Communication Engineering Systems

Introduction to Communication Systems (1)

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"All things are difficult before they are easy"

Course Information

- Instructor: Assoc. Prof. Piya Kovintavewat, Ph.D.
  - Email: piya@npru.ac.th
  - Office Hours: 13:00 – 16:00 pm., Monday.
- Location: ETB
- Class time: 8:30 – 11:30 pm., Tuesday.
- Class Homepage: http://home.npru.ac.th/piya
- Book: หลักการไฟฟ้าสื่อสาร (ลัญฉกร วุฒิสิทธิกุลกิจ, 2554)
- Useful URL: http://home.npru.ac.th/piya/webscilab
- Grading: HWs 10% Attendant 10%
  Quiz I 20% Quiz II 20% Final 40%

Course Syllabus

- Course description: พื้นฐานสัญญาณและระบบ สเปกตรัมของสัญญาณ การประยุกต์ใช้อนุกรมฟูเรียร์และการแปลงฟูเรียร์ การกลำสัญญาณแบบแอนะล็อก เชิงแอมพลิจูด เชิงความถี่ เชิงเฟส สัญญาณรบกวนในระบบสื่อสารแอนะล็อก การกลำสัญญาณแถบฐาน ทฤษฎีการชักตัวอย่างในควิสต์และการแจงหน่วย การกลำสัญญาณพัลส์แบบต่างๆ การกลำรหัสพัลส์ การกลำสัญญาณแบบเดลตา สหสัญญาณ สหสัญญาณแบบแบ่งเวลา พื้นฐานของสายส่ง การแพร่กระจายคลื่นวิทยุ องค์ประกอบของไมโครเวฟ การสื่อสารผ่านดาวเทียม และการสื่อสารทางแสง
- Q&A Session: Should one has any question or help on the homework, ask me after class or email me.
- Homework: Be distributed weekly. HW is due at the beginning of the next class. **No late HW is accepted**.
- Absence of Exams: Please tell me in advance if you will be absent, only legitimate reasons are noticed. In case of sickness, bring proof together with the doctor's phone number

Grading

- A $\geq$ 80
- 75 $\leq$ B+ $<$ 80
- 70 $\leq$ B $<$ 75
- 65 $\leq$ C+ $<$ 70
- 55 $\leq$ C $\leq$ 65
- 47 $\leq$ D+ $<$ 55
- 40 $\leq$ D $<$ 47
- E $<$ 40

Outline

- Variety of Today's Communication Systems
- Design Challenges
- Basic of Communication Systems
- Fundamental Limitation
- Bandwidth
- Performance Metric
- Data Rate Limit
- Introduction to Modulation & Coding

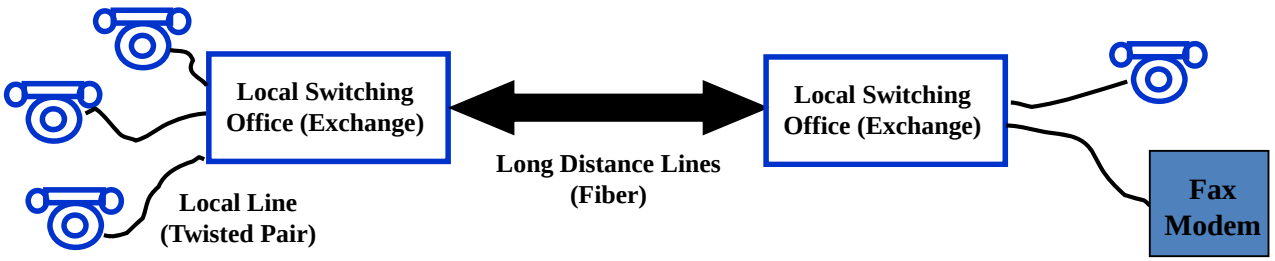
Communication Systems

- Convey information from one place (source) to another place (destination)
- Information:
  - Voice, data, video, music, email, web pages, etc.
- Goal: To reproduce an acceptable replica of the source message at the destination

Today's Communication Systems

- Radio and TV broadcasting
- Public Switched Telephone Network (voice, fax, modem)
- Cellular Phones
- Computer networks (LANs, WANs, and the Internet)
- Satellite systems (pagers, voice/data, movie broadcasts)
- Bluetooth, WiMAX, UWB, VLC, etc.

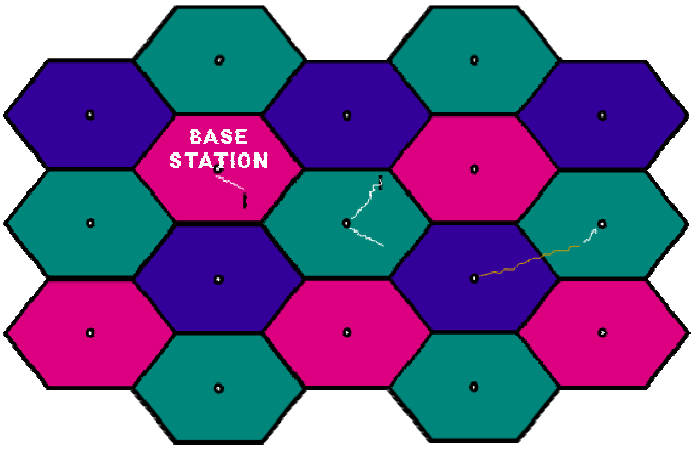
PSTN Design



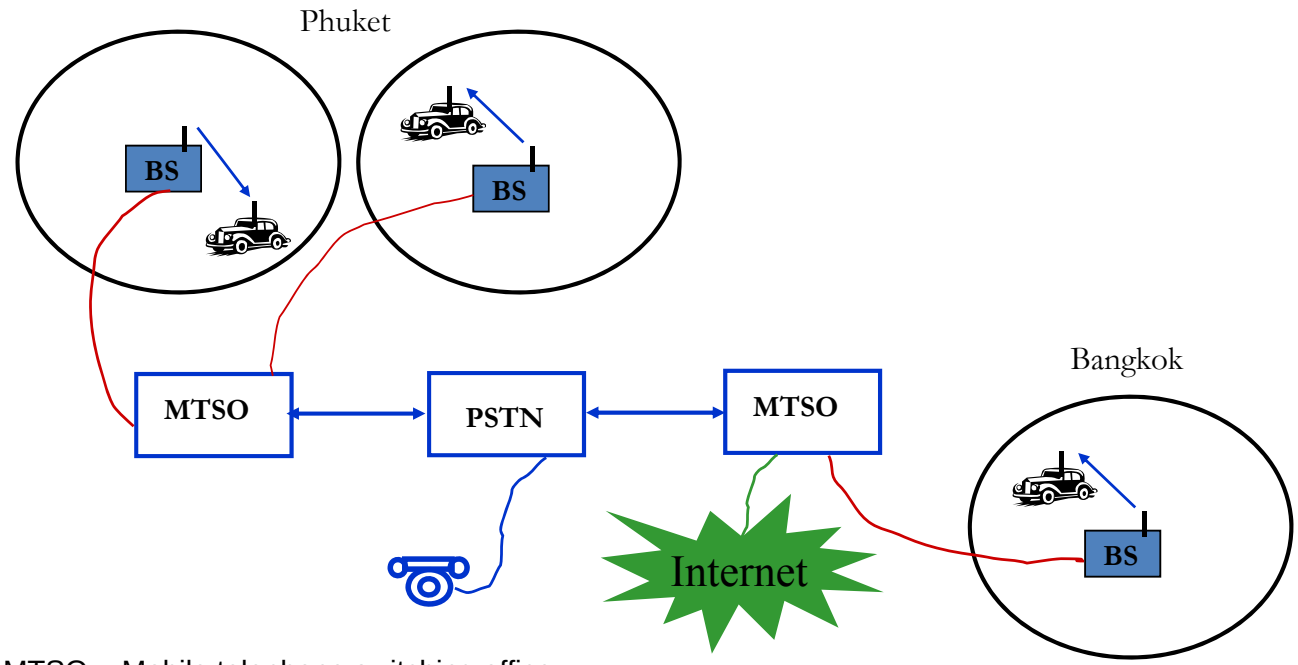
- Local exchange
  - Handle local calls
  - Route long distance calls over high-speed lines
- Circuit switched network suitable for voice (56 kbps)
- Faxes and modems modulate data for voice channel
- DSL uses advanced modulation to get 1.5 Mbps

Cellular System Basics

- Geographic region divided into cells (in hexagon shape)
- Frequencies/timeslots/codes reused at spatially-separated locations (analog systems use FD, digital use TD or CD)
- Co-channel interference between same color cells.
- Handoff and control coordinated through cell base stations

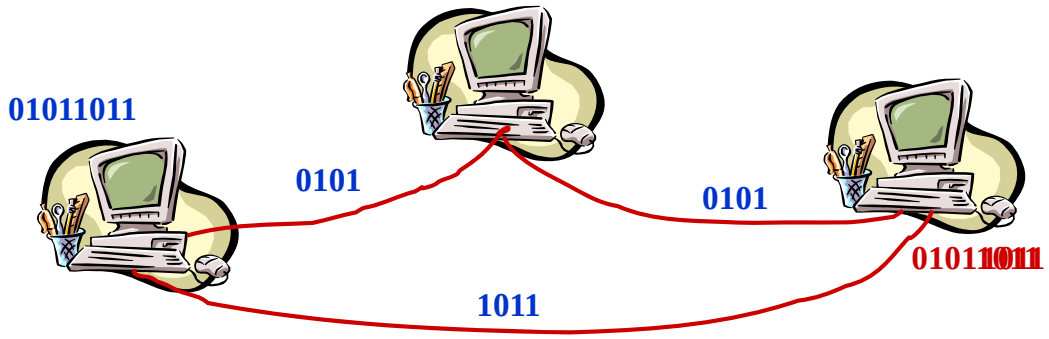


Cell Phone Backbone Network



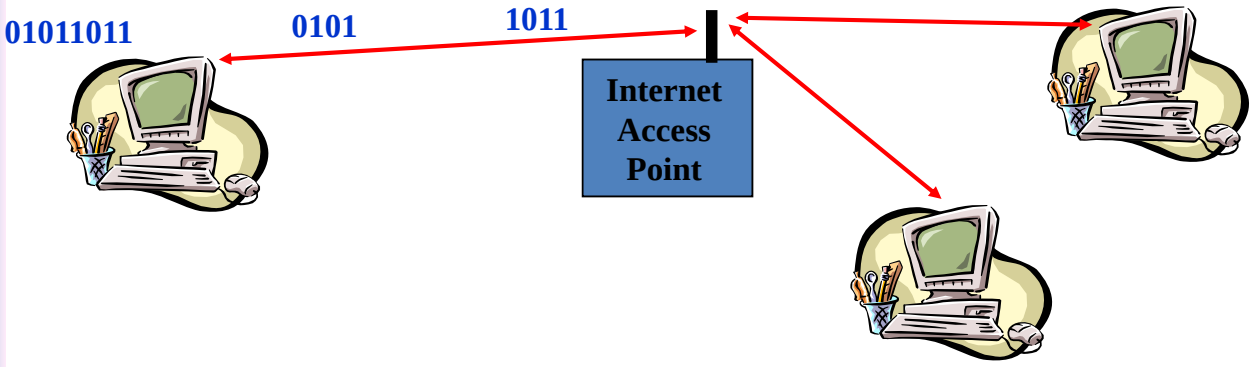
MTSO = Mobile telephone switching office

Local Area Networks (LANs)



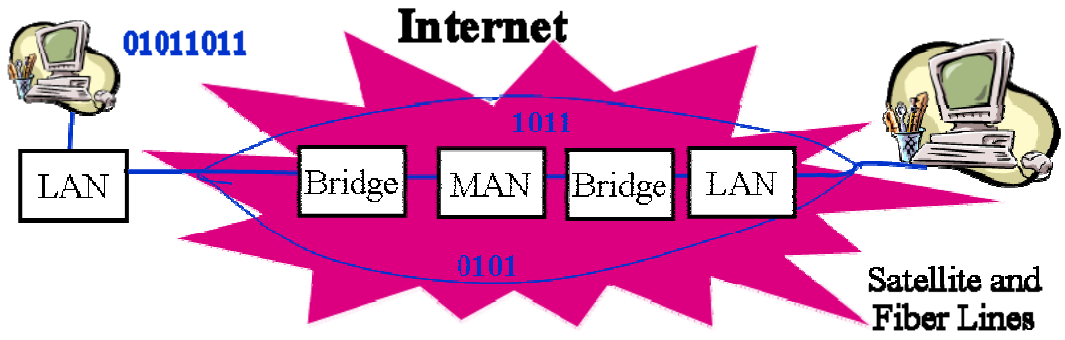
- LANs connect “local” computers
- Breaks data into packets
- Packet switching (no dedicated channels)
- Proprietary protocols (access,routing, etc.)

Wireless Local Area Networks (WLANs)



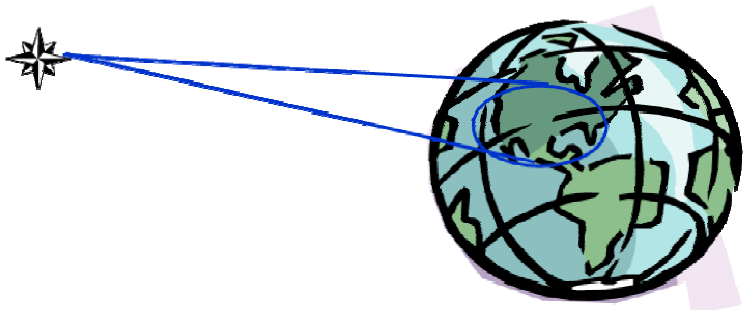
- WLANs connect “local” computers (100m range)
- Breaks data into packets
- Channel access is shared (random access)
- Backbone Internet provides best-effort service

Wide Area Networks – The Internet



- Many LANs and MANs bridged together
- Universal protocol: TCP/IP (packet based).
- Guaranteed rates or delays cannot be provided.
- Hard to support user mobility.
- Highly scalable and flexible topology

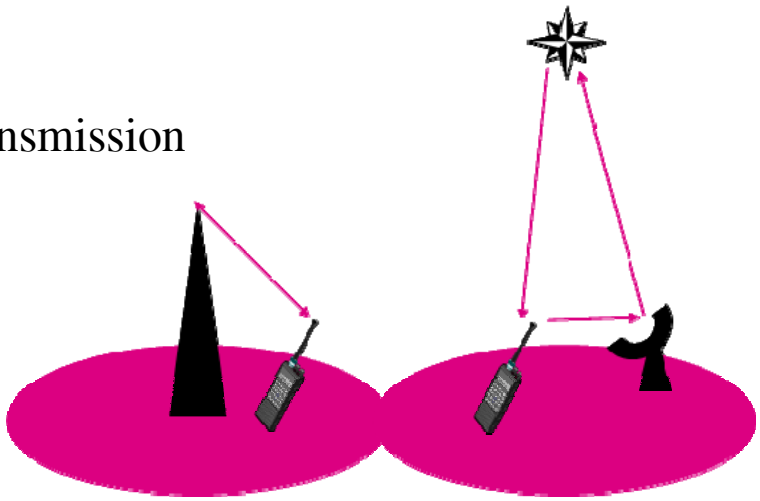
Satellite Systems



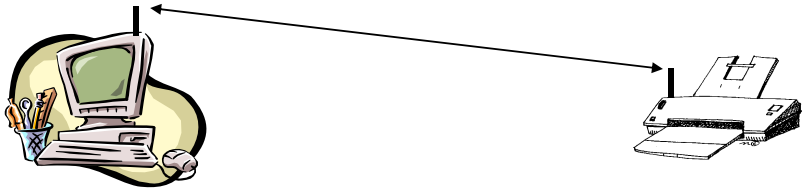
- Cover very large areas
- Different orbit heights
  - GEOs (39000 Km) versus LEOs (2000 Km)
- Applications:
  - Radio (XM, DAB)
  - Movie (SatTV) broadcasting
  - Internet
  - Etc.

Paging Systems

- Broad coverage for short messaging
- Message broadcast from all base stations
- Simple terminals
- Optimized for 1-way transmission
- Answer-back hard
- Overtaken by cellular

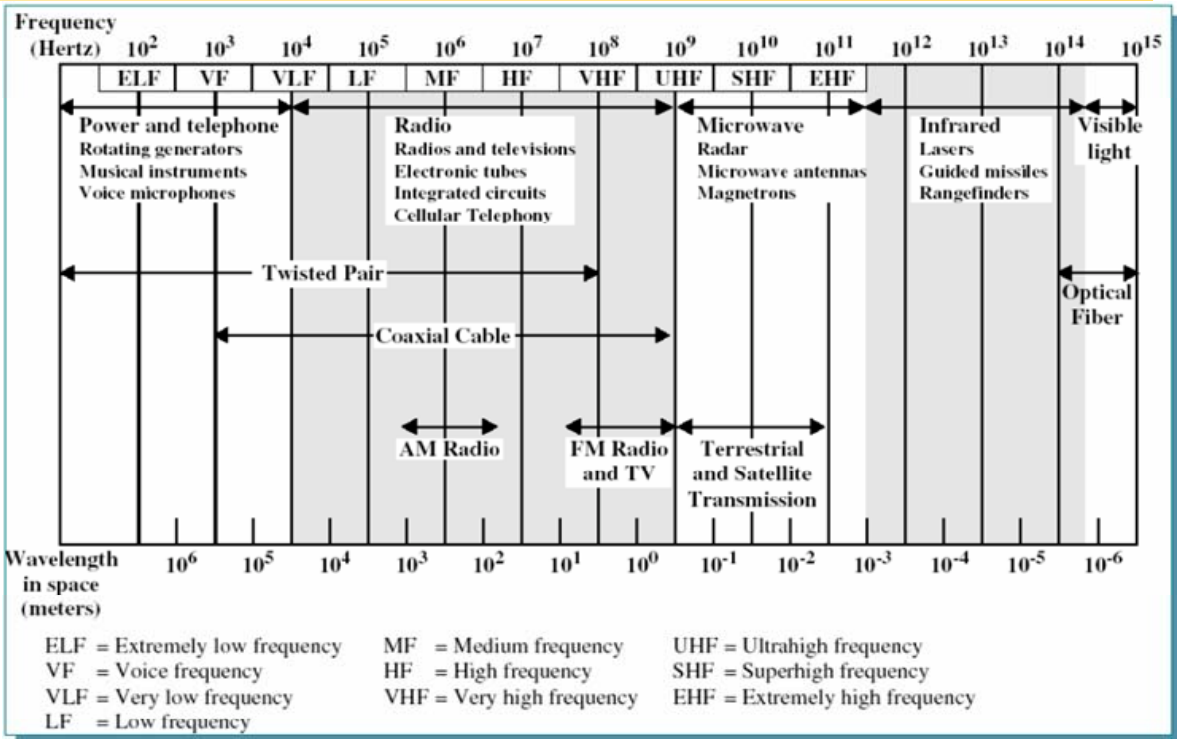


Bluetooth



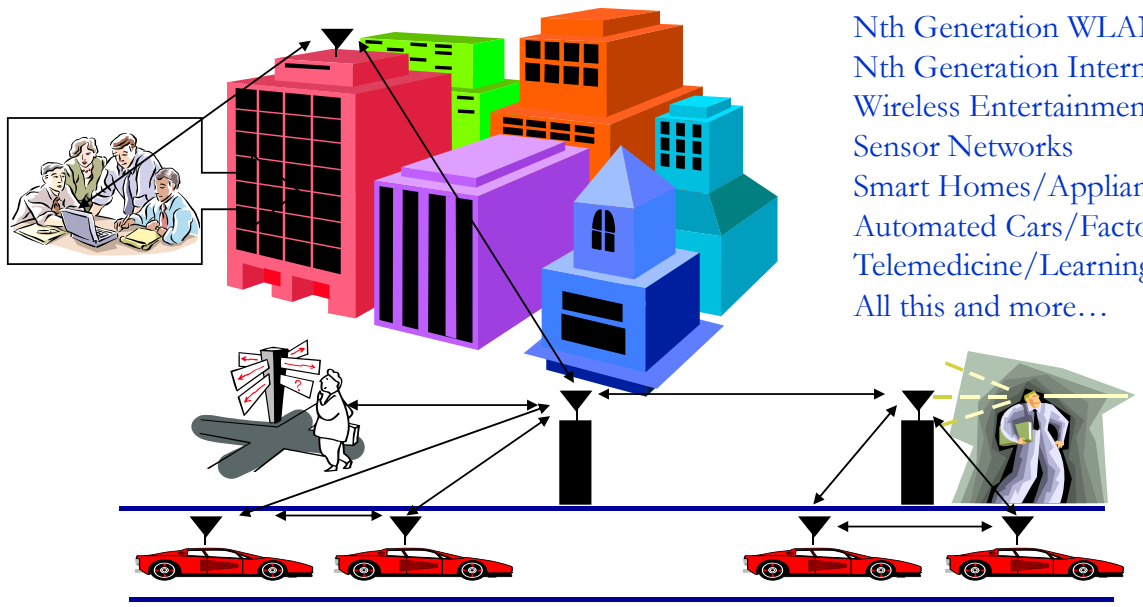
- Cable replacement for electronic devices
  - Cell phones
  - Laptops
  - PDAs
  - etc.
- Short range connection (10-100 m)

Medium and Electromagnetic Spectra



Future Systems

Ubiquitous Communication Among People and Devices



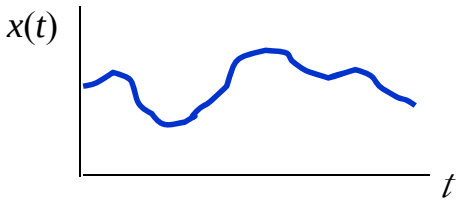
Nth Generation Cellular
Nth Generation WLANs
Nth Generation Internet
Wireless Entertainment
Sensor Networks
Smart Homes/Appliances
Automated Cars/Factories
Telemedicine/Learning
All this and more…

Design Challenges

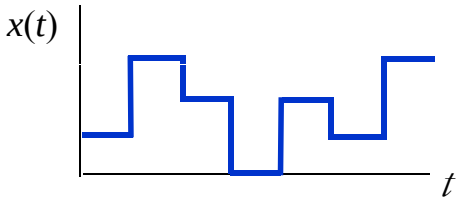
- Hardware Design
  - Precise components
  - Small, lightweight, low power
  - Cheap
  - High frequency operation
- System Design
  - Converting and transferring information
  - High data rates
  - Robust to noise and interference
  - Supports many users
- Network Design
  - Connectivity and high speed
  - Energy and delay constraints

Analog and Digital Signals

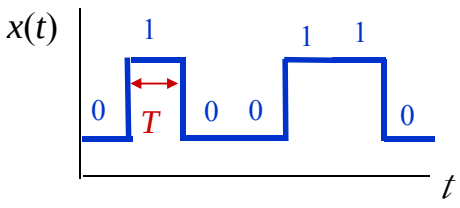
- Analog signals
  - Value varies continuously with time



- Digital signals
  - Value limited to a finite set



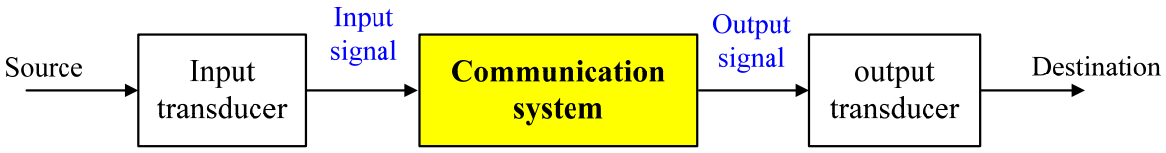
- Binary signals
  - Has at most 2 values
  - Used to represent bit values
  - Bit time T needed to send 1 bit
  - Data rate $R=1/T$ bits per second (bps)



Information Representation

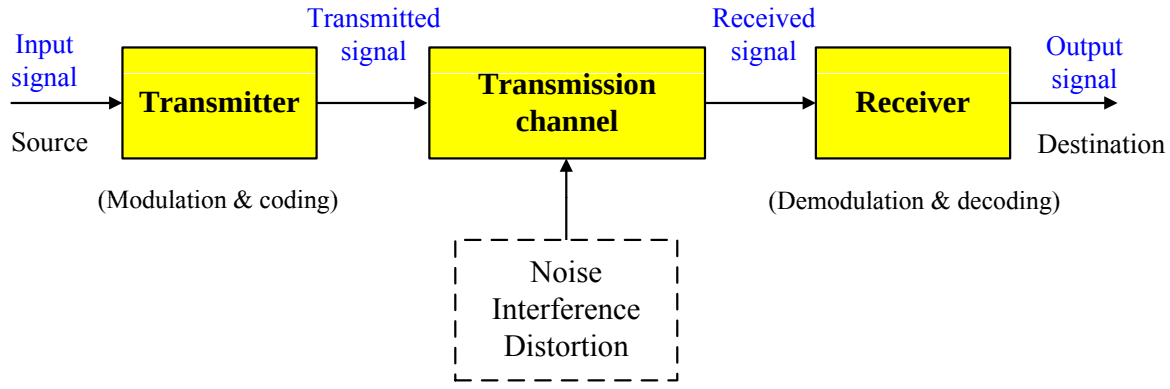
- Communication systems convert information into a format appropriate for the transmission medium.
  - Channels convey electromagnetic waves (signals).
- **Analog communication** systems convert (modulate) analog signals into modulated (analog) signals
- **Digital communication** systems convert information in the form of bits into digital signals
  - Computers naturally generate information as bits
  - Analog signals can be converted into bits by quantizing and digitizing.

Block Diagram of Communication System



- Most communication systems have input and output transducers.
- Input transducer ⇒ convert the message to an electrical signal, e.g. microphone.
- Output transducer ⇒ convert the output signal to the desired message form, e.g., loudspeaker.

Block Diagram of Communication System II



- Transmitter processes the input signal to produce the transmitted signal suited to the characteristics of the transmission channel.
- Transmission channel is the electrical medium that bridges the distance from source to destination.
- Receiver operates on the output signal before sending to the destination.

Disturbances

- Noise refers to random and unpredictable electrical signals produced by natural (cannot be completely eliminated), e.g., thermal noise.
- Interference is contamination by extraneous signal from human sources (occurs most often in radio systems).
- Distortion is waveform perturbation caused by imperfect response of the system to the desired signal itself (can be relieved with the help of special filters called *equalizer*.
- Normally, we measure noise relative to an information signal in terms of signal-to-noise ratio (SNR).

Fundamental Limitation

- Two constraints when designing a system
  - Technological problem
    - Some can be solved in theory but some cannot
  - Fundamental physical limitation
    - Ultimately dictate what can or cannot be accomplished regardless of the technological problems
- Fundamental limitations of information transmission by electrical means are noise and bandwidth.

Bandwidth

- A measure of speed
  - If the signal changes rapidly, its frequency content or **spectrum** extends over a wide range $\Rightarrow$ implies the signal has large bandwidth (BW).
- Every communication system has a finite BW that limits the rate of signal variation.
- If channel BW << signal BW $\Rightarrow$ Severe distortion (under real-time condition).
  - Ex. For a digital signal with r symbols/sec $\Rightarrow$ $BW \geq r/2$ to avoid severe distortion.

Performance Metrics

- Analog Communication Systems
  - Metric is fidelity
  - Want $m(t) = \hat{m}(t)$
- Digital Communication Systems
  - Metrics are data rate (R bps) and probability of bit error $P_b = p\left(\hat{b} \neq b\right)$
  - Without noise, never make bit errors
  - With noise, P_b depends on signal and noise power, data rate, and channel characteristics.
- Performance metric for analog systems is fidelity, for digital it is rate and error probability.

Data Rate Limits

- Data rate R limited by signal power, noise power, distortion, and bit error probability
- Without distortion or noise, can have infinite data rate with $P_b = 0$.
- Shannon capacity defines ***maximum*** possible data rate for systems with noise and distortion
  - Rate achieved with bit error probability close to zero
  - In white Gaussian noise channels, $C = BW \log(1+SNR)$, which is an *upper limit* on the performance of a communication system for a given BW and SNR.
  - Does not show how to design real systems
- C = 32 Kbps for Phone channel (1.5 Mbps with DSL)

Modulation

- Modulation is an operation performed at the transmitter to achieve efficient and reliable information transmission.
- Modulation involves two waveforms:
  - A modulating signal $\Rightarrow$ a message
  - A carrier $\Rightarrow$ suit the particular application
- A modulator systematically alters the carrier wave in correspondence with the variations of the modulating signal.
- The resulting modulated signal "carriers" the message information.
- Purpose $\Rightarrow$ to generate a modulated signal suited to the channel characteristics.

Coding

- Coding is a symbol-processing operation for improved communication when the information is digital or can be approximated in the form of discrete symbols.
- Binary symbol $\Rightarrow$ correspond to the binary digits 0 and 1
- M-ary symbols when coded by binary coding will require at least K binary digits, where

$$K = \log_2(M)$$

Coding (Cont.)

- If the source produces r symbols/sec
  - Binary code will have Kr digits/sec
  - The transmission BW requirement is K times the BW of an uncoded signal
- In summary, binary coding provides two advantages:
  - Less complicated hardware
  - Noise has less effect on a binary signal

Coding (Cont.)

- Suppose we have a binary data source and a communication system with adequate SNR and limited BW.
- Encoding blocks of K binary digits as M-ary symbols reduces the signal BW by a factor of $K = \log_2(M)$, thus allowing an increased data rate on a band-limited channel.
- This technique refers to as source coding.