DIRECT LINK COMMUNICATION II: WIRELESS MEDIA

Current Trend

• WLAN explosion (also called WiFi)
  → took most by surprise
• cellular telephony: 3G/4G
  → cellular providers/telcos/data in the same mix
• self-organization by citizens for local access
  → free WiFi hot spots
• large-scale hot spots: coffee shops, airport lounges, trains, university/enterprise campuses, cities, etc.
  → part of everyday life
  → difficult to turn back
• boundary between local and wide area wireless blurring
  → cellular: long-distance vs. WLAN: local
  → 802.16 (WiMax): designed to compete with cellular

• also very short distances (“wireless personal area networks”)
  → bluetooth, UWB, Zigbee: in general, 802.15
  → multi-use: cordless phones, WLANs, etc.
  → 2.4 and 5 GHz spectra: very busy

Integral part of the Internet: where it’s happening
  → good news and bad news
  → good old #$%&? radio technology
Basics of Wireless Communication

Use electromagnetic waves in wireless media (air/space) to transmit information.

- NIC: air interface

- directed signal propagation: e.g., directed antenna or IR (infrared)

- undirected signal propagation: e.g., omni-directional antenna

- mainly: microwaves

- e.g., 2–66 GHz
Key differences with wired communication:

- increased exposure to interference and noise
  → lack of physical shielding

- same frequency spectrum must be shared among all users

- inter-user interference cannot be localized at switch
  → cannot use buffering
  → problem for QoS (e.g., VoIP)

→ information is inherently exposed
→ bad for networking
→ bad for security
→ good for convenient access
• signal propagation and variation is more complex
  \[\rightarrow\] attenuation
  \[\rightarrow\] refraction, absorption, reflection, diffraction
  \[\rightarrow\] multi-path fading
  \[\rightarrow\] mobility

Network bandwidth: two extremes
  \[\rightarrow\] high and low bandwidth coexist
  \[\rightarrow\] e.g., 10 Gbps and 11 Mbps
  \[\rightarrow\] here to stay
  \[\rightarrow\] speed mismatch: makes things interesting
Electromagnetic spectrum (logarithmic scale):

Radio Wave | IR | Visible | UV | Gamma
---|---|---|---|---
1 Hz | 1 kHz | 1 MHz | 1 GHz | 1 THz | 1 PHz | $10^{18}$ Hz | $10^{21}$ Hz

Microwave

Cellular, GPS, Satellite, PCS, WLAN, Microwave Oven

Optical Fiber

→ RF: 9 kHz−300 GHz
→ Microwave: 1 GHz−1 THz
→ Wireless: concentration $\sim 0.8$ GHz−6 GHz
→ Optical fiber: $\sim 200$ THz; 25 THz bandwidth
Miscellaneous spectrum allocations (U.S.) & uses:

→ FCC (Federal Communications Commission)

• Voice: 300 Hz–3300 Hz
• AM Radio: 0.535 MHz–1.7 MHz
• FM Radio: 88 MHz–108 MHz
• TV: 174 MHz–216 MHz, 470 MHz–825 MHz
  → audio (FM), video (AM)
• GPS (Global Positioning System): 1.2276 GHz–1.57542 GHz
  → DS-CDMA
  → 24 satellites (DoD), 10900 miles
  → navigation service: trilateration
• Cellular telephone: 824 MHz–849 MHz (upstream), 869 MHz–894 MHz (downstream)
  → AMPS: FDM, analog
  → GSM: TDMA, digital
  → IS-95: CDMA, digital

• PCS: 1.85 GHz–1.99 GHz
  → CDMA, TDMA
- WLAN: IEEE 802.11b 2.4 GHz–2.4835 GHz
  — DSSS or FHSS with CSMA/CA
  — same frequency range for 802.11g
- WLAN: Bluetooth 2.4 GHz–2.4835 GHz
  — FH with TDD
- WLAN: IEEE 802.11a 5.725 GHz–5.850 GHz
  — OFDM with CSMA/CA
- WiMax: IEEE 802.16 2 GHz–66 GHz
  — TDMA based
• Satellite: C-band 3.7 GHz–4.2 GHz (downlink), 5.925 GHz–6.425 GHz (uplink)
  \[\rightarrow\] FDMA/TDMA

• Satellite: Ku-band 11.7 GHz–12.2 GHz (downlink), 14 GHz–14.5 GHz (uplink)

• Many other frequency bands
  \[\rightarrow\] cf. FCC chart
Signal Propagation and Power

Free space loss:

- transmitting antenna: signal power $P_{\text{in}}$
- receiving antenna: signal power $P_{\text{out}}$
- distance: $d$
- frequency: $f$

$$P_{\text{out}} \propto P_{\text{in}} \frac{1}{d^2 f^2}$$

$\rightarrow$ quadratic decrease in distance & frequency
Design implications:

- effective coverage limited by distance
  
  $\rightarrow$ SNR: signal-to-noise ratio

  $\rightarrow$ SIR: signal-to-interference ratio

$\rightarrow$ pros & cons?
- low power output decreases cell size
  -→ increased battery life
  -→ enables frequency reuse
  -→ more antennas required
  -→ handoff coordination overhead
  -→ e.g., I65 from Lafayette to Indy
Cellular Networks

Hexagonal cells:

→ both affect tiling of the plane

→ why hexagonal?

Frequency reuse: adjacent cells do not use common carrier frequency.

→ avoid interference

→ how many frequencies are required?
For example, using seven frequencies:

\[
\begin{array}{cccccccc}
2 & 3 & 4 & 5 & 6 & 7 & 1 \\
7 & 6 & 5 & 2 & 1 & 3 & 4 \\
1 & 4 & 5 & 2 & 7 & 6 & 3 \\
6 & 5 & 2 & 3 & 1 & 4 & 7 \\
2 & 3 & 4 & 5 & 6 & 7 & 1 \\
7 & 6 & 5 & 2 & 1 & 3 & 4 \\
1 & 4 & 5 & 2 & 7 & 6 & 3 \\
6 & 5 & 2 & 3 & 1 & 4 & 7 \\
\end{array}
\]

\[\rightarrow\] why does it work?

\[\rightarrow\] in general, coloring problem
4-coloring of U.S. map:

\[\rightarrow\] Y. Kanada, Y. Sato; Univ. of Tokyo
CS Building:

First floor frequency reuse:
Second floor frequency reuse:

Ground floor frequency reuse:
Long Distance Wireless Communication

Principally satellite communication:

- LOS (line of sight) communication
  \[\rightarrow\text{ satellite base station is relay}\]
- Effective for broadcast
- Limited bandwidth for multi-access
  \[\rightarrow\text{ not scalable}\]
Multi-access protocols:

- FDM + TDMA: dominant
  \[\rightarrow\] broadband
  \[\rightarrow\] GSM cellular
- CDMA: e.g., GPS and defense related systems
  \[\rightarrow\] CDMA cellular (Qualcomm)
- CSMA/CA: impractical due to large RTT
  \[\rightarrow\] low utilization/throughput

Long-distance wireless communication: effective when broadcasting

  \[\rightarrow\] special applications
  \[\rightarrow\] e.g., TV, GPS, digital radio, atomic clock
Short Distance Wireless Communication

- very short: wireless PAN
- short: wireless LAN
- medium: wireless MAN

→ TDMA, FDMA, CDMA, polling
→ contention-based multiple access w/o priority
Cellular telephony: frequency & time division

Ex.: GSM (U.S. IS-136) with 25 MHz frequency band

- uplink: 890–915 MHz
- downlink: 935–960 MHz
- 125 channels 200 kHz wide each (= 25000 ÷ 200)
  → separation needed due to cross-carrier interference
  → FDM portion
• 8 time slots within each channel
  → TDM portion

• total of 1000 possible user channels
  → $125 \times 8 \ (124 \times 8$ realized$)$

• codec/vocoder: 13.4 kb/s

• compare with T1 standard
  → 24 users at 64 kb/s data rate each
Cellular telephony: code division multiplexing

→ same frequency band; different codes

Ex.: IS-95 CDMA with 25 MHz frequency band

• uplink: 824–849 MHz; downlink: 869–894 MHz
  → downlink: prepared; uplink: physical diversity
  → capture effect: closer station has advantage
• codec: 9.6 kb/s
Packet radio: ALOHA

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downlink broadcast channel $F1$

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shared uplink channel $F1'$

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both baseband

Ex.: ALOHANET

- data network over radio

- Univ. of Hawaii, 1970; 4 islands, 7 campuses
• Norm Abramson
  → precursor to Ethernet (Bob Metcalfe)
  → pioneering Internet technology
  → parallel to packet switching technology
• FM radio carrier frequency
  → uplink: 407.35 MHz; downlink: 413.475 MHz
• bit rate: 9.6 kb/s
• contention-based multiple access: MA
  → plain and simple
  → needs explicit ACK frames
  → ALOHA
Wireless LAN (WLAN): infrastructure mode

→ shared uplink & downlink channel $F1$

→ single baseband channel

• basic service set (BSS)

• base station: access point (AP)

• mobile stations must communicate through AP
WLAN: ad hoc mode

→ homogeneous: no base station
→ everyone is the same
→ share forwarding responsibility

• independent basic service set (IBSS)
• mobile stations communicate peer-to-peer
  → also called peer-to-peer mode
WLAN: internetworking

→ internetworking between BSS’s through APs
→ mobility and handoff

• extended service set (ESS)
• APs are connected by distribution system (DS)
• DS: wireline or wireless
  → common: Ethernet switch
• How do APs and Ethernet switches know where to forward frames?
  → bridge: link layer forwarding device
  → i.e., switch using MAC address relay
  → learning bridge: source address discovery
  → spanning tree: IEEE 802.1 (Perlman’s algorithm)
  → distributed ST & leader election
Additional headache: mobility

→ how to perform handoff
→ mobility management at MAC
→ mobility management at IP (Mobile IP)

Mobility between BSSes in an ESS

• association
  → registration process
  → mobile station (MS) associates with one AP

• disassociation
  → upon permanent departure: notification

• reassociation
  → movement of MS from one AP to another
  → inform new AP of old AP
  → forwarding of buffered frames
WLAN spectrum 2.4–2.4835 GHz:

→ 11 channels (U.S.)

→ 2.412 GHz, 2.417 GHz, . . . , 2.462 GHz

Non-interference specification:

• each channel has 22 MHz bandwidth

• require 25 MHz channel separation

→ thus, only 3 concurrent channels possible

→ e.g., channels 1, 6 and 11

→ 3-coloring . . .