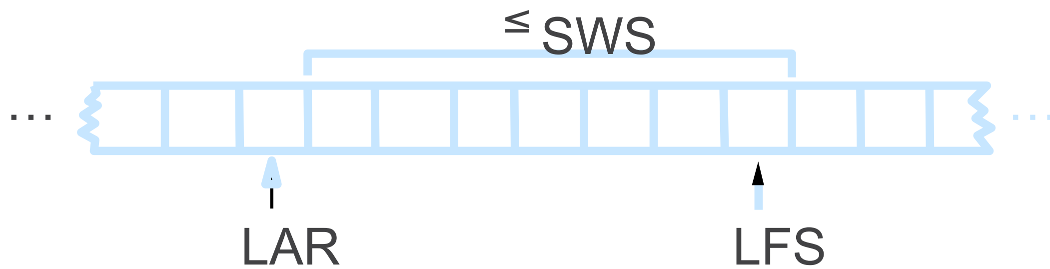
SW: Sender

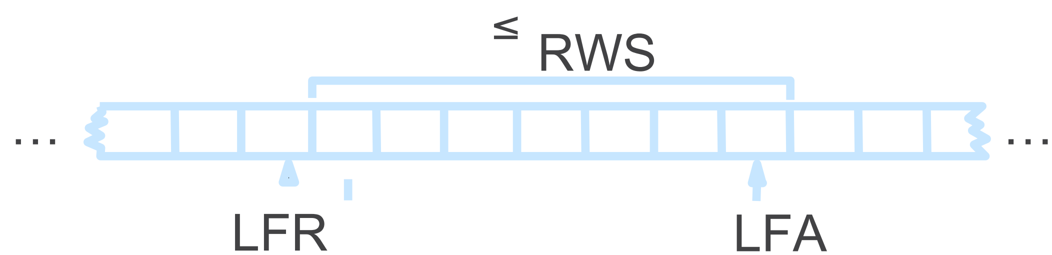
- Assign sequence number to each frame (SeqNum)
- Maintain three state variables:
  - send window size (SWS)
  - last acknowledgment received (LAR)
  - last frame sent (LFS)
- Maintain invariant: LFS - LAR <= SWS



- Advance LAR when ACK arrives
- Buffer up to SWS frames

SW: Receiver

- Maintain three state variables
  - receive window size (RWS)
  - largest frame acceptable (LFA)
  - last frame received (LFR)
- Maintain invariant: LFA - LFR <= RWS



- Frame SeqNum arrives:
  - if LFR < SeqNum < = LFA → accept
  - if SeqNum < = LFR or SeqNum > LFA → discarded
- Send cumulative ACKs

Acknowledgements

- Negative acknowledgment (NAK)
  - When receiver receives frame which has a sequence number higher than the next frame expected, receiver proactively informs the sender to resend the missing frame
- Selective ACK
  - Acknowledge frames that it has received, not just the last frame received

Sequence Number Space

- SeqNum field is finite; sequence numbers wrap around
- Sequence number space must be larger then number of outstanding frames
- SWS <= MaxSeqNum-1 is not sufficient
  - suppose 3-bit SeqNum field (0..7)
  - SWS=RWS=7
  - sender transmit frames 0..6
  - arrive successfully, but ACKs lost
  - sender retransmits 0..6
  - receiver expecting 7, 0..5, but receives second incarnation of 0..5
- SWS < (MaxSeqNum+1)/2 is correct rule
- Intuitively, SeqNum “slides” between two halves of sequence number space

Concurrent Logical Channels

- Multiplex 8 logical channels over a single link
- Run stop-and-wait on each logical channel
- Maintain three state bits per channel
  - channel busy
  - current sequence number out
  - next sequence number in
- Header: 3-bit channel num, 1-bit sequence num
  - 4-bits total
  - same as sliding window protocol
- Separates reliability from order

Take away message

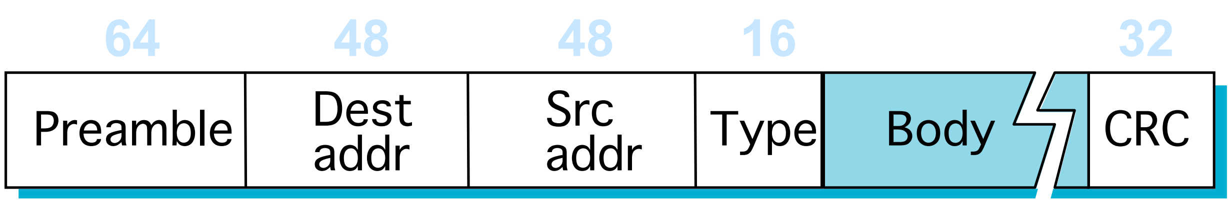
- Reliable delivery means receiver should send acknowledgement.
  - Need to keep timeout just right.
  - Send enough frames to fill pipe (bandwidth delay product)

Broadcast networks

- Next, we will look at some common network technologies. First we will look at broadcast networks such as Ethernet and wireless. These networks are CSMA/

Ethernet Overview

- History
  - developed by Xerox PARC in mid-1970s
  - roots in Aloha packet-radio network
  - standardized by Xerox, DEC, and Intel in 1978
  - similar to IEEE 802.3 standard
- CSMA/CD
  - carrier sense
  - multiple access
  - collision detection
- Frame Format



Ethernet (cont)

- Addresses
  - unique, 48-bit unicast address assigned to each adapter
  - example: 8:0:e4:b1:2
  - broadcast: all 1s
  - multicast: first bit is 1
- Bandwidth: 10Mbps, 100Mbps, 1Gbps
- Length: 2500m (500m segments with 4 repeaters)
- Encoding
  - 10 Mbps - Manchester encoding
  - 100 Mbps - 4B/5B
  - 1000 Mbps - 8B/10B
- Problem: Distributed algorithm that provides fair access

Transmit Algorithm (CSMA/CD)

- If line is idle…
  - send immediately
  - upper bound message size of 1500 bytes (messages can go from 10 to 100 to 1000 Mbit without processing)
    - 9000 bytes for Gbit Ethernet (Jumbo frame)
      - 12000 byte limit for CRC32
  - must wait 9.6us between back-to-back frames
    - 96 bit time (960 ns for 100 Mbps, 96 ns for 1 Gbps)
- If line is busy…
  - wait until idle and transmit immediately
  - called 1-persistent (special case of p-persistent)
    - When channel idle, station transmits with probability 1

Algorithm (cont)

- If collision…
  - jam for 32 bits, then stop transmitting frame
  - minimum frame is 64 bytes (header + 46 bytes of data) for 10/100 Mbps ethernet and 512 bytes for Gigabit Ethernet frame
  - delay and try again
    - 1st time: 0 or 51.2us
    - 2nd time: 0, 51.2, or 102.4us
    - 3rd time: 0, 51.2, 102.4, or 153.6us
    - nth time: k x 51.2us, for randomly selected k=0..2n - 1
    - give up after several tries (usually 16)
    - exponential backoff

Duplex

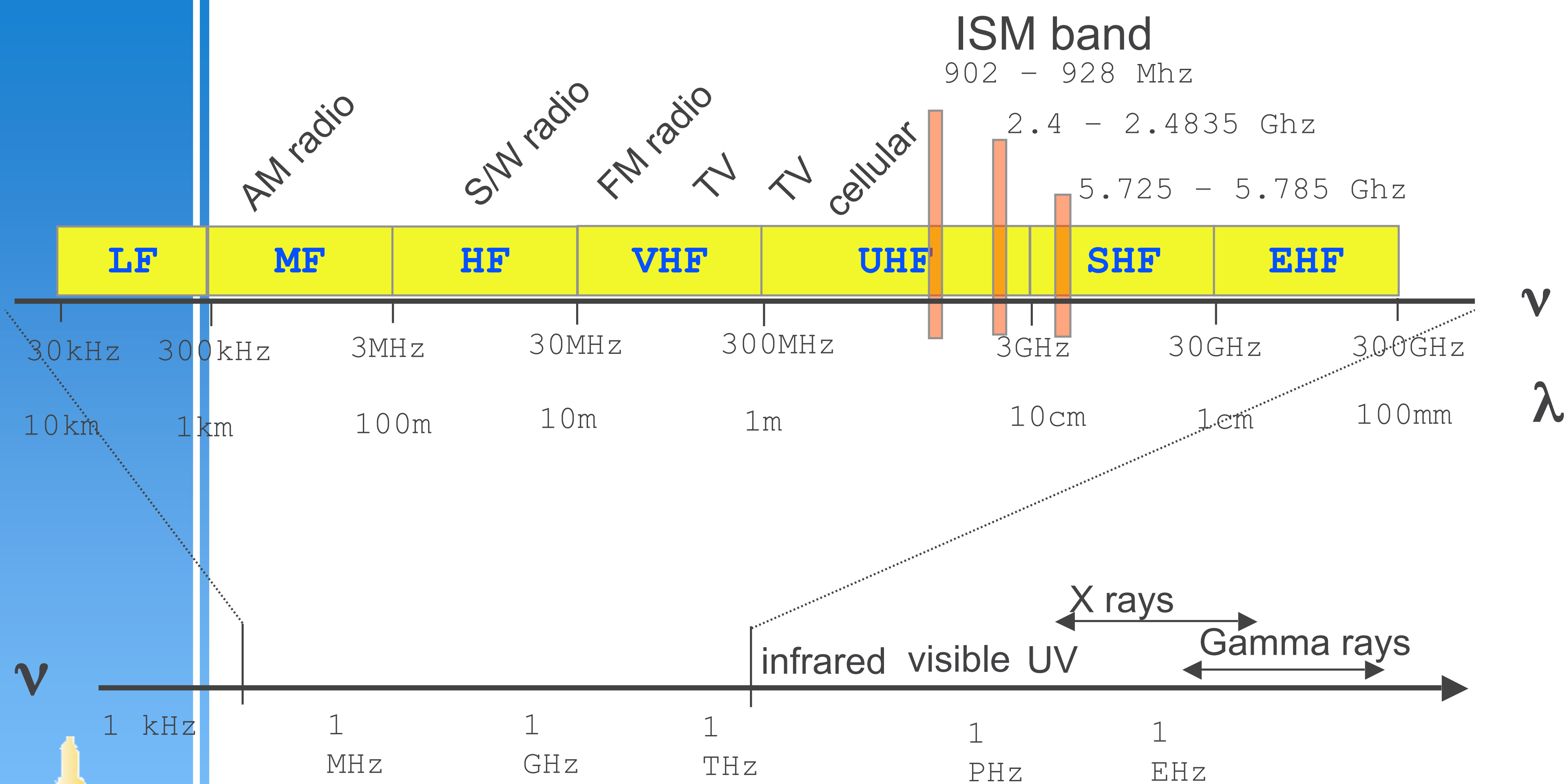
- Half duplex - CSMA/CD, Full duplex: both sender and receiver can talk simultaneously
- Peak utilization ~37%

Wireless LANs (CSMA/CA)

- IEEE 802.11
  - Bandwidth: 1 or 2 Mbps
  - 802.11b - 11 Mbps (2.4 GHz)
  - 802.11g - 54 Mbps (2.4 GHz)
  - 802.11a - 54 Mbps (5 GHz)
- Physical Media
  - spread spectrum radio (2.4 GHz)
  - diffused infrared (10 m)

- Wireless LAN
- irDA
- Bluetooth

EM Spectrum



Propagation characteristics are different in each frequency band

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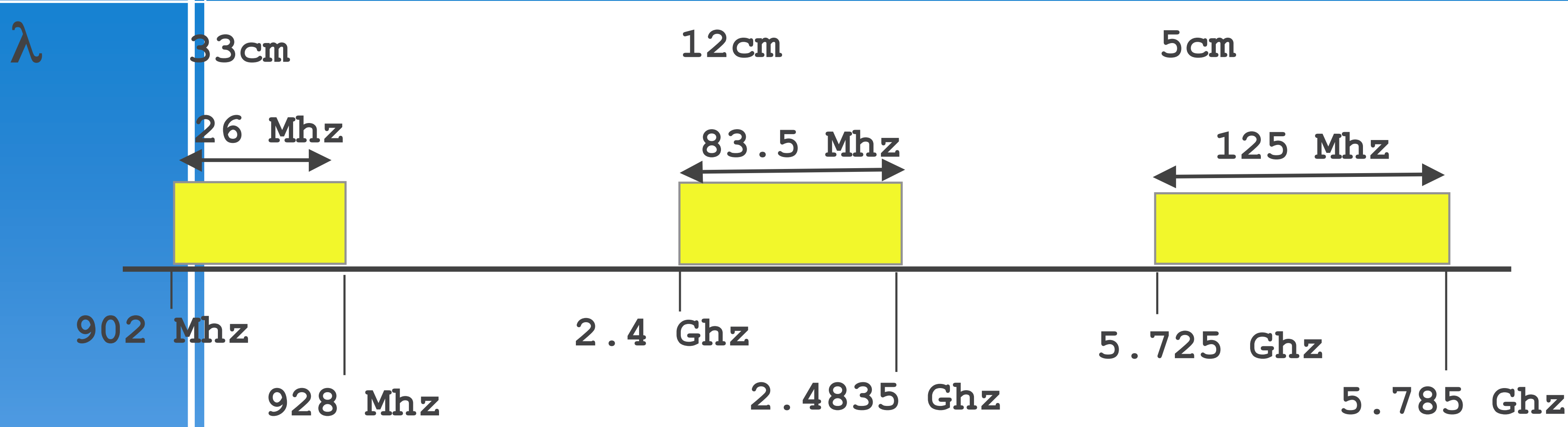
Unlicensed Radio Spectrum



cordless phones
baby monitors
Wireless LANs

802.11
Bluetooth
Microwave oven

802.11a

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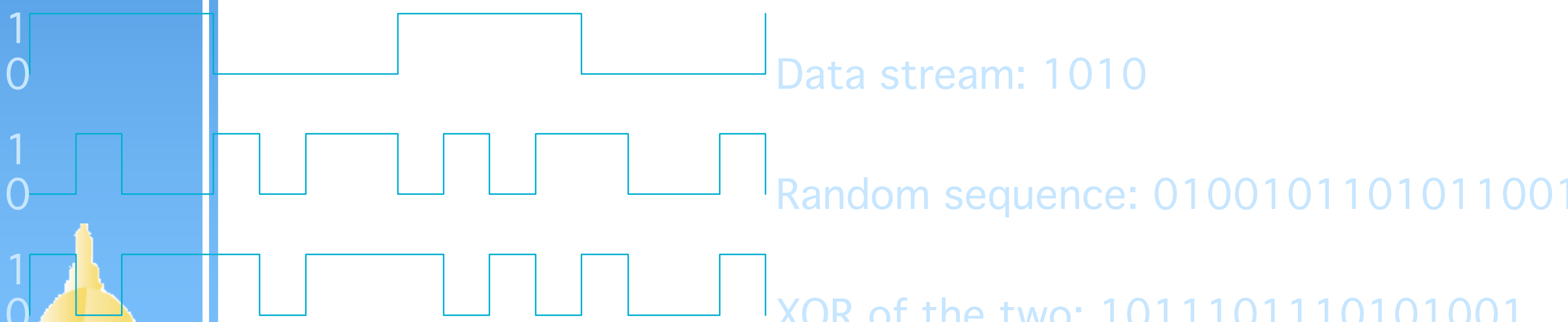
Spread Spectrum

- Idea
  - spread signal over wider frequency band than required
  - originally designed to thwart jamming
- Frequency Hopping
  - transmit over random sequence of frequencies
  - sender and receiver share…
    - pseudorandom number generator
    - seed
  - 802.11 uses 79 x 1MHz-wide frequency bands

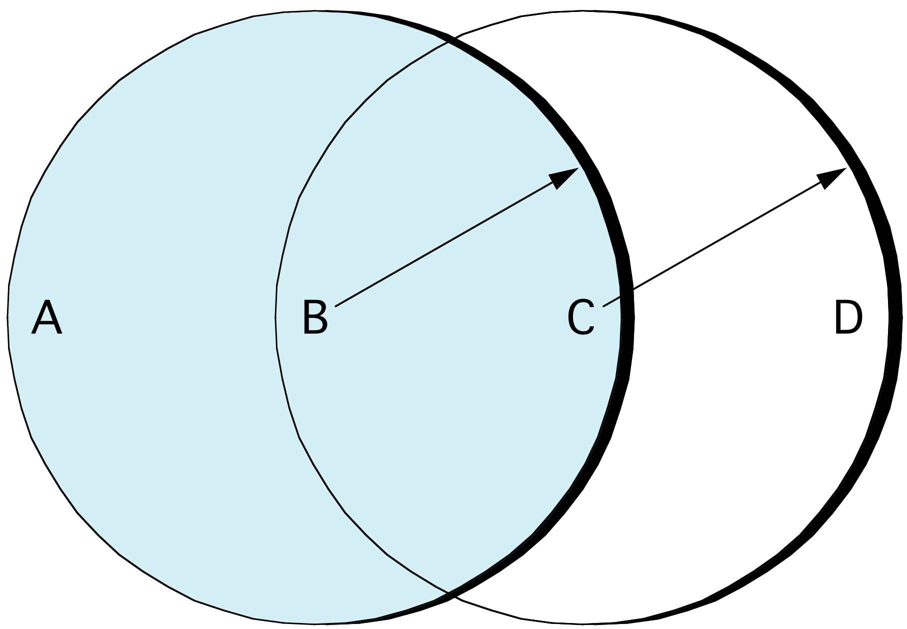
Spread Spectrum (cont)

- Direct Sequence
  - for each bit, send XOR of that bit and n random bits
  - random sequence known to both sender and receiver
  - called n-bit chipping code
  - 802.11 defines an 11-bit chipping code



Collisions Avoidance

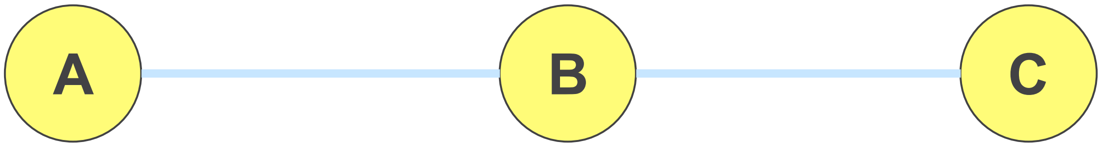
- Similar to Ethernet
- Problem: hidden and exposed nodes



Hidden Terminal Problem

- Node B can communicate with A and C both
- A and C cannot hear each other

- When A transmits to B, C cannot detect the transmission using the *carrier sense* mechanism
- If C transmits, collision will occur at node B



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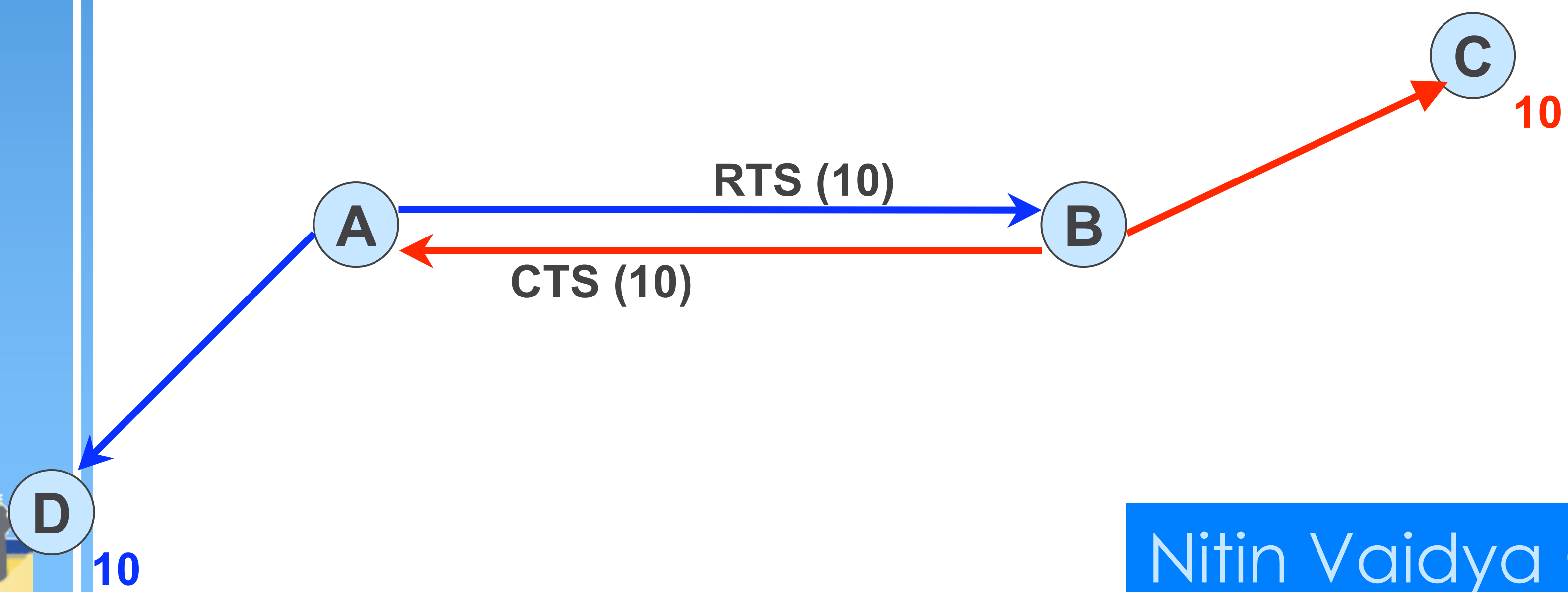
MACAW

- Sender transmits RequestToSend (RTS) frame
- Receiver replies with ClearToSend (CTS) frame
- Neighbors…
  - see CTS: keep quiet
  - see RTS but not CTS: ok to transmit
- Receive sends ACK when has frame
  - neighbors silent until see ACK
- Collisions
  - no collisions detection
  - known when don’t receive CTS
  - exponential backoff

RTS/CTS Handshake

- Sender sends Ready-to-Send (RTS)
- Receiver responds with Clear-to-Send (CTS)
- RTS and CTS announce the duration of the transfer
- Nodes overhearing RTS/CTS keep quiet for that duration
- RTS/CTS used in IEEE 802.11



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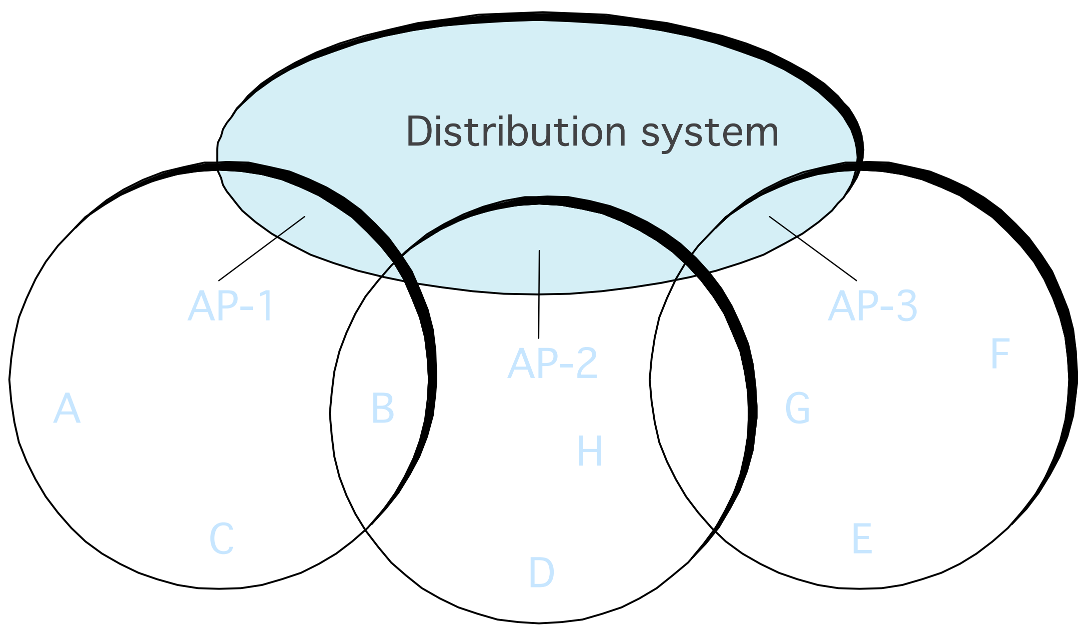
Supporting Mobility

- Case 1: ad hoc networking
- Case 2: access points (AP)
  - tethered
  - each mobile node associates with an AP



Mobility (cont)

- Scanning (selecting an AP)
  - node sends Probe frame
  - all AP’s w/in reach reply with ProbeResponse frame
  - node selects one AP; sends it AssociateRequest frame
  - AP replies with AssociationResponse frame
  - new AP informs old AP via tethered network
- When
  - active: when join or move
  - passive: AP periodically sends Beacon frame

Challenges

- Limited wireless transmission range
- Broadcast nature of the wireless medium
  - Hidden terminal problem
- Packet losses due to transmission errors
- Mobility-induced route changes
- Mobility-induced packet losses
- Battery constraints
- Potentially frequent network partitions
- Ease of snooping on wireless transmissions (security hazard)

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Bluetooth

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@ AT&T Labs

- A cable replacement technology
- 1 Mb/s symbol rate
- Range 10+ meters
- Single chip radio + baseband
  - at low power & low price point

Why not use Wireless LANs?
- power
- cost

Synchronization

- User benefits
- Automatic synchronization of calendars, address books, business cards
- Push button synchronization
- Proximity operation

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Cordless Headset

- User benefits
- Multiple device access
- Cordless phone benefits
- Hands free operation

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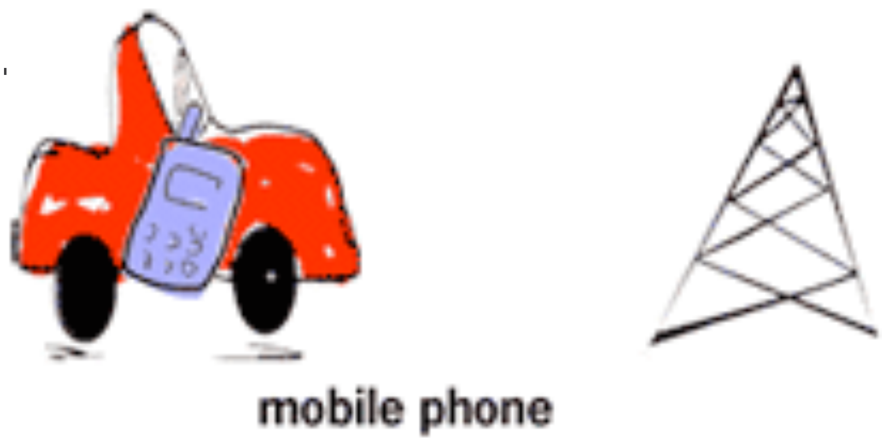
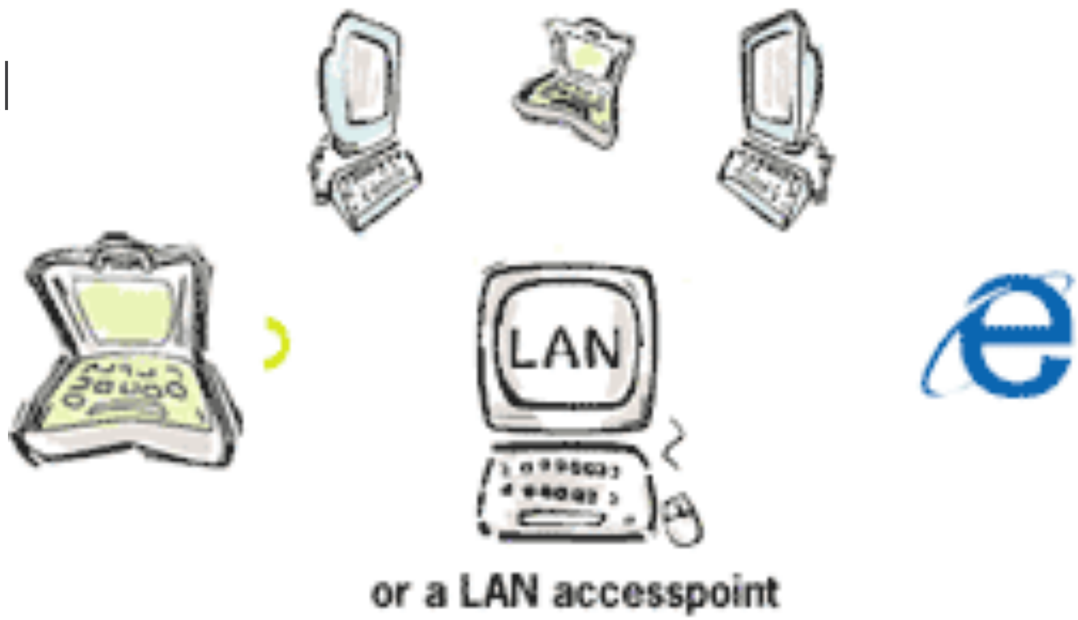
Three-in-one phone

- At home, your phone functions as a portable phone (fixed line charge). When you're on the move, it functions as a mobile phone (cellular charge). And when your phone comes within range of another mobile phone with built-in Bluetooth wireless technology it functions as a walkie talkie (no telephony charge)
- Source: bluetooth.



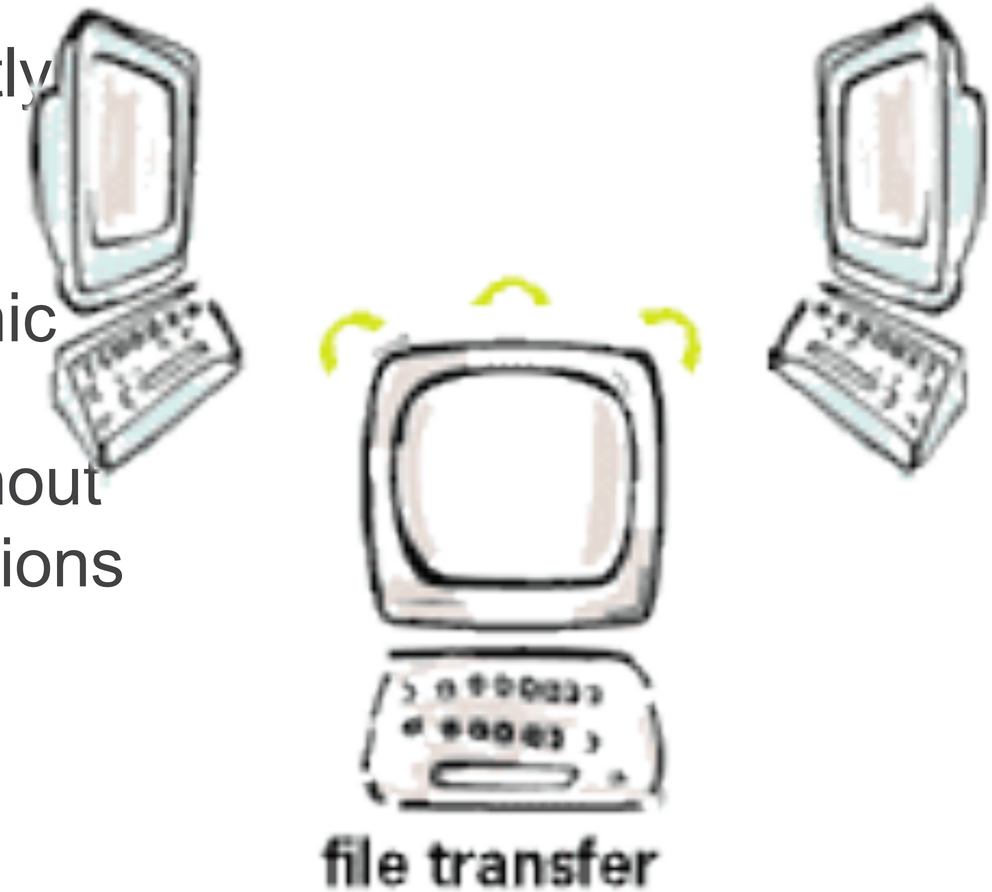
The Internet Bridge

- Use your mobile computer to surf the Internet wherever your are, and regardless if you're cordlessly connected through a mobile phone (cellular) or through a wire-bound connection (e.g. PSTN, ISDN, LAN, xDSL).
- Source: bluetootl



The Interactive Conference

- In meetings and conferences you can transfer selected documents instantly with selected participants, and exchange electronic business cards automatically, without any wired connections
- Source: bluetooth.com



The Ultimate Headset

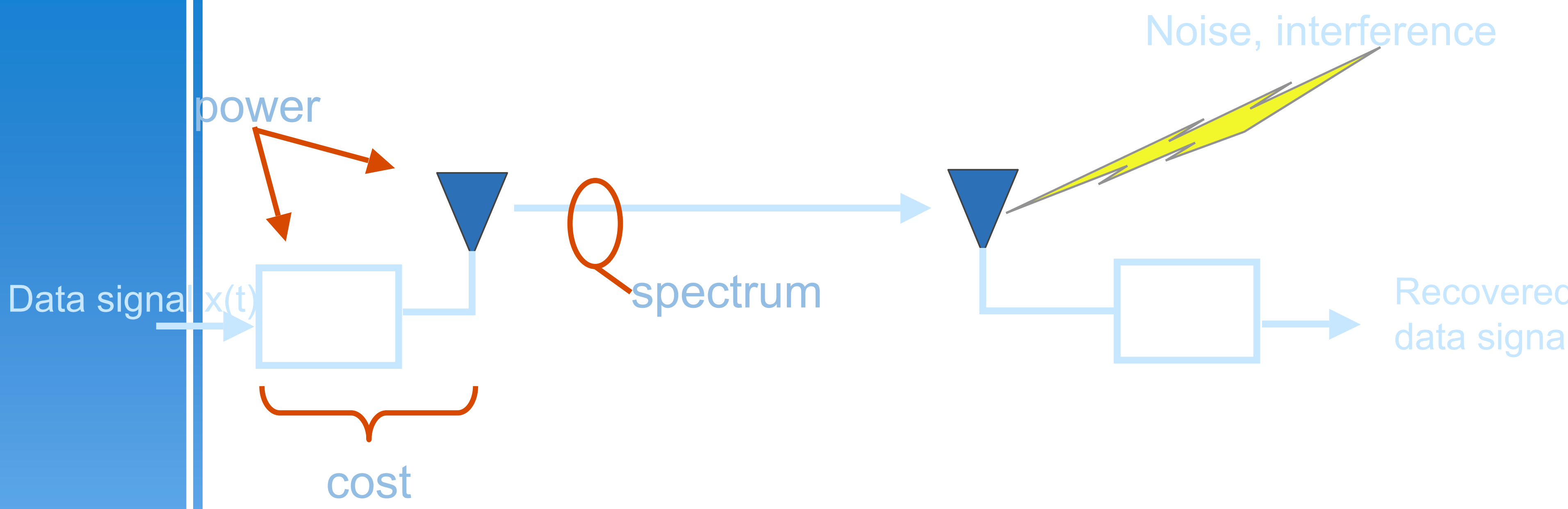
- Connect your wireless headset to your mobile phone, mobile computer or any wired connection to keep your hands free for more important tasks when you're at the office or in your car
- Source: bluetooth.com

The Automatic Synchronizer

- Automatic synchronization of your desktop, mobile computer, notebook (P and PC-HPC) and your phone. For instance, as as you enter your office address list and calend your notebook will automatically be update agree with the one in yo desktop, or vice versa.

- Source: bluetooth.com

Design considerations



Goal

- high bandwidth
- conserve battery power
- cost < $10

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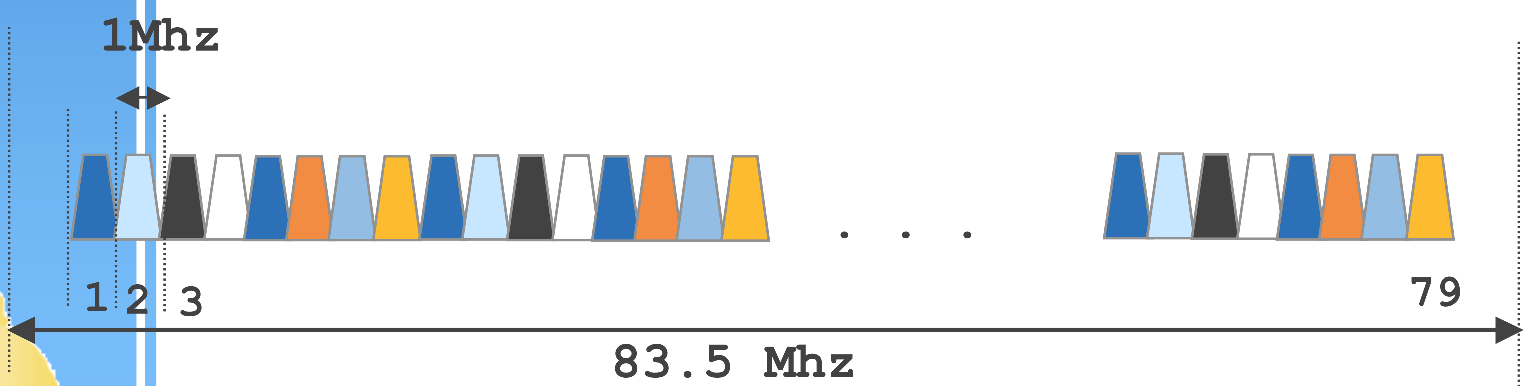
Bluetooth radio link

- frequency hopping spread spectrum
  - 2.402 GHz + k MHz, k=0, …, 78
  - 1,600 hops per second
- GFSK modulation
  - 1 Mb/s symbol rate
- transmit power
  - 0 dbm (up to 20dbm with power control)



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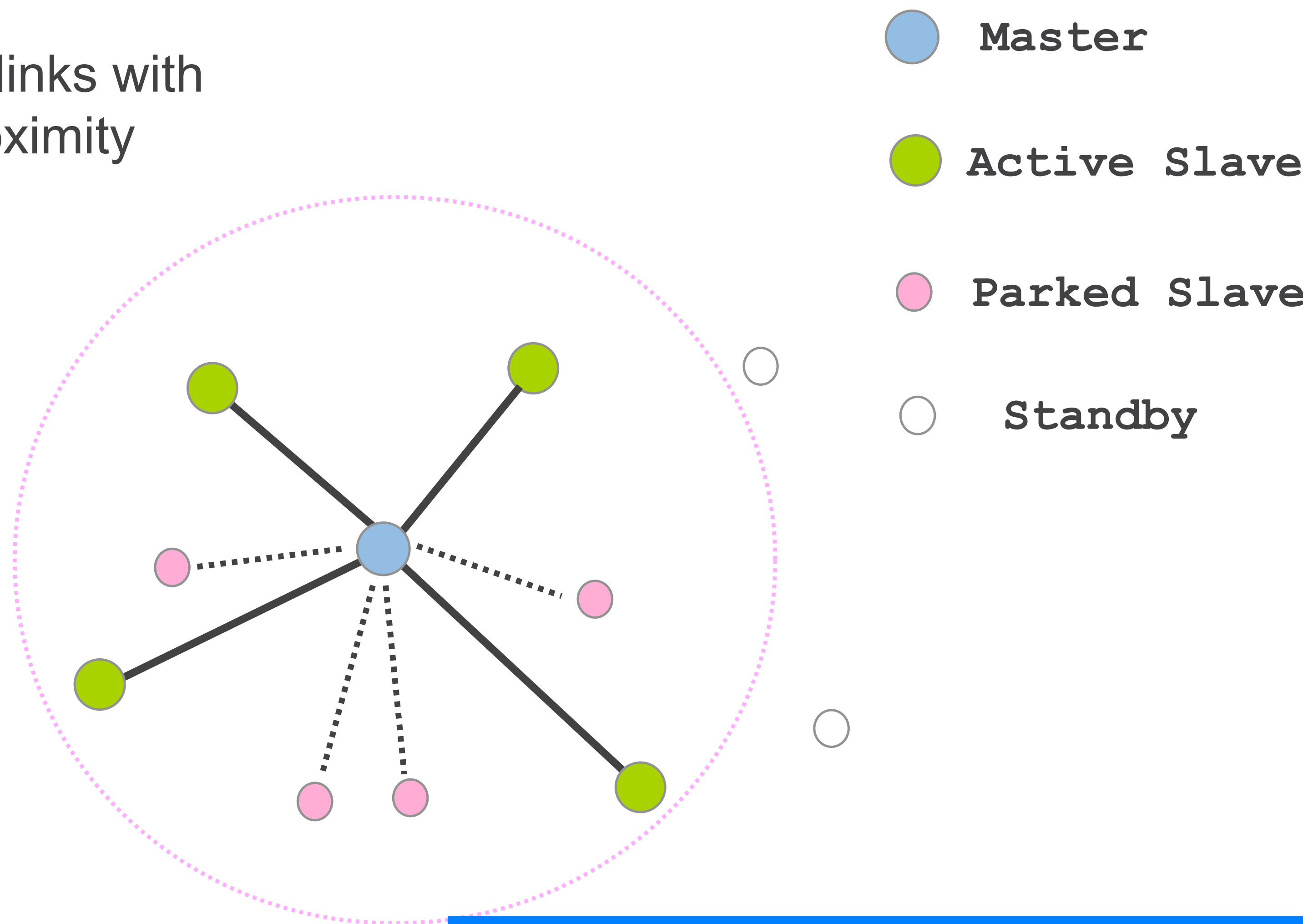
Piconet formation

- Page
  - to establish links with nodes in proximity



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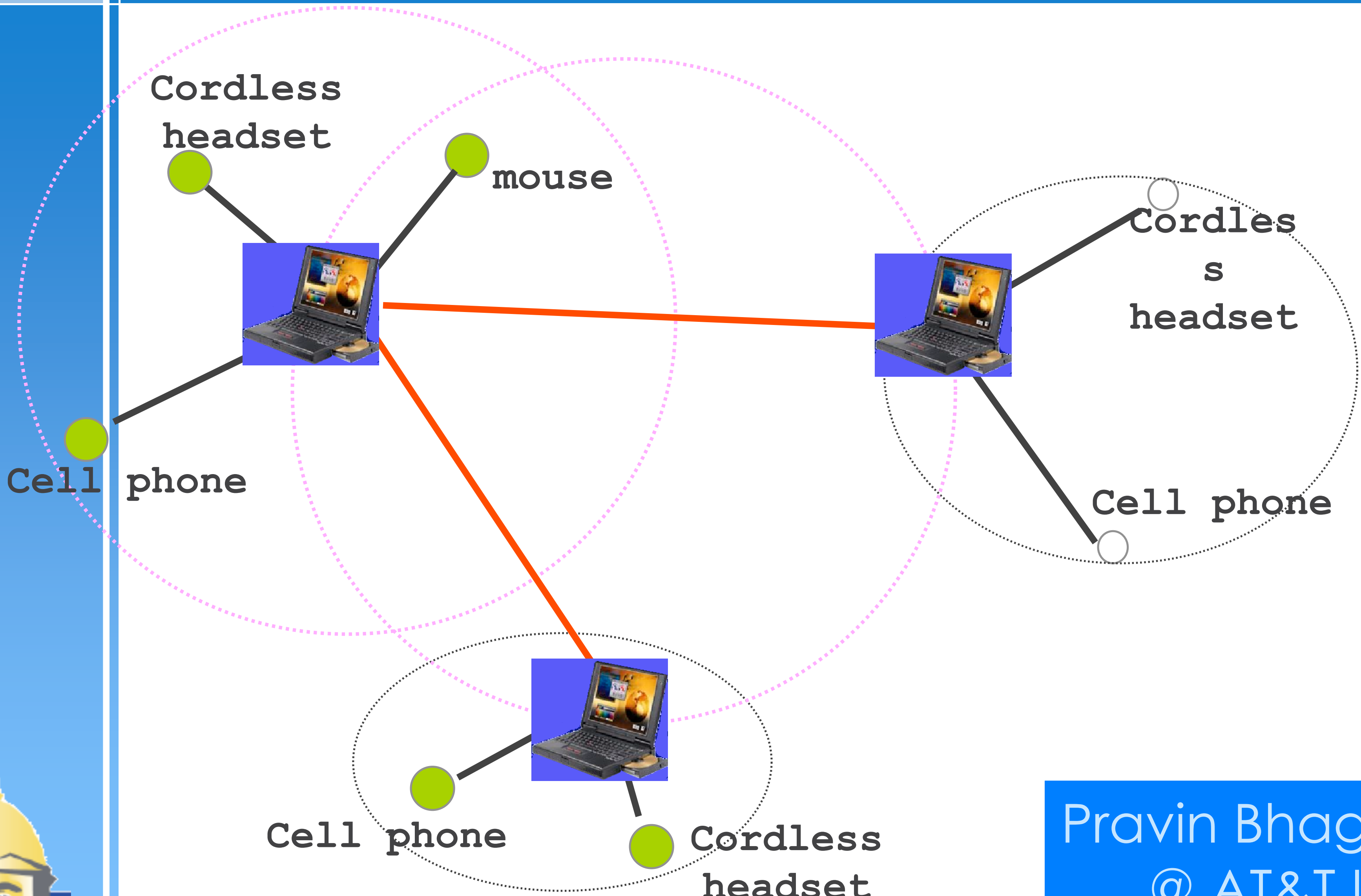
Inter piconet communication



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