Computer Networking

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Chapter 7 Wireless and Mobile Networks

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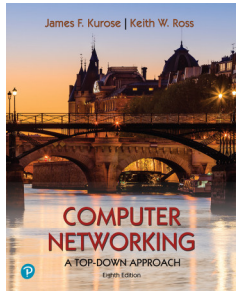


Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

7-2

Homework (ver.8, CN)

- 1, 5, 8, 11, 12
- Keywords: CDMA, CDMA encode/decode, CSMA/CA, mobile IP,

Ch. 7: Wireless and Mobile Networks

Background:

- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers (5-to-1)!
- # wireless Internet-connected devices equals # wireline 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

6-4

Chapter 7 outline

7.1 Introduction

Wireless

7.2 Wireless links, characteristics
- CDMA

7.3 IEEE 802.11 wireless LANs ("Wi-Fi")

7.4 Cellular Internet Access
- architecture
- standards (e.g., GSM)

Mobility

7.5 Principles: addressing and routing to mobile users

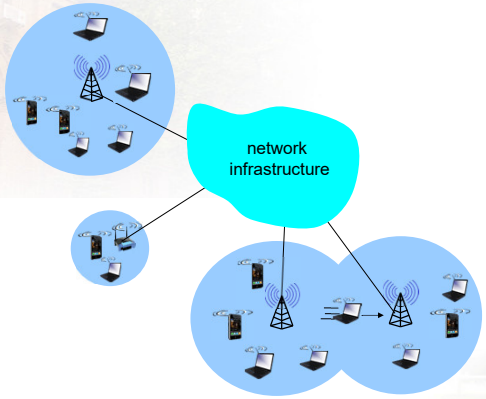
7.6 Mobile IP

7.7 Handling mobility in cellular networks

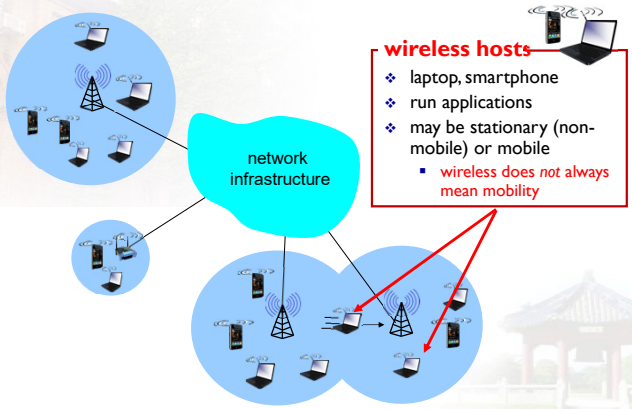
7.8 Mobility and higher-layer protocols

7.9 Summary

Elements of a wireless network

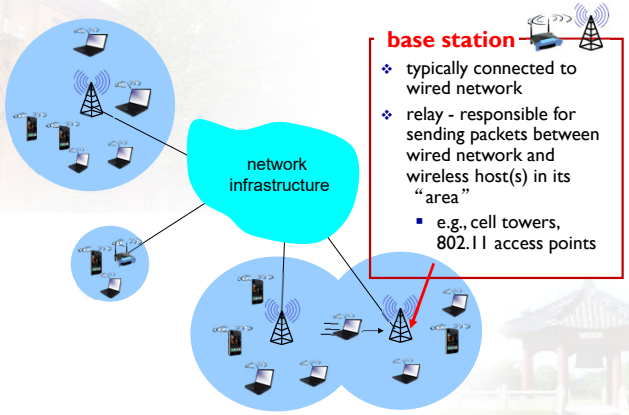


Elements of a wireless network



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

Elements of a wireless network



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

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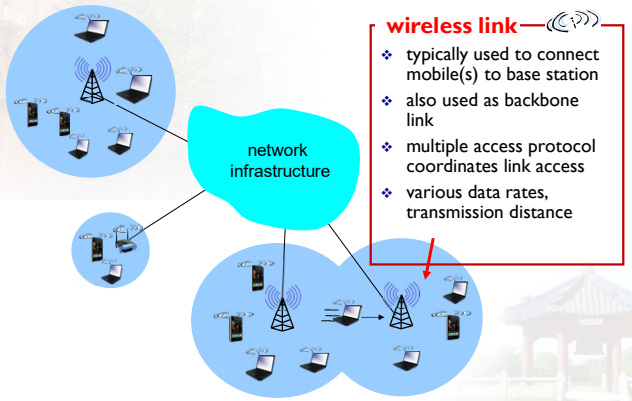

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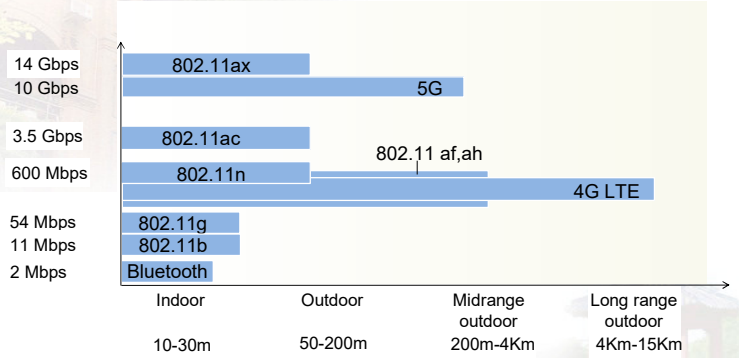
Characteristics of selected wireless links



Wireless and Mobile Networks: 7- 10

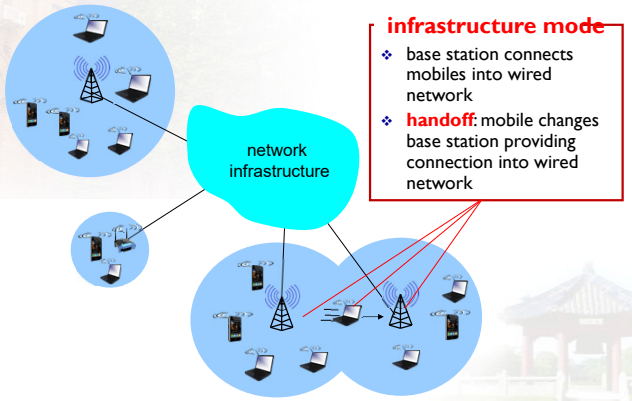
5G 频率域	频率范围	名称
FR1	450MHz - 6GHz	Sub6G
FR2	24GHz - 52GHz	mmWave

中国的5G频谱规划

高频/低频	候选频谱
FR1	3.4 - 3.6GHz 3.3 - 3.4GHz 4.4 - 4.5GHz 4.8 - 4.99Ghz
FR2	24.25 - 27.5GHz 37 - 43.5GHz

11

Elements of a wireless network



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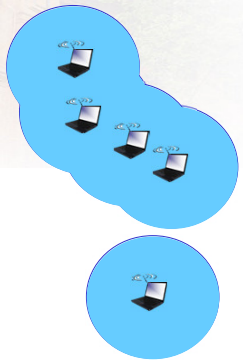
Elements of a wireless network



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

6-13

Wireless network taxonomy

	single hop	multiple hops
infrastructure (e.g., APs)	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 upper network)	no base station, no connection to larger Internet (Bluetooth, ad hoc nets)	no base station, no connection to larger Internet. May have to relay to reach other a given wireless node MANET, VANET

6-14

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6-15

Wireless Link Characteristics (1)

important **differences from wired link ….**

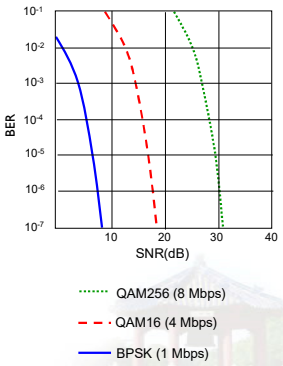
- ***decreased signal strength:*** radio signal attenuates as it propagates through matter (path loss)
- ***interference from other sources:*** standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- ***multipath propagation:***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

…. make communication across (even a point to point) wireless link much more "difficult"

6-16

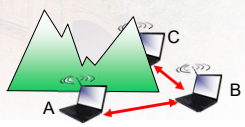
Wireless Link Characteristics (2)

- **SNR: signal-to-noise ratio**
  - **larger SNR – easier to extract signal from noise (a "good thing")**
- ***SNR versus BER tradeoffs***
  - ***given physical layer:* increase power -> increase SNR->decrease BER**
  - ***given SNR:* choose physical layer that meets BER requirement, giving highest thruput**
    - **SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)**



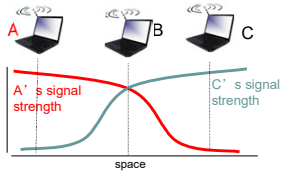
Wireless network characteristics

Multiple wireless senders and receivers create additional problems (beyond multiple access):



Hidden terminal problem

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



Signal attenuation:

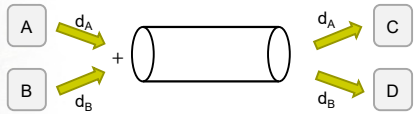
- B, A hear each other
- B, C hear each other
- A, C can not hear each other interfering at B

Code Division Multiple Access (CDMA)

- **unique "code" assigned to each user; i.e., code set partitioning**
  - **all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data**
  - **allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")**
- ***encoded signal* = (original data) X (chipping sequence)**
- ***decoding:* inner-product of encoded signal and chipping sequence**

Code Division Multiple Access (CDMA)

- A发送数据d_A, A的CDMA地址码c_A
- B发送数据d_B, B的CDMA地址码c_B
- c_A与c_B正交：
  - $c_A \odot c_B = 0$;
  - $c_A \odot c_A = 1$;
  - $c_B \odot c_B = 1$;
- 发送数据：
  - A: $d_A \cdot c_A$;
  - B: $d_B \cdot c_B$;
  - A+B: $d_A \cdot c_A + d_B \cdot c_B$
- 接收数据：
  - C: $(d_A \cdot c_A + d_B \cdot c_B) \odot c_A = d_A$
  - D: $(d_A \cdot c_A + d_B \cdot c_B) \odot c_B = d_B$



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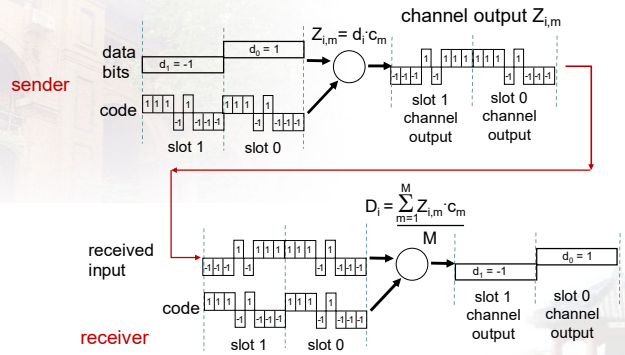
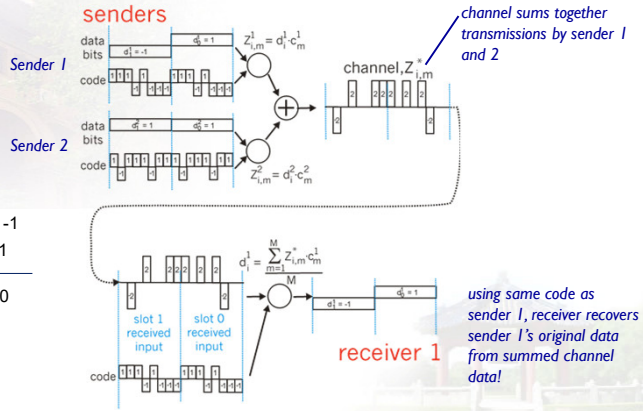
CDMA encode/decode



CDMA: two-sender interference



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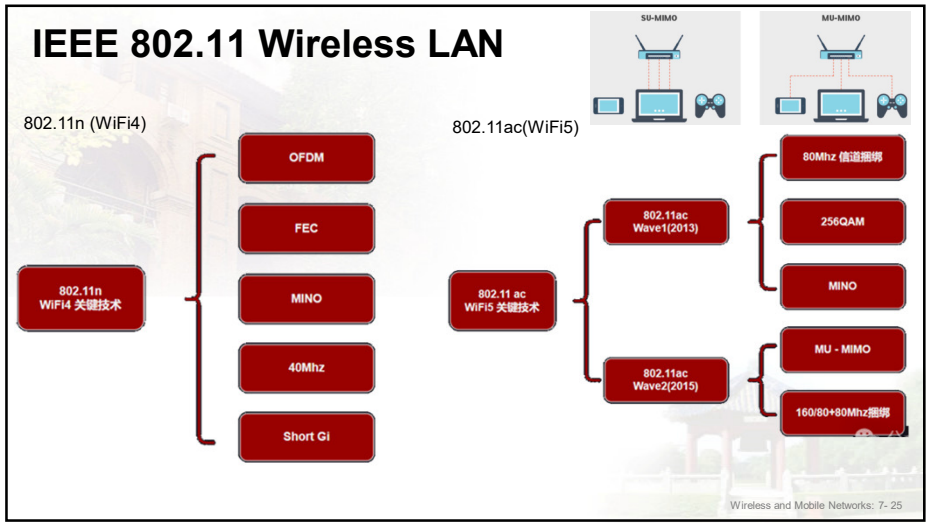
IEEE 802.11 Wireless LAN

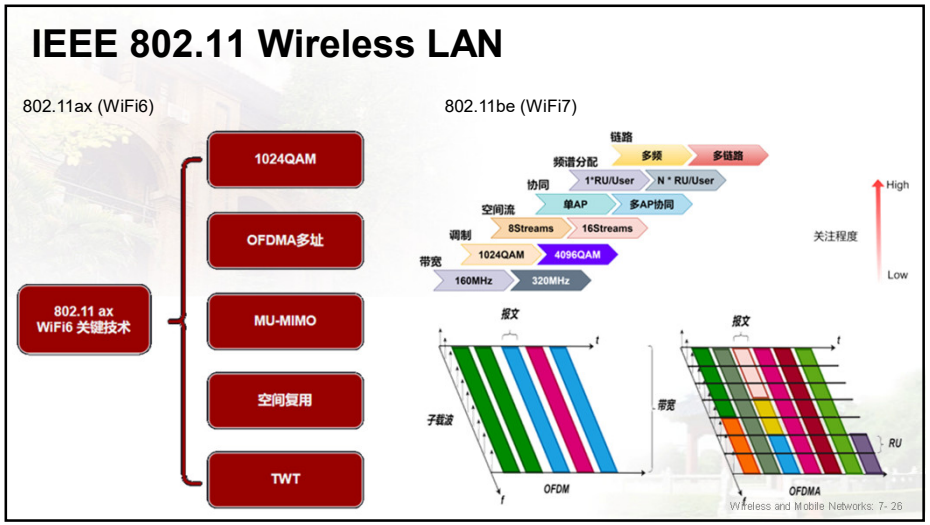
标准		发布年份	频段	物理层技术	编码方式	空间流数	信道带宽(MHz)	理论速率
-	802.11	1997	2.4 GHz	IR、FHSS和DSSS	-	-	20	2 Mbps
-	802.11 b	1999	2.4 GHZ	DSSS/CCK	-	-	22	11 Mbps
-	802.11 a	1999	5 GHz	OFDM	-	-	20	54 Mbps
-	802.11 g	2003	2.4 GHz	OFDM	64-QAM	-	20	54 Mbps
Wi-Fi 4	802.11 n	2009	2.4 GHz或5 GHz	OFDM DSSS/CCK	64-QAM	4	20、40	2.4GHz: 450 Mbps 5GHz: 600 Mbps
Wi-Fi 5	802.11 ac Wave1	2013	5 GHz	OFDM SU-MIMO	64-QAM	4+4	20、40	3.74 Gbps
	802.11 ac Wave2	2015	5 GHz	OFDM 下行MU-MIMO	256-QAM	8	20、40、80、160和80+80	6.9 Gbps
Wi-Fi 6	802.11 ax	2019	2.4 GHz或5 GHz	OFDMA 下行MU-MIMO 上行MU-MIMO	1024-QAM	4+8	20、40、80、160和80+80	2.4GHz: 1.15 Gbps 5GHz: 9.6 Gbps
Wi-Fi 7	802.11 be	2024	2.4 GHz 5GHz或6GHz	OFDMA MU-MIMO CMU-MIMO	4096-QAM	16	20、40、80、160、320	46Gbps

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

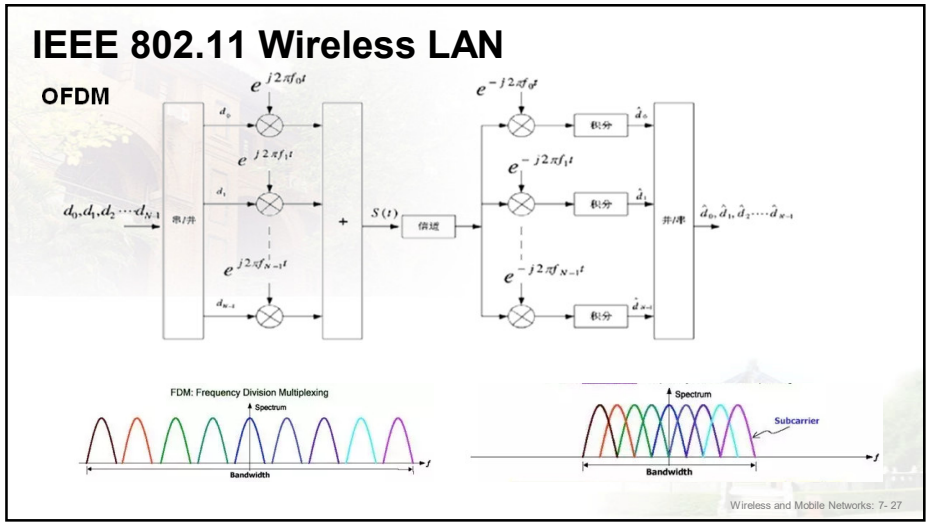
IEEE 802.11 Wireless LAN



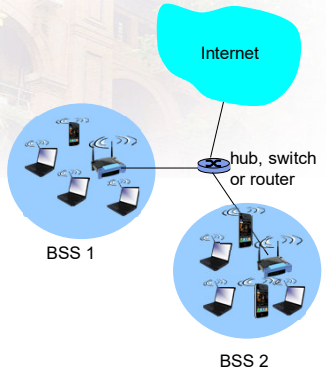
IEEE 802.11 Wireless LAN



IEEE 802.11 Wireless LAN



802.11 LAN architecture



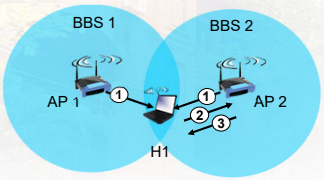
- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

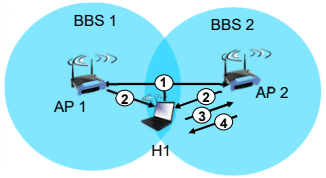
6-29

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 [Chapter 8]
  - will typically run DHCP to get IP address in AP's subnet

802.11: passive/active scanning



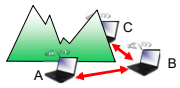


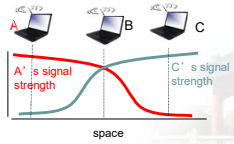
passive scanning:
(1) beacon frames sent from APs
(2) association Request frame sent: H1 to selected AP
(3) association Response frame sent from selected AP to H1

active scanning:
(1) Probe Request frame broadcast from H1
(2) Probe Response frames sent from APs
(3) Association Request frame sent: H1 to selected AP
(4) Association Response frame sent from selected AP to H1

IEEE 802.11: multiple access

- avoid collisions: 2+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - Don't collide with ongoing transmission by other node
- 802.11: *no* collision detection!
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - Can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





IEEE 802.11 MAC Protocol: CSMA/CA

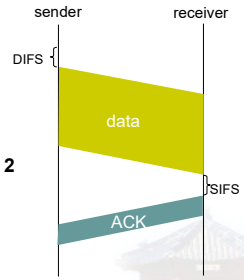
DCF Interframe Space(DIFS):在DCF协议中，节点在开始发送数据之前需要监测信道是否空闲。如果信道已经空闲，则节点仍需等待DIFS段时间才开始发送数据；而如果在DIFS时间段内任一时刻信道被监测为忙，则节点不得不推迟它的数据发送。

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 idle
  transmit when timer expires
  if no ACK, increase random backoff interval, repeat 2

802.11 receiver

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



Short Interframe Space（SIFS）

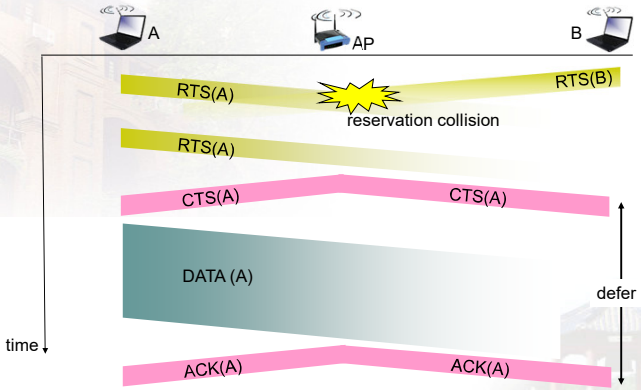
Avoiding collisions (more)

idea: allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames

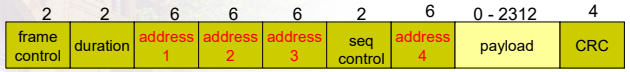
- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing



Why?

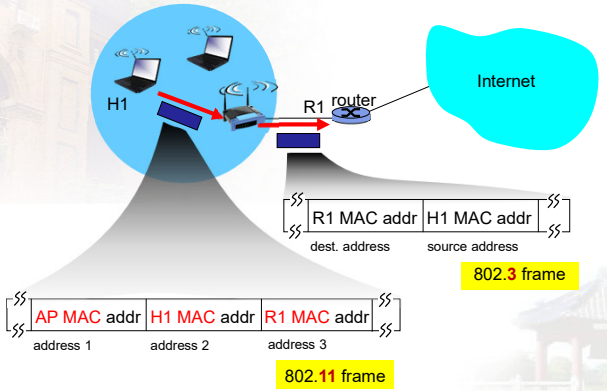
Address 1: MAC address of **wireless host** or **AP** to **receive** this frame

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

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

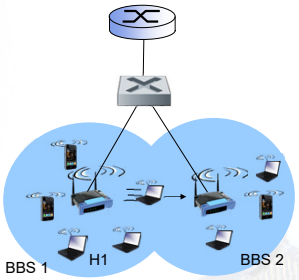
Address 4: used only in ad hoc mode

802.11 frame: addressing



802.11: mobility within same subnet

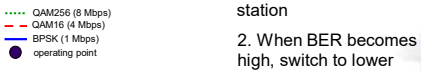
- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1

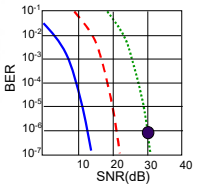


802.11: advanced capabilities

Rate adaptation

- 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

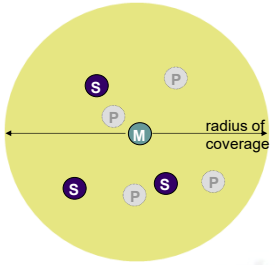
802.11: advanced capabilities

power management

- node-to-AP: "I am going to sleep until next beacon frame"
  - AP knows not to transmit frames to this node
  - node wakes up before next beacon frame
- beacon frame: contains list of mobiles with AP-to-mobile frames waiting to be sent
  - node will stay awake if AP-to-mobile frames to be sent; otherwise sleep again until next beacon frame

802.15: personal area network

- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- master/slaves:
  - slaves request permission to send (to master)
  - master grants requests
- 802.15: evolved from Bluetooth specification
  - 2.4-2.5 GHz radio band
  - up to 721 kbps



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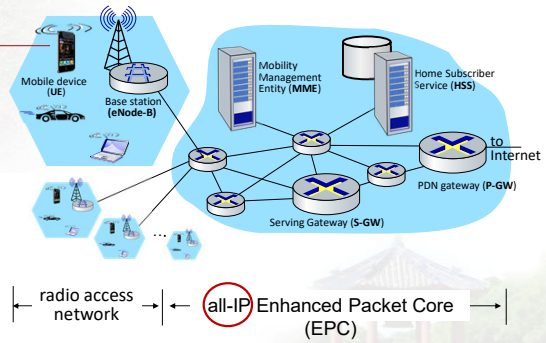
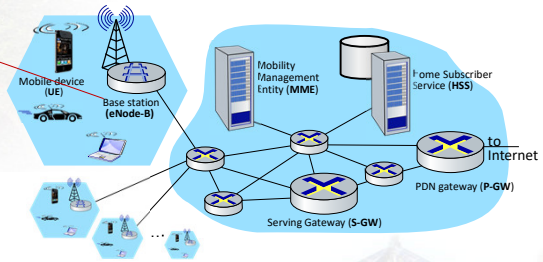
Elements of 4G LTE architecture

Mobile device:
- smartphone, tablet, laptop, IoT, ... with 4G LTE radio
- 64-bit International Mobile Subscriber Identity (IMSI), stored on SIM (Subscriber Identity Module) card
- LTE jargon: User Equipment (UE)



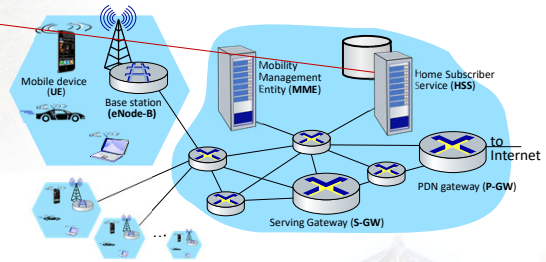
Elements of 4G LTE architecture

Base station:
- at "edge" of carrier's network
- manages wireless radio resources, mobile devices in its coverage area ("cell")
- coordinates device authentication with other elements
- similar to WiFi AP but:
  - active role in user mobility
  - coordinates with nearly base stations to optimize radio use
- LTE jargon: eNode-B



Elements of 4G LTE architecture

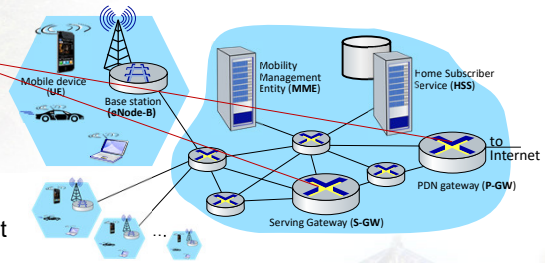
Home Subscriber Service
- stores info about mobile devices for which the HSS's network is their "home network"
- works with MME in device authentication



Elements of 4G LTE architecture

Serving Gateway (S-GW), PDN Gateway (P-GW)

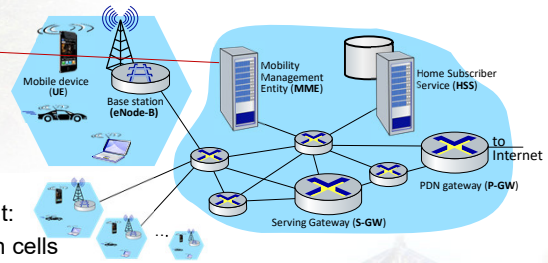
- lie on data path from mobile to/from Internet
- P-GW
  - gateway to mobile cellular network
  - Looks like nay other internet gateway router
  - provides NAT services
- other routers:
  - extensive use of tunneling



Elements of 4G LTE architecture

Mobility Management Entity

- device authentication (device-to-network, network-to-device) coordinated with mobile home network HSS
- mobile device management:
  - device handover between cells
  - tracking/paging device location
- path (tunneling) setup from mobile device to P-GW



Chapter 7 summary

Wireless

- **wireless links:**
  - **capacity, distance**
  - **channel impairments**
  - **CDMA**
- **IEEE 802.11 ("Wi-Fi")**
  - **CSMA/CA reflects wireless channel characteristics**
- **cellular access**
  - **architecture**
  - **standards (e.g., GSM, 3G, 4G LTE)**

Mobility

- **principles: addressing, routing to mobile users**
  - **home, visited networks**
  - **direct, indirect routing**
  - **care-of-addresses**
- **case studies**
  - **mobile IP**
  - **mobility in GSM**
- **impact on higher-layer protocols**

The End of Chapter 7

Thanks

Q & A

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