16.36: Communication Systems Engineering

Lecture 1: Introduction

Eytan Modiano
Administrative matters

• Instructors: Eytan Modiano

• Meeting times: Tuesdays and Thursdays

• Text: Communications Systems Engineering, Proakis and Salehi

• Grading
  – 10% weekly Homework Assignments
  – 30% each of 3 exams
  – Final exam during final exam period!
Timeline of modern communication

Analog
Comm Systems
• 1876 - Bell Telephone
• 1920 - Radio Broadcast
• 1936 - TV Broadcast

Digital
Comm Systems
• 1960’s - Digital communications
• 1965 - First commercial satellite

Networked
Comm Systems (packets)
• 1970 - First Internet node
  Darpa-net, Aloha-net
• 1980 - Development of TCP/IP
• 1993 - Invention of Web
Typical Communication Classes

• Old days (1980s): Teach analog and digital communications in separate classes
  – Networking was sometimes taught as a graduate class, but most people did not see much use to it!

• Today: Most communication classes focus mainly on digital
  – Some classes may teach some analog for “historical” reasons
  – Networking classes are offered at both undergraduate and graduate levels

• MIT: one graduate level digital communication class and one graduate level networking class (6.450, 16.37/6.263)

• This class will introduce concepts of communications and networking at the undergraduate level
  – First attempt at combining concepts from both
    Importance of not thinking of the two systems as separate systems
Why communications in AA?

• AA Information Initiative
  – Communications
  – Software and computers
  – Autonomous systems

• Computers are a vital part of an Aerospace system
  – Control of system, Human interface
  – Involves computers, software, communications, etc.
  – E.g., complex communication networks within spacecraft or aircraft

• Space communications is a booming industry
  – Satellite TV, Internet Access

• Information technology is a critical engineering discipline
  – These skills are as fundamental today as the knowledge of basic math or physics
## Course Syllabus

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Communication Applications

- **Broadcast TV/Radio**
  - Little new here

- **Digital telephony**
  - Wired and wireless

- **Computer communications/networks**
  - Resource sharing
    - Computing: mainframe computer (old days)
    - Printers, peripherals
    - Information, DB access and update
  - Internet Services
    - Email, FTP, Telnet, Web access

- **Today, the majority of network traffic is for internet applications**
Types of Networks

• **Wide Area Networks (WANS)**
  - Span large areas (countries, continents, world)
  - Use leased phone lines (expensive!)
    - 1980’s: 10 Kbps, 2000’s: 2.5 Gbps
    - User access rates: 56Kbps – 155 Mbps typical
  - Shared comm links: switches and routers
    - E.g, IBM SNA, X.25 networks, Internet

• **Local Area Networks (LANS)**
  - Span office or building
  - Single hop (shared channel) (cheap!)
  - User rates: 10 Mbps – 1 Gbps
    - E.g., Ethernet, Token rings, Apple-talk

• **Metro Area networks (MANS)**

• **Storage area networks**
Network services

- **Synchronous (stream)**
  - Session appears as a continuous stream of traffic (e.g., voice)
  - Usually requires fixed and limited delays
- **Asynchronous (bursty)**
  - Session appears as a sequence of messages
  - Typically bursty
  - E.g., Interactive sessions, file transfers, email
- **Connection oriented services**
  - Long sustained session
  - Orderly and timely delivery of packets
  - E.g., Telnet, FTP
- **Connectionless services**
  - One-time transaction (e.g., email)
- **QoS**
Switching Techniques

• **Circuit Switching**
  – Dedicated resources
  – Traditional telephone networks

• **Packet Switching**
  – Shared resources
  – Modern data networks
Circuit Switching

• Each session is allocated a fixed fraction of the capacity on each link along its path
  – Dedicated resources
  – Fixed path
  – If capacity is used, calls are blocked
    E.g., telephone network

• Advantages of circuit switching
  – Fixed delays
  – Guaranteed continuous delivery

• Disadvantages
  – Circuits are not used when session is idle
  – Inefficient for bursty traffic
  – Circuit switching usually done using a fixed rate stream (e.g., 64 Kbps)
    Difficult to support variable data rates
Packet Switched Networks

Messages broken into Packets that are routed To their destination

Packet Network

Packet Switch
7 Layer OSI Reference Model

Application

Virtual network service

Presentation

Virtual session

Session

Virtual link for end-to-end messages

Transport

Virtual link for end-to-end packets

Network

Virtual link for reliable packets

Data link Control

DLC DLC DLC DLC

physical interface

physical interface

Physical link

External Site

subnet node

subnet node

External site
Layers

- **Presentation layer**
  - Provides character code conversion, data encryption, data compression, etc.

- **Session layer**
  - Obtains virtual end to end message service from transport layer
  - Provides directory assistance, access rights, billing functions, etc.

- **Standardization has not proceeded well here, since transport to application are all in the operating system and don't really need standard interfaces**

- **Focus: Transport layer and lower**
Transport Layer

- The transport layer is responsible for reliable end-to-end transmission of messages across the network
  - The network layer provides a virtual end to end packet pipe to the transport layer.
  - The transport layer provides a virtual end to end message service to the higher layers.

- The functions of the transport layer are:
  1) Break messages into packets and reassemble packets of size suitable to network layer
  2) Multiplex sessions with same source/destination nodes
  3) Resequence packets at destination
  4) recover from residual errors and failures
  5) Provide end-to-end flow control
Network layer

- The network layer is responsible for routing of packets across the network
  - The network layer module accepts incoming packets from the transport layer and transit packets from the DLC layer
  - It routes each packet to the proper outgoing DLC or (at the destination) to the transport layer
  - Typically, the network layer adds its own header to the packets received from the transport layer. This header provides the information needed for routing (e.g., destination address)

Each node contains one network Layer module plus one Link layer module per link
Link Layer

- Responsible for error-free transmission of packets across a single link
  - Framing
    - Determine the start and end of packets
  - Error detection
    - Determine which packets contain transmission errors
  - Error correction
    - Retransmission schemes (Automatic Repeat Request (ARQ))
Internet Sub-layer

- A sublayer between the transport and network layers is required when various incompatible networks are joined together.

- This sublayer is used at gateways between the different networks.

- It looks like a transport layer to the networks being joined.

- It is responsible for routing and flow control between networks, so it looks like a network layer to the end-to-end transport layer.

- In the internet this function is accomplished using the Internet Protocol (IP).
  - Often IP is also used as the network layer protocol, hence only one protocol is needed.
Internetworking with TCP/IP

FTP client ↔ FTP Protocol ↔ FTP server

TCP ↔ TCP Protocol ↔ TCP

IP ↔ IP Protocol ↔ IP

Ethernet driver ↔ Ethernet Protocol ↔ Ethernet
token driver ↔ token ring Protocol ↔ token ring driver

ROUTER

Ethernet

token ring
Encapsulation

Application

TCP

IP

Ethernet
driver

user data

Appl
header

TCP
header

application
data

TCP segment

IP
header

TCP
header

application
data

IP
datagram

Ethernet
frame

46 to 1500 bytes

Eytan Modiano
Slide 21
Physical Layer

• Responsible for transmission of bits over a link

• Propagation delays
  – Time it takes the signal to travel from the source to the destination
    Signal travel approximately at the speed of light, \( C = 3 \times 10^8 \) meters/second
  – E.g.,
    LEO satellite: \( d = 1000 \) km \( \Rightarrow \) 3.3 ms prop. delay
    GEO satellite: \( d = 40,000 \) km \( \Rightarrow \) 1/8 sec prop. delay
    Ethernet cable: \( d = 1 \) km \( \Rightarrow \) 3 \( \mu \)s prop. delay

• Transmission errors
  – Signals experience power loss due to attenuation
  – Transmission is impaired by noise
  – Simple channel model: Binary Symmetric Channel
    \( P = \text{bit error probability} \)
    Independent from bit to bit
  – In reality channel errors are often bursty
• In the traditional view of communication system the input was an analog information source (typically voice)
• In order to digitally transmit analog information one needs to convert this analog waveform into a digital waveform
  – Sampling, Quantization, Source coding
• In modern computer networks the information source is often digital to begin with
  – Analog to digital conversion is not viewed as a part of the communication system, but as a higher layer function (application)
Transmission of Information

• Information source
  – Continuous - e.g., Voice, video
  – Discrete - e.g., text, computer data

• Signal
  – Analog (continuous valued)
  – Digital (discrete valued)

• Why digital transmission?
  – Can remove unwanted “noise” to reproduce digital signal
  – Can eliminate redundancy

• Digital transmission of continuous data
  – Sample
  – Quantize
  – Encode
Elements of a digital communication system

- **Source coding**
  - Used to compress the data
    - Lossy, lossless

- **Channel coding**
  - Used to overcome unwanted channel noise
  - Introduce “redundancy” to protect against errors

- **Modulation**
  - Represent bits using continuous valued signals suited for transmission
    - Impose discrete valued signals on an analog waveform
    - Typically use sine or cosine wave
Transmission channels

- **Electro-magnetic transmission**
  - Guided medium: twisted pair, coaxial cable
  - Unguided medium (air): radio transmission, satellite

- **Optical Transmission**
  - Media: optical fiber, free space (satellite)

- **Storage**
  - Magnetic (tape, disk)
  - Optical (CD)
Frequency spectrum

- Transmission over the airwaves uses different frequency bands
- Useful frequency bands are not limitless
- Spectrum is a natural resource that must be used efficiently
- Spectrum is allocated to operators by the Government
  - Federal Communications Commission (FCC)