EENG 373

Communication Systems II

Lecture 1

Introduction to Digital Communication Systems

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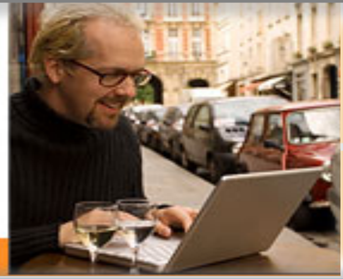
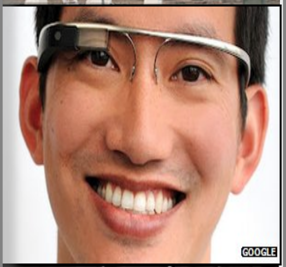


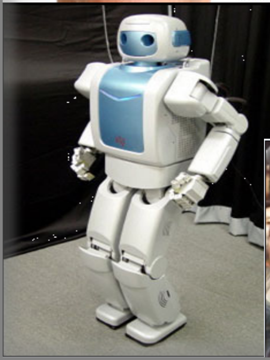




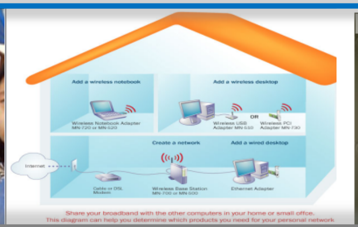
<u>Week 1</u>

Introduction to Digital Communication Systems







Course information

- Practical information
  - Staff
  - Grading
  - Course material
  - Schedule
- Scope of the course
  - Digital Communication systems

Introduction to digital communication systems

Instructor Information

- Office location: 14-224
- Office hours: T, H 12:30pm -2:00pm
- Email: mmangoud@uob.bh
- website:

Mangoud.com

- My Research interests:

  Wireless communications, Spread-spectrum, smart antennas, Space-time coding and MIMO systems, Antenna Design, Optimization techniques for Electromagnetics.

Textbook and Course webpage and Software

- Require textbooks:

1) Simon Haykin, *Communication Systems*, 4th edition, John Wiley and Sons, Inc.

2) Bernard Sklar, Digital communications: Fundamentals and applications, Prentice Hall, 2000.

- Course Homepage:

https://www.mangoud.com/eeng-373-communication-systems-ii/

Material accessible from : News, Lecture slides (pdf), Laboratory syllabus (Lab), Set of exercises and assignments.

- Require Software: MATLAB: http://www.mathworks.com/ with communications and DSP toolboxes. Both m files programming and simulink models will be used for the simulation of digital communication systems.

Homework, Project, and Exam

– Quiz1	5%
– Quiz 2	5%
– Test 1	15%
– Test 2	15%
– Home works	5%
– Labs	15%
– Final exam	40%

Hardware term project (hardware circuit) Bonus 10%

“The instructor reserves the right to change the grading scheme”

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Scope of the course

Introduction + Random Processes (chapter 1) (4 weeks)

Digital Passband Transmission (chapter 5) (2 Weeks)

Digital Modulation Schemes (chapter 6) (5 weeks)

- Introduction to Coherent Modulation Schemes
- Binary Phase-Shift Keying (BPSK)
- Binary Frequency-Shift Keying (BFSK)
- Binary Amplitude-Shift Keying (BASK)
- Performances & Comparisons Between the Modulation Techniques
- M-ary Modulation Schemes
- Non-Coherent Digital Modulation Schemes
- Performances & Comparisons Between the Modulation Techniques

Information theory and Forward Error correcting Coding (chapter 10) (3 weeks)

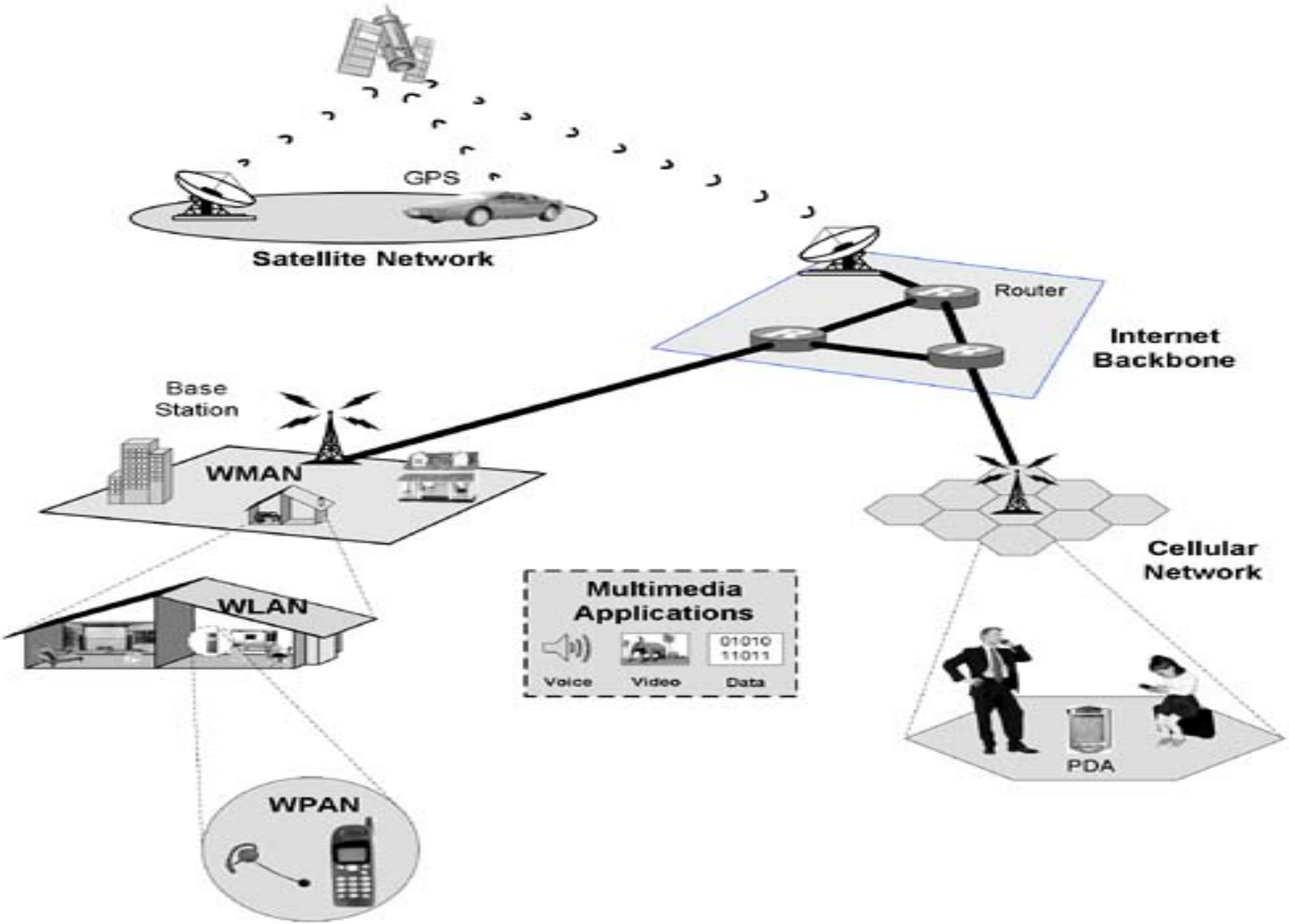
Motivations

- Recent Development
  - Satellite Communications, Mobile Communications, Wireless Communications, Computer networks, Optical Communications.
  - Telecommunication: Internet boom at the end of last decade
  - Wireless Communication: next boom?

    WIMAX-4G (Smart mobile phone)-

    VANET (mobile Ad-hoc networks)
- Job Market
  - Probably one of most easy and high paid majors recently
  - Almost all IT companies change to wireless com.,

Modern Telecommunications Systems



The Evolution Of mobile phone networks enables new applications

- **VoIP (VoLTE)** and high definition videos streaming

Wireless Cloud Computing

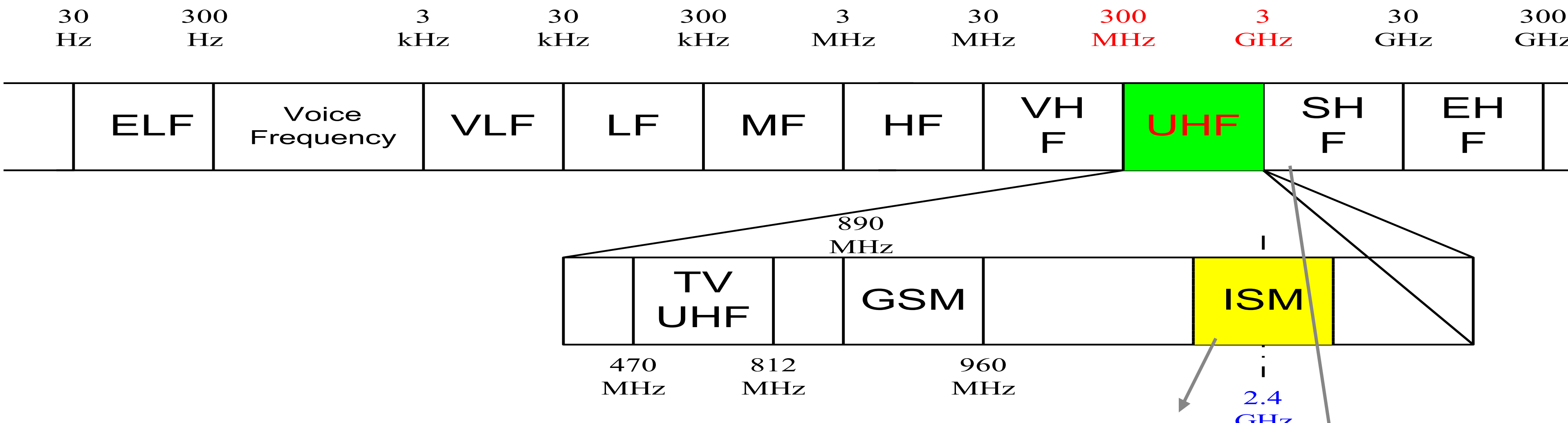
Telemedicine
Virtual Clinics

smart grid technologies

Google unveils 'Project Glass' virtual-reality glasses..

Wireless AR

Frequency Allocation



Note: The **Industrial, Scientific and Medical (ISM)** radio bands were originally reserved internationally for non-commercial use of RF electromagnetic fields for industrial, scientific and medical purposes.

In recent years they have also been used for license-free error-tolerant communications applications such as Bluetooth and IEEE 802.11b

–Standard for 5.2 GHz NII band (300 MHz)

–Unlicensed National Information Infrastructure (U-NII) band , USA

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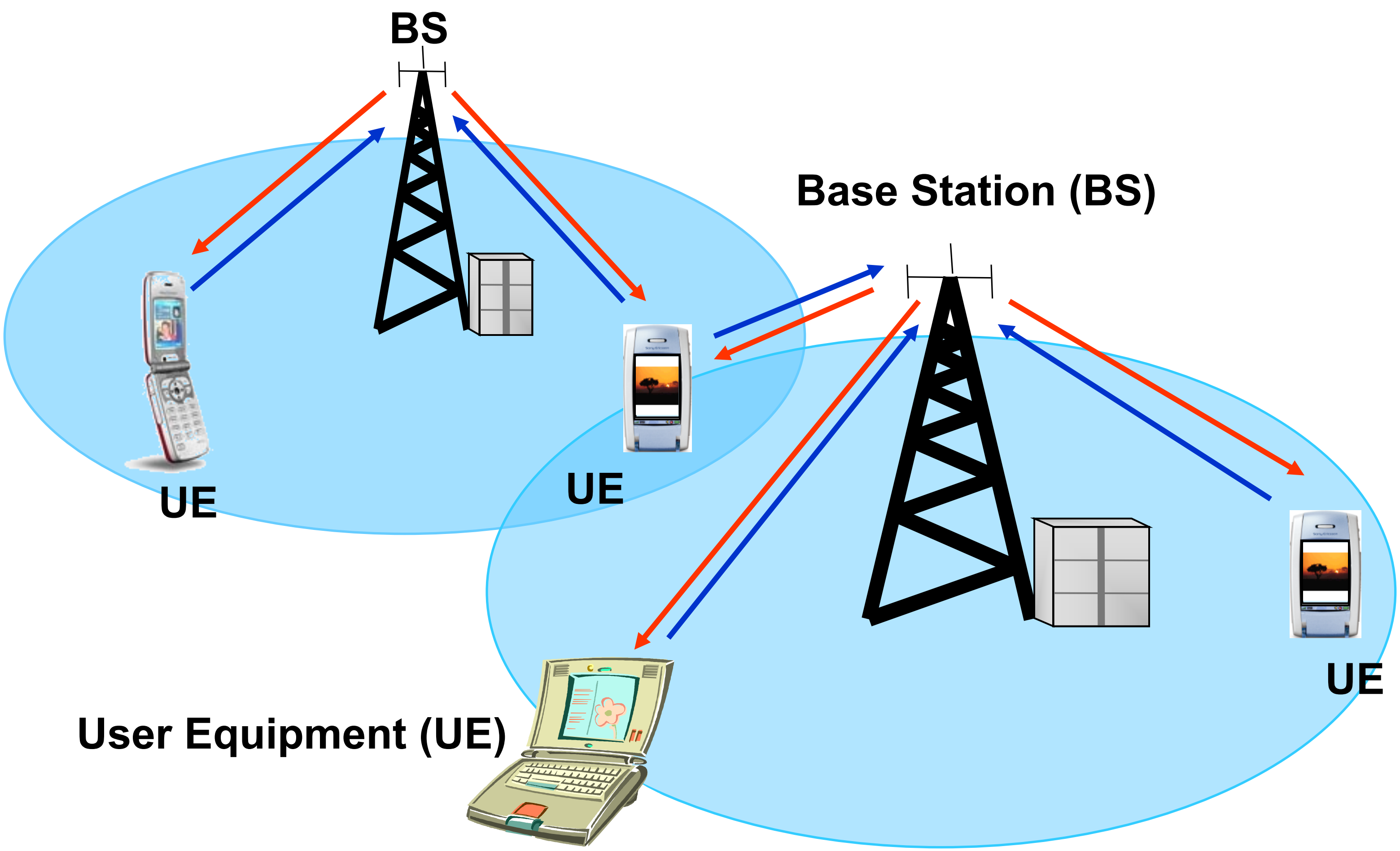
- Examples of a (digital) communication systems:

1) Cellular wireless communication systems



1) Mobile Communications

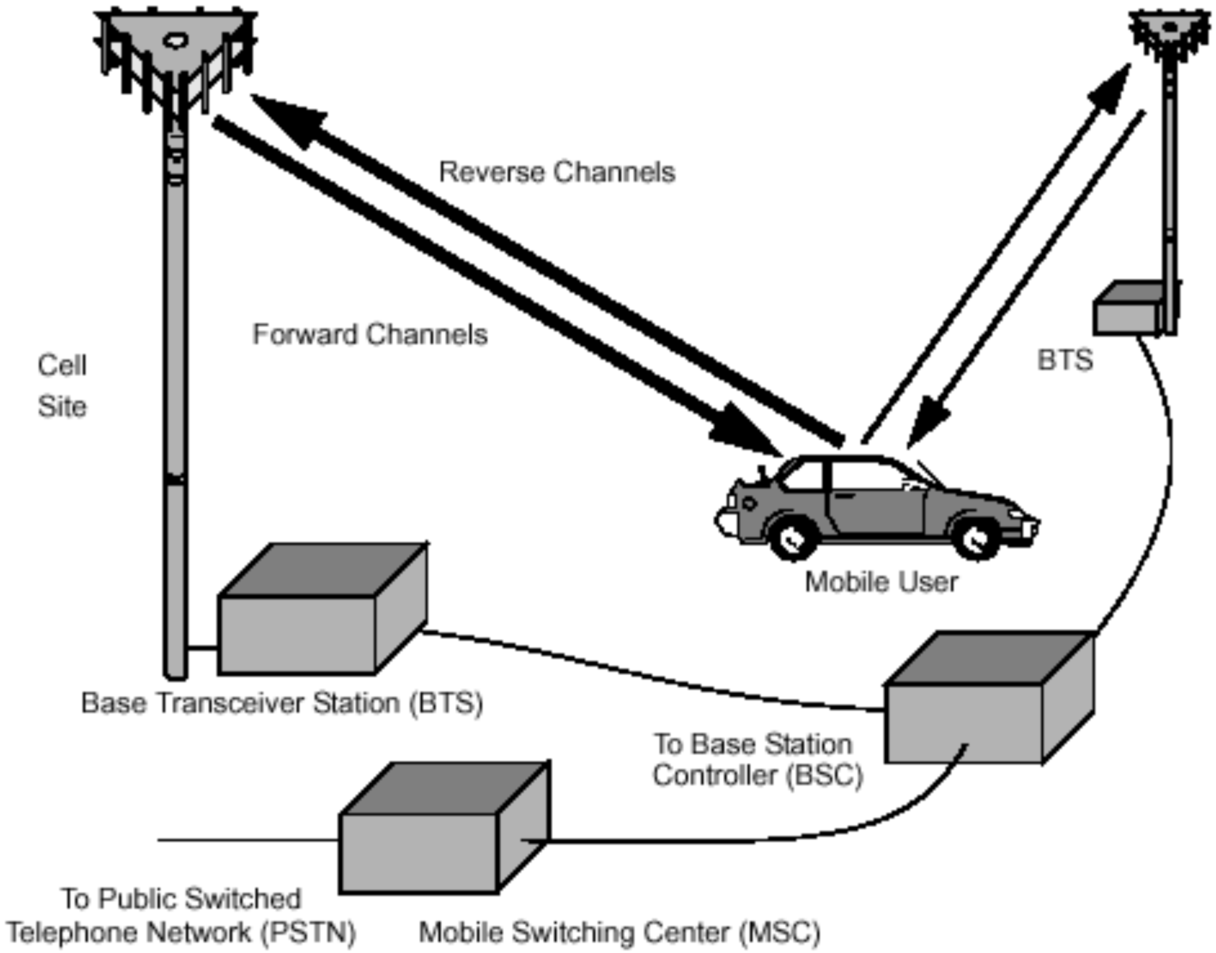


Figure 1–3 There are two main types of forward channels. Control and access channels are used to set up calls and provide security and management functions. Traffic channels are used to carry voice traffic. The reverse channels are also divided into access channels and traffic channels. In some systems, the Base Station Controller (BSC) may be integrated directly into the cell site. In other systems, as shown here, the Base Transceiver Stations (BTSs) are connected to a Base Station Controller.

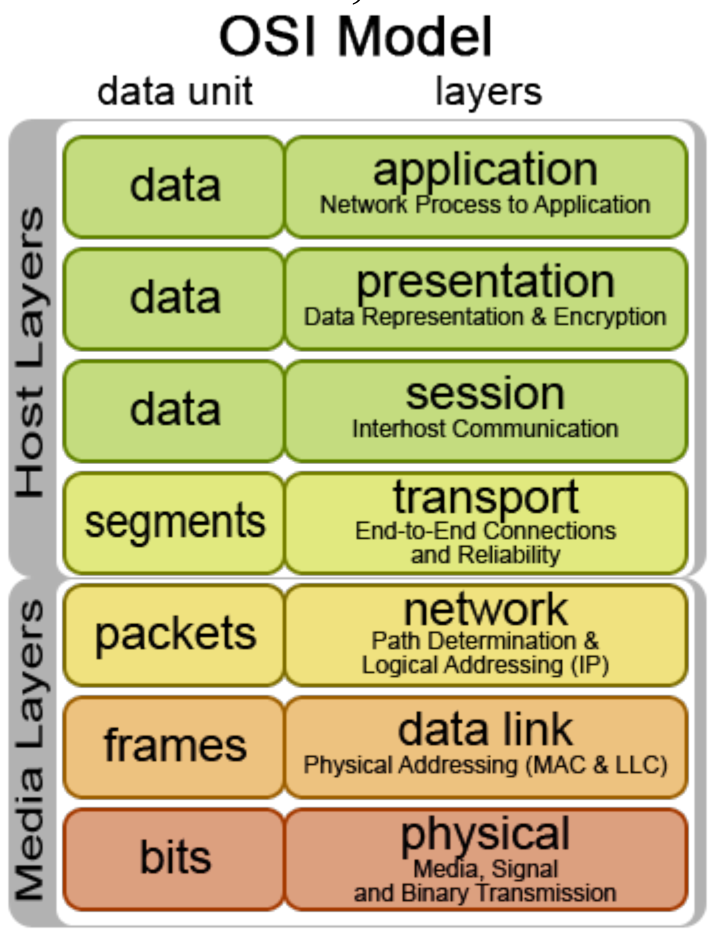
2) Satellite Communications

Types of satellite services

1. **Fixed satellite service (FSS)**
   - Links for existing telephone networks
   - Transmitting TV signals to cable companies.
2. **Broadcasting Satellite Service (BSS)**
   - Direct to home (DTH) =Direct broadcasting satellites (DBS)
3. **Mobile satellite service (MSS)**
   - Land mobile , maritime mobile and aeronautical mobile
4. **Navigation satellite service (GPS)**
   - Global positioning system (S&R)
5. **Meteorgolical satellite service (Weather Forecast)**
6. **Deep Space Satellites**

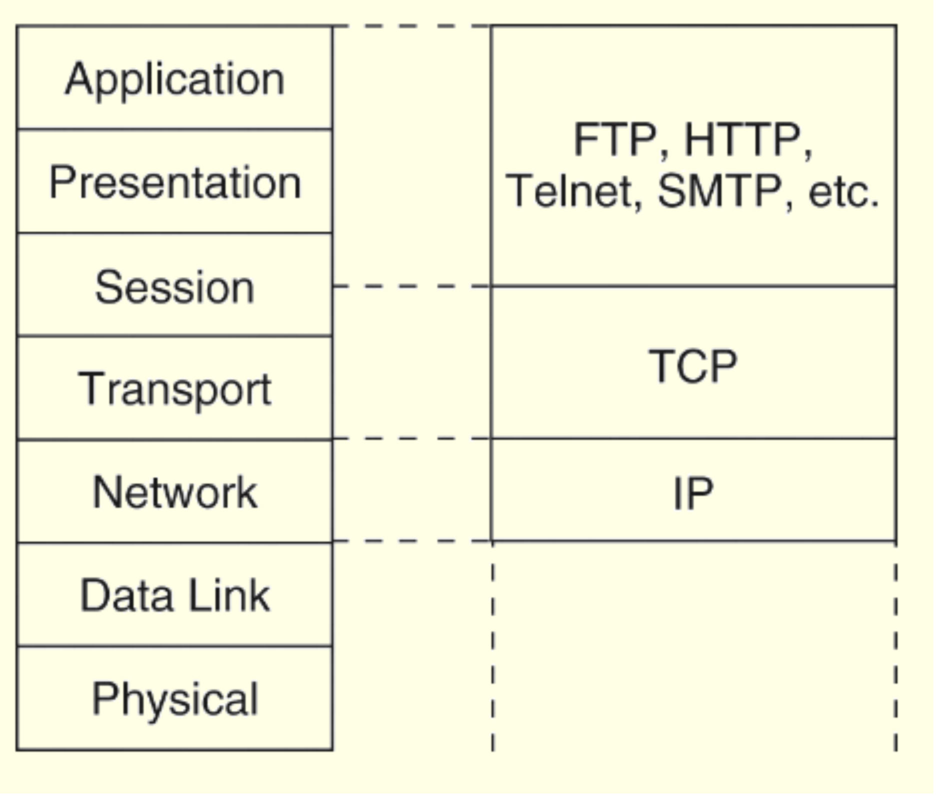
3) Computer networks and Internet

Open Systems Interconnections; Course offered next semester



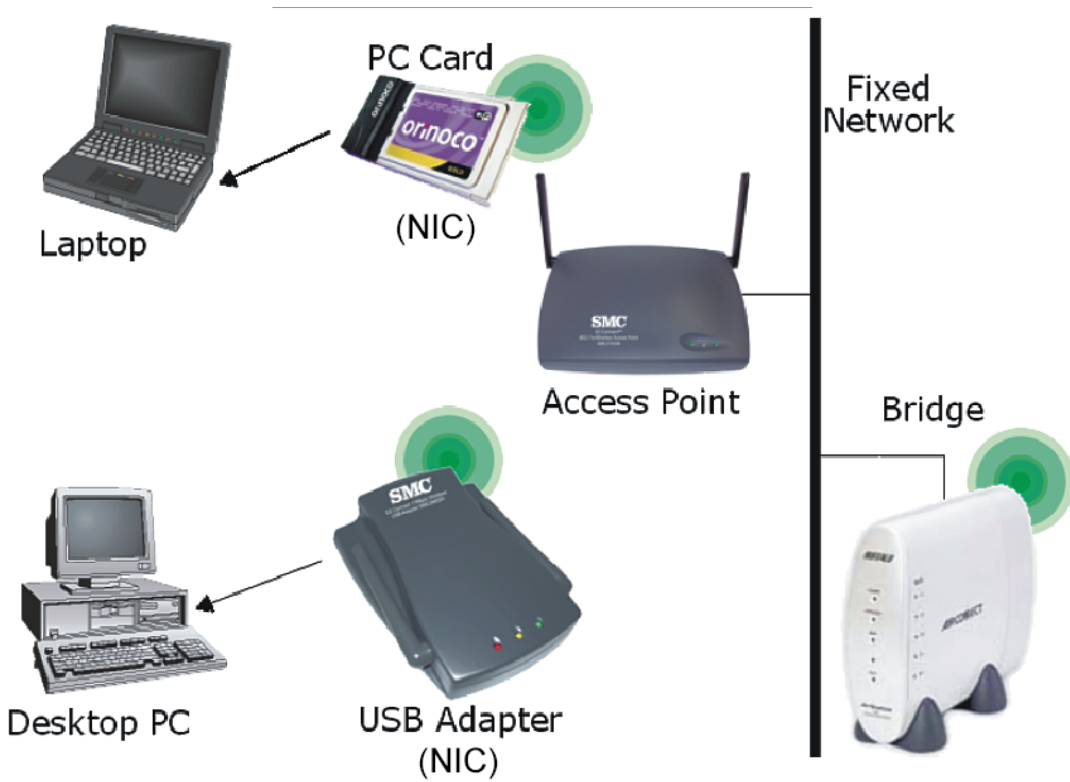
TCP/IP Architecture

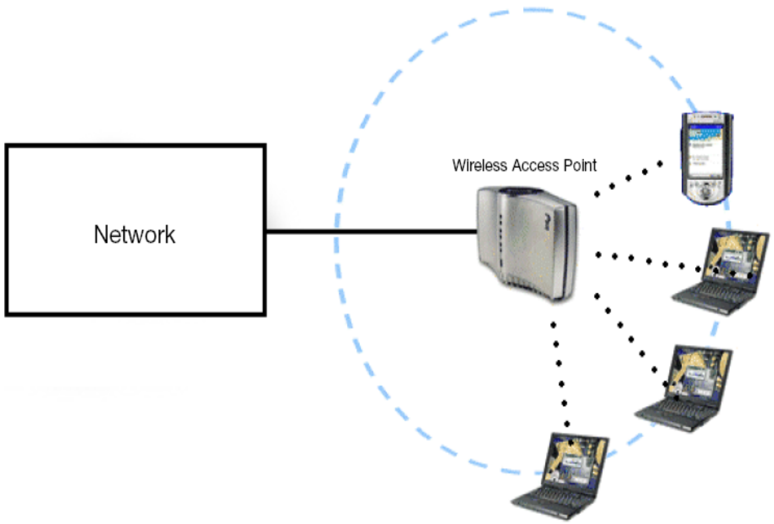
- TCP/IP is the de facto global data communications standard.
- It has a lean 3-layer protocol stack that can be mapped to five of the seven in the OSI model.
- TCP/IP can be used with any type of network, even different types of networks within a single session.



4) Wireless Computer LANs

- Basically, a WLAN is simply a wireless version of an Ethernet LAN
- Main WLAN components are **Wireless Terminals** (or Stations) and **Access Points** (linking the WLAN to other networks)





Wireless LANs provide high-speed data within a small region, e.g. a campus or small building, as users move from place to place. Wireless devices that access these LANs are typically stationary or moving at pedestrian speeds.

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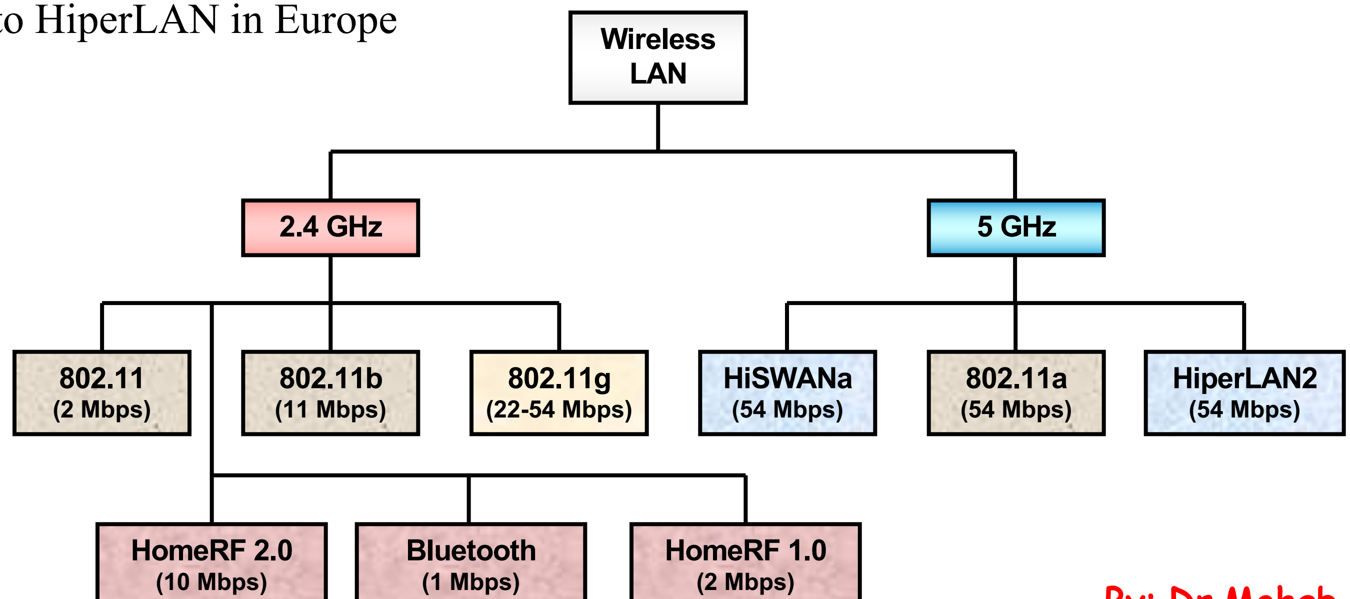
Wireless LAN Standards

- 1st Generation WLANs not standardized
  - These systems flopped
- 802.11b (Current Generation)
  - Standard for 2.4GHz ISM band (80 MHz)
  - Frequency hopped spread spectrum
  - 1.6-10 Mbps, 150 m range
- 802.11a (Emerging Generation)
  - Standard for 5GHz NII band (300 MHz)
    - Unlicensed National Information Infrastructure (U-NII) band , USA
  - 20-70 Mbps, variable range
  - OFDM with time division
  - Similar to HiperLAN in Europe



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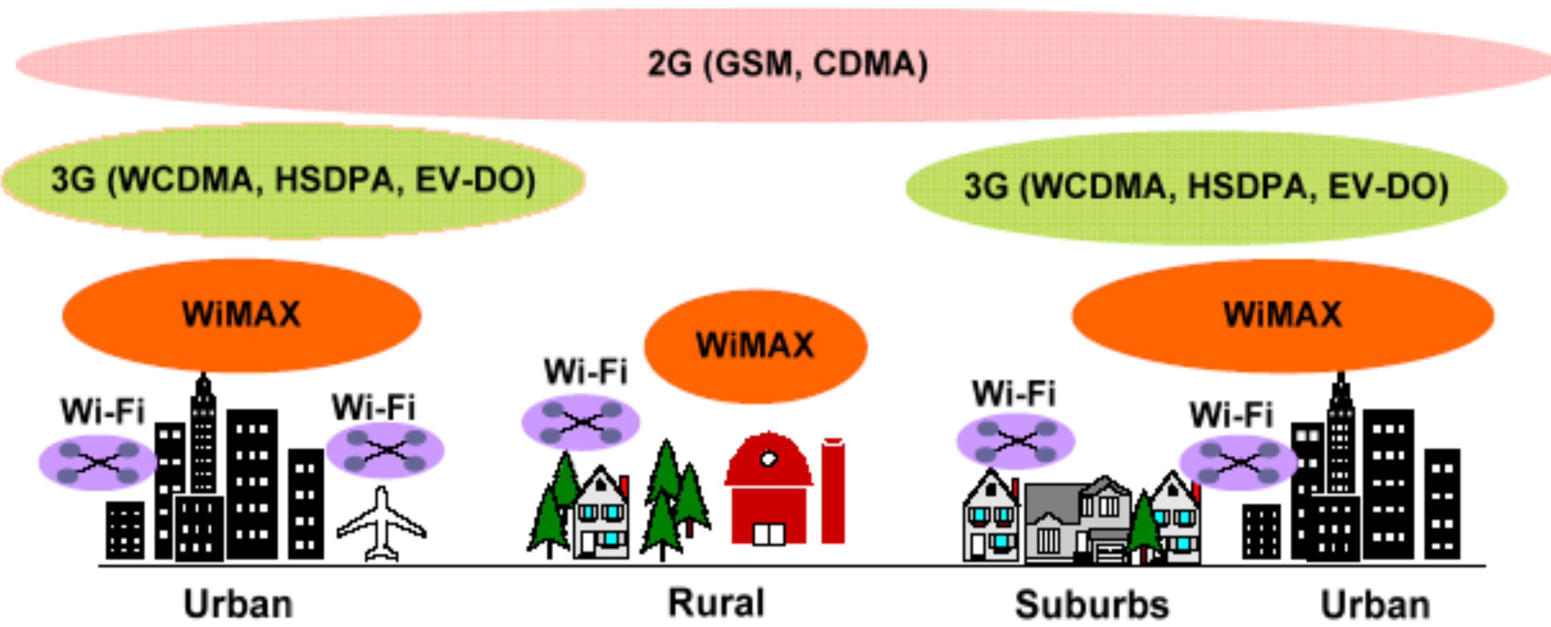


Figure 2. Wi-Fi, WiMAX, 3G and 2G coverage. Source: WiMAX Forum

The Next Battle: WiMax vs. 3G

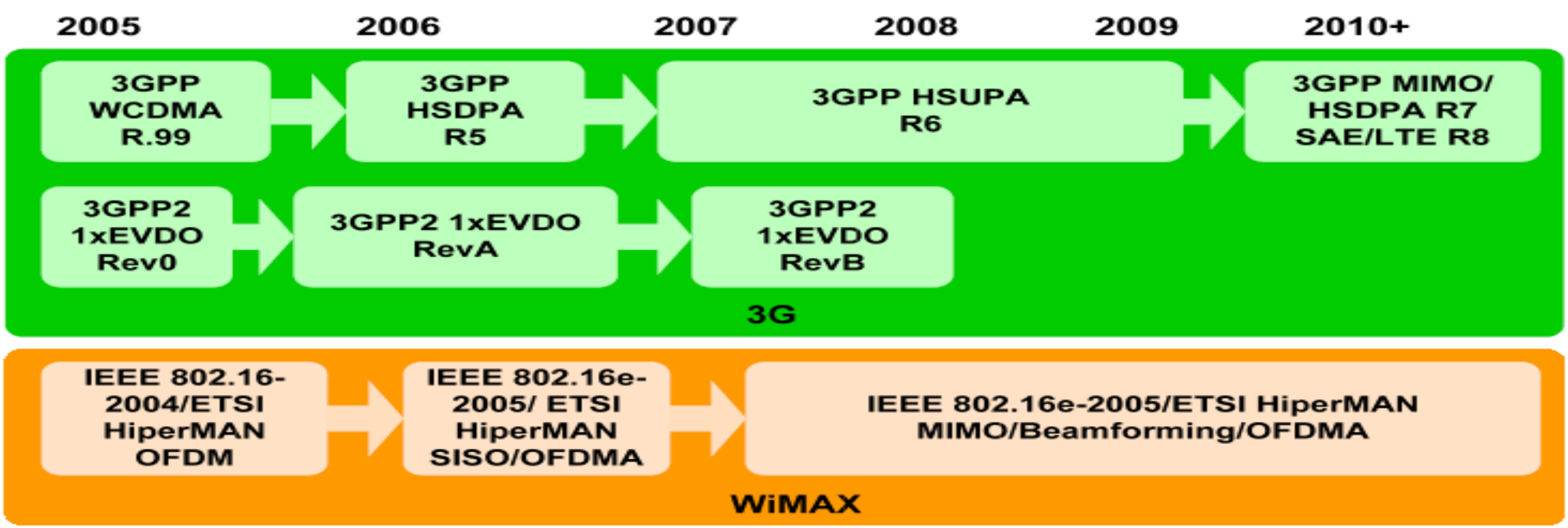


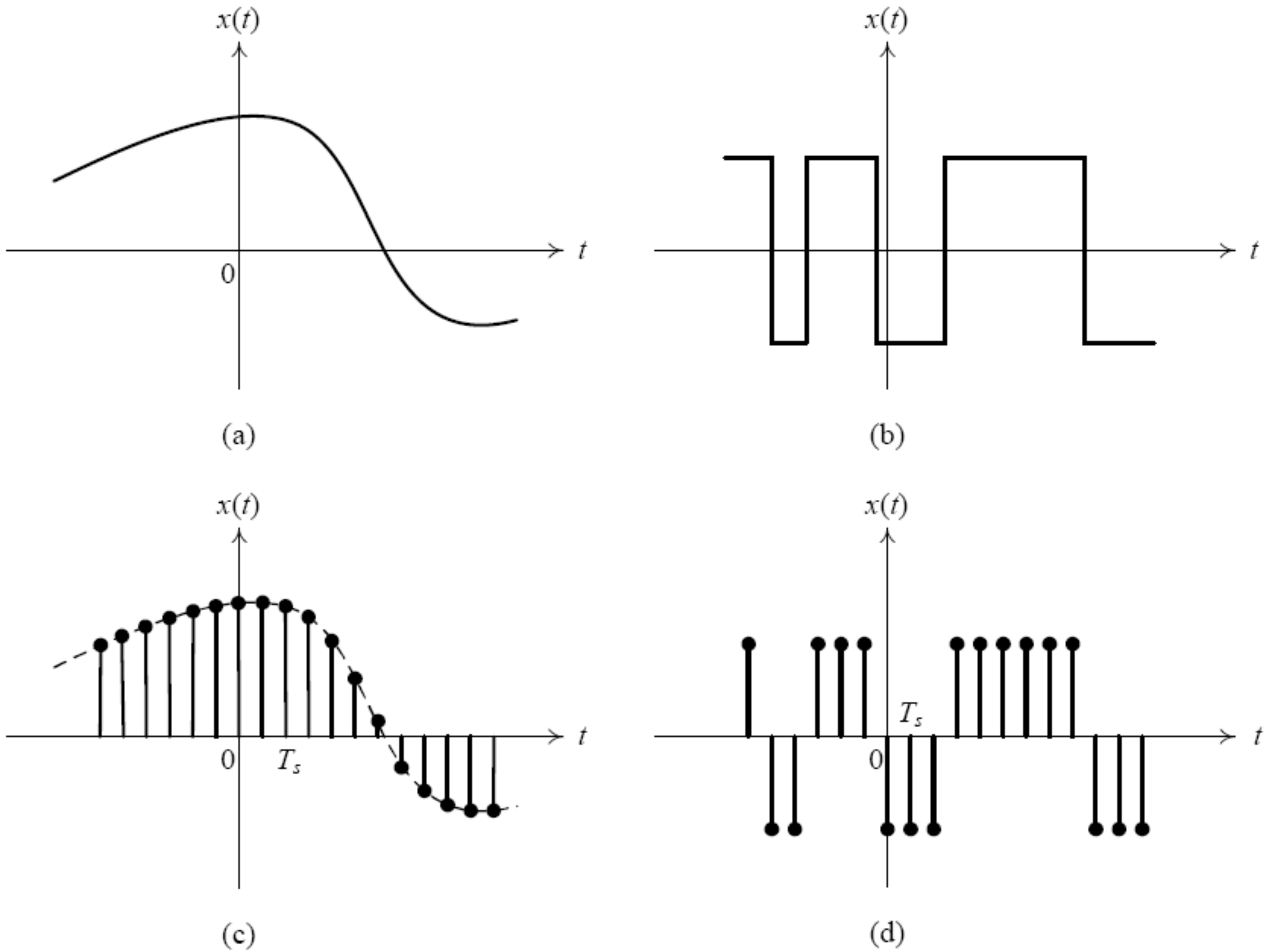
Figure 4. Evolution of 3G and WiMAX. Source: WiMAX Forum

Part II

Analog or Digital

- Common Misunderstanding: Any transmitted signals are ANALOG. NO DIGITAL SIGNAL CAN BE TRANSMITTED
- Analog Message: continuous in amplitude and over time
  - AM, FM for voice sound
  - Traditional TV for analog video
  - First generation cellular phone (analog mode)
  - Record player
- Digital message: 0 or 1, or discrete value
  - VCD, DVD
  - 2G/3G cellular phone
  - Data on your disk
  - Your grade
- Digital age: why digital communication will prevail

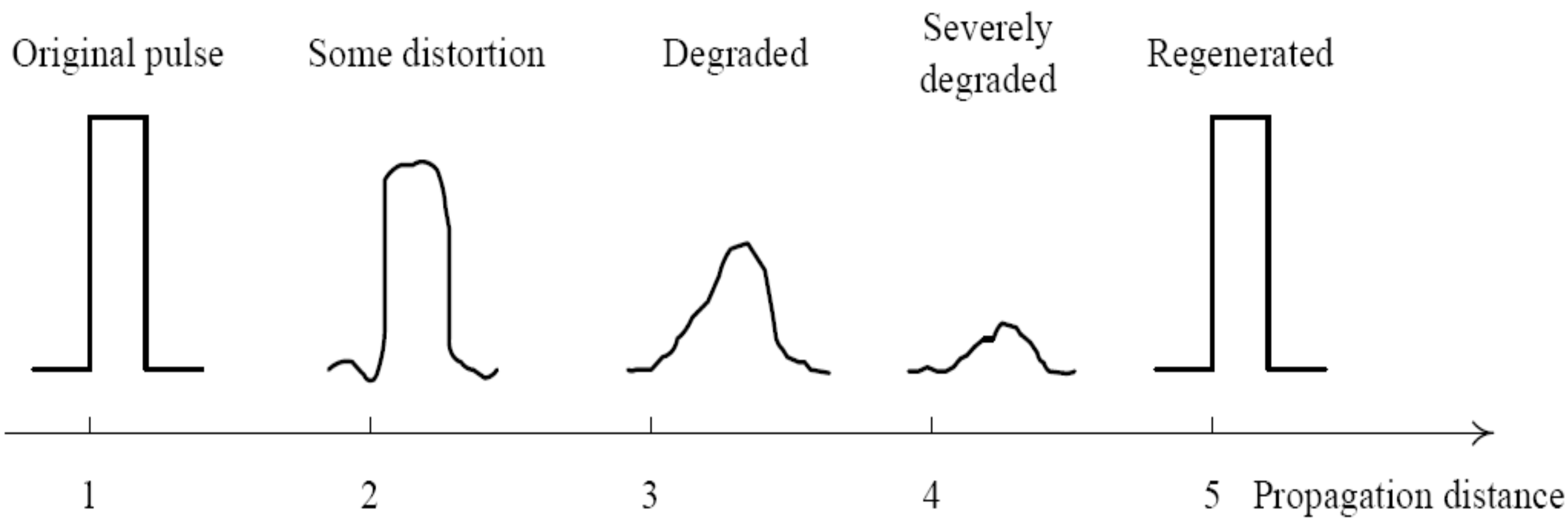
What is Digital Communication?



Digital vs. Analog

- Advantages:
  - Digital signals are much easier to be regenerated.
  - Digital circuits are less subject to distortion and interferenc
  - Digital circuits are more reliable and can be produced at a lower cost than analog circuits.
  - It is more flexible to implement digital hardware than analo hardware.
  - Digital signals are beneficial from digital signal processing (DSP) techniques.
- Disadvantages:
  - Heavy signal processing.
  - Synchronization is crucial.
  - Larger transmission bandwidth.
  - Non-graceful degradation.

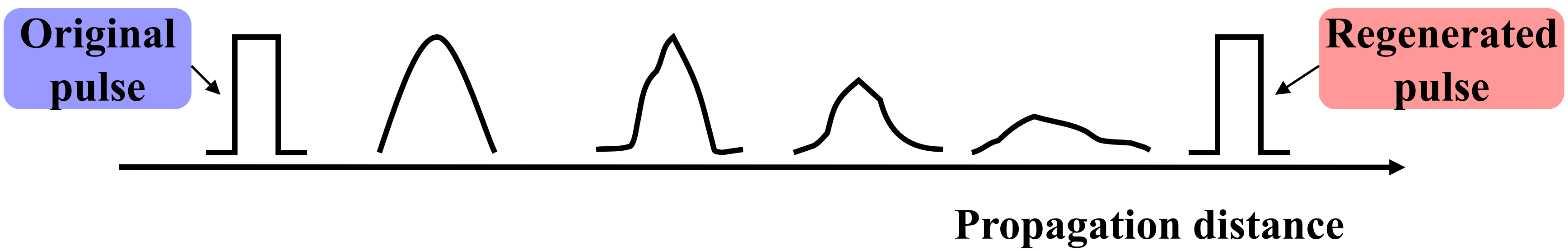
Regenerative Repeater in Digital Communications



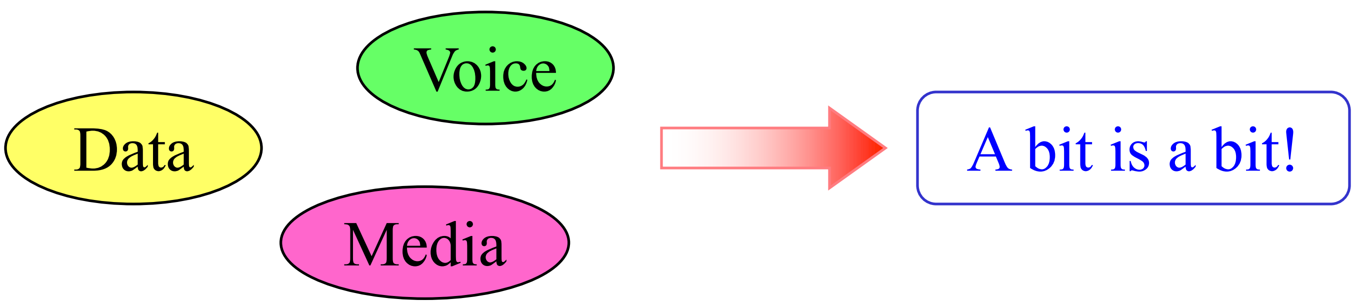
- Digital communications: Transmitted signals belong to a finite set of waveforms → The distorted signal can be recovered to its ideal shape, hence removing all the noise.
- Analog communications: Transmitted signals are analog waveforms, which can take infinite variety of shapes → Once the analog signal is distorted, the distortion cannot be removed.

Digital versus analog

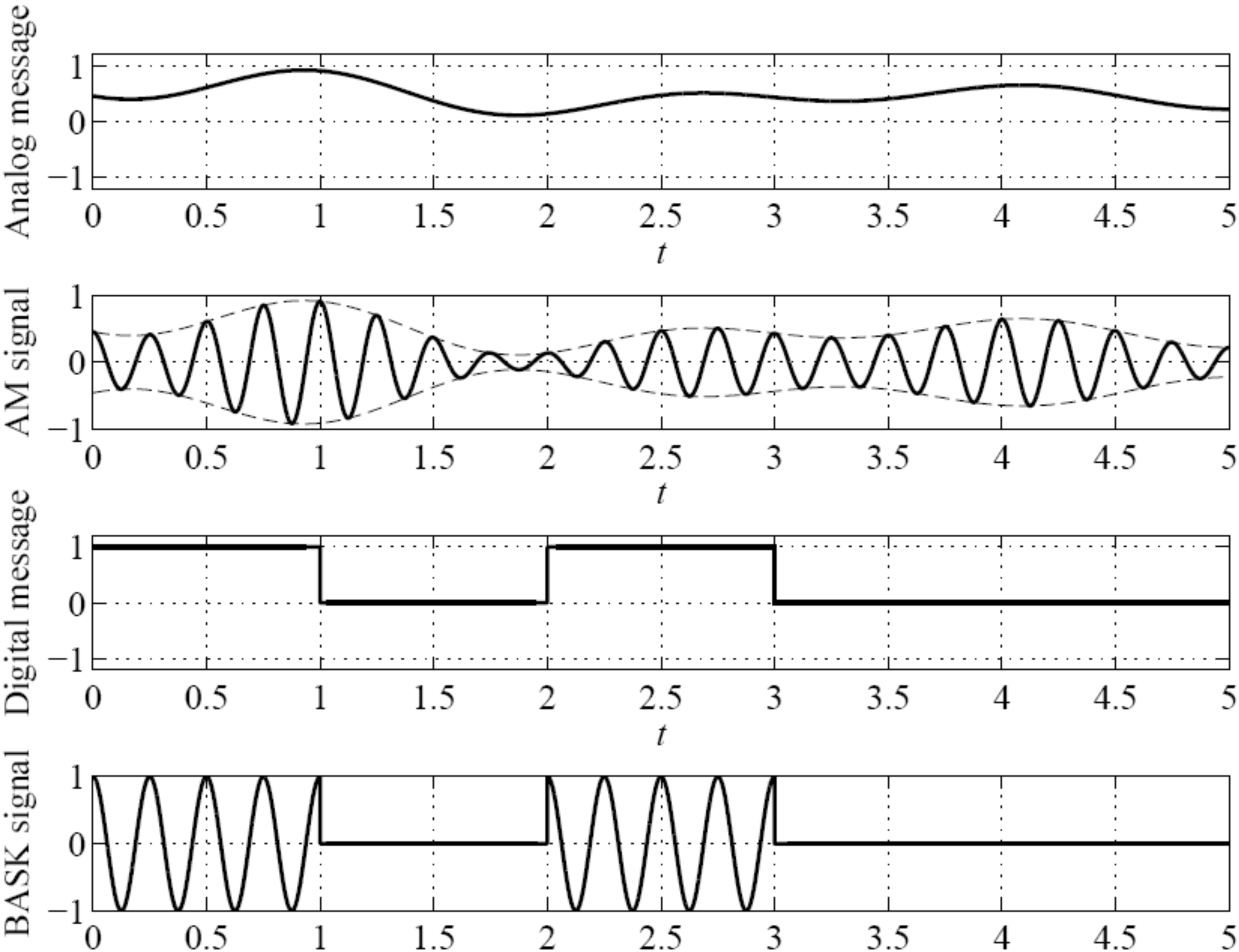
- Advantages of digital communications:
  - Regenerator receiver



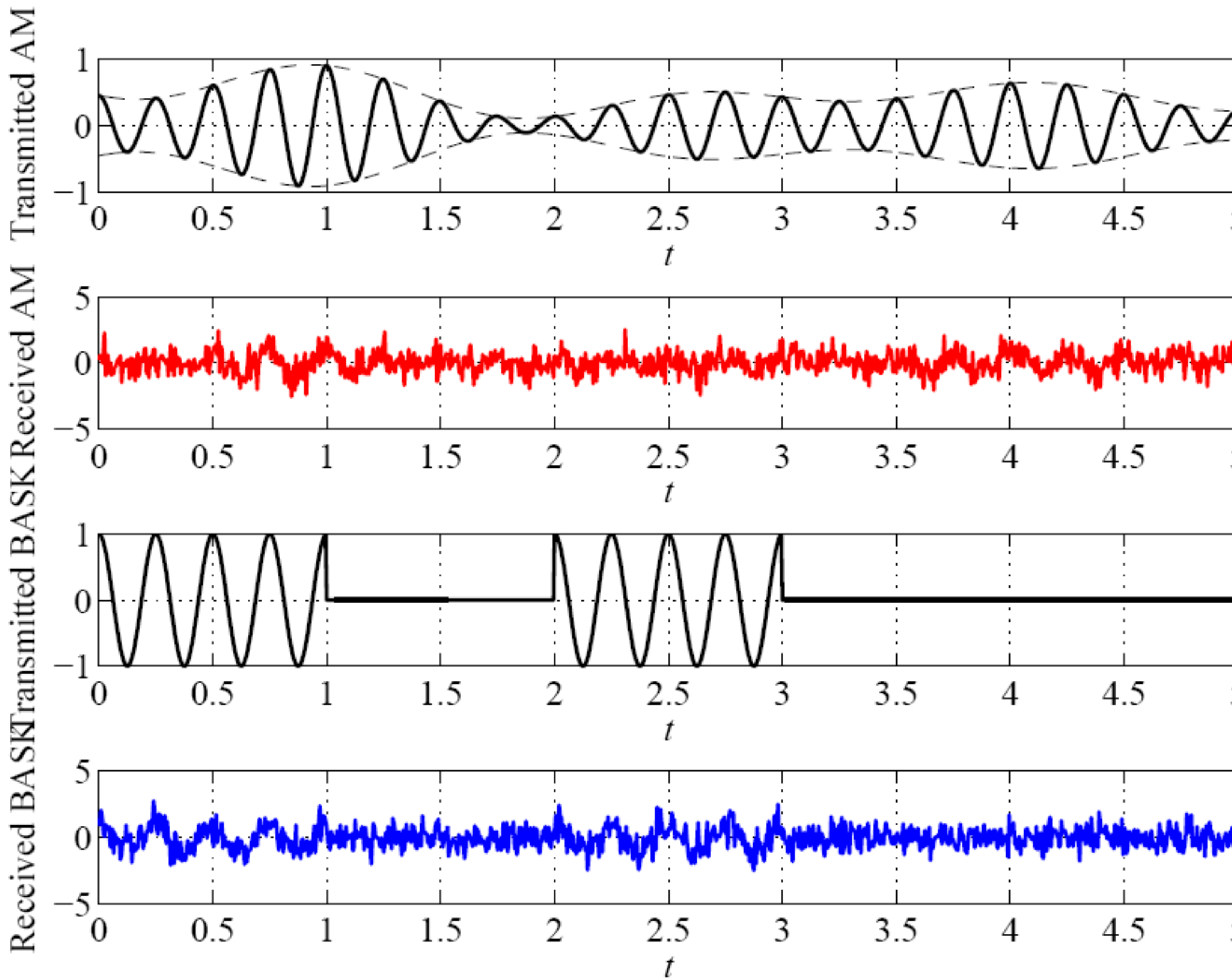
  - Different kinds of digital signal are treated identically.



Analog and Digital Amplitude Modulations



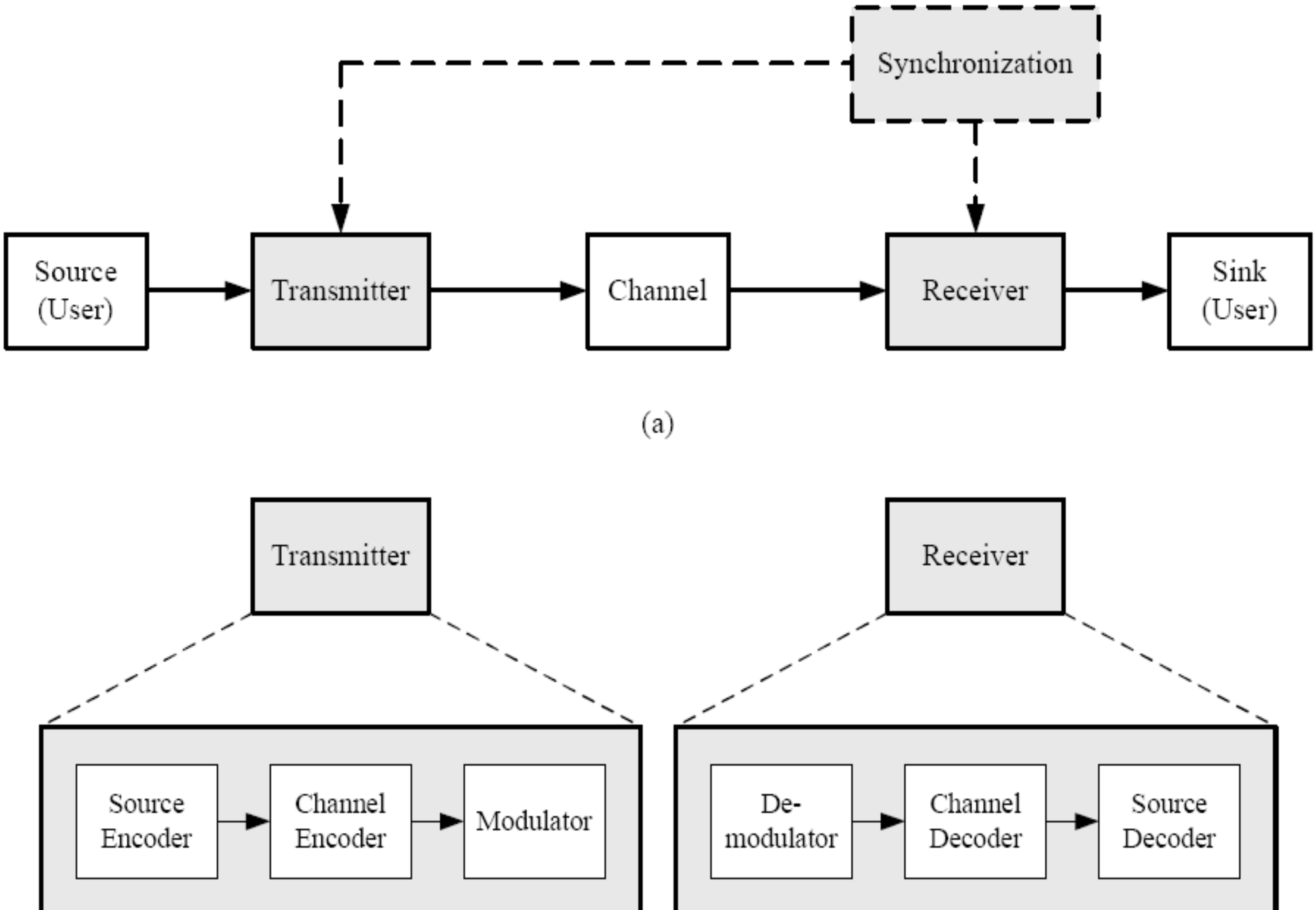
Why Digital Communications?



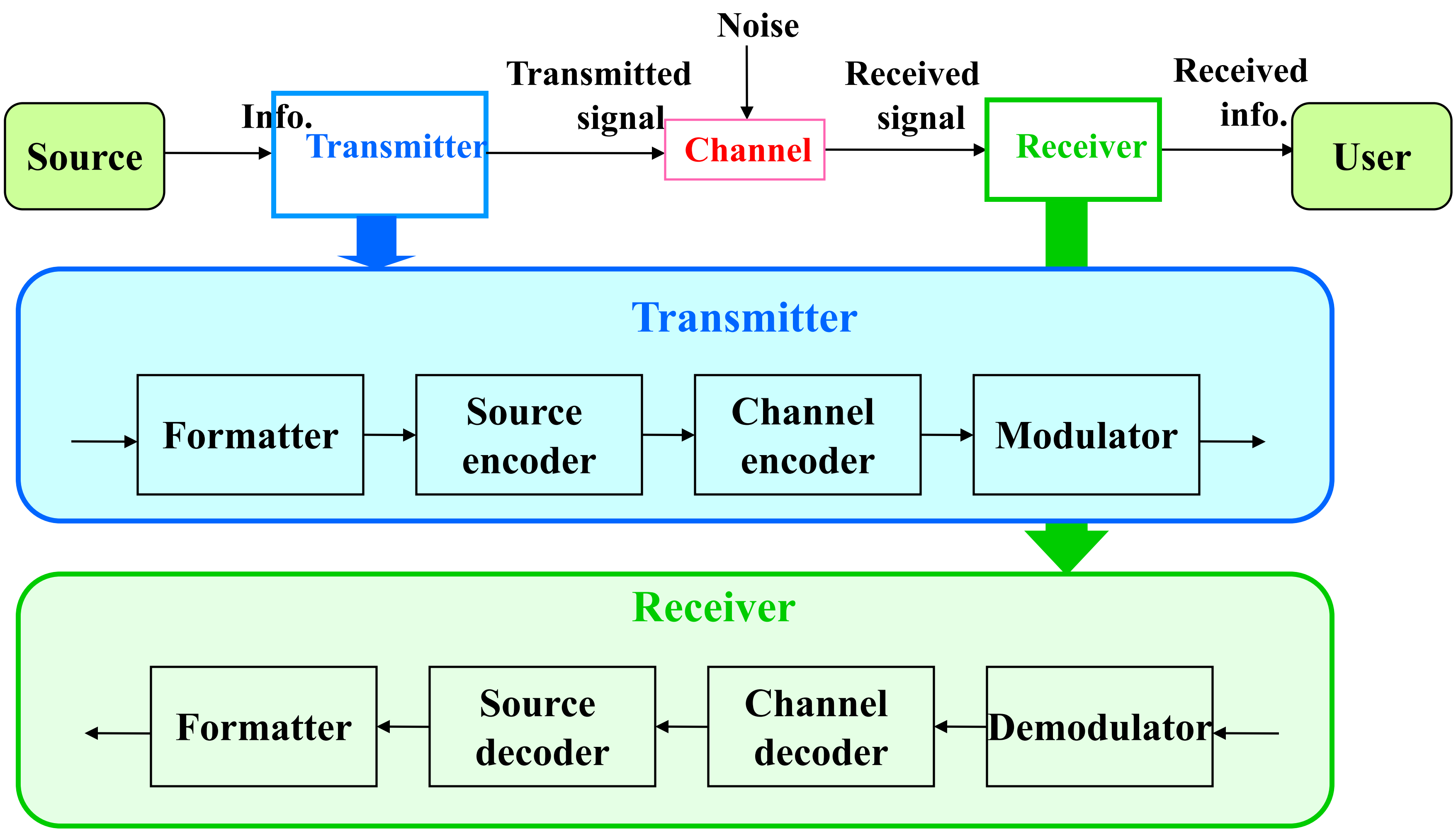
Why digital communications?

- Any noise introduces distortion to an analog signal. Since a digital receiver need only distinguish between two waveforms it is possible to exactly recover digital information.
- Many signal processing techniques are available to improve system performance: source coding, channel (error-correction) coding, equalization, encryption
- Digital ICs are inexpensive to manufacture. A single chip can be mass produced at low cost, no mater how complex
- Digital communications allows integration of voice, video, and data on a single system (ISDN)
- Digital communications systems provide a better tradeoff of bandwidth efficiency and energy efficiency than analog

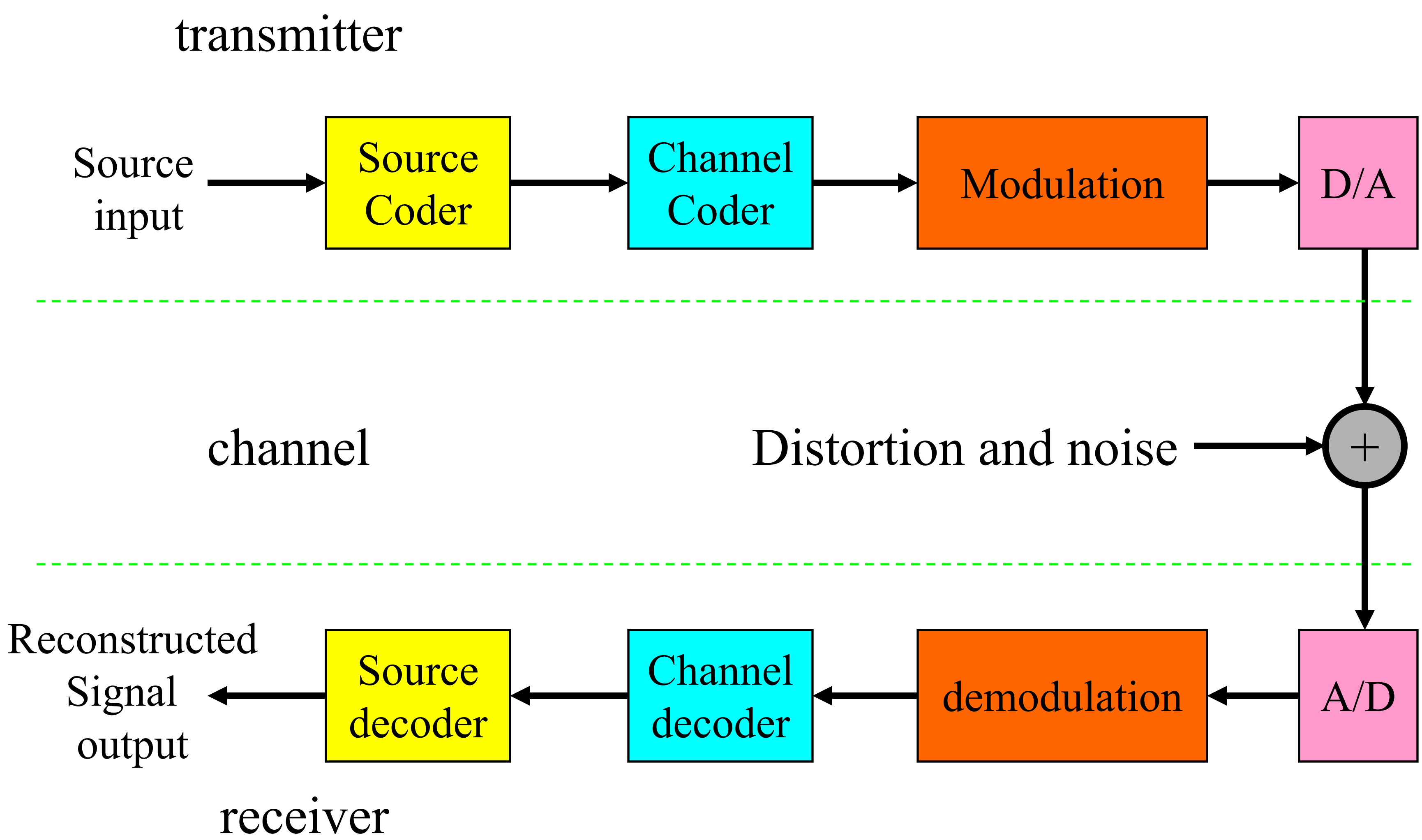
Block Diagram of a Communication System



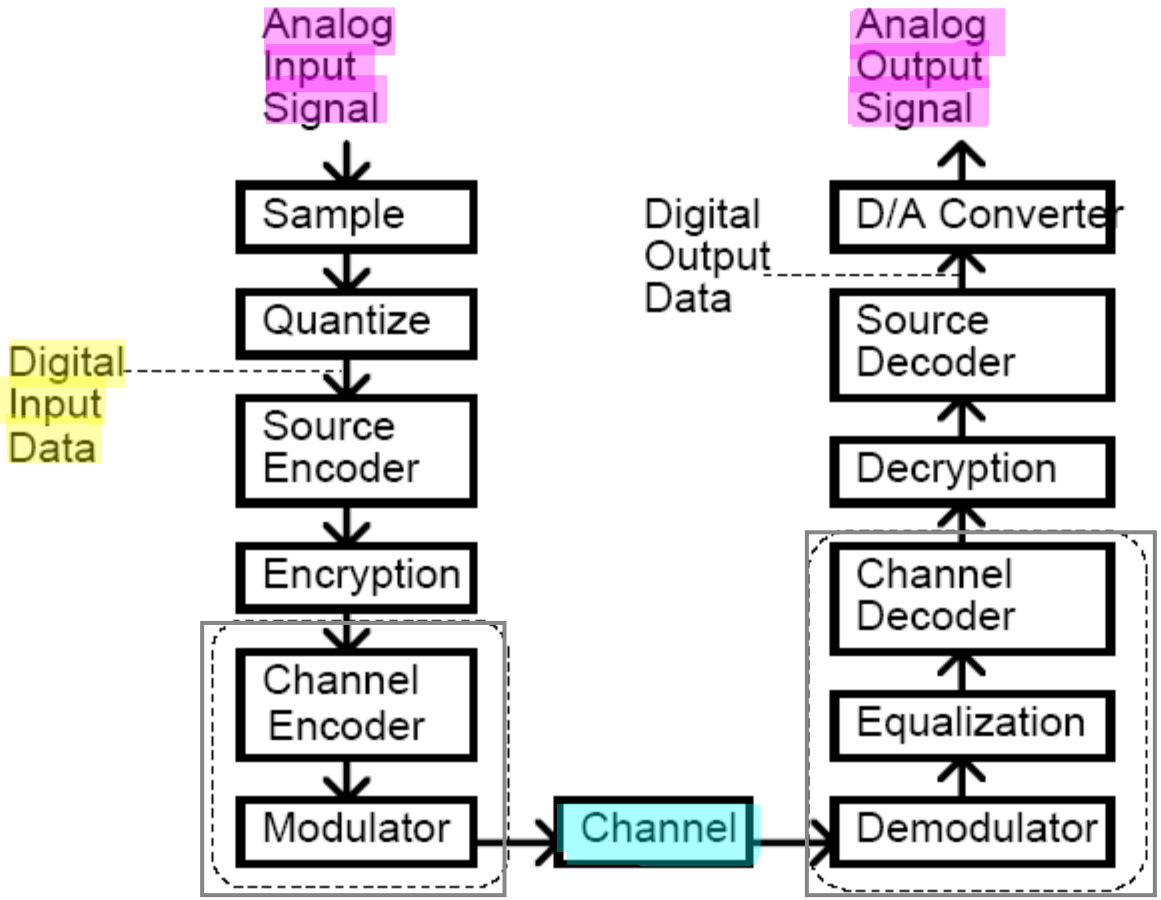
General structure of a communication systems

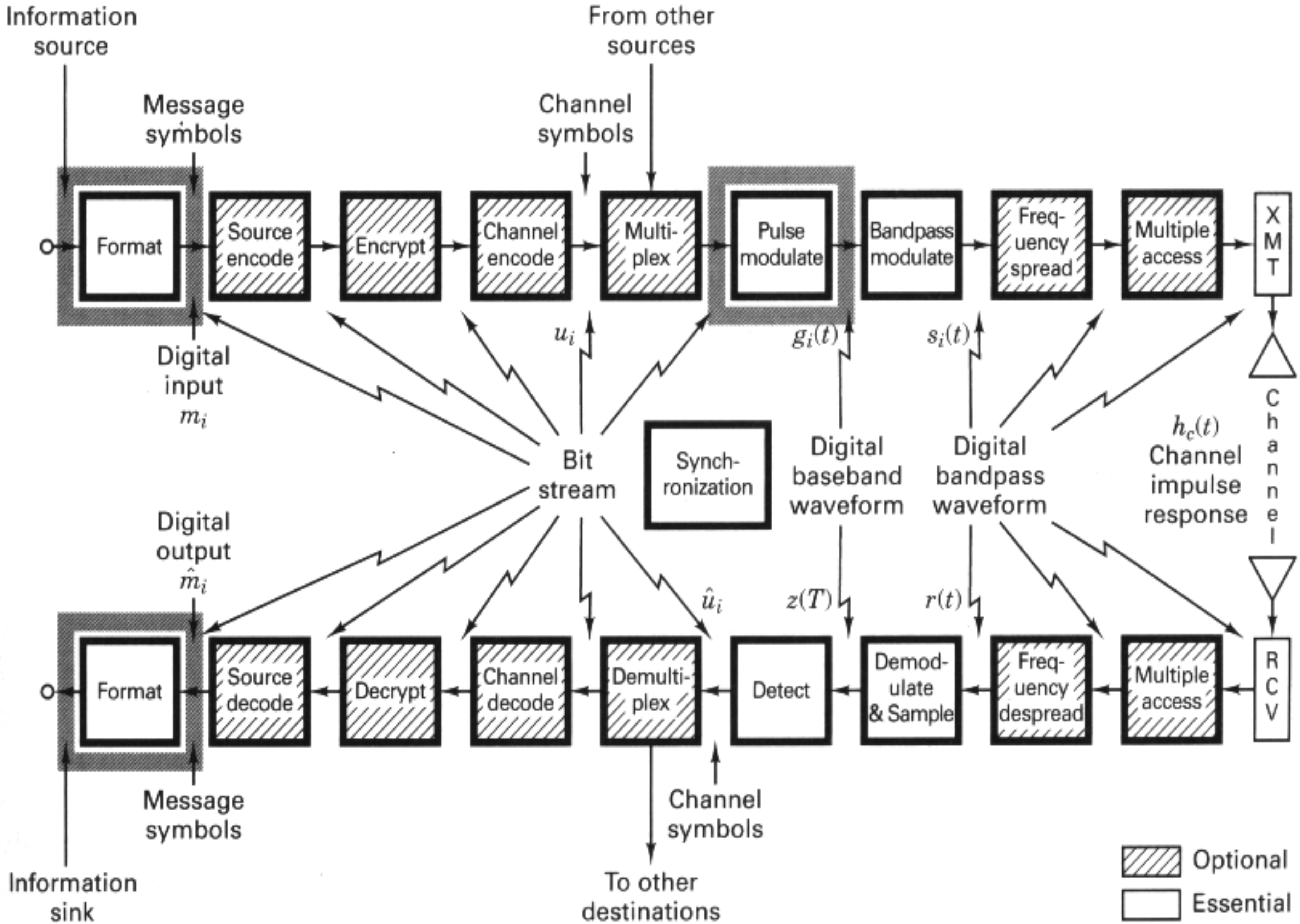


Communication System Components



Block Diagram of Typical Digital Communications System




Information source
Message symbols
Channel symbols
From other sources
Format
Source encode
Encrypt
Channel encode
Multi-plex
Pulse modulate
Bandpass modulate
Freq-uency spread
Multiple access
XMT
Digital input m_i
u_i
$g_i(t)$
$s_i(t)$
Bit stream
Synch-ronization
Digital baseband waveform
Digital bandpass waveform
$h_c(t)$ Channel impulse response
Channel
Digital output $\hat{m}_i$
$\hat{u}_i$
$z(T)$
$r(t)$
Format
Source decode
Decrypt
Channel decode
Demulti-plex
Detect
Demod-ulate & Sample
Freq-uency despread
Multiple access
RCV
Message symbols
Channel symbols
Information sink
To other destinations
Optional
Essential

Sampling

- Sampling makes signal discrete in time
- Sampling Thereom says that bandlimited signal can be sampled without introducing distortion

Quantization

- Quantizer makes signal discrete in amplitude
- Quantizer introduces some distortion
- Good quantizers are able to use few bits and introduce small distortion
- We will study optimum scalar and vector quantizers

Digital Data

- After quantization, data is in digital (0,1) form
- Inherently digital information (e.g. computer files) do not require sampling or quantization

Source Coding

- Compression of digital data to eliminate redundant information
- Source coding is like quantization because its goal is to reduce bit rate
- Source coding is unlike quantization because it does not introduce distortion
- We will study two simple source coding algorithms

Encryption

- Encryption techniques can ensure data privacy
- Encryption is what we think of when we think of spies and secret decoder rings - Communications engineers use the word "coding" for other ideas
- Very good "public key" encryption algorithm exist - this worries the folks at NSA
- We will not talk about encryption in detail, but encryption would make a good project

Channel Coding

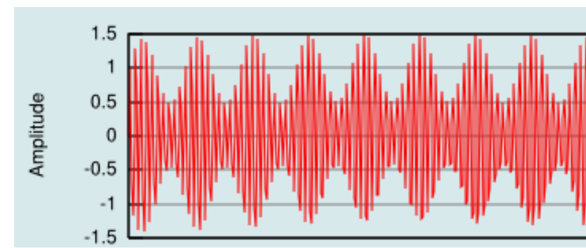
- Purpose
  - Deliberately add redundancy to the transmitted information, so that if the error occurs, the receiver can either detect or correct it.
- Source-channel separation theorem
  - If the delay is not an issue, the source coder and channel coder can be designed separately, i.e. the source coder tries to pack the information as hard as possible and the channel coder tries to protect the packet information.
- Popular coder
  - Linear block code
  - Cyclic codes (CRC)
  - Convolutional code (Viterbi, Qualcom)
  - LDPC codes, Turbo code, 0.1 dB to Channel Capacity

Channel Encoder

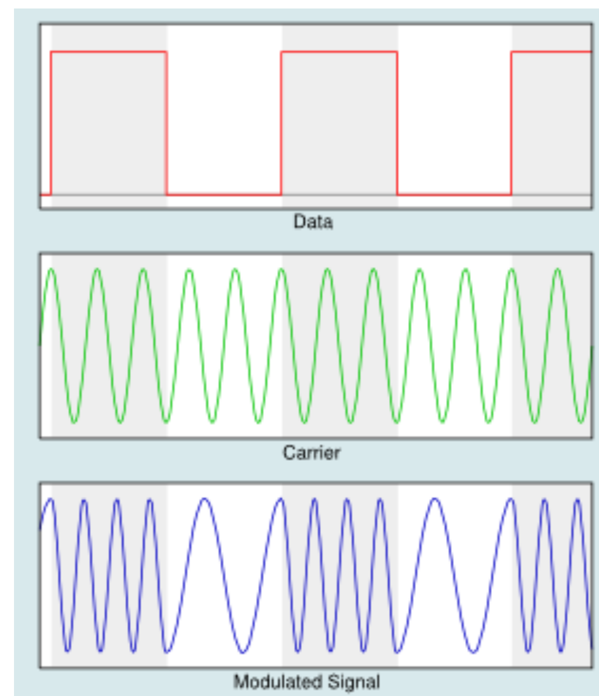
- Provides protection against transmission errors by selectively inserting redundant data
- Note that quantizer and source encoder work to squeeze out redudant information. The channel encoder inserts redundant information in a very selective manner
- Also called (FEC) Forward Error Correcting Coding
- We will study the role that error correction coding plays in system design, including trellis and turbo codes

Modulator

- Converts digital data to a continuous waveform suitable for transmission over channel - usually a sinusoidal wave
- Information is transmitted by varying one or more parameters of waveform:
  - Amplitude
  - Phase
  - Frequency



- Process of varying a carrier signal in order to use that signal to convey information
  - Carrier signal can transmit far away, but information cannot
  - Modem: amplitude, phase, and frequency
  - Analog: AM, amplitude, FM, frequency, Vestigial sideband modulation, TV
  - Digital: mapping digital information to different constellation: Frequency-shift key (FSK)



Examples of Modulation

- Amplitude Shift Keying (ASK) or On/Off Keying (OOK):

$$1 \Rightarrow A\cos(2\pi f_c t)$$
$$0 \Rightarrow 0$$

- Frequency Shift Keying (FSK):

$$1 \Rightarrow A\cos(2\pi f_1 t)$$
$$0 \Rightarrow A\cos(2\pi f_0 t)$$

- Phase Shift Keying (PSK):

$$1 \Rightarrow A\cos(2\pi f_C t)$$
$$0 \Rightarrow A\cos(2\pi f_C t + \pi) = -A\cos(2\pi f_C t)$$

Channel

- Carries signal - could be a telephone wire, free space
- Presents distorted signal to demodulator. Effects include attenuation, noise, fading.
- Fading is very important - studied in Cellular and Personal Communications class
  - Rayleigh fading
  - Ricean fading
  - Log-normal “shadowing”
- We will *usually* assume a very simple channel - additive Gaussian noise (AWGN)

What Makes a Good Communication System?

- Large data rate (measured in bits/sec)
- Small bandwidth (measured in Hertz)
- Small signal power (measured in Watts or dBW)
- Low distortion (measured in *S/N* or bit error rate)
- Low cost - with digital communications, large complexity does not always result in large cost
- In practice, there must be tradeoffs made in achieving these goals

Tradeoffs in System Design: Data Rate vs. Bandwidth

- Increased data rate leads to shorter data pulses which leads to larger bandwidth.
- This tradeoff cannot be avoided - however, some systems use bandwidth more efficiently than others.
- We will define Bandwidth Efficiency as the ratio of data rate R_b to bandwidth W: $\eta_B = R_b / W$
- We want large bandwidth efficiency η_B

Bits/s/Hz

Tradeoffs in System Design: Fidelity vs. Signal Power

- One way to get an error free signal would be to use huge amounts of power to blast over the noise.
- Some types of modulation achieve relative error free transmission at lower powers than others.
- We define Energy Efficiency: $\eta_E = E_b / N_o \big|_{P_b = \text{target error rate}}$
- We desire small η_E

Tradeoffs in System Design: Bandwidth Efficiency vs. Energy Efficiency

- It is possible for a system design to trade between bandwidth efficiency and energy efficiency.
- Examples:
  - Binary modulation sends only one bit per use of the channel. *M*-ary modulation can send multiple bits, but is more vulnerable to errors.
  - Error correction coding: inserting redundant bits improves bit error rate, but increases bandwidth.
- This is a fundamental tradeoff in digital communications.