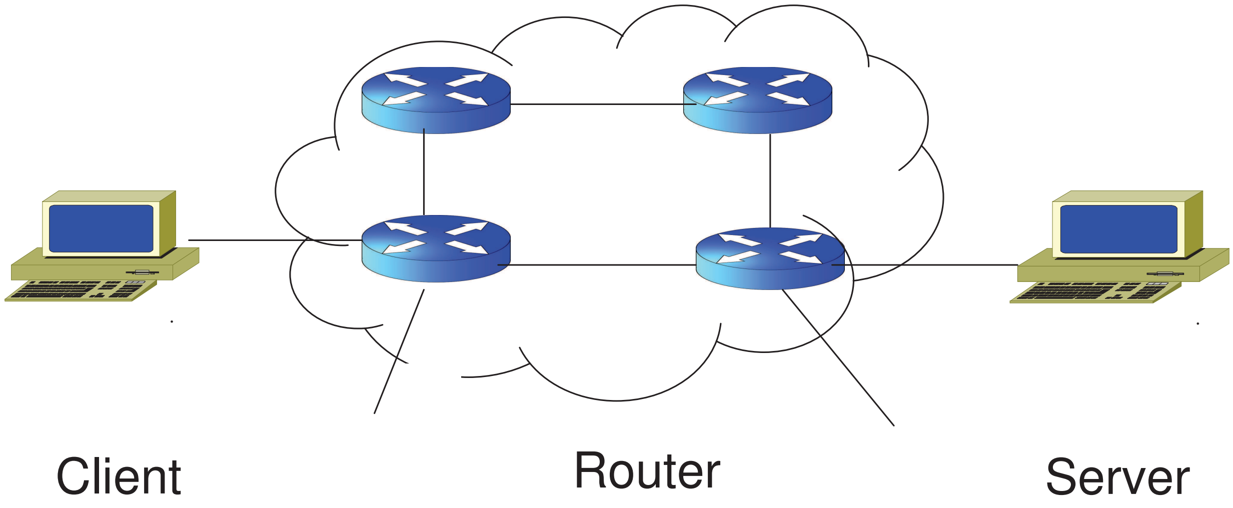
Today's Lecture

- Many kinds of networking functionality
  - *Addressing: How to specify a node?*
  - *Routing: Which path should I follow?*
  - *Flow Control: How to avoid congestions?*
  - *Security: How can privacy and integrity be maintained?*

- How should they be organized?
- How should they interact?

Example

- Transfer file from node A to node B
- What’s involved?

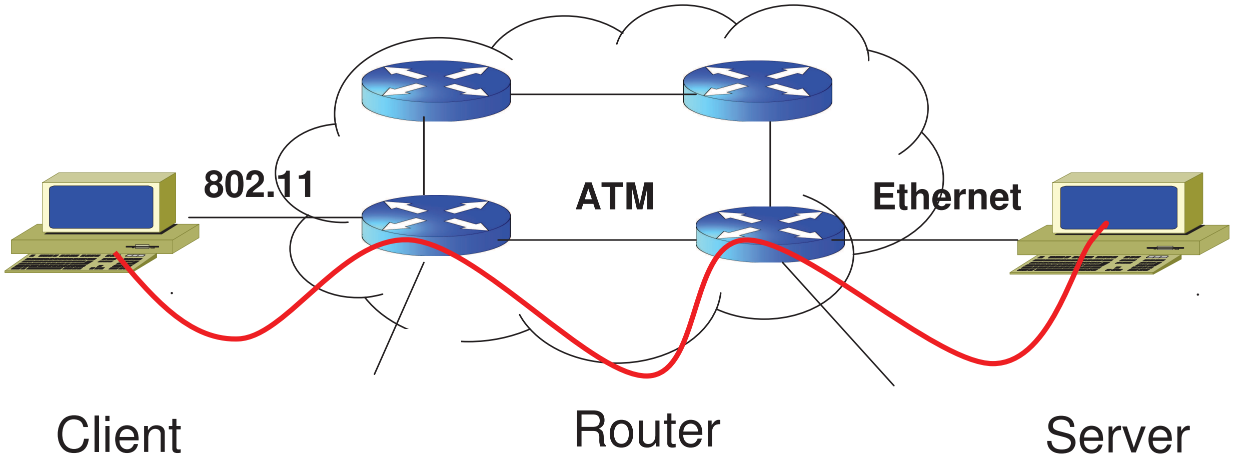


Application View

- How to authenticate client and ensure it has permission to access the record?
- What if file requested is not available?
- Should file be encrypted to ensure transmission is confidential?

Network View

- How to identify/”address” server?
- Which routers/path must be picked?
- How to ensure reliable, in-order delivery?
- How to get packet to traverse each hop?

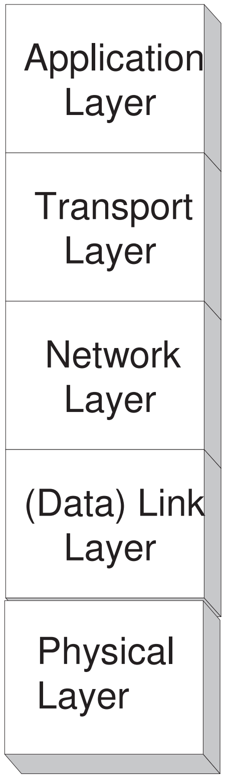


Internet: Layered Architecture

- Network functionality organized into layers
- ISO OSI Reference Model
  - ISO – International Standard Organization
  - OSI – Open System Interconnection
  - 7 layer protocol stack
- In practice today: TCP/IP stack
  - Effectively 5 layers.

Practice: TCP/IP Layering

- The TCP/IP suite has five layers
- Computers (hosts) implement all five layers. Routers (gateways) only have the bottom three layers.

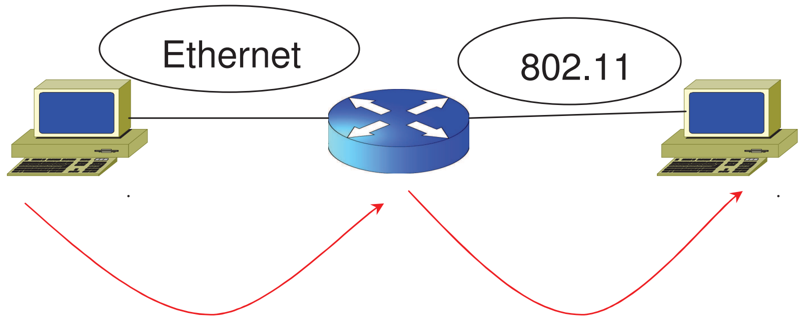


Application Layer	telnet, ftp, email
Transport Layer	TCP, UDP
Network Layer	IP, ICMP, IGMP
(Data) Link Layer	Device Drivers
Physical Layer	

Data Link Layer

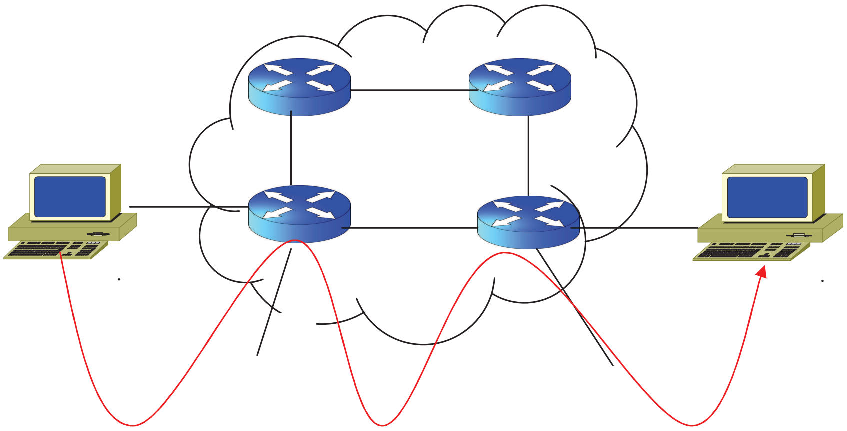
- Service: Transfer of frames over a link.
- Functions: Synchronization,
  channel access,
  error control,
  flow control

Application Layer	telnet, ftp, email www, AFS
Transport Layer	TCP, UDP
Network Layer	IP, ICMP, OSPF RIP, BGP
(Data) Link Layer	Ethernet, WiFi PoS, T1



Network Layer (IP)

- Service: Moves packets inside the network.
- Functions: Routing, addressing,



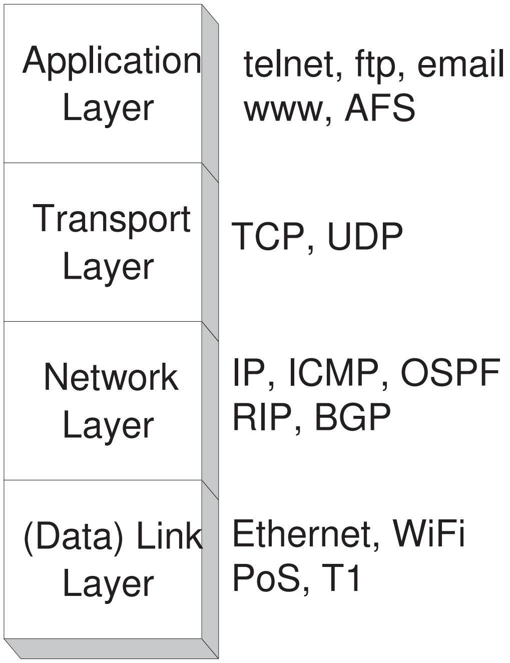
Application Layer	telnet, ftp, email www, AFS
Transport Layer	TCP, UDP
Network Layer	IP, ICMP, OSPF RIP, BGP
(Data) Link Layer	Ethernet, WiFi PoS, T1

IP Delivery Model

- Best-effort delivery
- Given a packet, send to remote point but:
  - Could be lost
  - Could be reordered
  - Could be delayed.

Transport Layer

- Service: Controls delivery of data between hosts.
- Functions: Connection Establishment, Termination, Error control, flow control.

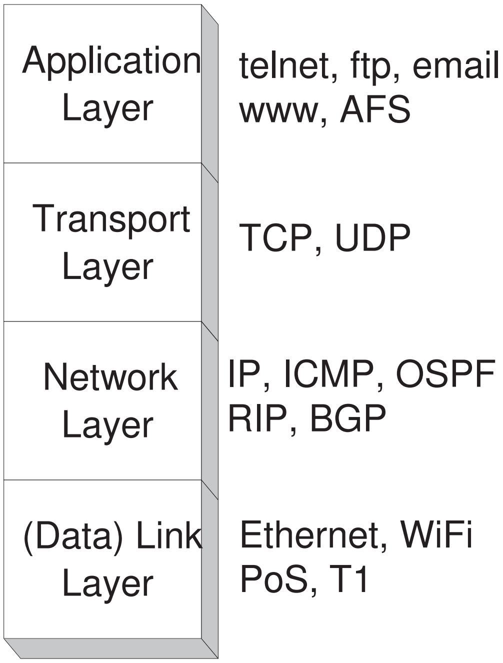


TCP and UDP

- Both sit on top of IP
- TCP:
  - Connection-oriented
  - Ensures reliable, in-order delivery
  - Mechanisms for congestion control
  - But latencies could be high!
- UDP:
  - Barebones functionality
  - Connectionless
  - Retains IP delivery model

Application Layer

- Service: Handles details of application programs.
- Functions:

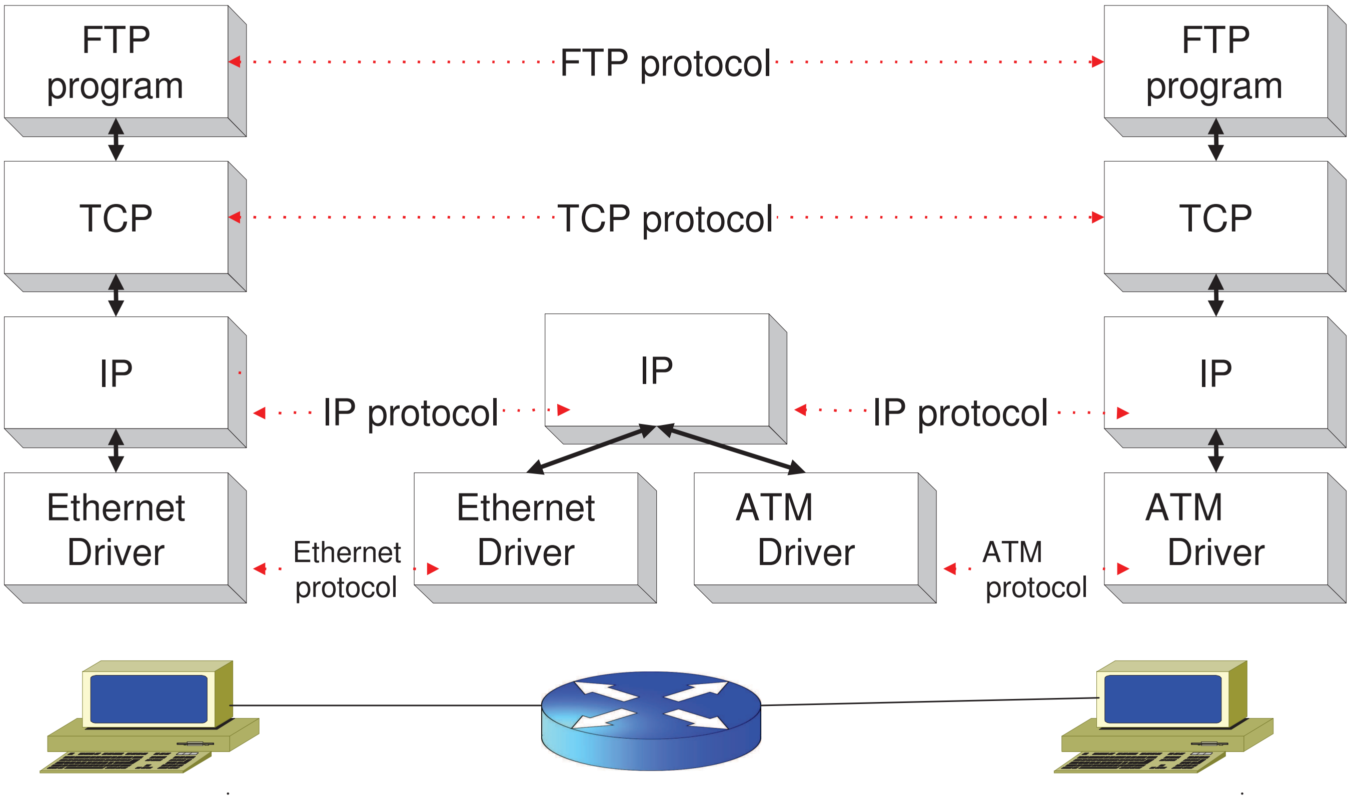


Key Concepts

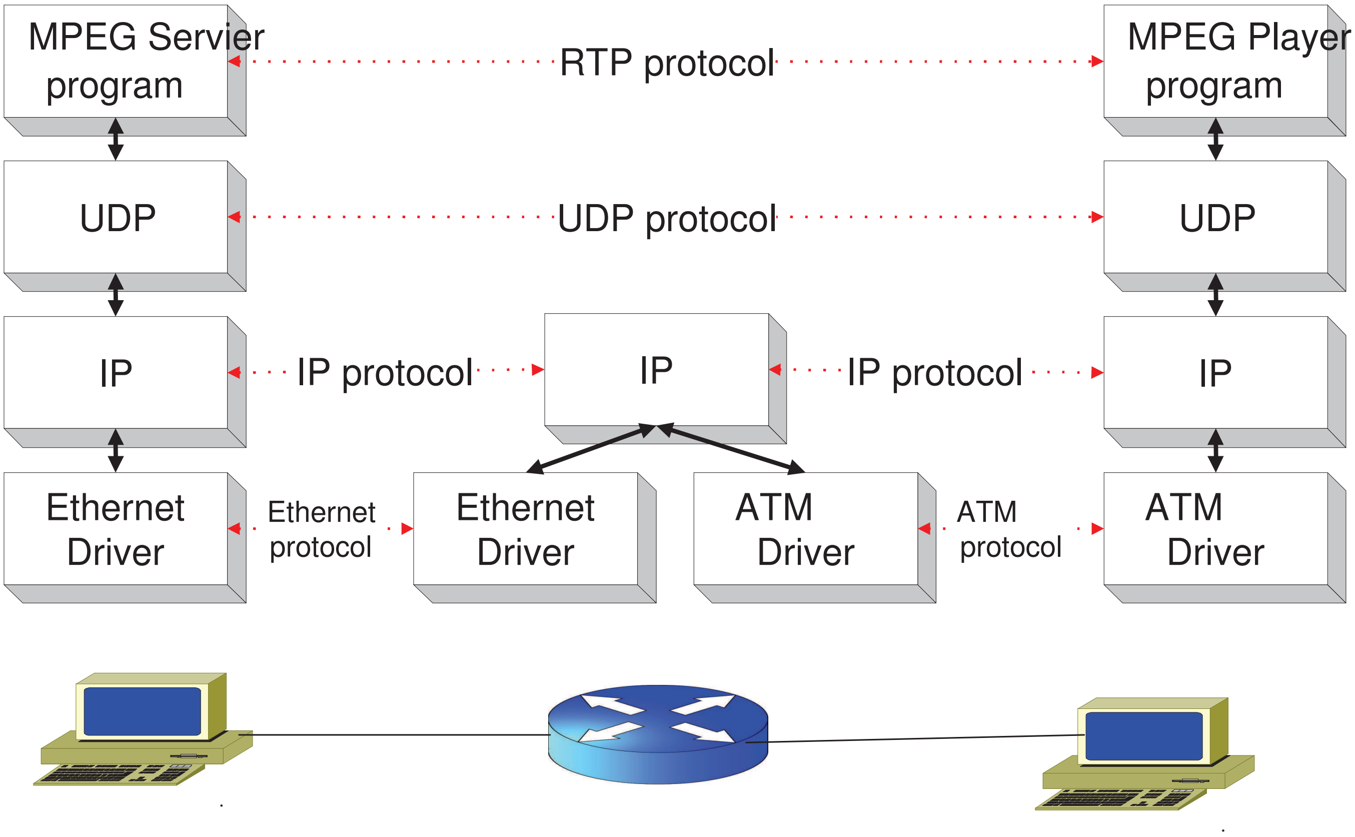
- Service – says what a layer does
  - E.g. TCP: reliable bytestream service
- Interface – says how to access the service
  - E.g. socket interface
- Protocol – says how the service is implemented
  - a set of rules and formats that govern the communication between two peers

Protocol Standardization

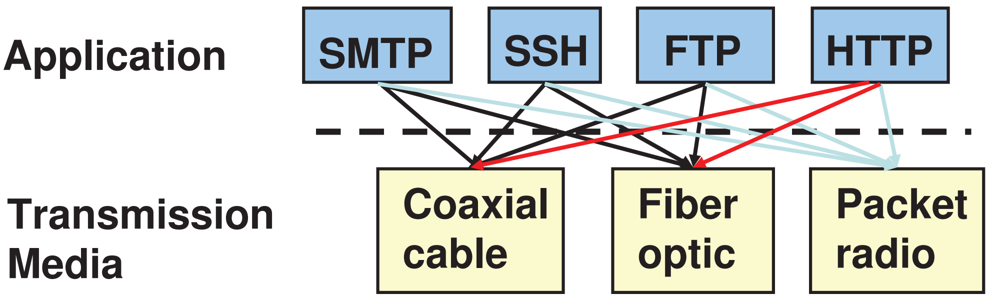
- Standards necessary for communication across devices
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force
- Other standard bodies
  - ISO,ITU, IEEE,ANSI



- IP protocol implemented on hosts and routers
- TCP and application only implemented on hosts


MPEG Servier program
RTP protocol
MPEG Player program
UDP
UDP protocol
UDP
IP
IP protocol
IP
IP protocol
IP
Ethernet Driver
Ethernet protocol
Ethernet Driver
ATM Driver
ATM protocol
ATM Driver

Benefits of Layering

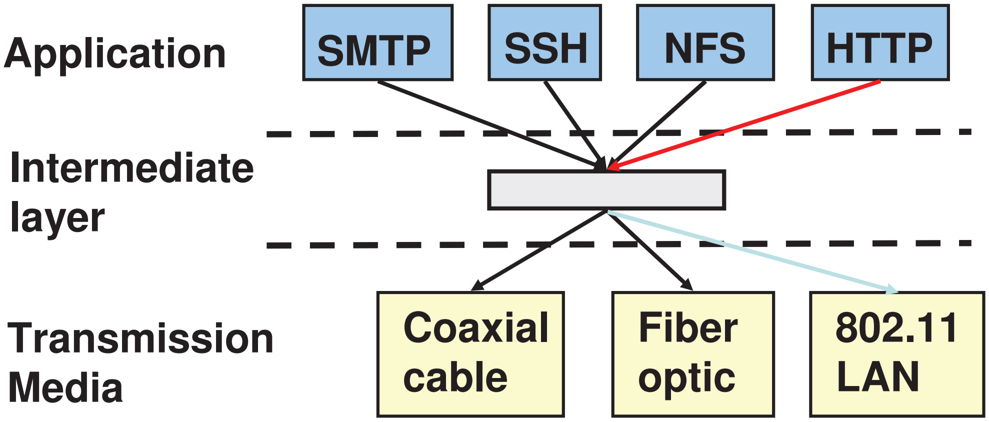


- New application: interface to all existing media
  - requires O(m) work, m = number of media
- New media: modify all existing applications
  - requires O(a) work, a = number of applications

- Application end points may not be on the same media!

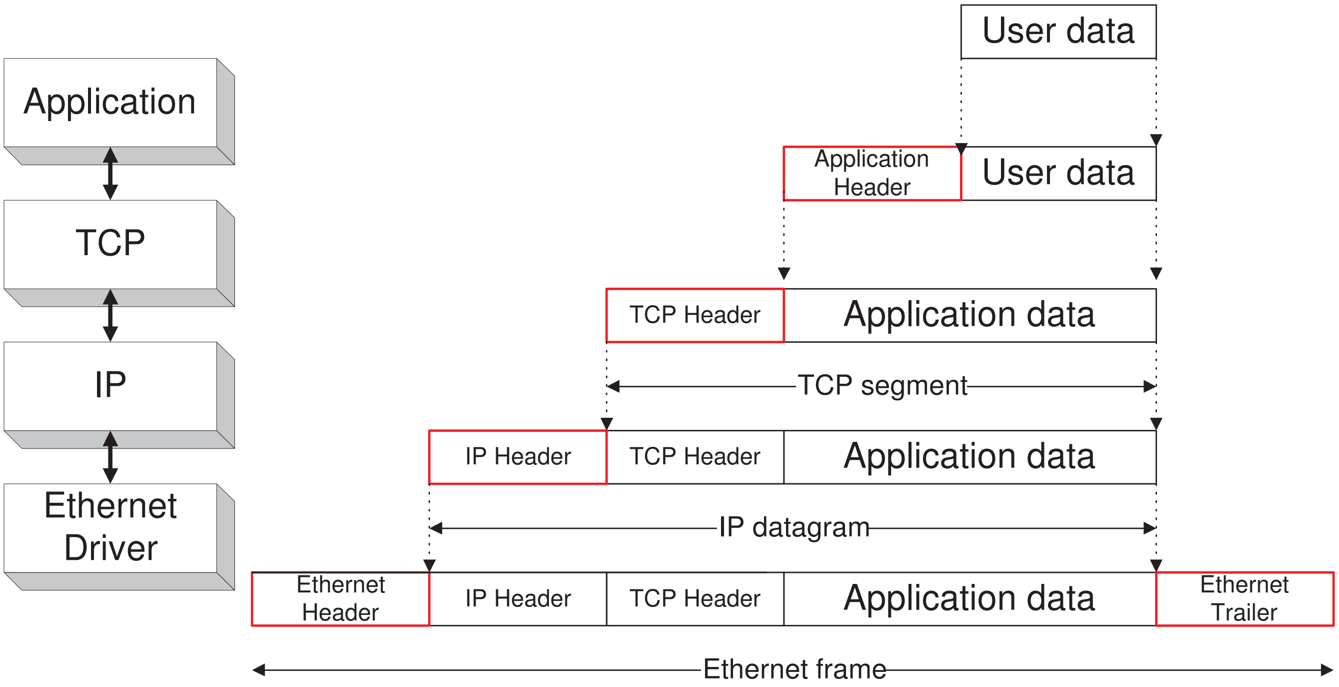
Benefits of Layering

- Solution: Intermediate layer that provides a single abstraction for various network technologies
  - O(1) work to add app/media
  - variation on "add another level of indirection"



Encapsulation

- As data is moving down the protocol stack, each protocol is adding layer-specific control information.



Layering Issues

- Where to put functionality? What layer must implement which functionality?
- General Internet Approach
  - Keep routers simple.
  - Thin waist of IP layer
- Example:
    - Reliable transmission
    - Congestion.