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

Date	Lecture	Topic	Reading
4-Feb	L1	Introduction	Chapter 1
6-Feb	L2	Measure of Information	Section 6.1
11-Feb	L3	Sampling Theorem	Sec. 2.2, 2.4
13-Feb	L4	Quantization	Sec. 6.5
18-Feb		**MONDAY SCHEDULE**	
20-Feb	L5	Source coding	Sec. 6.2-6.3
25-Feb	L6	Modulation	Sec. 7.1 - 7.3
27-Feb	L7	Modulation	
4-Mar	L8	Signal reception in noise	Sec. 7.5
6-Mar	L9	Signal reception in noise	Sec. 7.5
11-Mar	**L10**	**Quiz 1**	
13-Mar	L11	BER analysis	Sec. 7.6
18-Mar	L12	Channel Capacity and coding	Chapter 9
20-Mar	L13	Channel Coding	Sec. 9.5 - 9.6
25-Mar		**Spring Break**	
27-Mar		**Spring Break**	
1-Apr	L14	Link budget analysis	Sec. 7.7
3-Apr	L15	Spectra of digitally modulated signals	Sec. 8.1 - 8.3

Course Syllabus

Date	Lecture	Topic	Reading
8-Apr	L16	Packet communications, DLC, error checking using CRC	Tanenbaum 3
10-Apr	L17	ARQ techniques	Tanenbaum 3.4, 3
15-Apr	L18	Multiple access: TDMA, FDMA, CDMA	Class Notes
17-Apr	**L19**	**Quiz 2**	
22-Apr		**Patriots Day**	
24-Apr	L20	Intro to queueing	Class Notes
29-Apr	L21	Intro to queueing	Class Notes
1-May	L22	Packet multiple access: Aloha/CSMA	Tanenbaum 4
6-May	L23	Local area networks	Tanenbaum 4
8-May	L24	Packet routing	Tanenbaum 5
13-May	L25	Packet routing	Tanenbaum 5
15-May	L26	TCP/IP and the Internet	Tanenbaum 6: 6.4
5/19 - 5/23		**FINAL EXAM PERIOD**	

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

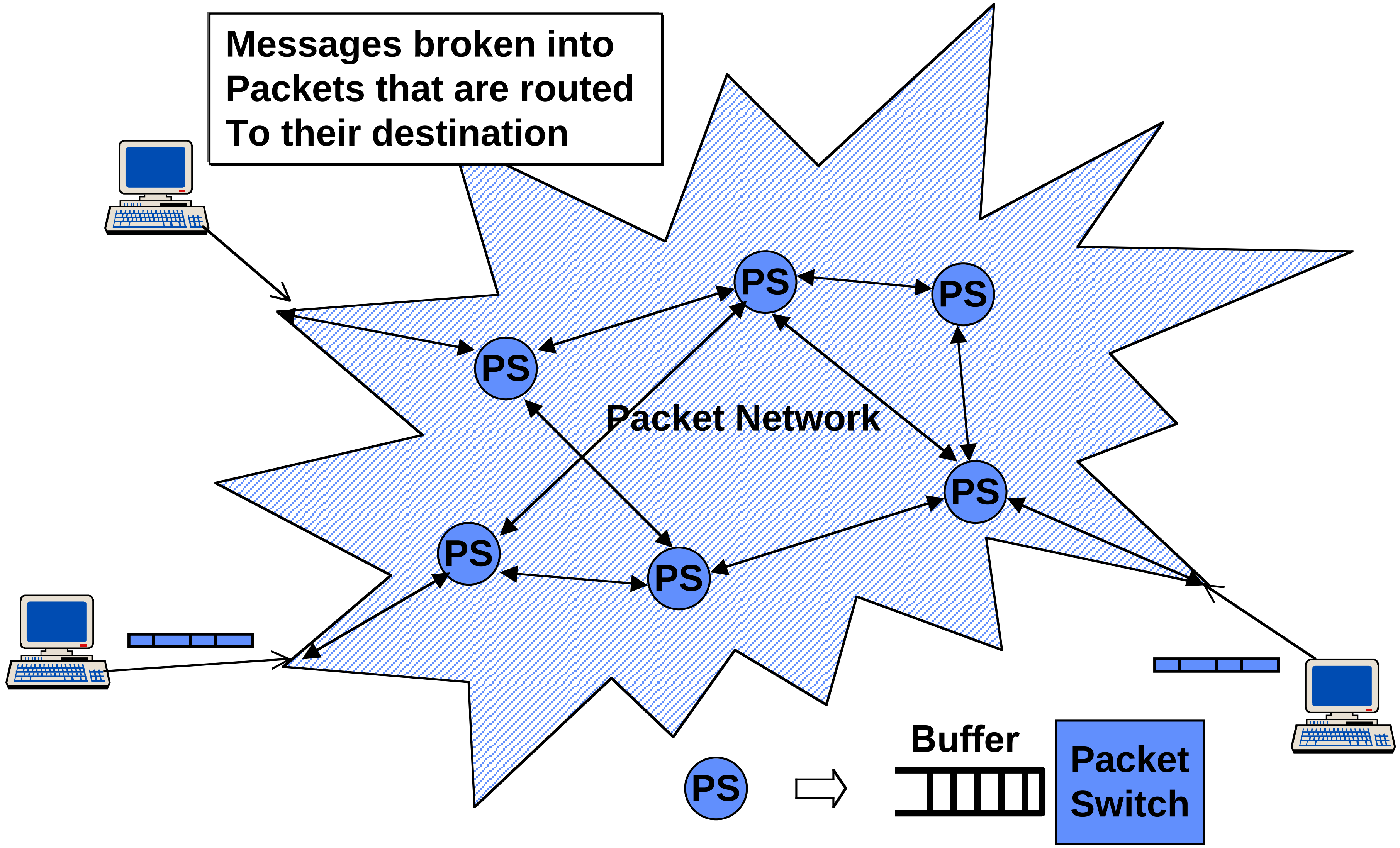
- **Circuit Switching**
  - Dedicated resources
  - Traditional telephone networks

- **Packet Switching**
  - Shared resources
  - Modern data networks

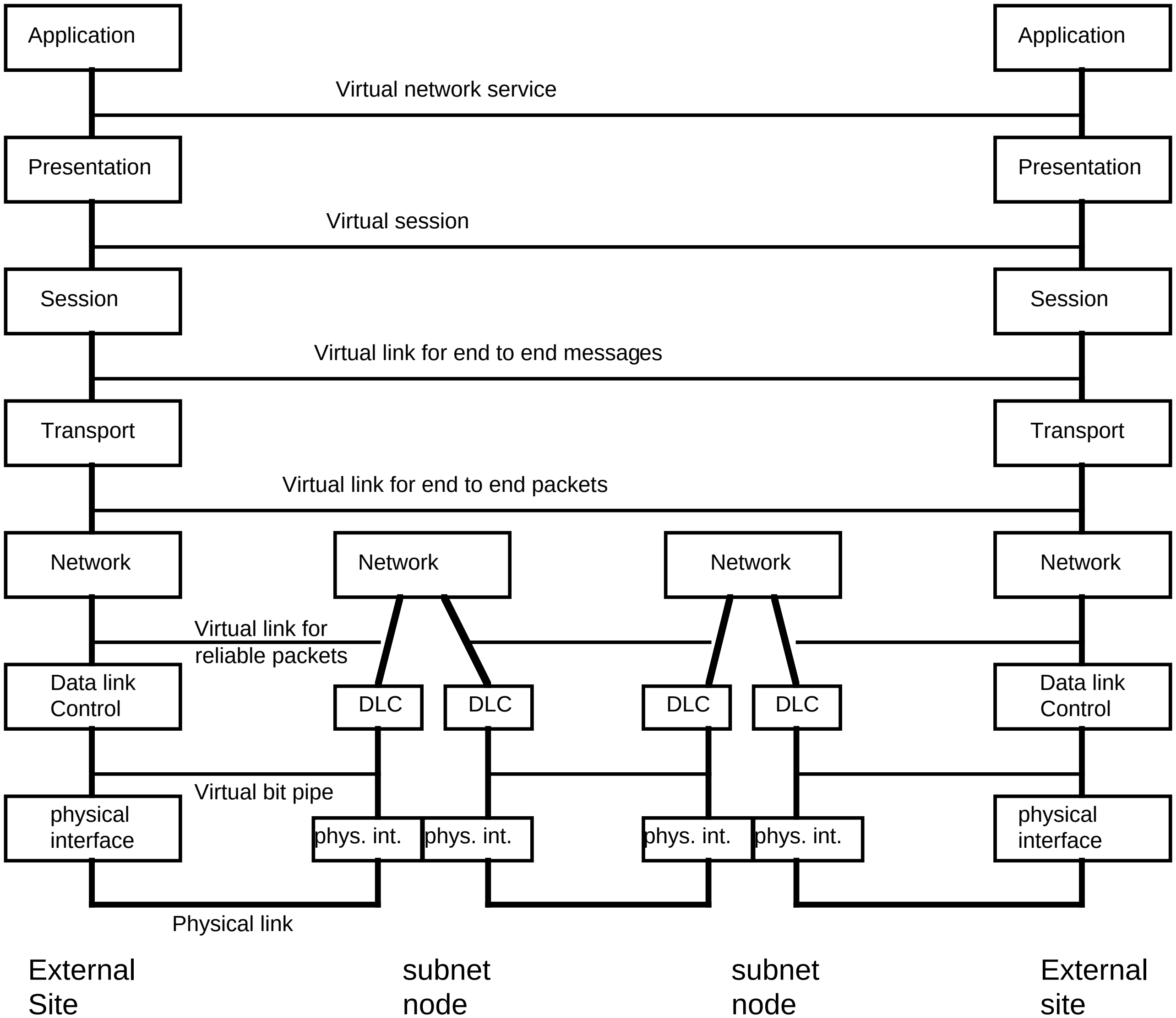
Circuit Switching

- 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



7 Layer OSI Reference Model



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

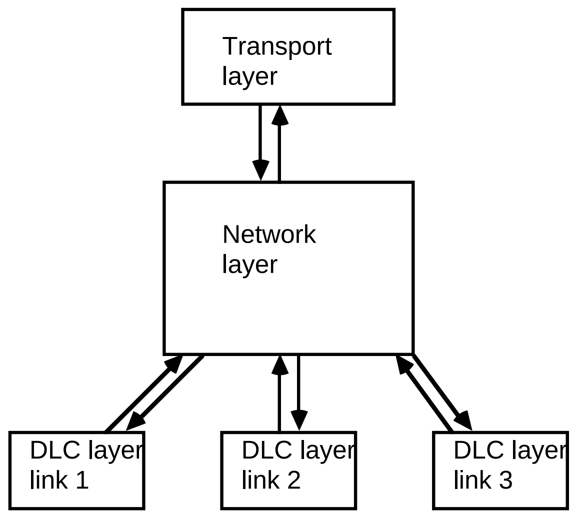
  4) recover from residual errors and failures

  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 <u>single link</u>**
  - **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

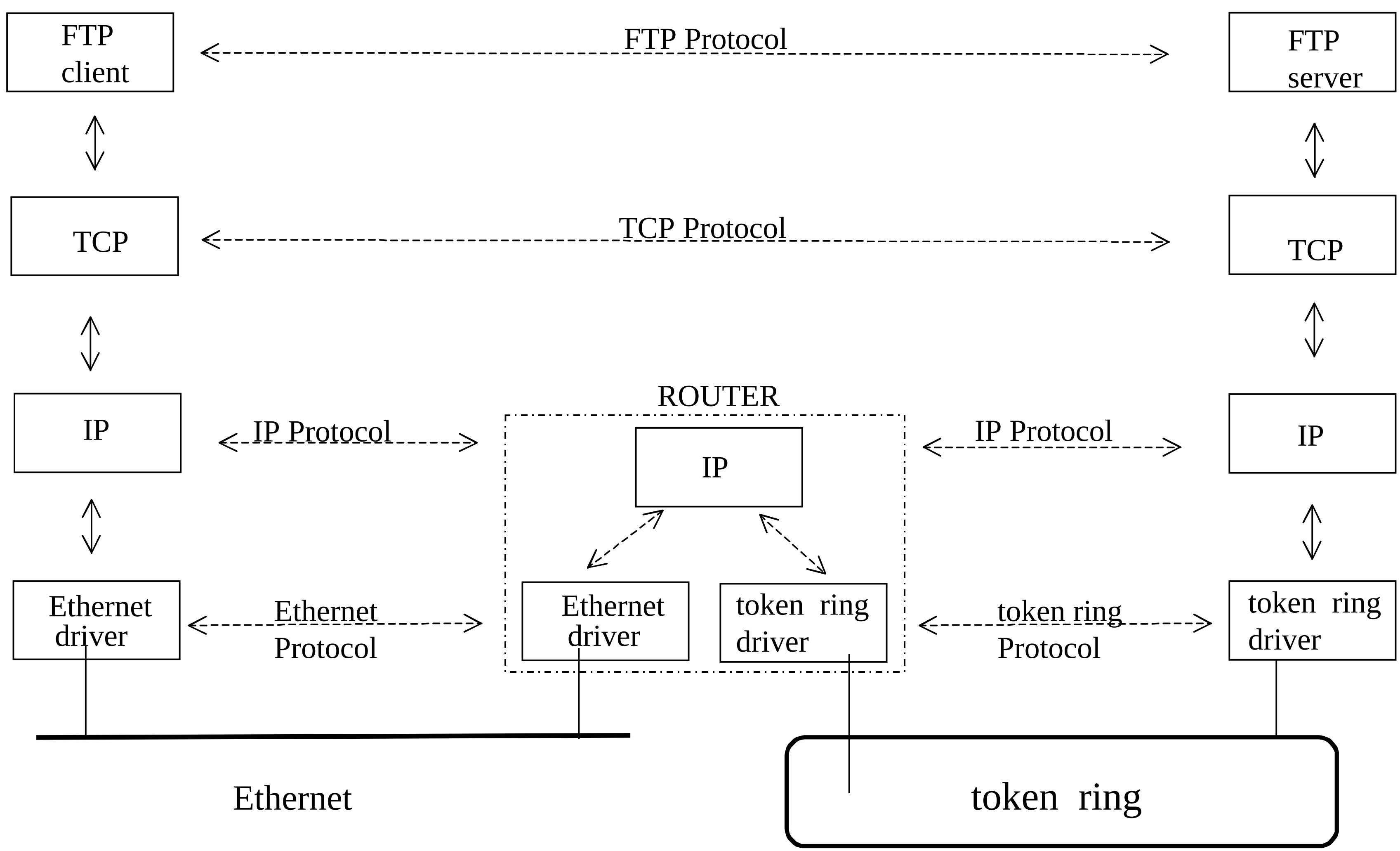
- This sublayer is used at gateways between the different networks

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

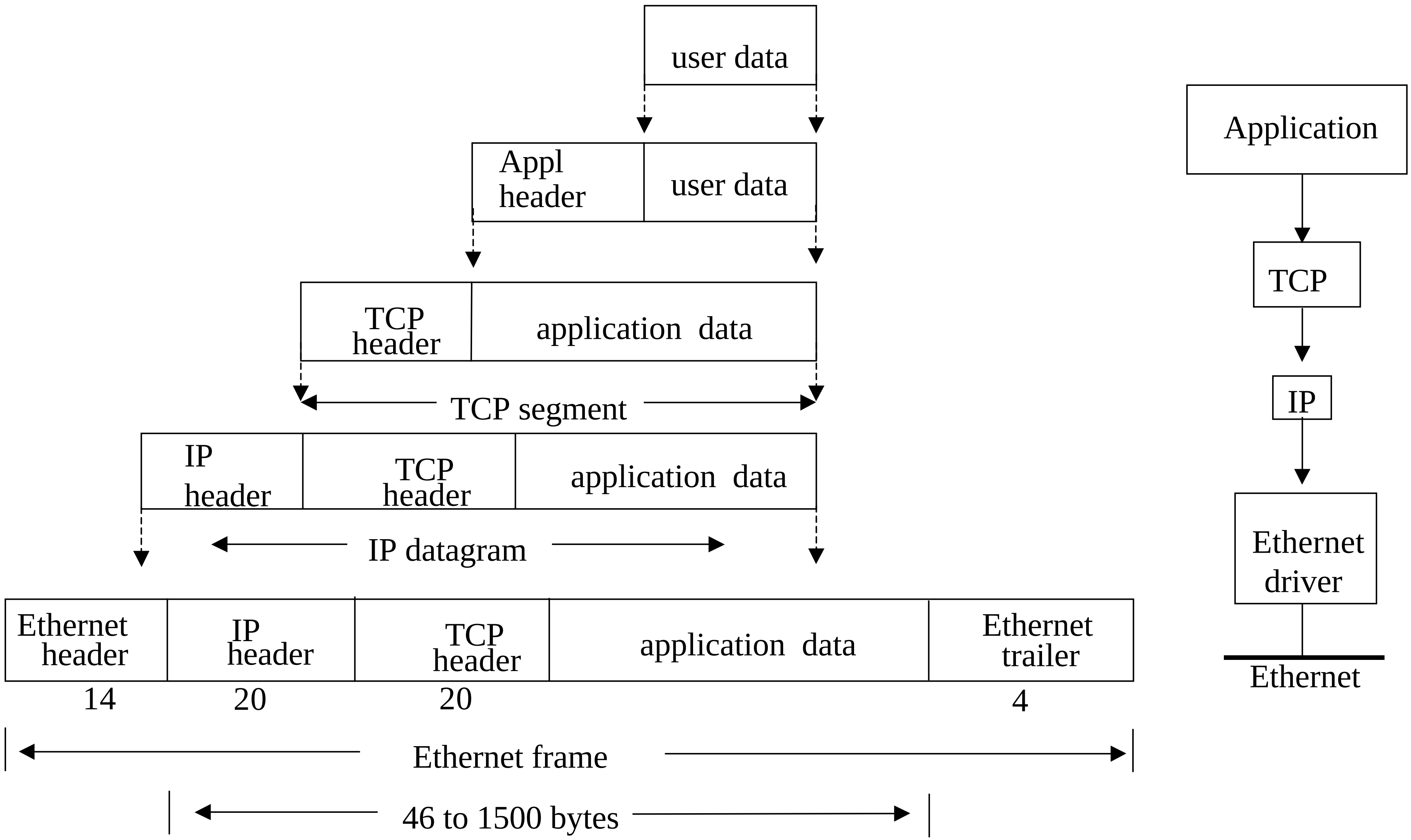
- It is responsible for routing and flow control between networks, so looks like a network layer to the end-to-end transport layer

- 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

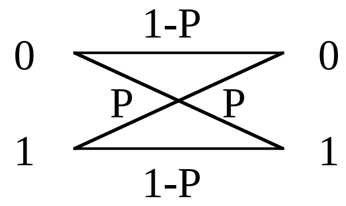


Encapsulation

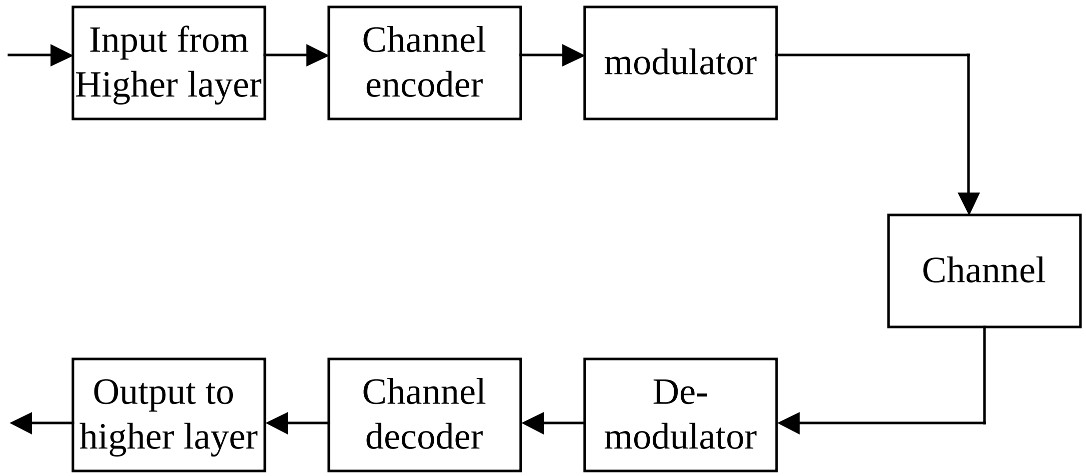


Physical Layer

- 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, $C = 3x10^8$ meters/second
  - E.g.,
    - LEO satellite: d = 1000 km => 3.3 ms prop. delay
    - GEO satellite: d = 40,000 km => 1/8 sec prop. delay
    - Ethernet cable: d = 1 km => 3 μs 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



- **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)**