Computer Networking: A Top Down Approach 7th Edition
Jim Kurose, Keith Ross
Pearson
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A Top-Down Approach

CHAPTER 7

Wireless and Mobile Networks

CHAPTER 7

Roadmap:

7.1 Background & Introduction

Wireless:

7.2 Wireless links, characteristics
- CDMA

7.3 WiFi: 802.11 Wireless LANs

7.4 Cellular Networks: 4G/5G
- Architecture & Elements
- LTE

Mobility:

7.5 Mobility Management:
- Principles
- Mobile IP
- Handling Mobility in Cellular Networks

7.7 Wireless and Mobility: Impact on higher-layer protocols

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CHAPTER 7

(7.1) Introduction

Wireless and mobile networks

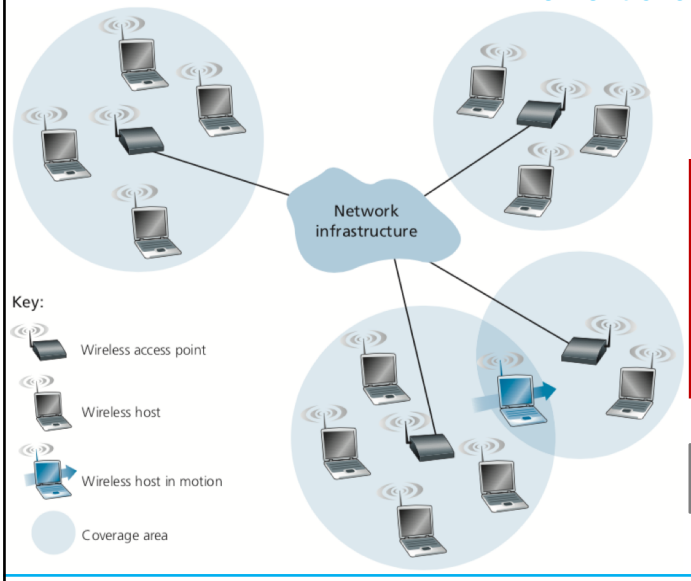
Background:

- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers (5-to-1)!
- # wireless Internet-connected devices equals # wired Internet-connected devices
  - laptops, Internet-enabled phones promise anytime untethered Internet access
- Two important (but different) challenges
  - *wireless:* communication over wireless link
  - _____ *:* handling the mobile user who changes point of attachment to network

6-3

CHAPTER 7

Element of a wireless networks



Wireless hosts:

- laptop, smartphone
- run applications
- may be stationary (non-mobile) or mobile

Wireless does *not* always mean mobility

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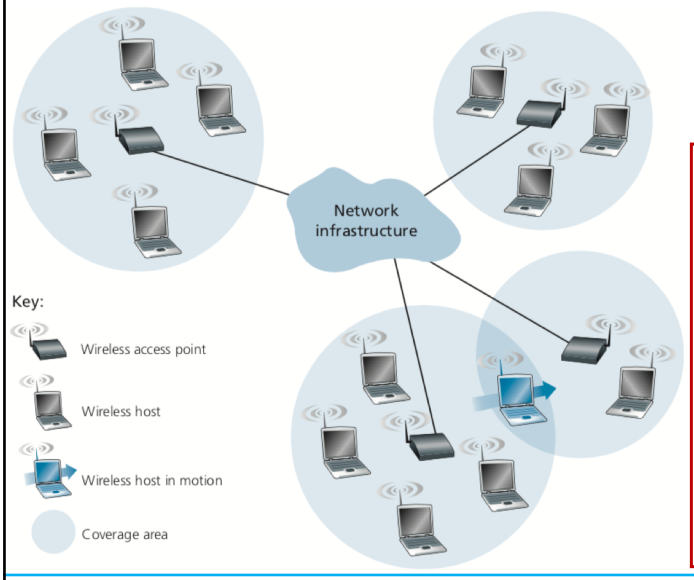
Element of a wireless networks



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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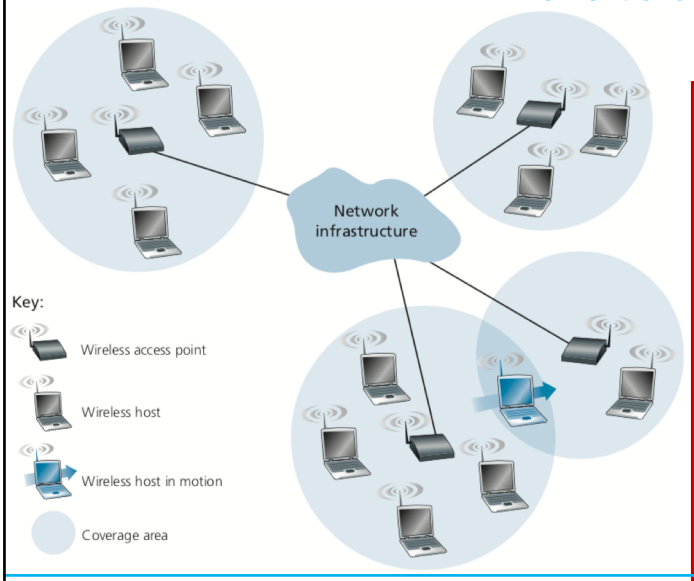
Element of a wireless networks



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

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Element of a wireless networks

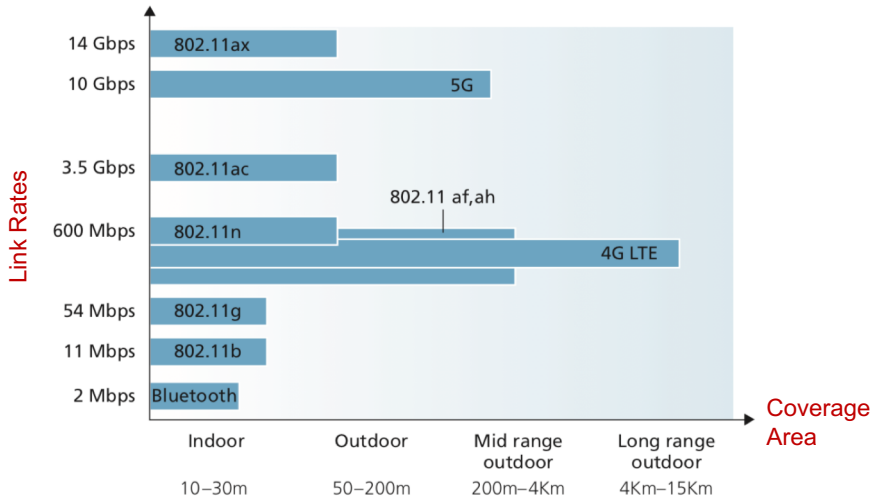

Figure: Wireless transmission rates and range for WiFi, cellular 4G/5G and Bluetooth standards (note: axes are not linear)

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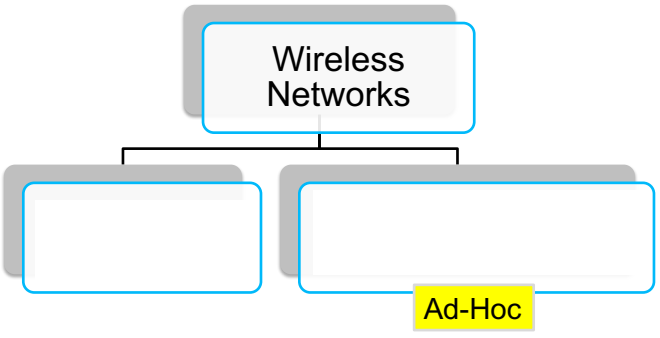
Element of a wireless networks



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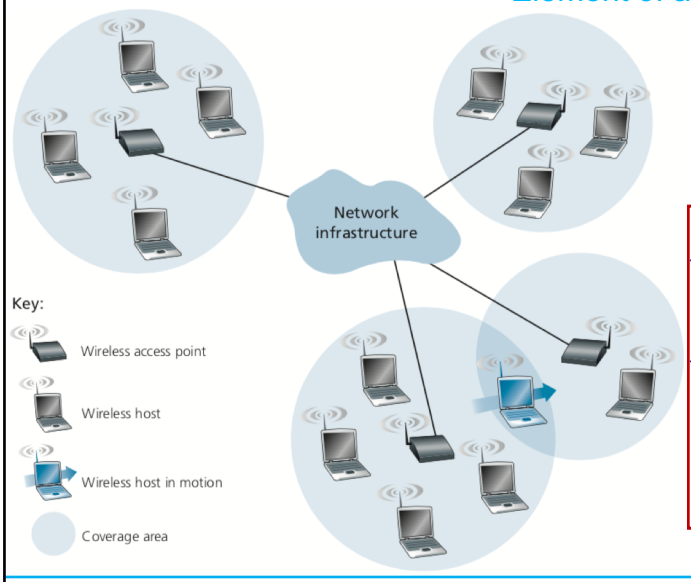
Element of a wireless networks



Infrastructure mode:

- Base station connects mobiles into wired network.
- *Handoff* : mobile changes base station providing connection into wired network.

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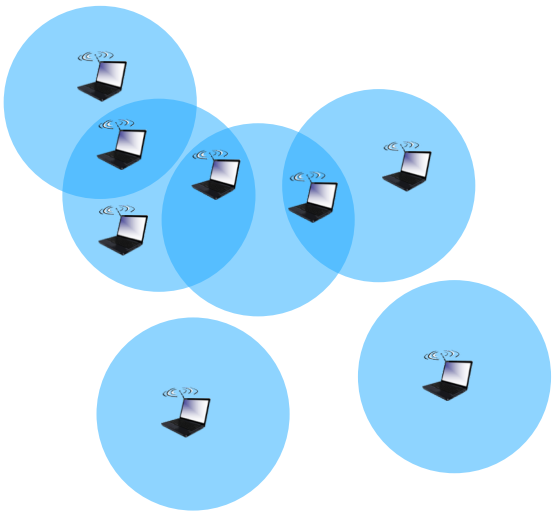
Element of a wireless networks



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.

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Element of a wireless networks

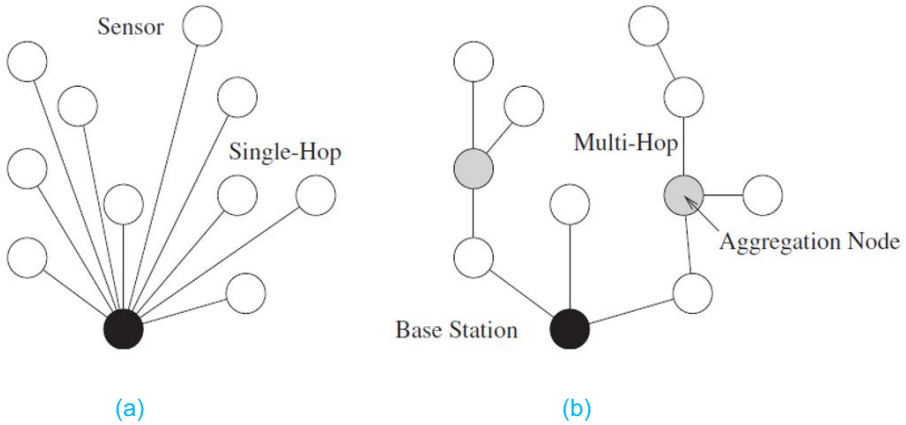

Figure: (a) Single hop versus (b) multiple hops

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Wireless network taxonomy

	Single hop	Multiple hops
Infrastructure-based (e.g., APs)	Host connects to base station which connects to larger Internet (*WiFi, WiMAX, cellular*)	Host may have to relay through several wireless nodes to connect to larger Internet (*mesh network*)
No Infrastructure	No base station, no connection to larger Internet (*Bluetooth, ad hoc networks*)	No base station, no connection to larger Internet. May have to relay to reach other a given wireless node. (*Piconet, MANET, VANET*)

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CHAPTER 7

Roadmap:

7.1 Background & Introduction

Wireless:

7.2 Wireless links & Network characteristics
- **CDMA**

7.3 WiFi: 802.11 Wireless LANs

7.4 Cellular Networks: 4G/5G
- Architecture & Elements
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Mobility:

7.5 Mobility Management:
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7.7 Wireless and Mobility: Impact on higher-layer protocols

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CHAPTER 7 (7.2) Wireless Links & Network Characteristic

- *Important* differences from wired link as wireless link can have:
  - *Decreased signal strength:* radio signal attenuates as it propagates through matter (_____).
  - *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.
  - *Multi-path propagation:* radio signal reflects off objects ground, arriving at destination at slightly different times.

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

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BPSK (Binary phase-shift keying)
QAM (Quadrature Amplitude Modulation)

- *SNR: Signal-to-Noise Ratio*
  - larger SNR – easier to extract signal from noise (a "good thing")
- *SNR versus BER tradeoffs*
  - *Bit Error Rate (BER)* is the number of bit errors divided by the total number of transferred bits
  - *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)

decreased signal strength

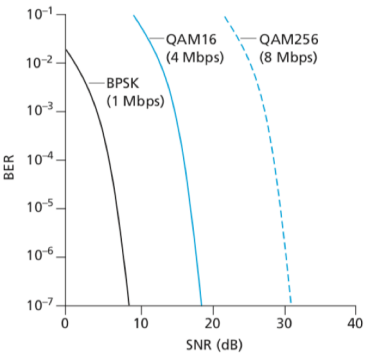

Figure: Bit error rate, transmission rate, and SNR.

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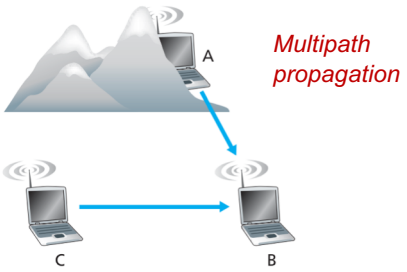
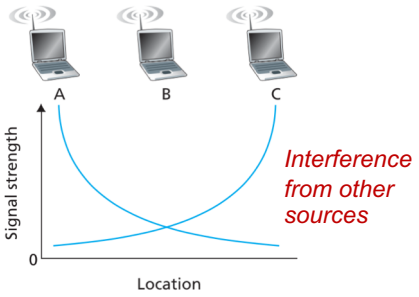
Multiple wireless senders and receivers create additional problems (beyond multiple access):



Multipath propagation



Interference from other sources

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 / Fading:

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

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CHAPTER 7 (7.2) Wireless Links & Network Characteristic

(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
(Sender)	(Receiver)

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CHAPTER

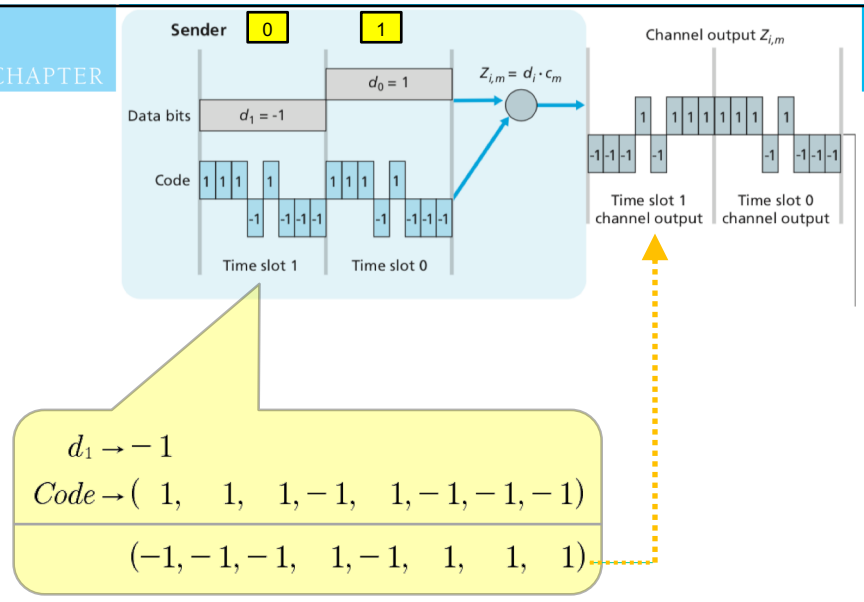

Figure: A simple CDMA example: Sender encoding, receiver decoding

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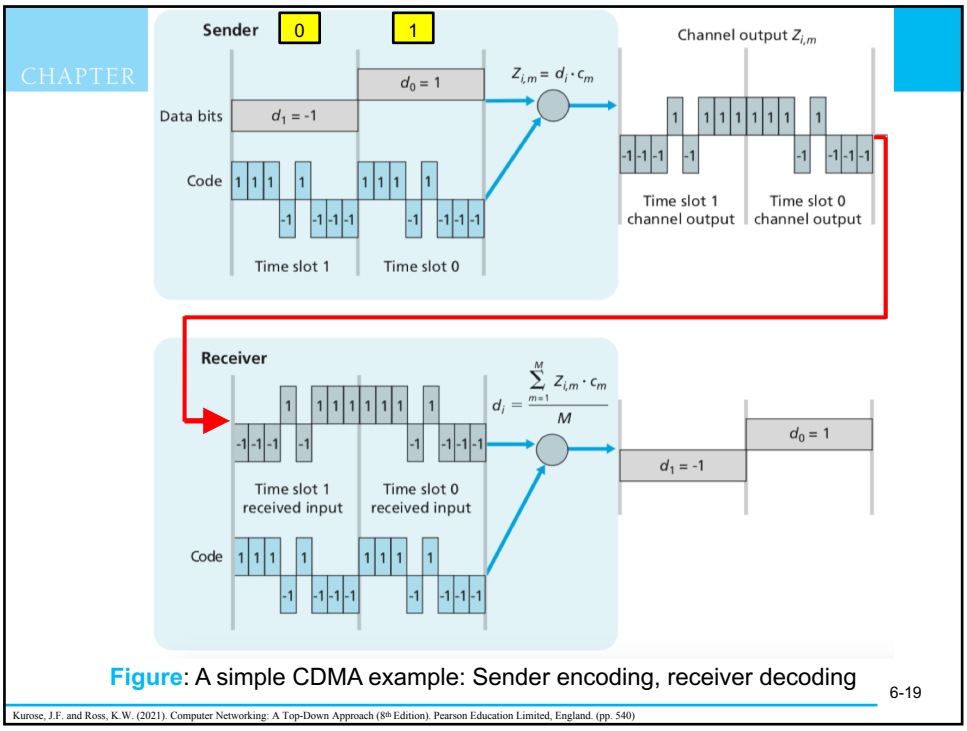

Figure: A simple CDMA example: Sender encoding, receiver decoding

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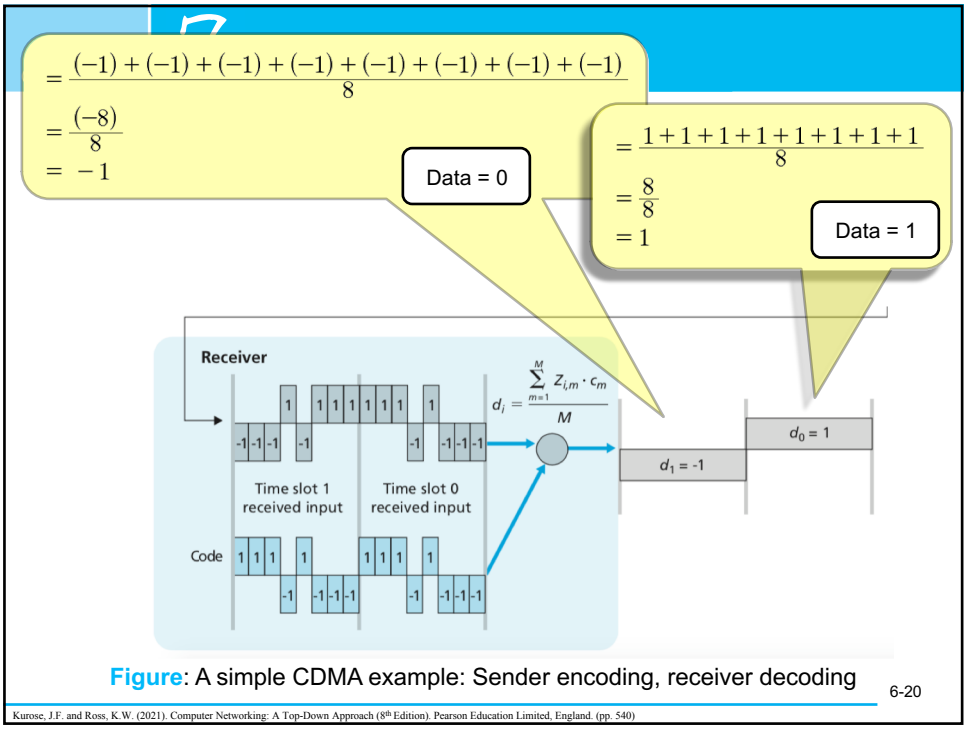

Figure: A simple CDMA example: Sender encoding, receiver decoding

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Exercise 7.1a

Consider the single-sender CDMA. What would be the sender's output (encode) for the data bit 0 and 1 if the sender's CDMA code were (1, 1, –1, 1, 1, –1, –1, 1)? Show your working.

Solution 7.1a:

Encode: $Z_{i,m} = d_i \times c_m$

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CHAPTER 7

Exercise 7.1b

Based on Exercise 7.1a, decode the received inputs at the receiver. Show your working.

Solution 7.1b:

Decode: $d_i = \frac{\sum_{m=1}^{M} Z_{i,m} \times c_m}{M}$

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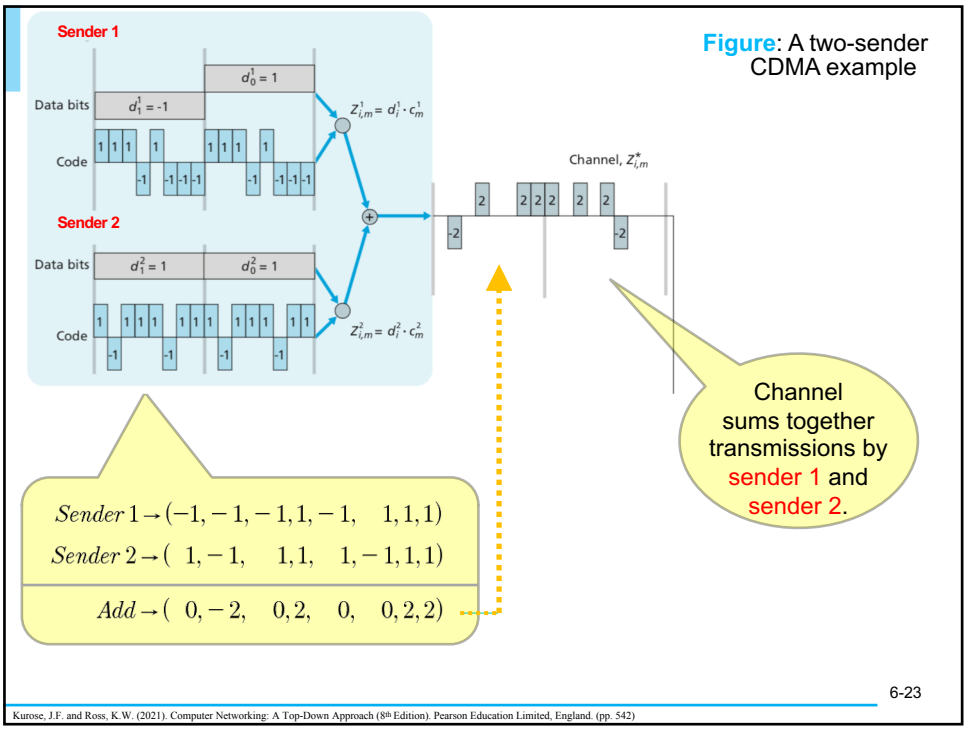

Figure: A two-sender CDMA example

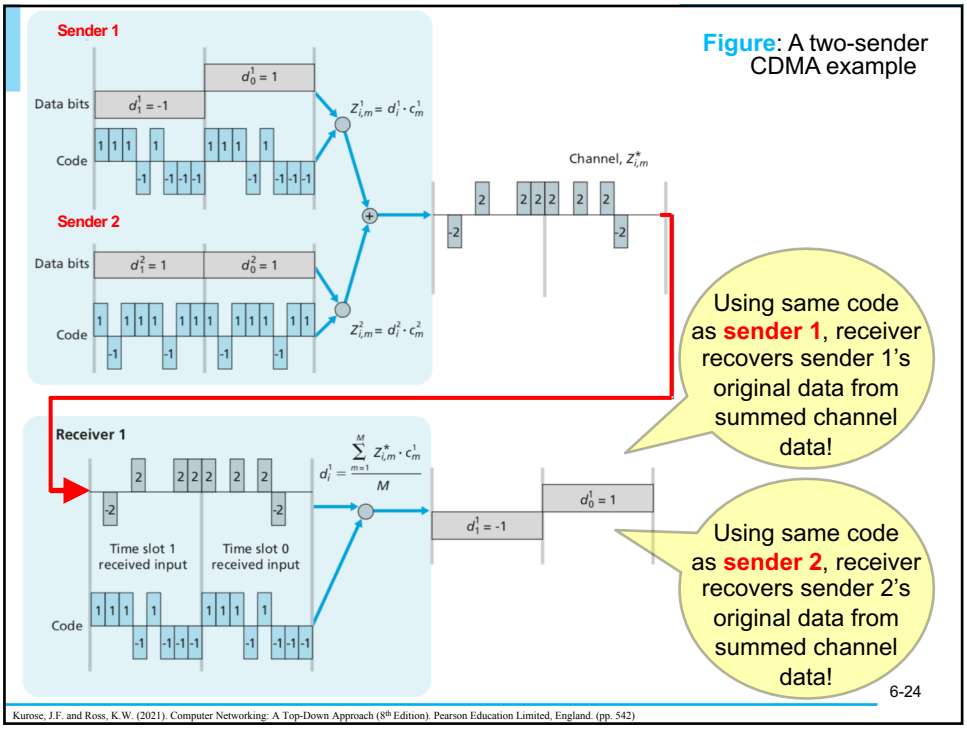

Figure: A two-sender CDMA example

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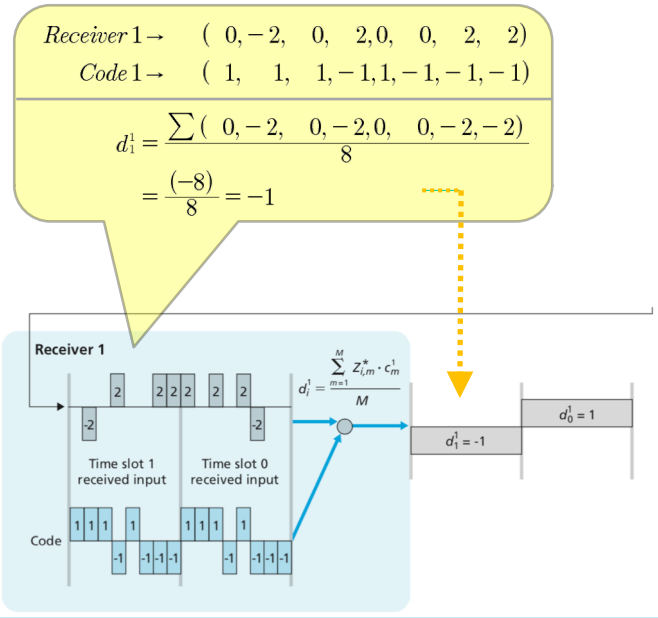

Seft-test:

Try for receiver 2

6-25

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Exercise 7.2a

Consider two senders CDMA. Assume that the first two bits sent by sender 1 are (0, 1) with the CDMA code (1, 1, 1, –1, 1, –1, –1, –1) and sender 2 are (0, 0) with the CDMA code (1, –1, 1, 1, 1, –1, 1, 1).

What are the sender's outputs (encode) to the channel:

i) before being added to both?

ii) after being added to both?

Show your working.

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CHAPTER 7

Exercise 7.2a

Solution 7.2a: i) before being added to both

Sender 1:

Sender 2:

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CHAPTER 7

Exercise 7.2a

Solution 7.2a: ii) after being added to both

Final Encode: $Z^*_{i,m} = Z^1_{i,m} + Z^2_{i,m}$

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CHAPTER 6

Exercise 7.2b

Based on Exercise 7.2a, decode the received inputs at the each receiver 1 and 2. Show your working.

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CHAPTER 7

(7.3) WiFi: 802.11 Wireless LANs

Overview

- IEEE 802.11 wireless LAN also known as WiFi.
- Several 802.11 standards for this wireless LAN technology → but all share some common characteristics.
- All use the same medium access protocol → _____
- All have base-station and ad-hoc network versions.

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

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Table: Summary of IEEE 802.11 standards

Standard	Year	Max data rate	Range	Frequency
802.11b	1999	11 Mbps	30 m	2.4 Ghz
802.11g	2003	54 Mbps	30m	2.4 Ghz
802.11n (WiFi 4)	2009	600	70m	2.4, 5 Ghz
802.11ac (WiFi 5)	2013	3.47Gpbs	70m	5 Ghz
802.11ax (WiFi 6)	2020 (expected)	14 Gbps	70m	2.4, 5 Ghz
802.11af	2014	35 – 560 Mbps	1 Km	unused TV bands (54-790 MHz)
802.11ah	2017	347Mbps	1 Km	900 Mhz

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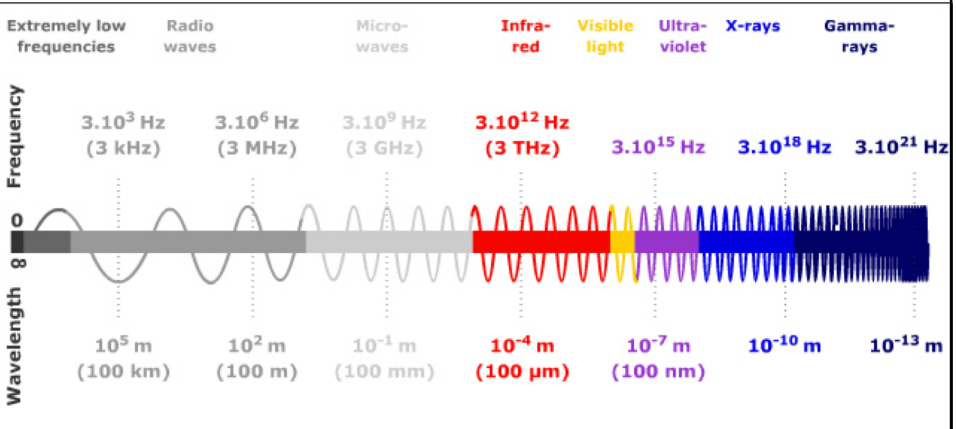
Electromagnetic Spectrum

Additional



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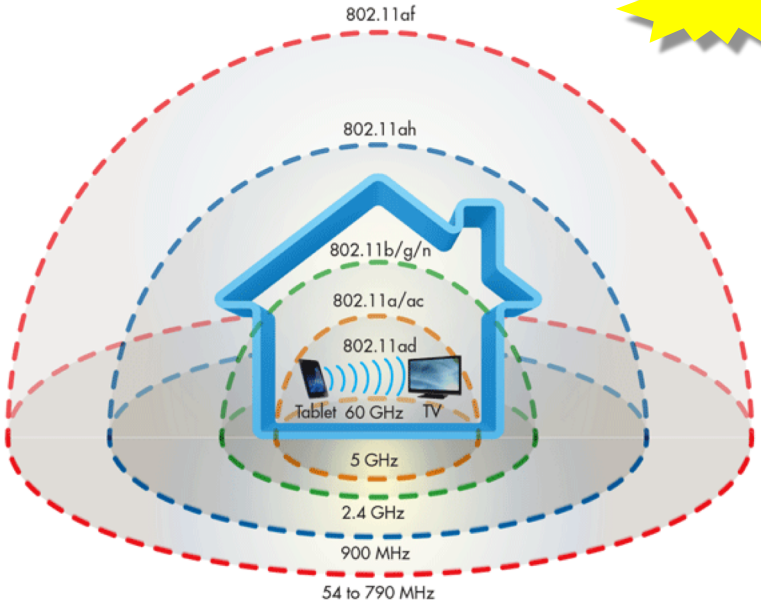
http://www.bbemg.be/uploads/images/modulebase/EN/b10.jpg

The different between IEEE 802.11

Additional



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http://mwrf.com/site-files/mwrf.com/files/uploads/2015/02/RF_Essentials_Fig1.gif

The 802.11 LAN Architecture

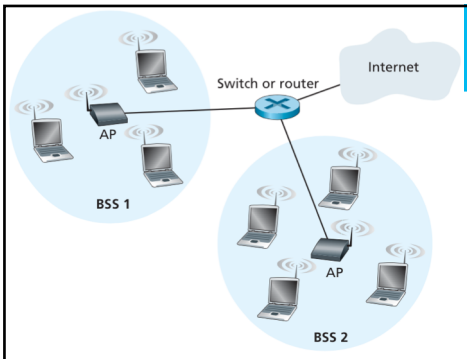

Figure: An IEEE 802.11 LAN architecture

- Wireless host communicates with base station
  - Base station =

- *Basic Service Set* (BSS) (aka "cell") in infrastructure mode contains:
  - Wireless hosts.
  - *AP*: base station.
  - *Ad hoc* mode: hosts only.

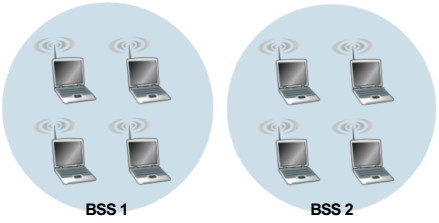

Figure: An IEEE 802.11 ad hoc network

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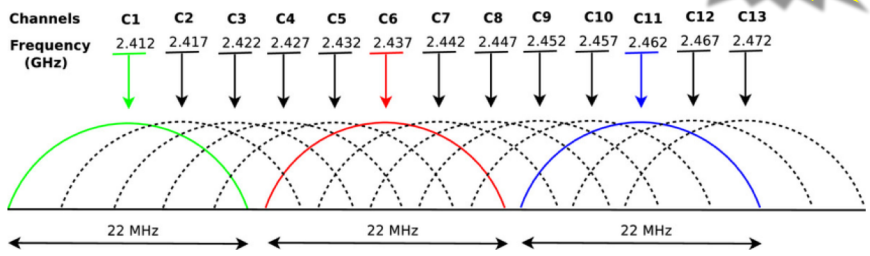
The 802.11 LAN Architecture

Channels, association (Host-AP)

- 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!

Additional

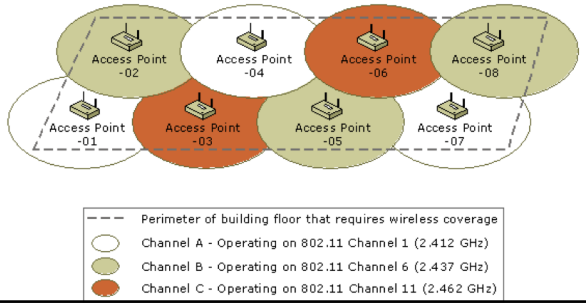


https://www.researchgate.net/profile/Hanan_Abdullah/publication/257877785/figure/fig7/AS:267856508092462@1440873376957/Figure-3-Three-non-overlapping-channels-in-IEEE-80211b-standard.png

The 802.11 LAN Architecture

Channels, association (Host-AP)

- Host: must *associate* with an AP
  - scans channels, listening for *beacon frames* containing AP's name 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.



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The 802.11 LAN Architecture

Channels, association (Host-AP)

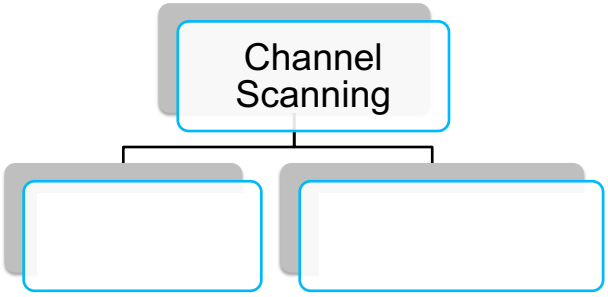

Figure: The process of scanning channels and listening for access points.

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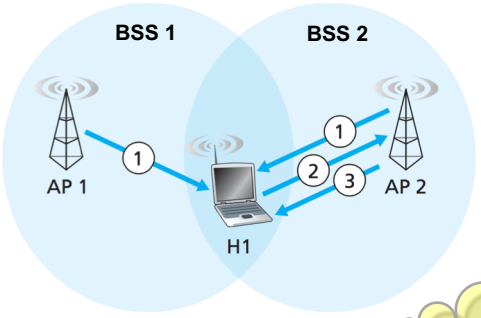
The 802.11 LAN Architecture

Channels, association (Host-AP)



Beacon frame:
- contains all information about the network
- transmitted periodically to announce the presence of a wireless LAN
- transmitted by APs in an infrastructure *Basic Service Set* (BSS)

(A) Passive scanning:

1. **Beacon frames** sent from APs
2. Association Request frame sent: H1 to selected AP2
3. Association Response frame sent from selected AP2 to H1

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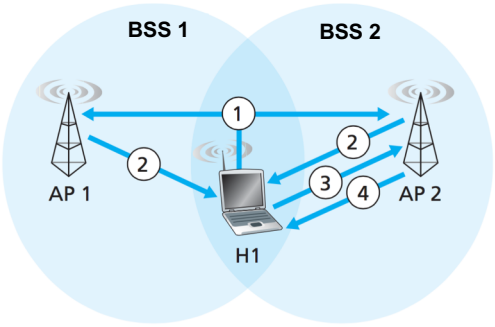
The 802.11 LAN Architecture

Channels, association (Host-AP)

Probe Request frame:
- sends to APs to obtain information about the network

Probe Response frame:
- Contains all information about the network from APs



(B) Active scanning:

1. **Probe Request frame** broadcast from H1
2. **Probe Response frames** sent from APs
3. Association Request frame sent: H1 to selected AP2
4. Association Response frame sent from selected AP2 to H1

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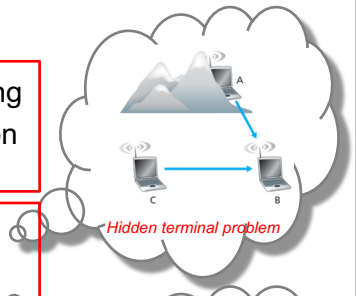
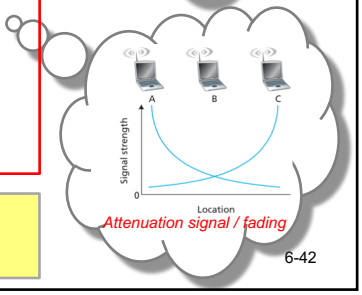
The 802.11 MAC Protocol

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/CA (*Collision Avoidance*)





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CHAPTER 7

The 802.11 MAC Protocol

CSMA/CA

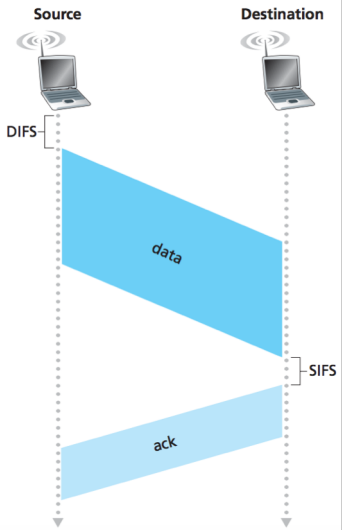
802.11 sender

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)



DIFS (Distributed Inter-Frame Spacing)
SIFS (Short Inter-Frame Spacing)
CD (Collision Detection)

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CHAPTER 7

The 802.11 MAC Protocol

[Optional]

Collision Avoidance: RTS-CTS exchange

Idea → The 802.11 MAC protocol also allow sender to "reserve" channel rather than random access of data frames to **avoid collisions / reduce frame collisions** of long data frames introduced by the hidden terminal problem.

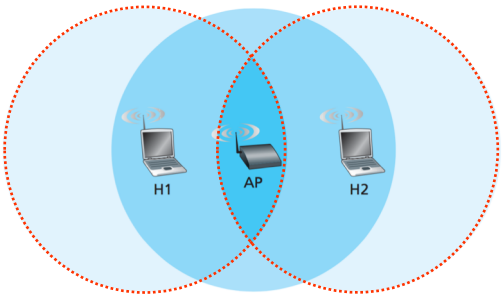

Figure: Hidden terminal example: H1 is hidden from H2, and vice versa.

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

6-44

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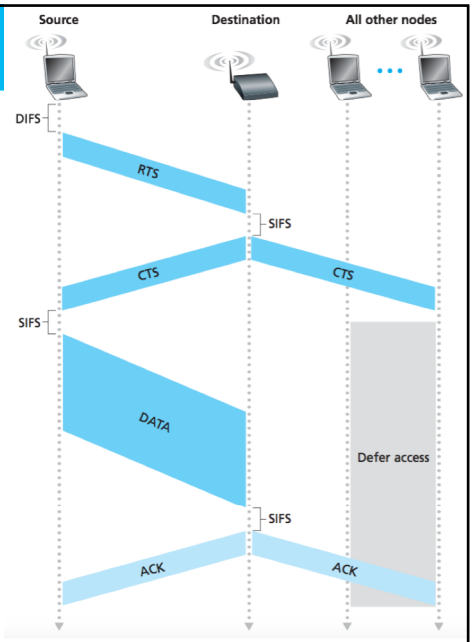
CHAPTER 7

Collision Avoidance: RTS-CTS exchange

- sender first transmits *small* Request-To-Send (RTS) packets to AP using CSMA
  - RTSs may still collide with each other (but they're short)
- AP 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!

DIFS (Distributed Inter-Frame Spacing) | SIFS (Short Inter-Frame Spacing)

CHAPTER 7

The 802.11 Frame

Addressing

Frame (numbers indicate field length in bytes):

2	2	6	6	6	2	6	0-2312	4
Frame control	Duration	Address 1	Address 2	Address 3	Seq control	Address 4	Payload	CRC

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.

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The 802.11 Frame

Addressing

duration of reserved transmission time (RTS/CTS)

frame seq# (for RDT)

Frame (numbers indicate field length in bytes):

2	2	6	6	6	2	6	0-2312	4
Frame control	Duration	Address 1	Address 2	Address 3	Seq control	Address 4	Payload	CRC

Frame control field expanded (numbers indicate field length in bits):

2	2	4	1	1	1	1	1	1	1	1
Protocol version	Type	Subtype	To AP	From AP	More frag	Retry	Power mgt	More data	WEP	Rsvd

frame type (RTS, CTS, ACK, data)

6-47

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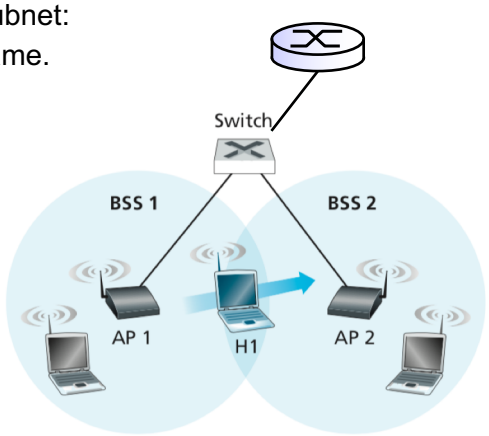
Mobility in the Same IP Subnet

- 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.



BSS (Basic Service Set)

6-48

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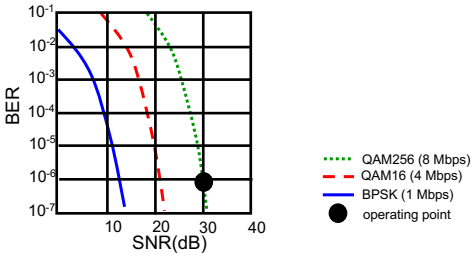
CHAPTER 7

Advance Features in 802.11

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

SNR (Signal-to-Noise Ration)
BER (Bit Error Rate)

6-49

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CHAPTER 7

Advance Features in 802.11

Power Management

- Node-to-AP:

  - 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.

6-50

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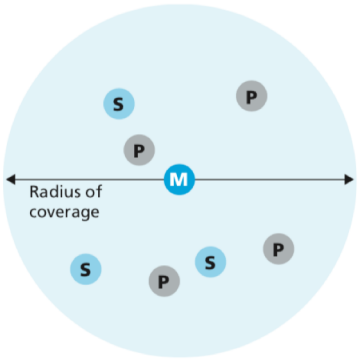
CHAPTER 7

Personal Area Networks

(Bluetooth)

- Less than 10m diameter.
- Replacement for cables (mouse, keyboard, headphones).
- Ad hoc: No infrastructure.
- Organized into a piconet (up to 8 active devices)
- Master/Slaves:
  - Slaves request permission to send (to master).
  - Master grants requests.



Key:
M Master device
S Slave device
P Parked device

- 802.15.1: evolved from Bluetooth specification.
  - 2.4-2.5 GHz radio band.
  - up to 3 Mbps.

6-51

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CHAPTER 7

Roadmap:

7.1 Background & Introduction

Wireless:

7.2 Wireless links & Network characteristics
- CDMA

7.3 WiFi: 802.11 Wireless LANs

7.4 Cellular Networks: 4G/5G
- **Architecture & Elements**
- **LTE**

Mobility:

7.5 Mobility Management:
- Principles
- Mobile IP
- Handling Mobility in Cellular Networks

7.7 Wireless and Mobility: Impact on higher-layer protocols

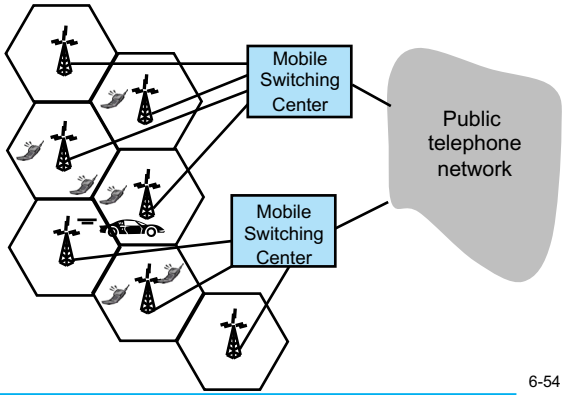
6-53

CHAPTER 7

(7.4) Cellular Networks: 4G/5G

Overview of Cellular Network Architecture

- This section will adopts the terminology of the *Global System for Mobile* (GSM) standards.
- GSM describes the protocols for a _____ technology that often classify as belonging to one of several "generation".
- The term cellular refers to the region covered by a cellular network → _____.



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CHAPTER 7

(7.4) Cellular Networks: 4G/5G

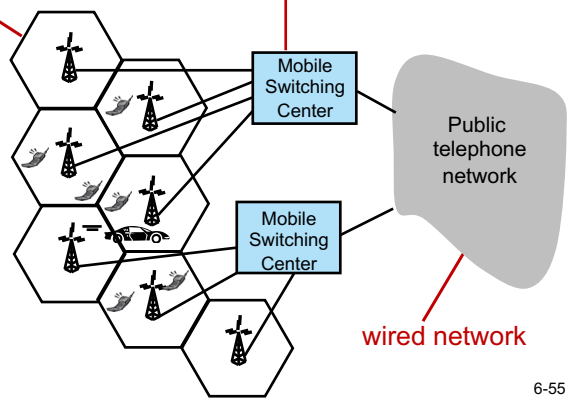
Components

Cell

- covers geographical region.
- *Base Station* (BS) analogous to 802.11 AP.
- *mobile users* attach to network through BS.
- *air-interface:* physical and link layer protocol between mobile and BS.

MSC

- connects cells to wired telephone network.
- manages call setup.
- handles mobility.



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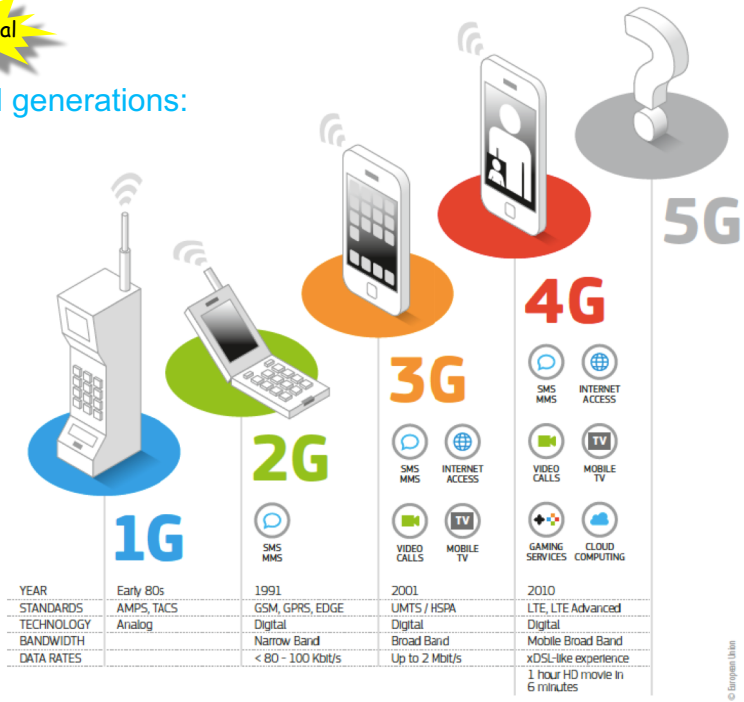
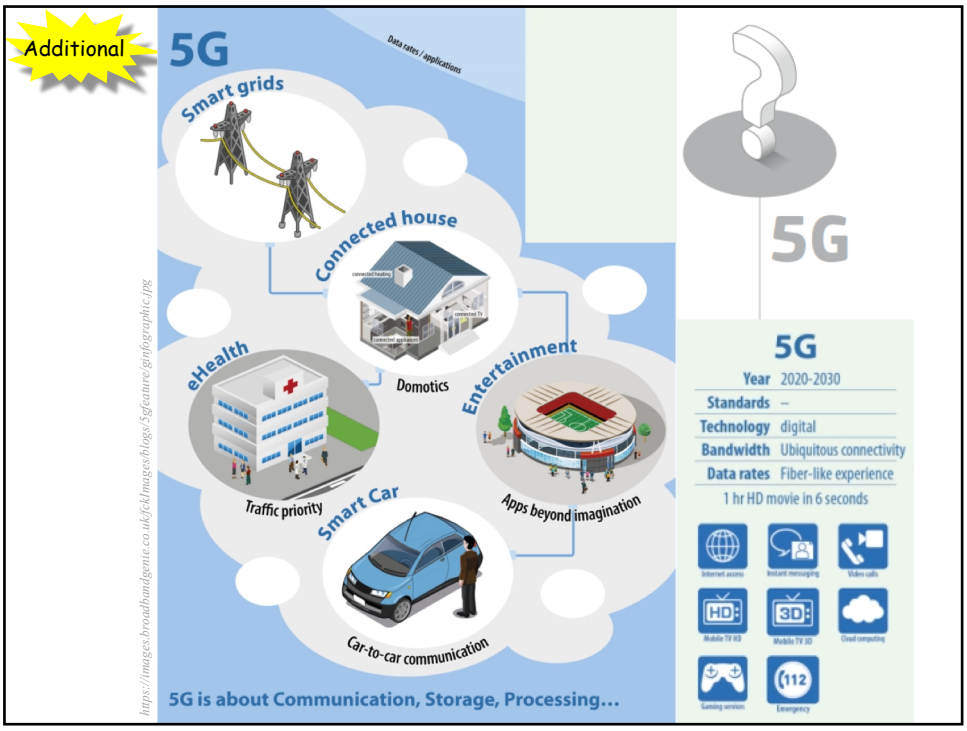
Additional

GSM generations:



YEAR	Early 80s	1991	2001	2010
STANDARDS	AMPS, TACS	GSM, GPRS, EDGE	UMTS / HSPA	LTE, LTE Advanced
TECHNOLOGY	Analog	Digital	Digital	Digital
BANDWIDTH		Narrow Band	Broad Band	Mobile Broad Band
DATA RATES		< 80 - 100 Kbit/s	Up to 2 Mbit/s	xDSL-like experience 1 hour HD movie in 6 minutes

6-56



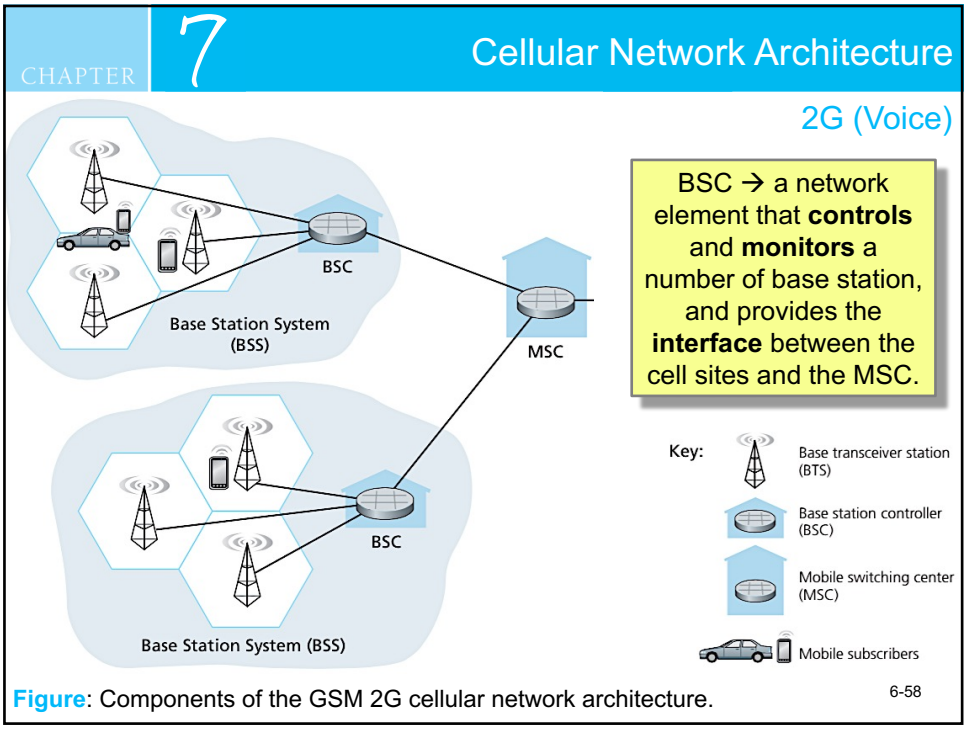


Figure: Components of the GSM 2G cellular network architecture.

CHAPTER 7

Cellular Network Architecture

2G (Voice)

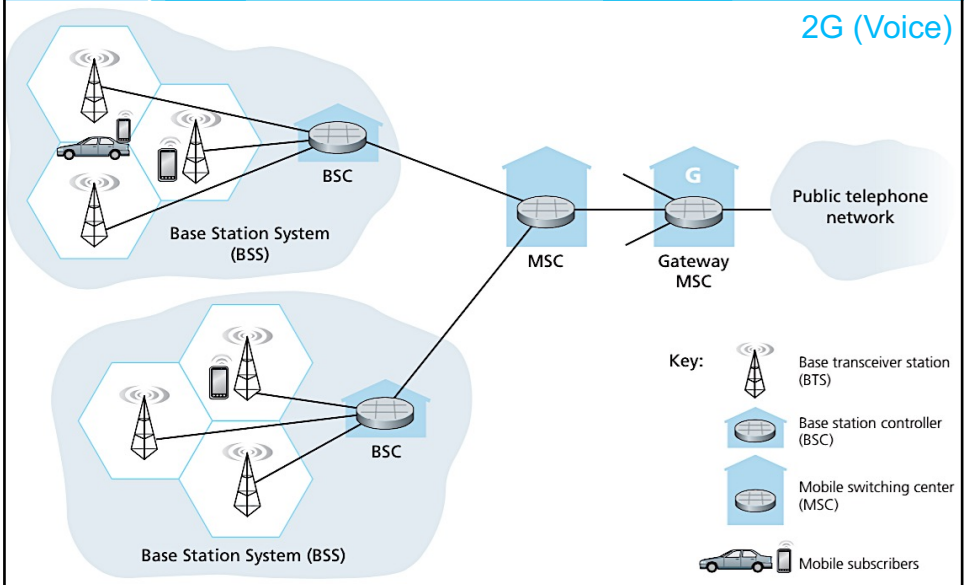


Figure: Components of the GSM 2G cellular network architecture.

6-59

CHAPTER 7

Cellular Network Architecture

3G (Voice + Data)

Overview

- To enable users access to the Internet requires technology beyond 2G.
  - read email, access the Web, and watch streaming video
    - required a full TCP/IP protocol stack and connect into the Internet via the cellular data network.
- focus on the UMTS (*Universal Mobile Telecommunications Service*) 3G standards.

Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

- voice network unchanged in core
- data network operates in parallel

6-60

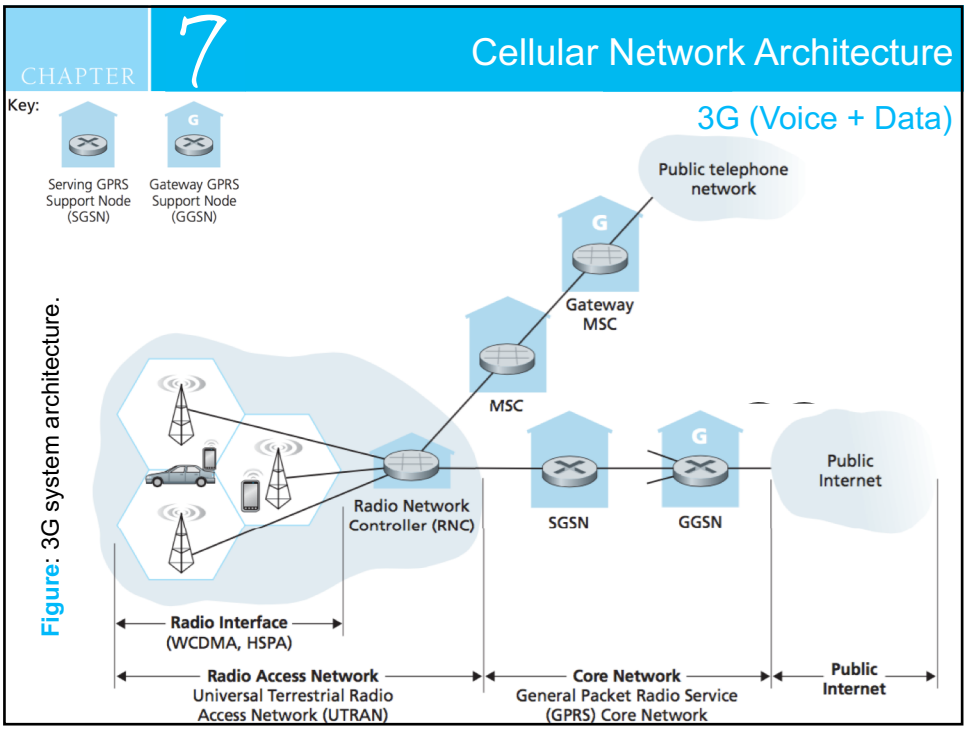
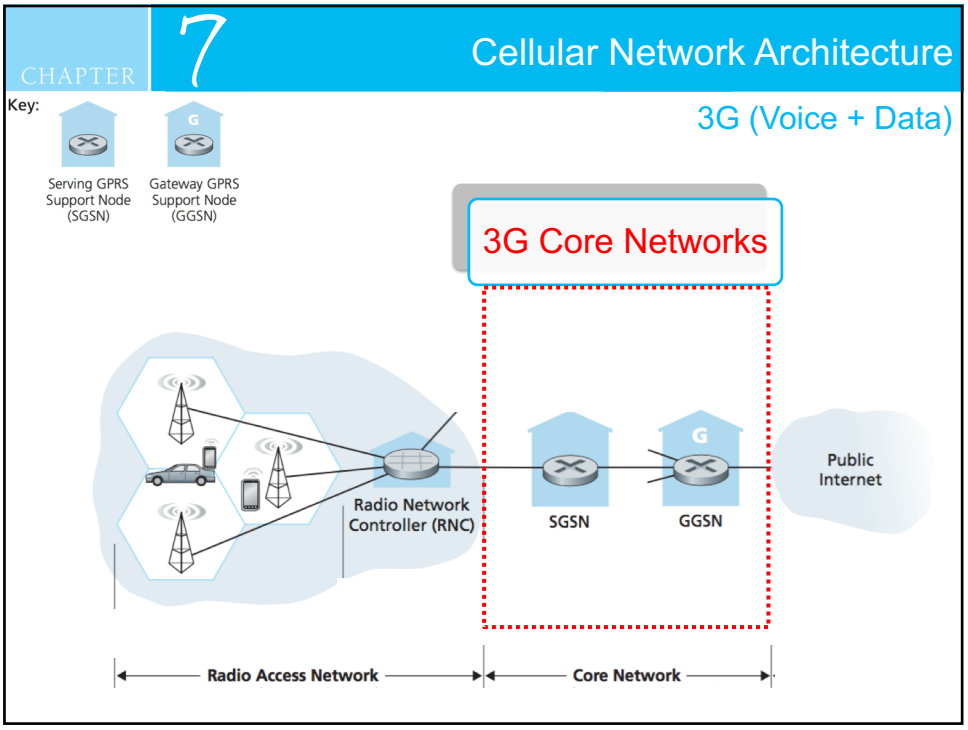


Figure: 3G system architecture.

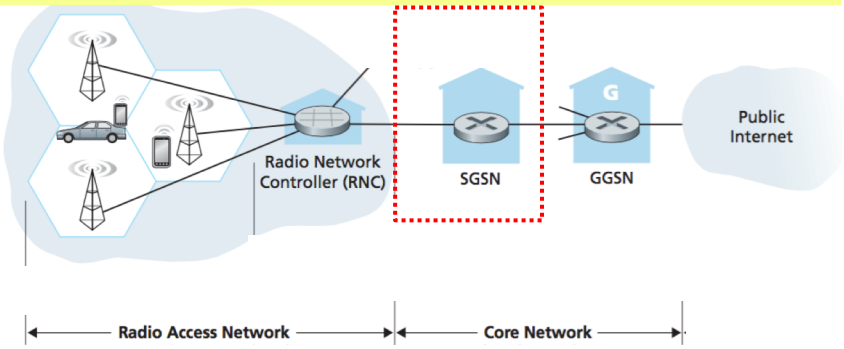


CHAPTER 7 Cellular Network Architecture

3G (Voice + Data)

Serving GPRS Support Nodes (SGSNs):

- responsible for delivering datagrams to/from the mobile nodes in the **Radio Access Network** to which the **SGSN** is attached.
- performing datagram forwarding between mobile nodes in the **Radio Access Network** and a **GGSN**.

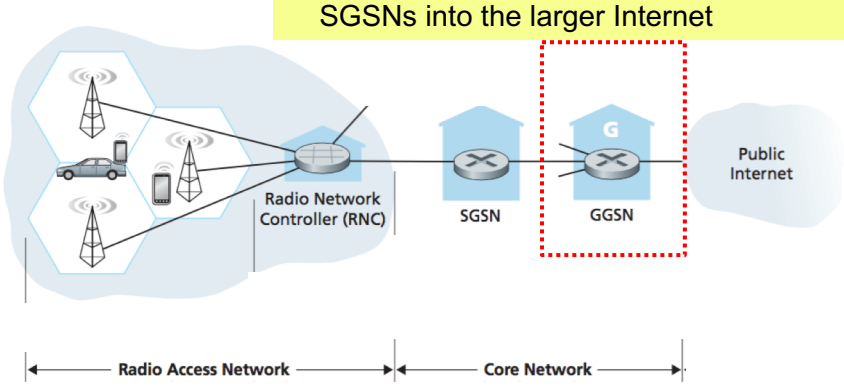


CHAPTER 7 Cellular Network Architecture

3G (Voice + Data)

Gateway GPRS Support Nodes (GGSNs):

- acts as a gateway, connecting multiple SGSNs into the larger Internet



4G-LTE in Malaysia

http://leapingpost.com/2013/09/21/4g-malaysia/

4G-LTE officially launched in Malaysia earlier this year (2013) with limited coverage and support

Malaysian Telcos Offering 4G:

	Maxis	Celcom	DiGi	YES	P1
Advertised Speed:	Up to 75 Mbps (avg: 10Mbps to 30Mbps)	Up to 42 Mbps	Up to 30 Mbps	Up to 20 Mbps	Up to 4 Mbps
Devices:	iPhone 5, SGS4, BB Q5, Q10, HTC One, One XL, Nokia Lumia 920, iPads	iPhone 5, Samsung Galaxy Mega, SGS4, BB Q10, Z10, Xperia Tablet Z	Currently only broadband and tablets	Eclipse 4G, Samsung Buzz, various dongles	Broadband & dongles
Coverage:	Klang Valley, Penang, Johor, Kota Kinabalu, Kuching	Selangor, KL, Penang, Perak, Kedah, Johor, Melaka	Only selected areas within KL	Major Cities and highways	Only selected areas within KL
Postpaid Price:	From RM50 / month	From RM78 / month	From RM15 / month	From RM49 / month	From RM39 / month

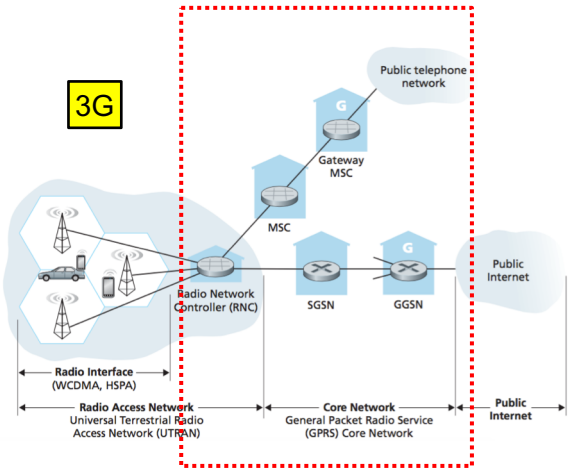
Wireless, Mobile Networks 6-65

CHAPTER 7 Cellular Network Architecture

4G: LTE
(Long-Term Evolution)

Differences from 3G

- All IP core: IP packets tunneled (through core IP network) from base station to gateway.
- No separation between voice and data – all traffic carried over IP core to gateway.



6-66

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CHAPTER 7

eNodeB (Evolved Node B)

Cellular Network Architecture

4G: LTE
(Long-Term Evolution)

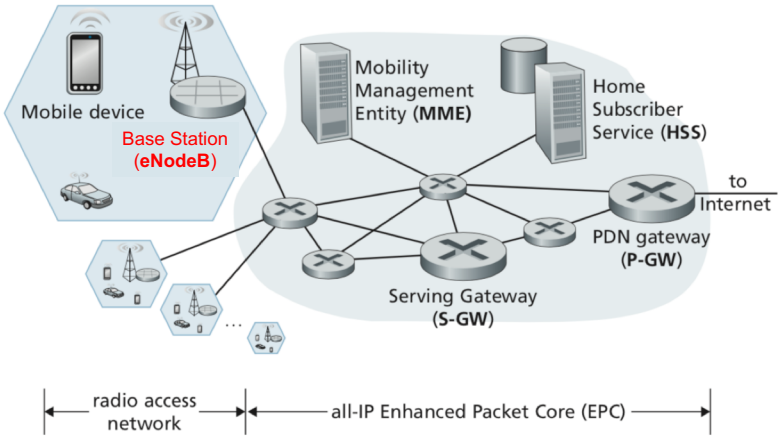

Figure: Elements of 4G LTE architecture.

6-67

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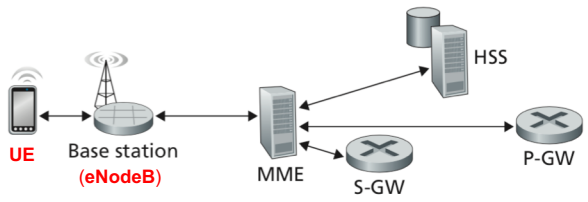
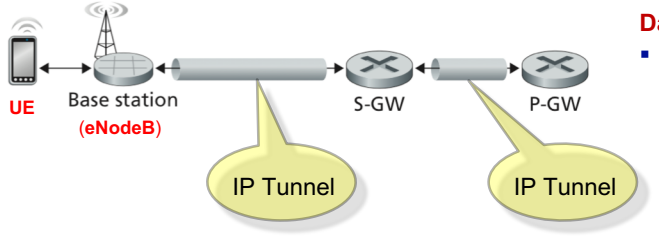
UE (User Equipment)
eNodeB (Evolved Node B)
MME (Mobility Management Entity)
HSS (Home Subsriber Server)
S-GW (Serving Gateway)
P-GW (Packet Data Gateway)

Cellular Network Architecture

4G: LTE
(Long-Term Evolution)



Control Plane
- new protocols for mobility management, security, authentication.



Data Plane
- extensive use of tunneling to facilitate mobility.

Figure: LTE data-plane and control-plane elements

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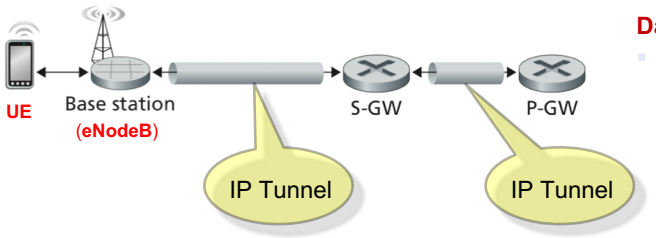
UE (User Equipment)
eNodeB (Evolved Node B)
MME (Mobility Management Entity)
HSS (Home Subsriber Server)
S-GW (Serving Gateway)
P-GW (Packet Data Gateway)

Cellular Network Architecture

Tunneling:

- Mobile datagram encapsulated using *GPRS Tunneling Protocol* (GTP), sent inside UDP datagram to S-GW.
- S-GW re-tunnels datagrams to P-GW.
- Supporting mobility → only tunneling endpoints change when mobile user moves.



Data Plane

- extensive use of tunneling to facilitate mobility.

Figure: LTE data-plane and control-plane elements

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UE (User Equipment)
eNodeB (Evolved Node B)
MME (Mobility Management Entity)
HSS (Home Subsriber Server)
S-GW (Serving Gateway)
P-GW (Packet Data Gateway)
iBGP (Internal Border Gateway Protocol)
eBGP (External Border Gateway Protocol)

Cellular Network Architecture

4G: LTE
(Long-Term Evolution)

Table: LTE elements, and similar WAN (WiFi) functions

LTE Elements	Description	Similar WAN function(s)
Mobile device (UE)	End user's IP-capable wireless/mobile device (*e.g.*, smartphone, tablet, laptop)	Host, end-system
Base Station (eNode-B)	Network side of wireless access link into LTE network	Access point (AP)
MME	Coordinator for mobile device services: authentication, mobility management	Access point (AP)
HSS	Located in a mobile device's home network, providing authentication, access privileges in home and visited networks	None
S-GW, P-GW	Routers in a cellular carrier's network, coordinating forwarding to outside of the carrier's network	iBGP and eBGP
Radio Access Network	Wireless link between mobile device and a base station	802.11 wireless link between mobile and AP

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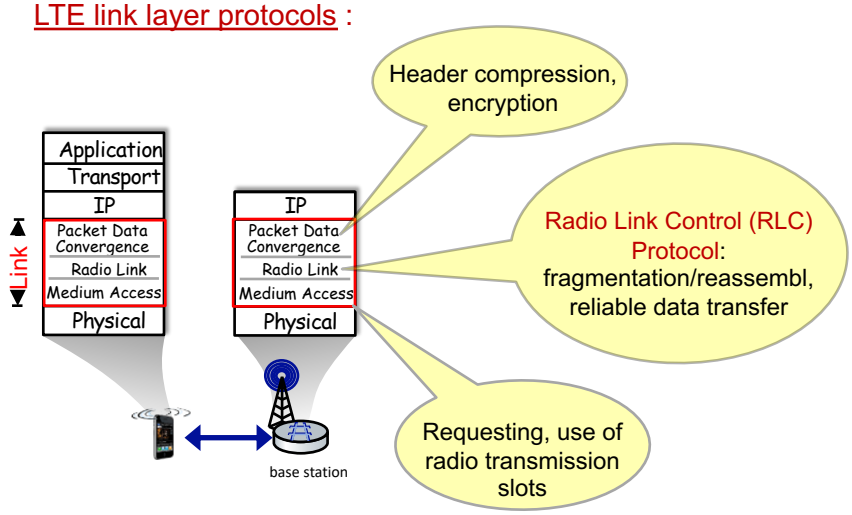
CHAPTER 7 Cellular Network Architecture

4G: LTE
(Long-Term Evolution)

LTE link layer protocols :



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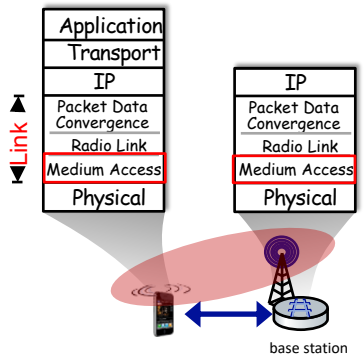
CHAPTER 7 Cellular Network Architecture

4G: LTE
(Long-Term Evolution)

LTE radio access network:

- Downstream channel: OFDM (*Orthogonal Frequency Division Multiplexing*) → Combination of FDM, TDM.
  - "orthogonal": minimal interference between channels.
- Upstream: FDM, TDM similar to OFDM.



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CHAPTER 7

Cellular Network Architecture

4G: LTE
(Long-Term Evolution)

- Each active mobile device allocated one or more 0.5 ms time slots over one or more of channel frequencies:
  - ❑ scheduling algorithm not standardized – up to operator.
  - ❑ 100's Mbps per device possible.
  - ❑ More time slots will increase higher transmission rates.

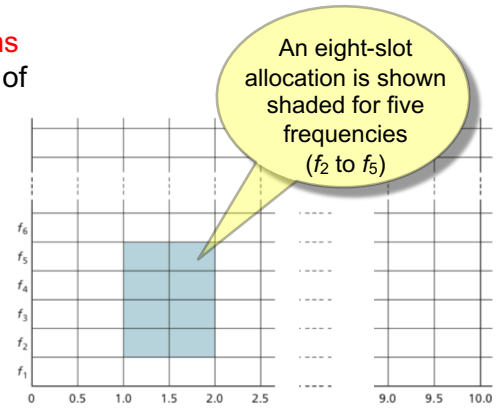

Figure: Twenty 0.5 ms slots organized into 10 ms frames at each frequency.

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CHAPTER 7

Cellular Network Architecture

5G Cellular Networks

Goal:
- ✓ 10x increase in peak bit rate;
- ✓ 10x decrease in latency;
- ✓ 100x increase in traffic capacity over 4G;

- 5G NR (New Radio):
  - Two frequency bands:
    - (a) FR1 (450 MHz – 6 GHz)
    - (b) FR2 (24 GHz – 52 GHz)
      → known as millimeter wave frequencies.
  - Not backwards-compatible with 4G.
  - MIMO: multiple directional antennae.
- Millimeter wave frequencies (FR2): much higher data rates, but over shorter distances.
  - pico-cells: cells diameters 10 m – 100 m.
  - massive, dense deployment of new base stations required.

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CHAPTER 7

Cellular Network Architecture

4G/5G compared to wired Internet

Similarities …

- edge/core distinction, but both below to same carrier.
- global cellular network: a network of networks.
- widespread use of protocols: HTTP, DNS, TCP, UDP, IP, NAT, separation of data/control planes, SDN, Ethernet, tunneling.
- interconnected to wired Internet.

Differences …

- different wireless link layer.
- mobility as a 1st class service.
- user "identity" (via SIM card).
- business model: users subscribe to a cellular provider.
  - strong notion of "home network" versus roaming on visited networks.
  - global access, with authentication infrastructure, and inter-carrier settlements.

CHAPTER 7

Roadmap:

7.1 Background & Introduction

Wireless:

7.2 Wireless links & Network characteristics
- CDMA

7.3 WiFi: 802.11 Wireless LANs

7.4 Cellular Networks: 4G/5G
- Architecture & Elements
- LTE

Mobility:

7.5 Mobility Management:
- **Principles**
- **Mobile IP**
- **Handling Mobility in Cellular Networks**

7.7 Wireless and Mobility: Impact on higher-layer protocols

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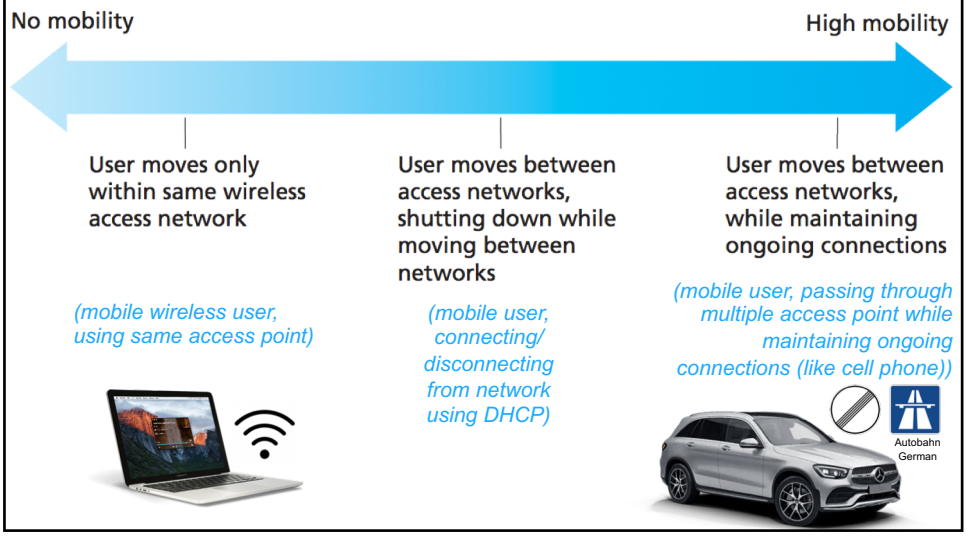
CHAPTER 7

(7.5) Mobility Management: Principles

Overview

- spectrum of mobility, from the *network* perspective:

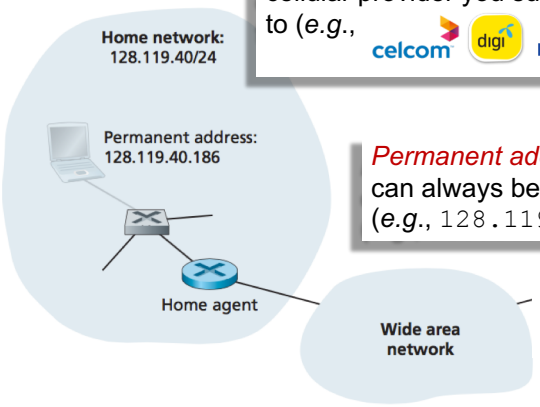


CHAPTER 7

Addressing

(Vocabulary)

Home network: network of cellular provider you subscribe to (*e.g.*, celcom digi maxis)



Permanent address: address in home network, can always be used to reach mobile (*e.g.*, `128.119.40.186`)

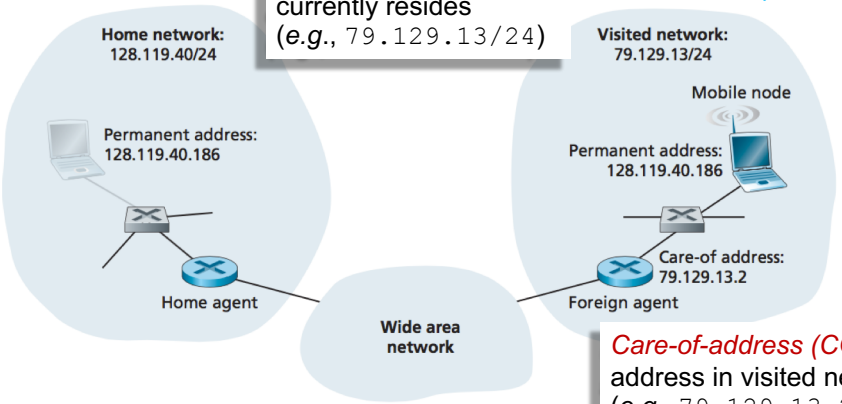
Home agent: entity that will perform mobility functions on behalf of mobile, when mobile is remote

CHAPTER 7

Addressing

(Vocabulary)

Visited network: network in which mobile currently resides (*e.g.*, `79.129.13/24`)



Care-of-address (COA): address in visited network. (*e.g.*, `79.129.13.2`)

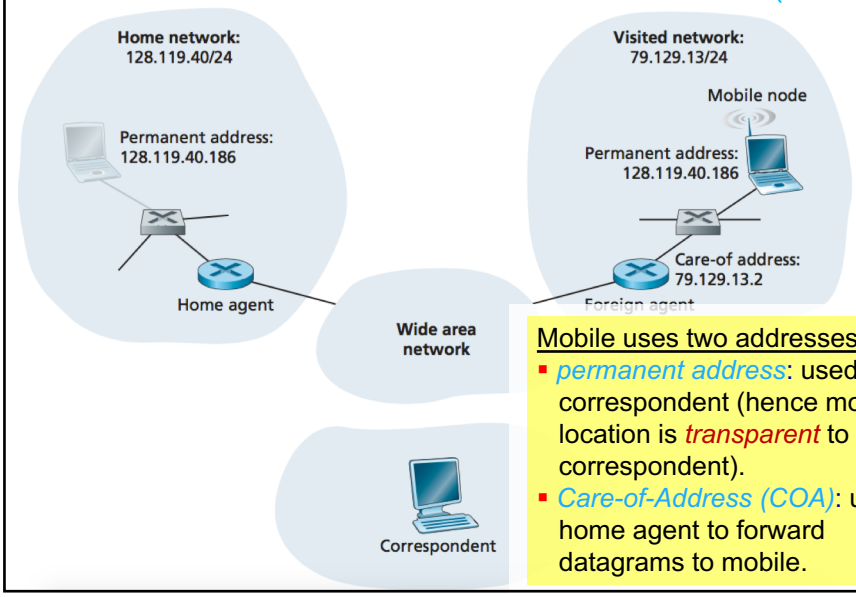
Correspondent: wants to communicate with mobile

Foreign agent: entity in visited network that performs mobility functions on behalf of mobile.

CHAPTER 7

Addressing

(Vocabulary)



Mobile uses two addresses:

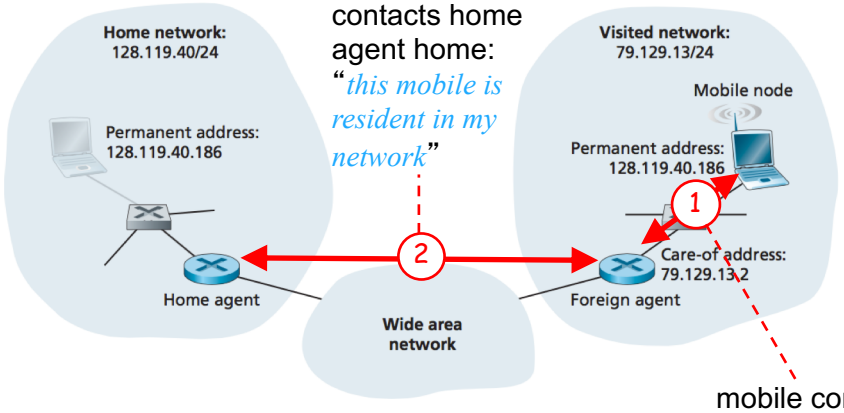
- *permanent address*: used by correspondent (hence mobile location is *transparent* to correspondent).
- *Care-of-Address (COA)*: used by home agent to forward datagrams to mobile.

CHAPTER 7

Routing to a Mobile Node

Registration

foreign agent contacts home agent home: "*this mobile is resident in my network*"



mobile contacts foreign agent on entering visited network

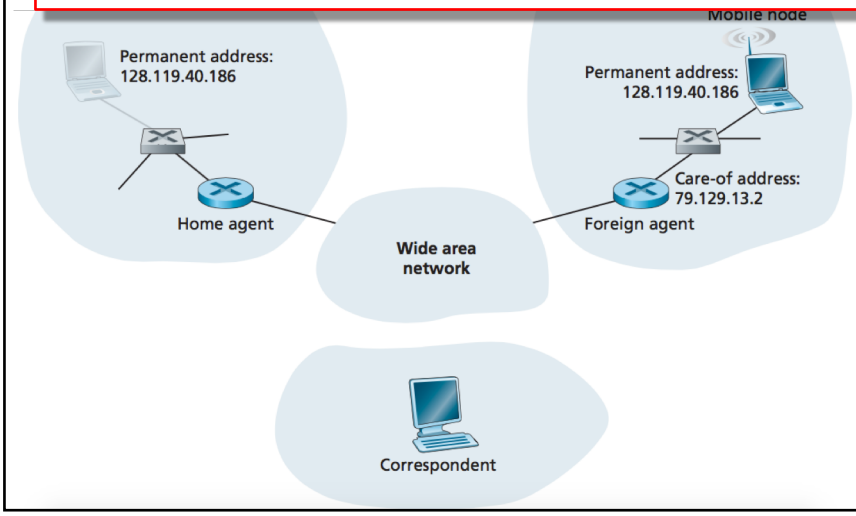
Mobility's registration end result:

- foreign agent knows about mobile
- home agent knows location of mobile

CHAPTER 7

Routing to a Mobile Node

How correspondent user wants to communicate with mobile user?



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CHAPTER 7

Routing to a Mobile Node

How correspondent user wants to communicate with mobile user?

Consider friend frequently changing addresses, how do you find him/her?

- search all phone books?
- call his/her parents?
- expect him/her to let you know where he/she is?
- Facebook!

6-84

CHAPTER 7

Routing to a Mobile Node

Mobility Approaches

- Let network (routers) handle it.
  - routers advertise well-known name, address (*e.g.*, permanent 32-bit IP address), or number (*e.g.*, cell #) of visiting mobile node via usual routing table exchange.
  - Internet routing could do this already *with no* changes!
  - Routing tables indicate where each mobile located via longest prefix match !

https://www.techlion.net/mobile-network-not-available/

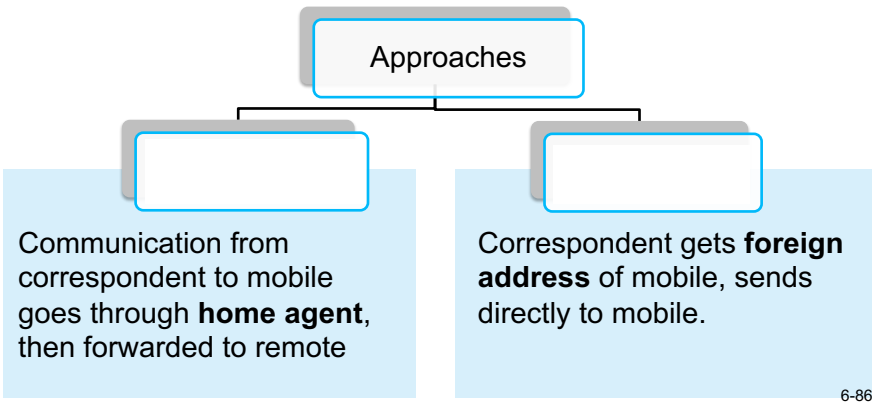
6-85

CHAPTER 7

Routing to a Mobile Node

Mobility Approaches

- Let end-systems handle it.
- Two approaches of routing to a mobile node:



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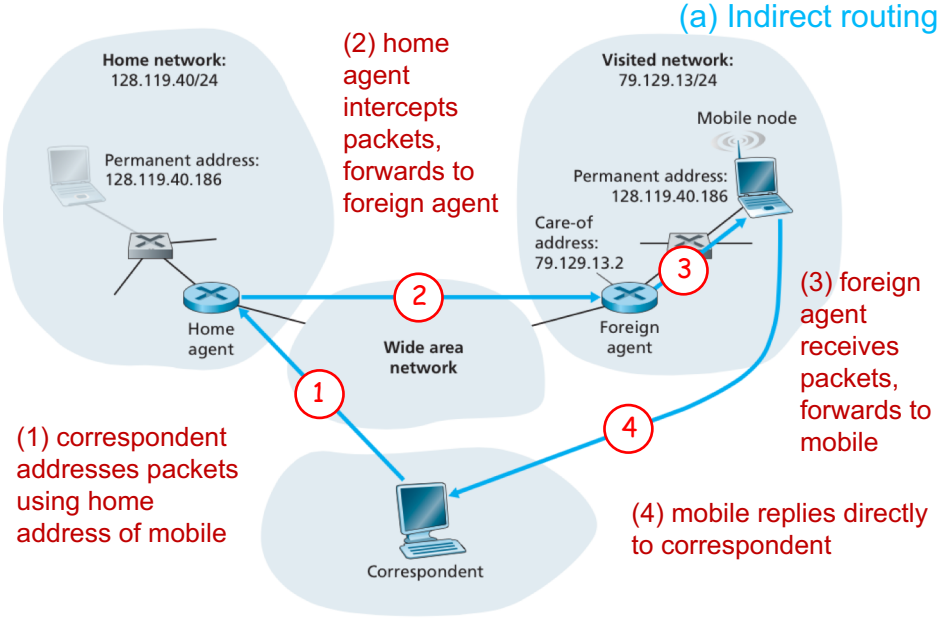
CHAPTER 7

Routing to a Mobile Node

(a) Indirect routing



CHAPTER 7

Routing to a Mobile Node

- suppose mobile user moves to another network
  - registers with new *foreign agent*
  - new *foreign agent* registers with *home agent*
  - *home agent* update *care-of-address* for mobile
  - packets continue to be forwarded to mobile (but with new *care-of-address*)
- mobility, changing foreign networks transparent :
  → *on going connections can be maintained!*

Indirect routing introduce →

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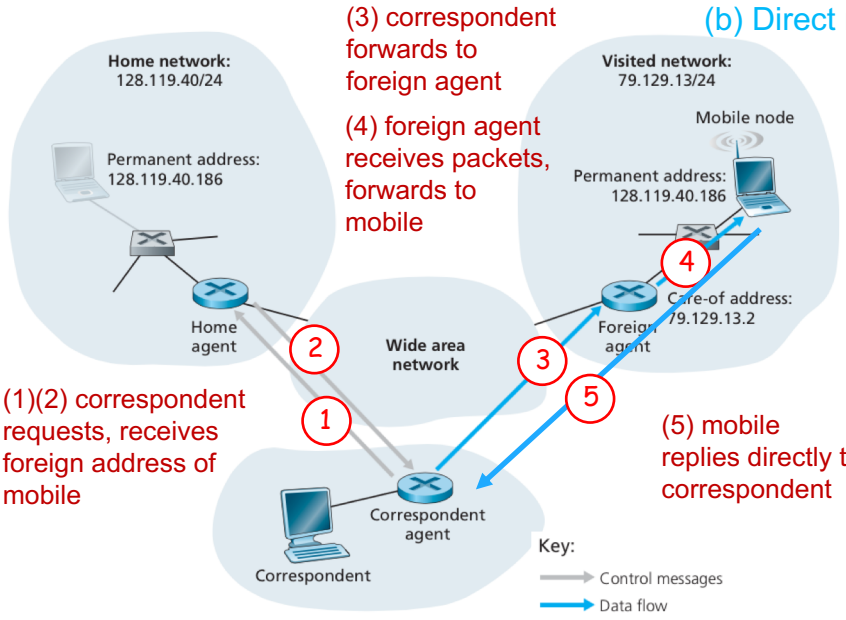
CHAPTER 7

Routing to a Mobile Node

(b) Direct routing



6-89

CHAPTER 7

Routing to a Mobile Node

(b) Direct routing

Comments:

- overcome triangle routing problem !
- *non-transparent to correspondent:* correspondent must get *care-of-address* from *home agent*
- packets continue to be forwarded to mobile (with new *care-of-address*)

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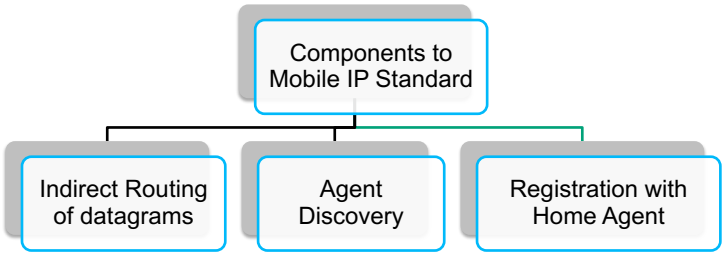
CHAPTER 7

(7.5) Mobility Management: Mobility IP

Overview

- Mobility IP → The Internet architecture and protocols for supporting mobility.
- Defined primarily in RFC 5944 for IPv4.
- We have seen many features:
  - home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet).



RFC (Request For Comments)

CHAPTER 7

Mobile IP

(a) Indirect routing of datagrams

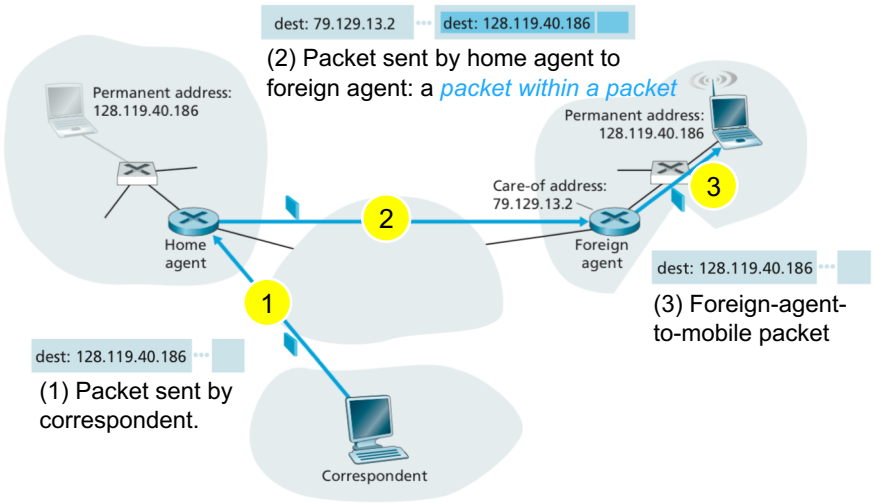


Figure: Encapsulation and decapsulation.

6-92

Kurose, J.F. and Ross, K.W. (2017). Computer Networking: A Top-Down Approach (7th Edition). Pearson Education Limited, England. (pp. 594)

CHAPTER 7

Mobile IP

(b) Agent Discovery

- *Agent advertisement:* foreign/home agents advertise service by broadcasting ICMP messages (typefield = 9)

H,F bits: home and/or foreign agent;
R bit: registration required.

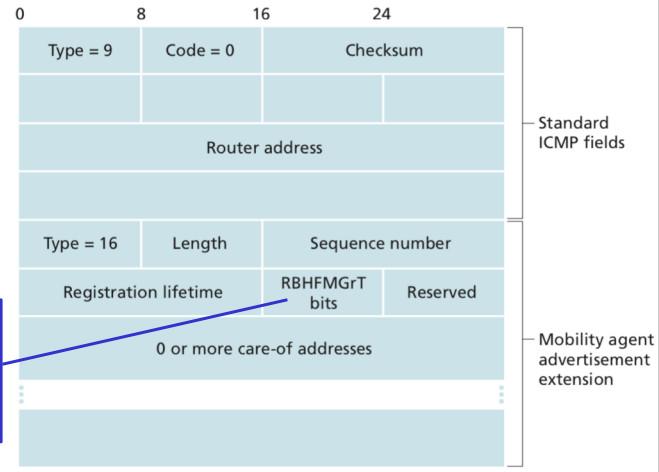


Figure: ICMP router discovery message with mobility agent advertisement extension.

Mobile IP

(c) Registration with Home Agent

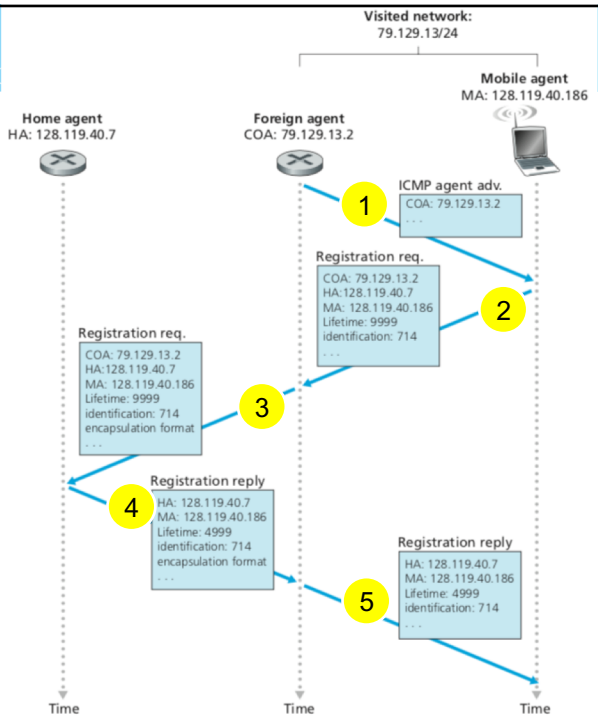


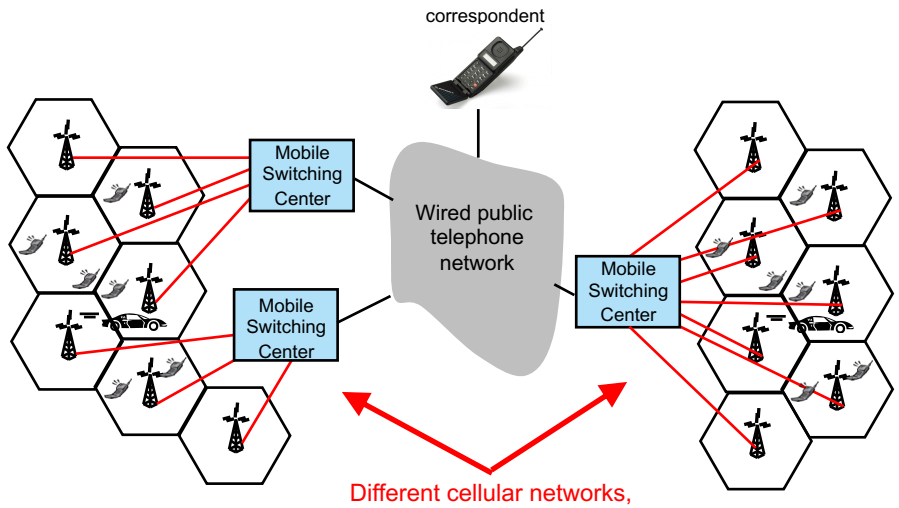
Figure:
Agent advertisement and mobile IP registration.

CHAPTER 7

Recall

(7.5) Mobility Management:

Handling Mobility in Cellular Networks



CHAPTER 7

Handling Mobility in Cellular Networks

Home Network

- Network of cellular provider you subscribe to (*e.g.*, Celcom, Maxis, Digi).
  - *Home Location Register (HLR):* database in home network containing permanent cell phone #, profile information (services, preferences, billing), information about current location (could be in another network).

Visited Network

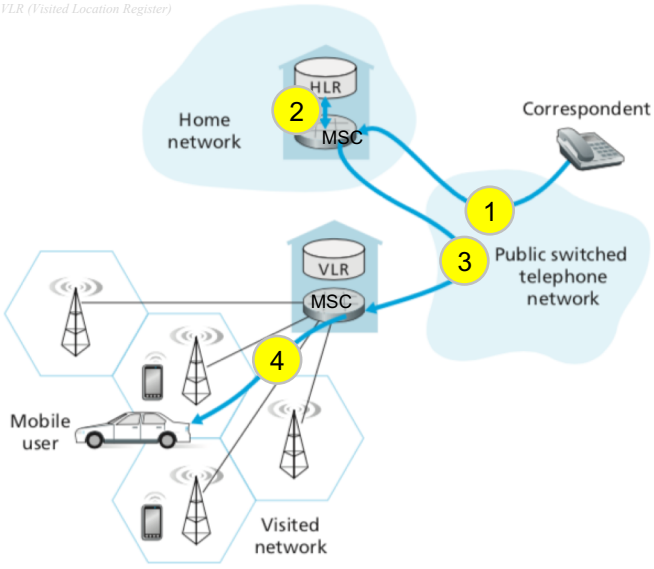
- Network in which mobile currently resides.
  - *Visitor Location Register (VLR):* database with entry for each user currently in network.
  - could be home network.

CHAPTER 7

Handling Mobility in Cellular Networks

GSM (Global System for Mobile)
MSC (Multi Swithing Center)
HLR (Home Location Register)
VLR (Visited Location Register)

GSM: Indirect Routing to Mobile



1) Call routed to home network;
2) Home MSC consults HLR, gets roaming number of mobile in visited network;
3) Home MSC sets up 2nd leg of call to MSC in visited network;
4) MSC in visited network completes call through base station to mobile.

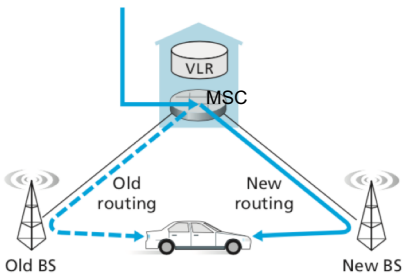
CHAPTER 7

Handling Mobility in Cellular Networks

GSM (Global System for Mobile)
VLR (Visited Location Register)
MSC (Multi Swithing Center)
BS (Base Station)

GSM: Handoff with common MSC

- *Handoff goal:* route call via new base station (without interruption).
- Handoff initiated by old BS.
- Reasons for handoff:
  - stronger signal to/from new BS (continuing connectivity, less battery drain).
  - load balance: free up channel in current BS.
- GSM doesn't mandate **why** to perform handoff (policy), only **how** (mechanism).



Kurose, J.F. and Ross, K.W. (2017). Computer Networking: A Top-Down Approach (7th Edition). Pearson Education Limited, England. (pp. 605)

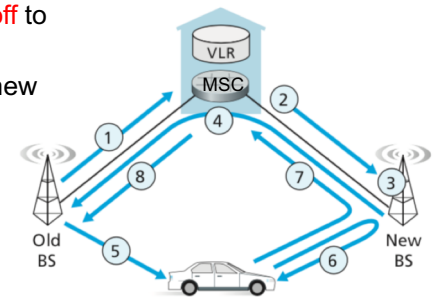
CHAPTER 7

Handling Mobility in Cellular Networks

GSM (Global System for Mobile)
VLR (Visited Location Register)
MSC (Multi Swithing Center)
BS (Base Station)

GSM: Handoff with common MSC

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



Kurose, J.F. and Ross, K.W. (2017). Computer Networking: A Top-Down Approach (7th Edition). Pearson Education Limited, England. (pp. 606)

CHAPTER 7

Roadmap:

7.1 Background & Introduction

Wireless:

7.2 Wireless links & Network characteristics
- CDMA

7.3 WiFi: 802.11 Wireless LANs

7.4 Cellular Networks: 4G/5G
- Architecture & Elements
- LTE

Mobility:

7.5 Mobility Management:
- Principles
- Mobile IP
- Handling Mobility in Cellular Networks

7.7 Wireless and Mobility: Impact on higher-layer protocols

CHAPTER 7

(7.7) Wireless and Mobility :

Impact on higher-layer protocols

- Logically, impact should be minimal …
  - best effort service model remains unchanged.
  - TCP and UDP can (and do) run over wireless, mobile.
- … but performance-wise:
  - packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handoff.
  - TCP interprets loss as congestion, will decrease congestion window un-necessarily.
  - delay impairments for real-time traffic.
  - limited bandwidth of wireless links.

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., 3G, LTE, 4G and 5G)

Mobility

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

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