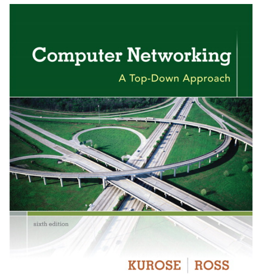
Chapter 6 Wireless and Mobile Networks



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Computer Networking: A Top Down Approach
6[th] edition
Jim Kurose, Keith Ross
Addison-Wesley
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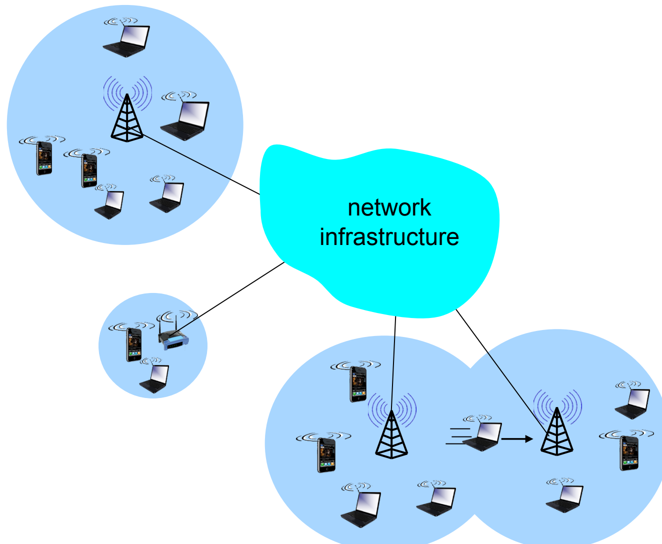
Ch. 6: Wireless and Mobile Networks

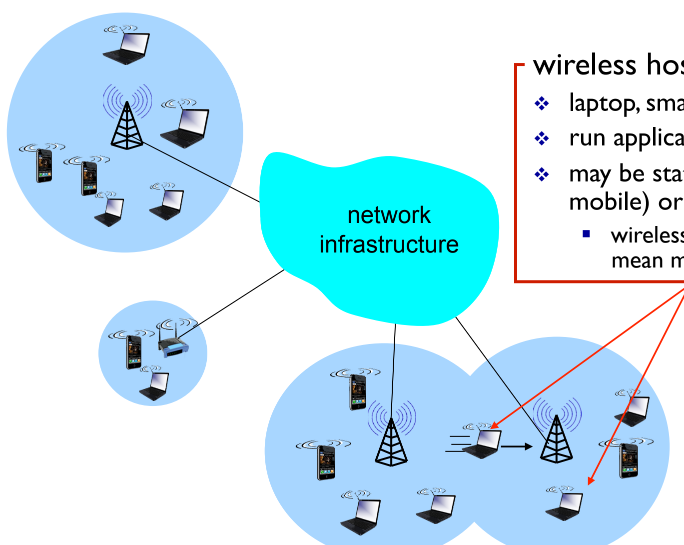
Background:

- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers (5-to-1)!
- # wireless Internet-connected devices equals # wireline Internet-connected devices
  - laptops, Internet-enabled phones 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

Elements of a wireless network



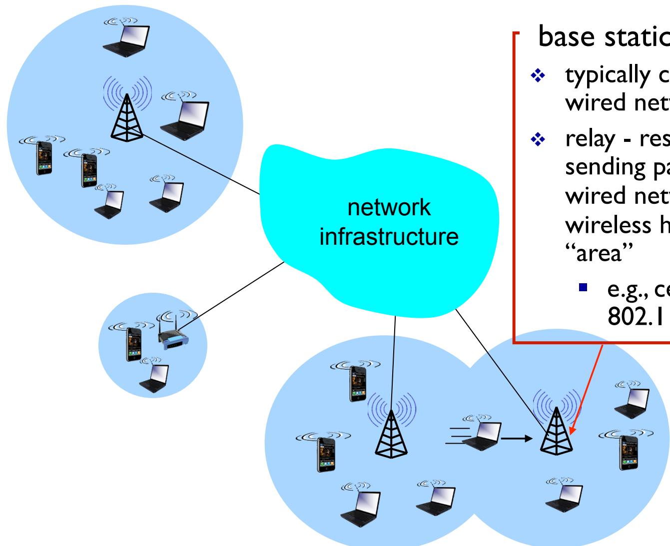
Elements of a wireless network



wireless hosts

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

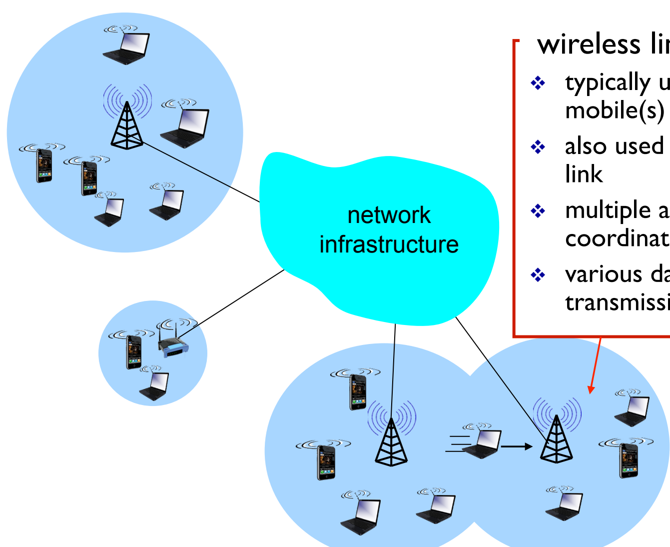
Elements of a wireless network



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

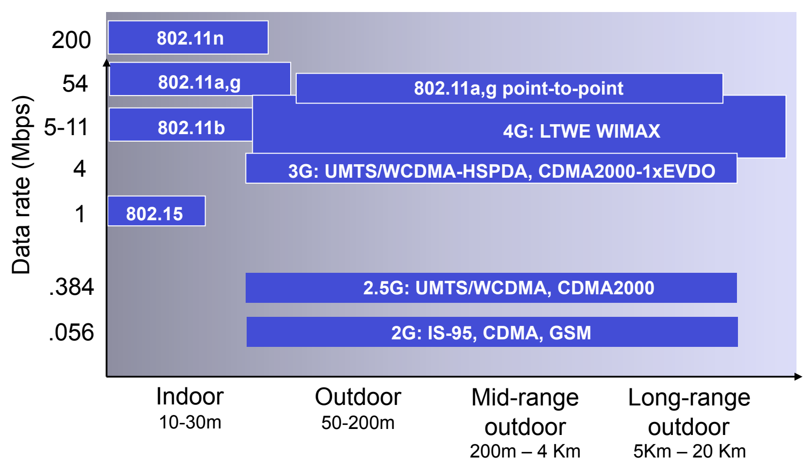
Elements of a wireless network



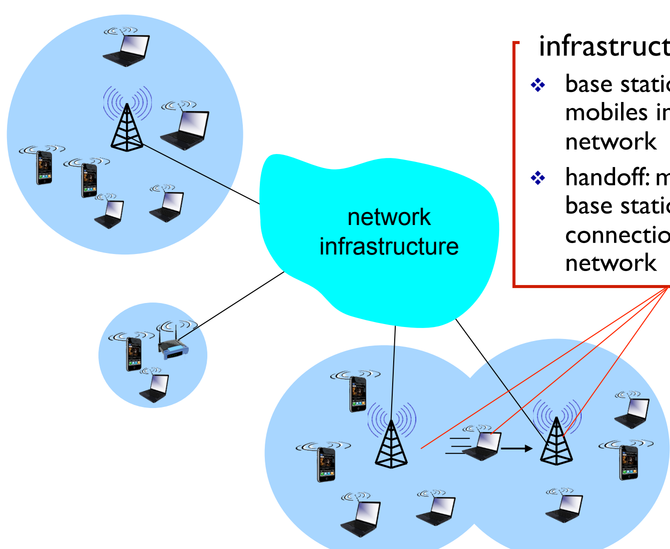
wireless link

- 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 links



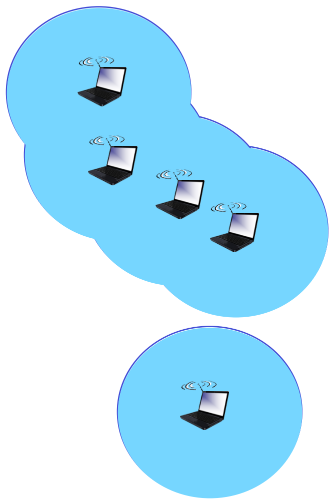
Elements of a wireless network



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, ad hoc nets)	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)

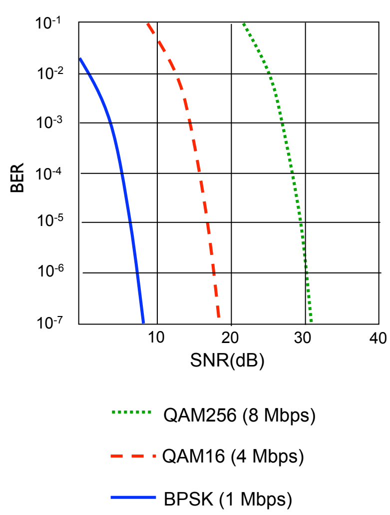
important differences from wired link ….

- *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 ad destination at slightly different times

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

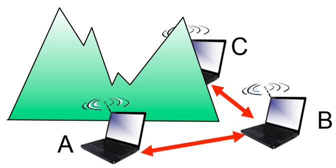
Wireless Link Characteristics (2)

- 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 thruput
    - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)



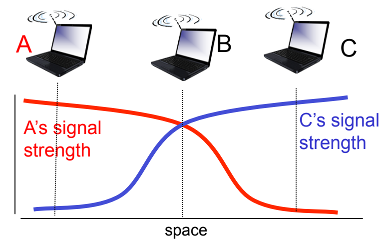
Wireless network characteristics

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

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

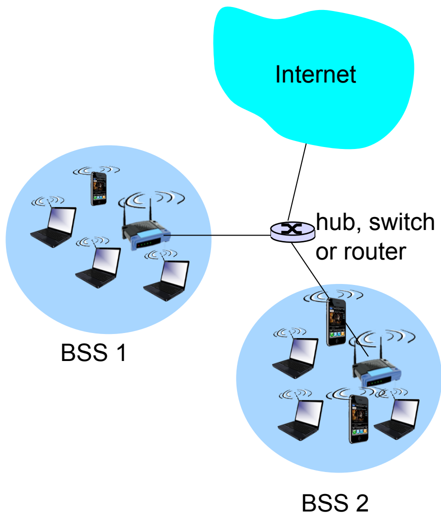
- 2.4-5 GHz range
- up to 54 Mbps

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

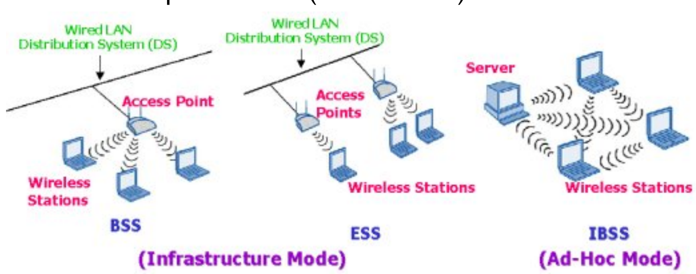
802.11 LAN architecture



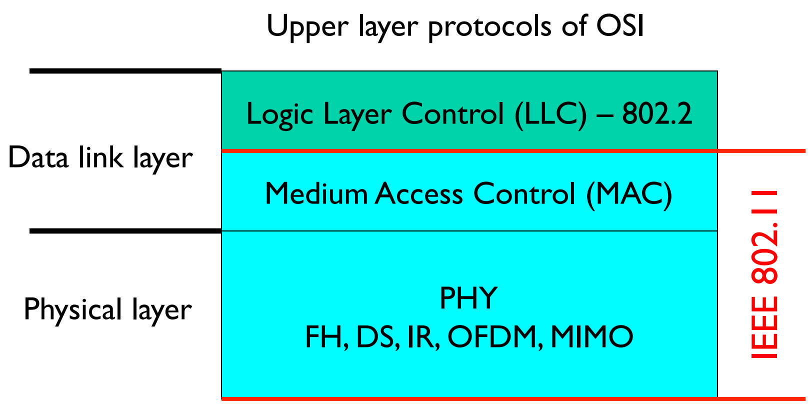
- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

802.11 WLAN

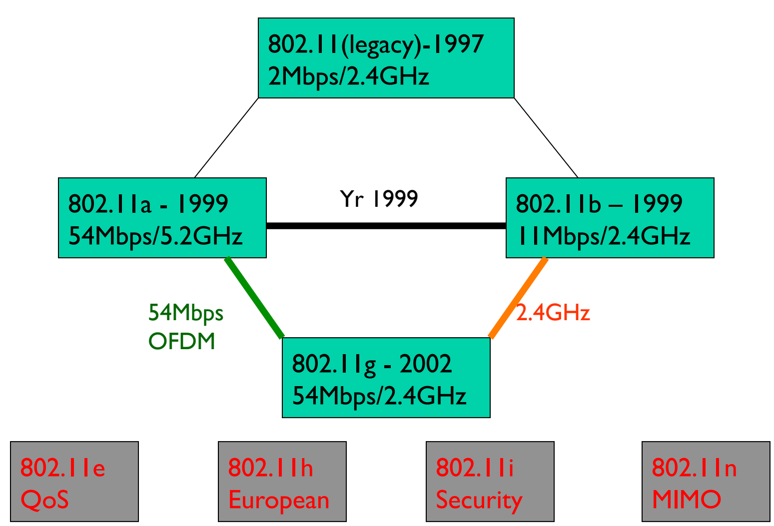
- 802.11 WLAN components
  - Access Point (AP) + Mobile Stations (STA) + Distribution System (DS)
- 802.11 WLAN Modes
  - BSS – basic service set (infrastructure mode)
    - ESS – extended service set (multiple AP's)
  - IBSS – independent BSS (ad hoc mode)



IEEE 802.11– Scope of Standard



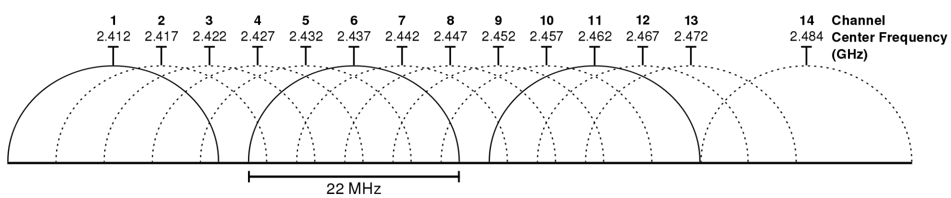
IEEE 802.11 Early Family Members



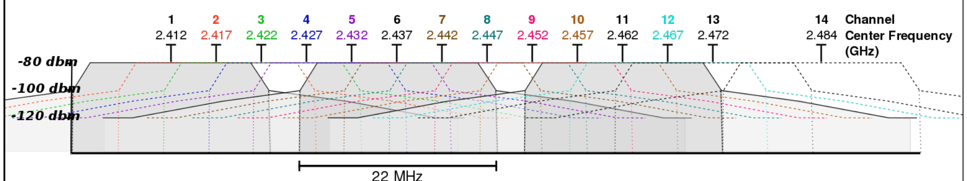
802.11: Channels, association

- 802.11b: 2.4GHz-2.485GHz spectrum divided into 14 channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- host: must *associate* with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - may perform authentication
  - will typically run DHCP to get IP address in AP's subnet

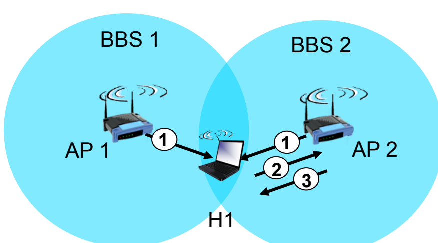
2.4 GHz ISM Band Channelization

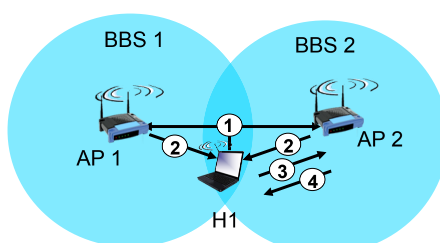


2.4 GHz ISM Band Channelization



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 from selected AP to H1

active scanning:

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

IEEE 802.11 Legacy

- Standardized by the .11 Working Group
- 1-2Mbps wireless LAN
- Multiple PHY layer choices
- Centralized and ad hoc control
- Great start point

PHY – Physical Layer (legacy)

- Diffused Infrared (IR)

2.4~2.483GHz ISM band:

- Frequency-Hopping Spread Spectrum (FHSS)
  - Dwell time = 20μs
  - 79 1MHz channels with 22 hopping patterns
- Direct-Sequence Spread Spectrum (DSSS)
  - Barker sequence – 11-bit chipping sequence
  - 14 partially overlapping 22MHz channels
    - Center frequencies 5MHz apart
  - Channels 1~11 available in N. America
    - 1, 6, 11 can operate at the same time with 25 MHz apart

PHY – Physical Layer (cont'd)

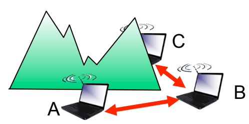
- HR-DSSS (802.11b)
  - CCK (Complementary Code Keying)
- OFDM (802.11 a/g/p)
  - Using multiple subcarriers at the same time
- MIMO (802.11n/ac)
  - Multiple simultaneous transmitters and receivers

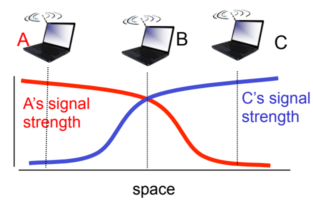
MAC Main Requirements

- Single MAC to support *multiple PHYs*
  - Support single and multiple channel PHYs
  - and PHYs with different *Medium Sense* Characteristics
- Should allow overlap of *multiple networks* in the same area and channel space
  - Need to be able to share the medium
  - Allow re-use of the same medium
- Need to be robust for interference
  - Microwave interferers
  - Other un-licensed spectrum users
  - Co-channel interference
- Need mechanisms to deal with *Hidden Terminals*
- Need provisions for *Time Bounded Services*
- Need provisions for *Privacy and Access Control*

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

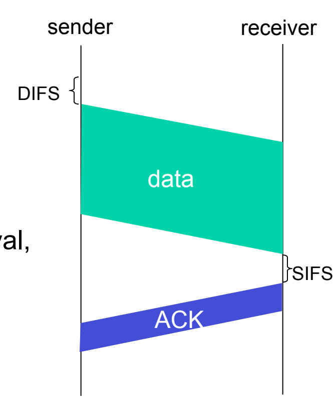
802.11 sender

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

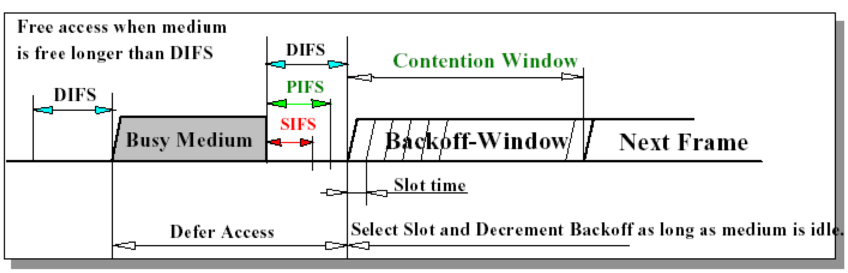
- if frame received OK
  return ACK after **SIFS** (ACK needed due to hidden terminal problem)



Coordination Functions

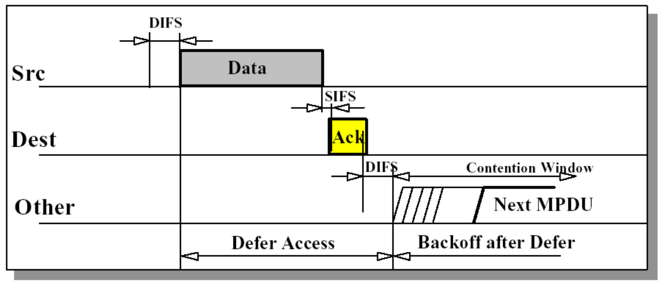
- PCF – Point Coordination Function
  - Infrastructure mode
  - Optional
- DCF – Distributed Coordination Function
  - Infrastructure and ad hoc modes
  - Mandatory
  - MAC protocol intended to implement ad hoc networks
- Implement different fixed priority levels
  - DIFS – distributed inter-frame space
  - PIFS – point inter-frame space
  - SIFS – short inter-frame space

CSMA/CA Explained



- Reduce collision probability where mostly needed
  - STAs are waiting for medium to become free for longer than DIFS
    - CCA from PHY and virtual carrier sense
  - Select random backoff in current collision window after a defer, resolving contention to avoid collisions
- Efficient backoff algorithm stable at high loads
  - Exponential contention window increases for retransmissions (up to max limit)
  - Resets to min value when transmission succeeds

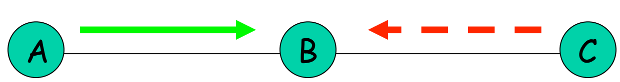
CSMA/CA + ACK



- Receiver sends ACK after receiving frame with correct CRC
- Direct access when medium is sensed free for longer than SIFS
  - No random backoff needed
- SIFS < DISF to give ACK higher priority than a new transmission of data frame
  - Such technique of using different inter-frame spaces to differentiate priorities is extensively used in 802.11 MAC

Hidden Terminal Problem

- A, B, C – three nodes
- B can talk to A and C directly, but A and C can't talk to each other
- When A transmits to B, node C, not aware of the ongoing transmission, may transmit and collide with A's transmission



Exposed Terminal Problem

- A, B, C, D – four nodes
- Only AB, BC, and CD can talk to each other directly
- When B transmits to A, node C, aware of the ongoing transmission, can't transmit to D, even though there will not be interference at D

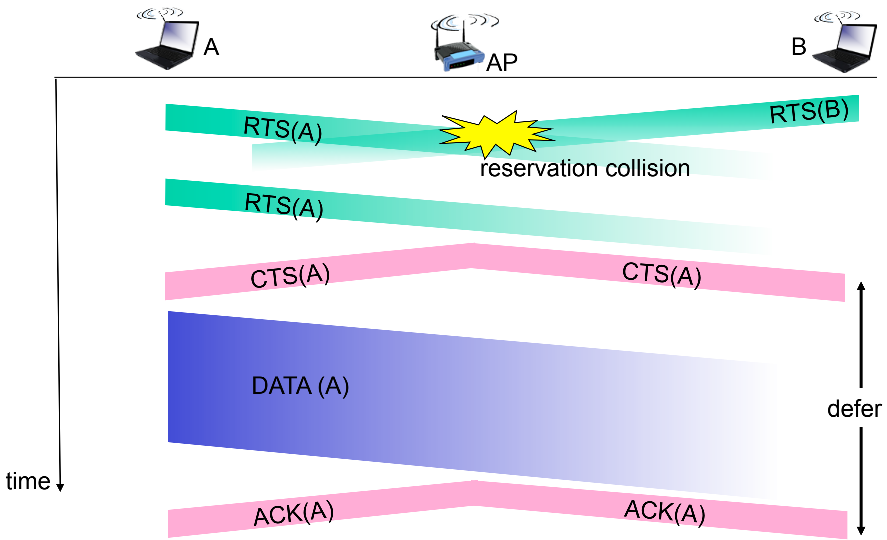
Avoiding collisions (more)

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

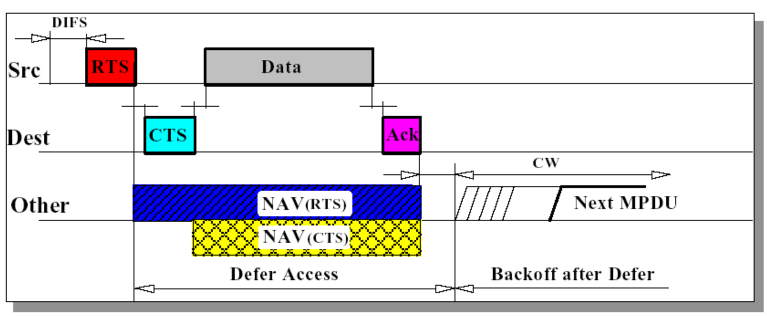
- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they' re short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange

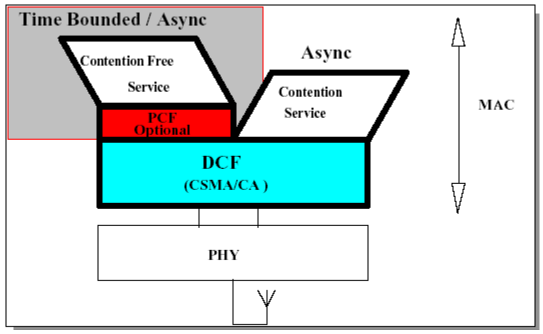


Hidden Terminal Resolution



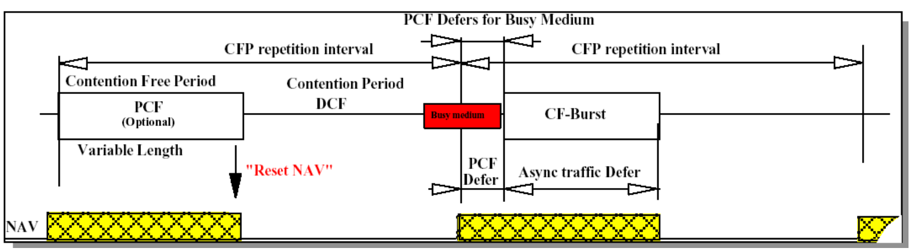
- Duration fields in RTS and CTS frames distributes medium reservation information, stored in an overhearing node's counter – Network Allocation Vector (NAV)
- Medium "busy" decided by CCA and NAV
- Use of RTS/CTS is optional but must be implemented
  - Use is controlled by an **`RTS_Threshold`** parameter in each STA to limit overhead

Optional Point Coordination Function (PCF)



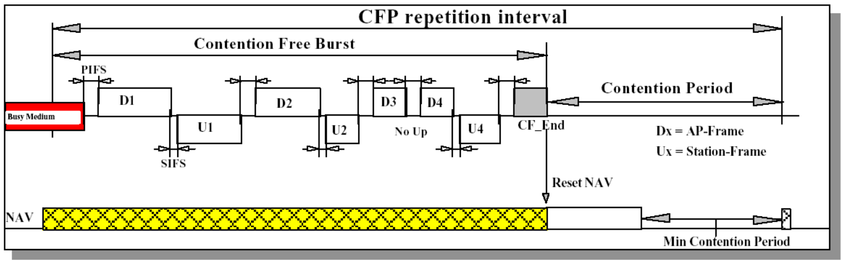
- Contention-free service uses PCF on a DCF foundation
  - PCF can provide lower transfer delay variations to support time bounded services
  - Async data, voice or mixed implementations are possible
  - Point Coordinator resides in AP
- Coexistence of contention and optional contention-free does not burden the implementation

Contention Free Operation



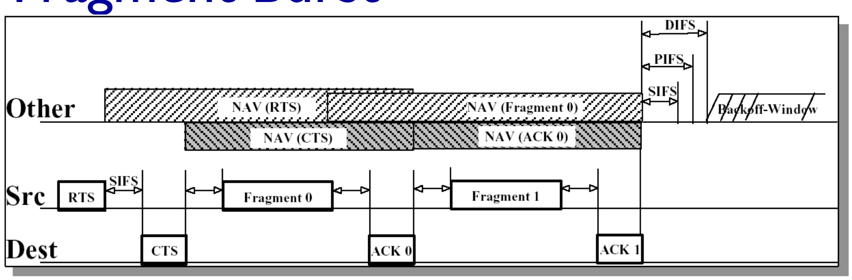
- Alternating contention-free and contention operation under PCF control
- NAV prevents contention traffic until reset by the last PCF transfer
  - Thus, variable length of contention-free period per interval
- Both PCF and DCF defer to each other

PCF Burst



- CF-burst by "polling" bit set in CF_Down frames
- Immediate (w/SIFS) response by STA on CF_poll
- STAs to maintain NAV to protect CF_traffic
- Responses can be of variable length
- "reset NAV" by last (CF_End) frame from AP
- "ACK Previous Frame" bit in headers

Fragment Burst



- Long MSDU (MAC Service Data Unit) fragmented
- Burst of fragments are ACKed individually
  - Separated by SIFSs
  - Unicast frames only
- Random backoff and retransmission of failing fragment when no ACK is returned
  - Can be interrupted when missing ACK
- Duration information in data fragments and ACKs causes NAV to be set, for medium reservation

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

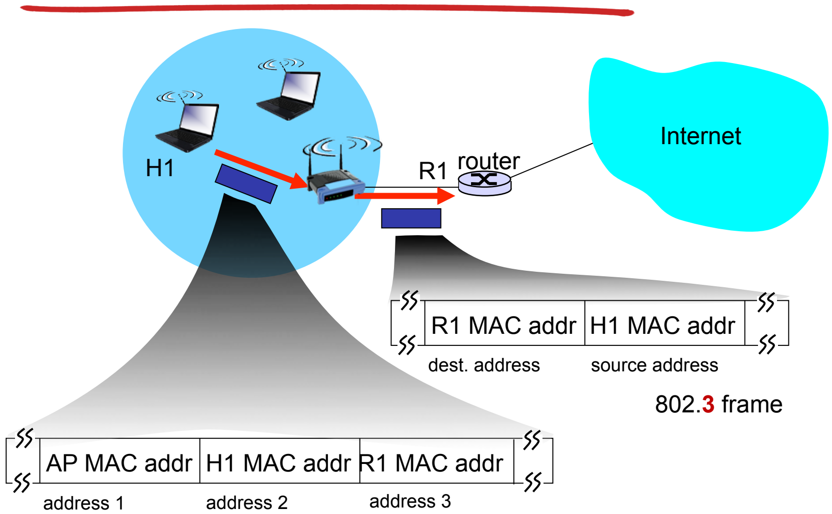
Address 1: MAC address of wireless host or AP to receive this frame

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

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

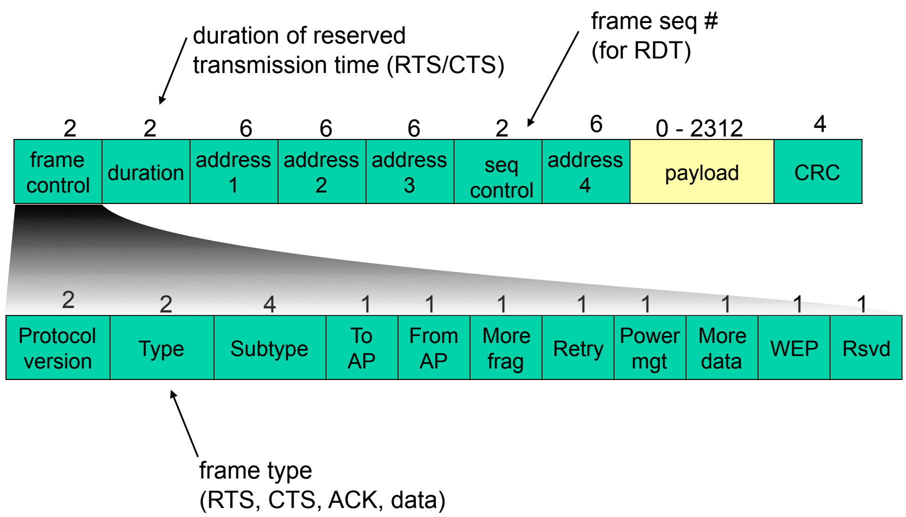
Address 4: used only in ad hoc mode

802.11 frame: addressing

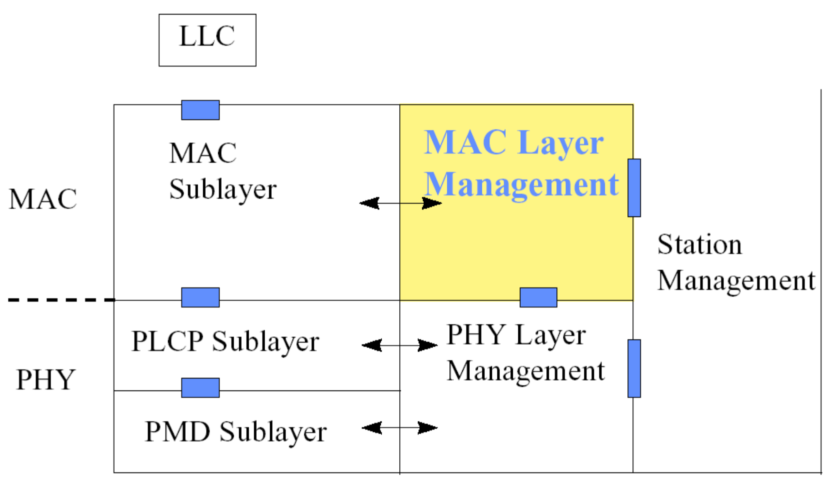


802.11 frame

802.11 frame: more



Support for Mobility

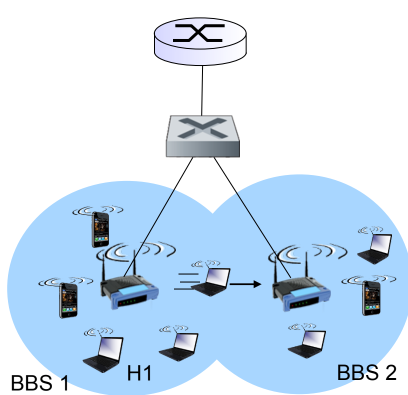


MAC Management Layer

- Synchronization
  - Finding and staying with a WLAN
  - Synchronization functions
    - TSF timer, beacon generation
- Power management
  - Sleeping without missing any message
  - Power management functions
    - Periodic sleep, frame buffering, traffic indication map
- Association and de-association
  - Joining a network
  - Roaming – moving from AP to AP
  - Scanning

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



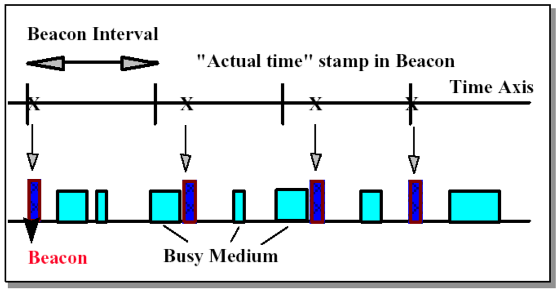
Synchronization in 802.11

- Timing Synchronization Function (TSF)
- Used for power management
  - Beacons sent at well known intervals
  - All STA timers in BSS are synchronized
- Used for PCF timing
  - To predict CP/CFP alternation period
- Used for hop timing for FH PHY
  - Dwell interval
  - STA synchronization

Synchronization Approach

- Each STA maintains a local timer
- Timing Synchronization Function (TSF)
  - Keeps timers from all STAs in synch
  - AP controls timing in infrastructure mode
  - Distributed function for ad hoc mode
- Timing conveyed by periodic beacon transmissions
  - Beacons contain timestamps for the BSS
  - Timestamps in beacons used to calibrate local clocks
  - Not required to hear each beacon
  - Beacons contain other management information
    - Also used in power management and roaming

Infrastructure Beacon Generation

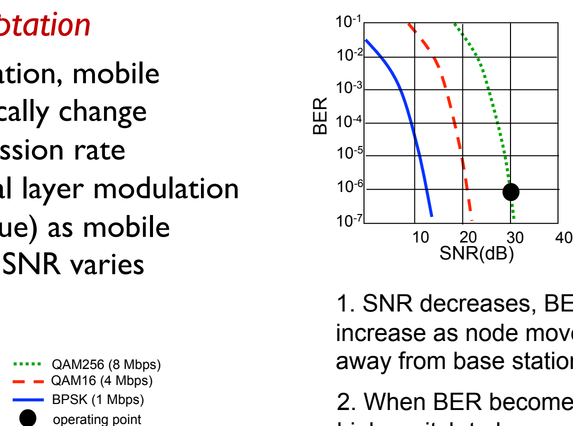


- AP's send beacons in infrastructure mode
- Beacons scheduled at beacon intervals
- Transmission may be delayed by CSMA deferral
  - Subsequent transmissions at expected beacon interval
  - Not relative to last transmission
  - Next beacon sent at target beacon transmission time
- Timestamps contains timer values at transmit time

802.11: advanced capabilities

Rate adaptation

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



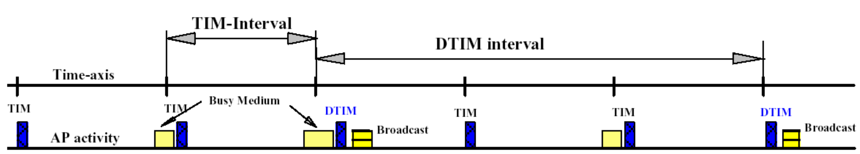
1. SNR decreases, BER increase as node moves away from base station
2. When BER becomes too high, switch to lower transmission rate but with lower BER

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

Infrastructure Power Management



- Broadcast frames also buffered in AP
  - All broadcasts/multicasts are buffered
  - Broadcasts/multicasts only sent after DTIM
  - Delivery TIM – sent every several TIM intervals
- STAs wakeup prior to an expected (D)TIM
- If (D)TIM indicates frame buffered
  - STA sends PS_Poll and stays awake for the TIM interval to receive data
  - Else STA sleeps again

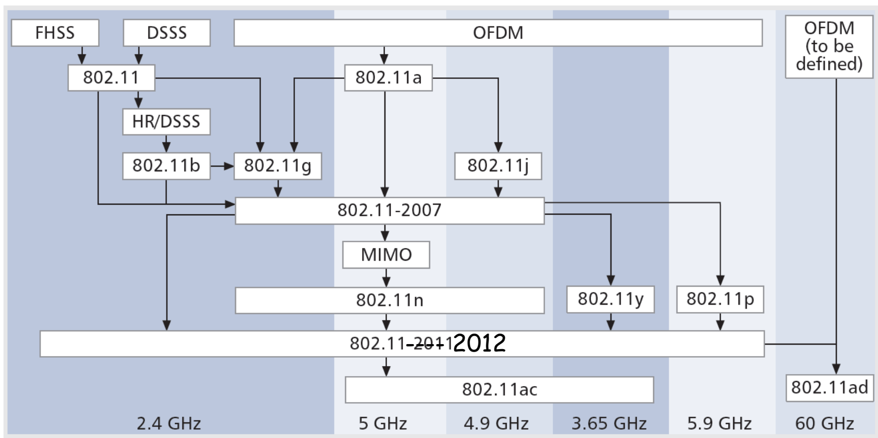
MAC Management Frames

- Beacon
  - Timestamp, beacon interval, capabilities, ESSID, supported rates, parameters
  - TIM
- Probe
  - ESSID, capabilities, supported rates
- Probe response
  - Timestamp, beacon interval, capabilities, ESSID, supported rates, parameters
  - Same as beacon except for TIM
- Association request
  - Capabilities, listen interval, ESSID, supported rates
- Association response
  - Capabilities, status code, STA ID, supported rates

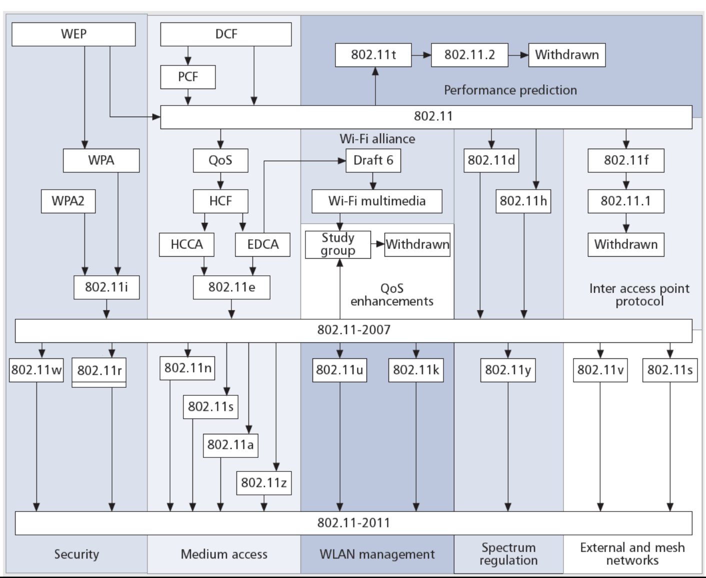
More MAC Management Frames

- Re-association request
  - capabilities, listen interval, ESSID, supported rates, current AP address
- Re-association response
  - capabilities, status code, STA ID, supported rates
- Disassociation
  - Reason code
- Authentication
  - Algorithm, sequence, status, challenge text
- De-authentication
  - Reason

PHY Amendments and Dependency



MAC Amendments and Dependency



HIPERLAN & HIPERLAN/2

- ETSI's Project BRAN
  - High performance radio LAN
  - Frequency band: 5.2GHz U-NII
  - Ver. 1 (1997): 23.5Mbps
  - Ver. 2 (2000): 54Mbps
- Components:
  - Distribution System (DS)
  - Access Point (AP)
  - Mobile Terminal (MT)

HIPERLAN & HIPERLAN/2

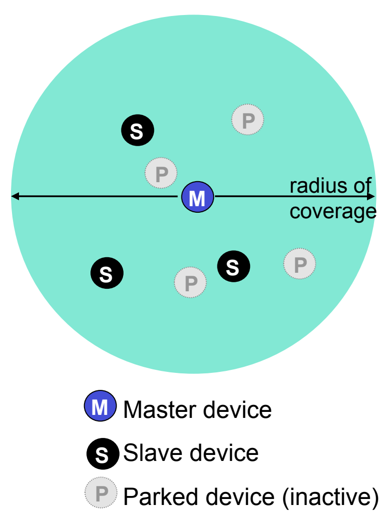
- PHY
  - OFDM (like 802.11a and g)
- MAC
  - TDMA/TDD
  - Under control of an AP or CC (central controller, regular MT acting as AP)
  - Transmission through AP/CC or directly between MT's
  - *Better QoS provisioning*

IEEE 802.15 Working Group

- Personal Area Network (PAN)
  - Communication within a person's operating space
- IEEE 802.15.1 – Bluetooth
- IEEE 802.15.3a – High data rate (UWB)
- IEEE 802.15.4 – Low energy (ZigBee)
- (802.15.2 – interoperability between 802.15 and 802.11)

802.15.1: personal area network

- less than 100 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- master/slaves:
  - slaves request permission to send (to master)
  - master grants requests
- 802.15.1: evolved from Bluetooth specification
  - 2.4-2.5 GHz radio band
  - up to 721 kbps



Bluetooth

- Originally by Japp Haartsen and Sven Mattison of Ericsson in 1994
- Replacement for RS-232 cables
  - Short-range (~1m to ~100m)
  - Low data rate
    - BT 1.x 1Mbps – GFSK
    - BT 2.x (EDR) 3Mbps – GFSK+PSK
    - BT 3.0 (AMP) – 802.11 rates
    - BT 4.0 (LE)
  - Low power (~40mA/0.2mA)
- Connects multiple devices
- Bluetooth Special Interest Group (SIG)
  - 1998 – started with 5 companies
    - Ericsson, Nokia, IBM, Toshiba, Intel
  - Now – over 10,000

Who is Bluetooth?

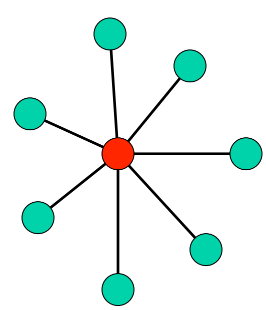
- **Harald Blaatand "Bluetooth" II**
- **King of Denmark 940-981**
  - Son of Gorm the Old (King of Denmark) and Thyra Danebod (daughter of King Ethelred of England)
- **This is one of two Runic stones erected in his capital city of Jelling (central Jutland)**
  - This is the front of the stone depicting the chivalry of Harald
  - Harald controlled Denmark and Norway
  - Harald thinks mobile PCs and cellular phones should seamlessly communicate

Bluetooth 1.0 PHY

- 2.4 GHz ISM band
- Modulation – GFSK
- Frequency hopping
  - Over 79 1MHz carriers world-wide (except for France, Spain and Japan – 23 carriers)
  - 1600/sec (dwell time = 625μs)
- Long repetition interval of frequency-hop sequence
  - Over 23 hours

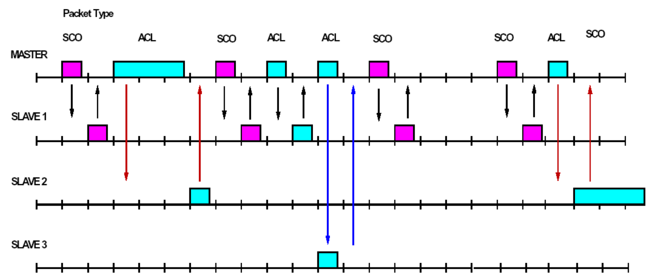
Piconet – Basic Topology

- Star shape
- 1 master node controls up to 7 active slave nodes
  - And controls up to 255 parked nodes (in energy save mode)
- All nodes follow the same hopping sequence as the master



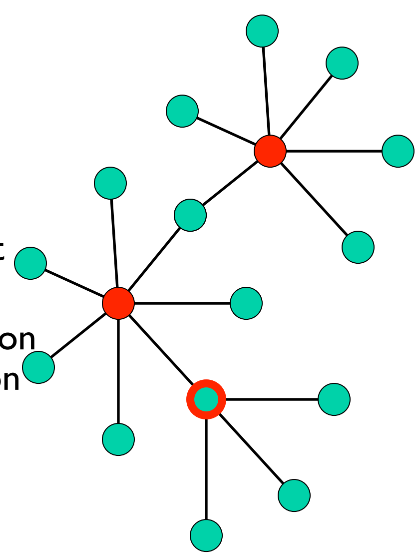
Links in Piconet – TDD/TDMA

- SCO – synchronous connection oriented
  - Period negotiated with master
  - Supports symmetric, circuit-switched connections
  - Usually for voice
- ACL – asynchronous connectionless
  - Master polls each slave
  - Slave responds immediately
  - Response can take 1, 3, or 5 slots



Scatternet

- Piconets interconnected
  - Slave in multiple piconets
  - Master also a slave
- Nodes in the same piconet hop with the master
- Inter-piconet communication not specified in specification



IEEE 802.15.3 – UWB

- High data rate WPAN
- UWB
- Motivation: The need for higher bandwidths than currently supported by 802.15.1
  - 100 Mpbs within 10 meter
  - 400 Mpbs within 5 meter
- Data, High quality TV, Home cinema
- Wireless USB

IEEE 802.15.4 & ZigBee

- Short range
  - <30m
- Low rate
  - < 250kbps
- Low power consumption
  - Attractive for sensor networking
- PHY

	2450 MHz	915 MHz	868 MHz
Gross data rate	250 kbps	40 kbps	20 kbps
No. of Channel	16	10	1
Modulation	O-QPSK	BPSK	BPSK
Chip pseudo-noise sequence	32	15	15
Bit per symbol	4	1	1
Symbol period	16 µs	24 µs	49 µs

IEEE 802.15.4 & ZigBee (cont'd)

- Types of devices
  - Reduced Function Devices (RFDs)
  - Full Function Devices (FFDs)
- Roles of a devices in the network
  - Network coordinator
  - Router
  - End-device
- Topologies
  - Star
  - Tree
  - Mesh

Selected Comparisons

Standard	Bandwidth	Power	Protocol stack size	Stronghold	Applications
Wi-Fi	<=54Mbps	400mA TX 20mA ST	100+KB	Data rate	Internet, PC networking
Bluetooth	<1Mbps	40mA TX 0.2mA ST	~100KB	Interoperability	Cable replacement: wireless USB & headset
ZigBee	<=250kbps	30mA TX .356mA ST	34KB	Low power	Sensor networks, remote control

IEEE 802.16 WiMAX

- Broadband MAN
- IEEE 802.16
  - Wireless last-mile alternative
  - stationary subscribers, e.g. transceivers mounted on top of business or residential buildings
  - 2-10GHz
  - Supports thousands of users simultaneously
  - TDMA+OFDM / OFDMA
- IEEE 802.16e
  - Support low speed mobile users

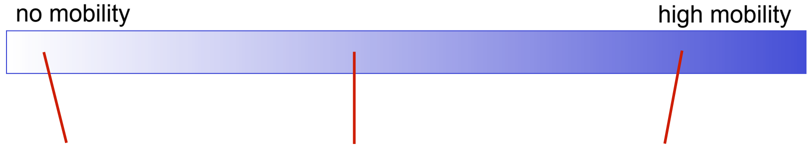
IEEE 802.20 Mobile Broadband

- Supports mobile users at very high speed
  - <= 250 km/hr
- Operates in licensed 500MHz~3.5GHz band
- Data rate <= 1Mbps

What is mobility?

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

no mobility high mobility



mobile wireless user, using same access point

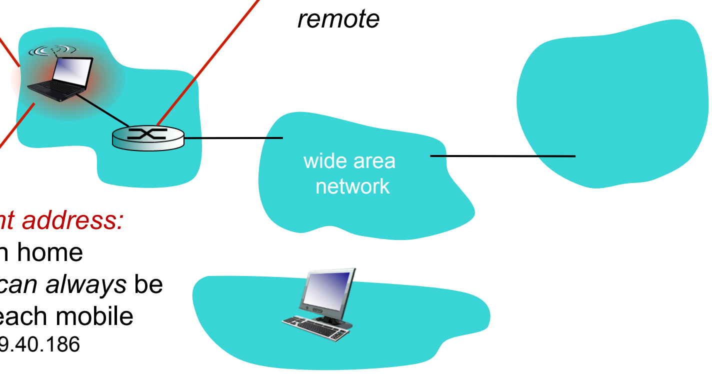
mobile user, connecting/ disconnecting from network using DHCP.

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

Mobility: vocabulary

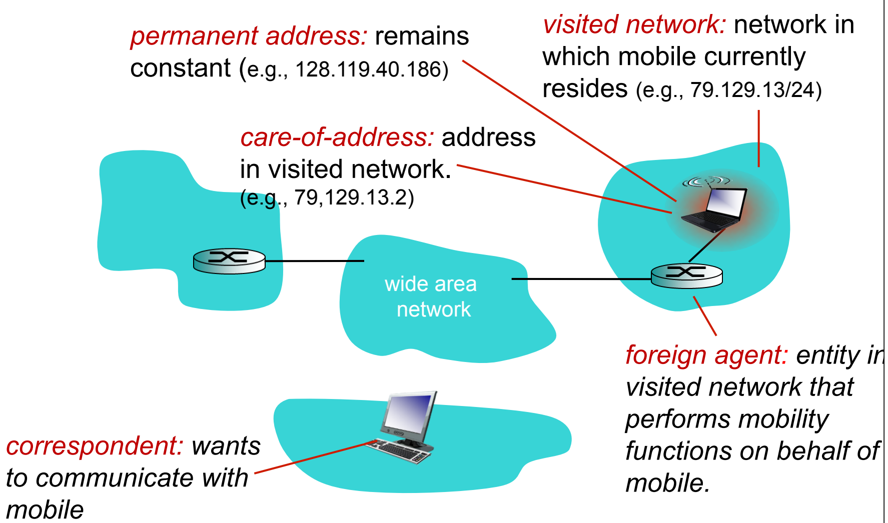
home network: permanent "home" of mobile
(e.g., 128.119.40/24)

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



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

Mobility: more vocabulary

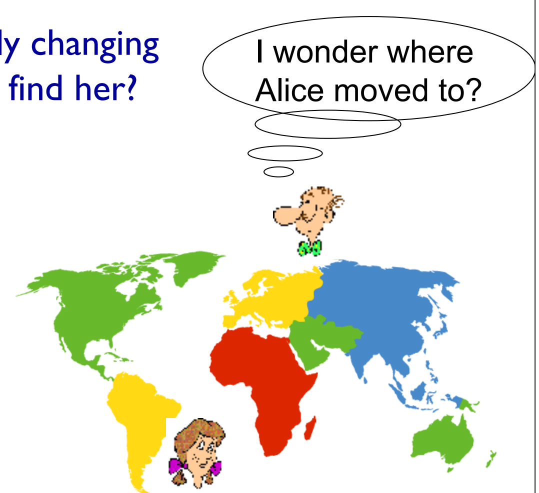


Wireless, Mobile Networks 6-75

How do *you* contact a mobile friend:

Consider friend frequently changing addresses, how do you find her?

- search all phone books?
- call her parents?
- expect her to let you know where he/she is?



Wireless, Mobile Networks 6-76

Mobility: approaches

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

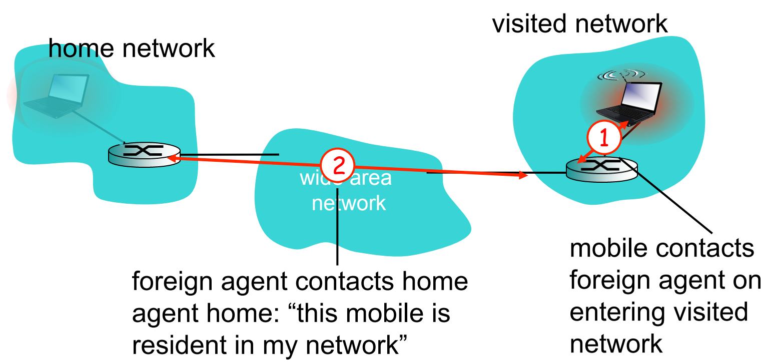
Mobility: approaches

- *let routing handle it:* ro... dvertise permanent address of mobile-nodes-in-r... sual routing table exchange.
  - routing tables ... each mobile located
  - no changes to e...

not scalable to millions of mobiles

- *let end-systems handle it:*
  - *indirect routing:* communication from correspondent to mobile goes through home agent, then forwarded to remote
  - *direct routing:* correspondent gets foreign address of mobile, sends directly to mobile

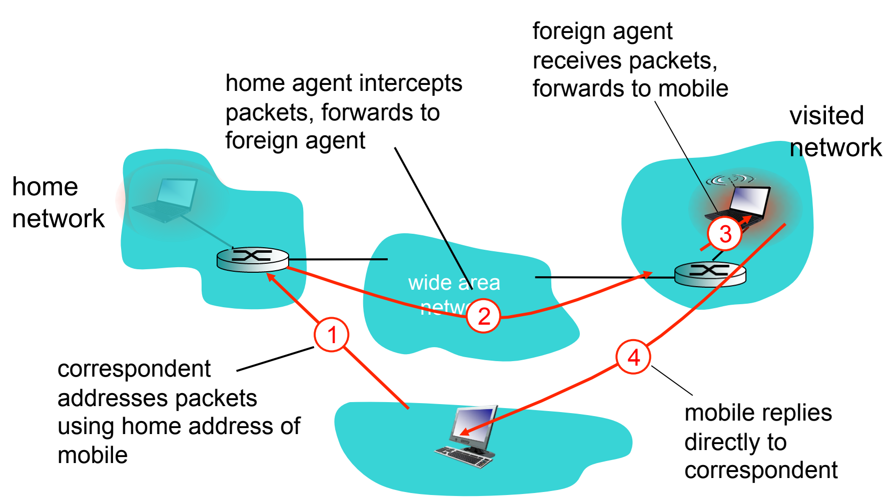
Mobility: registration



end result:

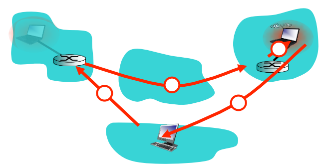
- foreign agent knows about mobile
- home agent knows location of mobile

Mobility via indirect routing



Indirect Routing: comments

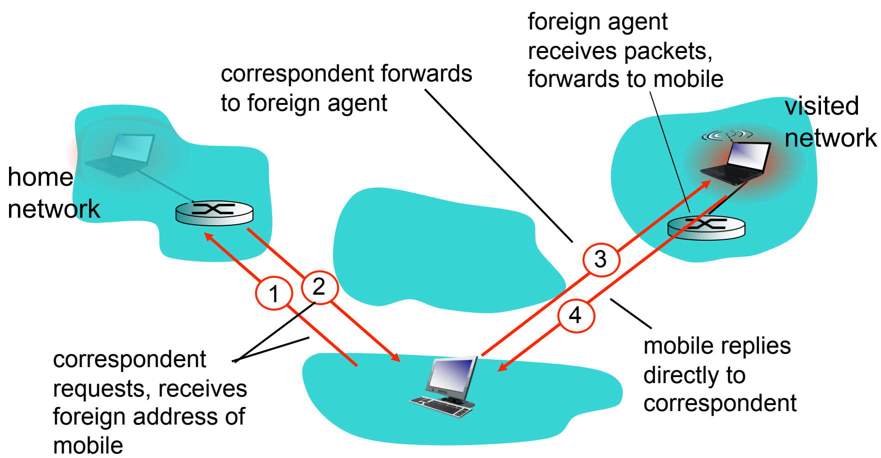
- mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- foreign agent functions may be done by mobile itself
- triangle routing: correspondent-home-network-mobile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



Indirect routing: moving between networks

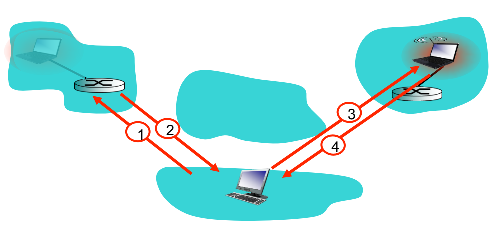
- suppose mobile user moves to another network
  - registers with new foreign agent
  - new foreign agent registers with home agent
  - home agent update care-of-address for mobile
  - packets continue to be forwarded to mobile (but with new care-of-address)
- mobility, changing foreign networks transparent: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

Mobility via direct routing



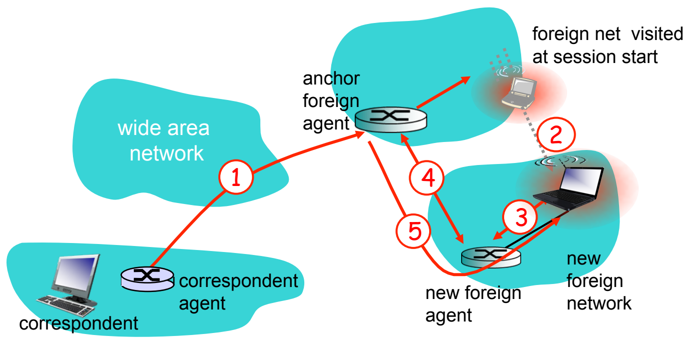
Mobility via direct routing: comments

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



Accommodating mobility with direct routing

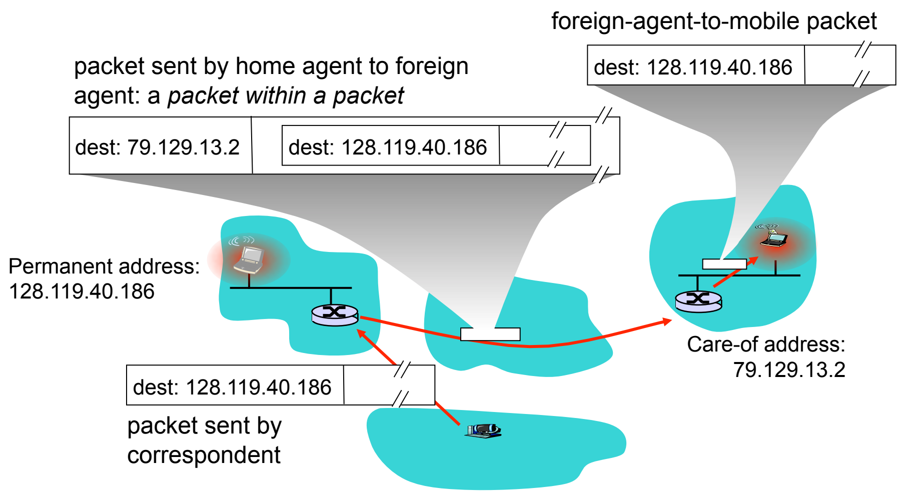
- anchor foreign agent: FA in first visited network
- data always routed first to anchor FA
- when mobile moves: new FA arranges to have data forwarded from old FA (chaining)



Mobile IP

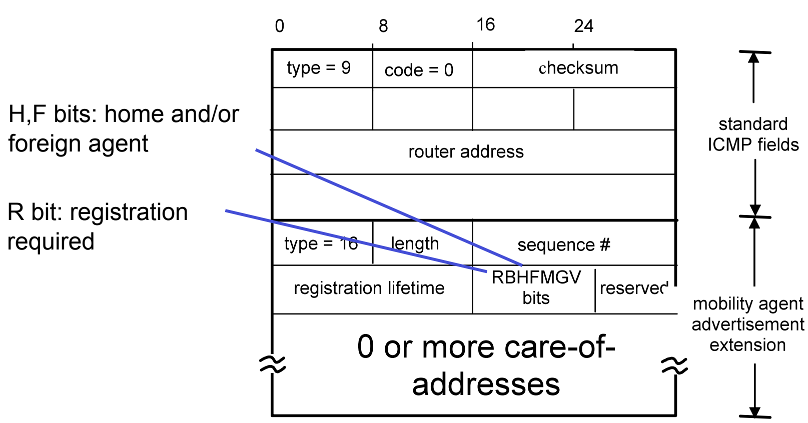
- RFC 3344
- has many features we've seen:
  - home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet)
- three components to standard:
  - indirect routing of datagrams
  - agent discovery
  - registration with home agent

Mobile IP: indirect routing

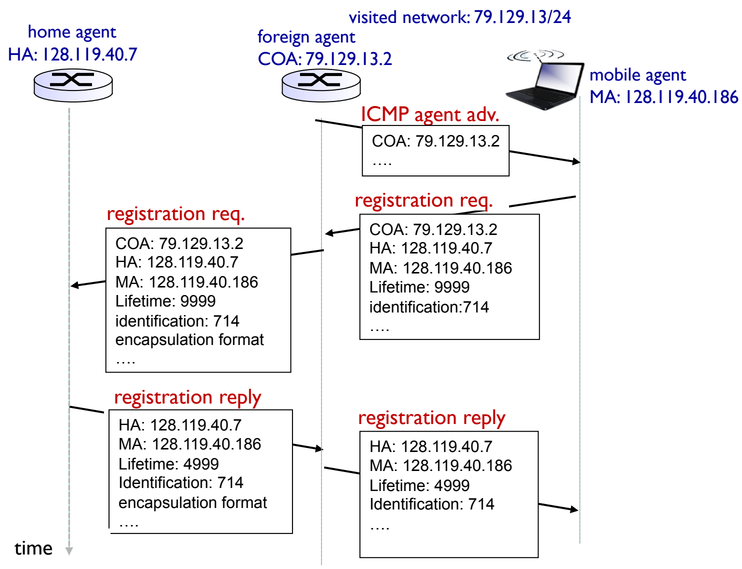


Mobile IP: agent discovery

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



Mobile IP: registration example



Wireless, mobility: impact on higher layer protocols

- logically, impact *should* be minimal …
  - best effort service model remains unchanged
  - TCP and UDP can (and do) run over wireless, mobile
- … but performance-wise:
  - packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handoff
  - TCP interprets loss as congestion, will decrease congestion window un-necessarily
  - delay impairments for real-time traffic
  - limited bandwidth of wireless links