Introduction and Layered Network Architecture

EEE 538

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Fundamental Aspects of Network 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: Nail Akar x2337 akar@ee.bilkent.edu.tr**
- **Office Hour: Friday 9:30 – 11:30**
- **Grading**
  - 4 Quiz Exams (3 BEST will be counted, 15 %)
  - Project (20 % of grade)
  - Midterm exam (25 %)
  - Final Exam week (40 %)
- **Textbook:** Bertsekas & Gallager, Data Networks (2nd Edition)
- Other Books
  - Schwartz, Telecommunication Networks
  - Kleinrock, Queueing Systems

Syllabus

- 1 Introduction, Layered Network Architecture, Data Link Control Layer, Framing, Error Correction
- 2 Retransmission Algorithms, Introduction to Queueing Models
- 3 Markov Chains
- 4 M/M/1, M/M/c, M/M/c/c queues etc.
- 5 M/G/1 queues, M/G/1 w/ vacations, priority queues
- 6 Networks of Queues
- 7 Multiple Access, Aloha

Syllabus

- 8 Carrier Sensing, CSMA/CD, Ethernet, Packet Radio
- MIDTERM
- 9 Packet Switching Architectures, input/output queueing
- 10 Routing
- 11 Shortest Path Routing Algorithms
- 12 Optimal Routing
- 13 Flow and Congestion Control
- 14 Flow and Congestion Control Continued
- 15 Technology Primer, TCP/UP, ATM, MPLS, Optical

Network Applications

- Resource sharing
  - Computing
  - Mainframe computer (old days)
    - Today, computers cheaper than communications (except LANS)
  - Printers, peripherals
  - Information
  - Database 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 Gbp
  - 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 (Quality of Service)

Switching Techniques

- Circuit Switching
  – Dedicated resources
- Packet Switching
  – Shared resources
  – Virtual Circuits
  – Datagrams

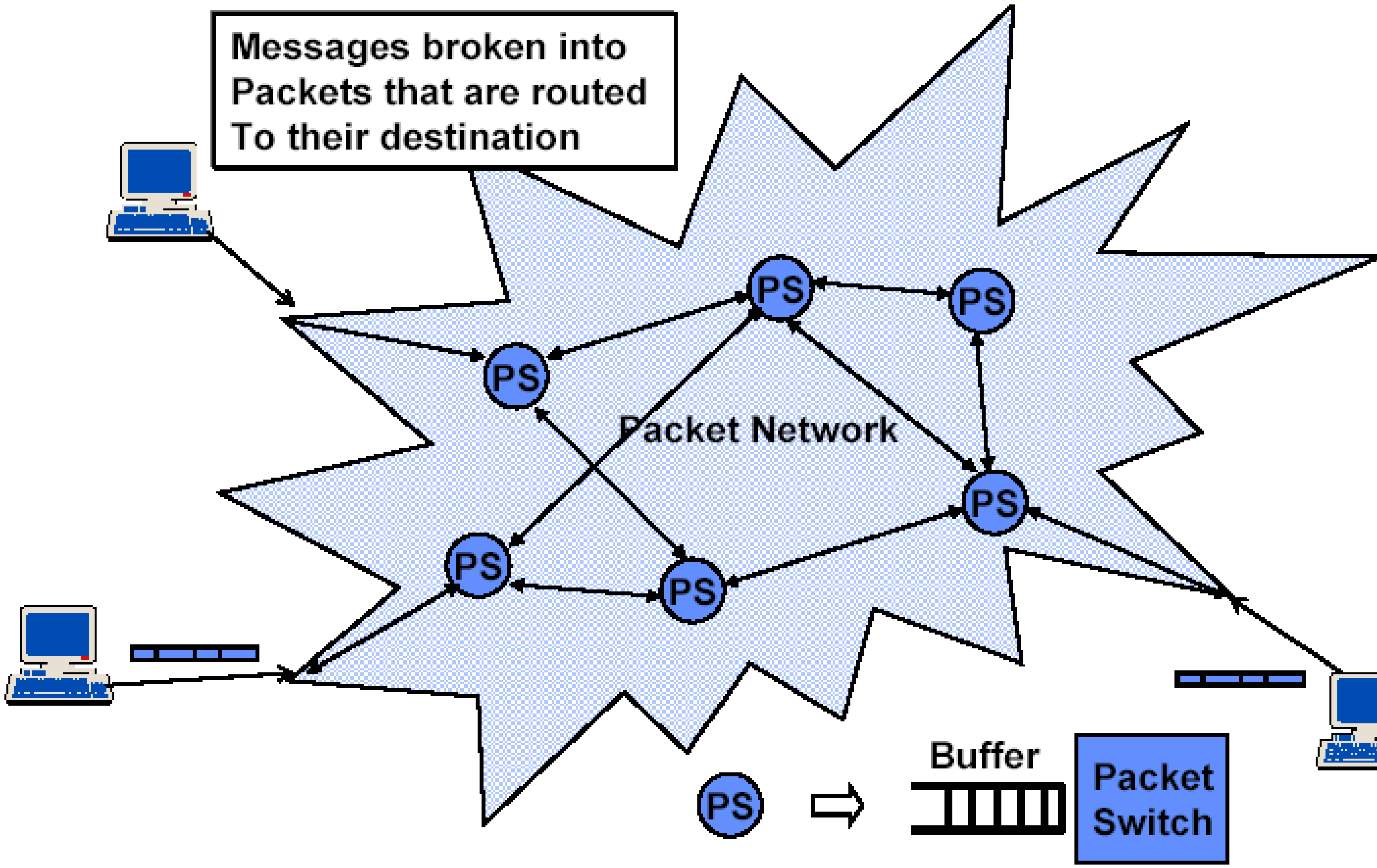
Circuit Switching

- 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, 2G wireless systems like GSM
- 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 of Circuit Switching

- 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 => $\lambda X << 1$ => 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 Switching

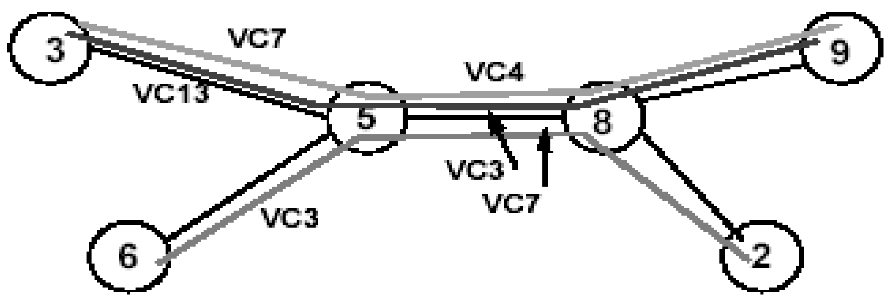


Packet Switching

- 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 Circuit 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



Node 5 table

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

Merits of virtual circuits
- Save on route computation, fixed size lookup table
- Need only be done once at start of session
– Save on header size
– Facilitate QoS provisioning
– More complex
– Less flexible

Circuit vs Packet Switching

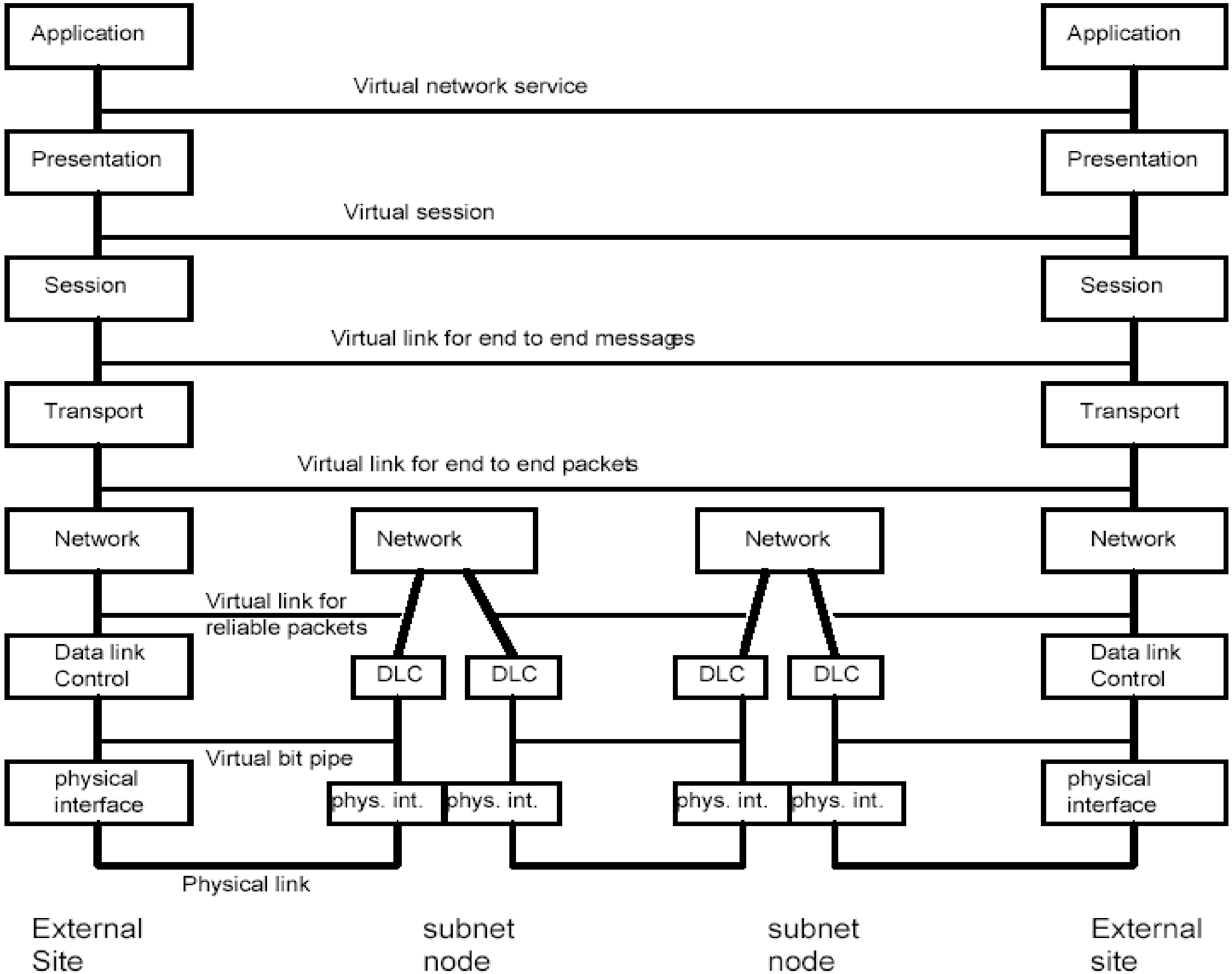
- Advantages of packet switching
  - Efficient for bursty data
  - Easy to provide bandwidth on demand with variable rates
- Disadvantages of packet switching
  - Variable delays
  - Difficult to provide QoS assurances (Best-effort service)
  - Packets can arrive out-of-order

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

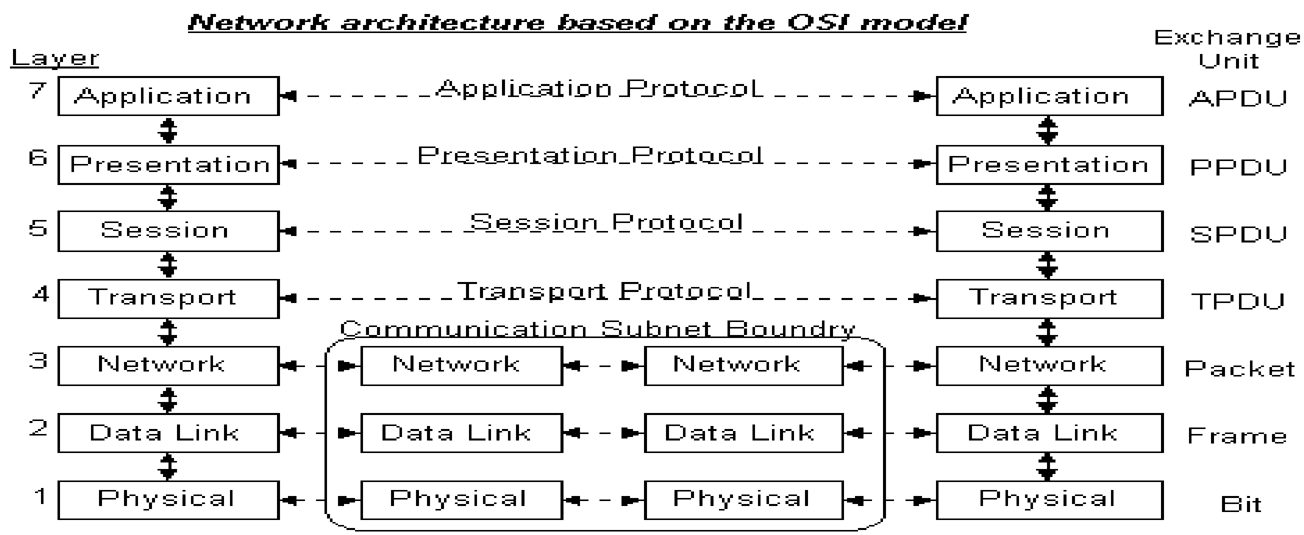
- Can circuit switched network be used to support data traffic?
- Can packet switched network be used for connection oriented traffic (e.g., voice)?
- Need for Quality of service (QoS) mechanisms in packet networks
  - Guaranteed bandwidth
  - Guaranteed delays
  - Guaranteed delay variations
  - Packet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

OSI 7-Layer Model



Layers

- OSI reference model
- Each layer communicates with its *peer* layer through the use of a protocol
- The communication between *n* and *n-1* is known as an *interface*



Layers

- Physical Layer
  - The physical later is concerned with transmitting raw bits over a communication channel.
  - The design issues have to do with making sure that when one side sends a 1 bit, it is received by the other side as a 1 bit, not as a 0 bit.
  - Typical questions here are how many volts should be used to represent a 1 and how many for a 0, how many microseconds a bit lasts, whether transmission may proceed simultaneously in both directions, how the initial connection is established and how it is torn down when both sides are finished, and how many pins the network connector has and what each pin is used for.
  - The design issues here deal largely with mechanical, electrical, and procedural interfaces, and the physical transmission medium, which lies below the physical layer. Physical layer design can properly be considered to be within the domain of the electrical engineer.
  - Examples: RS232C, X.25, Ethernet

Layers

- Data Link Control Layer
  - Sometimes called the link layer transmits chunks of information across a link.
  - It deals with problems such as
    - Framing
    - Checksumming to detect data corruption
    - Error correction
      - Retransmissions
    - Coordinating the use of shared media as in LAN (Local Area Network); and addressing (when multiple systems are reachable as in a LAN)
  - It is common for different links to implement different data link layers and for a node to support several data link layer protocols, one for each of the types of links to which the node is attached.
  - Example: HDLC, SDLC, X.25, Ethernet, ATM

Layers

- Network Layer
  - The network layer enables any pair of systems to communicate with each other.
  - A fully connected network is one in which every pair of nodes has a direct link between its nodes, but this kind of topology does not scale beyond a few nodes
  - Network layer must find a path through a series of connected nodes and nodes along the path should forward packets in the appropriate direction.
  - The network layer deals with problems such as route calculation, packet assembly and reassembly (when different links on the path have different maximum packet sizes), and congestion control.
  - Examples: IP, IPX, ATM
  - The network layer provides a virtual end to end packet pipe to the transport layer packets

Layers

- Transport Layer
  - This layer provides a reliable communications stream between a pair of systems
  - It deals with errors that can be introduced by the network layer, such as lost packets, duplicated packets, packet reordering, and fragmentation and reassembly
  - It is also nice if the transport layer reacts to congestion in the network
  - Example: TCP (Transmission Control Protocol)
  - The transport layer provides a virtual end to end message service to the higher layers.
  - The functions of the transport layer are:
    - Break messages into packets and reassemble packets of size suitable to network layer
    - Multiplex sessions with same source/destination nodes
    - Resequence packets at destination
    - Recover from residual errors and failures
    - Provide end-to-end flow control

Layers

- Session Layer
  - The session layer assumes that a reliable virtual point-to-point connection has been made and contains specs for the dialog between the two end systems such as dialog discipline, data grouping, and recovery of an interrupted session. Specs are also included for initiating and concluding a session. Many network specs contain little or no session specs and leave these decisions to the applications.
- Presentation Layer
  - Provides transformation of data to standardize the application interface. Also provides some network services such as encryption, compression, and text re-formatting.
- Application Layer
  - This layer plays the same role as the 'application interface' in operating systems. Provides network services to users (applications) of the network in a distributed processing environment: examples transaction server, file transfer protocol, network management, electronic mail, and terminal access to remote applications.

Service Models

- Layer *n-1* can provide either a connectionless service or connection-oriented service
  - Communication consists of three phases in a CO-service
    - Connection setup
    - Data transfer
    - Connnection release
  - Associated with each of these phases are two functions:
    - *Layer n* initiates the function
    - *Layer n-1* informs *layer n* that some *layer n* process in some other node is requesting a connection
- Services can vary in their degree of reliability
  - Datagram service (also known as best-effort) accepts data but makes no guarantees as to delivery in that data may be lost, duplicated, delivered out of order, or mangled.
  - A reliable service guarantees the data will be delivered in the order transmitted, without corrupting, duplication or loss.

Examples

Service	Connection-oriented	Connectionless
Datagram	ATM	IP, IPX, DECnet
Reliable	X.25	

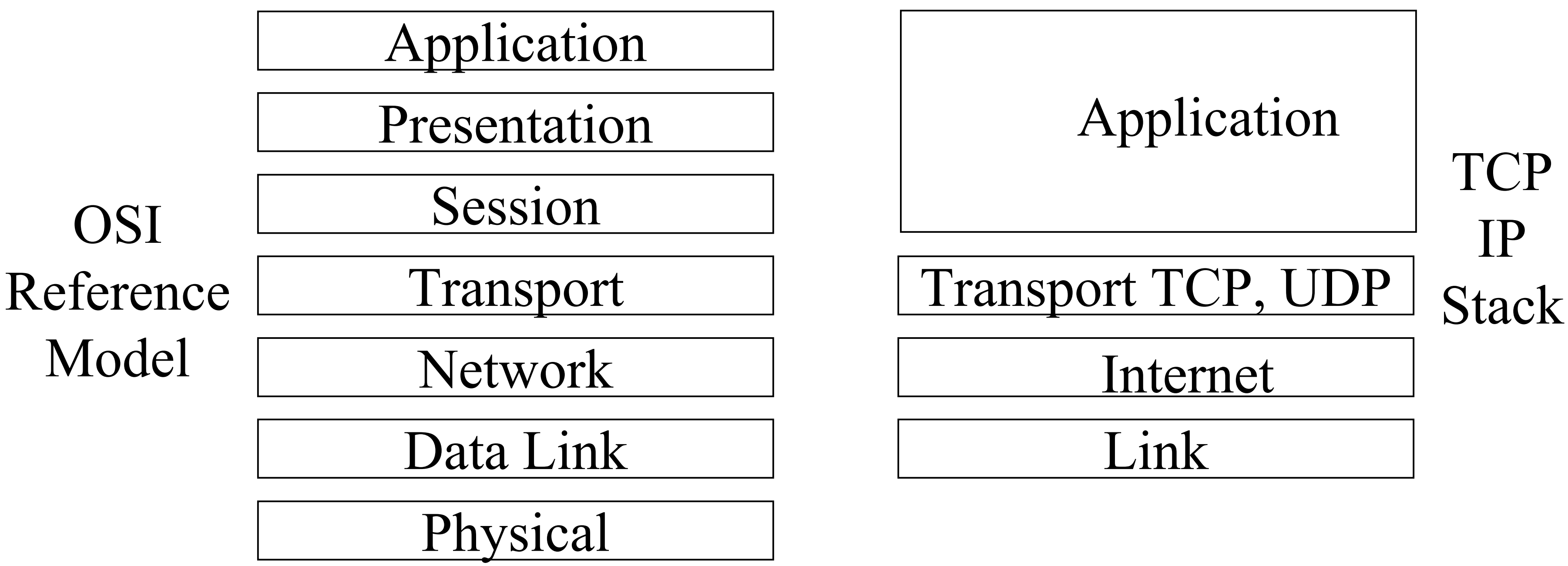
- In the TCP/IP protocol suite, network layer is connectionless, TCP offers reliable connection-oriented service, UDPs datagram service
- ATM offers a connection-oriented, unreliable service that can be viewed as a network layer. For IP over ATM, ATM is viewed by IP as a data link layer
- It’s good to know about layering but it should not be taken that seriously; however it is a good learning and communication tool.

TCP/IP Stack

- **Application**
  - Some TCP/IP application layer protocols are full-fledged user applications which generate network-service requests, such as TELNET and FTP. Other protocols provide support to applications in the form of services, such as the Domain Name System (DNS) and the Simple Network Management Protocol (SNMP).
- **Transport**
  - As in the OSI model, the transport layer provides end-to-end communications services in the form of two protocols: the Transmission Control Protocol (TCP) and the User Datagram Protocol (UDP).
- **Internet**
  - The internet layer contains IP (the Internet Protocol), which is responsible for the packaging, addressing, and routing of data to its destination. Also operating at this layer are the Internet Control Message Protocol (ICMP) and the Internet Group Management Protocol (IGMP).

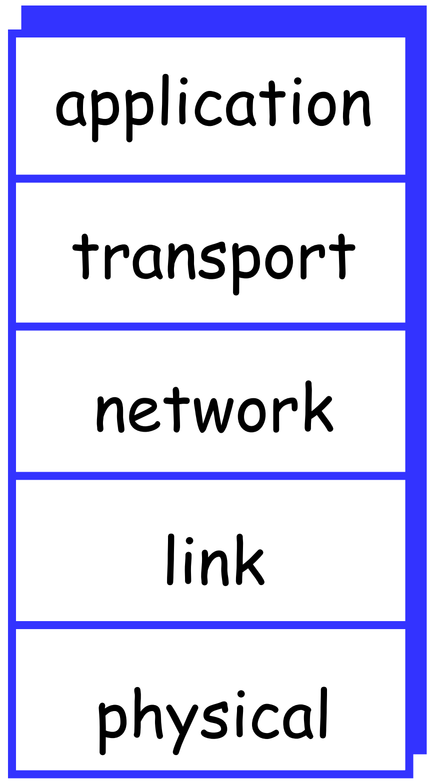
TCP/IP Stack

- **Link**
  - The link layer contains protocols used to facilitate the transmission of IP data over the existing network medium. The TCP/IP standards do not define the functionality of the OSI data link and physical layers. Instead, the standards define protocols like the Address Resolution Protocol (ARP) that provide an interface between TCP/IP and physical layer



Internet protocol stack

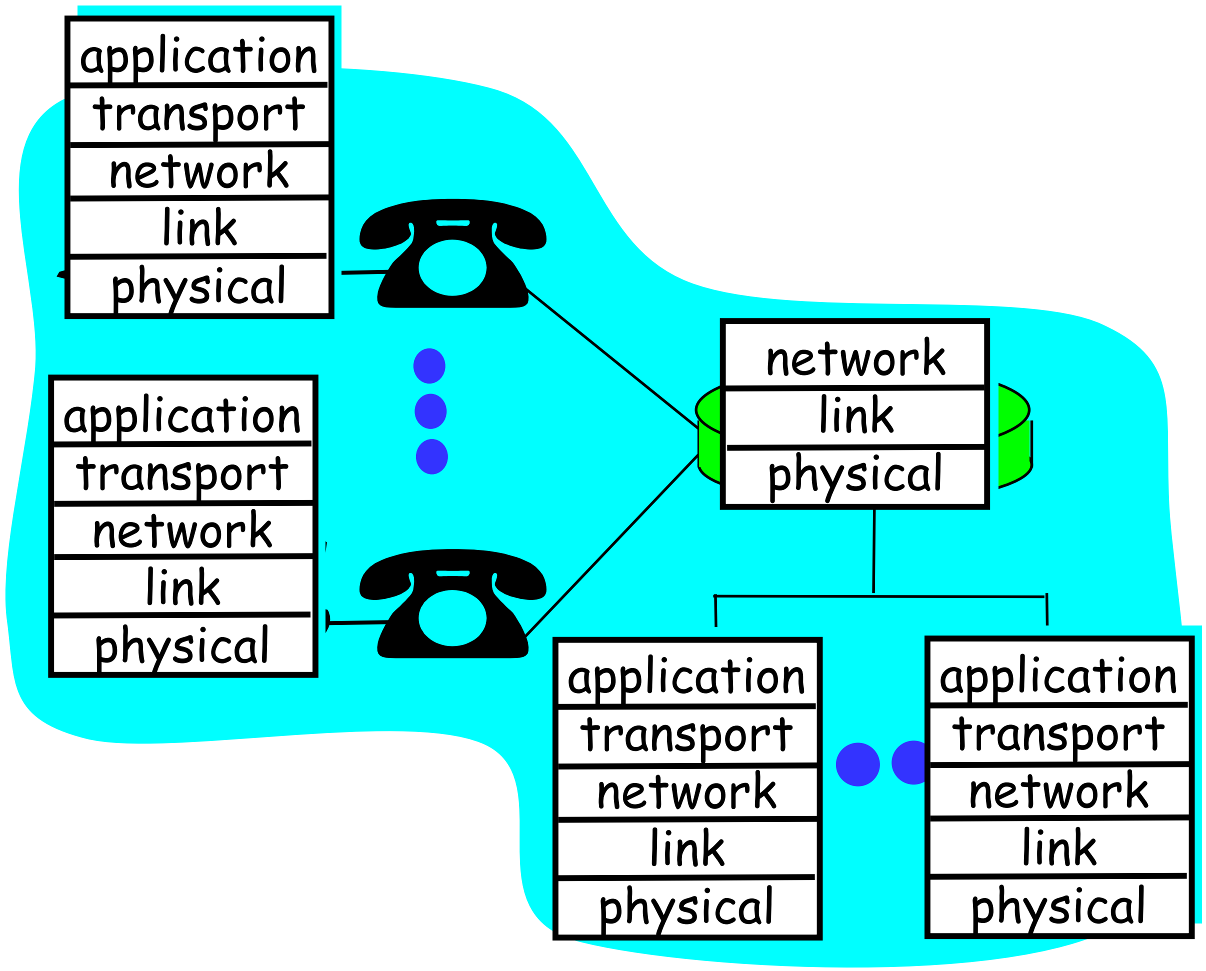
- application: supporting network applications
  - ftp, smtp, http
- transport: host-host data transfer
  - tcp, udp
- network: routing of datagrams from source to destination
  - ip, routing protocols
- link: data transfer between neighboring network elements
  - ppp, ethernet
- physical: bits “on the wire”



Layering: logical communication

Each layer:

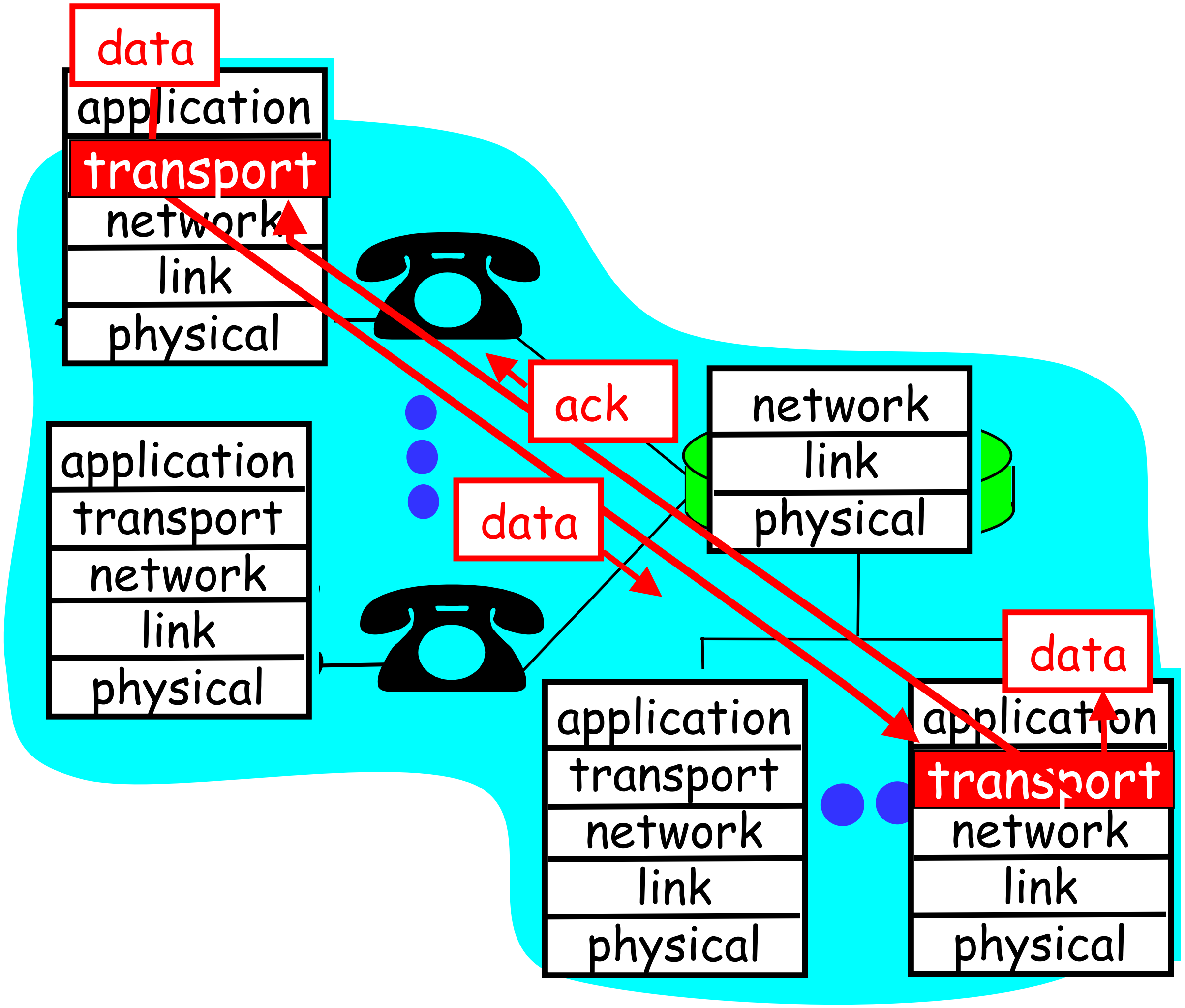
- Distributed "entities" implement layer functions at each node
- entities perform actions, exchange messages with peers



Layering: *logical* communication

E.g.: transport

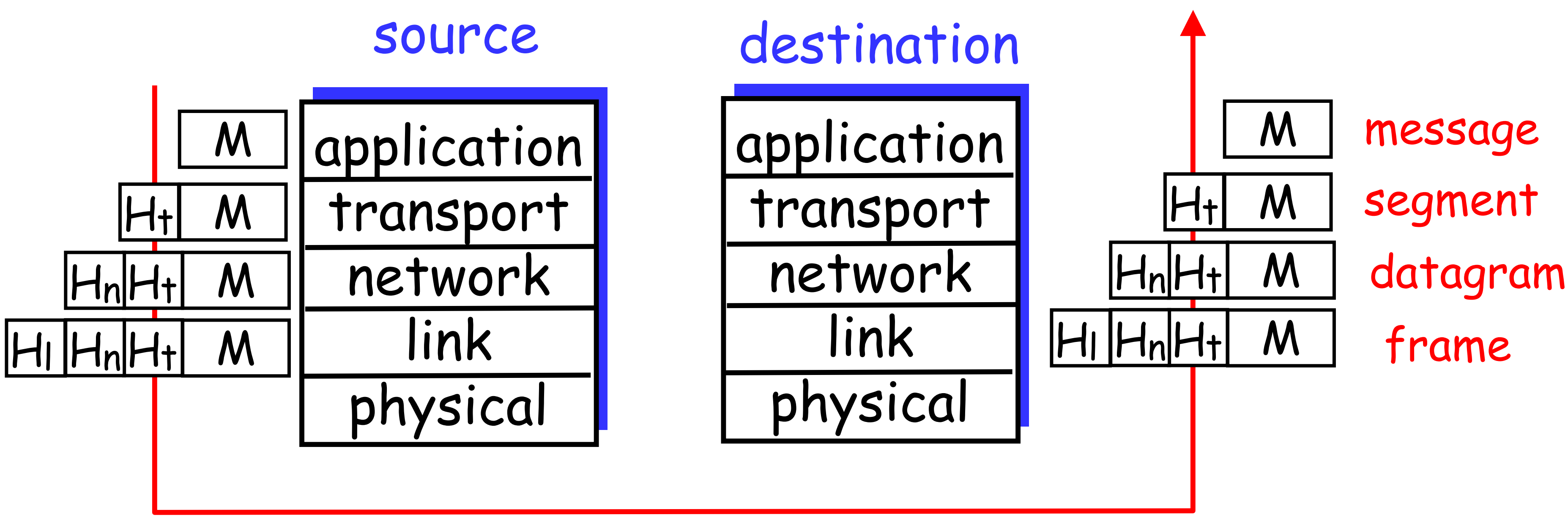
- take data from app
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt



Protocol layering and data

Each layer takes data from above

- adds header information to create new data unit
- passes new data unit to layer below



Internet structure: network of networks

- roughly hierarchical
- national/international backbone providers (NBPs)
  - e.g. BBN/GTE, Sprint, AT&T, IBM, UUNet
  - interconnect (peer) with each other privately, or at public Network Access Point (NAPs)
- regional ISPs
  - connect into NBPs
- local ISP, company
  - connect into regional ISPs