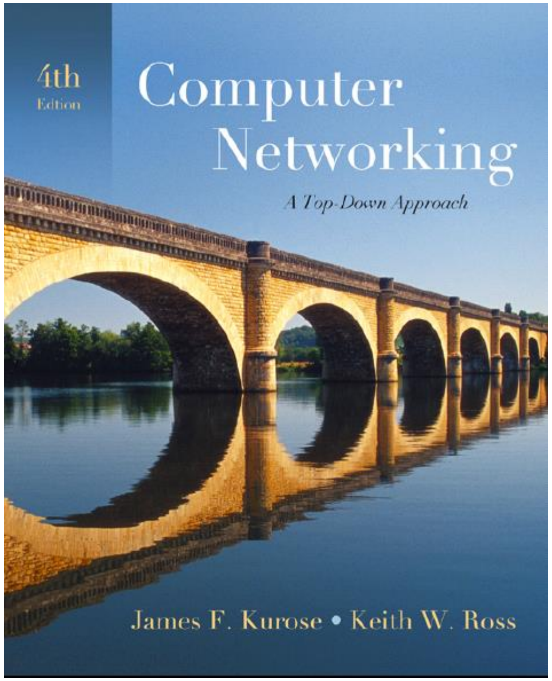
Wireless and Mobile Networks



Computer Networking: A Top Down Approach
4th edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2007.

A note on the use of these ppt slides:

Wireless and Mobile Networks

Background:

- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers!
- Computer nets: laptops, palmtops, PDAs, Internet-enabled phone 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

Outline

4.1 Introduction

Wireless

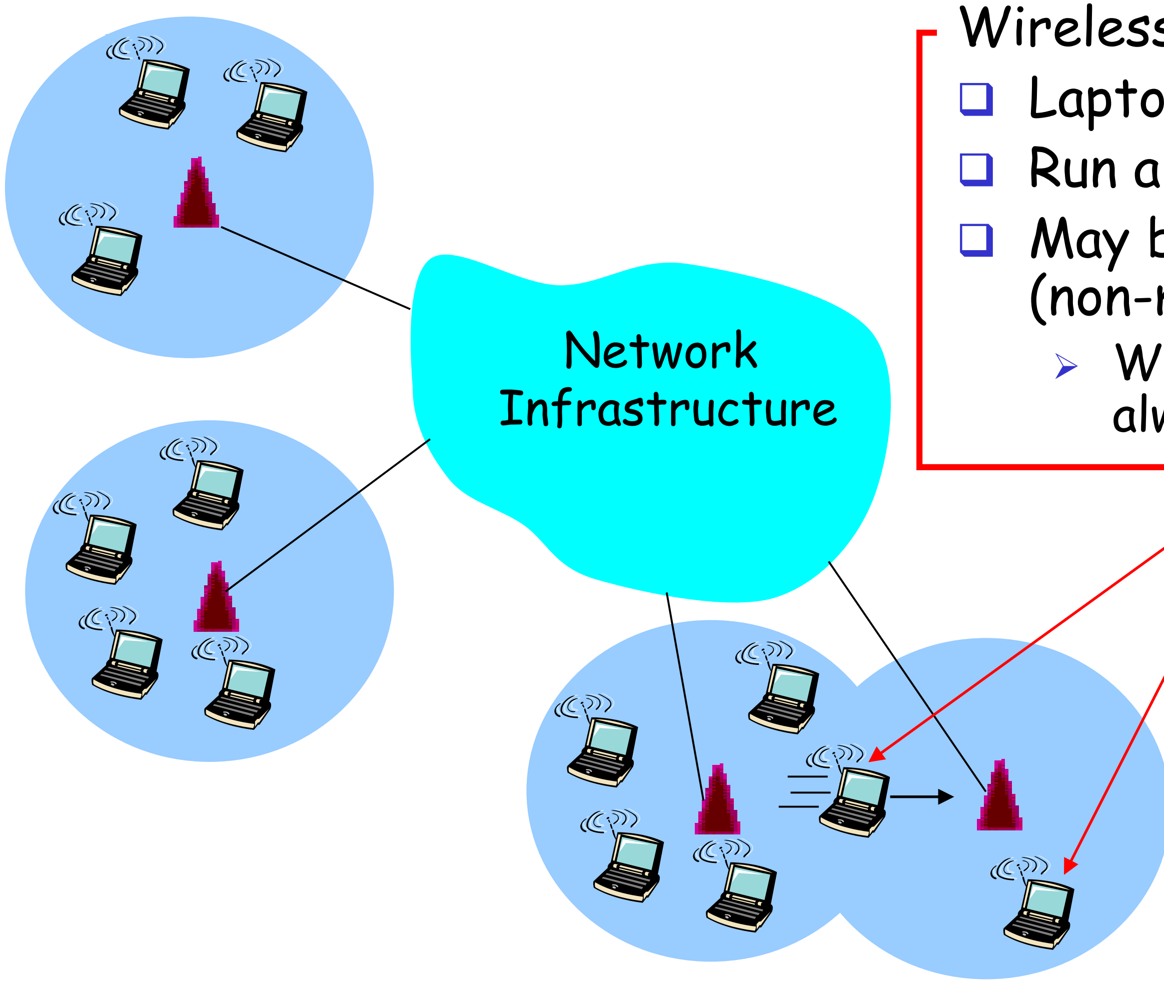
- 4.2 Wireless links, characteristics
- 4.3 IEEE 802.11 wireless LANs ("wi-fi")
- 4.4 Cellular Internet Access
  - Architecture
  - Standards (e.g., GSM)
- 4.5 wireless TCP

Mobility

- 4.6 Principles: addressing and routing to mobile users
- 4.7 Mobile IP
- 4.8 Handling mobility in cellular networks
- 4.9 End-to-end mobility
- 4.10 Mobility and higher-layer protocols

4.11 Summary

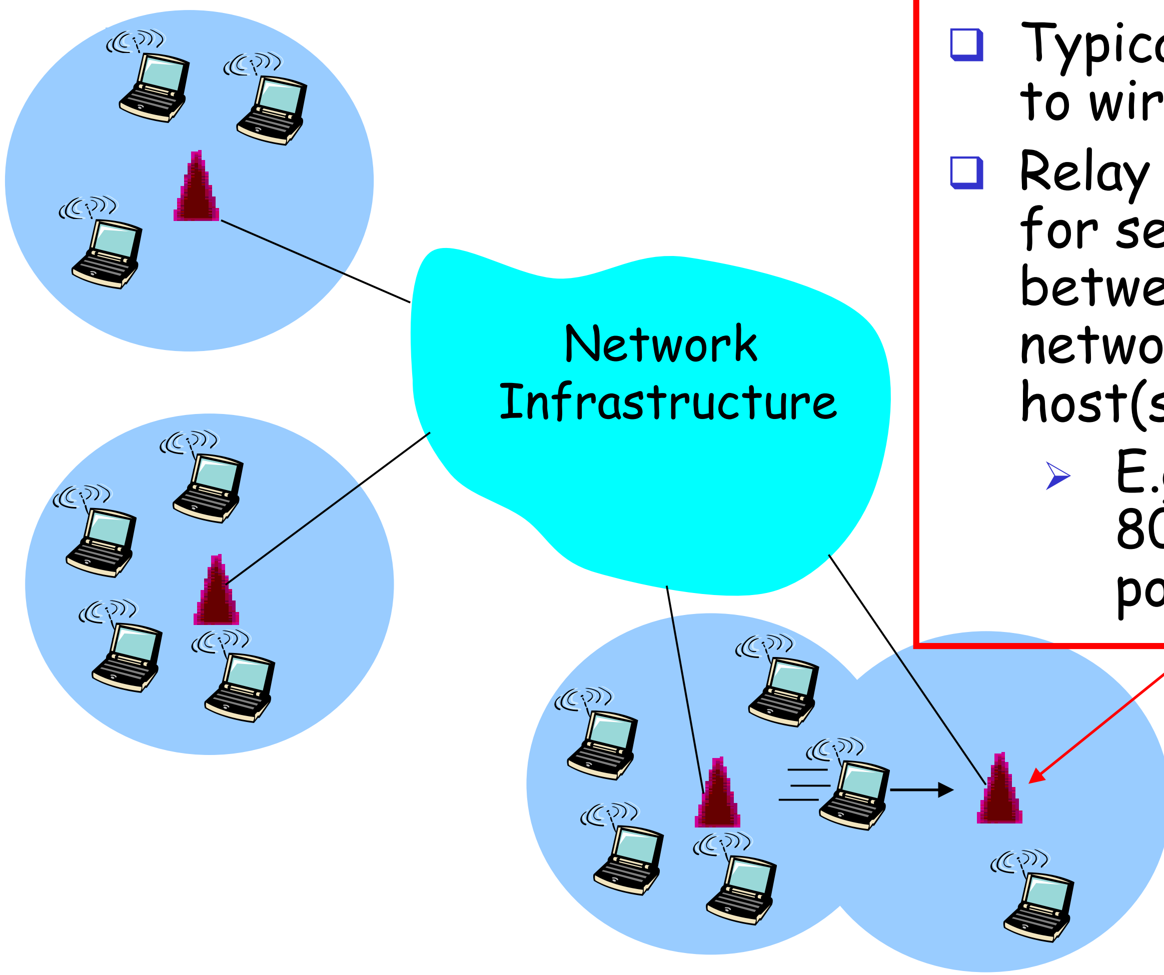
Elements of a Wireless Network



Wireless Hosts

- Laptop, PDA, IP phone
- Run applications
- May be stationary (non-mobile) or mobile
  - Wireless does *not* always mean mobility

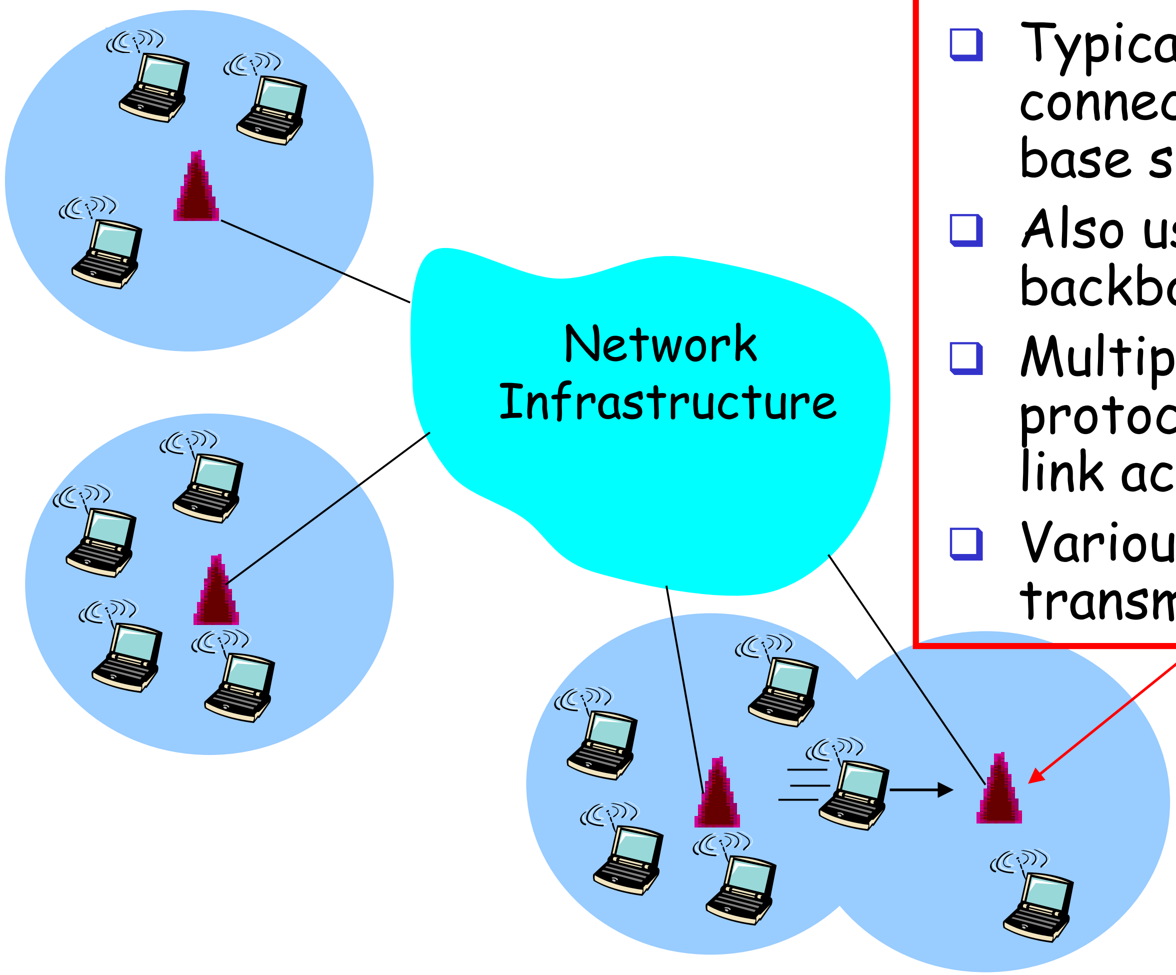
Elements of a Wireless Network



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

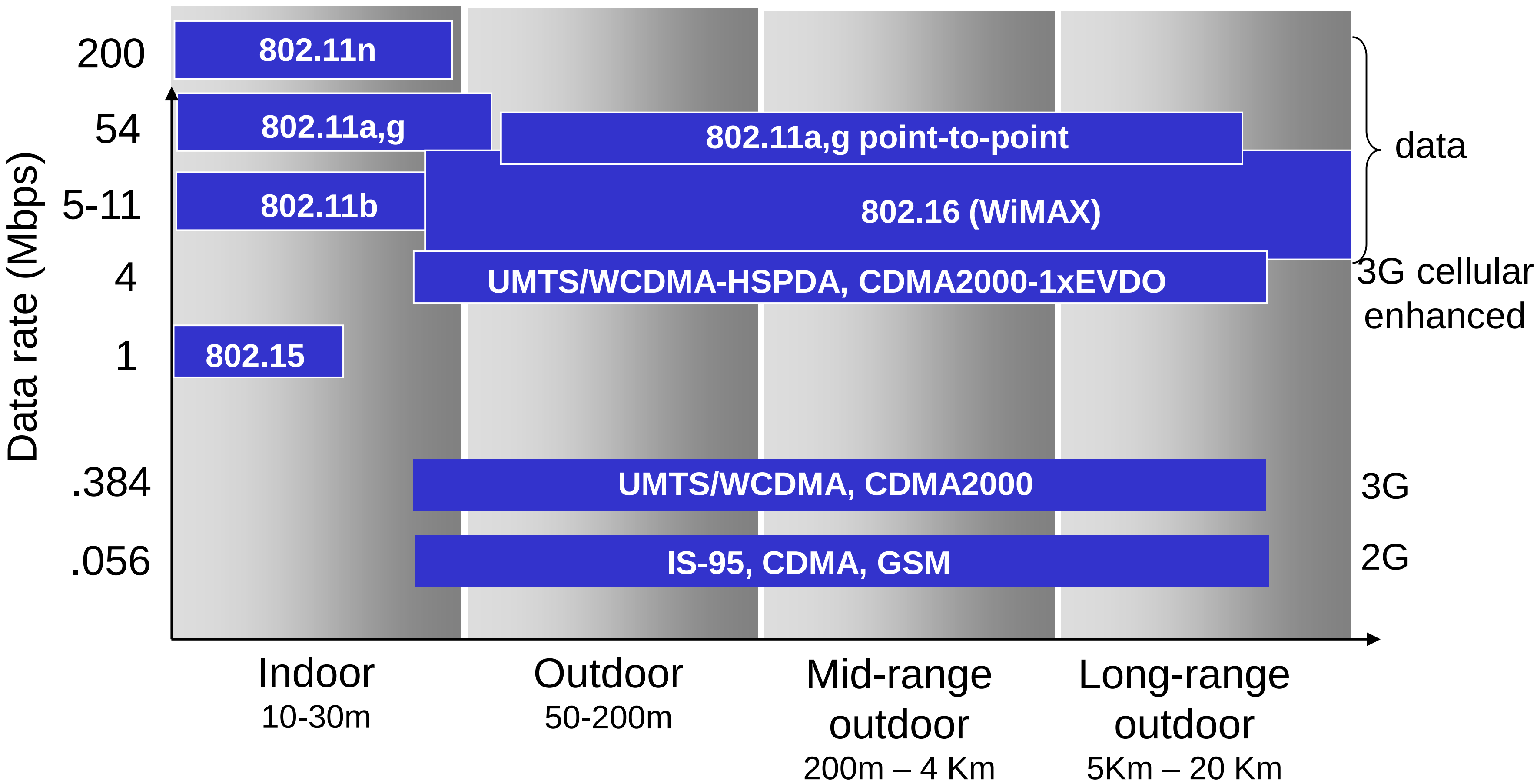
Elements of a Wireless Network



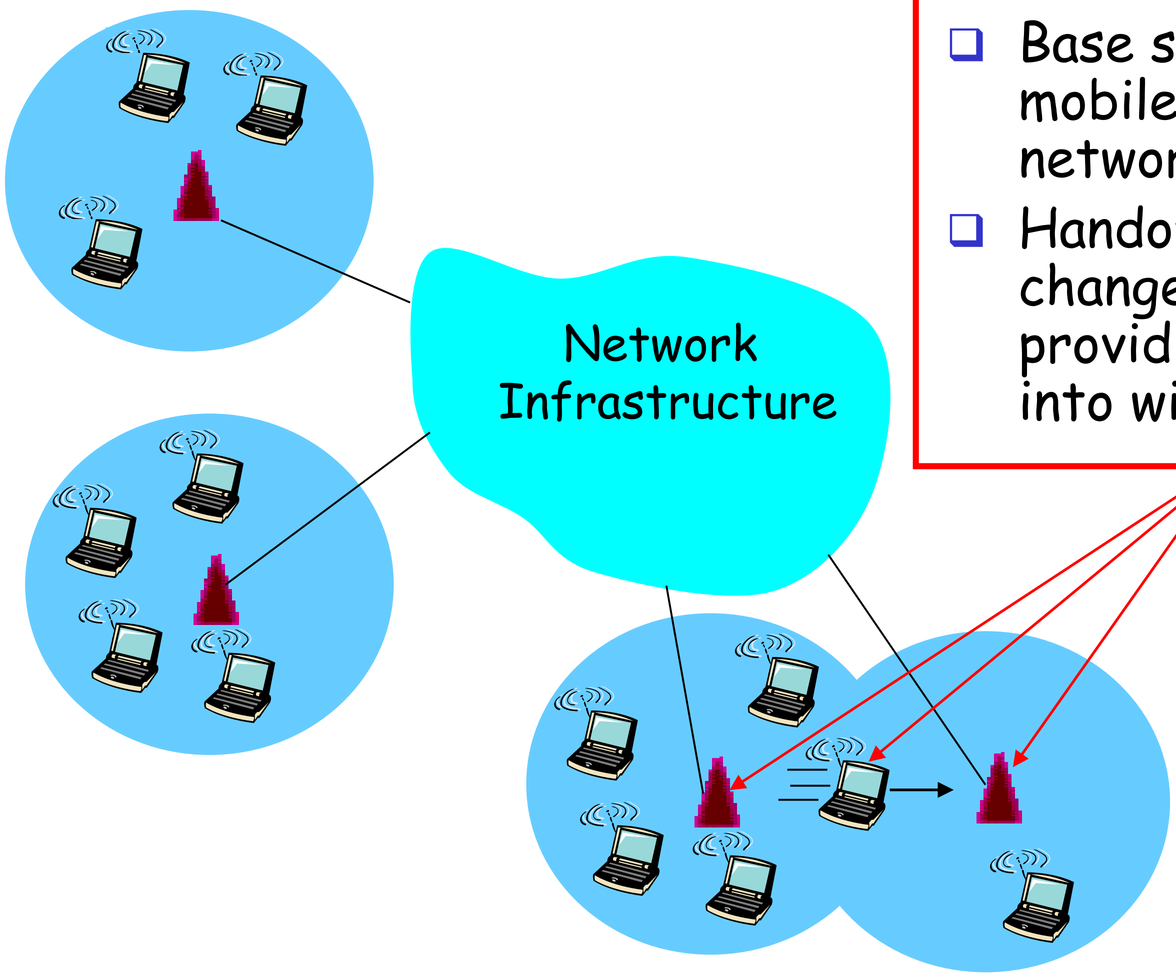
Wireless Link

- 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

Characteristics of Selected Wireless Link Standards



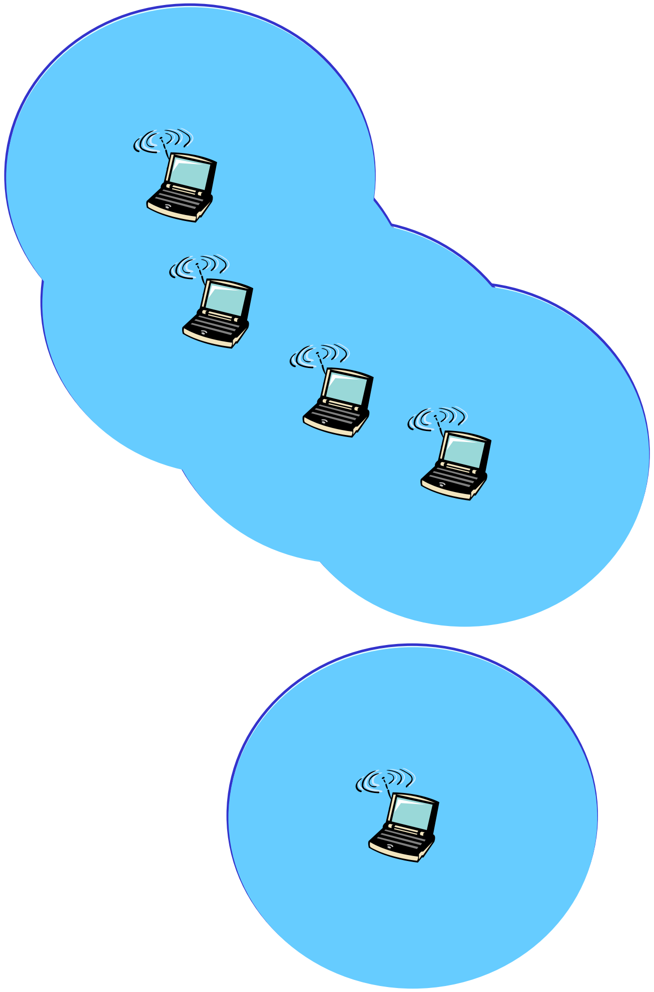
Elements of a Wireless Network



Infrastructure Mode

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

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

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 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

Wireless Link Characteristics (1)

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"

Why?

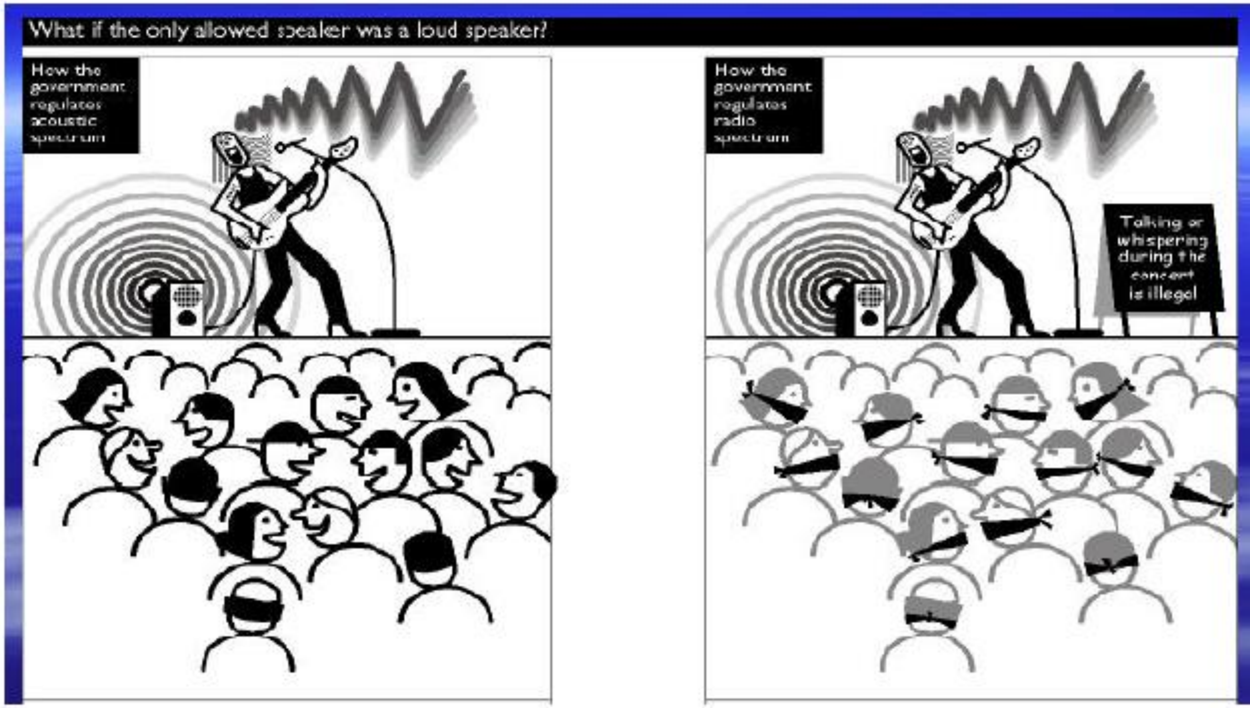
- Interference
  - Your signal is noise to others
  - Broadcast nature

signal - to - noise - ratio

$$SNR = \frac{P(recv)}{\text{noise} + \text{interference}}$$

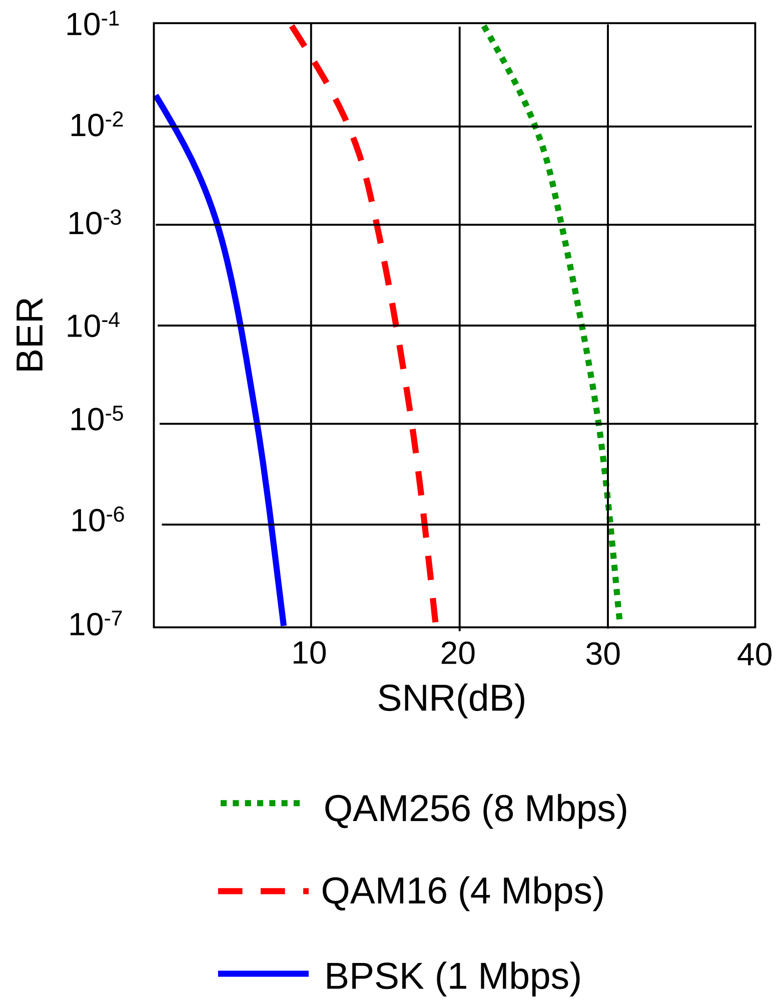
$$rate \propto W \log(1 + SNR)$$

$$W : bandwidth$$



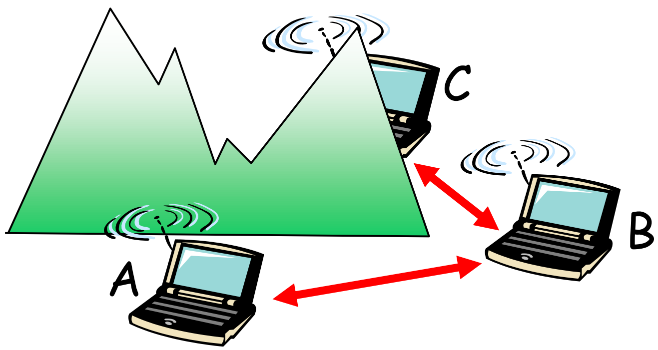
Wireless Link Characteristics (2)

- 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 throughput
    - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)



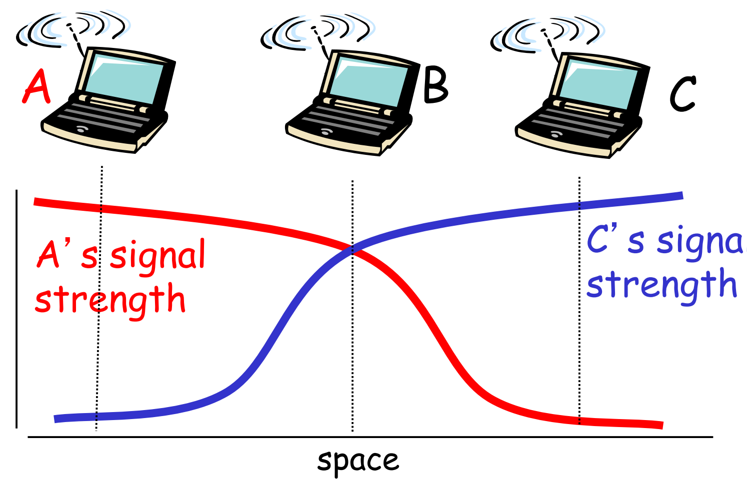
Wireless Network Characteristics

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



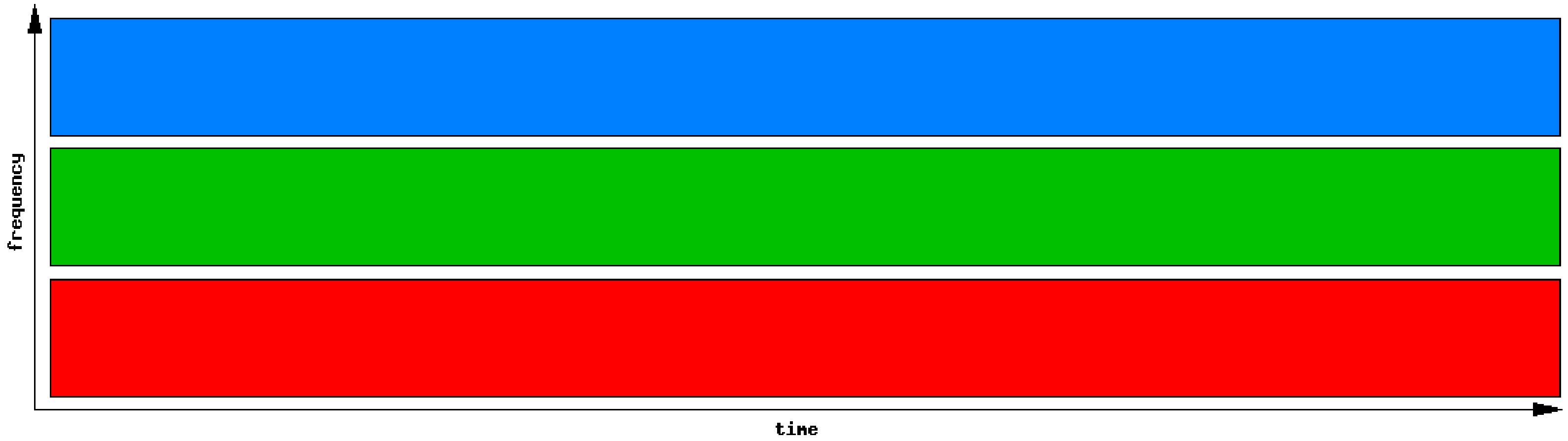
Signal attenuation:

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

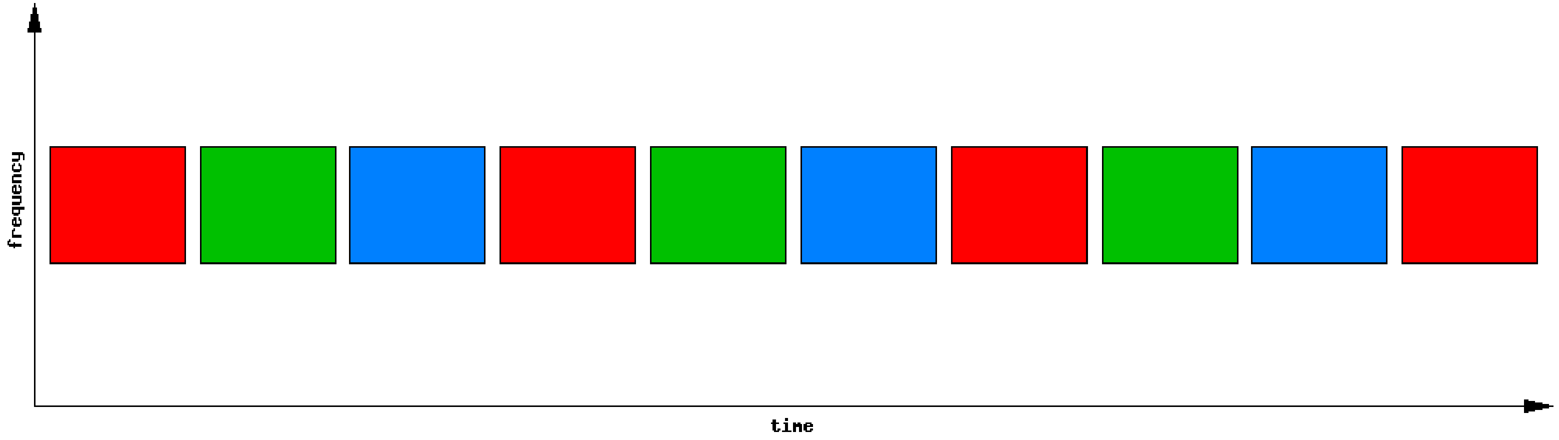
Multiple Access Methods for Cellular Systems

- There are predominantly three types of multiple access methods
  - FDMA (Frequency Division Multiple Access)
  - TDMA (Time Division Multiple Access)
  - CDMA (Code Division Multiple Access)

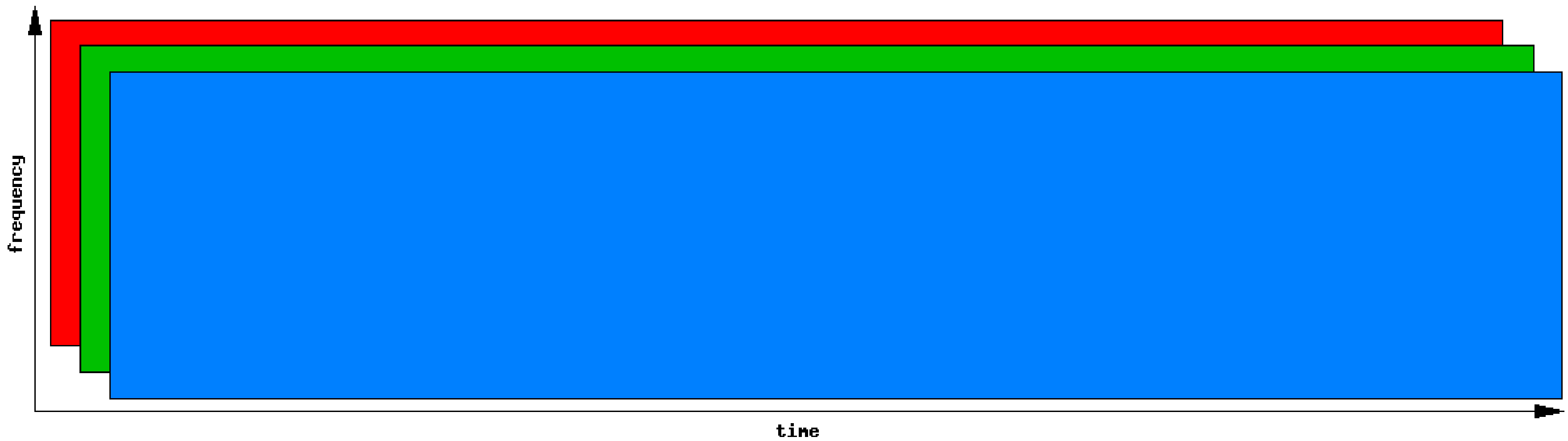
FDMA



TDMA



CDMA

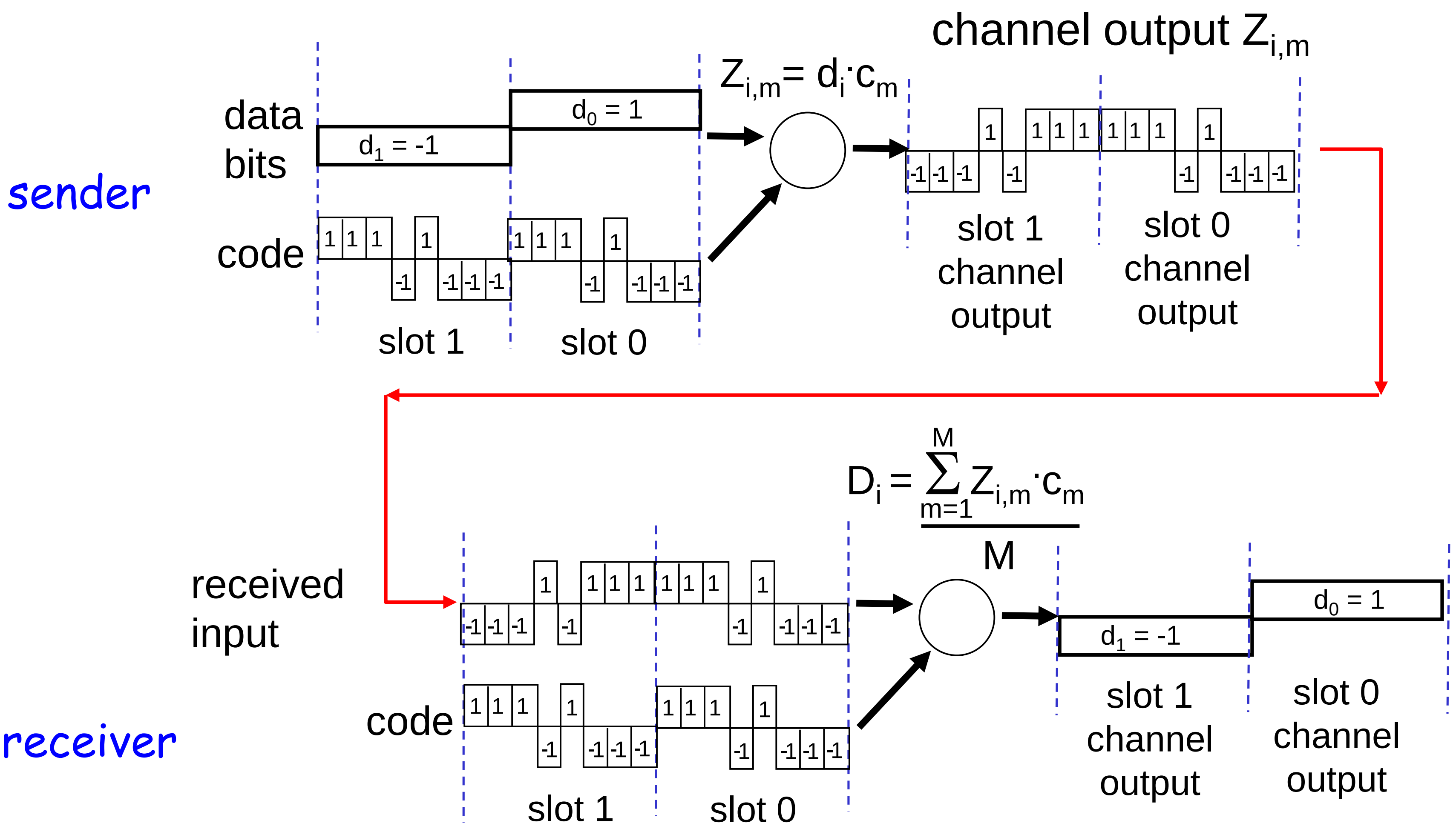


- Uses the whole band, for the whole time
- Everyone transmits on top of everyone else

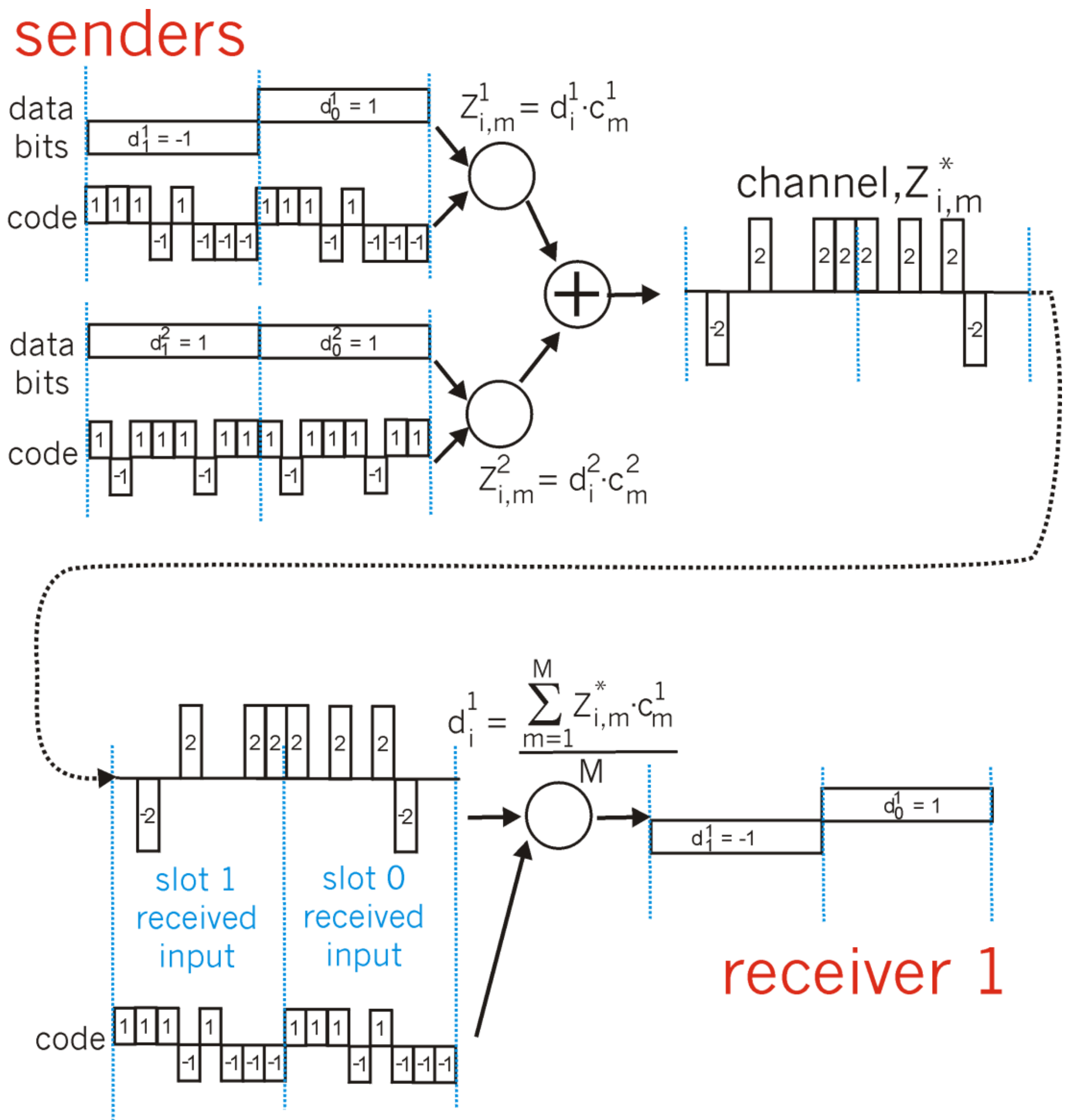
Code Division Multiple Access (CDMA)

- Used in several wireless broadcast channels (cellular, satellite, etc.) standards
- 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
- *Encoded signal* = (original data) X (chipping sequence)
- *Decoding:* inner-product of encoded signal and chipping sequence
- Allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

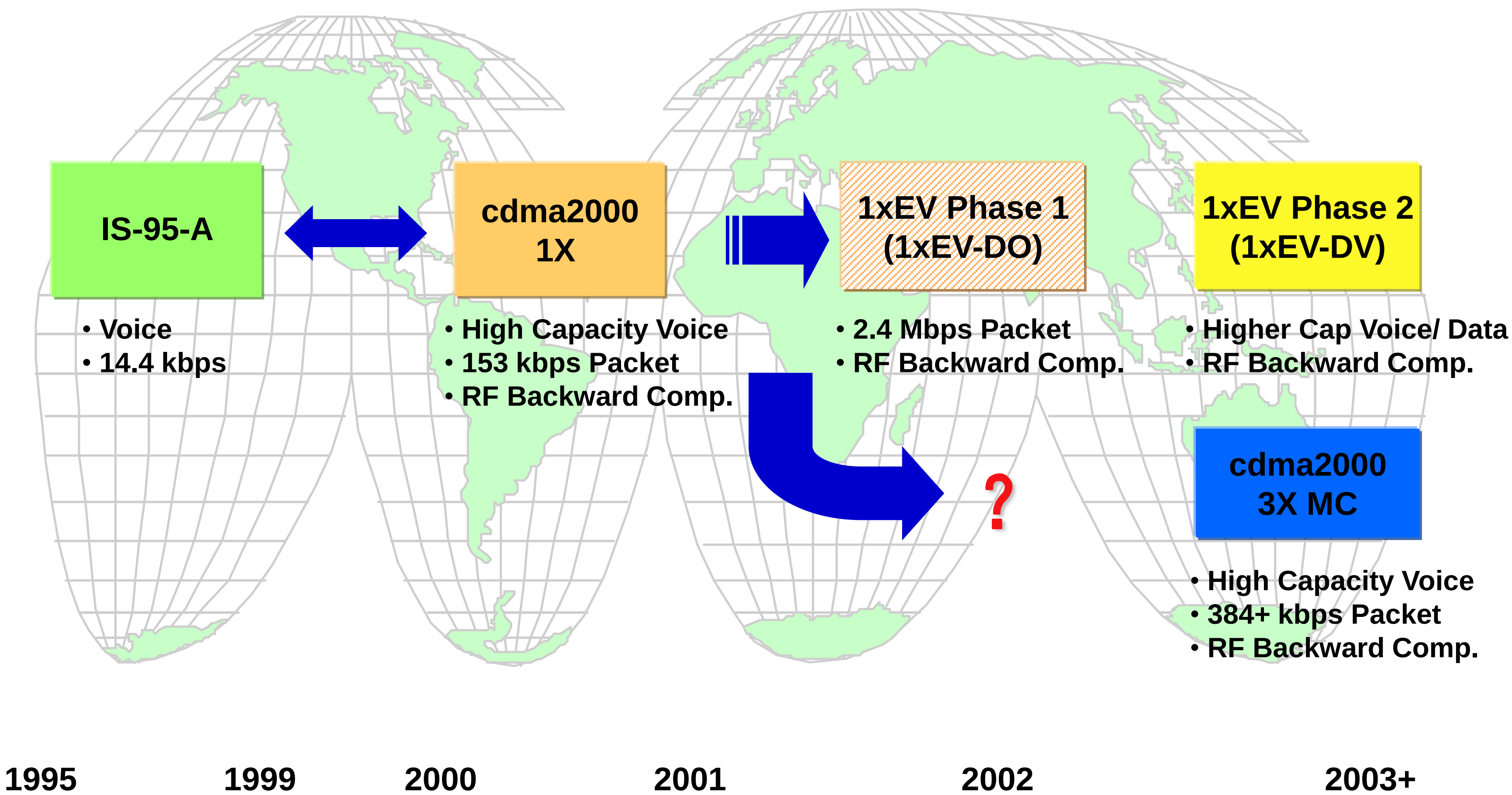
CDMA Encode/Decode



CDMA: Two-Sender Interference



CDMA's Evolution



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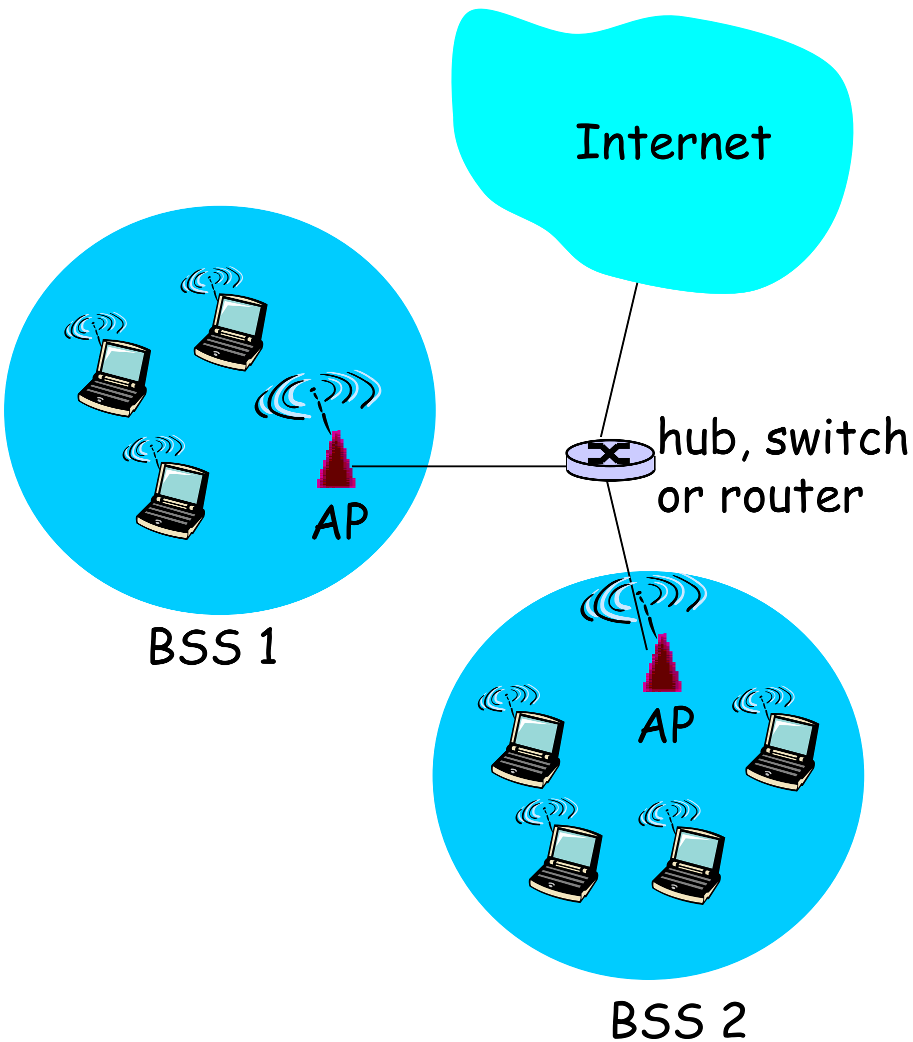
4.11 Summary

IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-5 GHz unlicensed spectrum
  - Up to 11 Mbps
  - Direct sequence spread spectrum (DSSS) in physical layer
    - All hosts use same chipping code
- 802.11a
  - 5-6 GHz range
  - Up to 54 Mbps
- 802.11g
  - 2.4-5 GHz range
  - Up to 54 Mbps
- 802.11n: multiple antennae
  - 2.4-5 GHz range
  - Up to 200 Mbps

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

802.11 LAN Architecture

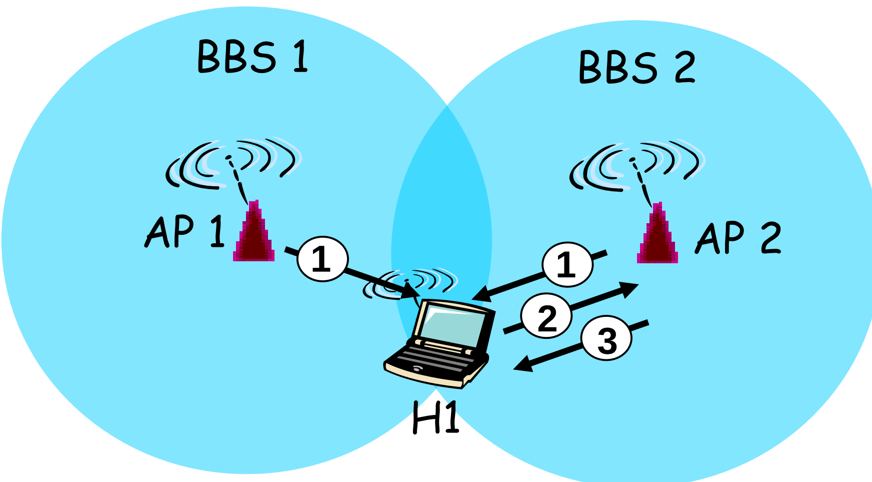


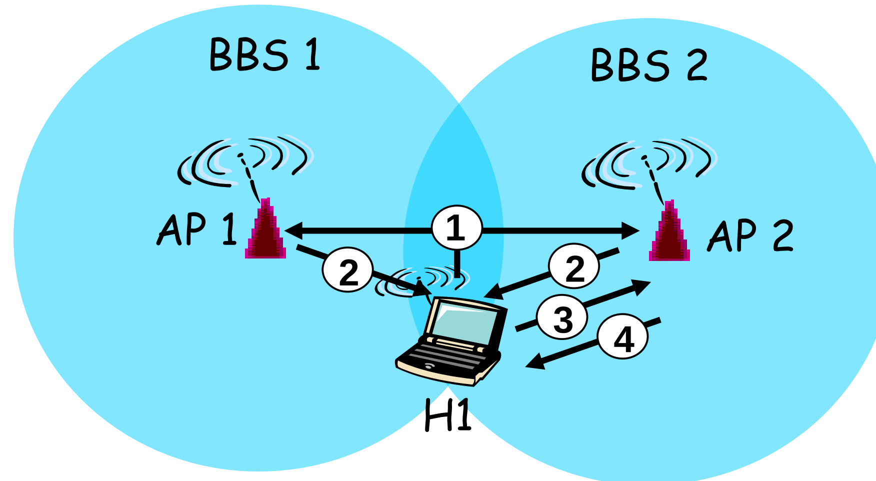
- Wireless host communicates with base station
  - Base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - Wireless hosts
  - Access point (AP): base station
  - Ad hoc mode: hosts only

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: H1 to selected AP

Active Scanning:

(1) Probe Request frame broadcast from H1

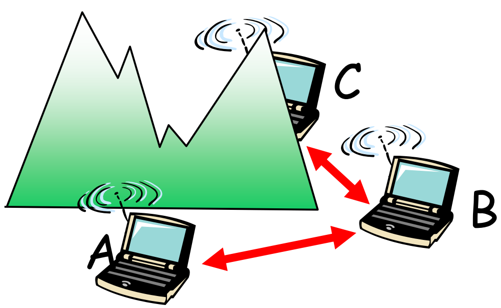
(2) Probes response frame sent from APs

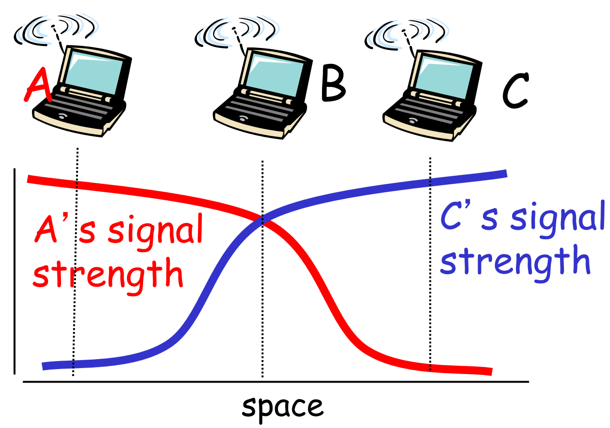
(3) Association Request frame sent: H1 to selected AP

(4) Association Response frame sent: H1 to selected AP

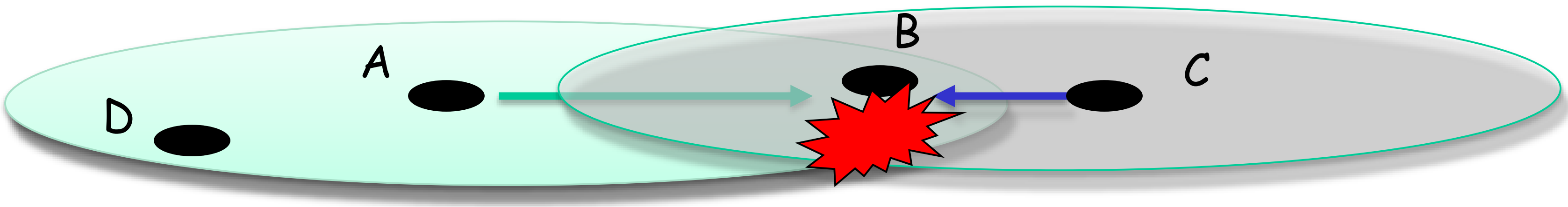
IEEE 802.11: Multiple Access

- 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)





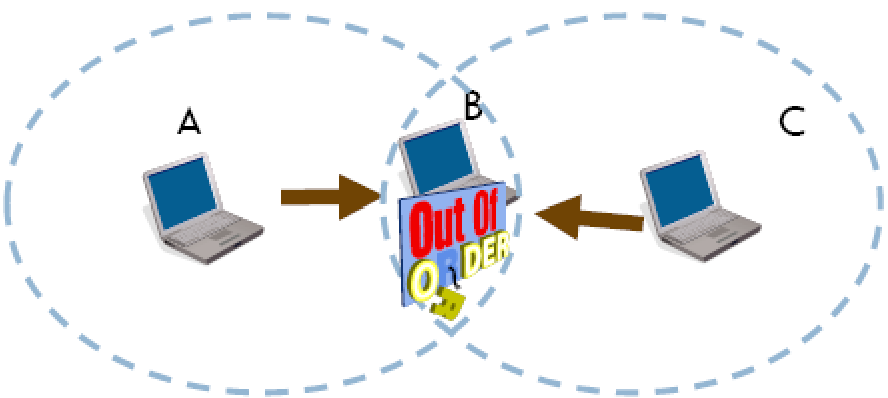
Collision Detection Difficult



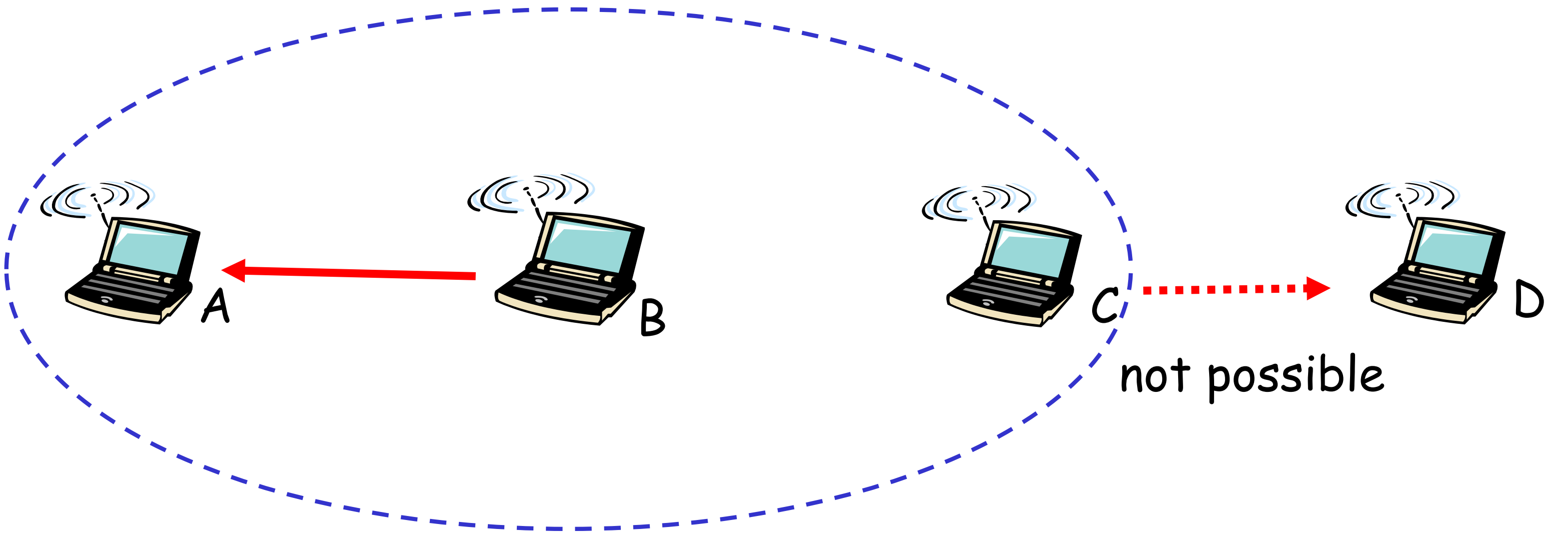
- Signal reception based on SINR
  - Transmitter can only hear itself
  - Cannot determine signal quality at receiver

Hidden Terminal Problem (HTP)

- Reason: limited transmit/sensing capabilities
  - B can communicate with A and C
  - A and C can not hear each other
  - If A transmits to B & C transmits to B, collision occurs at B



Exposed Terminal Problem



- B talks to A
- C wants to talk to D
- C senses channel and finds it to be busy (as B is transmitting to A)
- C stays quiet (when it could have ideally transmitted)

Hidden and Exposed Terminal Problems

- Hidden Terminal
  - More collisions
  - Wastage of resources

Carrier sense at sender may not prevent collision at receiver

- Exposed Terminal
  - Underutilization of channel
  - Lower effective throughput

IEEE 802.11 MAC Protocol: CSMA/CA

802.11 sender

1 If sense channel idle for **DIFS** then

transmit entire frame (no CD)

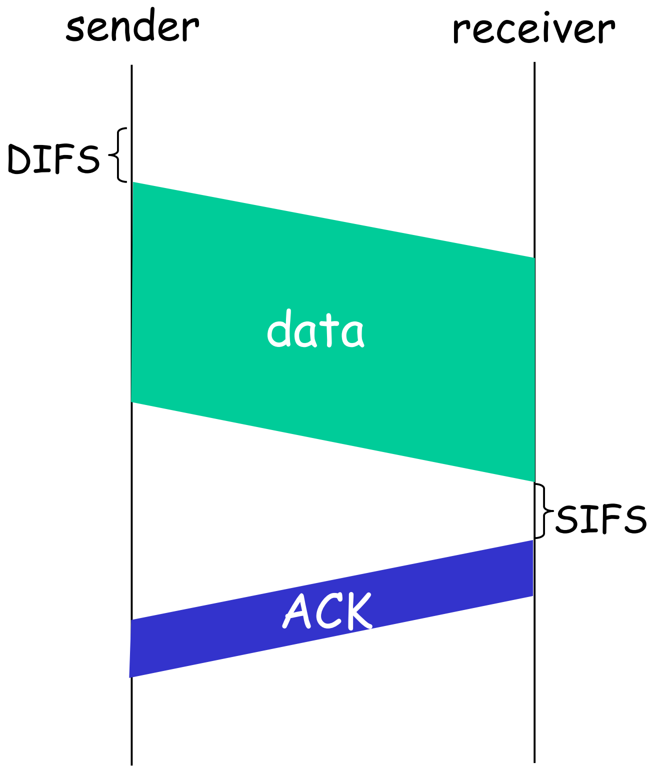
2 If sense channel busy then

- 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)

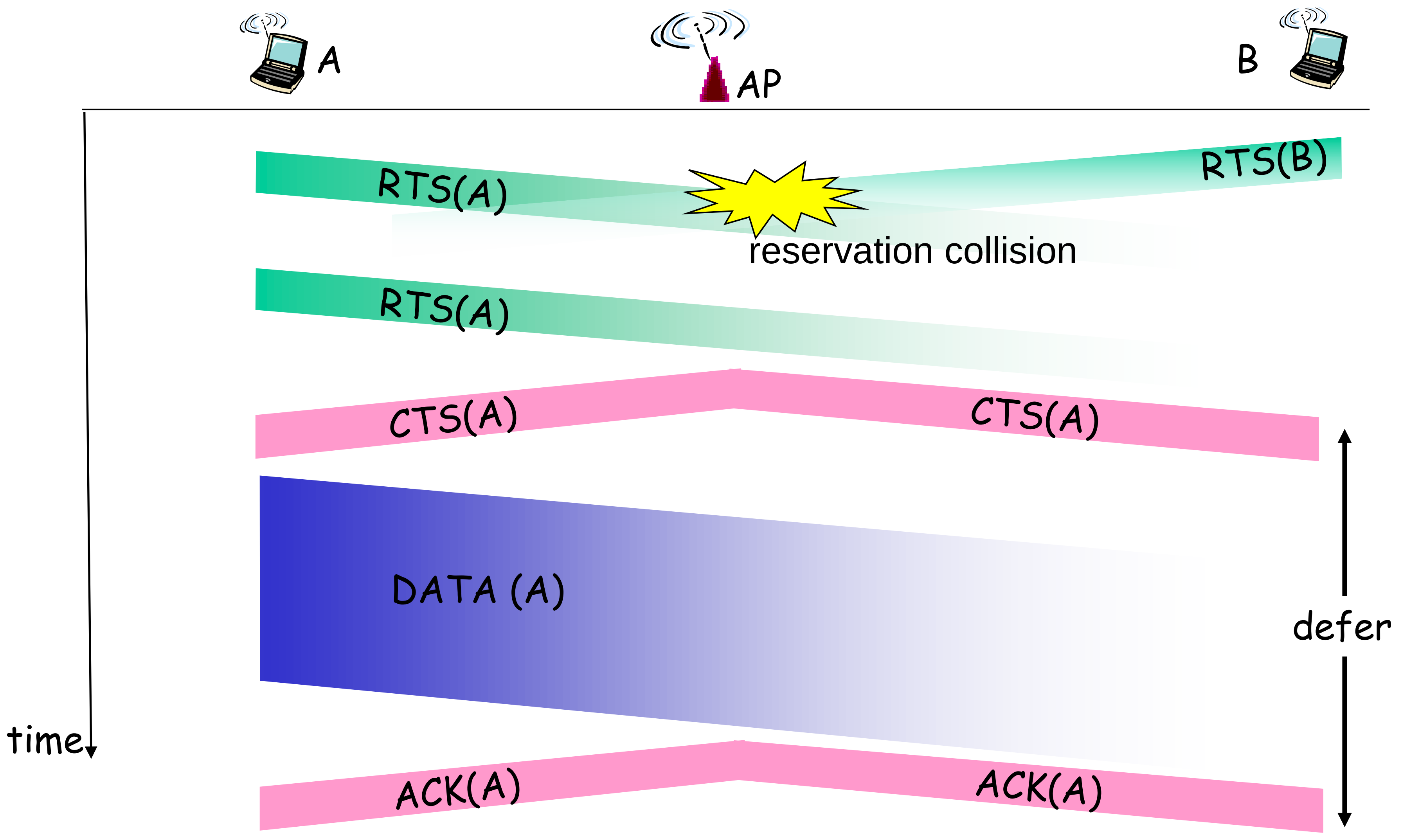


Avoiding Collisions (more)

- *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
- RTS 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

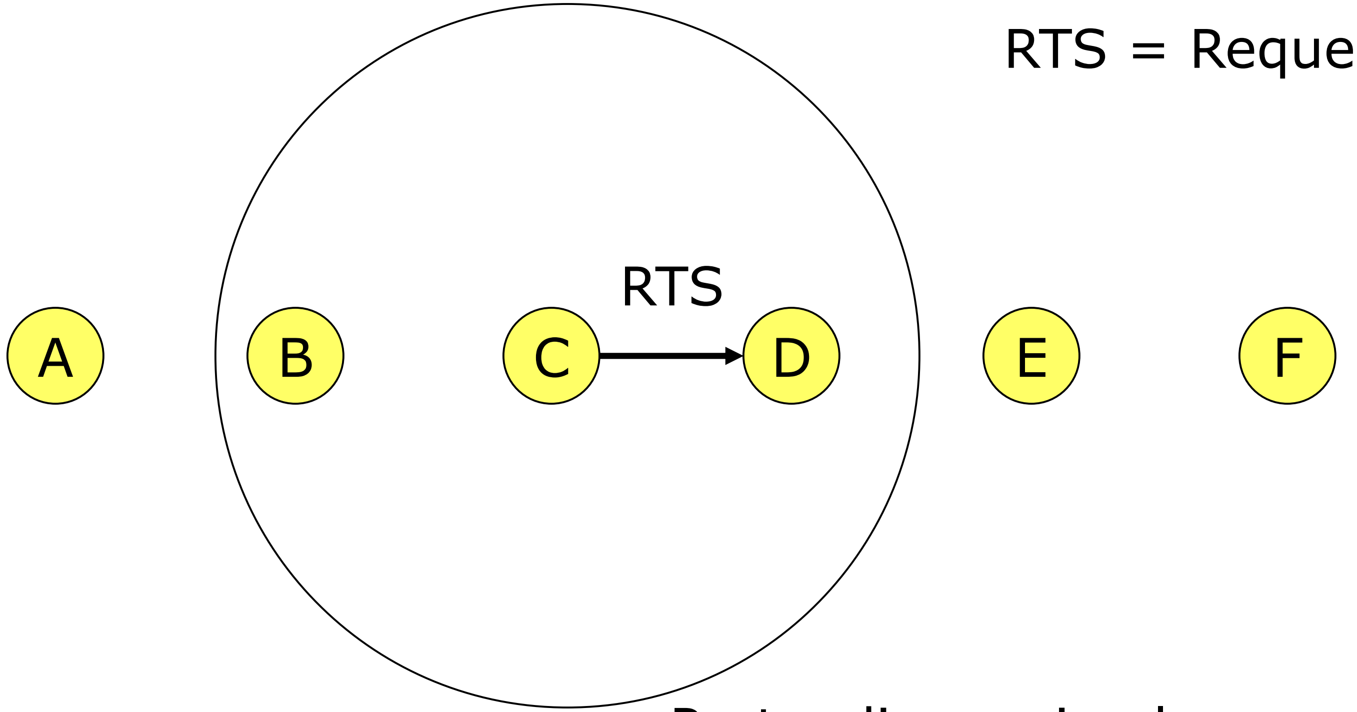


RTS-CTS Exchange

- Uses RTS-CTS exchange to avoid hidden terminal problem
  - Question: how long should sender “reserve” the channel?
  - Network Allocation Vector (NAV): each message includes length of time other nodes must wait to send
  - Any node receiving the RTS cannot transmit for the duration of the transfer
  - Any node overhearing a CTS cannot transmit for the duration of the transfer

RTS-CTS and NAV

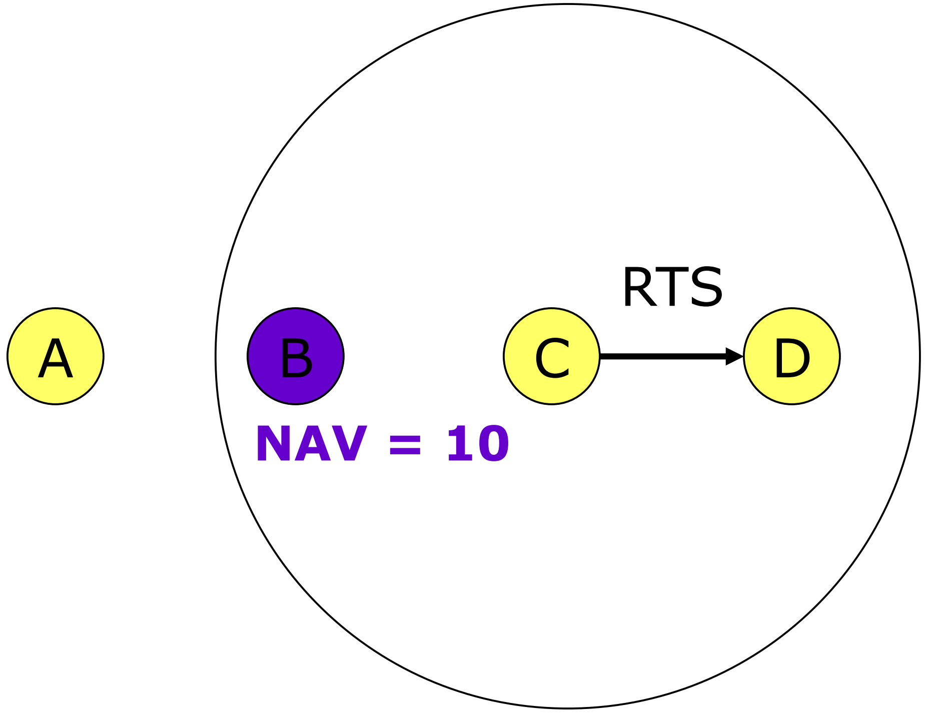
RTS = Request-to-Send



Pretending a circular range

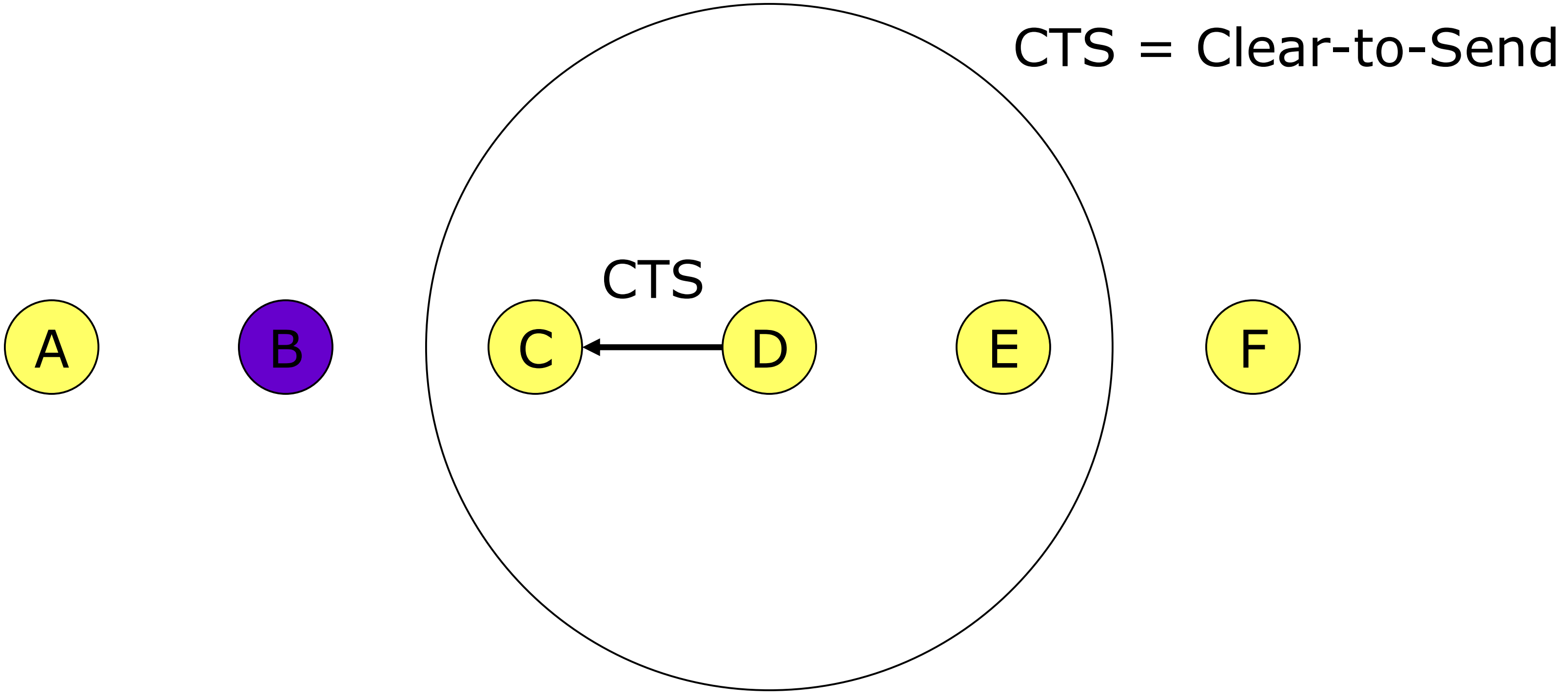
RTS-CTS and NAV

RTS = Request-to-Send



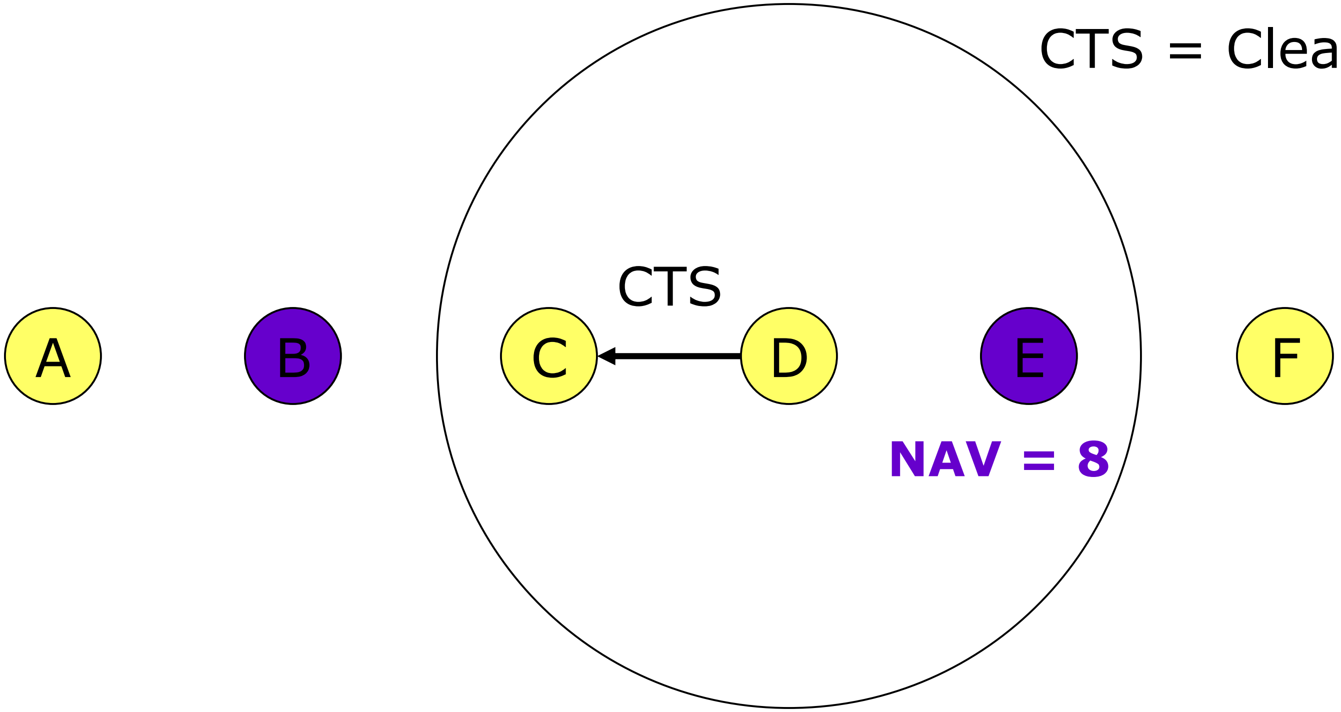
NAV = remaining duration to keep quiet

RTS-CTS and NAV



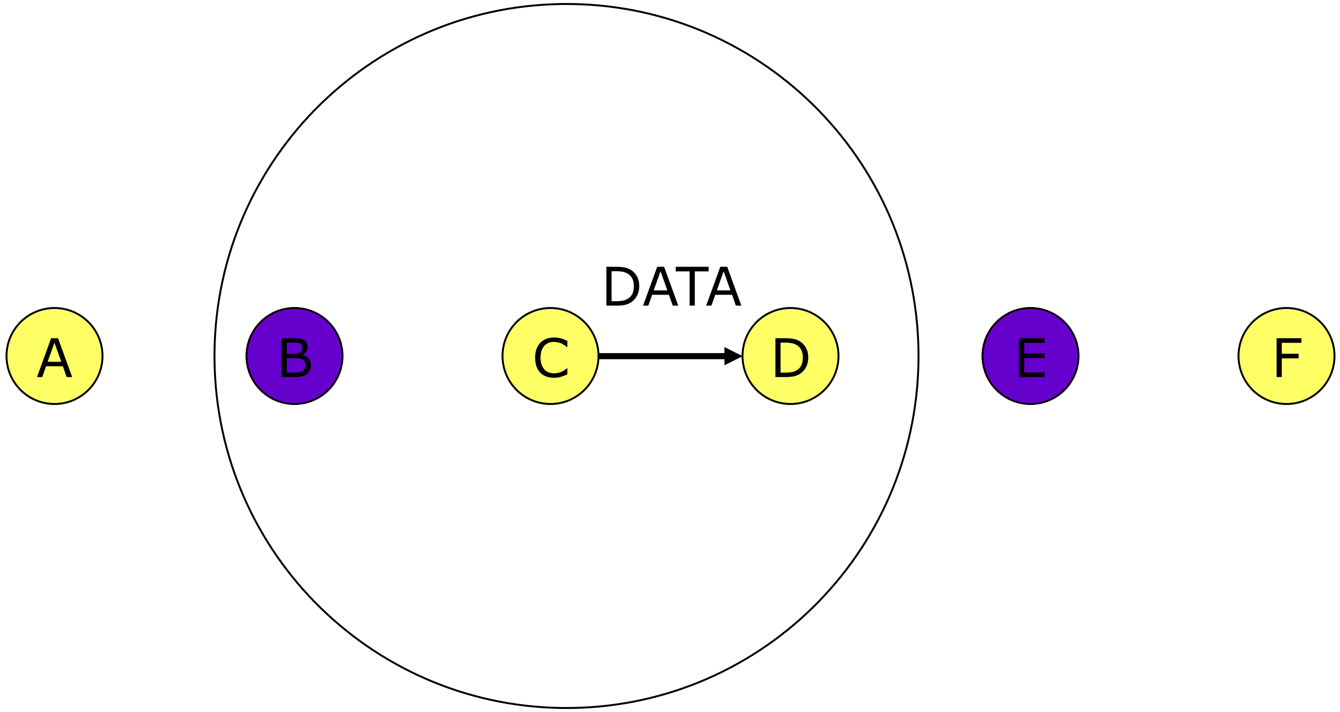
RTS-CTS and NAV

CTS = Clear-to-Send

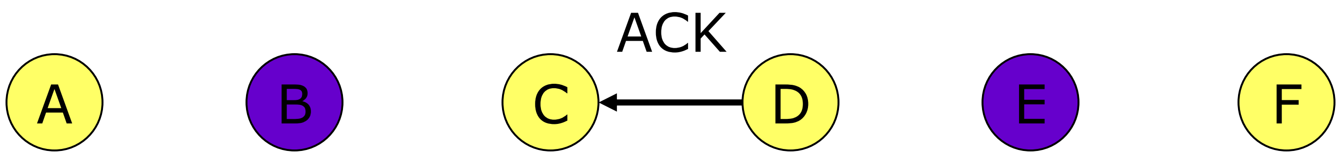


RTS-CTS and NAV

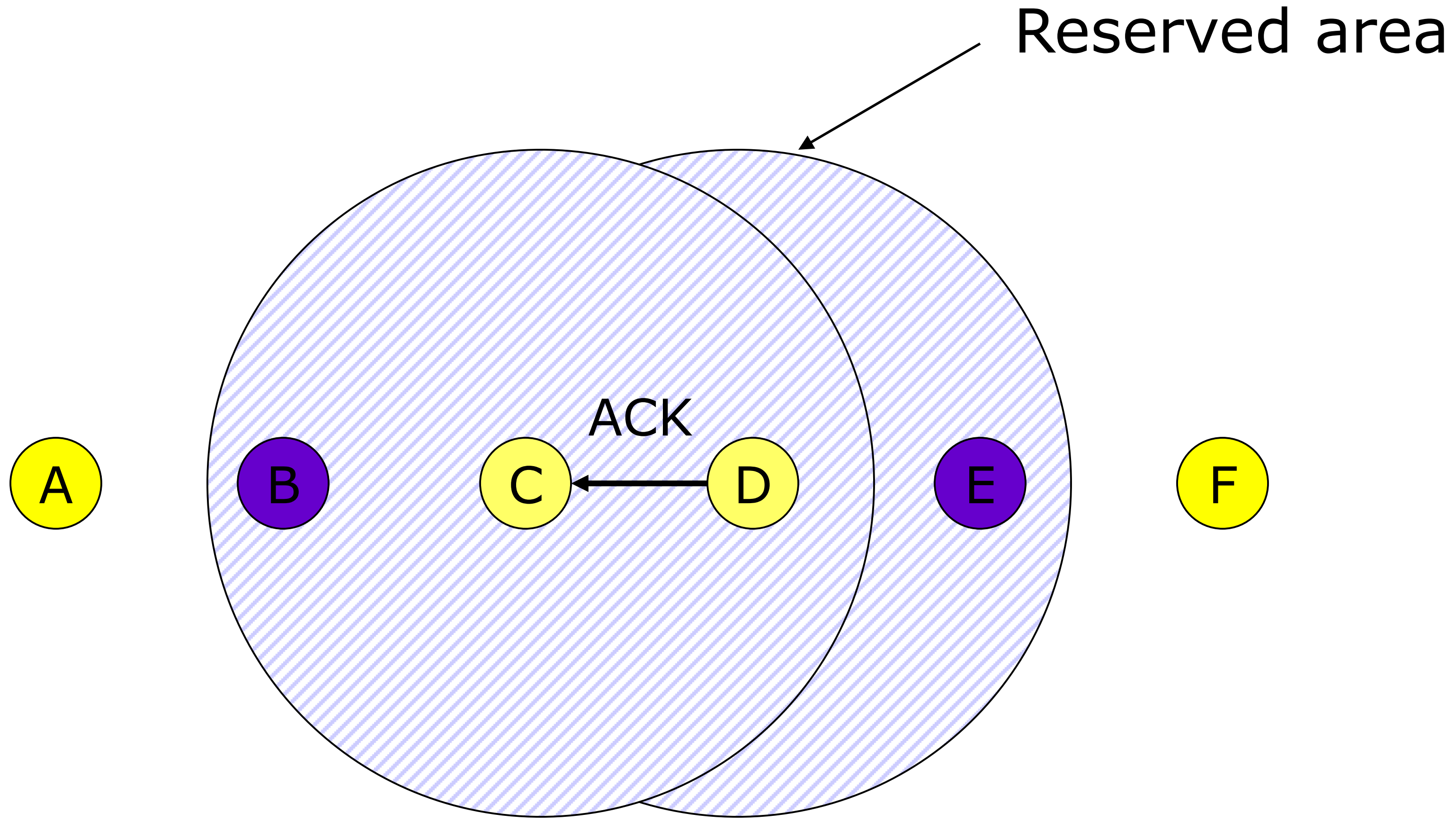
- DATA packet follows CTS
- Successful data reception acknowledged using ACK



RTS-CTS and NAV



RTS-CTS and NAV



802.11 Frame: Addressing

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

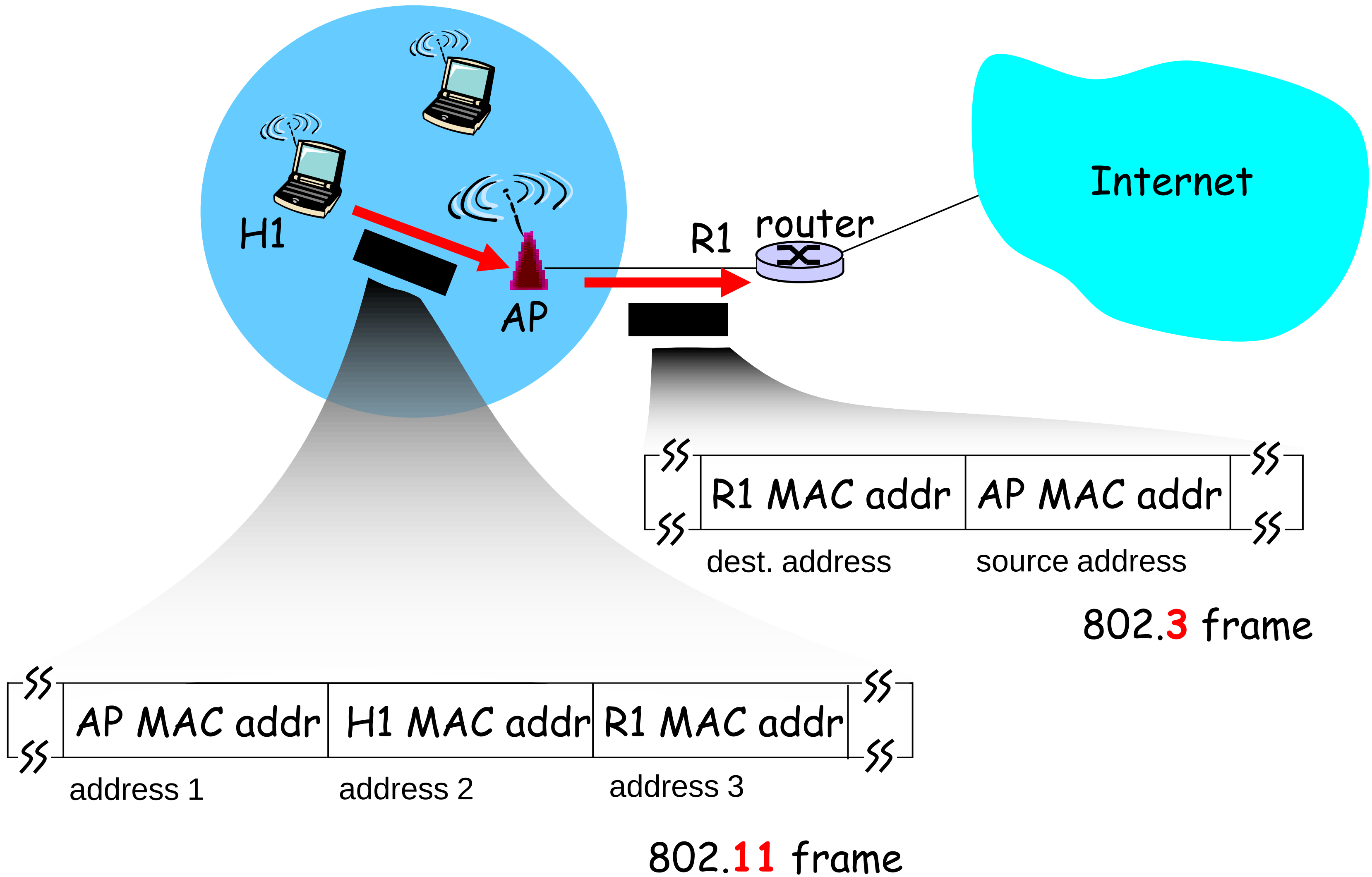
Address 1: MAC address of wireless host or AP to receive this frame

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

802.11 Frame: Addressing



802.11 Frame: More

duration of reserved transmission time (RTS/CTS)

frame seq # (for reliable ARQ)

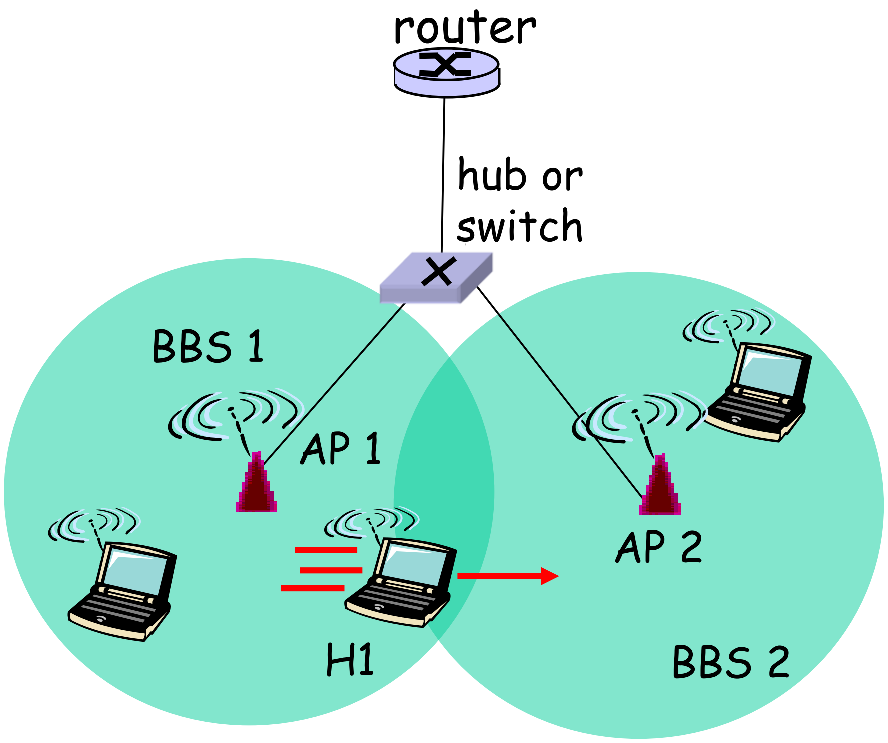
2	2	6	6	6	2	6	0 - 2312	4
frame control	duration	address 1	address 2	address 3	seq control	address 4	payload	CRC

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)

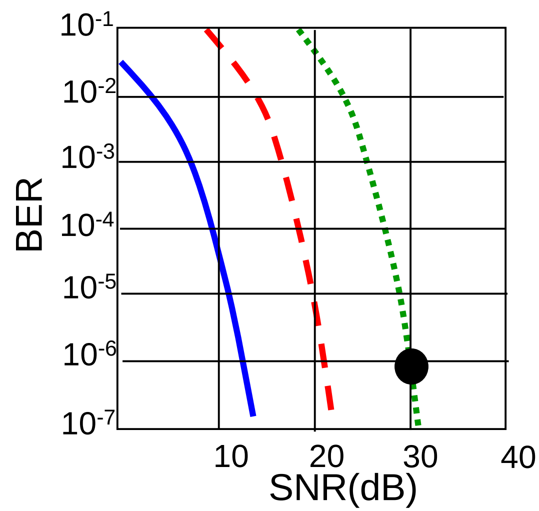
802.11: Mobility within Same Subnet

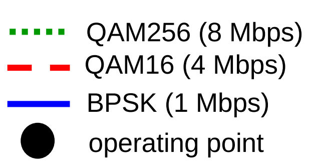
- H1 remains in same IP subnet: IP address can remain same
- Switch: which AP is associated with H1?
  - Self-learning (Ch. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1



802.11: Advanced Capabilities

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





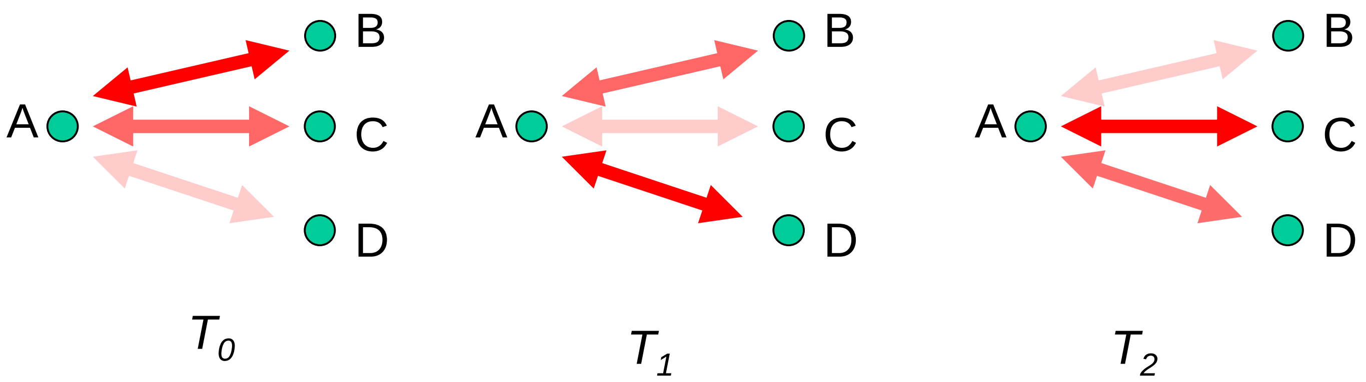
1. SNR decreases, BER increase as node moves away from base station

2. When BER becomes too high, switch to lower transmission rate but with lower BER

Rate Adaptation

- Multiple rates are supported by each wireless standard according to the channel quality
  - 802.11b supports 1M, 2M,5.5M and 11Mbps
  - 802.11g supports 6M,9M,12M,18M,36M,48M,54M
- The channel conditions vary
  - Temporal dimension
  - Spatial dimension (multiuser diversity)
  - Each user has independent channel condition
- Multiple rates can be exploited to improve the transmission performance
  - Throughput, latency, etc.

A Simple Example



Scheme 1:

A➔D A➔C A➔B

Scheme 2:

A➔B A➔D A➔C

Of course, scheme 2 is better than scheme 1

802.11: Advanced Capabilities

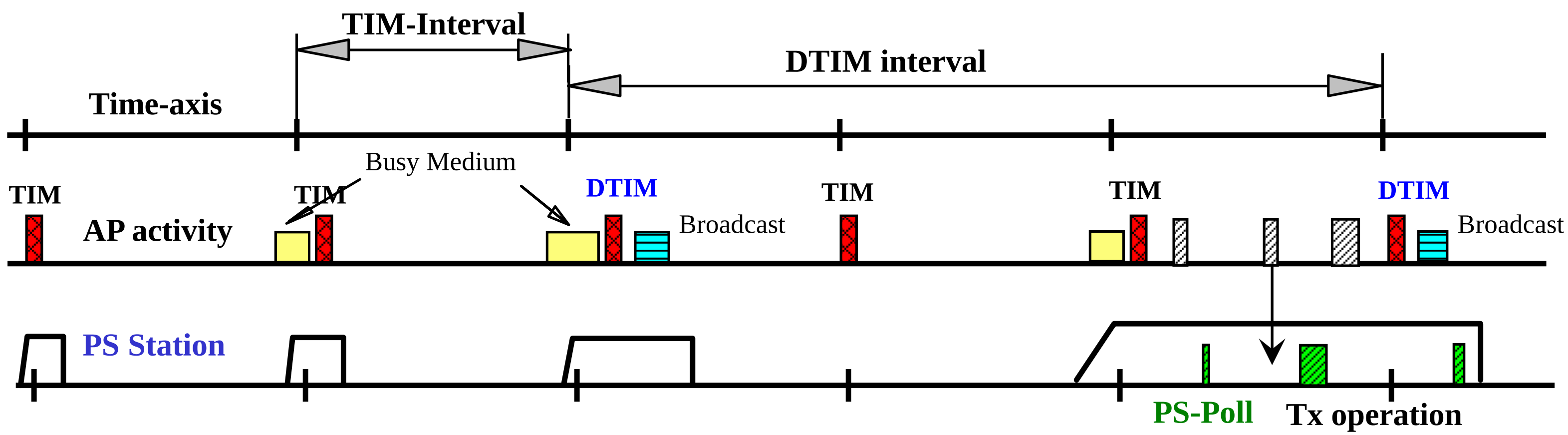
Power Management

- Mobile devices are battery powered
- Current LAN protocols assume stations are always ready to receive
  - Idle receive state dominates LAN adapter power consumption over time
- How can we power off during idle periods, yet maintain an active session?
- 802.11 *Power Management* protocol
  - Allows transceiver to be off as much as possible
  - Is transparent to existing protocols
  - Is flexible to support different applications
    - Possible to trade off throughput for battery life

Power Management Approach

- Allow idle stations to go to sleep
  - Station's power save mode stored in AP
- APs buffer packets for sleeping stations
  - AP announces which stations have frames buffered
  - Traffic Indication Map (TIM) sent with every Beacon
- Power saving stations wake up periodically
  - Listen for Beacons
- Time Synchronization Function (TSF) assures AP and power save stations are synchronized
  - Stations will wake up to hear a Beacon
  - Synchronization allows extreme low power operation

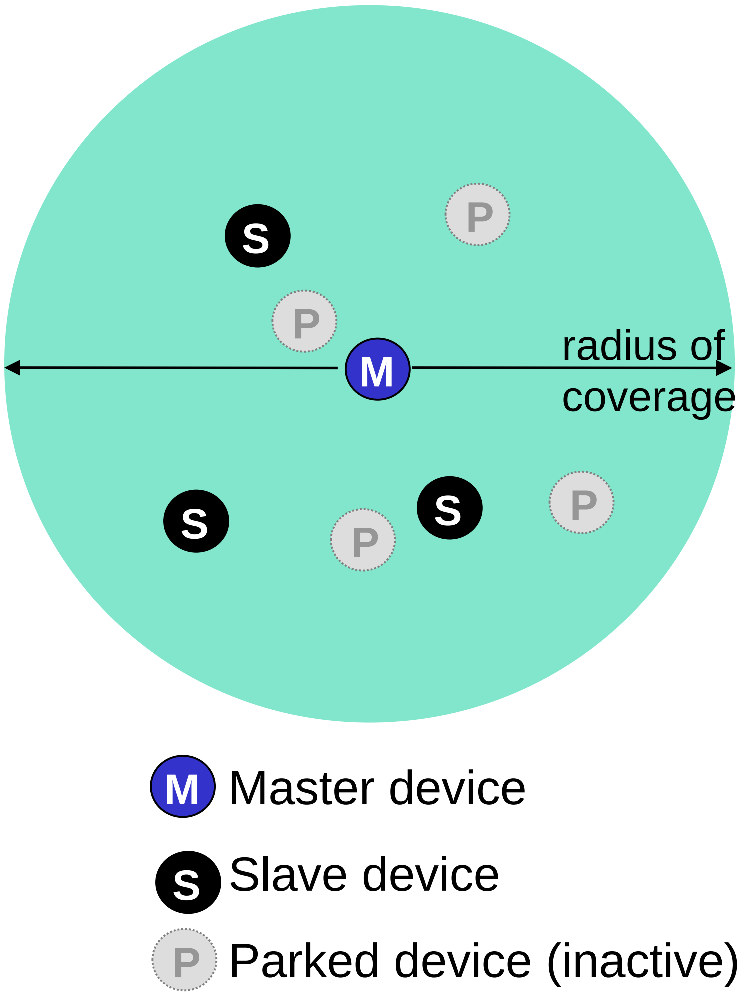
Infrastructure Power Management



- Broadcast frames are also buffered in AP
  - Broadcasts/multicasts are only sent after DTIM
  - DTIM interval is a multiple of TIM interval
- Stations wake up prior to an expected (D)TIM
- If TIM indicates frame buffered
  - Station sends PS-Poll and stays awake to receive data

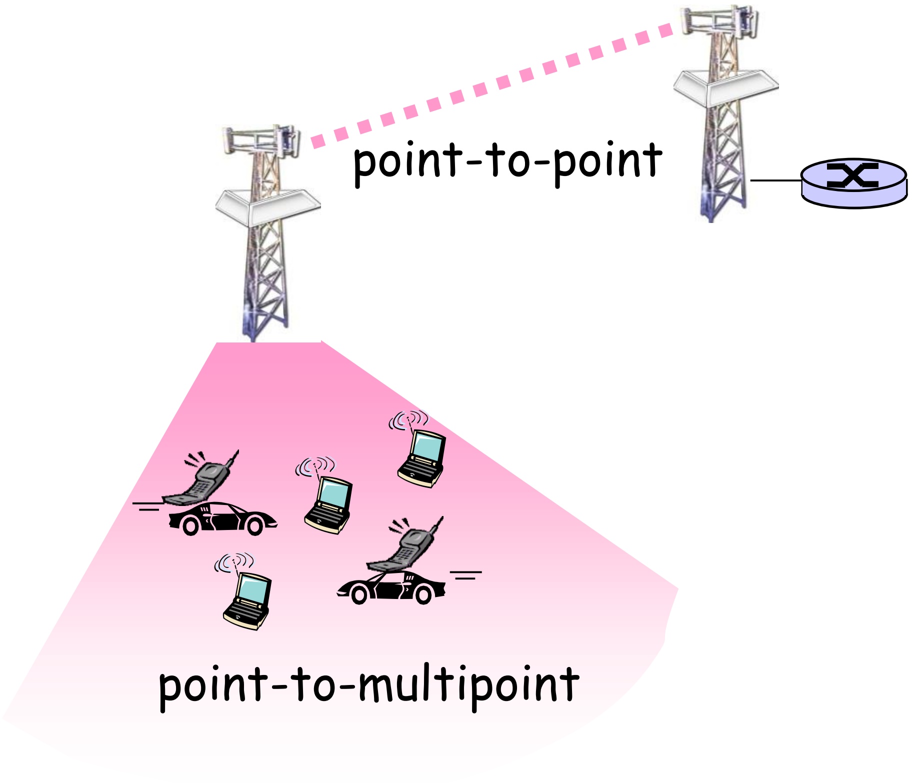
802.15: Personal Area Network

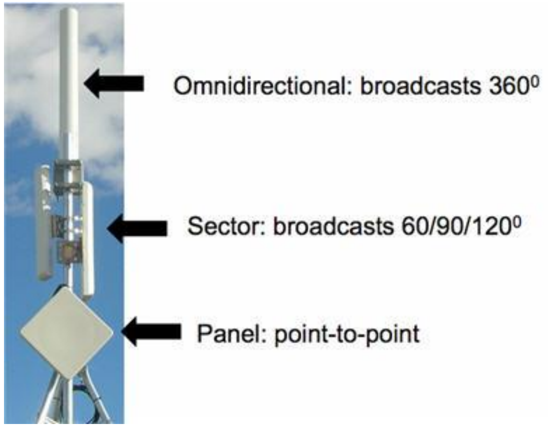
- Less than 10 m diameter
- Replacement for cables (mouse, keyboard, headphones)
- Ad hoc: no infrastructure
- Master/slaves:
  - Slaves request permission to send (to master)
  - Master grants requests
- 802.15: evolved from Bluetooth specification
  - 2.4-2.5 GHz radio band
  - Up to 721 kbps



802.16: WiMAX

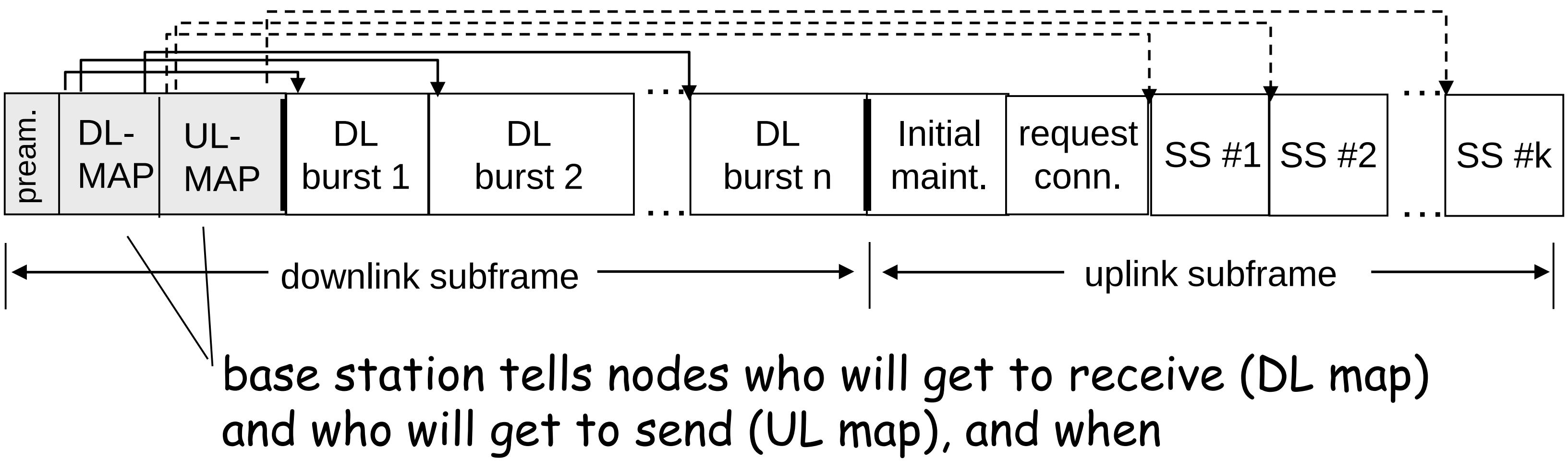
- Like 802.11 & cellular: base station model
  - Transmissions to/from base station by hosts with omnidirectional antenna
  - Base station-to-base station backhaul with point-to-point antenna
- Unlike 802.11:
  - Range ~ 6 miles ("city rather than coffee shop")
  - ~14 Mbps





802.16: WiMAX: Downlink, Uplink Scheduling

- Transmission frame
  - Down-link subframe: base station to node
  - Uplink subframe: node to base station

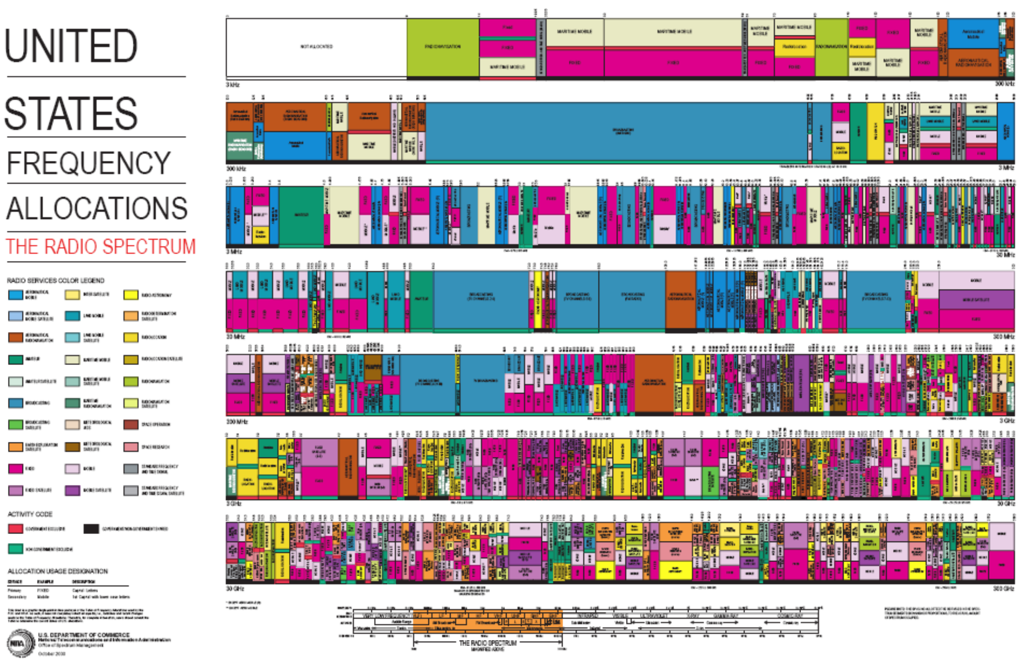


- WiMAX standard provide mechanism for scheduling, but not scheduling algorithm

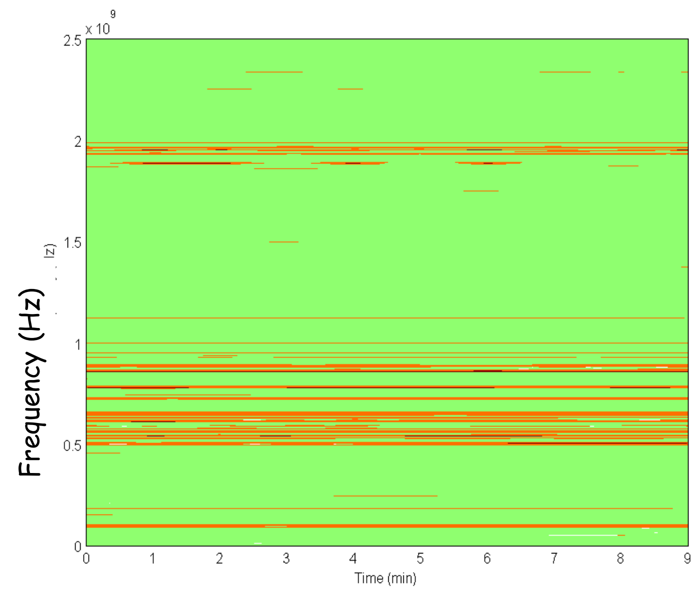
Cognitive Radio

Window of Opportunity

- Bandwidth is expensive and good frequencies are taken
- Unlicensed bands – biggest innovations in spectrum efficiency



- Recent measurements by the FCC in the US show 70% of the allocated spectrum is not utilized
- Time scale of the spectrum occupancy varies from msecs to hours



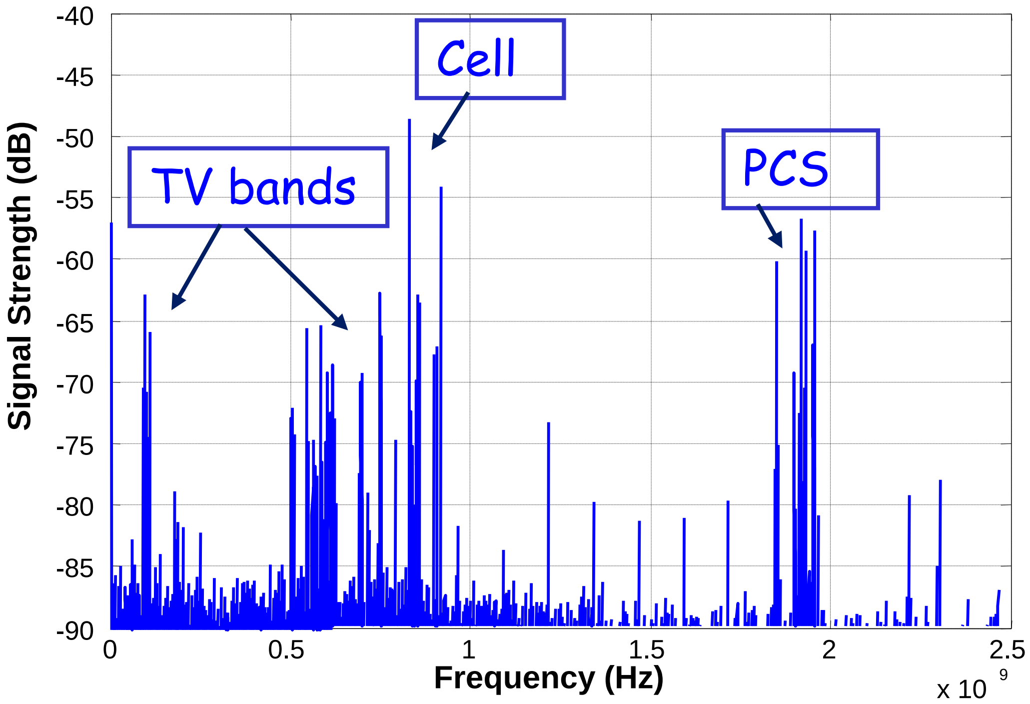
Time (min)

http://www.ntia.doc.gov/osmhome/allochrt.pdf

Radio Spectrum Use

- Measured signal strength in the air
- The length of duration also matters – how long a specific frequency band is used

Spectrum usage in (0, 2.5) GHz



Spectrum Sharing

- Existing techniques for spectrum sharing:
  - Unlicensed bands (WiFi 802.11 a/b/g)
  - Underlay licensed bands (UWB)
  - Opportunistic sharing
  - Recycling (exploit the SINR margin of legacy systems)
  - Spatial Multiplexing and Beamforming
- Drawbacks of existing techniques:
  - No knowledge or sense of spectrum availability
    - Limited adaptability to spectral environment
  - Fixed parameters: BW, Fc, packet lengths, synchronization, coding, protocols, …
- New radio design philosophy: all parameters are adaptive
  - Cognitive Radio Technology

What is a Cognitive Radio?

- Cognitive radio requirements
  - co-exists with legacy wireless systems
  - uses their spectrum resources
  - does not interfere with them
- Cognitive radio properties
  - RF technology that "listens" to huge swaths of spectrum
  - Knowledge of primary users' spectrum usage as a function of location and time
  - Share the available resources (time, frequency, space)
  - Intelligently determine parameters based on the spectral environment

Cognitive Radio Functions

Sensing Radio

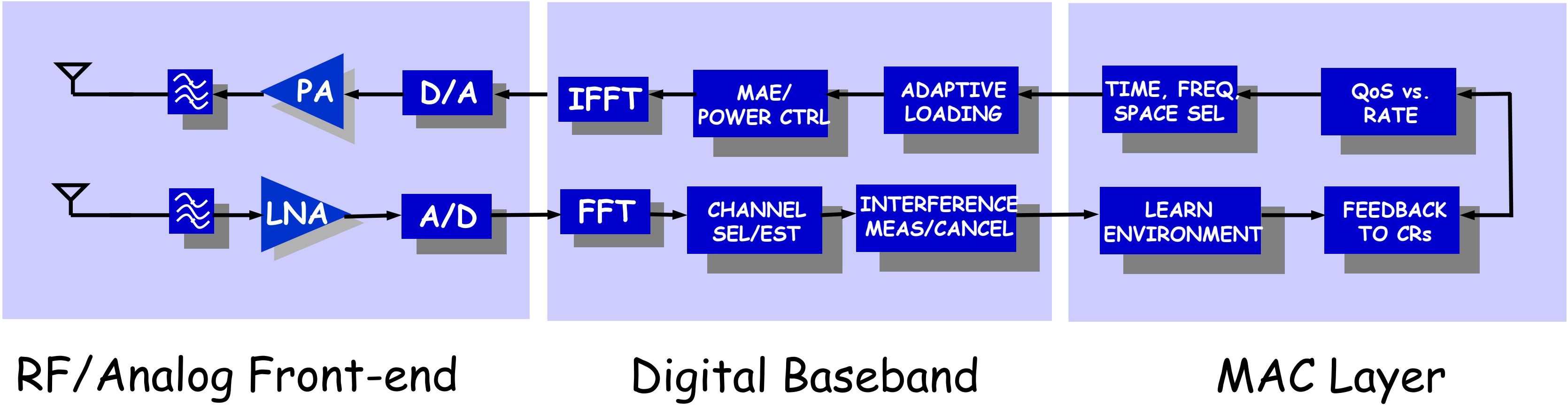
- Wideband Antenna
- High speed A/D & D/A, moderate resolution
- Simultaneous Tx & Rx

Physical Layer

- OFDM transmission
- Spectrum monitoring
- Dynamic frequency selection, modulation, power control

MAC Layer

- Optimize transmission parameters
- Adapt rates through feedback
- Negotiate or opportunistically use resources



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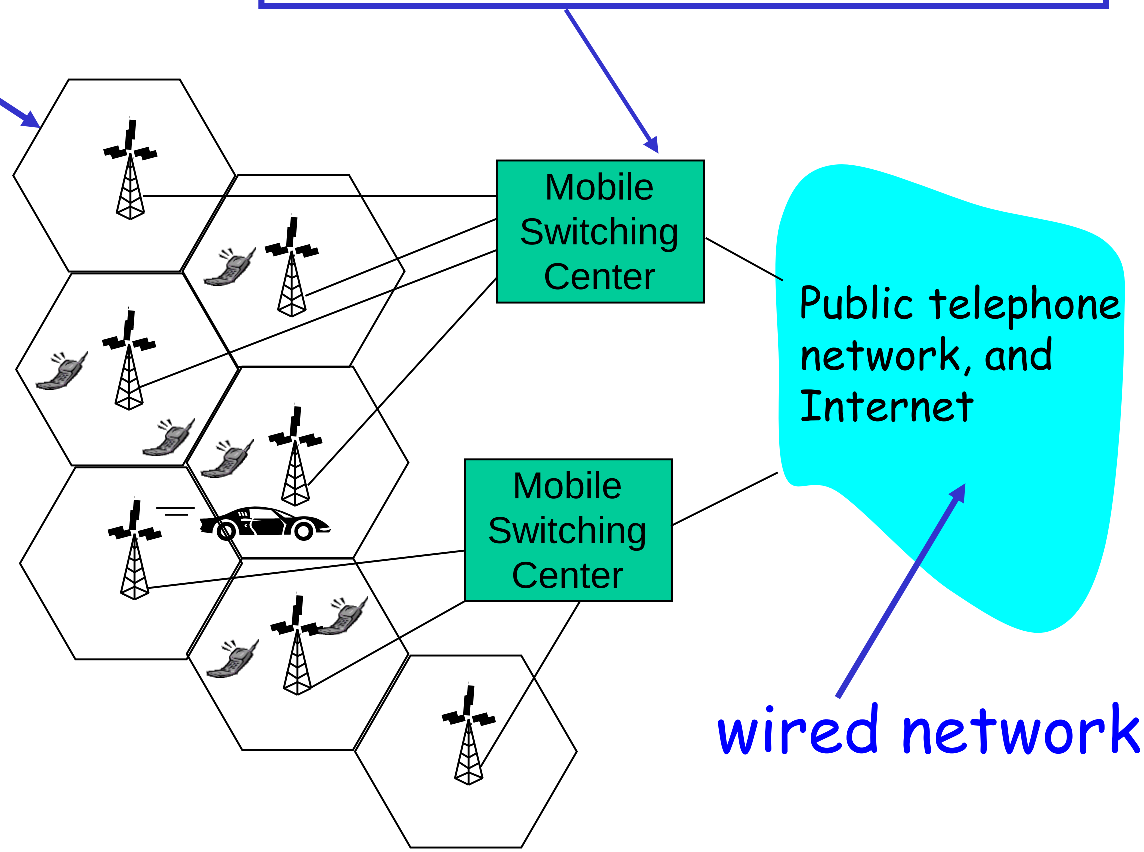
Components of Cellular Network Architecture

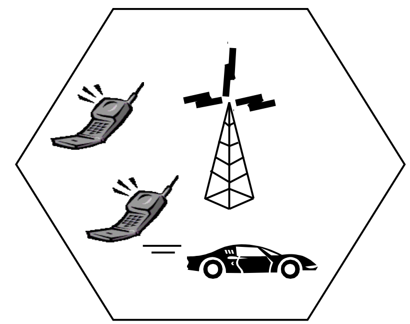
cell
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

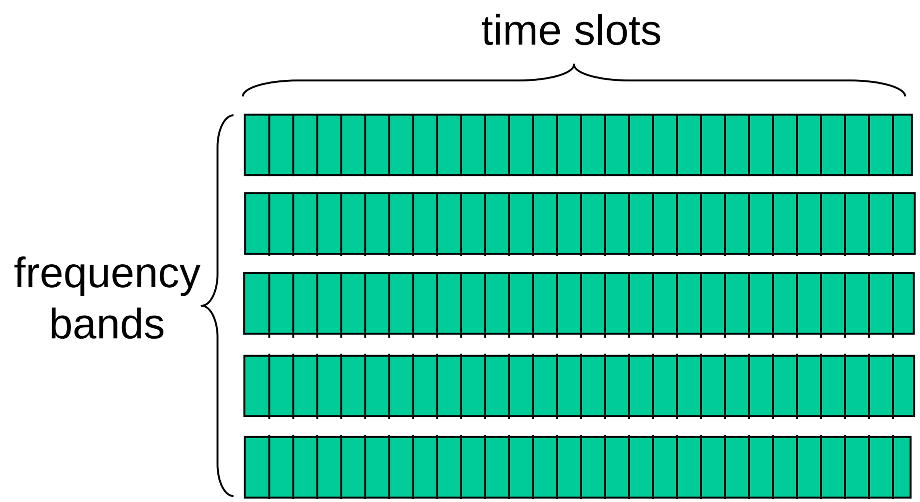
MSC
- connects cells to wide area net
- manages call setup (more later!)
- handles mobility (more later!)



Cellular Networks: the First Hop

- Two techniques for sharing mobile-to-BS radio spectrum
- Combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access

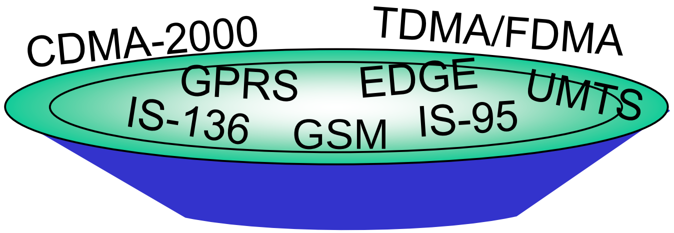




Cellular Standards: Brief Survey

2G systems: voice channels

- IS-136 TDMA: combined FDMA/TDMA (north america)
- GSM (global system for mobile communications): combined FDMA/TDMA
  - most widely deployed
- IS-95 CDMA: code division multiple access



Don't drown in a bowl of alphabet soup: use this for reference only

Cellular Standards: Brief Survey

2.5G systems: voice and data channels

- For those who can't wait for 3G service: 2G extensions
- General packet radio service (GPRS)
  - Evolved from GSM
  - Data sent on multiple channels (if available)
- Enhanced data rates for global evolution (EDGE)
  - Also evolved from GSM, using enhanced modulation
  - Data rates up to 384K
- CDMA-2000 (phase 1)
  - Data rates up to 144K
  - Evolved from IS-95

Cellular Standards: Brief Survey

3G systems: voice/data

- Universal Mobile Telecommunications Service (UMTS)
  - Data service: High Speed Uplink/Downlink packet Access (HSDPA/HSUPA): 3 Mbps
- CDMA-2000: CDMA in TDMA slots
  - Data service: 1xEvlution Data Optimized (1xEVDO) up to 14 Mbps

….. more (and more interesting) cellular topics due to mobility (stay tuned for details)

Cellular standards: brief survey

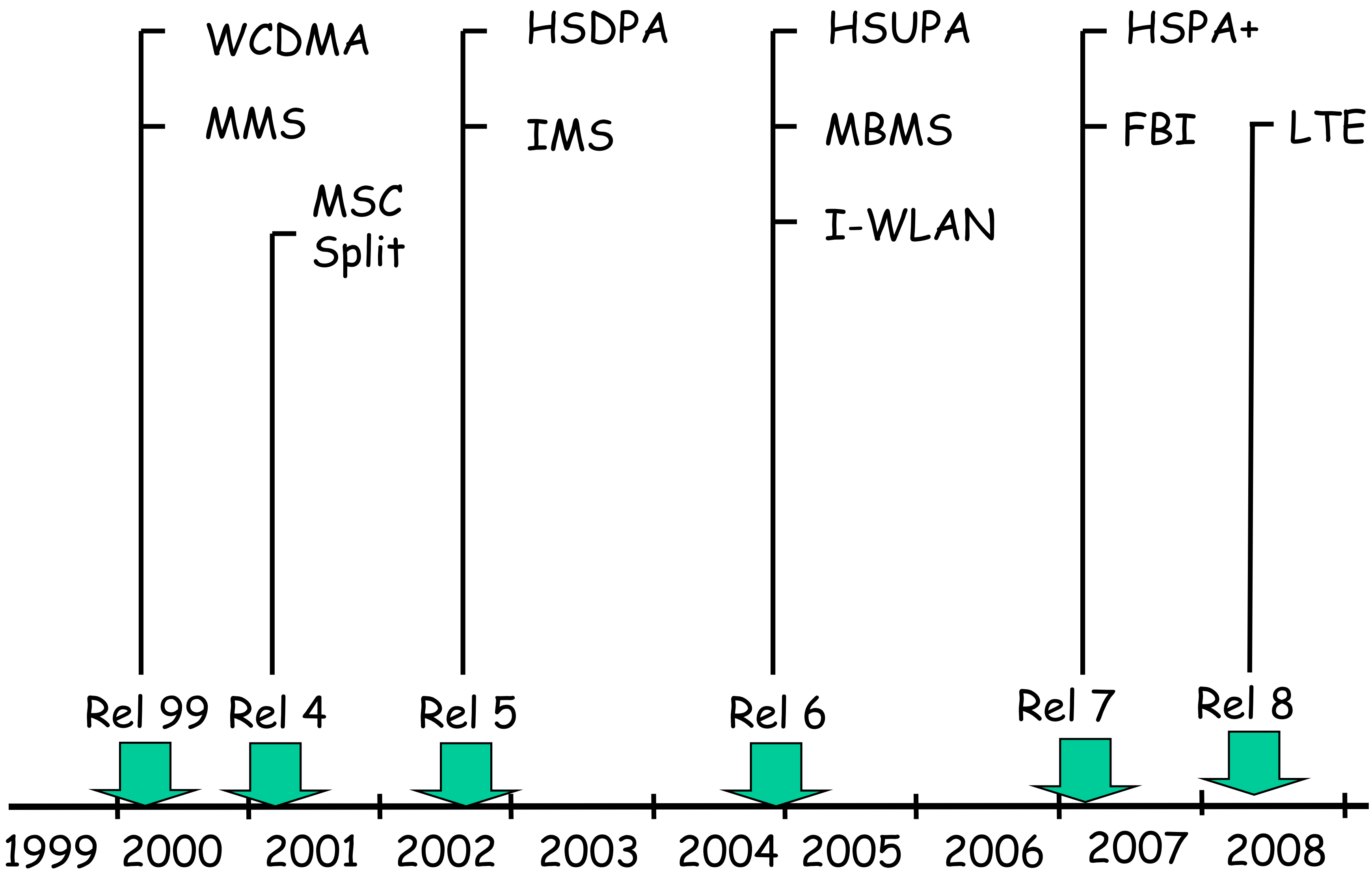
4G systems: broadband voice/data

- No formal definition, but no doubt 4G systems will appear and, very likely, dominate
- Expected:
  - Much higher data rates: 1 Gbps or more (stationary), 100 Mbps (moving)
  - Seamless roaming across heterogeneous networks
- Pre-4G or potential 4G standards
  - LTE (Long Term Evolution), WiMAX, UMB, …

The 3GPP Long Term Evolution (LTE)

- 3GPP Long Term Evolution - the next generation of wireless cellular technology beyond 3G
- Initiative taken by the 3rd Generation Partnership Project in 2004
- Introduced in Release 8 of 3GPP
- Mobile systems likely to be deployed by 2010

3GPP Release/Freeze Timeline



Introduction

- LTE is the latest standard in the mobile network technology tree that previously realized the GSM/EDGE and UMTS/HSxPA network technologies
  - Evolve from currently leading 3G technology

- LTE is the next step toward '4G' mobile systems, offering a smooth evolutionary path to higher speeds and lower latency

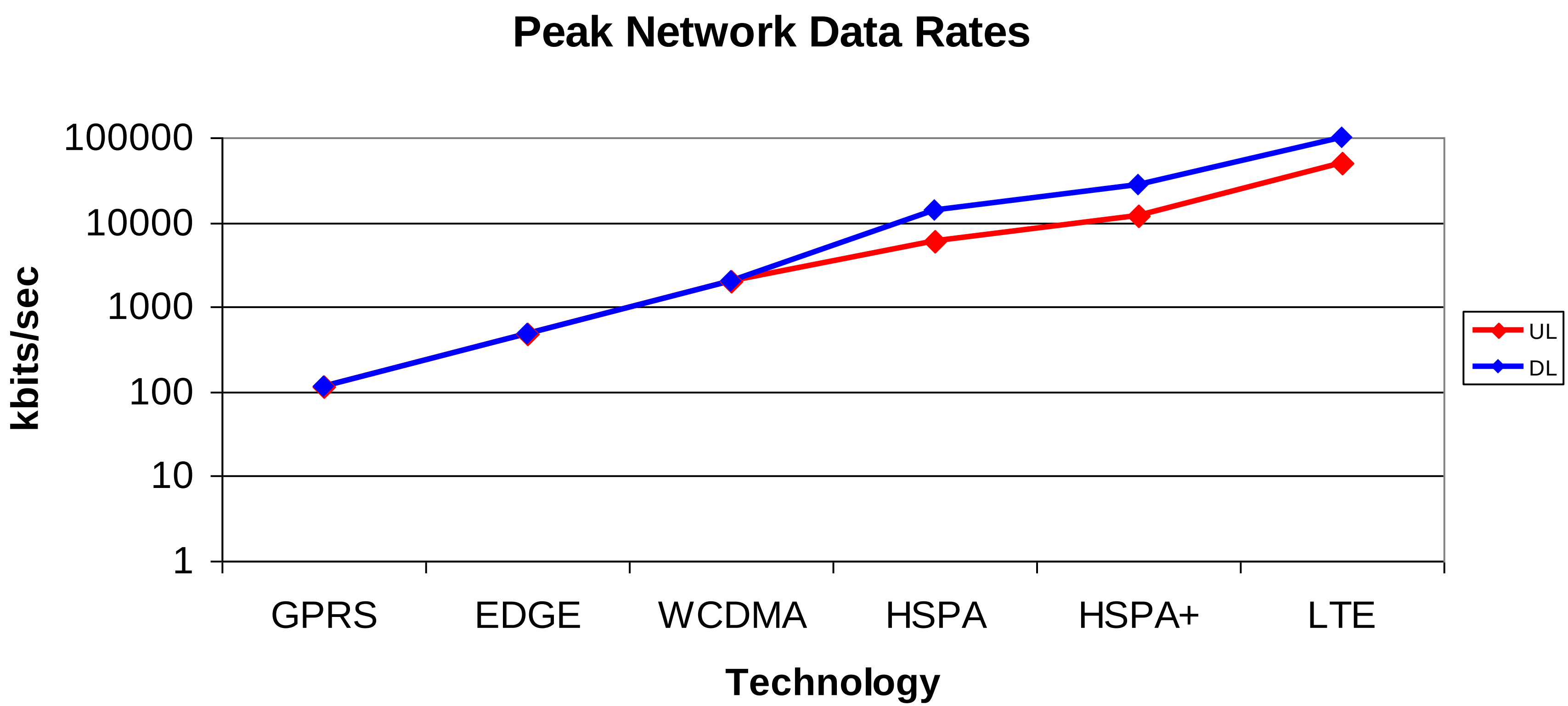
Introduction

- Designed to meet carrier needs for high-speed data and media transport as well as high-capacity voice support for the next decade
- Enables operators to offer high performance, mass-market mobile broadband services – high bit-rates, high system throughput (uplink and downlink), low latency
- Designed to be simple to deploy and operate, through flexible technology that can be deployed in a wide variety of frequency bands
- Offers scalable bandwidths, from less than 5MHz up to 20MHz, together with support for both FDD (Frequency Division Duplex) paired and TDD (Time Division Duplex) unpaired spectrum
- LTE–SAE will interoperate with GSM, WCDMA/HSPA, TD-SCDMA and CDMA

LTE performance requirements

- Data Rates:
  - Instantaneous downlink peak data rate of 100Mbit/s in a 20MHz downlink spectrum (i.e. 5 bit/s/Hz)
  - Instantaneous uplink peak data rate of 50Mbit/s in a 20MHz uplink spectrum (i.e. 2.5 bit/s/Hz)
- Cell range
  - 5 km - optimal size
  - 30km sizes with reasonable performance
  - up to 100 km cell sizes supported with acceptable performance
- Cell capacity
  - up to 200 active users per cell (5 MHz)

Evolution of 3GPP Radio Rates



LTE performance requirements

- Mobility
  - Optimized for low mobility(0-15km/h) but supports high speed
- Improved spectrum efficiency
  - Scalable bandwidth of 20MHz, 15MHz, 10MHz, 5MHz and <5MHz
- Co-existence with legacy standards
  - users can transparently start a call or data transfer in an area using an LTE standard, and, when there is no coverage, continue the operation using GSM/GPRS or W-CDMA-based UMTS

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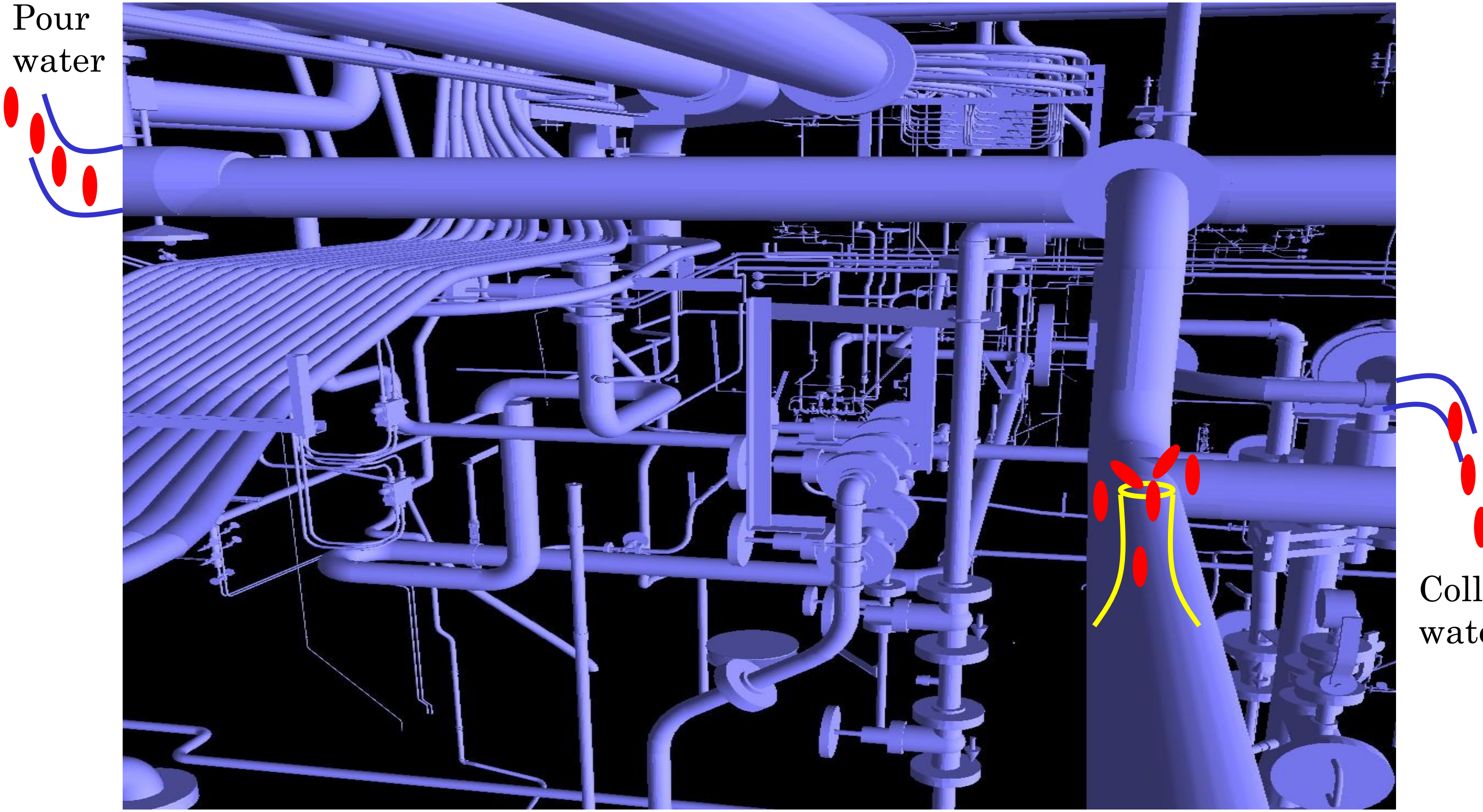
The TCP Intuition

Pour water



Collect water

The Control Problem

- Two main components in TCP
  - Flow Control and Congestion Control
- Flow Control
  - If receiver's bucket filling up, pour less water
- Congestion Control
  - Don't pour too much if there are leaks in intermediate pipes
  - Regulate your flow based on how much is leaking out
    - Aggressive pouring → calls for retransmission of lost packets
    - Conservative pouring → lower e2e capacity
- Challenge: At what rate(t) should you pour ?

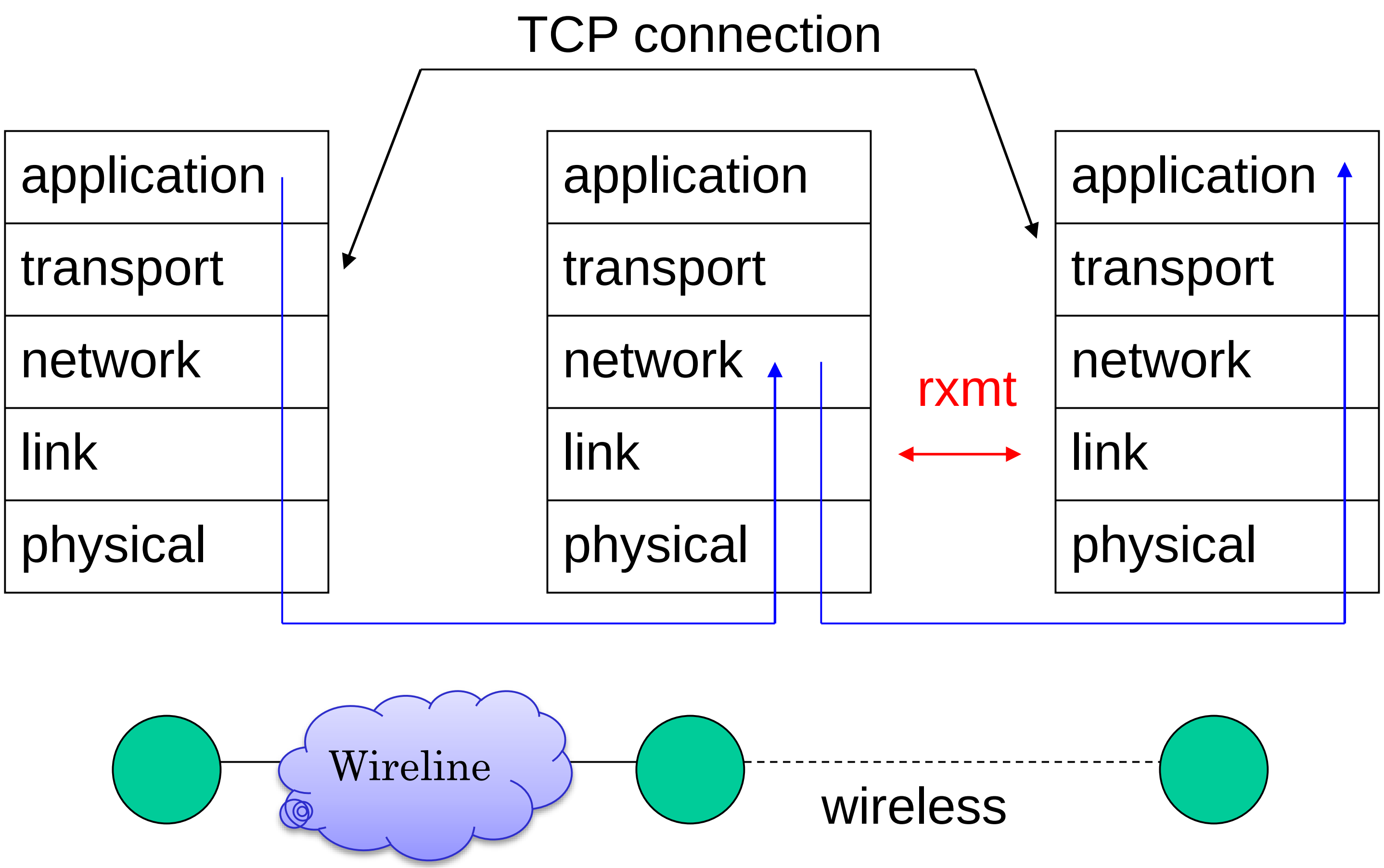
Renewed Challenge

- Key assumption in TCP
  - A packet loss is indicative of network congestion
  - Source needs to regulate flow by reducing CW

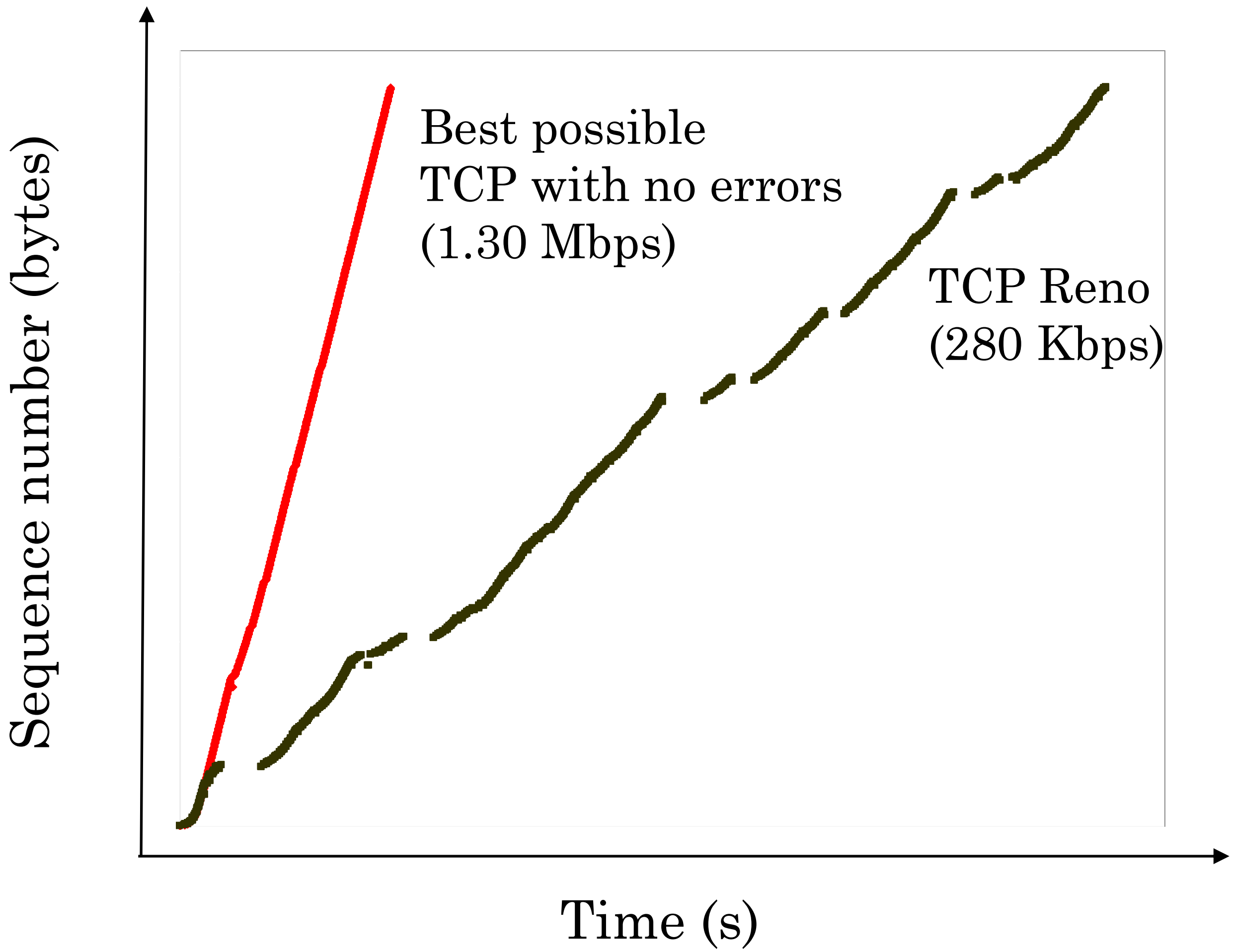
- Assumption closely true for wired networks
  - BER ~ 10^{-6}

- With wireless, errors due to fading, fluctuations
  - Need not reduce CW in response …
  - But, TCP is e2e → CANNOT see the network
  - Thus, TCP cannot classify the cause of loss → CHALLENGE

The Problem Model



Impact of Misclassification



2 MB wide-area TCP transfer over 2 Mbps WaveLAN

The Solution Space

- Much research on TCP over wireless
- Difficult to cover complete ground
- We peek into some of the key ideas
  - Link layer mechanisms
  - Split connection approach
  - TCP-Aware link layer
  - TCP-Unaware approximation of TCP-aware link layer
  - Explicit notification
  - Receiver-based discrimination
  - Sender-based discrimination

Link Layer Mechanisms

- Forward error corrections (FEC)
  - Add redundancy in the packets to correct bit-errors
  - TCP retransmissions can be alleviated

- Link layer retransmissions
  - MAC layer ACKnowledgments
  - Overhead only when errors occur (unlike FEC)

Such mechanisms require no change in TCP

Issues with Link Layer Mechanisms

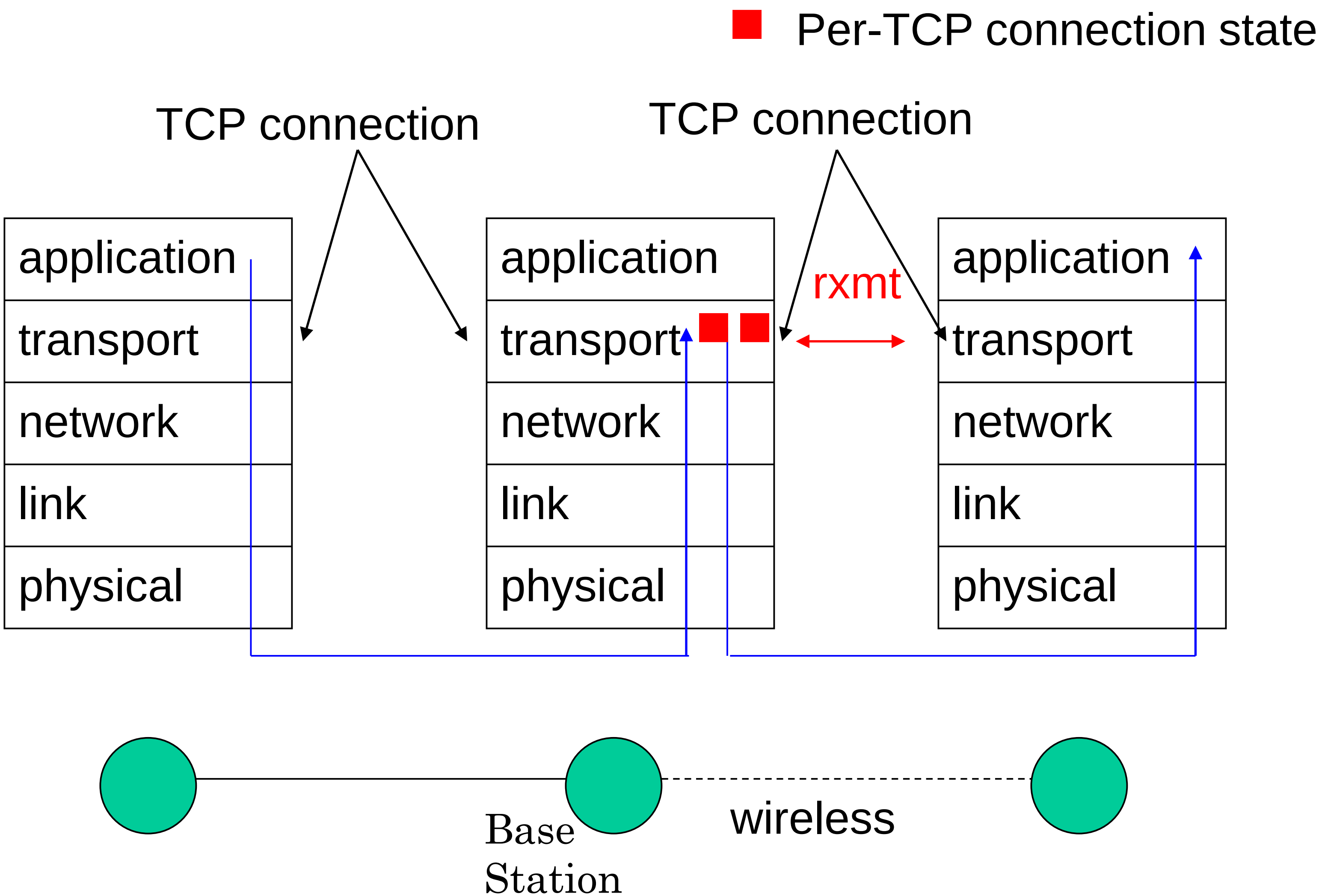
- Link layer cannot guarantee reliability
  - Have to drop packets after some finite limit
  - What is the retransmission limit (??)
- Retransmission can take quite long
  - Can be significant fraction of RTT
  - TCP can timeout and retransmit the same packet again
    - Increasing RTO can avoid this
    - But that impacts TCP's recovery from congestion
- Head of the line blocking
  - Link layer has to keep retransmitting even if bad channel
  - Blocks other streams

Findings

- Link layer retransmission good
  - When channel errors infrequent
  - When retransmit time << RTO
  - When modifying TCP is not an acceptable solution

Split Connection Approach

1 TCP = ½ TCP + ½ (TCP or XXX)



Splitting Approaches

- Indirect TCP [Baker97]
  - Fixed host (FH) to base station (BS) uses TCP
  - BS to mobile host (MH) uses another TCP connection
- Selective Repeat [Yavatkar94]
  - Over FH to BS: Use TCP
  - Over BS to MH: Use selective repeat on top of UDP
- No congestion control over wireless [Haas97]
  - Also use less headers over wireless
    - Header compression

Issues with Splitting

- E2E totally broken
  - 2 separate connections
- BS maintains hard state for each connection
  - What if MH disconnected from BS ?
  - Huge buffer requirements at BS
  - What if BS fails ?
  - Handoff between BS requires state transfer
- What if Data and ACK travel on different routes ?
  - BS will not see the ACK at all – splitting not feasible

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- 4.9 Homeless Mobile IP
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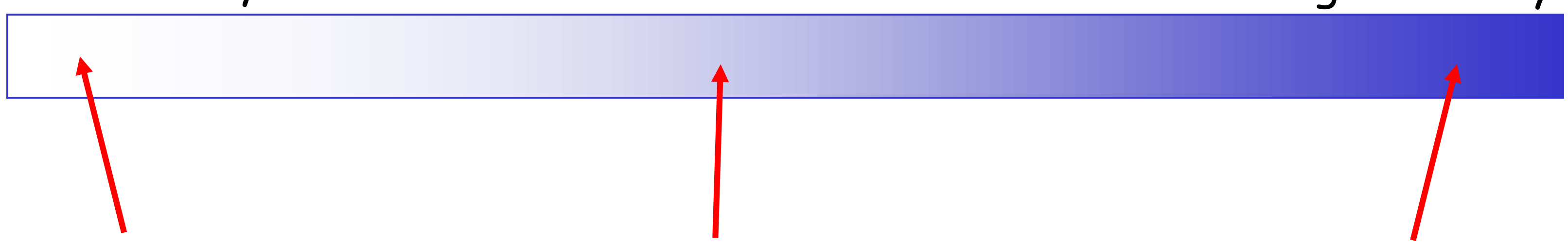
4.11 Summary

What is Mobility?

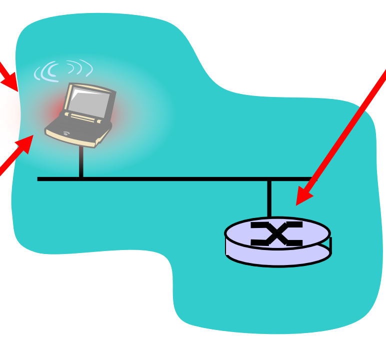
- Spectrum of mobility, from the *network* perspective:

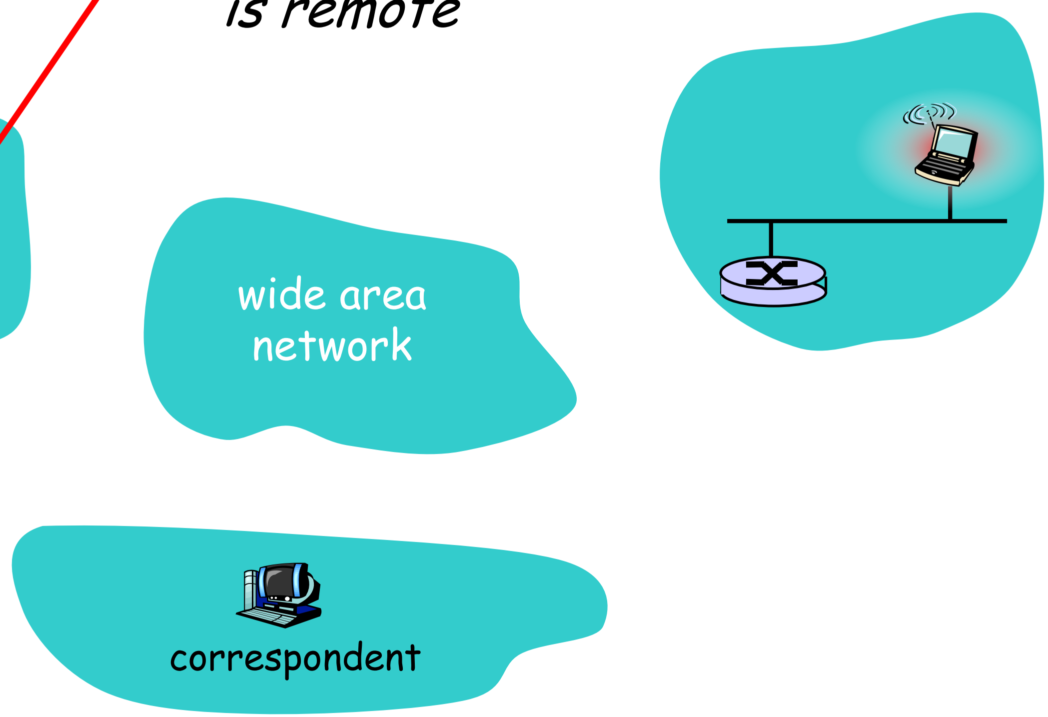


Mobility: Vocabulary

home network: permanent “home” of mobile (e.g., 128.119.40/24)

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





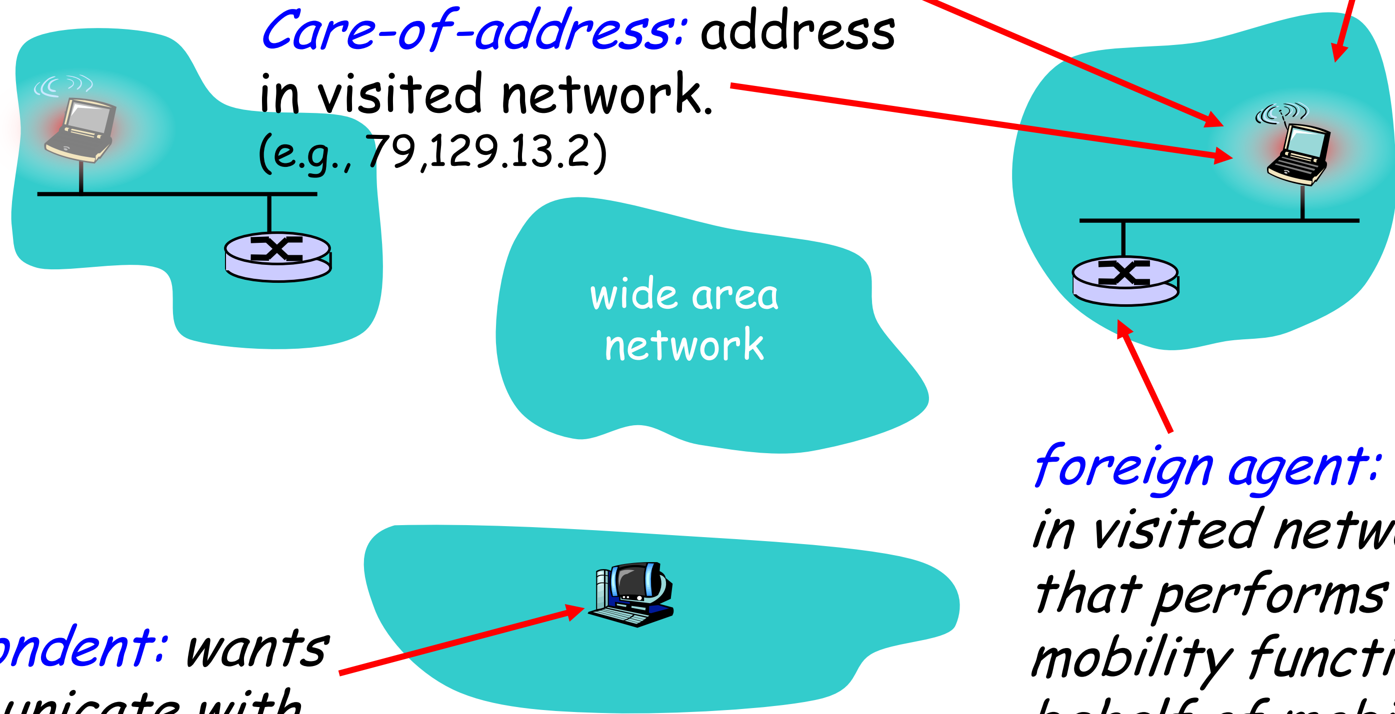
Permanent address: address in home network, *can always* be used to reach mobile e.g., 128.119.40.186

Mobility: more Vocabulary

Permanent address: remains constant (e.g., 128.119.40.186)

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

Care-of-address: address in visited network. (e.g., 79,129.13.2)



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

correspondent: wants to communicate with mobile

How do *You* Contact a Mobile Friend:

- Consider friend frequently changing addresses, how do you find her?
  - Search all phone books?
  - Call her parents?
  - Expect her to let you know where he/she is?

Mobility: Approaches

- *Let routing handle it:* routers advertise permanent address of mobile-nodes-in-residence via usual routing table exchange.
  - Routing tables indicate where each mobile located
  - No changes to end-systems
- *Let end-systems handle it:*
  - *Indirect routing:* communication from correspondent to mobile goes through home agent, then forwarded to remote
  - *Direct routing:* correspondent gets foreign address of mobile, sends directly to mobile

Mobility: Approaches

- *Let routing handle* ters advertise permanent address of mobi residence via usual routing table e
  - routing table ere each mobile located
  - no changes to e ems

not
scalable
to millions of
mobiles

- *Let end-systems handle it:*
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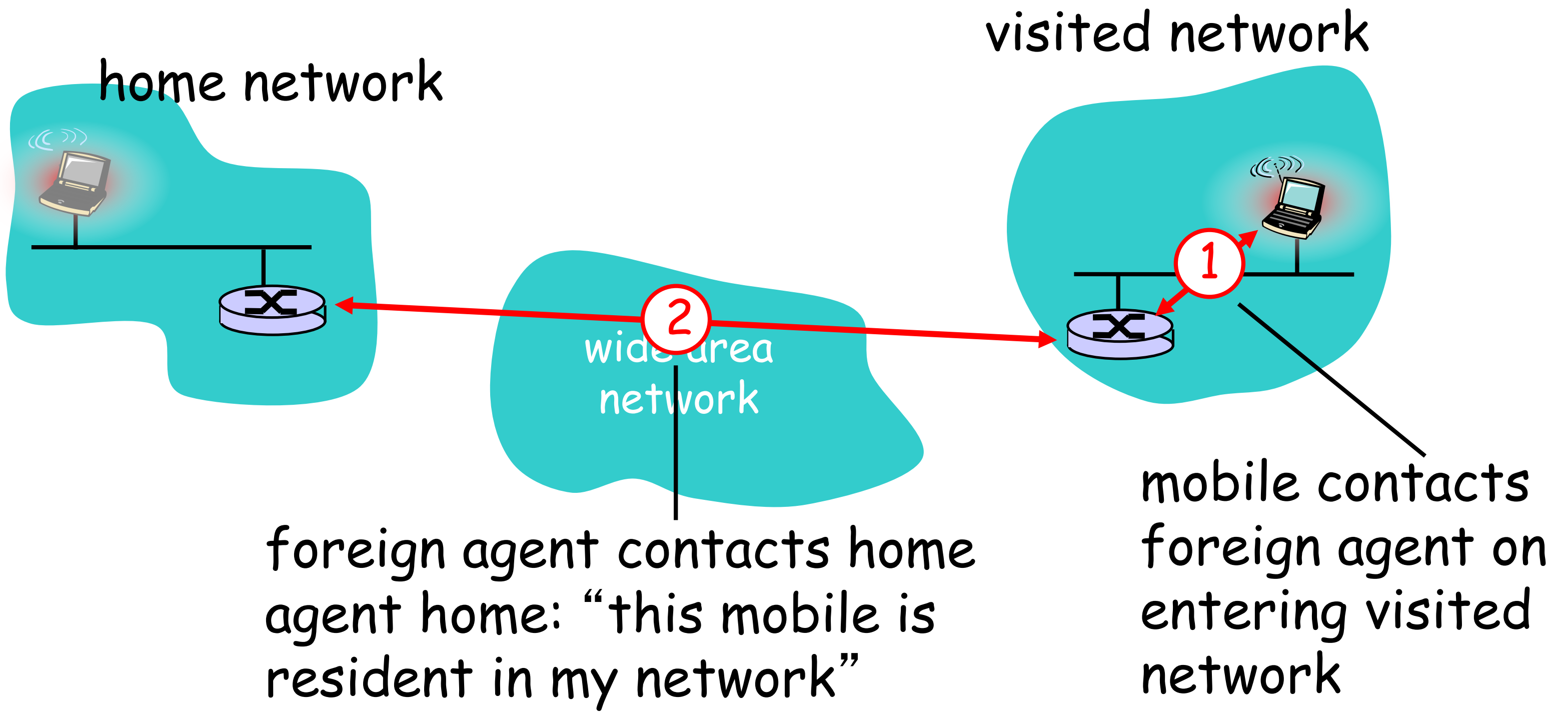
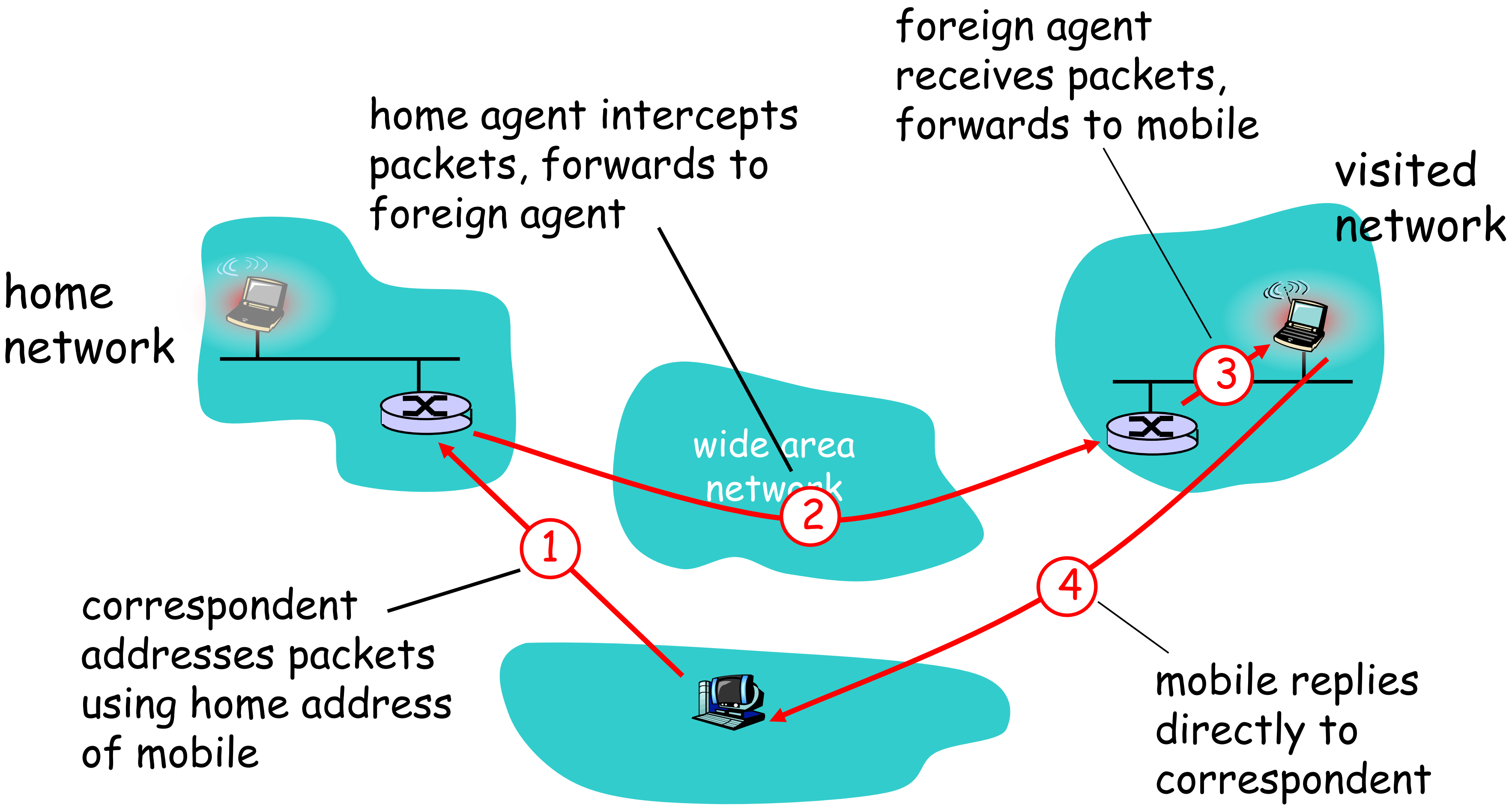
Mobility: Registration



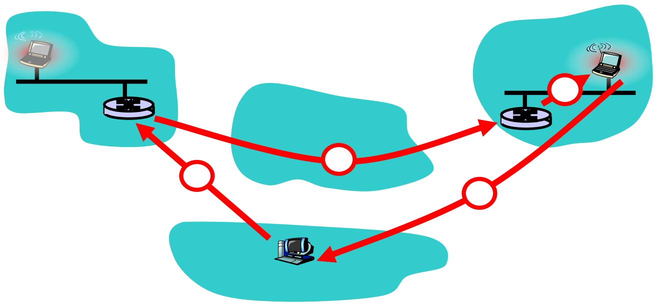
- End result:
  - Foreign agent knows about mobile
  - Home agent knows location of mobile

Mobility via Indirect Routing



Indirect Routing: Comments

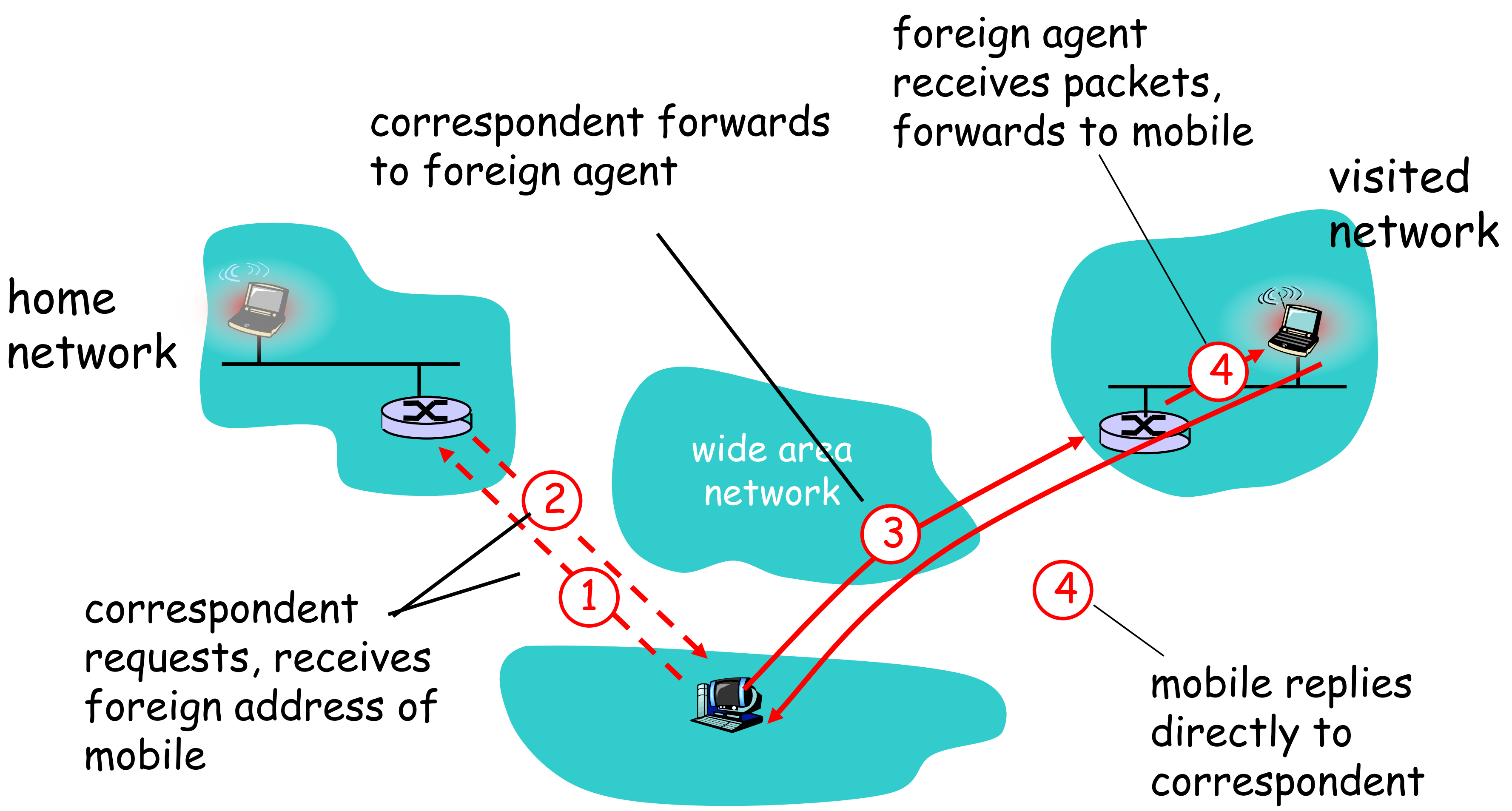
- Mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- Foreign agent functions may be done by mobile itself
- Triangle routing: correspondent-home-network-mobile
  - Inefficient when correspondent, mobile are in same network



Indirect Routing: Moving between Networks

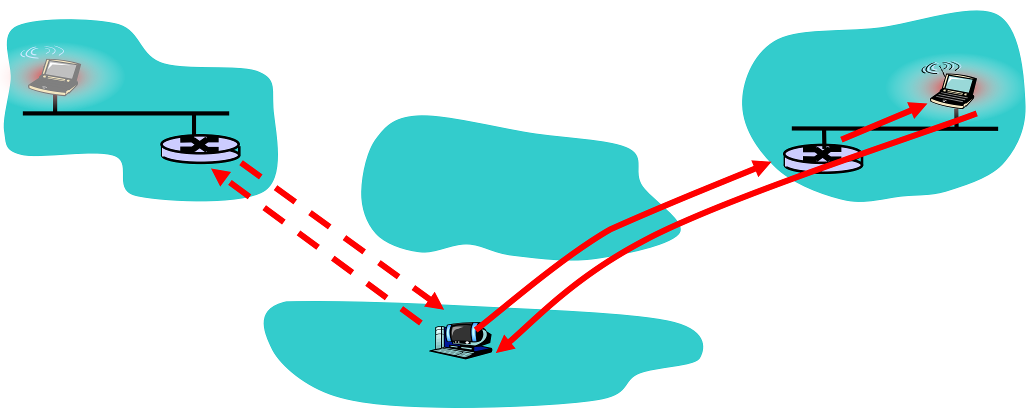
- Suppose mobile user moves to another network
  - Registers with new foreign agent
  - New foreign agent registers with home agent
  - Home agent update care-of-address for mobile
  - Packets continue to be forwarded to mobile (but with new care-of-address)
- Mobility, changing foreign networks transparent: *on going connections can be maintained!*

Mobility via Direct Routing



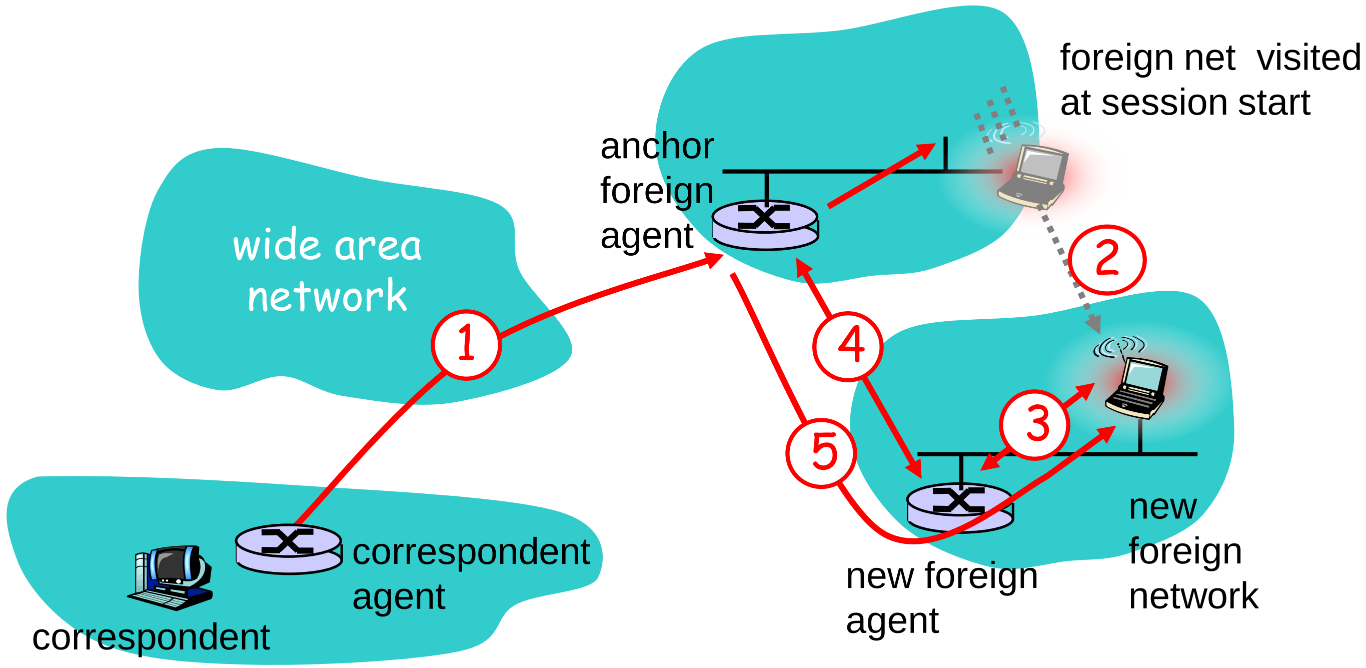
Mobility via Direct Routing: Comments

- Overcome triangle routing problem
- Non-transparent to correspondent: correspondent must get care-of-address from home agent
  - What if mobile changes visited network?



Accommodating Mobility with Direct Routing

- Anchor foreign agent: FA in first visited network
- Data always routed first to anchor FA
- When mobile moves: new FA arranges to have data forwarded from old FA (chaining)



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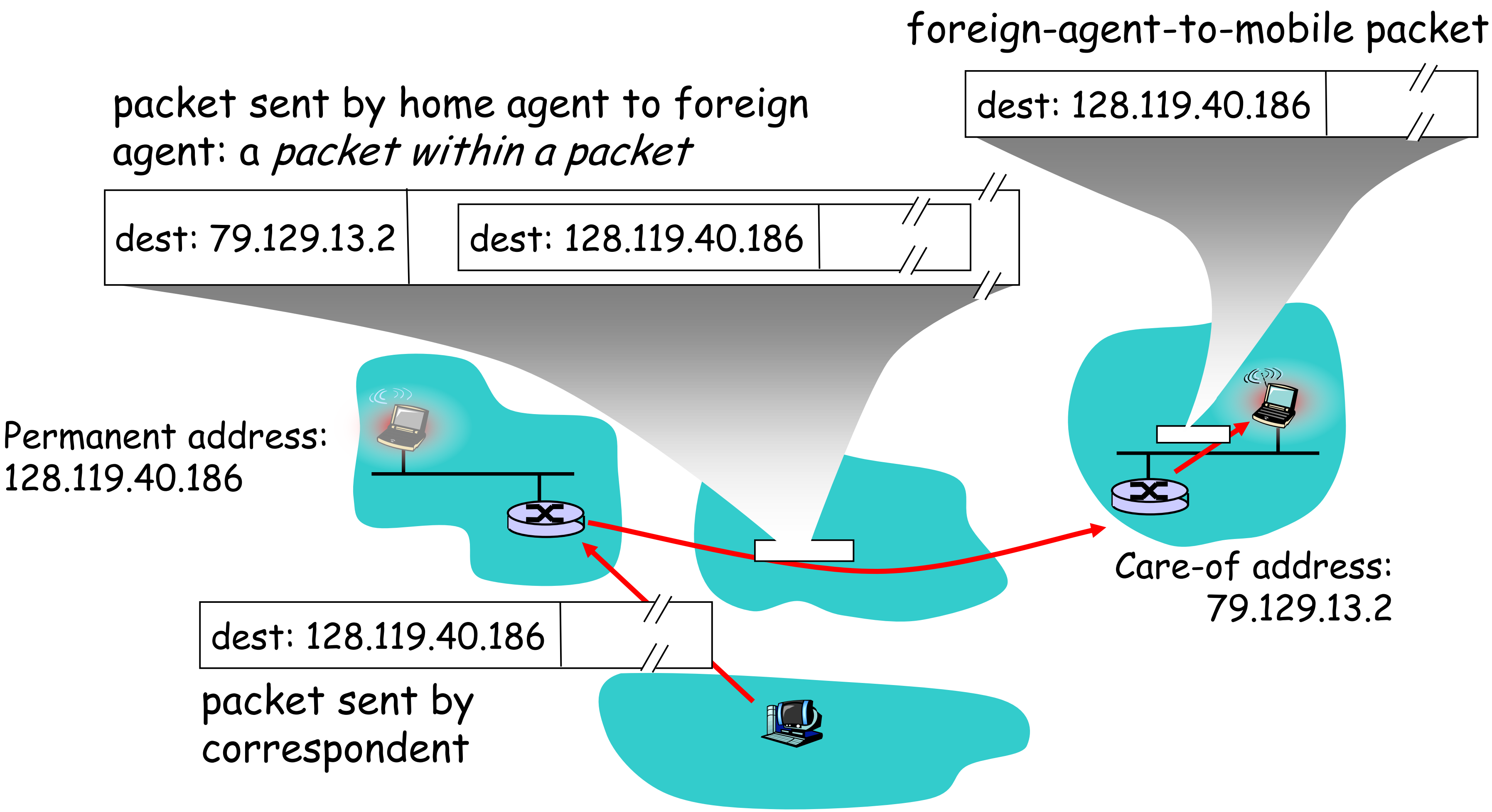
Mobile IP

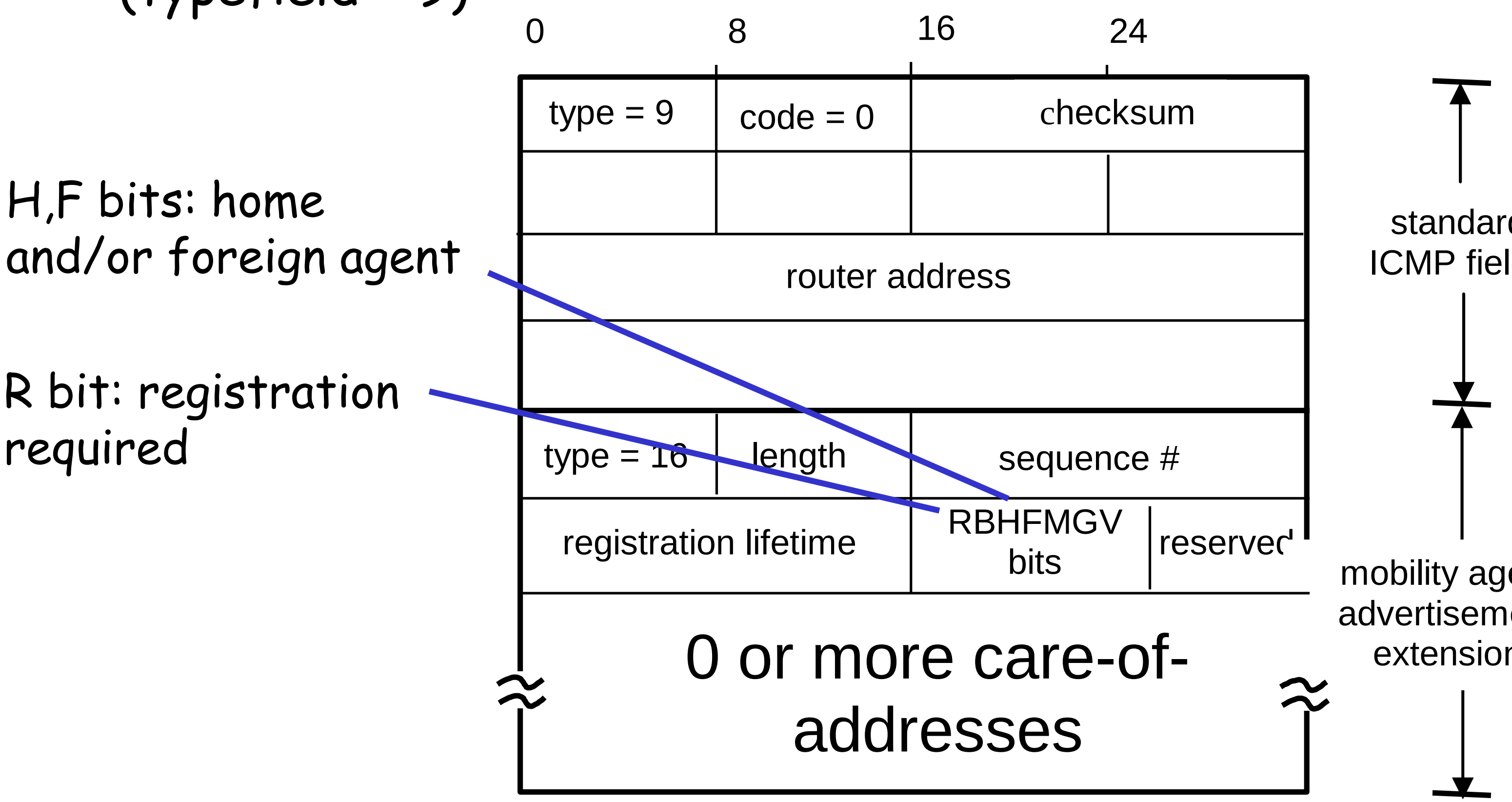
- RFC 3344
- Has many features we've seen:
  - Home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet)
- Three components to standard:
  - Indirect routing of datagrams
  - Agent discovery
  - Registration with home agent

Mobile IP: Indirect Routing

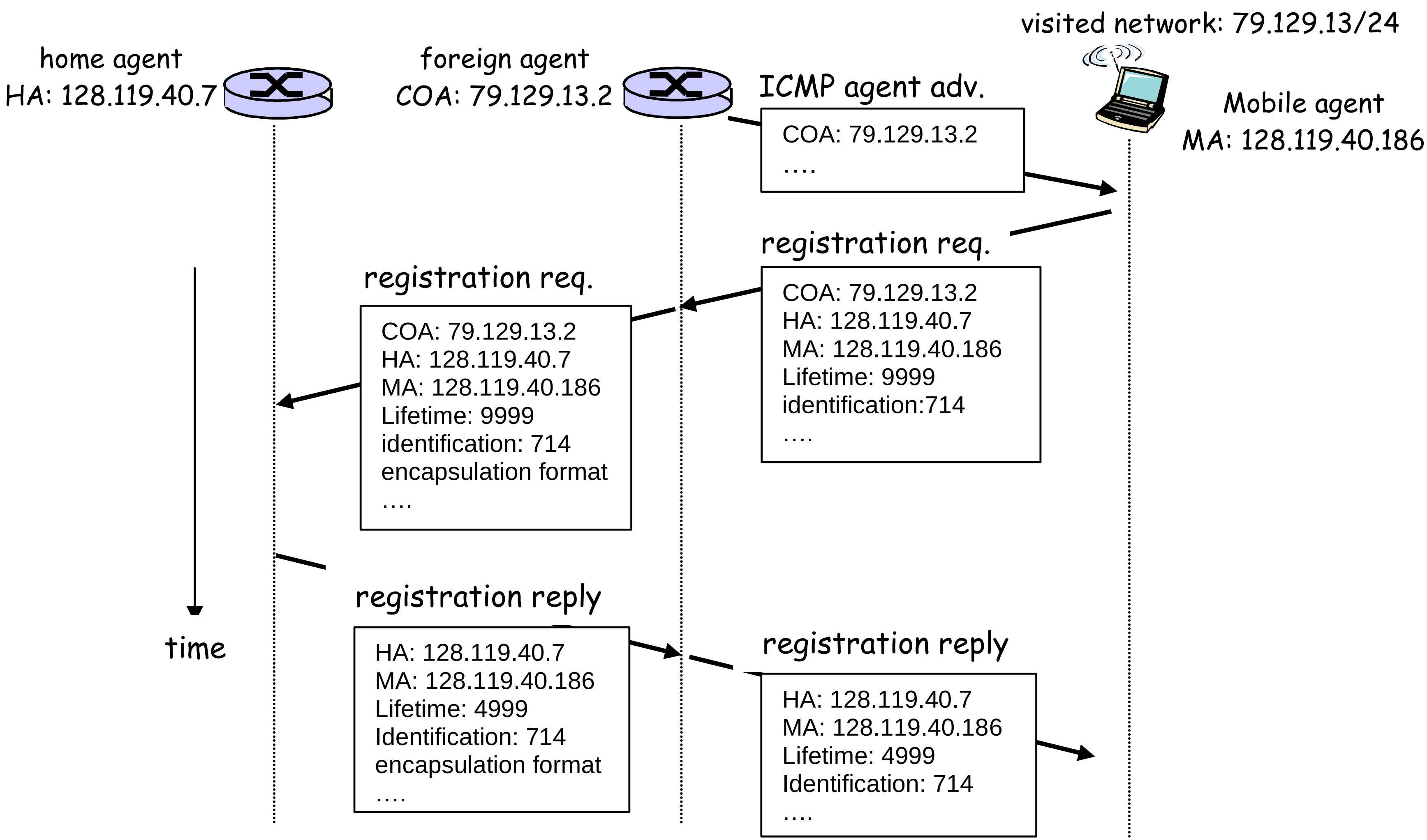


Mobile IP: Agent Discovery

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

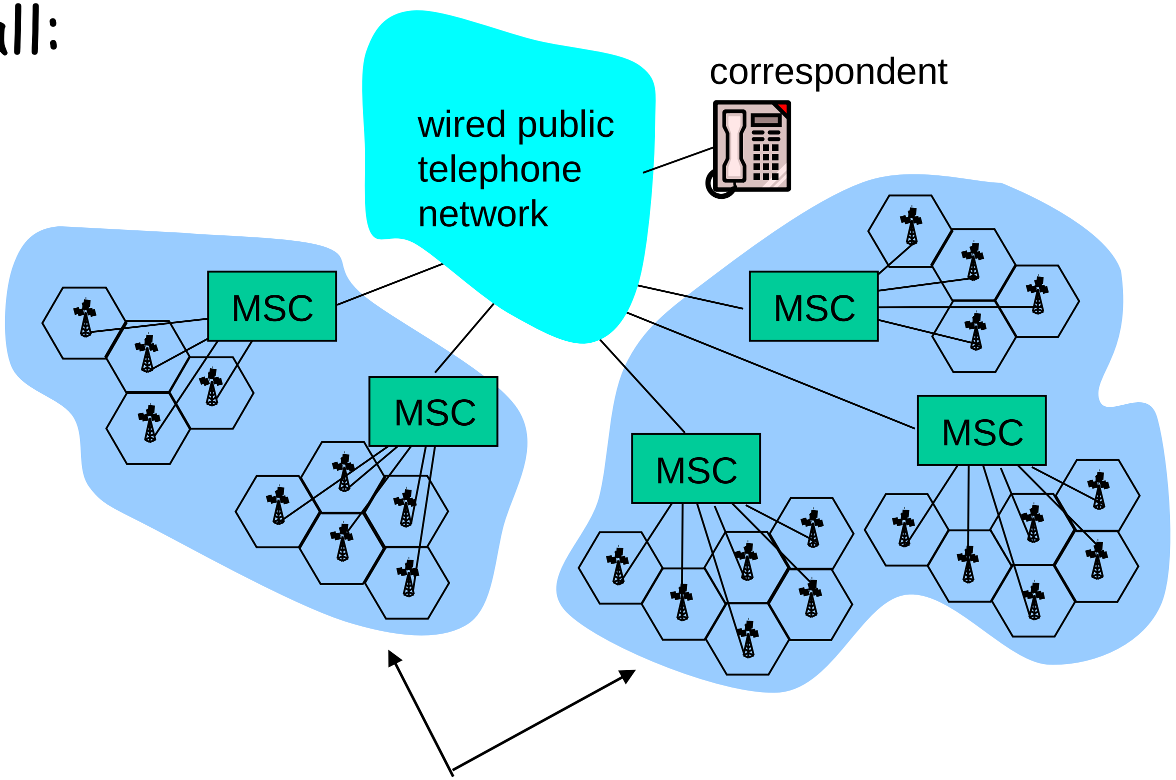


Mobile IP: Registration Example



Components of Cellular Network Architecture

recall:

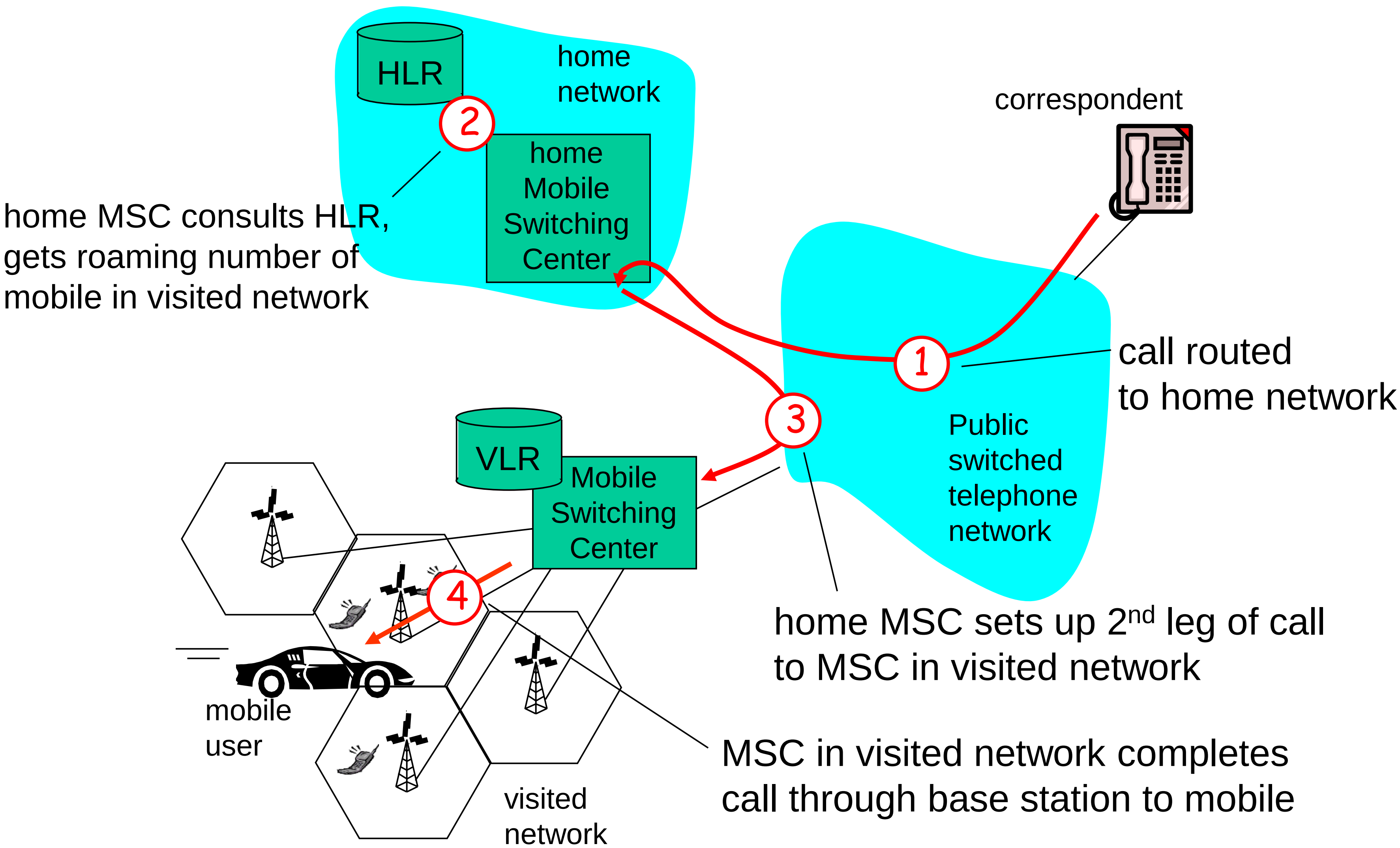


different cellular networks, operated by different providers

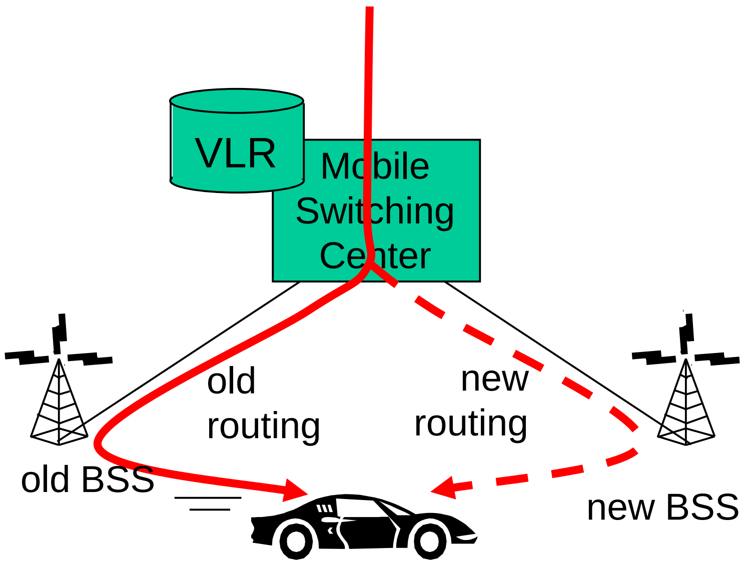
Handling Mobility in Cellular Networks

- *Home network:* network of cellular provider you subscribe to (e.g., Sprint PCS, Verizon)
  - *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

GSM: Indirect Routing to Mobile

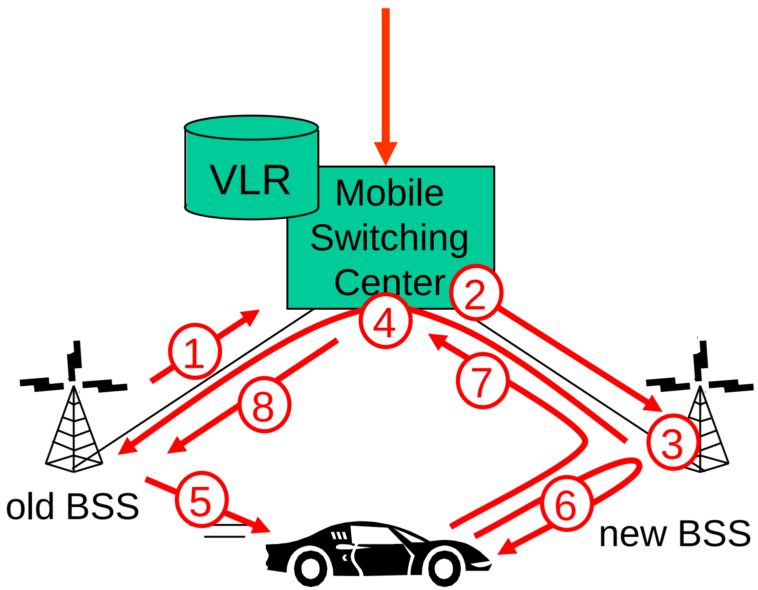


GSM: Handoff with Common MSC



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

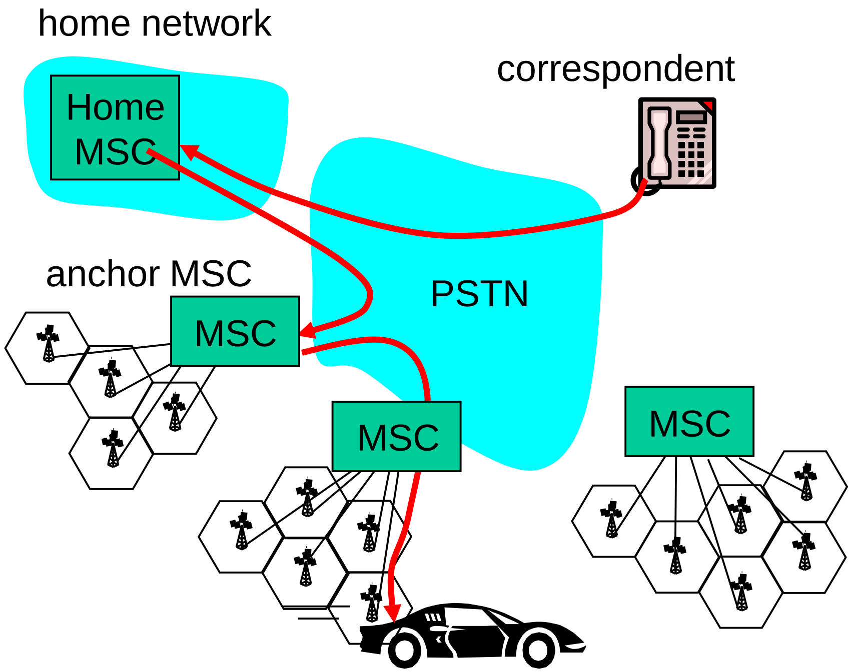
GSM: Handoff with Common MSC



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

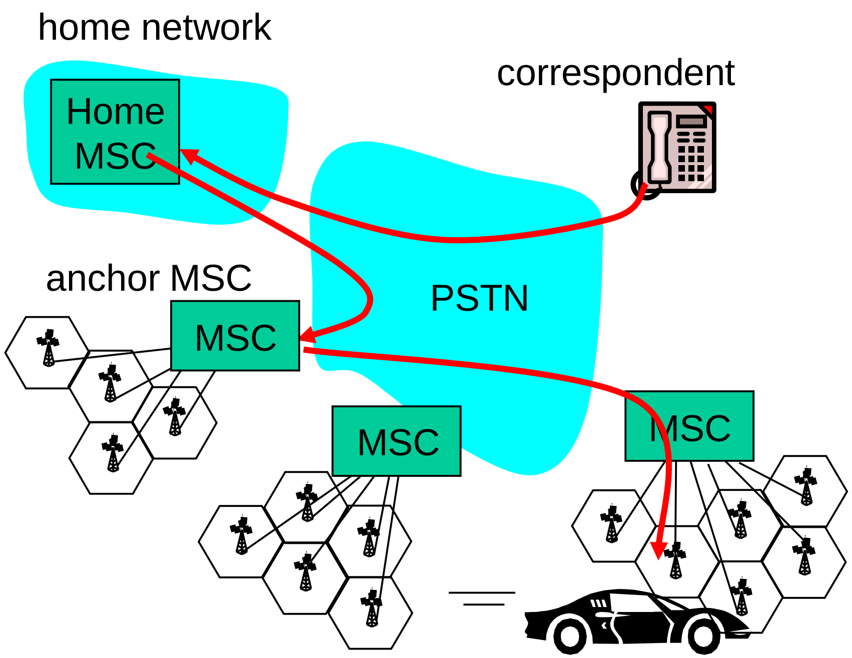
GSM: Handoff between MSCs



(a) before handoff

- *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

GSM: Handoff between MSCs



(b) after handoff

- *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

Mobility: GSM versus Mobile IP

GSM element	Comment on GSM element	Mobile IP element
Home system	Network to which mobile user's permanent phone number belongs	**Home network**
Gateway Mobile Switching Center, or "home MSC". Home Location Register (HLR)	Home MSC: point of contact to obtain routable address of mobile user. HLR: database in home system containing permanent phone number, profile information, current location of mobile user, subscription information	**Home agent**
Visited System	Network other than home system where mobile user is currently residing	**Visited network**
Visited Mobile services Switching Center. Visitor Location Record (VLR)	Visited MSC: responsible for setting up calls to/from mobile nodes in cells associated with MSC. VLR: temporary database entry in visited system, containing subscription information for each visiting mobile user	**Foreign agent**
Mobile Station Roaming Number (MSRN), or "roaming number"	Routable address for telephone call segment between home MSC and visited MSC, visible to neither the mobile nor the correspondent.	**Care-of-address**

Outline

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Wireless

- 4.2 Wireless links, characteristics
- 4.3 IEEE 802.11 wireless LANs ("wi-fi")
- 4.4 Cellular Internet Access
  - architecture
  - standards (e.g., GSM)
- 4.5 wireless TCP

Mobility

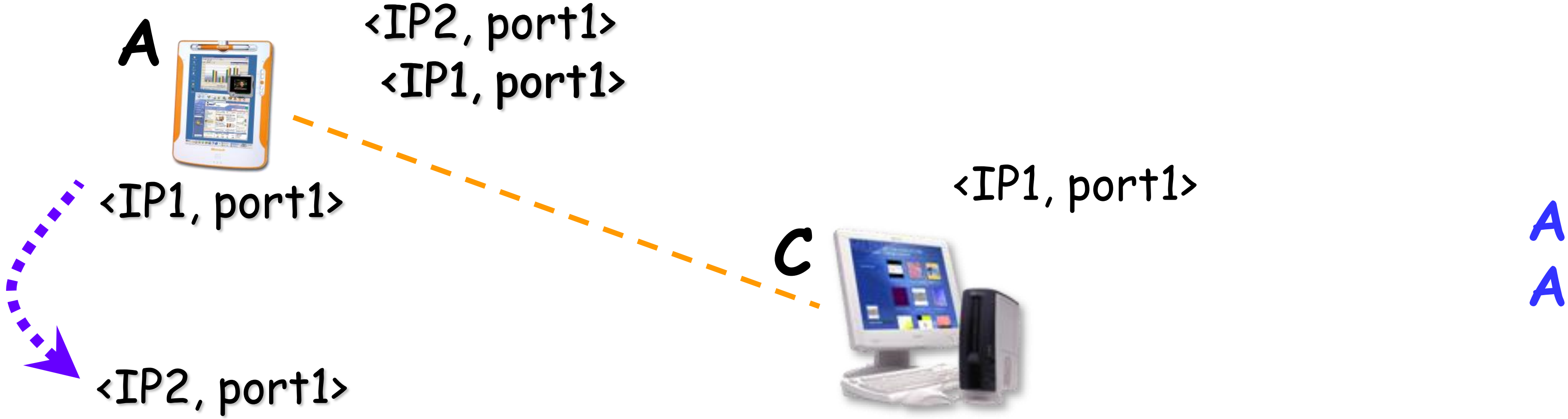
- 4.6 Principles: addressing and routing to mobile users
- 4.7 Mobile IP
- 4.8 Handling mobility in cellular networks
- 4.9 End-to-end mobility
- 4.10 Mobility and higher-layer protocols

4.11 Summary

End-to-End Mobility

- Re-visit Mobile IP solution
  - Network centric
  - Home Agent needs handle not only signaling but also data packets
  - Network is hard to change
- End-to-end mobility
  - Mobility solution without Home Agent!
  - Easy to deploy

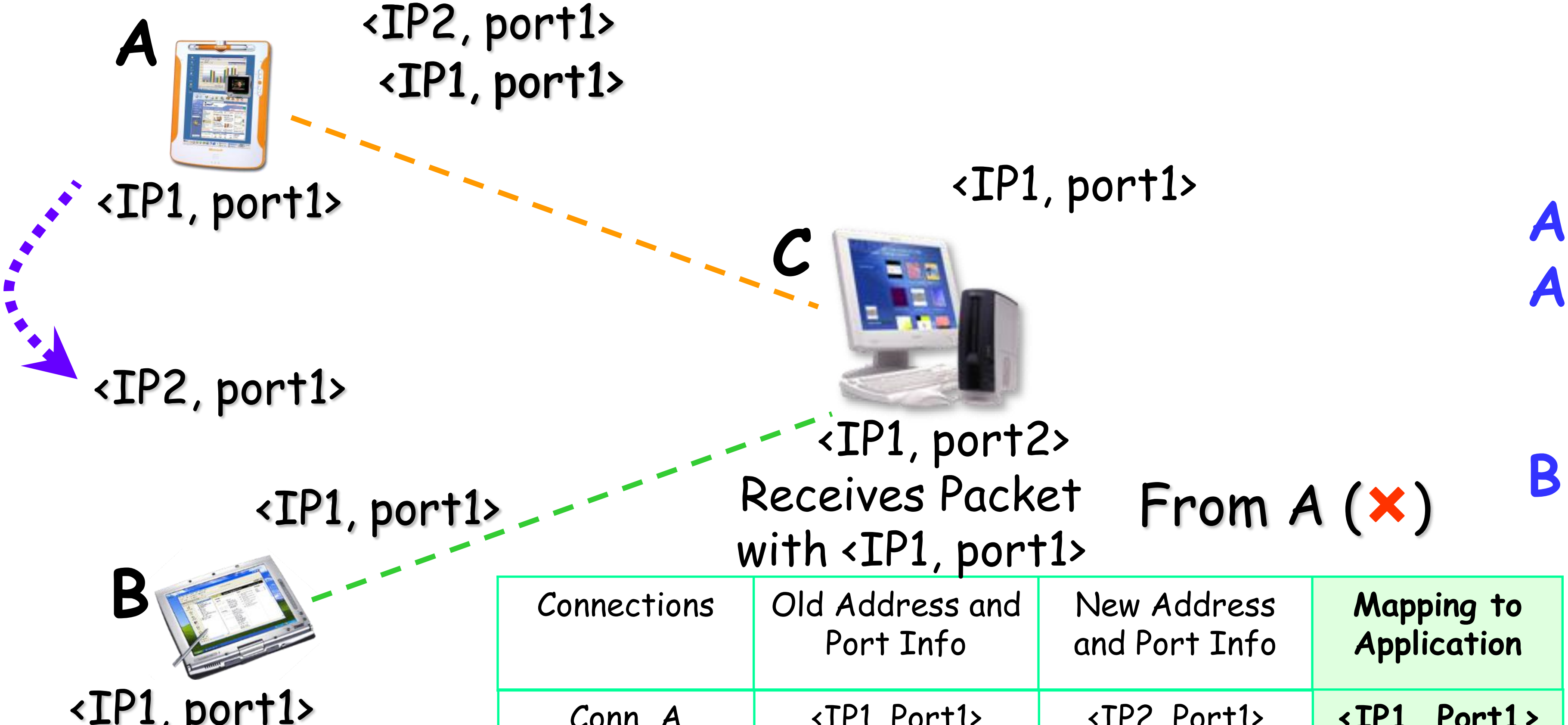
Local Address Translation



Connections	Old Address and Port Info	New Address and Port Info	**Mapping to Application**
Conn_A	<IP1, Port1>	<IP2, Port1>	**<IP1, Port1>**

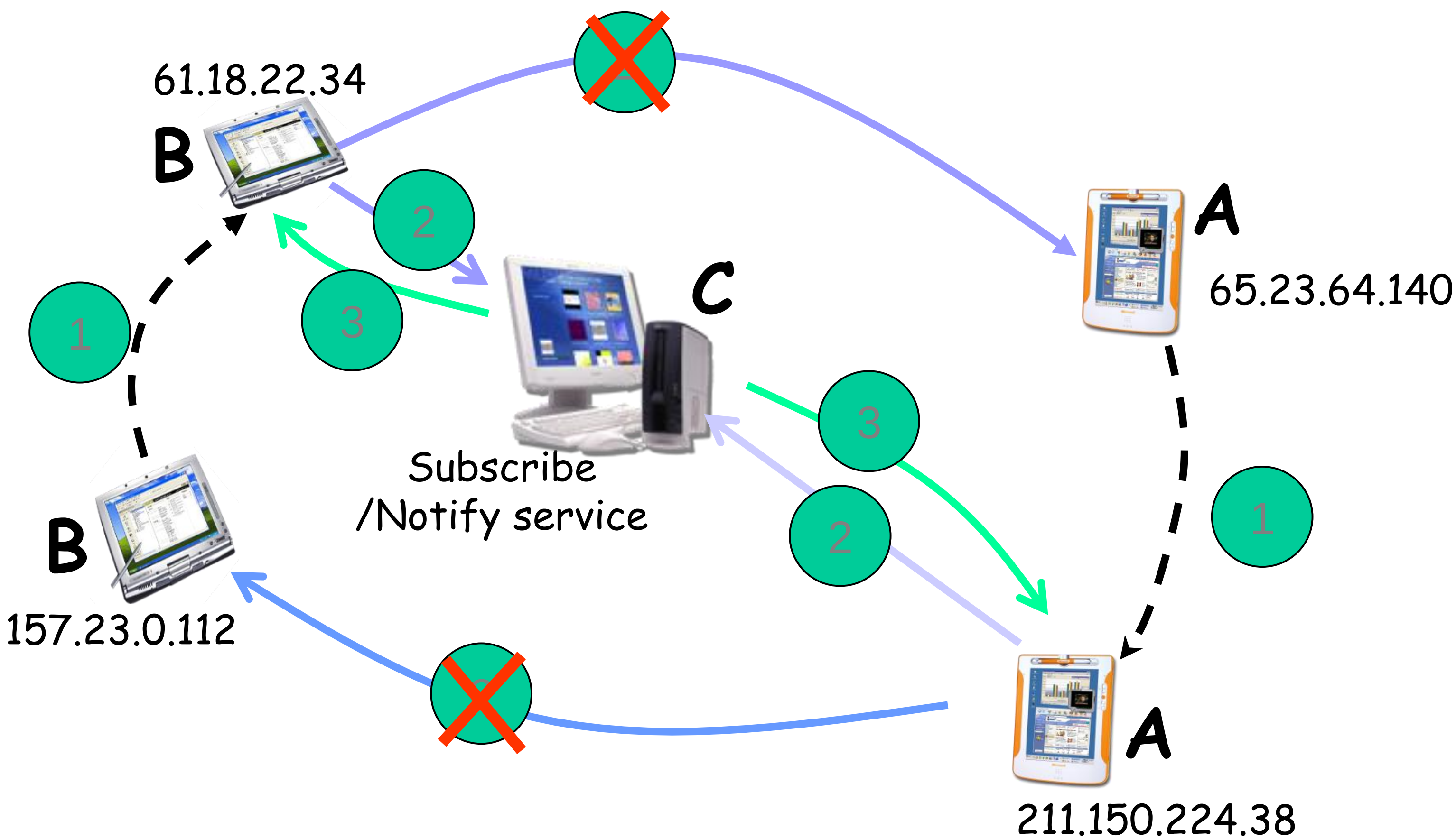
Transparent to Legacy Applications

- Issue
- Solution



Connections	Old Address and Port Info	New Address and Port Info	**Mapping to Application**
Conn_A	<IP1, Port1>	<IP2, Port1>	**<IP1, Port1>**
Conn_B		<IP1, Port1>	**<IP1, Port2>**

Simultaneous Movements Support



A moves from 65.23.64.140 to 211.150.224.38

B moves from 157.23.0.112 to 61.18.22.34

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Wireless, 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

Summary

Wireless

- Wireless links:
  - Capacity, distance
  - Channel impairments
- IEEE 802.11 (“wi-fi”)
  - CSMA/CA reflects wireless channel characteristics
- Cellular access
  - Architecture
  - Standards (e.g., GSM, CDMA-2000, UMTS)
- Wireless TCP

Mobility

- Principles: addressing, routing to mobile users
  - Home, visited networks
  - Direct, indirect routing
  - Care-of-addresses
- Case studies
  - Mobile IP
  - Mobility in GSM
  - End-to-end mobility
- Impact on higher-layer protocols