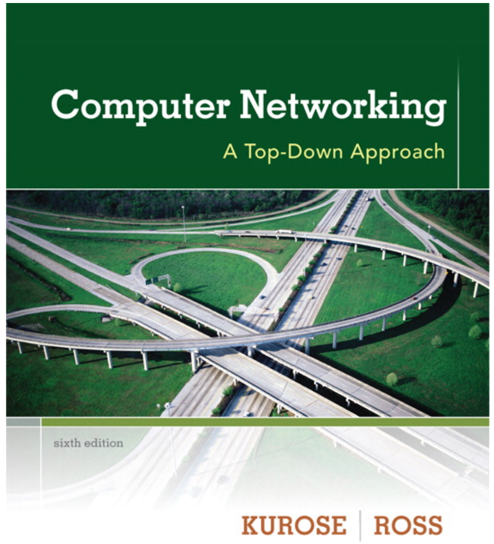
Chapter 6 Wireless and Mobile Networks



Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
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Reti degli Elaboratori
Canale AL
Prof.ssa Chiara Petrioli
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We thank for the support material Prof. Kurose-Ross

Chapter 6: Wireless and Mobile Networks

Background:

- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers!
  - With the introduction of mobile broadband technologies AND the evolution of mobile devices from conventional phones to smart-phones, laptops and devices such as itouch, Mobile Internet traffic is changing, with multimedia traffic becoming dominant.
  - Bandwidth demanding, energy demanding applications and limited available spectrum are driving development of wireless technologies
- computer nets: laptops, palmtops, PDAs, Internet-enabled phone promise anytime untethered Internet access
- two important (but different) challenges
  - *wireless:* communication over wireless link
  - *mobility:* handling the mobile user who changes point of attachment to network

Chapter 6 outline

6.1 Introduction

Wireless

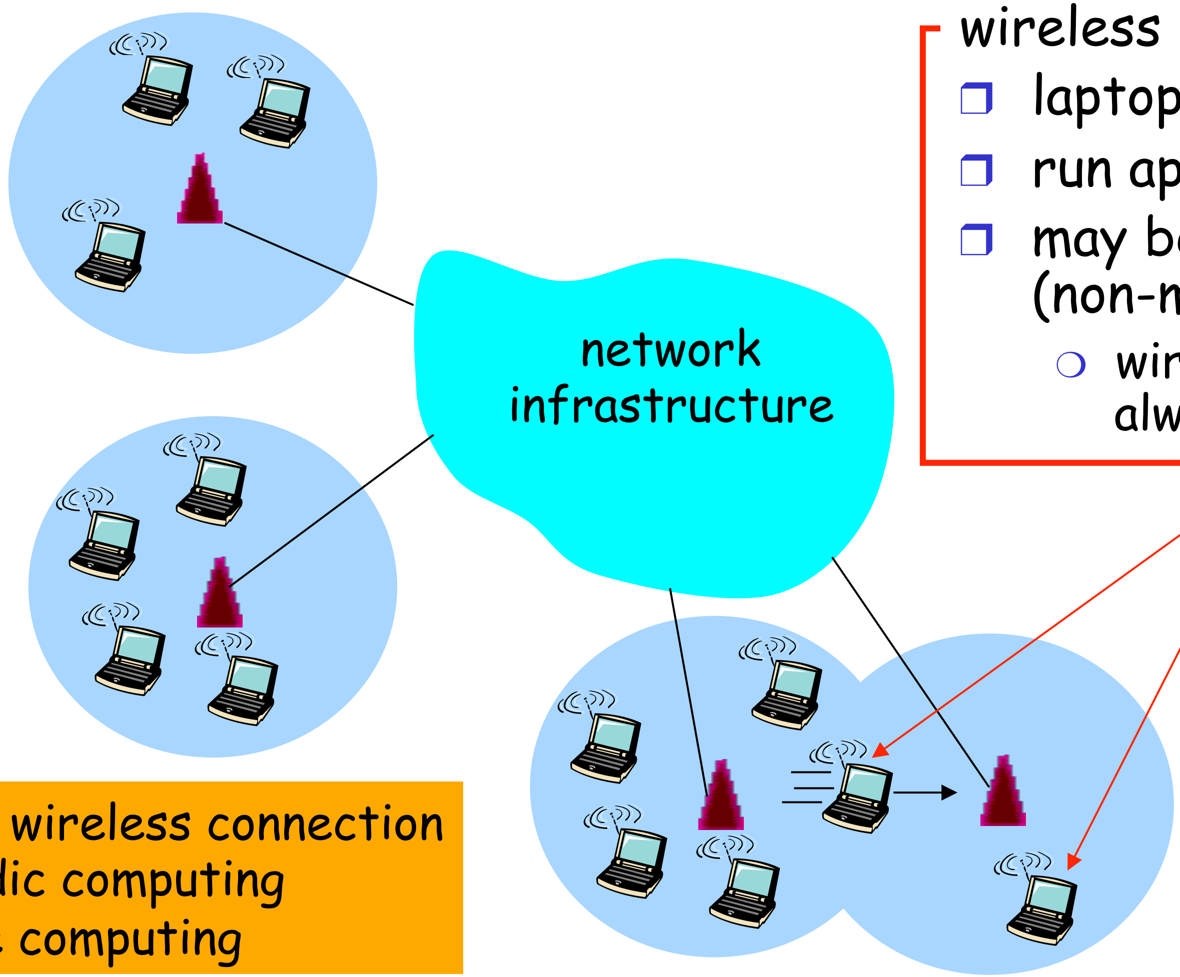
- 6.2 Wireless links, characteristics
  - CDMA
  - FDMA/TDMA
  - OFDMA
  - Different modulations and phy layers
- 6.3 IEEE 802.11 wireless LANs ("wi-fi")
- 6.4 Cellular Internet Access
  - architecture
  - standards (e.g., GSM)

Mobility

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

6.9 Summary

Elements of a wireless network

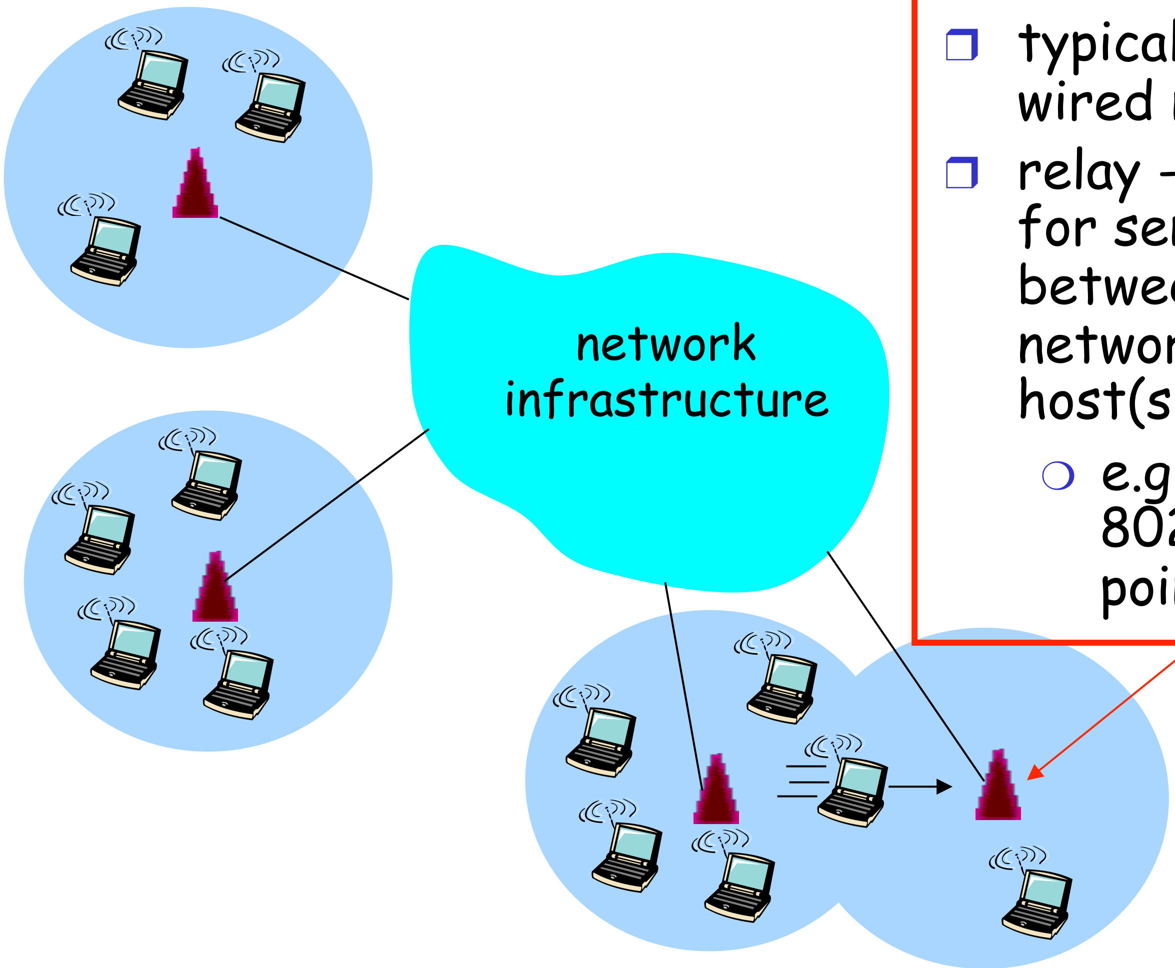


wireless hosts

- laptop, PDA, IP phone
- run applications
- may be stationary (non-mobile) or mobile
  - wireless does *not* always mean mobility

Static wireless connection
Nomadic computing
Mobile computing

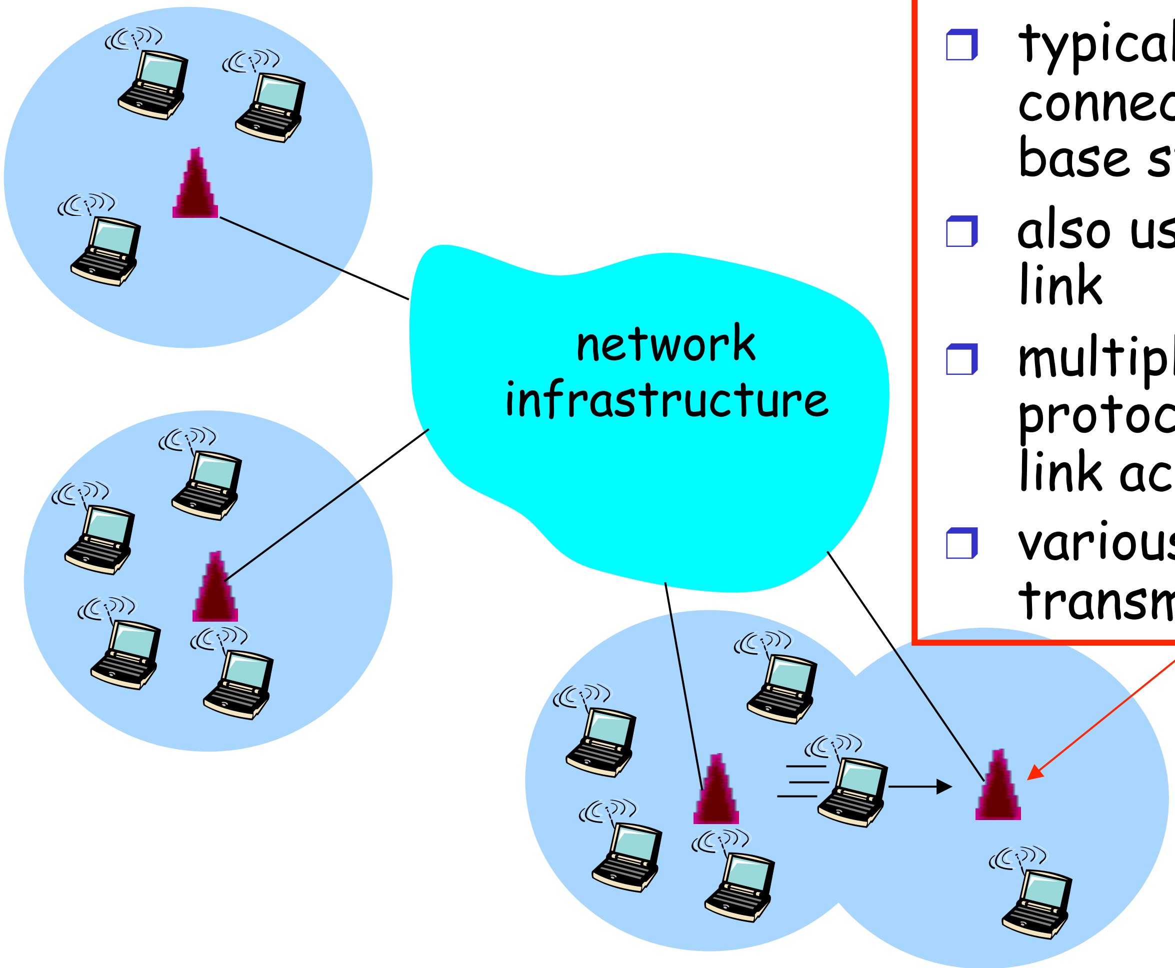
Elements of a wireless network



base station

- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - e.g., cell towers, 802.11 access points

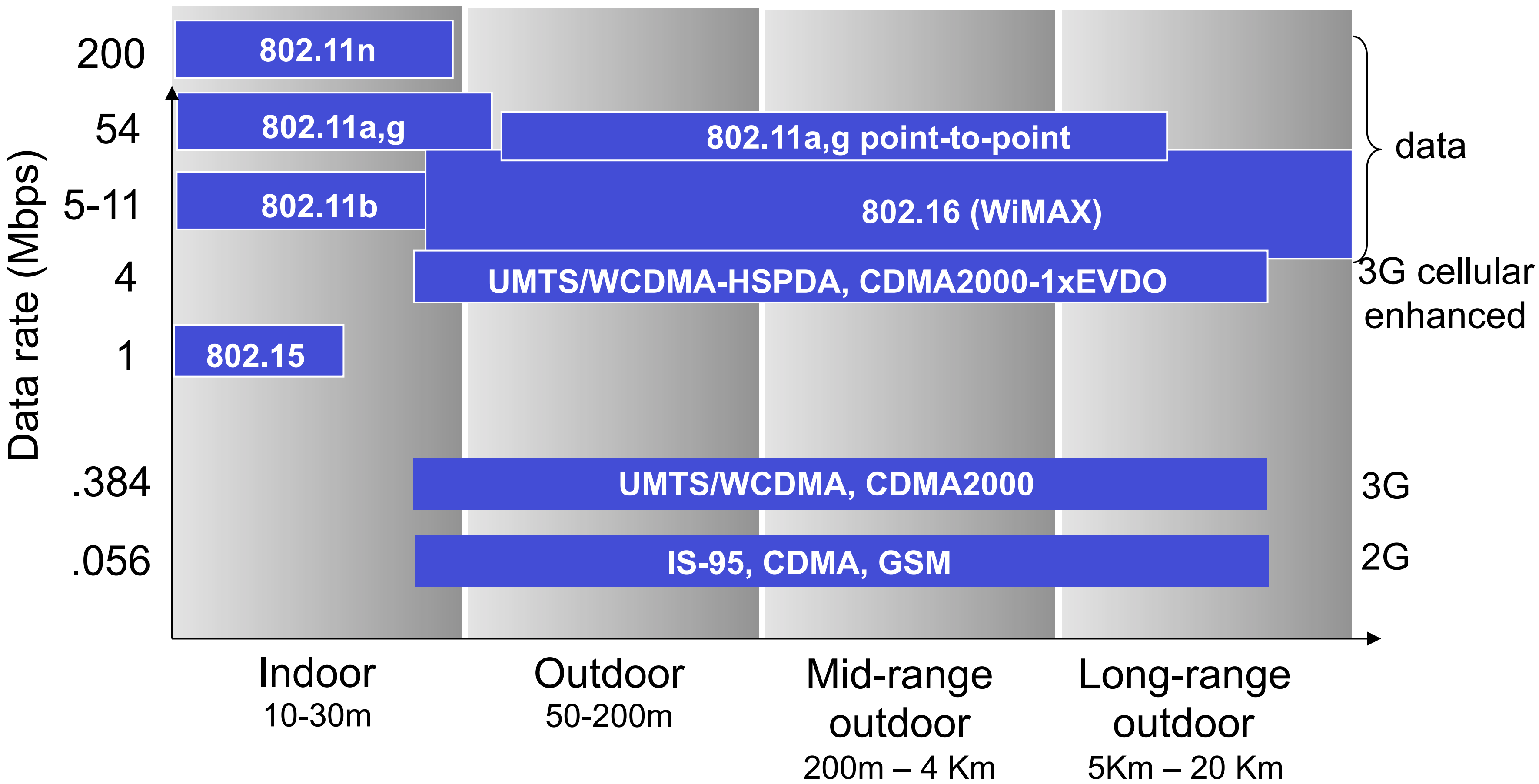
Elements of a wireless network



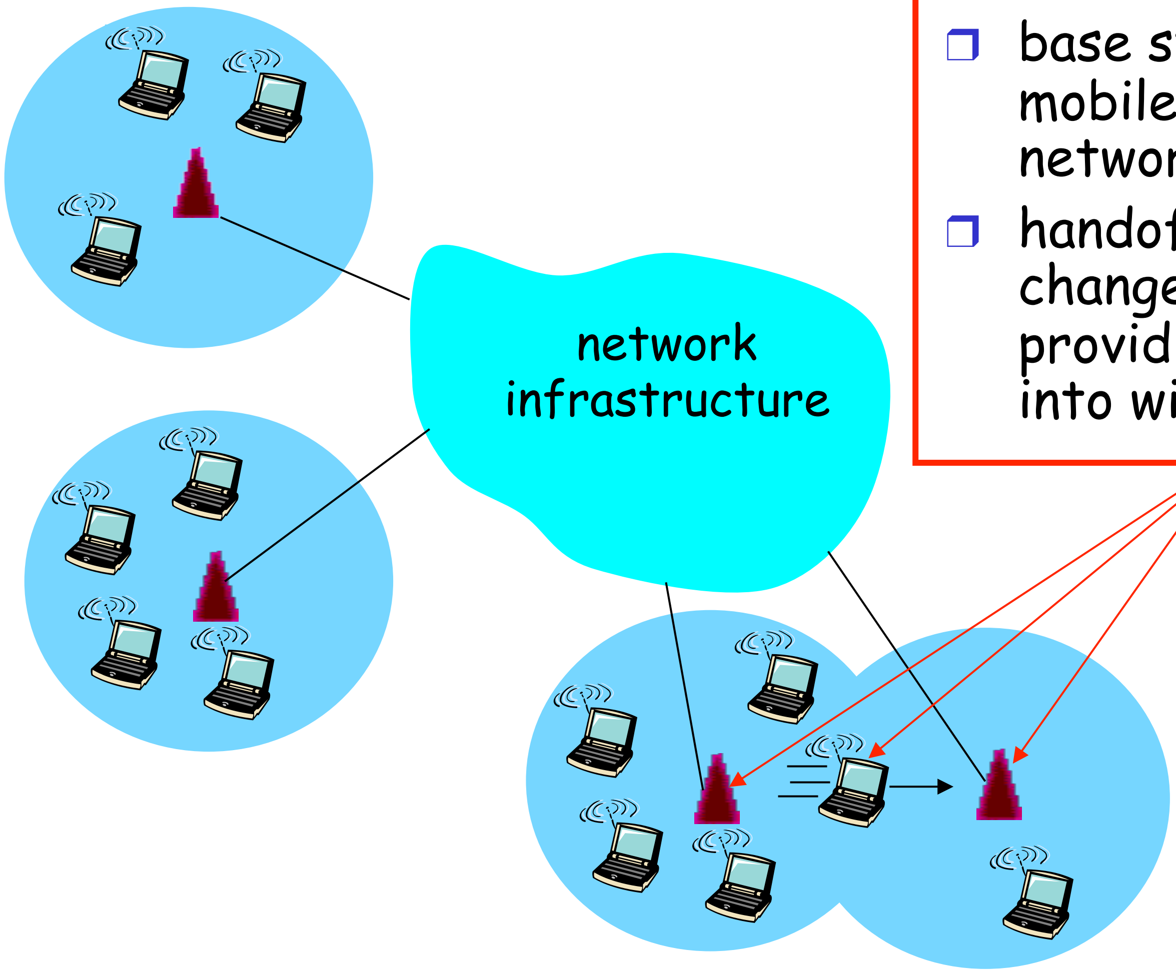
wireless link

- typically used to connect mobile(s) to base station
- also used as backbone link
- multiple access protocol coordinates link access
- various data rates, transmission distance

Characteristics of selected wireless link standards



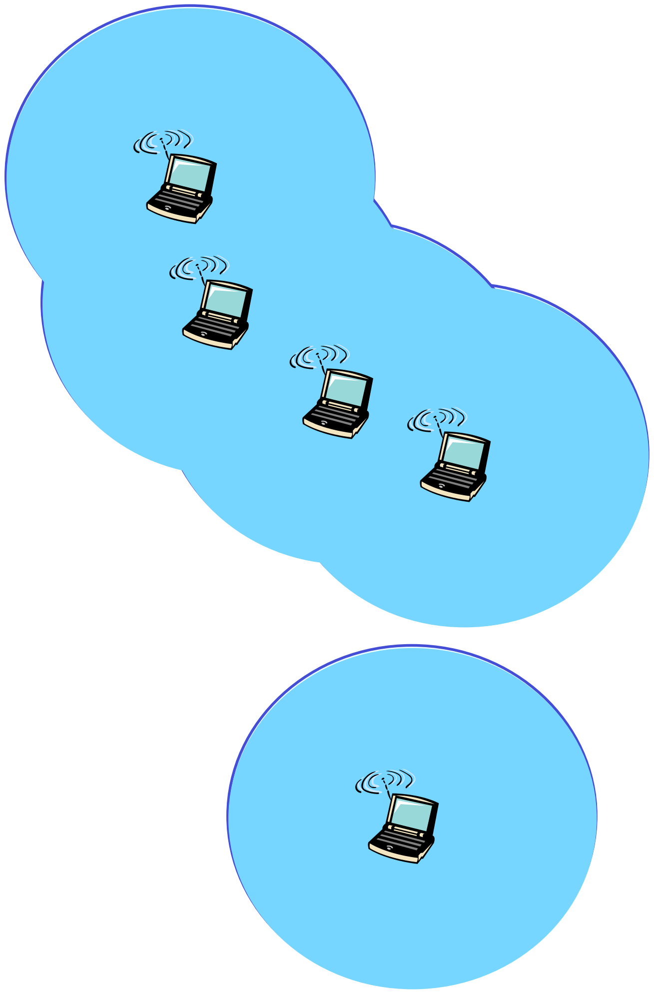
Elements of a wireless network



infrastructure mode

- base station connects mobiles into wired network
- handoff: mobile changes base station providing connection into wired network

Elements of a wireless network



ad hoc mode

- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves

Wireless network taxonomy

	single hop	multiple hops
infrastructure (e.g., APs)	host connects to base station (WiFi, WiMAX, cellular) which connects to larger Internet	host may have to relay through several wireless nodes to connect to larger Internet: *mesh net*
no infrastructure	no base station, no connection to larger Internet (Bluetooth)	no base station, no connection to larger Internet. May have to relay to reach other a given wireless node MANET, VANET

Wireless Link Characteristics (1)

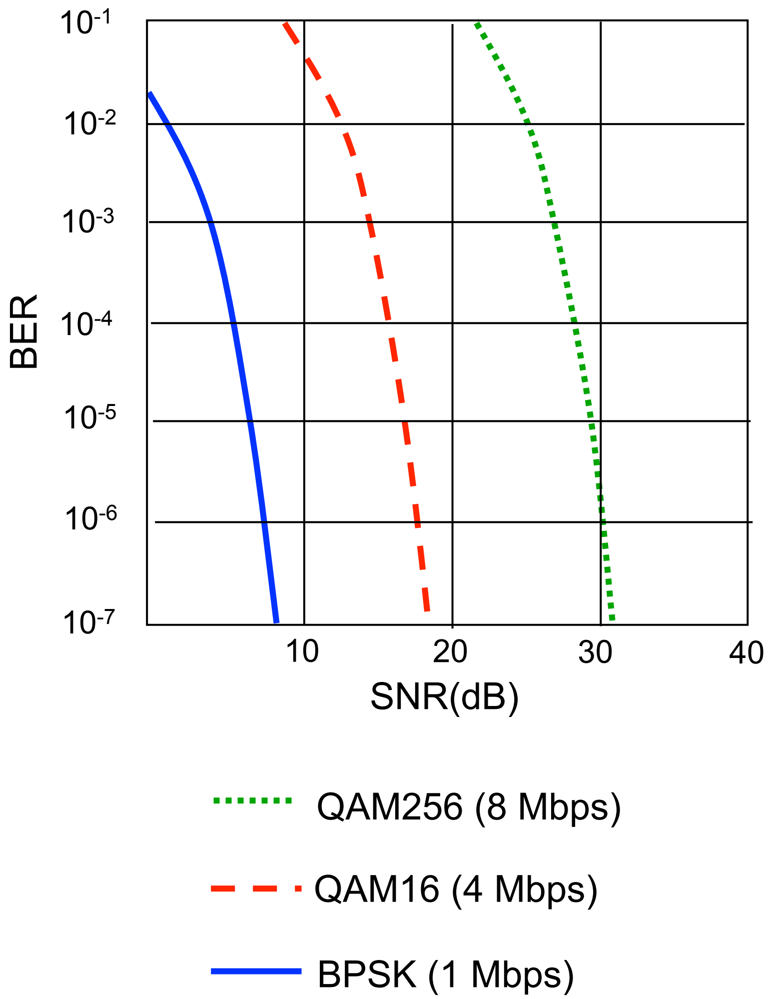
Differences from wired link ….

- decreased signal strength: radio signal attenuates as it propagates through matter (path loss)
- interference from other sources: standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- multipath propagation: radio signal reflects off objects ground, arriving at destination at slightly different times

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

Wireless Link Characteristics (2)

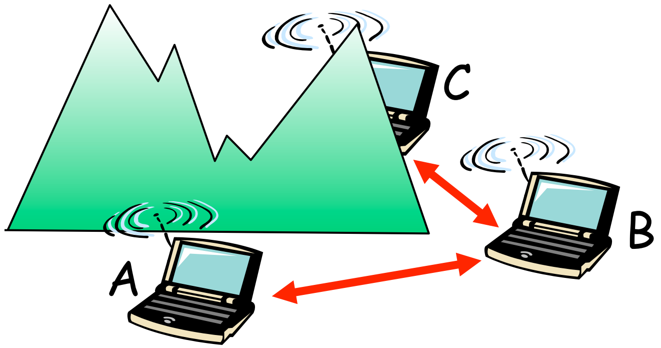
- SNR: signal-to-noise ratio
  - larger SNR – easier to extract signal from noise (a "good thing")
- *SNR versus BER tradeoffs*
  - *given physical layer:* increase power -> increase SNR->decrease BER
  - *given SNR:* choose physical layer that meets BER requirement, giving highest throughput
    - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)

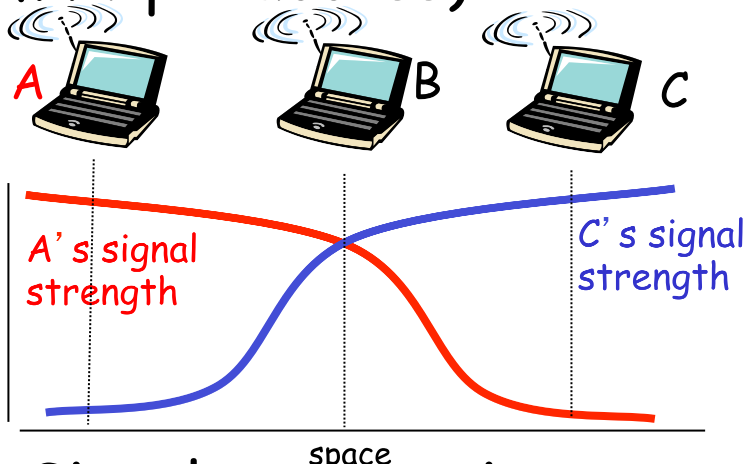


Wireless network characteristics

The wireless link is a broadcast channel

Multiple wireless senders and receivers create additional problems (beyond multiple access):





Hidden terminal problem

- B, A hear each other
- B, C hear each other
- A, C can not hear each other

means A, C unaware of their interference at B

Signal attenuation:

- B, A hear each other
- B, C hear each other
- A, C can not hear each other interfering at B

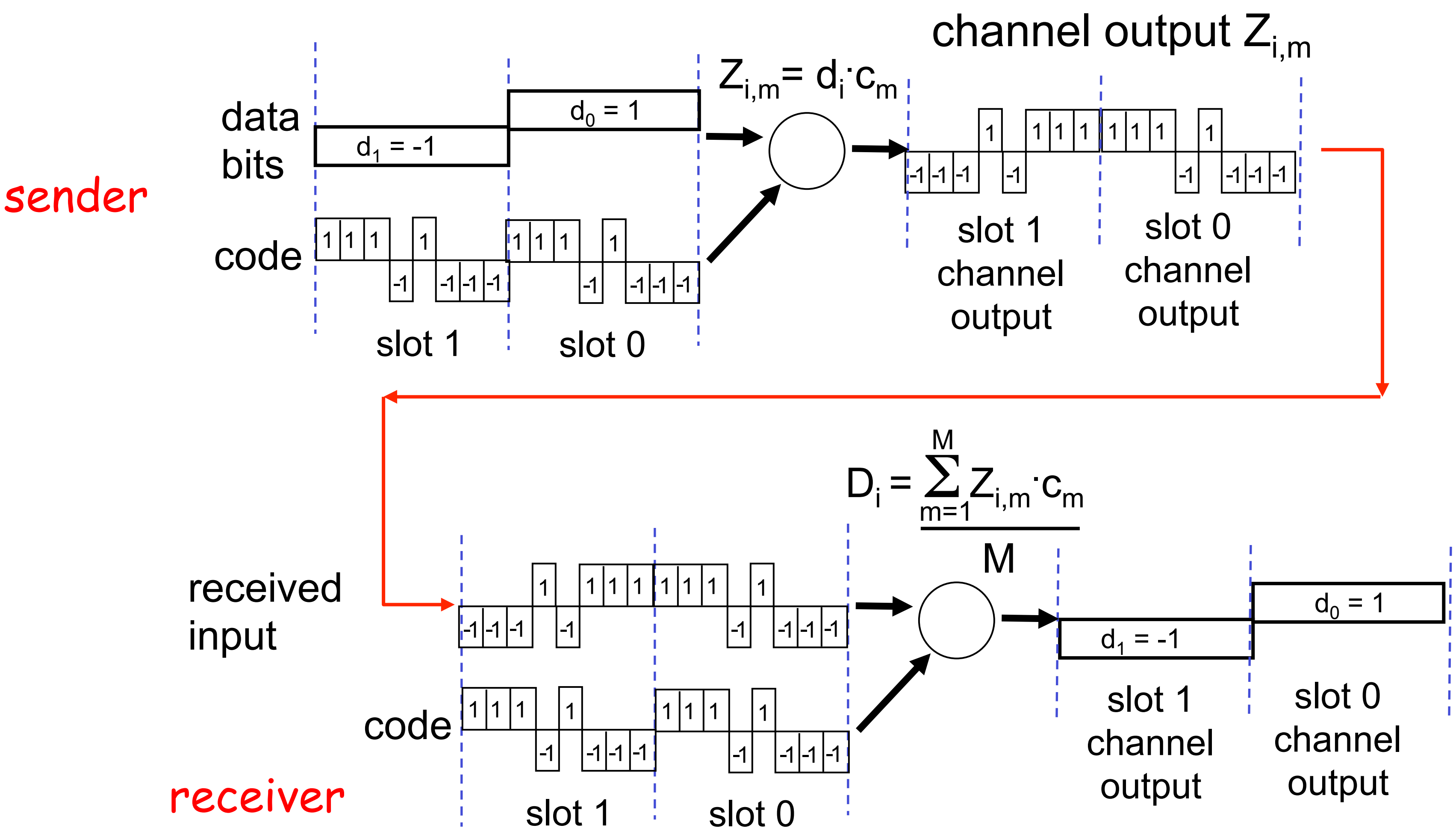
Explains why we cannot use CSMA/CD
Additional difference: typical devices cannot hear and transmit simoultaneously

Code Division Multiple Access (CDMA)

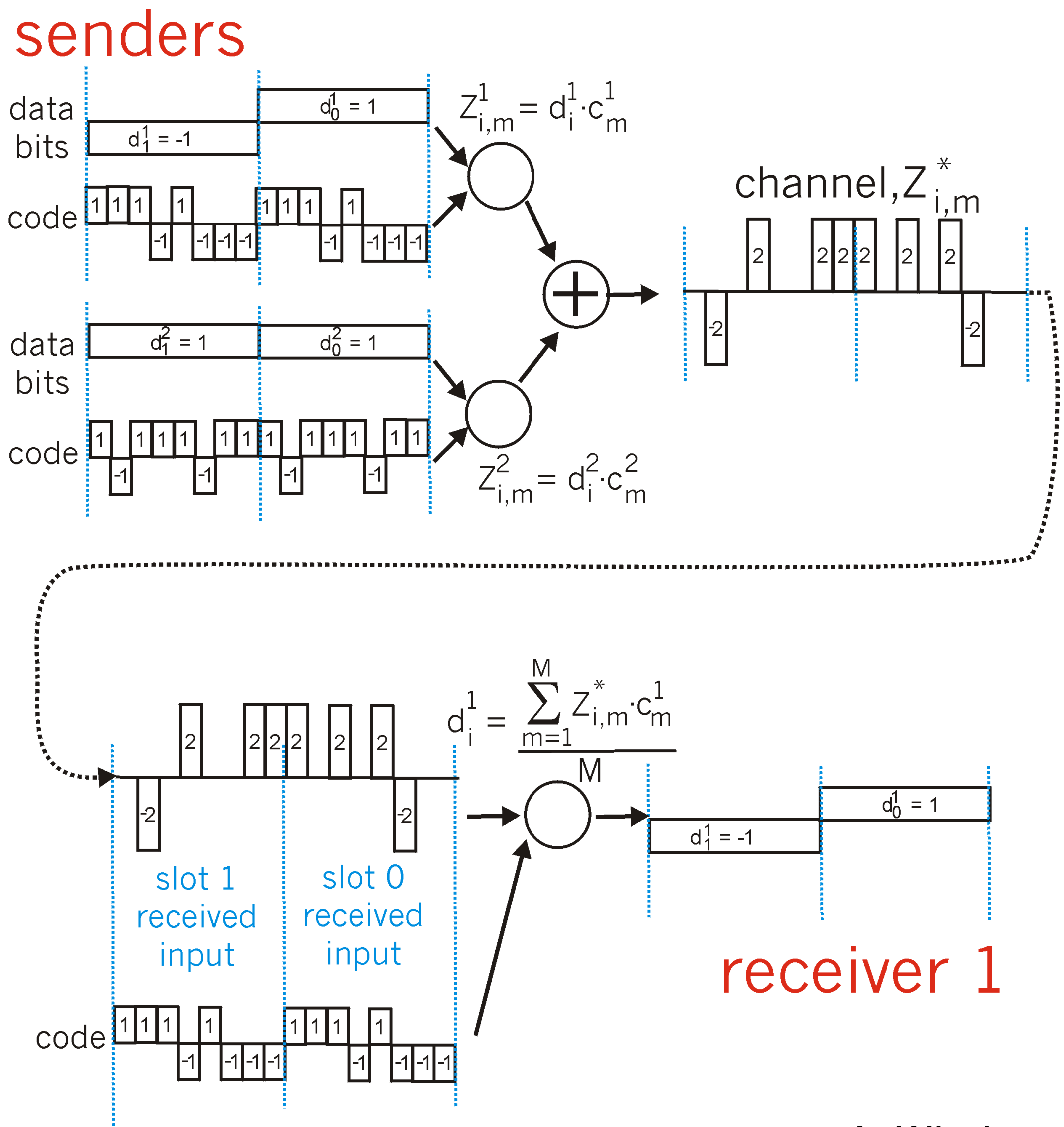
As an example of more efficient access techniques which have been developed to do a better use of the available spectrum

- used in several wireless broadcast channels (cellular, satellite, etc) standards
- unique "code" assigned to each user; i.e., code set partitioning
- all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence
- allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

CDMA Encode/Decode



CDMA: two-sender interference



Chipping codes must be orthogonal

Other requirements such as the fact signals arrivere with comparable power

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  - architecture
  - standards (e.g., GSM)

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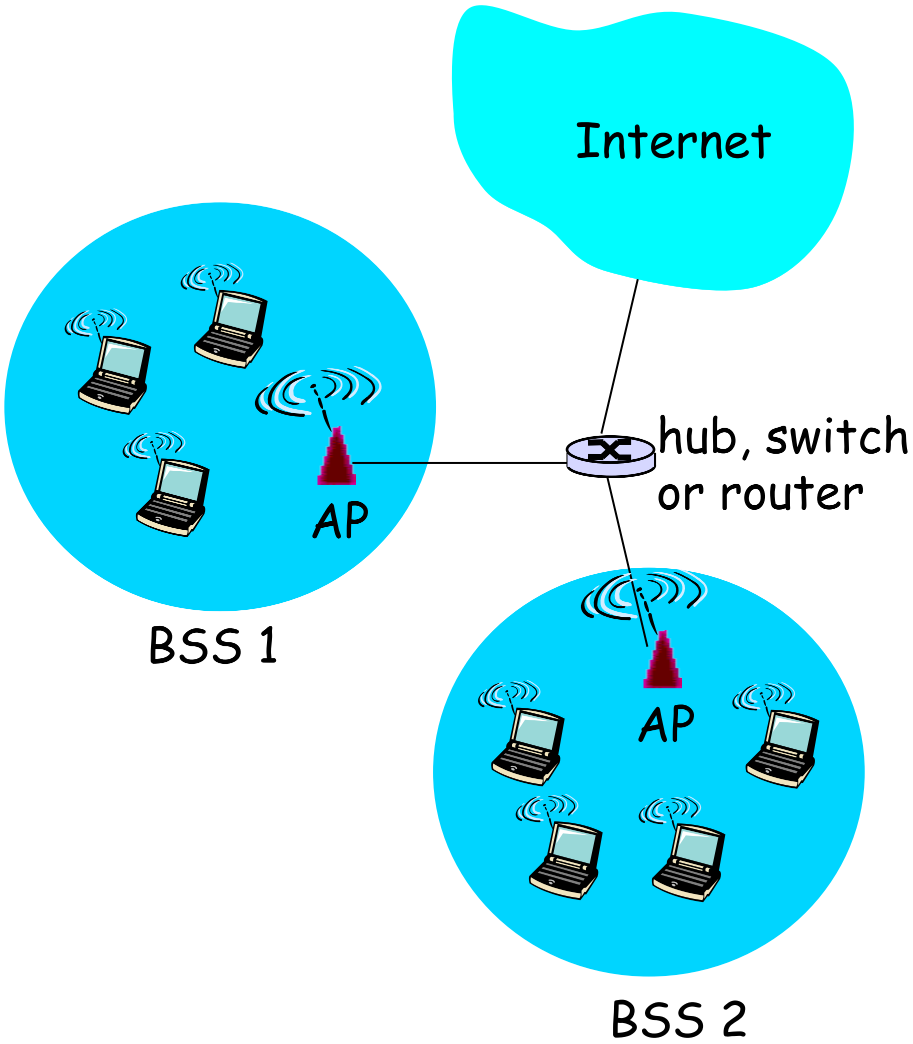
IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-5 GHz unlicensed spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - all hosts use same chipping code
- 802.11a
  - 5-6 GHz range
  - up to 54 Mbps
- 802.11g
  - 2.4-5 GHz range
  - up to 54 Mbps
- 802.11n: multiple antennae
  - 2.4-5 GHz range
  - up to 200 Mbps

- all use CSMA/CA for multiple access
- all have base-station and ad-hoc network versions

802.11 LAN architecture

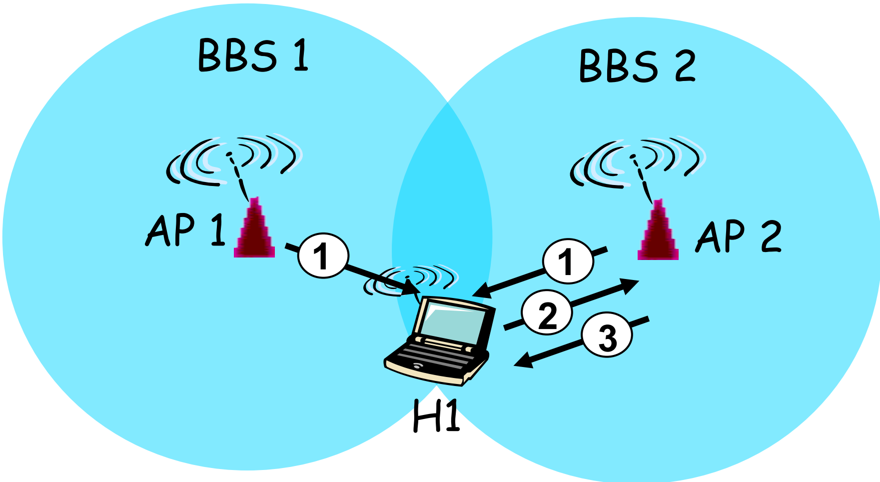


- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

802.11: Channels, association

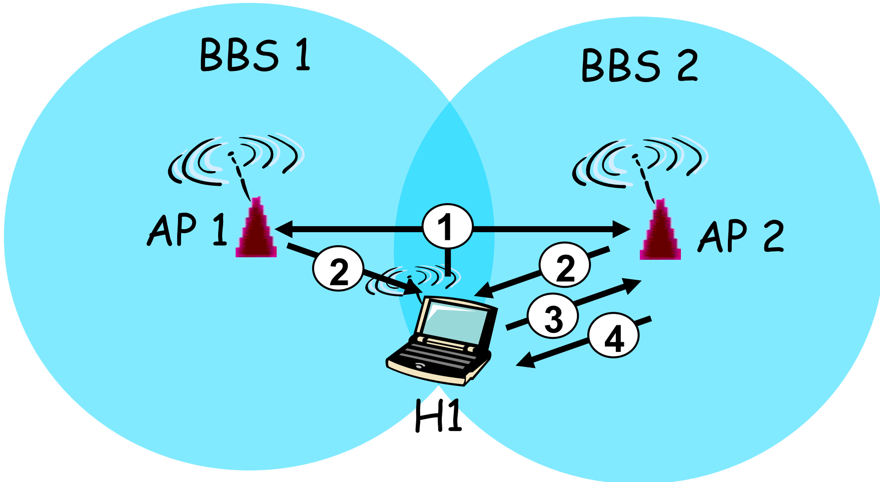
- 802.11b: 2.4GHz-2.485GHz spectrum is divided into 11 partially overlapping channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
  - maximum number of non interfering co-located AP: 3 (using channels 1,6,11), as channels are non overlapping only if they are separated by four or more channels
- host: must *associate* with an AP (usually many available, the WiFi jungle)
  - Passive scanning:
    - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
      - AP periodically sends a beacon frame
    - active scanning
      - a probe is sent by the user, APs with the range of the wireless host answer the probe
  - selects AP to associate with, sends an association request to which the AP answers
  - may need to perform authentication
  - will typically run DHCP to get IP address in AP's subnet

802.11: passive/active scanning



Passive Scanning:

(1) beacon frames sent from APs
(2) association Request frame sent: H1 to selected AP
(3) association Response frame sent: H1 to selected AP

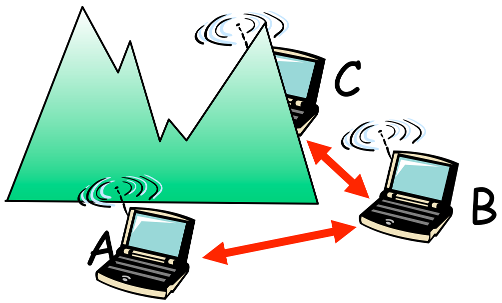


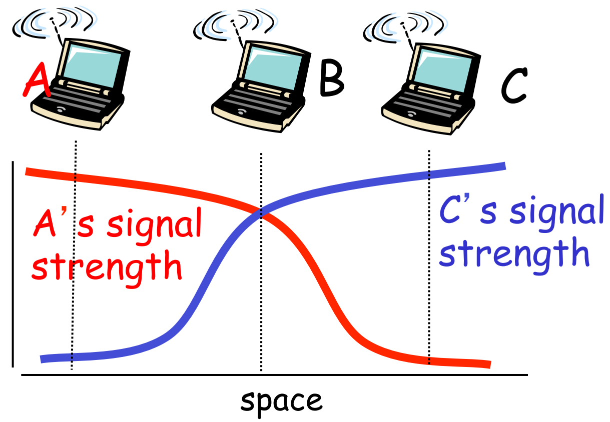
Active Scanning:

(1) Probe Request frame broadcast from H1
(2) Probes response frame sent from APs
(3) Association Request frame sent: H1 to selected AP
(4) Association Response frame sent: H1 to selected AP

IEEE 802.11: multiple access

- avoid collisions: 2$^+$ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don't collide with ongoing transmission by other node
- 802.11: *no* collision detection!
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





IEEE 802.11 MAC Protocol: CSMA/CA

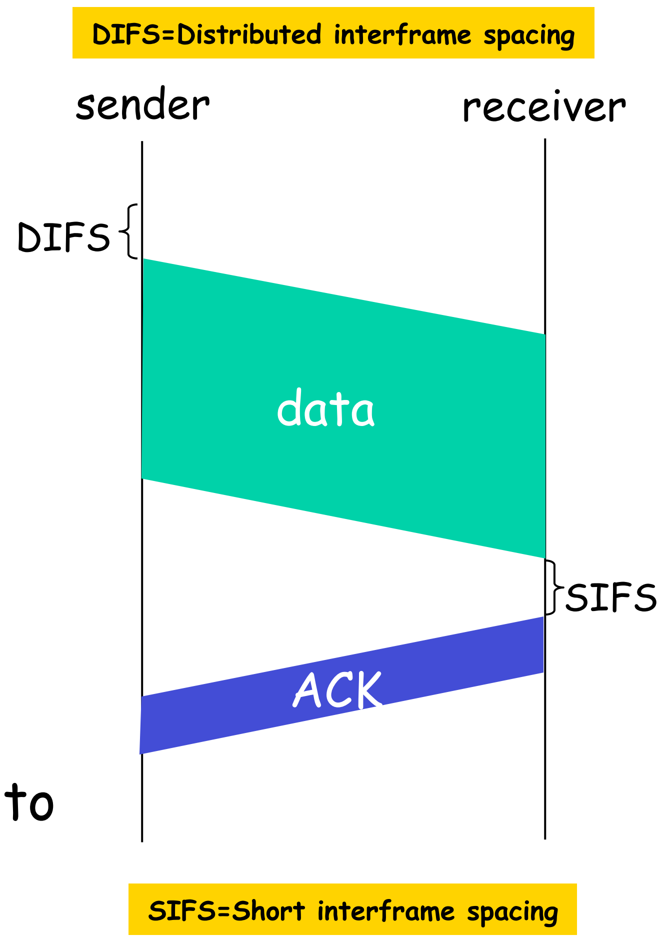
802.11 sender

1 if sense channel idle for **DIFS** then
   transmit entire frame (no CD)

2 if sense channel busy then
   start random backoff time
   timer counts down while channel idle
   transmit when timer expires
   if no ACK, increase random backoff interval, repeat 2

802.11 receiver

- if frame received OK
  return ACK after **SIFS** (ACK needed due to hidden terminal problem)
    - **SIFS <<DIFS**



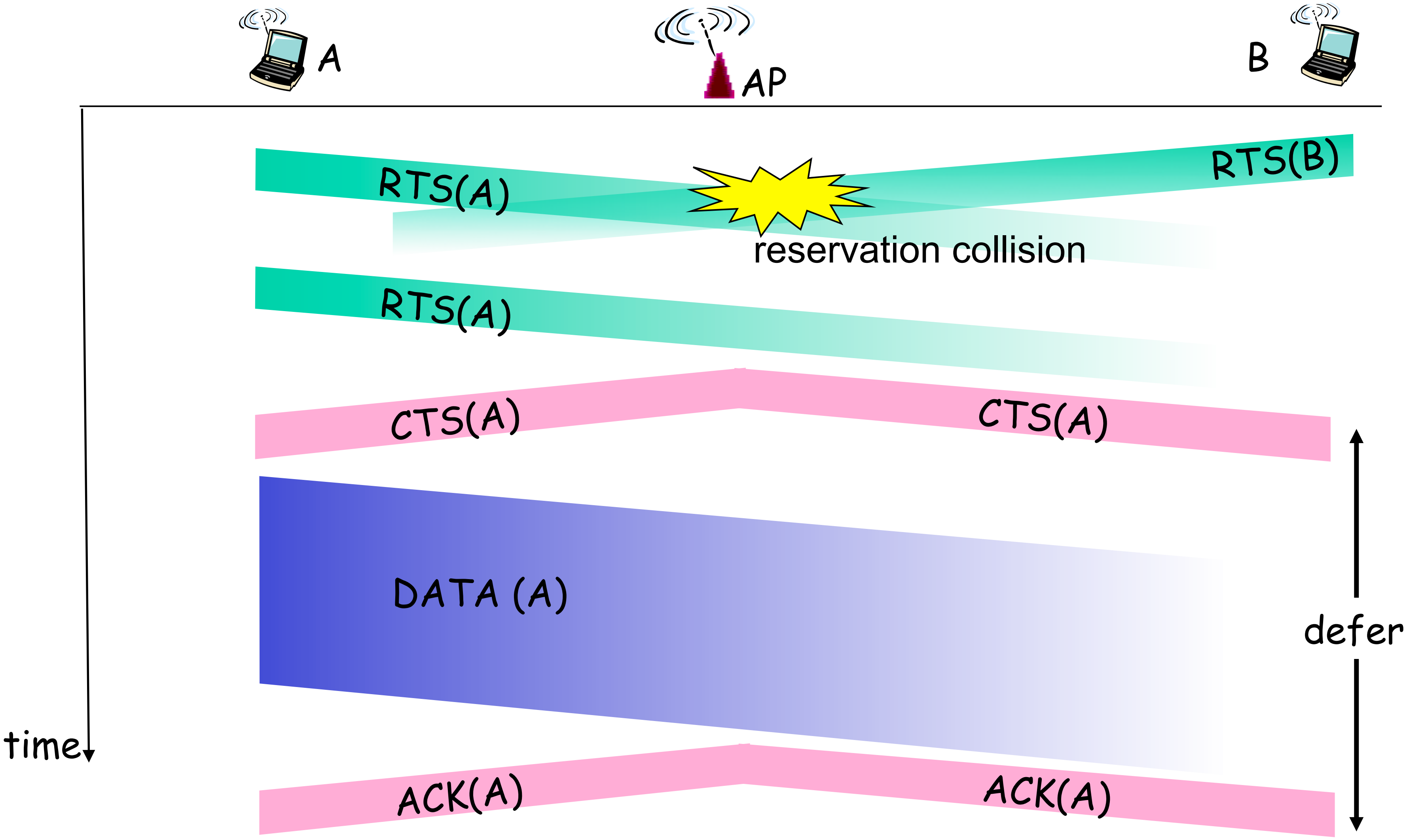
Avoiding collisions (virtual carrier sensing)

idea: allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames

- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing

2	2	6	6	6	2	6	0 - 2312	4
frame control	duration	address 1	address 2	address 3	seq control	address 4	payload	CRC

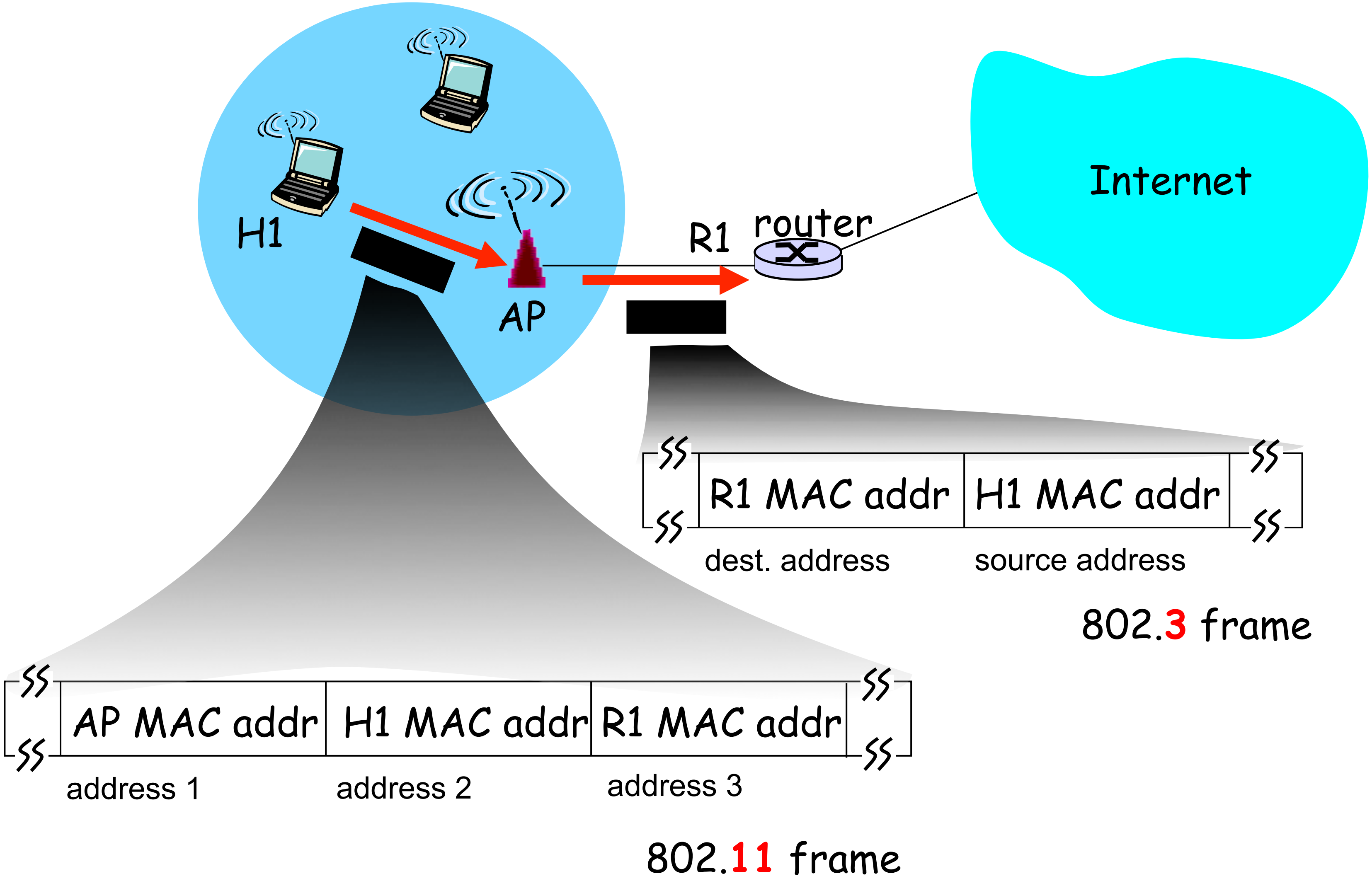
Address 1: MAC address of wireless host or AP to receive this frame

Address 2: MAC address of wireless host or AP transmitting this frame

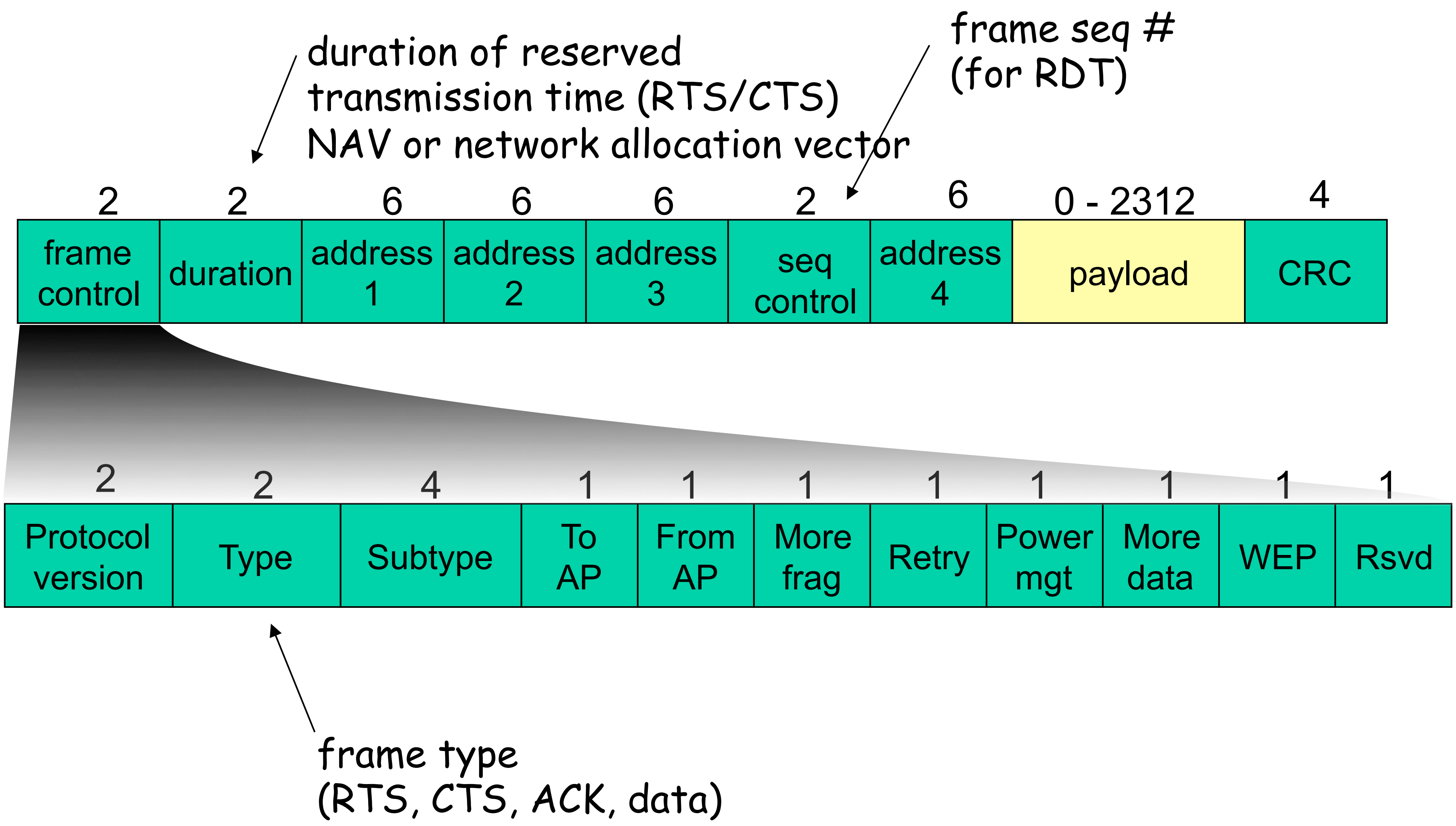
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing

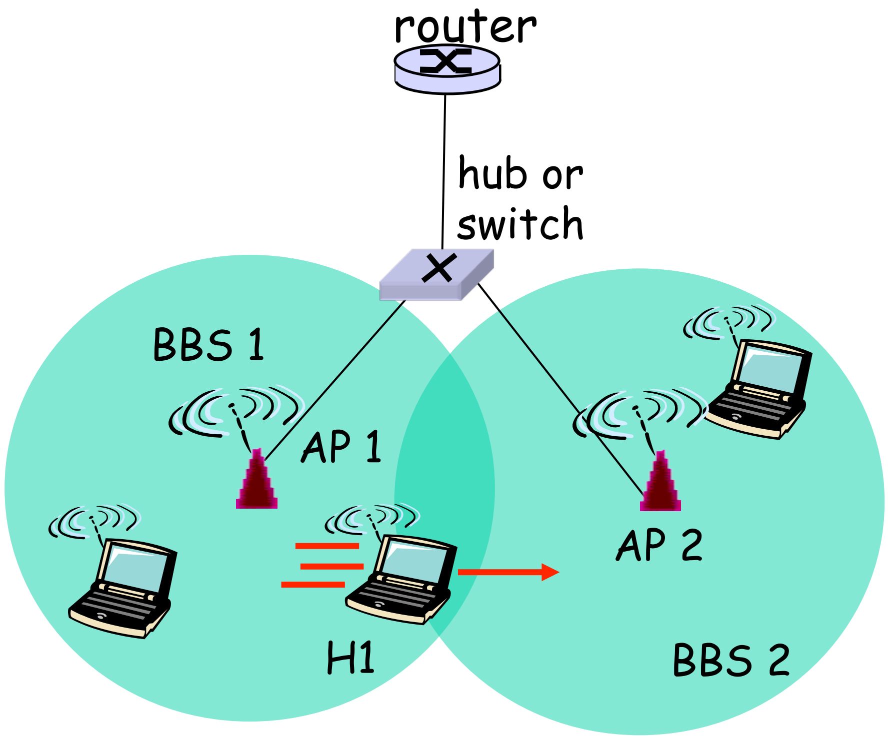


802.11 frame: more



802.11: mobility within same subnet

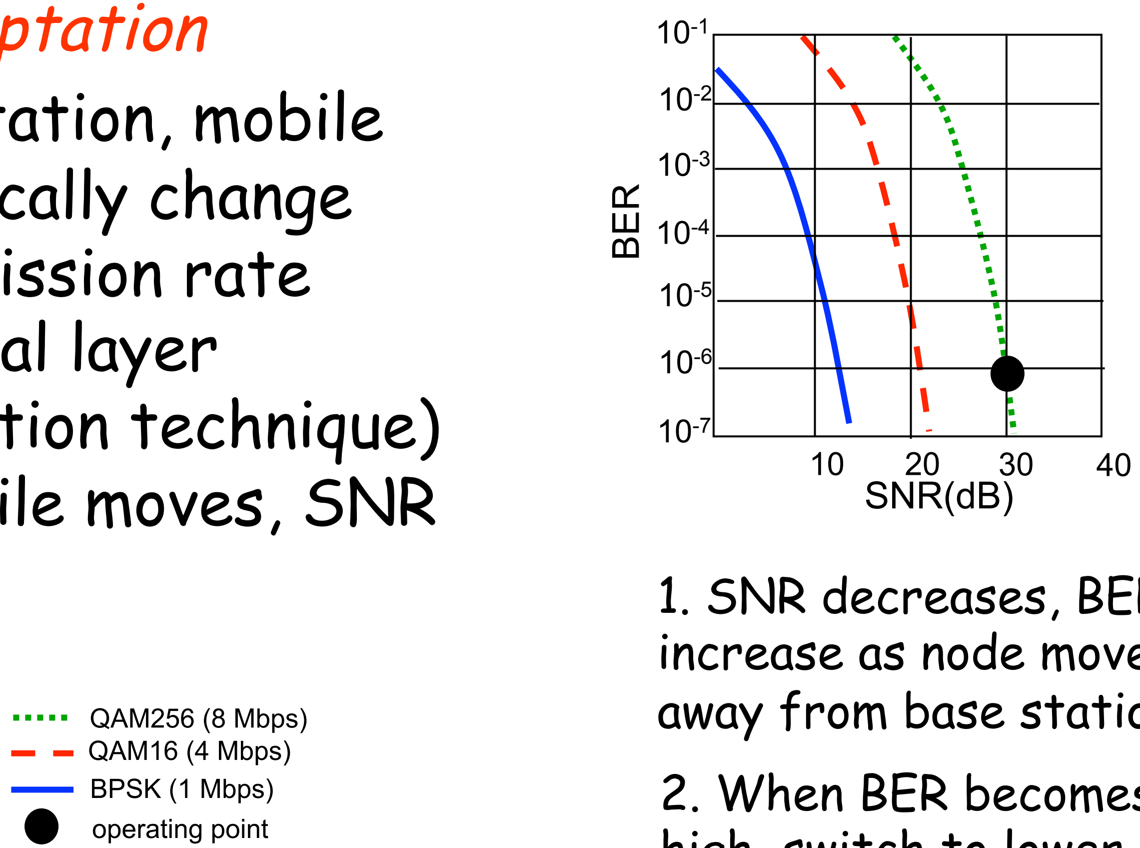
- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1



802.11: advanced capabilities

Rate Adaptation

- base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies



1. SNR decreases, BER increase as node moves away from base station

2. When BER becomes too high, switch to lower transmission rate but with lower BER

802.11: advanced capabilities

Power Management

- node-to-AP: "I am going to sleep until next beacon frame"
  - AP knows not to transmit frames to this node
  - node wakes up before next beacon frame
- beacon frame: contains list of mobiles with AP-to-mobile frames waiting to be sent
  - node will stay awake if AP-to-mobile frames to be sent; otherwise sleep again until next beacon frame

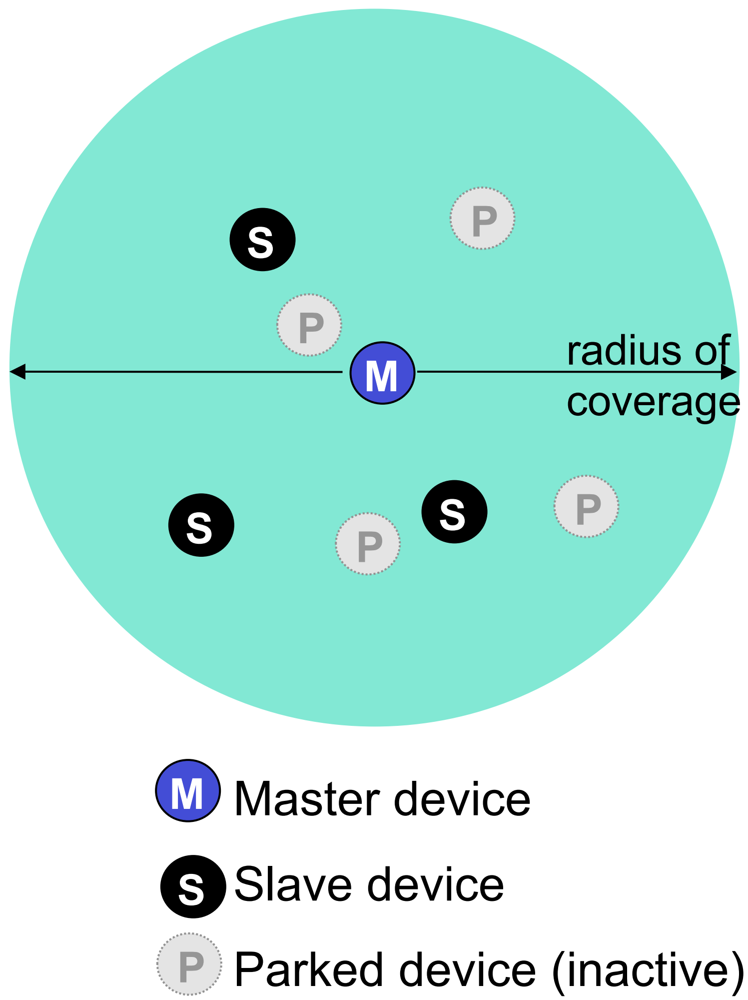
802.11: advanced capabilities

Power Management

- node-to-AP: "I am going to sleep until next beacon frame"
  - AP knows not to transmit frames to this node
  - node wakes up before next beacon frame
- duty cycle: ON time/ON+OFF
  - 250 microseconds for waking up, similar to listen to the beacon and see whether should wake up =< 1milliseconds
  - 100 milliseconds as time between two beacons
  - <1% duty cycle

802.15: personal area network

- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- master/slaves:
  - slaves request permission to send (to master)
  - master grants requests
- 802.15: evolved from Bluetooth specification
  - 2.4-2.5 GHz radio band
  - up to 721 kbps



Bluetooth (BT) History

- Named after a Danish Viking King who unified and controlled Denmark and Norway

  → BT aims at unifying telecom. and computing industries

- First standard release in 1999 (v 1.0)
- BT Special Interest Group counts over 1800 members, including Ericsson,Nokia, IBM, Intel, Toshiba,Microsoft, Lucent, 3Com, Motorola...
- All BT SIG members agree to provide key technologies for development, have BT license and BT brand for free

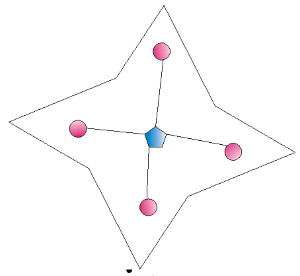
Bluetooth Technology (BT):

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

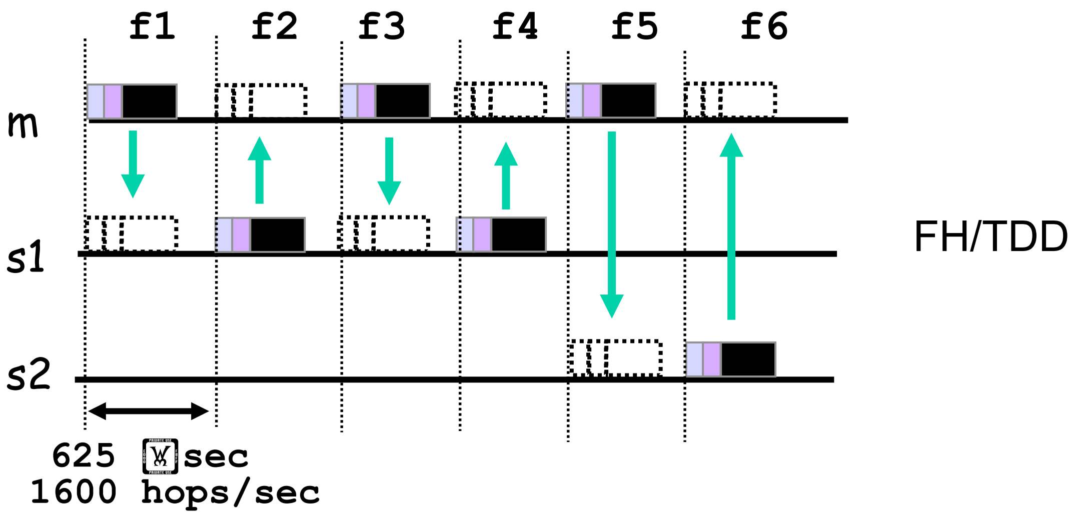
    ↓ low interference, security
- Time divided in slots (1 slot = 625 μs)
- Packet size: 1, 3 or 5 slots
- Short range communication (10 - 100 m)

Bluetooth: Piconets

- **BT devices are organized in *piconets*, clusters of :**
  - One master
  - Multiple slaves, no more than 7 actively communicating

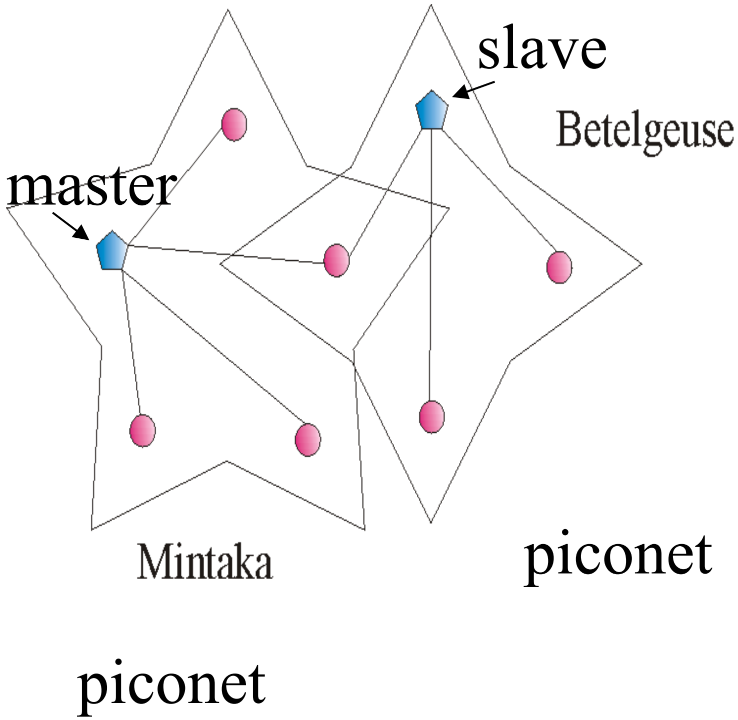


- **Synchronization based on master ID and clock**
  - Based on the master ID and clock a frequency hopping sequence is computed → all devices in a piconet use the same sequence
- **Master (M) – Slave (S) communication**



Bluetooth: Scatternets

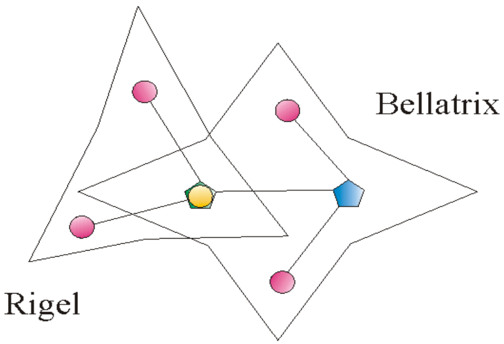
Figures from "Bluestar" description
A possible scatternet formation protocol
By Petrioli C. and Basagni S.

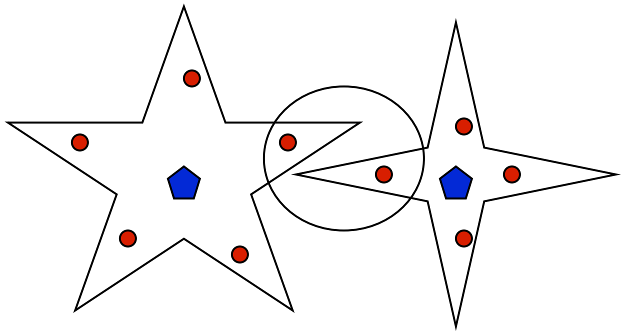


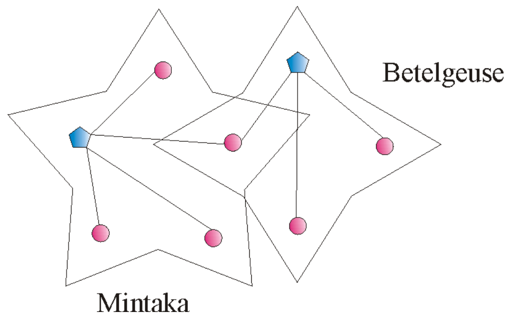
- Nodes can have multiple roles
- Nodes with multiple roles timeshare between multiple piconets
- A **scatternet** enables multi-hop communication

Piconets Interconnection

Problematic.
Why?







master/slave

additional piconet interconnecting neighbor slaves

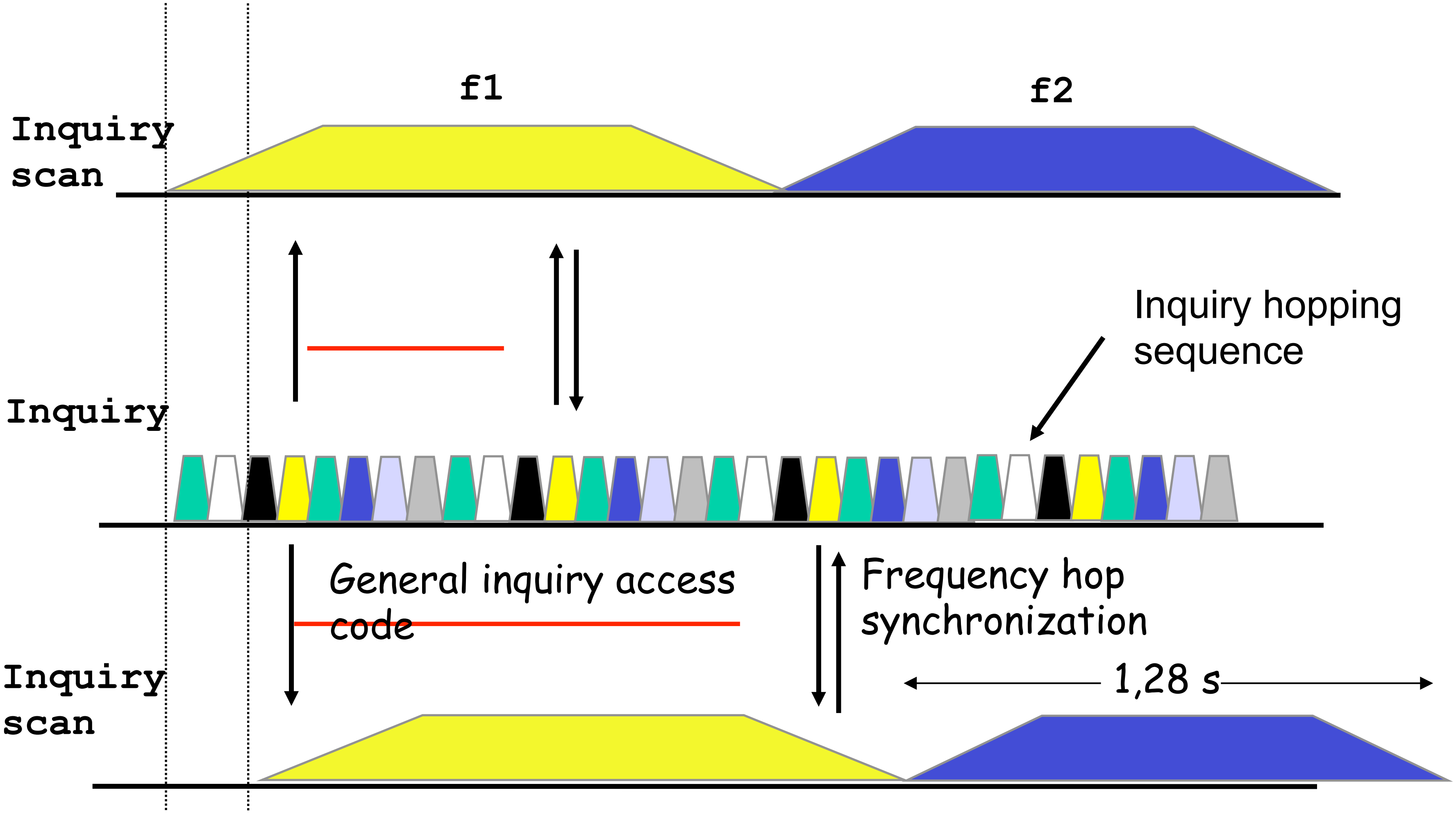
common slave

Efficiency

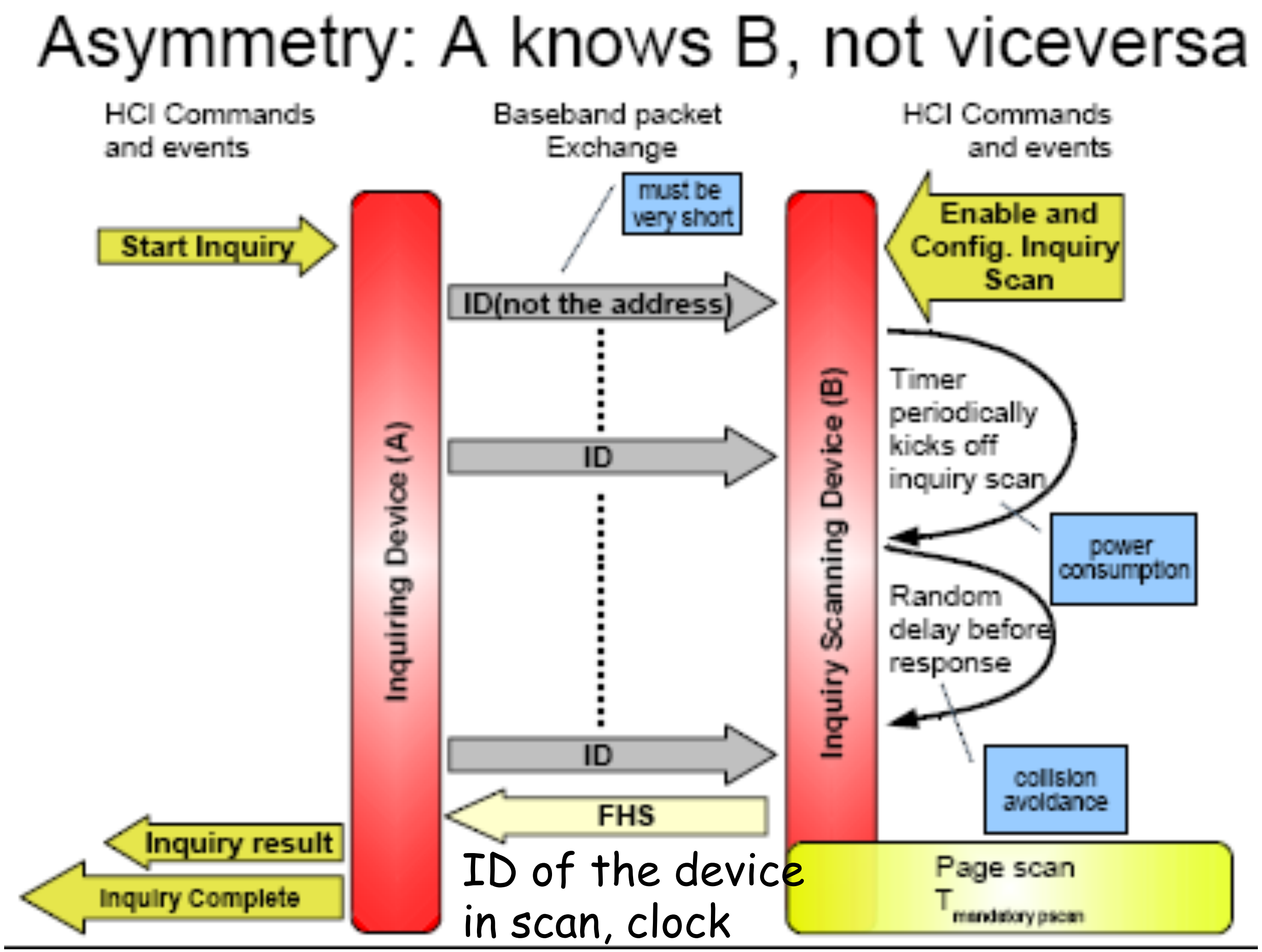
Scatternet Formation

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

Inquiry procedure



Device Discovery

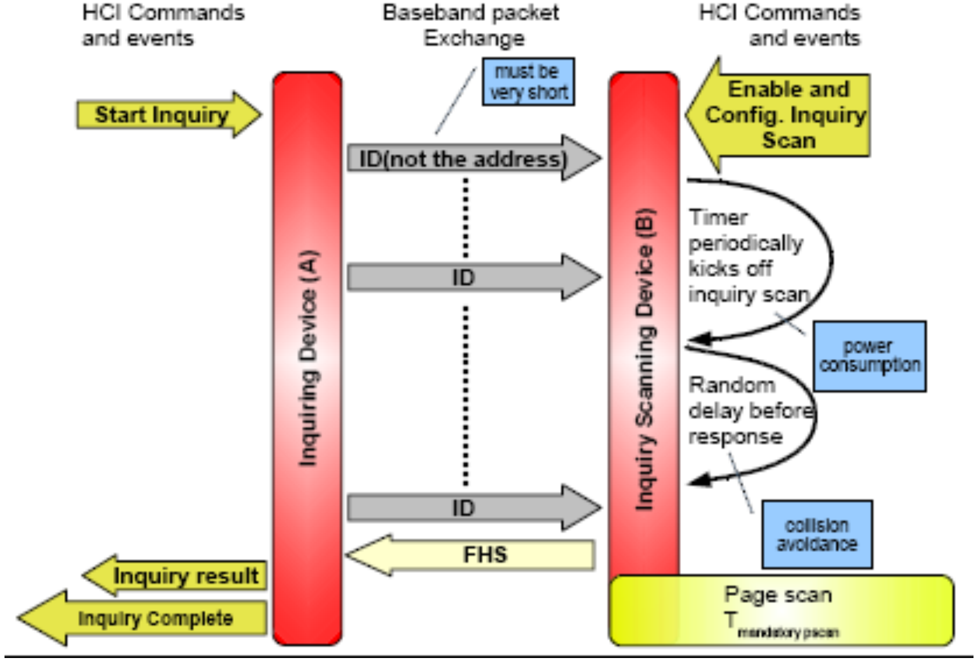


Device discovery in BT standard

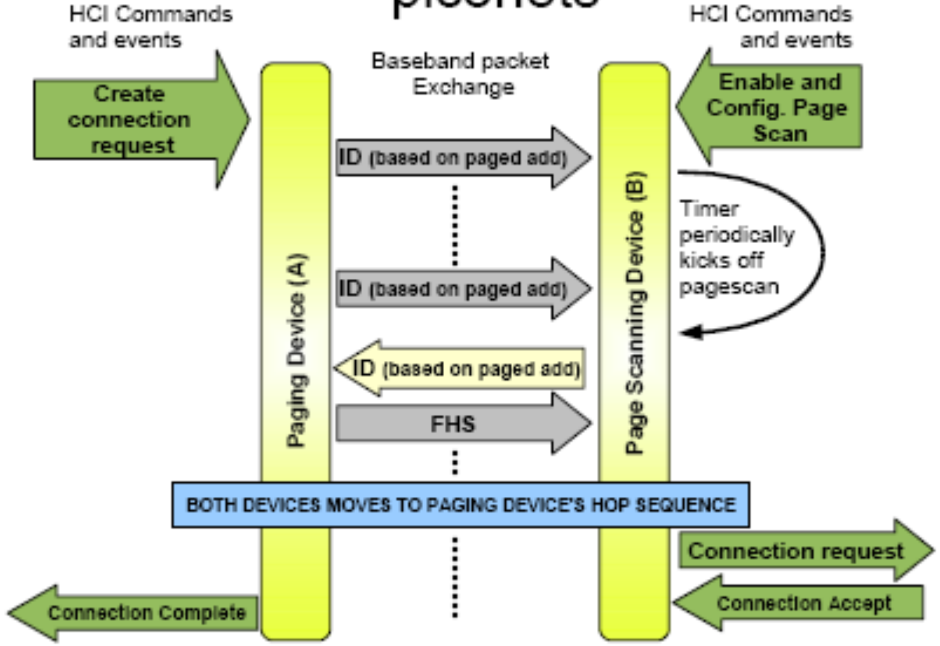
- Requires neighbor nodes to be in opposite modes (inquiry/inquiry scan)
- Leads to asymmetric neighbor discovery
  - The inquirer gather information on the neighbor BT clock and address, not viceversa

Device Discovery

Asymmetry: A knows B, not viceversa



Breaking asymmetry: "temporary" piconets



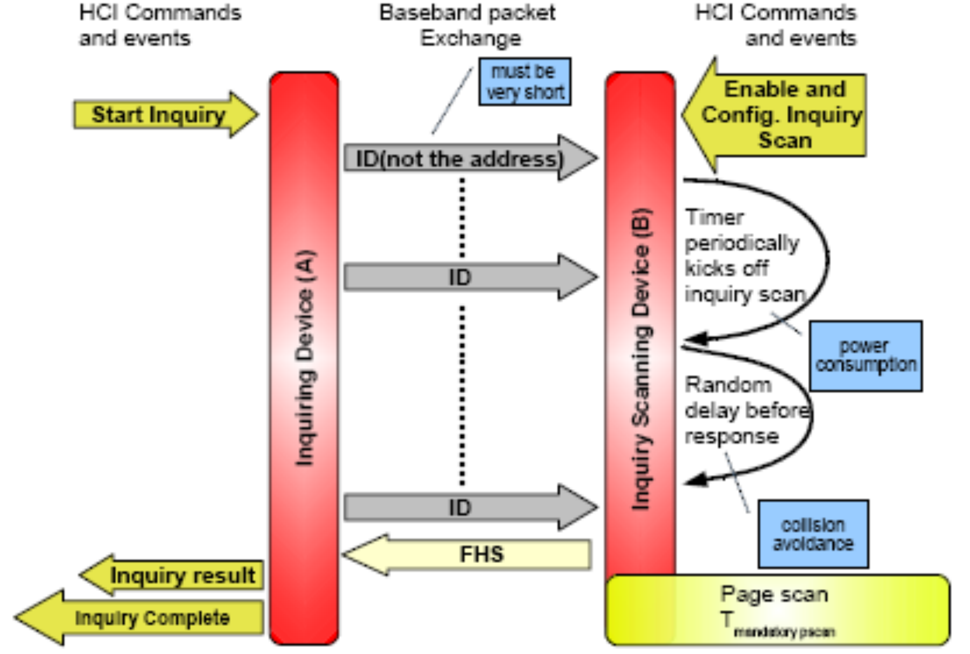
Symmetric device discovery

First proposed by Salonidis,Tassiulas, Baghwat, INFOCOM 2001

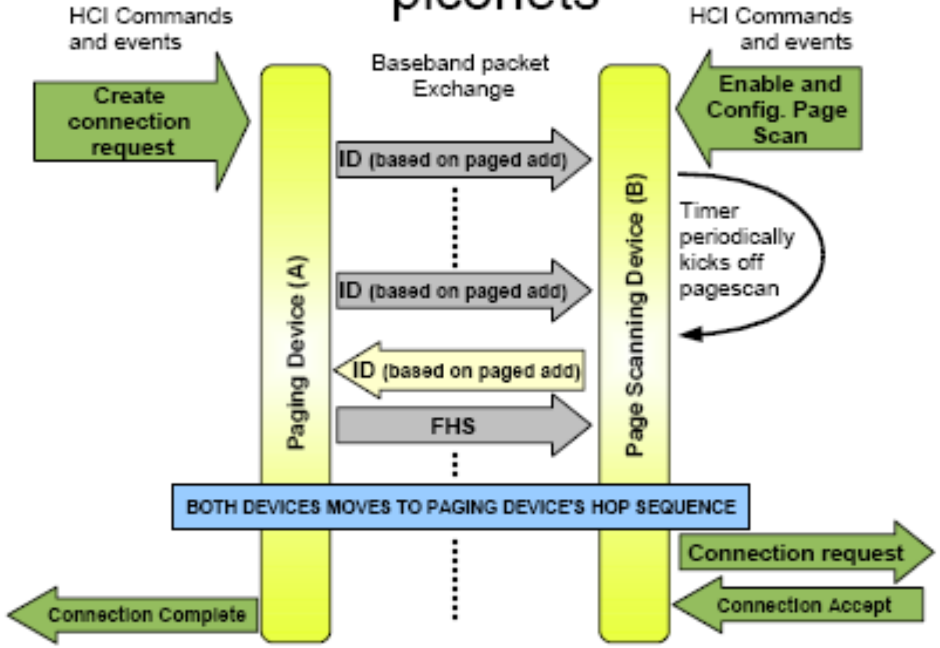
- Nodes alternate between inquiry and inquiry scan mode
- Random residence times in a mode
- Nodes perform standard inquiry (inquiry scan) procedures when in inquiry (inquiry scan) mode
- Idea: "two nodes discover each other when they are in opposite mode for sufficiently long time"

Device Discovery

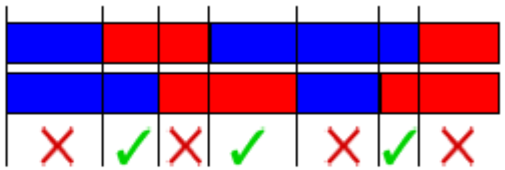
Asymmetry: A knows B, not viceversa



Breaking asymmetry: "temporary" piconets



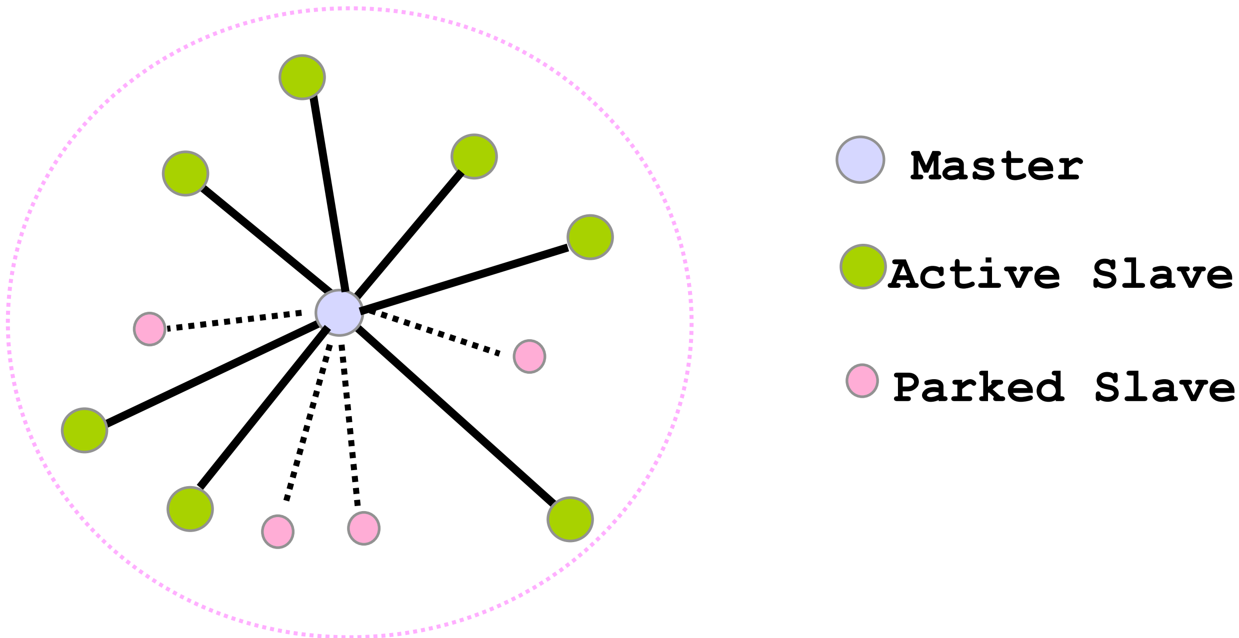
Nodes alternate between inquiry and inquiry scan, randomly selecting the lengths of these two phases



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

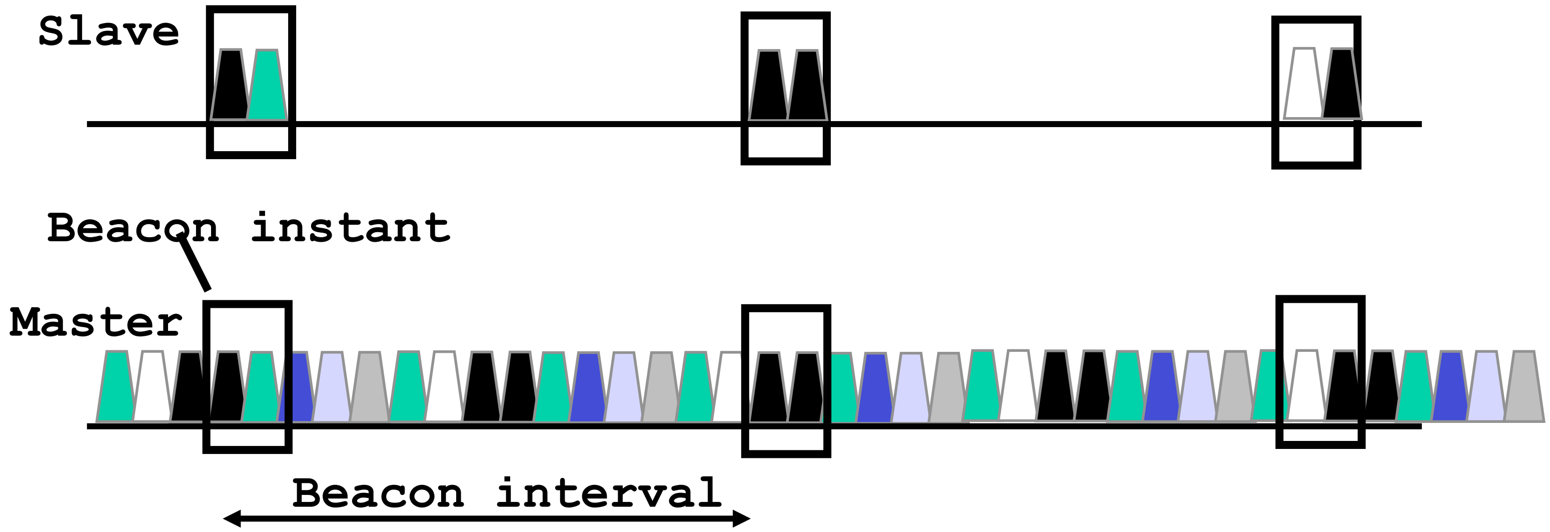
Piconet formation

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



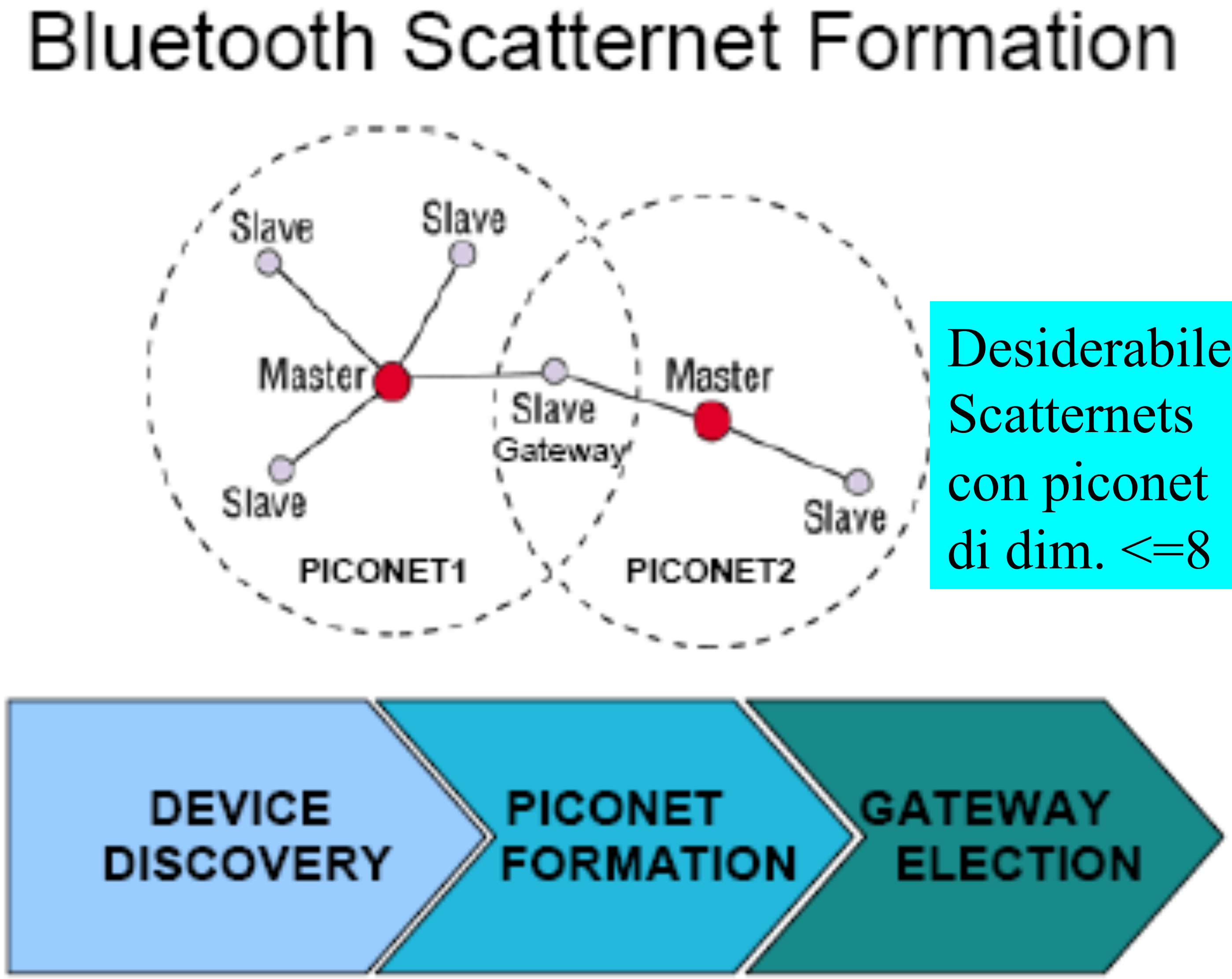
Low Power mode (Park)

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



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

Scatterner formation



Desiderabile Scatternets con piconet di dim. <=8

Scatternet formation protocols

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

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

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

Scheduling and Routing

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

Bluetooth in a Nutshell

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

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