Mobile and Sensor Systems

Lecture 2: Mobile Medium Access Control Protocols and Wireless Systems

Dr Cecilia Mascolo

UNIVERSITY OF CAMBRIDGE

In this lecture

- We will describe medium access control protocols and wireless systems (wifi networks, personal area networks, cellular networks)

Wireless Link Characteristics

Differences from wired networks:

– *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.

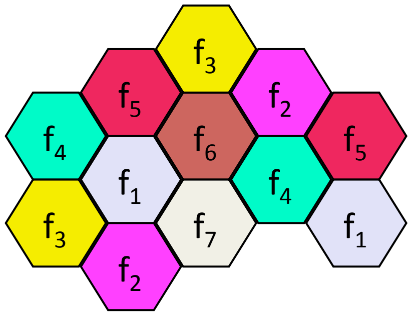
These characteristics make communication across (even a point to point) wireless link much more "difficult" .

Wireless Medium as Shared Medium

- The access to the wireless needs to be shared among the various transmitters.
- How?
  - Multiplexing the medium:
    - Time (fixed or dynamic)
    - Space
    - Frequency
    - Code

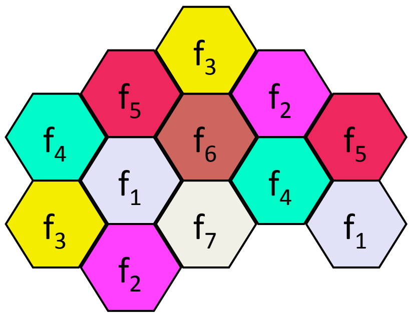
Multiplexing based Sharing

- FDMA (Frequency Division Multiple Access):
  - assign a certain frequency to a transmission channel between a sender and a receiver.
  - permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum).



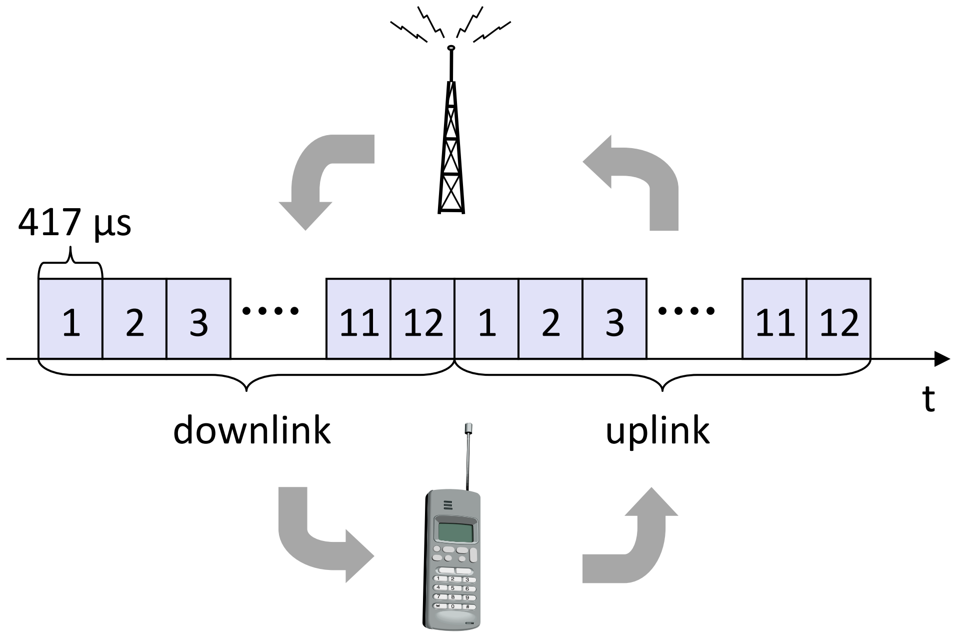
Multiplexing based Sharing

- SDMA (Space Division Multiple Access):
  - segment space into sectors, use directed antennas
  - cell structure



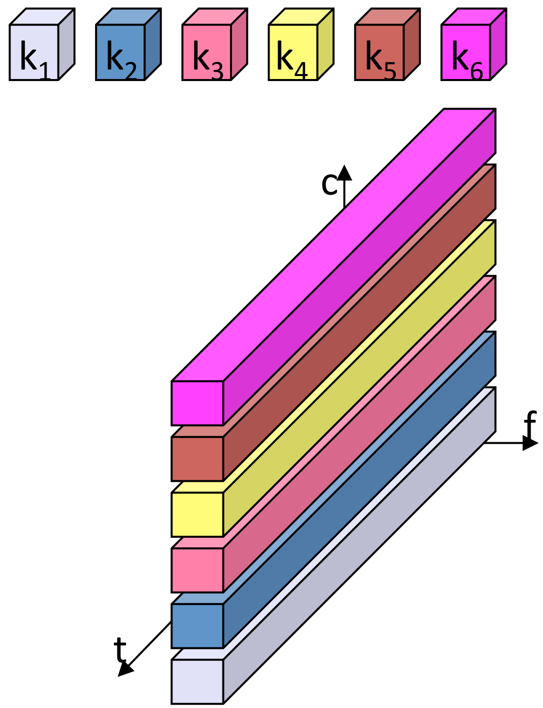
Multiplexing based Sharing

- TDMA (Time Division Multiple Access):
  - assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time.



Multiplexing based Sharing

- CDMA (Code Division Multiple Access)
  - Assign a code to each sender so that all of a sender's transmissions is on a unique "dimension"



Limitations of multiplexing

- Multiplexing is one way to share the medium through the definition of "channels".
- Once channels are established, packets will be sent through that:
  - Might be a bit rigid as a method; for example, frequency division multiplexing would have issues with large numbers of users.
  - Also depending on traffic and time some users might want to send more or less;
- More ad hoc approaches exist which allow channels to be shared in a "statistical" way.

Review: Ethernet Medium Access Control (MAC)

- In Ethernet based fixed networks where you have wires between computers:
- CS (Carrier Sense): listen for others' transmissions before transmitting; defer to others you hear.
- CD (Collision Detection): as you transmit, listen and verify you hear exactly what you send; if not, back off random interval, within exponentially longer range each time you transmit unsuccessfully.

Can CD be applied on wireless networks?

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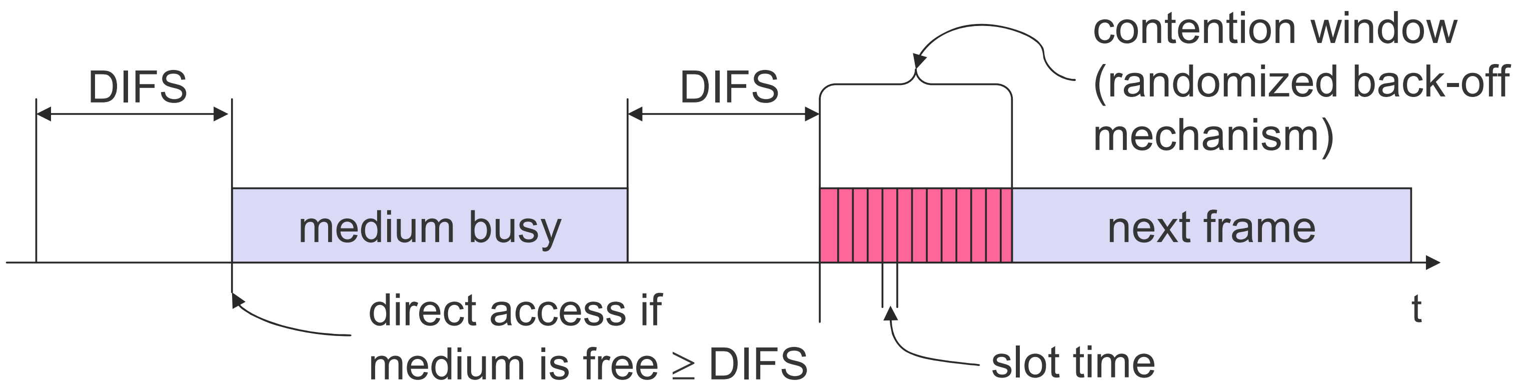
Can we apply the same MAC protocols in wireless?

- Problems in wireless networks:
  - signal strength decreases proportionally to the square of the distance;
  - the sender would apply CS and CD, but collisions happen at the receiver;
  - it might be the case that a sender cannot "hear" the collision, i.e., CD does not work;
  - furthermore, CS might not work if, e.g., a terminal is "hidden".

CSMA/CA: Carrier Sensing Multiple Access Protocol with Collision Avoidance



CSMA/CA: sense medium. If free transmit (although this might generate collision at the receiver). If not, wait with a back off strategy. Transmit when medium is sensed free.

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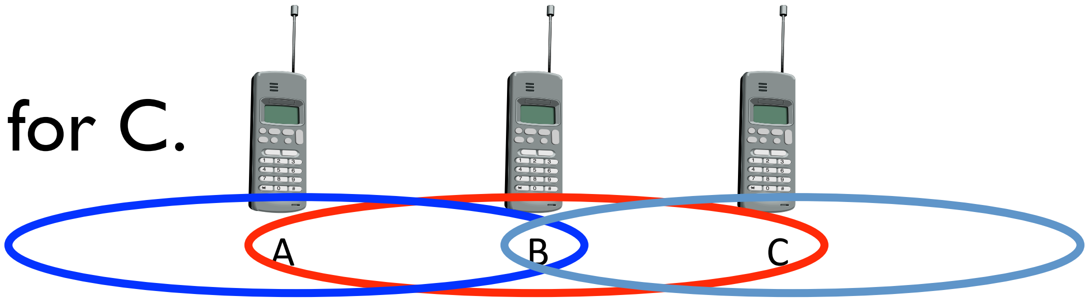
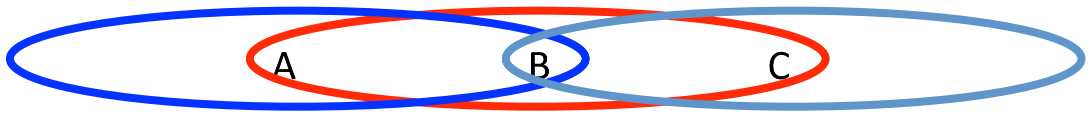
Hidden Terminal

- Hidden terminals:
  - A sends to B, C cannot receive from A.
  - C wants to send to B, C senses a "free" medium (CS fails).
  - Collision at B, A cannot receive the collision (CD fails).
  - A is "hidden" for C.



Exposed Terminal

- Exposed terminals:
  - B sends to A, C wants to send to another terminal (not A or B).
  - C has to wait, CS signals a medium in use.
  - but A is outside the radio range of C, therefore waiting is not necessary.
  - C is "exposed" to B.



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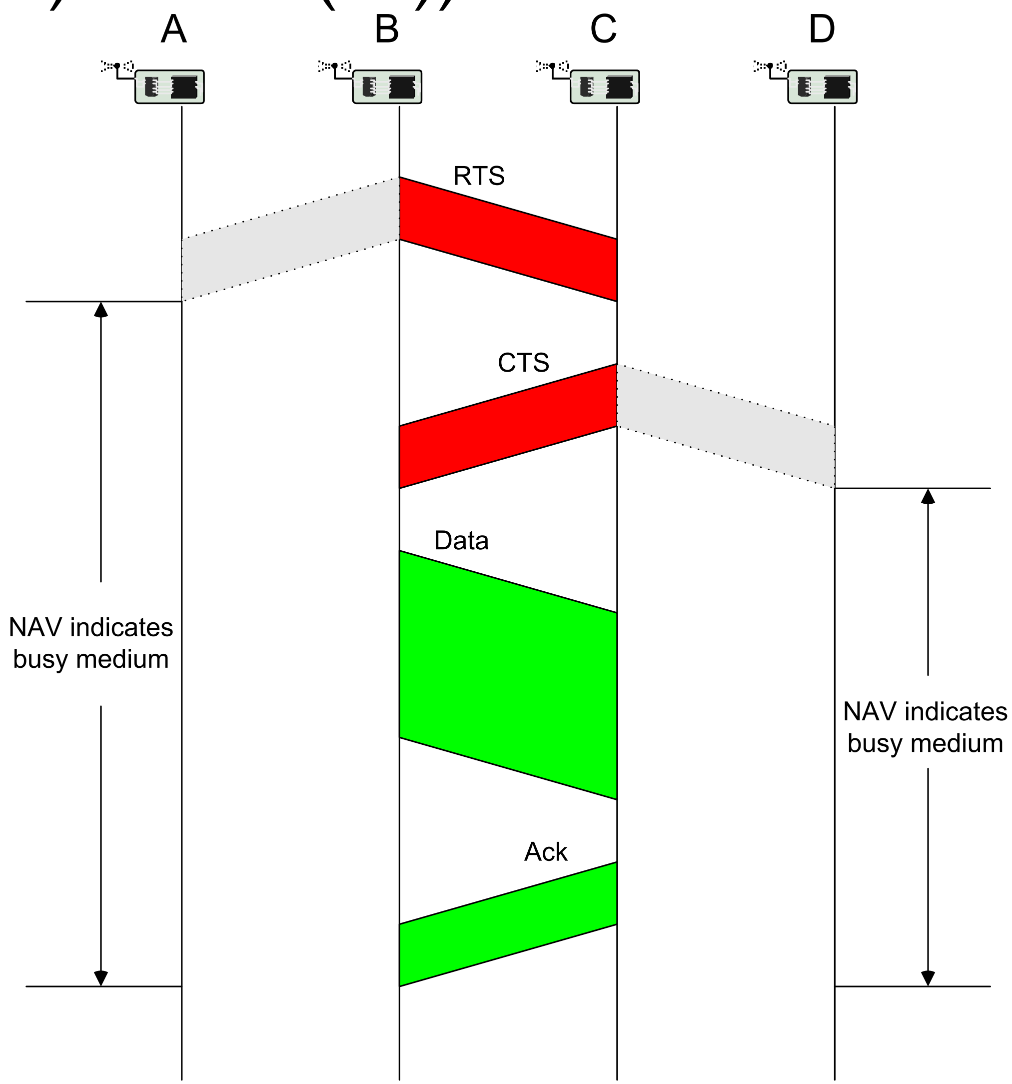
Multiple Access with Collision Avoidance (for Wireless): MACA(W))

- Sender B asks receiver C whether C is able to receive a transmission ***Request to Send (RTS).***
- Receiver C agrees, sends out a ***Clear to Send*** (***CTS***).
- Potential interferers overhear either RTS or CTS and know about impending transmission and for how long it will last.
  - Store this information in a ***Network Allocation Vector.***
- B sends, C acks:

! ***MACA(W) protocol*** (used e.g. in ***IEEE 802.11***).



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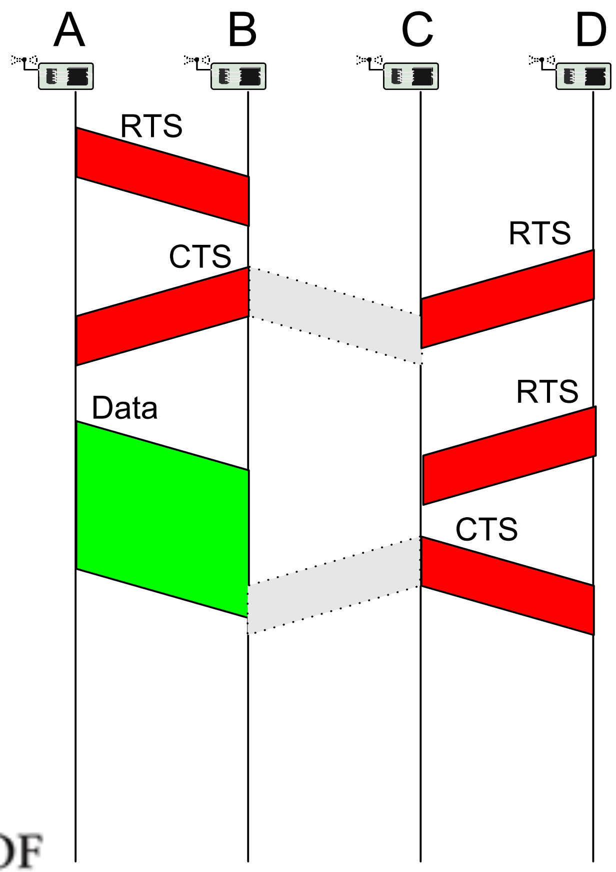
MACA(W)

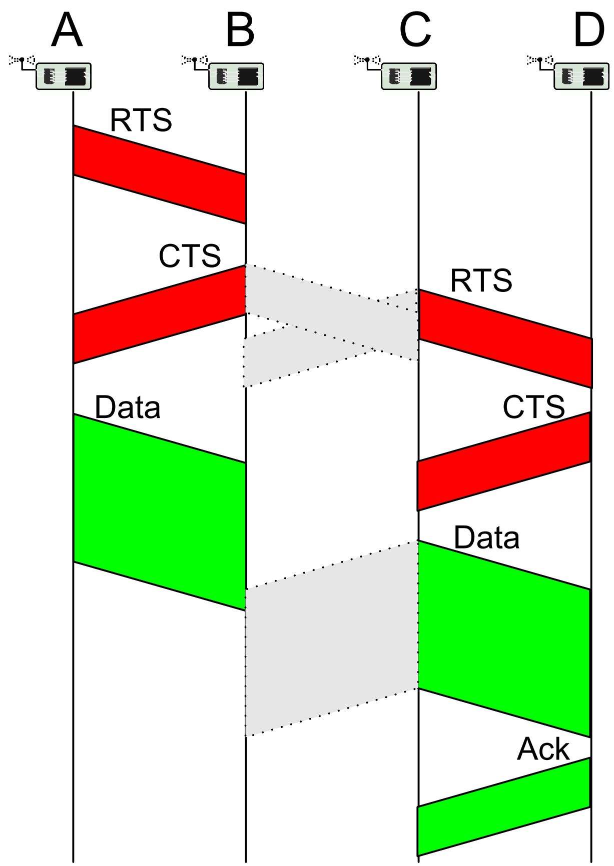
- Absent CTS, sender backs off exponentially before retrying.
- RTS and CTS can still themselves collide at their receivers; less chance as they're short.

- **What's the effect on exposed terminal problem?**

RTS/CTS

- RTS/CTS ameliorate, but do not solve hidden/exposed terminal problems.
- Example problem cases:





The 802.11 Protocol

- 802.11 uses 2 modes of operation: a basic CSMA/CA (in base station mode) and the RTS/CTS mode.
- Generally 802.11 drivers leave the RTS/CTS off by default.
- Also tests in practice show that hidden terminal might not be a problem in most cases as interference range is more than double communication range. Consider A->B<-C when A transmits it is very likely C can sense A's carrier directly.

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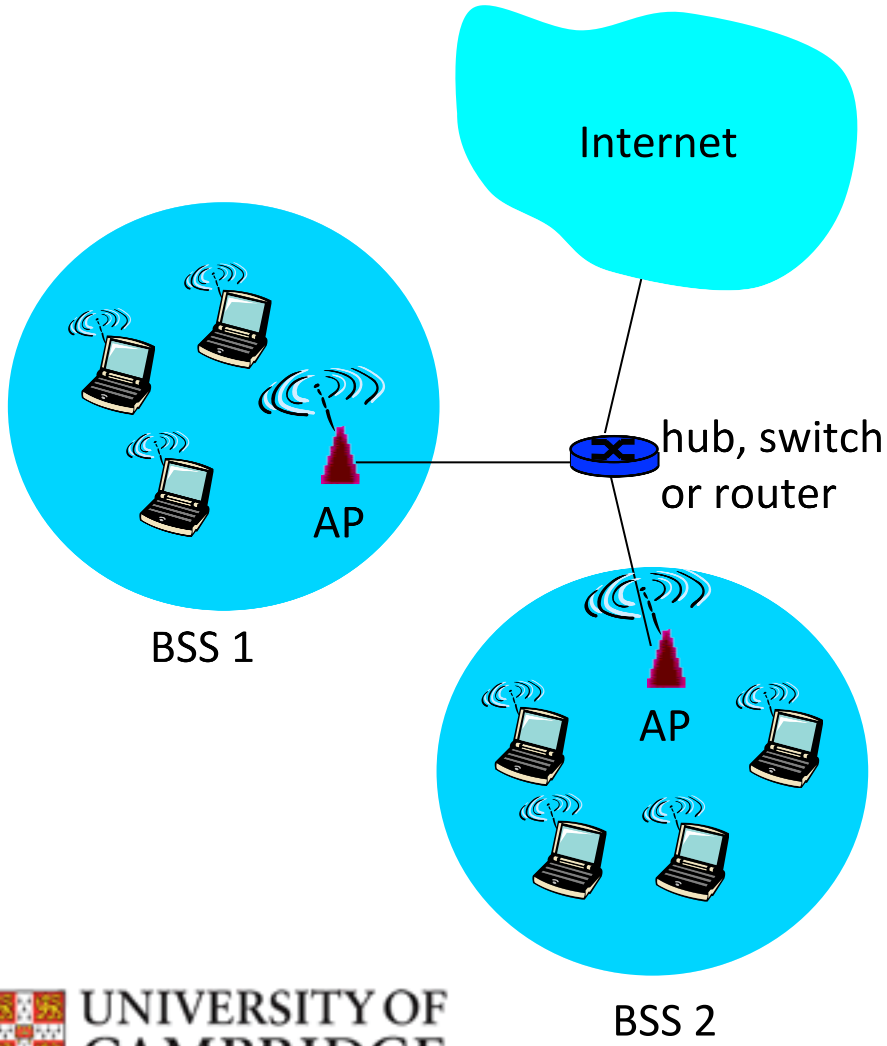
IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-5 GHz unlicensed spectrum
  - up to 11 Mbps

- 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 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

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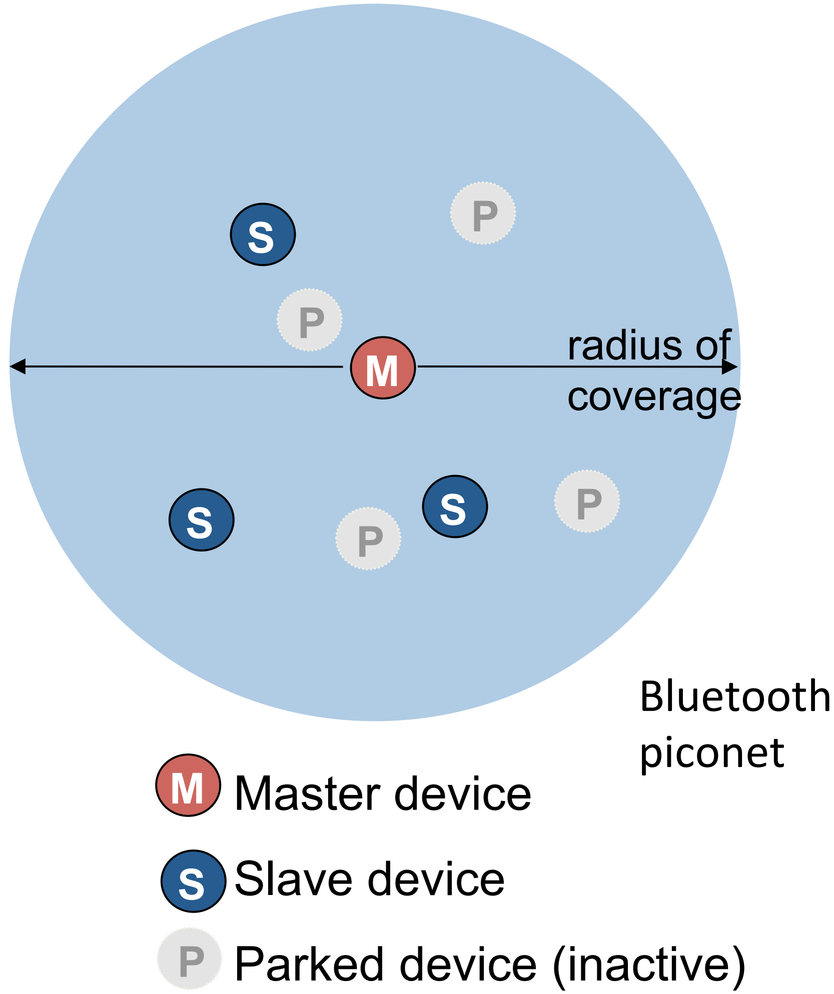
802.11: Channels, Association

- 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.
  - will typically run DHCP to get IP address in AP's subnet.

802.15: Personal Area Networks

- Less than 10m diameter.
- Ad hoc: no infrastructure.
- Master/slaves architecture:
  - slaves request permission to send (to master).
  - master grants requests.
- 802.15: evolved from Bluetooth specification.



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Bluetooth and Zigbee

- Two main short-range technologies:
  - Bluetooth (802.15.1)
  - Zigbee (802.15.4)
- Bluetooth provides a "cable replacement" data rate of over a Megabit per second.
- Zigbee is targeted at lower-powered, lower-data-rate, lower-duty-cycle applications:
  - Environmental sensors
  - Security devices
  - Wall-mounted devices
  - …

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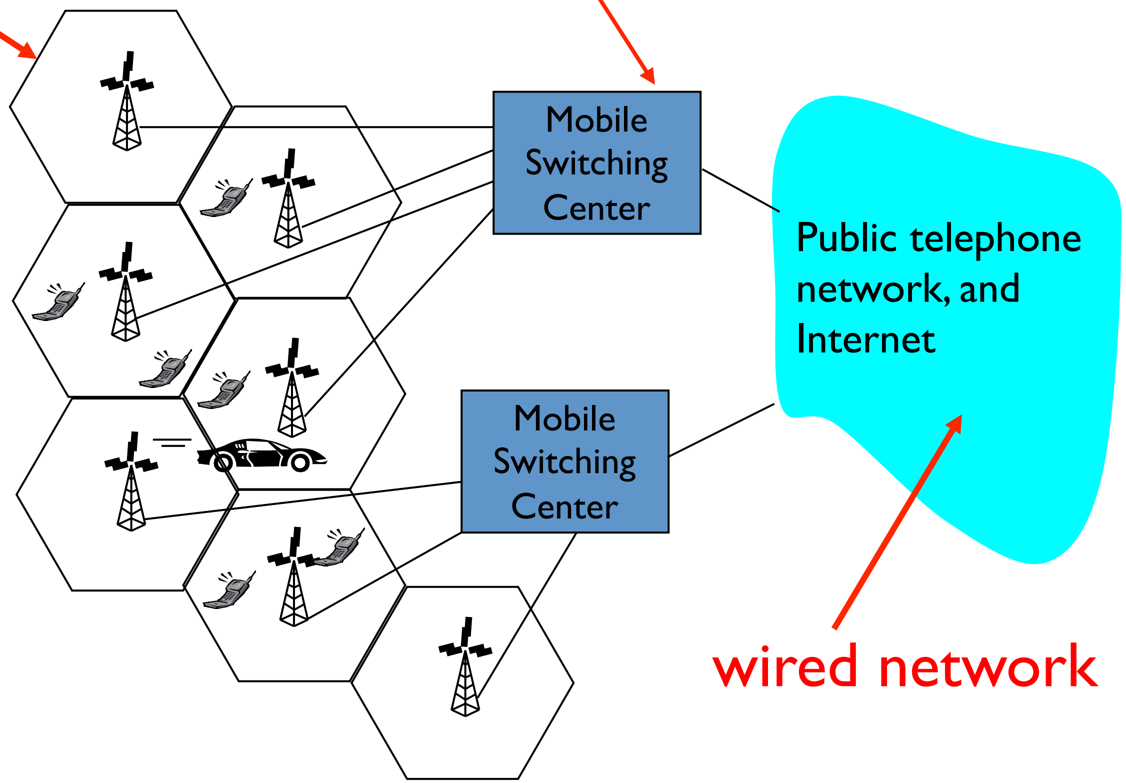
Components of cellular network architecture

MSC

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

cell

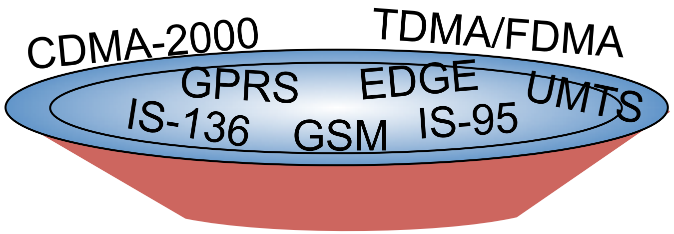
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS



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

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Cellular standards: brief survey

2.5 G systems: voice and data channels

- 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

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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: 1xEvolution Data Optimized (1xEVDO) up to 14 Mbps

Handling mobility in cellular networks

- *home network:* network of cellular provider you subscribe to (e.g., Vodafone, O2, etc.)
  - *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

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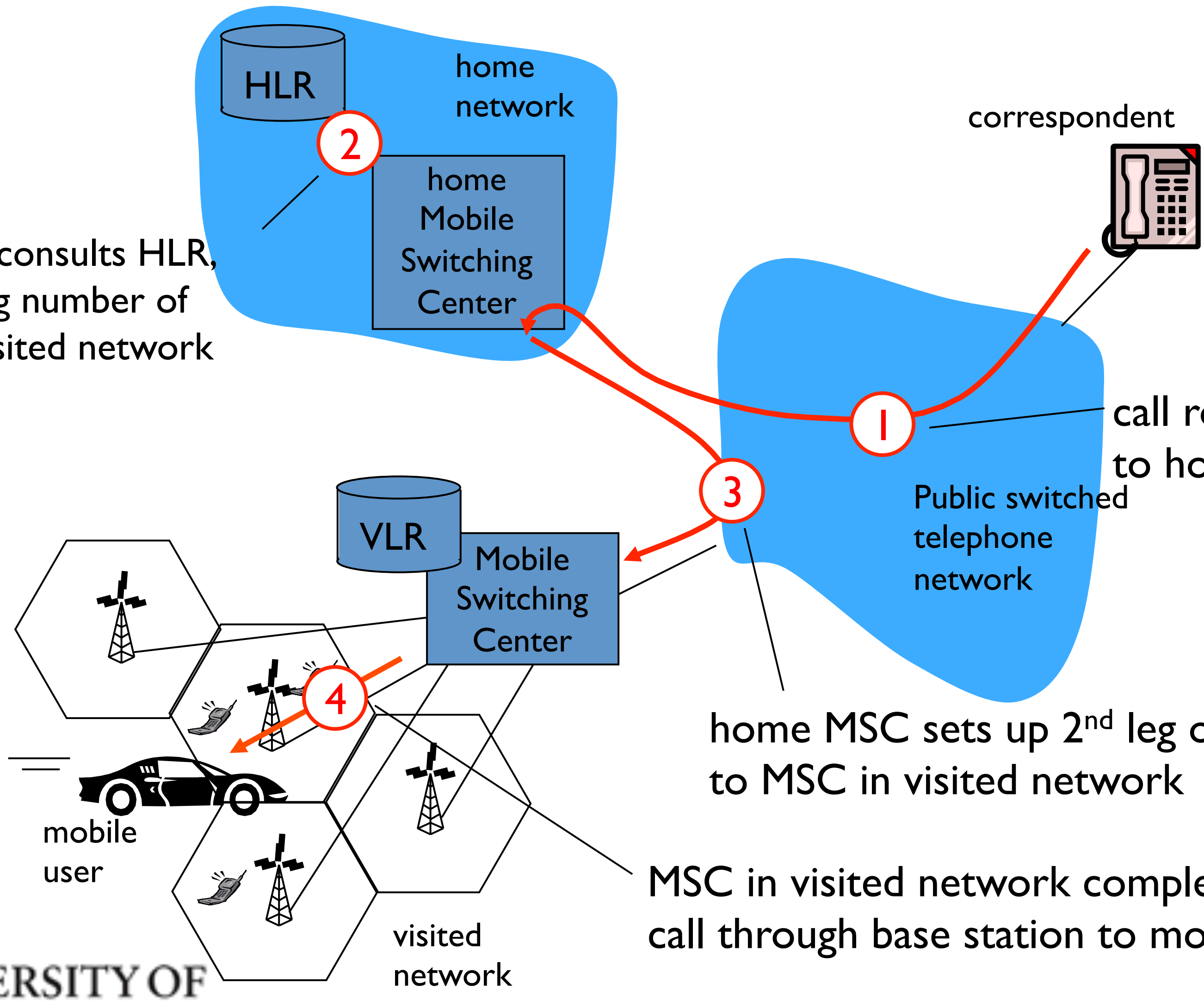
GSM: Indirect Routing to Mobile



home MSC consults HLR, gets roaming number of mobile in visited network

call routed to home network

home MSC sets up 2nd leg of call to MSC in visited network

MSC in visited network completes call through base station to mobile

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3G Networks

- 3G core network connects radio access networks to the public Internet.
- Given the considerable amount of existing infrastructure, the approach taken by the designers of 3G data services was to leave the existing core GSM cellular network untouched.
- Cellular data functionality was added in parallel to the existing cellular network.

LTE-4G Networks

- Currently being deployed around the world.
- Main differences with 3G are in the network core (“all-IP network” for voice and data) and radio access.
- The maximum data rate for LTE (long-term evolution) is 100 Mbps in the downstream direction and 50 Mbps in the upstream direction, when using 20 MHz worth of wireless spectrum.

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WiMAX

- An additional 4G wireless technology is WiMAX (which stands for World Interoperability for Microwave Access).
- LTE has significant more momentum.

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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.

Reference

- Chapter 6 of James F. Kurose and Keith W. Ross. Computer Networking. A Top Down Approach 6th Edition Pearson 2012.
- Schiller, J. (2003). Mobile communications. Pearson (2nd ed.).

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