Data Networks

Lecture 1: Introduction

September 4, 2008

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Learning Objectives

- **Fundamental aspects of network Design and Analysis:**
  - **Architecture: layering, topology design, switching mechanisms**
  - **Protocols: link, multiple access, routing, end-to-end transport**
  - **Algorithms: error recovery, scheduling, routing, flow control**
  - **Analysis tools: probabilistic modeling, queueing theory**
- **Current practice:**
  - **Network technologies: optical networks, wireless networks, LANs, switches, etc.**
  - **Protocol standards: TCP, IP, ATM, Ethernet, 802.11, etc.**

Course Information

- **Lecturer: Professor Eytan Modiano (modiano@mit.edu)**
  - Office hours: M :11-12 ; and by appointment (33 -412a)
- **TA: none**
- **Course web page:** http://web.mit.edu/modiano/www/teaching.htm
- **Requirements & Grading**
  - About one problem set per week (10% of grade)
  - Project (10% of grade)
  - Midterm exam (40%)
  - Final Exam during finals week (40%)
- **Prerequisite Policy**: 6.041, or an equivalent class in probability
- **Textbook:** Bertsekas & Gallager, Data Networks (2nd Edition)
- **Additional Reference books:**
  - Computer Networks, by Peterson and Davie
    Most current on the internet and its protocols
  - Network Optimization: Continuous and Discrete Models, by Dimitri Bertsekas
    Network algorithms and routing, network flows, optimization theory

Tentative syllabus

Lec#	Day	Date	Topic
L1	Th	9/4	Introduction, OSI 7-layer architecture
L2	T	9/9	Data Link Layer: Framing, error detection
L3	Th	9/12	Point-to-Point Retransmission Algorithms
L4	T	9/16	End-to-End Retransmission & TCP
L5	Th	9/18	Queueing Models - Introduction & Little's theorem
L6	T	9/23	M/M/1, M/M/m, queues etc.
L7	Th	9/25	Networks of queues
L8	T	9/30	M/G/1 queues, M/G/1 w/ vacations
L9	Th	10/2	Reservations, priority, queue stability
L10	T	10/7	M/G/1 queue occupancy distribution
L11	Th	10/9	Traffic Modeling – LRD & Self-similar traffic
L12	T	10/14	Multiple access & Aloha
L13	Th	10/16	Quiz

L14	T	10/21	Stabilized Aloha, Tree Algorithms
L15	Th	10/23	CSMA, CSMA/CD and Ethernet
L16	T	10/28	Wireless LANs
L17	Th	10/30	Introduction to switch architecture
L18	T	11/4	High Speed Switch Scheduling
L19	Th	11/6	Scheduling in wireless networks
	T	11/11	No Class – Veteran's Day
L20	Th	11/13	Routing algorithms: Broadcast and Shortest path
L21	T	11/18	Distributed routing algorithms, diffusion routing
L22	Th	11/20	Optimal routing
L23	T	11/25	IP, BGP, internet routing
	Th	11/27	No class – Thanksgiving holiday
L24	T	12/2	Flow Control - Window/Credit Schemes
L25	Th	12/4	Flow Control - Rate Based Schemes, optimal FC
L26	T	12/9	Transport layer: UDP & TCP, ATM

Final Exam during final exam week. Date and time to be announced.

Network Applications

- *Old days:* mainly resource sharing
  - Mainframe computer

    Today: computers are cheap!

  - DB access and updates: e.g., Financial, Airline reservations, etc.

    Today: much the same

- *Today:* Internet Services
  - Email, FTP, Telnet, Web access
  - Video and audio streaming
  - Client/server applications

Common Applications and their Requirements

- *"Non-Interactive" Data Transfers:* **Web download/upload, ftp of text files, images, audio, video, file sharing, email**
  - **Requirements: reliable (no data loss), "reasonable" response times**
  - **Bursty traffic ⇒ dynamic allocation of bandwidth**

- *Interactive data applications:* **remote terminal access (telnet), instant messaging, gaming, etc.**
  - **Requirements: reliable, low delays**
  - **Bursty, low-bandwidth applications**

- *Video/Audio streaming:* **internet radio, IPTV**
  - **Requirements: low delays, some variations in delay is ok, minimum BW guarantees**
  - **Typically not very bursty, can tolerate losses, call set-up times**

- *Interactive audio/video:* **internet telephony, video conferencing,, real-time broadcasts**
  - **Requirements: similar to above, but very low delays, minimal delay variations**

Classification of Network services

- Synchronous
  - Session appears as a continuous stream of traffic
  - Usually requires fixed and limited delays
  - E.g., audio and video streaming, interactive audio/video
- Asynchronous
  - Session appears as a sequence of messages
  - Typically bursty
- Asynchronous - *connection oriented services*
  - Long sustained session
  - Orderly and timely delivery of packets
  - E.g., interactive data applications
- Asynchronous - *connectionless services*
  - One time transaction (e.g., email)
  - E.g., Non-interactive data transfers
- Quality-of-service (QoS) requirements
  - Minimum rate guarantees, delay guarantees, loss probability, etc.

Resource Sharing (multiplexing)

- **Network cannot maintain permanent connections between all users**
  - **Cannot have a dedicated connection to everyone you ever want to call**
- **Switches in the network are used to Enable sharing of communications resources**
  - **Users (calls) are allocated resources only when active**
- **Circuit Switching**
  - **Each *active* call receives "dedicated resources"**
- **Packet Switching**
  - **Shared resources among different *active* calls**
  - **Packet switching mechanisms**

    Virtual Circuits packet switching

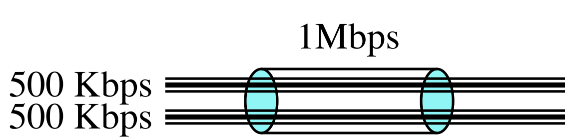
    Datagram packet switching

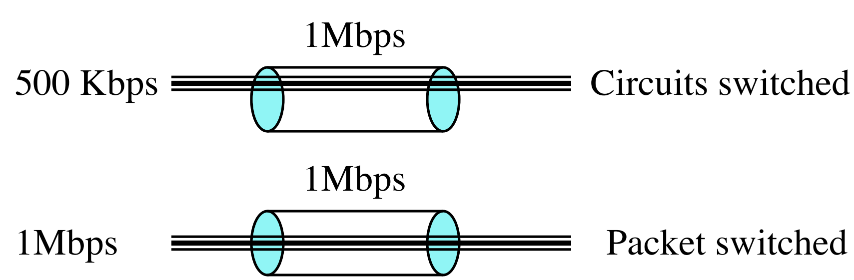
Circuit Switching

- **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**
    - **"inelastic" - cannot easily respond to changes in demand**
      - **E.g., when call departs, cannot easily reallocate its bandwidth to other existing calls**





Problems with circuit switching

- Many data sessions are low duty factor (bursty),

$$\rho = \lambda x = \text{(message arrival rate) * (message transmission time)} << 1$$

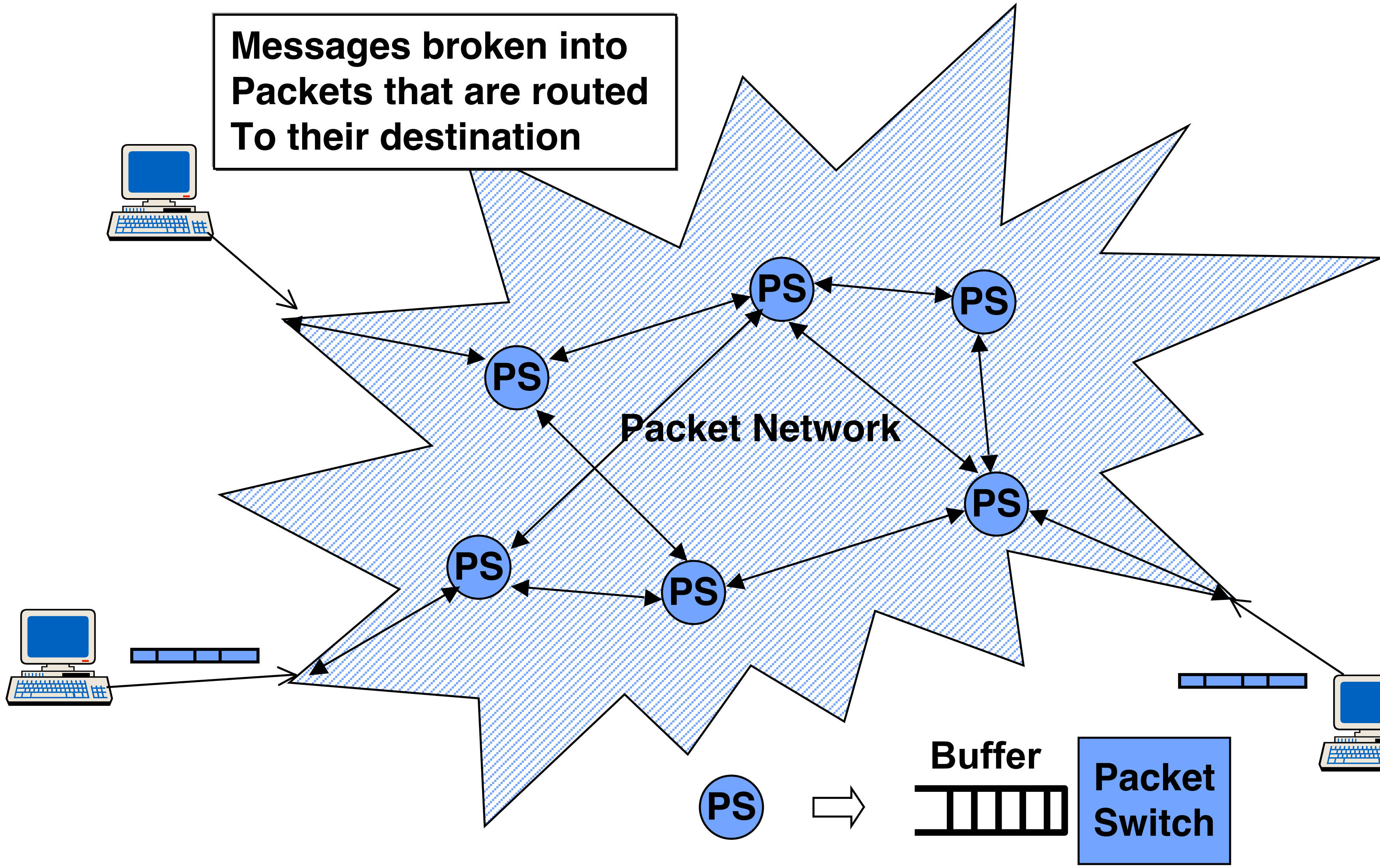
  – Message transmission time must be kept small enough to meet delay requirements

- Circuit switching also requires a call set-up
  – Resources not utilized during call set-up time
  – If messages are short, then highly inefficient
    More of a problem in high-speed networks
- Example
  – Message length: L = 8000 bits
  – Arrival rate: λ = 1 message per second
  – Delay requirement: X < 0.1 seconds

    $\Rightarrow$ R > 8000/0.1 = 80,000 bps
    $\Rightarrow$ Utilization = 8000/80000 = 10%

- With packet switching channel can be shared among many sessions to achieve higher utilization

Packet Switched Networks



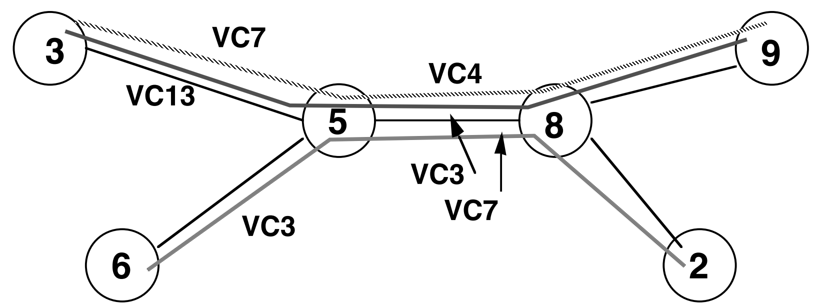
Packet Switching

- **Datagram packet switching**
  - Route chosen on packet-by-packet basis
  - Different packets may follow different routes
  - Packets may arrive out of order at the destination
  - E.g., IP (The Internet Protocol)

- **Virtual Circuit packet switching**
  - All packets associated with a session follow the same path
  - Route is chosen at start of session
  - Packets are labeled with a VC# designating the route
  - The VC number must be unique on a given link but can change from link to link
    - Imagine having to set up connections between 1000 nodes in a mesh
    - Unique VC numbers imply 1 Million VC numbers that must be represented and stored at each node
  - E.g., ATM (Asynchronous transfer mode)

Virtual Circuits Packet Switching

- **For datagrams, addressing information must uniquely distinguish each network node and session**
  - Need unique source and destination addresses
- **For virtual circuits, only the virtual circuits on a link need be distinguished by addressing**
  - Global address needed to set-up virtual circuit
  - Once established, local virtual circuit numbers can then be used to represent the virtual circuits on a given link: VC number changes from link to link



- **Merits of virtual circuits**
  - Save on route computation

    Need only be done once at start of session
  - Save on header size
  - Facilitate QoS provisioning
  - More complex
  - Less flexible

Node 5 table

(3,5) VC13 -> (5,8) VC3
(3,5) VC7 -> (5,8) VC4
(6,5) VC3 -> (5,8) VC7

Circuit vs Packet Switching

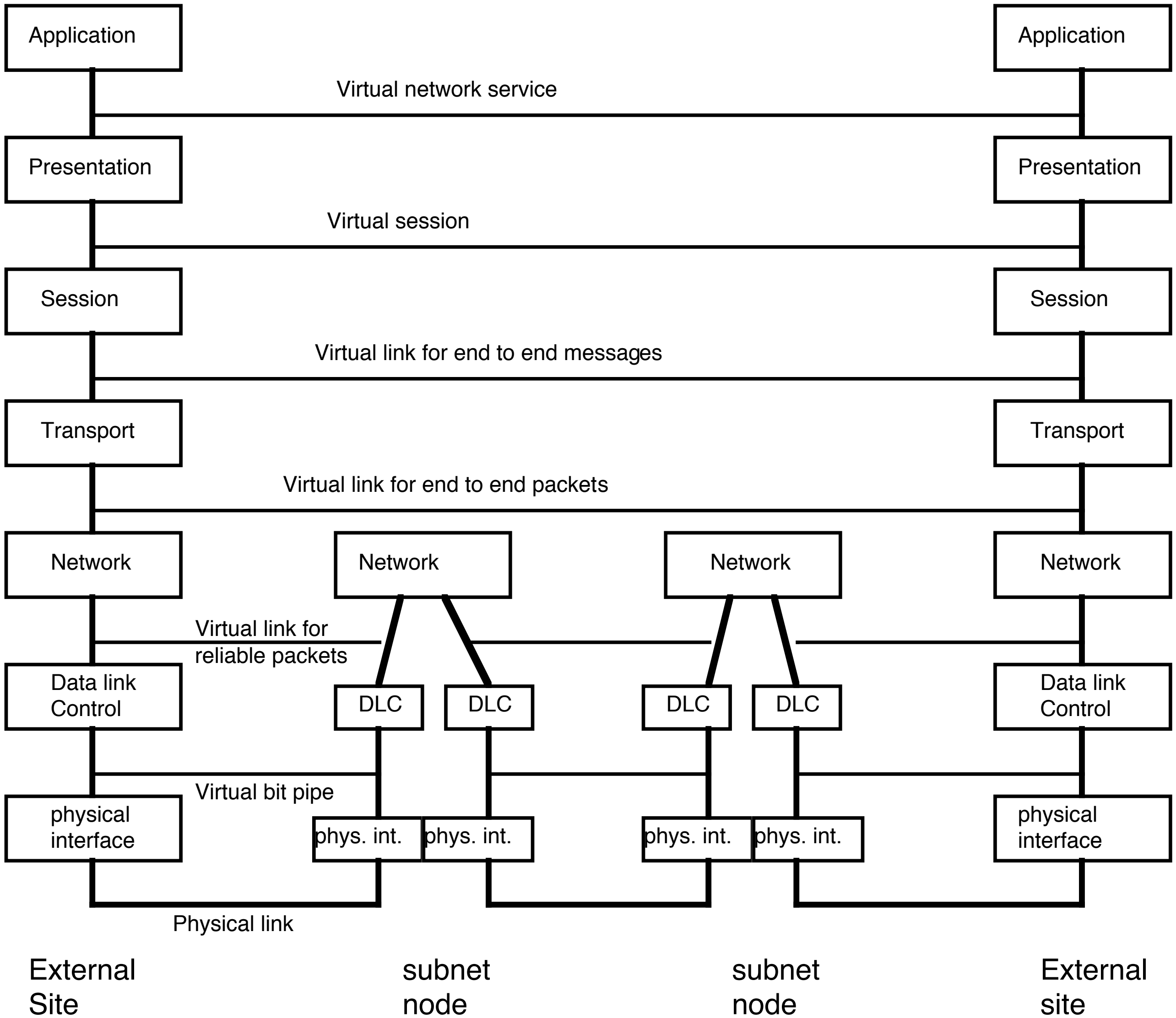
- Advantages of packet switching
  - Efficient for bursty data
  - Easy to provide bandwidth on demand with variable rates
- Disadvantages of packet switching
  - Variable delays
  - Difficult to provide QoS assurances (Best-effort service)
  - Packets can arrive out-of-order

Switching Technique		Network service
Circuit switching	=>	Synchronous (e.g., voice)
Packet switching	=>	Asynchronous (e.g., Data)
Virtual circuits	=>	Connection oriented
Datagram	=>	Connectionless

Circuit vs Packet Switching

- Can circuit switched network be used to support data traffic?
- Can packet switched network be used for connection oriented traffic (e.g., voice)?
- Need for Quality of service (QoS) mechanisms in packet networks
  - Guaranteed bandwidth
  - Guaranteed delays
  - Guaranteed delay variations
  - Packet loss rate
  - Etc...

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 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

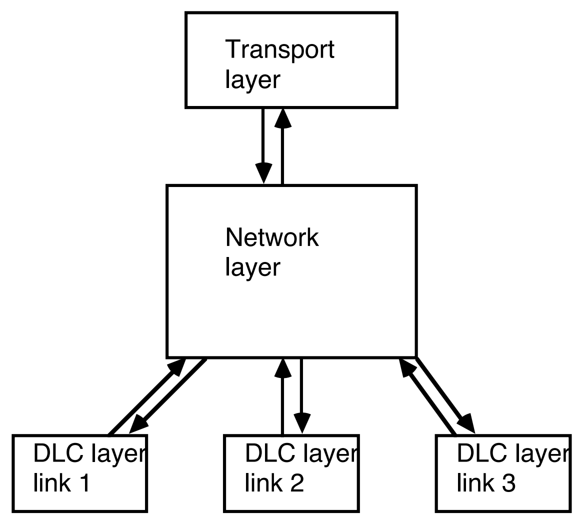
  4) recover from residual errors and failures

  5) Provide end-to-end flow control

Network layer

- The network layer 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**

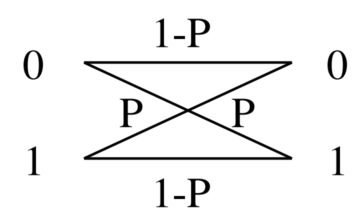
    Determine which packets contain transmission errors

  – **Error correction**

    Retransmission schemes (Automatic Repeat Request (ARQ))

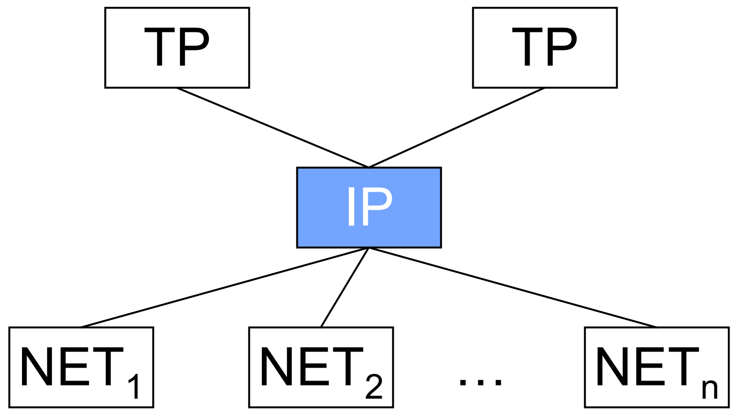
Physical Layer

- 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, $C = 3\times10^8$ 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



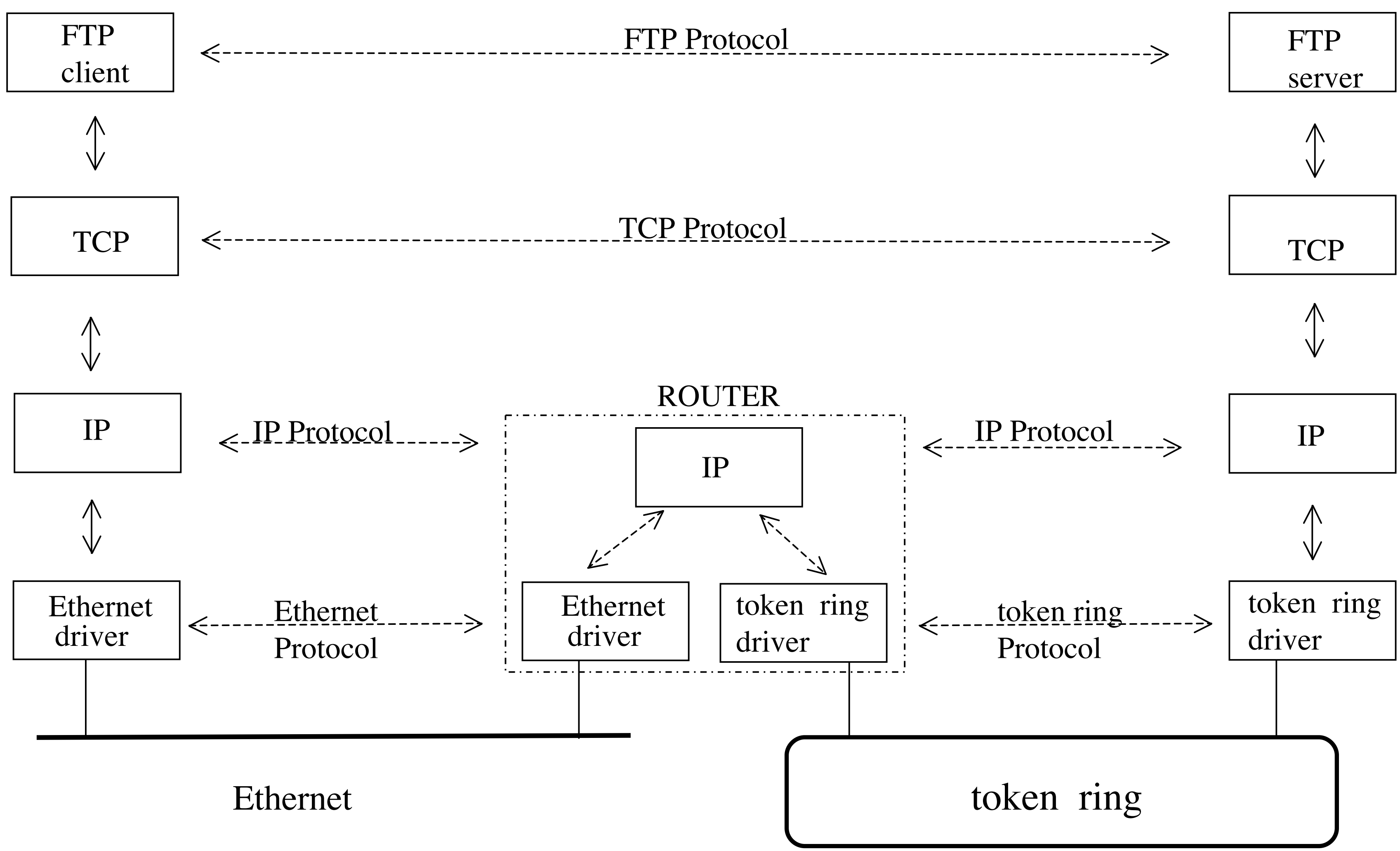
Internet Sub-layer

- **A sub-layer between the transport and network layers is required when various incompatible networks are joined together**
  - **This sub-layer is used at gateways between the different networks**
  - **In the internet this function is accomplished using the Internet Protocol (IP)**



IP enables interoperability

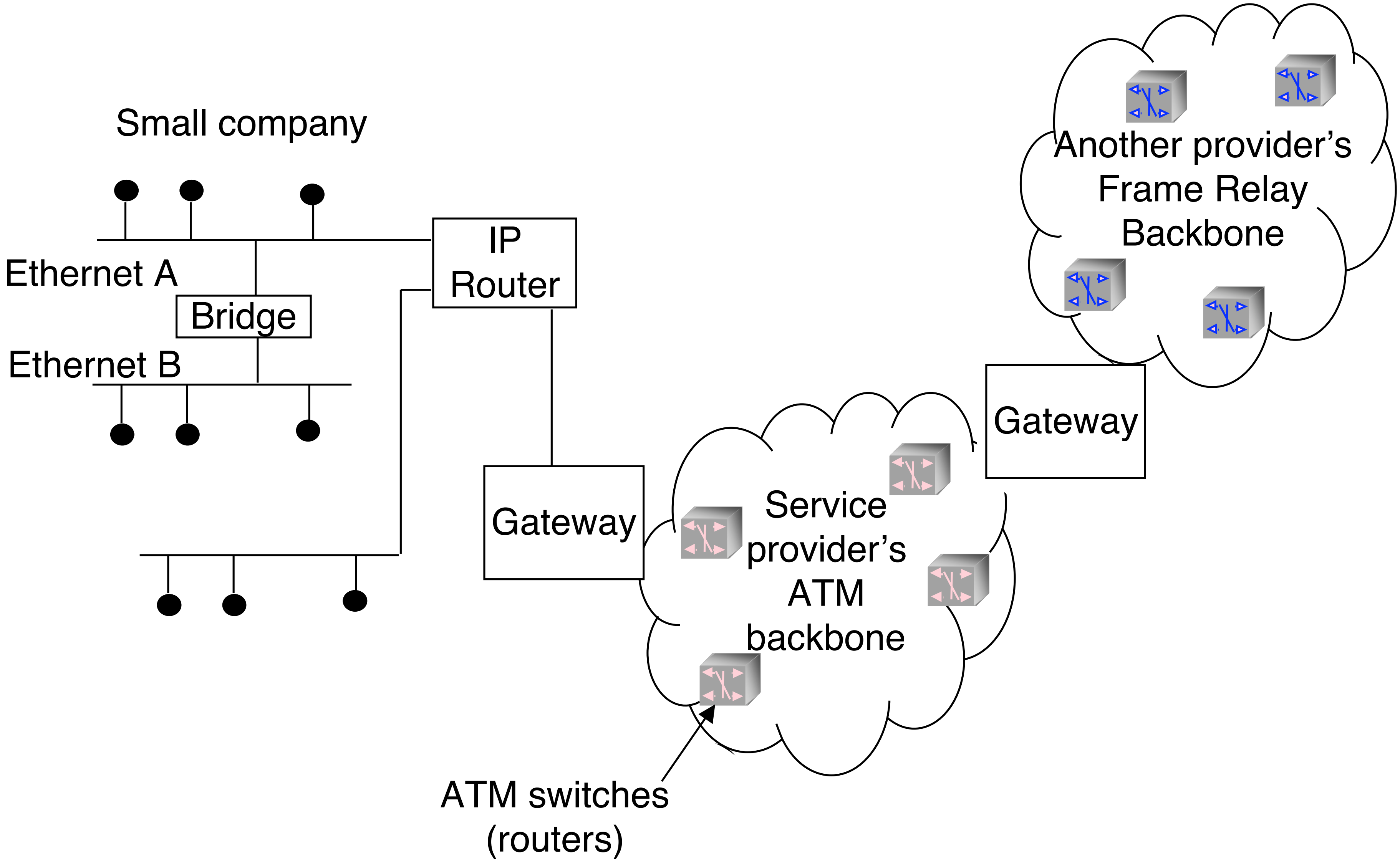
Internetworking with TCP/IP



Bridges, Routers and Gateways

- A Bridge is used to connect multiple LAN segments
  - Layer 2 routing (Ethernet)
  - Does not know IP address
  - Varying levels of sophistication
    - Simple bridges just forward packets
    - smart bridges start looking like routers
- A Router is used to route connect between different networks using network layer address
  - Within or between Autonomous Systems
  - Using same protocol (e.g., IP, ATM)
- A Gateway connects between networks using different protocols
  - Protocol conversion
  - Address resolution
- These definitions are often mixed and seem to evolve!

Bridges, routers and gateways



Encapsulation