Computer Networks

CMP2205

Lecture 2

Layering

- *What is it?*
- **Building complex systems is hard!**
  - **Approach: "Divide and conquer".**
  - **Split job into smaller jobs, or layers.**
- *Analogy to other fields.*
  - *Building a house: digging, foundation, framing, etc.*
  - *Car assembly line…*
- *Basic idea: each step dependent on the previous step but does not need to be aware of how the previous step was done.*

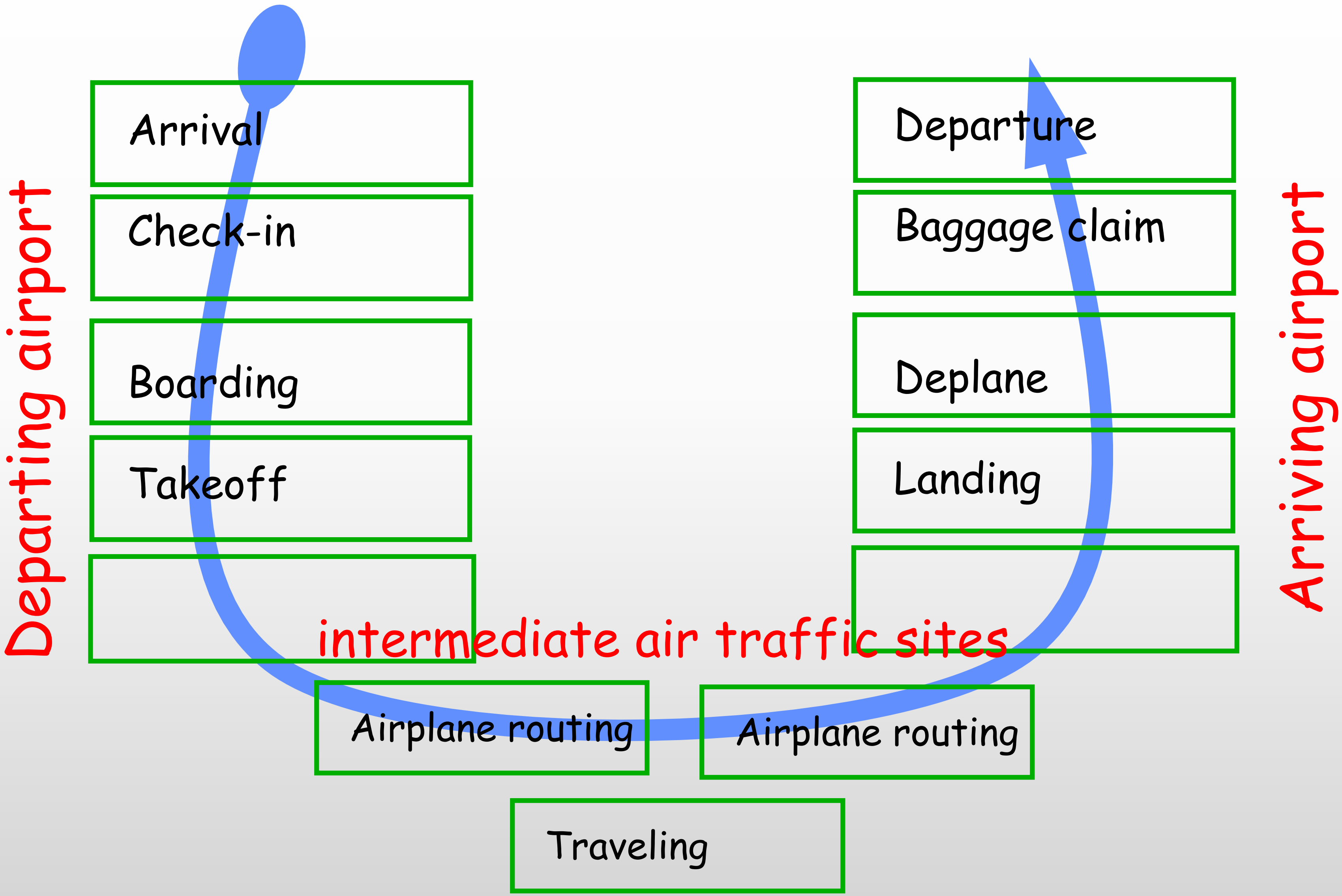
Analogy: Air Travel

- *The problem: air travel.*
- *Decomposed into series of steps:*

Arrival at airport	Departure from airport
Check-in	Baggage claim
Boarding	Deplane
Takeoff	Landing

Traveling

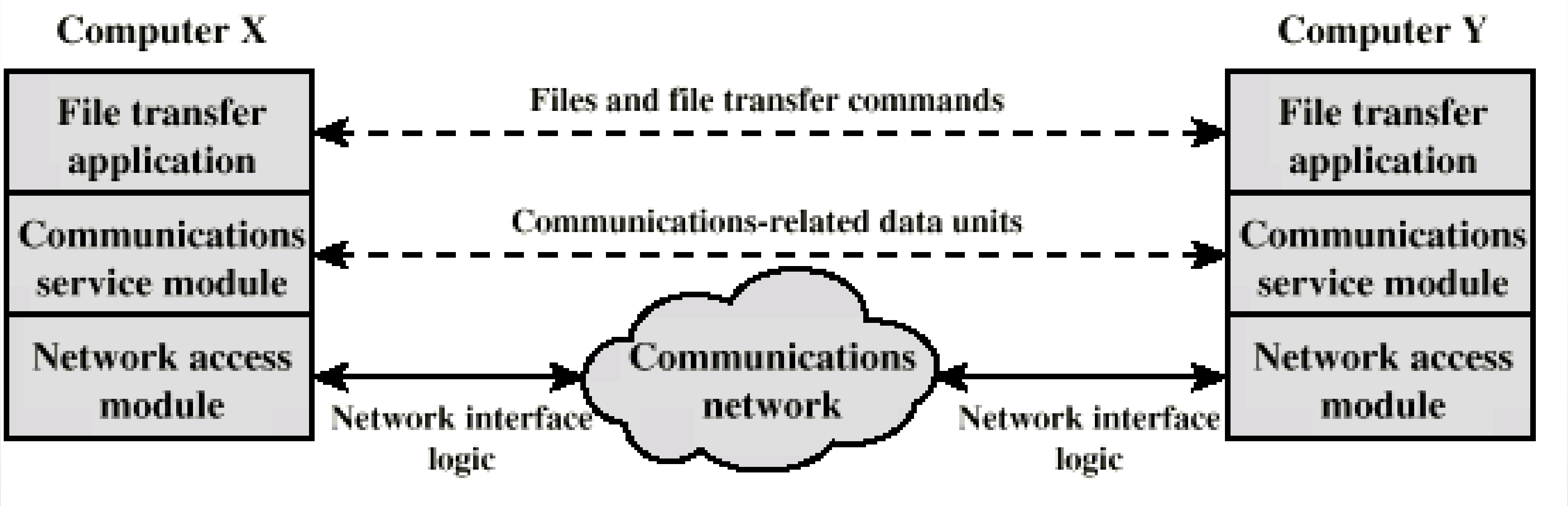
More on the air travel analogy…



Protocol Architecture

- *Task of communication broken up into modules*
- *For example file transfer could use three modules*
  - *File transfer application*
  - *Communication service module*
  - *Network access module*

Simplified File Transfer Architecture



A Three Layer Model

- *Application Layer*
- *Transport Layer*
- *Network Access Layer*

Network Access Layer

- *Exchange of data between the computer and the network*
- *Sending computer provides address of destination*
- *May invoke levels of service*
- *Dependent on type of network used (LAN, packet switched etc.)*

Transport Layer

- *Reliable data exchange*
- *Independent of network being used*
- *Independent of application*

Application Layer

- *Support for different user applications*
- *e.g. e-mail, file transfer*

Layered Protocol Design

- ***Layering model** is a solution to the problem of complexity in network protocols*
- *The model divides the network protocols into **layers**, each of which solves part of the network communication problem*
  - *Each layer has its own protocol!*
- *Each layer implements a **service** to the layer above*
  - *Relying on services provided by the layers below.*

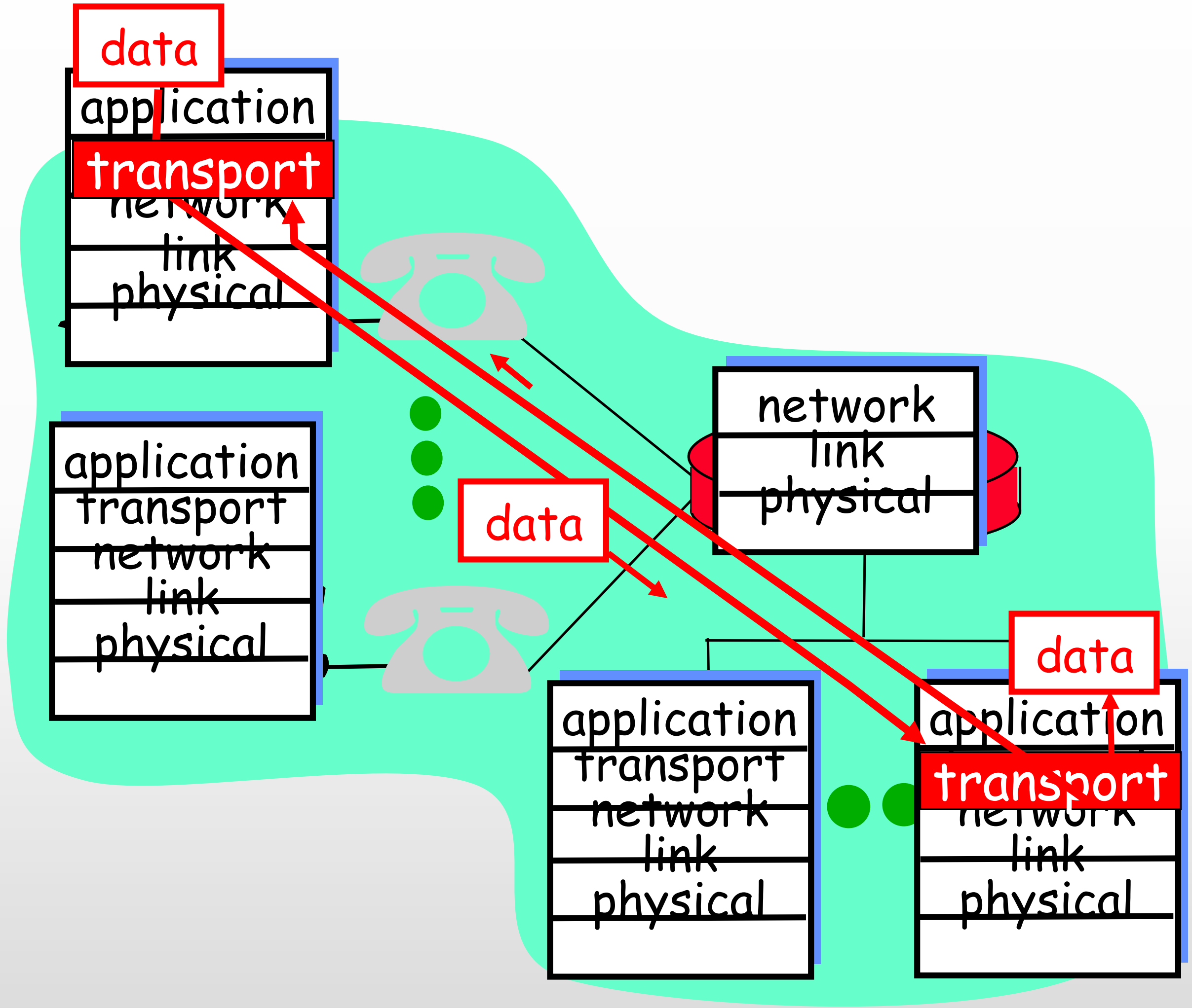
Layers

- *Layers are the different components that need to be designed/implemented when designing/implementing networks.*
- *Each layer responsible for a set of functions.*
- *Top layer relies on services provided by bottom layer.*
- *Layer makes it service available to higher layer through an* **interface***.*

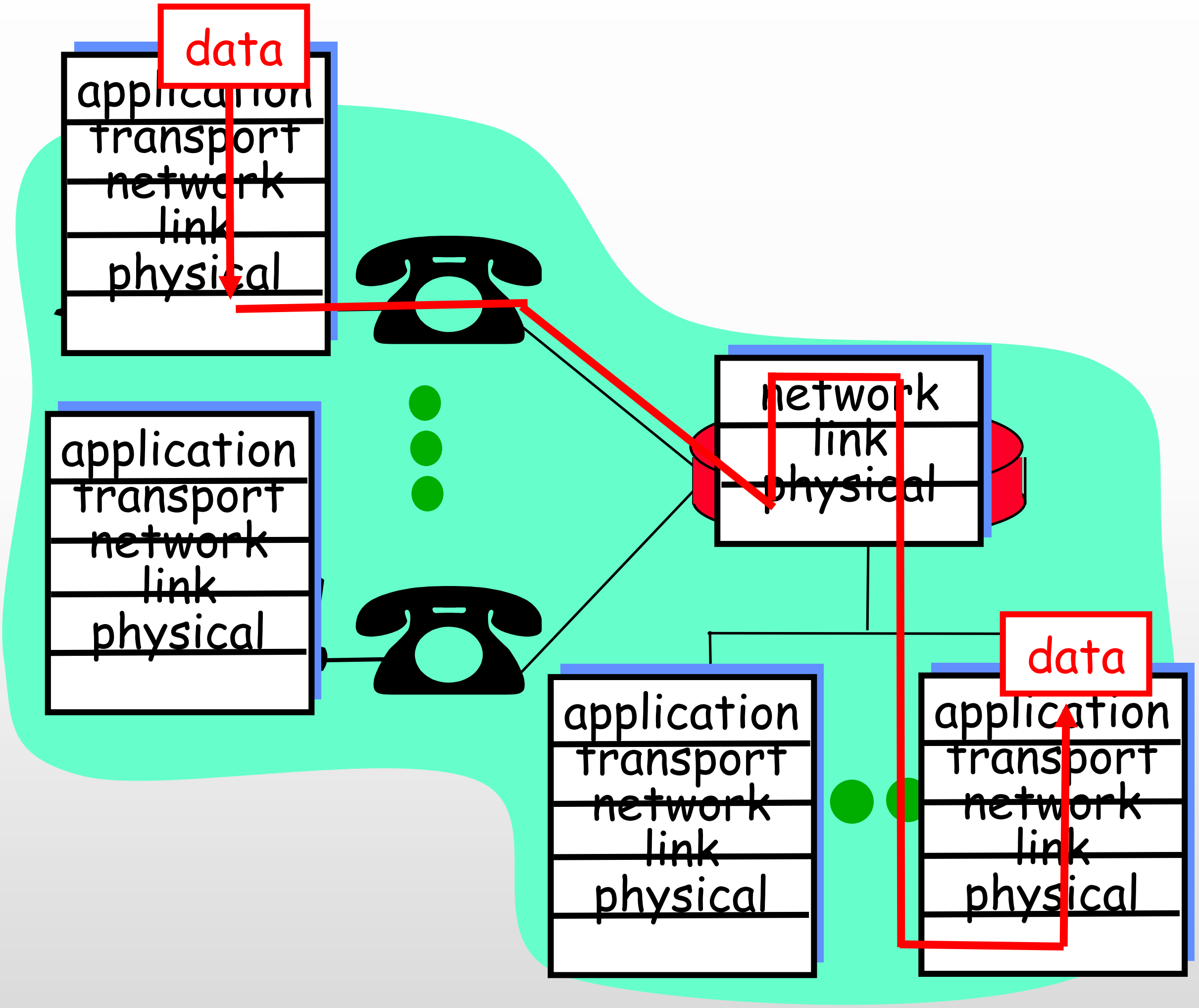
Layering: Logical Communication

E.g.: transport

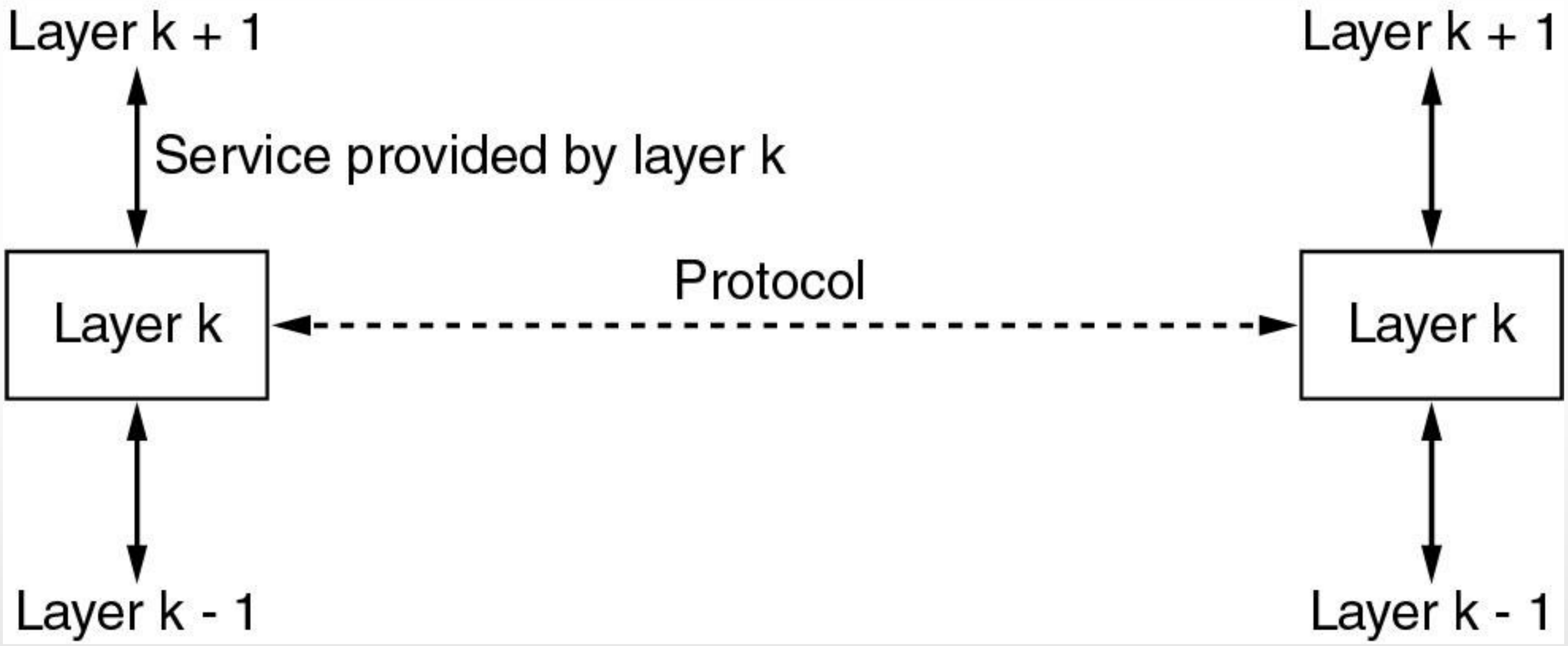
- *Take data from application*
- *Add addressing, information.*
- *Send result to peer.*
- *Analogy: sending a letter.*



Layering: Physical Communication



Layers and Protocols



The relationship between a service and a protocol.

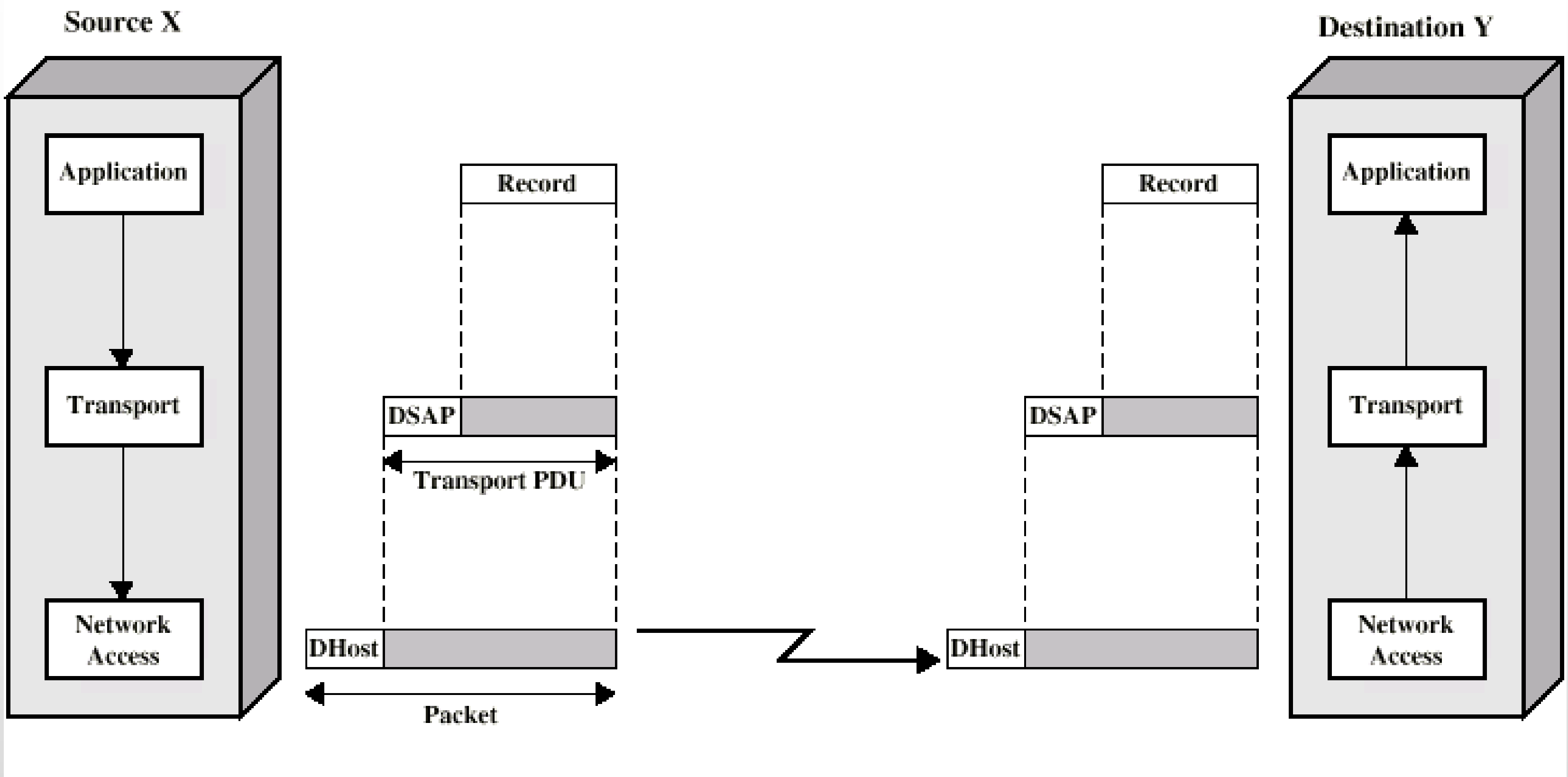
Network/Protocol Architecture

- *Set of layers, what their functions are, the services each of them provide, and the interfaces between them.*
- *A.k.a, protocol architecture or protocol stack.*
- *Examples:*
  - *ISO-OSI 7 layer architecture.*
  - *TCP-IP architecture (Internet).*

Protocol Data Units (PDU)

- *At each layer, protocols are used to communicate.*
- *At the source, control information is added to user data at each layer, a.k.a., encapsulation.*
- *At the receiver, control information is stripped off at each layer going up the stack, a.k.a., decapsulation.*

Operation of a Protocol Architecture



Example 1: ISO OSI Architecture

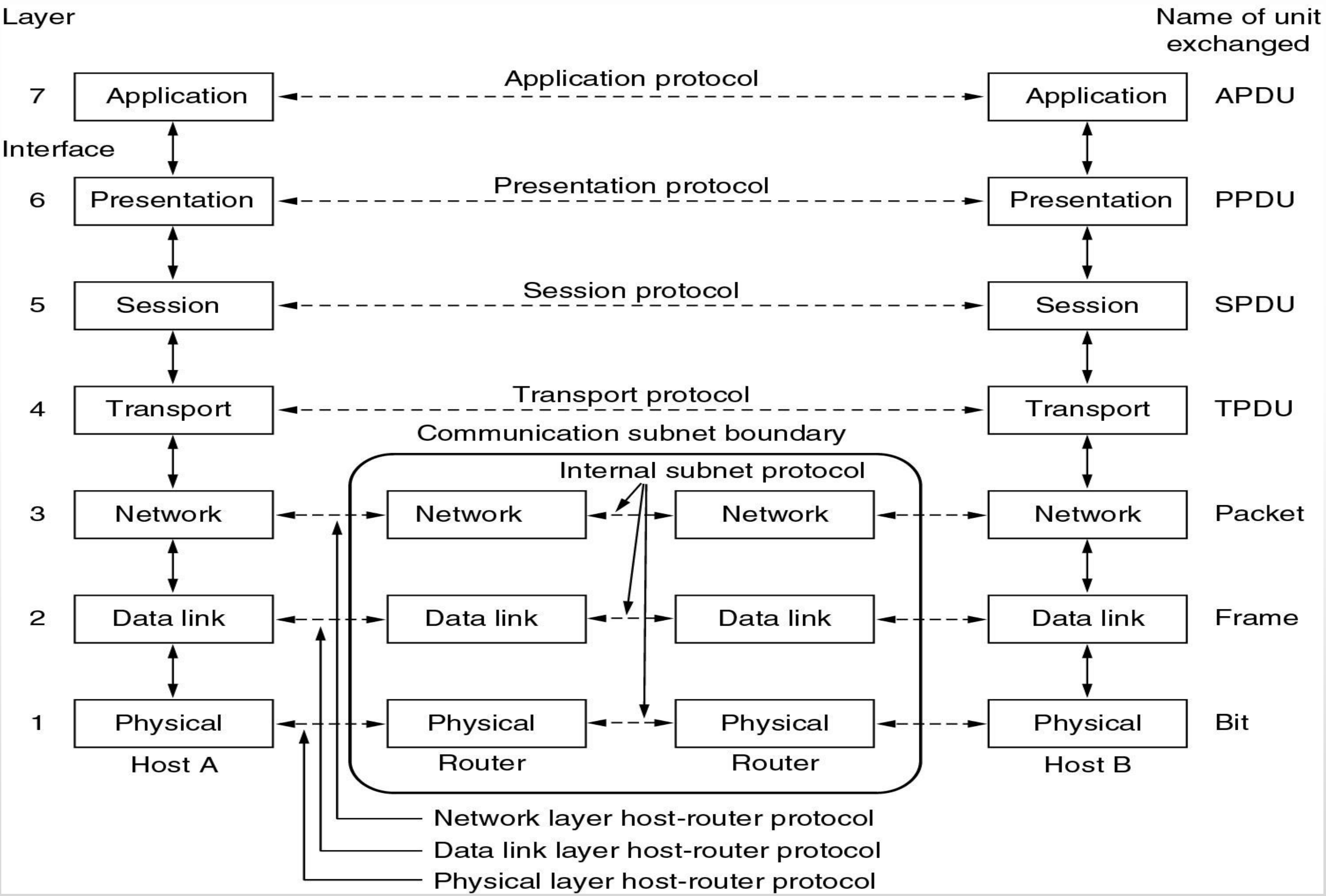
- *ISO: International Standards Organization*
- *OSI: Open Systems Interconnection.*

Application
Presentation
Session
Transport
Network
Data link
Physical

Layers of Interest in ISO Model

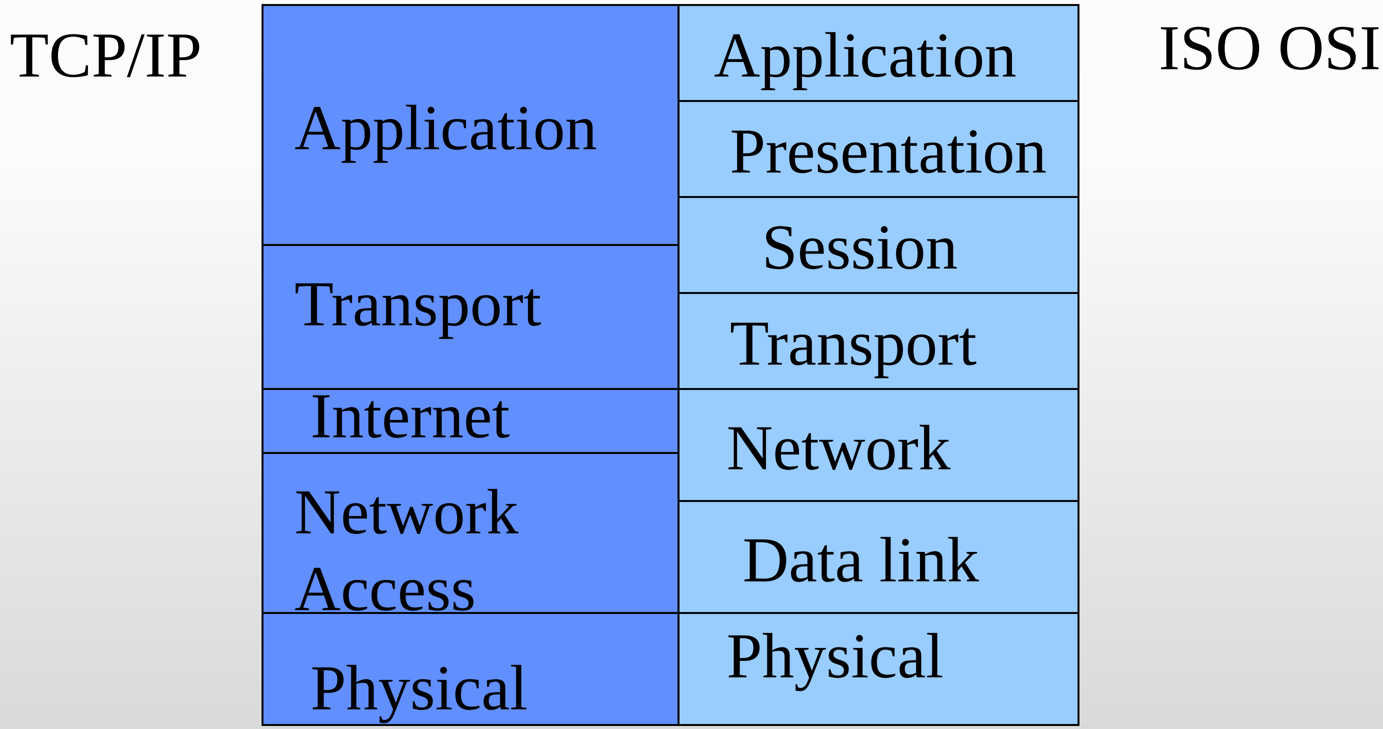
- *Layer 7:* ***Application***
  - *Application-specific protocols (e.g. ftp, http, smtp)*
- *Layer 4:* ***Transport***
  - *Delivery of data between computers (end-to-end).*
- *Layer 3:* ***Network***
  - *Data routing across a network.*
- *Layer 2:* ***Data Link***
  - *Reliable transmission over physical medium.*
- *Layer 1:* ***Physical***
  - *Transmission of bits between two nodes.*

OSI Protocol Stack

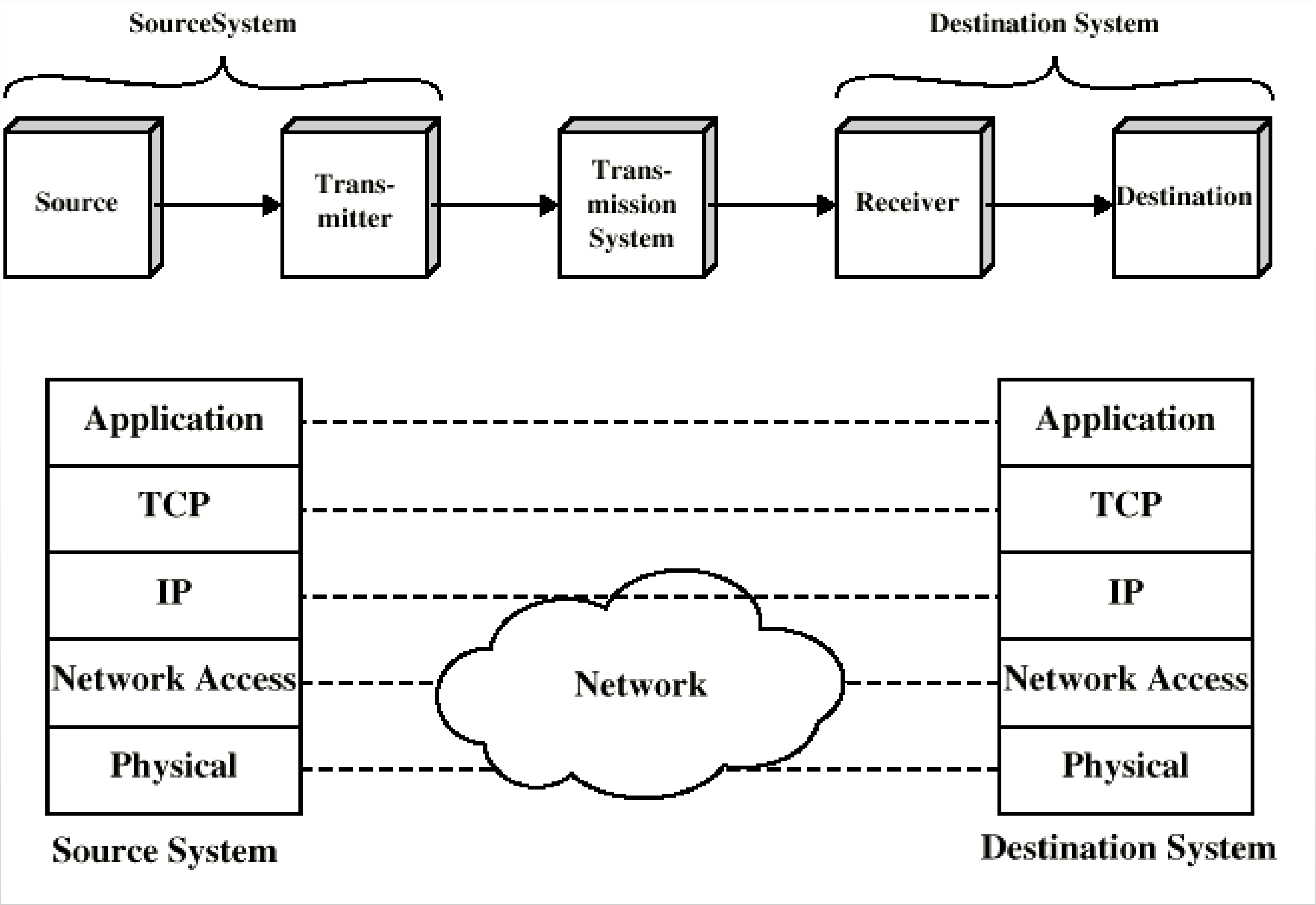


Example 2: TCP/IP Architecture

- *Model employed by the Internet.*

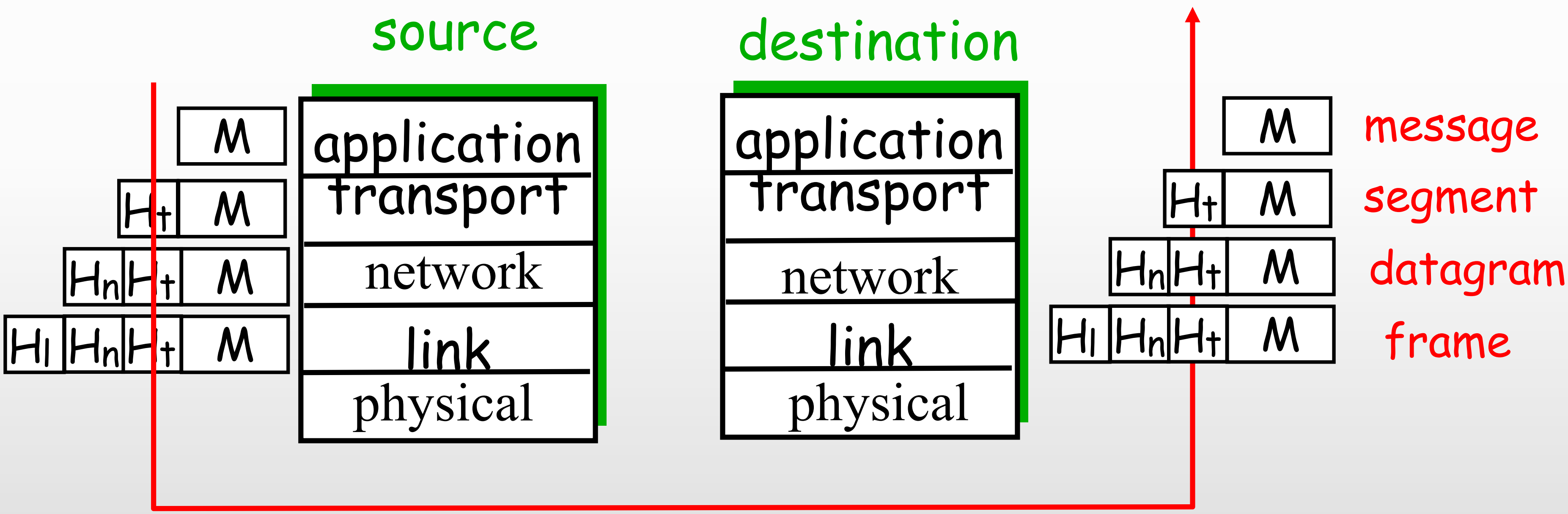


TCP/IP Protocol Architecture

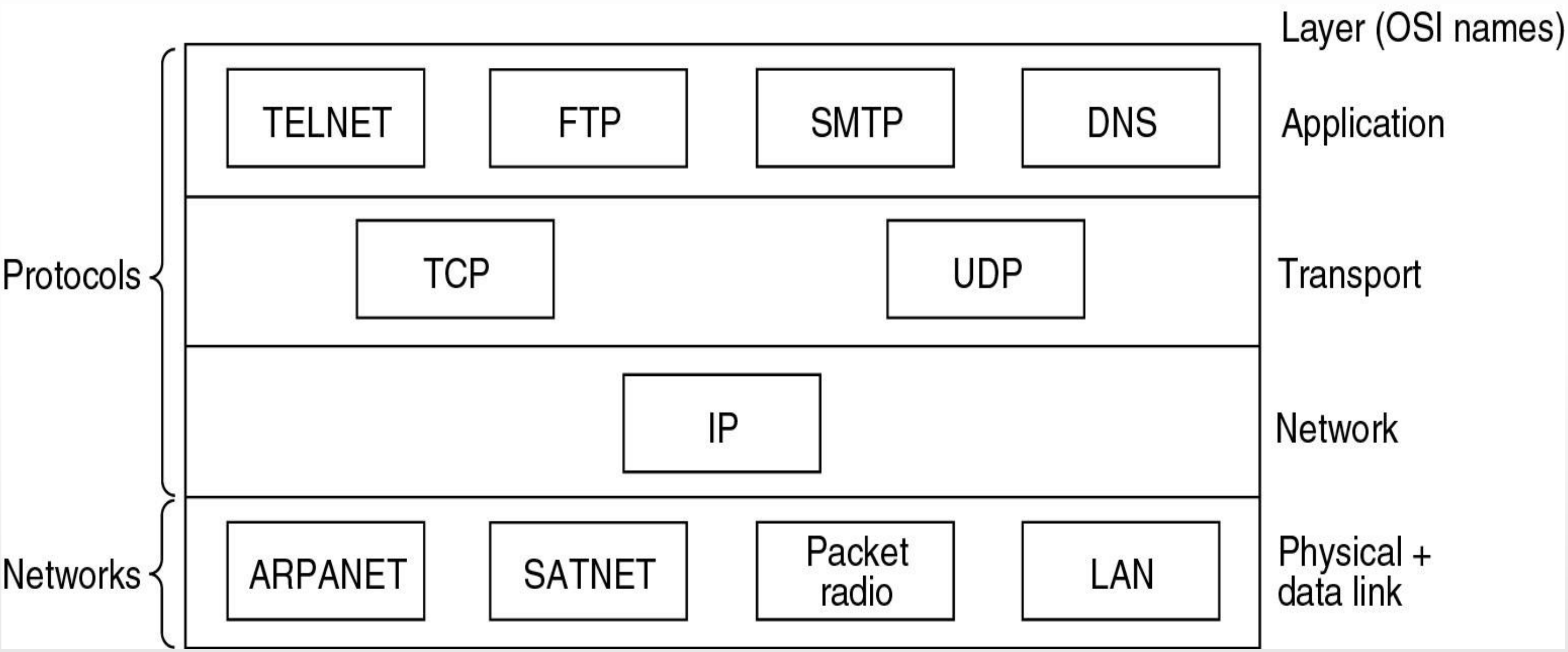


Messages and Protocol Stack

- *Example: Internet stack*

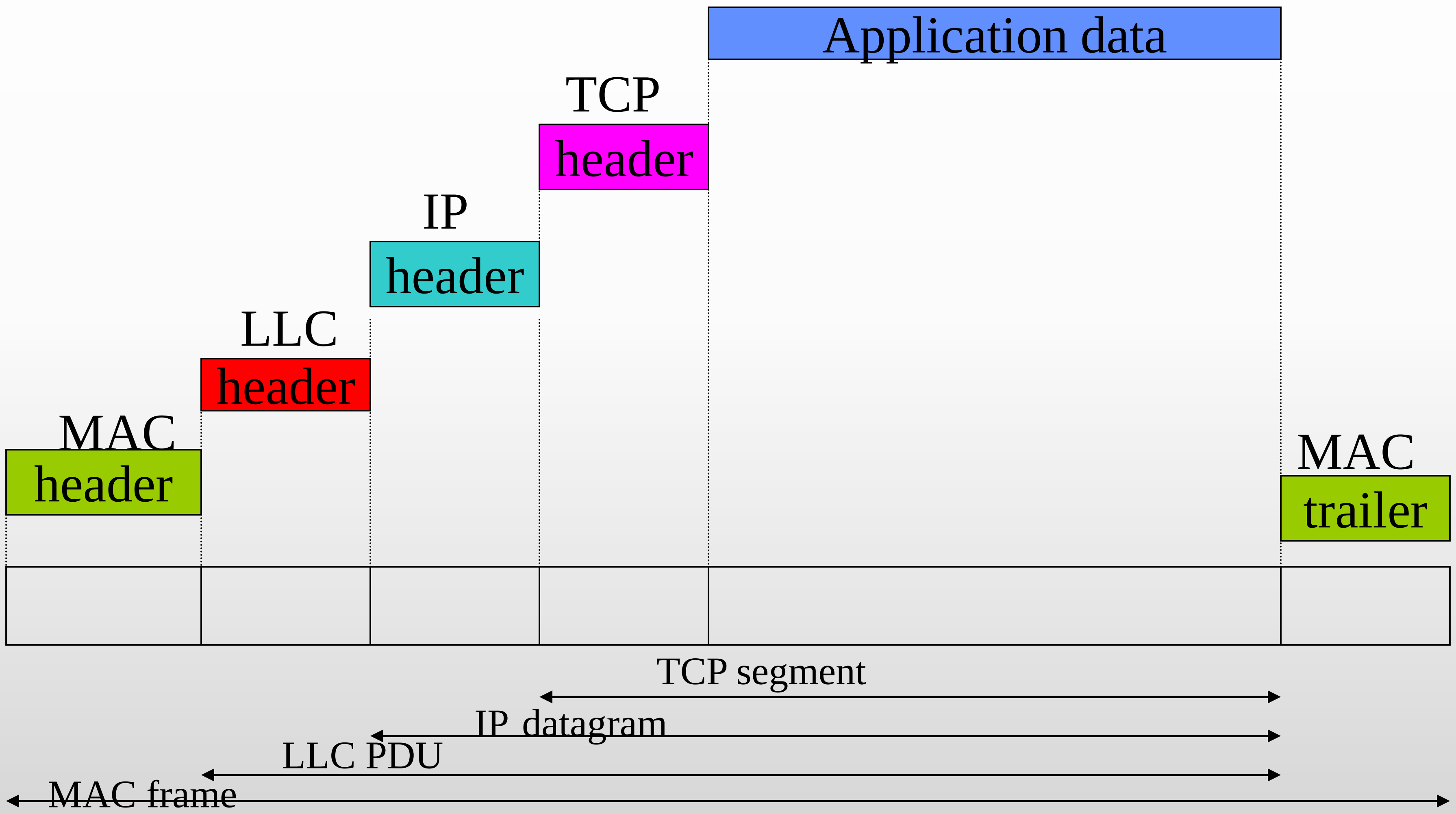


TCP/IP

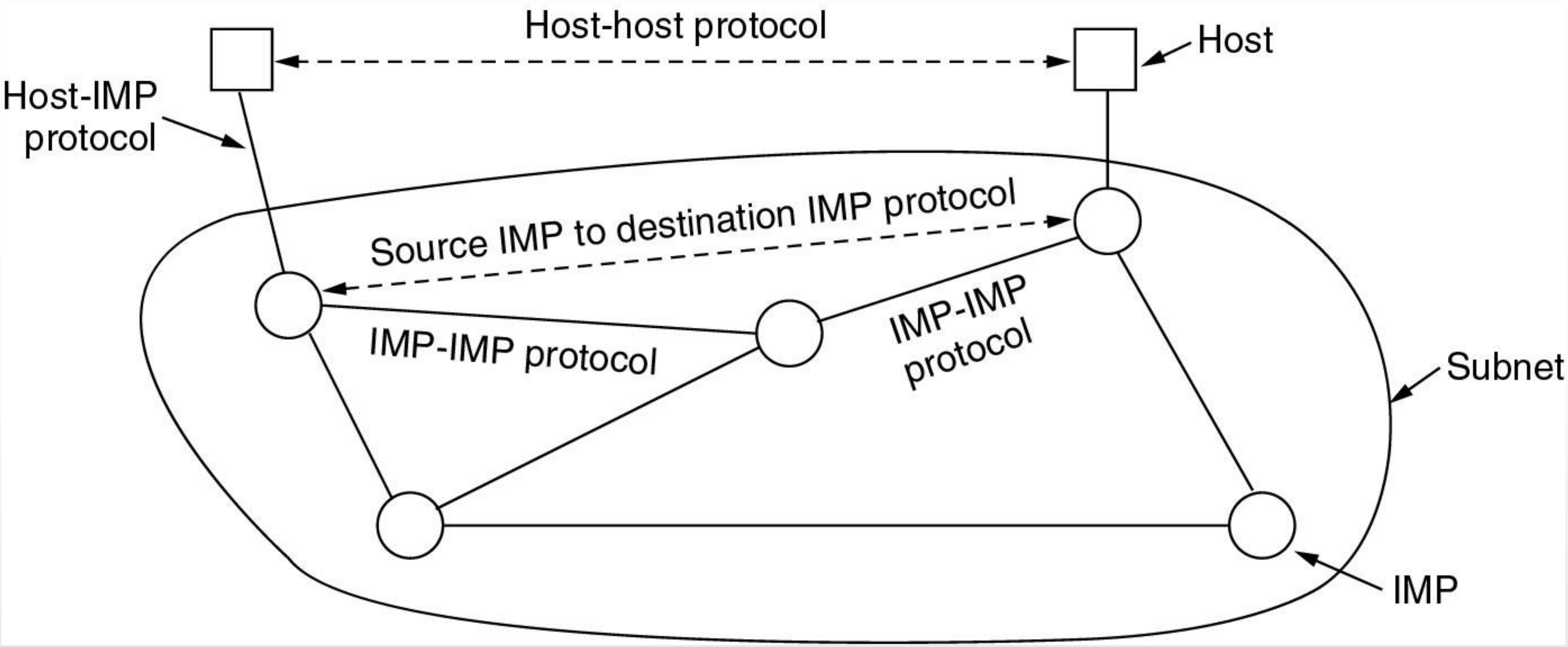


Layer (OSI names)
TELNET
FTP
SMTP
DNS
Application
Protocols
TCP
UDP
Transport
IP
Network
Networks
ARPANET
SATNET
Packet radio
LAN
Physical + data link

Encapsulation



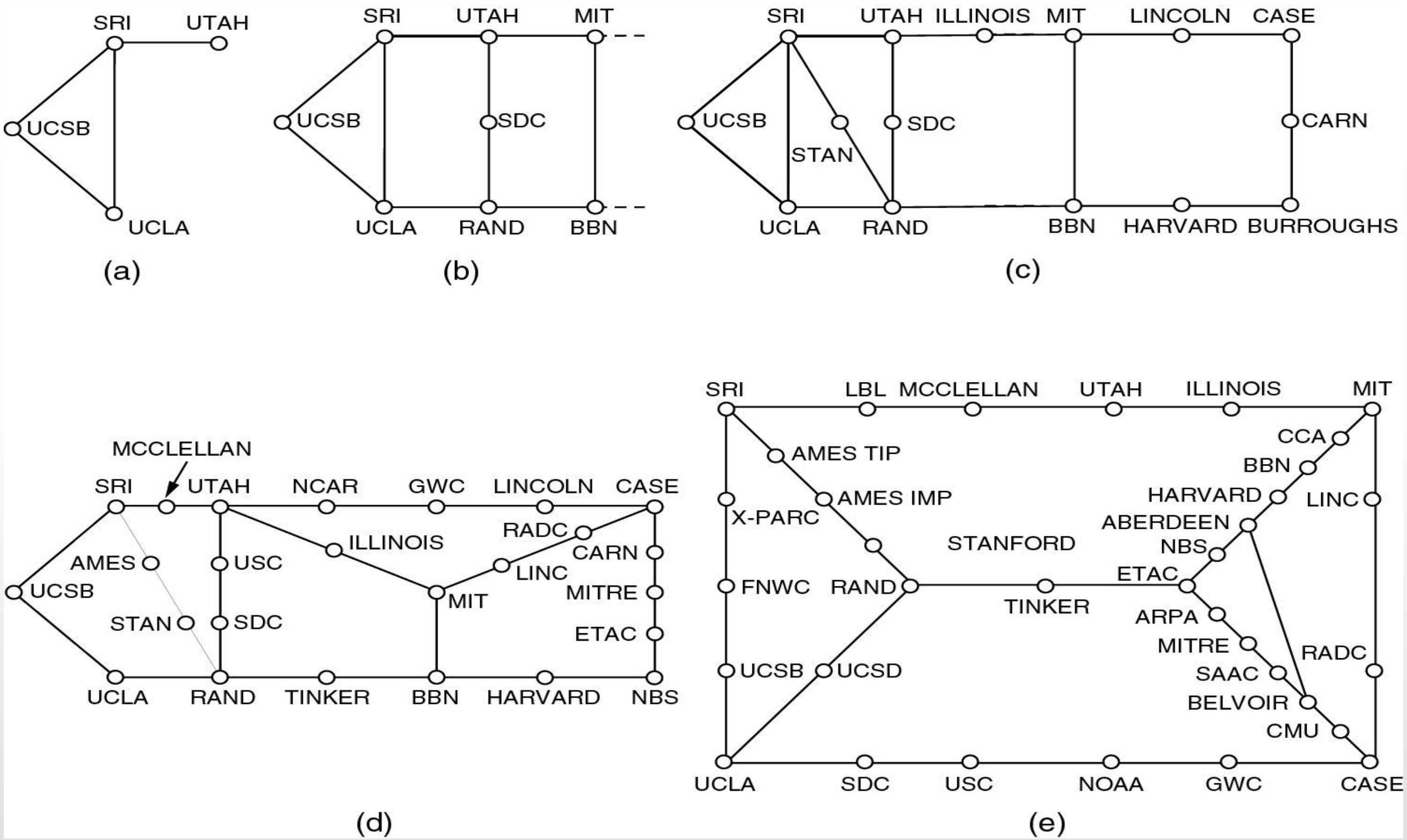
The ARPANET



The original ARPANET design.

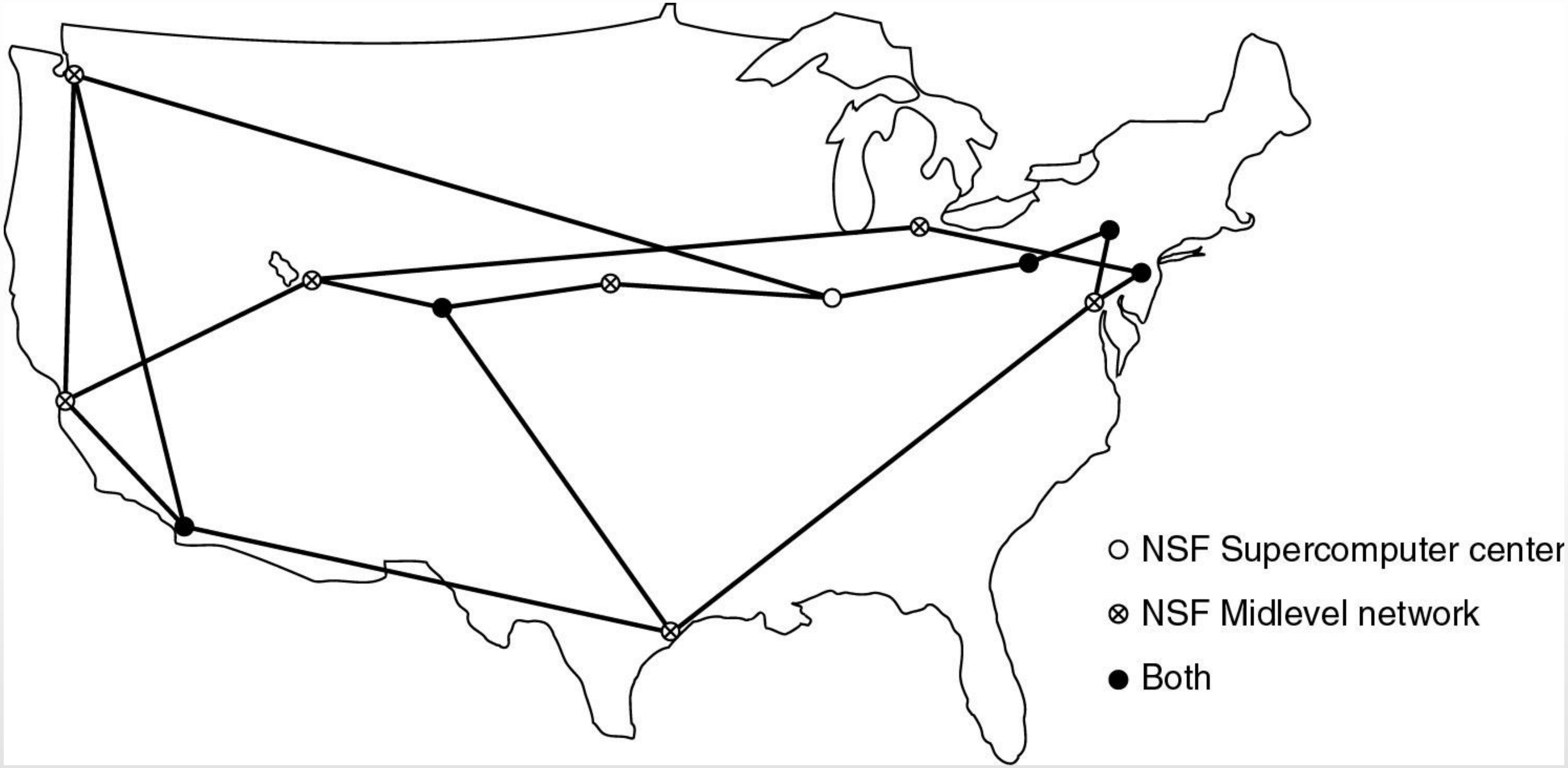
IMP = Interface Message Processor (Honeywell DDP-316)

The ARPANET Evolution



Growth of the ARPANET (a) December 1969. (b) July 1970. (c) March 1971. (d) April 1972. (e) Sept. 1972.

NSFNET

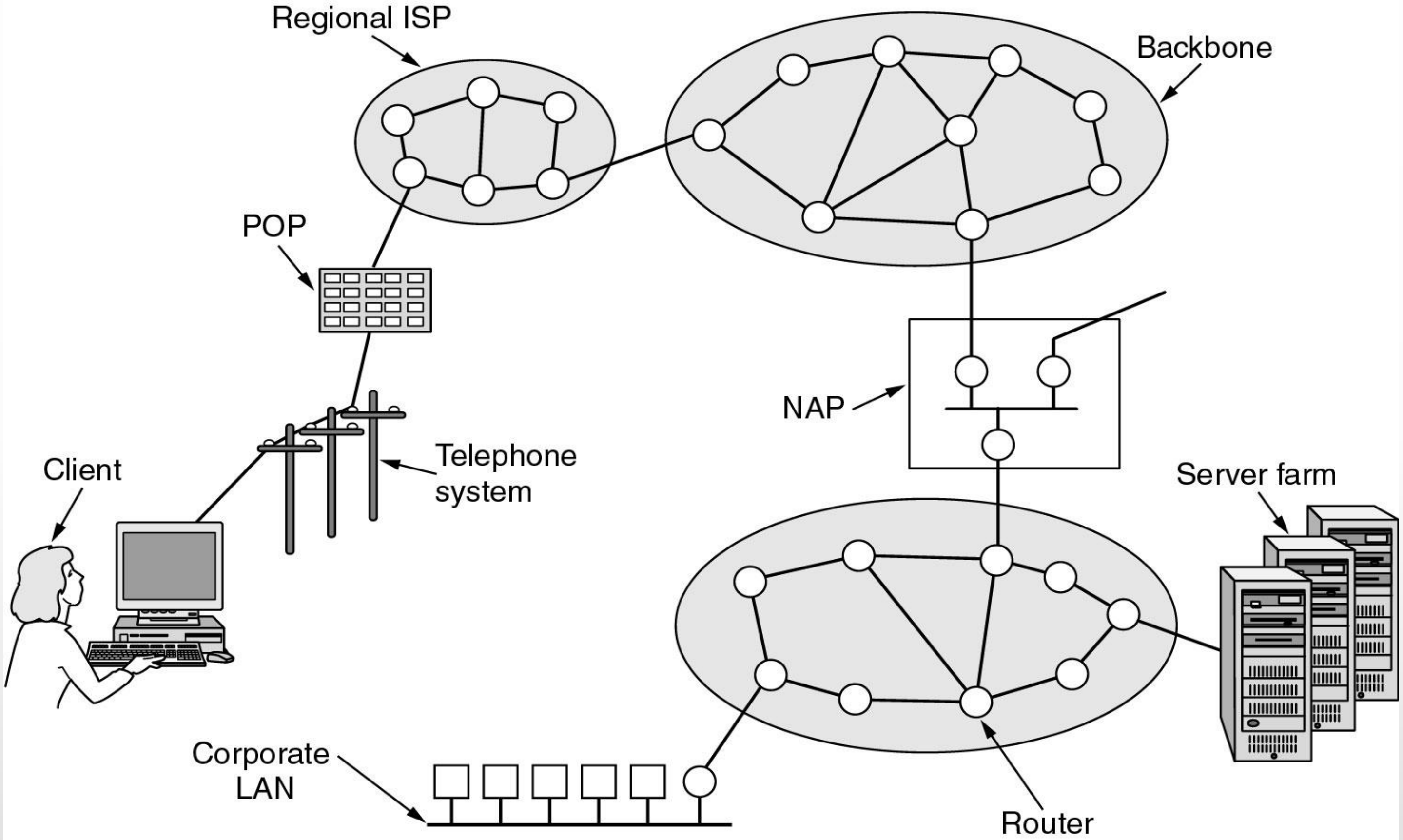


The NSFNET backbone in 1988.

Internet Usage

- *Traditional applications*
  (1970 – 1990)
- *E-mail*
- *News*
- *Remote login*
- *File transfer*

Architecture of the Internet



The Internet: Some Recent History

- *Between 1980 and 2000: the boom!*
  - *Internet changed from small, experimental research project into the world's largest network.*
  - *In 1981, 100 computers at research centers and universities.*
  - *20 years later, 60M computers!*
- *Early 1990's, the Web caused the Internet revolution: the Internet's killer app!*
- *Today:*
  - *Almost 60 million hosts as of 01.99.*
  - *Doubles every year.*

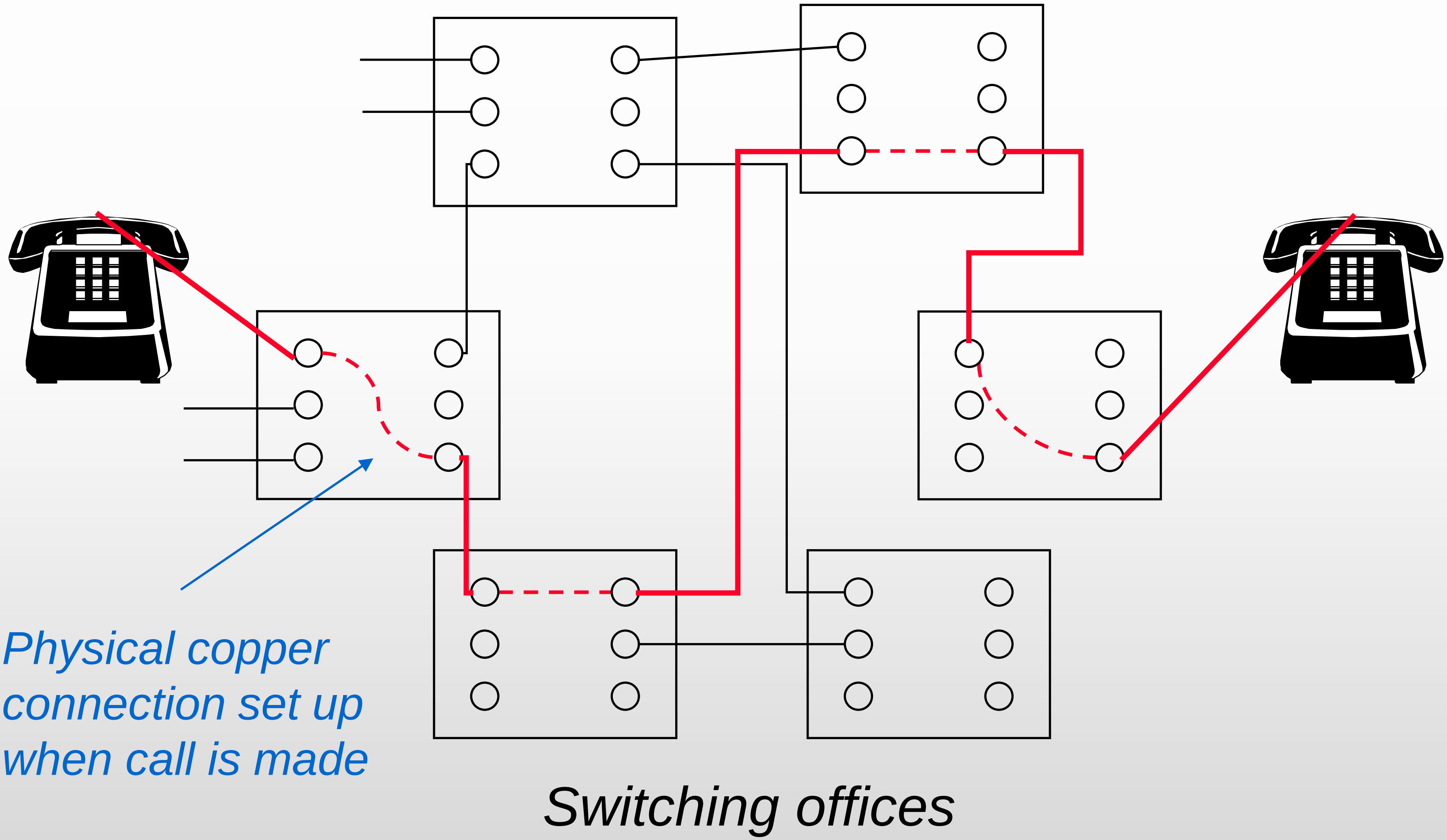
Types of Networks

- *Circuit switching versus message switching.*

Circuit Switching

- *Old telephone technology*
- *For each connection, physical switches are set in the telephone network to create a* ***physical "circuit"***
  - *That's the job of the switching office*

Circuit Switching - Example



Circuit Switching (cont'd)

- *Switches are set up at the beginning of the connection and maintained throughout the connection*
- *Network resources* ***reserved*** *and* ***dedicated*** *from sender to receiver*
- *Not a very efficient strategy*
  - *A connection "holds" a physical line even during "silence" periods (when there is nothing to transmit)*

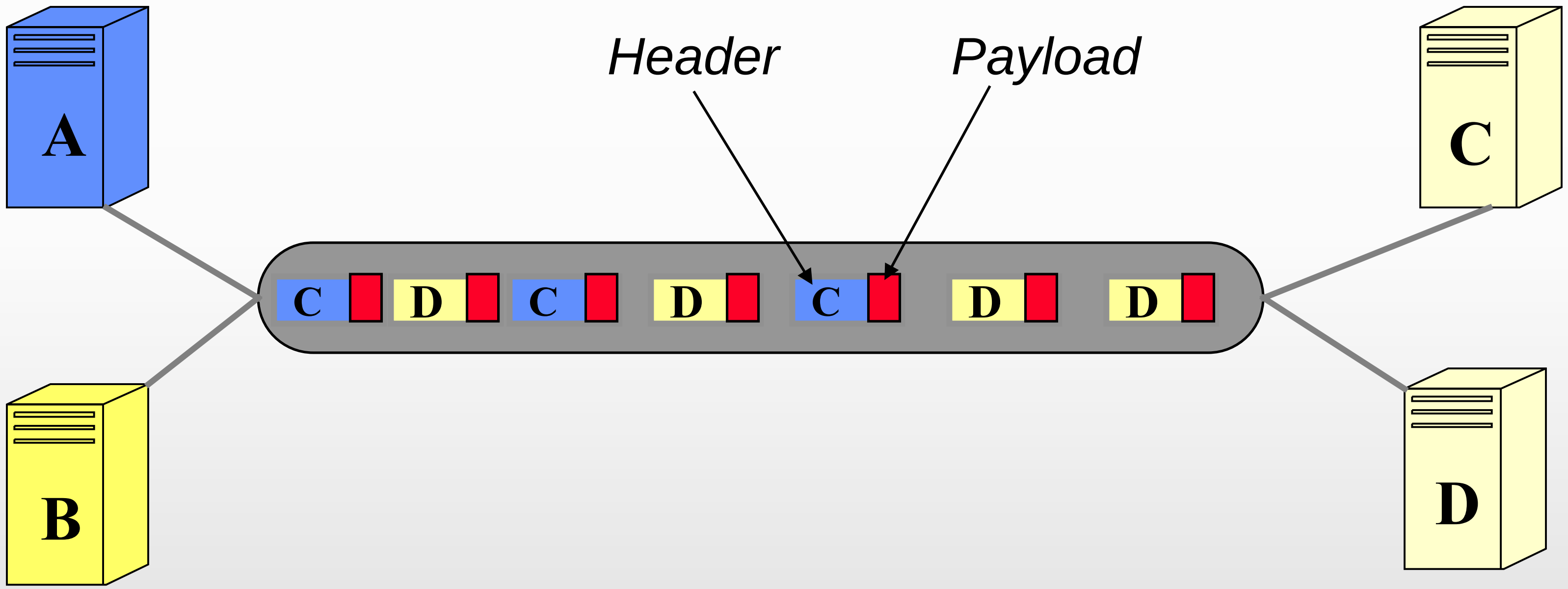
Message Switching

- *No physical path established!*
- *Whenever sender has data to send, sends it.*
  - *Data stored at first router then forwarded.*
  - **Store-and-forward** *networks.*
- *Sharing by taking turns.*
  - *Analogy: conveyor belt in a warehouse.*
  - *Items are picked from the storage room and placed on the conveyor belt every time a customer makes an order.*
  - *Different customers may request a different number of items.*
  - *Different users' items may be interspersed on the conveyor belt (they are "multiplexed").*

Packet Switching

- *Upper bound on size of unit to be handled at the network layer.*
- *Why?*
  - *Fairness.*
- *What kind of implementation used by Internet?*

Packet Switching Example



Packet Switching

- *Each packet is composed by the **payload** (the data we want to transmit) and a **header.***
  - *The header contains information useful for network layer functions.*
  - *Contains:*
    - *Source (sender's) address*
    - *Destination (recipient's) address*
    - *Packet size*
    - *Sequence number*
    - *Error checking information*

Packet Switching (cont'd)

- *The header introduces **overhead**, that is, additional bits to be sent.*
  - *Therefore, it is not wise to have packets that are too small.*
    - *What happens if the payload is just 1 bit?*
- ***Addresses***
  - *Each computer attached to a network is assigned a unique **number** (called **address**).*
  - *A packet contains the address of the sender and the receiver.*

Packet Switching (cont'd)

- *In general, packets need not be of the same size*
  - *Maximum transmission unit (MTU)*
  - *No minimum size*
    - *But, header size is fixed (e.g., 20 bytes for TCP/IP).*
- *Original data chopped up into packets.*
  - *The application (e.g., email) does not know that the data to be transmitted is packetized.*
  - *When packets are received, they are put together before the application accesses the data*

Packet Switching (cont'd)

- *What kind of **delay** should we expect?*
  - *Time-division multiplexing: **constant delay.***
  - *Packet switching multiplexing: **variable delay** (it depends on the **traffic** on the line).*
    - *Conveyor belt example: if there are many customers before you, you may have to wait more.*

Circuit Switching vs Packet Switching

Circuit switching

- *Must set up a connection (initial delay)*
- *Connection is reliable*
- *Resources are dedicated*
  - *Therefore they are used inefficiently!*

Packet switching

- *Very small set-up delay*
- *Efficient shared use of resources*
- *Possible congestion and consequent packet dropping*

Types of Network Services

- *Connectionless versus connection-oriented.*

Circuit Switching

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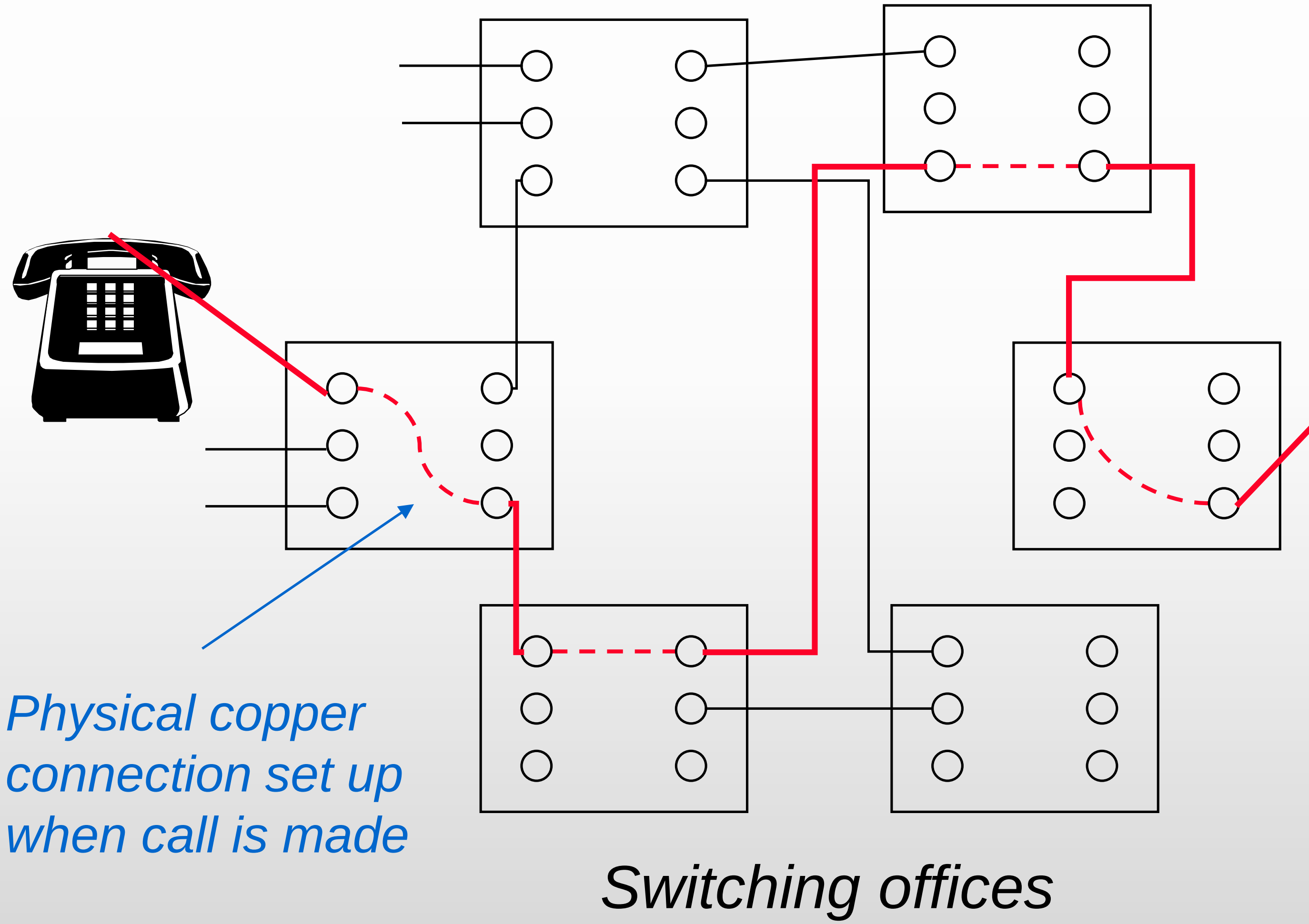
Circuit Switching - Example



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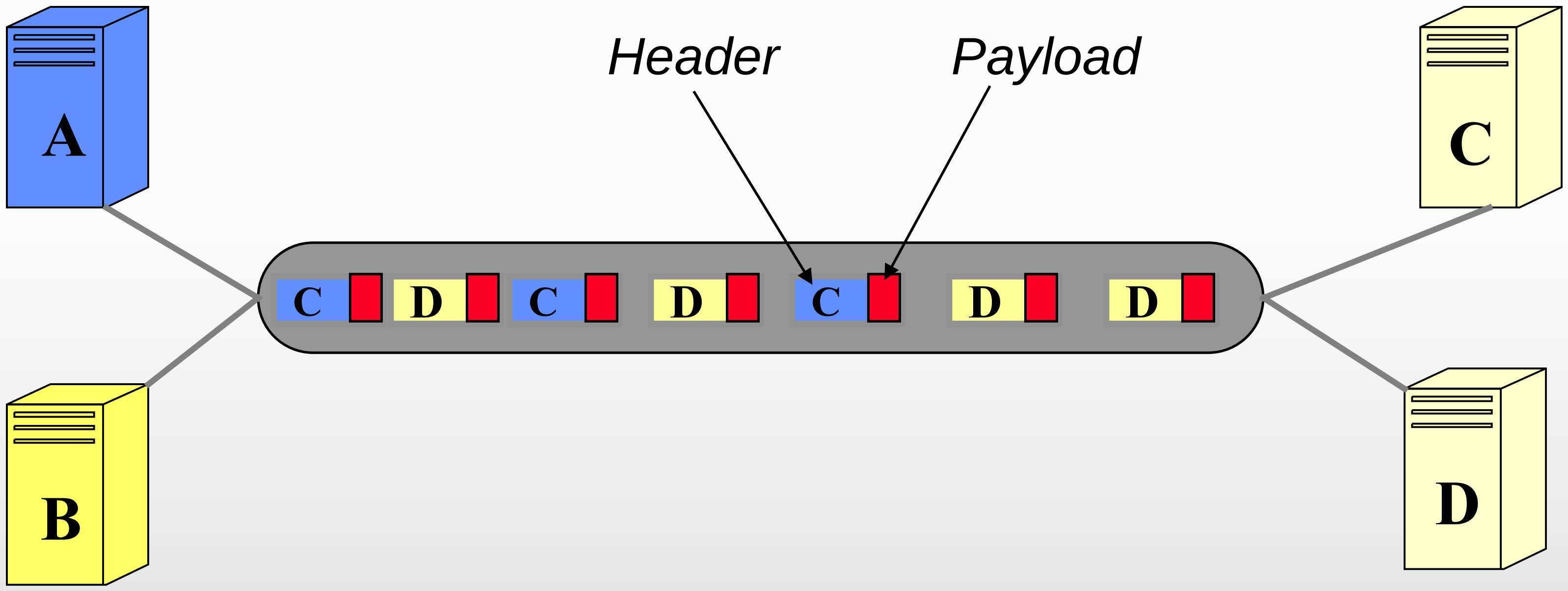
Packet Switching Example



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The Internet

- *Example of packet switching network!*

Packet Switching (cont'd)

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Circuit Switching vs Packet Switching

Circuit switching

- *Must set up a connection (initial delay).*
- *Resources are dedicated*
  - *Therefore they may be used inefficiently!*
- *But, performance is predictable as resources are reserved.*

Packet switching

- *Very small set-up delay.*
- *Efficient shared use of resources.*
- *Possible congestion and consequent packet dropping*
- *Performance is unpredictable and is a function of current traffic conditions.*

Types of Network Services

- *Connectionless versus connection-oriented.*

Datagram and Virtual Circuit

- *Packet switching networks can provide 2 different types of services to transport layer.*
  - *Virtual circuit or "connection-oriented" service.*
  - *Datagram or "connectionless" service.*

Virtual Circuit

- *Analogy to physical circuits used by telephone networks.*
- *At connection establishment time, path from source to destination is selected and used throughout connection lifetime.*
- *When connection is over, virtual circuit terminated.*

Datagram

- *No logical connection.*
- *Each packet (datagram) routed independently; successive packets may follow different routes.*
- *More work at intermediate routers, but more robust and adaptive to failures and congestion.*

The Internet

- *Datagram network!*
- *Datagrams are formed by **header** and **payload.***
- *IP Datagrams can have different sizes*
  - *Header is fixed (20 bytes)*
  - *Data area can contain between 1 byte and 65 KB*

Forwarding Datagrams

- *Header contains all information needed to deliver datagrams to **destination.***
  - *Destination address.*
  - *Source address.*
- *Router examines header of each datagram and forwards it along path to destination.*

Routers

- *For VCs, routers keep a table with (VC number, outgoing interface) entries.*
  - *Packets only need to carry VC number.*
- *For datagrams, routing table.*
  - *(destination, outgoing interface) entries.*
  - *Each packet must carry destination address.*

Examples

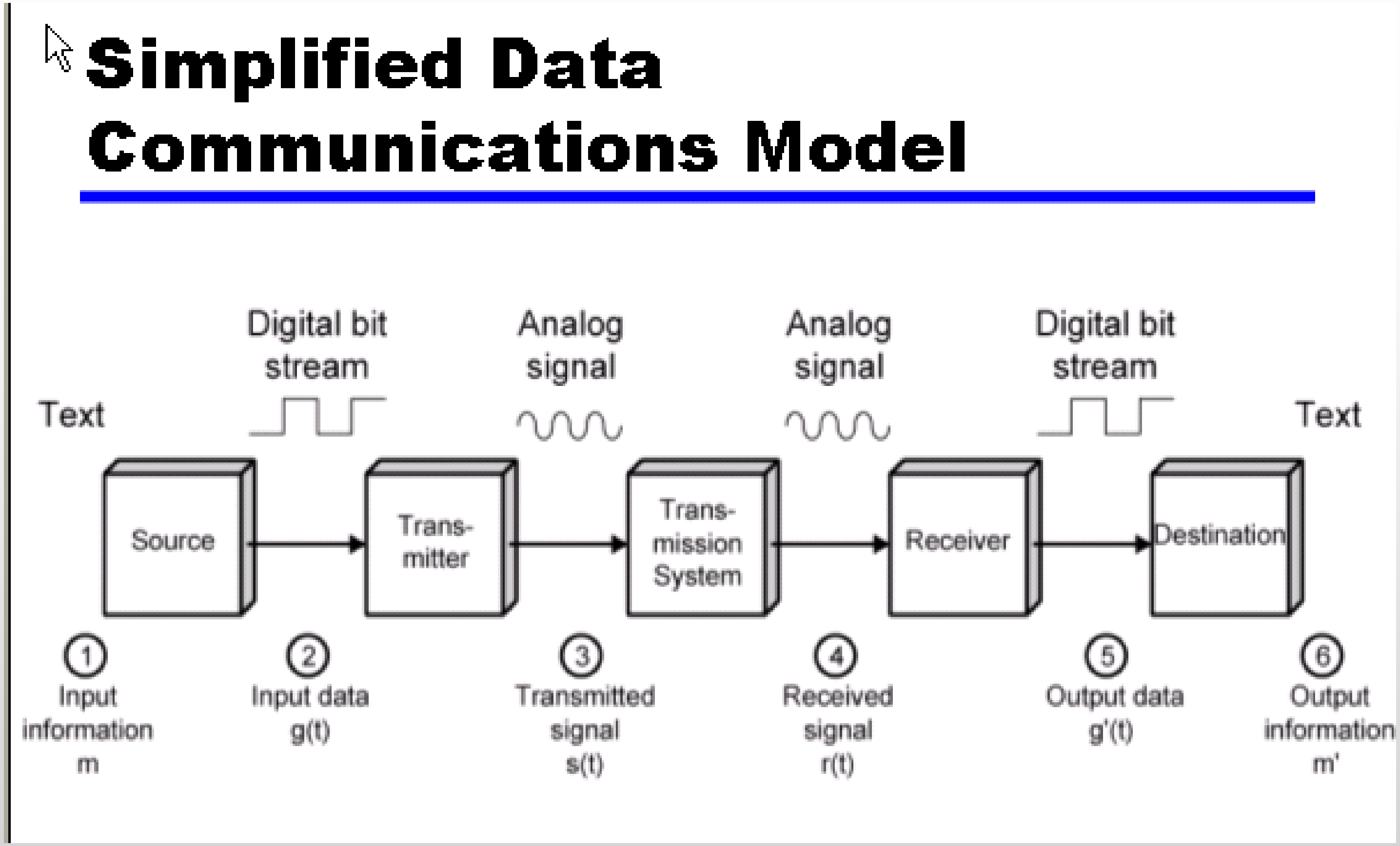
- ***Internet Layer***
  - *Connectionless*
  - *Internet Protocol (IP)*
  - *Task is to deliver packets to destination*
- ***Transport Layer***
  - *Transmission Control Protocol (TCP)*
    - *Connection-oriented*
    - *Reliable*
  - *User Datagram Protocol (UDP)*
    - *Connectionless*
    - *Unreliable*

The Physical (PHY) Layer

- *Transmitting information on wires.*
- *How is information represented?*
  - *Digital systems.*
  - *Analog systems.*

Signals and Systems

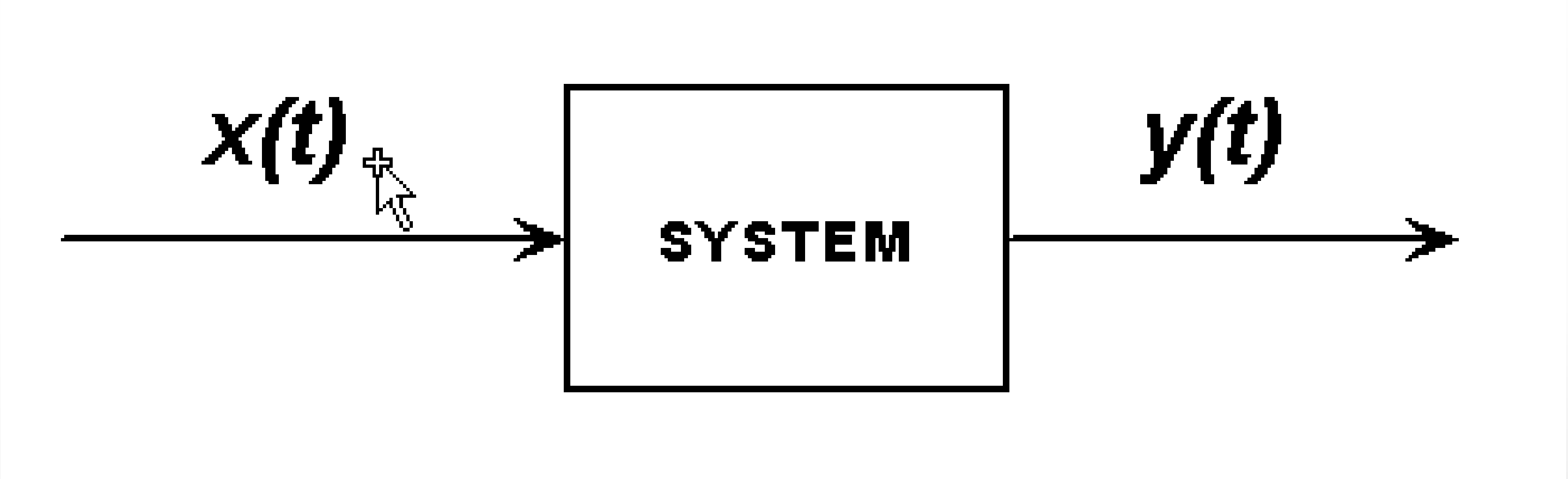
What is a *signal*?
What is a *system*?



Signals and Systems (cont'd)

- *Signal: electro-magnetic wave carrying information.*
  - Time varying function produced by physical device (voltage, current, etc.).
- System: device (or collection thereof) or process (algorithm) having signals as input and output.

Signals and Systems (cont'd)



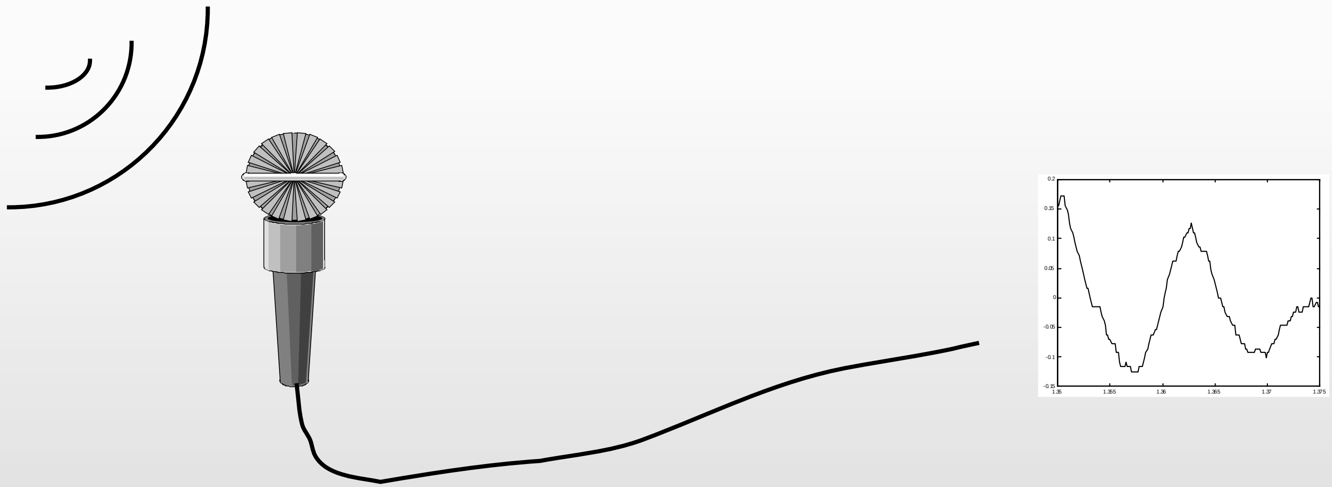
Signals and Systems (cont'd)

- Periodic signals:
  - $f(t+T) = f(t)$ Period = T (seconds)

- Frequency = 1/ Period
  - "cycles" / sec. = Hertz (Hz)

Analog Technology

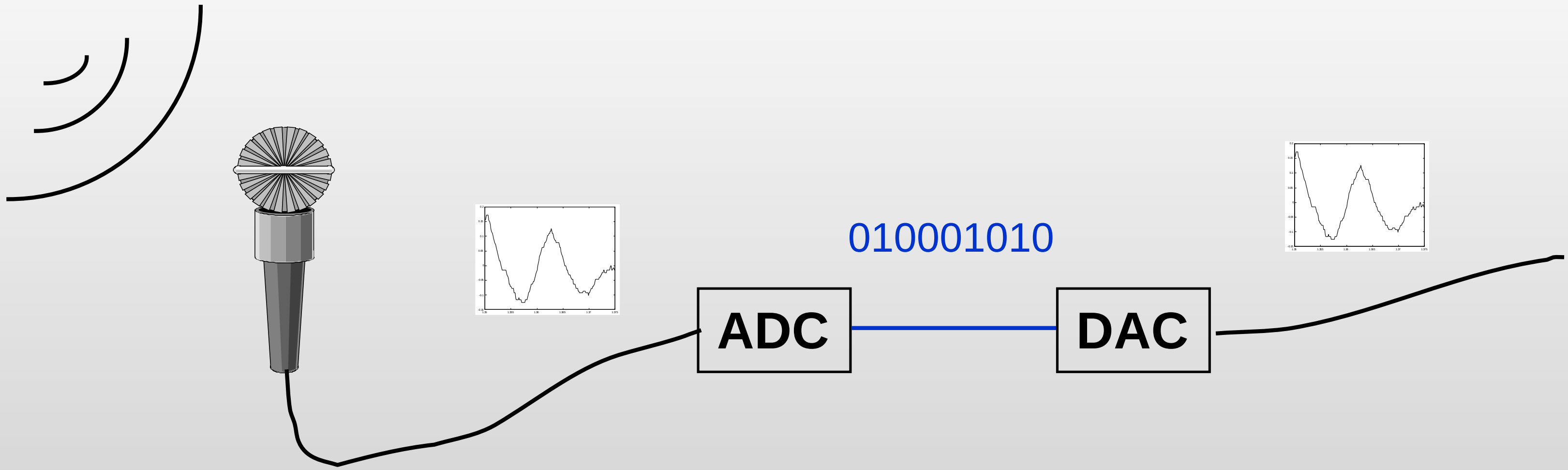
- *Analog devices maintain exact physical analog of information.*
  - *E.g., microphone: the voltage v(t) at the output of the mic is proportional to the sound pressure*



v(t)

Digital Technology

- *It uses **numbers** to record and process information*
  - *Inside a computer, all information is represented by numbers.*
    - *Analog-to-digital conversion: **ADC***
    - *Digital-to-analog conversion: **DAC***



Digital Technology

- *All signals (including multimedia) can be encoded in digital form.*
- *Digital information does not get distorted while being stored, copied or communicated.*

Digital Communication Technology

- *Early example: the **telegraph** (Morse code).*
  - *Uses dots and dashes to transmit letters.*
  - *It is digital even though uses electrical signals.*
- *The telephone has become digital.*
- *CDs and DVDs.*
- *Digital communication networks form the Internet.*
- ***The user is unaware that the signal is encoded in digital form.***

Two Levels are Sufficient

- *Computers encode information using only two levels: 0 and 1.*
- *A **bit** is a digit that can only assume the values 0 and 1 (it is a **bi**nary dig**it**).*
- *A **word** is a set of **bits***
  - *Example: <u>ASCII standard for encoding text</u>*
    - *A = 1000001; B = 1000010; …*
- *A **byte** is a word with **8 bits.***

Definitions

- *1 KB = 1 kilobyte = 1,000 bytes = 8,000 bits*
- *1 MB = 1 megabyte = 1,000 KB*
- *1 GB = 1 gigabyte = 1,000 MB*
- *1 TB = 1 terabyte = 1,000 GB*

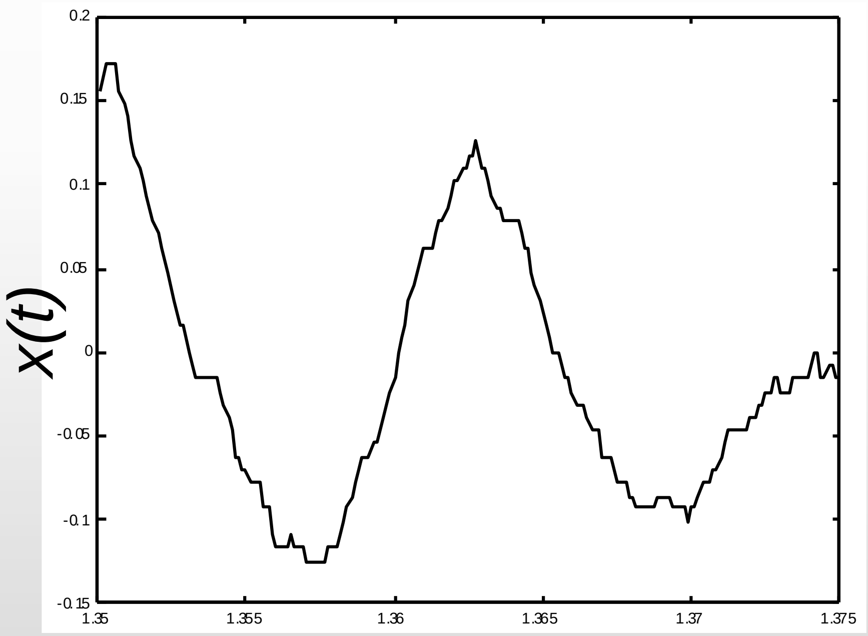
- *1 Kb = 1 kilobit = 1,000 bits*
- *1 Mb = 1 megabit = 1,000 Kb*
- *1 Gb = 1 gigabit = 1,000 Mb*
- *1 Tb = 1 terabit = 1,000 Gb*

Digitization

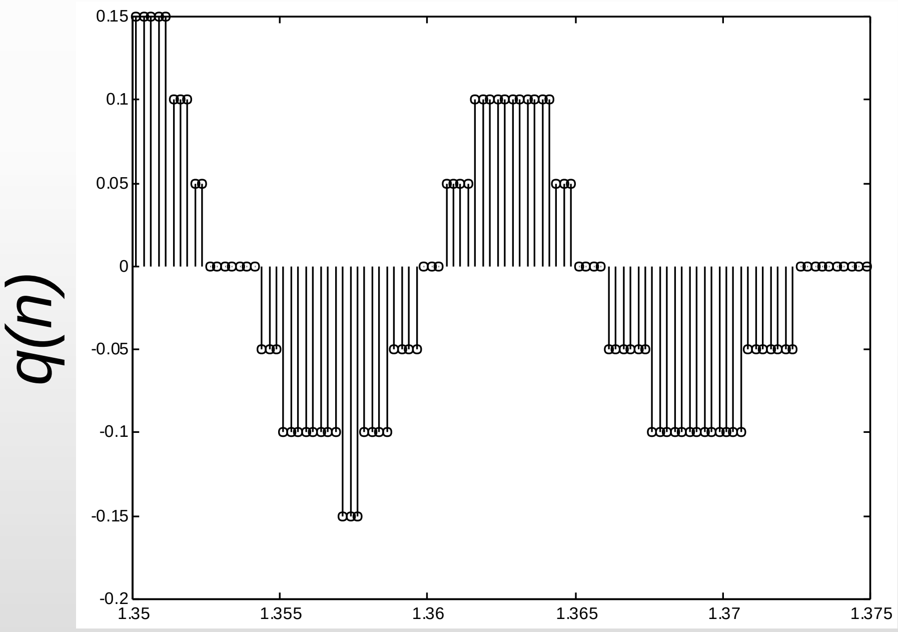
- ***Digitization*** *is the process that allows us to convert analog to digital (implemented by ADC).*
- ***Analog signals****: x(t)*
  - *Defined on continuum (e.g. time).*
  - *Can take on any real value.*
- ***Digital signals****: q(n)*
  - *Sequence of numbers (****samples****) defined by a discrete set (e.g., integers).*

Digitization - Example

Analog signal x(t)



Digitized signal q(n)



Some Definitions

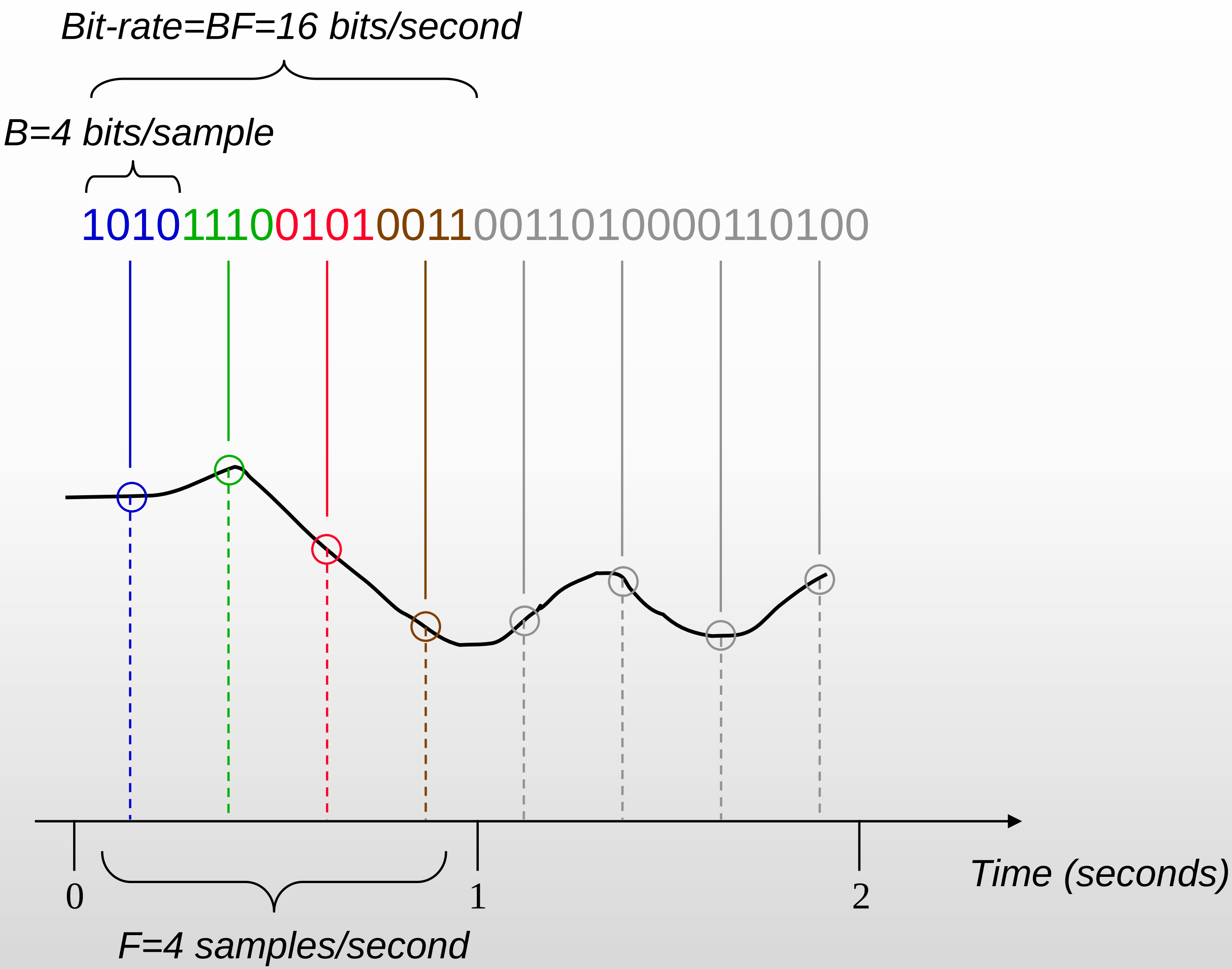
- *Interval of time between two samples:*
  - ***Sampling Interval** (**T**).*
- ***Sampling frequency F=1/T.***
- *E.g.: if the sampling interval is 0.1 seconds, then the sampling frequency is 1/0.1=10.*
  - *Measured in samples/second or Hertz.*
- *Each sample is defined using a **word** of B bits.*
  - *E.g.: we may use 8 bits (1 byte) per sample.*

Bit-rate

- ***Bit-rate*** *= numbers of bits per second we need to transmit*
  - *For each second we transmit F=1/T samples.*
  - *Each sample is defined with a word of B bits.*
  - ***Bit-rate = F*B.***

- *Example: if F is 10 samples/s and B=8, then the bit rate is 80 bits/s.*

Example of Digitization



Bit-rate - Example 1

- *What is the **bit-rate** of **digitized audio**?*
  - *Sampling rate: F= 44.1 KHz*
  - *Quantization with B=16 bits*
  - ***Bit-rate** = BF= 705.6 Kb/s*
  - *Example: 1 minute of uncompressed stereo music takes more than 10 MB!*

Bit-rate - Example 2

- *What is the bit-rate of **digitized speech?***
  - *Sampling rate: F = 8 KHz*
  - *Quantization with B = 16 bits*
  - ***Bit-rate** = BF = 128 Kb/s*

Data Transmission

- *Analog and digital transmission.*
  - *Example of analog data: voice and video.*
  - *Example of digital data: character strings*
    - *Use of codes to represent characters as sequence of bits (e.g., ASCII).*
- *Historically, communication infrastructure for analog transmission.*
  - *Digital data needed to be converted: modems (modulator-demodulator).*

Digital Transmission

- *Current trend: digital transmission.*
  - *Cost efficient: advances in digital circuitry. (VLSI).*
- *Advantages:*
  - *Data integrity: better noise immunity.*
  - *Security: easier to integrate encryption algorithms.*
  - *Channel utilization: higher degree of multiplexing (time-division mux’ing).*