Data Networks

Lecture 1

Introduction

Eytan Modiano

6.263: Data Networks

- **Fundamental aspects of network Design and Analysis:**
  - **Architecture**
    - **Layering**
    - **Topology design**
  - **Protocols**
    - **Pt.-to-Pt.**
    - **Multiple access**
    - **End-to-end**
  - **Algorithms**
    - **Error recovery**
    - **Routing**
    - **Flow Control**
  - **Analysis tools**
    - **Probabilistic modeling**
    - **Queueing Theory**

Course Information

- **Lecturer: Professor Eytan Modiano**

- **Requirements & Grading**
  - About one problem set per week (10% of grade)
  - Project (5% of grade)
  - Midterm exam (35 %)
  - Final Exam during finals week (50%)

- **Prerequisite Policy**: 6.041, or an equivalent class in probability

- **Textbook:** Bertsekas & Gallager, Data Networks (2nd Edition)

Tentative syllabus

LEC #	TOPICS
1	Introduction, OSI 7-layer architecture
2	Data Link Layers, Framing, error detection
3	Retransmission Algorithms
4	Retransmission Algorithms
5	Queueing Models - Introduction & Little's theorem
6	M/M/1, M/M/m, queues etc.
7	Networks of queues
8	M/G/1 queues, M/G/1 w/ vacations
9	M/G/1 queues and reservations, priority queues
10	Stability of queueing systems
11	M/G/1 queue occupancy distribution
12	**Quiz**

Tentative syllabus, continued

LEC #	TOPICS
13	Multiple access & Aloha
14	Stabilized Aloha, Tree Algorithms
15	CSMA, CSMA/CD and Ethernet
16	High-speed LANs, Token rings, Satellite reservations
17	Introduction to switch architecture
18	High Speed Switch Scheduling
19	Broadcast routing & Spanning trees
20	Shortest path routing
21	Distributed routing algorithms, optimal routing
22	Flow Control - Window/Credit Schemes
23	Flow Control - Rate Based Schemes
24	Transport layer and TCP/IP
25	ATM Networks
26	Special topic: Optical Networks, Wireless networks

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

Network Applications

- Resource sharing
  - Computing
  - Mainframe computer (old days)
    - Today, computers cheaper than comm (except LANS)
    - Printers, peripherals
  - Information
    - DB access and updates
      - E.g., Financial, Airline reservations, etc.

- Services
  - Email, FTP, Telnet, Web access
  - Video conferencing
  - DB access
  - Client/server applications

Network coverage areas

- 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
  - Session appears as a continuous stream of traffic (e.g, voice)
  - Usually requires fixed and limited delays
- Asynchronous
  - 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
- Packet Switching
  - Shared resources
  - Virtual Circuits
  - Datagrams

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

Problems with circuit switching

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

  (message transmission time)/(message interarrival time) << 1

  Same as: (message arrival rate) * (message transmission time) << 1

- The rate allocated to the session must be large enough to meet the delay requirement. This allocated capacity is idle when the session has nothing to send
- If communication is expensive, then circuit switching is uneconomic to meet the delay requirements of bursty traffic

- Also, circuit switching requires a call set-up during which resources are not utilized. If messages are much shorter than the call set-up time then circuit switching is not economical (or even practical)
  - More of a problem in high-speed networks

Circuit Switching Example

L = message lengths

λ = arrival rate of messages

R = channel rate in bits per second

X = message transmission delay = L/R

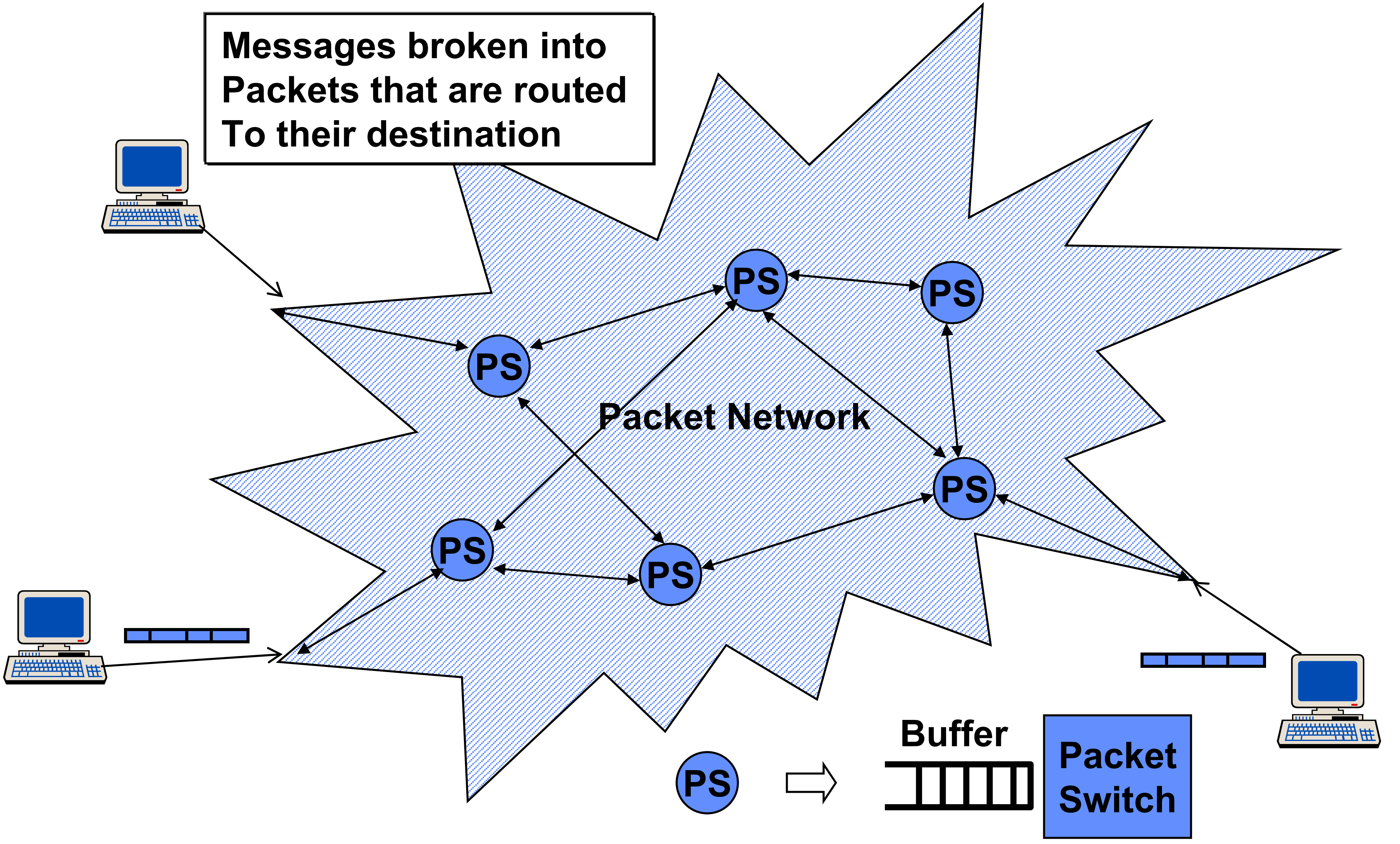
- R must be large enough to keep X small
- Bursty traffic => $\lambda x \ll 1$ => low utilization

- Example
  - L = 1000 bytes (8000 bits)
  - λ = 1 message per second
  - X < 0.1 seconds (delay requirement)
  - => R > 8000/0.1 = 80,000 bps

    Utilization = 8000/80000 = 10%

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

Packet Switched Networks



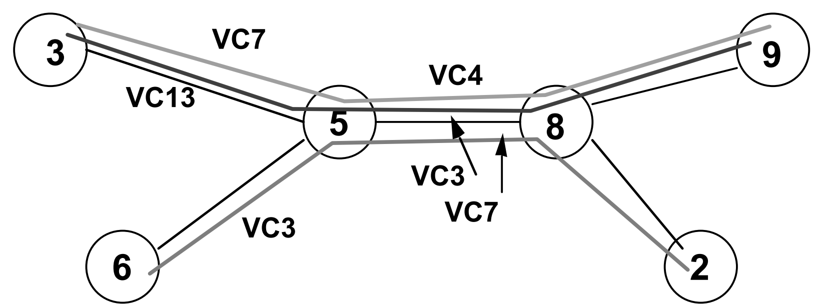
Packet Switching

- **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

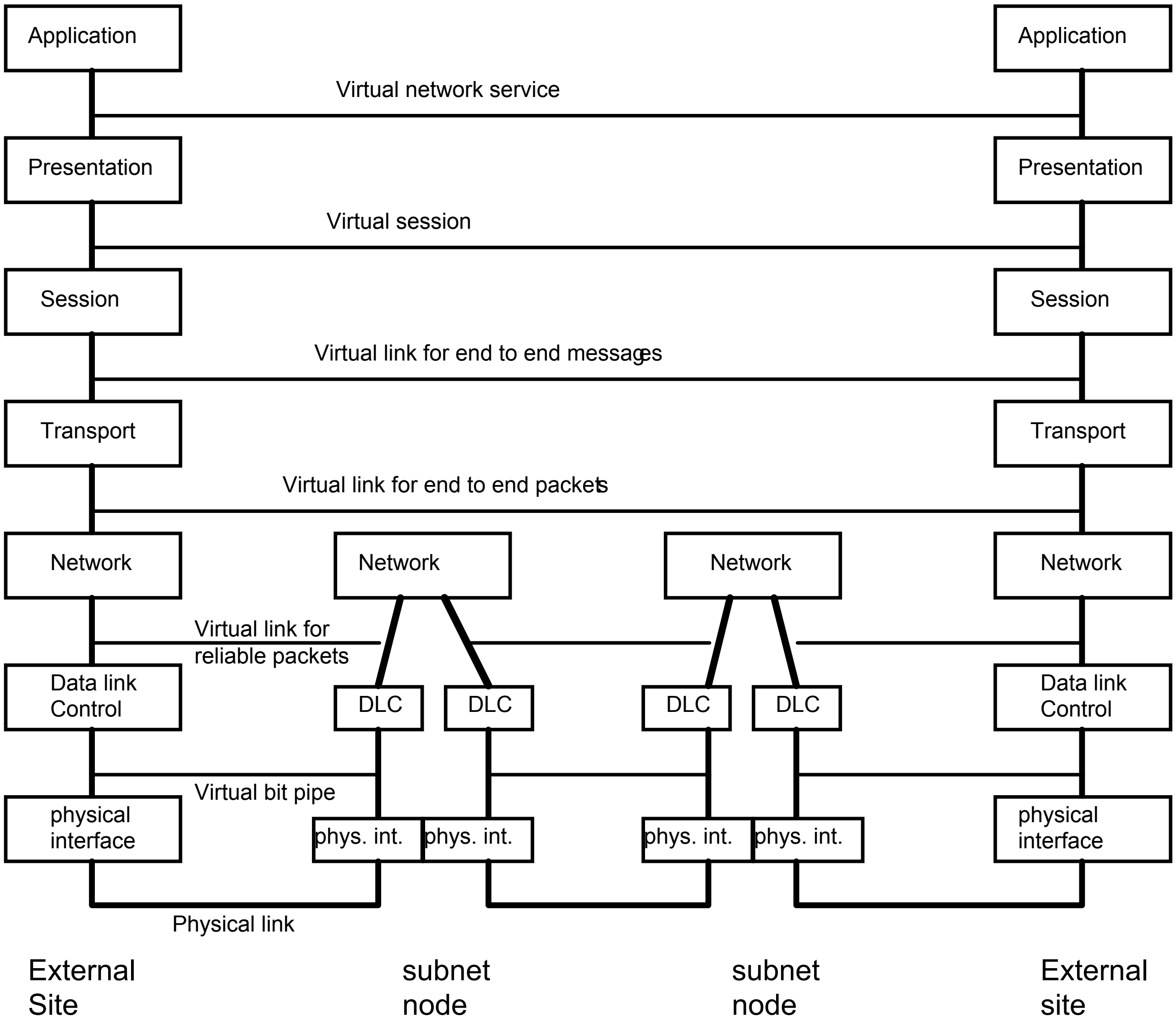
- Can circuit switched network be used to support data traffic?

- 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

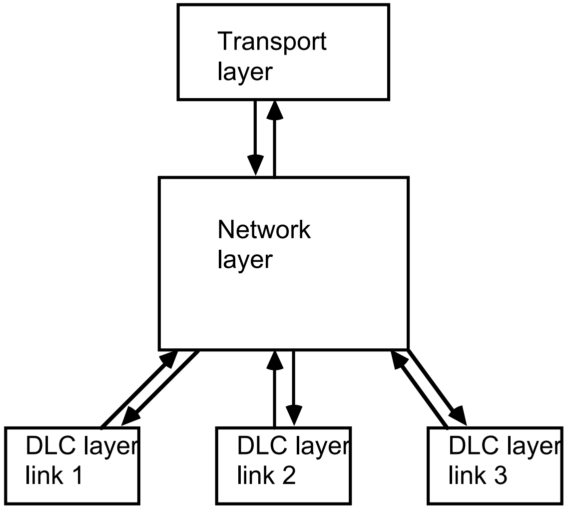
  4) recover from residual errors and failures

  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

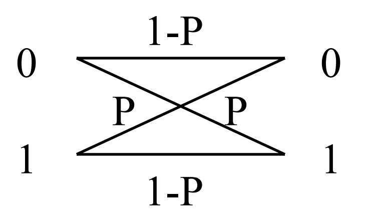


Link Layer

- 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 = 3×10^8 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 sublayer between the transport and network layers is required when various incompatible networks are joined together

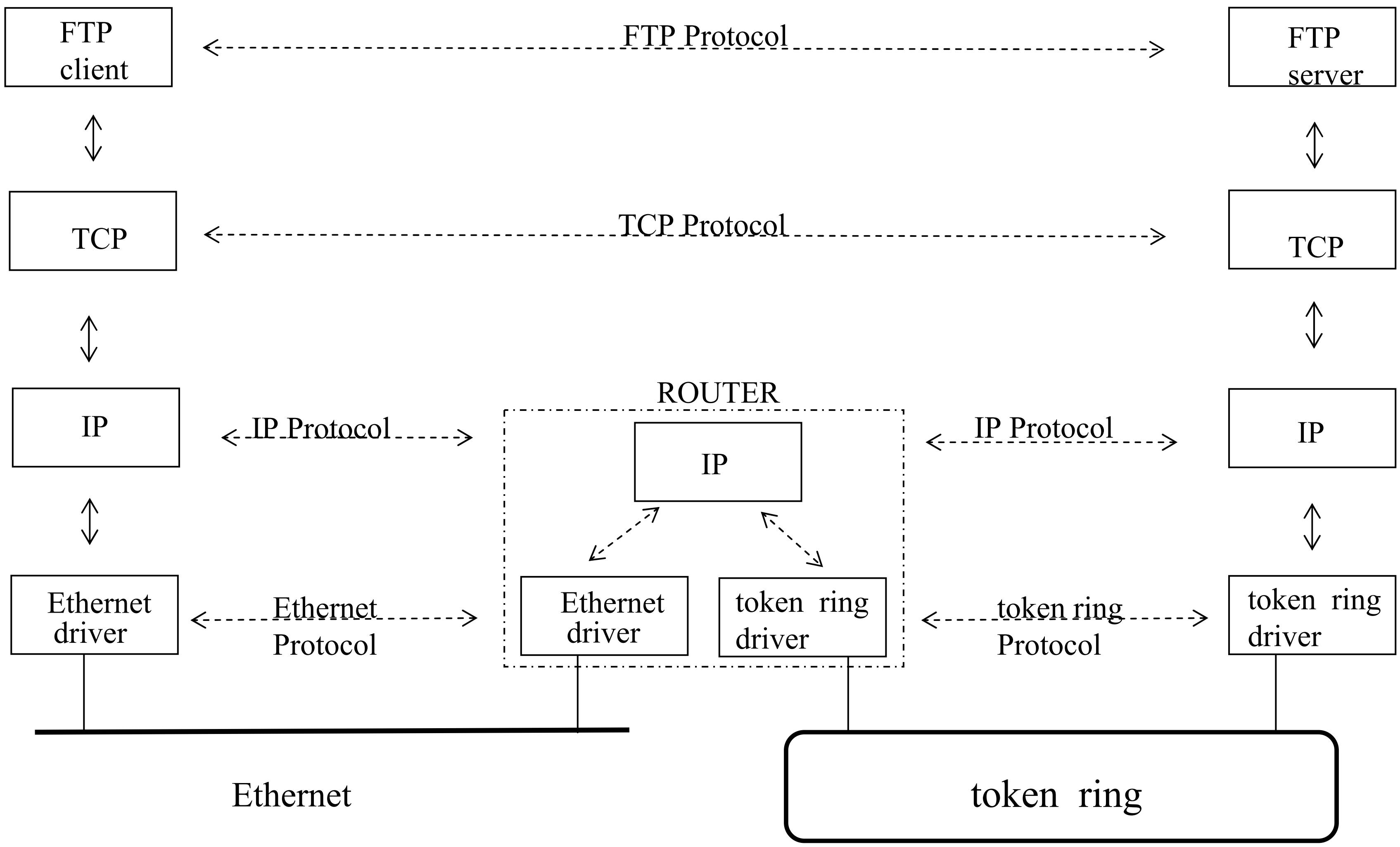
- This sublayer is used at gateways between the different networks

- 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