CSE 3231
Computer Networks

Mobile and Wireless Networks
part 1

William Allen, PhD

Fall 2020

Mobile and Wireless Networks

- Smartphones combine aspects of mobile phones and mobile computers
  - Provide networked communications via cellular telephone system and local area networking
  - Support standard Internet protocols (TCP/IP, etc.)
  - Use computer-like Operating Systems and apps
- Wireless networks also communicate via radios, but are based on the IEEE 802.11 standard instead of cellular telephony standards
  - Wireless networking and mobile computing are related but not identical

Mobile and Wireless Networks

- M-commerce (mobile-commerce) uses mobile phones
- NFC (Near Field Communication) allows mobile device to act as an RFID smartcard and interact with a nearby reader for payment
- Sensor networks use nodes for gathering and relaying information about the physical state of the world
  - Nodes may be small, separate devices
    - Examples: cameras or phones
  - Or, nodes may be embedded in familiar devices
    - Examples: cars, appliances, wireless parking meters

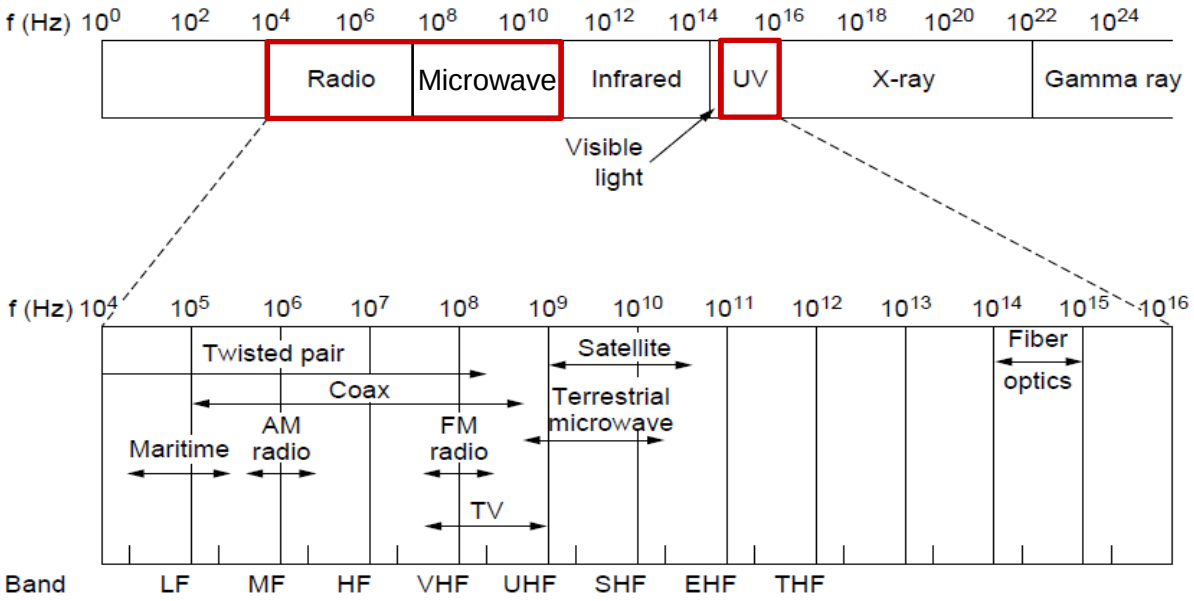
They Use the Electromagnetic Spectrum for Communications

- Radio transmission
  - Omnidirectional waves, easy to generate, travel long distances, penetrate buildings
- Microwave transmission
  - Directional waves requiring focused antennas and repeaters, do not penetrate into buildings
- Infrared transmission
  - Unguided waves for short-range communication, cheap, easy to build, does not penetrate solid walls

Electromagnetic Spectrum

Networks use a range of frequency bands:

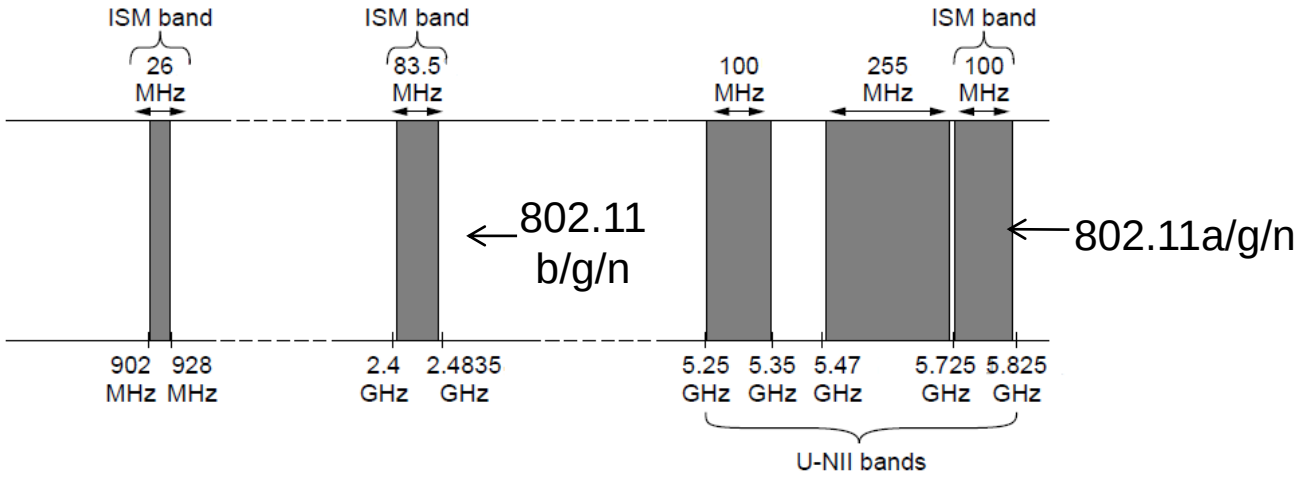
- Radio band: wide-area broadcast, RFID
- Microwave band: LANs and 3G/4G, IoT devices
- Fiber Optic often uses light in the UV-range



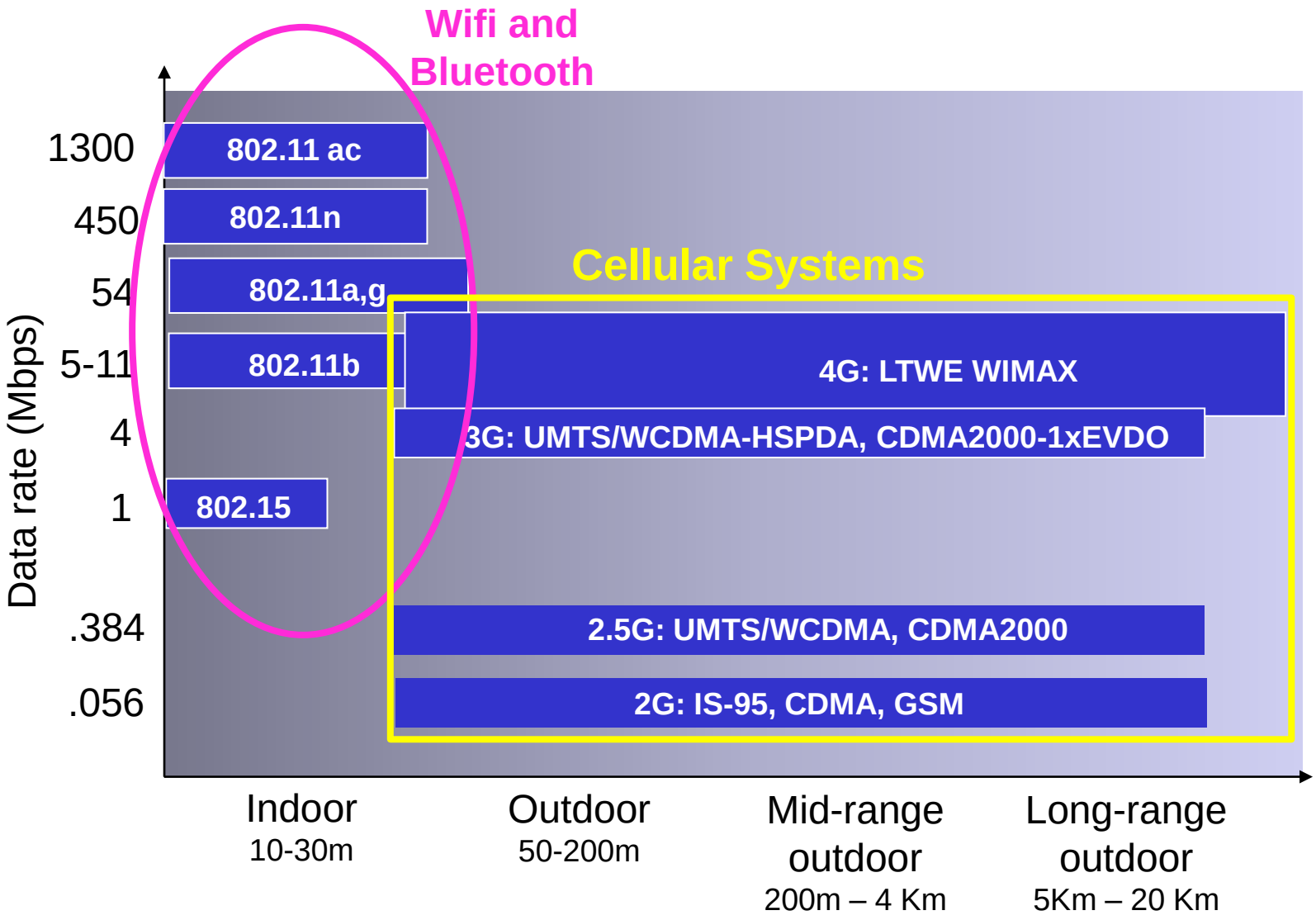
Electromagnetic Spectrum

There are special frequency bands for *Industrial, Scientific, Medical* (ISM) communications:

- No license required for use at low power
- Widely used for home/business networking
  - WiFi, Bluetooth, Zigbee, Z-wave, etc.



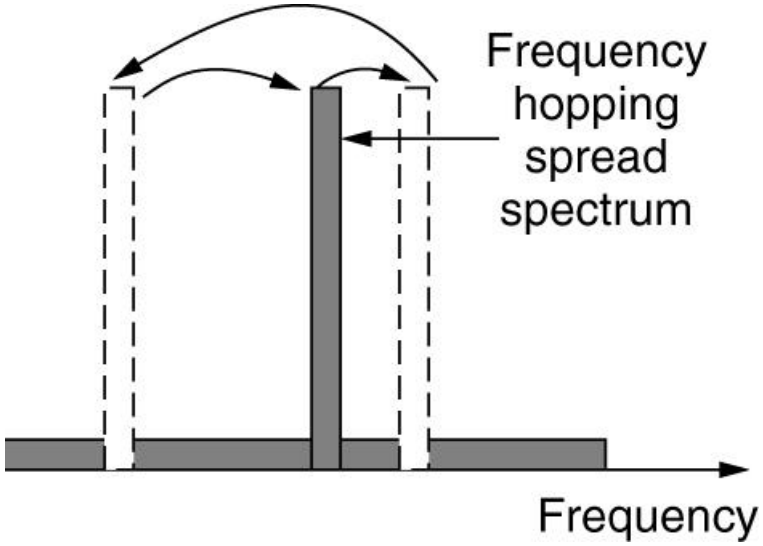
Characteristics of selected wireless links



Wireless Transmission

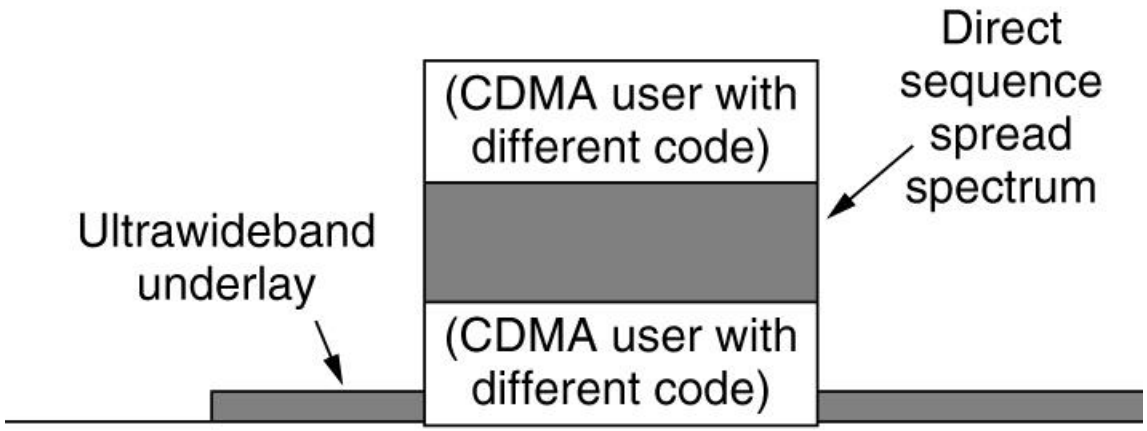
- The electromagnetic spectrum
  - Modulate wave amplitude, frequency, or phase
- Frequency hopping spread spectrum
  - Transmitter hops from frequency to frequency hundreds of times per second
- Direct sequence spread spectrum
  - Code sequence spreads data signal over wider frequency band
- Ultra-wideband communication
  - Sends a series of low-energy rapid pulses, varying their carrier frequencies to communicate information

Frequency Hopping Spread Spectrum



Frequency hopping spread spectrum changes frequency along a pre-determined sequence to avoid interference. The sender and receiver follow the same sequence.

Direct Sequence Spread Spectrum



Direct sequence spread spectrum uses a code sequence to spread the data signal over a wider frequency band.

Mobile Networks

- Early systems used circuit switching because they were derived from the telephone system
  - Connection-oriented networks
  - Caller must dial the called party's number and wait for a connection before talking or sending data
  - Route maintained until call is terminated
- Modern systems moved to packet switching
  - Connectionless networks
  - Every packet is routed independently
  - If some routers go down during a session, the system can dynamically reconfigure itself

Mobile Networks

- First-generation mobile phone systems
  - Transmitted voice calls as continuously varying (analog) signals
- Second-generation (2G) mobile phone systems
  - Transmitted voice calls in digital form to increase capacity, improve security, and offer text messaging
- Third generation (3G) offered both digital voice and broadband digital data services
- 4G: e.g., LTE (Long Term Evolution) technology offers faster speeds than 3G
- 5G technologies have even faster speeds, up to 10 Gbps
  - Main distinction between 4G & 5G: frequency spectrum they use

First-Generation (1G) Technology: Analog Voice

- 1946 push-to-talk systems
- 1960 IMTS (Improved Mobile Telephone System)
  - Two frequencies: one for sending, one for receiving
- 1983 AMPS (Advanced Mobile Phone System)
  - Analog mobile phone system
  - Cells are typically 10 to 20 km across
  - Used FDM to separate channels
  - 832 full-duplex channels that consist of a pair of simplex channels used (Frequency Division Duplex)
  - Each simplex channel is 30 kHz wide
  - 832 channels in AMPS are divided into four categories

Call Management

- Outgoing calls
  - Phone switched on, number entered, CALL button hit
  - Phone transmits called number and its own identity on the access channel
  - Base Station informs the Mobile Switching Center (MSC) and it looks for an available channel for the call
- Incoming calls
  - Idle phones continuously listen to the paging channel to detect messages directed at them
  - Packet sent to base station in the current cell as a broadcast on the paging channel
  - The called phone responds on the access channel
  - Called phone switches to channel and starts ringing sound

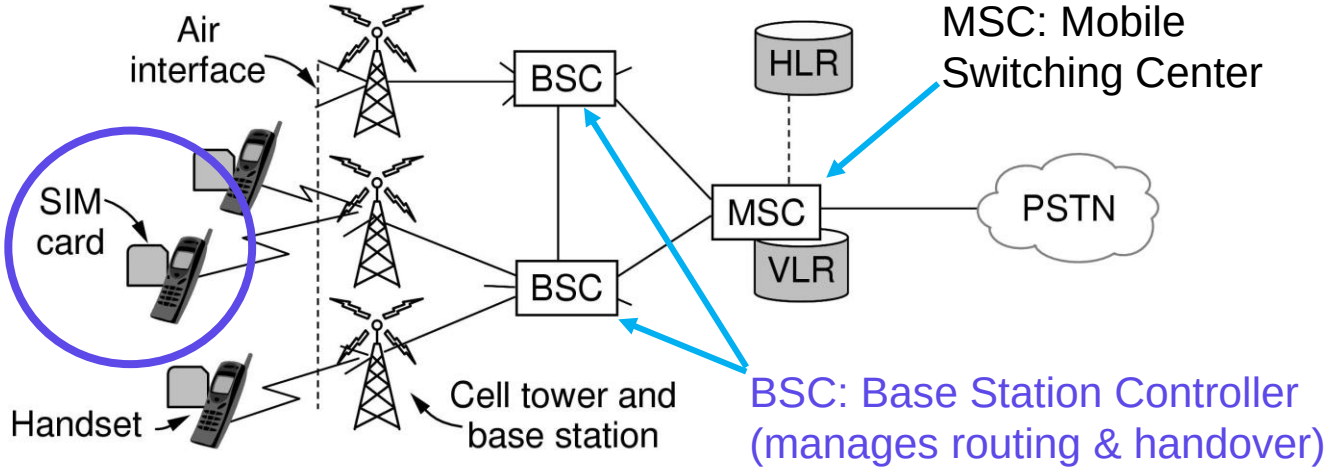
Second-Generation (2G) Technology: Digital Voice

- Digital advantages
  - Provided capacity gains by allowing voice signals to be digitized and compressed
  - Improved security by allowing voice and control signals to be encrypted
  - Deterred fraud and eavesdropping, whether from intentional scanning or echoes of other calls due to RF propagation
  - Enabled new services such as text messaging
- Three main systems were developed
  - D-AMPS (Digital Advanced Mobile Phone System)
  - GSM (Global System for Mobile communications)
  - CDMA (Code Division Multiple Access)

GSM: Global System for Mobile Communications

Mobile contains a Subscriber Identity Module (SIM card) where user credentials are stored

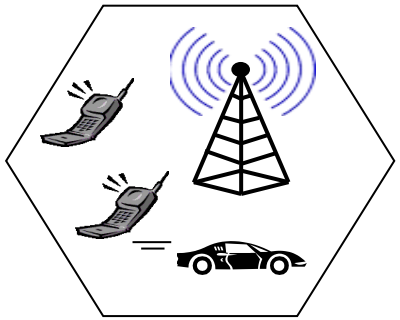
- Also stored the mobiles' last known location in the HLR (Home Location Register) for call routing
- Base Station Controllers keep track of visiting mobiles in the VLR (Visitor Location Register)

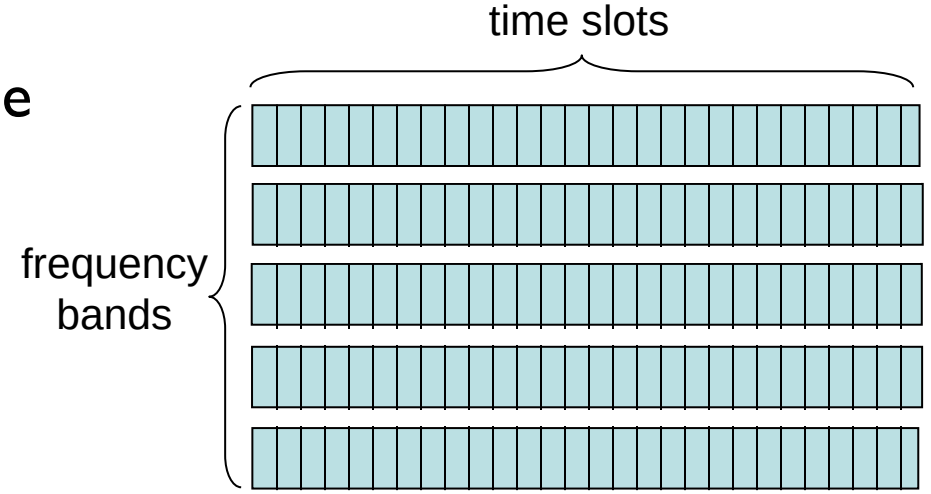


Cellular networks: the first hop

Two techniques for sharing mobile-to-BaseStation radio spectrum

- combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots (GSM)
- CDMA: code division multiple access

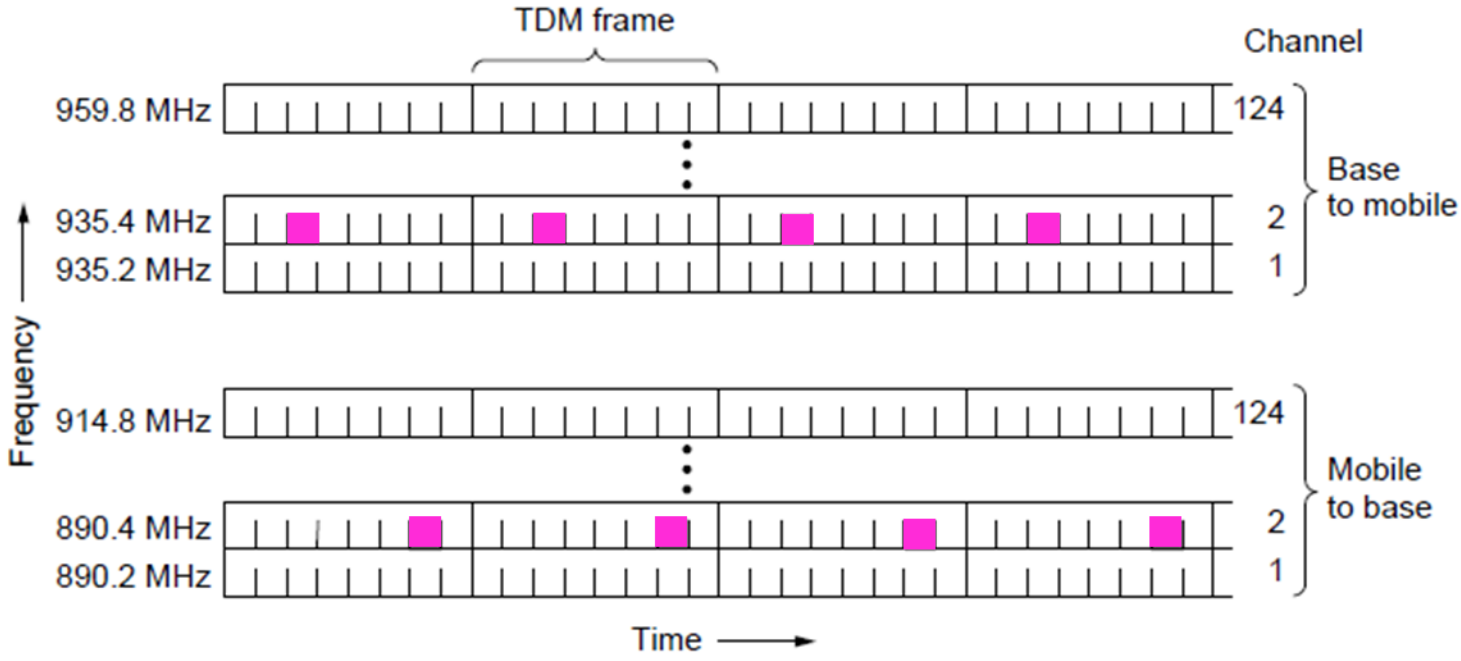




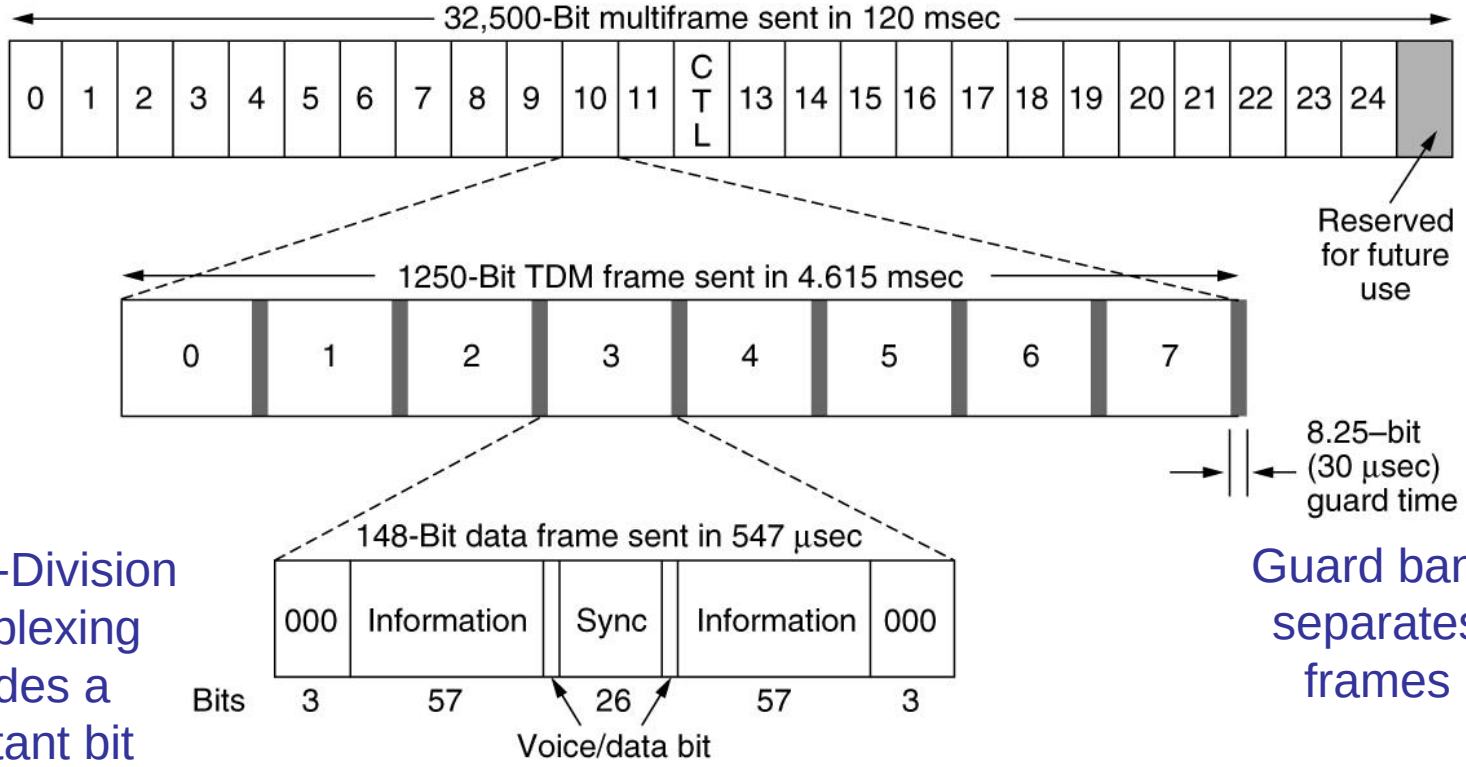
GSM: Global System for Mobile Communications

Air interface uses 200 KHz FDM channels with an eight-slot TDM frame every 4.615 ms

- Mobile is assigned up- and down-stream slots to use
- Each slot is 148 bits long, data rate is 27.4 kbps



GSM: Global System for Mobile Communications



Time-Division Multiplexing provides a constant bit rate for voice and data

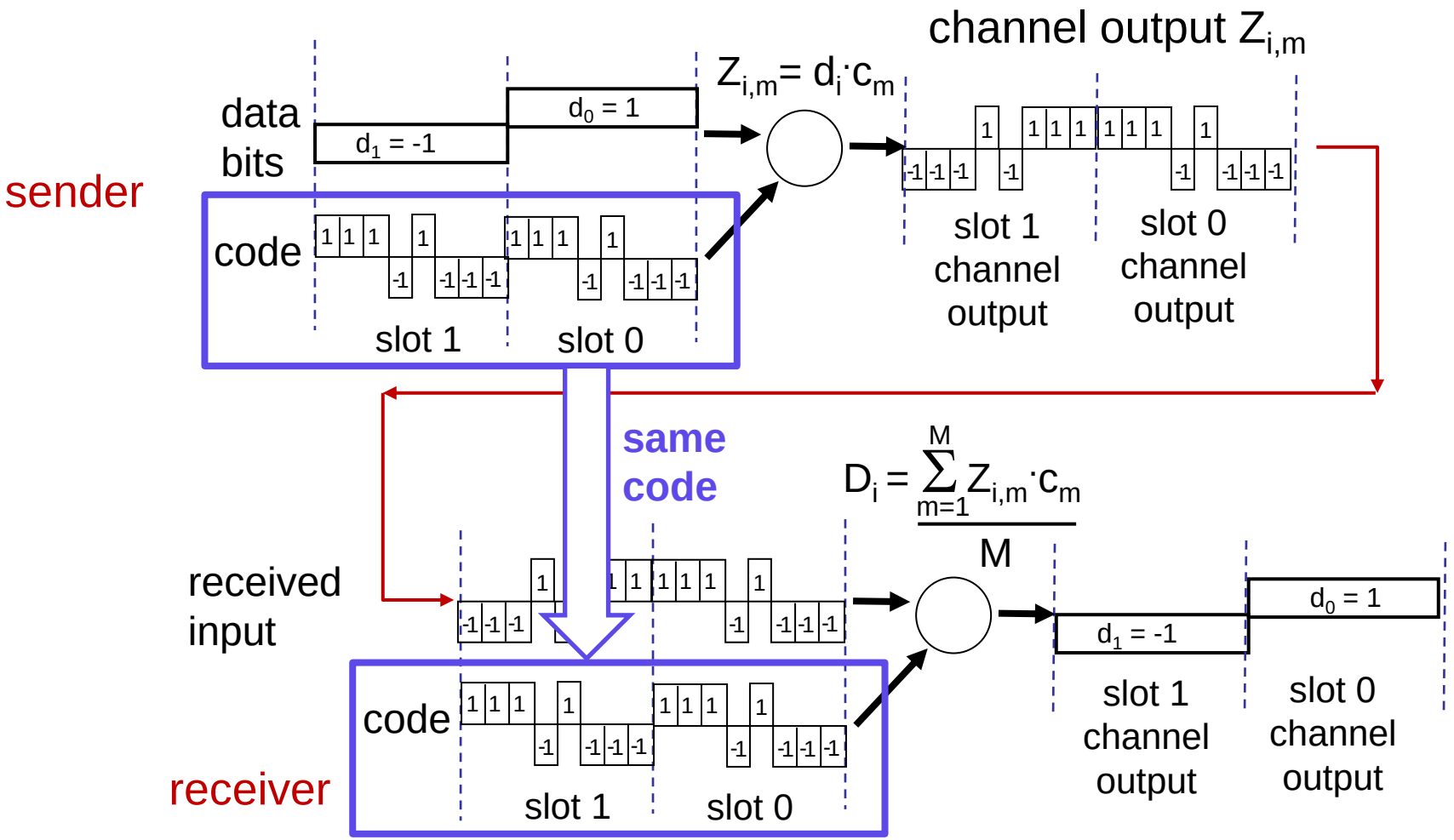
Guard band separates frames

A portion of the GSM framing structure.

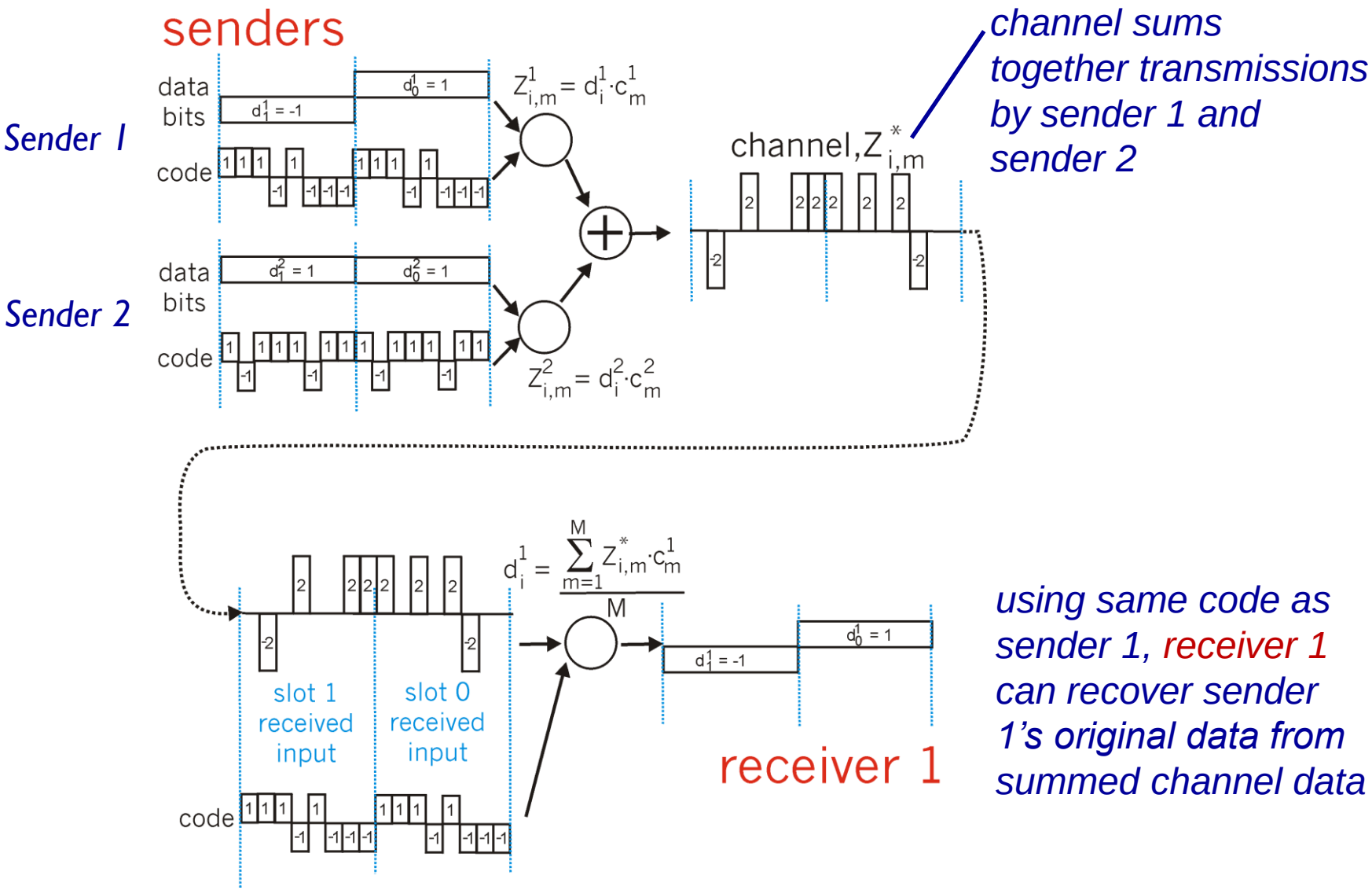
Code Division Multiple Access (CDMA)

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

CDMA encode/decode



CDMA: two-sender interference



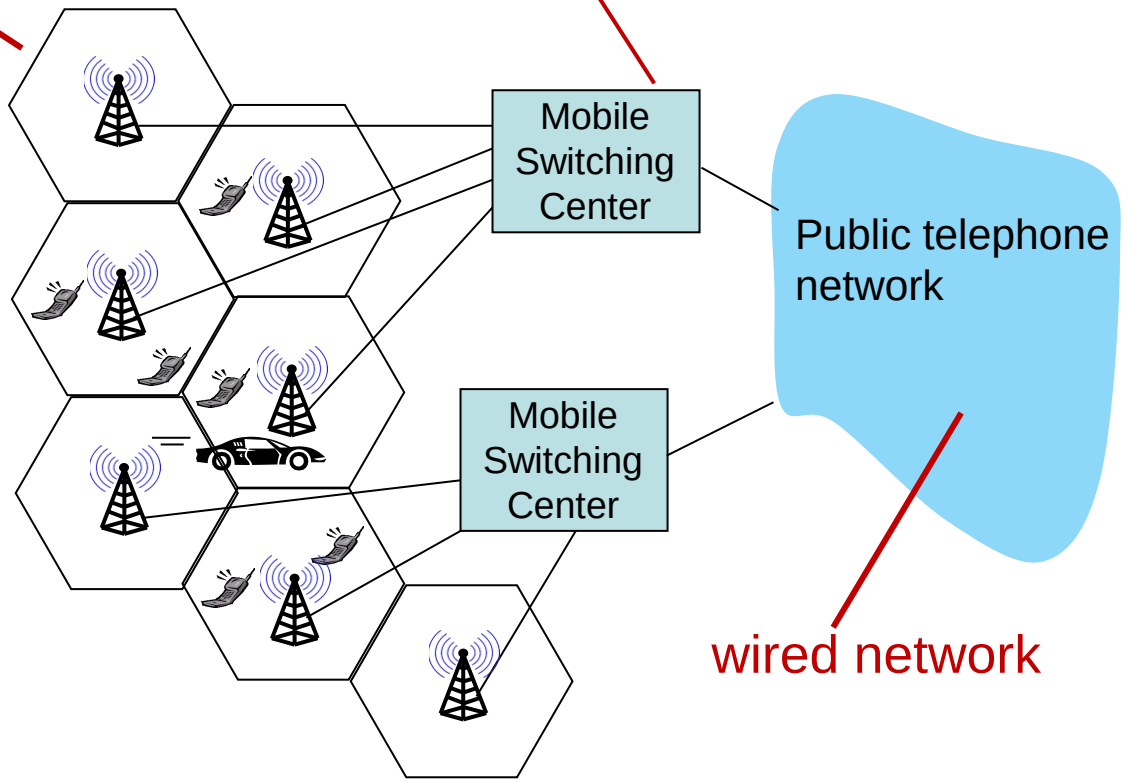
Third-Generation (3G) Technology: Digital Voice+Data

- With packet switching of digitized voice, voice and data can both be transmitted simultaneously
  - Provided broadband access, initially around 100Kilobits/sec but evolved into the Megabit/sec range
  - Improved security for communications by authentication of the network the user is connecting to
  - Most 3G systems are being dropped in favor of 4G
    - Verizon this year, T-Mobile in 2021, AT&T in 2022
- Many systems were based on enhanced 2G technology
  - W-CDMA (Wideband CDMA)
  - HSPA (High-Speed Packet Access)
  - CDMA2000 (another updated version of CDMA)

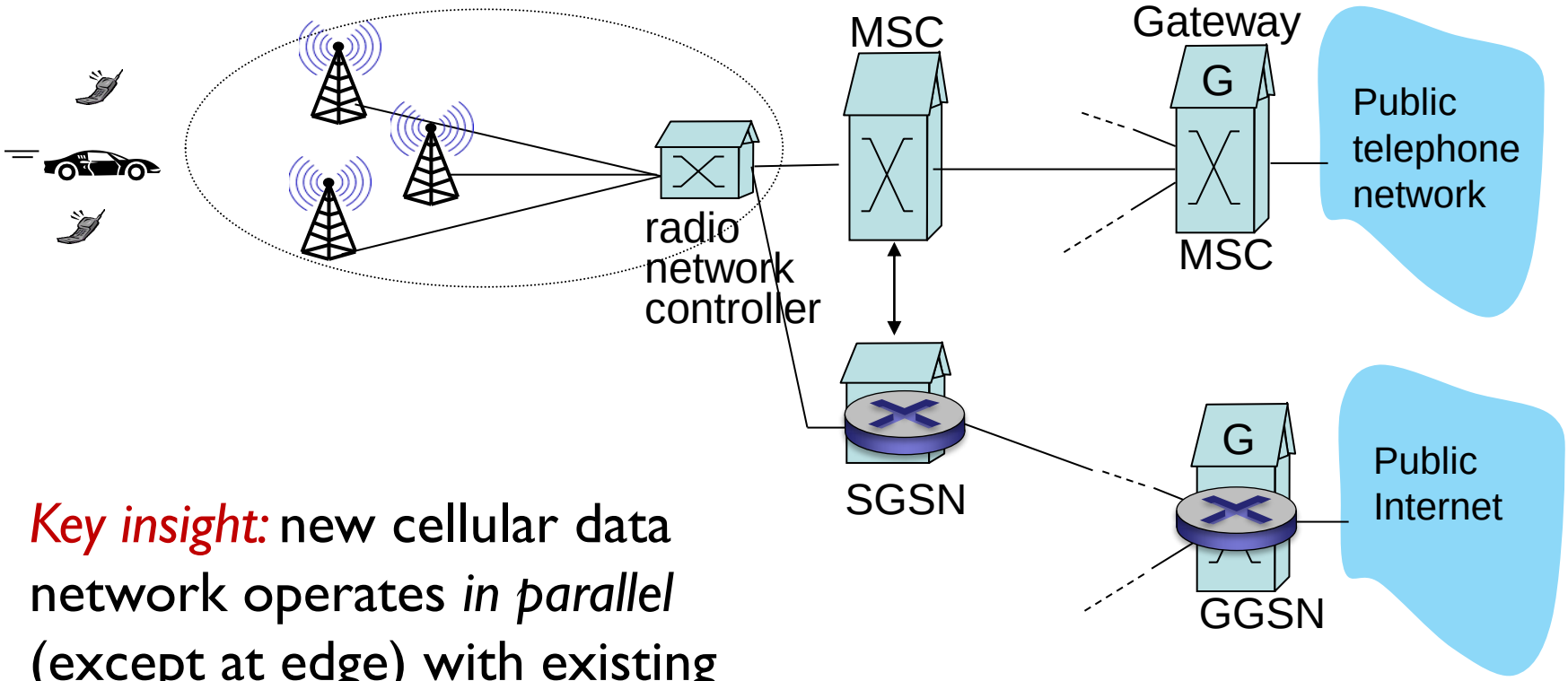
Architecture of a 3G cellular network

MSC
- connects cells to wired tel. 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



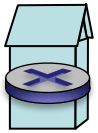
3G (voice+data) network architecture



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

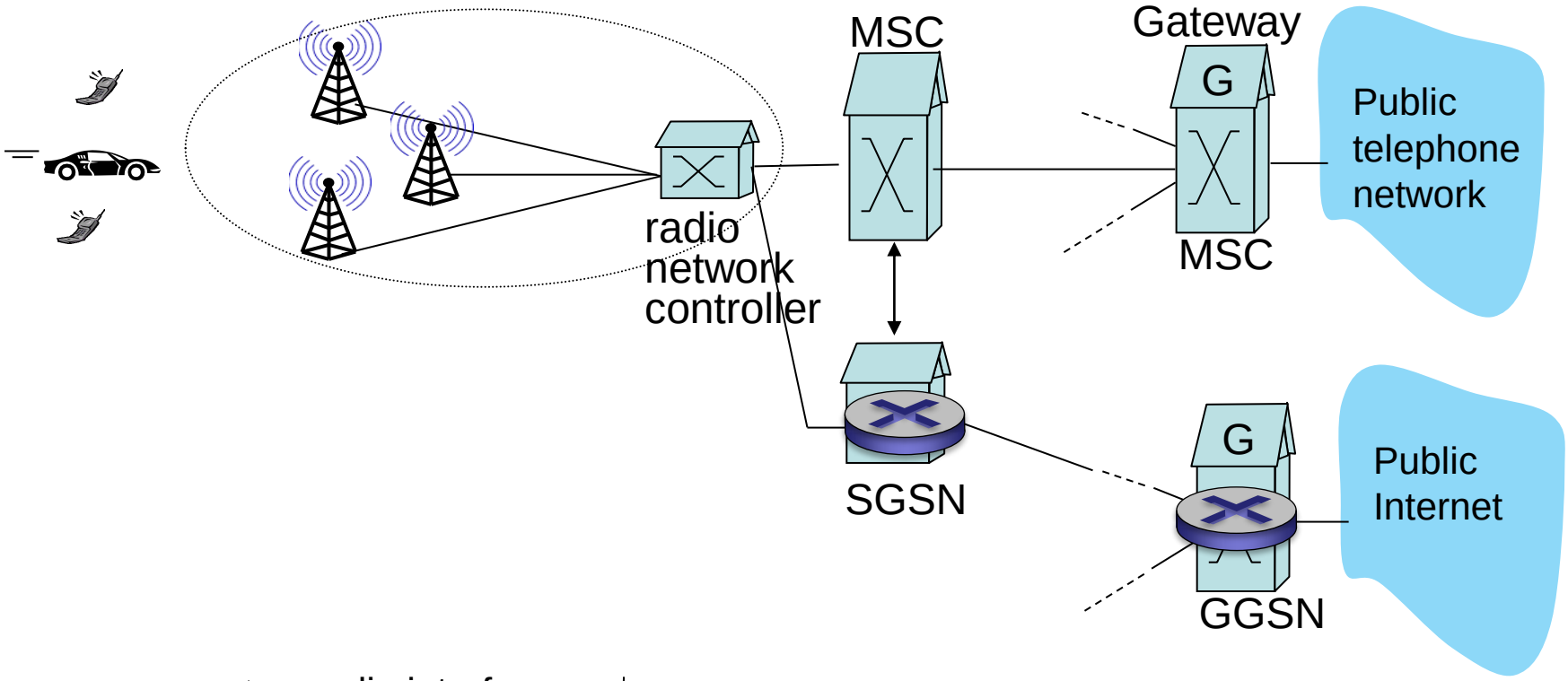
- voice network *unchanged* in core
- data network operates in parallel

Serving GPRS Support Node (SGSN)

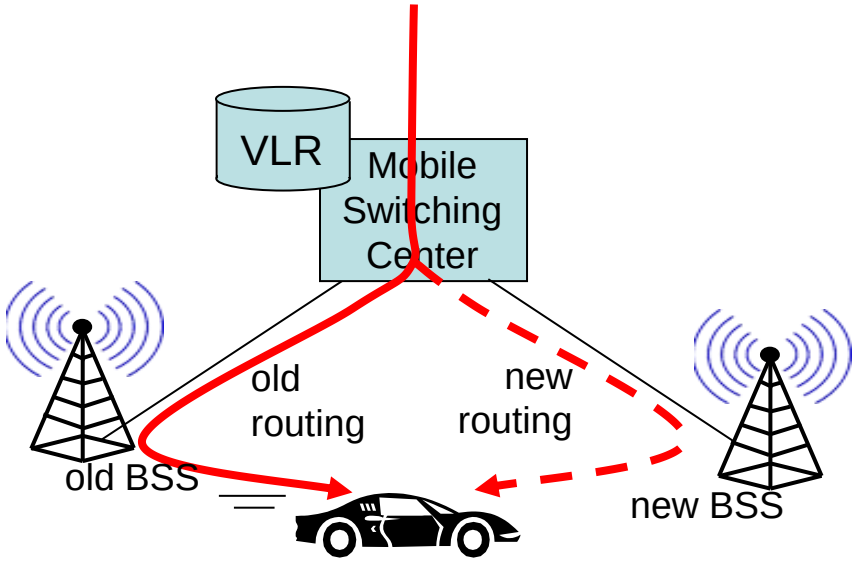


Gateway GPRS Support Node (GGSN)

3G (voice+data) network architecture

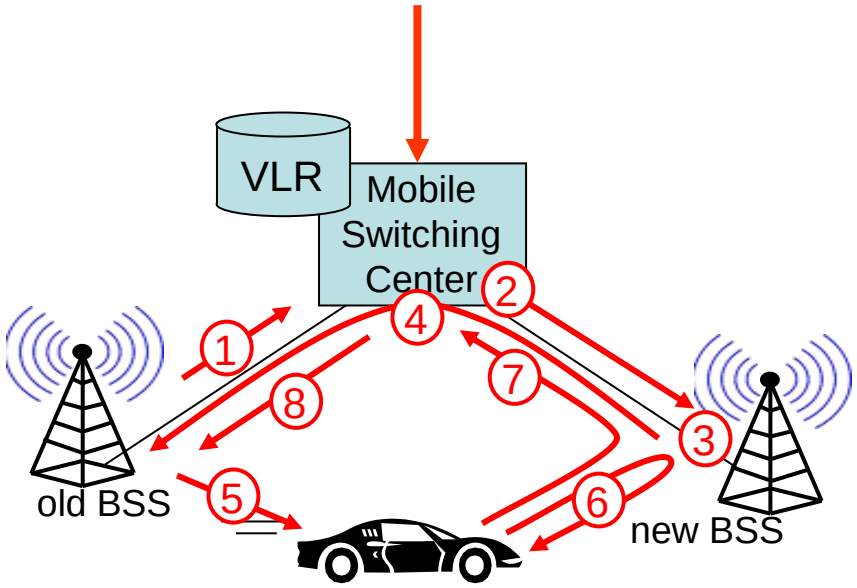


GSM: handoff with a common MSC



- *handoff goal:* route call via a new base station (without call 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

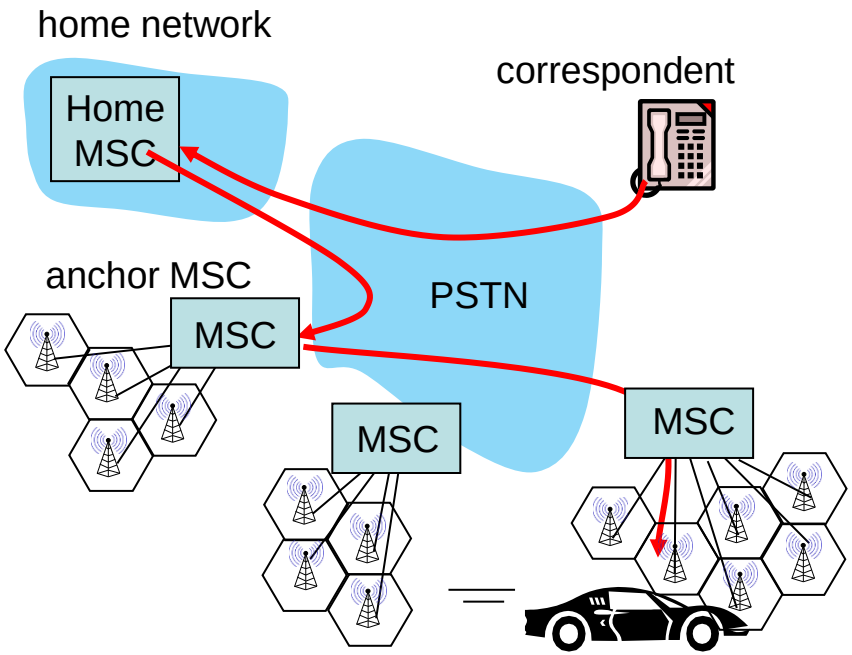
GSM: handoff with a common MSC



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 says it is ready to handoff
5. old BSS tells mobile to perform handoff to new BSS
6. mobile and 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



(b) after handoff

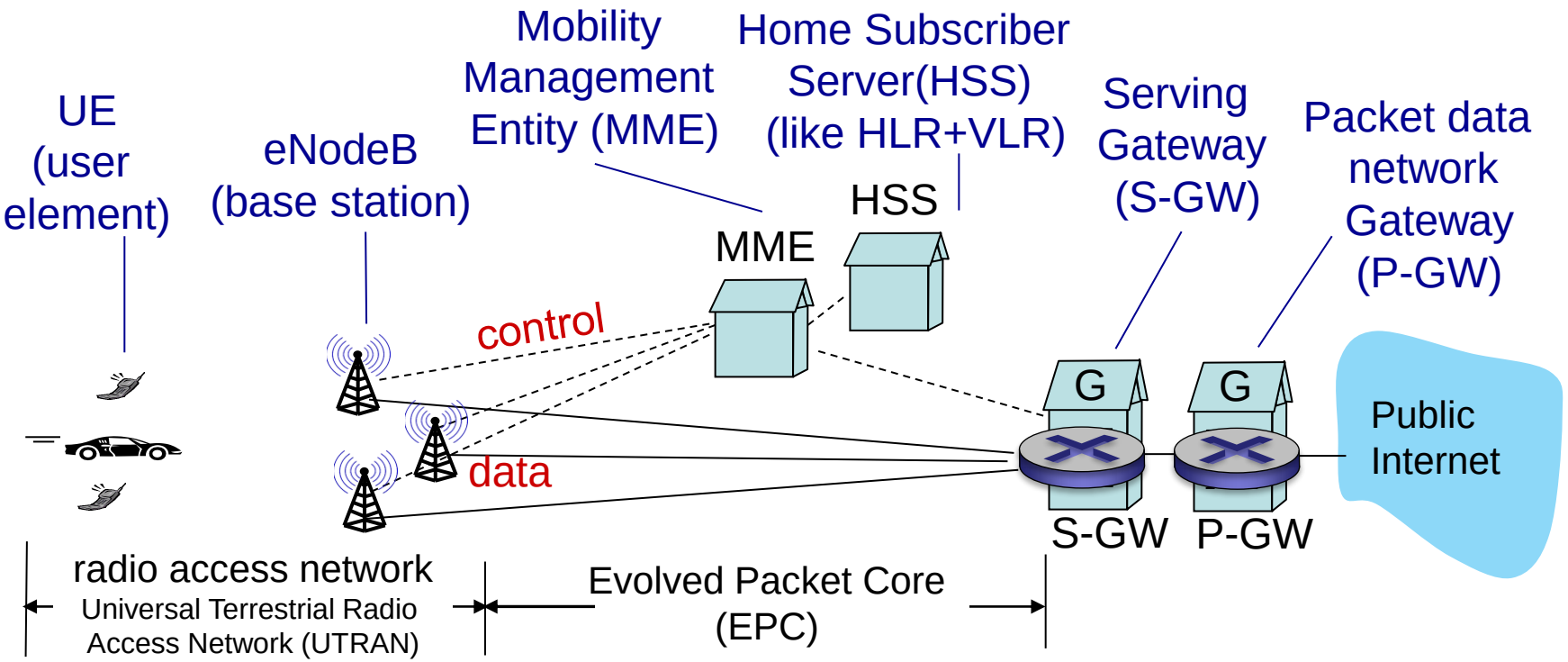
- *anchor MSC:* first MSC visited during call
  - call remains routed through anchor MSC
- new MSCs add on to end of MSC chain as mobile moves to new MSC
- initially path gets longer, then optional path minimization step can be used to shorten multi-MSC chain

Fourth-Generation (4G) Technology: Packet Switching

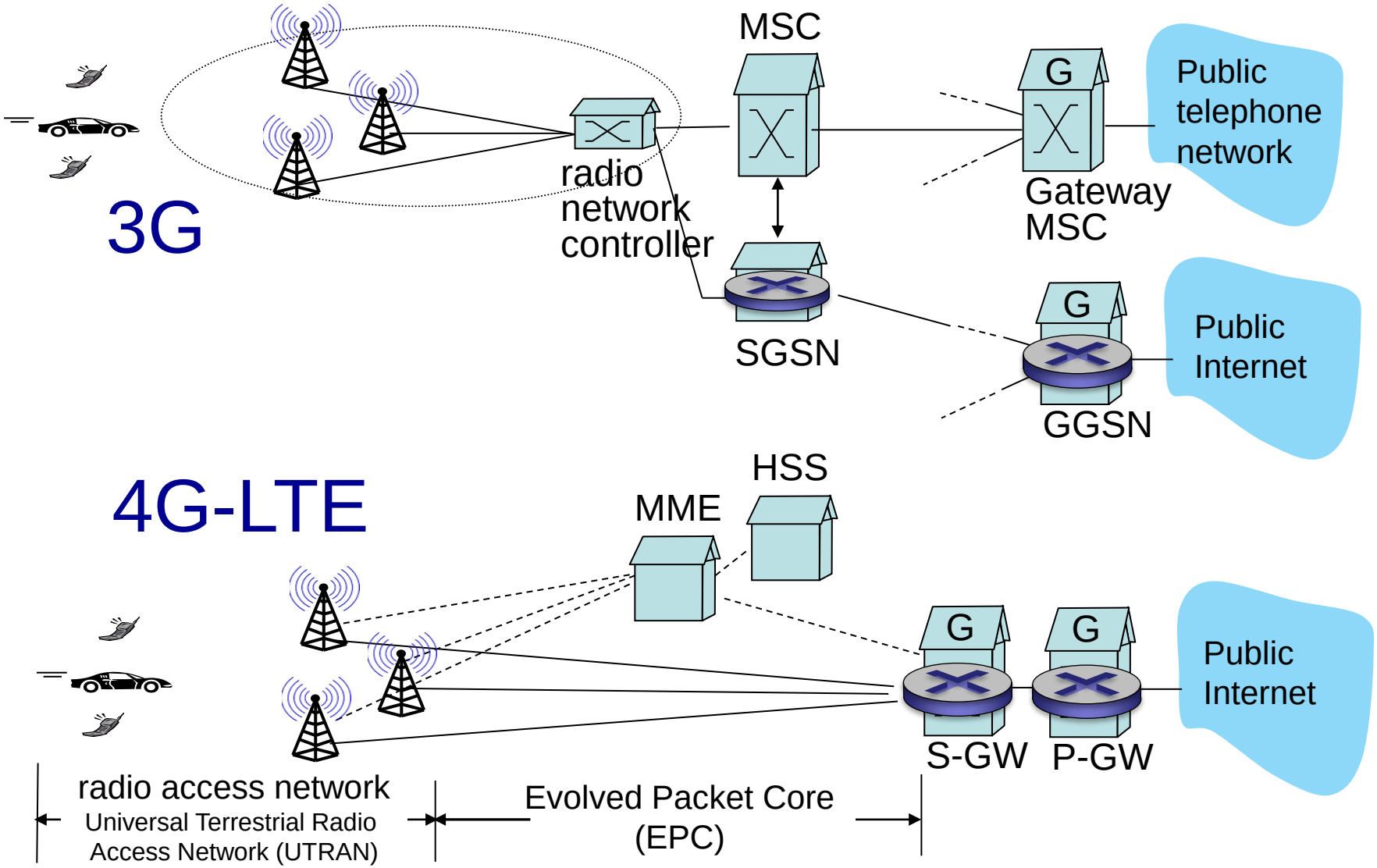
- Also called IMT Advanced
- Based completely on *packet-switched* technology
- EPC (Evolved Packet Core) allows packet switching
  - Simplified IP network separating voice traffic from the data network
    - Carries both voice and data in IP packets
  - *Voice over IP* (VoIP) network with resources allocated using the statistical multiplexing approaches
  - The EPC must manage resources in such a way that voice quality remains high in the face of network resources that are shared among many users

4G: 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



3G versus 4G LTE network architecture

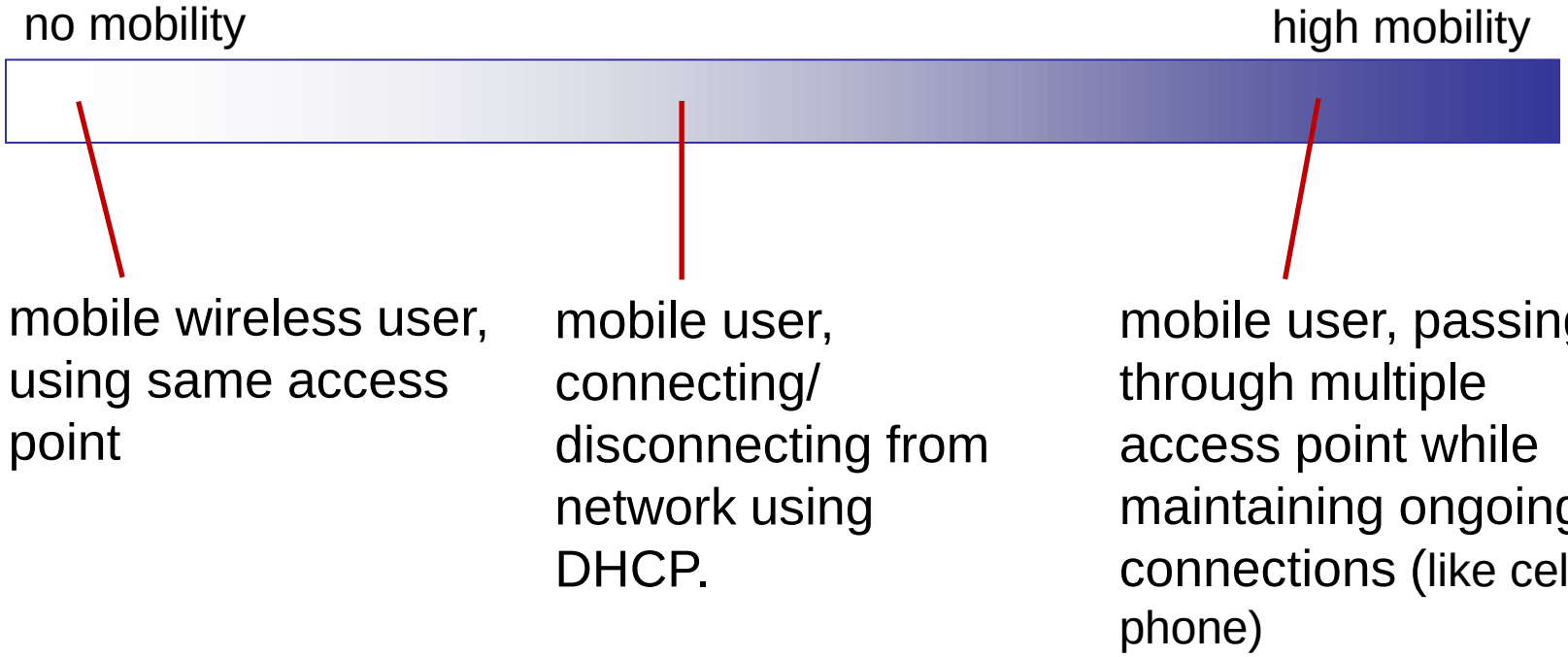


Fifth-Generation (5G) Technology

- Two main advantages:
  - *Higher data rates* and *lower latency* than 4G technologies
- Technology used to increase network capacity
  - Smaller cells using ultra-densification, faster offloading
  - *Increased bandwidth* with millimeter waves
  - *Increased spectral efficiency* through advances in massive MIMO (Multiple-Input Multiple-Output) technology
- Provides a network slicing feature
  - Lets cellular carriers create *multiple virtual networks* on top of the same shared physical infrastructure
  - Can devote network portions to specific customer use cases

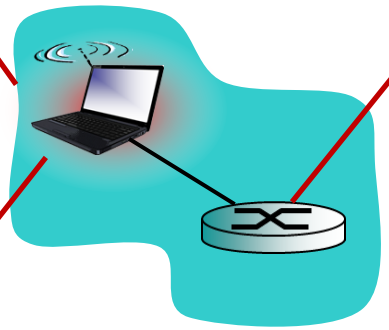
What is mobility?

- From the *network* perspective, there is a wide spectrum of mobility



Mobility: vocabulary

home network: permanent "home" of the mobile
(e.g., 128.119.40/24)



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

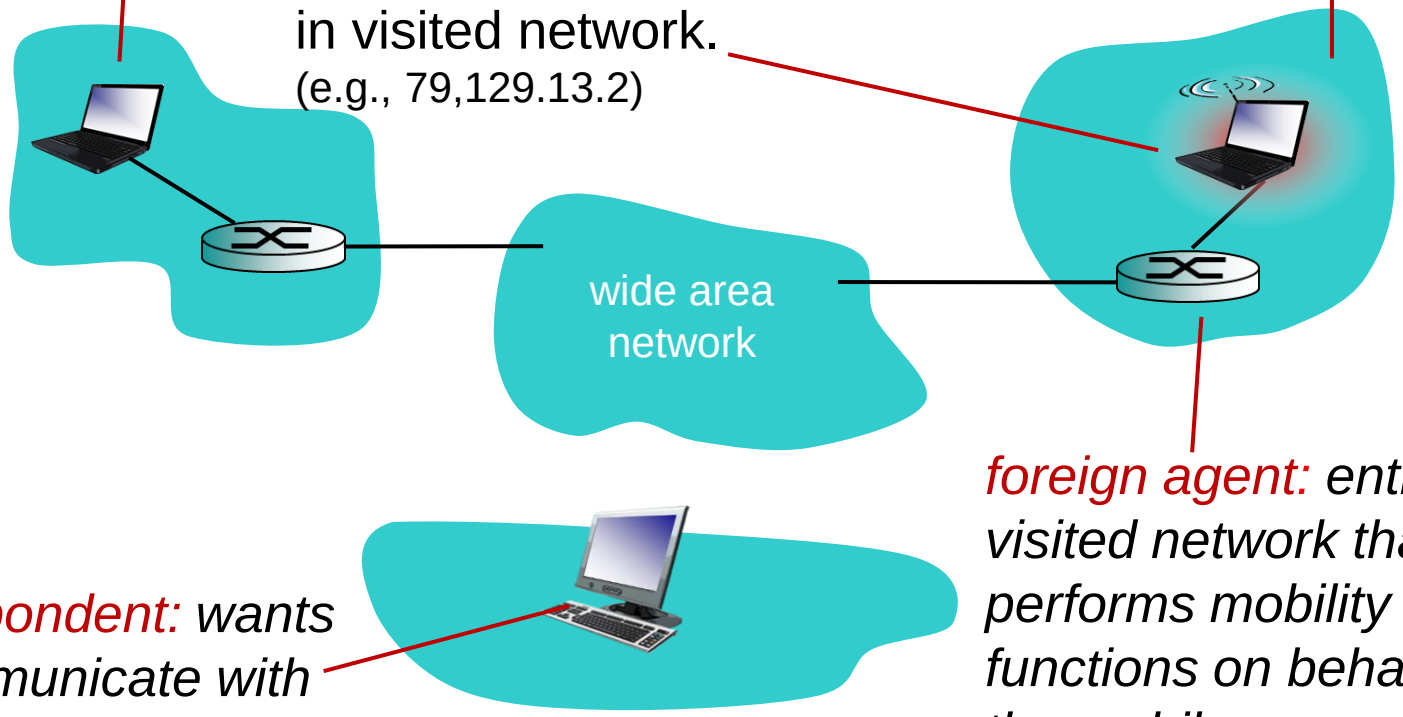
permanent address: address in home network, *can always* be used to reach mobile
e.g., 128.119.40.186

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)



correspondent: *wants to communicate with the mobile*

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

Mobility: two approaches

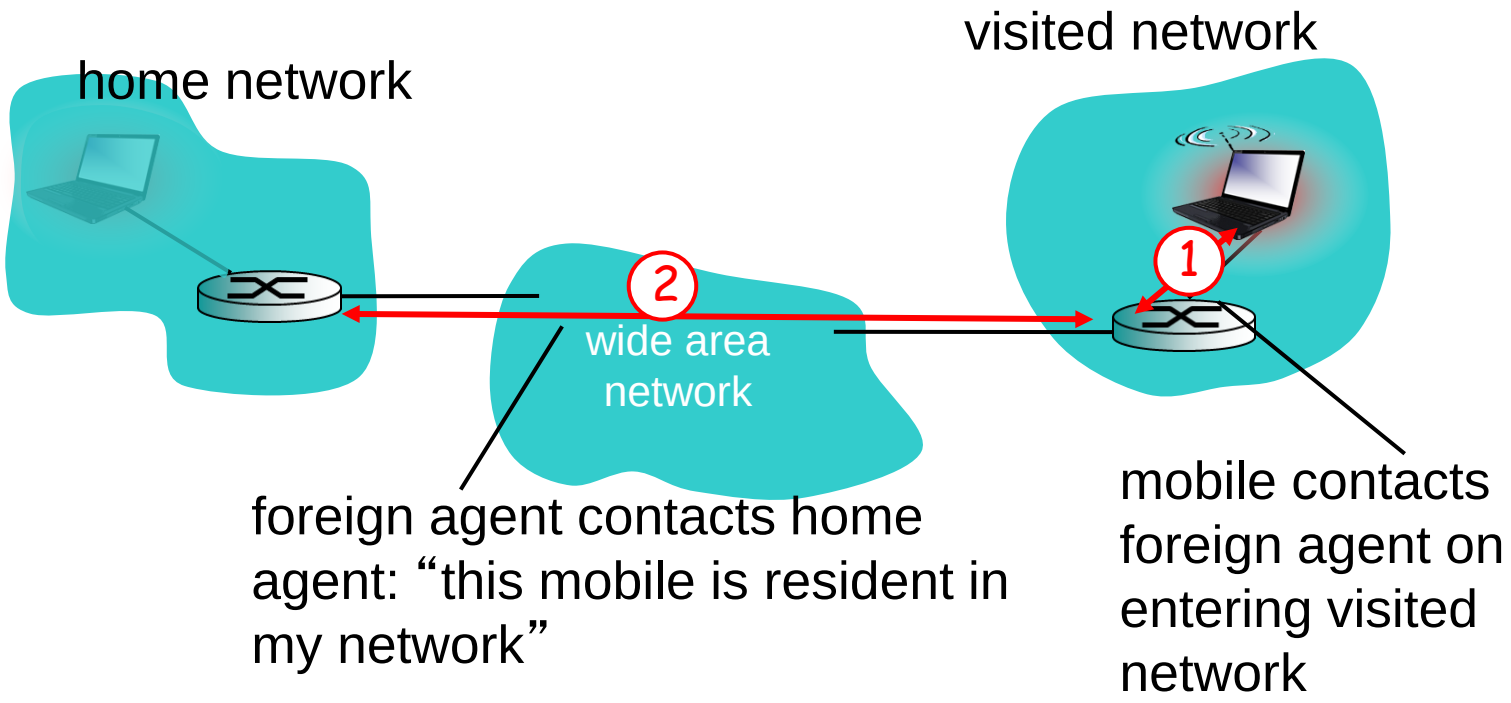
- *let routing handle it:* routers advertise permanent address of mobile-nodes-in-residence via usual routing table exchange.
  - routing tables indicate where each mobile located
  - no changes to end-systems
- *let end-systems handle it:*
  - *indirect routing:* communication from correspondent to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

Mobility: two approaches

- *let routing handle it:* routers advertise permanent addresses of mobile-nodes-in-residence via 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

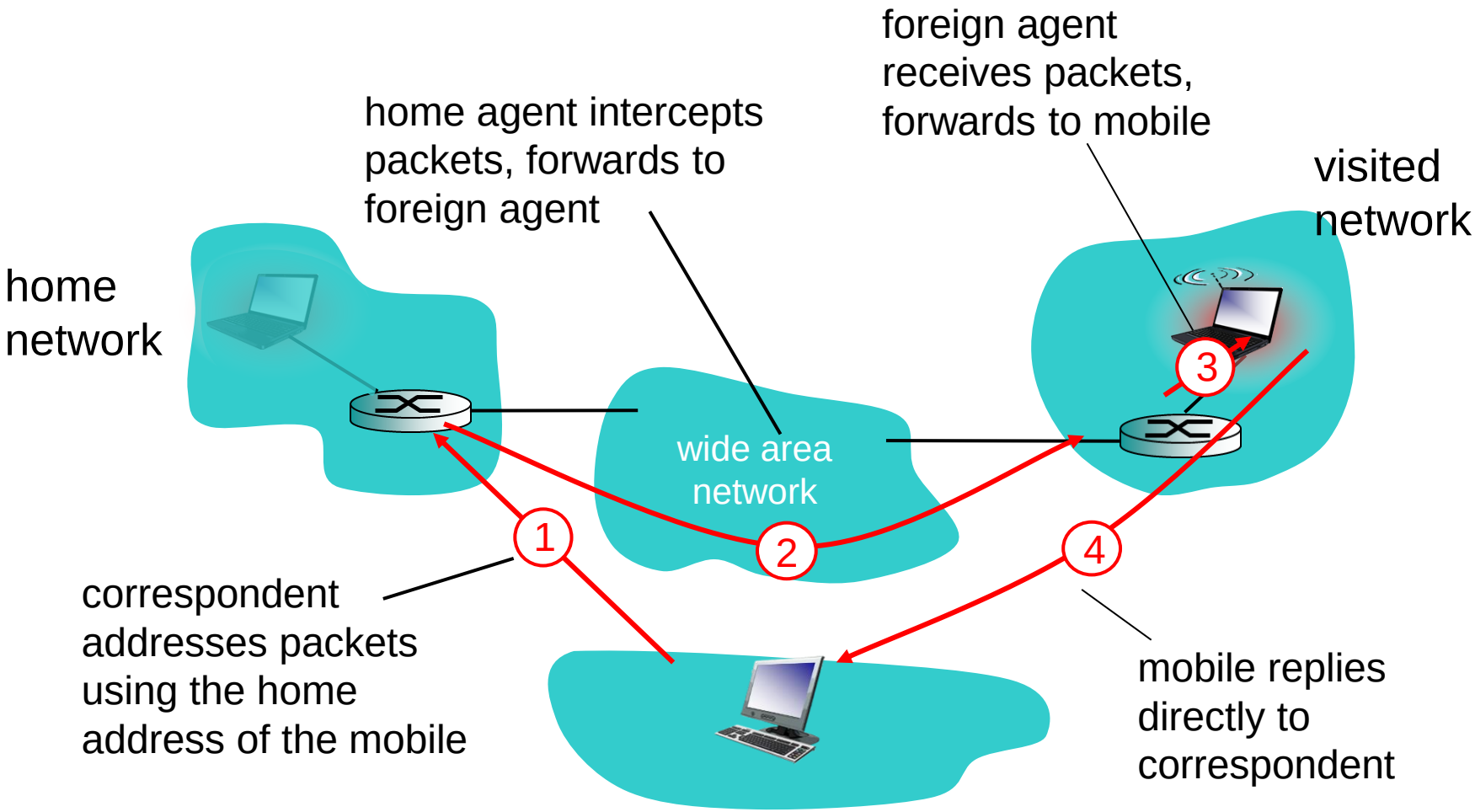
Mobility: registration



end result:

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

Mobility via indirect routing



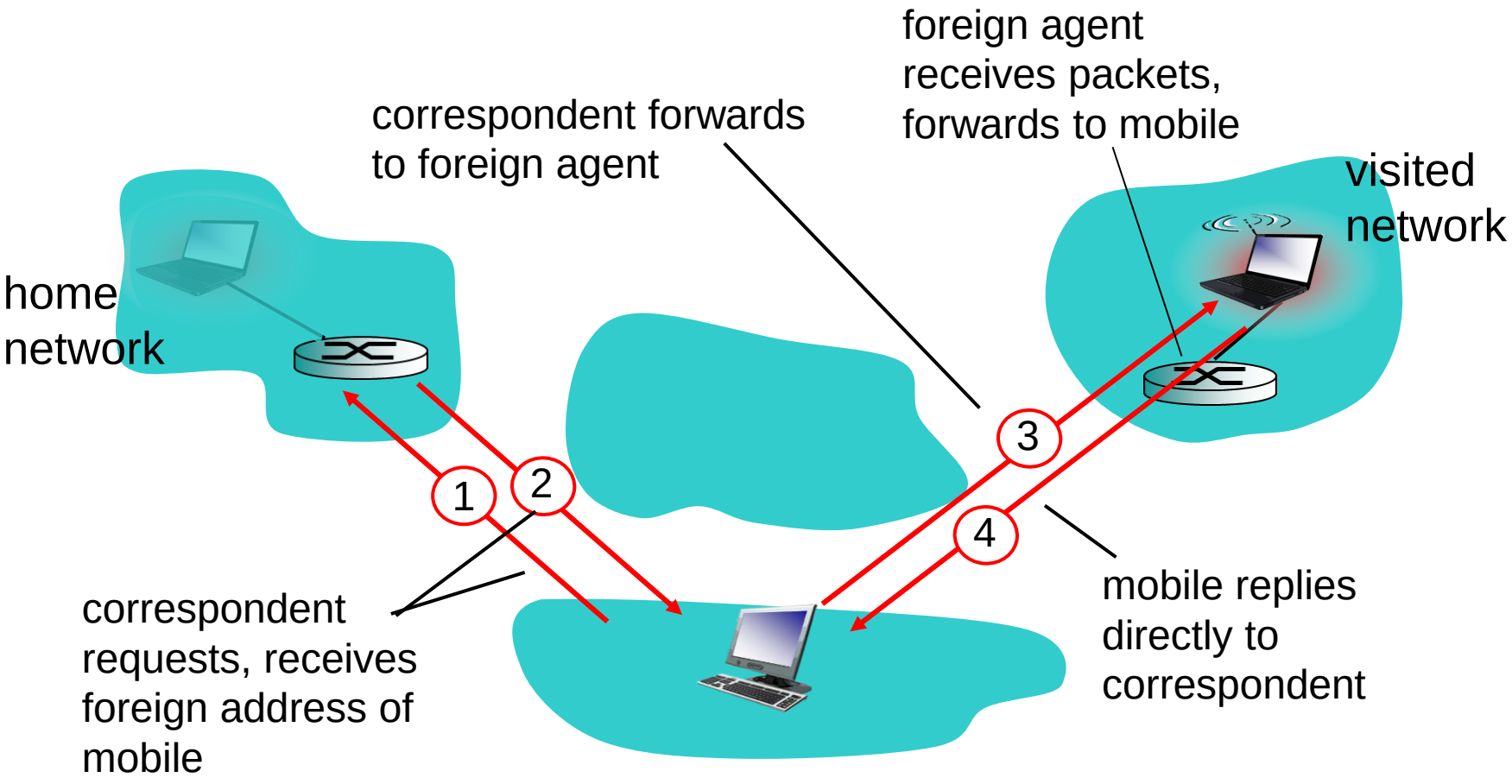
Indirect Routing: comments

- mobile uses two addresses:
  - permanent address: used by correspondent, 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 the mobile itself
- causes triangle routing: packets flow from correspondent to home-network to mobile
  - inefficient when both are in the same network

Indirect routing: moving between networks

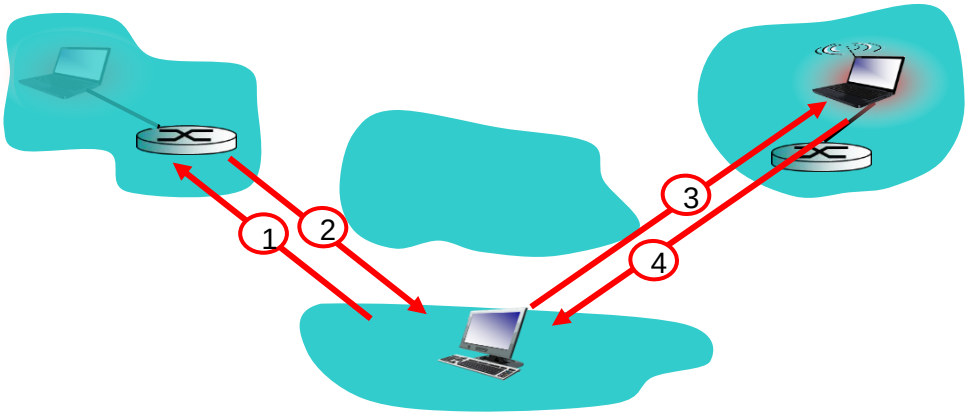
- suppose mobile user moves to another network
  - registers with new foreign agent and new foreign agent registers with home agent
  - home agent updates care-of-address for mobile
  - packets continue to be forwarded to mobile (but with new care-of-address)
- transparent when changing foreign networks: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

Mobility via direct routing



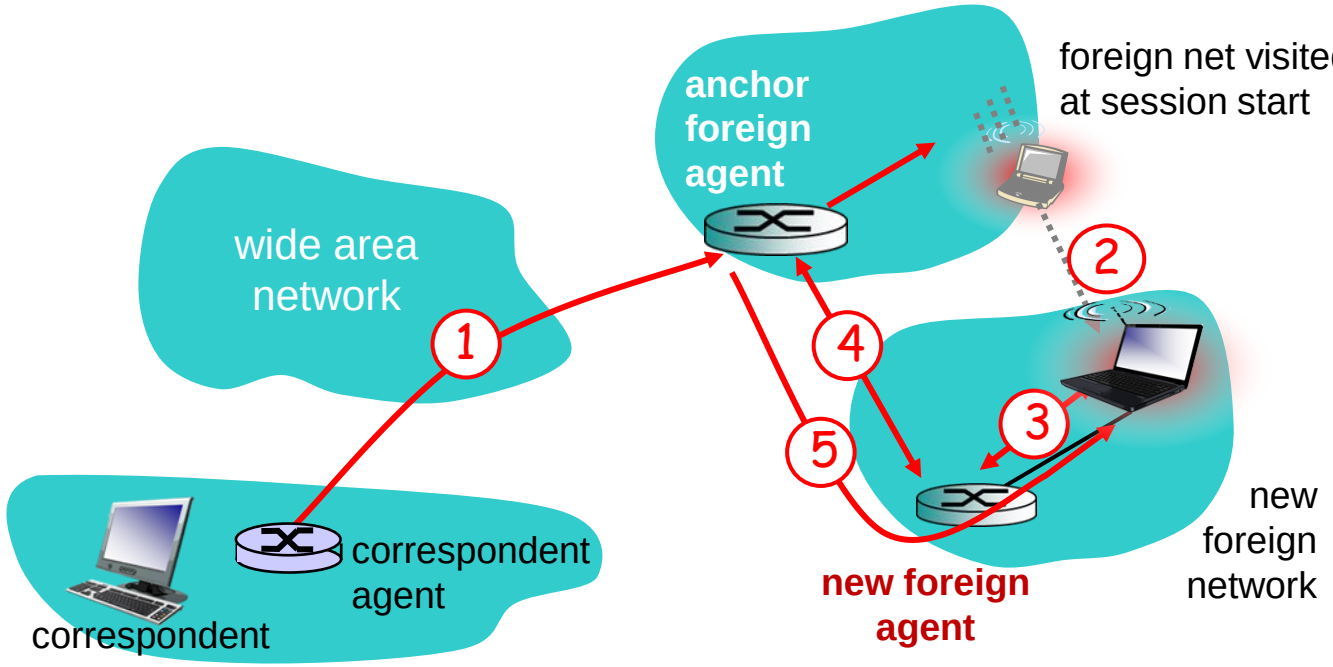
Mobility via direct routing: comments

- overcomes triangle routing problem
- *non-transparent to correspondent:* correspondent must get care-of-address from home agent
  - what if mobile changes visited network again?



Accommodating mobility with direct routing

- Foreign agent (FA) is anchored in the first visited network
  - data always routed first to that anchor FA
  - when mobile moves: new FA arranges to have data forwarded from old FA (chaining the series of FA's)



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), and information about its current location
- *visited network:* network in which mobile currently resides
  - *visitor location register (VLR):* database with entry for each user currently in network
  - could be in its home network

GSM: indirect routing to mobile