Wireless and Mobile Networks

Raj Jain
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@wustl.edu

Audio/Video recordings of this lecture are available on-line at:

http://www.cse.wustl.edu/~jain/cse473-22/

Student Questions

Overview

1. Wireless Link Characteristics
2. Wireless LANs and PANs
3. Cellular Networks
4. Mobility Management
5. Impact on Higher Layers

Note: This class lecture is based on Chapter 7 of the textbook (Kurose and Ross) and the figures provided by the authors.

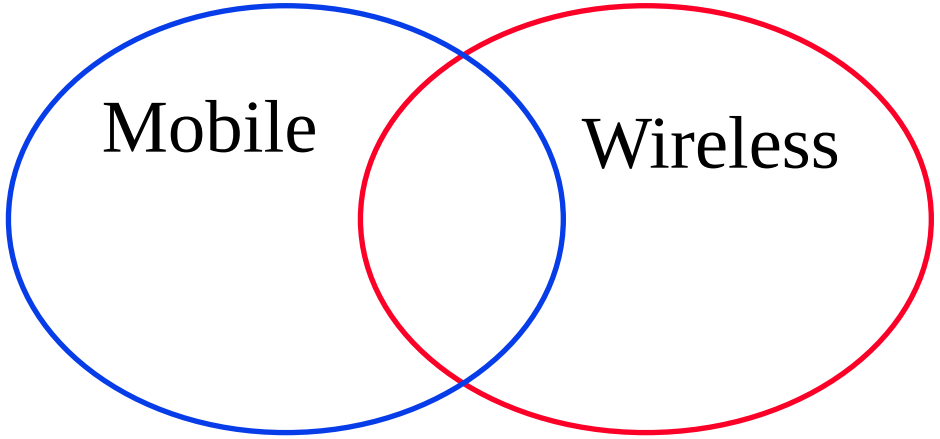
Student Questions

Wireless Link Characteristics

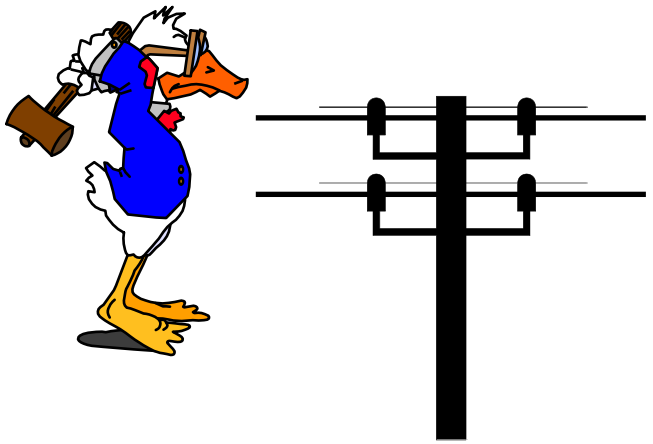
- Mobile vs. Wireless
- Wireless Networking Challenges
- Peer-to-Peer or Base Stations?
- Code Division Multiple Access (CDMA)
  - Direct-Sequence Spread Spectrum
  - Frequency Hopping Spread Spectrum

Student Questions

Mobile vs Wireless



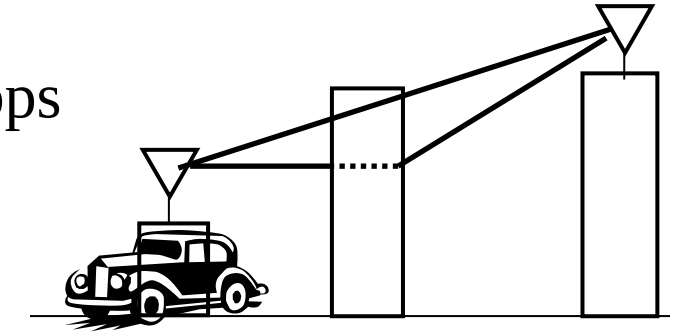
- Mobile vs Stationary
- Wireless vs Wired
- Wireless ⇒ media sharing issues
- Mobile ⇒ routing, addressing issues



Student Questions

Wireless Networking Challenges

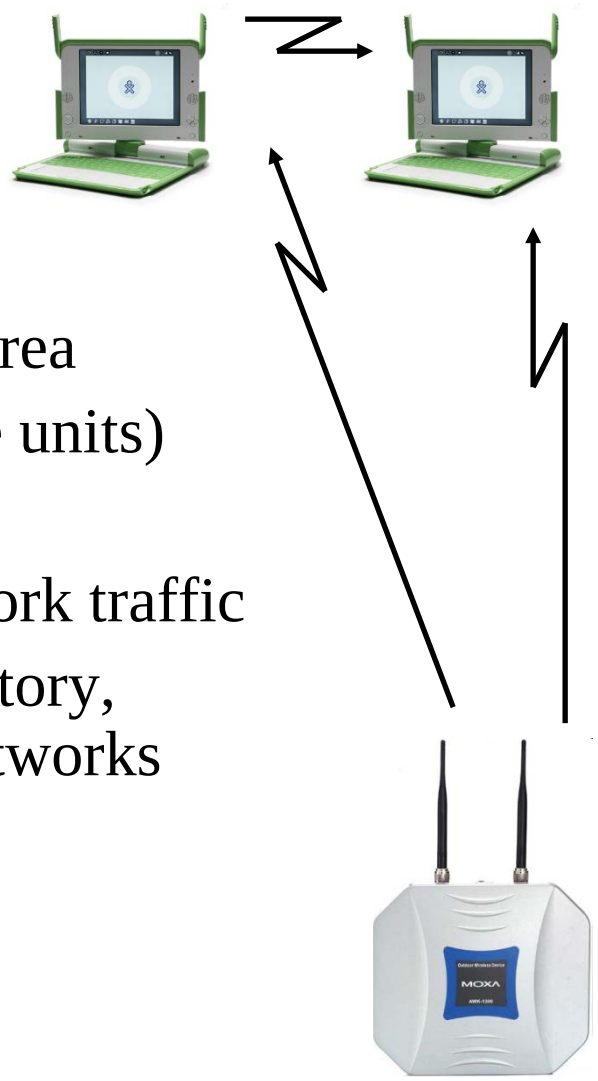
1. Propagation Issues: Shadows, Multipath
2. Interference ⇒ High loss rate, Variable Channel
   ⇒ Retransmissions and Cross-layer optimizations
3. Transmitters and receivers moving at high speed
   ⇒ Doppler Shift
4. Low power transmission ⇒ Limited reach
   100mW in WiFi base station vs. 100 kW TV tower
5. License-Exempt spectrum ⇒ Media Access Control
6. Limited spectrum ⇒ Limited data rate
   Original WiFi (1997) was 2 Mbps.
   New standards allow up to 200 Mbps
7. No physical boundary ⇒ Security
8. Mobility ⇒ Seamless handover



Student Questions

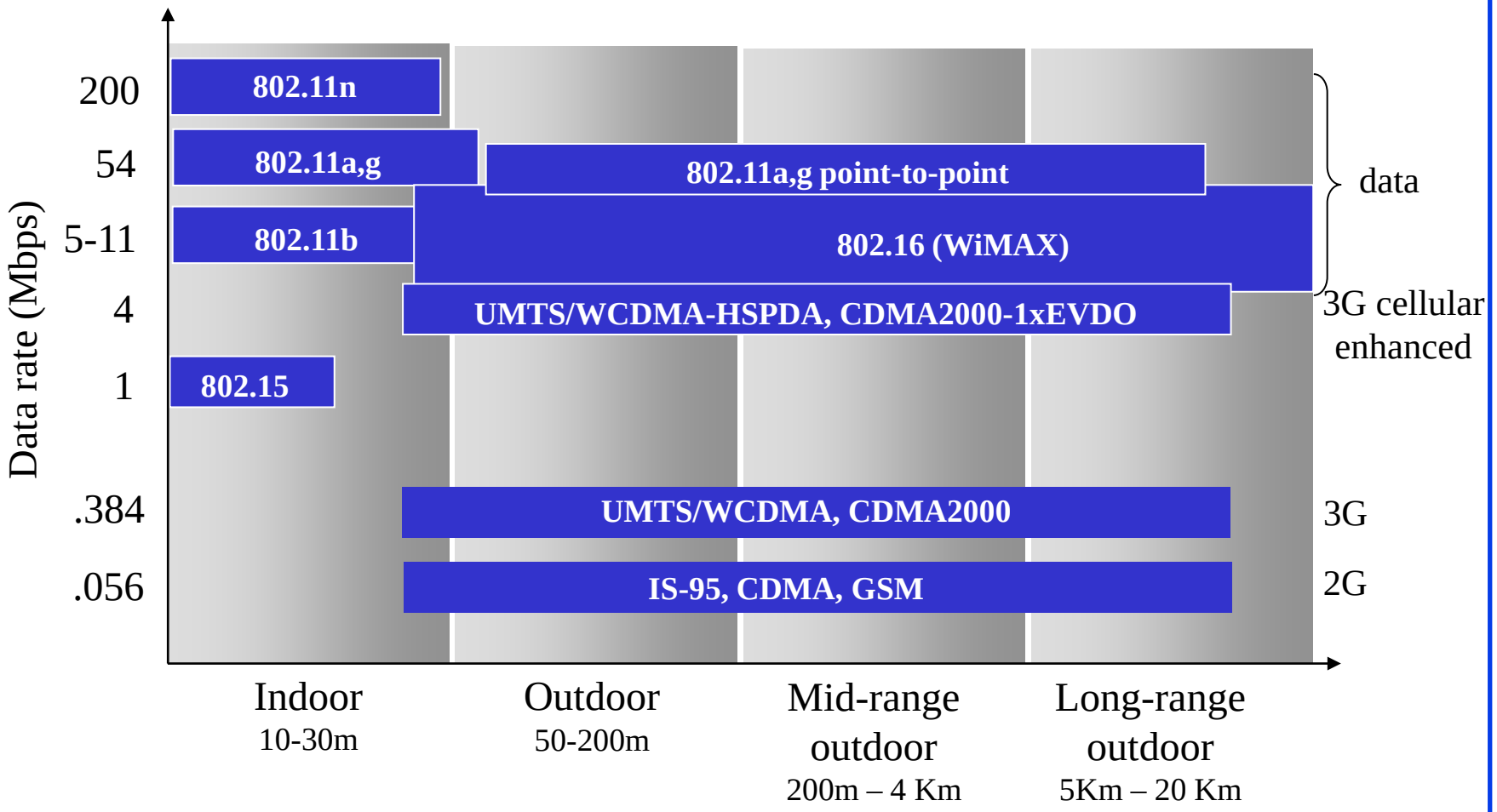
Peer-to-Peer or Base Stations?

- Ad-hoc (Autonomous) Group:
  - Two stations can communicate
  - All stations have the same logic
  - No infrastructure, Suitable for small area
- Infrastructure Based: Access points (base units)
  - Stations can be simpler than bases.
  - Base provide connection for off-network traffic
  - Base provides location tracking, directory, authentication ⇒ Scalable to large networks
- IEEE 802.11 provides both.



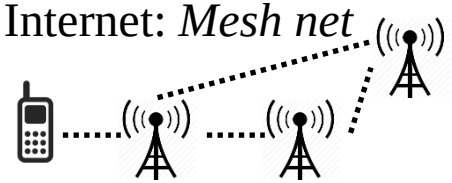
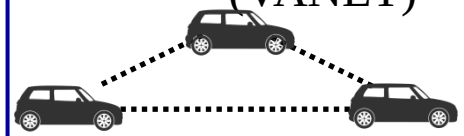
Student Questions

Characteristics of Selected Wireless Link Standards



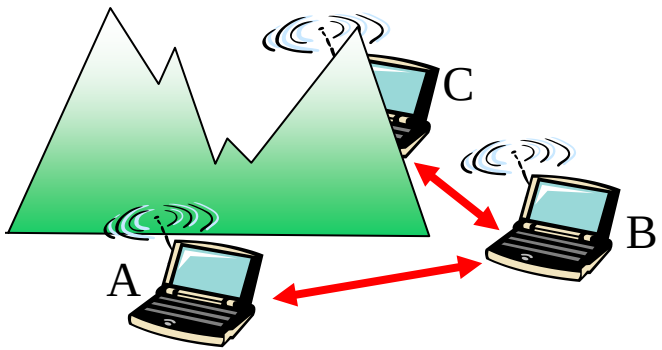
Student Questions

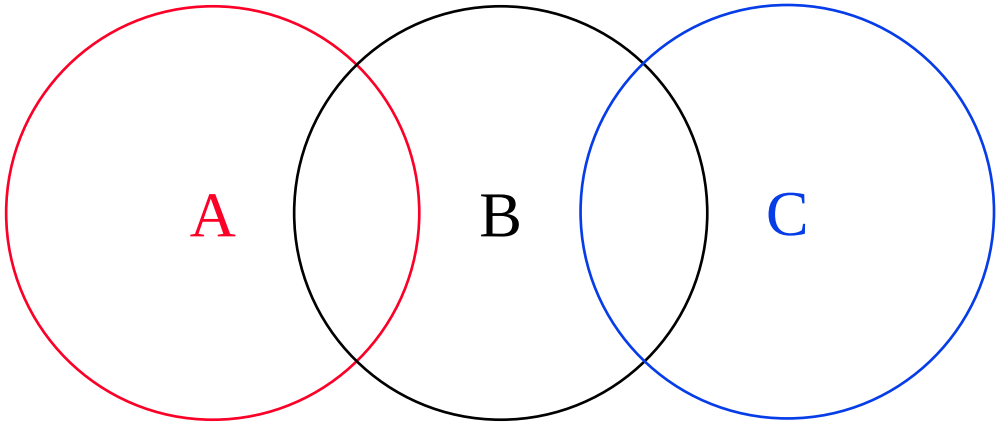
Wireless Network Taxonomy

	Single hop	Multiple hops
Infrastructure (Access Points, Towers)	Host connects to base station (WiFi, WiMAX, cellular) which connects to larger Internet 	Host may have to relay through several wireless nodes to connect to larger Internet: *Mesh net* 
No Infrastructure	No base station (Bluetooth, ad hoc nets) 	Relay to reach other a given wireless node. Mobile Ad-hoc Network (MANET), Vehicular Ad-hoc Network (VANET) 

Student Questions

Hidden Node Problem

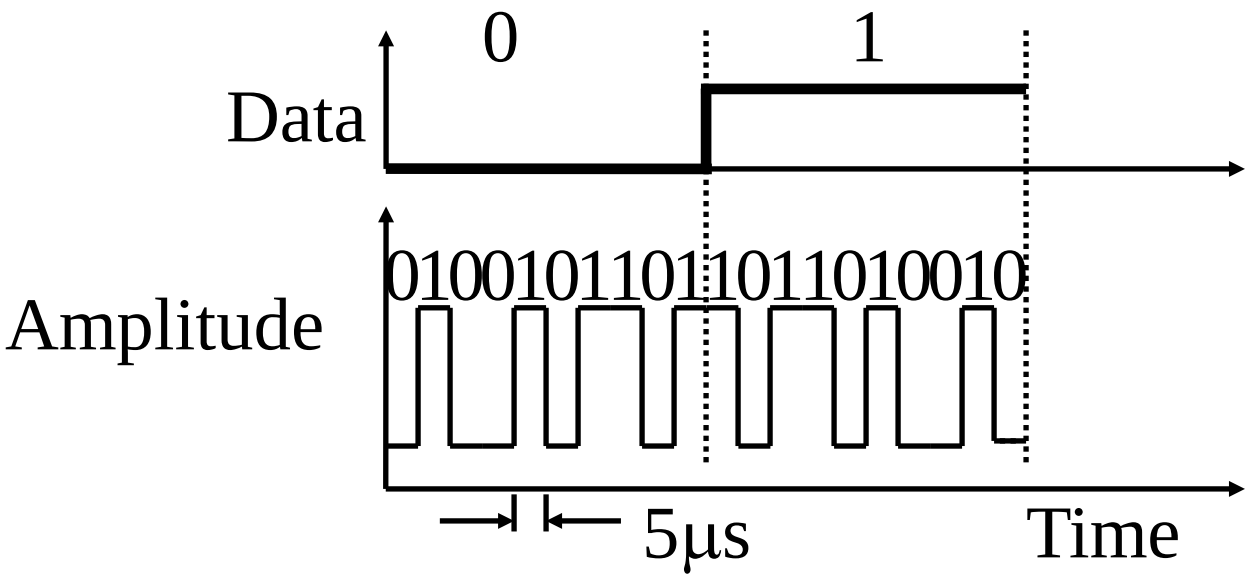




- B and A can hear each other
  B and C can hear each other
  A and C cannot hear each other
  ⇒ C is hidden for A and vice versa
- C may start transmitting while A is also transmitting
  A and C can't detect collision.
- Only the receiver can help avoid collisions

Student Questions

Direct-Sequence Spread Spectrum CDMA



- Spreading factor = Code bits/data bit, 10-100 commercial (Min 10 by FCC), 10,000 for military
- Signal bandwidth >10 × data bandwidth
- Code sequence synchronization
- Correlation between codes ⇒ Interference ⇒ Orthogonal

Student Questions

- Would you clarify the meanings of "bandwidth" here?

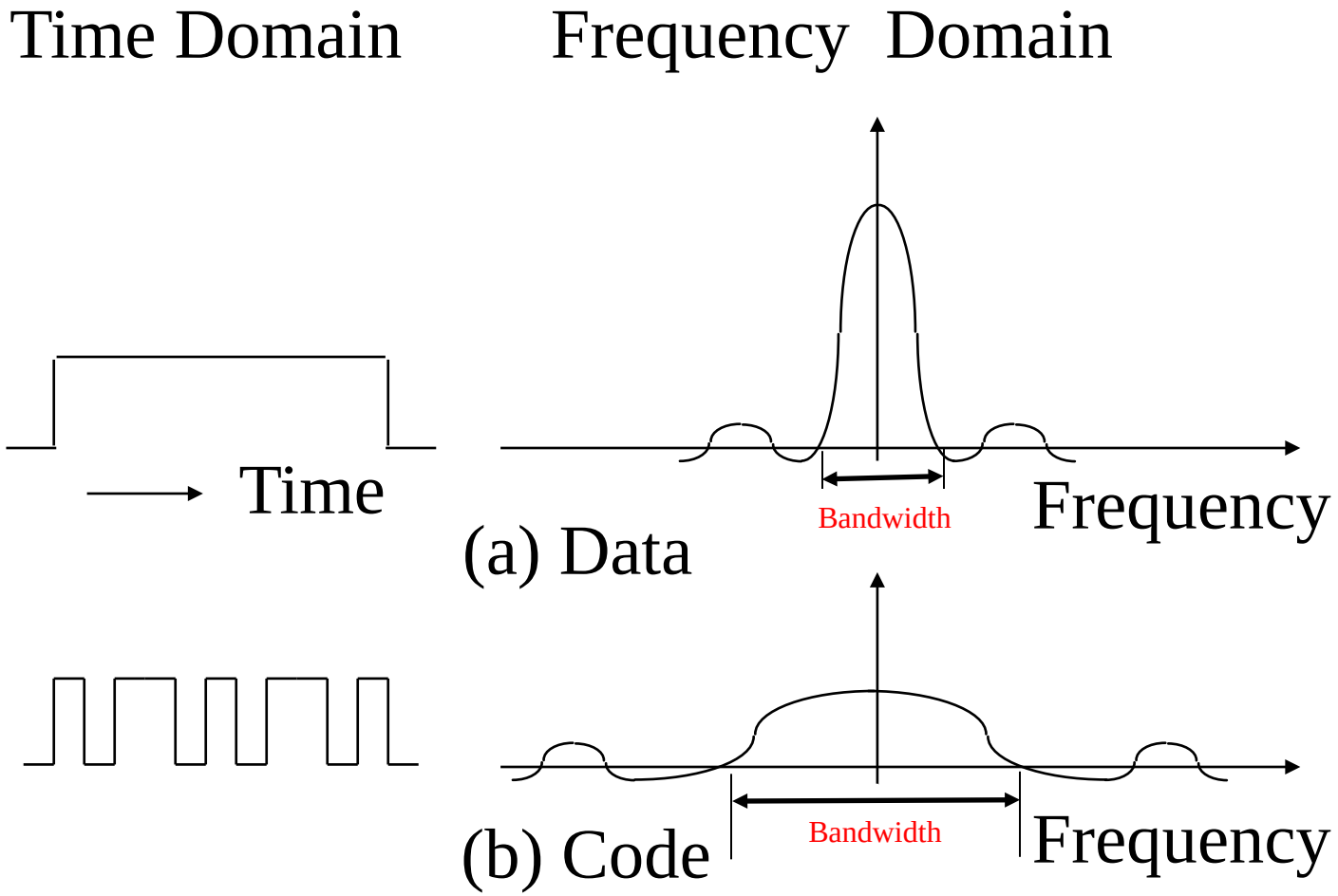
Band = Frequency Band

Bandwidth=Width of the Frequency Band
(See next slide)

- What's an example of orthogonal code?

See example on slide 7-12

DS Spectrum



Student Questions

- Why is the second graph horizontally stretched?

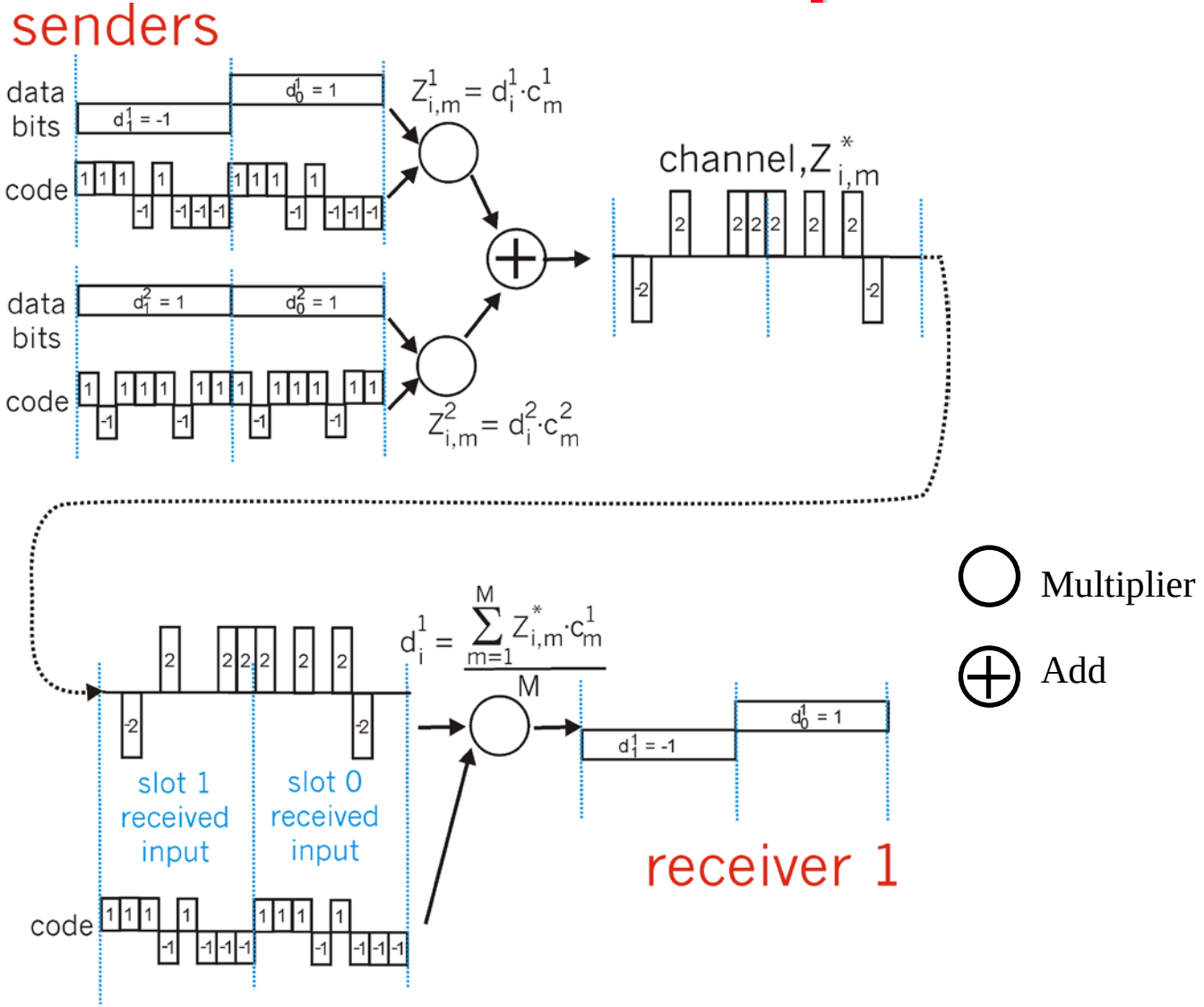
It has higher frequency bandwidth.

- Could you reexplain this slide? Is the benefit of this transmission method to allow two signals be transmitted at once? Unsure how this improves things.

Allows user multiplexing.

FDMA = Frequency Division (1G)
TDMA = Time Division (2G)
CDMA = Code Division (3G)

Two Sender CDMA Example



Student Questions

- What are the codes for 0 and 1, respectively, in this depiction?

0 is -1. 1 is +1

User 1: 1 data = 11101000 code

User 2: 1 data = 10111011 code

Homework 7A: CDMA Coding

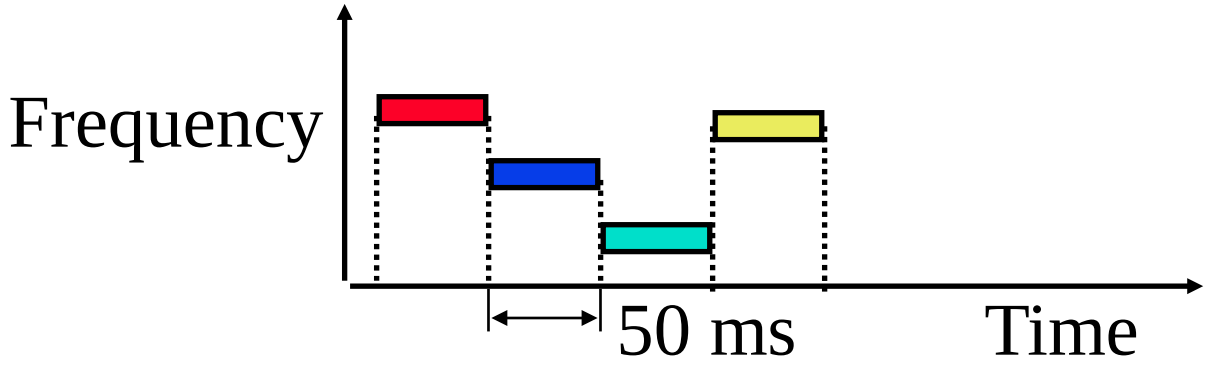
- [6 points] Two CDMA sender use the codes of (1, -1, 1, -1) and (1, -1, -1, 1). First sender transmits data bit 1 while the 2nd transmits –1 at the same time. What is the combined signal waveform seen by a receiver? Draw the waveform.

Student Questions

- Which of those codes corresponds to 0 and 1?

1 data = code seq
0 data = -code seq
User 1:
1 ={1, -1, 1, -1}
0 = {-1, 1, -1, 1}

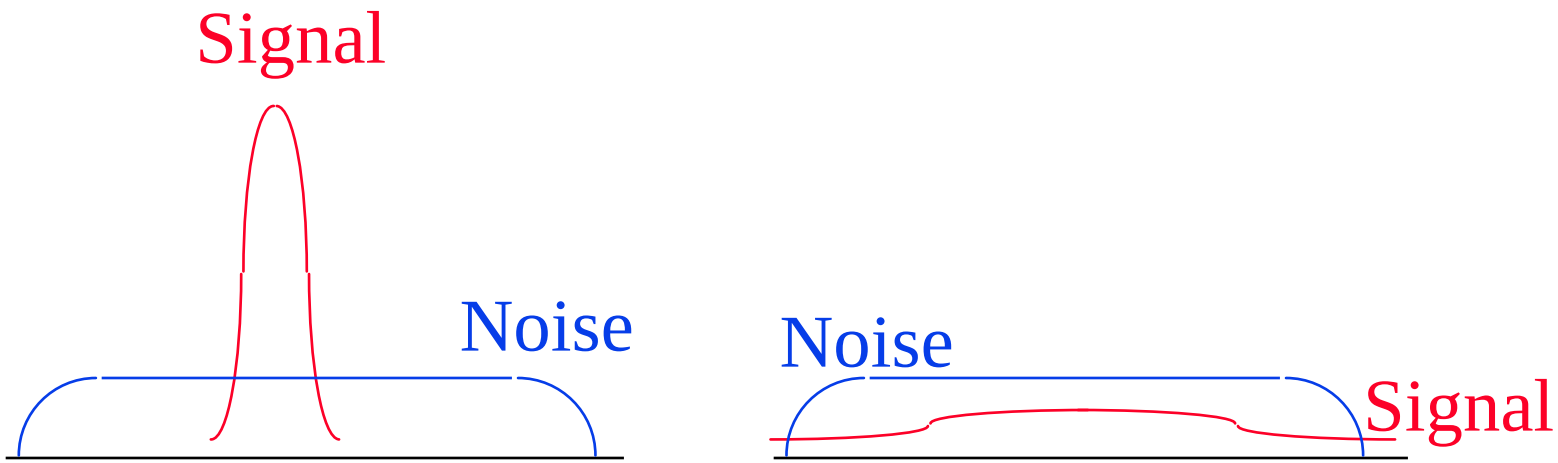
Frequency Hopping Spread Spectrum



- Pseudo-random frequency hopping
- Spreads the power over a wide spectrum
  ⇒ Spread Spectrum
- Developed initially for military
- Patented by actress Hedy Lamarr (1942)
- Narrowband interference can't jam

Student Questions

Spectrum

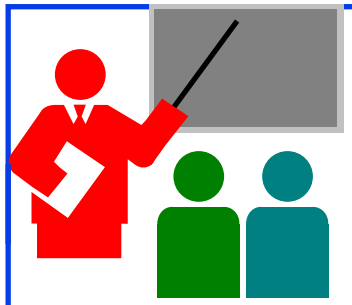


(a) Normal (b) Frequency Hopping

Student Questions

- How do adversaries jam a non-frequency hopping signal?

Transmitting at the same frequency at the same time



Review: Wireless Link Characteristics

1. Wireless is not the same as mobile.
   However, most mobile nodes are wireless.
2. Wireless signal is affected by shadows, multipath, interference, Doppler shift
3. A wireless network can be ad-hoc or infrastructure based.
4. Multi-hop ad-hoc networks are called MANET
5. It is not possible to do collision detection in wireless
6. Code division multiple access is commonly used in wireless

Student Questions

- What is the difference between a MANET and a VANET?

MANET = Mobile Ad-Hoc Network
VANET = Vehicular Area Network

Ref: Section 7.2, Review Exercises R3-R4

Wireless LANs and PANs

- IEEE 802.11 Wireless LAN PHYs
- 4-Way Handshake
- IEEE 802.11 MAC
- 802.11 Frame Format
- 802.11 Frame Addressing
- 802.11 Rate Adaptation
- Power Management
- IEEE 802.15.4
- IEEE 802.15.4 MAC
- ZigBee Overview

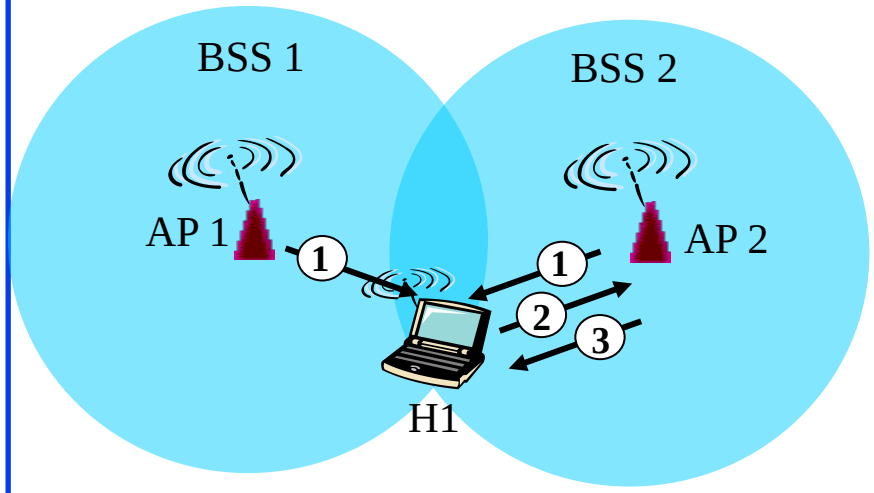
Student Questions

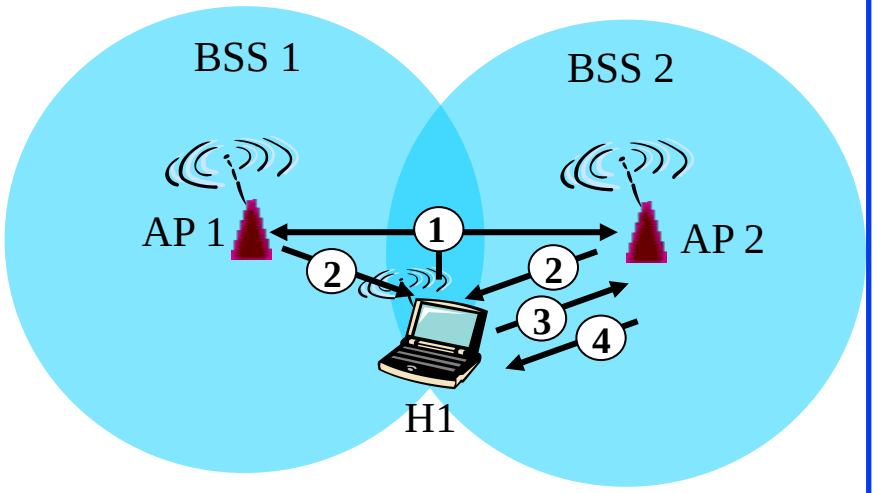
IEEE 802.11 Wireless LAN PHYs

- **802.11**: 2.4 GHz, 1-2 Mbps
- **802.11b**: 2.4 GHz, 11 Mbps nominal
  - Direct sequence spread spectrum (DSSS) in physical layer
  - All hosts use the same chipping code
- **802.11a**: 5.8 GHz band, 54 Mbps nominal
- **802.11g**: 2.4 GHz band, 54 Mbps nominal
- **802.11n**: 2.4 or 5.8 GHz, Multiple antennae, up to 200 Mbps
- These are different PHY layers. All have the same MAC layer.
- All use CSMA/CA for multiple access
- All have base-station and ad-hoc network versions
- Supports multiple priorities
- Supports time-critical and data traffic
- Power management allows a node to doze off

Student Questions

802.11: Passive/Active Scanning





Passive Scanning:

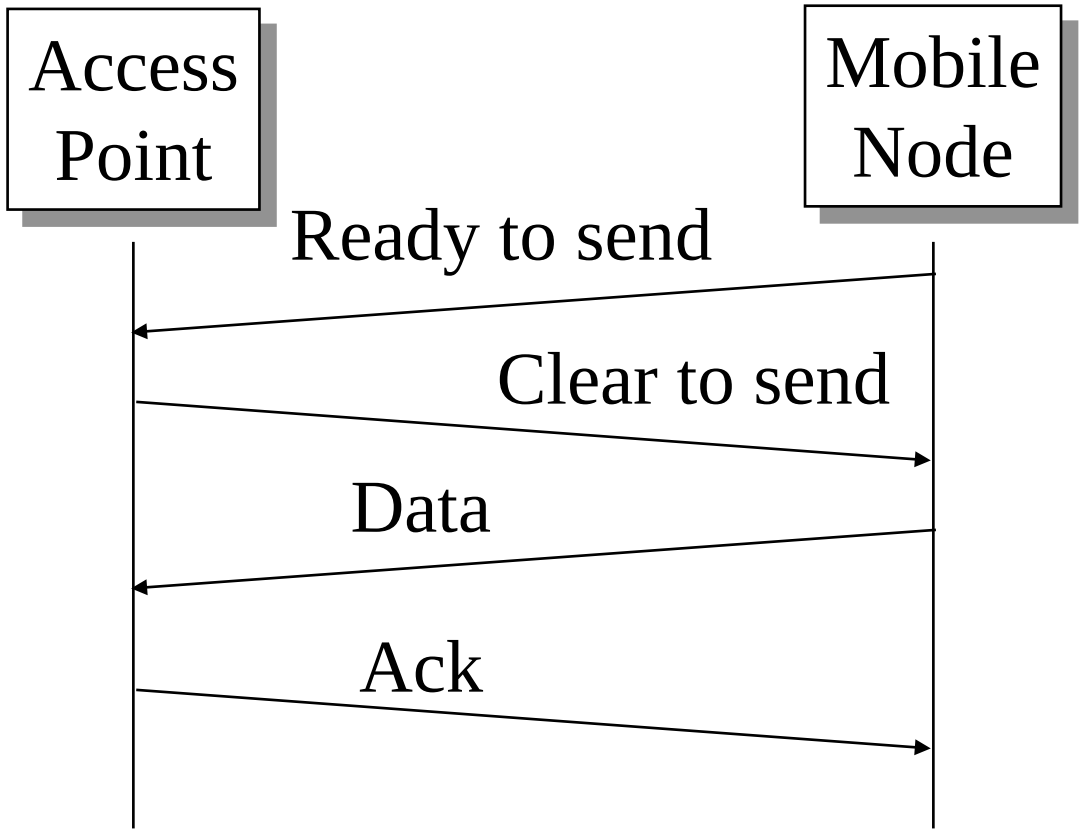
(1) Beacon frames sent from APs
(2) Association Request frame sent: H1 to selected AP
(3) Association Response frame sent: selected AP to H1

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

Student Questions

4-Way Handshake



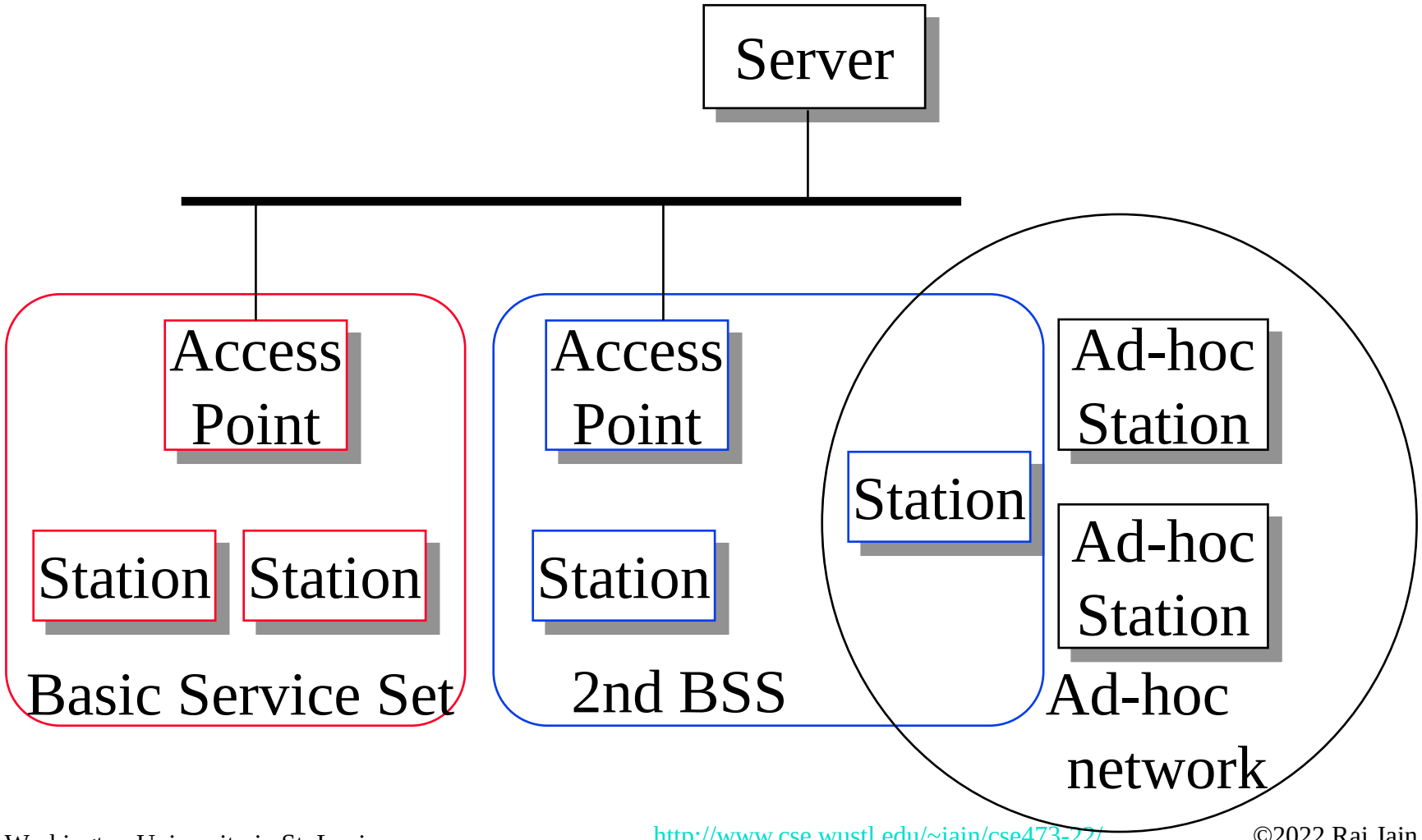
Student Questions

IEEE 802.11 MAC

- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
- Listen before you talk. If the medium is busy, the transmitter backs off for a random period.
- Avoids collision by sending a short message:
  Ready to send (RTS)
  RTS contains dest. address and duration of message.
  Tells everyone to backoff for the duration.
- Destination sends: Clear to send (CTS)
- Can not detect collision ⇒ Each packet is acked.
- MAC level retransmission if not acked.

Student Questions

IEEE 802.11 Architecture



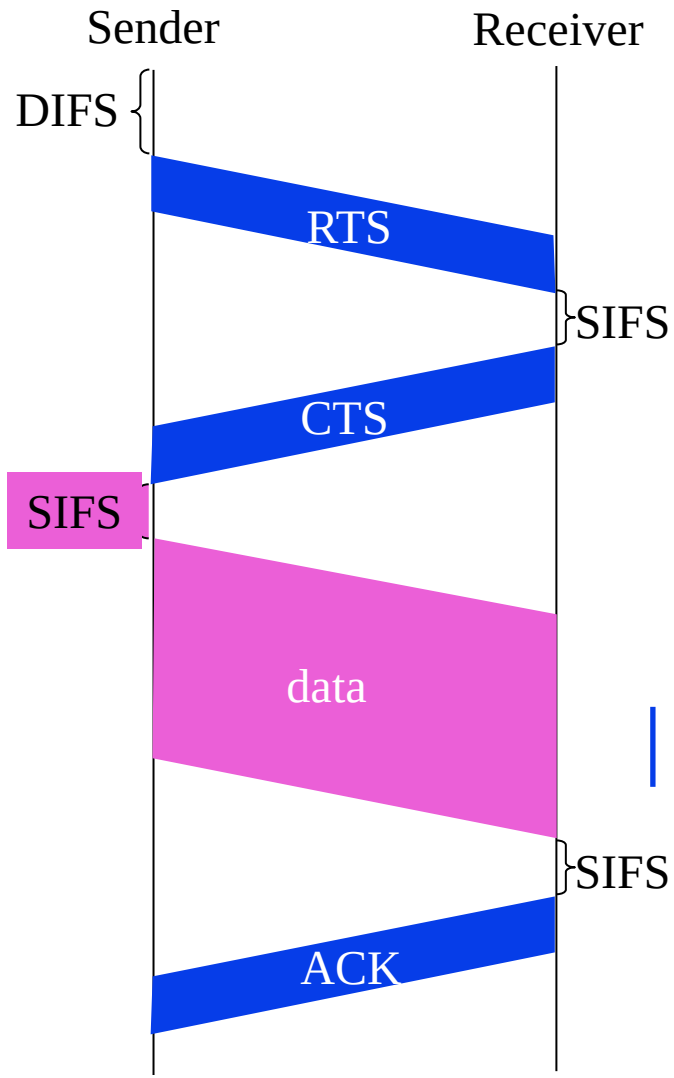
Student Questions

Architecture (Cont.)

- Basic Service Area (BSA) = Cell
  Area: Geographical area = a room, or a building
- Each BSA may have several wireless LANs
- Extended Service Area (ESA) = Multiple BSAs interconnected via Access Points (AP) = Multiple rooms in your home with different extenders advertising the same SSID
- Basic Service Set (BSS)
  = Set of stations associated with an AP = $\{MAC_1,\ldots,MAC_n\}$.
  Each BSS has a Service Set ID (SSID), e. g., WUSTL-Guest
- Extended Service Set (ESS)
  = Set of stations in an ESA
- Ad-hoc networks coexist and interoperate with infrastructure-based networks.

Student Questions

Transmission Example



SIFS, DIFS are intervals set by the standards. 11b and 11ac have different values.

RTS, CST, ACK are each one slot time long.

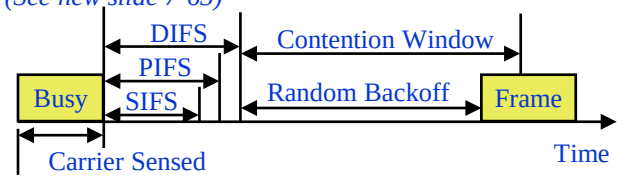
Each frame has a duration field.

Every frame is heard by every one.

Student Questions

- What is DIFS and what are 11b and 11ac?

DIFS = Distributed Inter-Frame Spacing
(See new slide 7-63)



- Initial inter-frame space (IFS)
- Highest priority frames, e.g., Acks, use short IFS (SIFS)
- Medium priority time-critical frames use "Point Coordination Function IFS" (PIFS)
- Asynchronous data frames use "Distributed coordination function IFS" (DIFS)

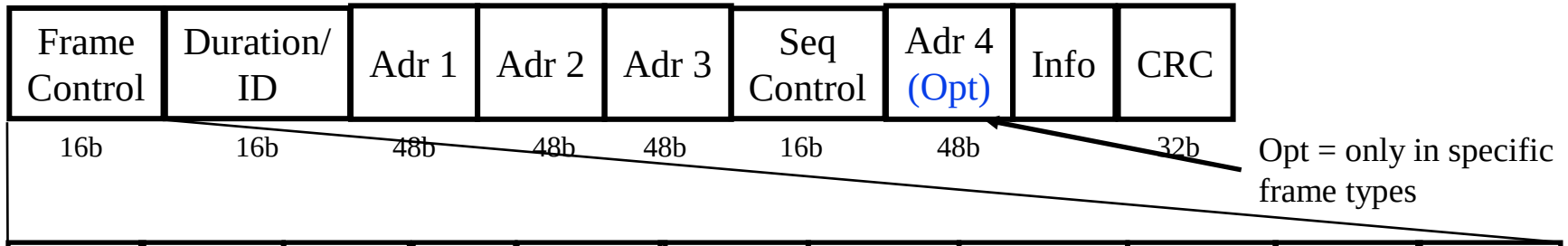
Homework 7B: WiFi Transmission

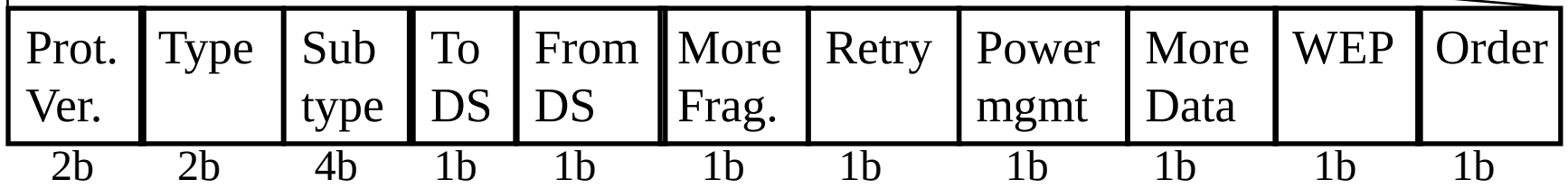
- [6 points] Suppose an 802.11b station is configured to always reserve the channel with the RTS/CTS sequence. Suppose this station suddenly wants to transmit 1,200 bytes of data, and all other stations are idle at this time. Using SIFS of 13us and DIFS of 60us, and ignoring propagation delay and assuming no bit errors, calculate the time required to transmit the frame and receive the acknowledgment. Assume a frame without data (RTS/CTS/Ack) is 64 bytes long and the transmission rate is 14 Mbps.

Ref: Problem P7

Student Questions

Wi-Fi Frame Format





- Type: Control, management, or data
- Sub-Type: Association, disassociation, re-association, probe, authentication, de-authentication, CTS, RTS, Ack, …
- Retry/retransmission
- Going to Power Save mode
- More buffered data at AP for a station in power save mode
- Wireless Equivalent Privacy (Security) info in this frame
- Strict ordering

Student Questions

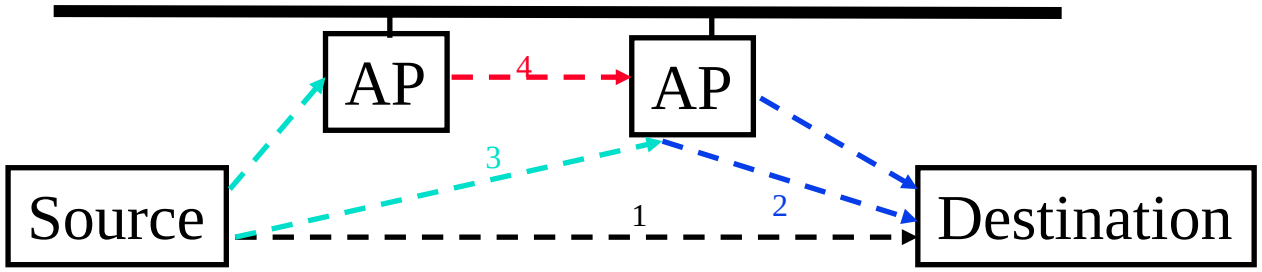
MAC Frame Fields

- **Duration/Connection ID**:
  - If used as duration field, indicates time (in μs) channel will be allocated for successful transmission of MAC frame. Includes time until the end of Ack
  - In some control frames, contains association or connection identifier
- **Sequence Control**:
  - 4-bit fragment number subfield
    - For fragmentation and reassembly
  - 12-bit sequence number
  - Number frames between given transmitter and receiver

Student Questions

802.11 Frame Address Fields

- All stations filter on "Address 1"



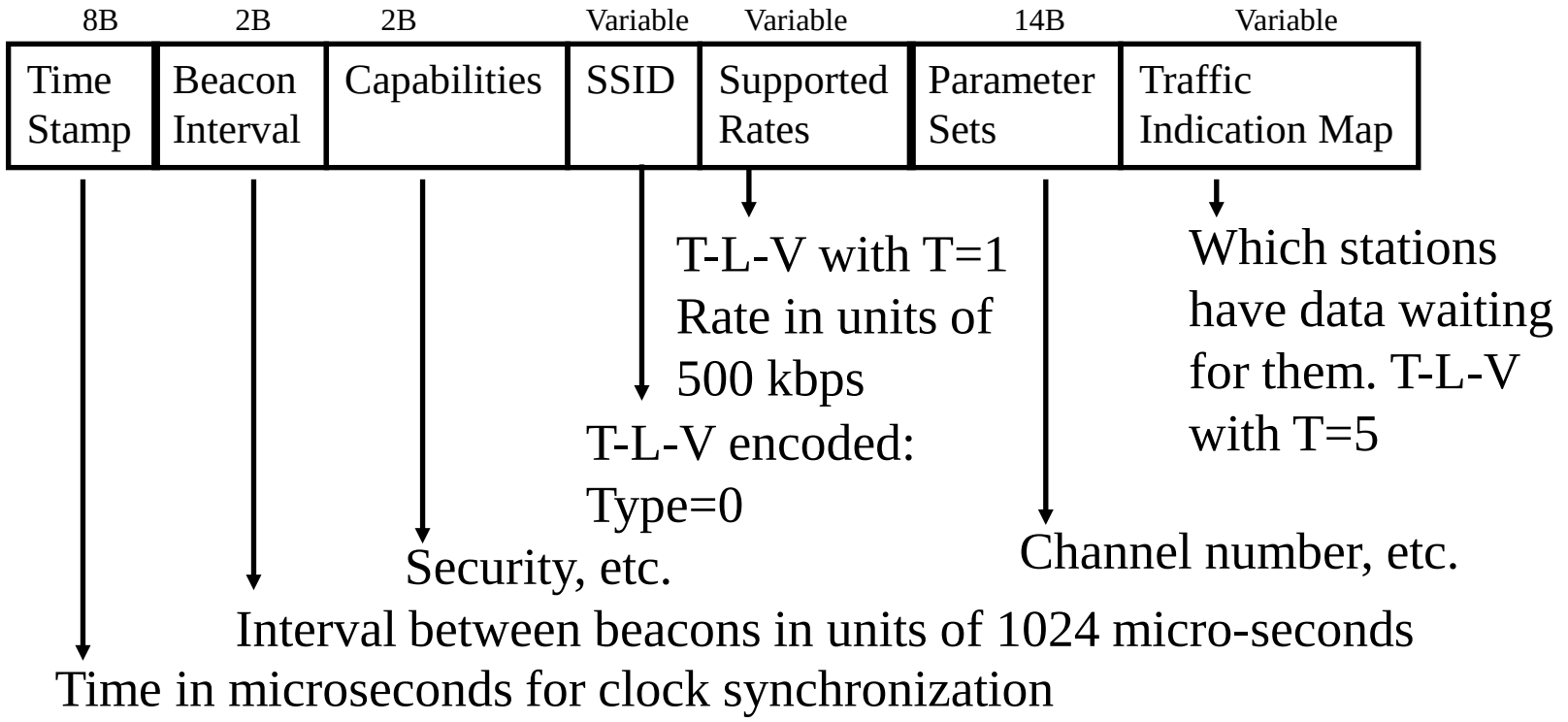
	To Distribution System	From Distribution System	Address 1	Address 2	Address 3	Address 4
1	0	0	Destination Address	Source Address	BSS ID	-
2	0	1	Destination Address	BSS ID	Source Address	-
3	1	0	BSS ID	Source Address	Destination Address	-
4	1	1	Receiver Address	Transmitter Address	Destination Address	Source Address

Student Questions

- Why doesn't the last row need a BSS ID?
- *BSS ID is basically a multicast to all base stations on this SSID. Any AP can receive and forward. In the last row, the packet is addressed to a specific AP identified by the receiver address.*

Beacon Frame Format

- Info field in the 802.11 frame (after Address 4)



Ref: Nayarasi, "802.11 Mgmt: Beacon Frame," https://mrncciew.com/2014/10/08/802-11-mgmt-beacon-frame/
Washington University in St. Louis http://www.cse.wustl.edu/~jain/cse473-22/

Student Questions

- Why do SNR ratios use decibels over another unit of measurement?

Ratios are divisions. It is easy to deal with ratios in log scale. dB is a log scale unit.

- Is there a tradeoff between SNR and BER? Is there an extent that an SNR that is too high starts to cause problems (like in machine learning with bias variance tradeoff)?

SNR = Cause

BER = Effect

Coding and retransmission decide acceptable BER ⇒ SNR

Lab 7:WiFi

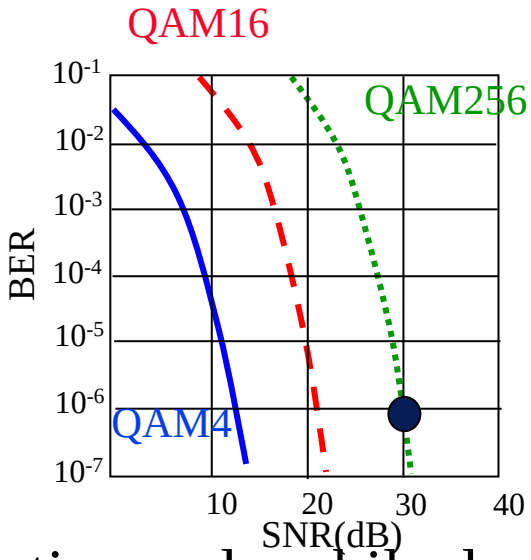
[14 Points] Download the Wireshark traces from http://gaia.cs.umass.edu/wireshark-labs/wireshark-traces.zip

Open *Wireshark_802_11.pcap* in Wireshark. Select **View → Expand All**. Answer the following questions. There is no need to attach screen captures.

1. Frame 1 is a beacon frame. Ignore the first 24 bytes. (The frame control field is 80:00.) What is the SSID of the access point that is issuing this beacon frame?
2. What (in hexadecimal notation) is the source MAC address on Frame 1.
3. What (in hexadecimal notation) is the destination MAC address on the Frame 1?
4. What (in hexadecimal notation) is the MAC BSS ID in Frame 1?
5. Frame 50 is a Probe Request and Frame 51 is a Probe response. What are the sender, receiver and BSS ID MAC addresses in these frames? What is the purpose of these two types of frames?

Student Questions

802.11 Rate Adaptation



QAM=Quadrature Amplitude Modulation

QAM2^n = n bits/Hz

dB = Deci-Bel

$$= 10 \log_{10} \frac{\text{Power Out}}{\text{Power In}}$$

- Base station and mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies
- SNR decreases ⇒BER increase as node moves away from base station
- When BER becomes too high, switch to lower transmission rate but with lower BER

Student Questions

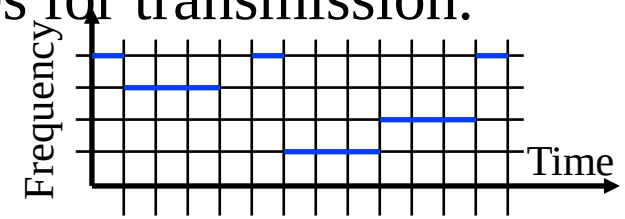
Power Management

- A station can be in one of three states:
  - Transmitter on
  - Receiver only on
  - Dozing: Both transmitter and receivers off.
- Access point (AP) buffers traffic for dozing stations.
- AP announces which stations have frames buffered.
  Traffic indication map included in each beacon.
  All multicasts/broadcasts are buffered.
- Dozing stations wake up to listen to the beacon.
  If there is data waiting for it, the station sends a poll frame to get the data.

Student Questions

Bluetooth

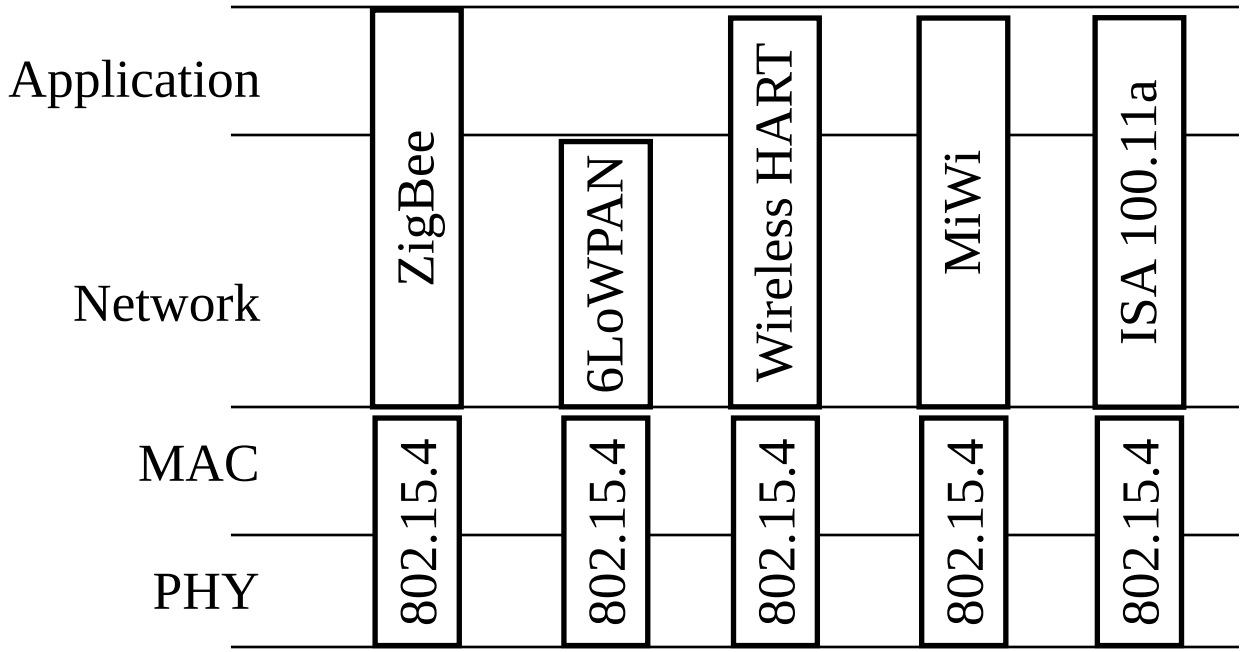
- Started with Ericsson's Bluetooth Project in 1994
- Named after Danish king Herald Blatand (AD 940-981) who was fond of blueberries
- Radio-frequency communication between cell phones over short distances
- IEEE 802.15.1 approved in early 2002 is based on Bluetooth
- Key Features:
  - Lower Power: 10 μA in standby, 50 mA while transmitting
  - Cheap: $5 per device
- A piconet consists of a master and several slaves. Master determines the timing and polls slaves for transmission.
- Frequency hopping spread spectrum



Student Questions

IEEE 802.15.4

- Low Rate Wireless Personal Area Network (LR-WPAN)
- Used by several "Internet of Things" protocols: ZigBee, 6LowPAN, Wireless HART, MiWi, and ISA 100.11a
- Lower rate, short distance ⇒ Lower power ⇒ Low energy

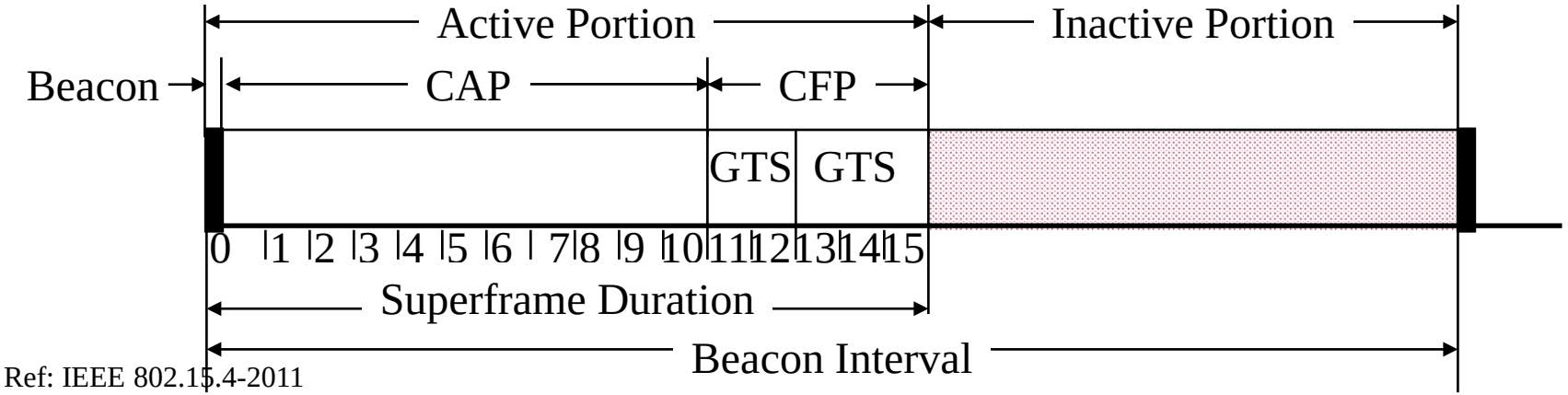


Student Questions

IEEE 802.15.4 MAC

Beacon-Enabled CSMA/CA

- Coordinator sends out beacons periodically
- Part of the beacon interval is inactive ⇒ Everyone sleeps
- Active interval consists of 16 slots
- Contention Access Period (CAP). Slotted CSMA.
- Contention Free Period (CFP)
  - Guaranteed Transmission Services (GTS): For real-time services. Periodic reserved slots.

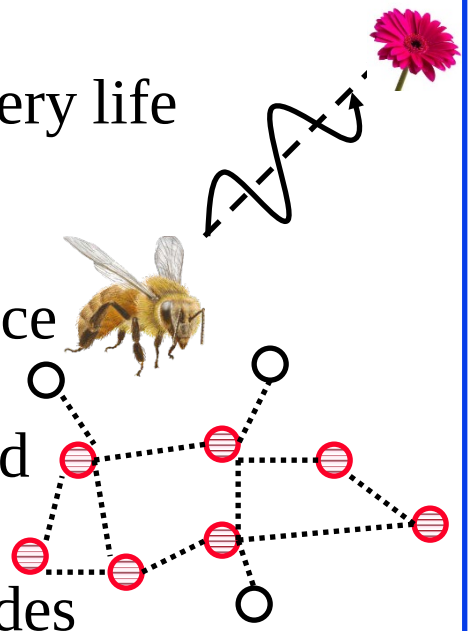


Ref: IEEE 802.15.4-2011

Student Questions

ZigBee Overview

- Industrial monitoring and control applications requiring small amounts of data, turned off most of the time (<1% duty cycle), e.g., wireless light switches, meter reading
- Ultra-low power, low-data rate, multi-year battery life
- **Range**: 1 to 100 m, up to 65000 nodes.
- IEEE 802.15.4 MAC and PHY.
  Higher layer, interoperability by ZigBee Alliance
- Named after zigzag dance of the honeybees
  Direction of the dance indicates location of food
- Multi-hop ad-hoc mesh network



Multi-Hop Routing: message to non-adjacent nodes

Ad-hoc Topology: No fixed topology. Nodes discover each other

Mesh Routing: End-nodes help route messages for others

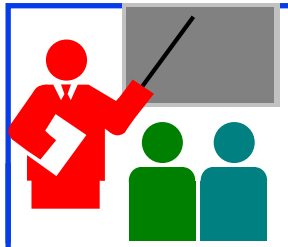
Mesh Topology: Loops possible

Ref: ZigBee Alliance, http://www.ZigBee.org
Washington University in St. Louis

Student Questions

- Can you explain more on the difference between Mesh Routing and Mesh Topology?

Routing = Method.
End nodes route other end node's packets
Topology: The nodes are connected not in a star or bus but as a mesh.
It is possible to have all 4 combination of routing and topologies.



Review: Wireless LANs and PANs

1. IEEE 802.11 PHYs: 11, 11b, 11g, 11a, 11n, …
2. IEEE 802.11 MAC uses CSMA/CA with a 4-way handshake: RTS, CTS, data, and ack
3. IEEE 802.11 network consists of ESS consisting of multiple BSSs each with an AP.
4. 802.11 Frame Format may have up to 4 addresses and includes final destination's MAC which may not be wireless
5. Power management allows stations to sleep.
6. Bluetooth uses frequency hopping spread spectrum
7. IEEE 802.15.4 PHY layer allows coordinators to schedule transmissions of other nodes
8. ZigBee uses IEEE 802.15.4

Ref: Section 7.3, Review Exercises R5-R12

Student Questions

- If APs buffer traffic for dozing stations, do the APs also send TCP acks on behalf of the dozing stations? If not, then it seems like there will be a lot of timeouts and redundant TCP segments.

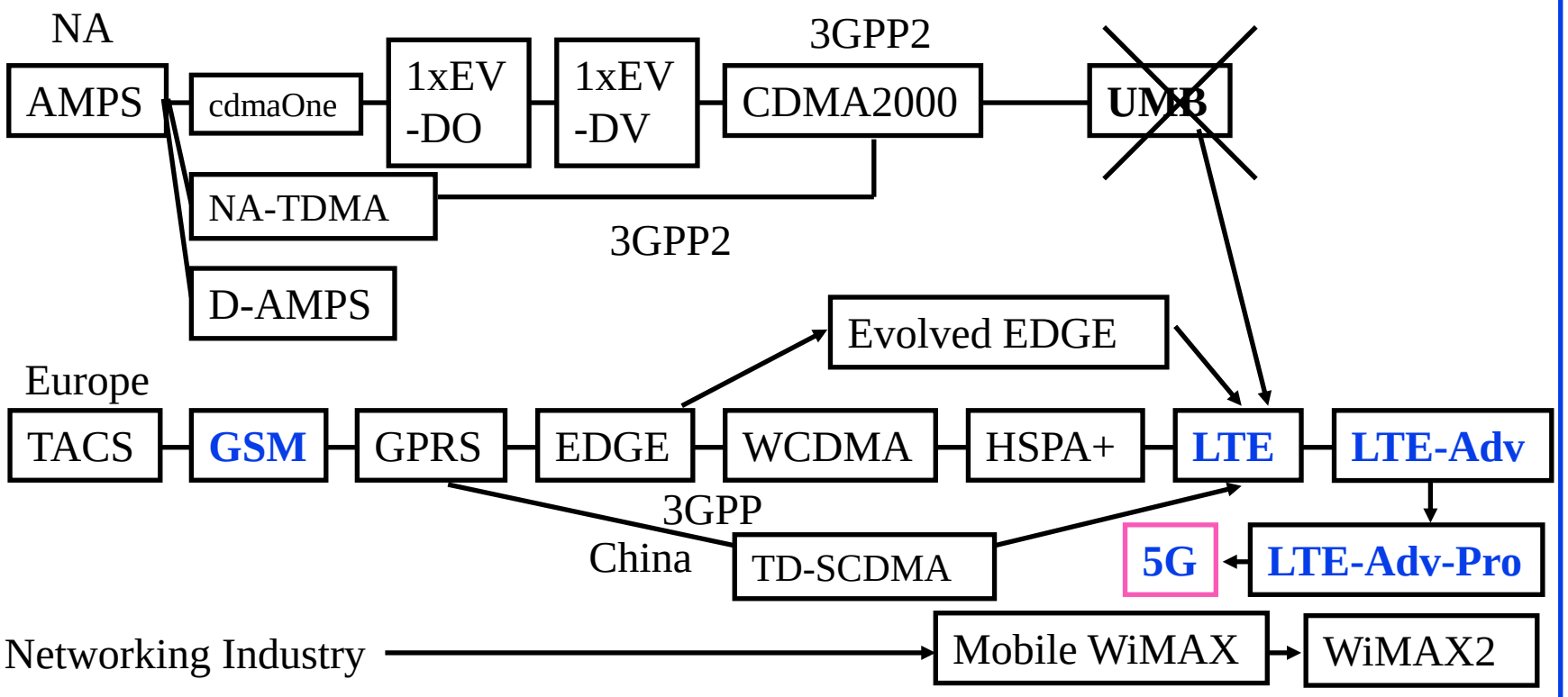
No APs are MAC-layer devices. They do not understand L3 or L4 and do not send any TCP acks. They may send L2 MAC Acks. Stations should wake up frequently enough to avoid TCP timeouts, if they have a TCP connection.

Cellular Networks

- Evolution of Cellular Technologies
- GSM Cellular Architecture
- Evolved Packet System (EPS)

Student Questions

Cellular Telephony Generations

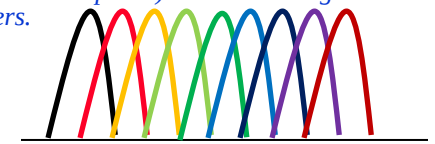


Student Questions

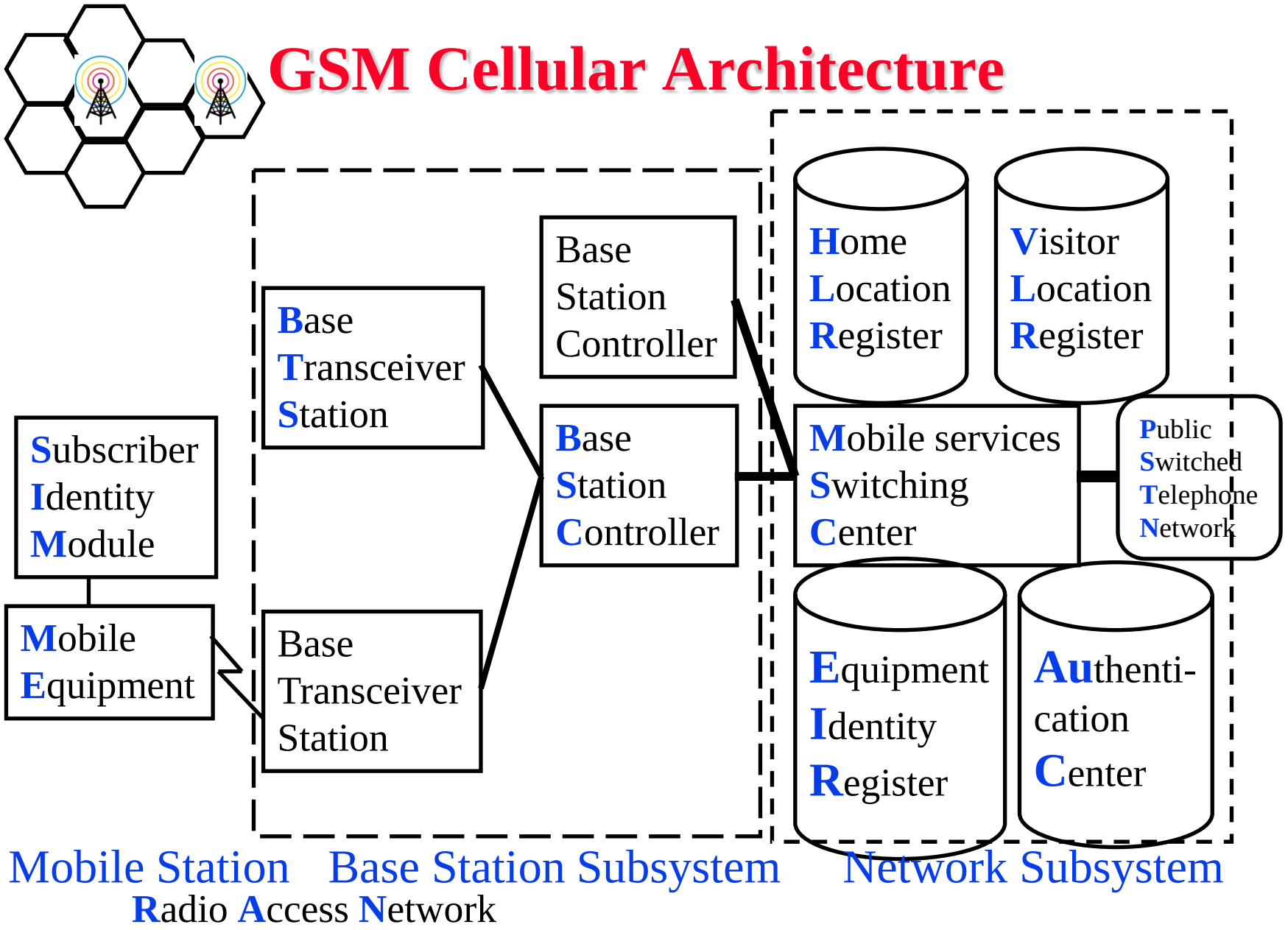
- Could you briefly explain what OFDMA is?

Orthogonal Frequency Division Multiplexing

Large number of subcarriers that are orthogonal (all others are zero when one peaks). A user is assigned several subcarriers.



GSM Cellular Architecture



Student Questions

- Does each carrier have its own PSTN or do they all share a common PSTN?

Each carrier is supposed to have its own PSTN. However, increasingly they have started sharing using SDN or other virtualization techniques.

Cellular Architecture (Cont.)

- Base station controller (BSC) and Base transceiver station (BTS)
- One BTS per cell.
- One BSC can control multiple BTS.
  - Allocates radio channels among BTSs.
  - Manages call handoffs between BTSs.
  - Controls handset power levels
- Mobile Switching Center (MSC) connects to PSTN and switches calls between BSCs. Provides mobile registration, location, authentication. Contains Equipment Identity Register.

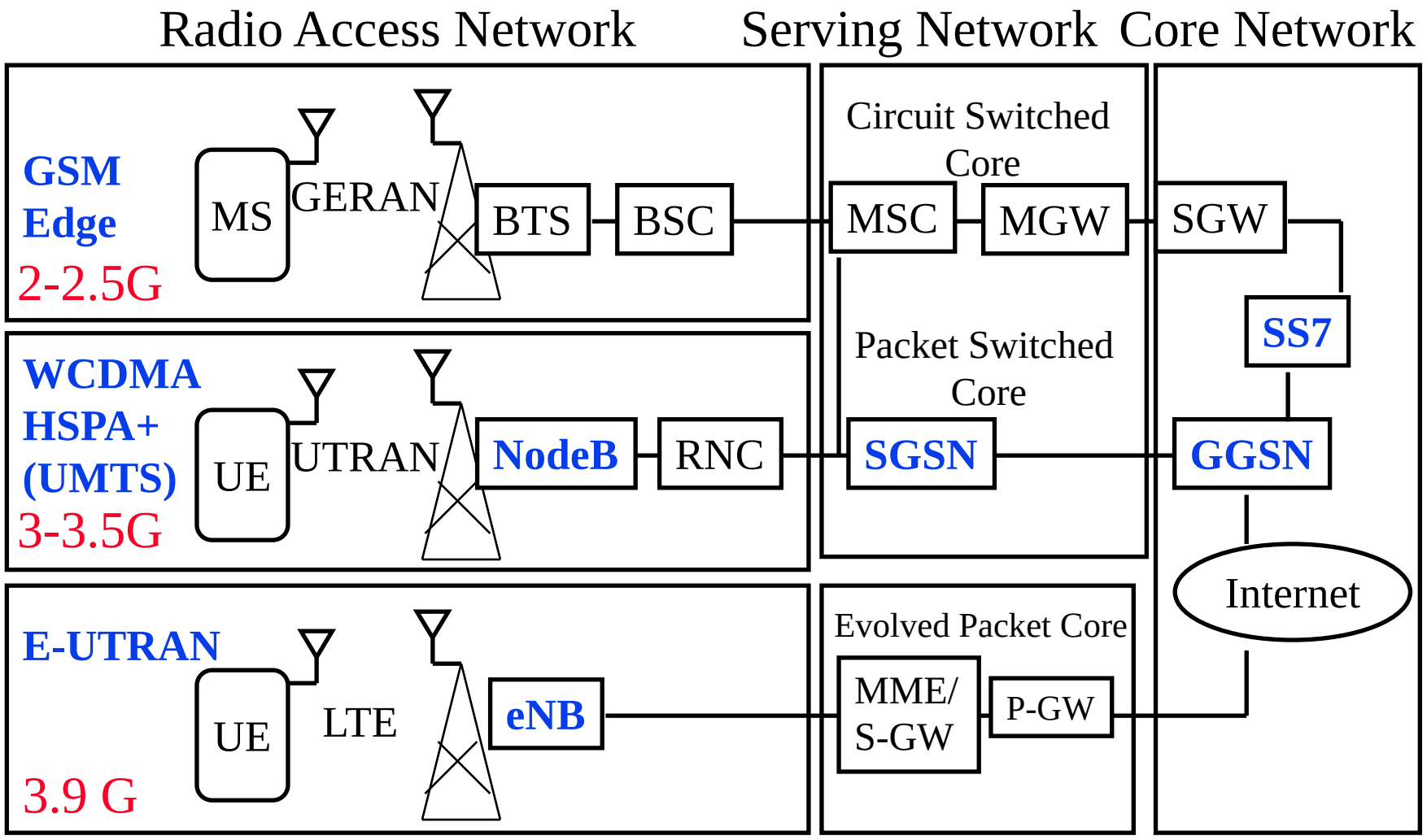
Student Questions

Cellular Architecture (Cont.)

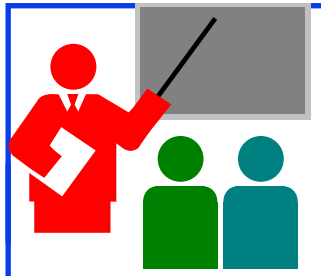
- Home Location Register (HLR) and Visitor Location Register (VLR) provide call routing and roaming
- VLR+HLR+MSC functions are generally in one equipment
- Equipment Identity Register (EIR) contains a list of all valid mobiles.
- Authentication Center (AuC) stores the secret keys of all SIM cards.
- Each handset has a International Mobile Equipment Identity (IMEI) number.

Student Questions

Evolved Packet System (EPS)



Student Questions



Review: Cellular Networks

1. 1G was Analog voice, 2G was Digital voice, 3G was CDMA with voice and high-speed data, 4G is high-speed data
2. A cellular system has a RAN with BTS, BSC and a network subsystem with HLR, VLR, MSC, EIR, and AuC
3. 3G replaced RAN with UTRAN and BTS with NodeB. 4G uses eNB.

Student Questions

Ref: Section 7.4, Review Exercises R14-R17

Mobility Management

- Mobile IP
- GSM: Routing to Mobile
- GSM Handoff
- Mobility: GSM versus Mobile IP

Student Questions

Mobility: Mr. Smith Goes to Washington

Mr. Smith's office

Can I speak to Mr. Smith

Hello Senator Taylor

Jim Taylor

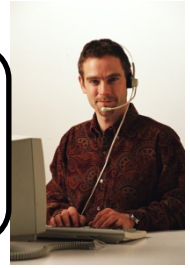
Can you connect me to Mr. Smith?

Mr. Smith! Call from Taylor

Hello Senator Taylor

Mr. Smith

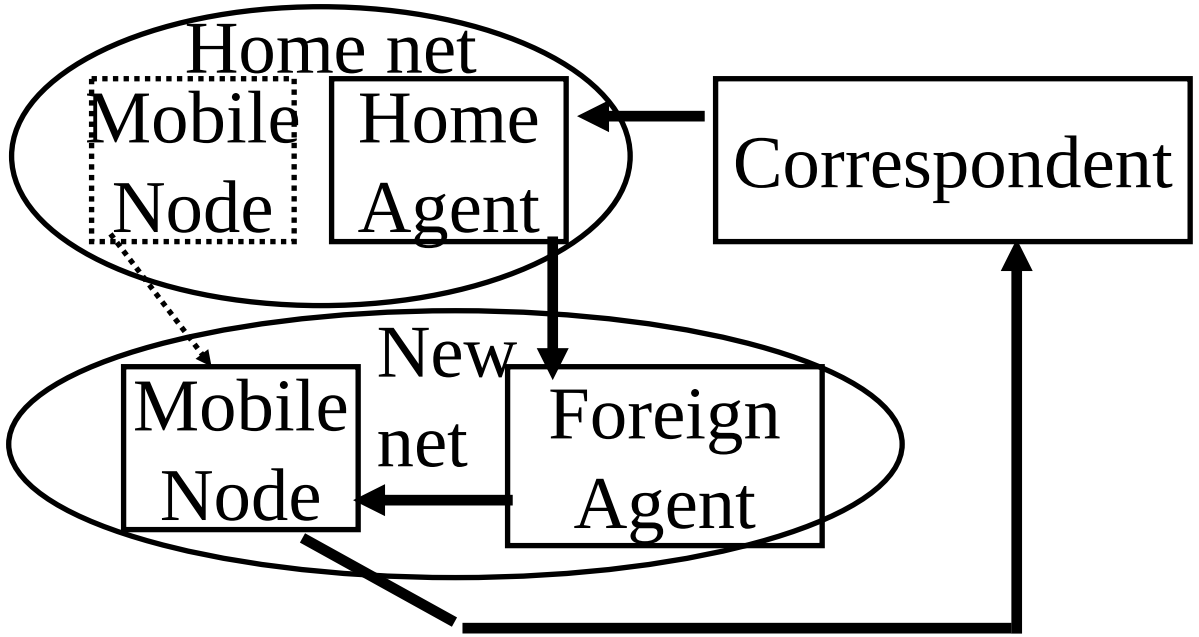
Hotel Operator



- We need:
  - An agent at home office: Home Agent
  - An agent at foreign office: Foreign Agent

Student Questions

Mobile IP: Mechanisms



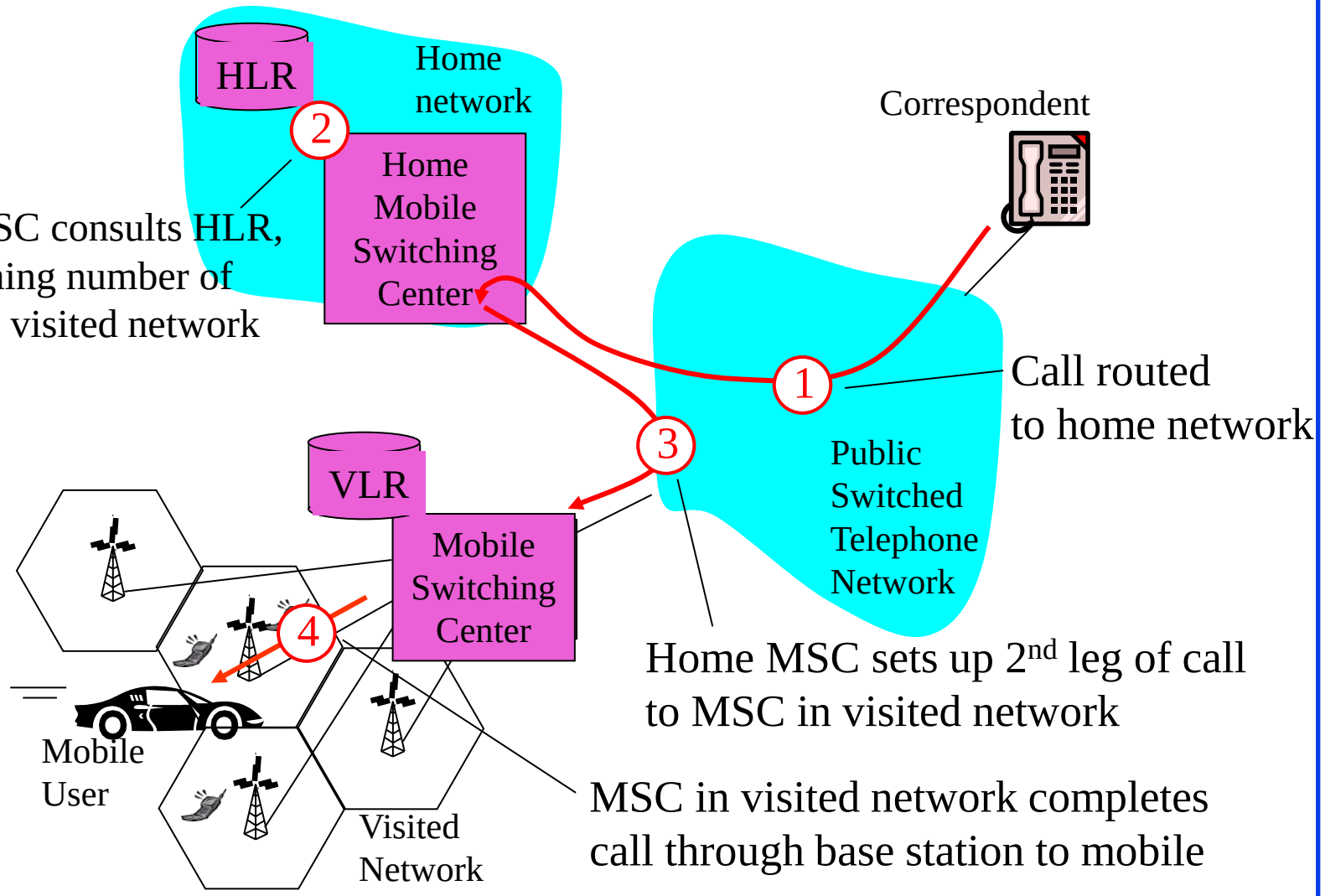
Student Questions

Mechanism (Cont.)

- Mobile node finds foreign agents via solicitation or advertising
- Mobile registers with the foreign agents and informs the home agent
- Home agent intercepts mobile node's datagrams and forwards them to the care-of-address
- Care-of-address (COA): Address of the end-of-tunnel towards the mobile node. May or may not be foreign agent
- At COA, datagram is extracted and sent to mobile

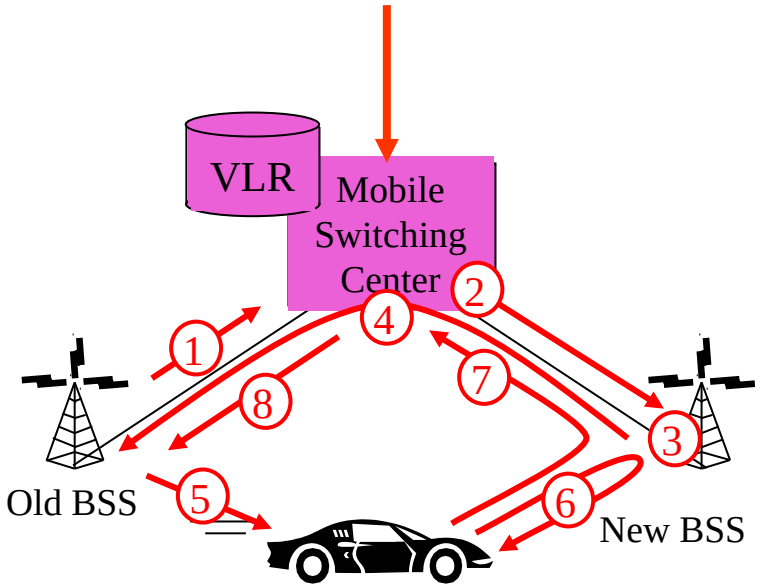
Student Questions

GSM: Routing to Mobile



Student Questions

GSM: Handoff with Common MSC

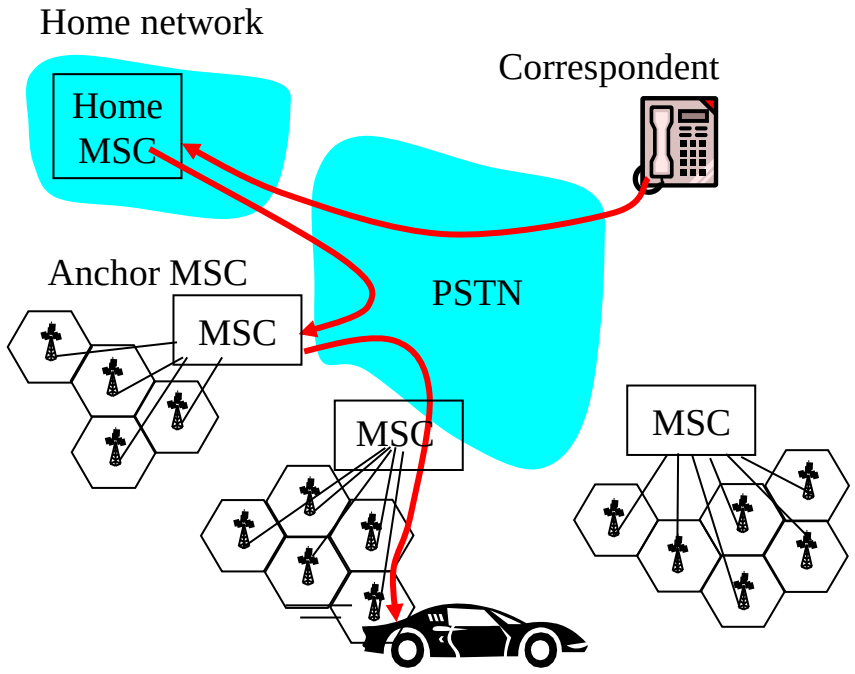


1. Old BSS informs MSC of impending handoff, provides list of 1^+ new BSSs
2. MSC sets up path (allocates resources) to new BSS
3. New BSS allocates radio channel for use by mobile
4. New BSS signals MSC, old BSS: ready
5. Old BSS tells mobile: perform handoff to new BSS
6. Mobile, new BSS signal to activate new channel
7. Mobile signals via new BSS to MSC: handoff complete. MSC reroutes call

8 MSC-old-BSS resources released

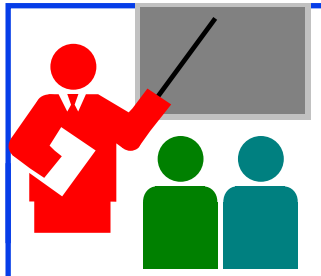
Student Questions

GSM: Handoff between MSCs



- *Anchor MSC:* first MSC visited during call
  - Call remains routed through anchor MSC
- New MSCs add on to end of MSC chain as mobile moves to new MSC
- IS-41 allows optional path minimization step to shorten multi-MSC chain

Student Questions



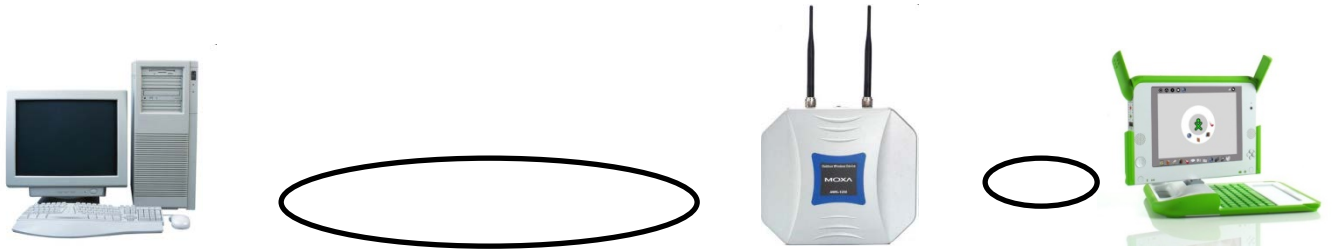
Review: Mobility Management

- Mobile IP uses Home Agent as an Anchor
  Packets are tunneled from Home Agent to Care-of-Address
- GSM uses HLR and VLR for mobility. All packets are routed through home network
- Handoff between towers in a single network is done through MSC

Student Questions

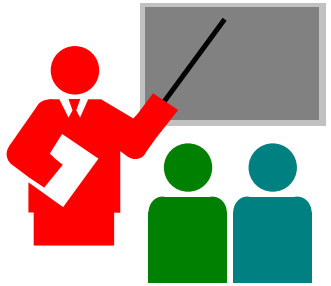
Impact on Higher Layer Protocols

- Layered Architecture ⇒ Upper layers are independent of lower layers
- Wireless ⇒ High error rate ⇒ Frequent packet losses
  ⇒ Triggers TCP congestion control even if no overload
- TCP modifications:
  - Local Recovery: Link level retransmissions and error correction
  - Wireless-aware TCP Sender:
    Distinguish overload (sustained) and random errors
  - Split-Connection: Host1-to-AP + AP-to-Host2



Student Questions

Summary



1. Code division multiple access "was" commonly used in wireless networks
2. IEEE 802.11 uses CSMA/CA with RTS, CTS, data, and ack. A frame may have up to 4 addresses.
3. Bluetooth and ZigBee are PANs that use very little energy
4. Cellular networks have evolved from analog voice to digital voice and finally to high-speed data.
5. Mobile IP uses home agents as anchors.
6. Cellular networks use MSCs to manage mobility.
7. Frequent packet losses due to errors may confuse TCP as network congestion.

Student Questions

CSE 574S: Wireless and Mobile Networking

1. How is wireless different from wired communication?
2. What are the protocols that are used in **IoT**?
3. Why do we need new protocols for IoT?
4. How does **WiFi** work? How 10 Mbps to 10 Gbps?
5. How is **Bluetooth** different from WiFi?
6. How is **ZigBee** different from WiFi?
7. What are other newer wireless protocols for IoT? LORAWAN
8. What is the basic difference between 1G/2G/3G/4G/5G
9. What new features came in with **4G**?
10. What new techniques enabled **5G**?
11. What about 6G? When and how?

Student Questions

Acronyms

- 1xEV-DO 1 times Evolution to Data Only
- 1xEV-DV 1 times Evolution to Data and Voice
- 3GPP1 3rd Generation Partnership Project
- 6LowPAN IPv6 over Low Power Personal Area Networks
- ACK Acknowledgement
- AMPS Advanced Mobile Phone System
- AP Access Point
- BER Bit Error Rate
- BSA Basic Service Area
- BSC Base station controller
- BSS ID Basic Service Set Identifier
- BTS Base transceiver station
- CA Collision Avoidance
- CAP Contention Access Period
- CDMA Code Division Multiple Access
- CEPT Committee of European Posts and Telecom

Student Questions

Acronyms (Cont)

- CFP Contention Free Period
- COA Care-Of-Address
- CRC Cyclic Redundancy Check
- CSMA Carrier Sense Multiple Access
- CTS Clear to Transmit
- D-AMPS Digital Advanced Mobile Phone System
- dB Deci-Bel
- DCN Data Communication Network
- DHCP Dynamic Host Control Protocol
- DIFS Distributed Inter-Frame Spacing
- DSSS Direct Sequence Spread Spectrum
- E-UTRAN Evolved UTRAN
- EDGE Enhanced Data rate for GSM evolution
- EGPRS Enhanced GPRS
- EIA Electronic Industry Association
- EIR Equipment Identity Register

Student Questions

Acronyms (Cont)

- eNB evolved Node B
- ESA Extended Service Area
- ESS Extended Service Set
- FCC Federal Communications Commission
- FDMA Frequency Division Multiple Access
- GERAN GSM Enhanced Radio Access Network
- GGSN Gateway GPRS Support Node
- GHz Giga-Hertz
- GPRS General Packet Radio Service
- GSM Global System for Mobile Communications
- GTS Guaranteed Transmission Service
- GW Gateway
- HART Highway Addressable Remote Transducer Protocol
- HLR Home Location Register
- HSPA High Speed Packet Access
- HSPDA High Speed Packet Download Access

Student Questions

Acronyms (Cont)

ID	Identifier
IEEE	Institution of Electrical and Electronics Engineers
IFS	Inter-frame space
IMEI	International Mobile Equipment Identity
IP	Internet Protocol
IS	International Standard
ISA	International Society of Automation
ISDN	Integrated Switched Digital Network
kW	Kilo-Watt
LAN	Local Area Network
LR	Long-Range
LTE	Long-Term Evolution
mA	Milli-Ampere
MAC	Media Access Control
MANET	Mobile Ad-hoc Network
MGW	Media Gateway

Student Questions

Acronyms (Cont)

- MHz Mega Hertz
- MIMO Multiple Input Multiple Output
- MME Mobility Management Entity
- MS Mobile Subscriber
- MSC Mobile Switching Center
- mW Milli-Watt
- NA North America
- NAT Network Address Translator
- NodeB Node B (Base Station)
- PAN Personal Area Network
- PC Personal Computer
- PHY Physical Layer
- PIFS Point-Coordination Inter-Frame Spacing
- PSTN Public Switched Telephone Network
- QAM Quadrature Amplitude Modulation

Student Questions

Acronyms (Cont)

RAN	Radio Access Network
RNC	Radio Network Controller
RTS	Ready to send
SCDMA	Synchronous CDMA
SGSN	Service GPRS Support Node
SGW	Serving Gateway
SIFS	Short Inter-Frame Spacing
SIM	Subscriber Identification Module
SNR	Signal to Noise Ratio
SS7	Signaling System 7
SSID	Service Set Identifier
SYN	Synchronizing Frame
TACS	Total Access Communications System
TCP	Transmission Control Protocol
TD-SCDMA	Time Duplexed Synchronous Code Division Multiple Access
TDMA	Time Division Multiple Access

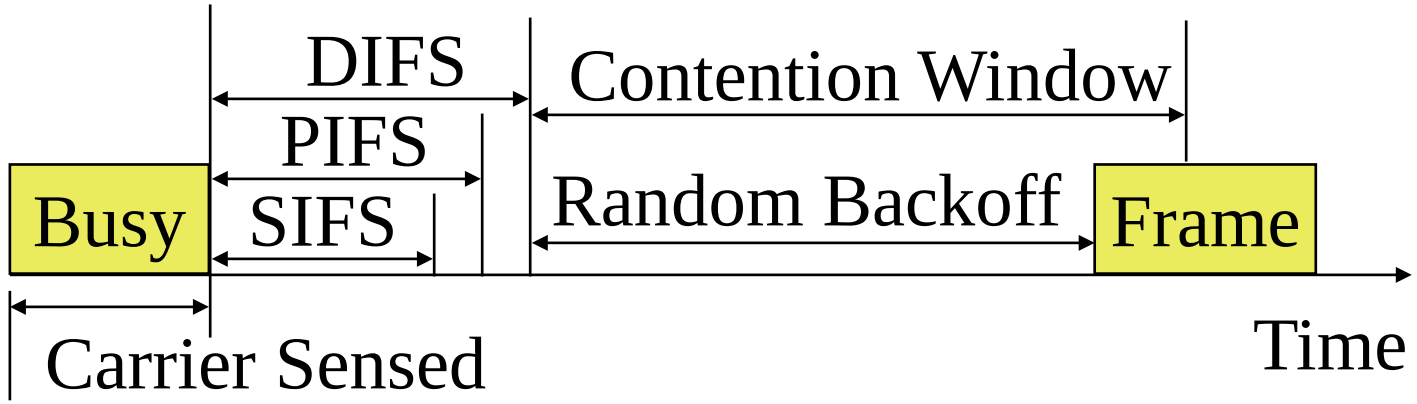
Student Questions

Acronyms (Cont)

TIA	Telecom Industry Association
TV	Television
UE	User Element
UK	United Kingdom
UMB	Ultra Mobile Broadband
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VANET	Vehicular Ad-hoc Network
VLR	Visitor Location Register
WCDMA	Wide-band CDMA
WEP	Wired Equivalend Privacy
WiFi	Wireless Fidelity
WPAN	Wireless Personal Area Network

Student Questions

IEEE 802.11 Priorities



- Initial inter-frame space (IFS)
- Highest priority frames, e.g., Acks, use short IFS (SIFS)
- Medium priority time-critical frames use "Point Coordination Function IFS" (PIFS)
- Asynchronous data frames use "Distributed coordination function IFS" (DIFS)

Student Questions

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Student Questions

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Video Podcasts of Prof. Raj Jain's Lectures,
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