DIPARTIMENTO
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Chapter 6
Wireless and Mobile Networks

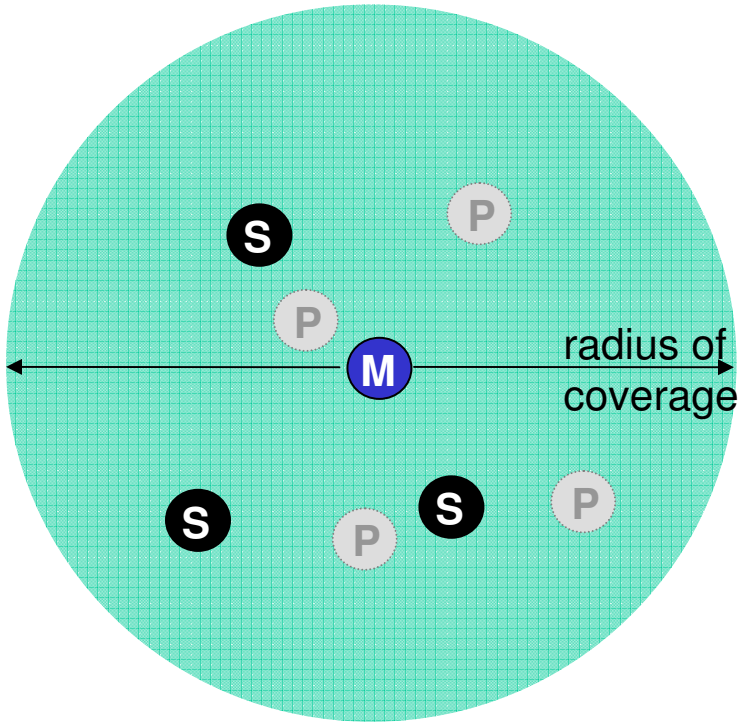
Reti di Elaboratori
Corso di Laurea in Informatica
Università degli Studi di Roma "La Sapienza"
Canale A-L
Prof.ssa Chiara Petrioli

Parte di queste slide sono state prese dal materiale associato al libro *Computer Networking: A Top Down Approach* , 5th edition.

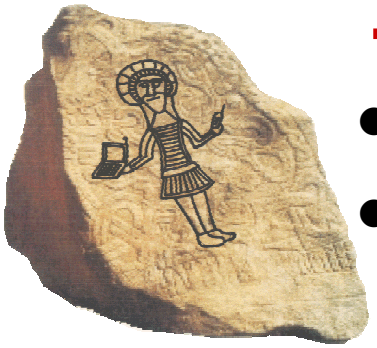
Thanks also to Antonio Capone, Politecnico di Milano, Giuseppe Bianchi and Francesco LoPresti, Un. di Roma Tor Vergata

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



Bluetooth (BT) History



- Named after a Danish Viking King who unified and controlled Denmark and Norway
  - → BT aims at unifying telecom. and computing industries
- First standard release in 1999 (v 1.0)
- BT Special Interest Group counts over 1800 members, including Ericsson,Nokia, IBM, Intel, Toshiba,Microsoft, Lucent, 3Com, Motorola...
- All BT SIG members agree to provide key technologies for development, have BT license and BT brand for free

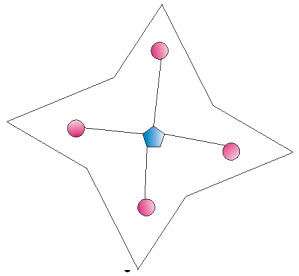
Bluetooth Technology (BT):

- Wireless technology in the 2.4GHz, globally available, license free ISM (Industrial, Scientific and Medical) band, originally introduced for cable replacement must be low cost, reliable
- 1MHz spaced channels, GFSK modulation → 1Mb/s
- Frequency Hopping Spread Spectrum
  - Devices follow a FHSS sequence
  - Frequency used for transmission changes for every packet

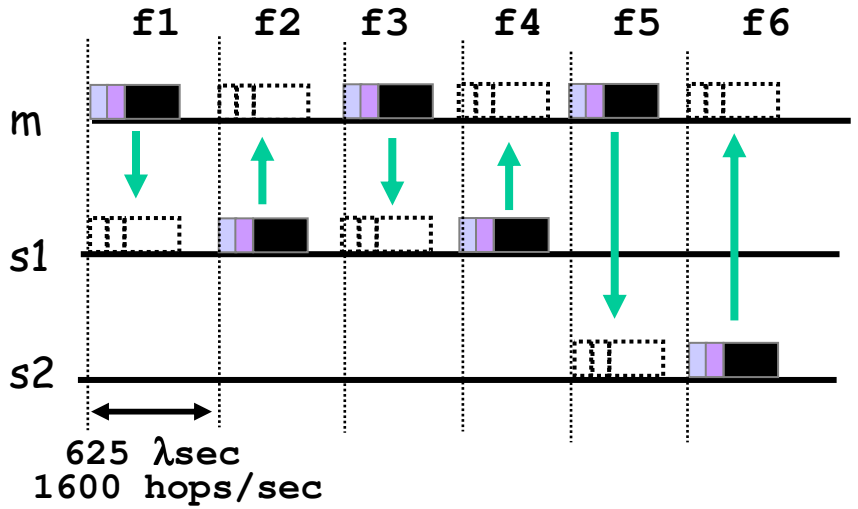
  ↓

  low interference, security
- Time divided in slots (1 slot = 625 μs)
- Packet size: 1, 3 or 5 slots
- Short range communication (10 - 100 m)

Bluetooth: Piconets



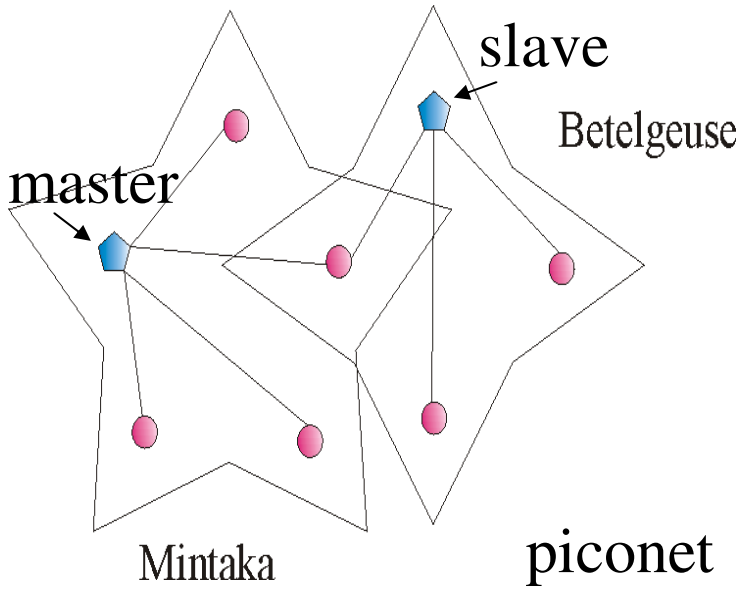
- **BT devices are organized in *piconets*, clusters of :**
  - One master
  - Multiple slaves, no more than 7 actively communicating
- **Synchronization based on master ID and clock**
  - Based on the master ID and clock a frequency hopping sequence is computed → all devices in a piconet use the same sequence
- **Master (M) – Slave (S) communication**



FH/TDD

Bluetooth: Scatternets

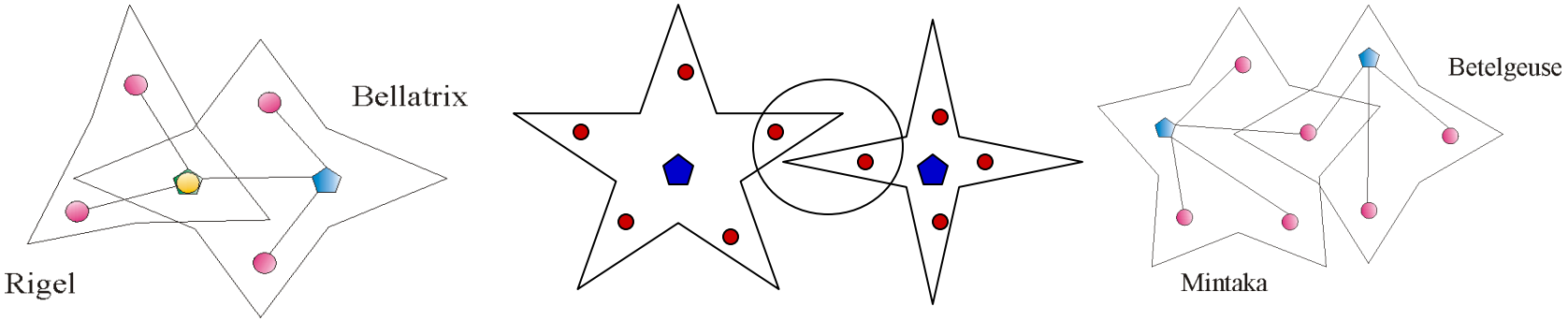
Figures from "Bluestar" description
A possible scatternet formation protocol
By Petrioli C. and Basagni S.



- Nodes can have multiple roles
- Nodes with multiple roles timeshare between multiple piconets
- A **scatternet** enables multi-hop communication

Piconets Interconnection

Problematic.
Why?



master/slave

additional piconet interconnecting neighbor slaves

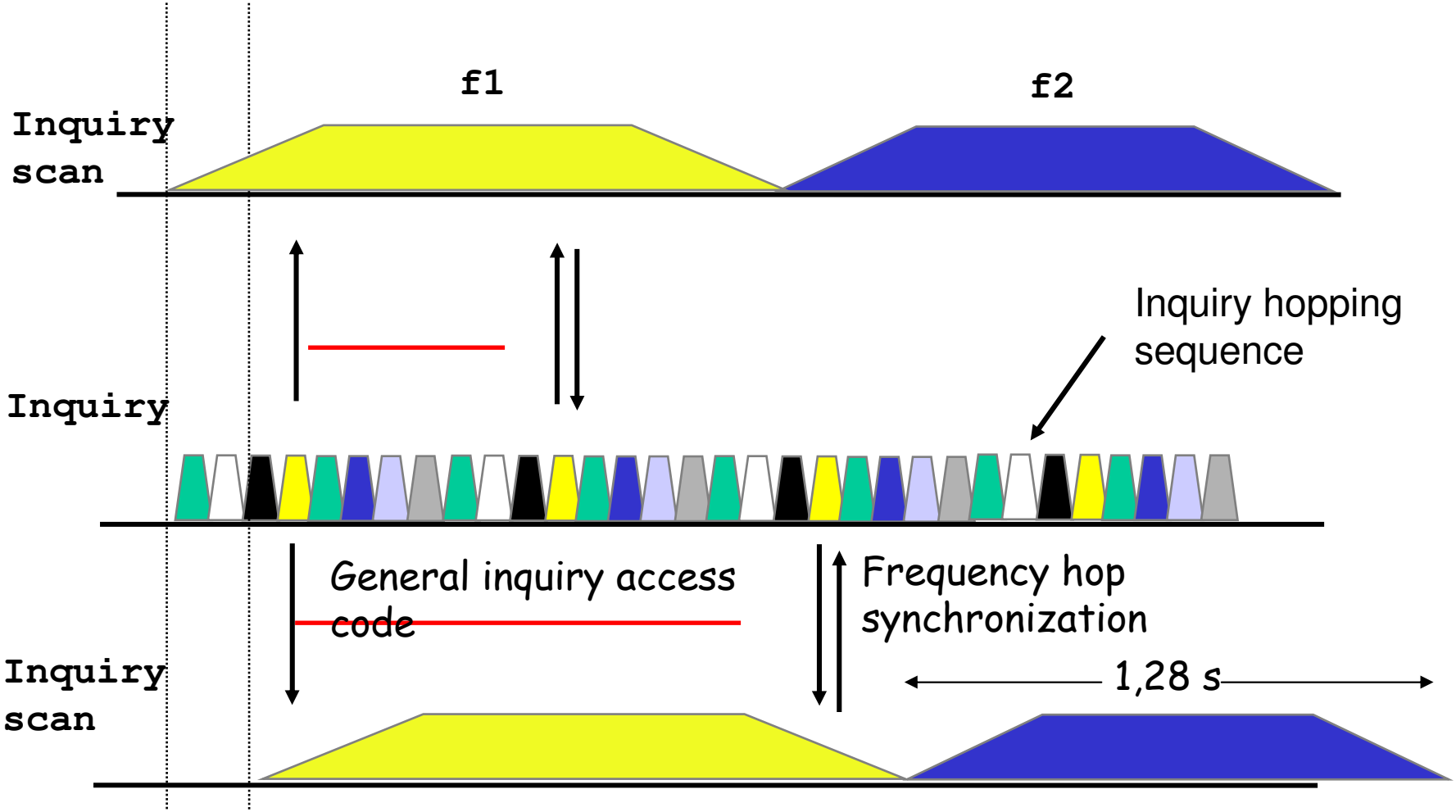
common slave

Efficiency

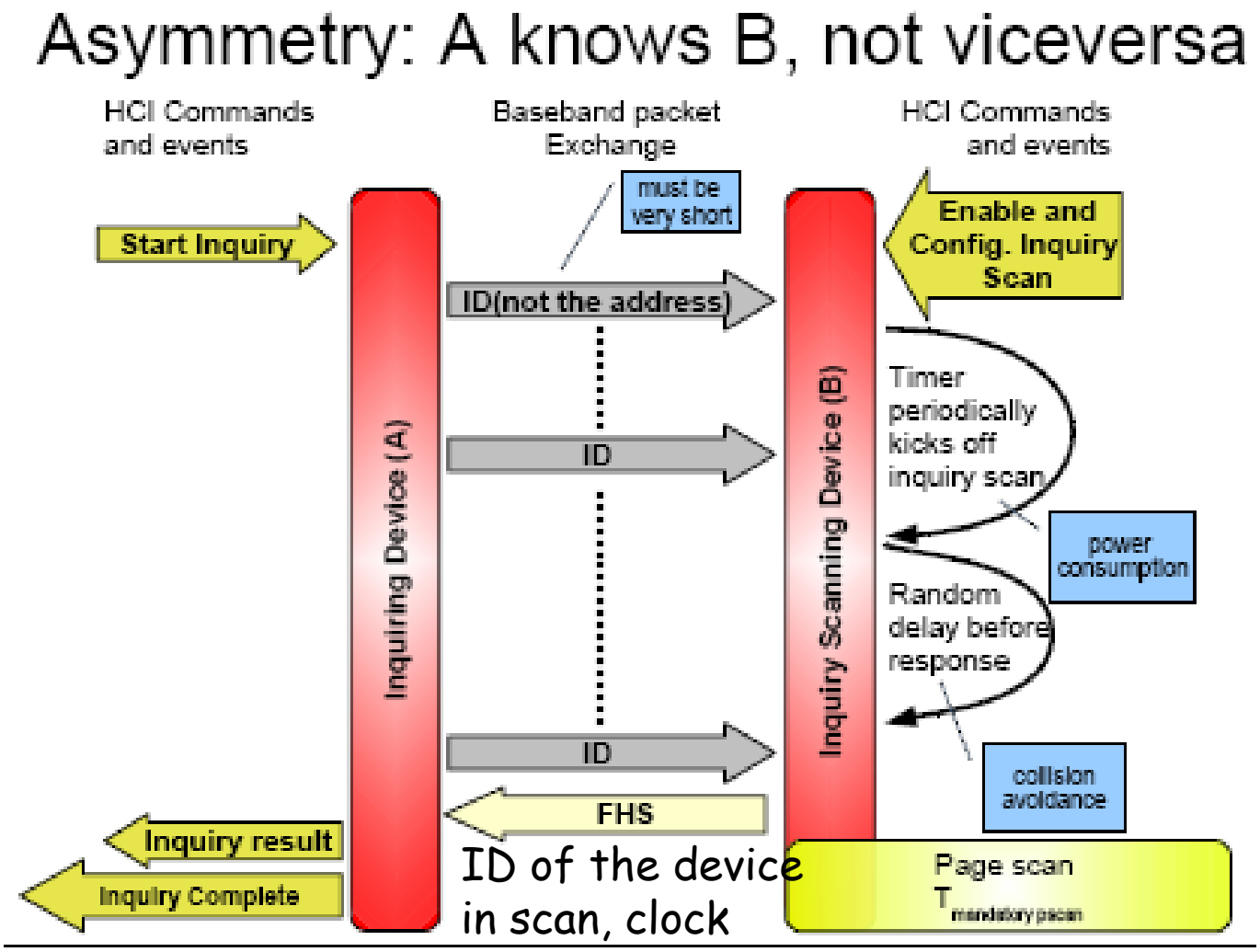
Scatternet Formation

- Forming connected ad hoc networks of Bluetooth device
- Three major problems:
  - Device discovery → use BT standard procedures (inquiry and paging)
  - Piconet formation
  - Piconet interconnection

Inquiry procedure



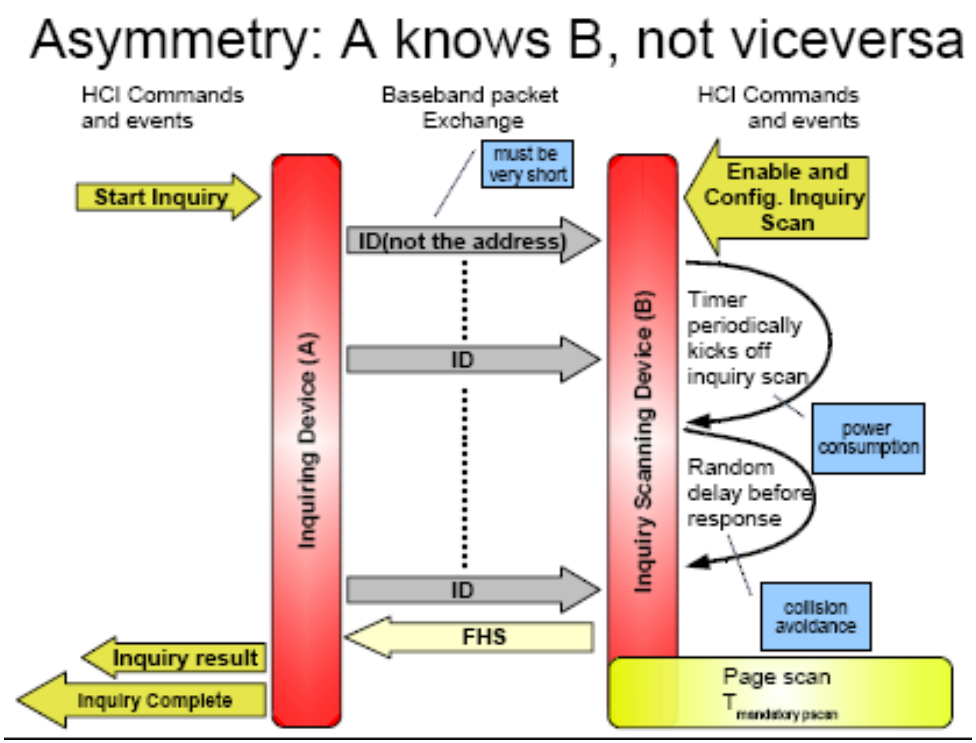
Device Discovery

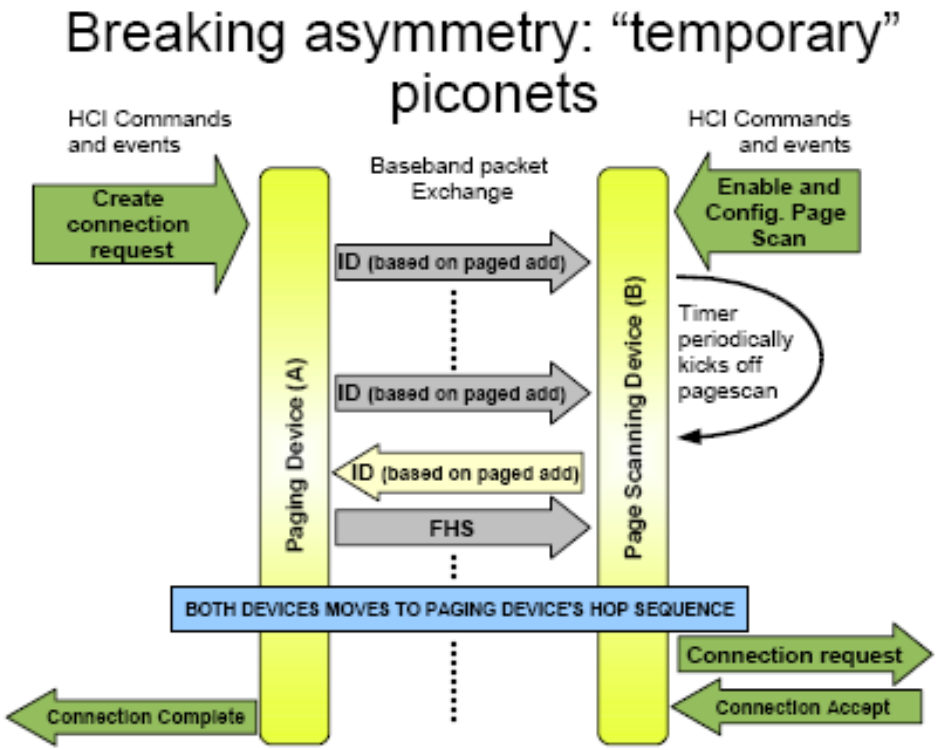


Device discovery in BT standard

- Requires neighbor nodes to be in opposite modes (inquiry/inquiry scan)
- Leads to asymmetric neighbor discovery
  - The inquirer gather information on the neighbor BT clock and address, not viceversa

Device Discovery



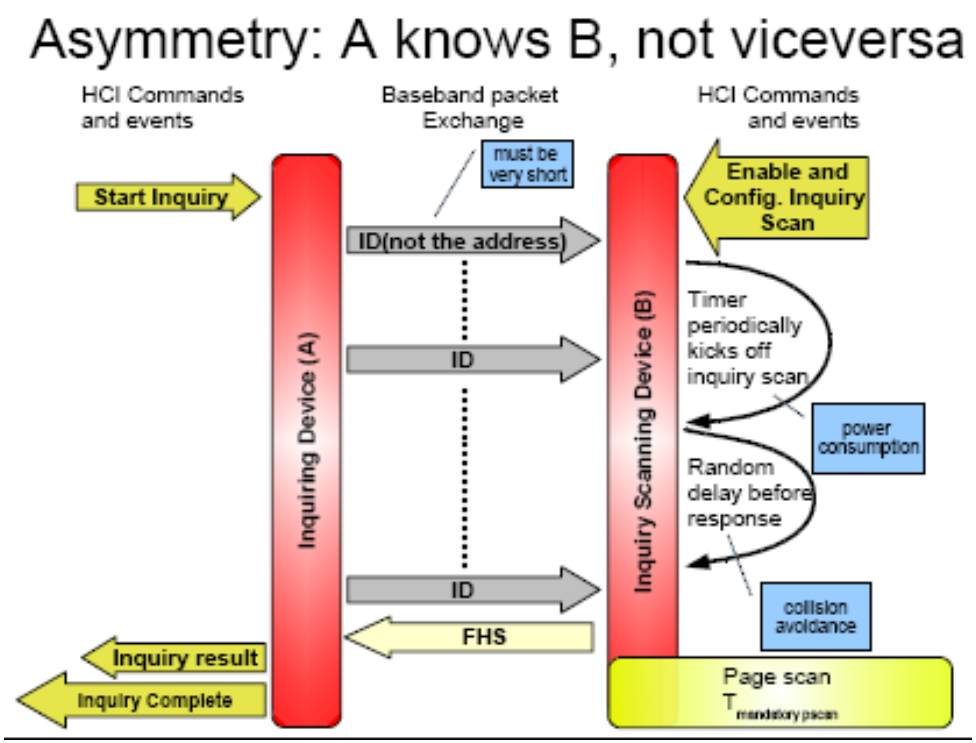


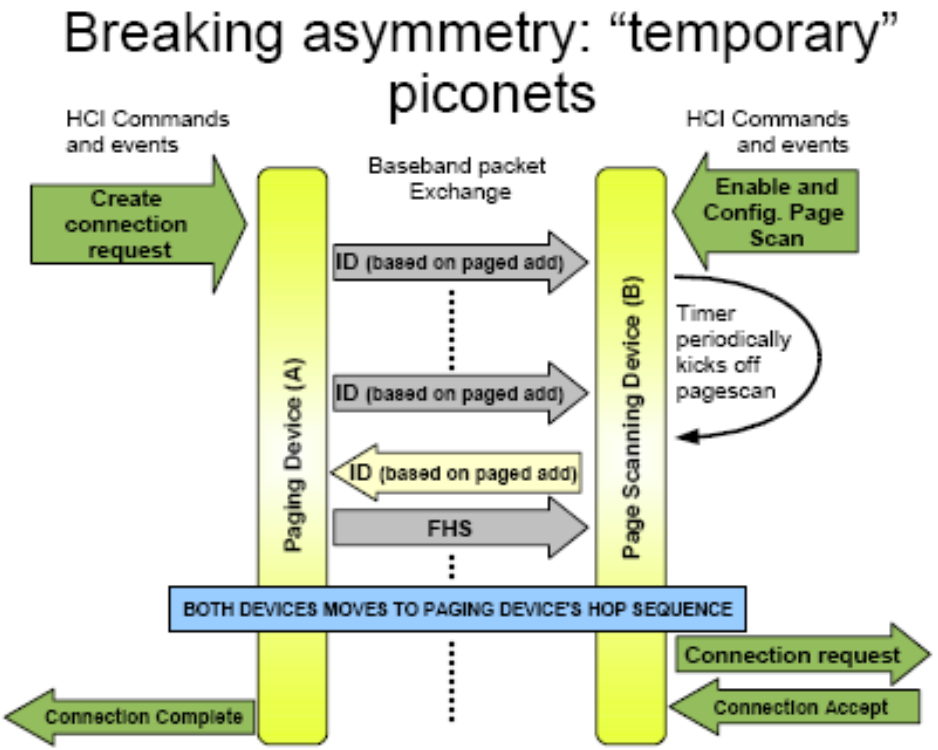
Symmetric device discovery

First proposed by Salonidis,Tassiulas, Baghwat, INFOCOM 2001

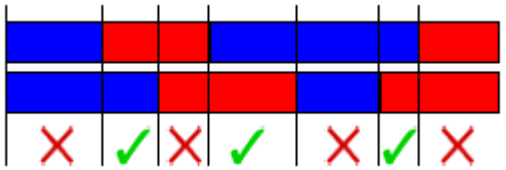
- Nodes alternate between inquiry and inquiry scan mode
- Random residence times in a mode
- Nodes perform standard inquiry (inquiry scan) procedures when in inquiry (inquiry scan) mode
- Idea: “two nodes discover each other when they are in opposite mode for sufficiently long time”

Device Discovery





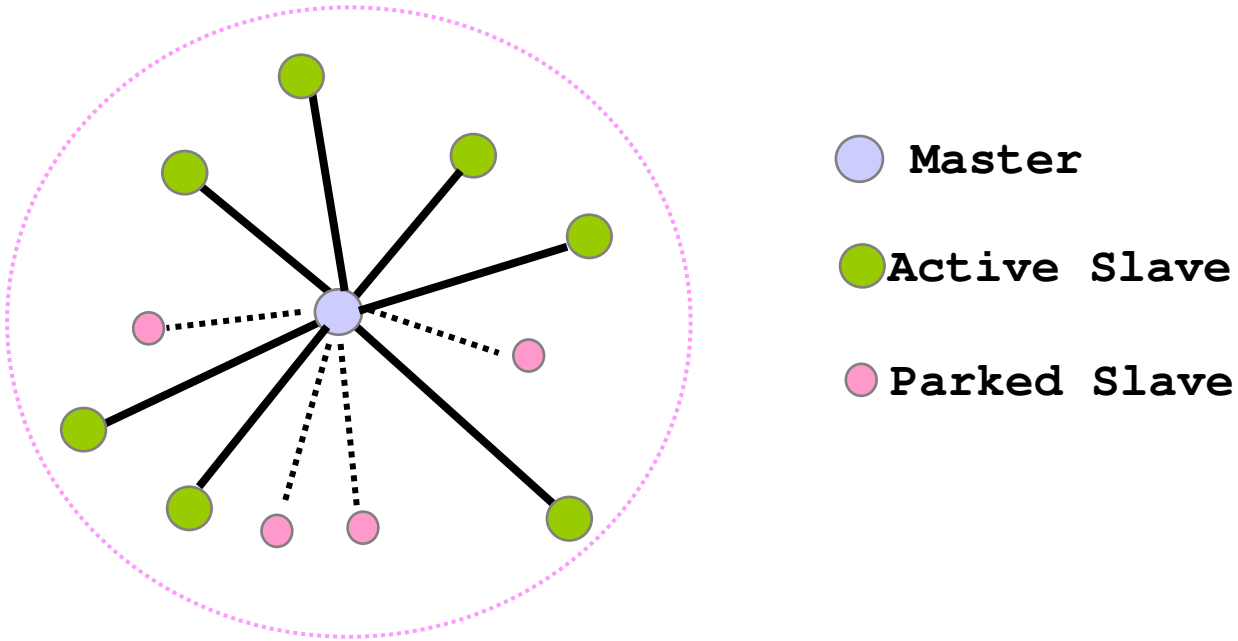
Nodes alternate between inquiry and inquiry scan, randomly selecting the lengths of these two phases



High probability that two nodes will be in opposite mode for enough time to discover each other → how long? Empirically 20s were shown enough…

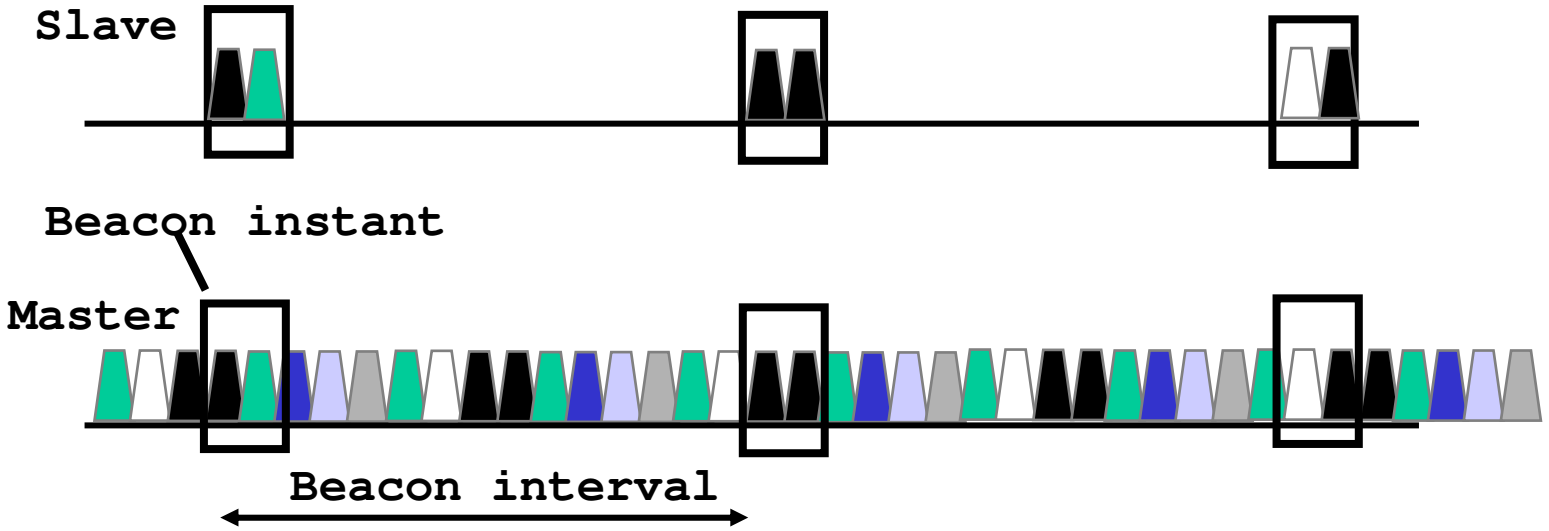
Piconet formation

- Page - scan protocol
  - to establish links with nodes in proximity



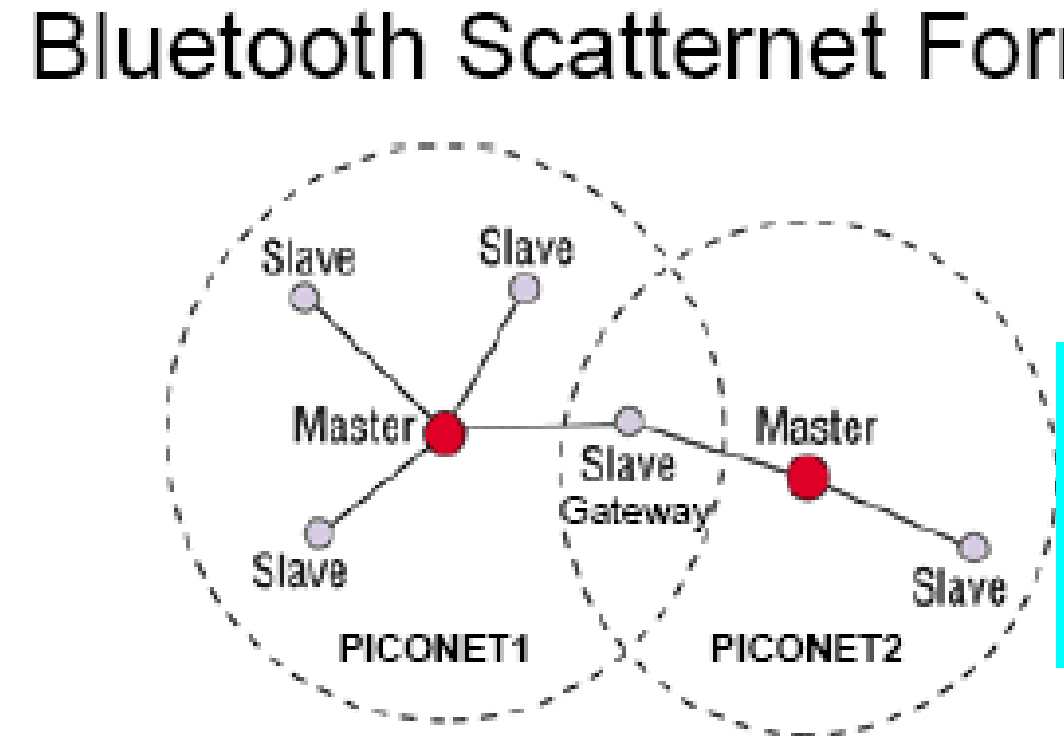
Low Power mode (Park)

(serve a gestire caso in cui una piconet abbia più di 7 slave)

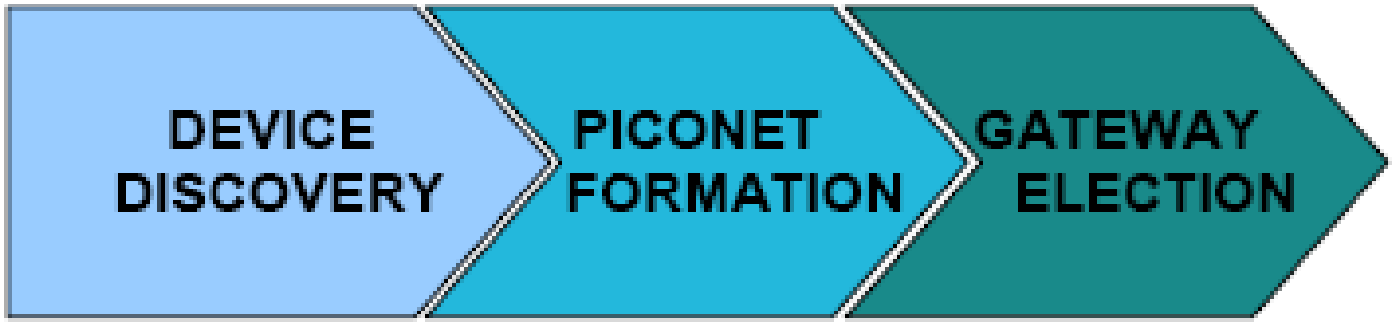


- Power saving + keep more than 7 slaves in a piconet
- Give up active member address, yet maintain synchronization
- Communication via broadcast LMP (Link manager protocol) messages

Scatterner formation



Desiderabile Scatternets con piconet di dim. <=8



Scatternet formation protocols

- **Device Discovery** (make a node aware of its neighbors ID and weight)
- **Piconet Formation** (nodes are partitioned in clusters)
- **Piconet Interconnection** (in a connected scatternet)

- **A good scatternet formation protocol should:**
  - ***Be fully distributed, rely on local info.***
  - ***Generate connected scatternets***
  - ***Be resilient to disconnection***
  - ***Have piconets of bounded size (magic number 7)***
  - ***Limit the number of intermediate gateways, avoid master-master direct interconnection, limit # of roles***
  - ***Select masters on a resource based basis***
  - ***Have multiple routes (for robustness)***
  - ***Be self-healing***

Scatternet formation in Bluetooth Networks, Basagni, Bruno, Petrioli Wiley IEEE Press, book on Ad Hoc Networks (uploaded to the web site).

Scheduling and Routing

- Once a scatternet is formed, gateways must be scheduled
  - Determine when and for how long they reside as active slaves in their piconets
    - Interpiconet scheduling
  - Determine the polling scheme to adopt in each piconet (Intra-piconet scheduling)
    - Accounting for node availability in the piconet
    - Being able to adapt to traffic while ensuring fairness
      - credit based schemes
  - In case of a scatternert also routing solutions should be adopted
    - Major objective: Load balancing in a limited data rate technology

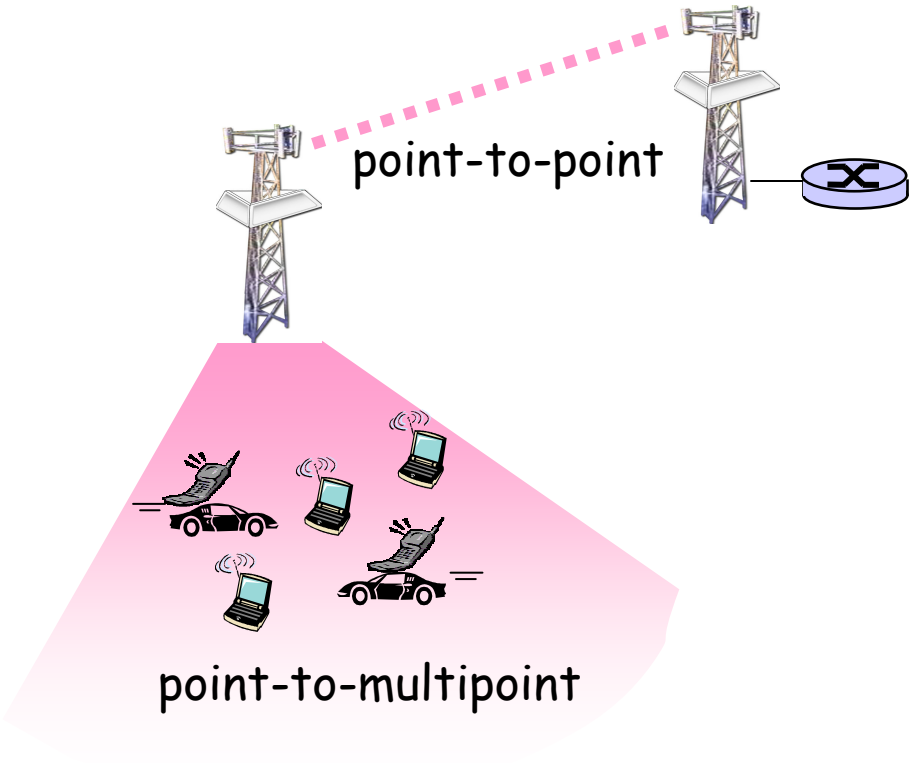
Bluetooth in a Nutshell

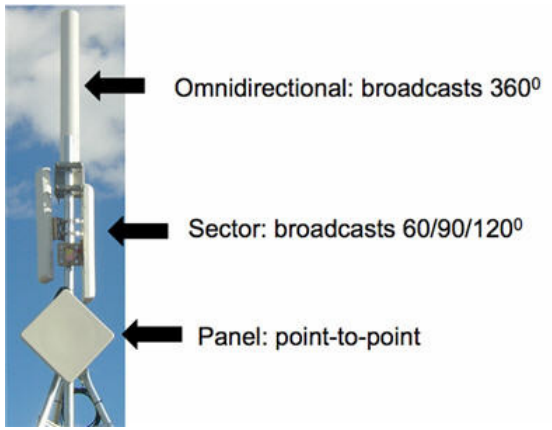
- Not trivial to go from a piconet to a scatternet operation
- Some problems related to standard implementations
  - which do not allow devices to select the inquiry train
  - which do not allow nodes to fast move from inquiry to page
  - some pseudorandom generation problems and link instability problems

  have compromised performance wrt what is possible with the standard
- Bluetooth evolution on going
- Used especially in mobile health applications in addition to cable replacement

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") Wireless MAN
  - ~14 Mbps

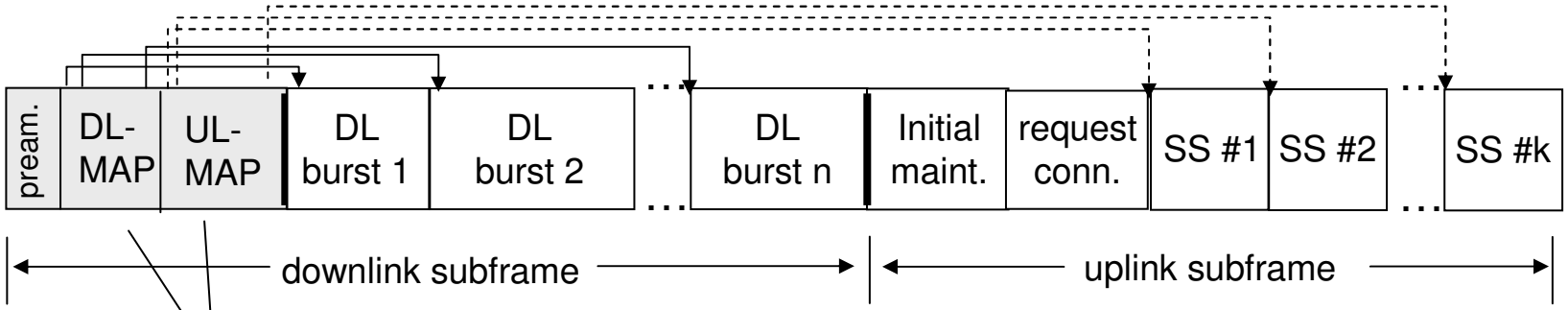




802.16: WiMAX: downlink, uplink scheduling

Separation of uplink and downlink either in TDD or FDD

- transmission frame
  - down-link subframe: base station to node
  - uplink subframe: node to base station



base station tells nodes who will get to receive (DL map), and which phy (modulation) and data link (FEC) parameters to use per burst, and who will get to send (UL map), and when

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

Chapter 6 outline

6.1 Introduction

Wireless

- 6.2 Wireless links, characteristics
- 6.3 IEEE 802.11 wireless LANs ("wi-fi")
- 6.4 Cellular Internet Access
  - architecture
  - standards (e.g., GSM)

Mobility

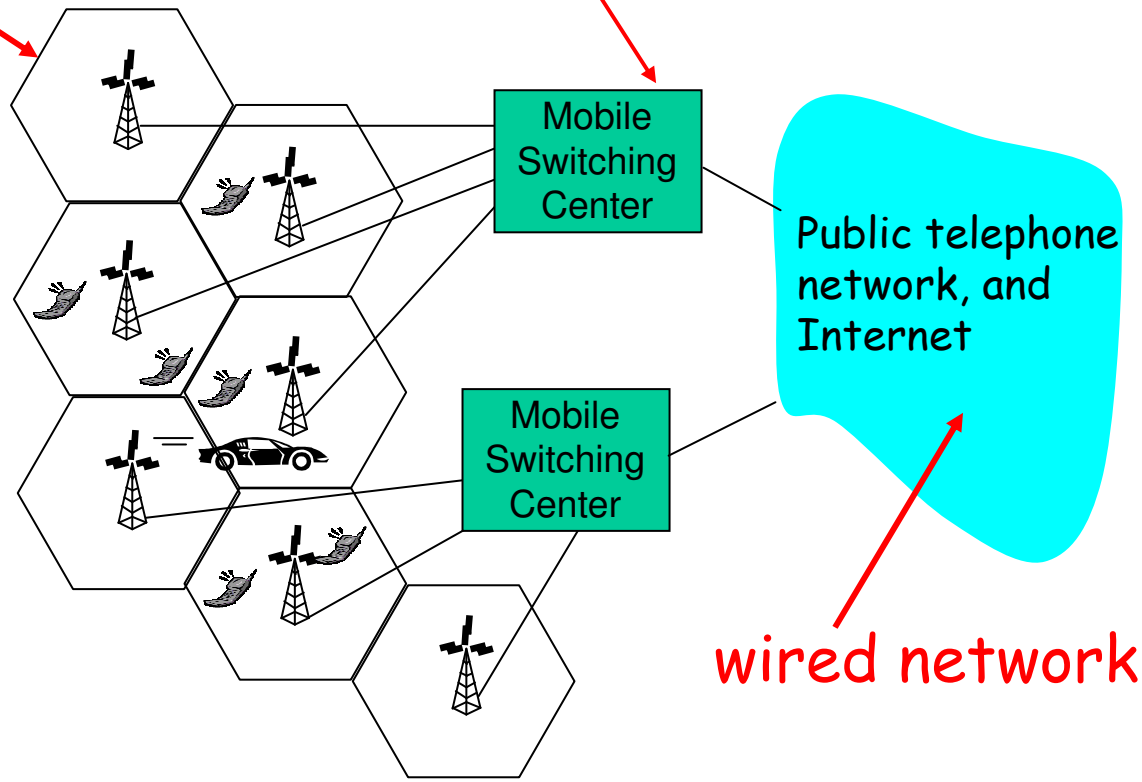
- 6.5 Principles: addressing and routing to mobile users
- 6.6 Mobile IP
- 6.7 Handling mobility in cellular networks
- 6.8 Mobility and higher-layer protocols

6.9 Summary

Components of cellular network architecture

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

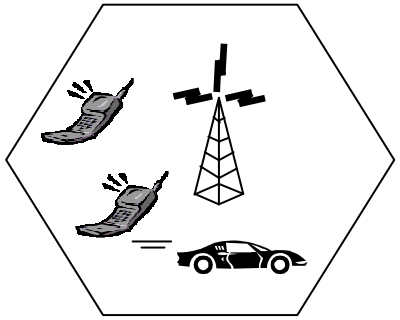
cell
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

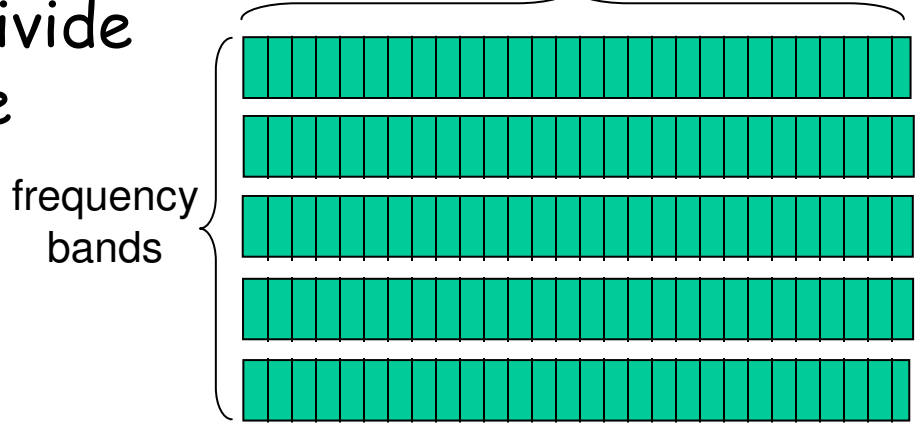


Cellular networks: the first hop

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

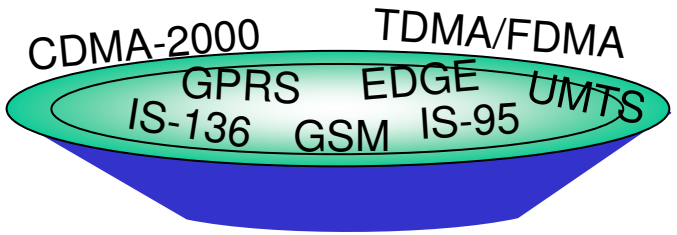




Cellular standards: brief survey

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

2.5 G 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

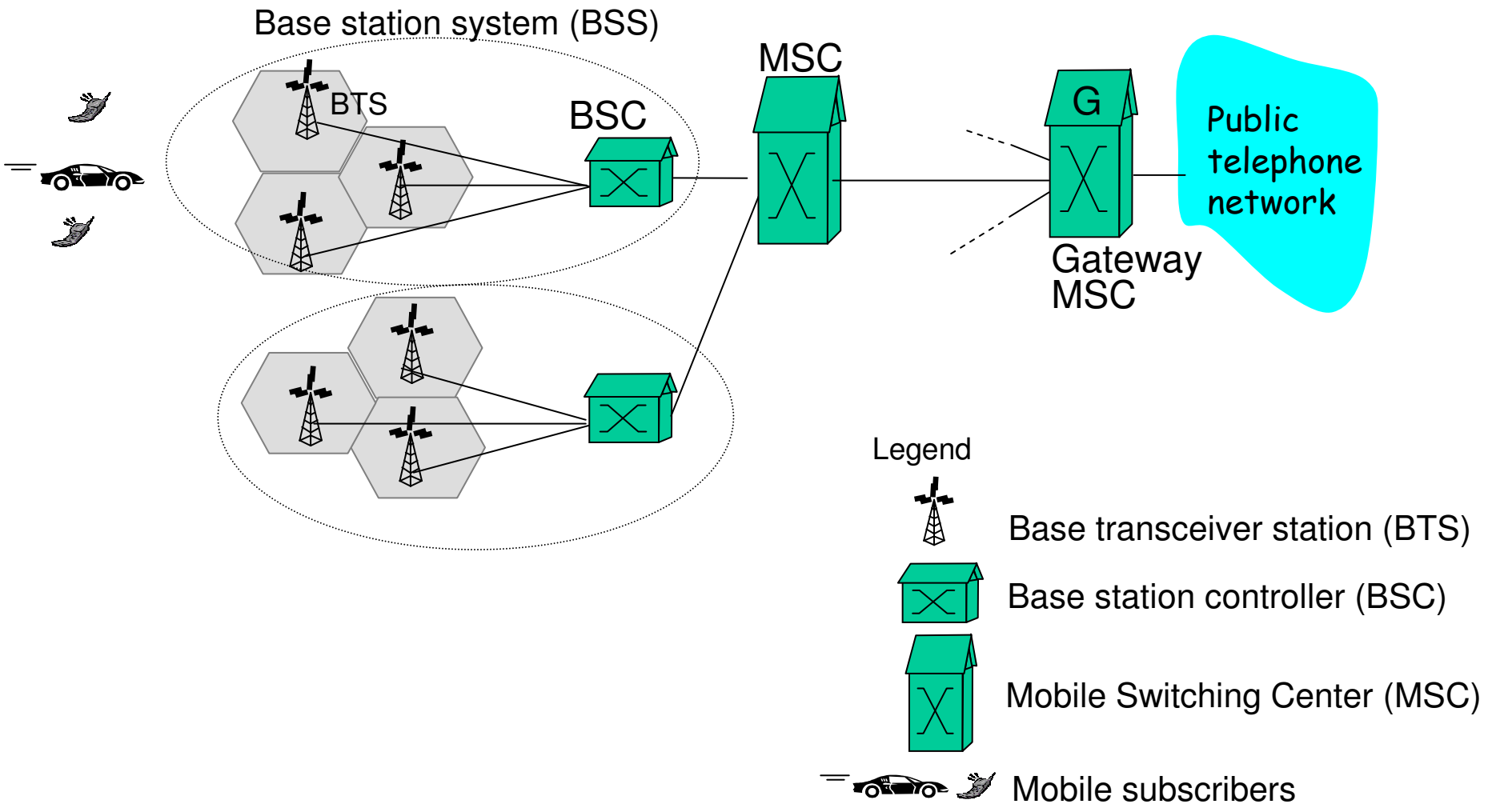
Cellular standards: brief survey

3G systems: voice/data

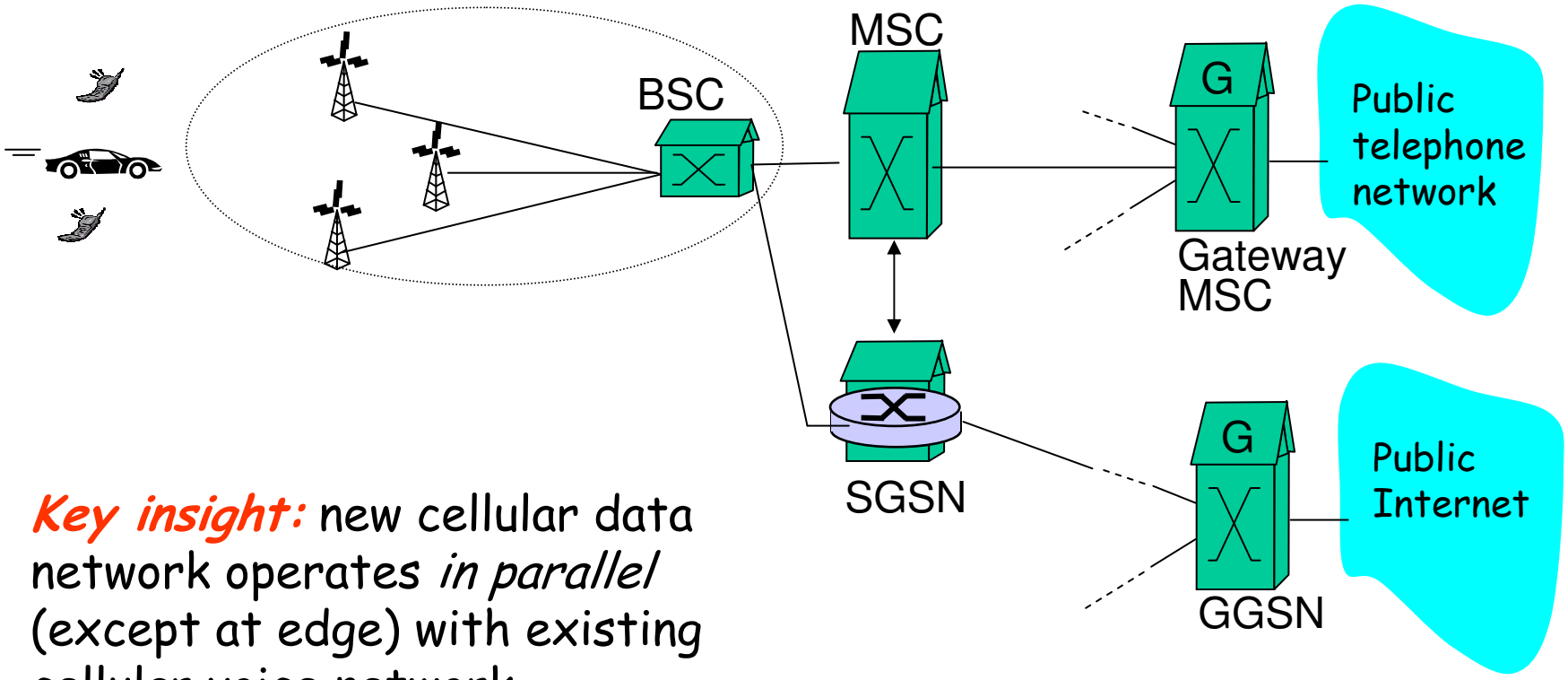
- Universal Mobile Telecommunications Service (UMTS)
  - data service: High Speed Uplink/Downlink packet Access (HSDPA/HSUPA): 3 Mbps
- CDMA-2000: CDMA in TDMA slots
  - data service: 1xEvolution Data Optimized (1xEVDO) up to 14 Mbps

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

2G (voice) network architecture



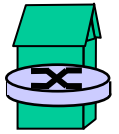
2.5G (voice+data) network architecture



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)

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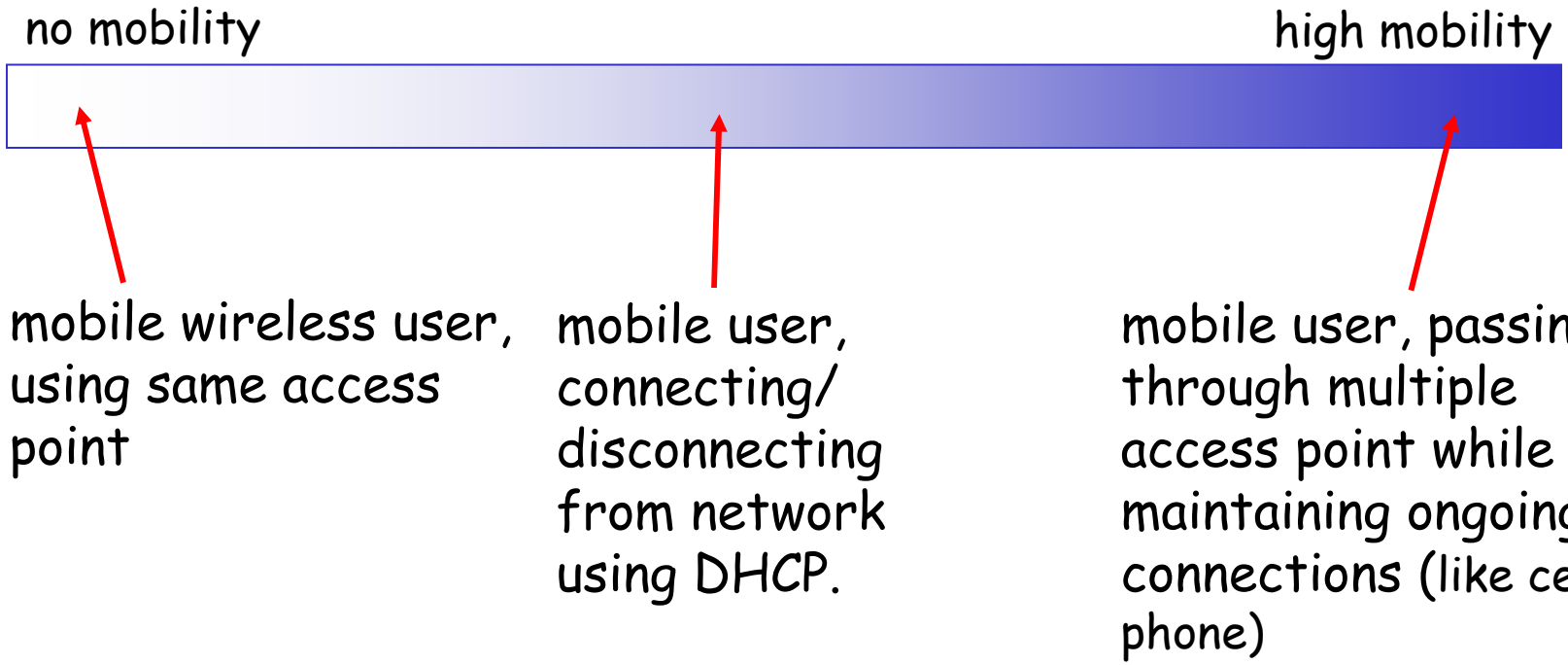
6.9 Summary

What is mobility?

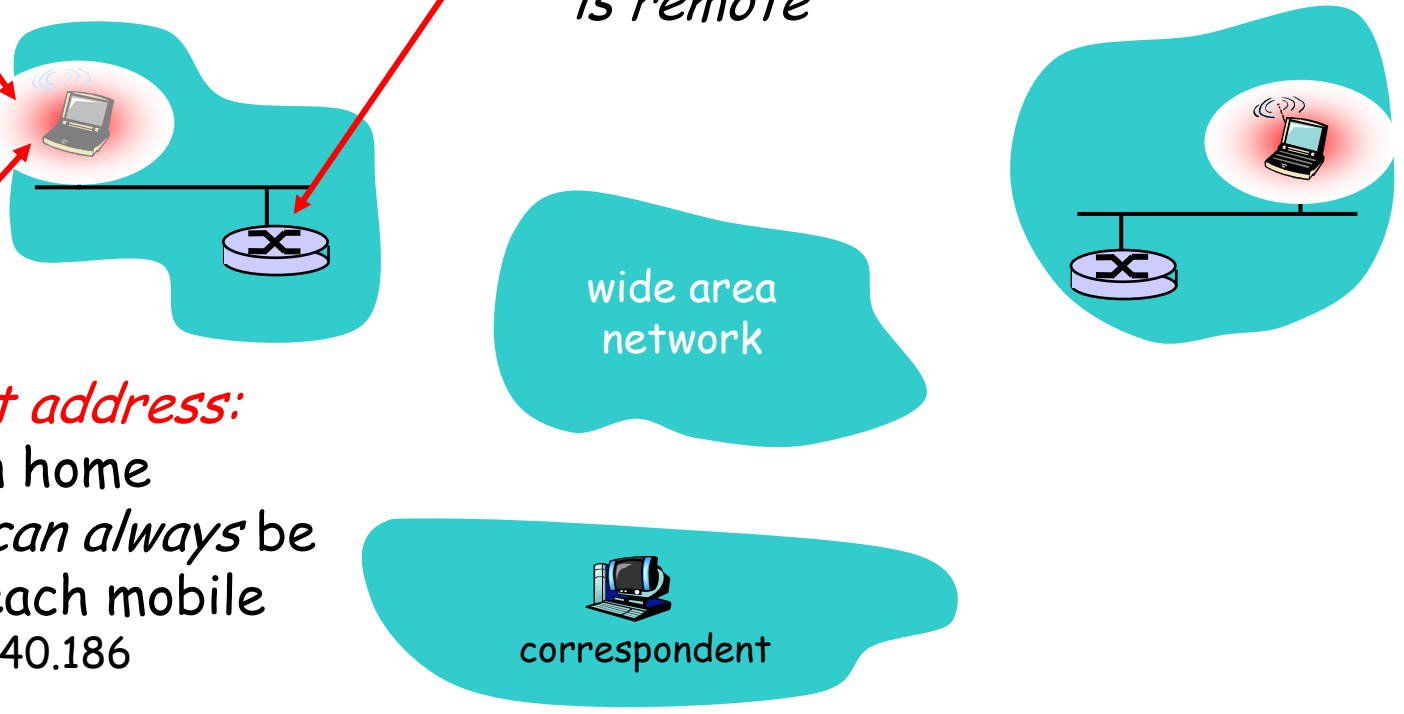
- spectrum of mobility, from the *network* perspective:



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*



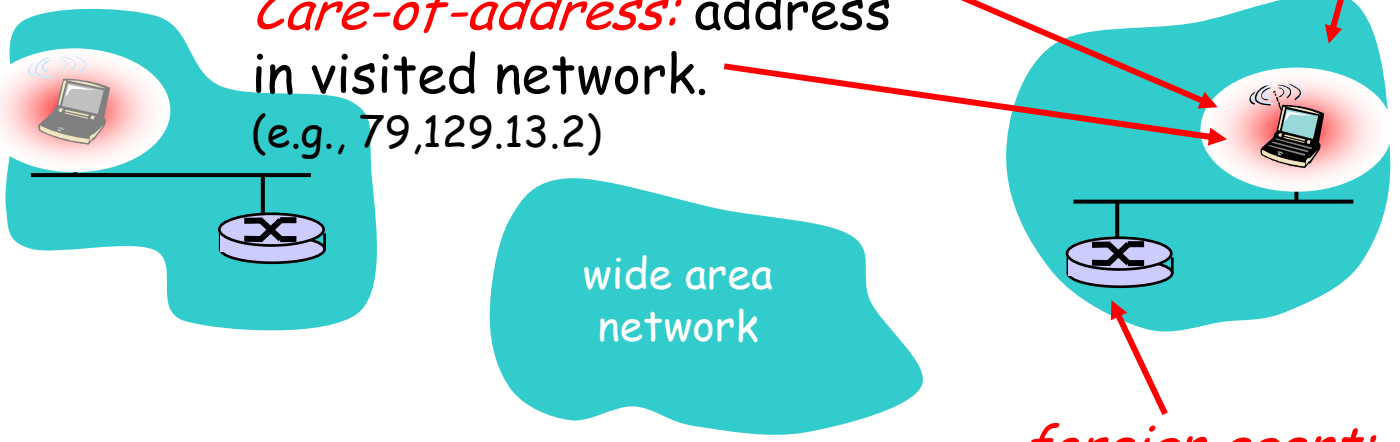
Permanent address: address in home network, *can always* be used to reach mobile e.g., 128.119.40.186

Mobility: more vocabulary

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

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

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

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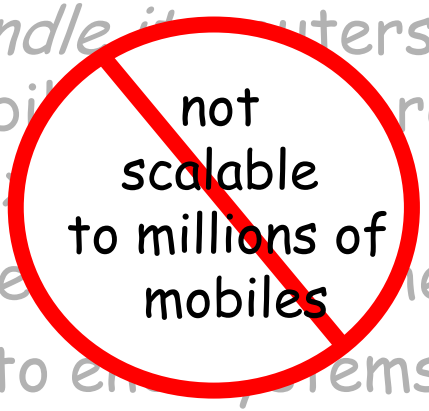
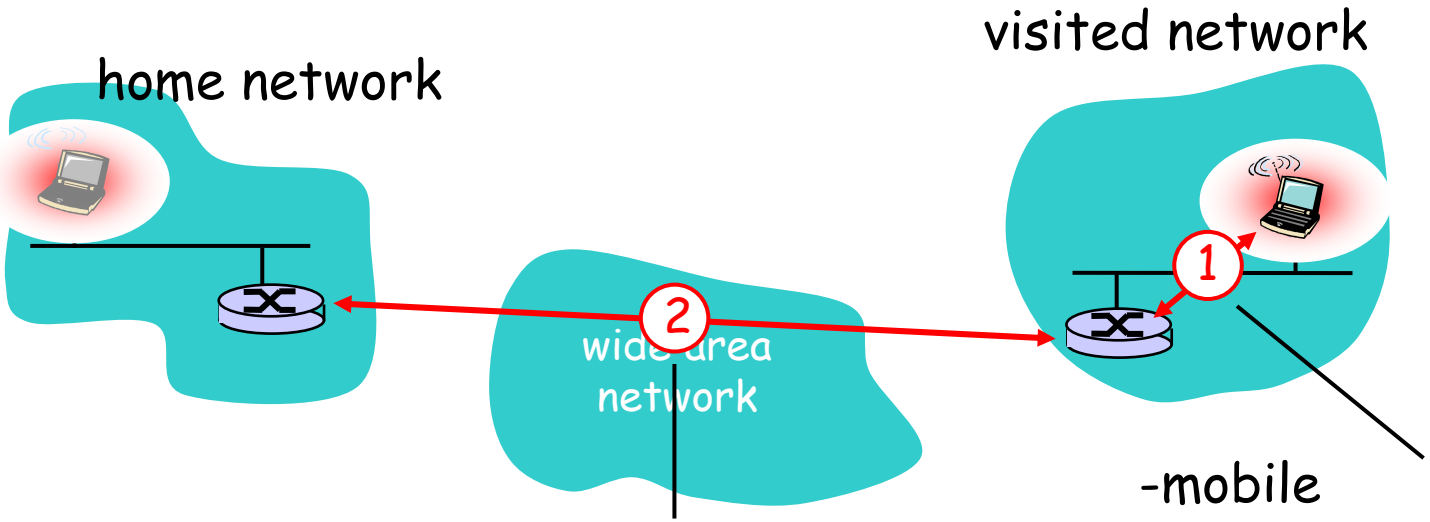


Mobility: registration



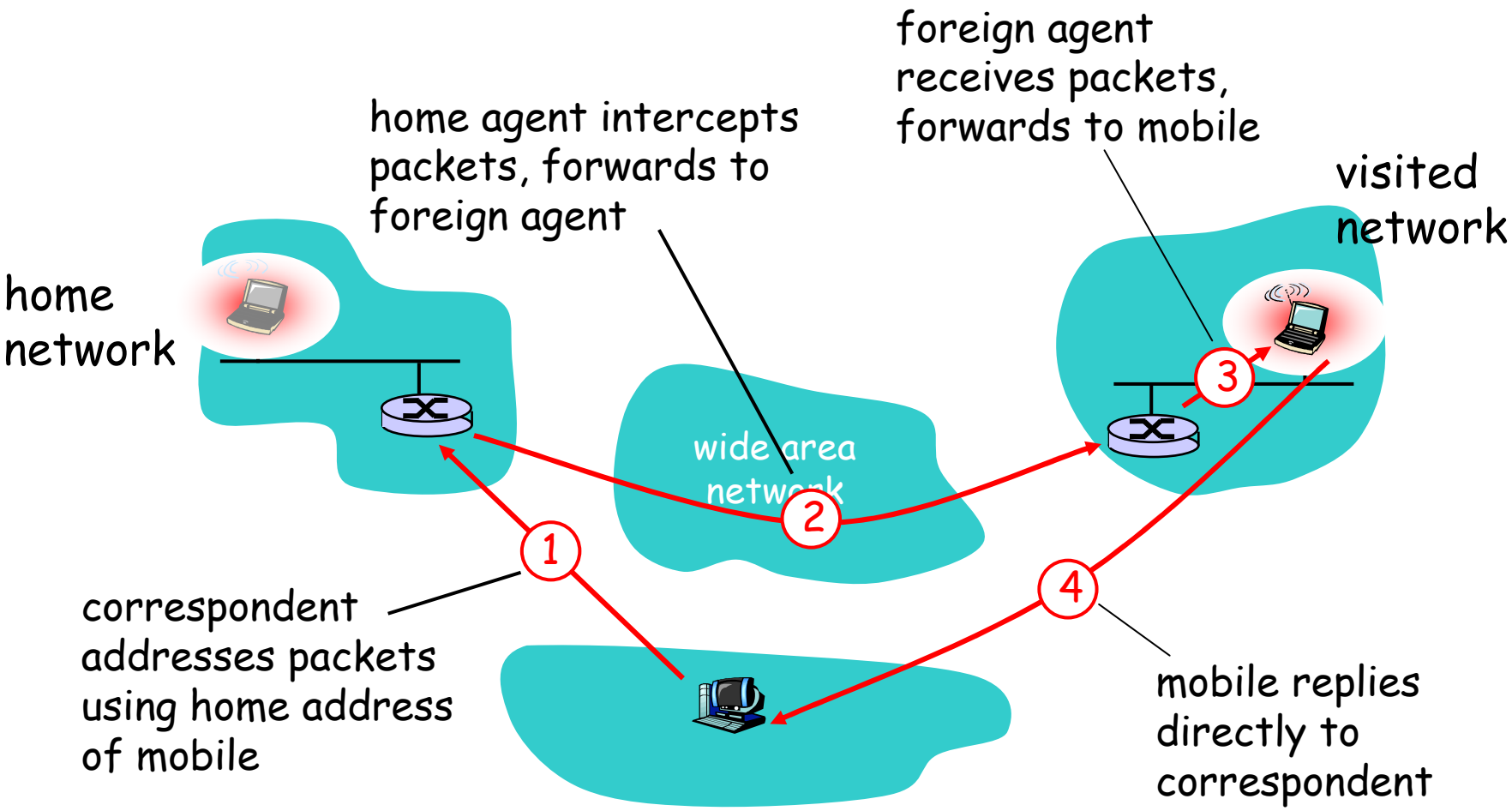
-foreign agent contacts home agent home: "this mobile is resident in my network"
-COA communicated

-mobile contacts foreign agent on entering visited network
-a Care of Address is assigned

End result:

- Foreign agent knows about mobile
- Home agent knows location of mobile

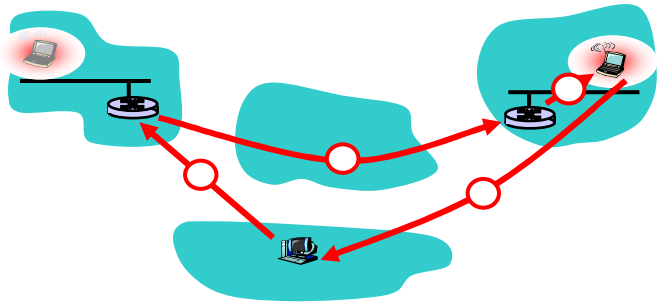
Mobility via Indirect Routing



Step 2: datagram transmitted by sources is encapsulated in a datagram transmitted by the home agent to the COA

Indirect Routing: comments

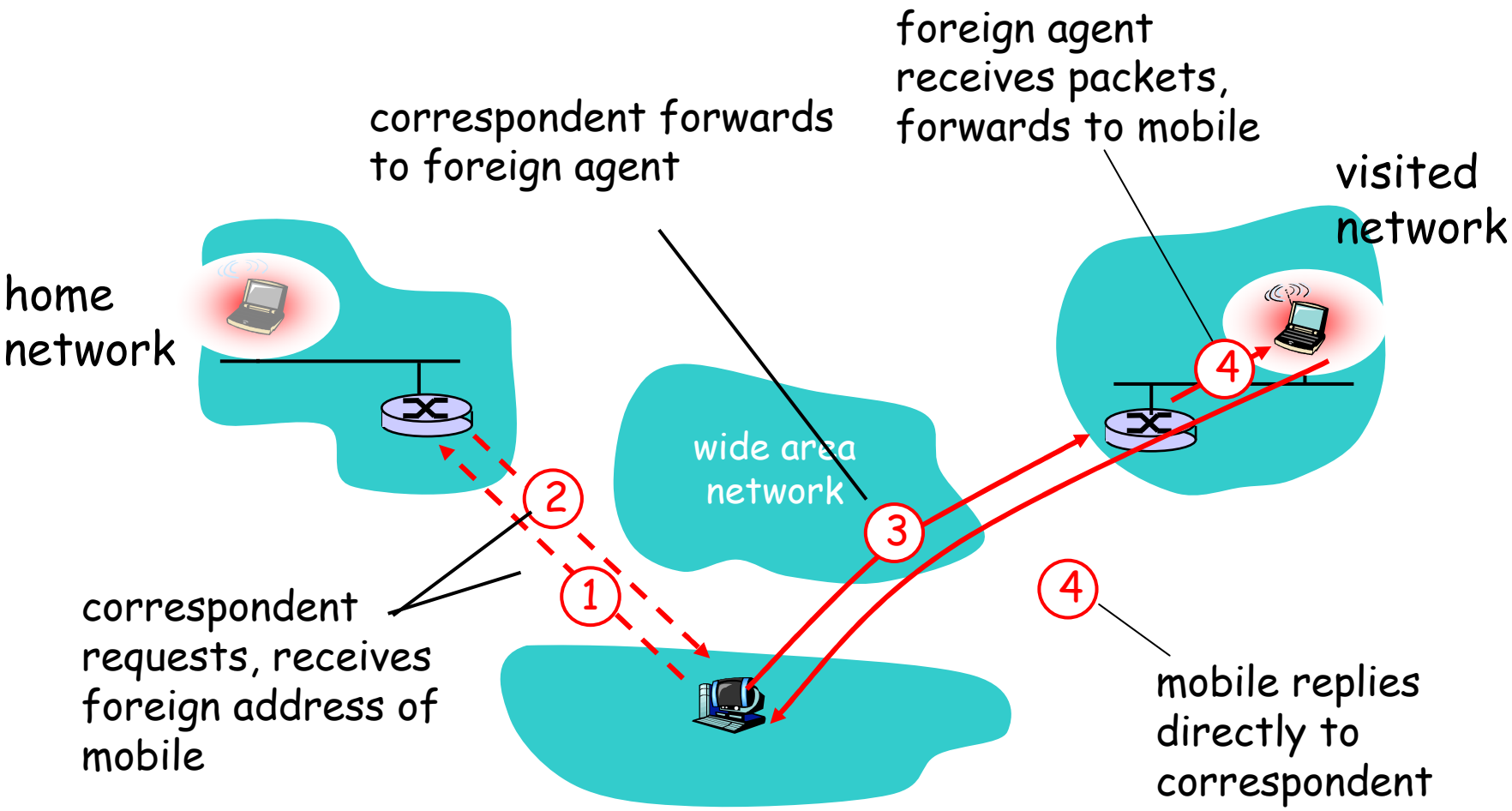
- Mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- foreign agent functions may be done by mobile itself
- triangle routing: correspondent-home-network-mobile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



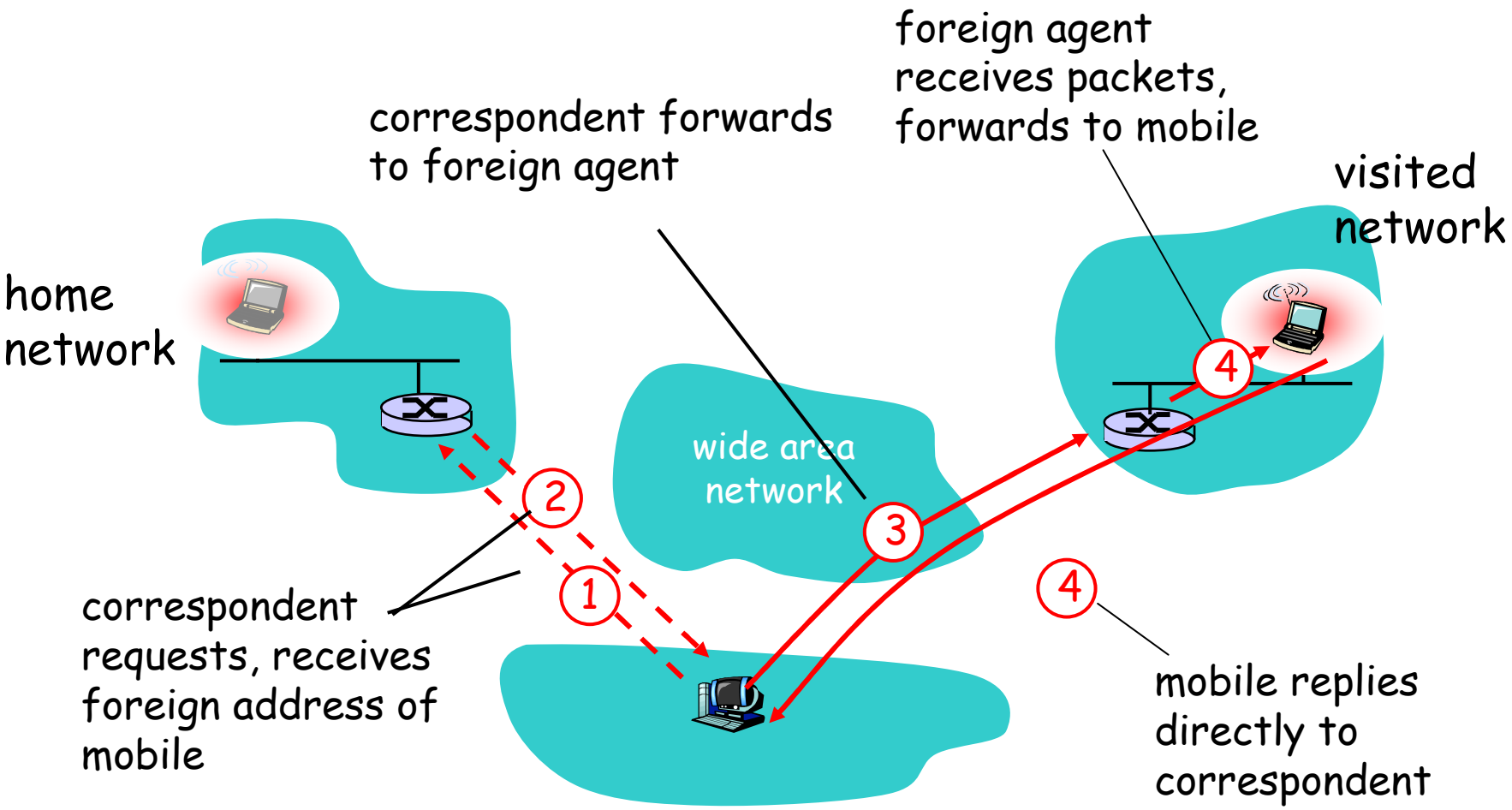
Indirect Routing: moving between networks

- 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



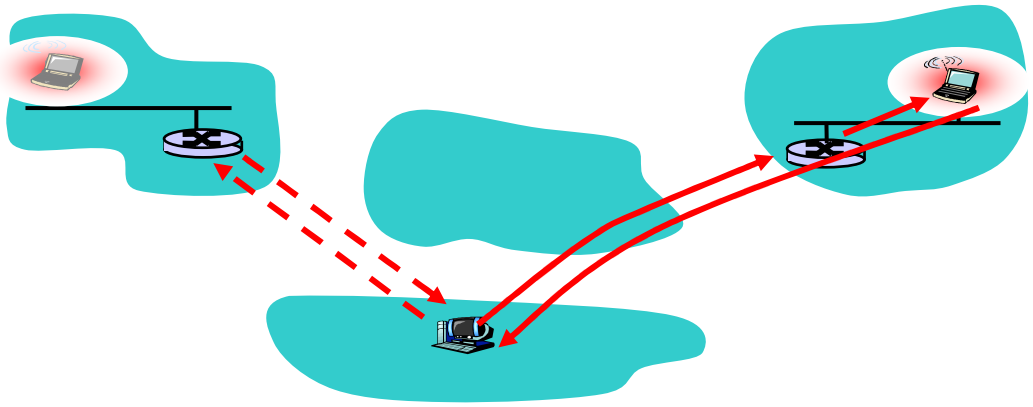
Mobility via Direct Routing



Mobile can act as foreign agent
Correspondent can act as corresponding agent

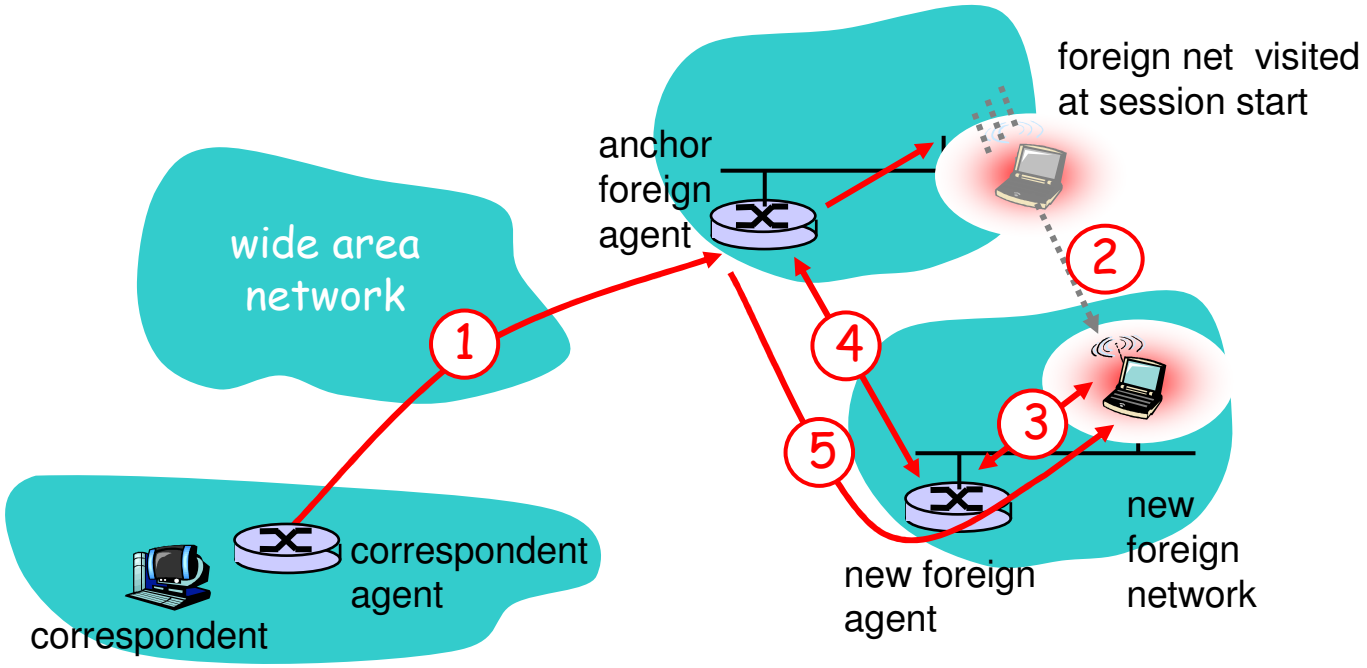
Mobility via Direct Routing: comments

- 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)



Chapter 6 outline

6.1 Introduction

Wireless

- 6.2 Wireless links, characteristics
  - CDMA
- 6.3 IEEE 802.11 wireless LANs ("wi-fi")
- 6.4 Cellular Internet Access
  - architecture
  - standards (e.g., GSM)

Mobility

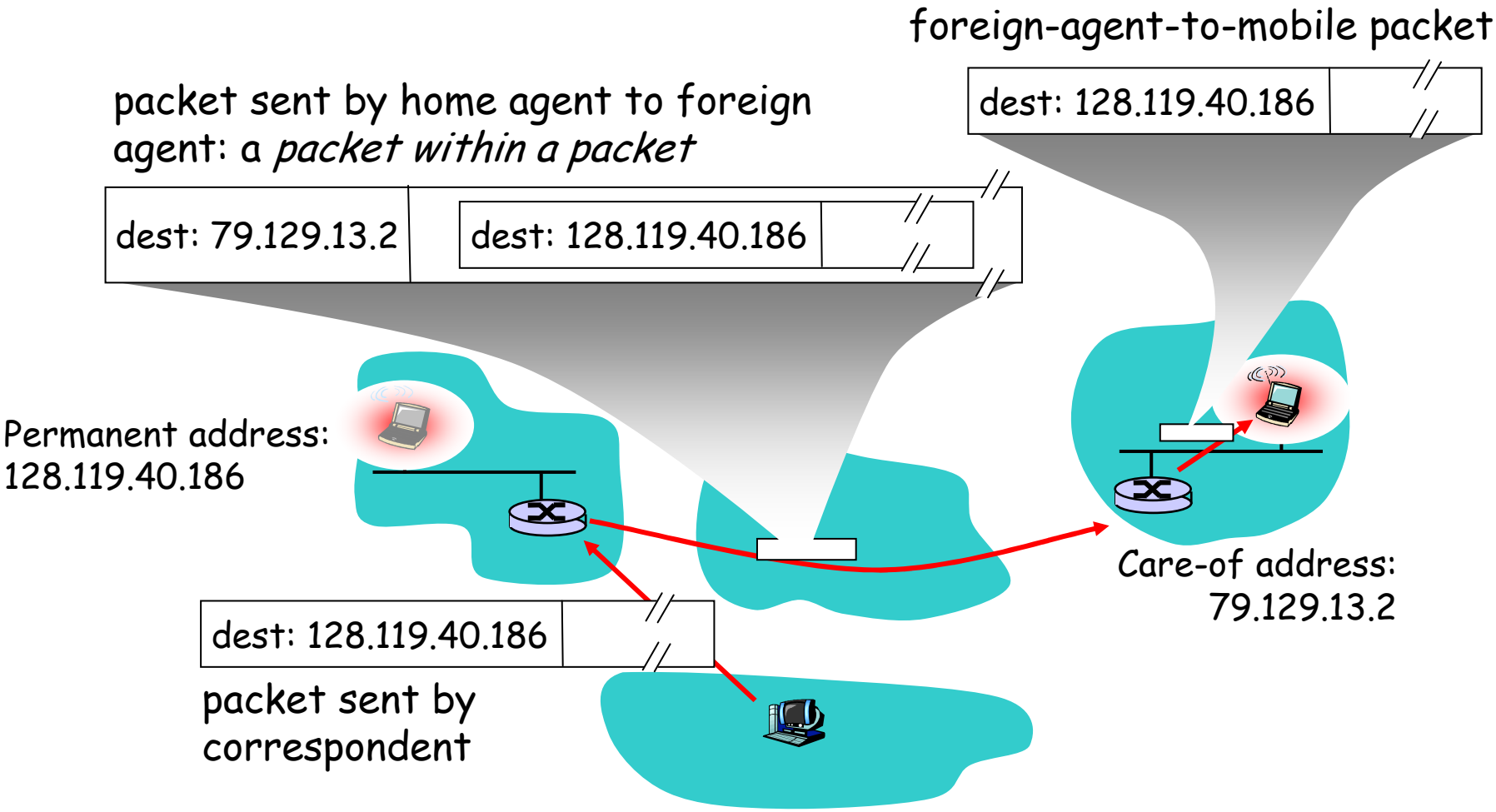
- 6.5 Principles: addressing and routing to mobile users
- 6.6 Mobile IP
- 6.7 Handling mobility in cellular networks
- 6.8 Mobility and higher-layer protocols

6.9 Summary

Mobile IP

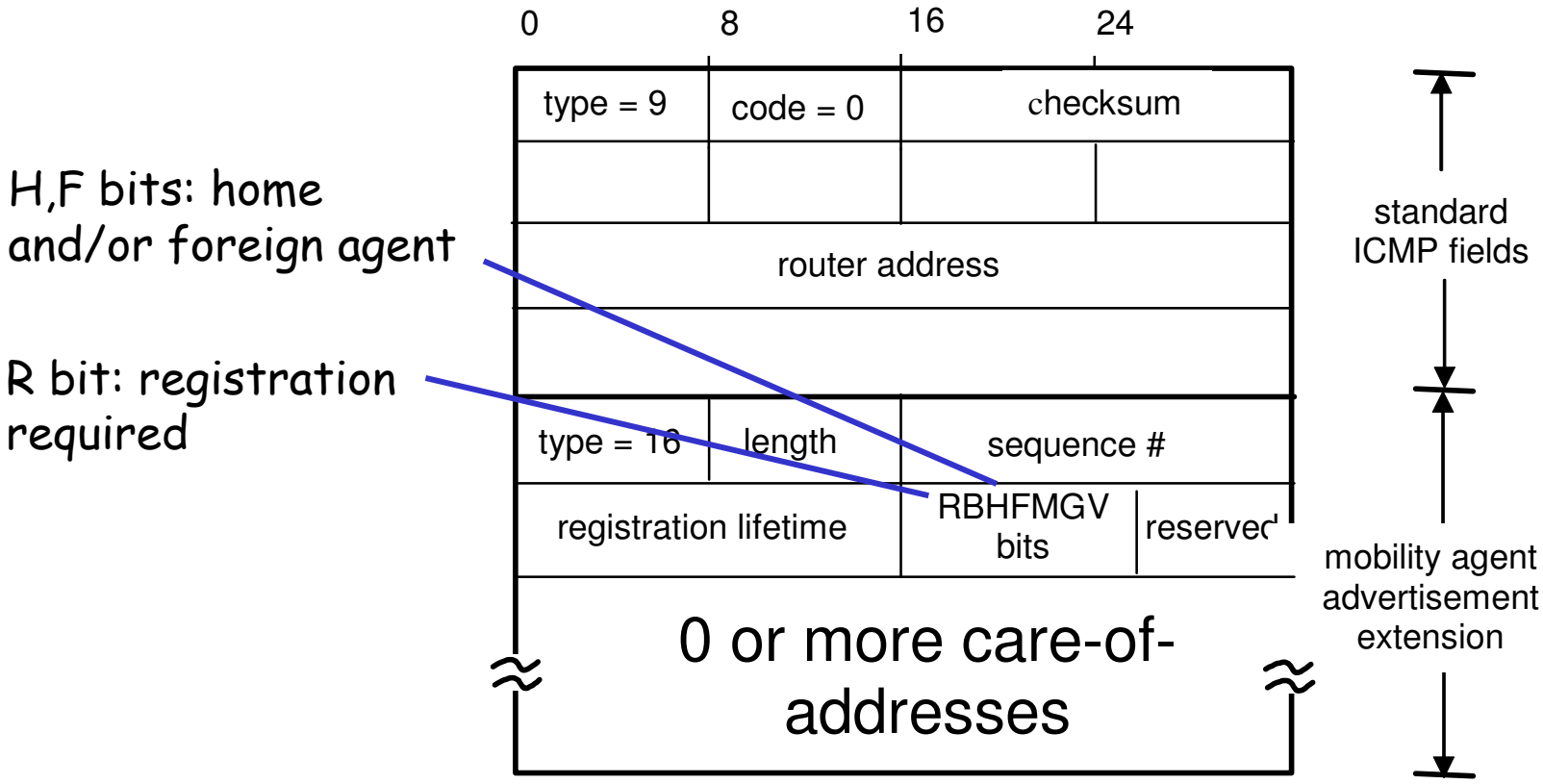
- RFC 3344
- has many features we've seen:
  - home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet)
- three components to standard:
  - indirect routing of datagrams
  - agent discovery
  - registration with home agent

Mobile IP: indirect routing

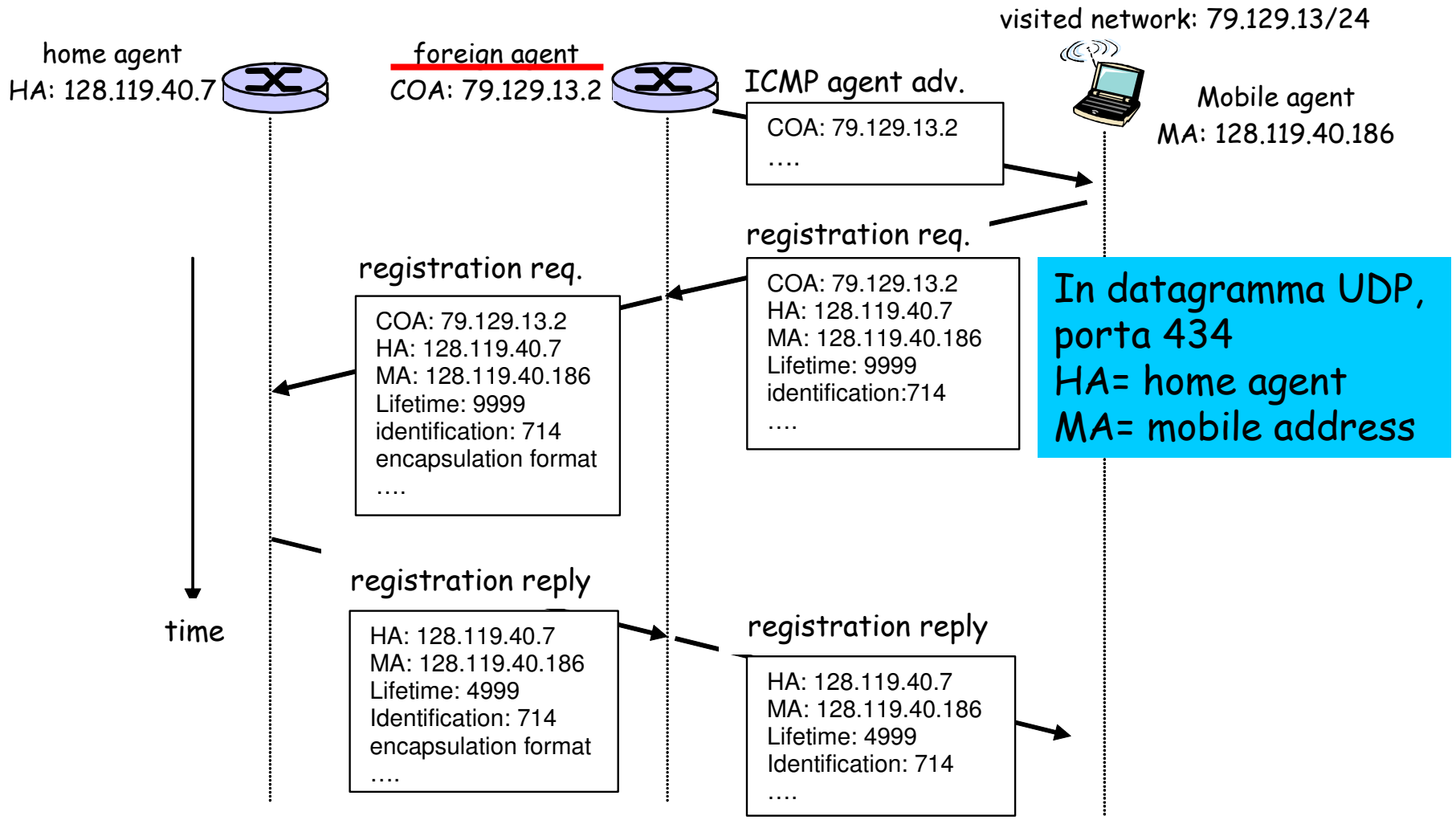


Mobile IP: agent discovery

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

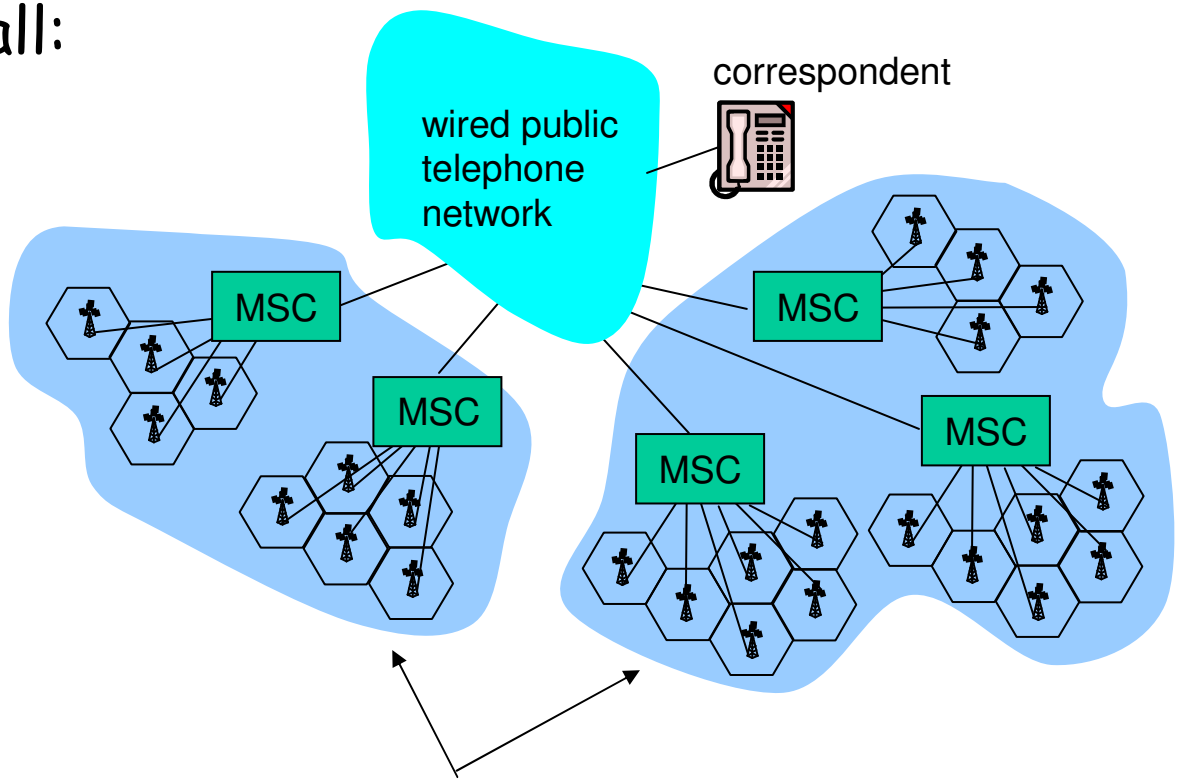


Mobile IP: registration example



Components of cellular network architecture

recall:

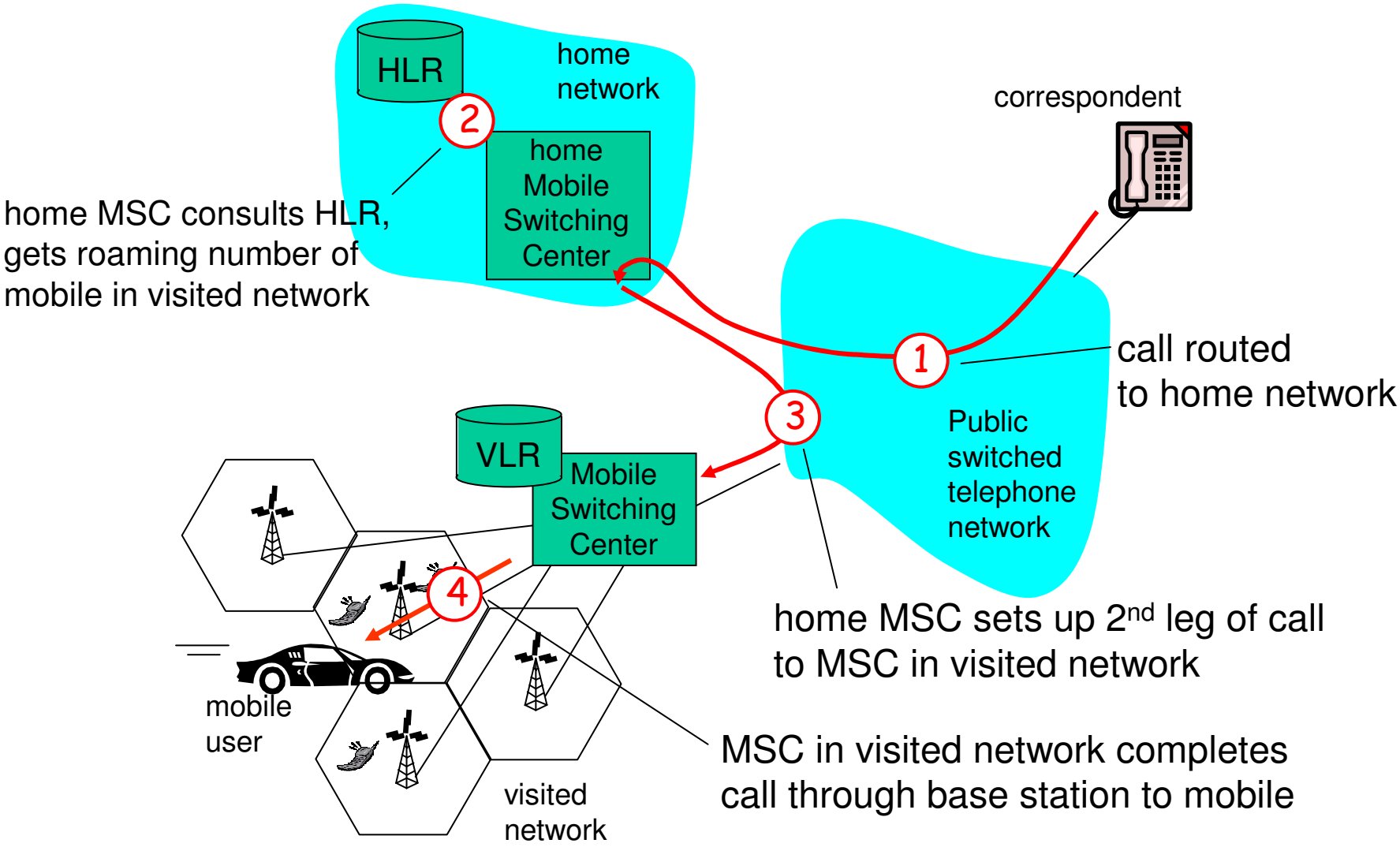


different cellular networks,
operated by different providers

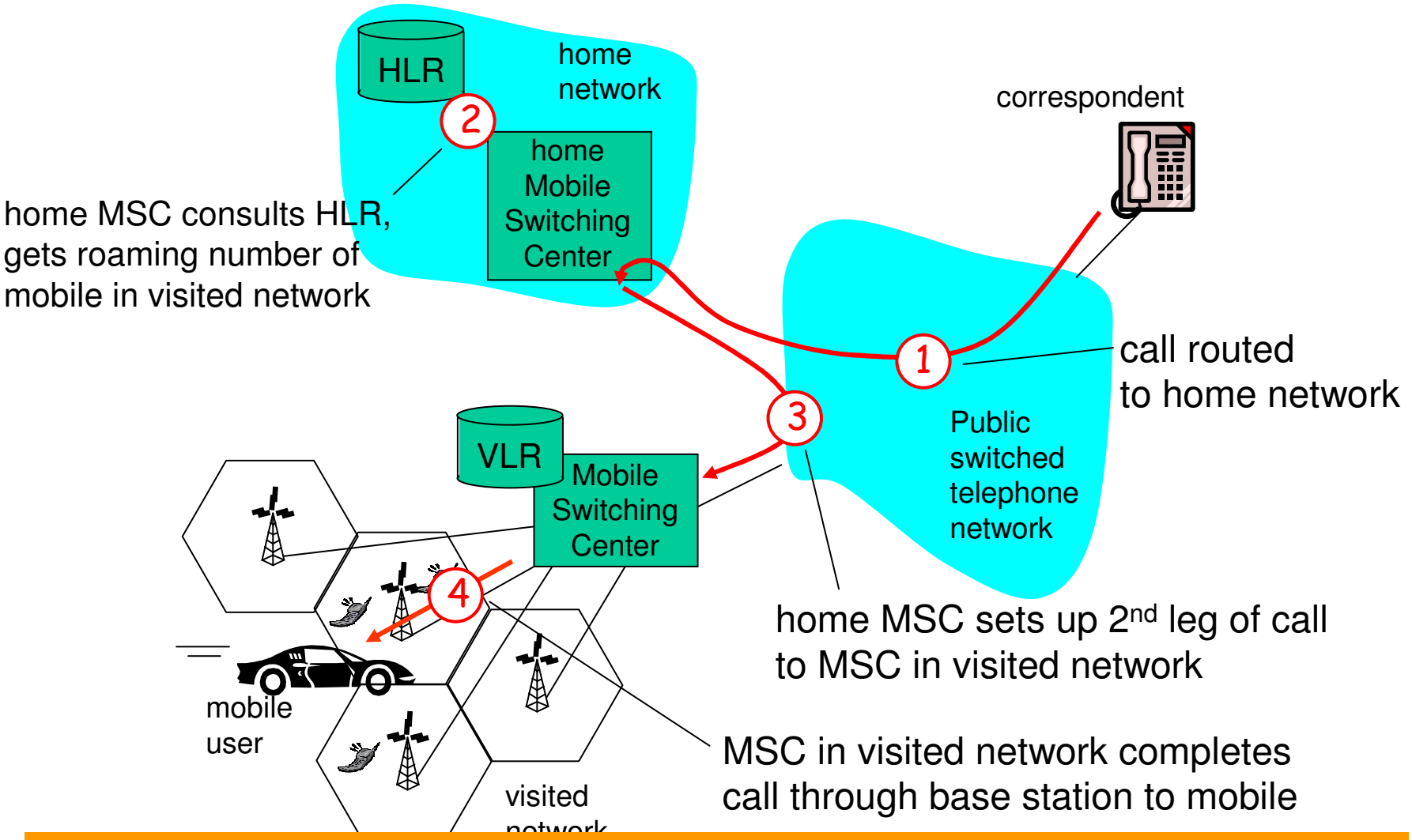
Handling mobility in cellular networks

- *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

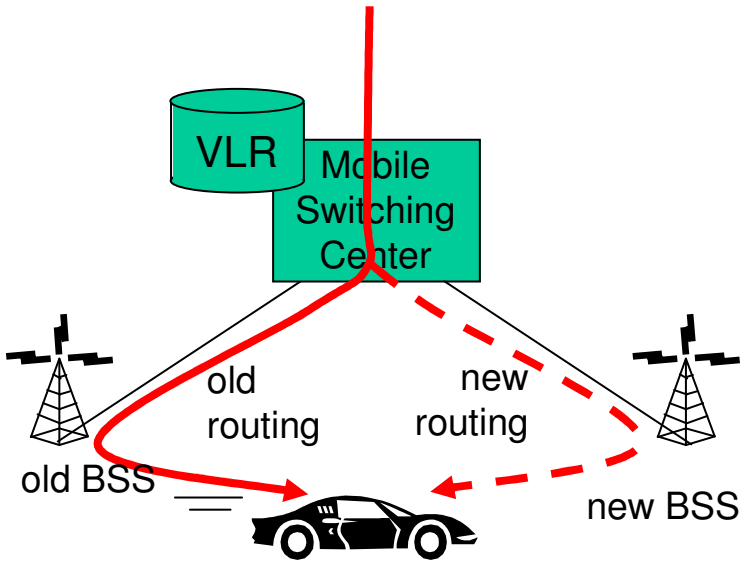


GSM: indirect routing to mobile



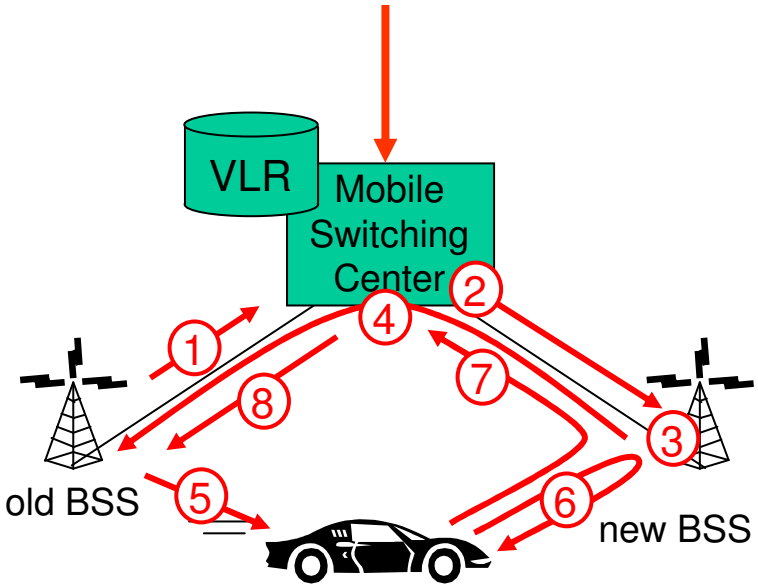
When MU switches on cell in the new network must register with VLR which communicates affiliation to HLR

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

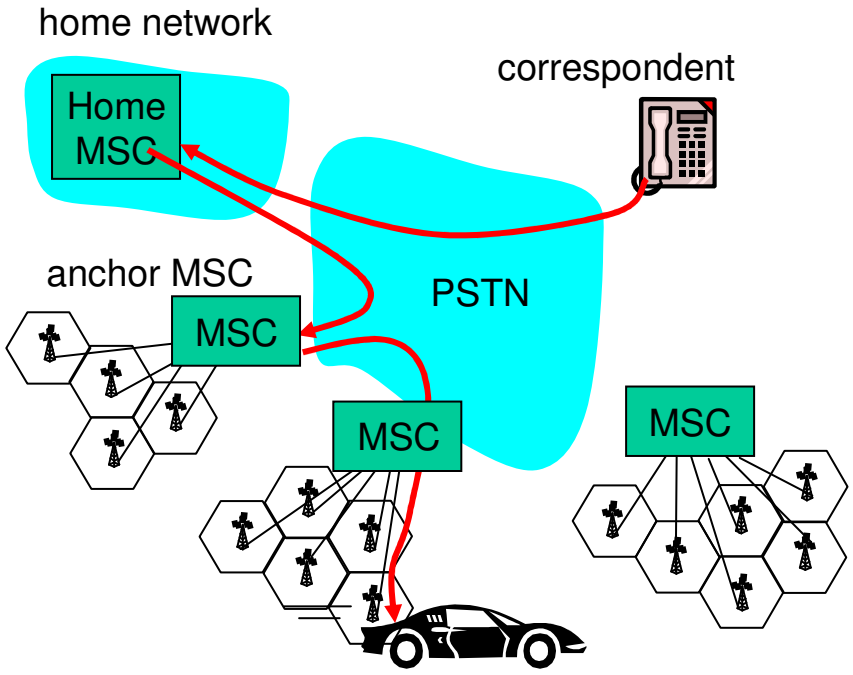
GSM: handoff with common MSC



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

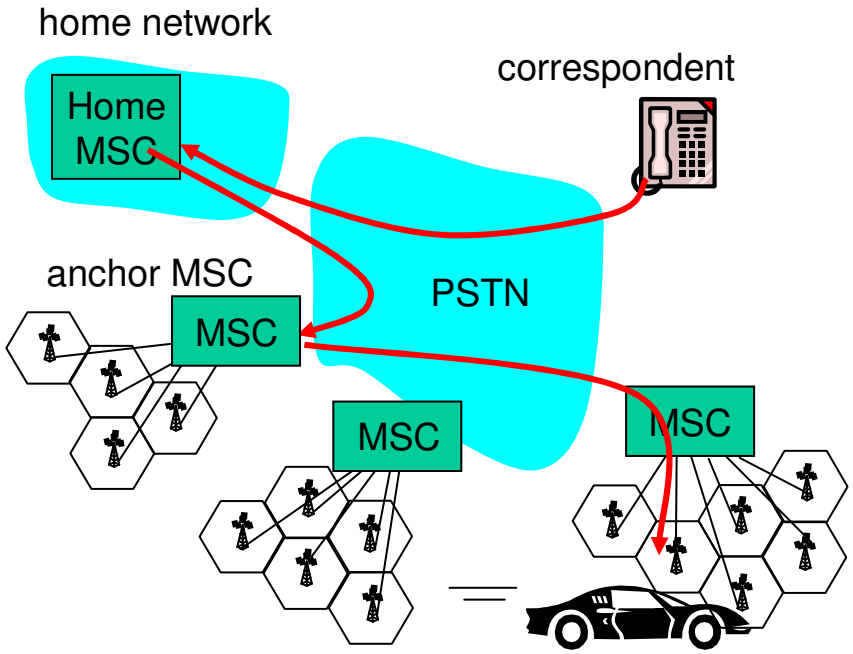
GSM: handoff between MSCs



(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**

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
    - ARQ based solutions
    - splitting of transport session (wired section/wireless section)
    - transparent approaches (e.g. TCP Westwood)

Chapter 6 Summary

Wireless

- wireless links:
  - capacity, distance
  - channel impairments
  - CDMA
- IEEE 802.11 ("wi-fi")
  - CSMA/CA reflects wireless channel characteristics
- cellular access
  - architecture
  - standards (e.g., GSM, CDMA-2000, UMTS)

Mobility

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