# MẠNG MÁY TÍNH

## Chương 6: Các mạng di động và không dây

# Nội dung

- Characteristics of wireless link.
- Link-level aspects of the IEEE 802.11 (WiFi) wireless LAN standard.
  - Bluetooth and other wireless PAN (personal area networks.)
- Overview of cellular Internet access
  - 3G and 4G cellular technologies that provide both voice and high-speed Internet access.
- Locating a mobile user, routing to the mobile user, and “handing off” the mobile user.

# Nội dung chương

- How mobility services are implemented in the mobile IP standard in enterprise 802.11 networks, and in LTE cellular networks.
- Impact of wireless links and mobility on transport-layer protocols and networked applications.

# Nội dung chương

- Giới thiệu
- Wireless Links and Network Characteristics
- WiFi: 802.11 Wireless LANs
- Cellular Internet Access
- Mobility Management: Principles
- Mobile IP
- Managing Mobility in Cellular Networks
- Wireless and Mobility: Impact on Higher-Layer Protocols

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# Giới thiệu chung

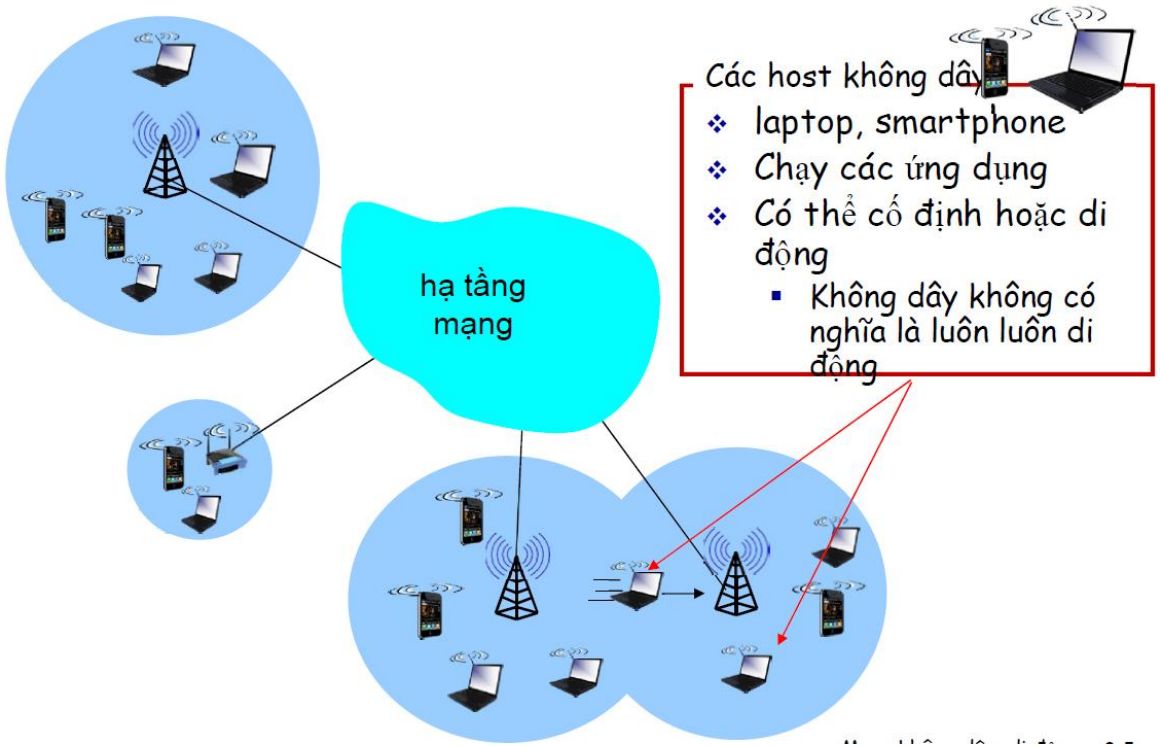
- Background:
  - Hiện nay, số lượng thuê bao mạng không dây (di động) vượt qua số lượng thuê bao mạng có dây (5 so với 1)!
  - Số lượng thiết bị được kết nối Internet không dây bằng với số lượng thiết bị được kết nối internet có dây
    - Máy tính xách tay, điện thoại Internet cho phép truy cập Internet bất cứ lúc nào

# Giới thiệu chung

- Background:
  - 2 thách thức quan trọng (nhưng khác nhau)
    - Không dây: truyền thông trên kết nối không dây
    - Di động (mobility): quản lý người dùng di động, là người sẽ thay đổi vị trí kết nối mạng

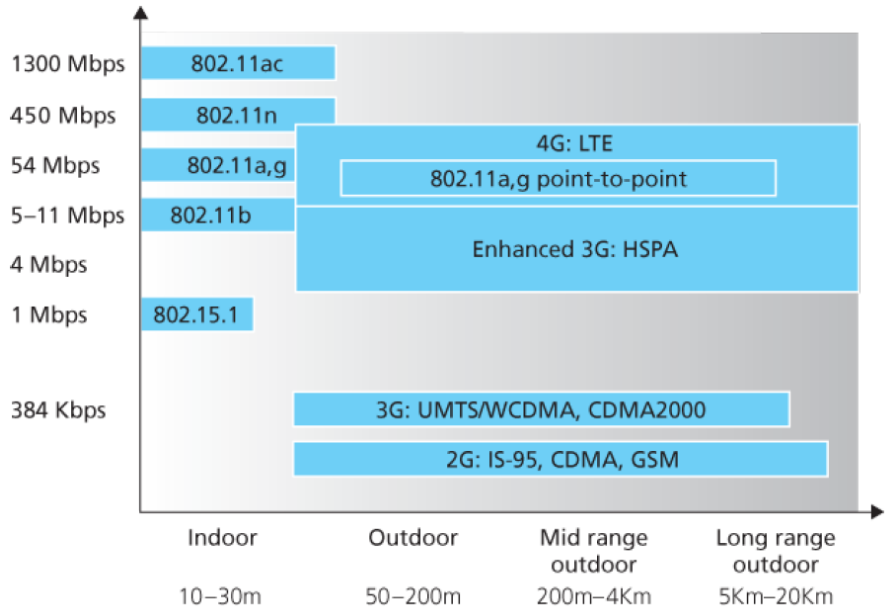
# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Wireless hosts
    - Laptop, tablet, smartphone, or desktop computer.
    - The hosts themselves may or may not be mobile



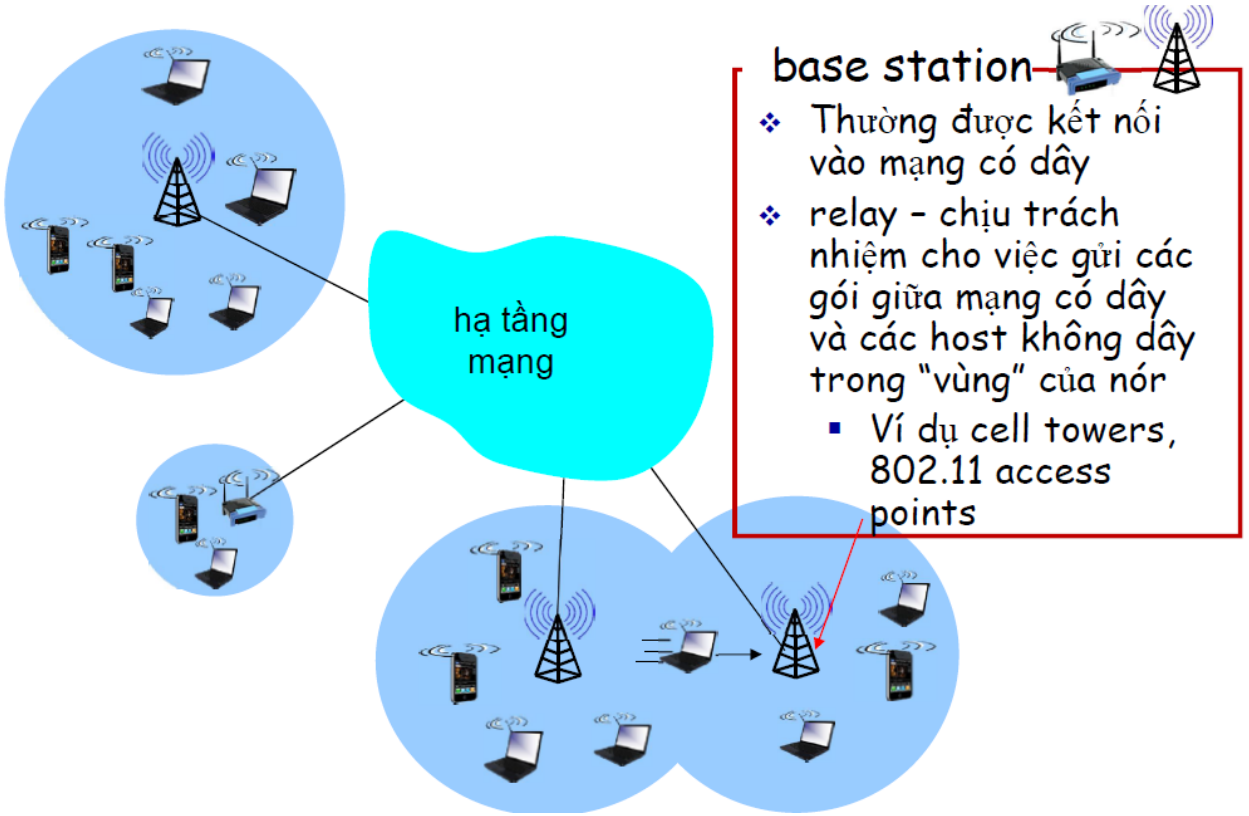
# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Wireless links
    - Different wireless link technologies have different transmission rates and can transmit over different distances
    - 2 key characteristics of the more popular wireless network standards
      - Coverage area
      - Link rate



# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Base station



# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Base station
    - A key part of the wireless network infrastructure
    - Nhiệm vụ
      - Sending and receiving data (e.g., packets) to and from a wireless host that is associated with that base station.
      - Coordinating the transmission of multiple wireless hosts with which it is associated.
    - A wireless host is “associated” with a base station
      - The host is within the wireless communication distance of the base station.
      - The host uses that base station to relay data between it (the
      - host) and the larger network

# Giới thiệu chung

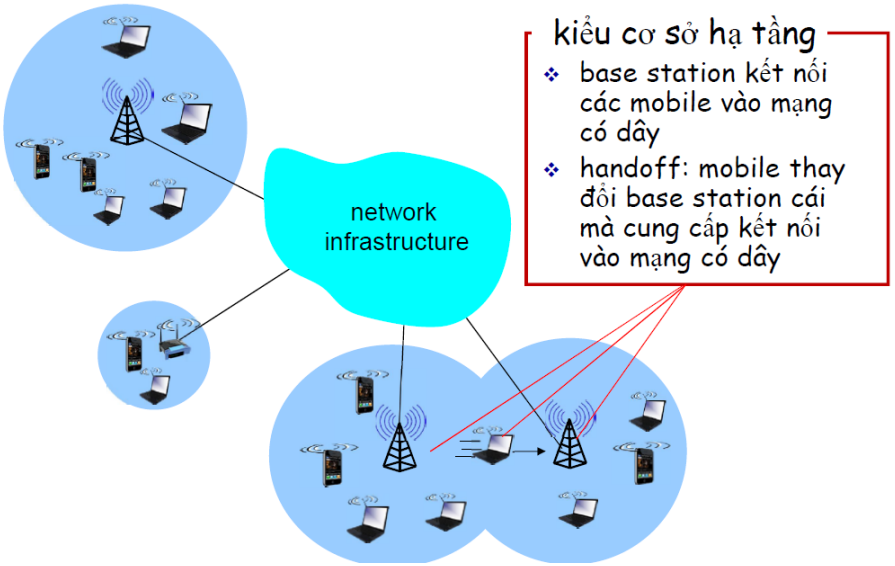
- Các thành phần cơ bản của mạng không dây
  - Base station
    - Ví dụ base station
      - Cell towers in cellular networks
      - Access points in 802.11 wireless LANs
    - Hosts associated with a base station are often referred to as operating in **infrastructure mode**
      - ad hoc networks: wireless hosts have no such infrastructure with which to connect

# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Base station
    - Handoff process
      - A mobile host moves beyond the range of one base station and into the range of another, it will change its point of attachment
      - Question?
        - » If a host can move, how to find the mobile host's current location in the network so that data can be forwarded to that mobile host?
        - » How is addressing performed?
        - » If the host moves during a TCP connection or phone call, how is data routed so that the connection continues uninterrupted?

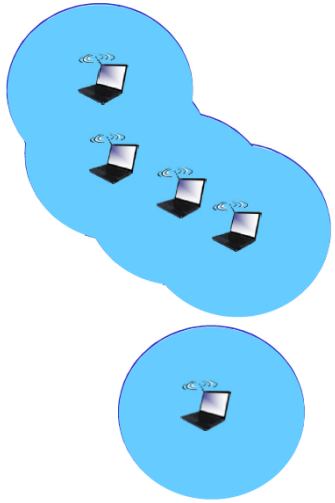
# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Các kiến trúc mạng không dây




kiểu cơ sở hạ tầng
- base station kết nối các mobile vào mạng có dây
- handoff: mobile thay đổi base station cái mà cung cấp kết nối vào mạng có dây

Infrastructure mode



Chế độ ad hoc
- Không có base stations
- Các node chỉ có thể truyền tới các node khác trong vùng phủ kết nối
- Các node tự tổ chức thành 1 mạng: tự định tuyến giữa chúng

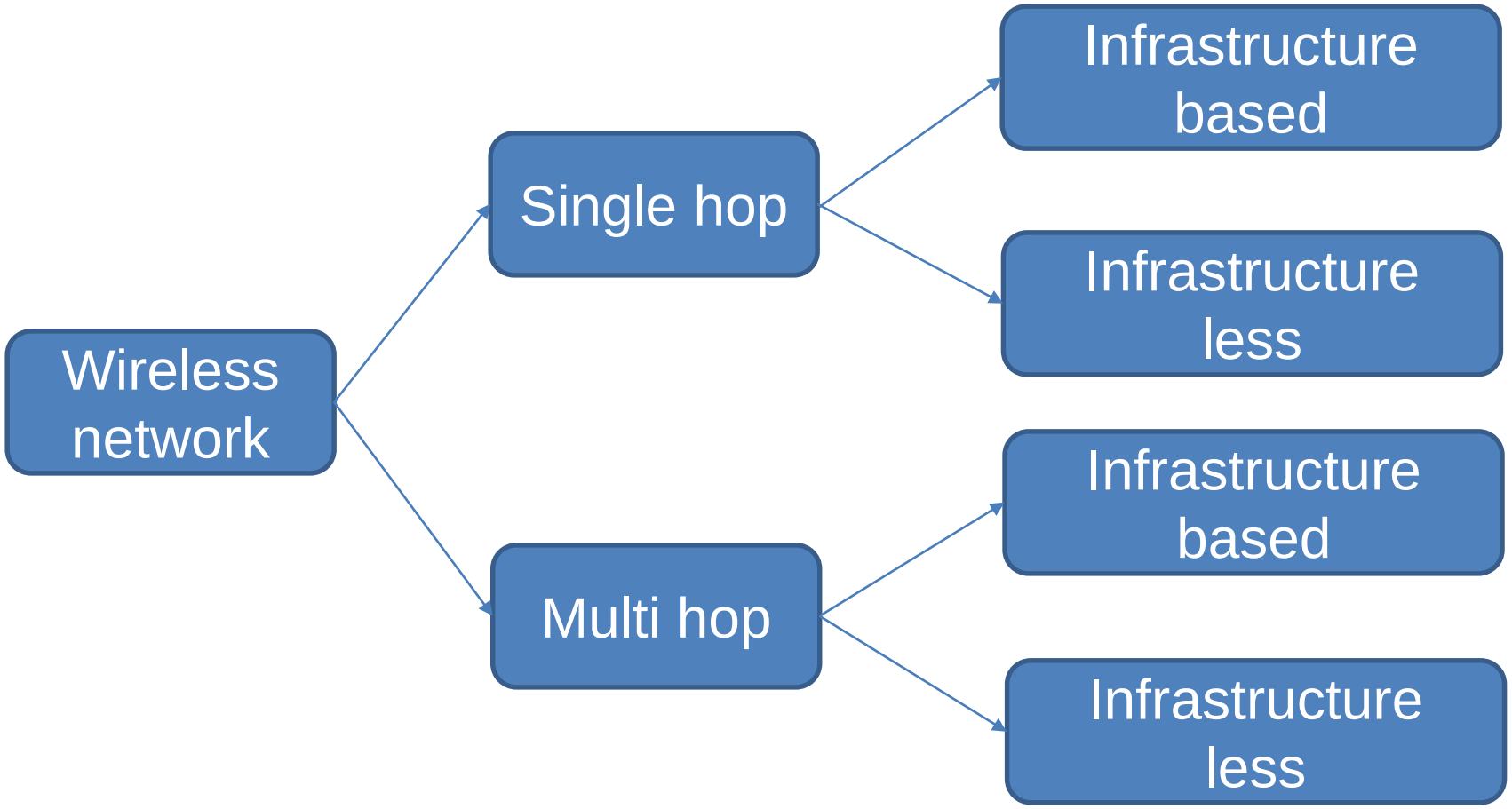
Ad hoc mode

# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Network infrastructure
    - The **larger network** with which a wireless host may wish to communicate.
    - At the highest level we can classify wireless networks according to 2 criteria:
      - Whether a packet in the wireless network crosses exactly one wireless hop or multiple wireless hops (**ad hoc mode**)
      - Whether there is **infrastructure** such as a base station in the network.

# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Network infrastructure



# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Network infrastructure
    - Single-hop, infrastructure-based
      - These networks have a base station connected to a larger wired network (e.g., the Internet).
      - All communication is between this base station and a wireless host over a single wireless hop.
      - Ví dụ
        - » The 802.11 networks in the classroom, café, or library
        - » 4G LTE data networks

# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Network infrastructure
    - Single-hop, infrastructure-less
      - There is no base station that is connected to a wireless network
      - One of the nodes in this single-hop network may coordinate the transmissions of the other nodes.
      - Ví dụ
        - » Bluetooth networks: keyboards, speakers, headsets..
        - » 802.11 networks in ad hoc mode

# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Network infrastructure
    - Multi-hop, infrastructure-based
      - A base station is present that is wired to the larger network
      - Some wireless nodes may have to relay their communication through other wireless nodes in order to communicate via the base station.
      - Ví dụ
        - » Some wireless sensor networks
        - » Wireless mesh networks

# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Network infrastructure
    - Multi-hop, infrastructure-less
      - No base station
      - Nodes may have to relay messages among several other nodes in order to reach a destination
      - Nodes may also be mobile, with connectivity changing among nodes - **mobile ad hoc networks (MANETs)**
      - Mobile nodes are vehicles, the network is a **vehicular ad hoc network (VANET)**

# Giới thiệu chung

- Các thành phần cơ bản của mạng không dây
  - Network infrastructure

| | single hop | multiple hops |
|---|---|---|
| infrastructure (ví dụ APs) | host kết nối tới base station (WiFi, WiMAX, cellular) cái mà sẽ kết nối tới mạng Internet lớn hơn | host có thể phải chuyển tiếp qua một vài node không dây để kết nối tới mạng Internet lớn hơn: *mesh net* |
| no infrastructure | Không có base station, Không kết nối tới mạng Internet lớn hơn (Bluetooth, ad hoc nets) | Không có base station, không kết nối tới mạng Internet lớn hơn. Có thể phải chuyển tiếp để tới được các node khác MANET, VANET |

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# Wireless Links and Network Characteristics

- Những điểm khác nhau quan trọng so với kết nối có dây
  - Decreasing signal strength
    - Tín hiệu radio giảm khi nó lan truyền trên đường đi (mất mát trên đường truyền (path loss))
  - Interference from other sources
    - Các tần số mạng không dây được chuẩn hóa (ví dụ 2.4 GHz) được chia sẻ bởi nhiều thiết bị (như là điện thoại); các thiết bị gây cũng gây nhiễu

# Wireless Links and Network Characteristics

- Những điểm khác nhau quan trọng so với kết nối có dây
  - Multipath propagation (lan truyền nhiều hướng)
    - Sóng radio phản xạ với các vật xung quanh, vì vậy đến đích tại các thời điểm khác nhau

=> Làm cho truyền thông thông qua kết nối không dây (thậm chí cả điểm điểm) gặp nhiều khó khăn.

# Wireless Links and Network Characteristics

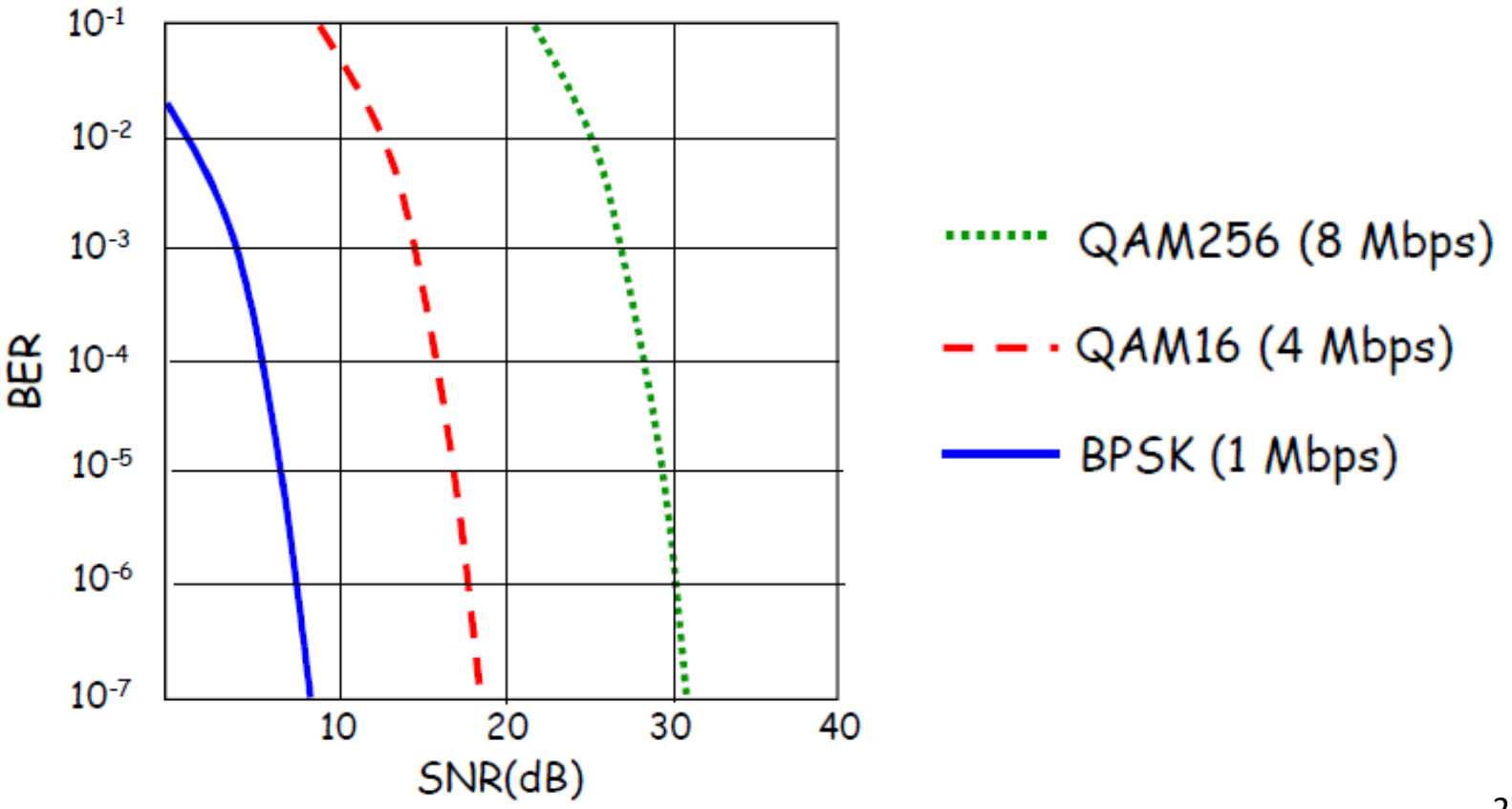
- Các đặc điểm kết nối không dây
  - Bit error rate (BER)
    - The probability that a transmitted bit is received in error at the receiver
  - SNR (signal-to-noise ratio)
    - Host receives an electromagnetic signal that is a combination of a degraded form of the original signal transmitted by the sender and background noise in the environment.
    - signal-to-noise ratio (SNR) is a relative measure of the strength of the received and background noise
    - Measured in dB
  - Transmission rate

# Wireless Links and Network Characteristics

- Các đặc điểm kết nối không dây
  - SNR: signal-to-noise ratio
    - SNR lớn hơn – dễ dàng hơn trong việc lấy tín hiệu từ nhiễu (noise)
  - So sánh SNR và BER tradeoffs
    - Given physical layer: tăng năng lượng -> tăng SNR-> giảm BER
    - Given SNR: chọn tầng vật lý mà đáp ứng được yêu cầu của BER, cho thông lượng cao nhất
      - SNR có thể thay đổi với tính di động: tự động thích ứng tầng vật lý (kỹ thuật điều chế, tốc độ)

# Wireless Links and Network Characteristics

- Các đặc điểm kết nối không dây
  - So sánh SNR và BER tradeoffs

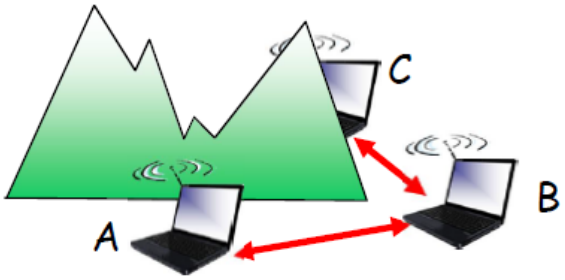


# Wireless Links and Network Characteristics

- Các đặc điểm kết nối không dây
  - Physical-layer characteristics
    - Dynamic selection of the physical-layer modulation technique can be used to adapt the modulation technique to channel conditions
      - The SNR (and hence the BER) may change as a result of mobility or due to changes in the environment.
      - Adaptive modulation and coding are used in cellular data systems and in the 802.11 WiFi and 4G cellular data networks allowing the selection of a modulation technique that provides the highest transmission rate possible subject to a constraint on the BER, for given channel characteristics.

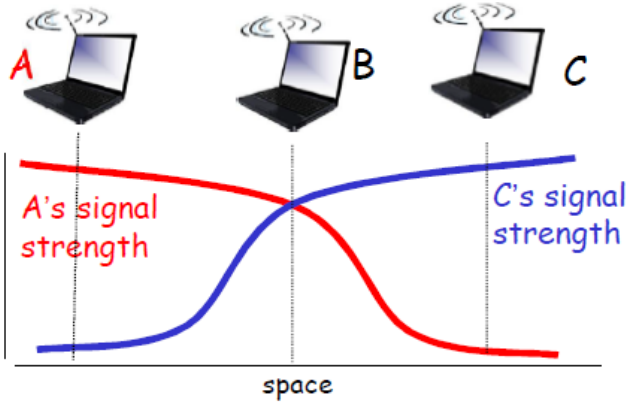
# Wireless Links and Network Characteristics

- Các đặc điểm kết nối không dây
  - Nhiều bên gửi và nhận không dây sinh ra nhiều vấn đề (ngoài vấn đề đa truy cập)




*Vấn đề thiết bị đầu cuối bị ẩn (Hidden terminal problem)*

- B, A nghe lẫn nhau
- B, C nghe lẫn nhau
- A, C không thể nghe lẫn nhau. Có nghĩa là A, C không biết sự giao thoa (interference) của chúng tại B




*Sự suy giảm tín hiệu (Signal attenuation)*

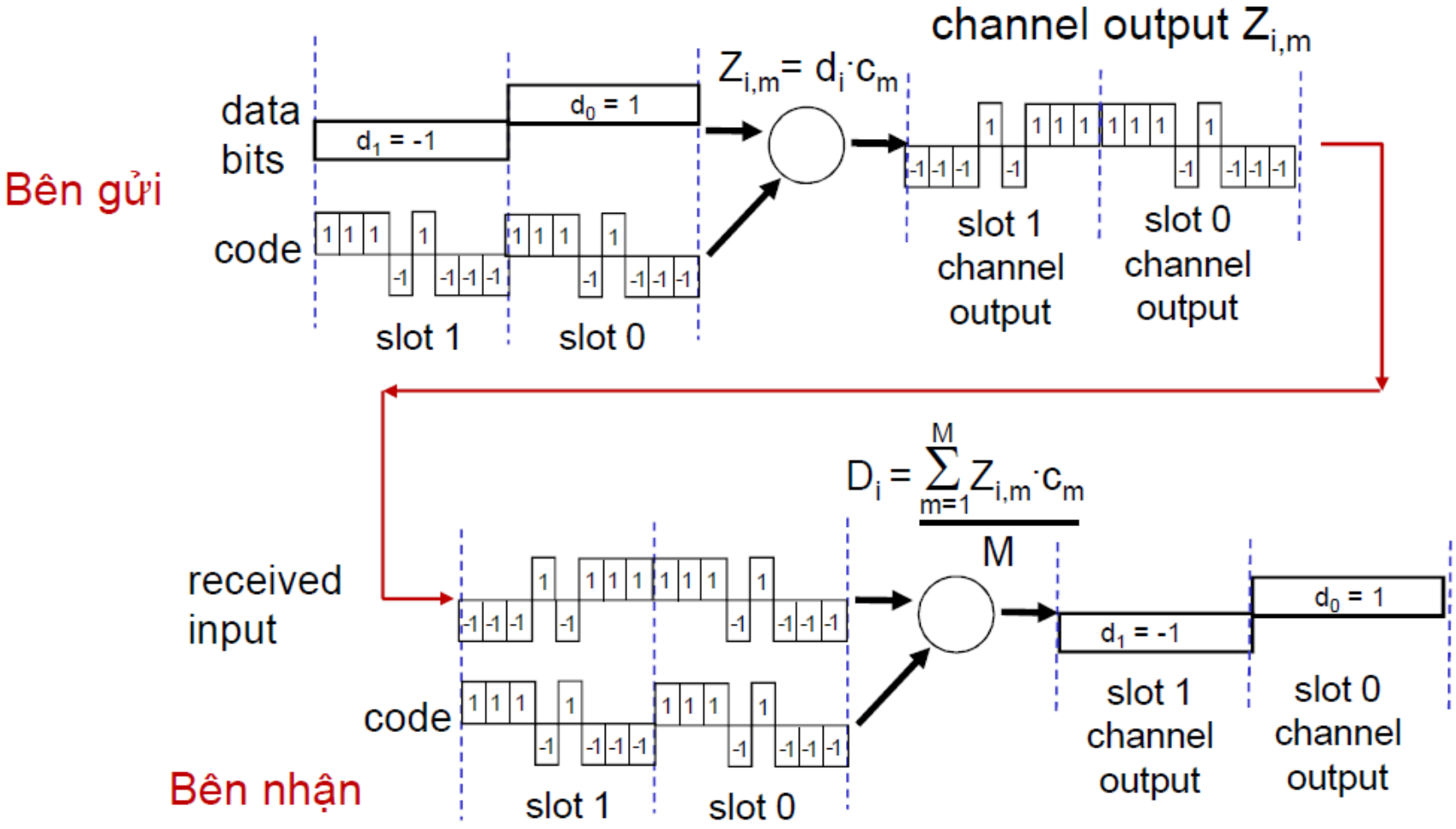
- B, A nghe lẫn nhau
- B, C nghe lẫn nhau
- A, C không thể nghe lẫn nhau dù giao thoa tại B

# Wireless Links and Network Characteristics

- 3 classes of medium access protocols
  - Channel partitioning
    - CDMA
  - Random access
  - Taking turns
- In a CDMA protocol
  - Each bit being sent is encoded by multiplying the bit by a signal (the code) that changes at a much faster rate (known as the chipping rate) than the original sequence of data bits.

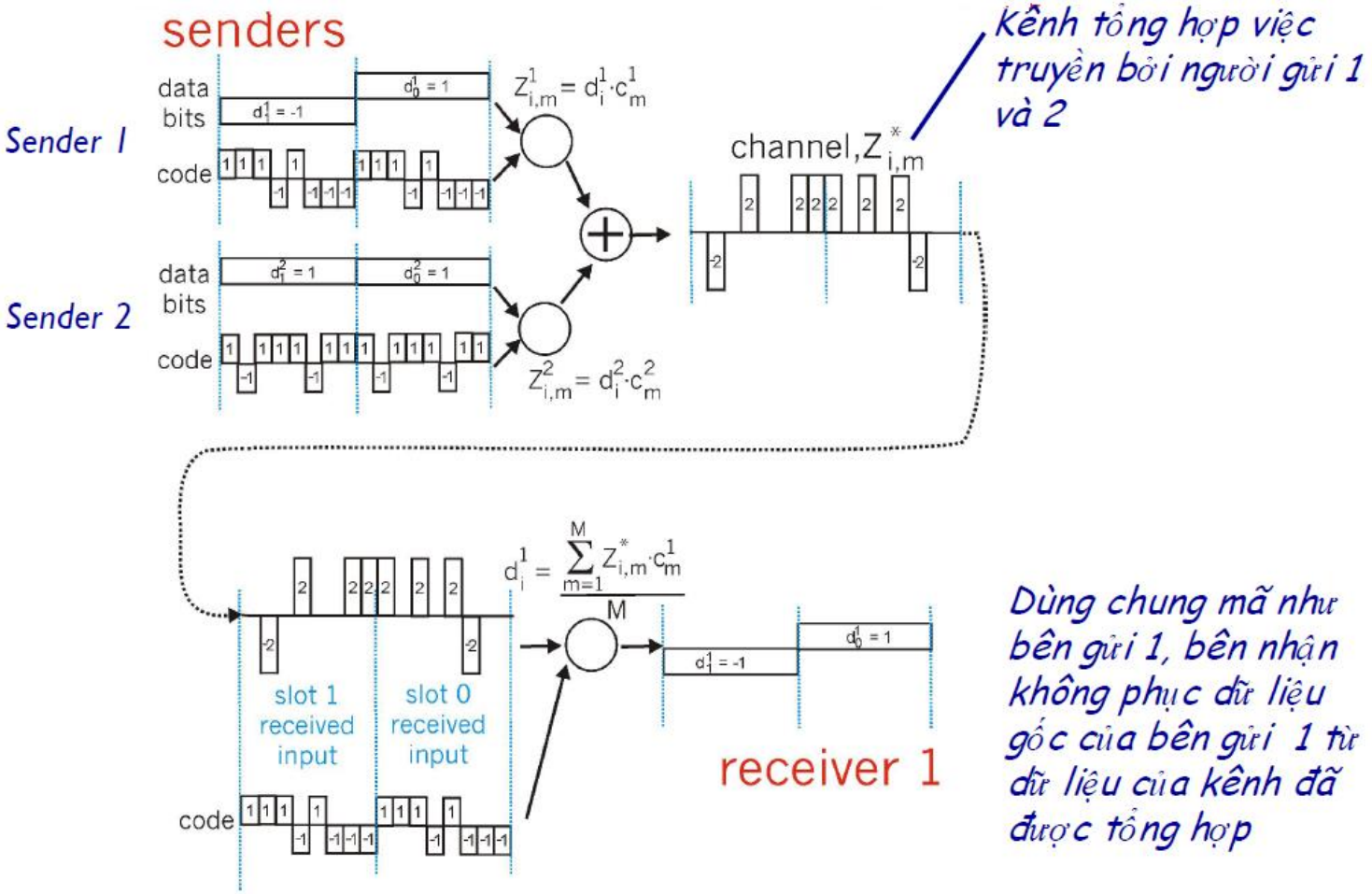
# Wireless Links and Network Characteristics

- CDMA encoding/decoding scenario



# Wireless Links and Network Characteristics

- CDMA nhiễu do 2 bên gửi (two-sender interference)



# Wireless Links and Network Characteristics

- Kết luận về CDMA
  - First, in order for the CDMA receivers to be able to extract a particular sender's signal, the CDMA codes must be carefully chosen.
  - Second, the discussion has assumed that the received signal strengths from various senders are the same; in reality this can be difficult to achieve

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# WiFi: 802.11 Wireless LANs

1. The 802.11 Architecture
2. The 802.11 MAC Protocol
3. The IEEE 802.11 Frame
4. Mobility in the Same IP Subnet
5. Advanced Features in 802.11
6. Personal Area Networks: Bluetooth and Zigbee

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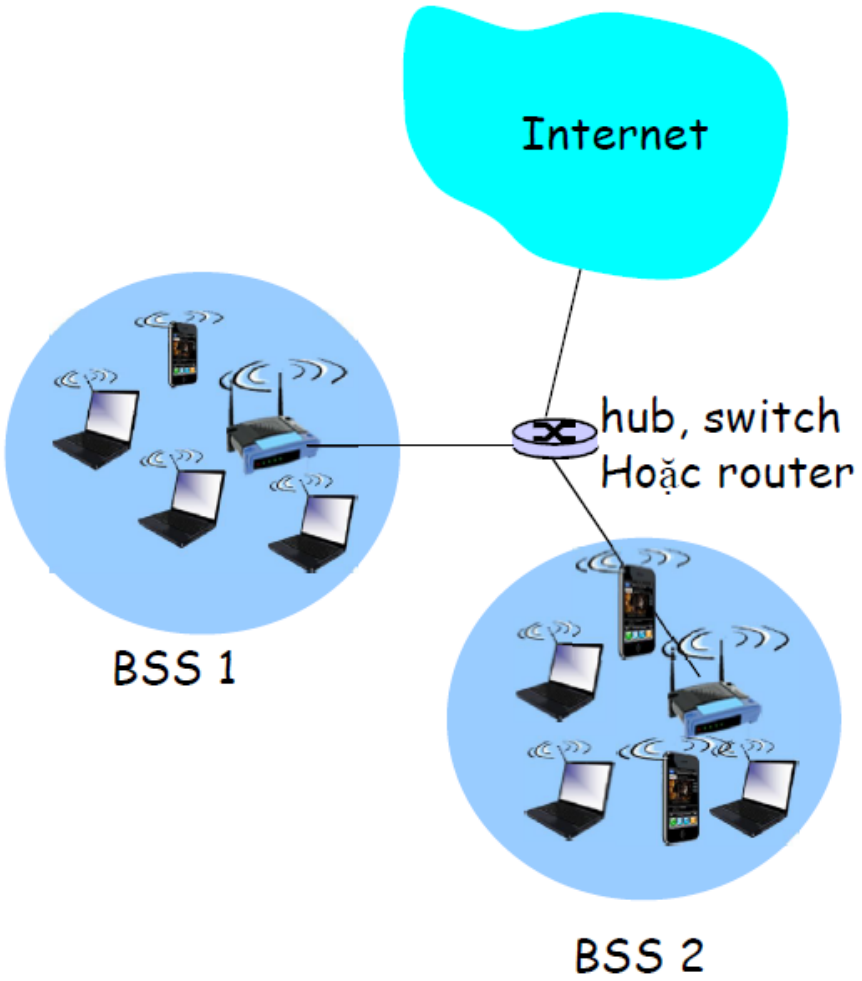
# WiFi: 802.11 Wireless LANs

- Standards for wireless LAN technology in the IEEE 802.11 (“WiFi”) family

| Standard | Frequency Range | Data Rate |
|---|---|---|
| 802.11b | 2.4 GHz | up to 11 Mbps |
| 802.11a | 5 GHz | up to 54 Mbps |
| 802.11g | 2.4 GHz | up to 54 Mbps |
| 802.11n | 2.5 GHz and 5 GHz | up to 450 Mbps |
| 802.11ac | 5 GHz | up to 1300 Mbps |

# WiFi: 802.11 Wireless LANs

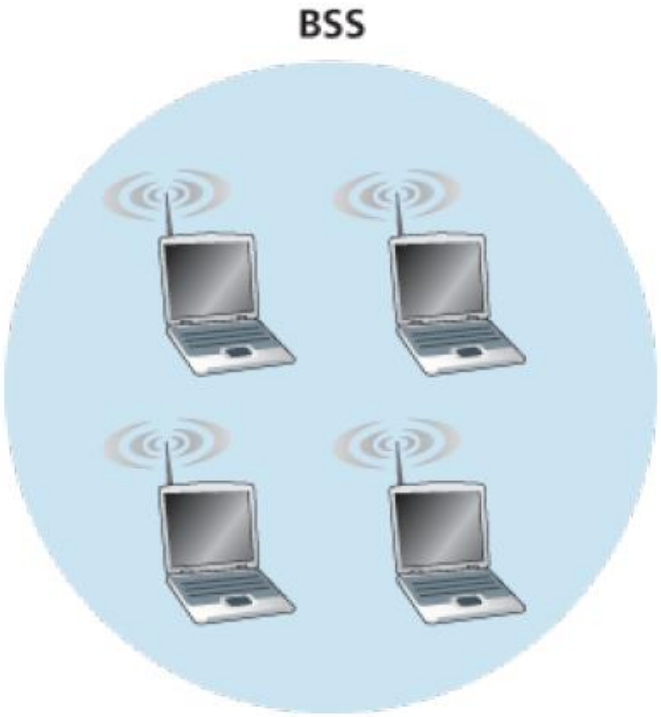
- Kiến trúc 802.11 LAN



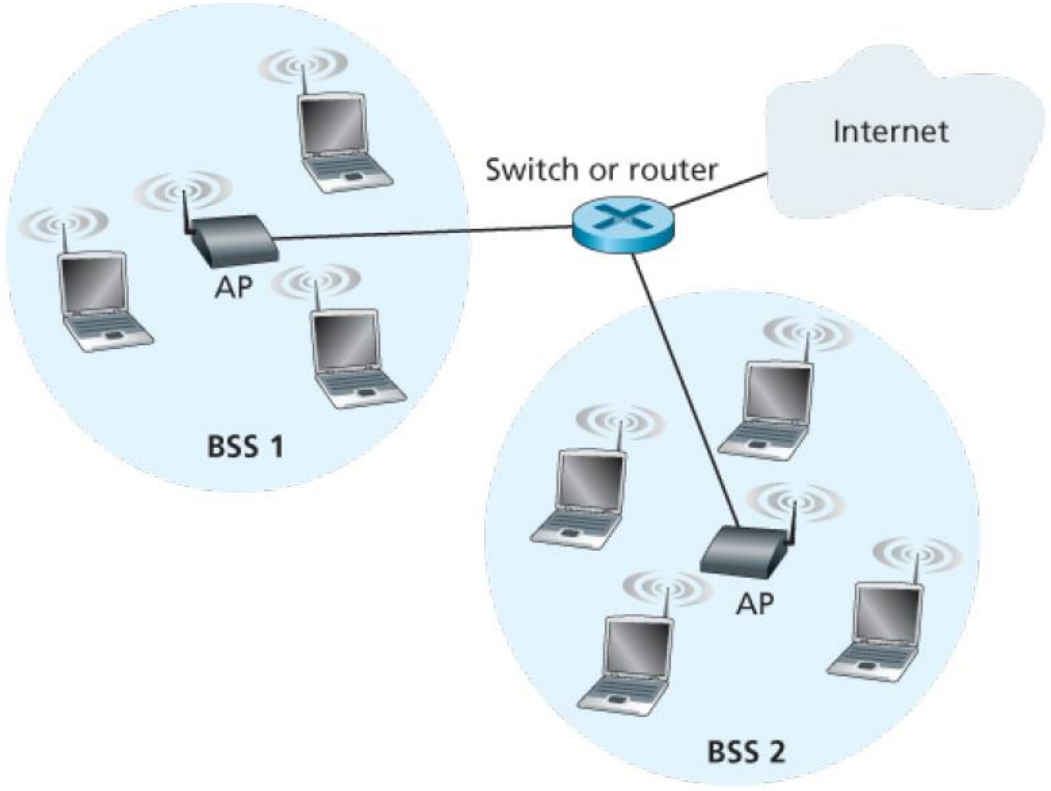

- Host không dây truyền thông với base station
  - base station = access point (AP)
- Basic Service Set (BSS) (gọi là "cell") trong infrastructure mode chứa:
  - Các host không dây
  - access point (AP): base station
  - ad hoc mode: chỉ có các host

# WiFi: 802.11 Wireless LANs

basic service set (BSS)




**ad hoc network**




**Infrastructure wireless LANs**

# WiFi: 802.11 Wireless LANs

- Kênh và sự liên kết (Channels and Association)
  - In 802.11, each wireless station needs to associate with an AP before it can send or receive network layer data
  - Mỗi AP được gán
    - One-or two-word Service Set Identifier (**SSID**)
    - A channel number
      - 802.11 operates in the frequency range of 2.4 GHz to 2.4835 GHz
      - Within this 85 MHz band, 802.11 defines 11 partially overlapping channels.
        - » Any two channels are non-overlapping if and only if they are separated by four or more channels.

# WiFi: 802.11 Wireless LANs

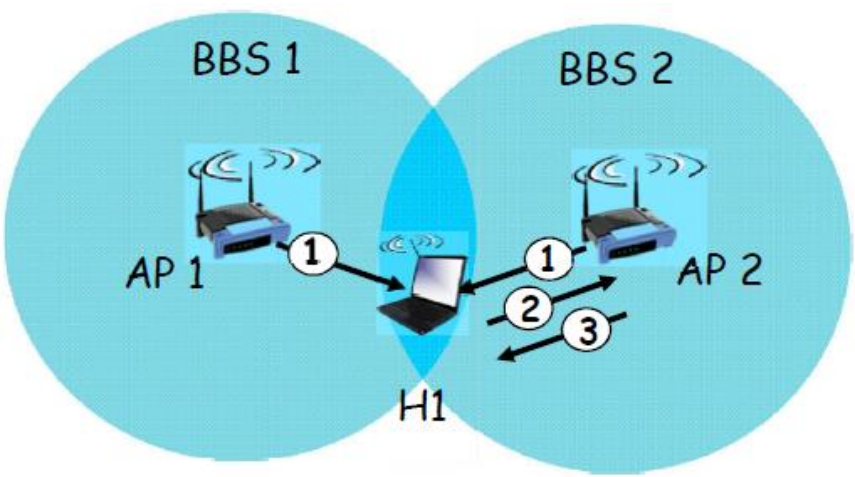
- Kênh và sự liên kết
  - WiFi jungle
    - Any physical location where a wireless station receives a sufficiently strong signal from two or more Aps.
      - For example, in many cafés in New York City, a wireless station can pick up a signal from numerous nearby Aps
        - » One of the Aps might be managed by the café, while the other APs might be in residential apartments near the café.
        - » Each of these APs would likely be located in a different IP subnet and would have been independently assigned a channel.

# WiFi: 802.11 Wireless LANs

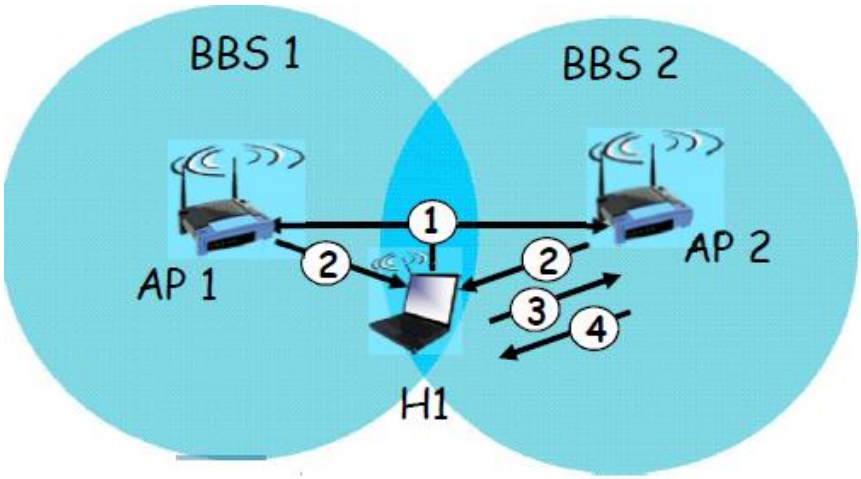
- Kênh và sự liên kết
  - WiFi jungle
    - Any physical location where a wireless station receives a sufficiently strong signal from two or more Aps.
      - Gỉa sử bạn đăng nhập vào WiFi jungle này bằng phone, tablet, or laptop để truy cập Internet.
        - » Gỉa sử có 5 APs trong WiFi jungle này
        - » To gain Internet access, your wireless device needs to join exactly one of the subnets and hence needs to associate with exactly one of the APs.

# WiFi: 802.11 Wireless LANs

- Kênh và sự liên kết
  - WiFi jungle
    - How Wireless device associate with a particular AP?
      - Quét thụ động
      - Quét bị động




Quét thụ động




Quét chủ động

# WiFi: 802.11 Wireless LANs

- Kênh và sự liên kết
  - WiFi jungle
    - How Wireless device associate with a particular AP?
      - Quét thụ động
        - » AP periodically send beacon frames (AP's SSID and MAC address).
        - » Wireless device, knowing that APs are sending out beacon frames, scans the 11 channels, seeking beacon frames from any APs that may be out there.
        - » Having learned about available APs from the beacon frames, wireless device select one of the APs for association.
          - The 802.11 standard does not specify an algorithm for selecting which of the available APs to associate with; that algorithm is left up to the designers of the 802.11 firmware and software in your wireless device.

# WiFi: 802.11 Wireless LANs

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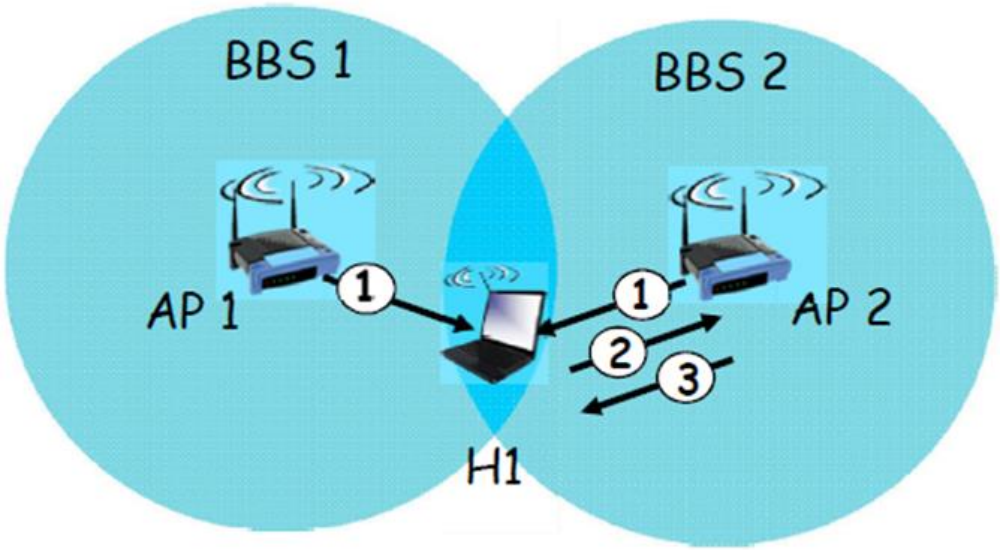
          - Typically, the device chooses the AP whose beacon frame is received with the highest signal strength.

# WiFi: 802.11 Wireless LANs

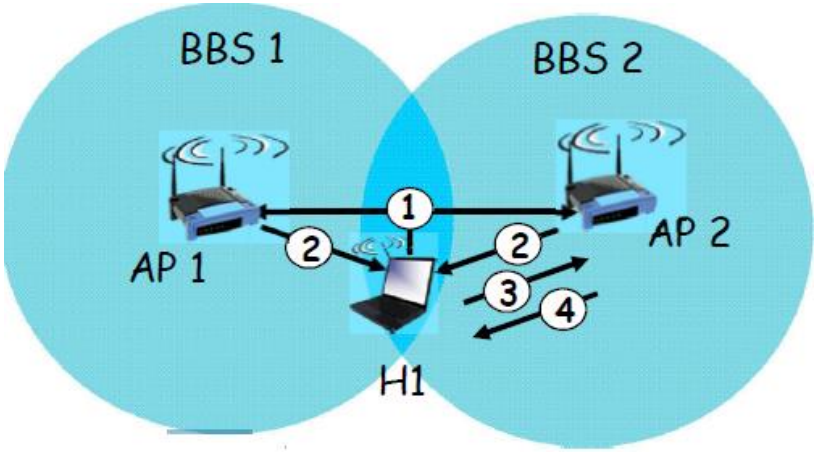
- Kênh và sự liên kết
  - WiFi jungle
    - How Wireless device associate with a particular AP?
      - Quét thụ động
        - » The process of scanning channels and listening for beacon frames is known as **passive scanning**



# WiFi: 802.11 Wireless LANs

- Kênh và sự liên kết
  - WiFi jungle
    - How Wireless device associate with a particular AP?
      - Quét chủ động **Active scanning**

(1) H1 quảng bá Probe Request frame
(2) AP gửi các Probe Response frame
(3) H1 gửi Association Request frame tới AP được lựa chọn
(4) Association Response frame được gửi từ AP được chọn lựa tới H1



# WiFi: 802.11 Wireless LANs

- Kênh và sự liên kết
  - WiFi jungle
    - Sau khi associated với AP, the wireless device want to join the subnet to which the AP belongs
      - The wireless device sends a **DHCP discovery message**

# WiFi: 802.11 Wireless LANs

- Kênh và sự liên kết
  - WiFi jungle
    - Wireless device may be required to authenticate itself to the AP
      - Wireless device's MAC address
      - Usernames and passwords

      Using **authentication server:** RADIUS or DIAMETER protocol
        - » One authentication server to serve many Aps
        - » Centralizing the decisions of authentication and access within the single server.
        - » Keeping AP costs and complexity low

## WiFi: 802.11 Wireless LANs

1. The 802.11 Architecture
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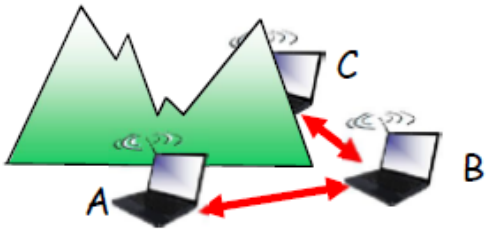
6. Personal Area Networks: Bluetooth and Zigbee

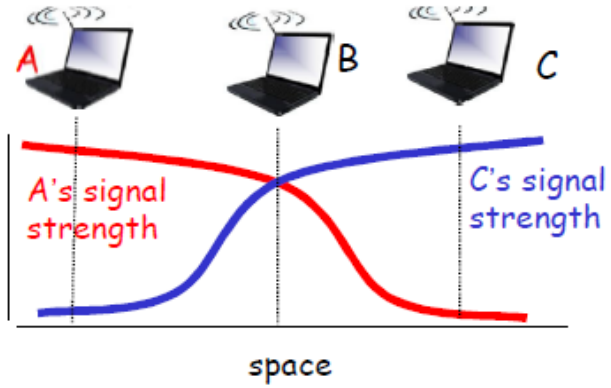
# WiFi: 802.11 Wireless LANs

- CSMA/CA (carrier sense multiple access/collision avoidance)
  - Thuộc loại MAC ngẫu nhiên
  - Each station senses the channel before transmitting and refrains from transmitting when the channel is sensed busy.
  - Khác CSMA/CD của Ethernet
    - Uses CA (collision avoidance) techniques thay cho CD (collision detection) của Ethernet
    - Uses a link-layer acknowledgment/retransmission (ARQ) scheme

# WiFi: 802.11 Wireless LANs

- CSMA/CA (carrier sense multiple access/collision avoidance)
  - 802.11: không phát hiện đụng độ!
    - Khó khăn để cảm nhận (cảm nhận đụng độ) khi truyền bởi vì tín hiệu nhận được yếu (fading)
    - Không thể cảm nhận tất cả các đụng độ trong những trường hợp: hidden terminal, fading
    - Mục tiêu: tránh đụng độ

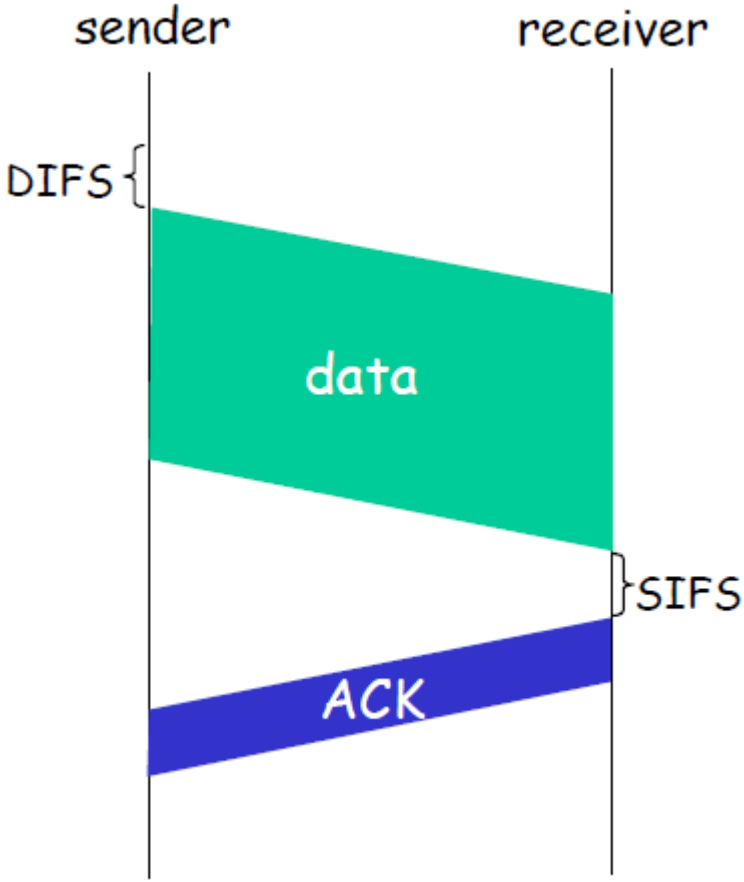


# WiFi: 802.11 Wireless LANs

- CSMA/CA
  - Đầu gửi

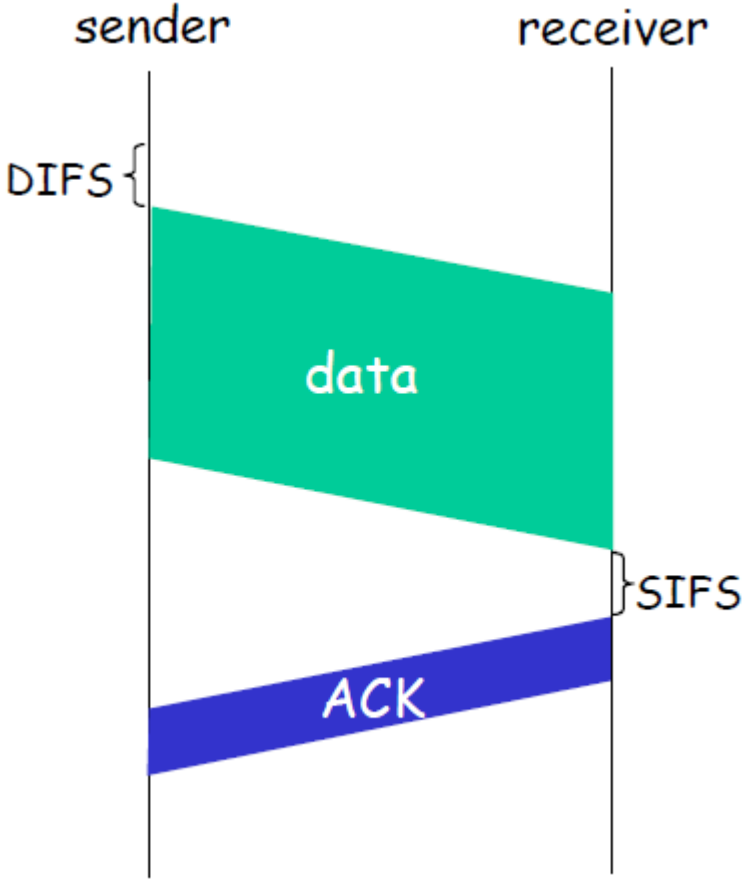
1. Nếu cảm nhận kênh rảnh trong khoảng thời gian **DIFS** thì truyền toàn bộ frame (không có phát hiện đụng độ)
2. Nếu cảm nhận kênh bận thì khởi tạo thời gian chờ ngẫu nhiên (**random backoff time**).
   - Timer giảm xuống khi kênh rảnh. Truyền khi Timer kết thúc.
   - Nếu không có ACK, tăng thời random backoff time, lặp lại bước 2.



# WiFi: 802.11 Wireless LANs

- CSMA/CA
  - Đầu nhận

Nếu frame được nhận thành công trả lại tín hiệu ACK sau khoảng thời gian SIFS

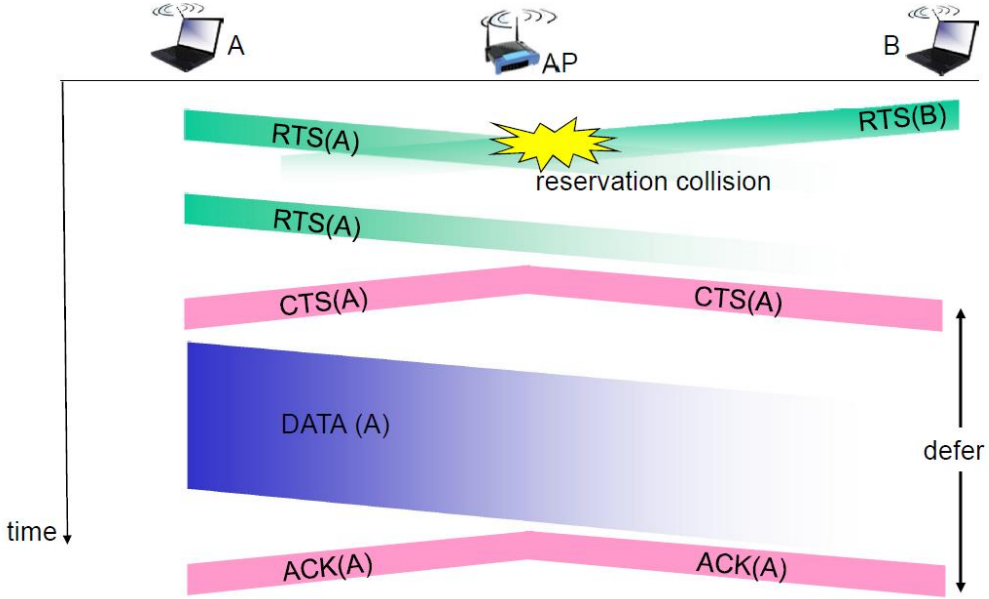


# WiFi: 802.11 Wireless LANs

- Tránh đụng độ
  - Ý tưởng: cho phép bên gửi được "đăng ký trước" kênh hơn là truy cập ngẫu nhiên: tránh đụng độ với các frame dữ liệu dài
  - Đầu tiên, bên gửi truyền các packet nhỏ được gọi là **request-to-send (RTS)** tới base station dùng cơ chế CSMA
    - Các RTS có thể vẫn đụng độ lẫn nhau (tuy nhiên chúng rất ngắn)
  - Base station quảng bá **clear-to-send CTS** để trả lời cho RTS

# WiFi: 802.11 Wireless LANs

- Tránh đụng độ
  - Tất cả các node lắng nghe CTS
    - Bên gửi truyền frame dữ liệu
    - Các trạm khác trì hoãn việc truyền




Tránh đụng độ frame dữ liệu một cách triệt để dùng các packet nhỏ để đăng ký trước

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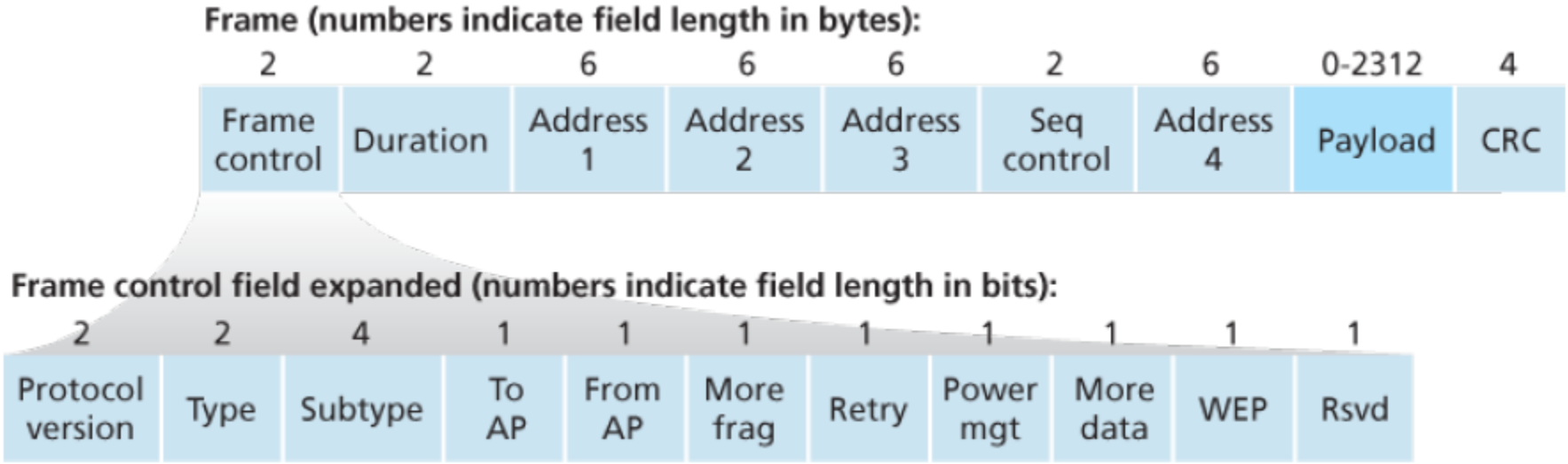
# WiFi: 802.11 Wireless LANs

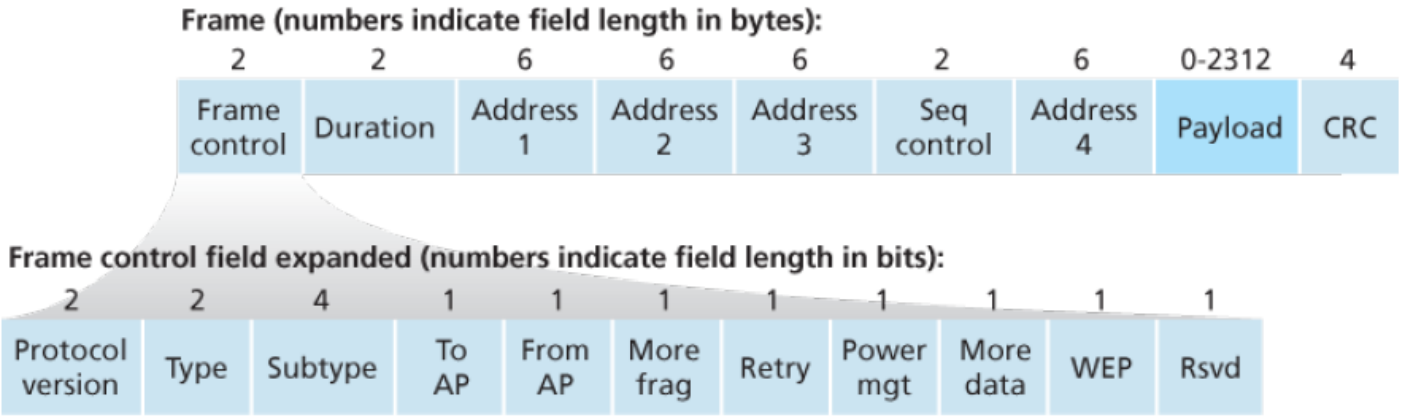
- 802.11 frame




  - Payload: IP datagram or an ARP packet
  - CRC

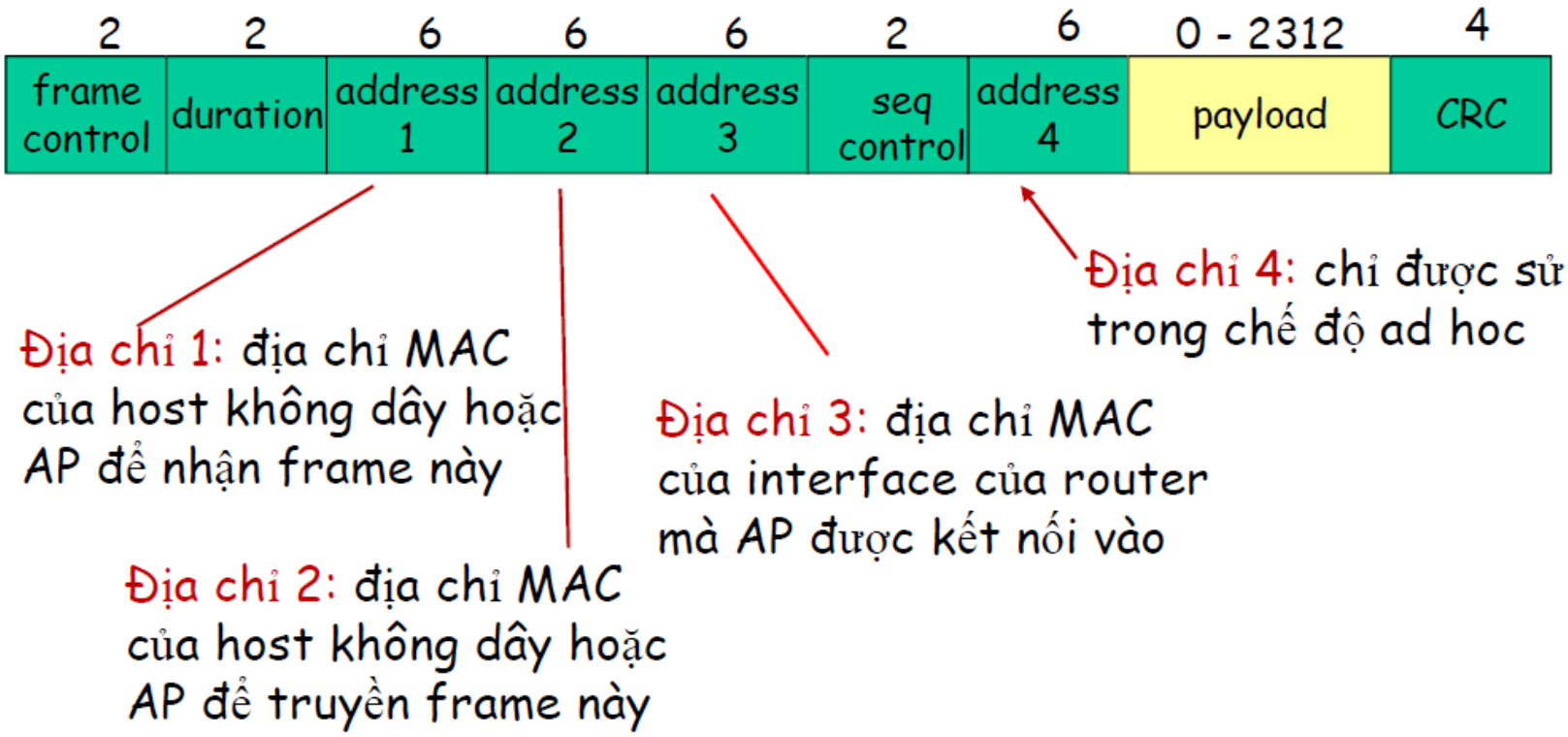
# WiFi: 802.11 Wireless LANs

- 802.11 frame



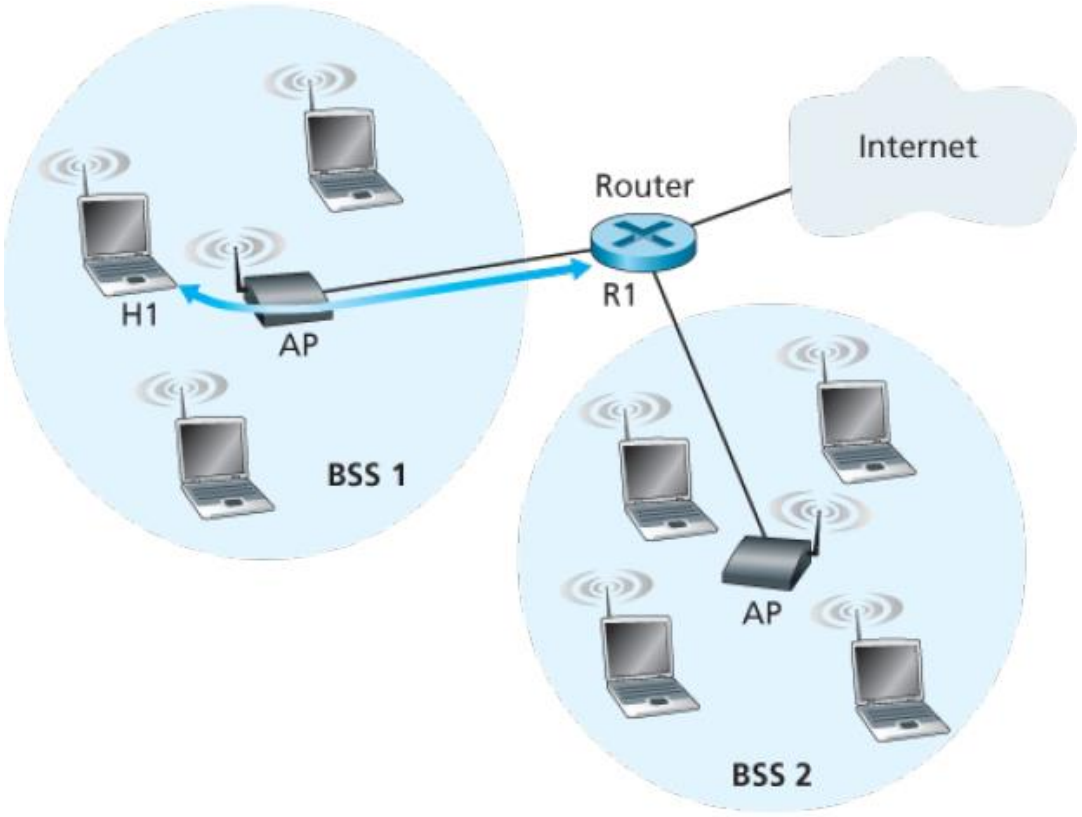

  - 4 address fields: each holds a 6-byte MAC address
    - Address 2: MAC address of the station that transmits the frame
    - Address 1: MAC address of the wireless station that is to receive the frame
    - Address 3: In BSS connect one subnet to others via router interface. Address 3 is MAC address of this router interface.
    - Address 4: used when APs forward frames to each other in ad hoc mode.

- 802.11 frame
  - 4 address fields: each holds a 6-byte MAC address



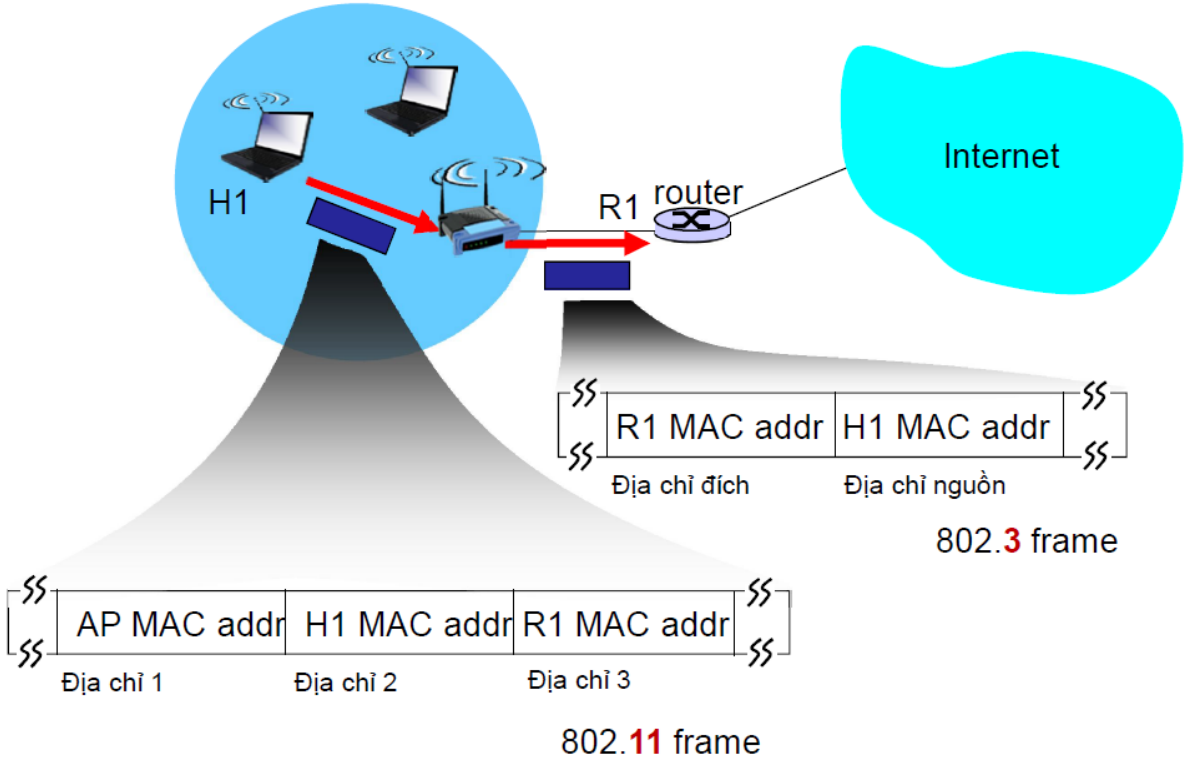
# WiFi: 802.11 Wireless LANs

- 802.11 frame
  - 4 Address
    - Truyền datagram từ R1 tới H1



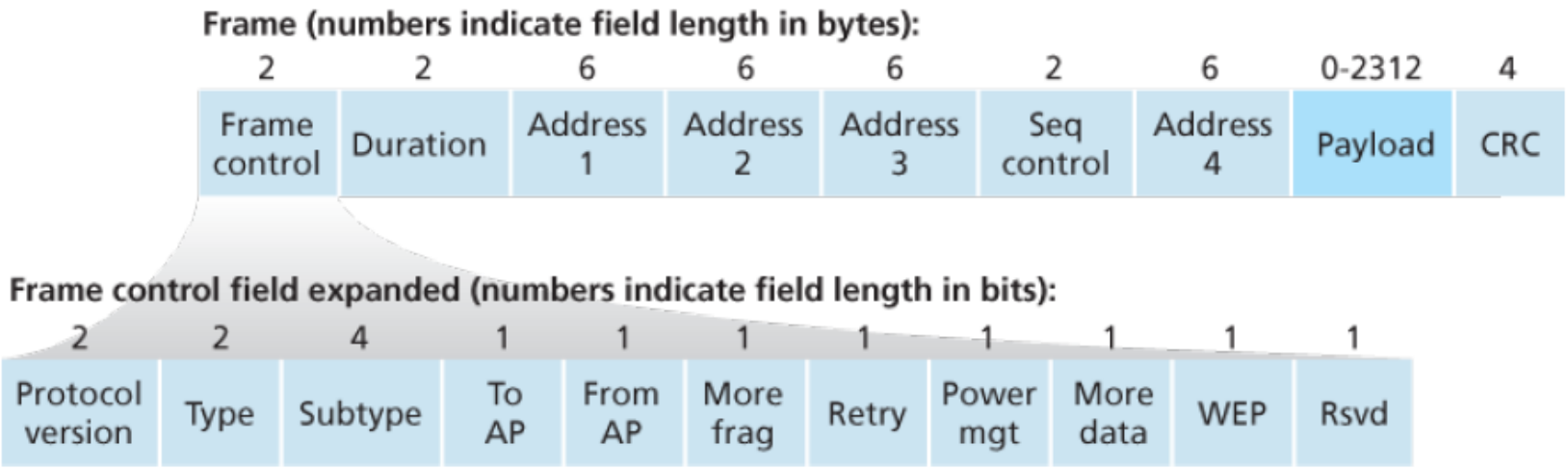
# WiFi: 802.11 Wireless LANs

- 802.11 frame
  - 4 Address
    - H1 responds by moving a datagram from H1 to R1



# WiFi: 802.11 Wireless LANs

- 802.11 frame
  - Sequence Number, Duration, and Frame Control



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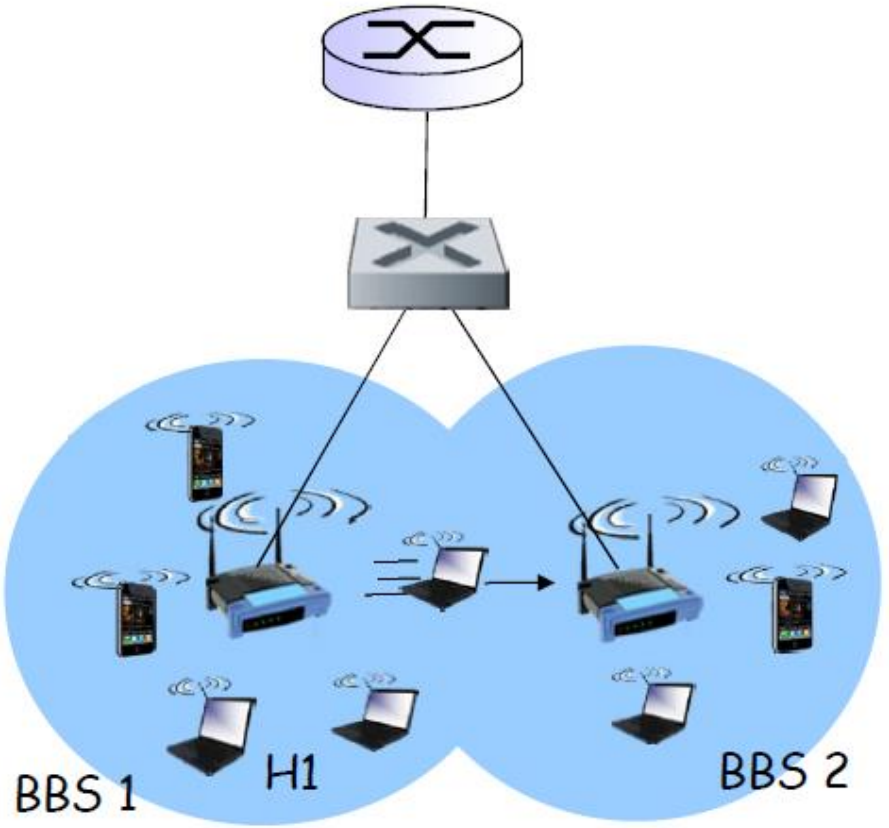
# WiFi: 802.11 Wireless LANs

- Tại sao cần quan tâm tới "Mobility in the Same IP Subnet"
  - Để tăng vùng phủ sóng một wireless LAN, các tổ chức thường triển khai multiple BSSs trong cùng một IP subnet
    - Vậy là thế nào để các wireless stations di chuyển liền mạch từ BSS này sang BSS khác mà vẫn duy trì được các TCP sessions hiện tại?

# WiFi: 802.11 Wireless LANs

- Mobility in the Same IP Subnet

- H1 vẫn còn trong cùng IP subnet: địa chỉ IP có thể duy trì giống vậy
- switch: AP nào được liên kết với H1?
  - Tự học (Ch. 5): switch sẽ thấy frame từ H1 và "nhớ" port nào của switch có thể được sử dụng để tới H1



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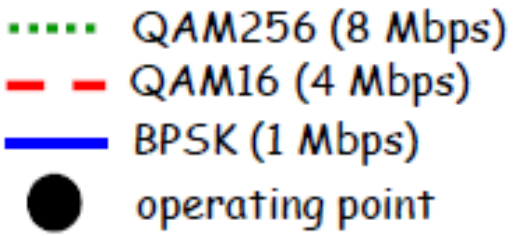
# WiFi: 802.11 Wireless LANs

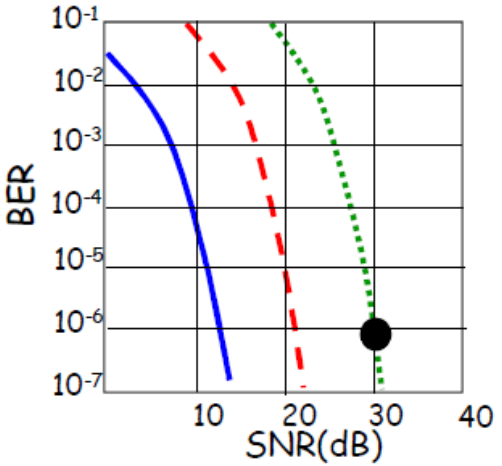
- Sự thích ứng  tốc độ (Rate Adaptation)
  - Tại sao cần
    - Different modulation techniques <=> different SNR scenarios
      - Ví dụ:
        - » Một user di động đầu tiên ở khoảng cách 20 meters so với base station, với một SNR cao. Với SRN cao này, user có thể truyền tin với base station sử dụng một modulation technique (ở tầng vật lý) để cung cấp **high transmission rates** while **maintaining a low BER** => good
        - » Nếu user di chuyển ra xa base station, với SNR càng giảm khi khoảng cách tăng lên => Nếu the modulation technique không thay đổi, BER sẽ cao không chấp nhận được khi SNR giảm, và cuối cùng không có frame đã truyền nào được nhận đúng.

# WiFi: 802.11 Wireless LANs

- 802.11 Rate Adaptation
  - Rate adaptation capability là gì?

Base station, mobile tự động thay đổi tốc độ truyền (kỹ thuật điều chế tầng physical) khi mobile di chuyển, thay đổi SNR




1. SNR giảm, BER tăng khi node di chuyển ra xa base station

2. Khi BER quá cao, chuyển sang tốc độ truyền thấp hơn nhưng với BER thấp hơn

# WiFi: 802.11 Wireless LANs

- Quản lý năng lượng (Power Management)
  - Một node có thể chuyển trạng thái sleep và wake. Nếu ở sleep thì nó sẽ set power-management bit trong phần header của 802.11 frame = 1.
  - Một timer trong node khi đó thiết lập node về trạng thái wake up ngay trước khi AP có kế hoạch gửi beacon frame của nó (thường AP gửi a beacon frame sau 100 msec).

# WiFi: 802.11 Wireless LANs

- Quản lý năng lượng (Power Management)
  - Do AP biết node sẽ sleep (từ power-transmission bit) => AP không gửi bất kỳ frames nào tới node, và sẽ lưu vào bộ nhớ đệm các frames được gửi tới host đang sleeping để truyền sau.

# WiFi: 802.11 Wireless LANs

- Quản lý năng lượng (Power Management)
  - Một node sẽ wake up ngay trước khi AP gửi một beacon frame, và nhanh chóng vào trạng thái fully active.
  - Các beacon frames do AP gửi chứa một list các nodes mà frames của nó đã được lưu trong bộ nhớ đệm của AP.

# WiFi: 802.11 Wireless LANs

- Quản lý năng lượng (Power Management)
  - Nếu như không có frame nào trong bộ nhớ đệm, node có thể chuyển trở lại trạng thái sleep. Ngược lại, node có thể yêu cầu gửi frame trong bộ nhớ đệm bằng cách gửi một thông điệp thăm dò (polling message) tới AP.

# WiFi: 802.11 Wireless LANs

- Quản lý năng lượng (Power Management)
  - Với inter-beacon time là 100 msec, wakeup time 250 microseconds, và a similarly small time để nhận một beacon frame và kiểm tra để đảm bảo rằng không có frame nào trong bộ nhớ đệm, node không có frame để gửi hay nhận có thể ở trạng thái sleep 99% thời gian => tiết kiệm đáng kể năng lượng.

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# WiFi: 802.11 Wireless LANs

- Bluetooth
  - Defined in the IEEE 802.15.1 standard
  - Known as WPAN (wireless personal area network).
  - Operates over a short range, at low power, and at low cost.
  - Interconnecting a computer with wireless keyboard, mouse or other peripheral device; cellular phones, speakers, headphones, and many other devices.

# WiFi: 802.11 Wireless LANs

- Bluetooth
  - Operate in the 2.4 GHz unlicensed radio band in a TDM manner, with time slots of 625 microseconds.
  - During each time slot, a sender transmits on one of 79 channels, with the channel changing in a known but pseudo-random manner from slot to slot.
  - This channel hopping, known as frequency-hopping spread spectrum (FHSS), spreads transmissions in time over the frequency spectrum.

# WiFi: 802.11 Wireless LANs

- Bluetooth
  - Can provide data rates up to 4 Mbps.
  - Ad hoc networks, no network infrastructure (AP) is needed to interconnect 802.15.1 devices => 802.15.1 devices must organize themselves.

# WiFi: 802.11 Wireless LANs

- Bluetooth
  - 802.15.1 devices must organize themselves.
    - 802.15.1 devices are first organized into a **piconet** of up to eight active devices.
    - One of these devices is designated as the master, the remaining devices acting as slaves.
    - The master node truly rules the piconet—its clock determines time in the piconet, it can transmit in each odd-numbered slot, and a slave can transmit only after the master has communicated with it in the previous slot and even then the slave can only transmit to the master.

# WiFi: 802.11 Wireless LANs

- Bluetooth
  - 802.15.1 devices must organize themselves.
    - In addition to the slave devices, there can also be up to 255 parked devices in the network. These devices cannot communicate until their status has been changed from parked to active by the master node.

# WiFi: 802.11 Wireless LANs

- Zigbee
  - WPAN network, 802.15.4 standard
  - Targeted at lower-powered, lower-data-rate, lower-duty-cycle **applications** than Bluetooth
    - Ví dụ:
      - Home temperature and light sensors
      - Security devices
      - Wall-mounted switches
  - Defines channel rates of 20, 40, 100, and 250 Kbps, depending on the channel frequency.

# WiFi: 802.11 Wireless LANs

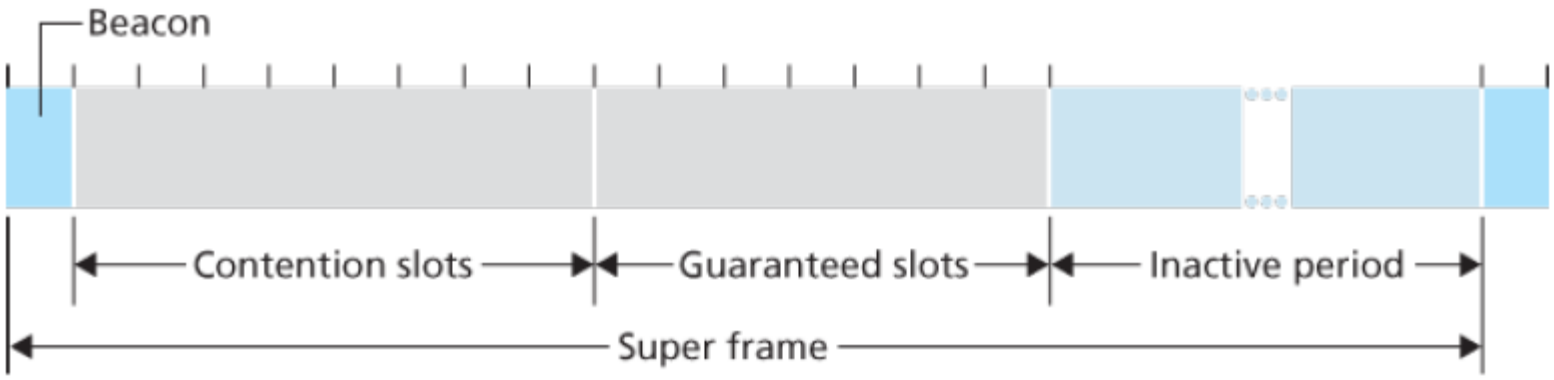
- Zigbee
  - Nodes in a Zigbee network
    - Operate as slave devices = reduced-function devices
    - Operate as a master device = full-function device
      - Controlling multiple slave devices
      - Multiple full-function devices can additionally be configured into a mesh network in which full function devices route frames amongst themselves

# WiFi: 802.11 Wireless LANs

- Zigbee
  - Zigbee shares many protocol mechanisms
    - Beacon frames
    - Link-layer acknowledgments
    - Carrier-sense random access protocols with binary exponential backoff
    - Fixed, guaranteed allocation of time slots (similar to DOCSIS).

# WiFi: 802.11 Wireless LANs

- Zigbee
  - Zigbee networks can be configured in many different ways
    - A simple case of a maste device controlling multiple slave devices in a time-slotted manner using beacon frames.



# Nội dung chương

- Giới thiệu
- Wireless Links and Network Characteristics
- WiFi: 802.11 Wireless LANs
- Cellular Internet Access
- Mobility Management: Principles
- Mobile IP
- Managing Mobility in Cellular Networks
- Wireless and Mobility: Impact on Higher-Layer Protocols

# Cellular Internet Access

1. Kiến trúc
2. Các chuẩn (GSM)
   - Cellular Network Architecture, 2G: Voice Connections to the Telephone Network
   - 3G Cellular Data Networks: Extending the Internet to Cellular Subscribers.
   - On to 4G: LTE

# Cellular Internet Access

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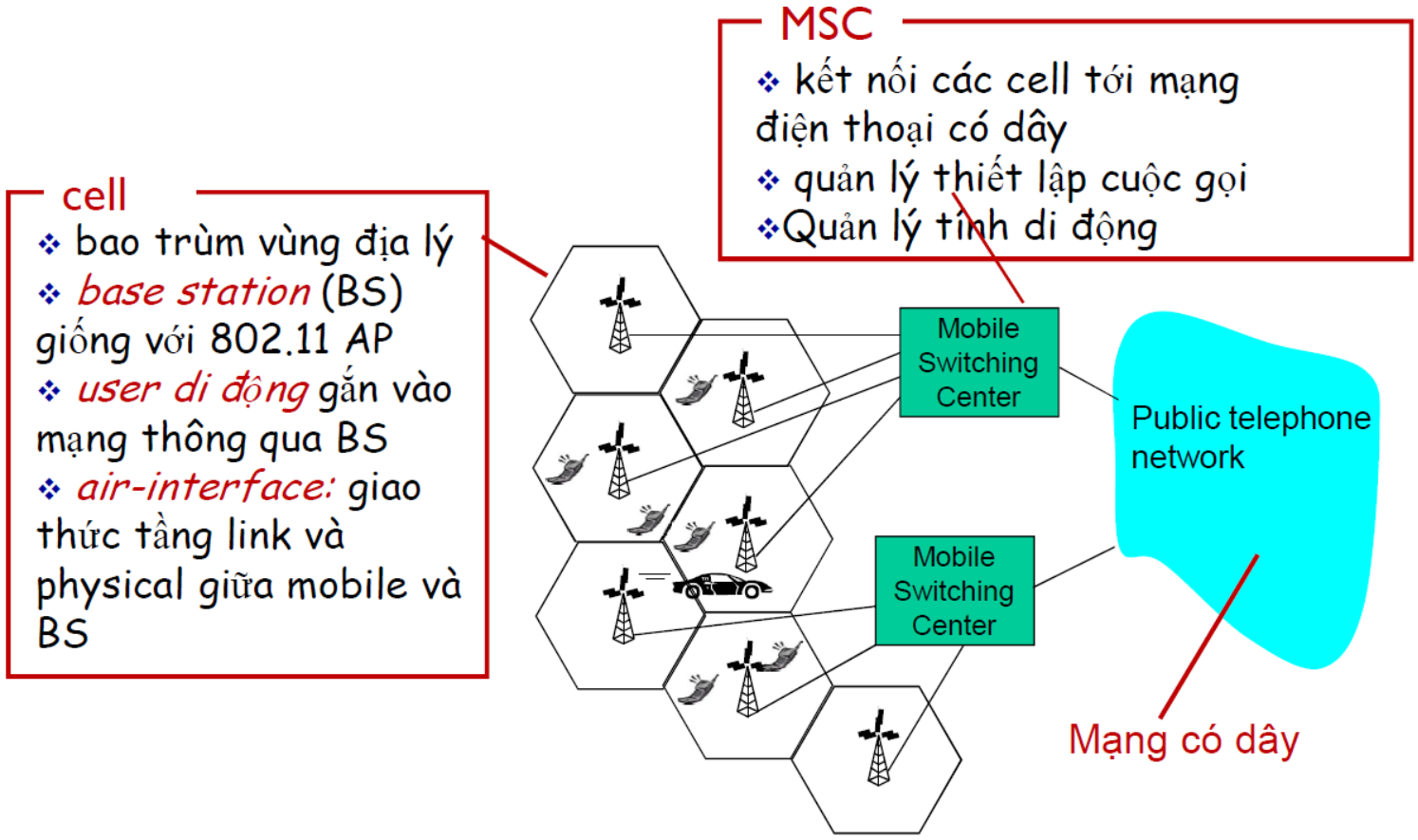
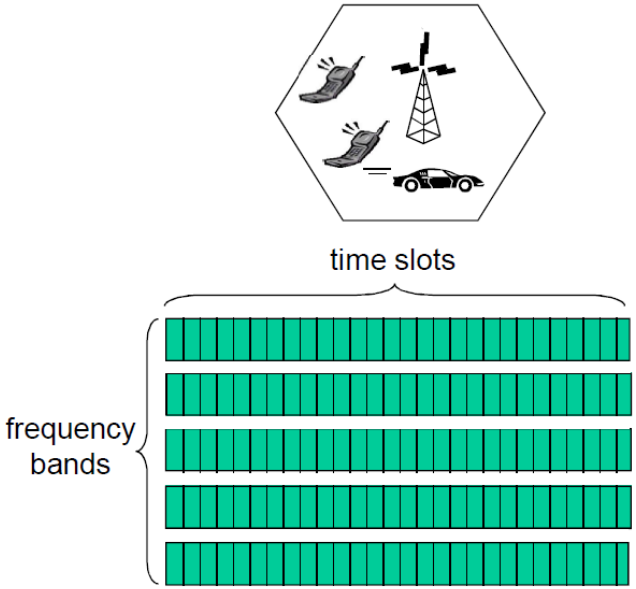
# Cellular Internet Access

- Các thành phần của kiến trúc mạng cellular



# Cellular Internet Access

- Mạng cellular: hop đầu tiên
  - 2 kỹ thuật để chia sẻ phổ sóng radio từ mobile-tới-BS
    - FDMA/TDMA kết hợp: chia phổ thành các kênh tần số, chia mỗi kênh thành các time slot
    - CDMA: code division multiple access




If the channel is partitioned into F sub-bands and time is partitioned into T slots, then the channel will be able to support F.T simultaneous calls

**GSM systems**

- 200-kHz frequency bands
- Each band supporting 8 TDM calls
- Encodes speech at 13 kbps and 12.2 kbps.

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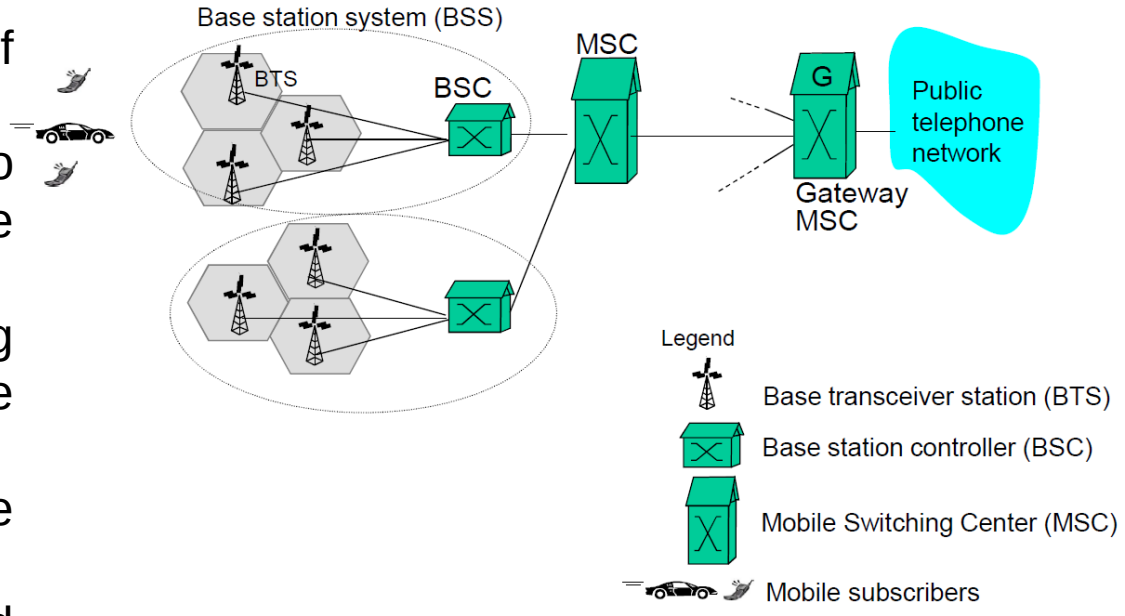
# Cellular Internet Access

- 2G (Voice) kiến trúc mạng

❖ GSM network's base station controller (**BSC**)
- Service several tens of base transceiver stations
- Allocate BTS radio channels to mobile subscribers
- Perform paging (finding the cell in which a mobile user is resident)
- Perform handoff of mobile users
- BSC and its controlled BTS collectively constitute a GSM BSS.



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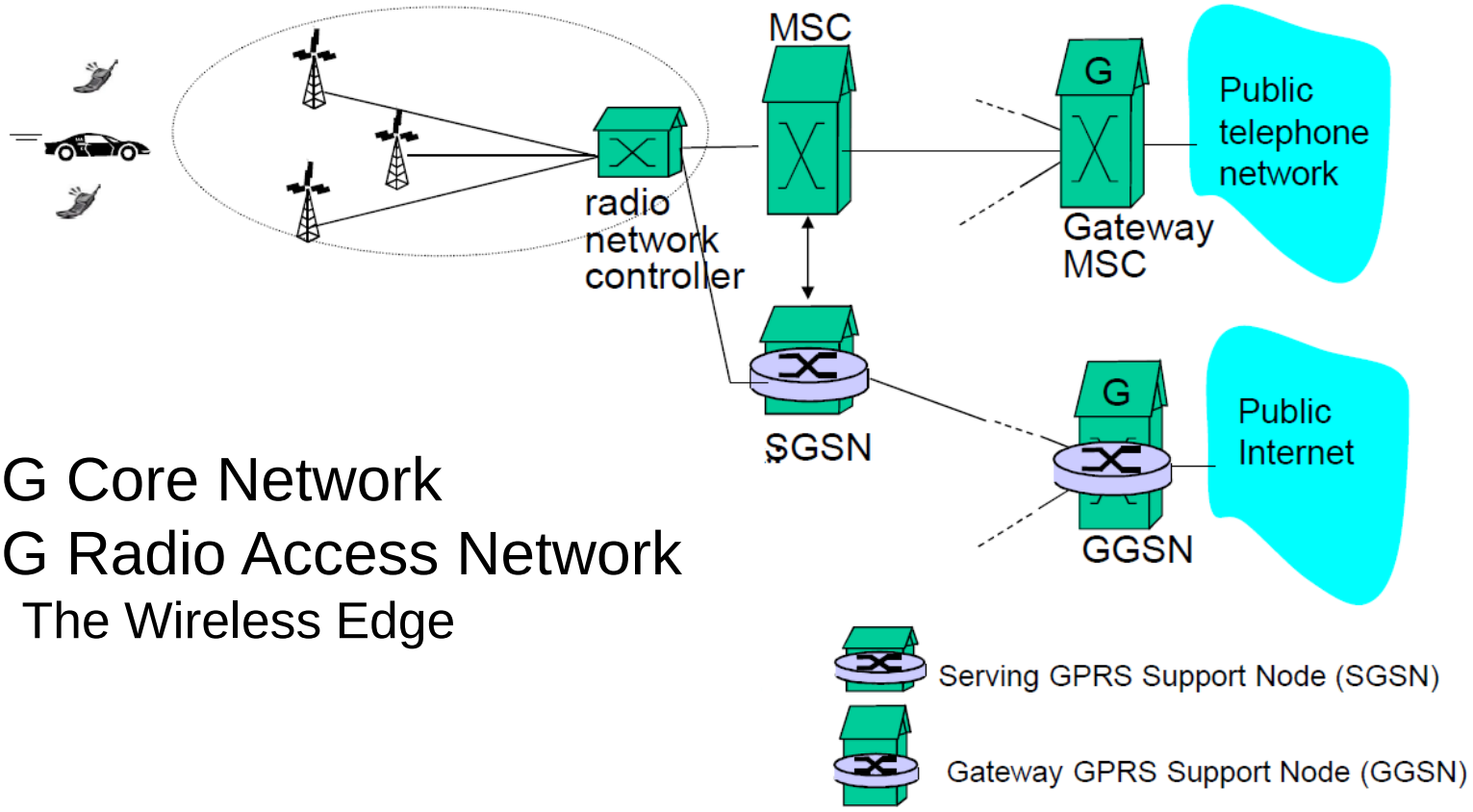
# Cellular Internet Access

- 3G (voice+data) kiến trúc mạng

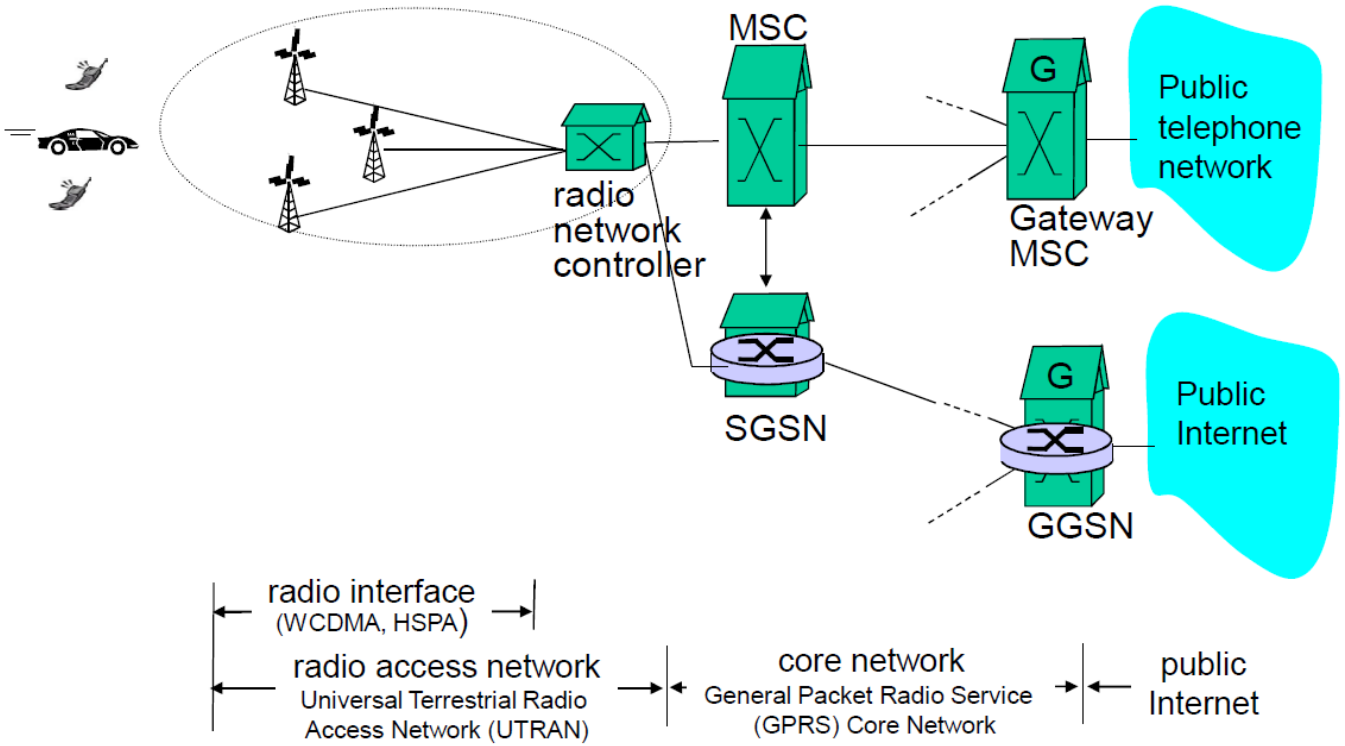



- 3G Core Network
- 3G Radio Access Network
  The Wireless Edge

# Cellular Internet Access

- 3G (voice+data) kiến trúc mạng
  - 3G Core Network
  - 3G Radio Access Network

    The Wireless Edge



# Cellular Internet Access

- 3G (voice+data) kiến trúc mạng
  - 3G Core Network
    - Connects radio access networks to the Internet
    - Interoperates with components of the existing cellular voice network (in particular, the MSC)
    - Leave the existing core GSM cellular voice network untouched, adding additional cellular data functionality in parallel to the existing cellular voice network.
    - There are 2 types of nodes in the 3G core network
      - Serving GPRS Support Nodes (SGSNs)
      - Gateway GPRS Support Nodes (GGSNs)

# Cellular Internet Access

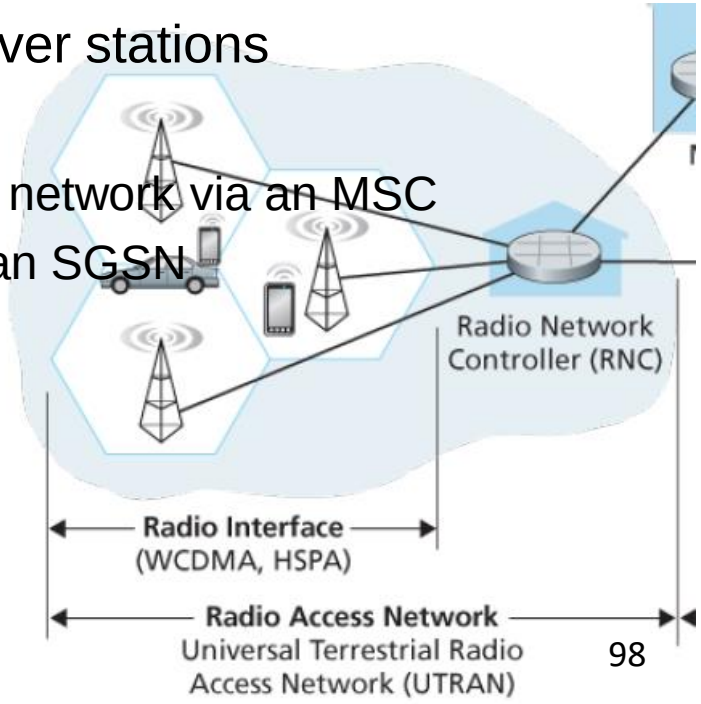
- 3G (voice+data) kiến trúc mạng
  - 3G Core Network
    - There are 2 types of nodes in the 3G core network
      - Serving GPRS Support Nodes (SGSNs)
        - » Responsible for delivering datagrams to/from the mobile nodes in the radio access network to which the SGSN is attached.
        - » Interacts with the cellular voice network's MSC for that area, providing user authorization and handoff, maintaining location (cell) information about active mobile nodes, and performing datagram forwarding between mobile nodes in the radio access network and a GGSN.

# Cellular Internet Access

- 3G (voice+data) kiến trúc mạng
  - 3G Core Network
    - There are 2 types of nodes in the 3G core network
      - Gateway GPRS Support Nodes (GGSNs)
        - » Acts as a gateway, connecting multiple SGSNs into the larger Internet.
        - » A GGSN is thus the last piece of 3G infrastructure that a datagram originating at a mobile node encounters before entering the larger Internet.
        - » To the outside world, the GGSN looks like any other gateway router; the mobility of the 3G nodes within the GGSN's network is hidden from the outside world behind the GGSN.

# Cellular Internet Access

- 3G (voice+data) kiến trúc mạng
  - 3G Radio Access Network: Wireless Edge
    - 3G radio access network
      - Wireless first-hop network that we see as a 3G user
    - Radio Network Controller (RNC)
      - Controls several cell base transceiver stations
      - Connects to both
        - » The circuit-switched cellular voice network via an MSC
        - » The packet-switched Internet via an SGSN




=> while 3G cellular voice and cellular data services use different core networks, they share a common first/last-hop radio access network.

# Cellular Internet Access

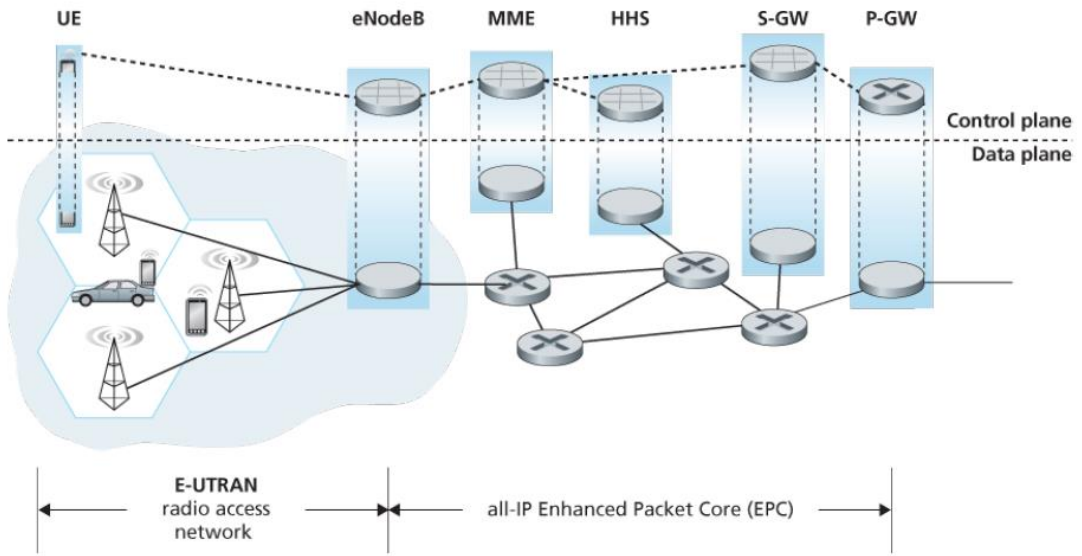
- Kiểm soát truy cập môi trường truyền
  - Uses a CDMA technique known as Direct Sequence Wideband CDMA (DS-WCDMA) within TDMA slots
    - The data service associated with the WCDMA specification is known as HSPA (High Speed Packet Access)

# Cellular Internet Access

1. Kiến trúc
2. Các chuẩn (GSM)
   - Cellular Network Architecture, 2G: Voice Connections to the Telephone Network
   - 3G Cellular Data Networks: Extending the Internet to Cellular Subscribers.
   - On to 4G: LTE

# Cellular Internet Access

- 4G System Architecture: An All-IP Core Network
  - A unified, all-IP network architecture
  - A clear separation of the 4G data plane and 4G control plane
  - A clear separation between the radio access network, and the all-IP-core network



# Cellular Internet Access

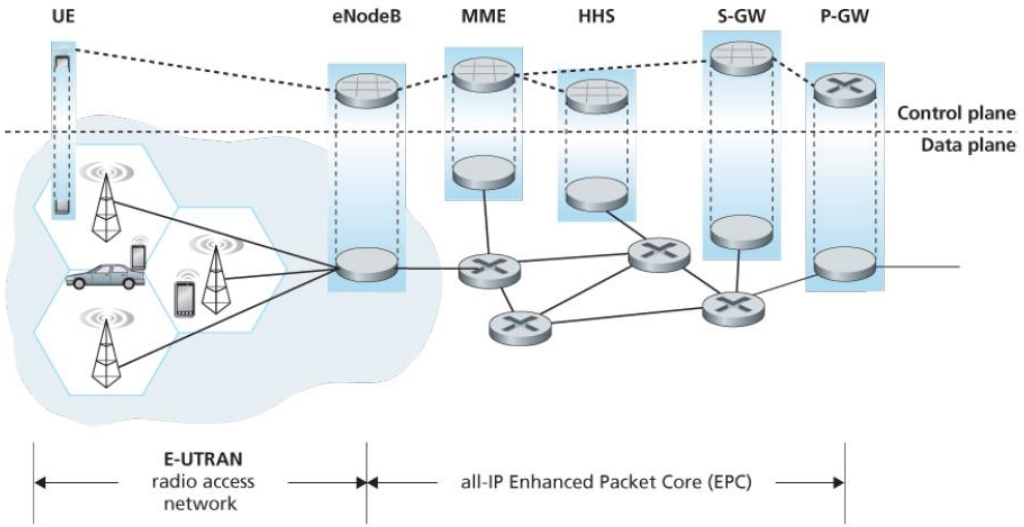
- 4G network architecture
  - A unified, all-IP network architecture
    - 3G network
      - Separate network components and paths for voice and data traffic
    - 4G network
      - Both voice and data are carried in IP datagrams to/from the wireless device to the gateway that connects the 4G edge network to the rest of the network.
      - Những dấu tích cuối cùng của mạng di động trong hệ thống điện thoại đã biến mất, nhường chỗ cho dịch vụ IP toàn cầu!

# Cellular Internet Access

- 4G network architecture
  - A clear separation of the 4G data plane and 4G control plane
    - Giống như ở tầng Mạng
  - A clear separation between the radio access network, and the all-IP-core network.
    - IP datagrams carrying user data are forwarded between the user (UE) and the gateway (P-GW) over a 4G-internal IP network to the external Internet.
    - Control packets are exchanged over this same internal network among the 4G's **control services components.**

# Cellular Internet Access

- Principal components of the 4G network
  - eNodeB
  - Packet Data Network Gateway (P-GW)
  - Serving Gateway (S-GW)
  - Mobility Management Entity (MME)
  - Home Subscriber



# Cellular Internet Access

- Principal components of the 4G network
  - eNodeB
    - "hậu duệ" của 2G base station and the 3G Radio Network Controller
      - Its data-plane role is to forward datagrams between UE (over the LTE radio access network) and the P-GW.
        - » UE datagrams are encapsulated at the eNodeB and tunneled to the P-GW through the 4G network's all-IP enhanced packet core (EPC).
      - In the control plane, the eNodeB handles registration and mobility signaling traffic on behalf of the UE.

# Cellular Internet Access

- Principal components of the 4G network
  - Packet Data Network Gateway (P-GW)
    - Allocates IP addresses to the UEs and performs QoS enforcement.
    - As a tunnel endpoint it also performs datagram encapsulation/decapsulation when forwarding a datagram to/from a UE.

# Cellular Internet Access

- Principal components of the 4G network
  - Serving Gateway (S-GW)
    - The data-plane mobility anchor point—all UE traffic will pass through the S-GW.
    - Also performs charging/billing functions and lawful traffic interception.
  - Mobility Management Entity (MME)
    - Performs connection and mobility management on behalf of the UEs resident in the cell it controls.
    - Receives UE subscription information from the HHS.

# Cellular Internet Access

- Principal components of the 4G network
  - Home Subscriber Server (HSS)
    - Contains UE information:
      - Roaming access capabilities
      - Quality of service profiles
      - Authentication information

# Cellular Internet Access

- LTE Radio Access Network
  - Uses a combination of FDM and TDM on the downstream channel, known as orthogonal frequency division multiplexing (OFDM).
  - In LTE, each active mobile node is allocated one or more 0.5 ms time slots in one or more of the channel frequencies
    - By being allocated increasingly more time slots, a mobile node is able to achieve increasingly higher transmission rates
    - Slot (re)allocation among mobile nodes can be performed as often as once every millisecond
    - Different modulation schemes can also be used to change the transmission rate

# Cellular Internet Access

- LTE Radio Access Network
  - The particular allocation of time slots to mobile nodes is not mandated by the LTE standard.
  - the decision of which mobile nodes will be allowed to transmit in a given time slot on a given frequency is determined by the scheduling algorithms provided by the LTE equipment vendor and/or the network operator

# Cellular Internet Access

- LTE Radio Access Network
  - With opportunistic scheduling, matching the physical-layer protocol to the channel conditions between the sender and receiver and choosing the receivers to which packets will be sent based on channel conditions allow the radio network controller to make best use of the wireless medium
  - User priorities and contracted levels of service (e.g.,silver, gold, or platinum) can be used in scheduling downstream packet transmissions

# Cellular Internet Access

- LTE Radio Access Network
  - LTE-Advanced allows for downstream bandwidths of hundreds of Mbps by allocating aggregated channels to a mobile node
  - An additional 4G wireless technology—WiMAX (World Interoperability for Microwave Access)—is a family of IEEE 802.16 standards that differ significantly from LTE.
    - WiMAX has not yet been able to enjoy the widespread deployment of LTE.

# Nội dung chương

- Giới thiệu
- Wireless Links and Network Characteristics
- WiFi: 802.11 Wireless LANs
- Cellular Internet Access
- Mobility Management: Principles
- Mobile IP
- Managing Mobility in Cellular Networks
- Wireless and Mobility: Impact on Higher-Layer Protocols

## Mobility Management: Principles

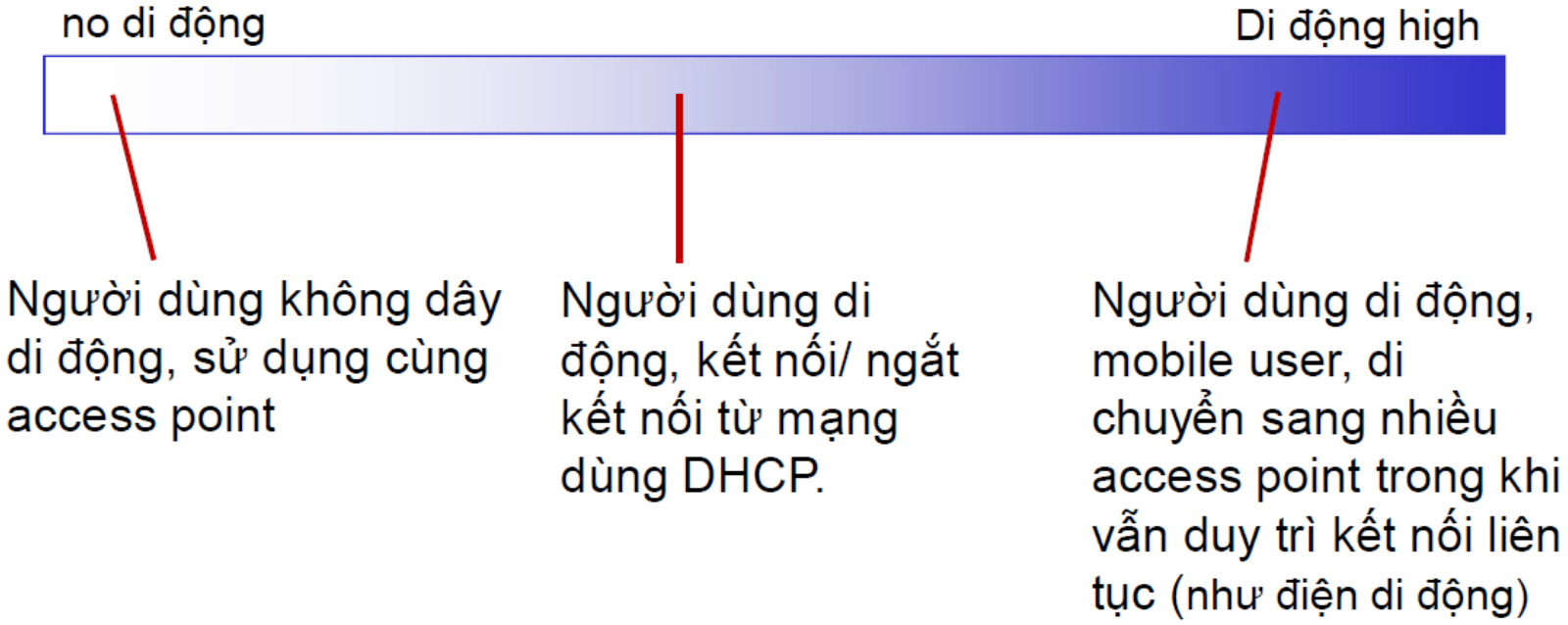
1. Mobility
2. Addressing
3. Routing to a Mobile Node

## Mobility Management: Principles

1. Mobility
2. Addressing
3. Routing to a Mobile Node

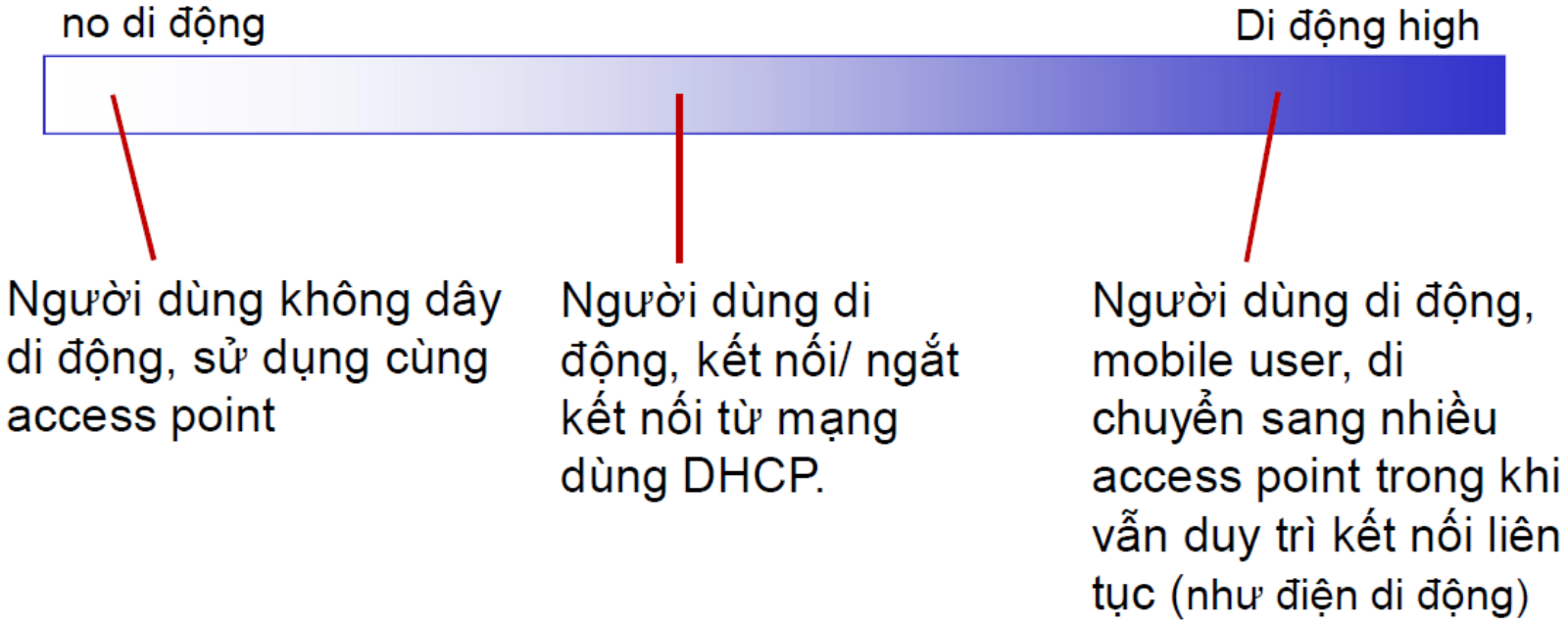
# Mobility Management: Principles

- Di động là gì
  - Quang phổ của tính di động, từ quan điểm mạng



# Mobility Management: Principles

- Di động là gì
  - Quang phổ của tính di động, từ quan điểm mạng



# Mobility Management: Principles

- How important is it for the mobile node's address to always remain the same?
  - With mobile telephony, your phone number—essentially the network-layer address of your phone—remains the same as you travel from one provider's mobile phone network to another.
  - Must a laptop similarly maintain the same IP address while moving between IP networks?
    - The answer will depend strongly on the applications being run

# Mobility Management: Principles

- How important is it for the mobile node's address to always remain the same?
  - Must a laptop similarly maintain the same IP address while moving between IP networks?
    - An Internet application needs to know the IP address and port number of the remote entity with which it is communicating.
    - If a mobile entity is able to maintain its IP address as it moves, mobility becomes invisible from the application standpoint.

# Mobility Management: Principles

- How important is it for the mobile node's address to always remain the same?
  - Must a laptop similarly maintain the same IP address while moving between IP networks?
    - There is great value to this transparency-an application need not be concerned with a potentially changing IP address, and the same application code serves mobile and nonmobile connections alike.

# Mobility Management: Principles

- How important is it for the mobile node's address to always remain the same?
  - Must a laptop similarly maintain the same IP address while moving between IP networks?
    - On the other hand, a less glamorous mobile user might simply want to turn off an office laptop, bring that laptop home, power up, and work from home.
    - If the laptop functions primarily as a client in client-server applications (e.g., send/read e-mail, browse the Web, Telnet to a remote host) from home, the particular IP address used by the laptop is not that important.

# Mobility Management: Principles

- How important is it for the mobile node's address to always remain the same?
  - Must a laptop similarly maintain the same IP address while moving between IP networks?
    - In particular, one could get by fine with an address that is temporarily allocated to the laptop by the ISP serving the home. DHCP already provides this functionality.

# Mobility Management: Principles

- What supporting wired infrastructure is available?
  - A fixed infrastructure to which the mobile user can connect
    - The home's ISP network
    - The wireless access network in the office
    - The wireless access networks lining the autobahn
  - if no such infrastructure exists? 2 users are within communication proximity of each other, can they establish a network connection in the absence of any other network-layer infrastructure?
    - **Ad hoc networking** provides precisely these capabilities.

## Mobility Management: Principles

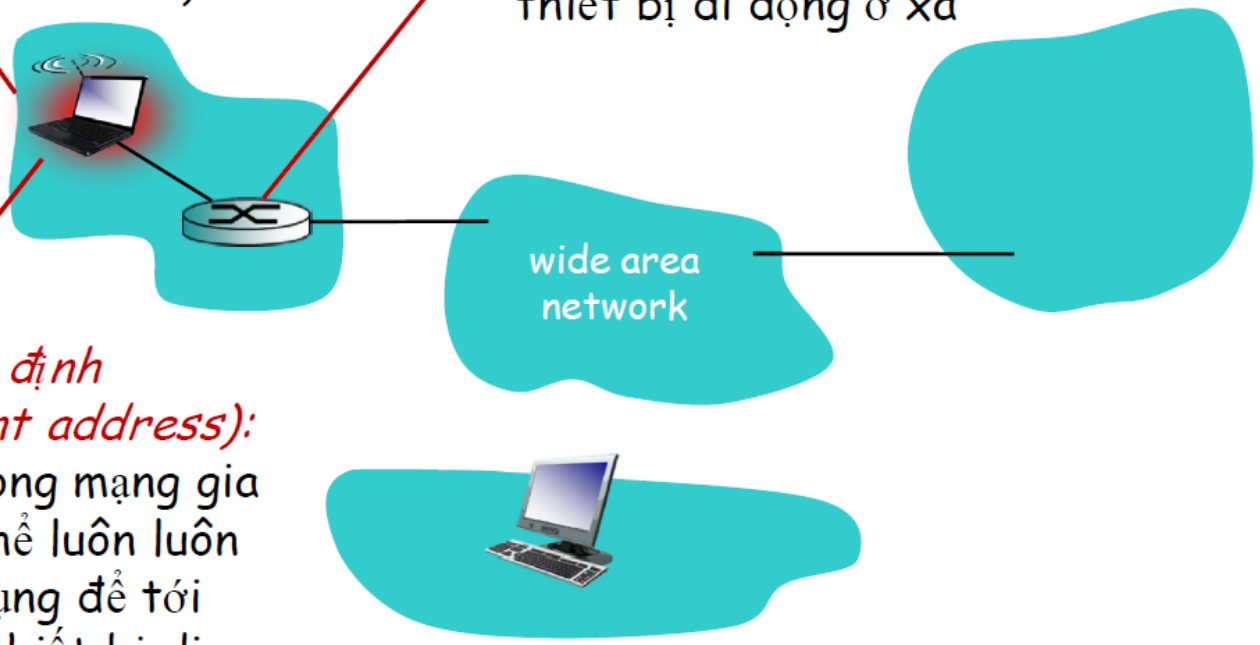
1. Mobility
2. Addressing
3. Routing to a Mobile Node

# Mobility Management: Principles

- Một số khái niệm

*Mạng gia đình:* "gia đình" bền vững của các thiết bị di động (e.g., 128.119.40/24)

*home agent:* thực thể sẽ thực hiện các chức năng di động với tư cách của thiết bị di động, khi thiết bị di động ở xa

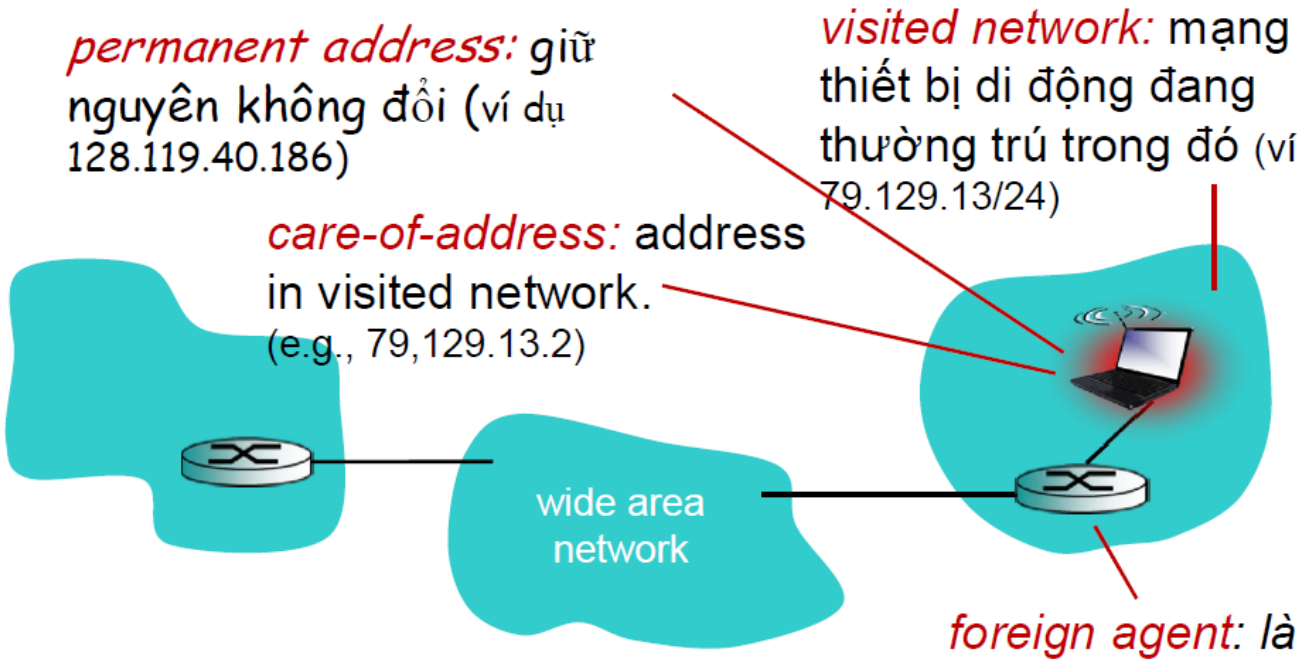



*Địa chỉ cố định (permanent address):* địa chỉ trong mạng gia đình, có thể luôn luôn được sử dụng để tới được các thiết bị di động

Ví dụ 128.119.40.186

# Mobility Management: Principles

- Một số khái niệm



# Mobility Management: Principles

- Làm cách nào liên lạc với một người bạn dùng thiết bị di động
  - Khảo sát trường hợp người bạn thường xuyên thay đổi địa chỉ, làm cách nào để tìm được cô ta?
    - Tìm tất cả danh bạ điện thoại?
    - Gọi cho cha mẹ cô ta?
    - Mong chờ cô ta sẽ cho bạn biết là cô ta đang ở đâu?

# Mobility Management: Principles

- Tính di động: cách tiếp cận
  - Để routing quản lý nó: router quảng cáo địa chỉ cố định của các node di động (mobile-nodes-in-residence ) thông qua việc trao đổi bảng định tuyến.
    - Các bảng định tuyến này chỉ ra từng thiết bị di động đang ở đâu
    - Không thay đổi gì ở các hệ thống đầu cuối

# Mobility Management: Principles

- Tính di động: cách tiếp cận
  - Để cho các hệ thống đầu cuối quản lý:
    - Định tuyến không trực tiếp (indirect routing): truyền thông từ correspondent tới thiết bị di động thông qua home agent, sau được chuyển tiếp đến thiết bị ở xa
    - Định tuyến trực tiếp: correspondent lấy địa chỉ ngoài của thiết bị di động (foreign address), gửi trực tiếp đến thiết bị di động

# Mobility Management: Principles

- Tính di động: cách tiếp cận
  - Để routing quản lý nó: router quảng cáo địa chỉ cố định của các node di động (mobile-nodes-in-residence ) thông qua việc trao đổi bảng định tuyến.
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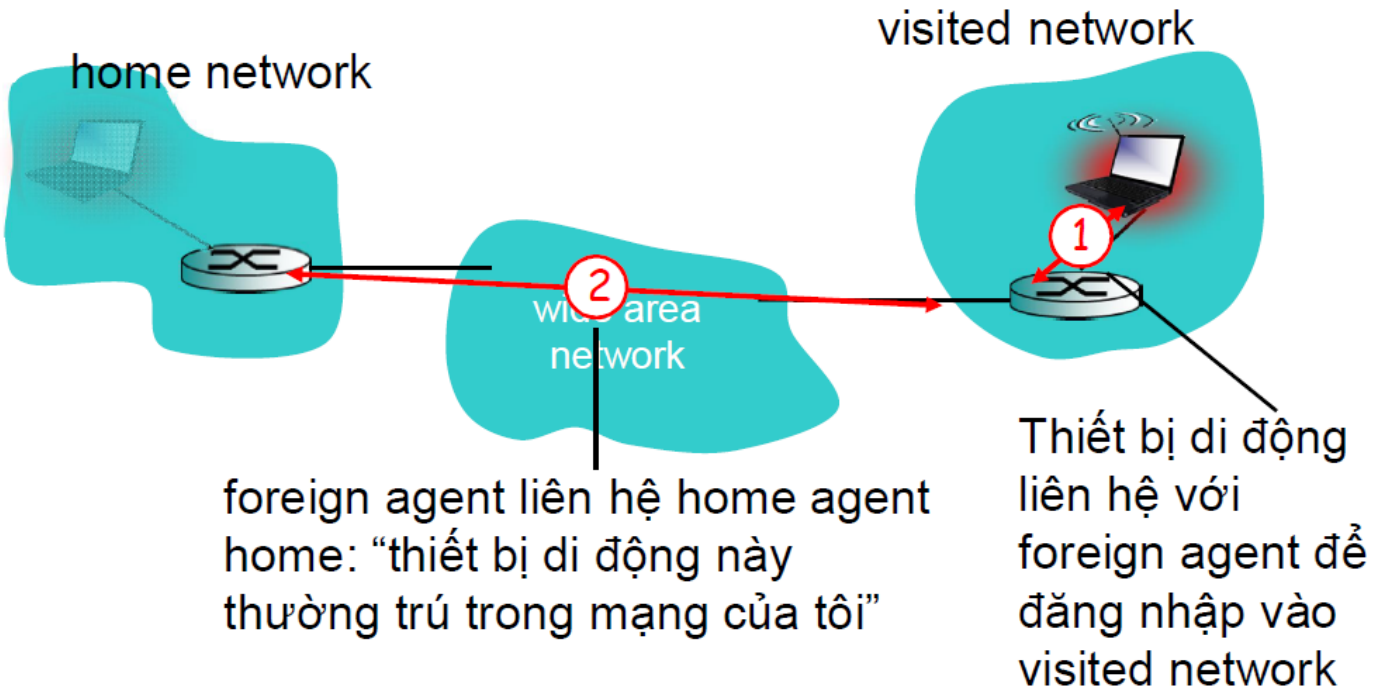
    - Không thay đổi gì ở các hệ thống đầu cuối

# Mobility Management: Principles

- Tính di động: đăng ký (registration)
  - Kết quả cuối cùng:
    - foreign agent biết về thiết bị di động này
    - home agent biết vị trí của thiết bị di động



# Mobility Management: Principles

- Addressing
  - In order for user mobility to be transparent to network applications, it is desirable for a mobile node to keep its address as it moves from one network to another.
  - When a mobile node is resident in a foreign network, all traffic addressed to the node's permanent address now needs to be routed to the foreign network. **How can this be done?**

# Mobility Management: Principles

- Addressing
  - **How can this be done?**
    - One option is for the foreign network to advertise to all other networks that the mobile node is resident in its network
      - This could be via the usual exchange of intradomain and interdomain routing information and would require few changes to the existing routing infrastructure
        - » The foreign network could simply advertise to its neighbors that it has a highly specific route to the mobile node's permanent address.
        - » These neighbors would then propagate this routing information throughout the network as part of the normal procedure of updating routing information and forwarding tables

# Mobility Management: Principles

- Addressing
  - **How can this be done?**
    - One option is for the foreign network to advertise to all other networks that the mobile node is resident in its network
      - When the mobile node leaves one foreign network and joins another, the new foreign network would advertise a new, highly specific route to the mobile node, and the old foreign network would withdraw its routing information regarding the mobile node.

# Mobility Management: Principles

- Addressing
  - **How can this be done?**
    - One option is for the foreign network to advertise to all other networks that the mobile node is resident in its network

      ⇒ This solves 2 problems at once, and it does so without making significant changes to the networklayer infrastructure.

      – Other networks know the location of the mobile node, and it is easy to route datagrams to the mobile node, since the forwarding tables will direct datagrams to the foreign network.

      => A significant drawback, however, is that of scalability

# Mobility Management: Principles

- Addressing
  - **How can this be done?**
    - Other approach (adopted in practice) is push mobility functionality from the network core to the network edge.
      - A natural way to do this is via the mobile node's home network.
      - The home agent in the mobile node's home network can track the foreign network in which the mobile node resides.
      - A protocol between the mobile node (or a foreign agent representing the mobile node) and the home agent will certainly be needed to update the mobile node's location.

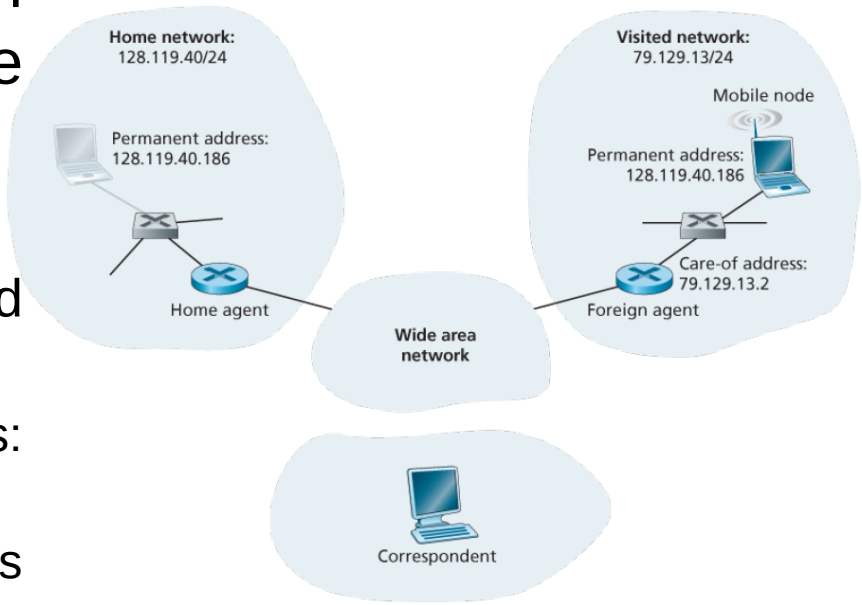
# Mobility Management: Principles

- Addressing
  - **How can this be done?**
    - Other approach (adopted in practice) is push mobility functionality from the network core to the **network edge**.
      - Foreign agent
        - » Locate foreign agents at the edge routers in the foreign network.
        - » 2 vai trò của foreign agent
          - Create a so-called care-of address (COA) for the mobile node, with the network portion of the COA matching that of the foreign network.
          - Inform the home agent that the mobile node is resident in its (the foreign agent's) network and has the given COA.

# Mobility Management: Principles

- Addressing
  - **How can this be done?**
    - Other approach (adopted in practice) is push mobility functionality from the network core to the **network edge**.
      - Foreign agent

      => 2 addresses associated with a mobile node
        - » its permanent address: **128.119.40.186**
        - » Its COA (sometimes known as a foreign address): **79.129.13.2**

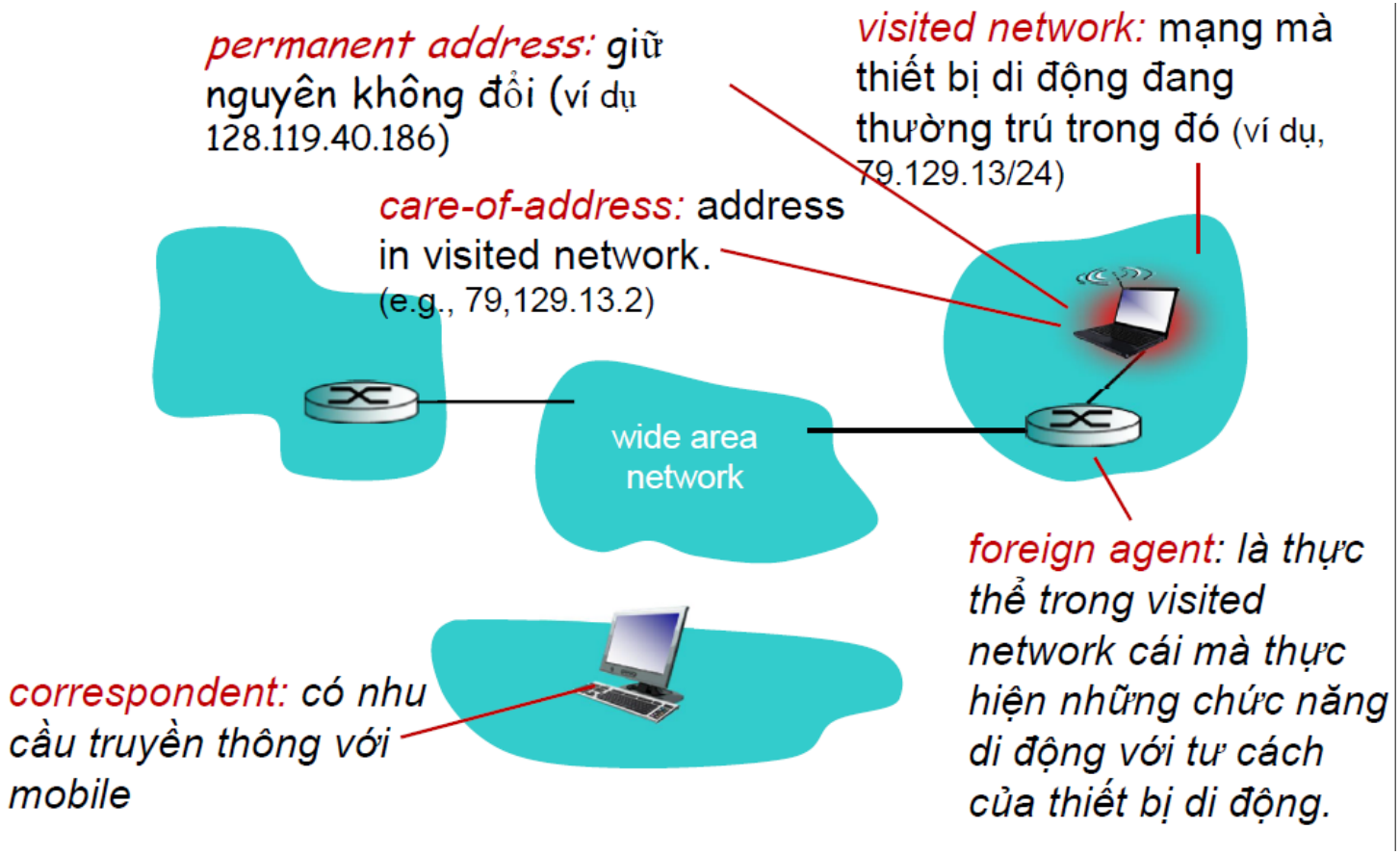


## Mobility Management: Principles

1. Mobility
2. Addressing
3. Routing to a Mobile Node

# Mobility Management: Principles

- Indirect Routing to a Mobile Node
- Direct Routing to a Mobile Node

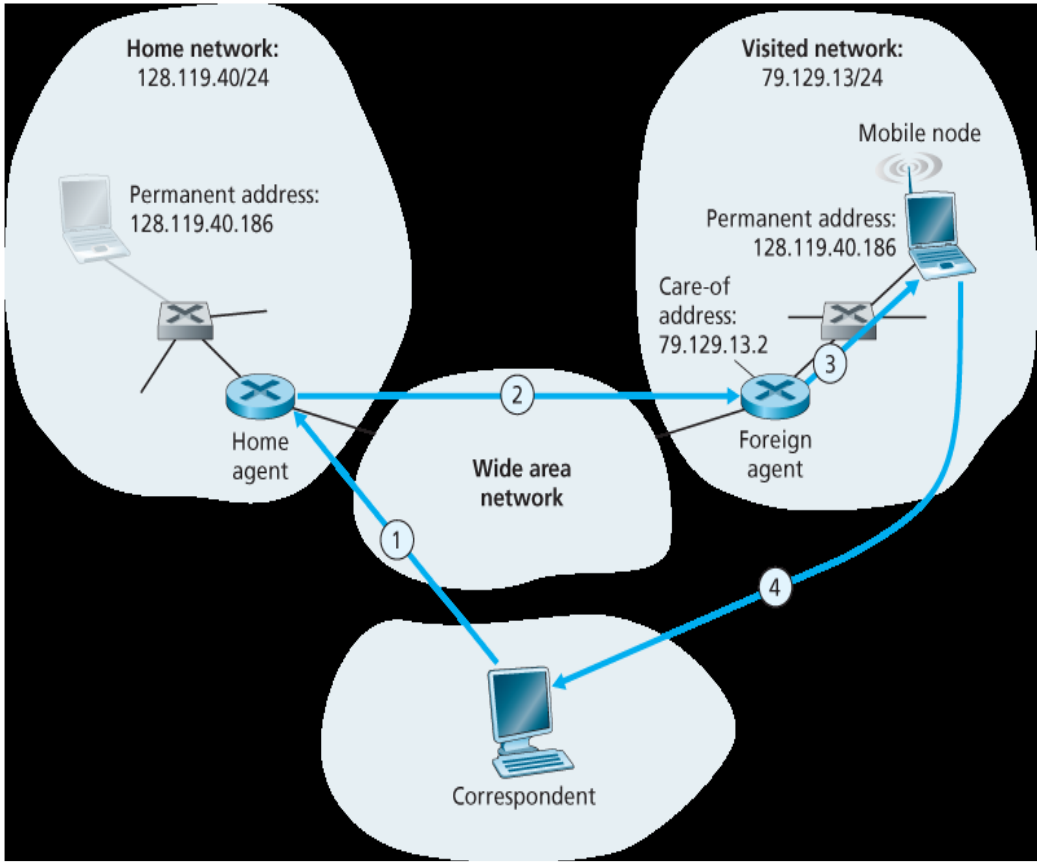


# Mobility Management: Principles

- Indirect Routing to a Mobile Node

Step 1:

- Correspondent gán permanent address của node di động vào gói tin và gửi gói tin lên mạng (không để ý node di động có còn trong home network hay ở một foreign network) => mobility is completely transparent to the correspondent.

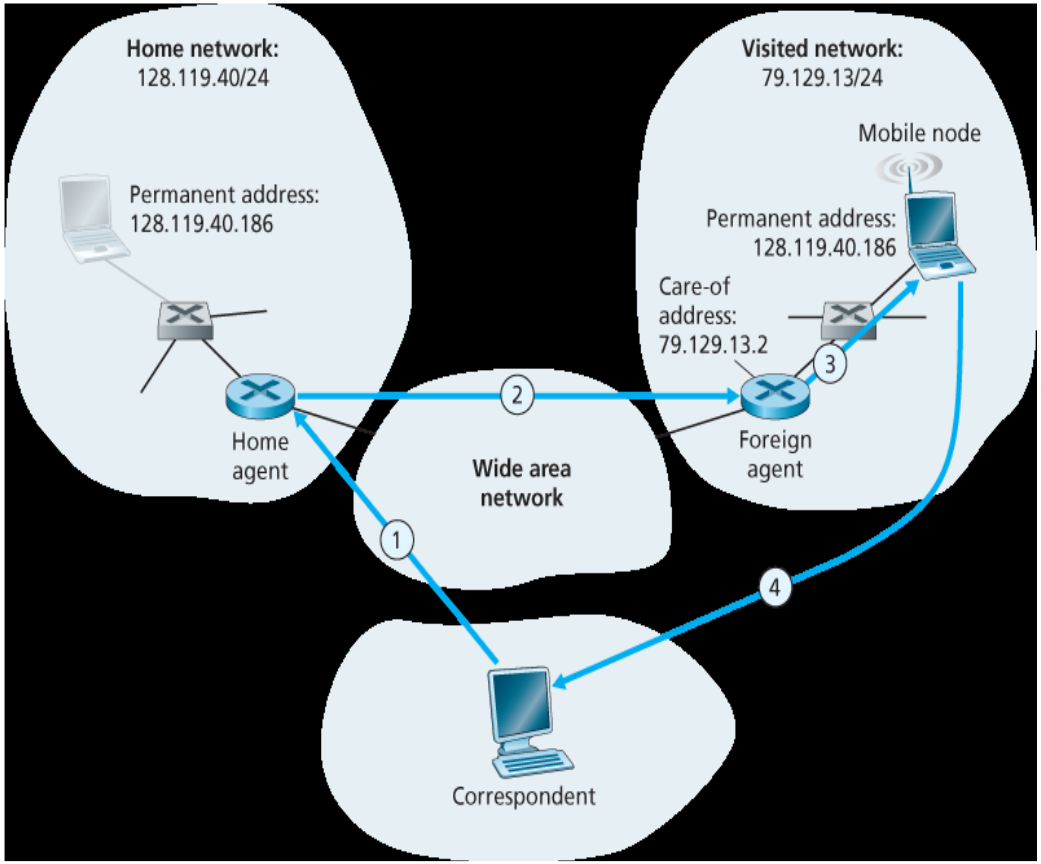


# Mobility Management: Principles

- Indirect Routing to a Mobile Node

Step 2:

- Home agent
  - Tương tác với foreign agent để theo vết COA của node di động
  - Tìm các datagram đến các node trong home network chứa trong home agent nhưng hiện đang ở một foreign network.
  - Chặn các datagram này và chuyển tiếp chúng tới một mobile node.

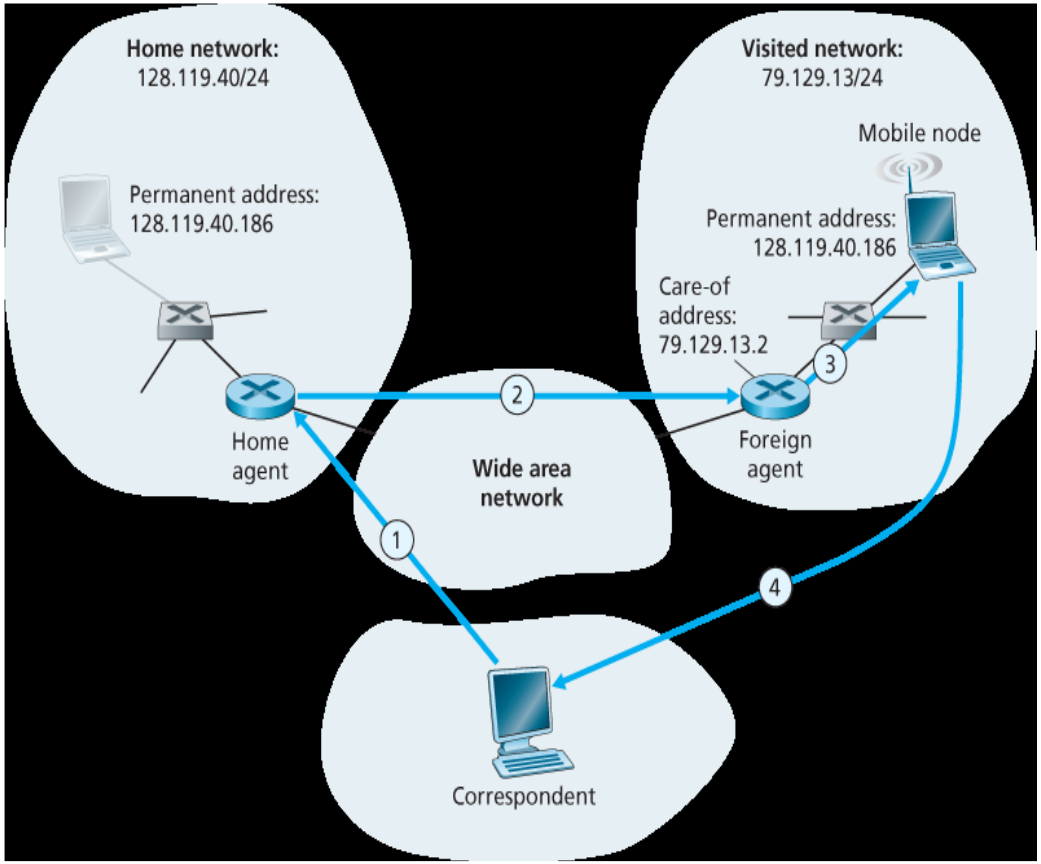


# Mobility Management: Principles

- Indirect Routing to a Mobile Node

Step 3:

- Home agent
  - The datagram is then forwarded from the foreign agent to the mobile node

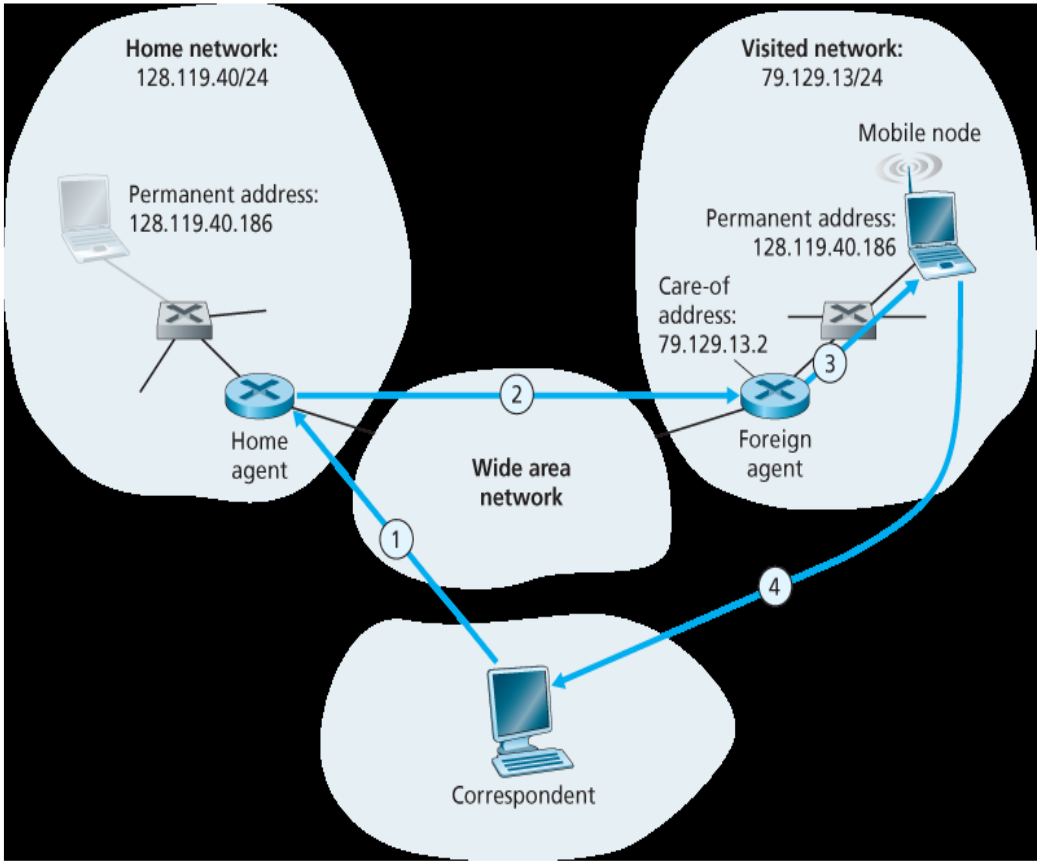


# Mobility Management: Principles

- Indirect Routing to a Mobile Node

Step 4:

- A mobile node sends datagrams to a correspondent using its own permanent address as the source address, and the correspondent's address as the destination address.
- Since the mobile node knows the correspondent's
- address, there is no need to route the datagram back through the home agent



# Mobility Management: Principles

- Indirect Routing to a Mobile Node
  - New network-layer functionality required to support mobility
    - A mobile-node–to–foreign-agent protocol
      - The mobile node will register with the foreign agent when attaching to the foreign network.
      - Similarly, a mobile node will deregister with the foreign agent when it leaves the foreign network.

# Mobility Management: Principles

- Indirect Routing to a Mobile Node
  - New network-layer functionality required to support mobility
    - A foreign-agent–to–home-agent registration protocol
      - The foreign agent will register the mobile node's COA with the home agent.
      - A foreign agent need not explicitly deregister a COA when a mobile node leaves its network, because the subsequent registration of a new COA, when the mobile node moves to a new network, will take care of this.

# Mobility Management: Principles

- Indirect Routing to a Mobile Node
  - New network-layer functionality required to support mobility
    - A home-agent datagram encapsulation protocol
      - Encapsulation and forwarding of the correspondent's original datagram within a datagram addressed to the COA.

# Mobility Management: Principles

- Indirect Routing to a Mobile Node
  - New network-layer functionality required to support mobility
    - A home-agent datagram encapsulation protocol
      - Encapsulation and forwarding of the correspondent's original datagram within a datagram addressed to the COA.
    - A foreign-agent decapsulation protocol
      - Extraction of the correspondent's original datagram from the encapsulating datagram, and the forwarding of the original datagram to the mobile node.
  - Indirect routing approach is used in the mobile IP standard [RFC 5944]

# Mobility Management: Principles

- Direct Routing to a Mobile Node
  - **Triangle routing** problem of indirect routing approach
    - Datagrams addressed to the mobile node must be routed first to the home agent and then to the foreign network, even when a much more efficient route exists between the correspondent and the mobile node.
    - In the worst case, imagine a mobile user who is visiting the foreign network of a colleague. The two are sitting side by side and exchanging data over the network.

# Mobility Management: Principles

- Direct Routing to a Mobile Node
  - **Triangle routing** problem of indirect routing approach
    - Datagrams from the correspondent (in this case the colleague of the visitor) are routed to the mobile user's home agent and then back again to the foreign network!

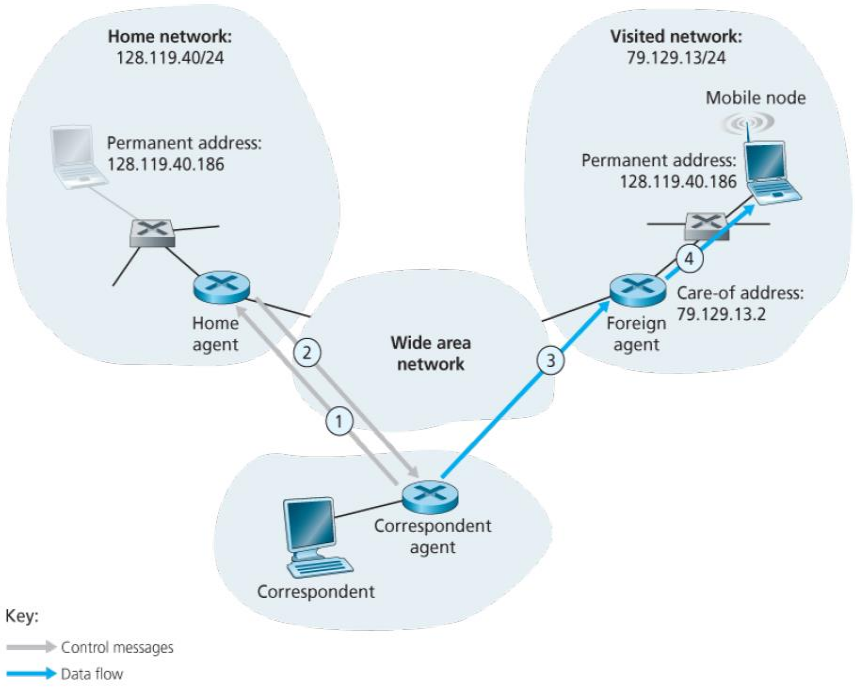
=> Direct routing overcomes the inefficiency of triangle routing, but does so at the cost of additional complexity.

# Mobility Management: Principles

- Direct Routing to a Mobile Node

Step 1, 2

- A correspondent agent in the correspondent's network first learns the COA of the mobile node
  - Correspondent agent query the home agent, assuming that (as in the case of indirect routing) the mobile node has an up-to-date value for its COA registered with its home agent
  - Correspondent itself to perform the function of the correspondent agent, just as a mobile node could perform the function of the foreign agent.

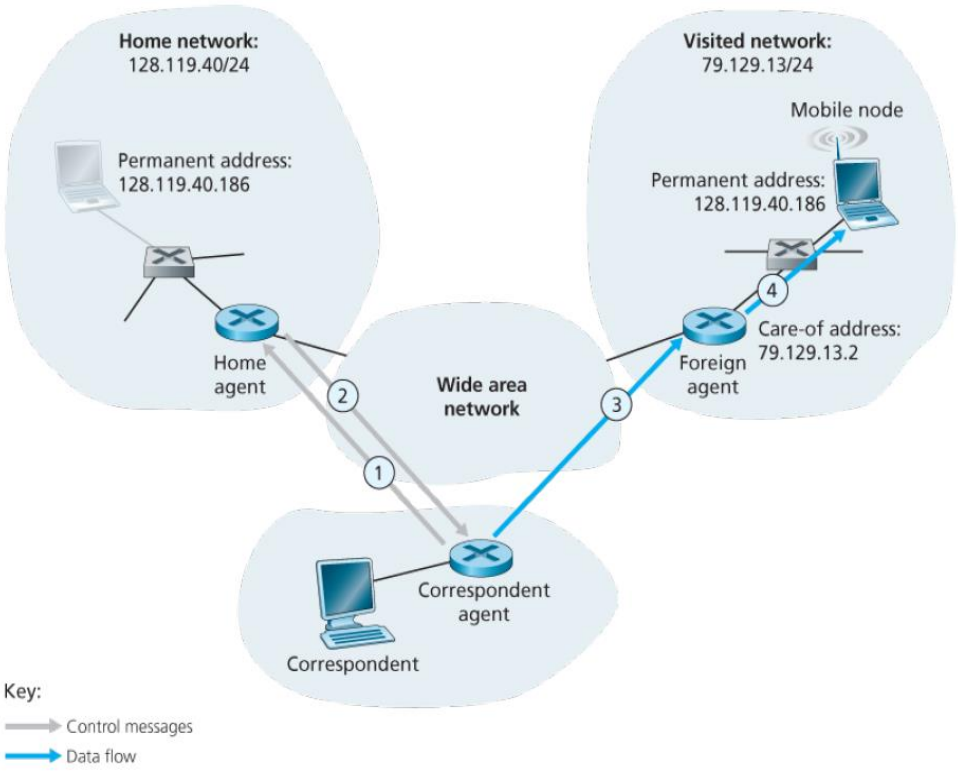


# Mobility Management: Principles

- Direct Routing to a Mobile Node

Step 3, 4

- The correspondent agent then tunnels datagrams directly to the mobile node's COA, in a manner analogous to the tunneling performed by the home agent



# Mobility Management: Principles

- Direct Routing to a Mobile Node
  - 2 important additional challenges
    - A mobile-user location protocol is needed for the correspondent agent to query the home agent to obtain the mobile node's COA (steps 1 and 2)
    - When the mobile node moves from one foreign network to another, how will data now be forwarded to the new foreign network?
      - Indirect routing: this easily solved by updating the COA maintained by the home agent.
      - Direct routing: home agent is queried for the COA by the correspondent agent only once, at the beginning of the session. Thus, updating the COA at the home agent, while necessary, will not be enough to solve the problem of routing data to the mobile node's new foreign network.

# Mobility Management: Principles

- Direct Routing to a Mobile Node
  - 2 important additional challenges
    - A mobile-user location protocol is needed for the correspondent agent to query the home agent to obtain the mobile node's COA (steps 1 and 2)

# Mobility Management: Principles

- Direct Routing to a Mobile Node
  - 2 important additional challenges
    - When the mobile node moves from one foreign network to another, how will data now be forwarded to the new foreign network?
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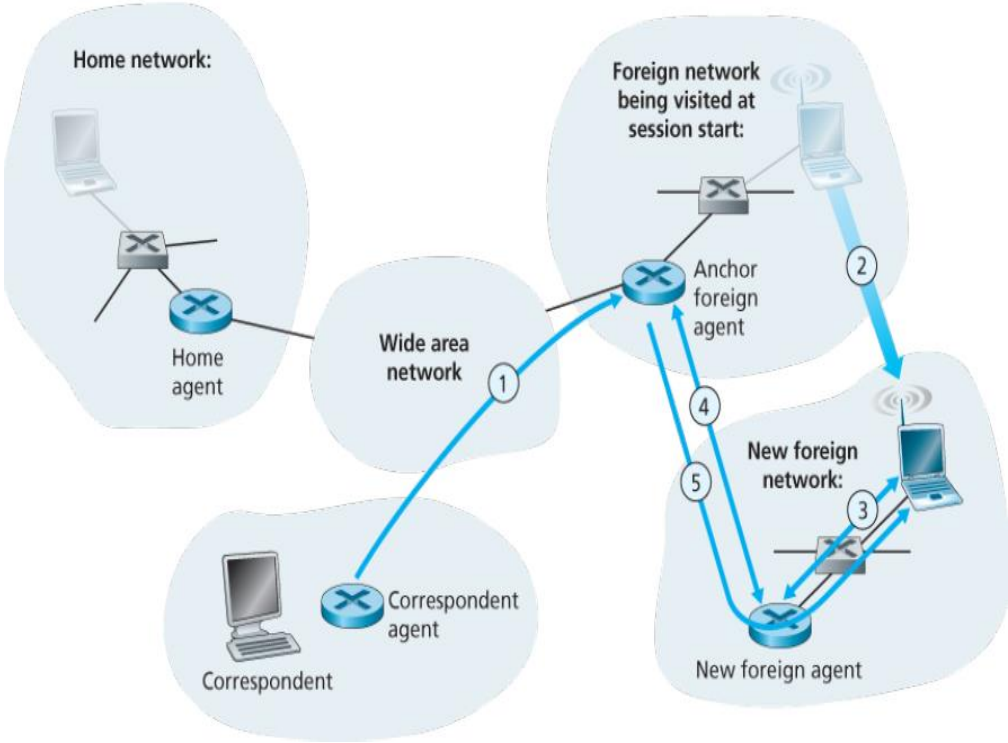
# Mobility Management: Principles

- Mobile transfer between networks with direct routing

Step 1

- Suppose data is currently being forwarded to the mobile node in the foreign network where the mobile node was located when the session first started.
- We'll identify the foreign agent in that foreign network where the mobile node was first found as the anchor foreign agent

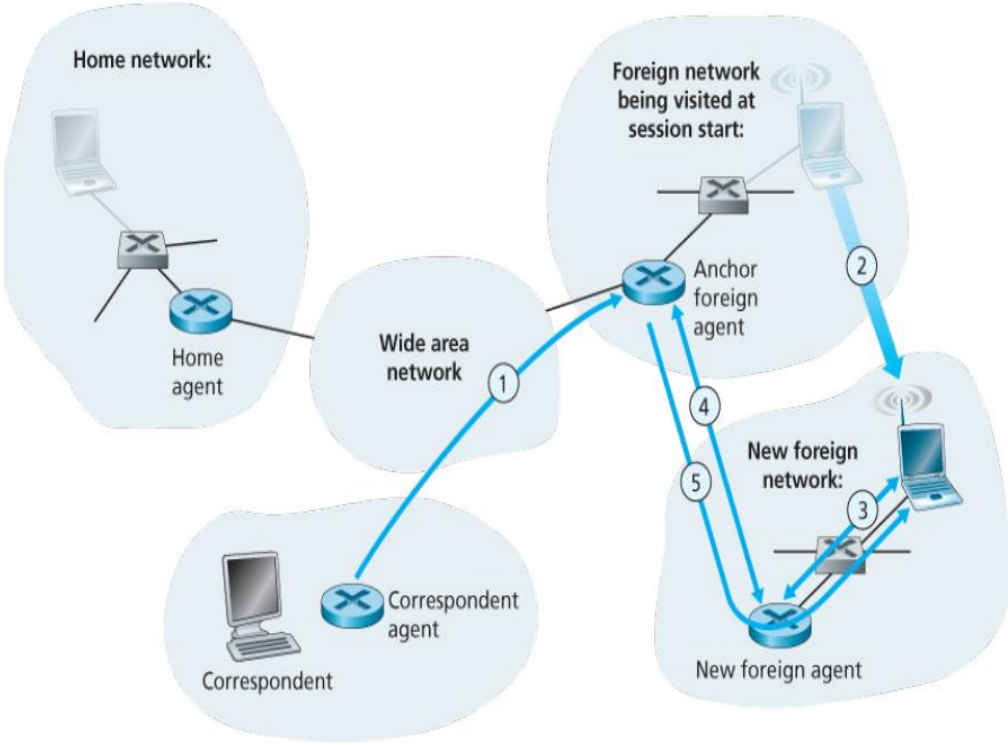


# Mobility Management: Principles

- Mobile transfer between networks with direct routing

Step 2, 3, 4

- When the mobile node moves to a new foreign network (Step 2).
- The mobile node registers with the new foreign agent (step 3).
- The new foreign agent provides the anchor foreign agent with the mobile node's new COA (step 4)

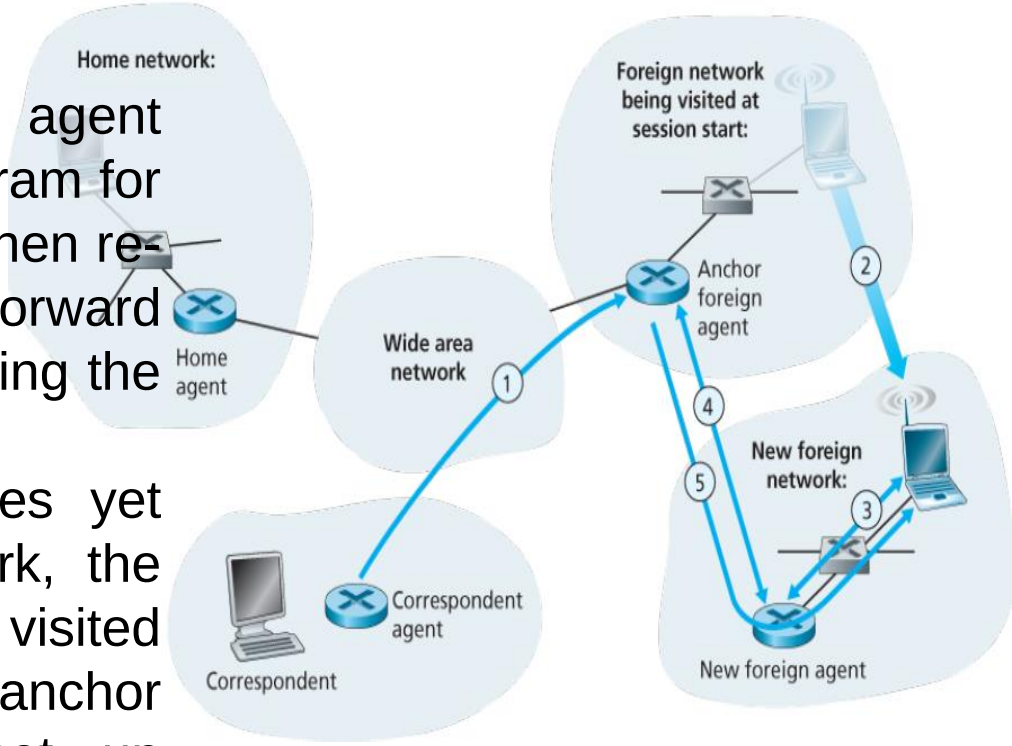


# Mobility Management: Principles

- Mobile transfer between networks with direct routing

Step 5

- When the anchor foreign agent receives an encapsulated datagram for a departed mobile node, it can then re-encapsulate the datagram and forward it to the mobile node (step 5) using the new COA.
- If the mobile node later moves yet again to a new foreign network, the foreign agent in that new visited network would then contact the anchor foreign agent in order to set up forwarding to this new foreign network.



# Nội dung chương

- Giới thiệu
- Wireless Links and Network Characteristics
- WiFi: 802.11 Wireless LANs
- Cellular Internet Access
- Mobility Management: Principles
- Mobile IP
- Managing Mobility in Cellular Networks
- Wireless and Mobility: Impact on Higher-Layer Protocols

# Mobile IP

- Mobile IP
  - The Internet architecture and protocols for supporting mobility, are defined primarily in RFC 5944 for IPv4.
- 3 thành phần cần chuẩn hóa
  - Phát hiện agent (Agent discovery)
  - Đăng ký với home agent (Registration with the home agent)
  - Định tuyến gián tiếp các datagrams (Indirect routing of datagrams)

# Mobile IP

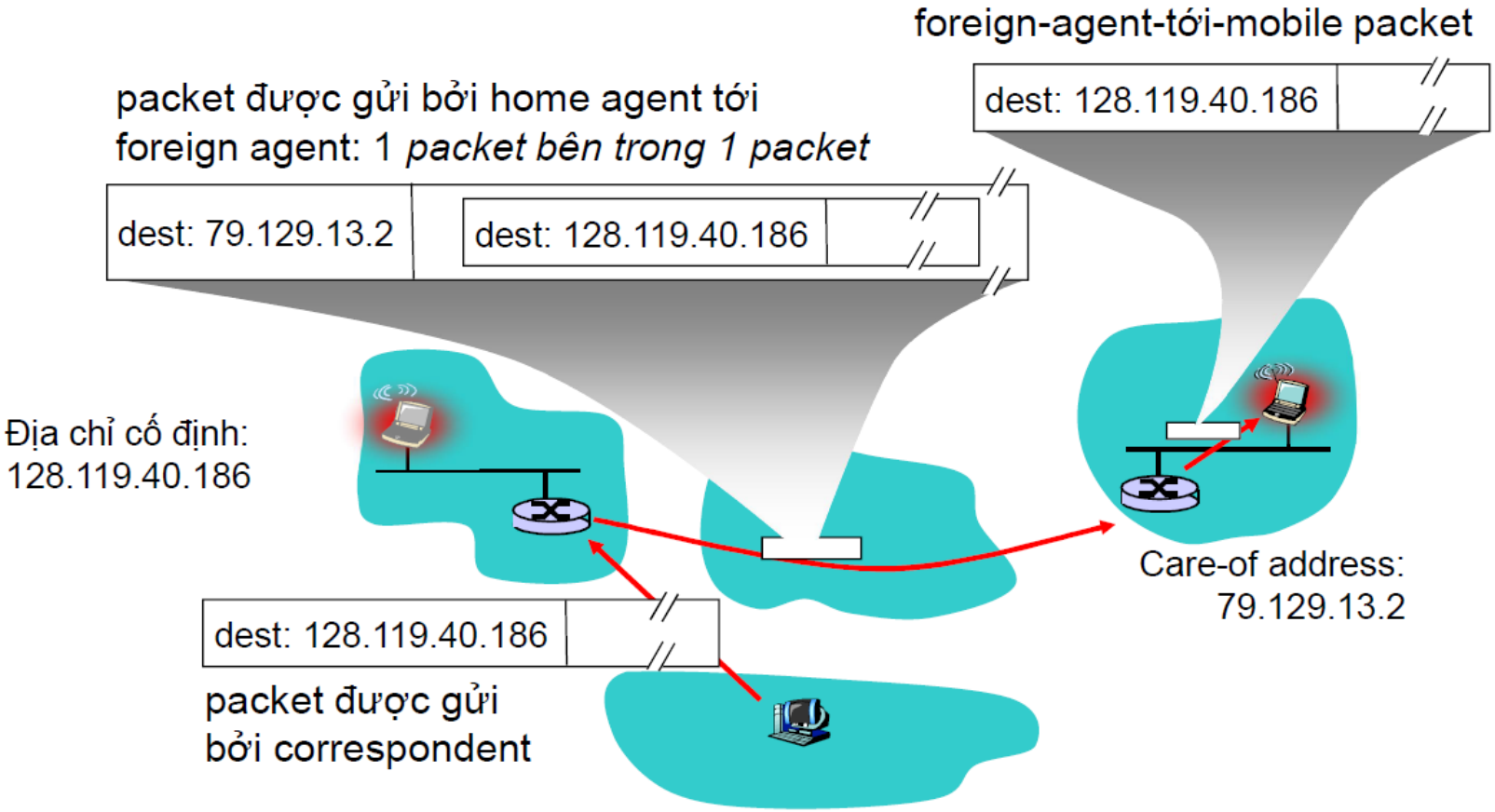
- 3 main pieces of mobile IP standard
  - Agent discovery
    - Mobile IP defines the protocols used by a home or foreign agent to advertise its services to mobile nodes, and protocols for mobile nodes to solicit the services of a foreign or home agent.
  - Registration with the home agent
    - Mobile IP defines the protocols used by the mobile node and/or foreign agent to register and deregister COAs with a mobile node's home agent.

# Mobile IP

- 3 main pieces of mobile IP standard
  - Indirect routing of datagrams
    - The standard also defines the manner in which datagrams are forwarded to mobile nodes by a home agent, including
      - Rules for forwarding datagrams
      - Rules for handling error conditions
      - Several forms of encapsulation [RFC 2003, RFC 2004].
  - Security (chapter 8)

# Mobile IP

- 3 main pieces of mobile IP standard
  - Indirect routing of datagrams



# Mobile IP

- Agent discovery
  - A mobile IP node arriving to a new network, whether attaching to a foreign network or returning to its home network, must learn the identity of the corresponding foreign or home agent.
  - Indeed it is the discovery of a new foreign agent, with a new network address, that allows the network layer in a mobile node to learn that it has moved into a new foreign network. This process is known as **agent discovery.**

# Mobile IP

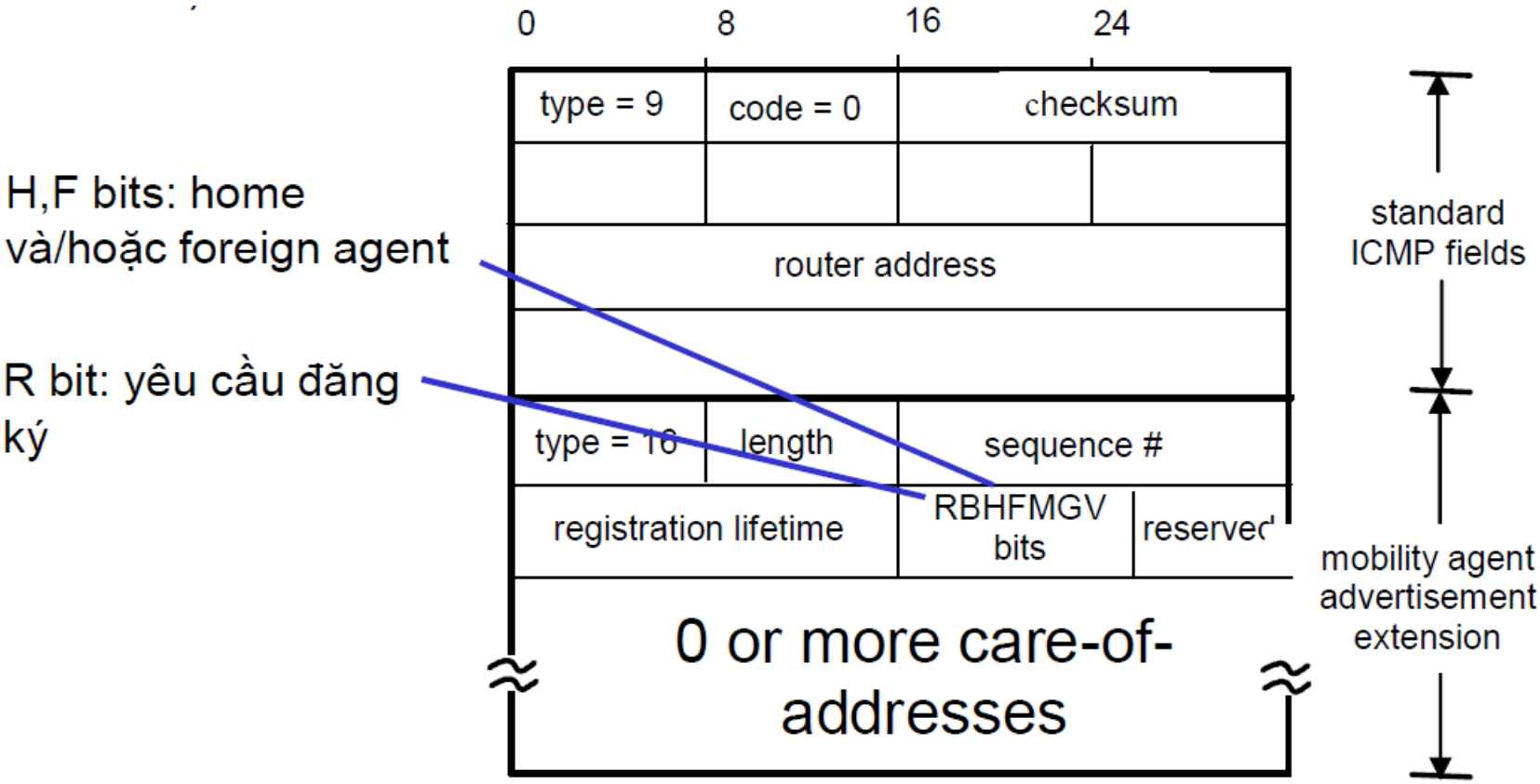
- Agent discovery
  - Agent discovery can be accomplished in one of two ways
    - Via agent advertisement
    - Or via agent solicitation

# Mobile IP

- Agent discovery
  - Agent discovery can be accomplished in one of two ways
    - Via agent advertisement
      - A foreign or home agent advertises its services using an extension to the existing router discovery protocol [RFC 1256].
      - The agent periodically **broadcasts an ICMP message** with a **type field of 9** (router discovery) on all links to which it is connected
      - The router discovery message contains the IP address of the router (that is, the agent), thus allowing a mobile node to learn the agent's IP address.
      - The router discovery message also contains a mobility agent advertisement extension that contains additional information needed by the mobile node

# Mobile IP

- Agent discovery
  - Via agent advertisement



# Mobile IP

- Agent discovery
  - Agent discovery can be accomplished in one of two ways
    - Via agent solicitation
      - A mobile node wanting to learn about agents without waiting to receive an agent advertisement can broadcast an agent solicitation message, which is simply an ICMP message with type value 10.
      - An agent receiving the solicitation will unicast an agent advertisement directly to the mobile node, which can then proceed as if it had received an unsolicited advertisement.

# Mobile IP

- Registration with the Home Agent
  - Once a mobile IP node has received a COA, that address must be registered with the home agent. This can be done either **via the foreign agent** (who then registers the COA with the home agent) or **directly by the mobile IP node** itself.

# Mobile IP

- Registration with the Home Agent
  - Via the foreign agent (who then registers the COA with the home agent). Gồm 4 bước:
    - Bước 1
      - Following the receipt of a foreign agent advertisement, a mobile node sends a mobile IP registration message to the foreign agent.
      - The registration message is carried within a UDP datagram and sent to port 434.
      - The registration message carries a COA advertised by the foreign agent, the address of the home agent (HA), the permanent address of the mobile node (MA), the requested lifetime of the registration, and a 64-bit registration identification

# Mobile IP

- Registration with the Home Agent
  - Via the foreign agent (who then registers the COA with the home agent). Gồm 4 bước:
    - Bước 1
      - The requested registration lifetime is the number of seconds that the registration is to be valid.
      - If the registration is not renewed at the home agent within the specified lifetime, the registration will become invalid.
      - The registration identifier acts like a sequence number and serves to match a received registration reply with a registration request.

# Mobile IP

- Registration with the Home Agent
  - Via the foreign agent (who then registers the COA with the home agent). Gồm 4 bước:
    - Bước 2
      - The foreign agent receives the registration message and records the mobile node's permanent IP address.
      - The foreign agent now knows that it should be looking for datagrams containing an encapsulated datagram whose destination address matches the permanent address of the mobile node.
      - The foreign agent then sends a mobile IP registration message (again, within a UDP datagram) to port 434 of the home agent. The message contains the COA, HA, MA, encapsulation format requested, requested registration lifetime, and registration identification.

# Mobile IP

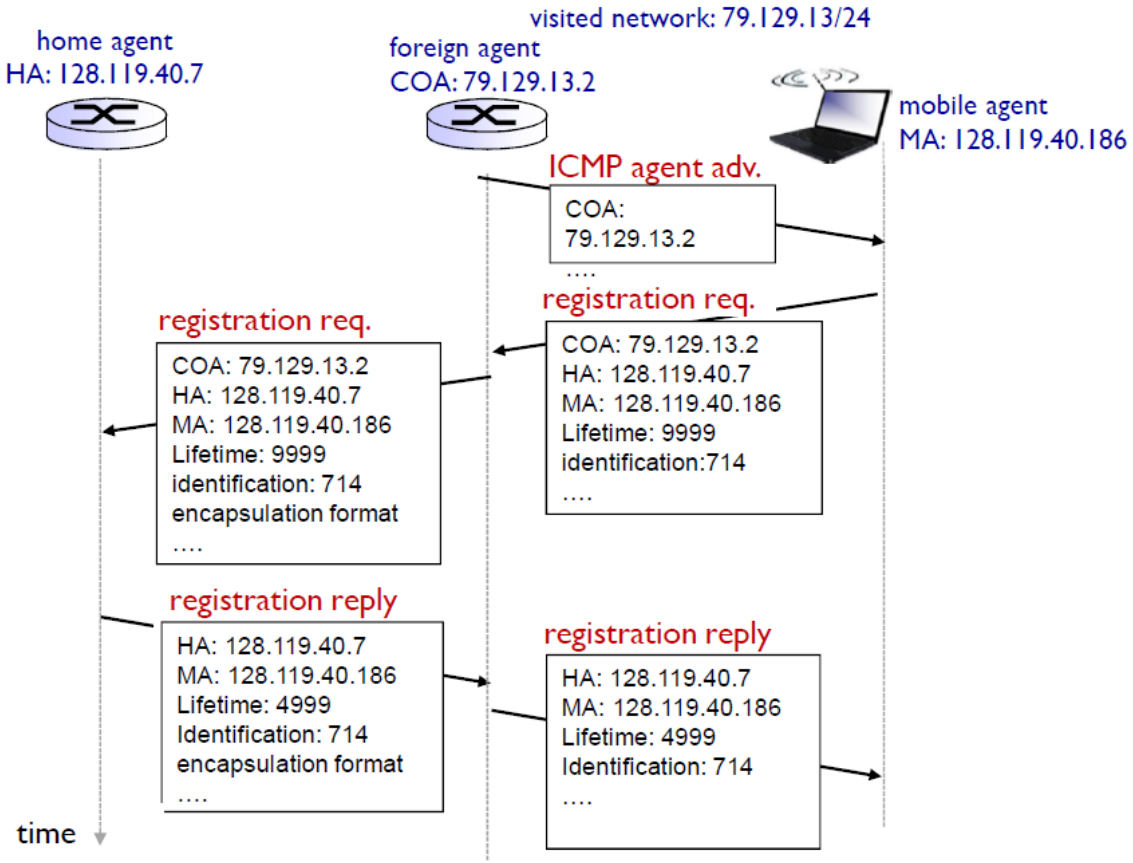
- Registration with the Home Agent
  - Via the foreign agent (who then registers the COA with the home agent). Gồm 4 bước:
    - Bước 3
      - The home agent receives the registration request and checks for authenticity and correctness.
      - The home agent binds the mobile node's permanent IP address with the COA; in the future, datagrams arriving at the home agent and addressed to the mobile node will now be encapsulated and tunneled to the COA.
      - The home agent sends a mobile IP registration reply containing the HA, MA, actual registration lifetime, and the registration identification of the request that is being satisfied with this reply.

# Mobile IP

- Registration with the Home Agent
  - Via the foreign agent (who then registers the COA with the home agent). Gồm 4 bước:
    - Bước 4
      - The foreign agent receives the registration reply and then forwards it to the mobile node.
      - At this point, registration is complete, and the mobile node can receive datagrams sent to its permanent address.

# Mobile IP

- Registration with the Home Agent
  - Via the foreign agent (who then registers the COA with the home agent). Gồm 4 bước:



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# Managing Mobility in Cellular Networks

- Home network: mạng của nhà cung cấp cellular mà bạn đăng ký (ví dụ: Sprint PCS, Verizon)
  - Home location register (HLR): cơ sở dữ liệu trong home network
    - Chứa số lượng cell phone cố định, thông tin hồ sơ (services, preferences, billing)
    - Thông tin về vị trí hiện tại (có thể đang ở trong mạng khác)

# Managing Mobility in Cellular Networks

- Home network: mạng của nhà cung cấp cellular mà bạn đăng ký (ví dụ: Sprint PCS, Verizon)
  - Home location register (HLR): cơ sở dữ liệu trong home network
    - If a mobile user is currently roaming in another provider's cellular network, the HLR contains enough information to obtain an address in the visited network to which a call to the mobile user should be routed

# Managing Mobility in Cellular Networks

- The responsibilities of the home and visited networks
  - Home networks
    - **GMSC** (Gateway Mobile services Switching Center) hay còn gọi là home MS là một switch đặc biệt trong home network, is contacted by a correspondent when a call is placed to a mobile user.

# Managing Mobility in Cellular Networks

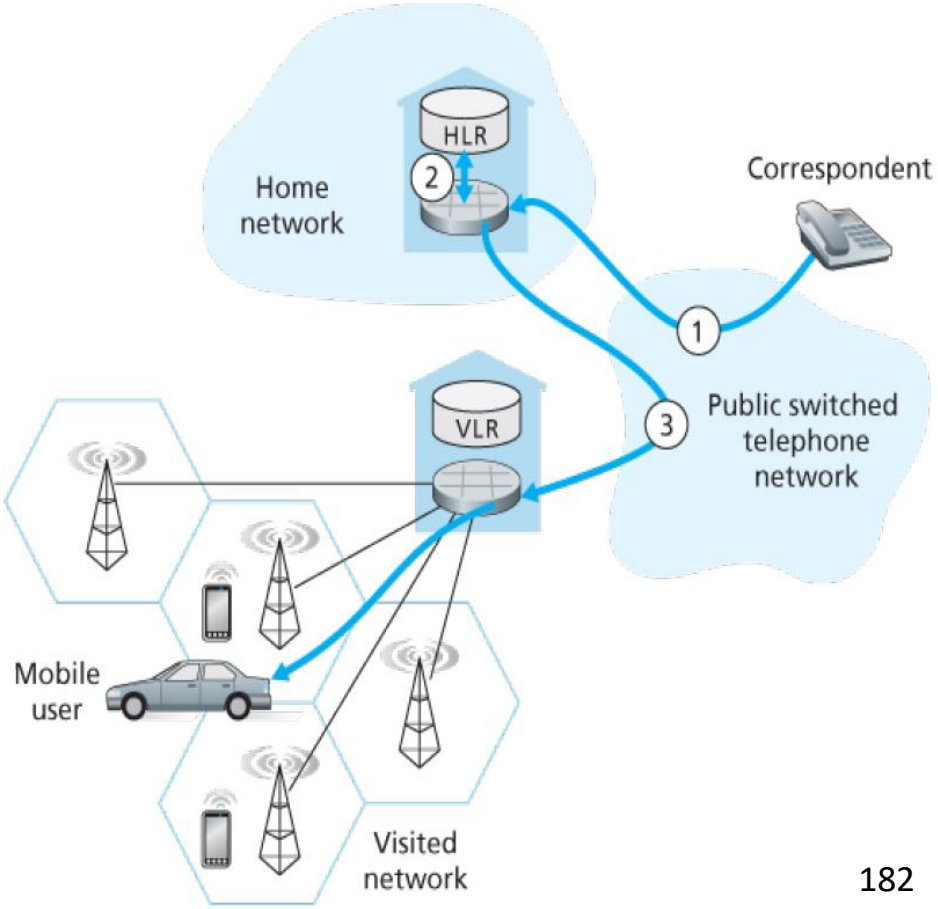
- Visited network: mạng mà trong đó thiết bị di động đang thường trú
  - Visitor location register (VLR): cơ sở dữ liệu với entry cho mỗi user hiện tại trong mạng
  - VLR entries thus come and go as mobile users enter and leave the network.
  - VLR is usually co-located with the mobile switching center (MSC) that coordinates the setup of a call to and from the visited network.

# Managing Mobility in Cellular Networks

# Managing Mobility in Cellular Networks

- GSM: định tuyến gián tiếp tới thiết bị di động

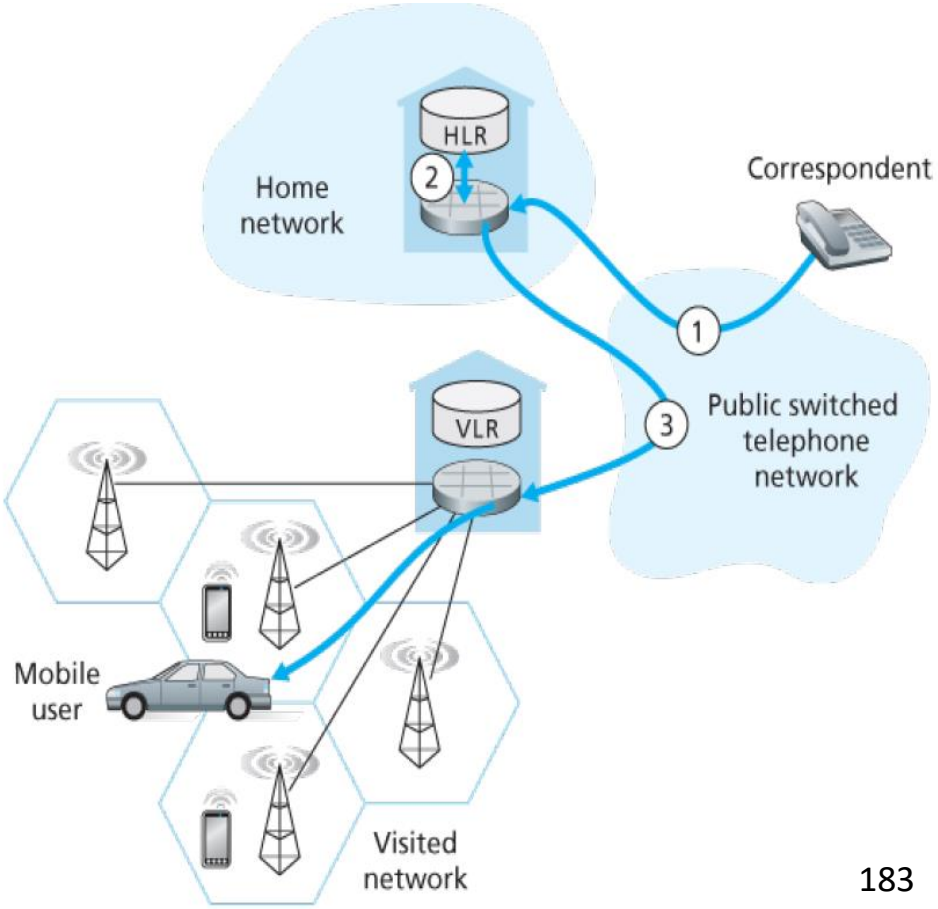
- The correspondent dials the mobile user's phone number. This number itself does not refer to a particular telephone line or location.
- The leading digits in the number are sufficient to globally identify the mobile's home network.
- The call is routed from the correspondent through the PSTN to the home MSC in the mobile's home network.



# Managing Mobility in Cellular Networks

- GSM: định tuyến gián tiếp tới thiết bị di động

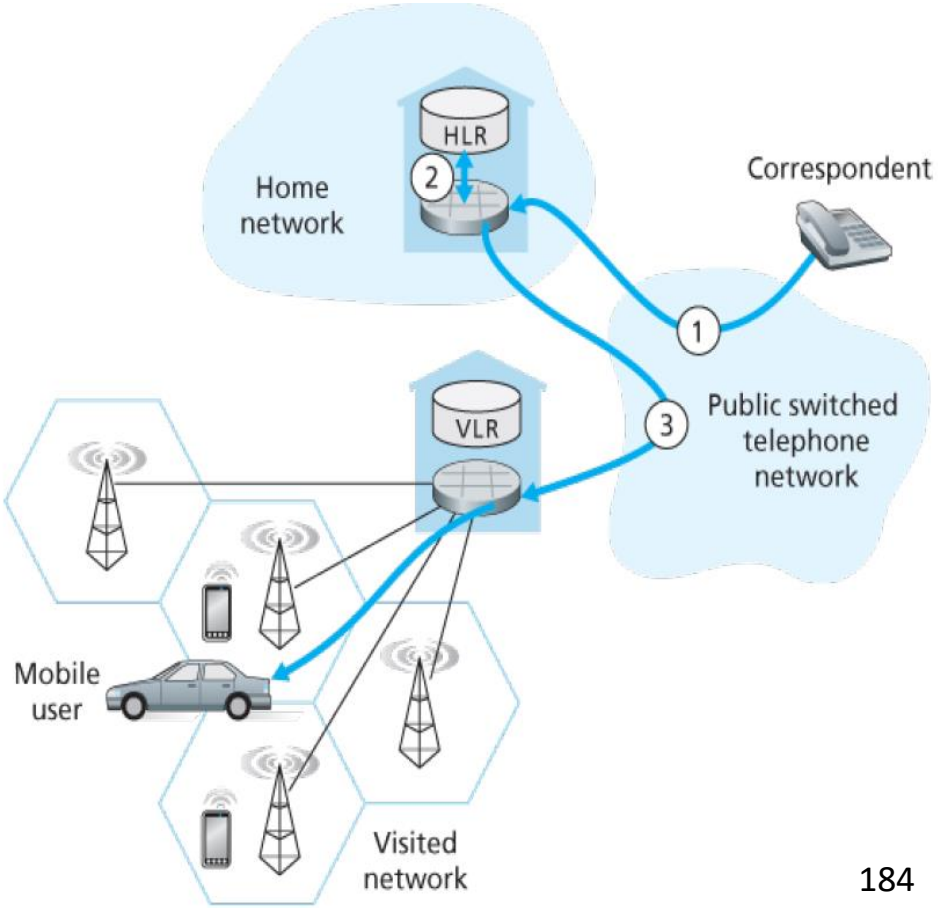
  - The home MSC receives the call and interrogates the HLR to determine the location of the mobile user. In the simplest case, the HLR returns the mobile station roaming number (MSRN) (this number is different from the mobile's permanent phone number, which is associated with the mobile's home network)



# Managing Mobility in Cellular Networks

- GSM: định tuyến gián tiếp tới thiết bị di động

- The roaming number is ephemeral: It is temporarily assigned to a mobile when it enters a visited network.
- The roaming number serves a role similar to that of the care-of address in mobile IP and, like the COA, is invisible to the correspondent and the mobile.



# Managing Mobility in Cellular Networks

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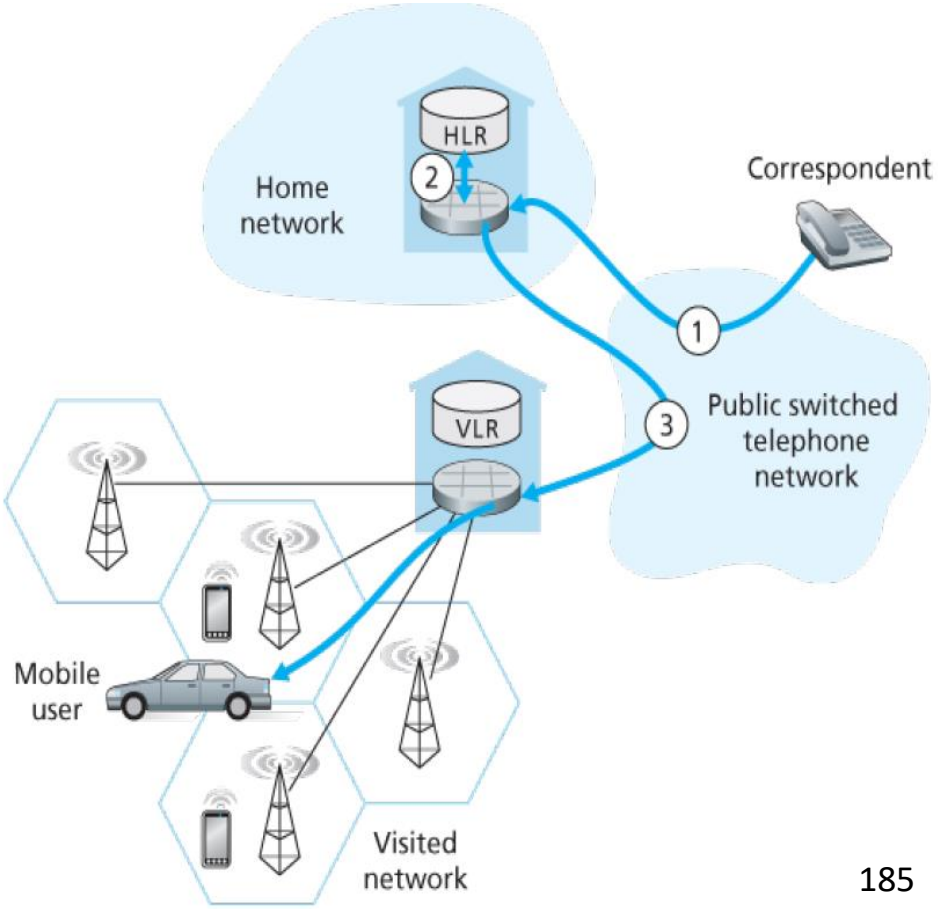
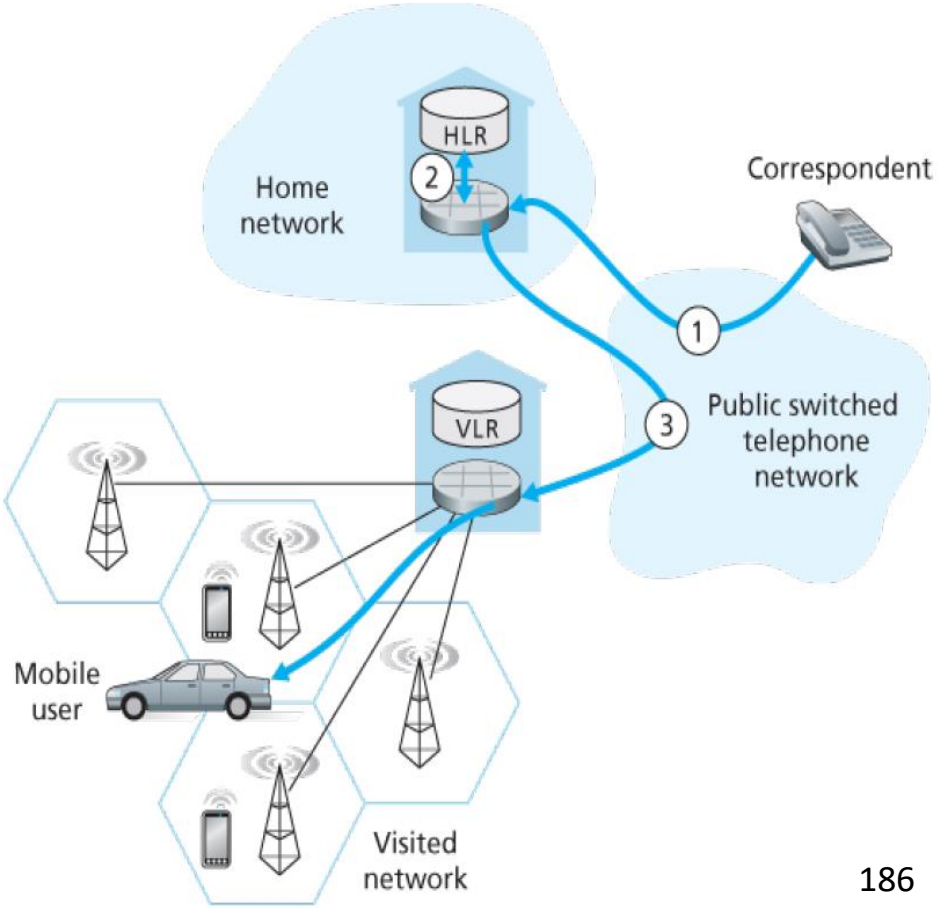


# Managing Mobility in Cellular Networks

- GSM: định tuyến gián tiếp tới thiết bị di động

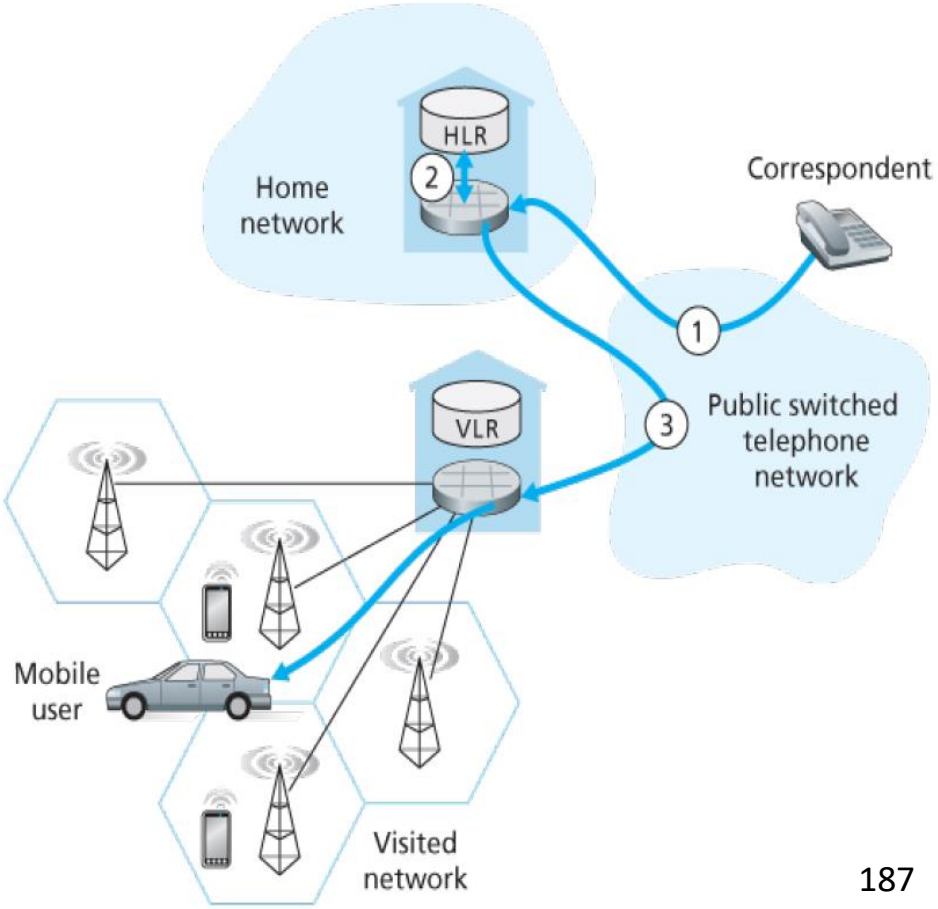
  - If HLR does not have the roaming number, it returns the address of the VLR in the visited network. In this case (not shown
  - in the figure), the home MSC will need to query the VLR to obtain the roaming number of the mobile node.



# Managing Mobility in Cellular Networks

- GSM: định tuyến gián tiếp tới thiết bị di động

  - Given the roaming number, the home MSC sets up the second leg of the call through the network to the MSC in the visited network.
  - The call is completed, being routed from the correspondent to the home MSC, and from there to the visited MSC, and from there to the base station serving the mobile user.



# Managing Mobility in Cellular Networks

- GSM: định tuyến gián tiếp tới thiết bị di động
  - How the HLR obtains information about the location of the mobile user?
    - When a mobile telephone is switched on or enters a part of a visited network that is covered by a new VLR, the mobile must register with the visited network. This is done through the exchange of signaling messages between the mobile and the VLR.

# Managing Mobility in Cellular Networks

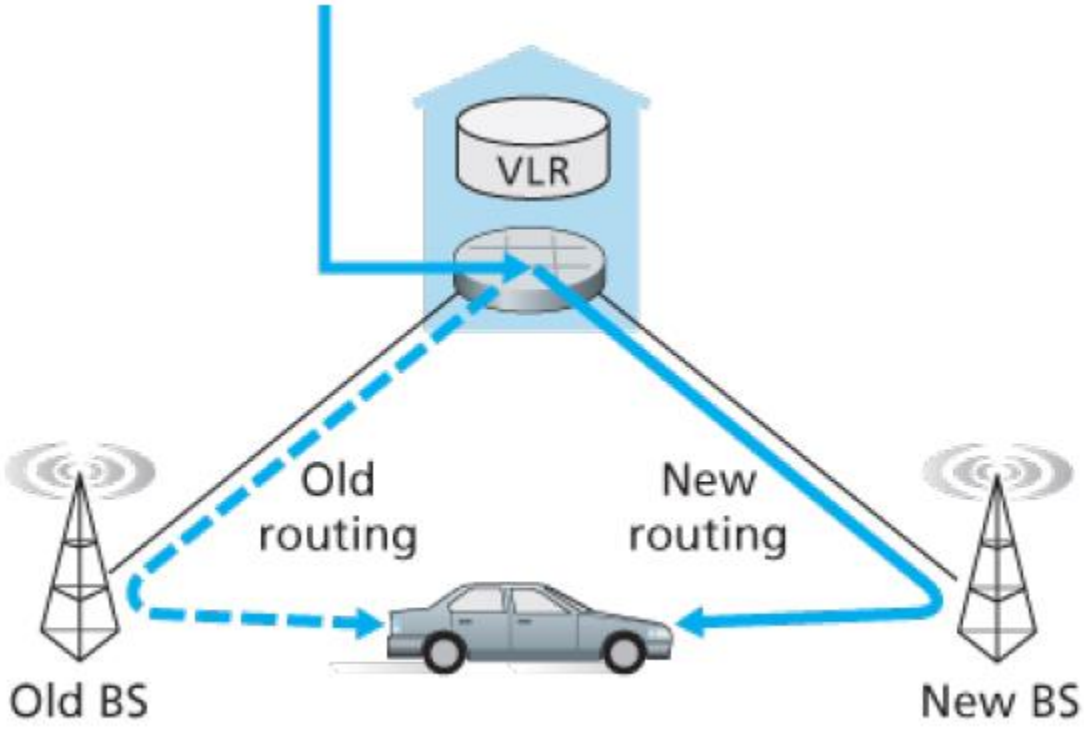
- GSM: định tuyến gián tiếp tới thiết bị di động
  - How the HLR obtains information about the location of the mobile user?
    - The visited VLR, in turn, sends a location update request message to the mobile's HLR. This message informs the HLR of either the roaming number at which the mobile can be contacted, or the address of the VLR (which can then later be queried to obtain the mobile number).

# Managing Mobility in Cellular Networks

- GSM: định tuyến gián tiếp tới thiết bị di động
  - How the HLR obtains information about the location of the mobile user?
    - As part of this exchange, the VLR also obtains subscriber information from the HLR about the mobile and determines what services (if any) should be accorded the mobile user by the visited network.

# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - A handoff occurs when a mobile station changes its association from one base station to another during a call.



# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - Các lý do handoff
    - (1) Tín hiệu giữa trạm hiện tại và trạn điện thoại di động có thể đã kém đi đến mức cuộc gọi có nguy cơ bị ngắt.
    - (2) Một cell có thể quá tải, xử lý một số lượng lớn các cuộc gọi => giảm tắc nghẽn bằng cách chuyển điện thoại di động đến các cell gần đó có ít tắc nghẽn hơn.

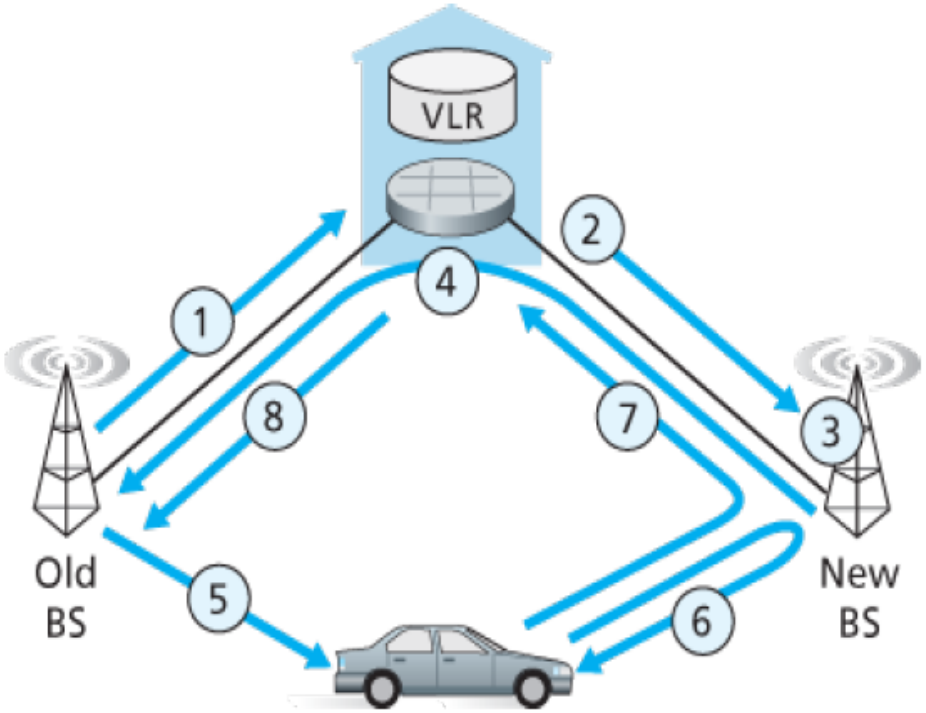
# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - Handoff in GSM is initiated by the old base station based on the current loads of mobiles in nearby cells, and other factors.
  - The GSM standard does not specify the specific algorithm to be used by a base station to determine whether or not to perform handoff.

# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - Steps involved when a base station does decide to hand off a mobile user

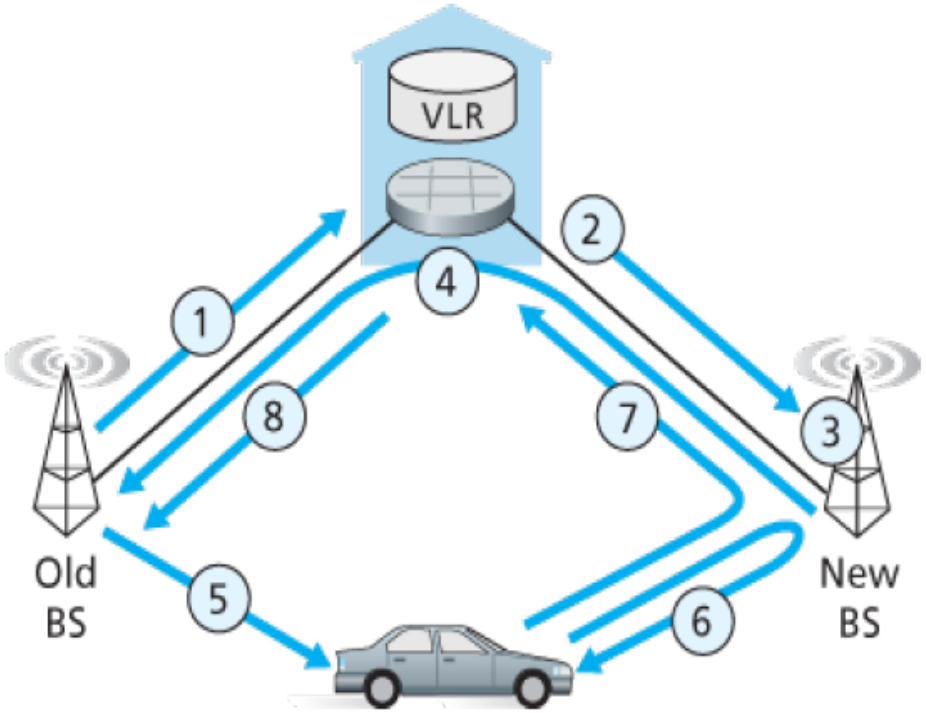
1. The old base station (BS) informs the visited MSC that a handoff is to be performed and the BS (or possible set of BSs) to which the mobile is to be handed off.



# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - Steps involved when a base station does decide to hand off a mobile user

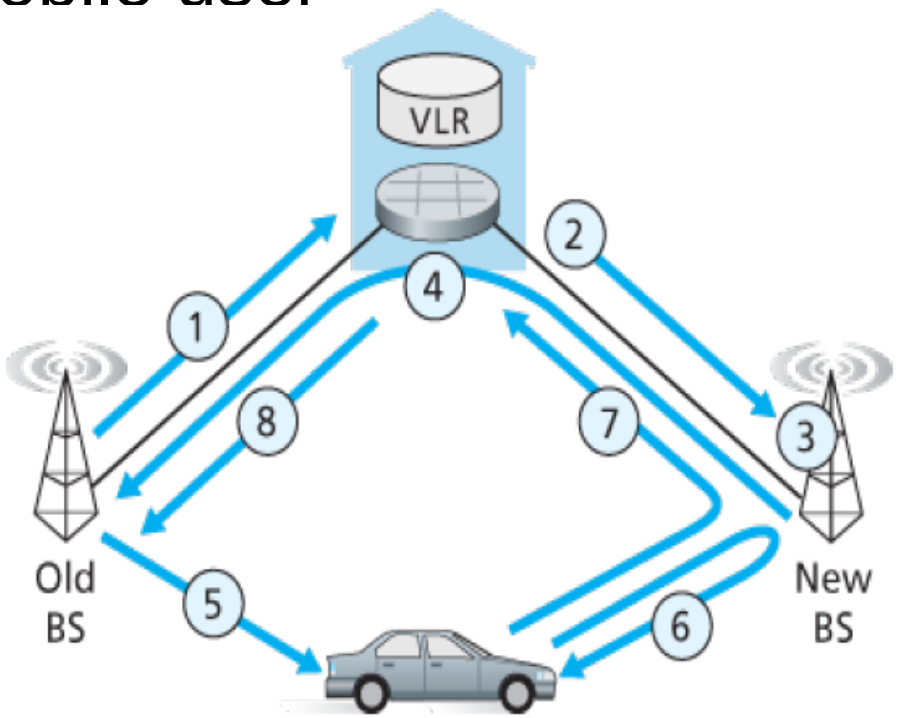
2. The visited MSC initiates path setup to the new BS, allocating the resources needed to carry the rerouted call, and signaling the new BS that a handoff is about to occur.



# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - Steps involved when a base station does decide to hand off a mobile user

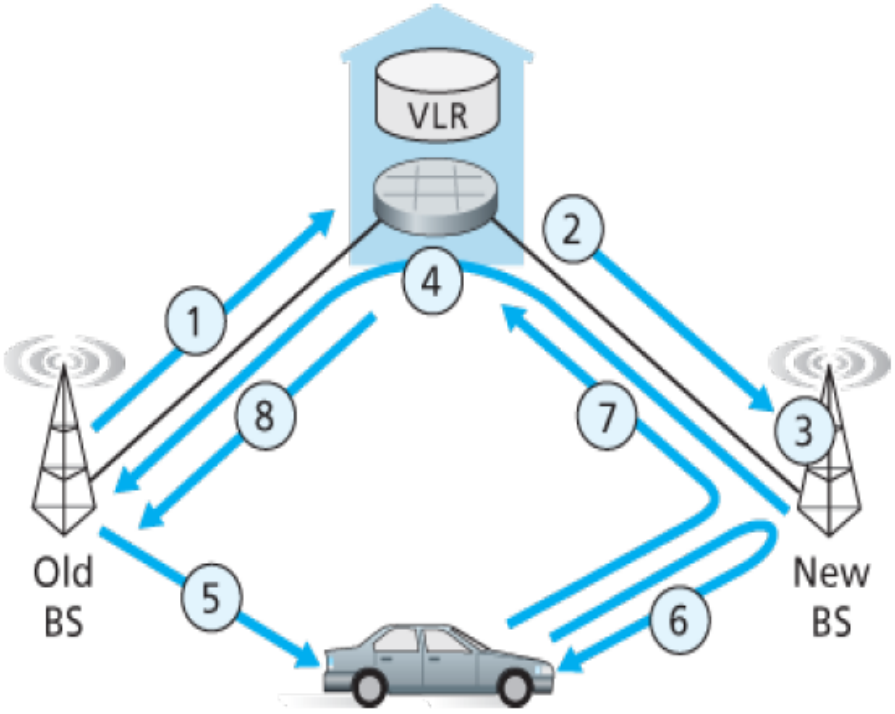
3. The new BS allocates and activates a radio channel for use by the mobile.



# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - Steps involved when a base station does decide to hand off a mobile user

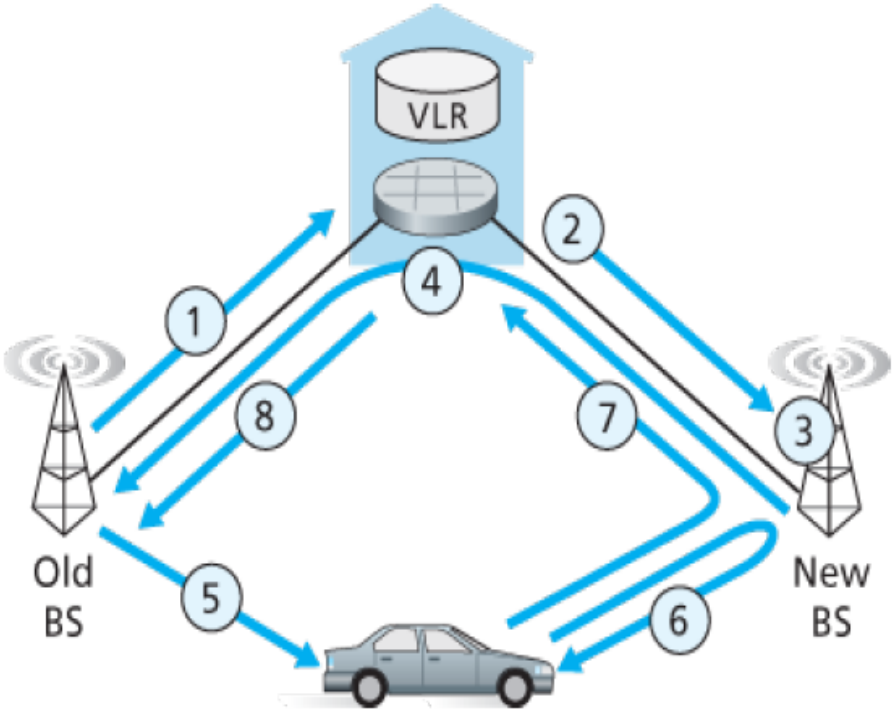
4. The new BS signals back to the visited MSC and the old BS that the visited-MSC-to-new-BS path has been established and that the mobile should be informed of the impending handoff.
- The new BS provides all of the information that the mobile will need to associate with the new BS.



# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - Steps involved when a base station does decide to hand off a mobile user

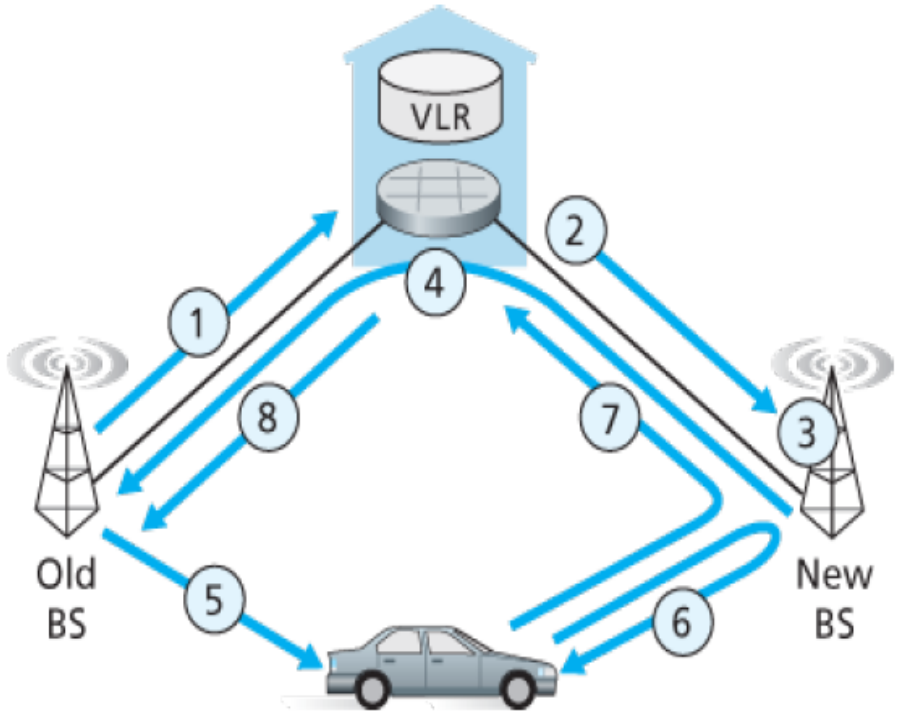
5. The mobile is informed that it should perform a handoff. Note that up until this point, the mobile has been blissfully unaware that the network has been laying the groundwork (e.g., allocating a channel in the new BS and allocating a path from the visited MSC to the new BS) for a handoff.



# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - Steps involved when a base station does decide to hand off a mobile user

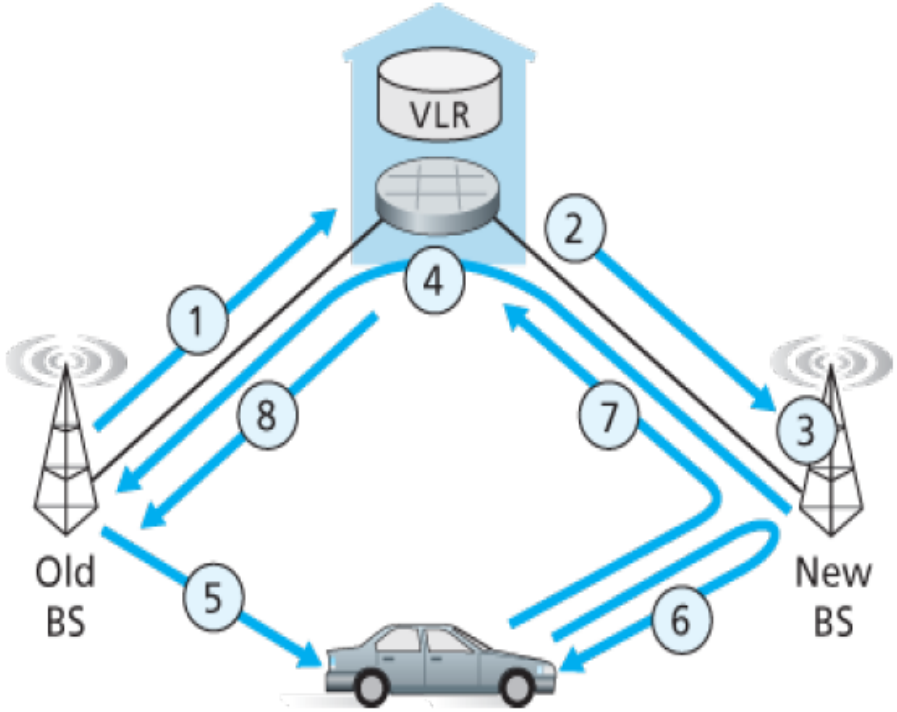
6. The mobile and the new BS exchange one or more messages to fully activate the new channel in the new BS.



# Managing Mobility in Cellular Networks

- GSM: handoff với MSC
  - Steps involved when a base station does decide to hand off a mobile user

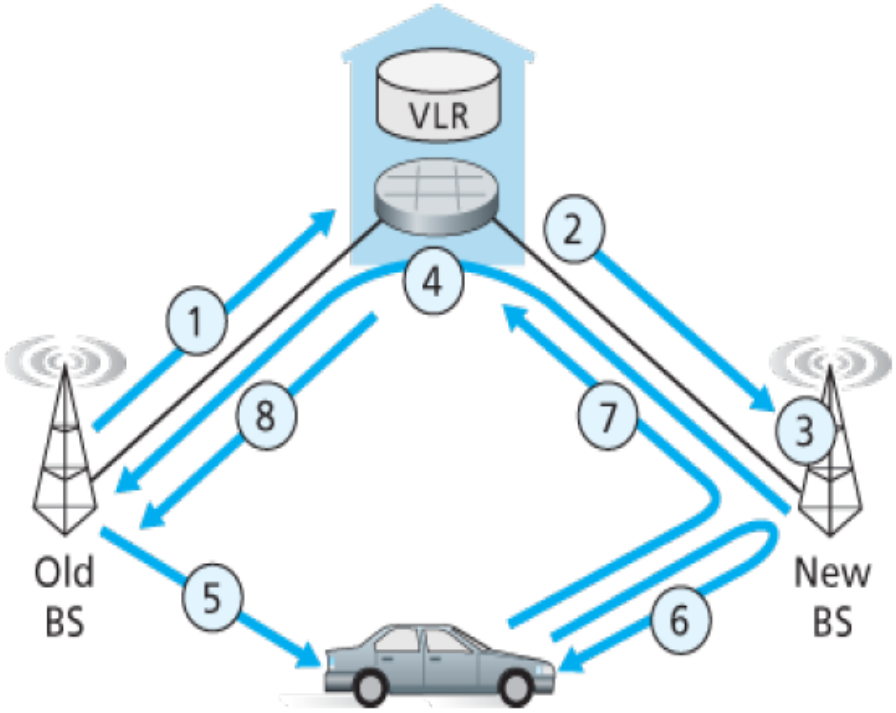
7. The mobile sends a handoff complete message to the new BS, which is forwarded up to the visited MSC.
- The visited MSC then reroutes the ongoing call to the mobile via the new BS.



# Managing Mobility in Cellular Networks

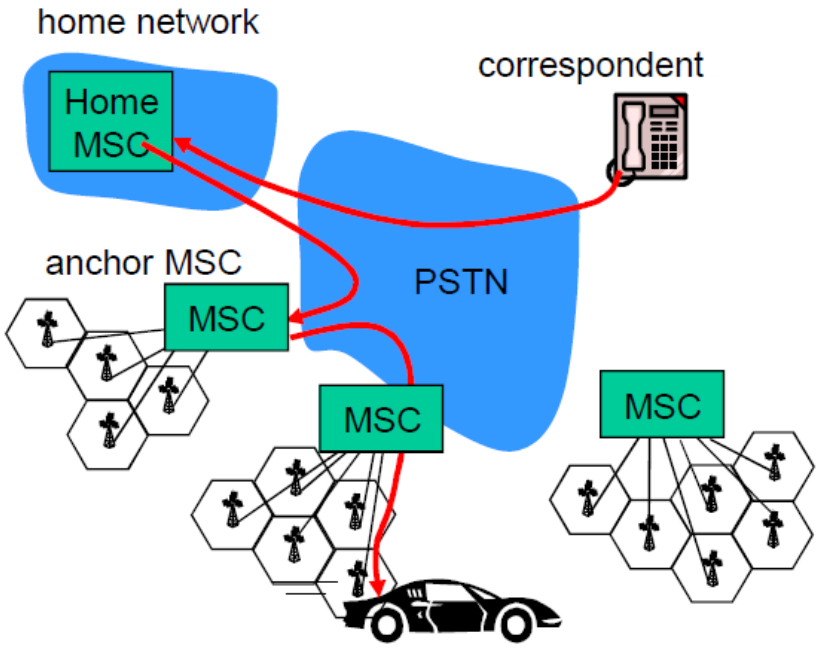
- GSM: handoff với MSC
  - Steps involved when a base station does decide to hand off a mobile user

8. The resources allocated along the path to the old BS are then released.



# Managing Mobility in Cellular Networks

- GSM: handoff giữa các MSC

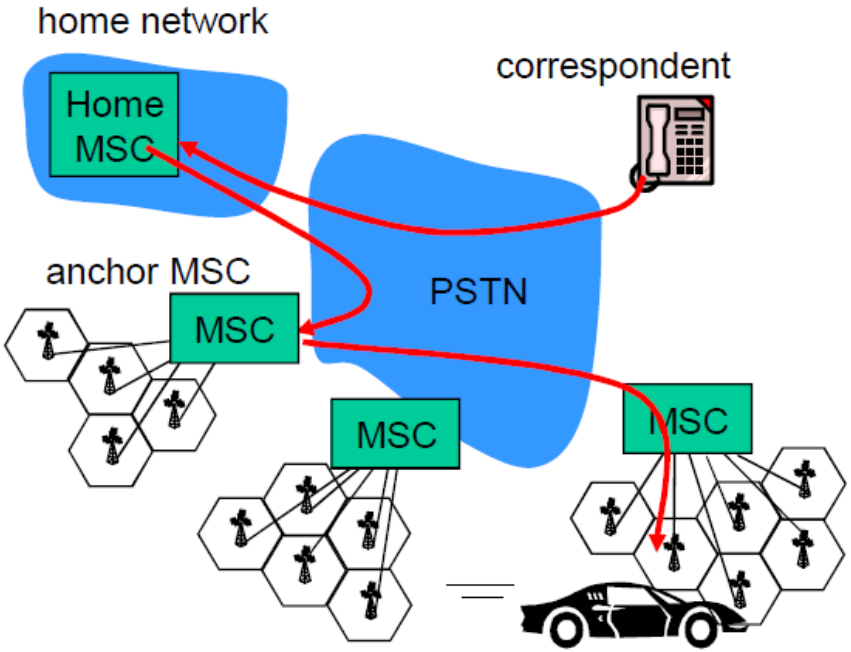



(a) Trước khi handoff

- *anchor MSC:* MSC đầu tiên trong suốt cuộc gọi
  - cuộc gọi vẫn còn được định tuyến thông qua MSC
- Các MSC mới thêm vào cuối dây chuyền MSC khi thiết bị di động di chuyển tới MSC mới
- Bước giảm thiểu đường đi tùy chọn để thu ngắn các dây chuyền MSC

# Managing Mobility in Cellular Networks

- GSM: handoff giữa các MSC




(b) Sau khi handoff

- *anchor MSC:* MSC đầu tiên trong suốt cuộc gọi
  - Cuộc gọi vẫn còn được định tuyến thông qua anchor MSC
- Các MSCs mới thêm vào cuối dây chuyền MSC chain khi thiết bị di động di chuyển tới MSC mới
- Bước giảm thiểu đường đi tùy chọn để thu ngắn các dây chuyền MSC

# Managing Mobility in Cellular Networks

- Tính di động : GSM với Mobile IP

| GSM element | Comment on GSM element | Mobile IP element |
|---|---|---|
| **Home system** | Mạng chứa các số điện thoại cố định của user di động | **Home network** |
| **Gateway Mobile Switching Center, or "home MSC". Home Location Register (HLR)** | Home MSC: điểm tiếp xúc để lấy được địa chỉ có thể định tuyến được của user di động. HLR: cơ sở dữ liệu trong home system chứa số điện thoại cố định, thông tin hồ sơ, vị trí hiện tại của người dùng di động, thông tin thuê bao | **Home agent** |
| **Visited System** | Mạng khác với home system, trong đó user di động đang thường trú | **Visited network** |
| **Visited Mobile services Switching Center. Visitor Location Record (VLR)** | Visited MSC: chịu trách nhiệm cho việc thiết lập cuộc gọi đến/từ các node di động trong các cell kết nối với MSC. VLR: entry cơ sở dữ liệu tạm thời trong visited system, chứa thông tin đăng ký cho mỗi người dùng di động đến thăm (visiting mobile user) | **Foreign agent** |
| **Mobile Station Roaming Number (MSRN), or "roaming number"** | Địa chỉ có thể định tuyến được cho mỗi phân đoạn cuộc gọi điện thoại giữa home MSC và visited MSC | **Care-of-address** |

# Nội dung chương

- Giới thiệu
- Wireless Links and Network Characteristics
- WiFi: 802.11 Wireless LANs
- Cellular Internet Access
- Mobility Management: Principles
- Mobile IP
- Managing Mobility in Cellular Networks
- Wireless and Mobility: Impact on Higher-Layer Protocols

# Impact on Higher-Layer Protocols

- Link-layer
  - Fading
  - Multipath
  - Hidden terminals
- Network layer
  - Mobile users change their points of attachment to the network.

# Impact on Higher-Layer Protocols

- Transport layer
  - TCP: retransmits a segment that is either lost or corrupted on the path between sender and receiver.
    - Mobile user, loss caused by
      - Network congestion (router buffer overflow)
      - Handoff (e.g., from delays in rerouting segments to a mobile's new point of attachment to the network)

# Impact on Higher-Layer Protocols

- Transport layer
  - TCP's receiver-to-sender ACK indicates only that a segment was not received intact;
  - The sender is unaware of whether the segment was lost due to congestion, during handoff, or due to detected bit errors.
  - In all cases, the sender's response is the same—to retransmit the segment

# Impact on Higher-Layer Protocols

- Transport layer
  - TCP's congestion-control
    - Response is also the same in all cases
      - TCP decreases its congestion window
      - By unconditionally decreasing its congestion window, TCP implicitly assumes that segment loss results from congestion rather than corruption or handoff
    - When such bit errors occur or when handoff loss occurs, there's really no reason for the TCP sender to decrease its congestion window (and thus decrease its sending rate).
      - Indeed, it may well be the case that router buffers are empty and packets are flowing along the end-to-end path unimpeded by congestion.

# Impact on Higher-Layer Protocols

- Transport layer
  - Các phương pháp TCP's congestion-control
    - Local recovery
    - TCP sender awareness of wireless links
    - Split-connection approaches

# Impact on Higher-Layer Protocols

- Transport layer
  - Các phương pháp TCP's congestion-control
    - Local recovery
      - Local recovery protocols recover from bit errors when and where (e.g., at the wireless link) they occur, e.g., the 802.11 ARQ protocol, or more sophisticated approaches that use both ARQ and FEC

# Impact on Higher-Layer Protocols

- Transport layer
  - Các phương pháp TCP's congestion-control
    - TCP sender awareness of wireless links
      - In the local recovery approaches, the TCP sender is blissfully unaware that its segments are traversing a wireless link.
      - An alternative approach is for the TCP sender and receiver to be aware of the existence of a wireless link, to distinguish between congestive losses occurring in the wired network and corruption/loss occurring at the wireless link, and to invoke congestion control only in response to congestive wired-network losses.

# Impact on Higher-Layer Protocols

- Transport layer
  - Các phương pháp TCP's congestion-control
    - Split-connection approaches
      - The end-to-end connection between the mobile user and the other end point is broken into two transport-layer connections
        - » One from the mobile host to the wireless AP
        - » One from the wireless AP to the other communication end point (which assumed here is a wired host). The end-to-end connection is thus formed by the concatenation of a wireless part and a wired part.
      - The transport layer over the wireless segment can be a standard TCP connection, or a specially tailored error recovery protocol on top of UDP
      - Split TCP connections are widely used in cellular data networks, and that significant improvements can indeed be made through the use of split TCP connections.

# Impact on Higher-Layer Protocols

- Application layer
  - Wireless links often have relatively low bandwidths => applications that operate over wireless links, particularly over cellular wireless links, must treat bandwidth as a scarce commodity.
  - Ví dụ
    - Web server serving content to a Web browser executing on a 4G phone will likely not be able to provide the same image-rich content that it gives to a browser operating over a wired connection.

# Impact on Higher-Layer Protocols

- Application layer
  - Although wireless links do provide challenges at the application layer, the mobility they enable also makes possible a rich set of location-aware and context-aware applications
    - Wireless and mobile networks will play a key role in realizing the ubiquitous computing environments.