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# **16.36: Communication Systems Engineering**

## **Lecture 1: Introduction**

**February 5, 2002**

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# Administrative matters

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- **Instructors: Eytan Modiano**
- **Meeting times: Tuesdays and Thursdays, 11:00 - 12: 30, RM: 33-319**
- **Office Hours:**
  - **M: 11:00-12:00, Th: 10:00-11:00, or by appointment**
- **Text: Communications Systems Engineering, Proakis and Salehi**
- **Grading**
  - **10% weekly Homework Assignments**
  - **30% each of 3 exams**
  - **Final exam during final exam period!**
- **Course web page: <http://web.mit.edu/modiano/www/teaching.htm>**

# Timeline of modern communication

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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

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- **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, 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?

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- **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**
- **Information technology is a critical engineering discipline**
  - These skills are as fundamental today as the knowledge of basic math or physics

# Communication Applications

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- **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

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- **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

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- **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

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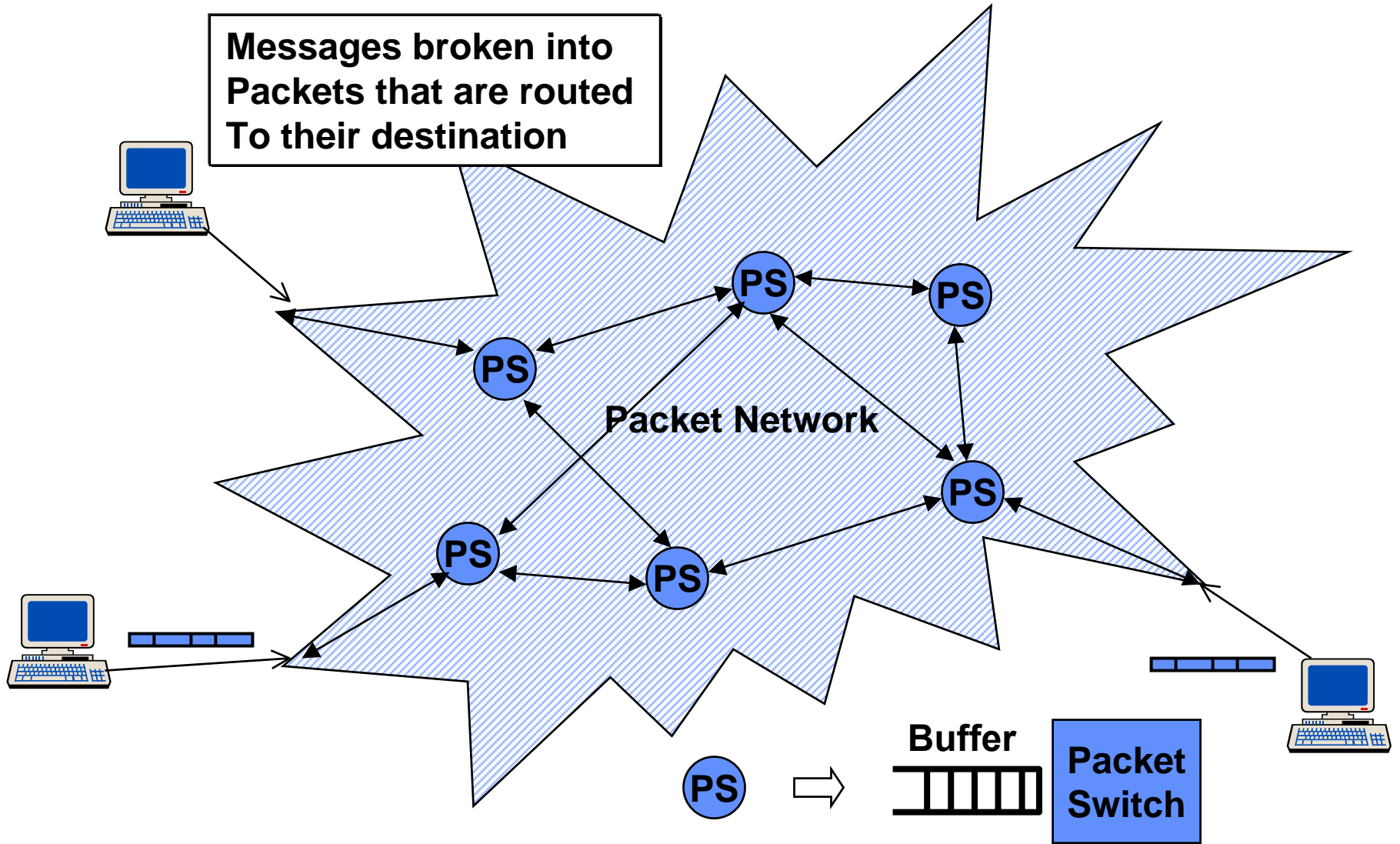
- **Circuit Switching**
  - Dedicated resources
  - Traditional telephone networks
- **Packet Switching**
  - Shared resources
  - Modern data networks

# Circuit Switching

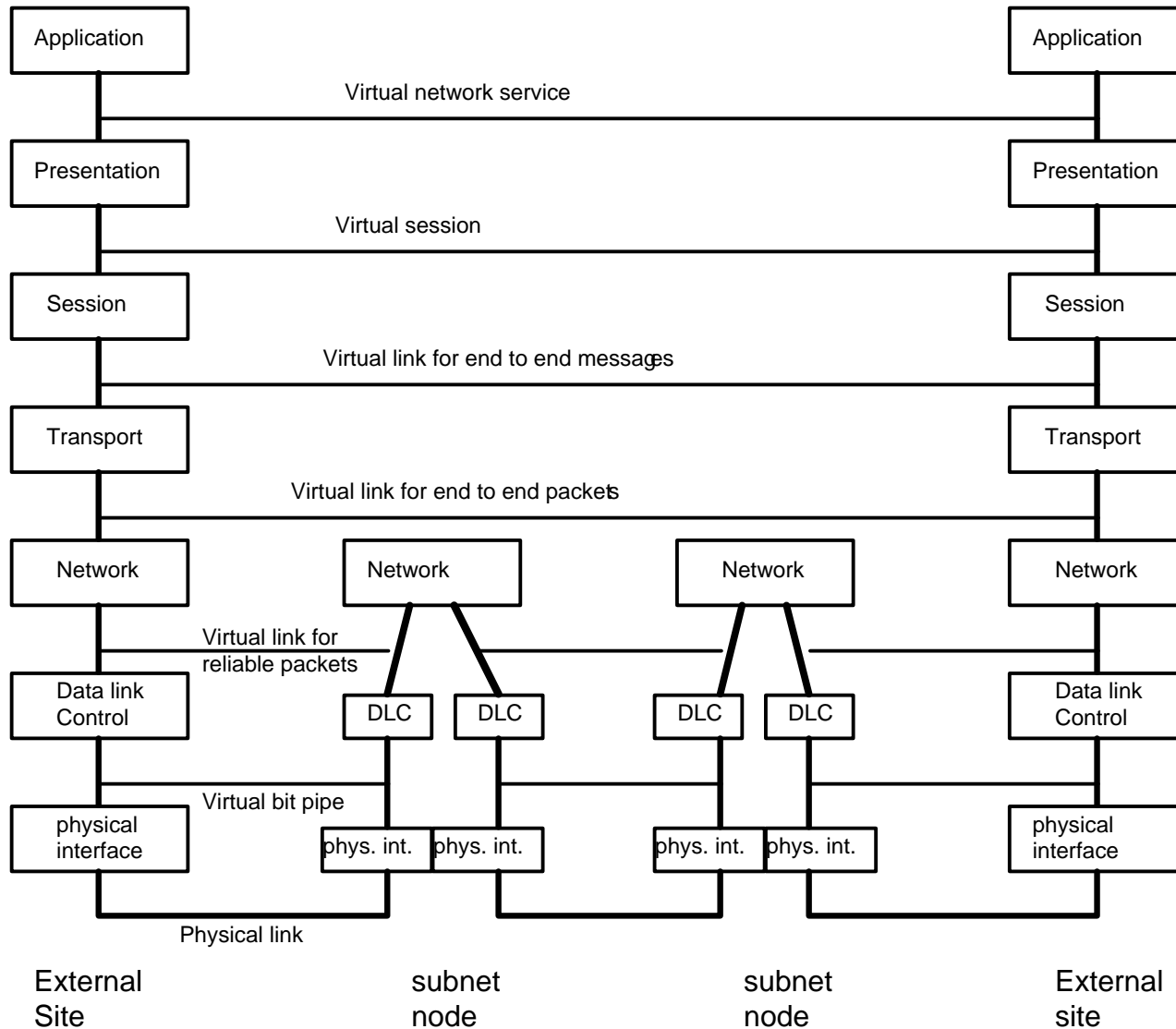
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- **Each session is allocated a fixed fraction of the capacity on each link along its path**
  - **Dedicated resources**
  - **Fixed path**
  - **If capacity is used, calls are blocked**  
E.g., telephone network
- **Advantages of circuit switching**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



# 7 Layer OSI Reference Model



# Layers

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- **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

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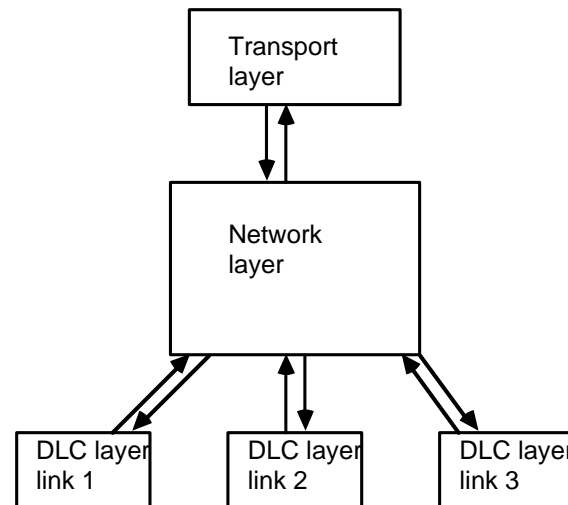
- **The transport layer is responsible for reliable end-to-end transmission of messages across the network**
  - **The network layer provides a virtual end to end packet pipe to the transport layer.**
  - **The transport layer provides a virtual end to end message service to the higher layers.**
- **The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

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- **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

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- **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))

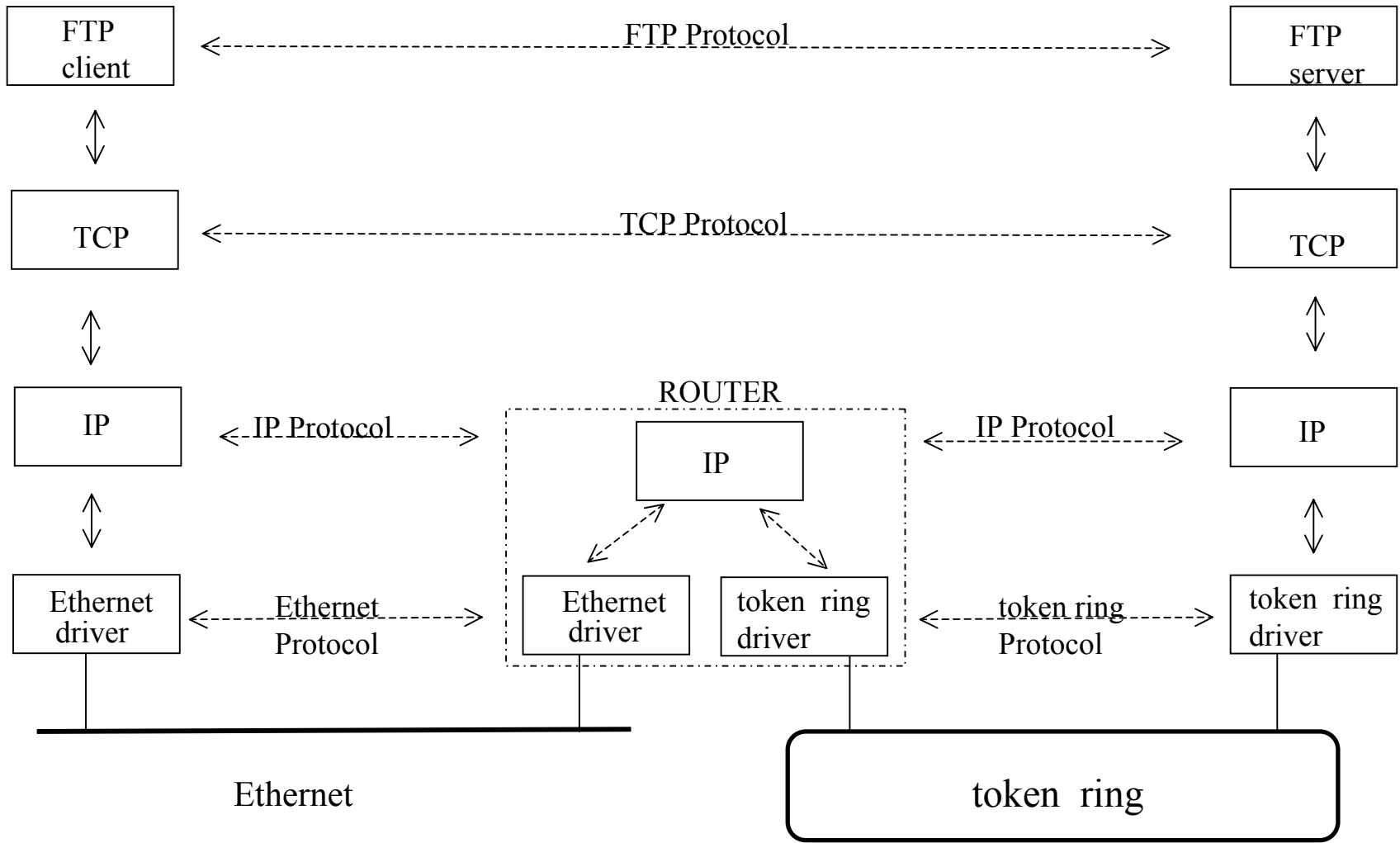


# Internet Sub-layer

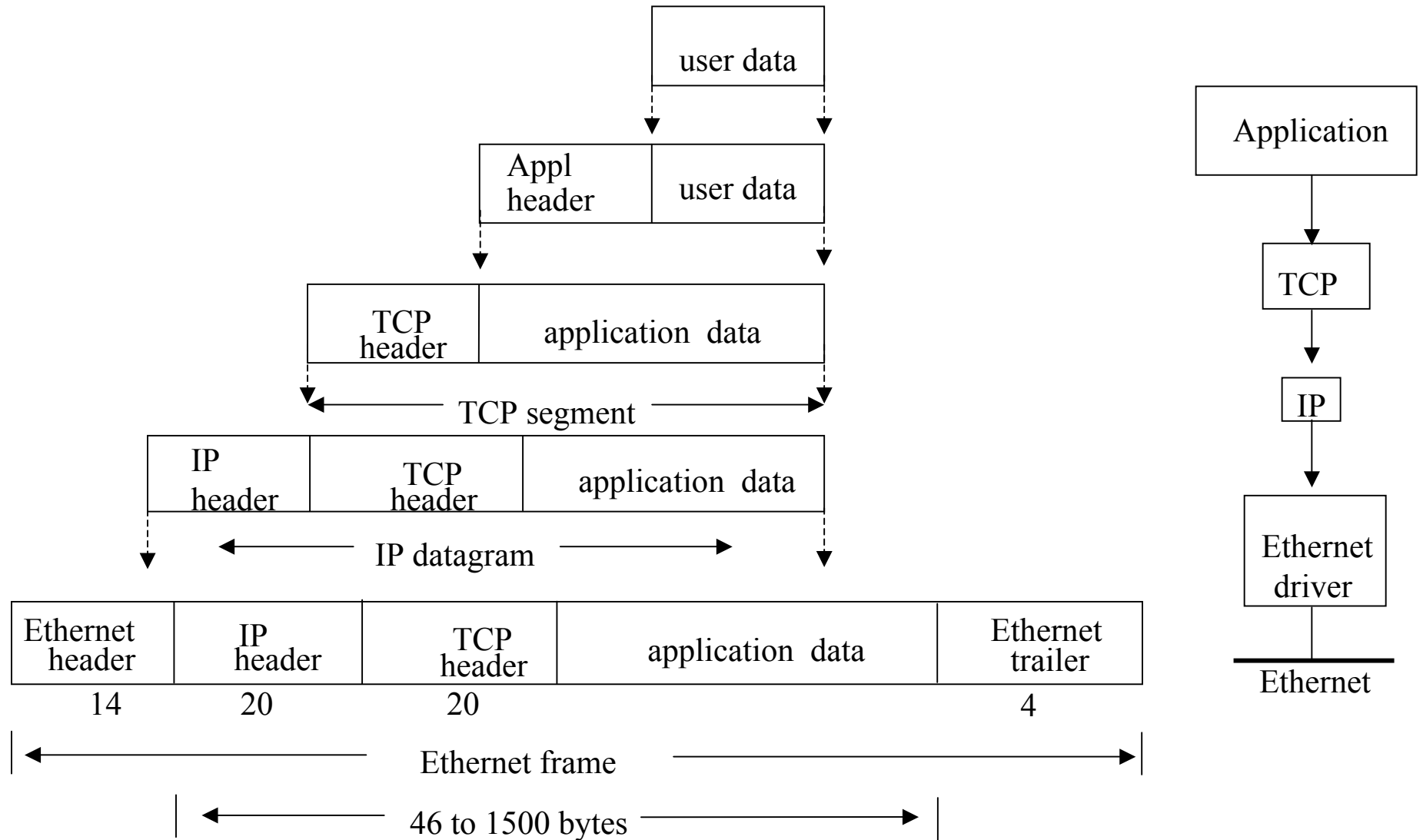
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- **A sublayer between the transport and network layers is required when various incompatible networks are joined together**
- **This sublayer is used at gateways between the different networks**
- **It looks like a transport layer to the networks being joined**
- **It is responsible for routing and flow control between networks, so 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



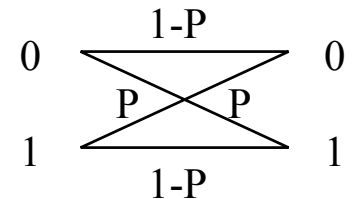
# Encapsulation



# Physical Layer

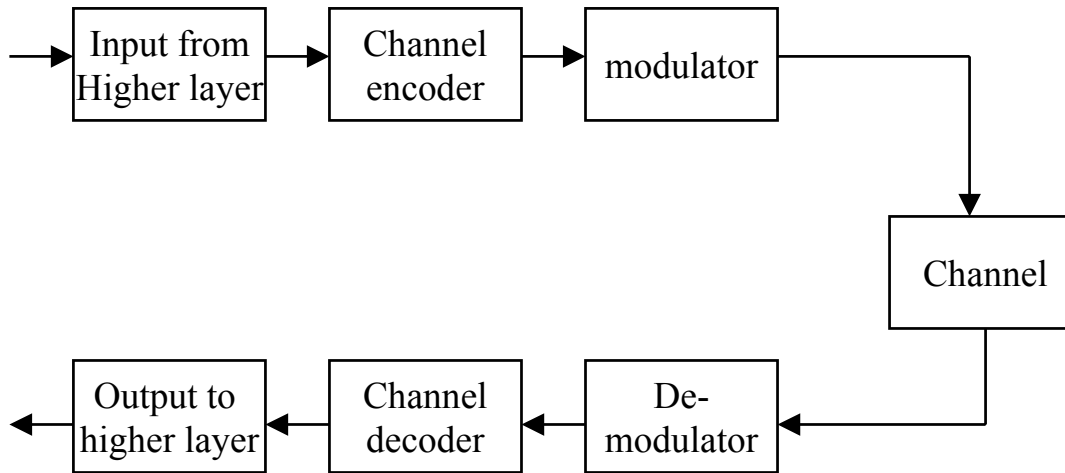
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- **Responsible for transmission of bits over a link**
- **Propagation delays**
  - Time it takes the signal to travel from the source to the destination  
Signal travel approximately at the speed of light,  $C = 3 \times 10^8$  meters/second
  - E.g.,
    - 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**
    - $P$  = bit error probability
    - Independent from bit to bit
  - In reality channel errors are often bursty



# Basic elements of the physical layer

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- 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

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- **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

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- **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

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- **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)**

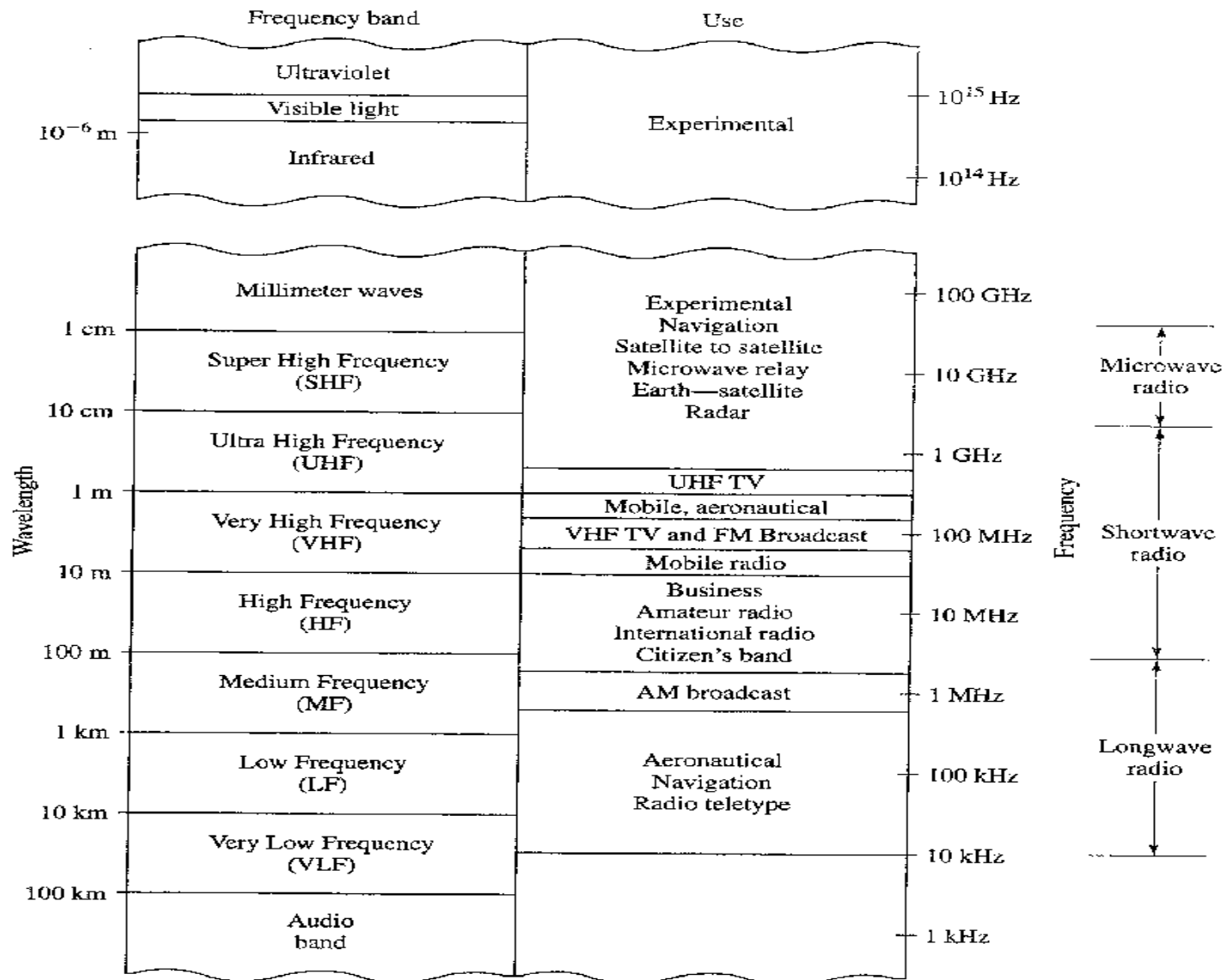


# Frequency spectrum

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- **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)**

# Frequency spectrum



**Figure 1.4** Frequency range for wireless electromagnetic channels. (Adapted from Carlson, Sec. Ed.; © 1975 McGraw-Hill. Reprinted with permission of the publisher.)