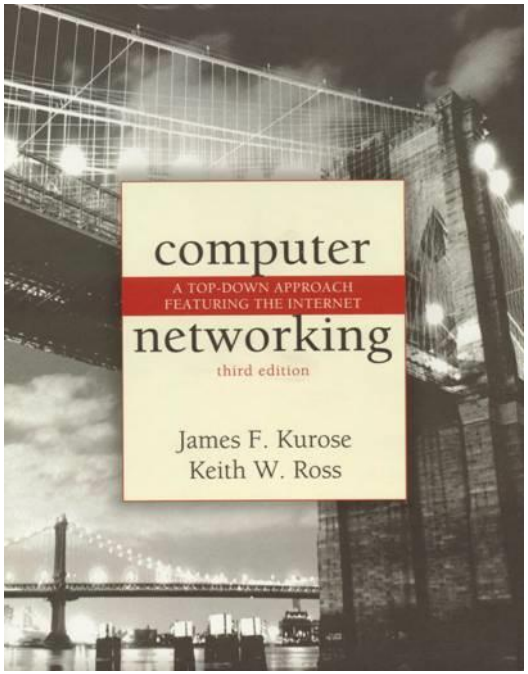
Chapter 6
Wireless and Mobile Networks



Computer Networking: A Top Down Approach Featuring the Internet, 3rd edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2004.

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Capítulo 6: Redes Sem Fio e Móveis

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
  - communication over wireless link
  - handling mobile user who changes point of attachment to network

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
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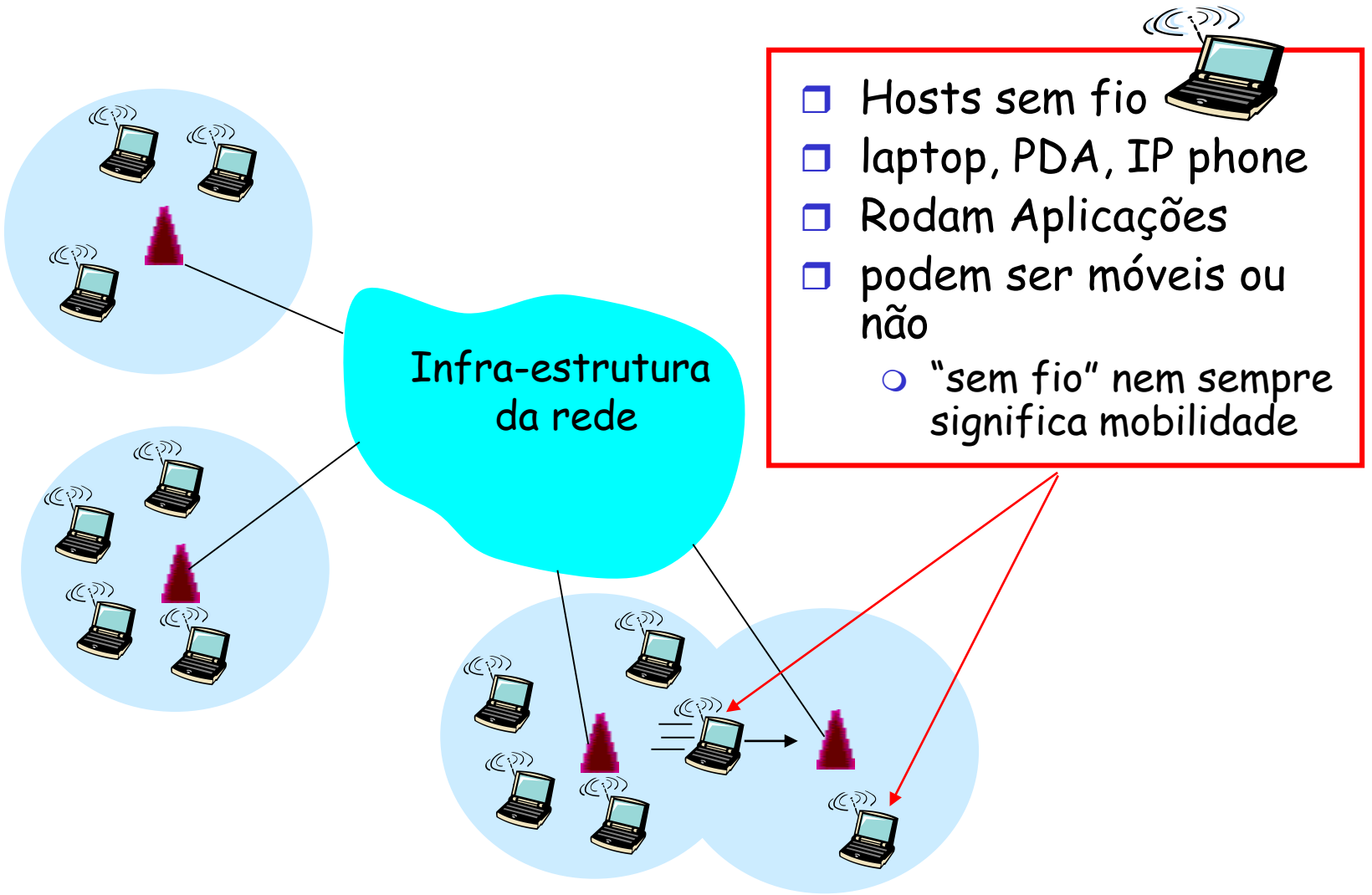
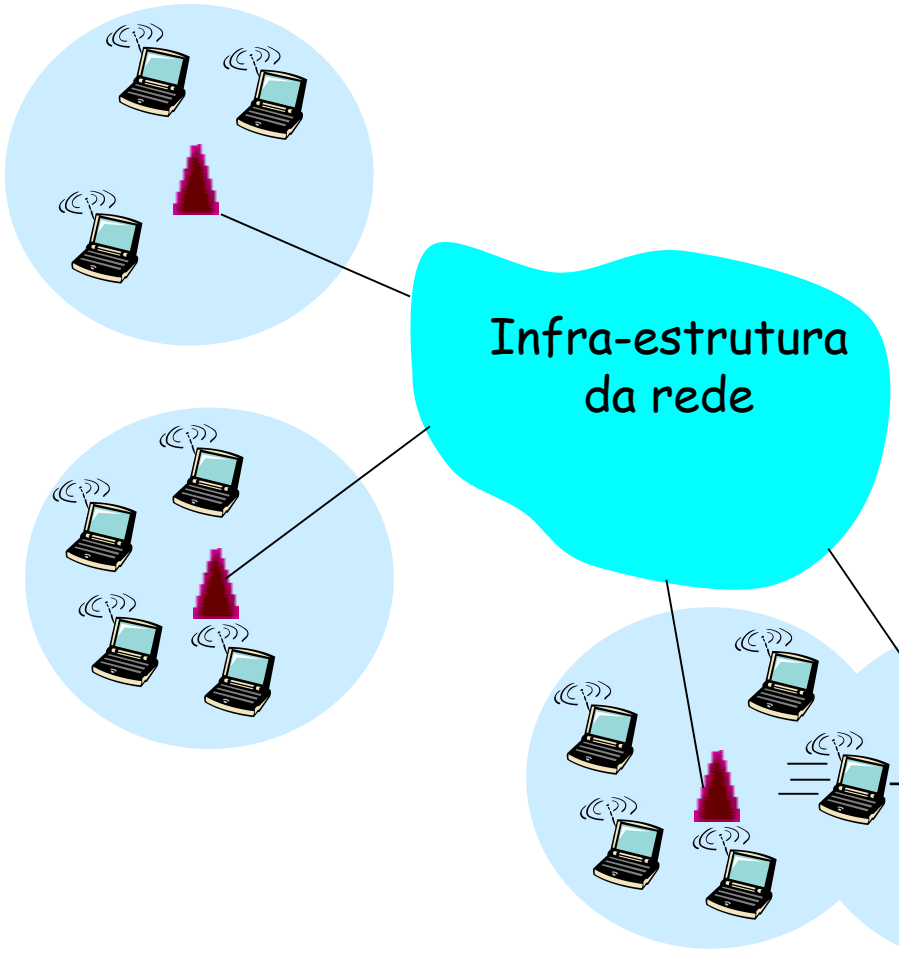
6.9 Summary

Elementos de uma rede sem fio



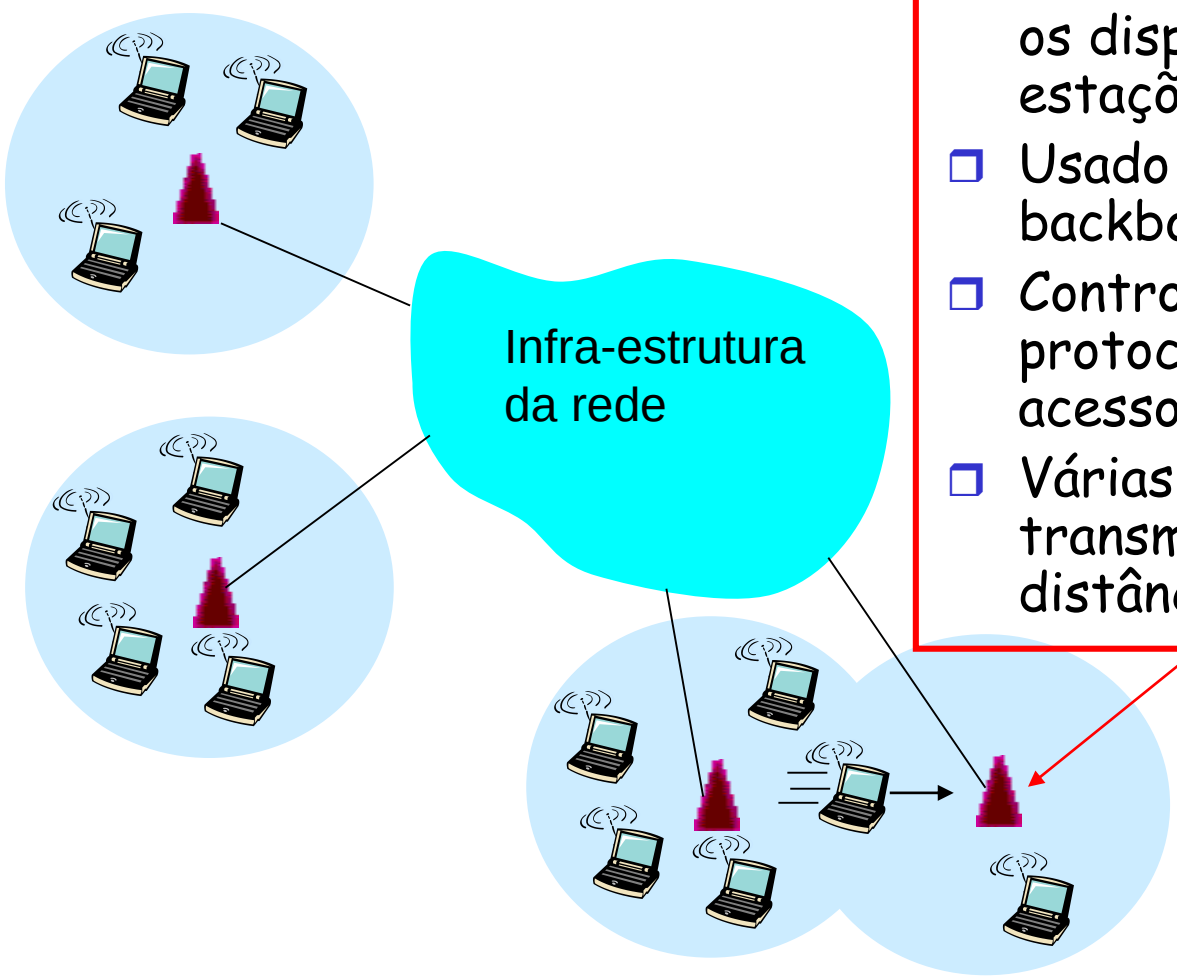
- Hosts sem fio
- laptop, PDA, IP phone
- Rodam Aplicações
- podem ser móveis ou não
  - "sem fio" nem sempre significa mobilidade

Elementos de uma rede sem fio



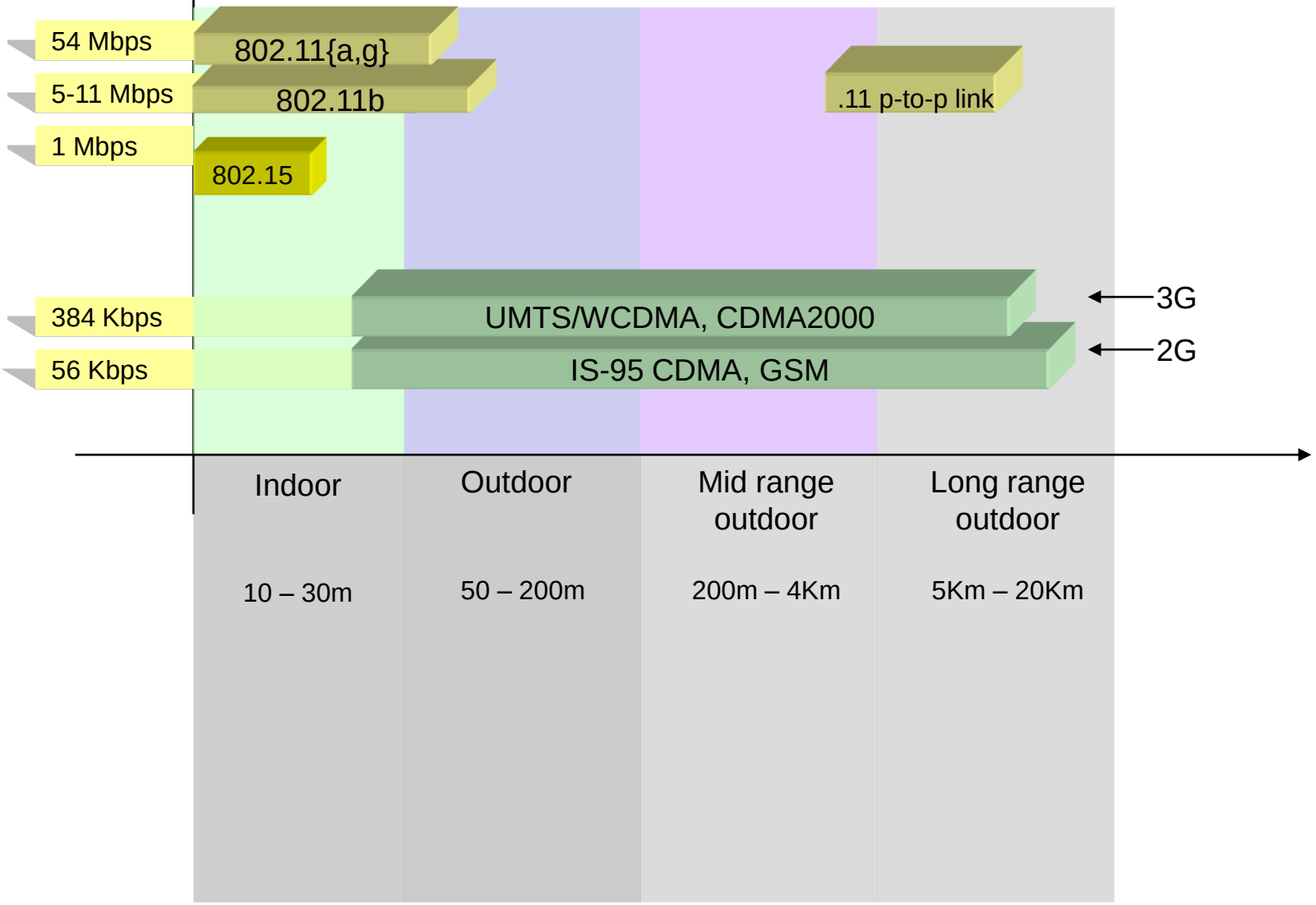
- estação base
- Tipicamente conectada a uma rede c/ fio
- Responsável pela comunicação entre os hosts móveis da sua área e os hosts das redes infra-estruturadas
- e.g., cell towers e 802.11 access points

Elementos de uma rede sem fio

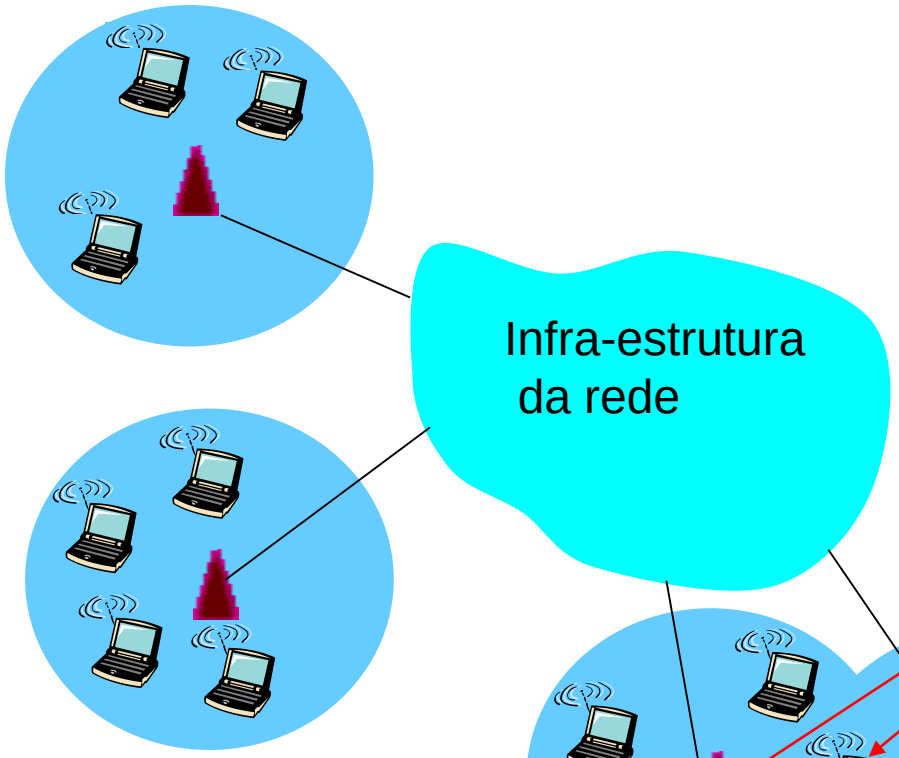


- enlace sem fio
- usado para conectar os disp. móveis às estações base
- Usado como enlace de backbone
- Controlado por protocolos de múltiplo acesso
- Várias taxas de transmissão e distâncias máximas

Características dos padrões de enlaces sem fio

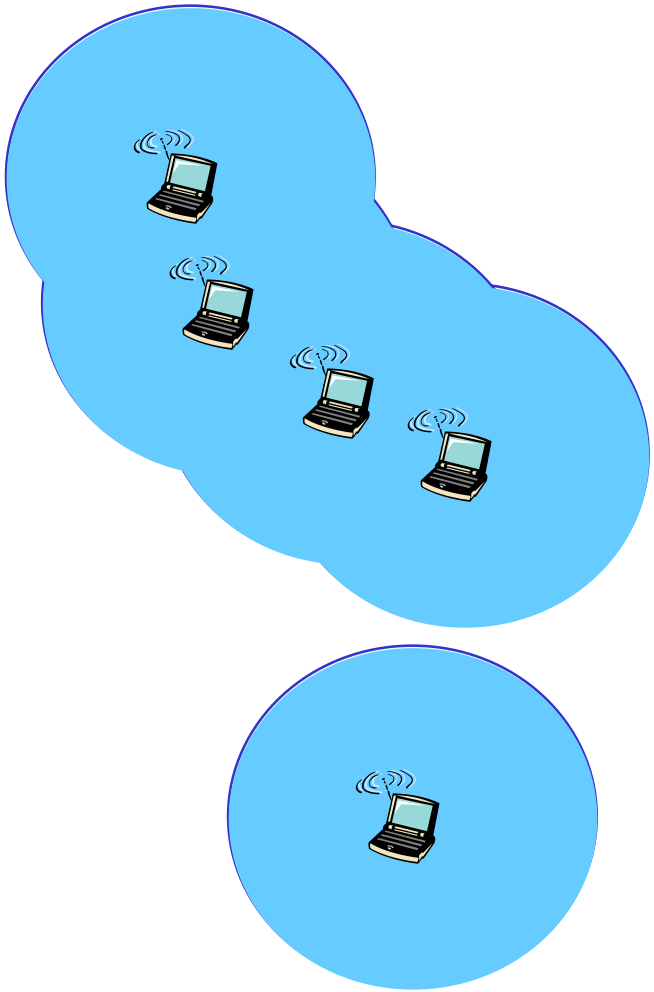


Elementos de uma rede sem fio



- Modo Infra-estruturado
- Estação base conecta os disp. móveis na rede com fio
- handoff: disp. móvel muda de estação base, se conectando à nova rede com fio

Elementos de uma rede sem fio



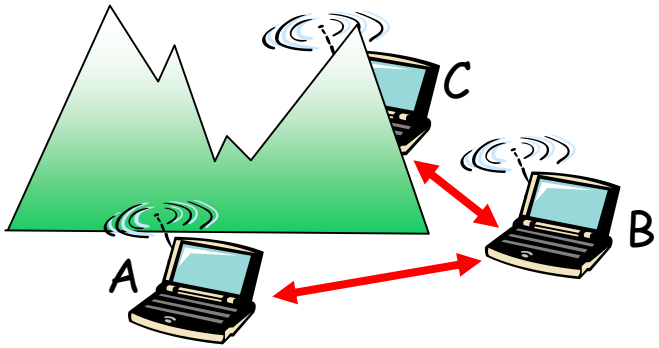
- Modo Ad hoc
- não existem estações base
- nós podem transmitir para outros somente dentro de uma determinada cobertura
- nós se organizam em uma rede e o roteamento só pode ser feito entre eles

Características de enlaces sem fio

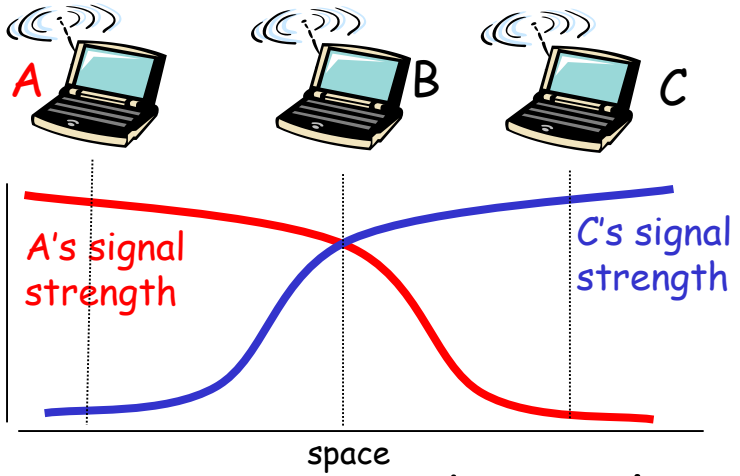
- Diferenças para os enlaces com fio:
  - Decremento na potência do sinal: sinais de rádio se atenuam ao longo do caminho (*path loss*)
  - Interferência de outras fontes: freqüências padronizadas para redes sem fio (por ex. 2.4 GHz) são compartilhadas por outros disp. (por ex., telefone); motores também interferem
  - Propagação *multipath*: sinal de rádio reflete em obstáculos terrestres, chegando no destino com pequenas diferenças de tempo
- ⇒ Faz da comunicação sobre um enlace sem fio (mesmo um ponto a ponto) muito mais difícil

Características das redes sem fio

- A existência de múltiplos transmissores e receptores sem fio cria problemas adicionais, que vão além do múltiplo acesso:



- Probl. terminal escondido
- B, A escutam um ao outro
- B, C escutam um ao outro
- A, C não podem escutar um ao outro ⇒ A e C não podem prever uma interf. em C

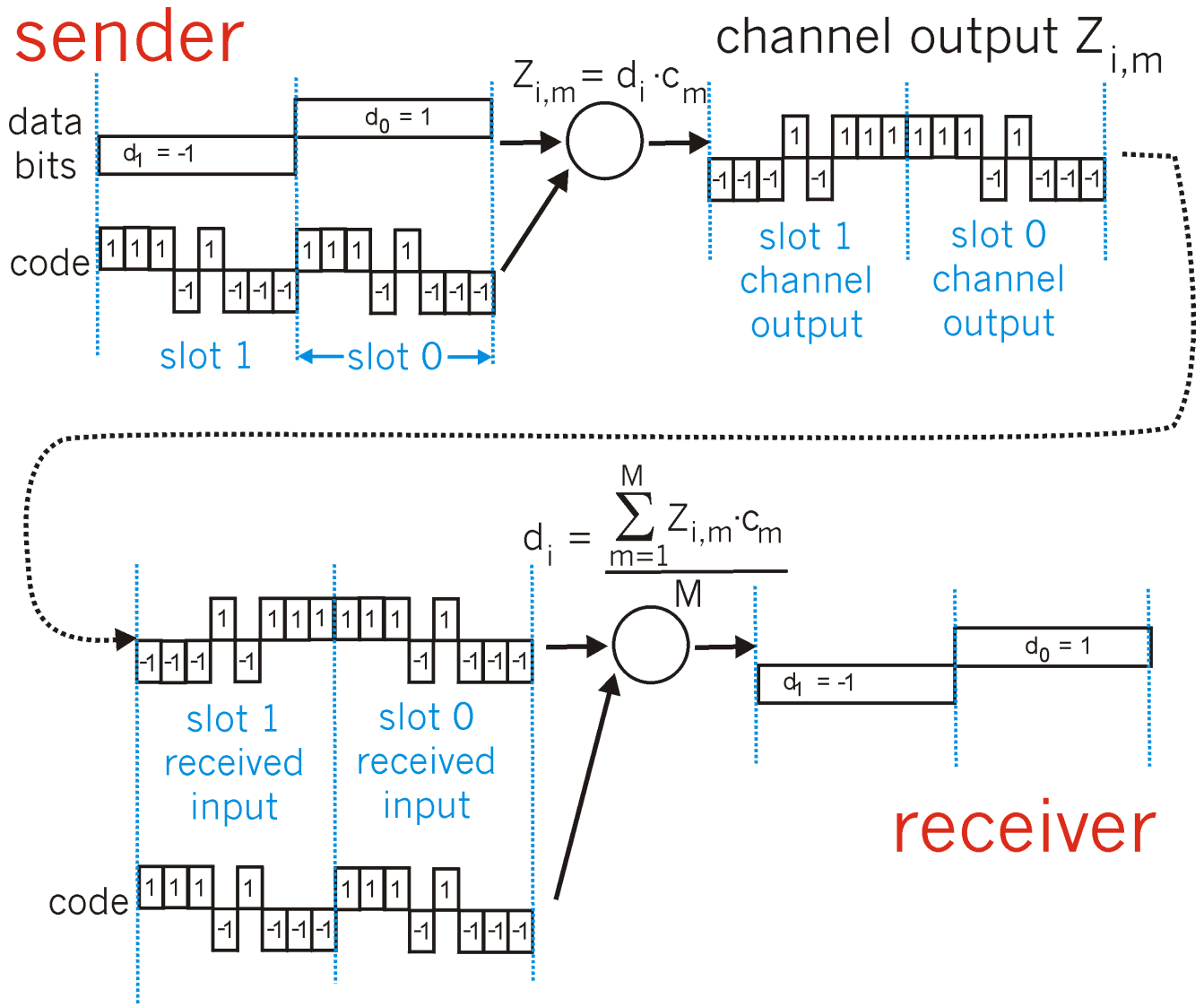


- Atenuação do sinal:
- B, A escutam um ao outro
- B, C escutam um ao outro
- A, C não podem escutar um ao
- outro ⇒ interf. em C

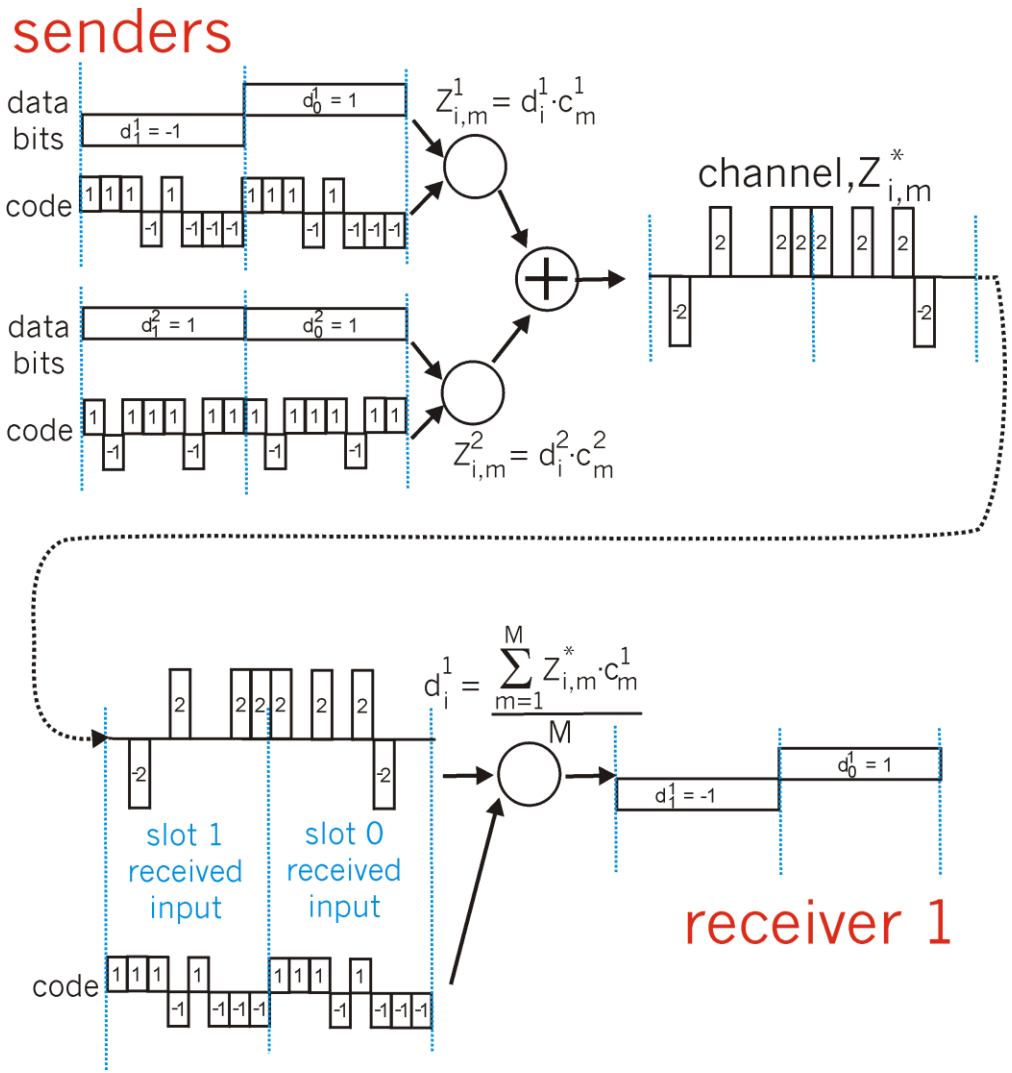
Particionamento do Canal com CDMA

- **CDMA (Múltiplo Acesso por Divisão por Código)**: explora esquema de codificação de **espectro espalhado** - DS (*Direct Sequence*) ou FH (*Frequency Hopping*)
- "código" único associado a cada canal; ié, particionamento do **conjunto de códigos**
- Mais usado em canais de **radiodifusão** (celular, satélite, etc)
- Todos usuários compartilham a **mesma freqüência**, mas cada canal tem **sua própria seqüência de "chipping"** (ié, código)
- Seqüência de chipping funciona como **máscara**: usado para **codificar** o sinal
- **sinal codificado** = (sinal original) X (seqüência de chipping)
- **decodificação**: produto interno do sinal codificado e a seqüência de chipping (observa-se que o produto interno é a soma dos produtos componente-por-componente)
- Para fazer CDMA funcionar, as seqüências de chipping devem ser mutuamente ortogonais entre si (i.é., produto interno = 0)

CDMA: Codificação/Decodificação



CDMA: interferência entre dois remetentes



Propriedades do CDMA

- protege usuários de interferência (inclusive a propositalmente)
  (usado desde a Segunda Guerra Mundial)

- protege usuários do "*multipath fading*"
  (interferência entre 2 trajetórias do mesmo sinal, p.ex. o direto e por reflexão) em rádio

- permite a "coexistência" de múltiplos usuários e suas transmissões simultâneas com um mínimo de interferência (se os códigos deles forem "ortogonais")

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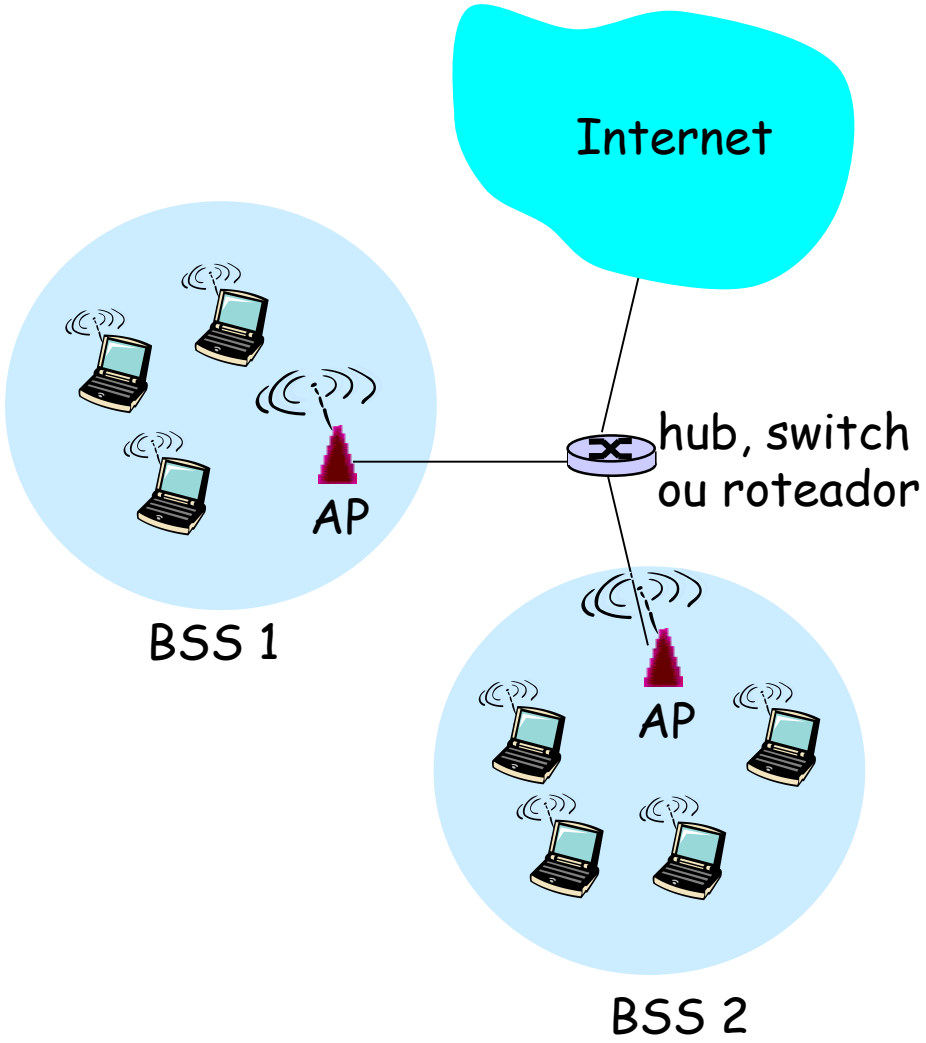
IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-5 GHz unlicensed radio spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - all hosts use same chipping code
  - widely deployed, using base stations
- 802.11a
  - 5-6 GHz range
  - up to 54 Mbps
- 802.11g
  - 2.4-5 GHz range
  - up to 54 Mbps
- All use CSMA/CA for multiple access
- All have base-station and ad-hoc network versions

IEEE 802.11 LAN - arquitetura



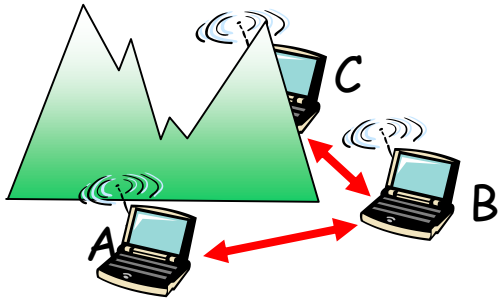
- Um *host* sem fio se comunica com a estação base
  - estação base = access point (AP)
- *Basic Service Set* (BSS) ("célula"):
  - no modo infra-estruturado contém:
    - *Hosts* sem fio
    - access point (AP): estação base
  - no modo *ad hoc*: somente *hosts* sem fio

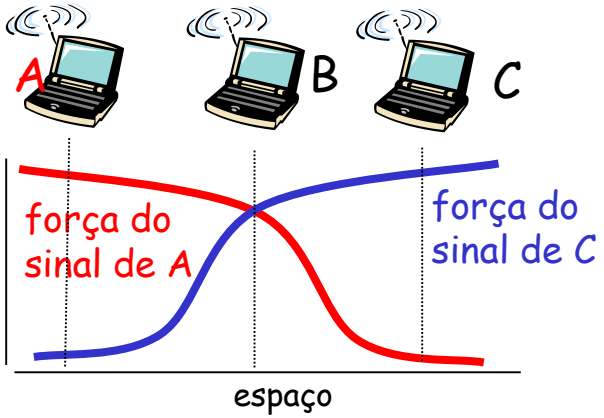
802.11: Canais, associação

- 802.11b: o espectro 2.4GHz-2.485GHz é dividido em 11 canais de diferentes freqüências
  - O administrador da rede escolhe um número de canal para o AP
  - Possível interferência: canal pode ser o mesmo que o escolhido por um AP vizinho!
- host: deve ser *associado* com um AP
  - Varre os canais, escuta quadros de sinalização que contêm a identificação do AP (SSID) e o endereço MAC
  - Seleciona um AP para se associar
  - Pode realizar autenticação [capítulo 8]
  - vai rodar, tipicamente, o protocolo DHCP para obter o endereço IP na sub-rede do AP

IEEE 802.11: múltiplo acesso

- Evita colisões (CSMA/CA): dois ou mais nós transmitindo ao mesmo tempo
- 802.11: CSMA – "escuta" o meio antes de transmitir
  - para não colidir com outras transmissões em andamento
- 802.11: *não realiza detecção de colisão*!
  - Dificuldade de receber ("escutar" colisões) quando está transmitindo devido à fraqueza dos sinais recebidos (*fading*)
  - Não pode escutar todas as colisões: terminal escondido, *fading*
  - objetivo: *evitar colisões:* CSMA/C(ollision)A(voidance)





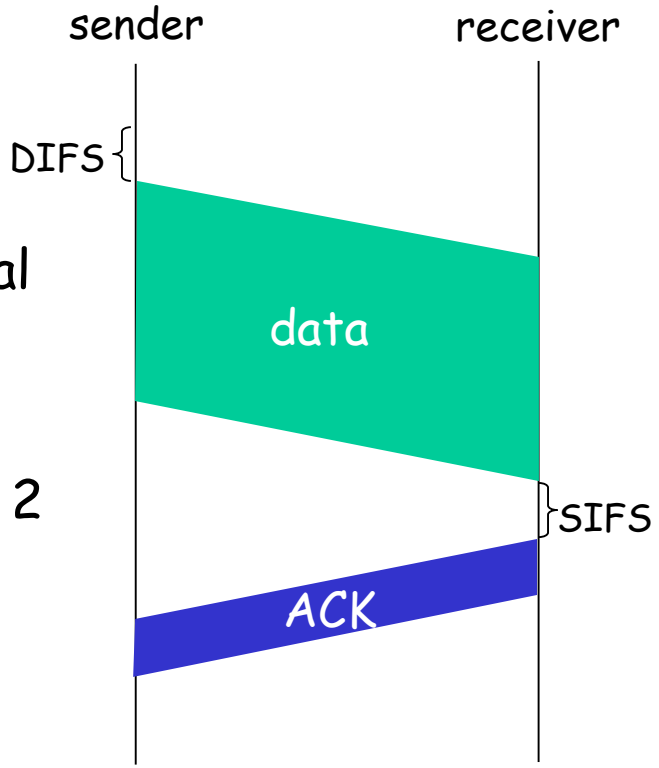
Protocolo MAC do IEEE 802.11 : CSMA/CA

Emissor 802.11

1 se o canal estiver livre, espera um pequeno tempo (**DIFS**) e então transmite todo o quadro (não há detecção de colisão)

2 se o canal estiver ocupado então

- inicia um tempo de *backoff* aleatório
- faz contagem regressiva enquanto o canal estiver livre
- transmite qdo o tempo expirar
- se não chegar um ACK, aumenta o intervalo de *backoff* e repete o passo 2



Receptor 802.11

- se o quadro recebido estiver OK

envia ACK depois de esperar um **SIFS** (o ACK é necessario devido ao problema do terminal escondido)

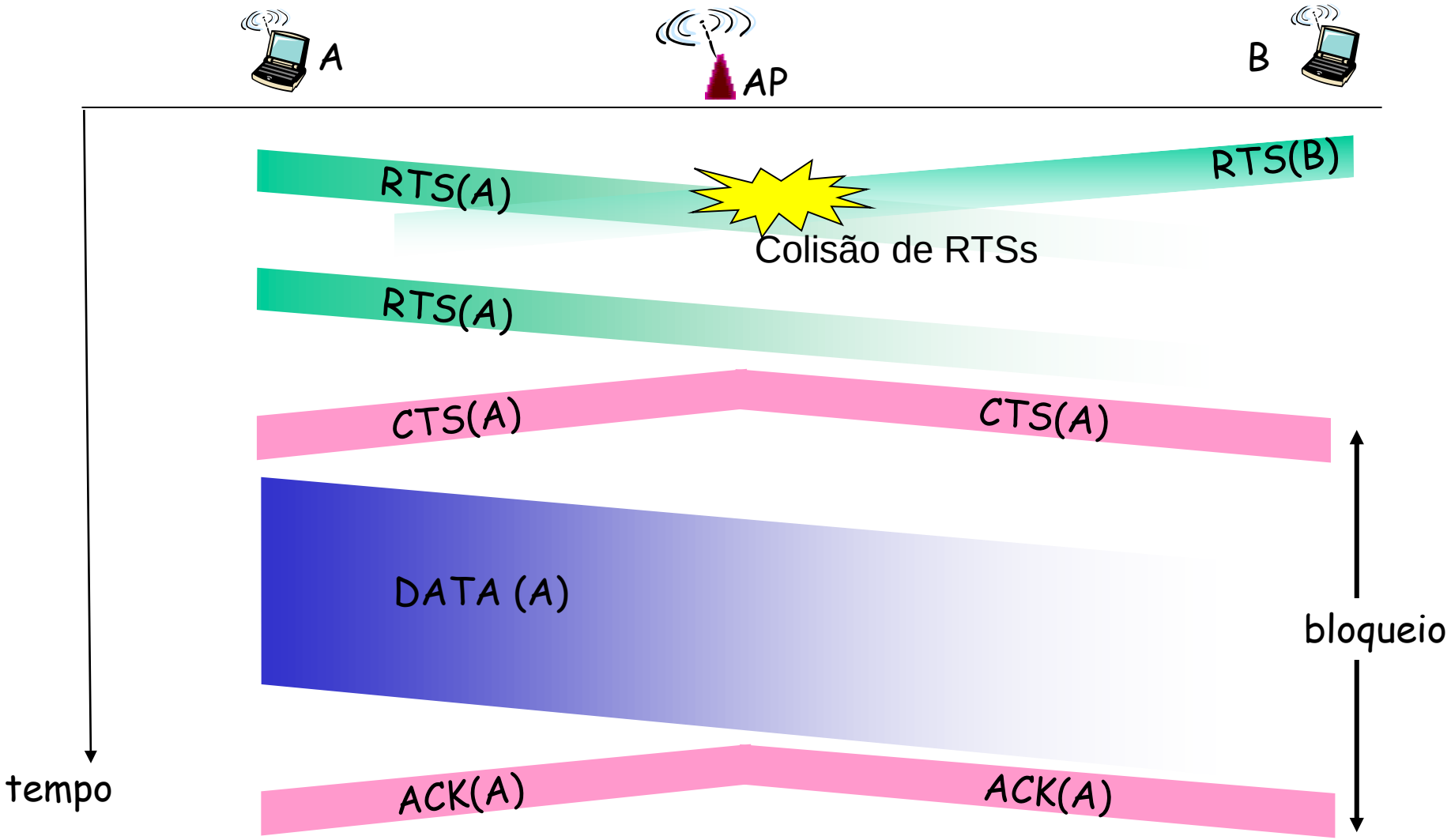
IEEE 802.11: Evitando colisões

idéia: permitir ao emissor reservar o canal ao invés de realizar um acesso aleatório dos quadros, evitando colisões de quadros longos

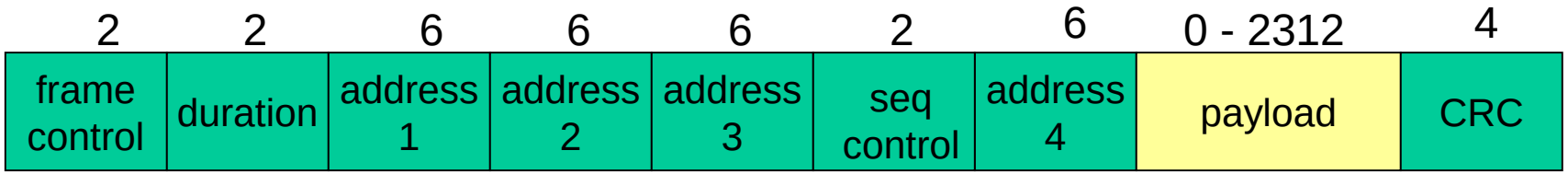
- Emissor primeiramente envia pequenos pacotes de controle request-to-send (RTS) para o AP usando o CSMA, mas que é ouvido por todas as estações ao seu alcance (inclusive o AP)
  - Obs: os pacotes RTS podem ainda colidir uns com os outros, mas como eles são pequenos, não causam longos atrasos
- AP envia um pct *clear-to-send* (CTS) para todas as estações que estão ao seu alcance, em resposta ao RTS
- Emissor transmite o quadro de dados
- Outras estações bloqueiam suas transmissões

Evita completamente as colisões de quadros de dados usando pequenos pcts de reserva!

Evitando Colisões: troca de RTS-CTS



Quadro 802.11: endereçamento



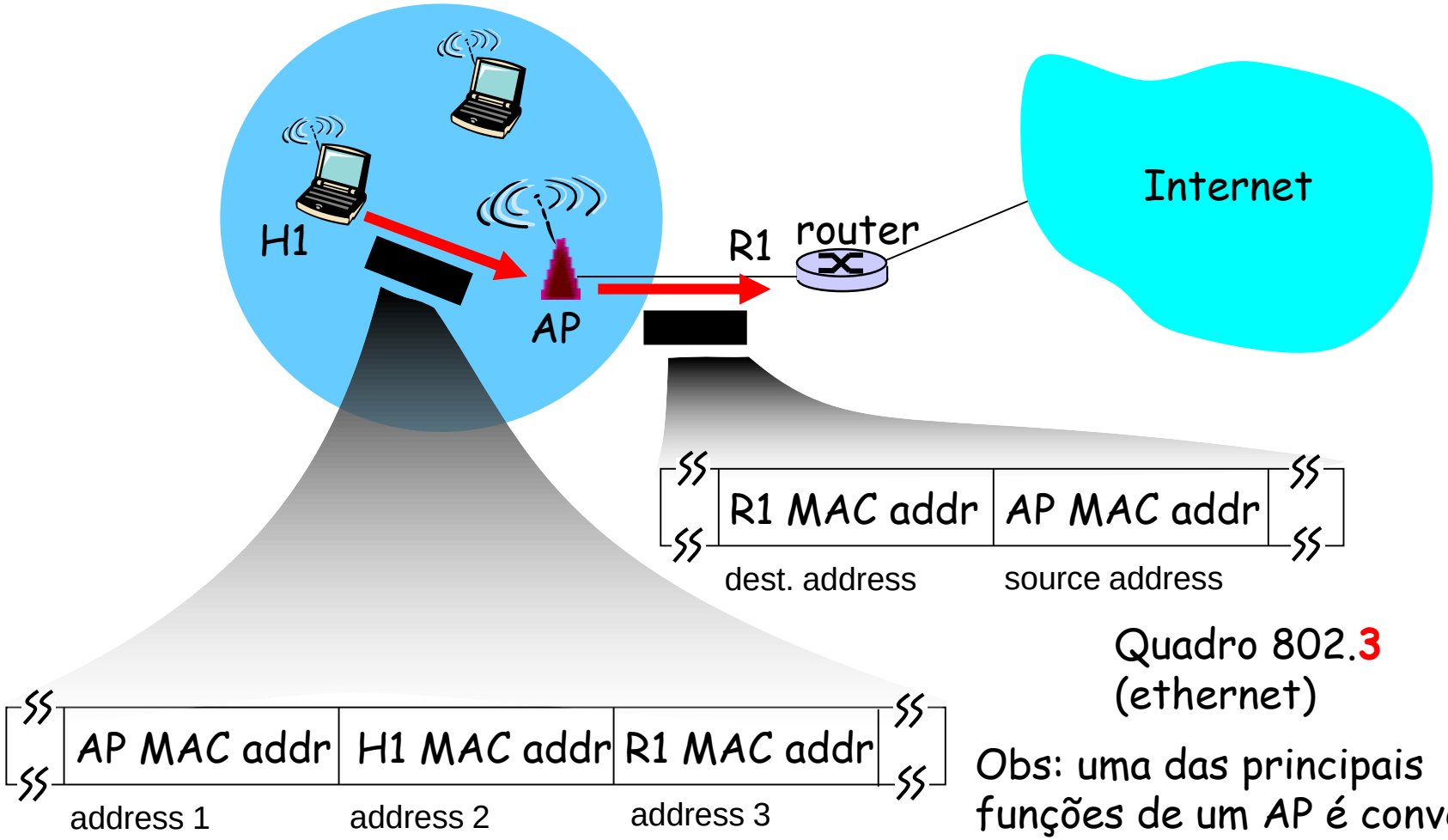
Address 1: endereço MAC *host* sem fio ou do AP Que vai receber o quadro

Address 2: endereço MAC do *host* sem fio ou do AP transmitindo o quadro

Address 3: endereço MAC da interface do rot. ao qual o AP esta conectado

Address 4: usado somente no modo *ad hoc*

Quadro 802.11 : endereçamento

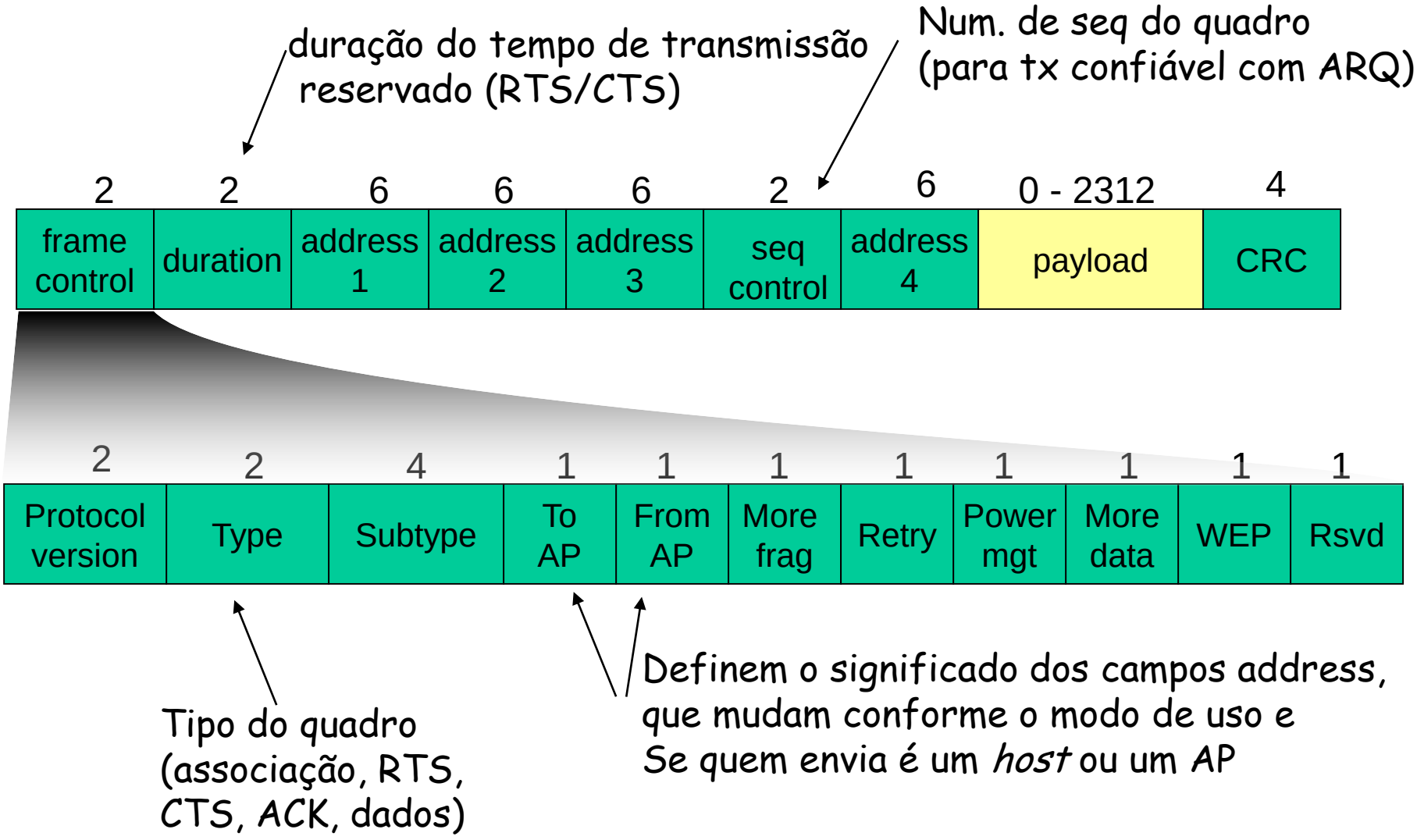


Quadro 802.3 (ethernet)

Quadro 802.11

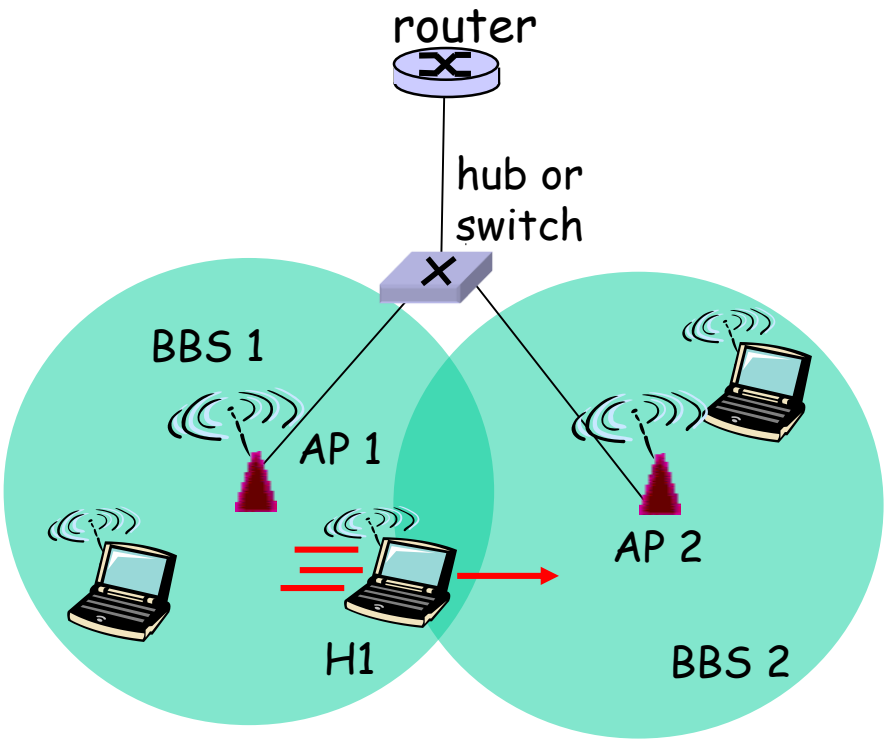
Obs: uma das principais funções de um AP é converter um quadro 802.11 para um quadro ethernet e vice-versa

Quadro 802.11 (cont.)



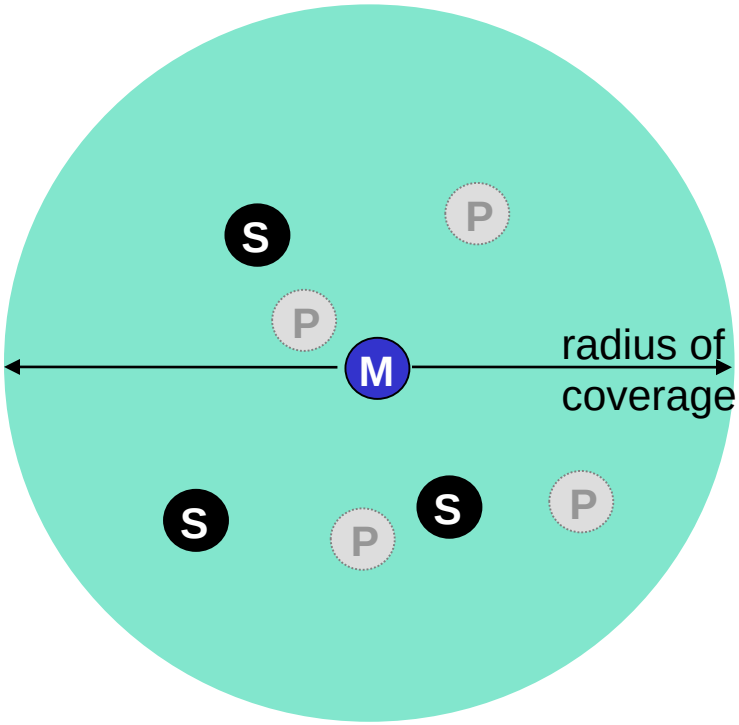
802.11: mobilidade dentro da mesma sub-rede

- H1 permanece na mesma sub-rede: endereço IP pode permanecer o mesmo (hub ou switch)
- switch: qual AP está associado com H1?
- "self-learning": switches montam suas tabelas automaticamente, as não estão aptos a manusear mobilidade excessiva. Existe um par entre o end. de sua interface e H1 Solução: AP2 *broadcasts* um quadro ethernet com o endereço fonte de H1 logo depois da associação



802.15: wireless personal area network (Piconet)

- Dispositivos separados por, no máximo, 10 m de diâmetro
- substitui dispositivos com fio por disp sem fio (mouses, teclados, headphones)
- *ad hoc*: sem infra-estrutura
- Mestre-escravo:
  - Escravos solicitam permissão para transmitir para o mestre
  - Mestre fornece permissão
- Dispositivos *parked* : não podem transmitir até que seu estado seja trocado para *ativo* pelo mestre
- 802.15: baseado na especificação Bluetooth
  - 2.4-2.5 GHz espectro de rádio
  - Taxa de tx de até 721 kbps



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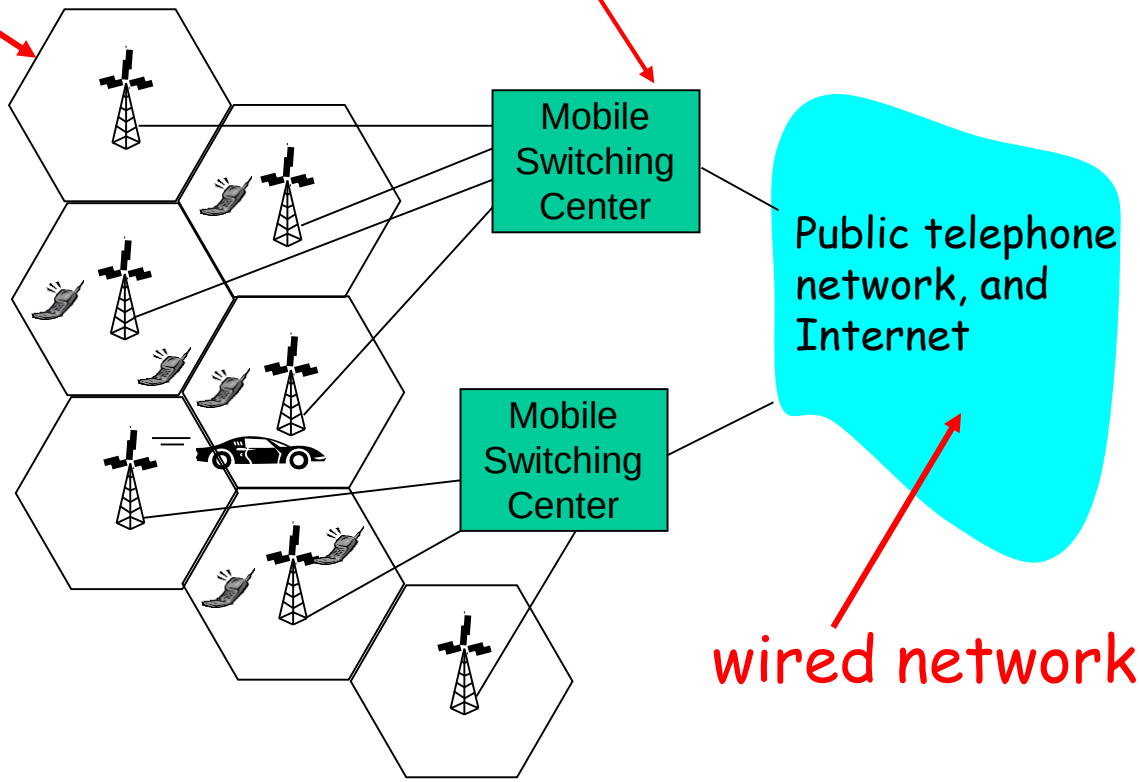
Components of cellular network architecture

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

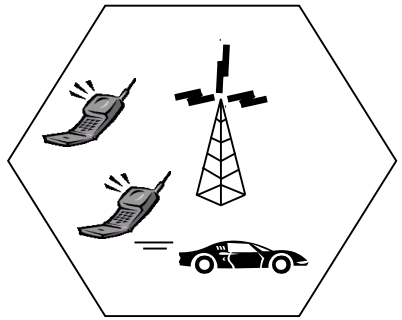
cell
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

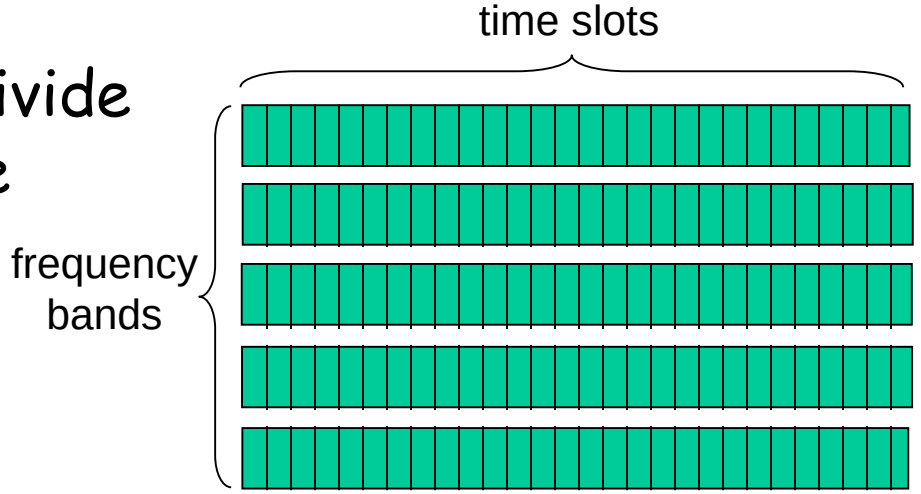


Cellular networks: the first hop

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

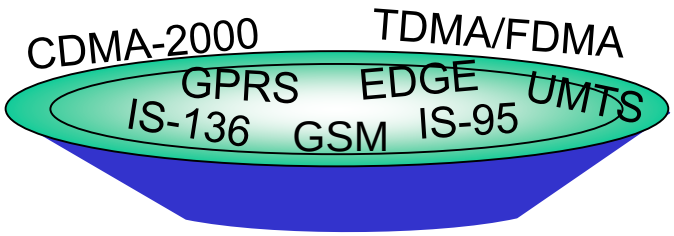




Cellular standards: brief survey

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
  - Date 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)
  - GSM next step, but using CDMA
- CDMA-2000

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

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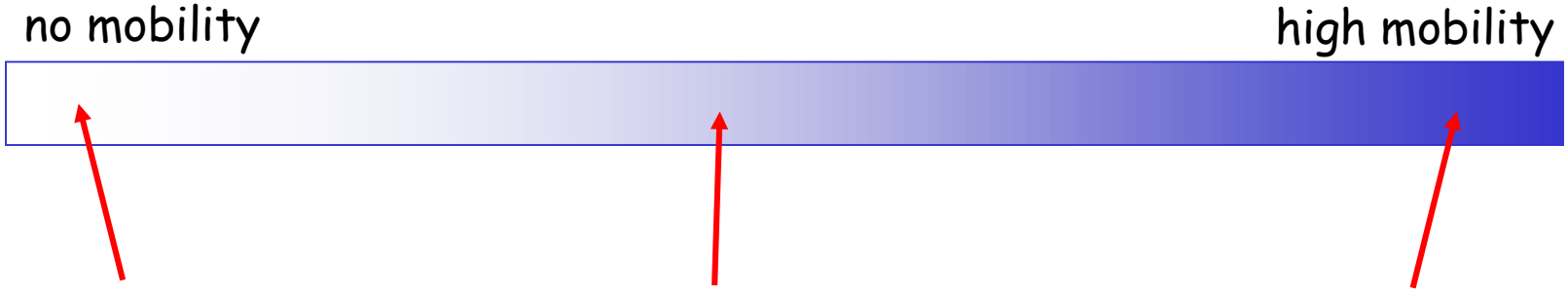
What is mobility?

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



mobile wireless user, using same access point

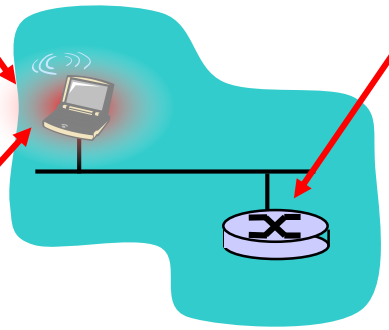
mobile user, connecting/ disconnecting from network using DHCP.

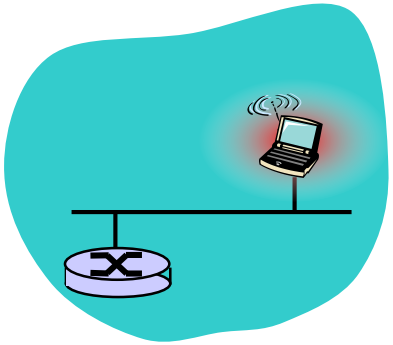
mobile user, passing through multiple access point while maintaining ongoing connections (like cell phone)

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*





wide area network

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

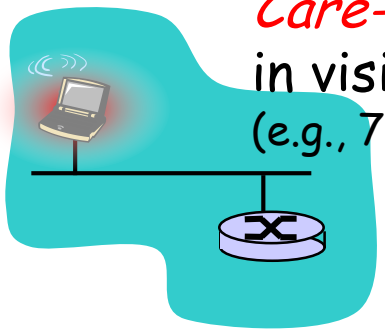
correspondent

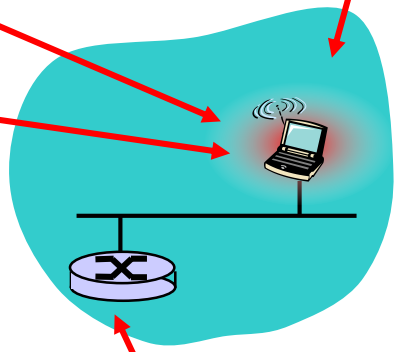
Mobility: more vocabulary

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

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

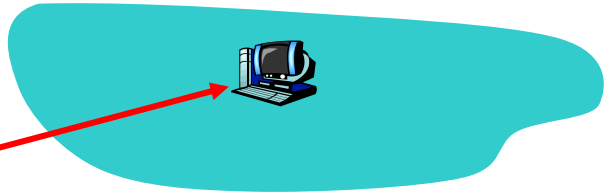
Care-of-address: address in visited network. (e.g., 79,129.13.2)





wide area network

home 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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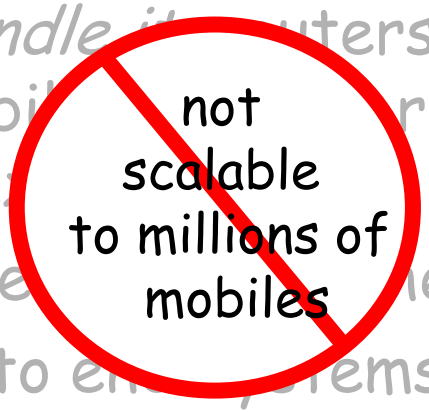
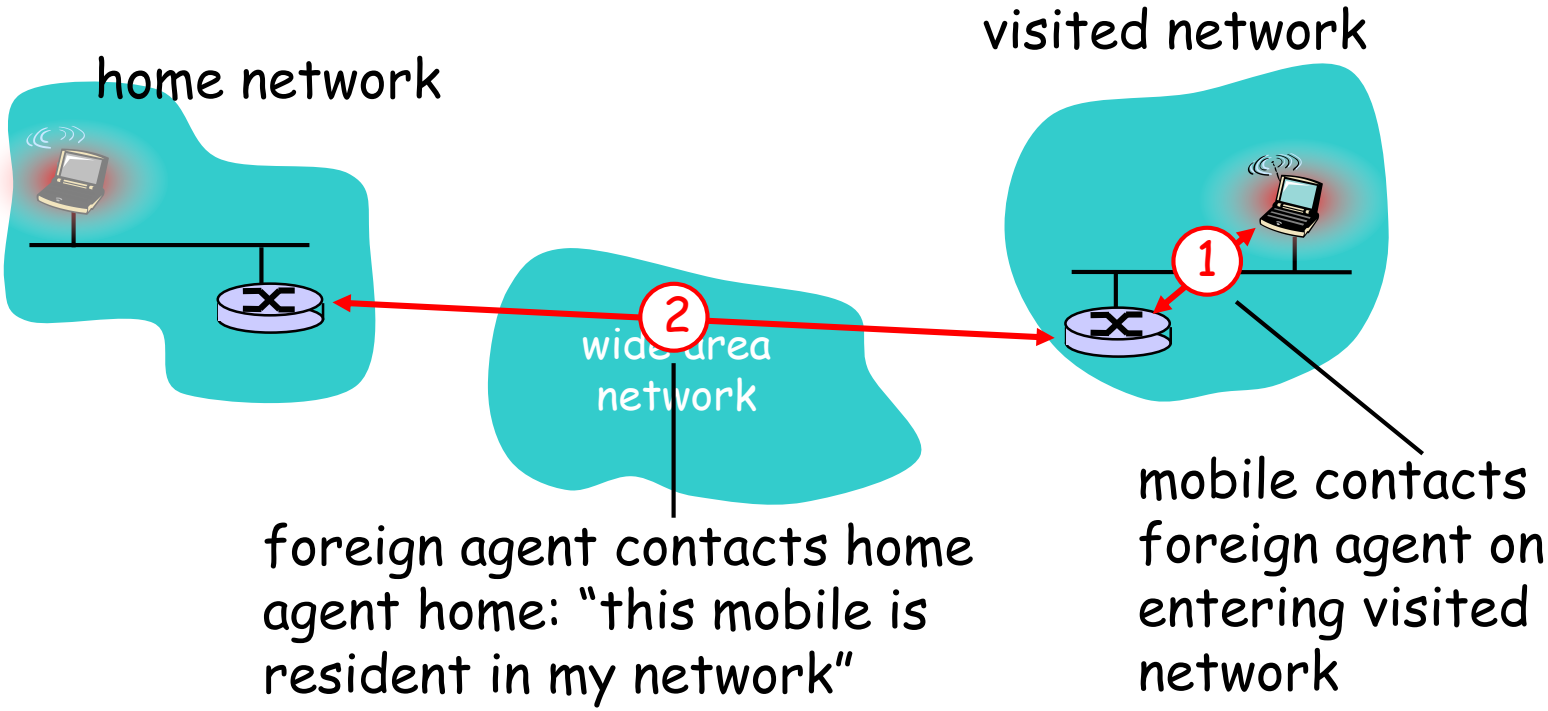


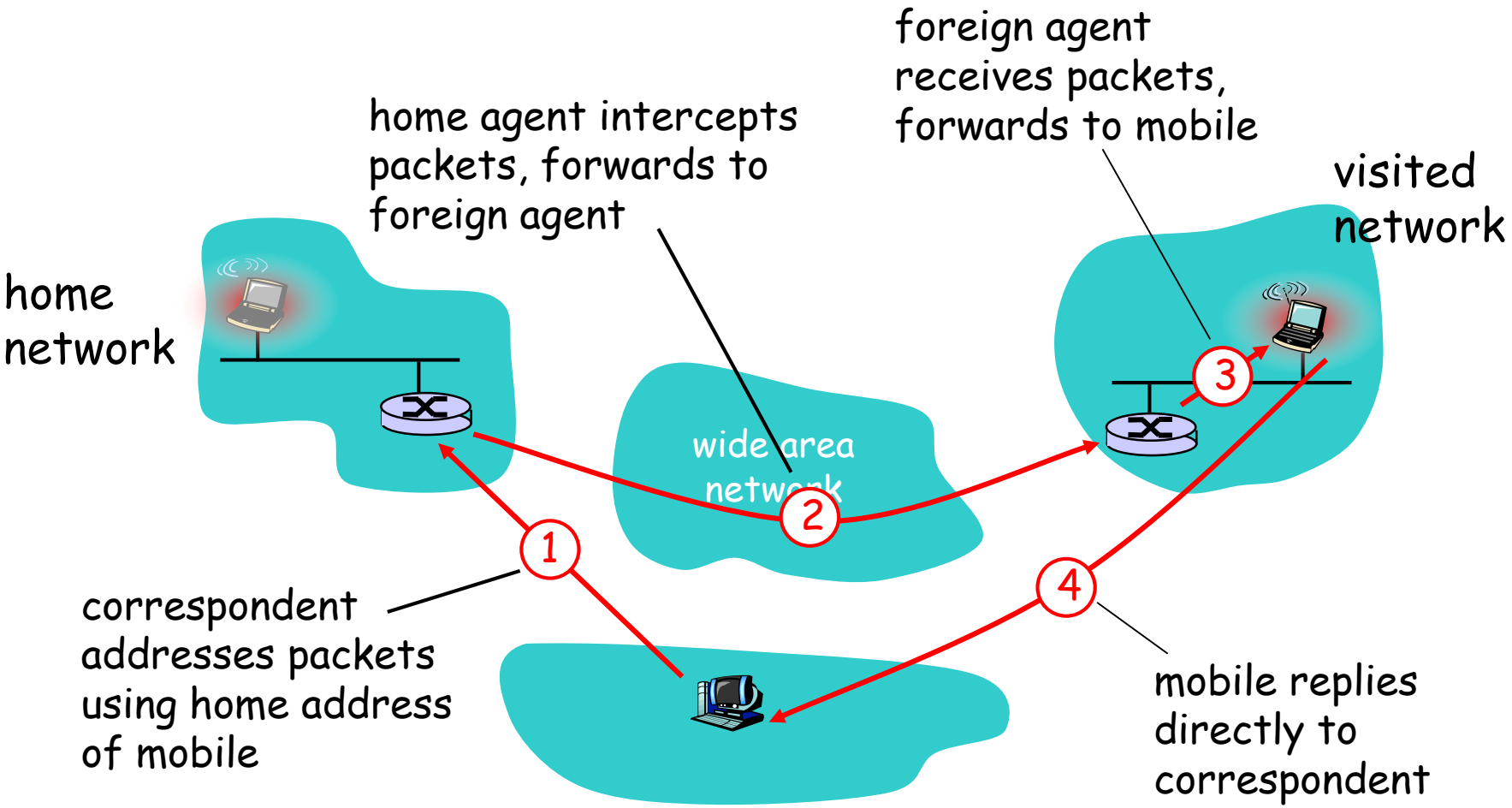
Mobility: registration



End result:

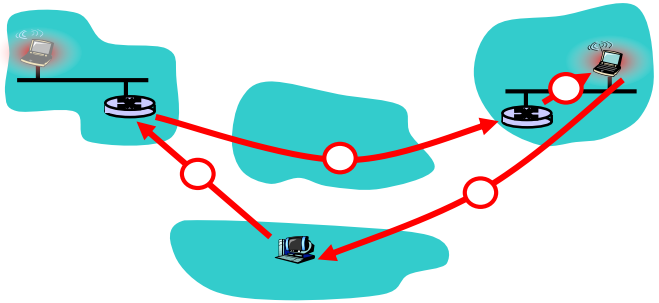
- Foreign agent knows about mobile
- Home agent knows location of mobile

Mobility via Indirect Routing



Indirect Routing: comments

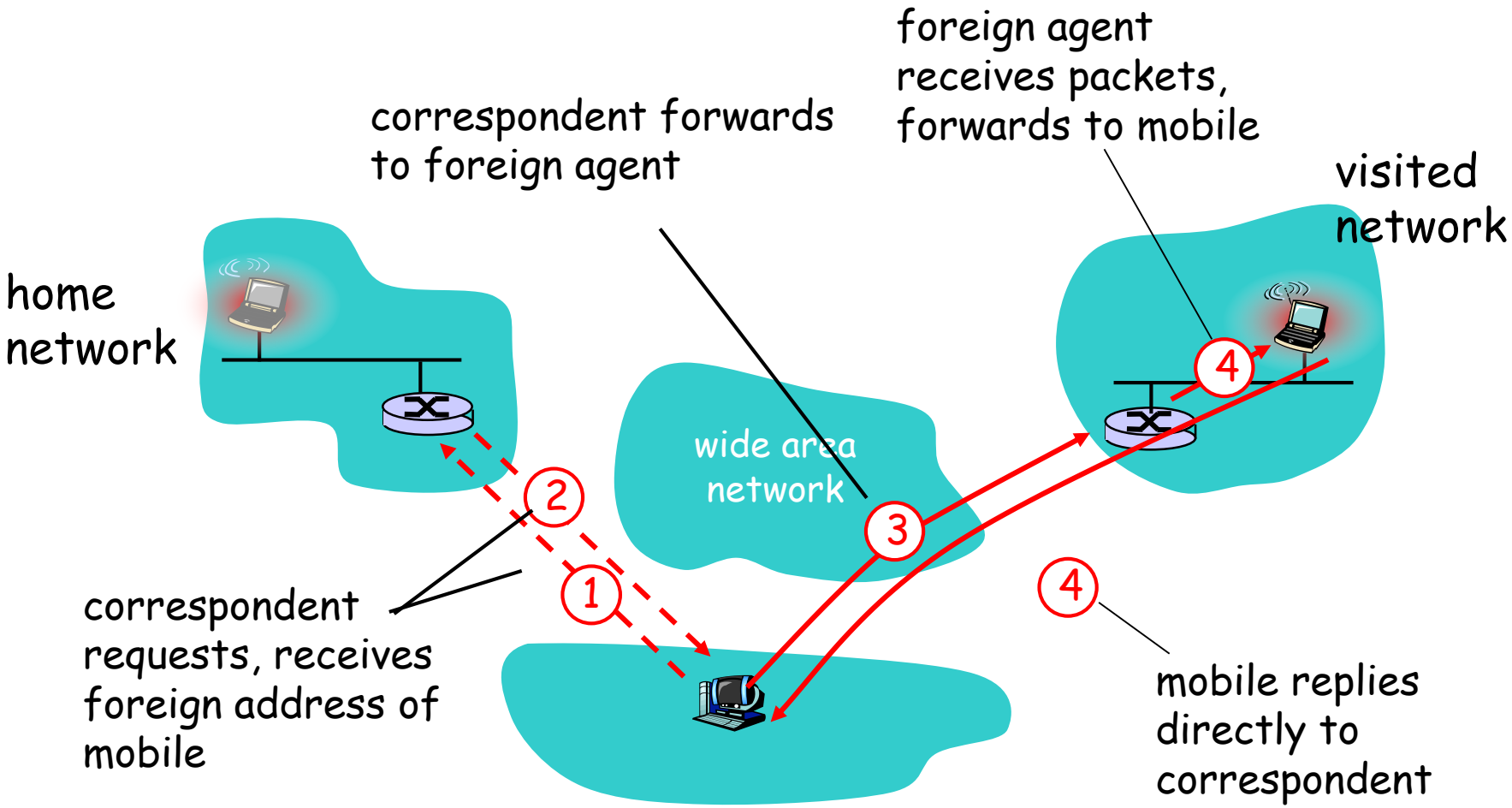
- Mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- foreign agent functions may be done by mobile itself
- triangle routing: correspondent-home-network-mobile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



Indirect Routing: moving between networks

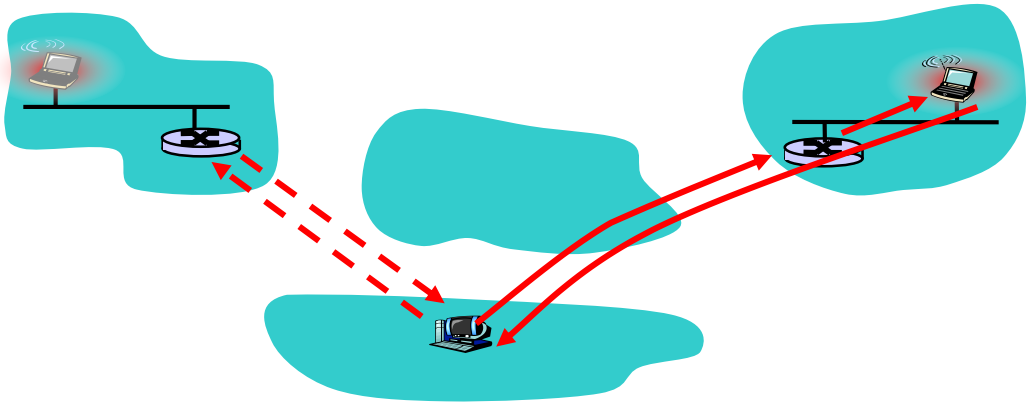
- suppose mobile user moves to another network
  - registers with new foreign agent
  - new foreign agent registers with home agent
  - home agent update care-of-address for mobile
  - packets continue to be forwarded to mobile (but with new care-of-address)
- mobility, changing foreign networks transparent: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

Mobility via Direct Routing



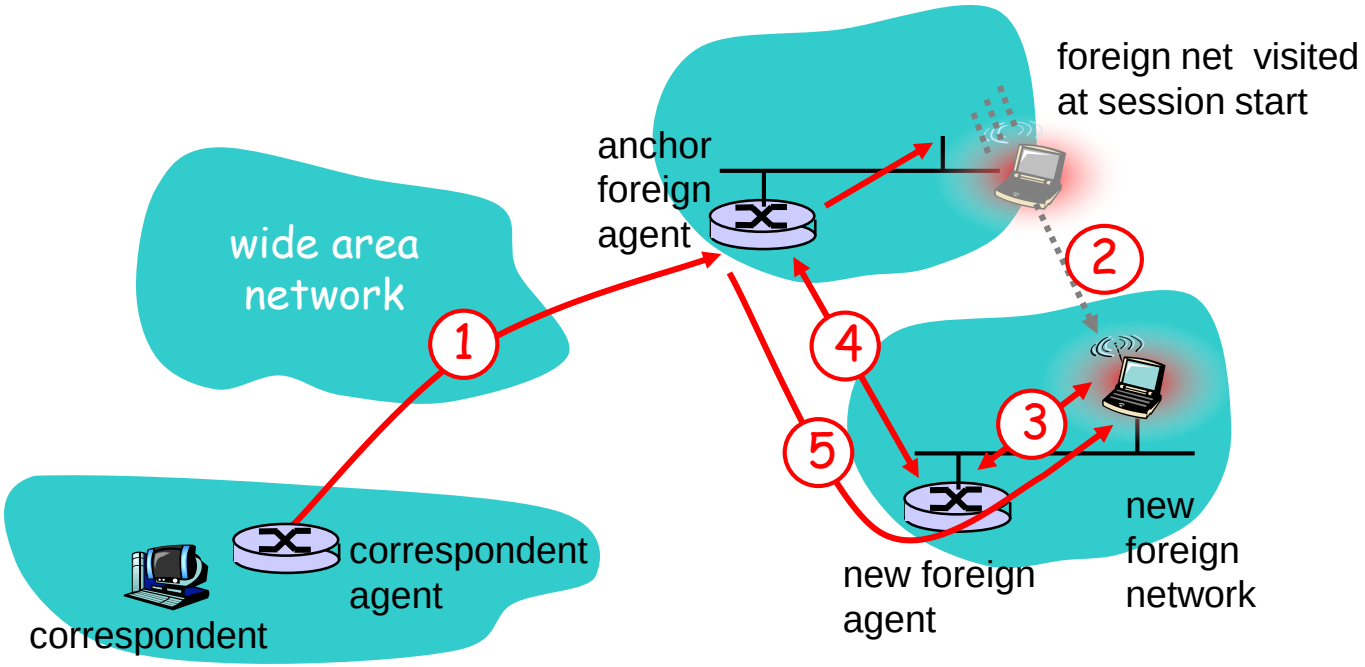
Mobility via Direct Routing: comments

- 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)



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

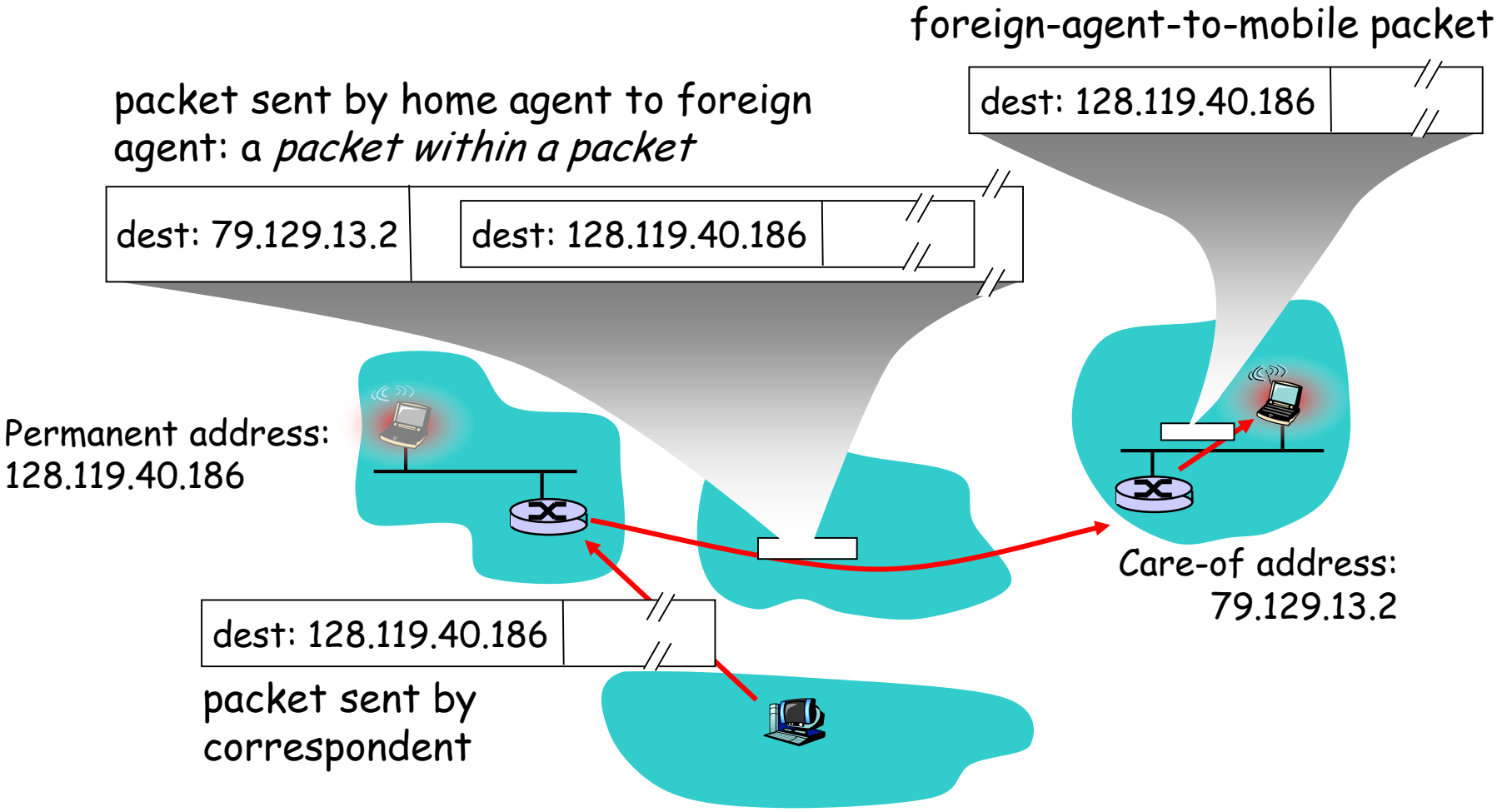
- 6.5 Principles: addressing and routing to mobile users
- 6.6 Mobile IP
- 6.7 Handling mobility in cellular networks
- 6.8 Mobility and higher-layer protocols

6.9 Summary

Mobile IP

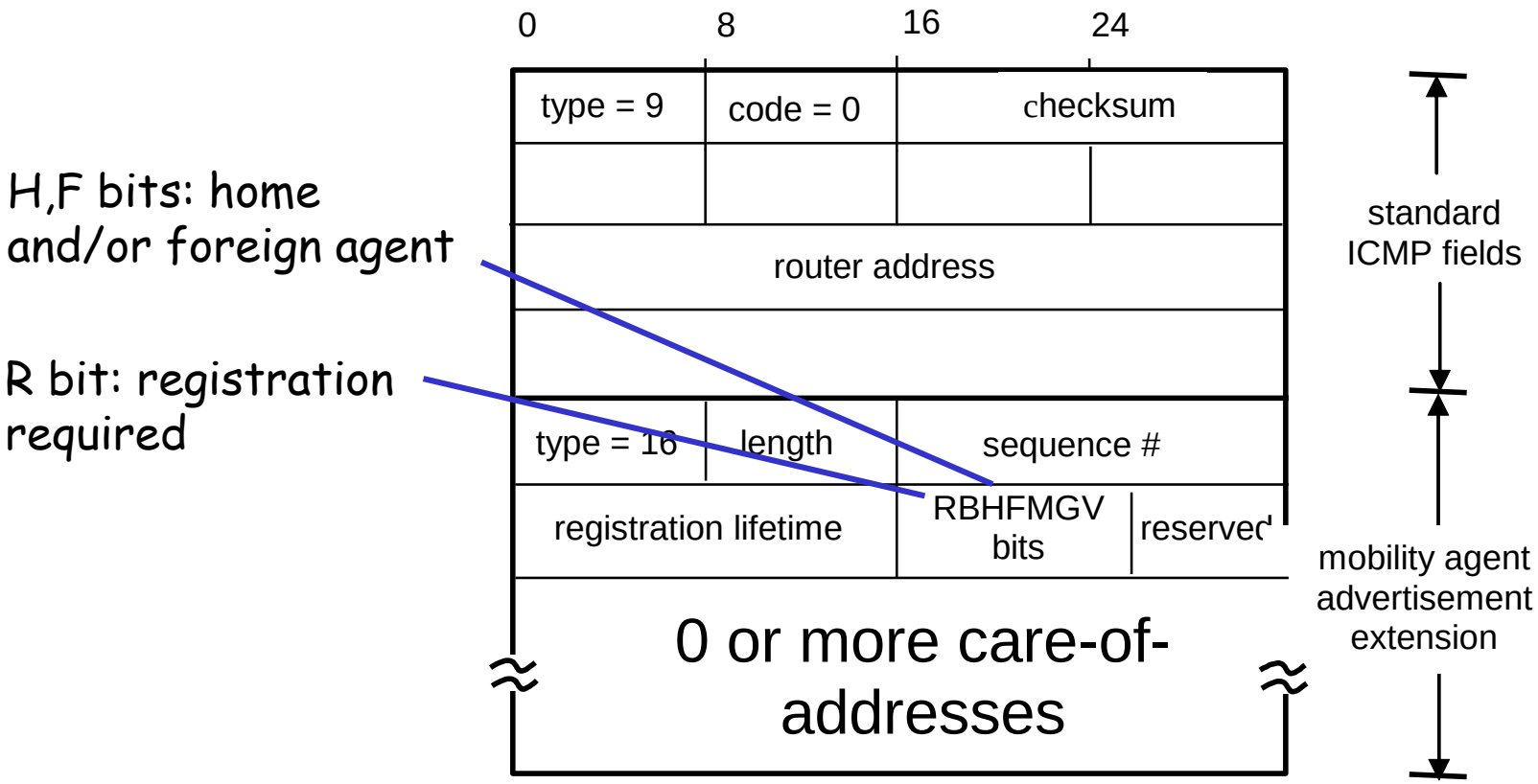
- RFC 3220
- has many features we've seen:
  - home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet)
- three components to standard:
  - indirect routing of datagrams
  - agent discovery
  - registration with home agent

Mobile IP: indirect routing

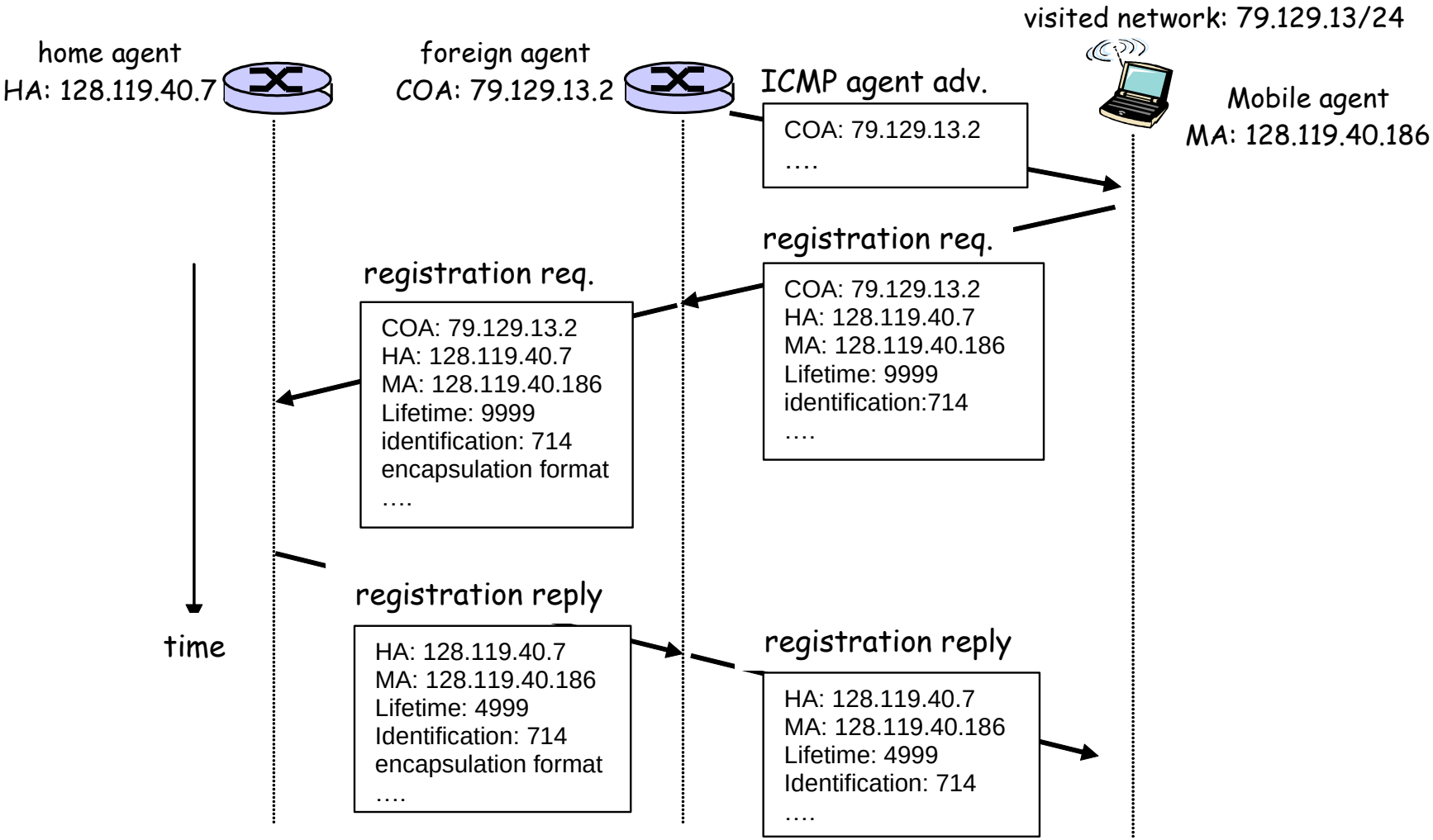


Mobile IP: agent discovery

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

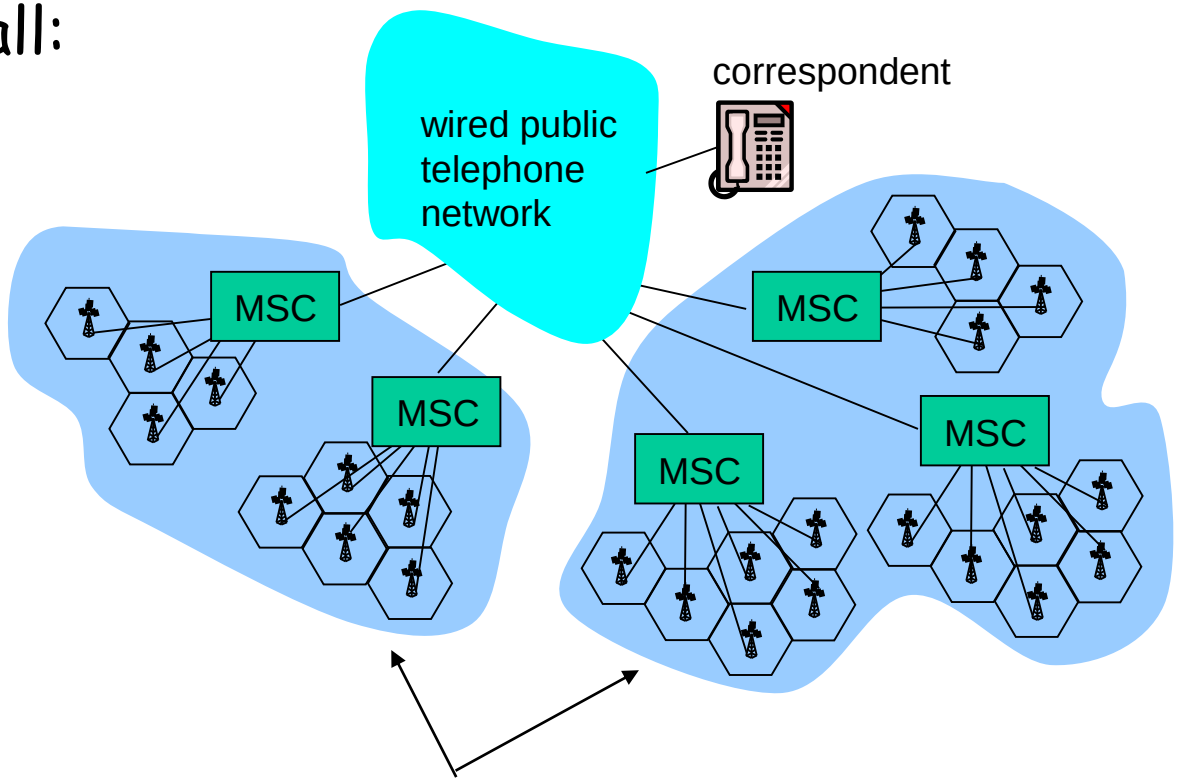


Mobile IP: registration example



Components of cellular network architecture

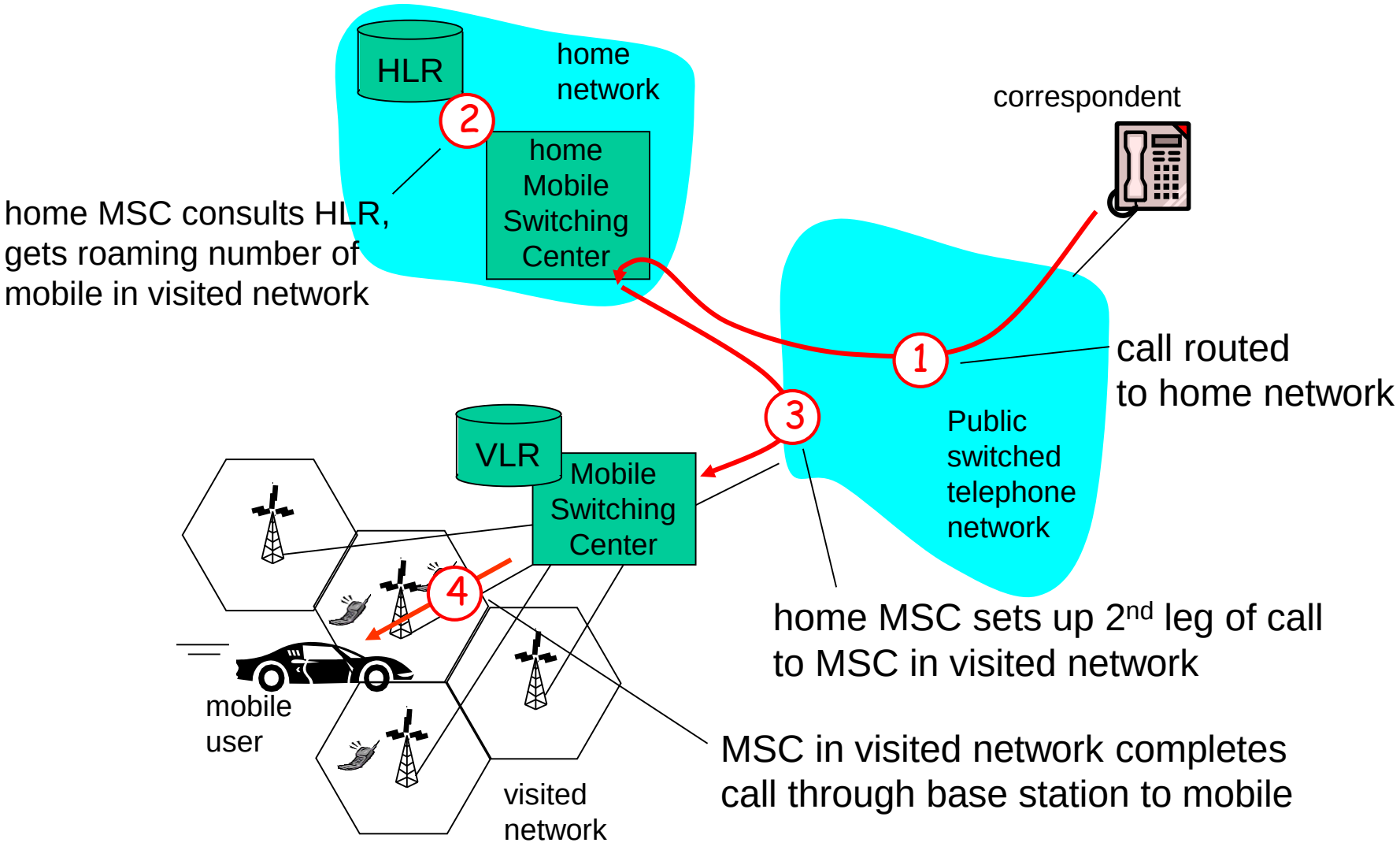
recall:



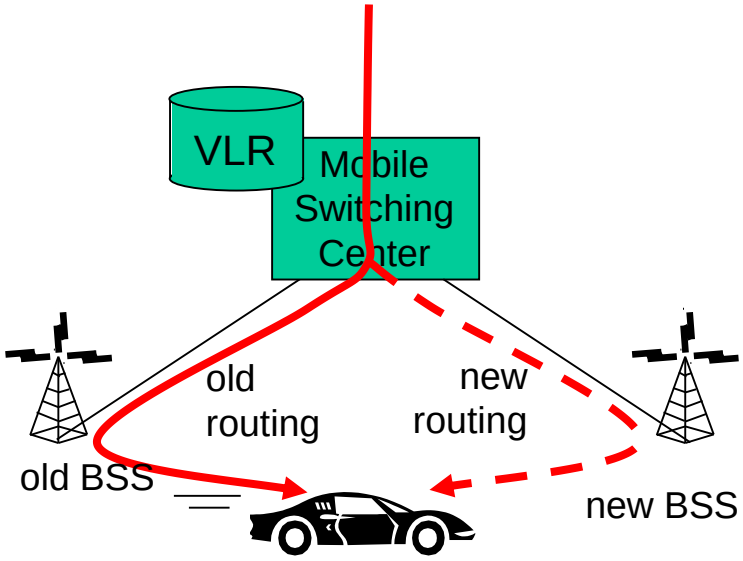
Handling mobility in cellular networks

- *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

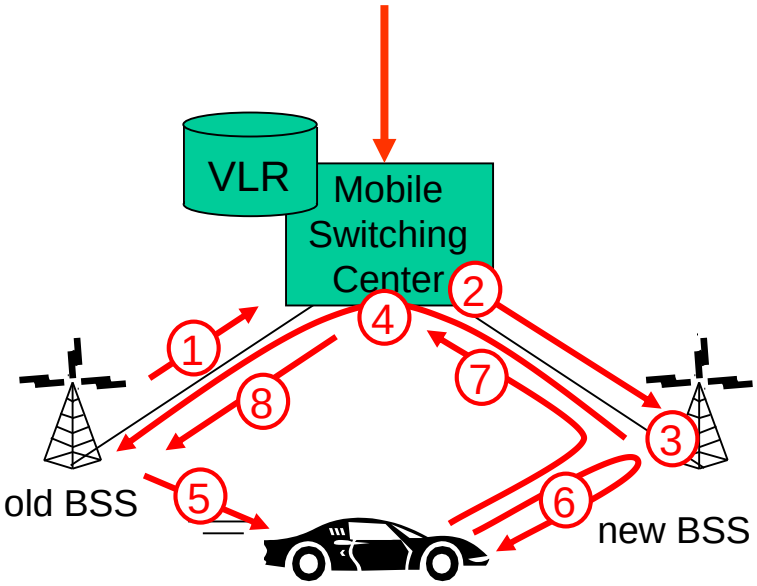


GSM: handoff with common MSC



- 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

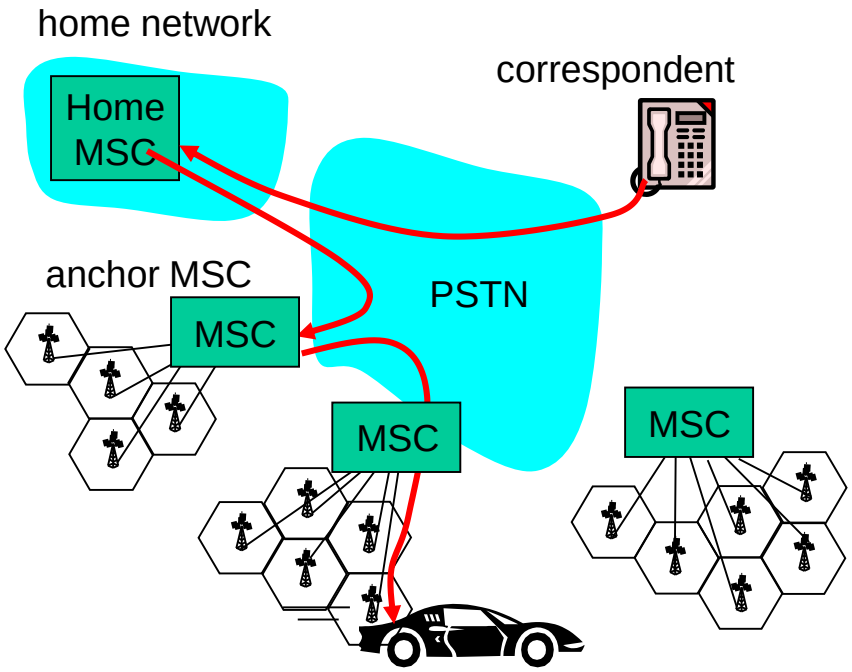
GSM: handoff with common MSC



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

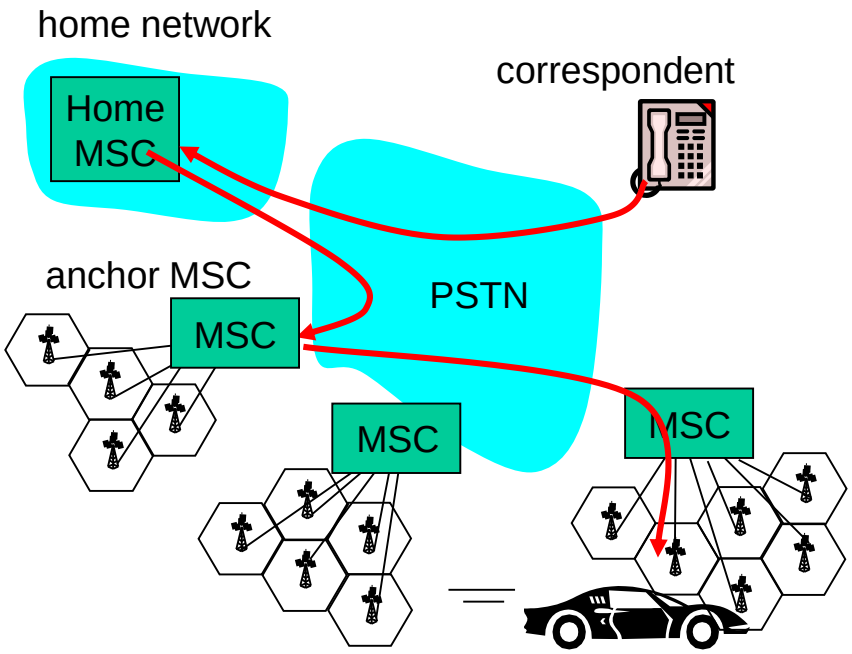
GSM: handoff between MSCs



(a) before handoff

- *anchor MSC:* first MSC visited during cal
  - 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 cal
  - 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 the 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

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