Chapter 1: Introduction to Comm. Eng'g

AAiT
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Undergraduate Program
School of Electrical and Computer Engineering

Outlines

- Introduction to communications
  - Key Evolutions in the world of communications
- Basics of communication technologies
  - Wireless and Wired technologies
- Elements of communication system
  - Channel characteristics
  - Mathematical models of a channel
- Signals and systems – Review
- The Hilbert Transform & Bandpass Signals
- Fundamentals of Analog Transmission

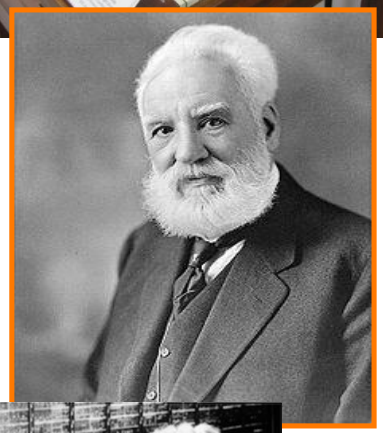
Introduction to Communication Systems

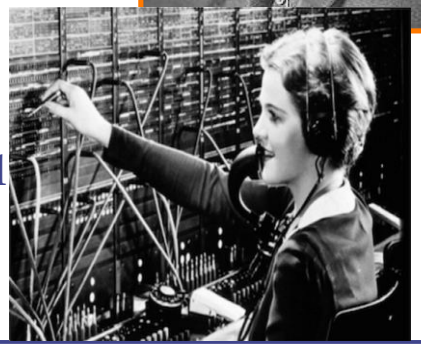
- Any means for transmission of information from one point to another using electrical systems.
  - This should be done
    - as efficiently as possible
    - with as much fidelity/reliability as possible
    - as securely as possible
- Types of communication systems
  - Wireline and wireless
  - Digital and analog
  - Point-to-point and broadcast
  - Low frequency and high frequency
  - ….
- Examples
  - Telephone, cell phone, TV, Internet, …

Key Evolutions in the world of communications

- Telegraph
  - 1844, Samuel Morse,
    - "What hath God wrought" transmitted by Morse's electric telegraph
    - Washington D.C ~ Baltimore, Maryland
    - Morse code : variable-length code (a dot, a dash, a letter space, a word space)

- Telephone
  - 1875, Alexander Graham Bell
    - Invented the telephone
  - 1897, A. B. Strowger
    - Devised the autiomatic step-by-step switch
  - 28 January 1878:
    - The first commercial US telephone exchange opened in New Haven, Connecticut.





Key Evolutions in the world of communications…

- Radio
  - 1864, James Clerk Maxwell
    - Formulated the electromagnetic theory of light
    - Predicted the existence of radio waves
  - 1887, Heinrich Hertz
    - The existence of radio waves was confirmed experimentally
  - 1894, Oliver Lodge
    - Demo : wireless communication over a relatively short distance (150 yards)
  - 1901, Guglielmo Marconi
    - Demo : wireless communication over a long distance (1700 miles)
  - 1906, Reginald Fessenden
    - Conducting the first radio broascast
  - 1918, Edwin H. Armstrong
    - Invented the superheterodyne radio receiver
  - 1933, Edwin H. Armstrong
    - Demonstrated another modulation scheme (Frequency nodulation)

Key Evolutions in the world of communications ….

- Electronics
  - 1904, John Abbrose Eleming
    - Invented the vacuum-tube diode
  - 1906, Lee de Forest
    - Invented the vacuum-tube triode
  - 1948, Walter H. Brattain, William Shockley (Bell Lab.)
    - Invented the transistor
  - 1958, Robert Noyce
    - The first silicon integrated circuit (IC) produce

- Television
  - 1928, Philo T. Farnsworth
    - First all-electronic television system
  - 1929, Vladimir K. Zworykin
    - all-electronic television system
  - 1939, BBC
    - Broadcasting television service on a commercial basis

Key Evolutions in the world of communications ….

- Digital Communications
  - 1928, Harry Nyquist
    - The theory of signal transmission in telegraphy
  - 1937, Alex Reeves
    - Invent pulse-code modulation
  - 1958, (Bell Lab.)
    - First call through a stored-program system
  - 1960, (Morris, Illinois)
    - The first commercial telephone service with digital switching begin.
  - 1962, (Bell Lab.)
    - The first T-1 carrier system transmission was installed
  - 1943, D. O. North
    - Matched filter for the optimum detection of a unknown signal in a additive white noise
  - 1948, Claude Shannon
    - The theoretical foundation of digital communications were laid

Key Evolutions in the world of communications ….

- Computer Networks
  - 1943~1946, (Moore School of Electrical Engineering of the Univ. of Pennsylvania)
    - ENIAC : first electronic digital computer
  - 1950s
    - Computers and terminals started communicating with each other
  - 1965, Robert Lucky
    - Idea of adaptive equalization
  - 1982, G. Ungerboeck
    - Efficient modulation techniques
  - 1950~1970
    - Various studies were made on computer networks
  - 1971
    - Advanced Research Project Agency Network(APRANET) first put into service
  - 1985,
    - APRANET was renamed the Internet
  - 1990, Tim Berners-Lee
    - Proposed a hypermedia software interface to internet (World Wide Web)

Key Evolutions in the world of communications ….

- Satellite Communications
  - 1945, C. Clark
    - Studied the use of satellite for communications
  - 1955, John R. Pierce
    - Proposed the use of satellite for communications
  - 1957, (Soviet Union)
    - Launched Sputnik I
  - 1958, (United States)
    - Launched Explorer I
  - 1962, (Bell Lab.)
    - Launched Telstar I

Key Evolutions in the world of communications ….

- Optical Communications
  - 1966, K.C. Kao, G. A. Hockham
    - Proposed the use of a clad glass fiber as a dielectric waveguide
  - 1959~1960
    - The laser had been invented and developed

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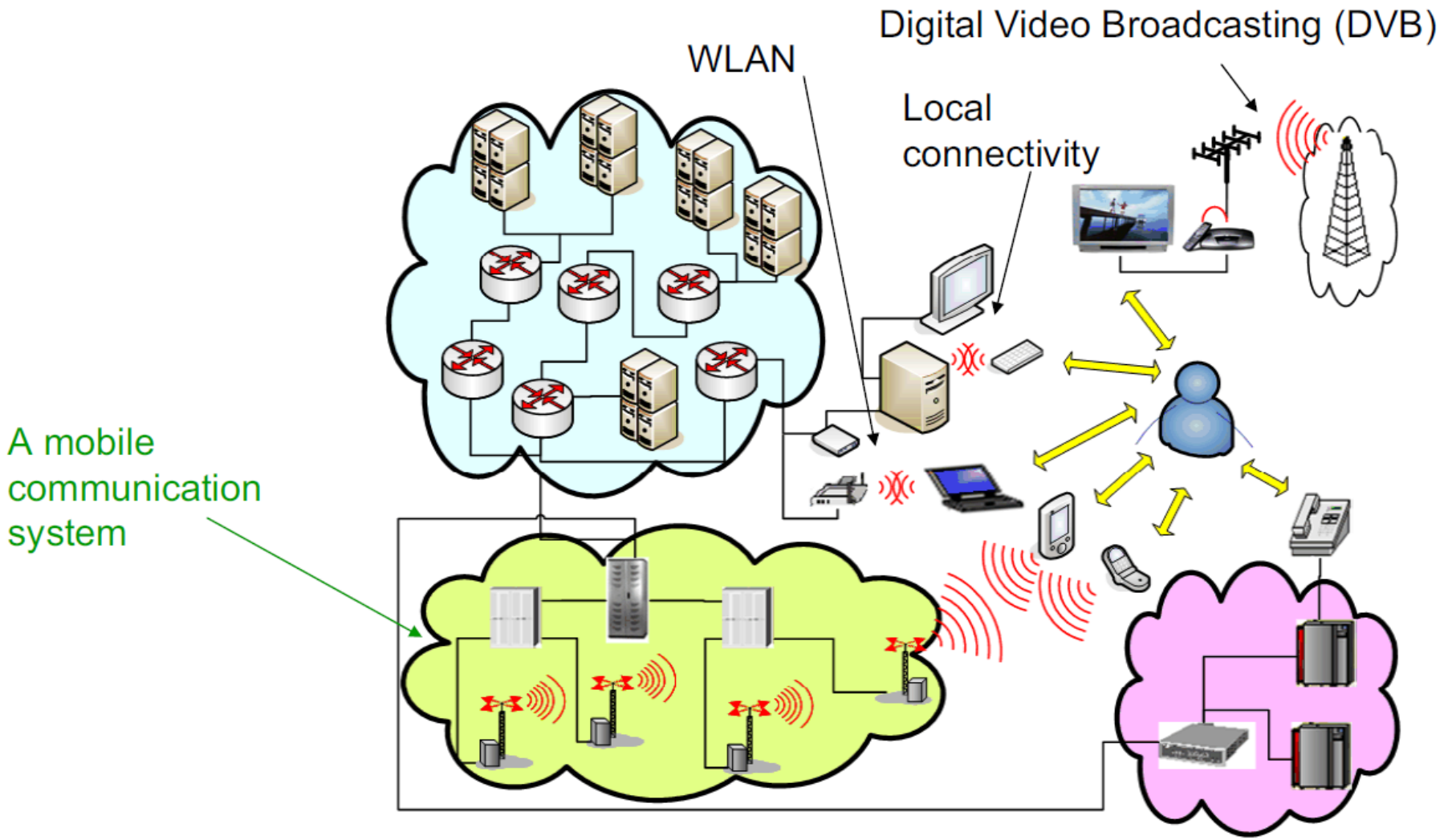
World of telecommunication



Wired Communication

- Transmission of data over a wire-based communication technology
  - No mobility
  - Reliable and secure data transmission
  - speed : Higher upload and download rate

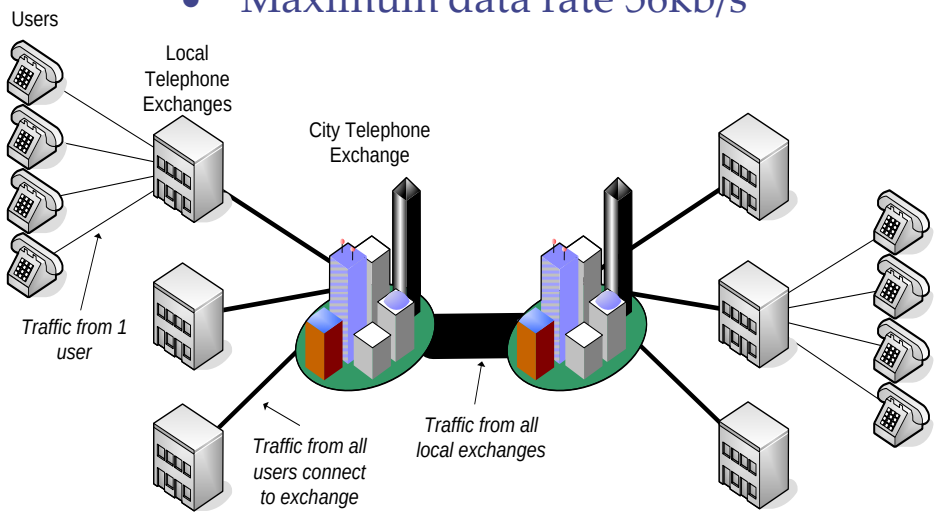
Wired Technologies

- Telephone Networks:
  - Public Switched Telecommunications Network
  - Digital Subscriber line
- Local Area Network (LAN), Ethernet
- Cable Television

Telephone Networks

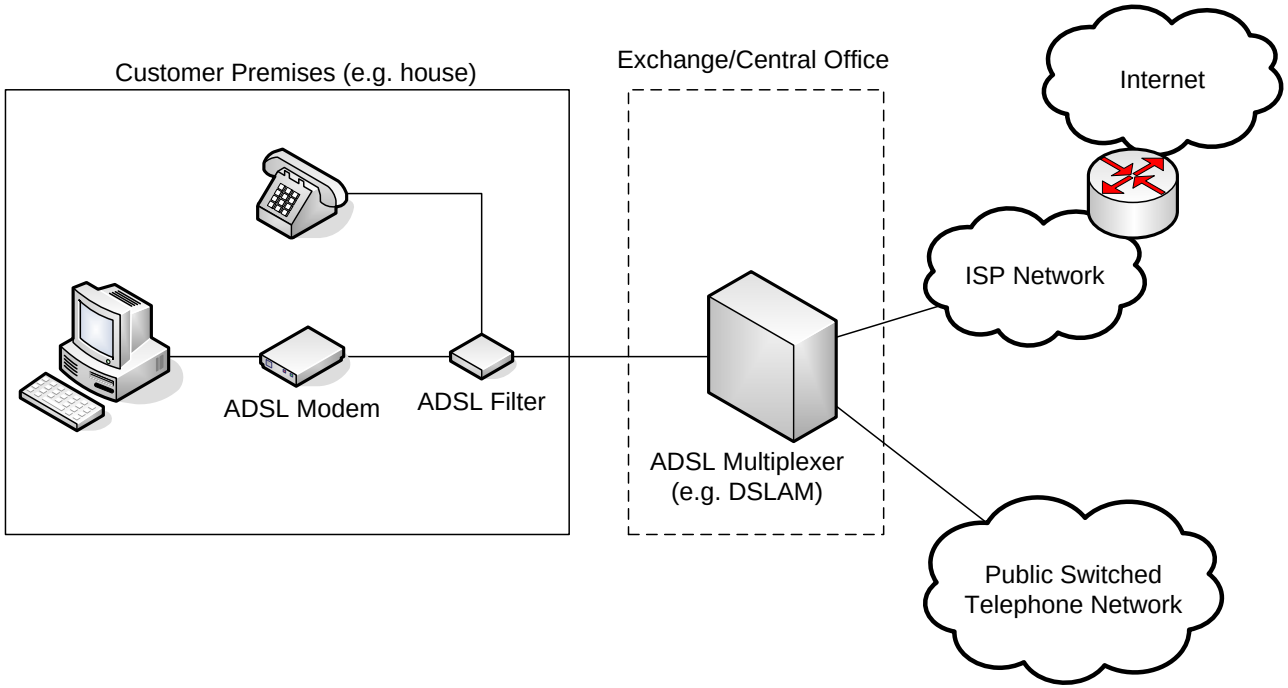
- Public Switched Telecommunications Network: Telephone Networks designed for the transmission of *voice-band Communication*
  - Real-time ; Low latency; High reliability
  - The service delivered to the end user is called the Plain Old Telephone Service (POTS)
- Features are :
  - Subscribers can be connected by entering *telephone numbers*
  - Multiple users connect to a local exchange via copper wires and connected in a hierarchy

- Later came *Dial-up access over telephone lines*
  - *Modem* converts digital data from computer into analog signal to be sent over telephone line (instead of analog voice)
    - Telephone system limits bandwidth to 4kHz (although copper cable can carry more)
    - Maximum data rate 56kb/s



Telephone Networks…

- The need to communicate digital data resulted in the invention of the *Digital Subscriber line* (DSL)
  - Copper line can actually transmit about 1MHz spectrum and DSL technologies make use of most of this (except the 4kHz for voice) to provide higher-speed access to the Internet.
  - Digital signals are sent from home (modem) to exchange (multiplexer)

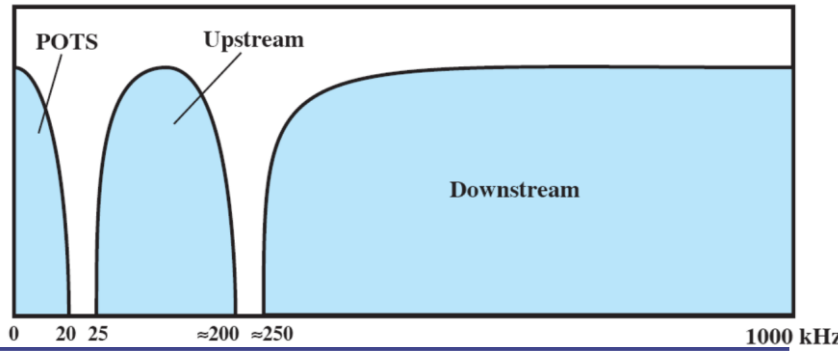


Telephone Networks…

- *Asymmetric Digital Subscriber Line (ADSL)*
  - Larger bandwidth (and hence data rate) for downstream (exchange to you) than upstream (you to exchange) traffic
    - ADSL Multiplexers (in exchange) can support larger bandwidths on transmission
    - Well suited to many Internet applications, e.g. web browsing, email
  - ADSL can adapt data rate depending on amount of noise on line
    - Lower speeds for longer distances and poor quality copper cables
  - Key Features:
    - Makes use of widely installed telephone network
    - Supports basic voice and video applications

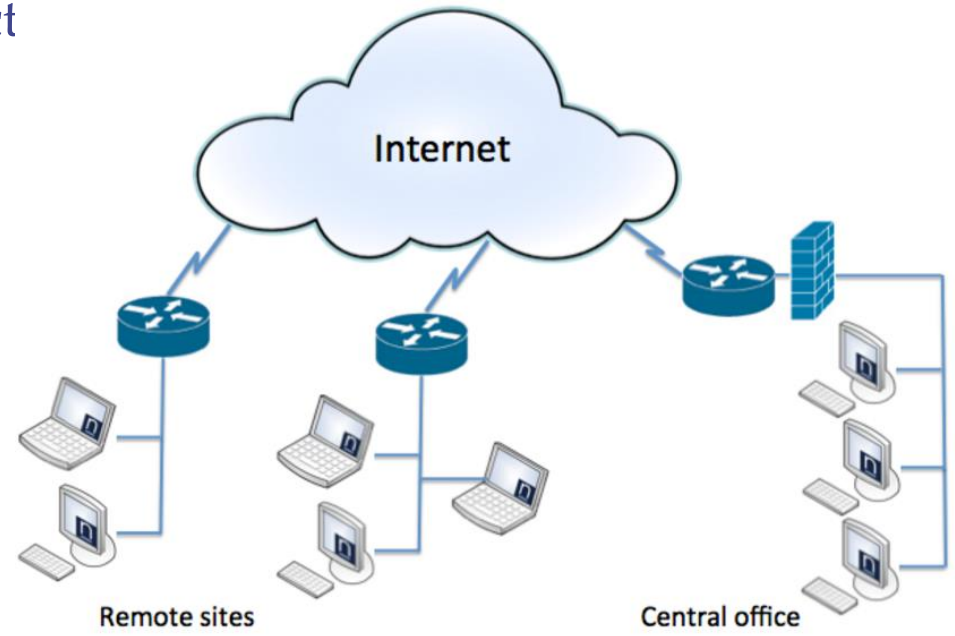
Technology	*Speed*	*Use*
HDSL	1.5Mb/s	Alternative of T1/E1
SHDSL	5.6Mb/s	Home/ business
VDSL	100Mb/s	FTTC

ADSL Example use of copper line spectrum



Wired LAN: thernet

- Operate in a limited geographical area
- Allow multiple access to high-bandwidth media
- Control the network privately under local administrative control
- Provide full time connectivity to local services
- Connect physically adjacent devices
- Provide up to Gbps connect
- WLAN, Internet



Wireless and Mobile Networks

- Wireless means transmitting signals using open space (atmosphere)
  - Mobility ; Reachability; Roaming Services
- Advances in wireless technology
  - *Radio & television broadcasting , Satellite communications, wireless networking (WiFi, Zegbi, IRFD), cellular technology*
- No. wireless (mobile) phone subscribers now exceeds No. wired phone subscribers
- No. wireless Internet-connected devices equals No. wireline Internet-connected devices
  - laptops, Internet-enabled phones promise anytime untethered Internet access

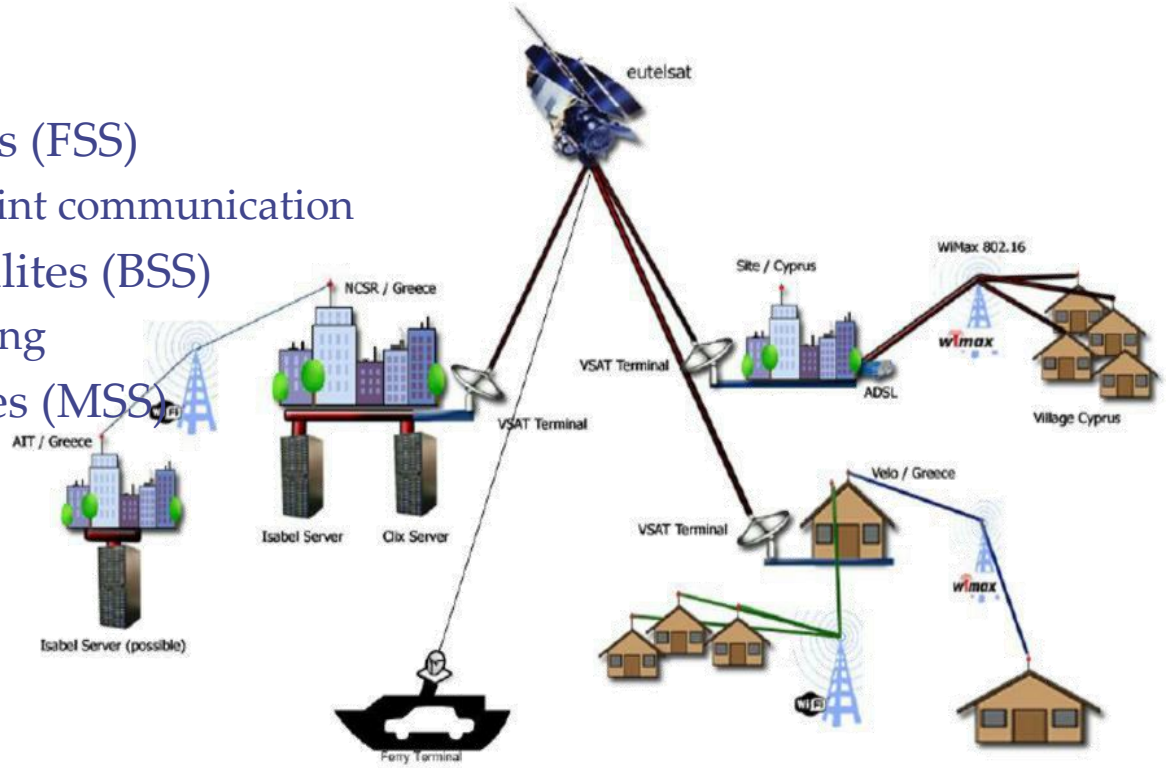
Advantages and Disadvantages of wireless communication

- Advantages:
  - Mobility
  - A wireless comm. network is a solution in areas where cables are impossible to install (e.g. hazardous areas, long distances etc.)
  - Easier to maintain
- Disadvantages:
  - Has security vulnerabilities
  - High costs for setting the infrastructure
  - Unlike wired comm., wireless comm. is influenced by physical obstructions, climatic conditions, interference from other wireless devices

Satellite Communication

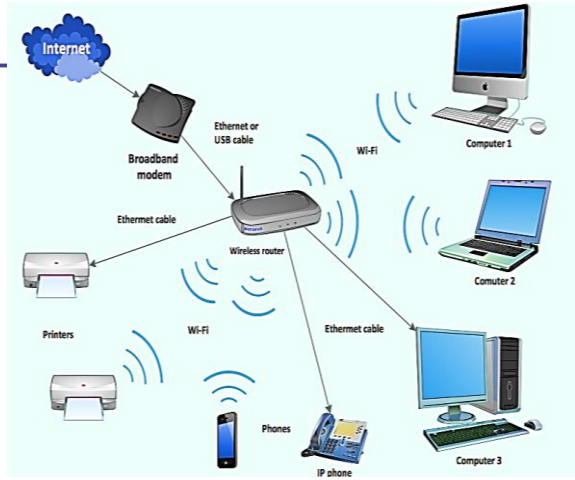
- The devices using satellite technology to communicate directly with the orbiting satellite through radio signals.
  - Covers a very large area.
  - consists of a space segment and a ground segment.

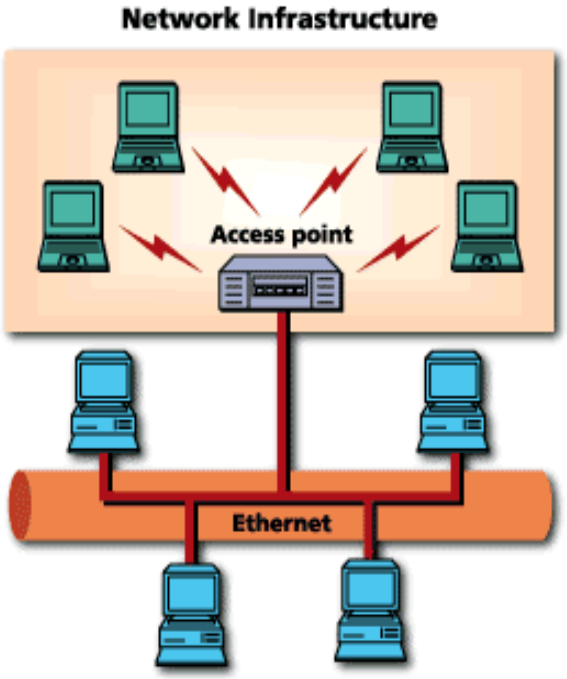
- Types:
  - Fixed Services Satellites (FSS)
    - Used for point to point communication
  - Broadcast Service Satellites (BSS)
    - Radio/Tv broadcasting
  - Mobile Service Satellites (MSS)
    - Satellite Phones



IEEE 802.11 Wireless LAN:WIFI

- The last link with the users is wireless, to give a network connection to all users in a building or campus.
- There is a need of an access point that bridges wireless LAN traffic into the wired LAN.
- The access point (AP) can also act as a repeater for wireless nodes, effectively doubling the maximum possible distance between nodes.
- Most wireless LAN products operate in *unlicensed radio bands*
  - 2.4 GHz is most popular
  - Available in most parts of the world
  - No need for user licensing



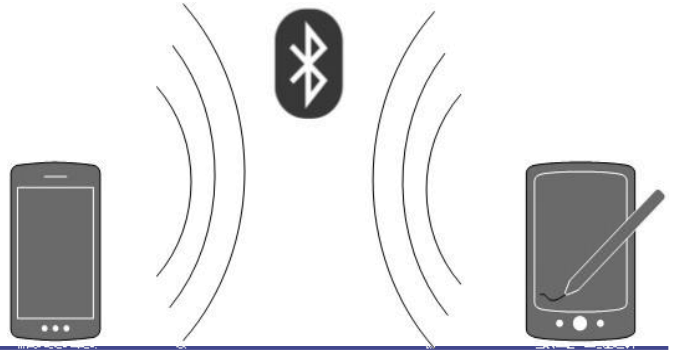


Applications

- Building-to-building connections
- Video, audio conferencing/streaming video, and audio
- Large file transfers, such as engineering
  CAD drawings
- Faster Web access and browsing
- High worker density or high throughput scenarios
  - Numerous PCs running graphics-intensive applications

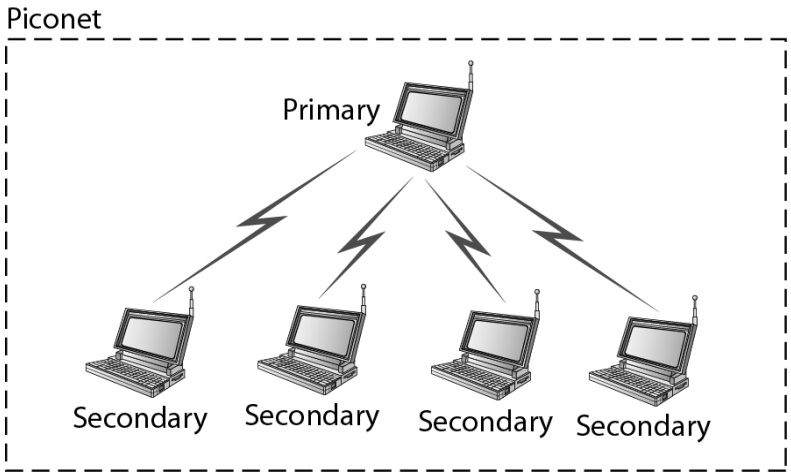
Wireless Network Technologies…

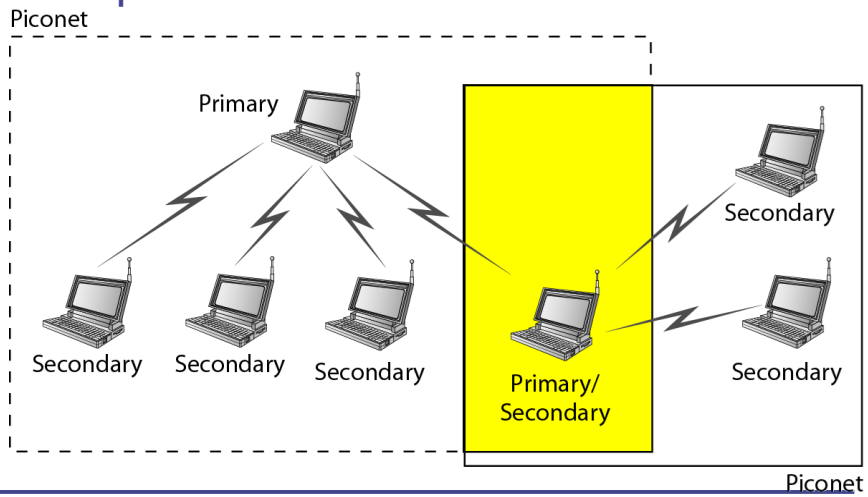
- IEEE 802.15.1 Wireless Personal Area Network technology : Bluetooth
  - *Coverage Area:* less than 10 m diameter
    - replacement for cables (mouse, keyboard, headphones)
  - *Ad hoc*: No infrastructure
  - 2.4-2.5 GHz radio band
  - Throughput: up to 3Mbps



Architecture

- *Piconet*
  - A piconet can have up to eight stations, one of which is called the primary; the rest are called secondary's.
- *Scatternet*
  - A secondary station in one piconet can be the primary in another piconet
  - receive messages from the primary in the first piconet (as a secondary) and, acting as a primary, deliver them to secondary's in the second piconet.





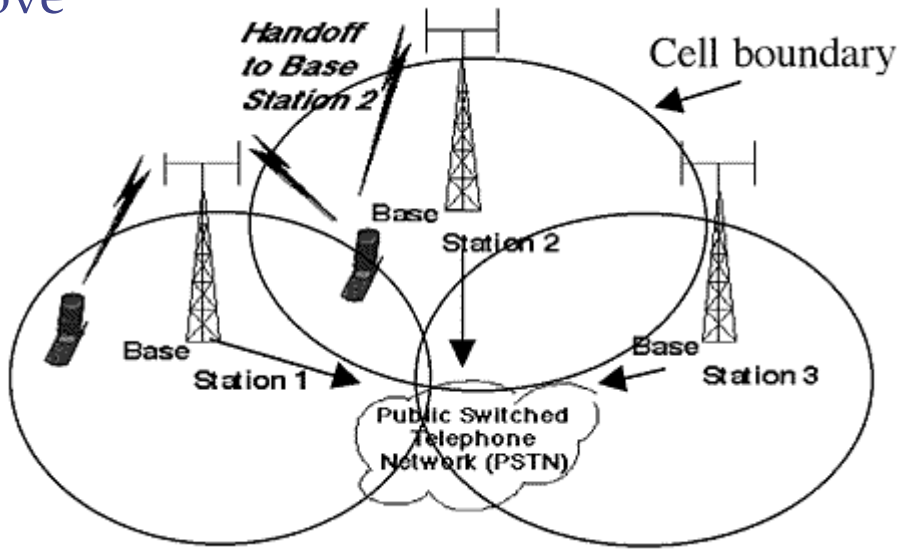
Wireless Network Technologies…

- IEEE 802.15.4 for Low-Rate WPAN (LR-WPAN) : Zigbee
  - Low-to-medium bit rates
  - Moderate delays without too strict requirements
  - Low cost, low energy consumption

- Applications
  - Home automation and security systems
  - Smart metering
  - Wireless data collection

Cellular Network

- Base stations transmit to and receive from mobiles at the assigned spectrum
  - Multiple base stations use the same spectrum (spectral reuse)
- Each mobile terminal is typically served by the 'closest' base stations
  - The service area of each base station is called a cell
  - Handoff when terminals move
- Applications:
  - mobile Internet access;
  - voice/video over IP;
  - data collection and monitoring

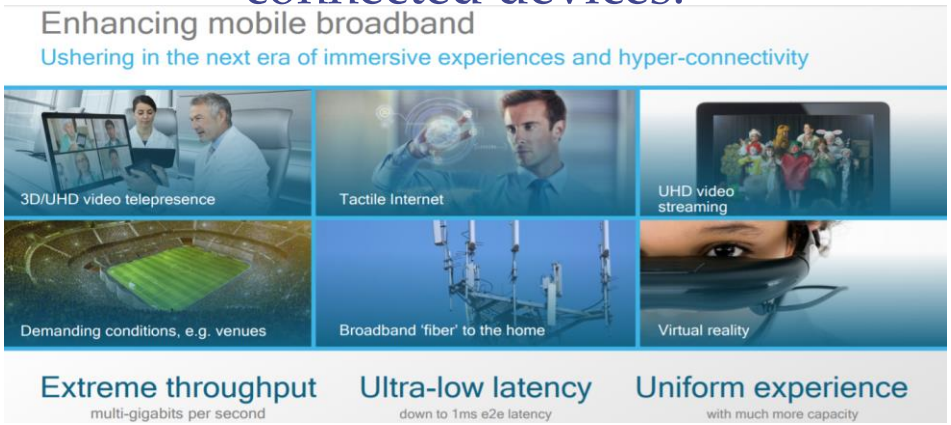


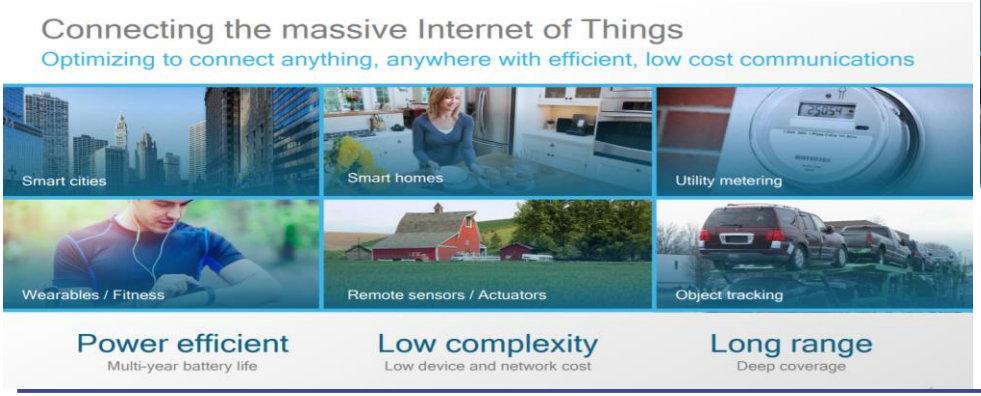
Cellular Networks

- It is useful to think of cellular Network/telephony in terms of *generations*:
  - *1G:* First generation wireless cellular: Early 1980s
    - Analog transmission, primarily speech: AMPS (Advanced Mobile Phone Systems
  - *2G:* Second generation wireless cellular: Late 1980s --- ***GSM***
    - Digital transmission
    - Primarily speech and low bit-rate data (9.6 Kbps)
  - *2.5G:* 2G evolved to medium rate (< 100kbps) data
  - *3G:* *High-speed* digital cellular telephony (including *video telephony*)
    - 144 kbps - 384 kbps for high-mobility, high coverage
    - 2 Mbps for low-mobility and low coverage
    - ***WCDMA, HSPA, HSPA+***
  - *4G :* IP-based "anytime, anywhere" voice, data, and multimedia telephony at *faster* data rates than 3G --- ***LTE***
    - Wireline capability evolution ; Need for additional wireless capacity
    - Need for lower cost wireless data delivery
    - Competition of other wireless technologies (WiMax)

With 5G Era

- **What we can expect in the 5G era**
  - Cisco…."By 2025, there will be an estimated 100 billion connected devices in the industrialized world. Each person will have 10–12 connected devices. "





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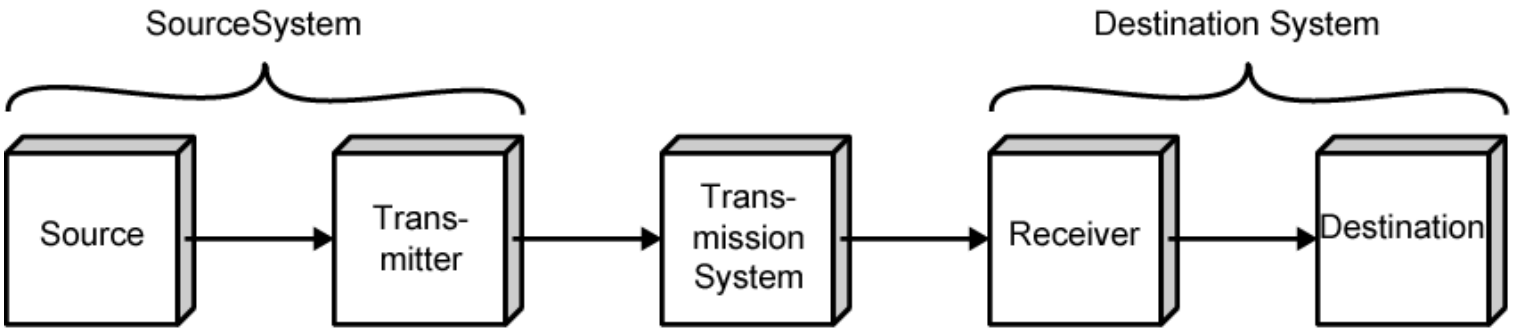
Elements of Communication Systems

- How do you model communication systems ?

Elements of Communication System

- High-level block diagrams



(a) General block diagram

(b) Example

Elements of Communication System

- Source
  - Generates information (speech, video, text, data, etc.)
- Transducer
  - Transforms source output into electrical signal (e.g., microphone) and back (at Rx end)
- Three major parts
  - Transmitter (Tx)
  - Channel
  - Receiver (Rx)

Transmitter

- Converts electrical signal into a form suitable for transmission through the channel (physical medium)
  - The transducer output signal cannot, in most cases, be transmitted directly (does not match the channel)
  - Transmitter converts message to a suitable form
- Conversion is made through modulation
  - Amplitude (AM), frequency (FM) and phase (PM)
  - Examples: AM and FM radio broadcast
- Other functions: Filtering, amplification, radiation
  - Intended recipient of the message signal

Receiver

- Main function: to recover the message from the received signal
  - Somewhat inverse of the transmitter function

- Demodulation: Inverse of the modulation
- Operates in the presence of noise and interference
  - Hence, some distortions are unavoidable
- Some other functions: filtering, suppression of noise and interference

Transmission Media (Channel)

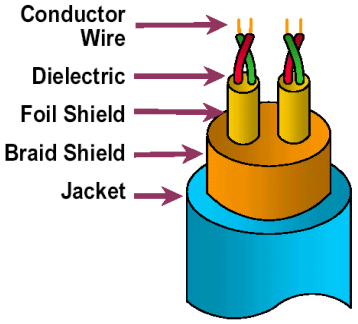
- *Physical medium* over which the information will be transmitted from the transmitter to the receiver
- Characterized by
  - Physical properties — Bandwidth
  - Signaling method(s) — Sensitivity to noise
- *Wireline channels* : a *guided medium* over which the information will be transmitted from the transmitter to the receiver
- *Wireless Channels*: an *unguided medium* where information transmission is via electromagnetic waves from antenna to antenna.

Selecting the Transmission Media/Channel

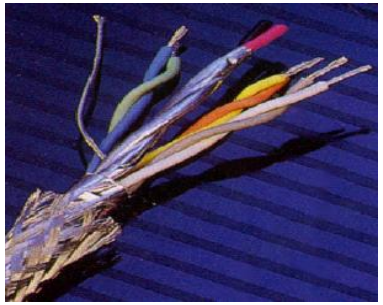
- What is amount of ***traffic*** to be distributed?
- What is the ***cost*** we can afford?
- What is the ***interference*** environment?
- Point-to-point or ***networking*** usage?
- Capability to transfer power (for instance for repeaters)?
- Often the first selection is done between
  - Wired & Wireless
- Often one can consider if ***digital*** or ***analog*** message is to be transmitted
  - analog PSTN takes 300-3400 kHz
  - digital PCM takes 64 kbit/s
  - digital, encoded GSM speech only 13 kbit/s
  - what is the adequate compression level?

Wireline channels: Twisted pair

- Comes in two flavors:
  - Shielded (STP) / Unshielded (UTP)

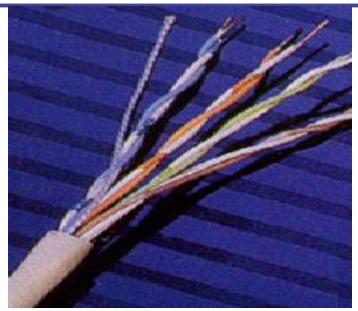


structure



STP-cable

•larger attenuation
•higher rates
•more expensive



UTP-cable

•more sensitive to interference
•easy to install and work with
•example: 10BaseT Ethernet

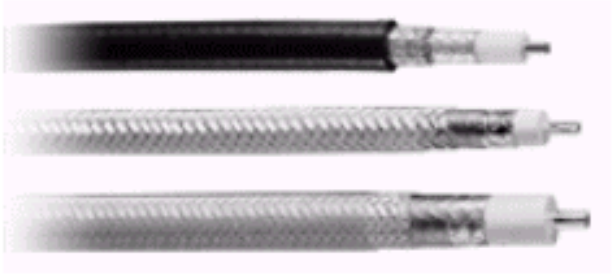
- Twisting reduces interference, and crosstalk (antenna-behavior)
- Applications
  - Connects ***data*** and especially ***PSTN local loop*** analog links (Intra-building telephone from wiring closet to desktop)
  - In old installations, ***loading coils*** added to improve quality in 3 kHz band, resulting more attenuation at higher frequencies (ADSL)
  - ***STP*** used especially in ***high-speed transmission*** as in token ring-networks.

Twisted pair - UTP categories in LANs

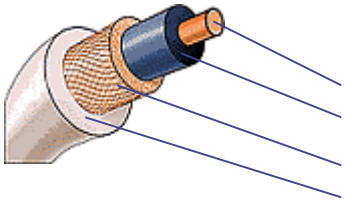
- **Category 1**: mainly used to **carry voice** (telephone wiring prior to 1980). Not certified to carry data of any type.
- **Category 2**: used to carry data at rates up to 4Mbps. Popular for older Token-passing ring LANs using **4Mbps** specs (IEEE 802.5). Rated bandwidth 4MHz.
- **Category 3**: known as voice grade. Used primarily in older **Ethernet 10base-T LANs** (IEEE 802.3). Certified to carry **10Mbps** data. 16Mhz. 3-4 twists/feet.
- **Category 4**: primarily used for token-based or 10Base-T. 20MHz.
- **Category 5**: most popular Ethernet cabling category. Capable of carrying data at rates up to **100 Mbps** (**Fast Ethernet,** IEEE 802.3u) and used for 100 base-T and 10base-T networks. Rated to **100 MHz**. 3-4 twists/inch.
- …….

Wireline channels: Coaxial cables

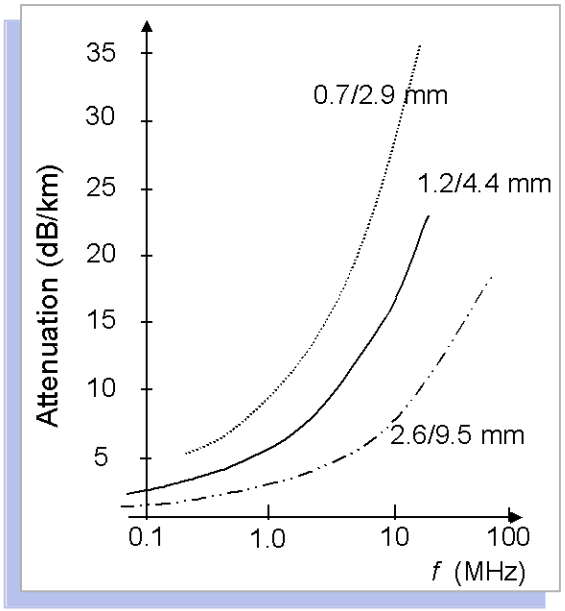
- Mechanics
  - Cylindrical braided outer conductor surrounds insulated inner wire conductor
- Properties
  - Well shielded structure -> immunity to external noise
  - High bandwidth, up to Ghz-range (distance/model)
- Applications
  - RG- 59 :CATV (Cable TV networks)
  - RG -58 :Ethernet LANs
  - RG – 11 :Earlier a backbone of PSTN



practical structures

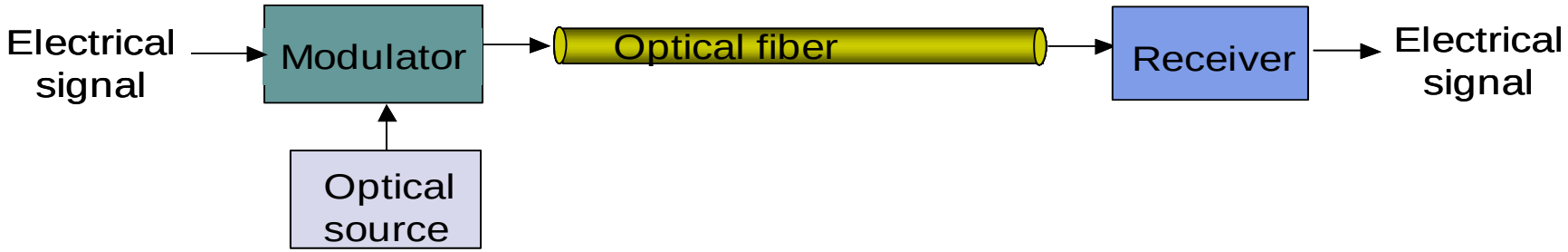


Center conductor (copper)
Dielectric material
Braided outer conductor (metal mesh)
Outer cover



Wired channels: Optical Fiber

***Source** :A. Leon-Garcia, I. Widjaja: Communication Networks (instructors slide set)*



- Light sources (lasers, LEDs) generate pulses of light that are transmitted on optical fiber
  - Very long distances (>1000 km)
  - Very high speeds (>40 Gbps/wavelength)
  - Nearly error-free (BER of 10^{-15})
- Profound influence on network architecture
  - Dominates long distance transmission
  - Distance less of a cost factor in communications
  - Plentiful bandwidth for new services

Optical Fiber Properties

Advantages

- ***Very low attenuation***
- ***Noise immunity***
- ***Extremely high bandwidth***
- Security: Very difficult to tap without breaking
- No corrosion
- More compact & lighter than copper wire

Disadvantages

- New types of optical signal impairments & dispersion
  - Polarization dependence
  - Wavelength dependence
- Limited bend radius
  - If physical arc of cable too high, light lost or won't reflect
  - Will break
- Difficult to splice
- Mechanical vibration becomes signal noise

Channel parameters

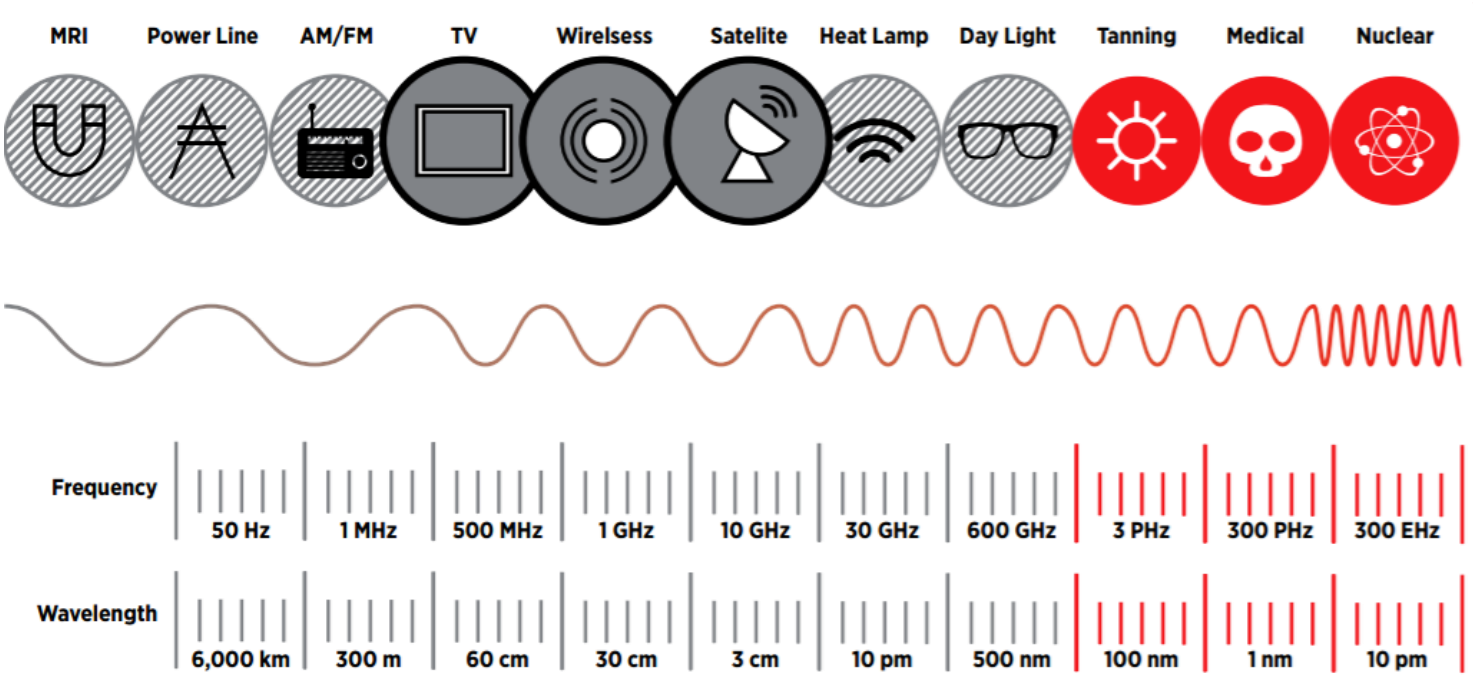
- Characterized by
  - Attenuation [dB/Km], transfer function
  - impedance [Ω], matching
  - bandwidth [Hz], data rate
- *Noise* is the unwanted and beyond our control waves that attenuates the transmission of signals.
  - *Shot noise*: the electrons are discrete and are not moving in a continuous steady flow, so the current is randomly fluctuating.
  - *Thermal noise:* caused by the rapid and random motion of electrons within a conductor due to thermal agitation. ($Thermal\ Noise\ Power = KB.T.BW$)
- *Interference:* cross-talk - leakage power from other users
- Channel parameters are a function of frequency, transmission length, temperature ...

Radio (Wireless) Communication Channels

- Unguided *electromagnetic wave*, radiated by the Tx antenna, is a carrier of the signal
- Strong **signal attenuation**
  - Up to 200 dB
  - Hence, high Tx power is required
- Antennas are required
  - Size of antenna: Comparable with wavelength

What is Radio Spectrum?

- One portion of the entire *electromagnetic spectrum* whose frequency is low compared to others such as optical waves, X-rays or Gamma rays (9Khz -300GHz)
  - carry information wirelessly for a vast number of services ranging from television and radio broadcasting, mobile phones and Wi-Fi to communications systems for the emergency services, baby monitors, GPS and radar.

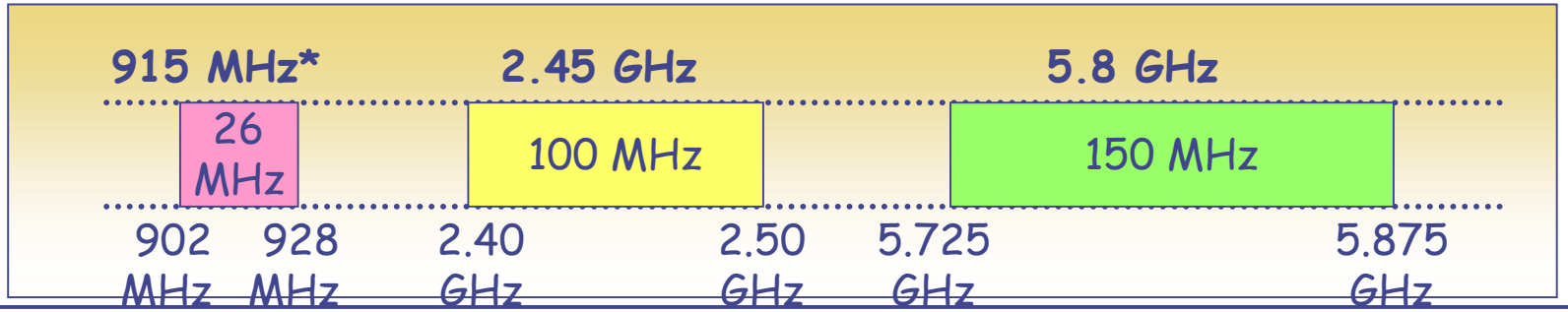


Quiz. 1

- Explain the basic blocks communication system.
- Briefly explain the three advantages of wireless media.

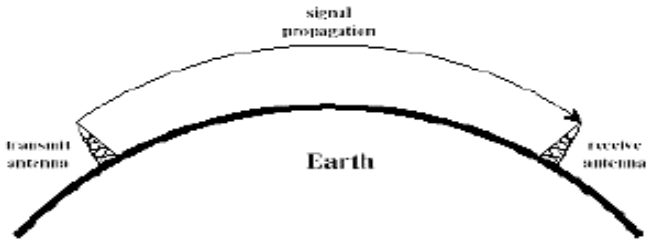
Electromagnetic Spectrum

- Government regulations make specific ranges of the electromagnetic spectrum available for communication
- A license is required to operate transmission equipment in some parts of the spectrum
  - Some parts are unlicensed
    - Industrial, Scientific, and Medical frequency bands
    - Tx output power ◎ 1 watt

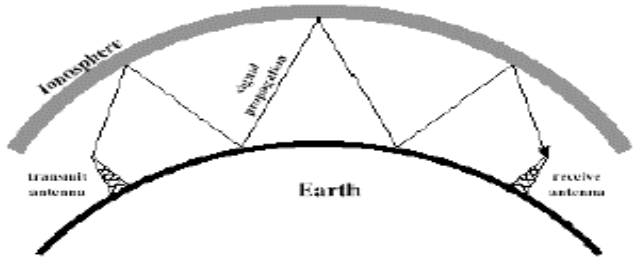


Radio Wave Propagation Modes

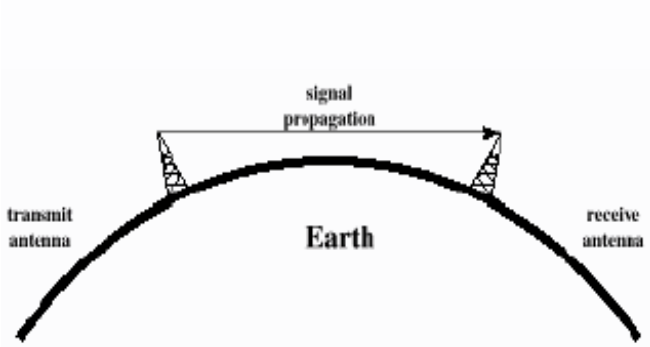
1. **Ground Wave Propagation**
   - Follows contour of the earth Can Propagate considerable distances
   - *Frequencies up to 2 MHz*
     - *Example : AM radio*



2. **Sky Wave Propagation**
   - Signal reflected from ionized layer of atmosphere. Signal can travel a number of hops, back and forth
     - *Examples SW radio*



3. **Line-of-Sight Propagation**
   - Transmitting and receiving antennas must be within line of sight
     - *Example: Satellite communication; Ground communication*



Wireless Link Characteristics …. propagation

- Key characteristic for spectrum is its propagation through a media.

- Radio signal propagation is impacted by
  - Spreading and attenuation, absorption, reflection, diffraction, refraction and interference
  - All are *frequency dependent*
  - Different frequencies are best for different applications

Band	Frequency
HF	3 – 30 MHz
VHF	30 – 300 MHz
UHF	300 – 1000 MHz
L	1 – 2 GHz
S	2 – 4 GHz
C	4 – 8 GHz
X	8 – 12 GHz
Ku	12 – 18 GHz
K	18 – 27 GHz
Ka	27 – 40 GHz
V	40 – 75 GHz
W	75 – 110 GHz
mm	110 – 300 GHz

Wireless Link Characteristics …. propagation

- ***Lower Frequencies.***
  - Generally the "pros" of lower frequencies are that :
    - Better propagation, i.e., the radio waves travel farther.
    - Better in-building penetration (easier to pass through objects such as walls with less attenuation).
  - The main "con" is that the ability of the radio waves to travel farther and through objects can be a negative when capacity is the goal (i.e. these characteristics inhibit spectrum reuse)

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- ***Higher Frequencies.***
  - Generally the "pros" of higher frequencies are that they:
    - Allow for greater capacity by providing more contiguous bandwidth and have fewer incumbency issues.
    - Support frequency reuse because the radio waves do not travel as far as lower frequencies.
  - The "con" is that to provide the same amount of coverage as for low band spectrum more infrastructure must be deployed, increasing infrastructure costs.

Wireless Link Characteristics …. (Cont.…)

- These factors restrict the
  - Range
  - Data rate
  - Reliability of the wireless transmission.

- The extent to which these factors affect the transmission depends upon
  - The *environmental conditions* and
  - The *mobility* of the transmitter and receiver

Goal of Communications Engineer

Primary Communication Resources → **Transmitted power**, **Channel bandwidth**

- To design transmitters and receivers that are
  - Cost efficient
  - Bandwidth efficient
    - Maximum information transfer (message at sink is a faithful representation of the source message)
  - Power efficient (uses as little power as necessary)

- Many of the above goals are contrary to one another
  - For example, one way to improve message **fidelity** at the receiver is to increase **transmit power**
  - Therefore, tradeoffs are required