacon frame to check if they have data to send.
  - The AP may tell another station to sleep to save on batteries.
  - The PCF can be built over the DCF and both operate simultaneously.

IEEE 802.11 MAC Layer

: PCF



Acknowledgement

- **This material was partly adapted from**
  - "Wireless Medium Access Control" by Romit Roy Choudhur at Duke University
  - "Wireless LAN 802.11 Tutorial" by Maximilian Riegel at SIEMENS Mobile