Smart Health – CSE 40816

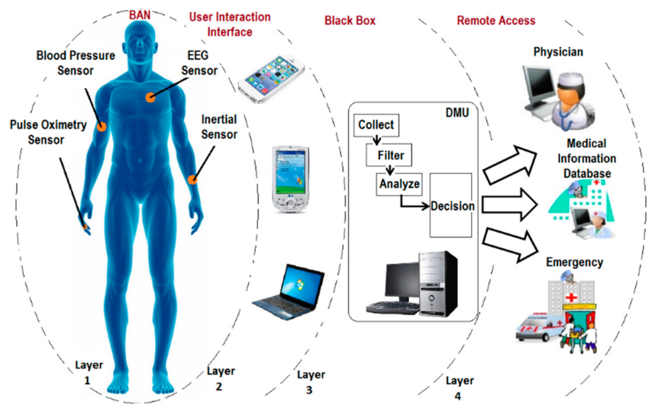
University of Notre Dame

Spring 2020

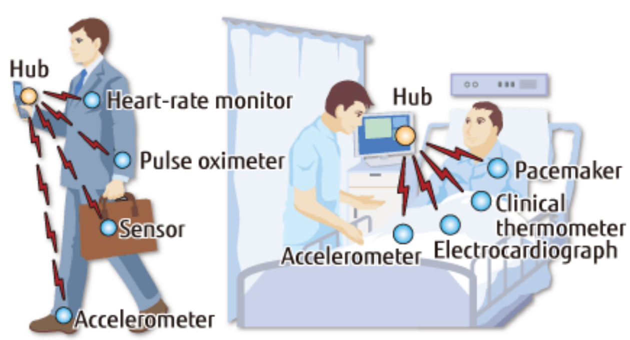
UNIVERSITY OF NOTRE DAME

Wireless Networks in Healthcare

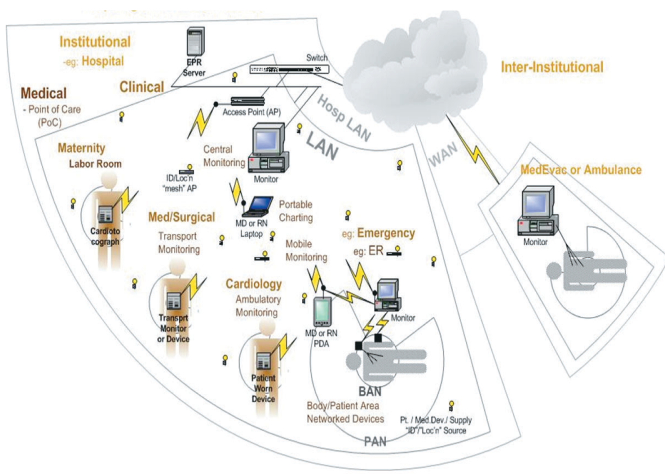
Wireless Networks in Healthcare



Wireless Networks in Healthcare

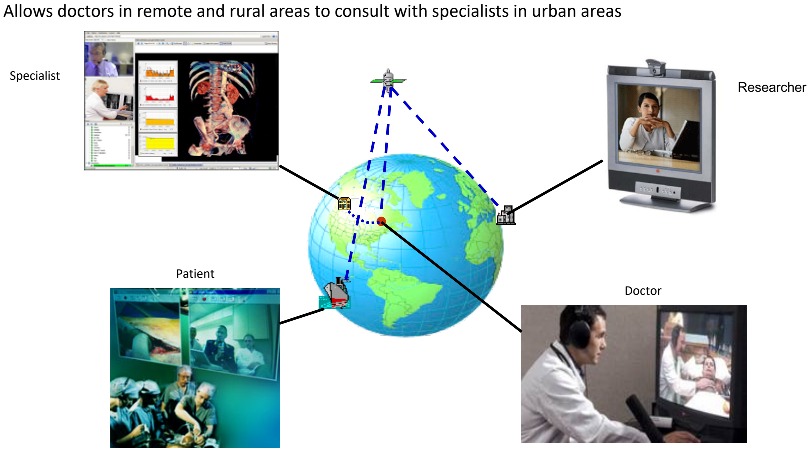


Wireless Networks in Healthcare



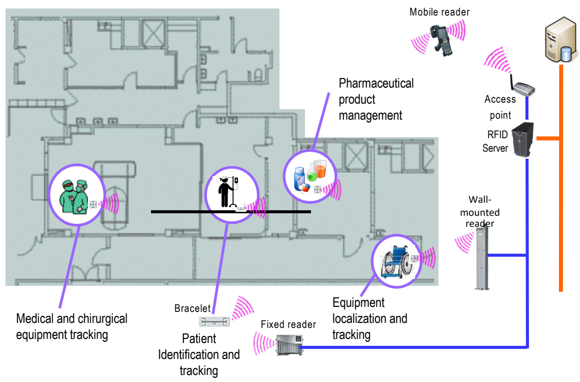
Telemedicine

- Utilization of different assets independent of their geographical location
- Multidisciplinary collaboration
- Facilitates the dissemination of medical knowledge to practicing doctors and medical students
- Allows doctors in remote and rural areas to consult with specialists in urban areas



Radio Frequency Identification (RFID)

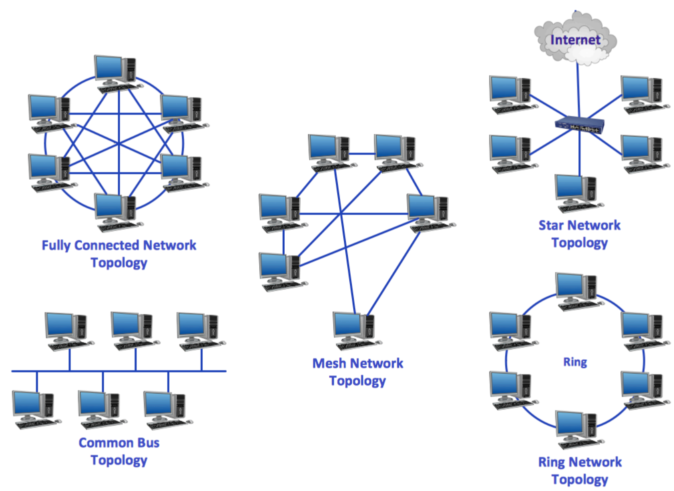
- Facilitates management of assets (wheel chairs, scanners, ambulatory equipment)
- Improves patient localization and helps caregivers to provide services without delays
- Enhances process of drug administration (identification, distribution, localization, returns and disposal)
- Facilitates automatic data capture and the follow-up of blood and biological samples



Computer Networks 101

- A ***network*** is a "group of computers and associated devices that are connected by communication facilities."
- Types of networks:
  - **Local Area Network (LAN):** laboratory/office-scale
  - **Metropolitan Area Network (MAN):** city-scale
  - **Wide Area Network (WAN)**: world-wide (Internet -> "collection of networks")

Network Topology

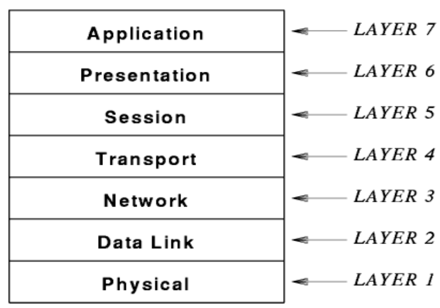


Examples

- **Ethernet:**
  - **popular, relatively inexpensive, easy-to-install LAN architecture**
  - uses the **CSMA/CD** media access control
  - data transmission normally occurs at 100 Mbps (10Mbps in the early forms and 10Gbps in the most recent forms)
  - partially described in the **IEEE 802.3** specification
- **Wi-Fi:**
  - **popular wireless LAN architect**ure
  - uses a modified version of the **CSMA/CA** protocol
  - partially described in the **IEEE 802.11** specification

ISO/OSI Model

- The International Standards Organization (ISO) Open Systems Interconnect (OSI) is a standard set of rules describing the transfer of data between each layer in a network operating system. Each layer has a specific function (i.e., the physical layer deals with the electrical and cable specifications).



ISO/OSI Model

- Physical Layer
  - **Physical/electrical characteristics**
  - Cable type, length, connectors, voltage levels, signal durations, ...
  - Binary data (bits) as electrical or optical signals.
- Data Link Layer
  - **Defines when/how medium will be accessed for transmission**
  - Units typically called "frames"; error detection/correction; divided into sublayers, including: **MAC = Medium Access Control** (MAC address 6f:00:2b:23:1f:32)
- Network Layer
  - **IP = Internet Protocol**
  - **Addressing and routing** (IP address 147.94.123.15)

ISO/OSI Model

- Transport Layer
  - **UDP** (User Datagram Protocol)
  - **TCP** (Transmission Control Protocol)
  - Addressing (“**ports**”), error correction, flow control, congestion control
- Session Layer
  - Management of “sessions”
- Presentation Layer
  - Data translation, formatting, encryption, compression
- Application Layer
  - Interface between user applications and lower network services

What is IP, TCP, UDP?

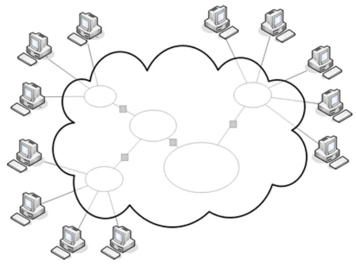
- Internet Protocol (IP):
  - Take your message and slap a “header” on it (“packet”)

Header	Data

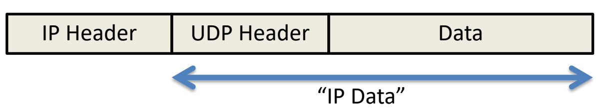
  - What’s in a header?
    - Sender address: 112.44.44.23
    - Receiver address: 147.12.68.211
    - Routers use it to figure out what to do with it (see next slide for routers)
  - What does IP do:
    - mostly addressing
    - used by routers

Internet + Routers

- **Router: links parts of a larger network together**
- Routing using **tables**:
  - "129.74" belongs to University of Notre Dame
  - How is the table built?
    - Routers talk to each other to exchange what they know about the world (using ICMP = Internet Control Message Protocol)
  - Why only remember parts of a network?
    - 32-bit address consists of network address and computer address
    - Class A, B, C networks: 8/16/24 bits for network, rest for computers
      - Example: C network 127.45.20.21: 127.45.20 is network address, 21 is computer address (out of 255 computers)
- Routing is based on (independent) **packets**! (Compare phone calls to mail delivery)



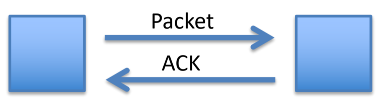
UDP = User Datagram Protocol



- Slap on another header
- Adds more addressing: "**ports**"
  - IP address tell you which computer
  - Ports tell you which application on that computer
  - Example: a web server "listens" to requests on port 80
  - Web browser: http://www.google.com:80 = http://216.58.216.100:80
    - HTTP: HyperText Transfer Protocol
    - :80: optional
  - **Unreliable!**
    - Packets can get lost; packets can arrive out of order

TCP = Transmission Control Protocol

- **Reliable** protocol
- Adds ports (just like UDP), but also provides:
  - In-order delivery of packets (using sequence numbers)
  - Reliable delivery: using acknowledgment (ACK) packets



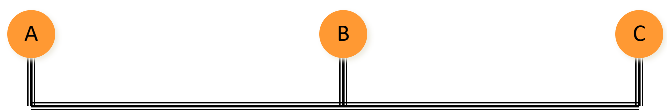
  - **Flow control:**
    - control of traffic between **sender and receiver**
    - receiver can throttle sender to avoid getting packets too fast
    - explicit: "advertised window" in ACK packet (how many more bytes)
  - **Congestion control:**
    - control of traffic flow into the **network**
    - routers can throttle sender to avoid getting too many packets
    - implicit: watch ACKs -> missing ACKs = router overload

UDP vs TCP

- TCP:
  - typical choice of most applications
  - do not want to lose data, out-of-order arrival, etc.
  - email, web traffic, financial transactions, etc.
- UDP:
  - can be "faster"
    - no flow/congestion control "slowing down" traffic
    - no retransmissions
    - good for "real-time" traffic
  - out-of-order arrival: can also "reorder" at application level
  - loss of data: can be acceptable
    - missing frames in video/audio stream

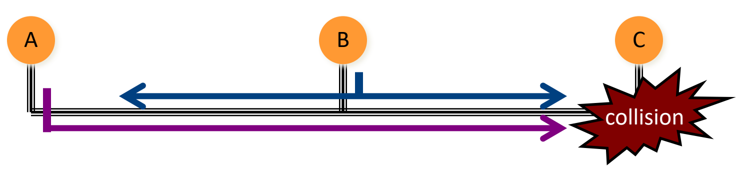
Medium Access Control (MAC)

- Responsible for deciding **when & how to transmit frames** over a network ("channel access problem")
  - Ethernet bus: computers connect to the same wire, i.e., two computers could "talk" at the same time: **collision**!
- MAC protocol is very important for "quality" of communications (successful transmissions, reliable transmissions, high throughput, low latency, fairness, …)

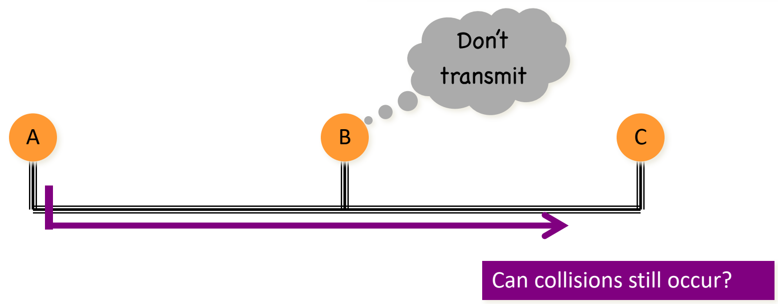


Example: Ethernet

- Medium Access Control (MAC) protocol
- **CSMA/CD** Protocol
  - **C**arrier **S**ense
  - **M**ultiple **A**ccess
  - **C**ollision **D**etection



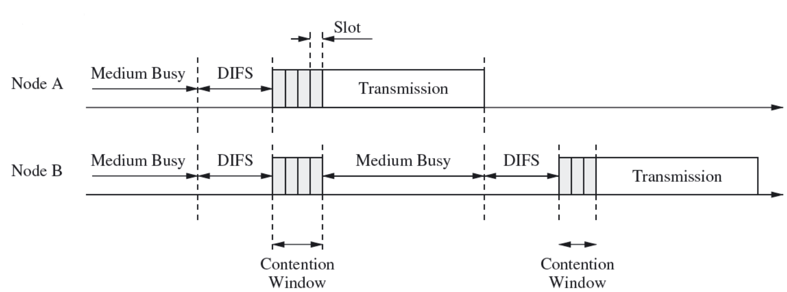
Example: Ethernet



- "Sense" (listen) carrier ("is anyone else talking right now?")
- If "busy": wait; if "idle": transmit
- CD: Keep listening while transmitting
  – If collision detected: retry at a later time

CSMA/CD

- Carrier Sense Multiple Access / Collision Detection
  – Carrier Sense: listen for inactivity on bus before transmitting
  – Multiple Access: multiple devices share same bus (wire)
  – Collision Detection: device detects if own transmission was corrupted (collision) and can retransmit at later time

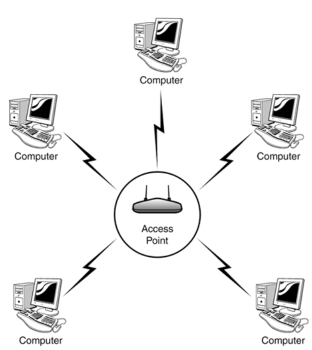


CSMA/CD

- Assumption: the received and transmitted signal are identical (non-dispersive)
- Assumption: receiver "sees" the same signals as transmitters on channel
- **Problem: both not true in wireless networks!**
- Transmitter does not know what the receiver "sees" and therefore does not know if transmission was successful

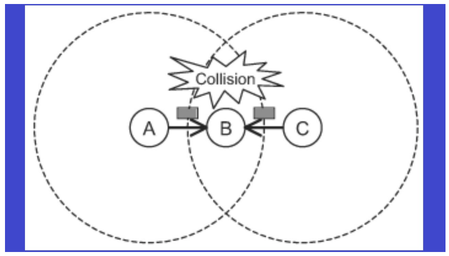
Example: Wi-Fi (802.11)

- Most popular wireless LAN architecture



Access point
Wi-Fi router
Base station
Hotspot

Example: Wi-Fi (802.11)



- **CSMA/CA** Protocol
  - **C**arrier **S**ense
  - **M**ultiple **A**ccess
  - **C**ollision **A**voidance
    - Channel reservations:
      - Transmitter sends request-to-send (RTS)
      - Receiver sends clear-to-send (CTS)
    - Advantages:
      - Nodes hearing RTS and/or CTS keep quiet
      - If collision, only small RTS or CTS packets are lost

Exponential Backoff

- Wait random amount of time before transmitting!
  - Choose a random number R = rand(0, CW_min)
- Each node counts down R
  - Continue carrier sensing while counting down
  - Once carrier busy, freeze countdown
- Whoever reaches ZERO transmits RTS
- If RTS or DATA collides (i.e., no CTS/ACK returns)
  - Indicates collision
  - Transmitter chooses new random R = rand(0, 2*CW_min)
  - Exponential Backoff Ri = rand(0, 2^i * CW_min)
  - Once successful transmission, reset to rand(0, CW_min)

Recap

- CSMA/CD: works good in wired networks; but doesn't work in wireless networks
- CMSA/CA ("collision avoidance"): goal is to reduce the occurrences of collisions instead of detecting and handling them

Next Up: Wireless Communications

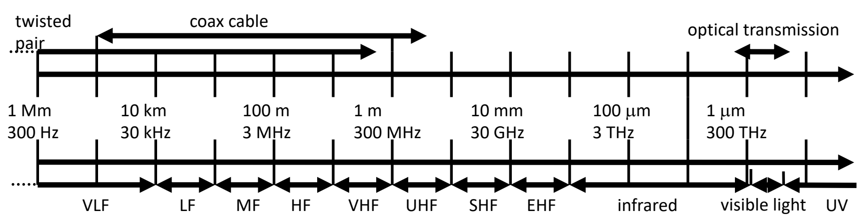
- Fundamental aspects of wireless networks and radio communications

Frequencies for Communication

- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

- Frequency and wave length
  - $\lambda = c/f$
  - wave length λ, speed of light $c \cong 3x10^8 m/s$, frequency f



Frequencies for Mobile Communication

- Low Frequencies:
  - low data rates
  - travel long distances
  - follow Earth's surface
  - penetrate objects and water (submarine communication)
- High Frequencies:
  - high data rates
  - short distances
  - straight lines
  - cannot penetrate objects ("**Line of Sight**" or **LOS**)

Frequencies and Regulations

- ITU-R holds auctions for new frequencies, manages frequency bands worldwide (WRC, World Radio Conferences)

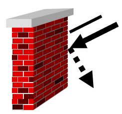
Examples	Europe	USA	Japan
Cellular phones	**GSM** 880-915, 925-960, 1710-1785, 1805-1880 **UMTS** 1920-1980, 2110-2170	**AMPS, TDMA, CDMA, GSM** 824-849, 869-894 **TDMA, CDMA, GSM, UMTS** 1850-1910, 1930-1990	**PDC, FOMA** 810-888, 893-958 **PDC** 1429-1453, 1477-1501 **FOMA** 1920-1980, 2110-2170
Cordless phones	**CT1+** 885-887, 930-932 **CT2** 864-868 **DECT** 1880-1900	**PACS** 1850-1910, 1930-1990 **PACS-UB** 1910-1930	**PHS** 1895-1918 **JCT** 245-380
Wireless LANs	**802.11b/g** 2412-2472	**802.11b/g** 2412-2462	**802.11b** 2412-2484 **802.11g** 2412-2472
Other RF systems	27, 128, 418, 433, 868	315, 915	426, 868

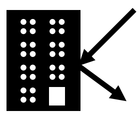
Signal Propagation

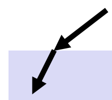
- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$ in vacuum – much more in real environments
  (d = distance between sender and receiver)
- **Path loss (attenuation)**
- Fundamental propagation behaviors:
  - **ground wave (<2MHz):** follow earth's surface, long distances (submarine communication, AM radio)
  - **sky wave (2-30MHz):** reflected at ionosphere, around the world (intl. broadcasts, amateur radio)
  - **line-of-sight (>30MHz)**: LOS, straight line, waves are bent by atmosphere due to refraction (mobile phones, satellite, cordless)
- Most systems we will discuss work with >100MHz: LOS (question: so how do mobile phones work then???)

Other Propagation Effects

- Receiving power additionally influenced by
  - **fading** (frequency dependent)
  - **shadowing**
  - **reflection** at large obstacles
  - **refraction** depending on the density of a medium
  - **scattering** at small obstacles
  - **diffraction** at edges


shadowing

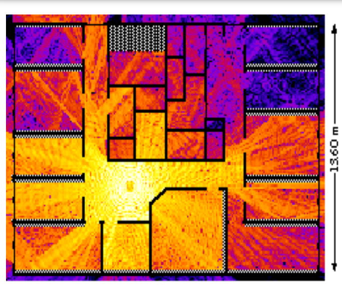

reflection

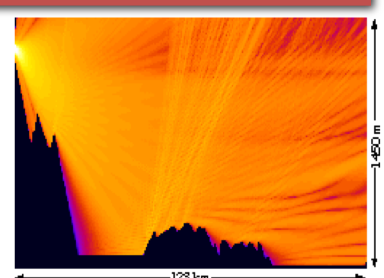

refraction

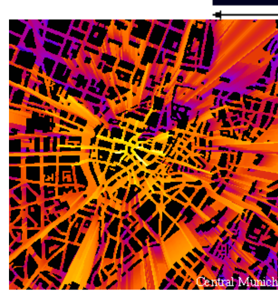
scattering


diffraction

Real World Examples

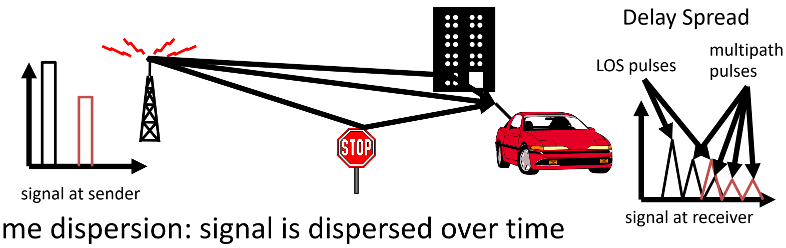






Multipath Propagation

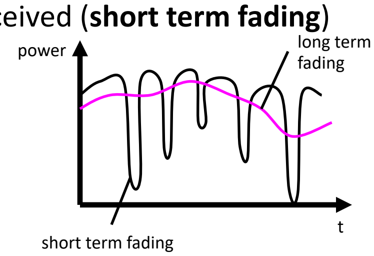
- Signal can take **many different paths** between sender and receiver due to reflection, scattering, diffraction



- Time dispersion: signal is dispersed over time
  - interference with "neighbor" symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
  - distorted signal depending on the phases of the different parts

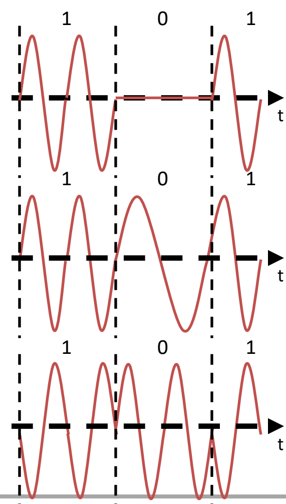
Effects of Mobility

- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
  - ➔ quick changes in the power received (**short term fading**)
- Additional changes in
  - distance to sender
  - obstacles further away
  - ➔ slow changes in the average power received (**long term fading**)



Digital Modulation

- Modulation of digital signals known as Shift Keying
- **Amplitude Shift Keying (ASK):**
  - very simple
  - low bandwidth requirements
  - very susceptible to interference
- **Frequency Shift Keying (FSK):**
  - needs larger bandwidth
- **Phase Shift Keying (PSK):**
  - more complex
  - robust against interference



Multiplexing