Computer Networks

Introduction

FIFTH EDITION

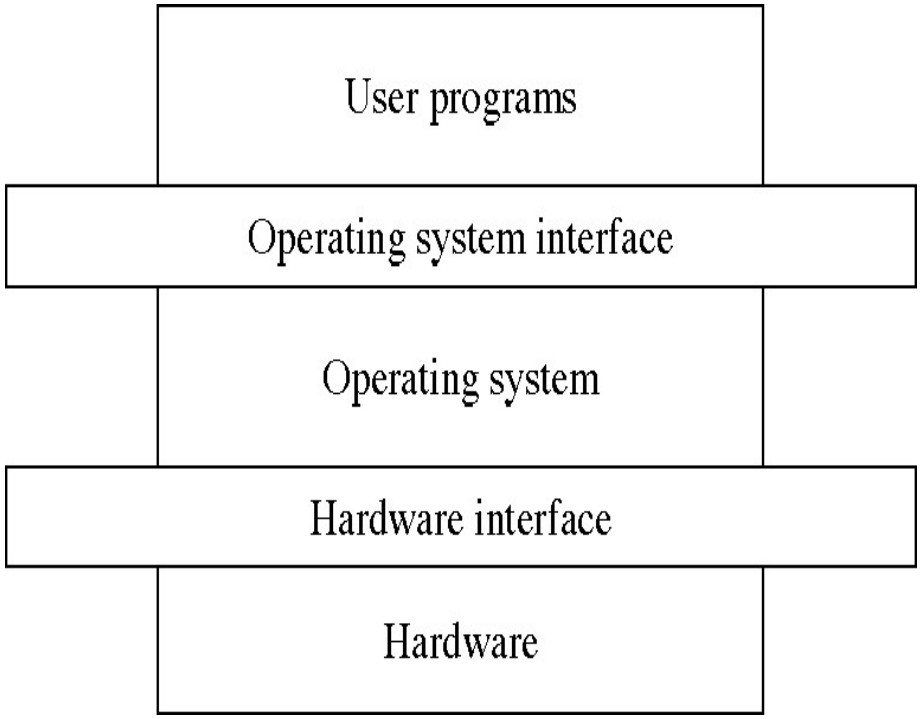
COMPUTER NETWORKS

TANENBAUM | WETHERALL

Topics completed: Operating system

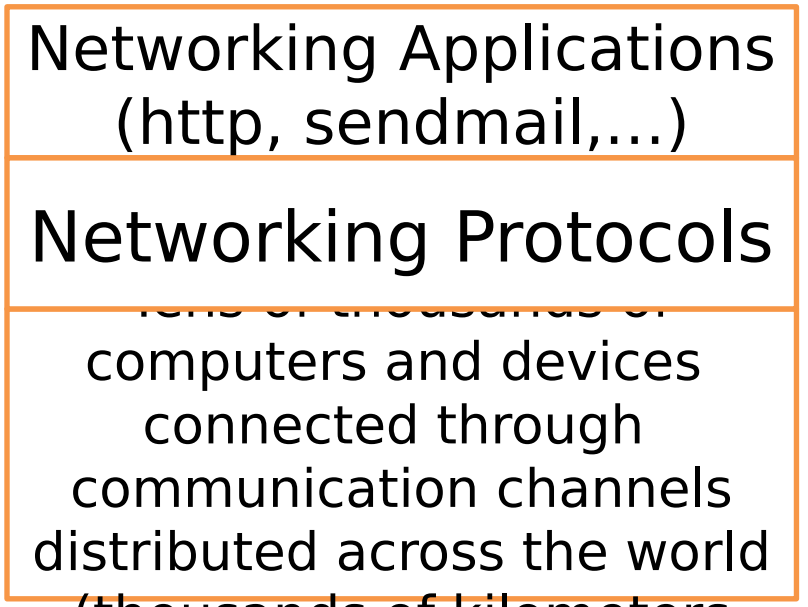
- Input: hardware
-
- Output is system calls to develop applications

- Objectives: to improve throughput and response time, deadlines, waiting time



Topics to be completed: Networking

- Input: thousands of computers connected through communication channels
- Output is primitives to develop applications
- Objectives: to improve throughput, reliability, and response time, deadlines, waiting time



How it is different from producer and consumer problem

- Producer places an item and consumer consumes an item from the buffer.
- Normally in the same computer
- Producer waits if the buffer is full, consumer waits if buffer is empty.
- How to enable producer and consumer to exchange data, suppose a video if
- Producer is in one computer
- Consumer is another computer
- Connected through long communication channel (thousands of kilometers)

- Issues
  Links might not be reliable
  All the data may not be delivered
  More mechanisms are needed.

Layered model

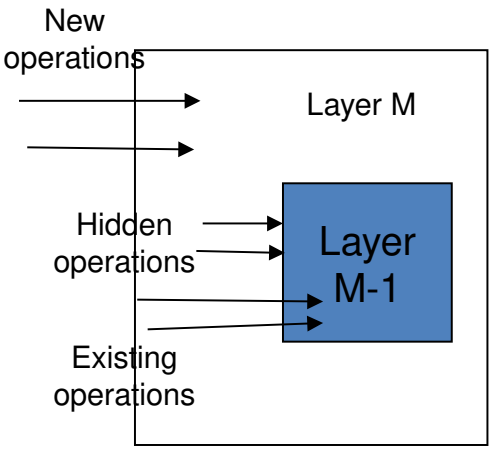
Layered model
- Divide the roles/issues among layers

Develop each layer
- Lower layer provides services to higher layer.

Structure view: layered system design

A general philosophy that builds on the above approach

- Decompose functionality into layers such that
  - Hardware is level 0, and layer t accesses functionality at layer (t-1) or less
  - Access via appropriately defined system calls.



Advantages

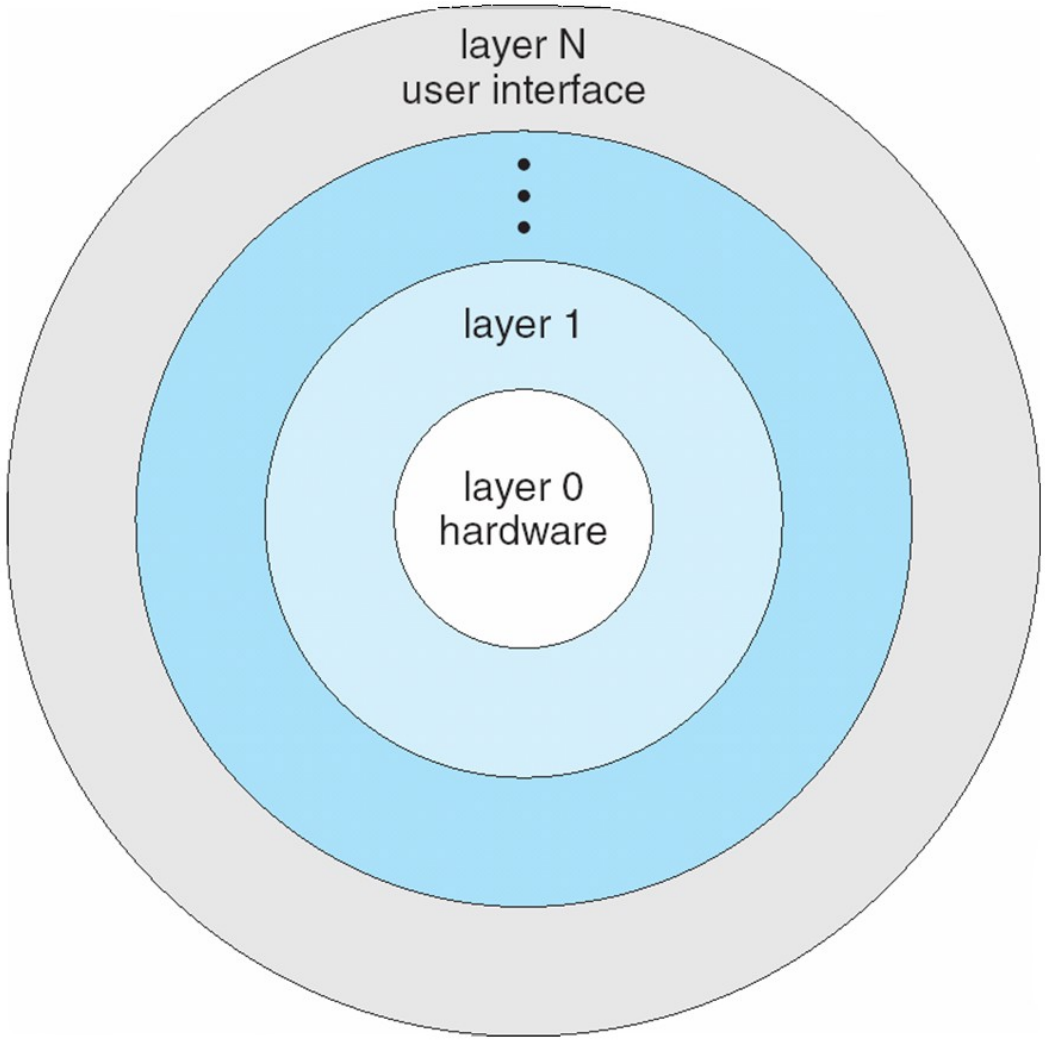
- Modular design: well defined interfaces between layers
- Prototyping/development
  - Association between function and layer eases overall OS design.
  - OS development and debugging is layer by layer.
  - Simplifies debugging and system verification

Layered Approach

- The operating system is divided into a number of layers (levels), each built on top of lower layers. The bottom layer (layer 0), is the hardware; the highest (layer N) is the user interface.

- With modularity, layers are selected such that each uses functions (operations) and services of only lower-level layers

Layered Operating System



OS design hierarchy: hypothetical model

Level	Name	Objects	Example operations
15	Shell	User programming environment	Statements in shell language
14	Directories (maintains association between external and internal identifiers of system resources and objects)	Directories	Create, destroy, search, list, access rights
13	User Processes	User process	Fork, quit, kill, suspend, resume
12	Stream I/O	streams	open., close
11	Devices (access to external devices)	Printers, displays, and key boards	Create, destroy, open, close, read, write
10	File system (long storage of named files)	files	Create, destroy, open, close
9	Communications	pipes	Create, destroy, open, close, read, write
8	Capabilities	Capabilities	Create, Validate, Attenuate
7	Virtual memory (creating logical address space for programs)	Segments, pages	Read, write, fetch
6	Local secondary storage (position of read/write heads)	Blocks of data, device channels	Read, write, allocate, free
5	Primitive processes	Primitive process, semaphores, synchronization premitives	Suspend, resume, wait, signal
4	Interrupts	Interrupts handling programs	Invoke, mask, unmask, retry
3	Procedures	Procedures, call stack	Mark stack, call, return
2	Instruction set	Evaluation, stack, micro-program, interpreter	Load, store, add, subtract, branch
1	Electronic circuits	Registers, gates, busses	Clear, transfer, activate, complement

Overview of this chapter

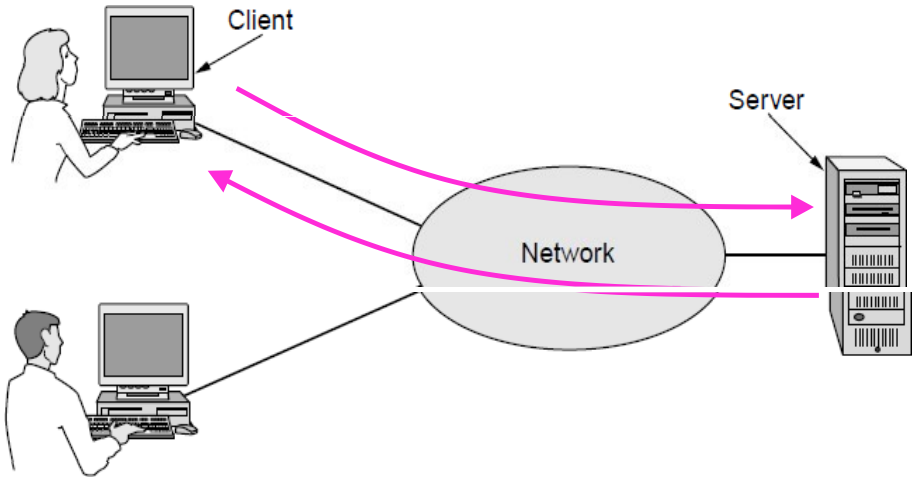
- Introduction
- Uses of Computer Networks
- Network Hardware
- Network Software
- Reference Models
- Example Networks
- Network Standardization
- Metric Units

Introduction

- 18th century is dominated by mechanical systems
- 19th century is the age of steam engine
- 20th century- Information Technology
  - Information gathering processing and distribution
  - Others: radio, television, telephones, communication satellites and Internet
- Computer network
  - Large number of separate but interconnected computers.
- Distributed system: A collection of independent computers which appears to users as single coherent system. Another layer such as world wide web is presented on the top of computer network
- In computer network, users are exposed to machines.

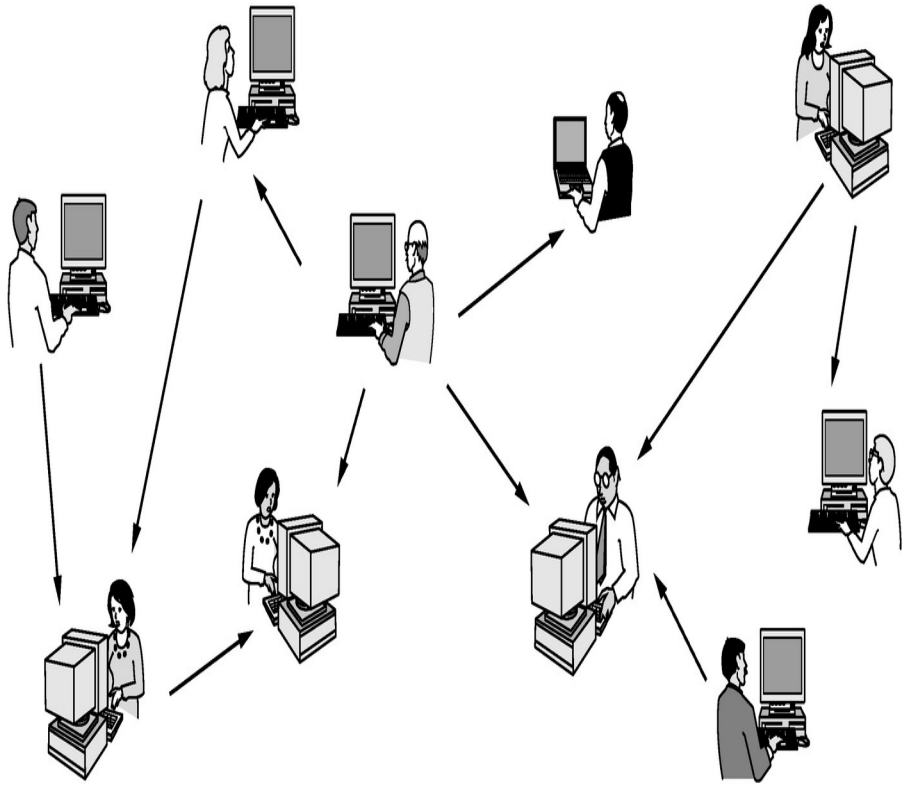
Users of computer networks

- Business applications
  - Resource sharing
  - To make programs, equipment, and data available to anyone on the network without regard to the location of the user.
  - Almost every



Home Applications

- Homes contain many networked devices, e.g., computers, TVs, connected to the Internet by cable, DSL, wireless, etc.
- Home users communicate, e.g., social networks, consume content, e.g., video, and transact, e.g., auctions
  - Wikipedia, facebook, twitter, sms, IP television
- Some application use the peer-to-peer model in which there are no fixed clients and servers:



In a peer-to-peer system there are no fixed clients and servers.

Tag	Full name	Example
B2C	Business-to-consumer	Ordering books online
B2B	Business-to-business	Car manufacturer ordering tires from supplier
G2C	Government-to-consumer	Government distributing tax forms electronically
C2C	Consumer-to-consumer	Auctioning second-hand products online
P2P	Peer-to-peer	Music sharing

Some forms of e-commerce.

Mobile Users

- Tablets, laptops, and smart phones are popular devices; WiFi hotspots and 3G cellular provide wireless connectivity.
- Mobile users communicate, e.g., voice and texts, consume content, e.g., video and Web, and use sensors, e.g., GPS.
- Sensor networks
- Wireless and mobile are related but different:

Wireless	Mobile	Typical applications
No	No	Desktop computers in offices
No	Yes	A notebook computer used in a hotel room
Yes	No	Networks in unwired buildings
Yes	Yes	Store inventory with a handheld computer

Social Issues

- Network neutrality – no network restrictions
- Content ownership, e.g., DMCA (Digital Millennium Copy right Act) takedowns
- Anonymity and censorship
- Privacy, e.g., Web tracking and profiling
- Theft, e.g., botnets and phishing

Network Hardware

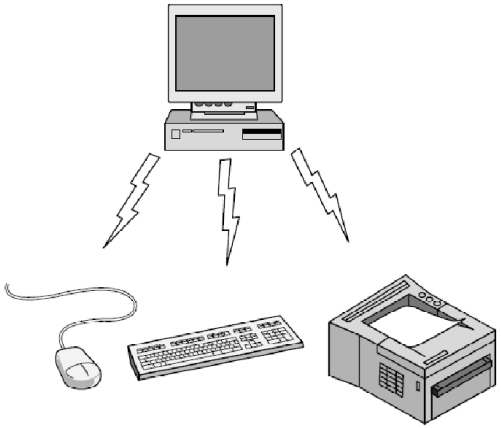
Scale	Type
Vicinity	PAN (Personal Area Network) »
Building	LAN (Local Area Network) »
City	MAN (Metropolitan Area Network) »
Country	WAN (Wide Area Network) »
Planet	The Internet (network of all networks)

About networking technology

- Two dimensions
  - Transmission technology
  - Scale
- Two types of transmission technology
  - Broadcast links
  - Point to point links
- Point-to-Point links
  - One sender and one receiver
  - Connect individual pairs of links
  - They may have to visit some intermediate machines.
- Broadcast link
  - Communication link is shared by several machines
  - A packet is received by all machines. The address in the packet specified intended recipient.
  - Broadcasting: message is sent to all machines

Personal Area Network

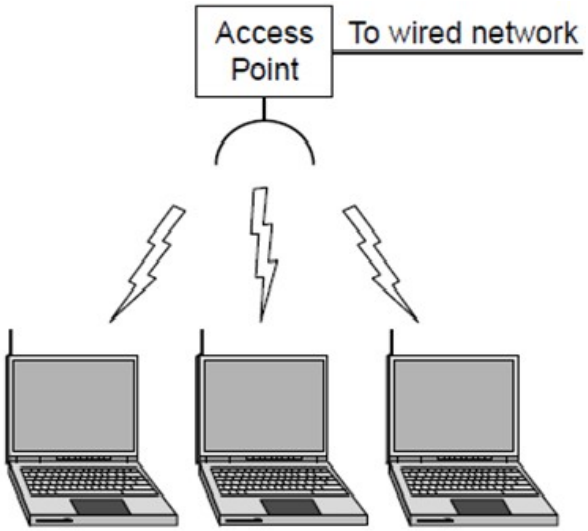
- Connect devices over the range of a person
- Example of a Bluetooth (wireless) PAN:



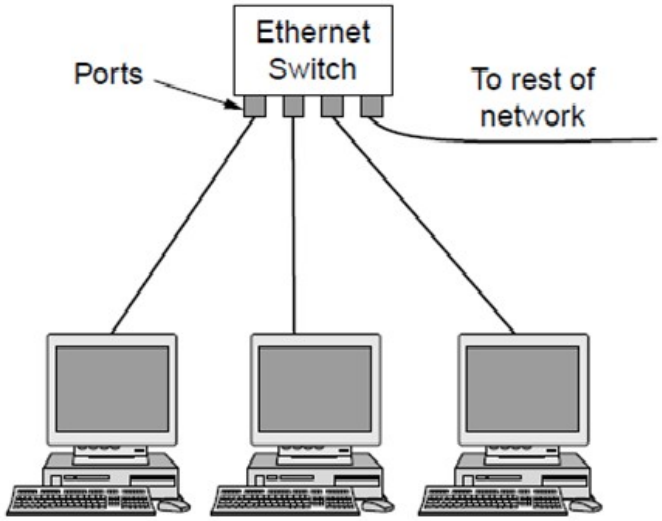
Local Area Networks

Connect devices in a home or office building

Called enterprise network in a company



Wireless LAN with 802.11

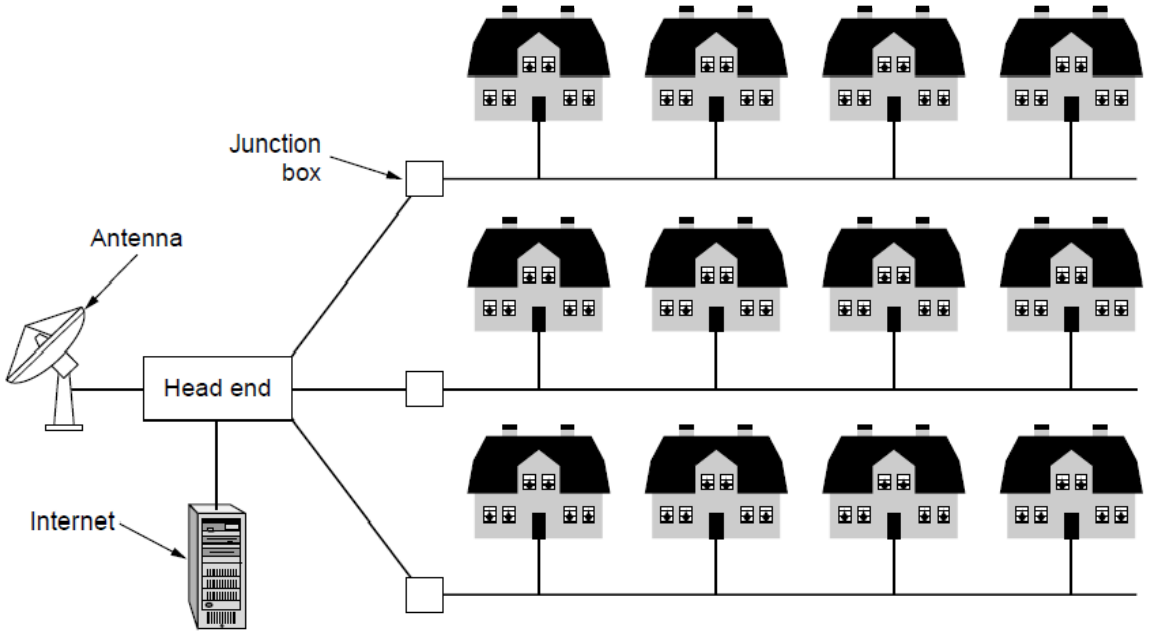


Wired LAN with switched Ethernet

Metropolitan Area Networks

Connect devices over a metropolitan area

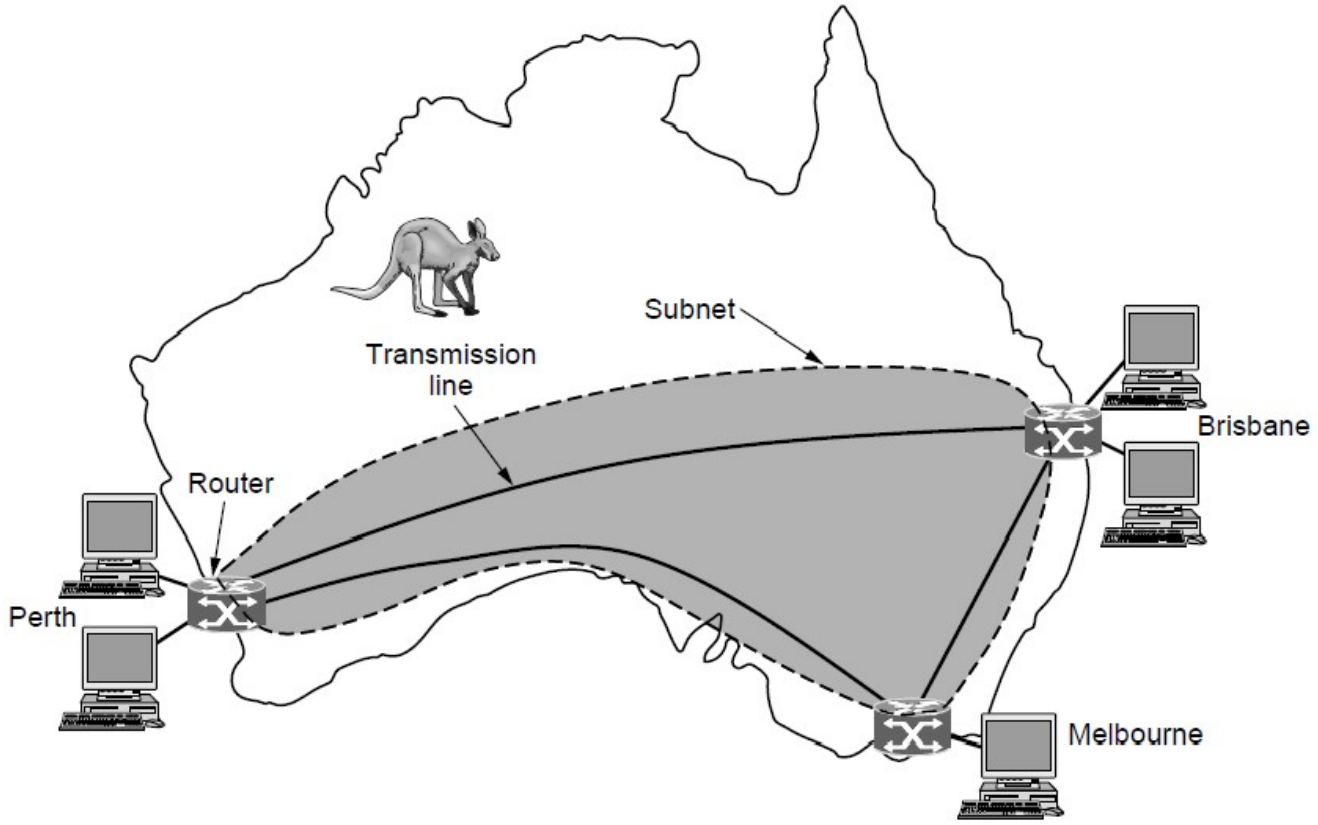
Example MAN based on cable TV:



Wide Area Networks (1)

Connect devices over a country

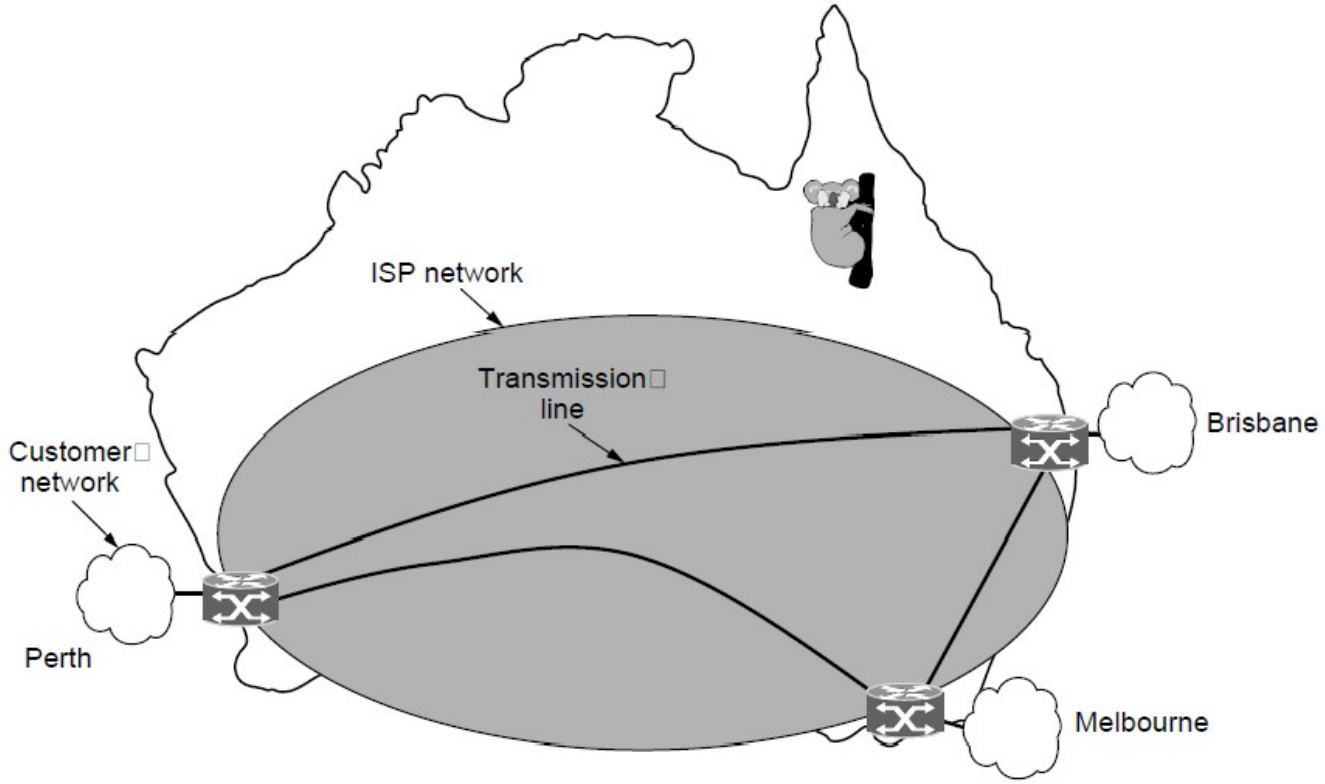
Example WAN connecting three branch offices:



Wide Area Networks (2)

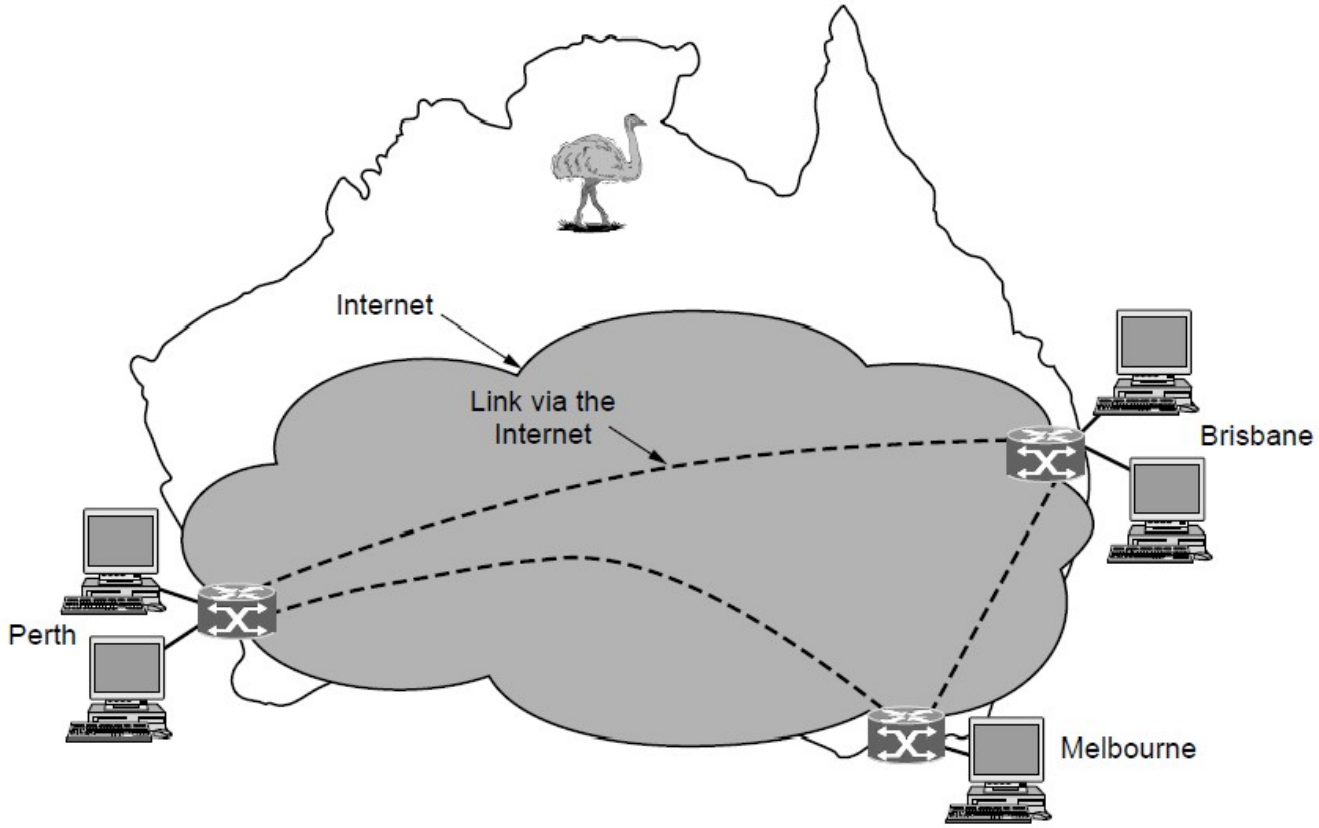
An ISP (Internet Service Provider) network is also a WAN.

Customers buy connectivity from the ISP to use it.



Wide Area Networks (3)

A VPN (Virtual Private Network) is a WAN built from virtual links that run on top of the Internet.



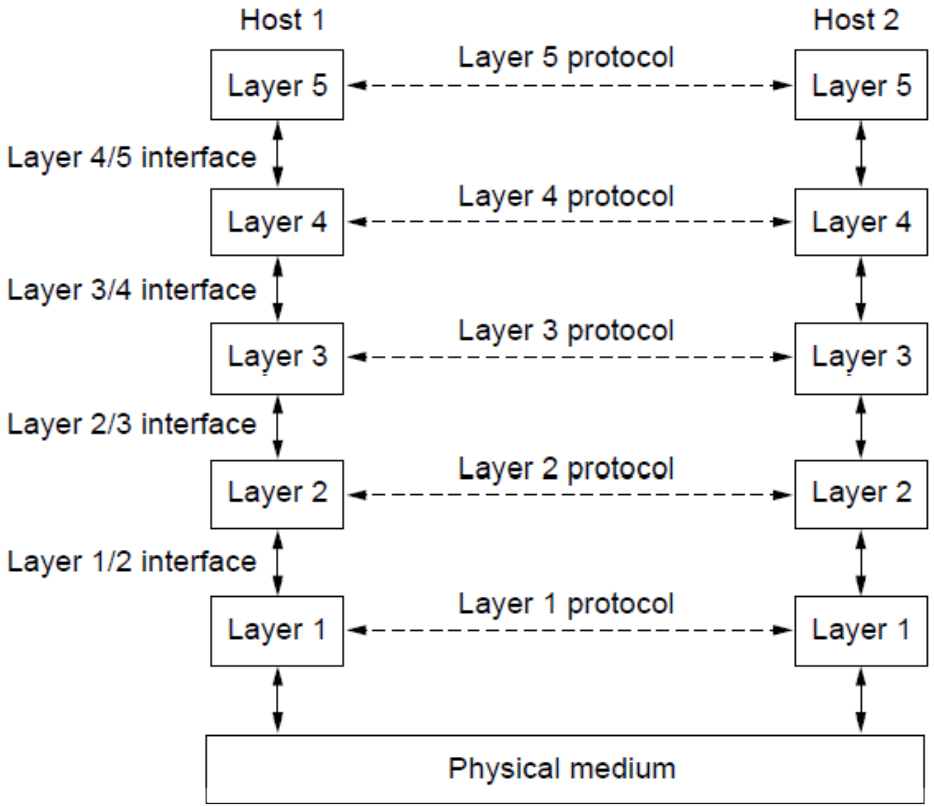
Network Software

- Protocol layers »
- Design issues for the layers »
- Connection-oriented vs. connectionless service »
- Service primitives »
- Relationship of services to protocols »

Protocol Layers (1)

Protocol layering is the main structuring method used to divide up network functionality.

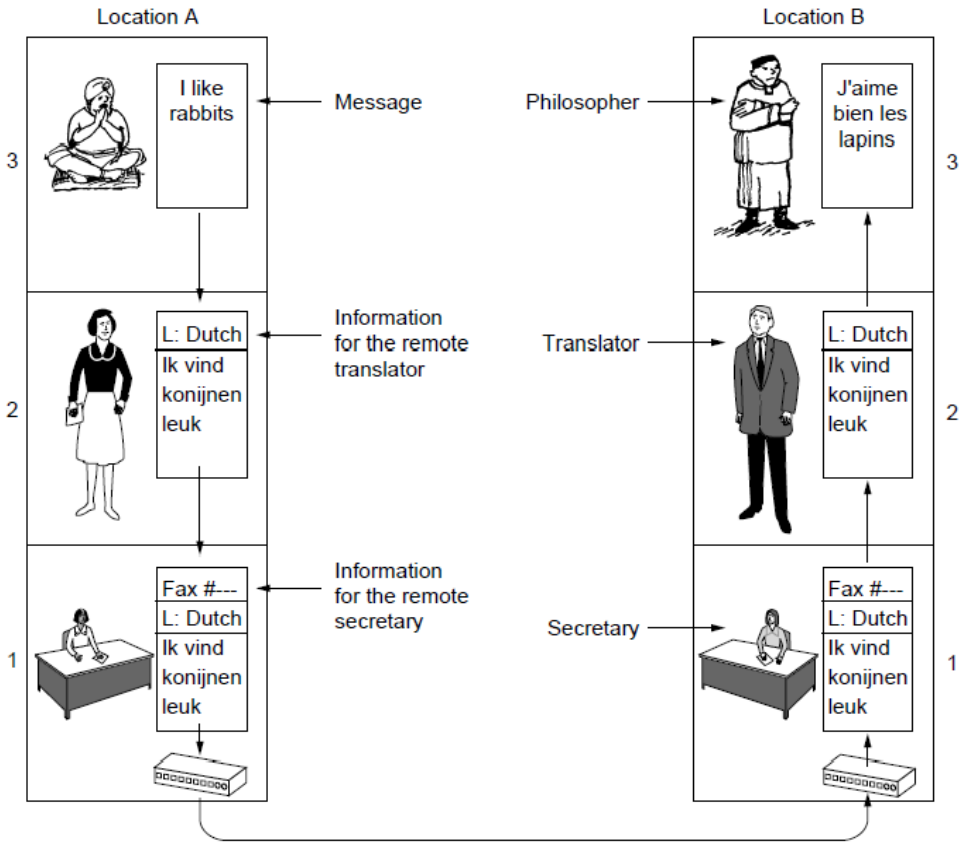
- Each protocol instance talks virtually to its peer
- Each layer communicates only by using the one below
- Lower layer services are accessed by an interface
  - At bottom, messages are carried by the medium



Protocol Layers (2)

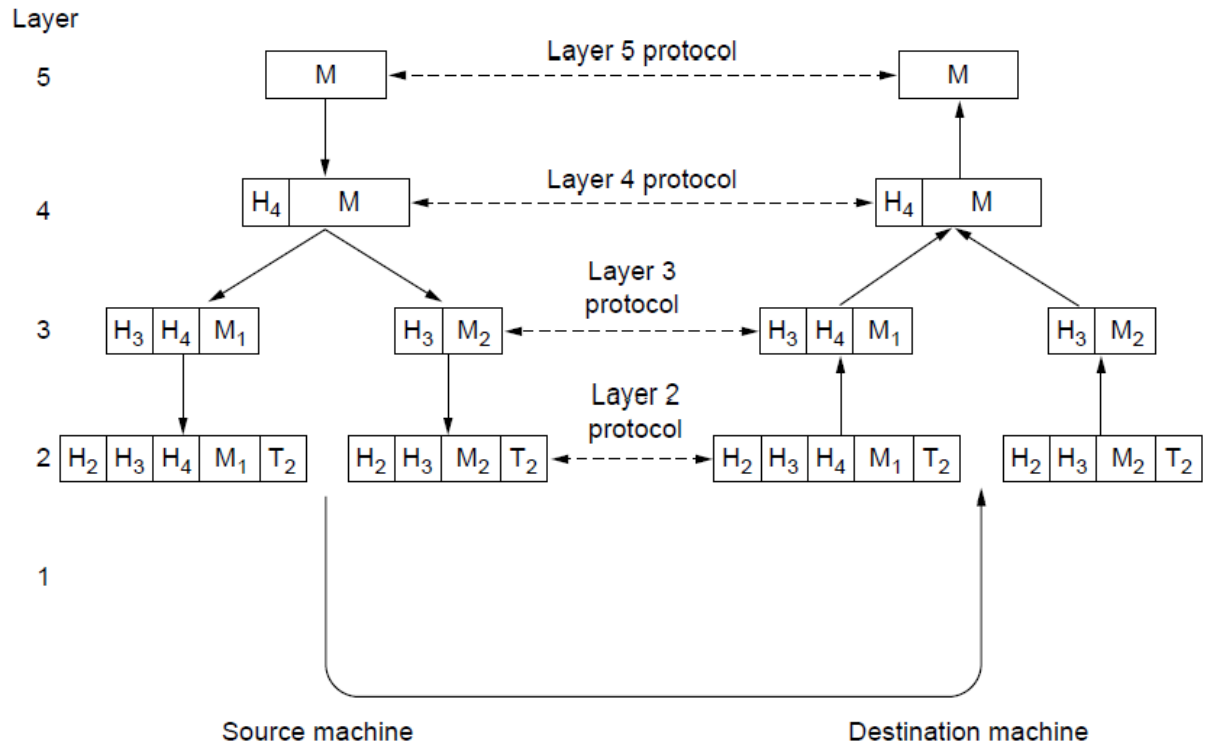
Example: the philosopher-translator-secretary architecture

Each protocol at different layers serves a different purpose



Protocol Layers (3)

Each lower layer adds its own header (with control information) to the message to transmit and removes it on receive



Layers may also split and join messages, etc.

Design Issues for the Layers

Each layer solves a particular problem but must include mechanisms to address a set of recurring design issues

Issue	Example mechanisms at different layers
Reliability despite failures	Codes for error detection/correction (§3.2, 3.3) Routing around failures (§5.2)
Network growth and evolution	Addressing (§5.6) and naming (§7.1) Protocol layering (§1.3)
Allocation of resources like bandwidth	Multiple access (§4.2) Congestion control (§5.3, 6.3)
Security against various threats	Confidentiality of messages (§8.2, 8.6) Authentication of communicating parties (§8.7)

Connection-Oriented vs. Connectionless

Service provided by a layer may be kinds of either:

- Connection-oriented, must be set up for ongoing use (and torn down after use), e.g., phone call
- Connectionless, messages are handled separately, e.g., postal delivery

	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Movie download
	Unreliable connection	Voice over IP
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Text messaging
	Request-reply	Database query

Service Primitives (1)

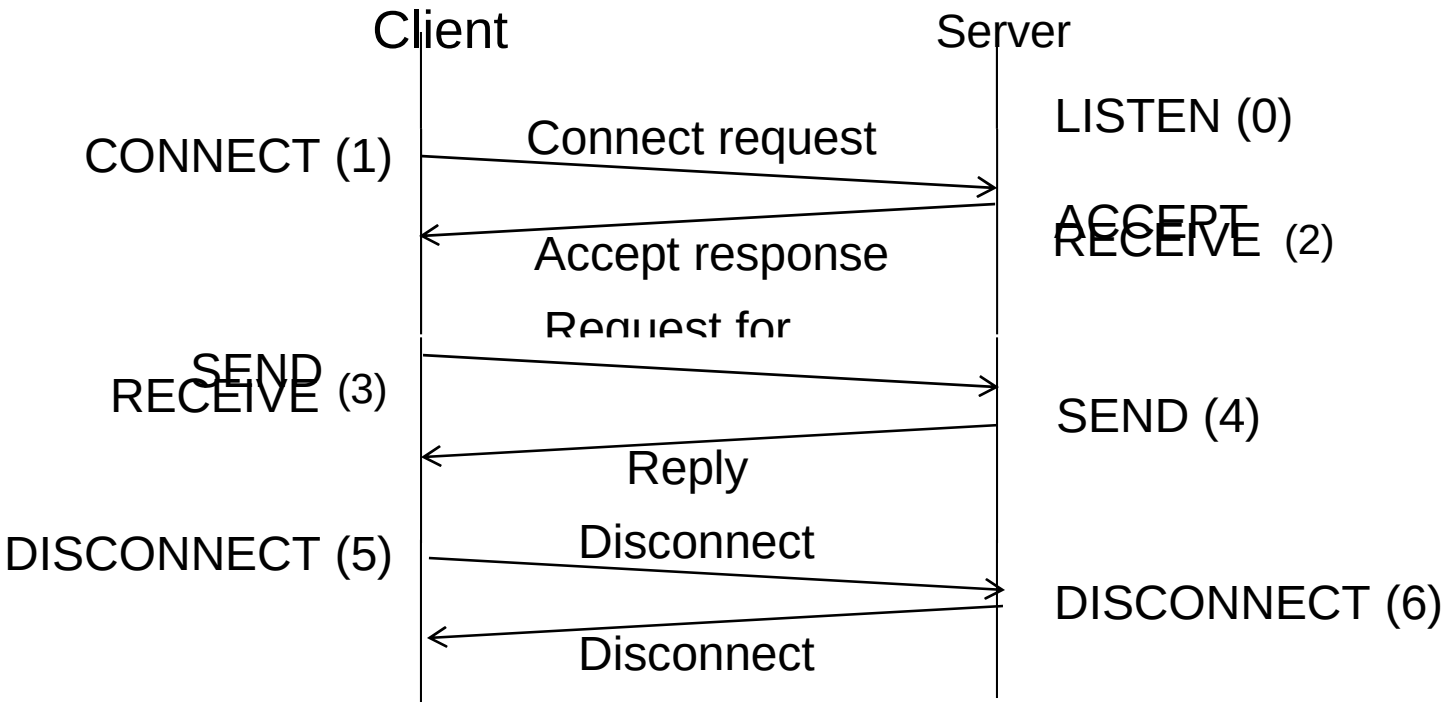
A service is provided to the layer above as primitives

Hypothetical example of service primitives that may provide a reliable byte stream (connection-oriented) service:

Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
ACCEPT	Accept an incoming connection from a peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

Service Primitives (2)

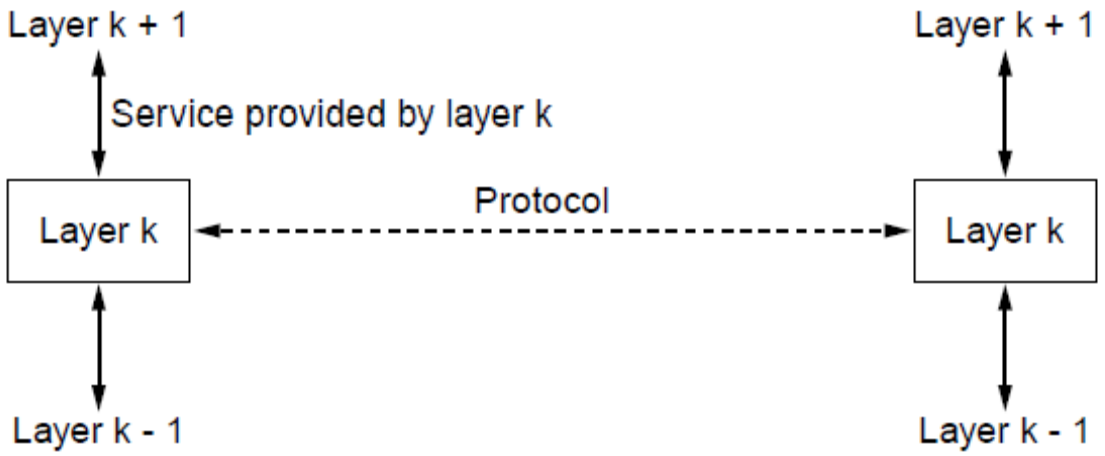
Hypothetical example of how these primitives may be used for a client-server interaction



Relationship of Services to Protocols

Recap:

- A layer provides a service to the one above [vertical]
- A layer talks to its peer using a protocol [h



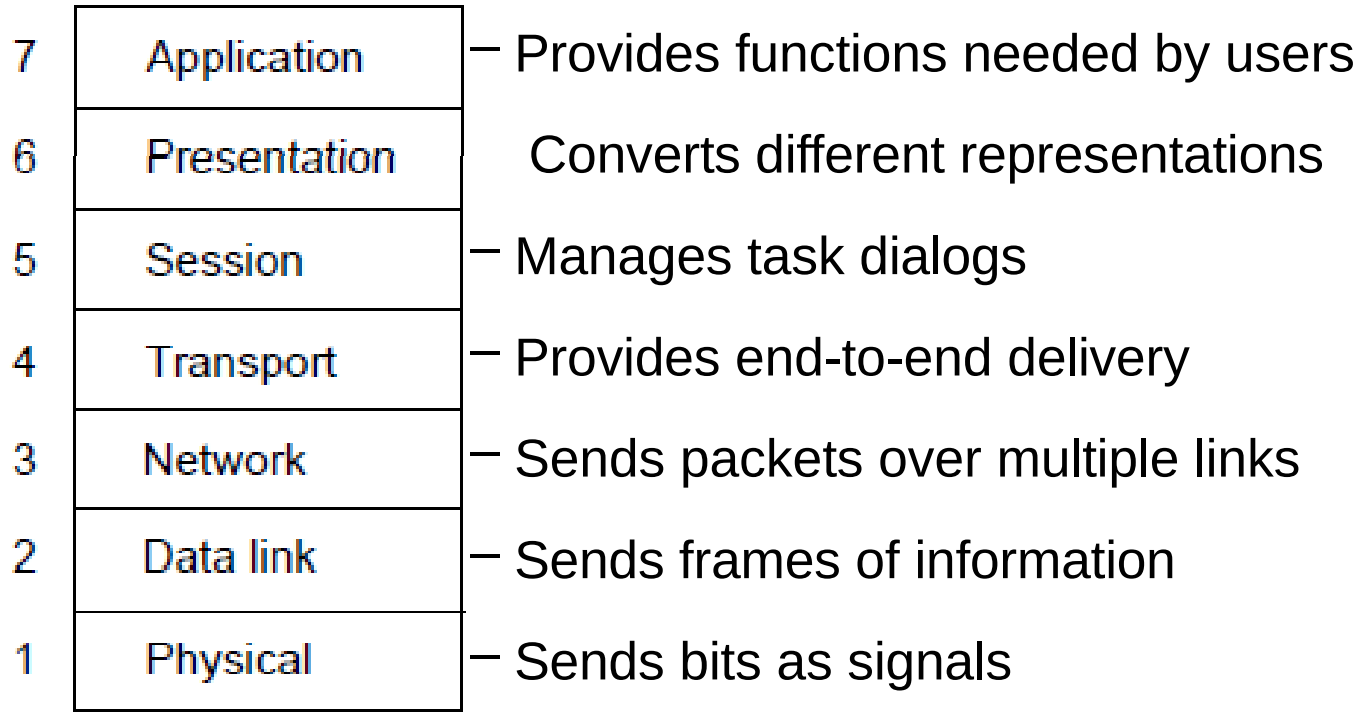
Reference Models

Reference models describe the layers in a network architecture

- OSI reference model »
- TCP/IP reference model »
- Model used for this text »
- Critique of OSI and TCP/IP »

OSI (Open Systems Interconnection) Reference Model

A principled, international standard, seven layer model to connect different systems



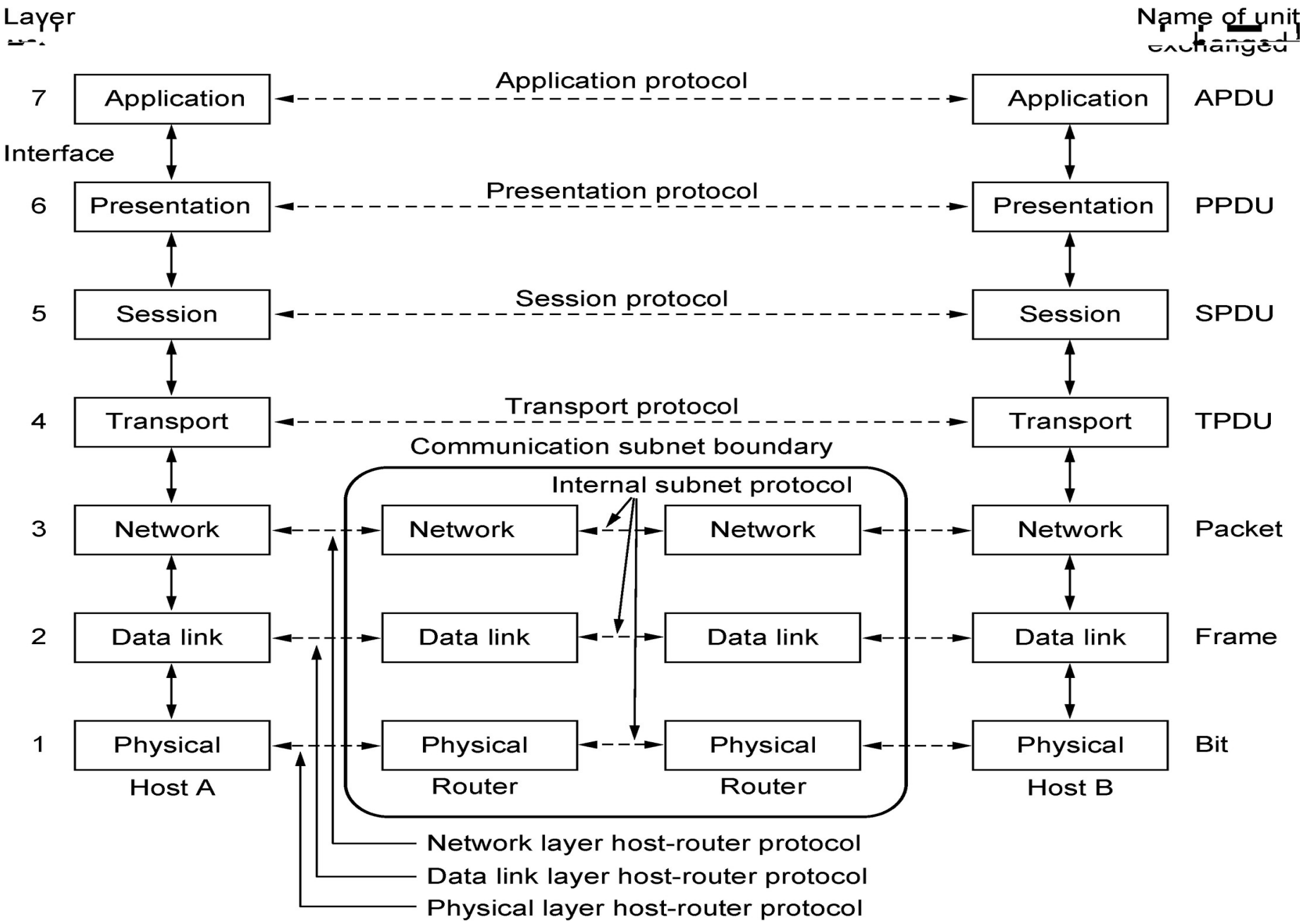
ISO OSI: International Standards Organization Open Systems Interconection

About Layers

- The Physical layer
  - Transmitting raw bits over a communication channel
  - One side sends 1/0 and the other side receives 1/0
  - Issue: What electrical signals should be used?
  - Design issues
    - Mechanical, electrical and timing interfaces
- The Data Link Layer
  - Transform a raw transmission facility into a like that appears free of undetected transmission errors.
  - Data frame and ack. Frame
  - Interface between fast transmitter and slow receiver
  - Broadcast networks: How to control access to shared channel?
- The network layer
  - Controls the operation of the subnet

About Layers

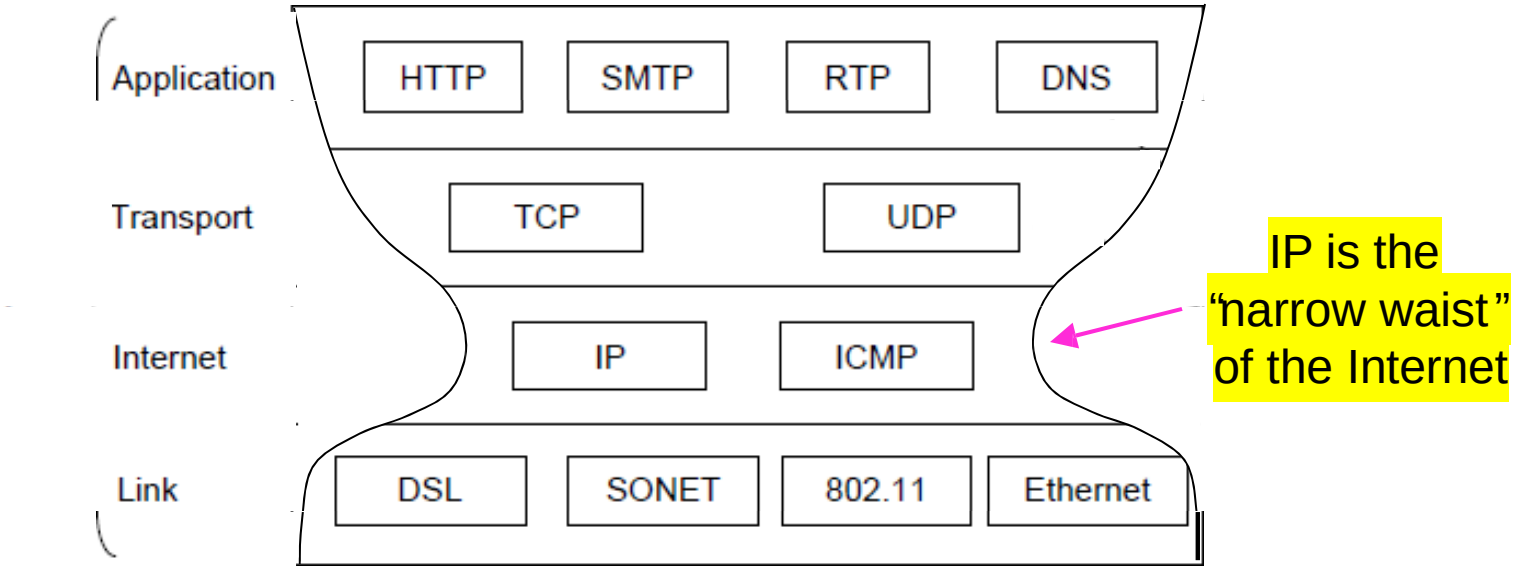
- The Transport layer
  - Accept data split into small units, if required, and pass it to network layer.
  - It isolates upper layer with the possible changes in the hardware technology.
  - It also determines the type of service: connection oriented or connectionless.
  - It is an end to end layer
  - One computer talks with other computer
  - In the lower layers the communication is between the source and
- The Session Layer
  - Helps to establish sessions
  - Dialog control, token management, synchronization
- The presentation layer
  - Syntax and semantics of the information
  - It allows computers with different data representations to communicate
- The application layer
  - Set of protocols
  - Popular one is HTTP (Hypertext transfer



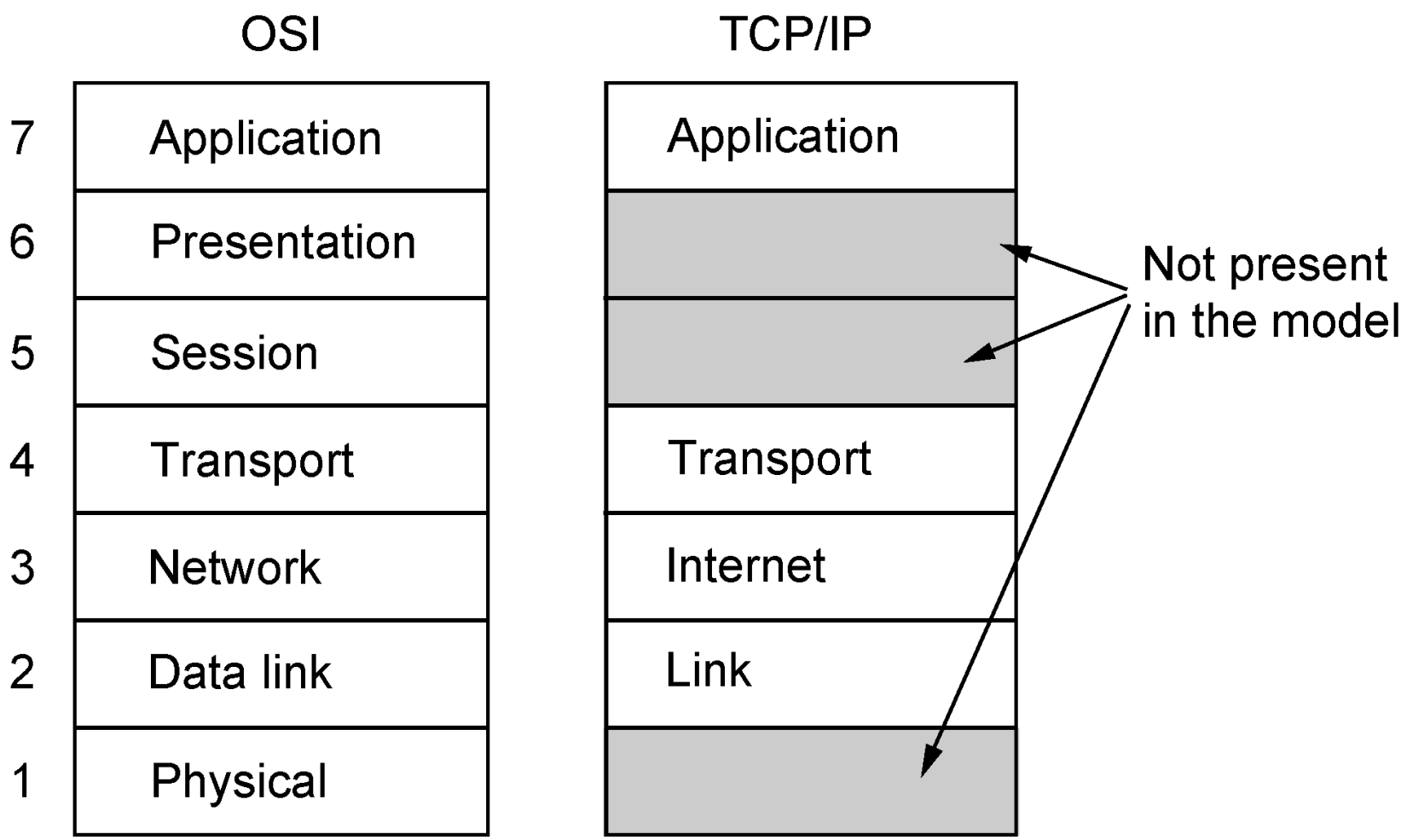
The OSI reference model.

TCP/IP Reference Model

A four layer model derived from experimentation; omits some OSI layers and uses the IP as the network layer.



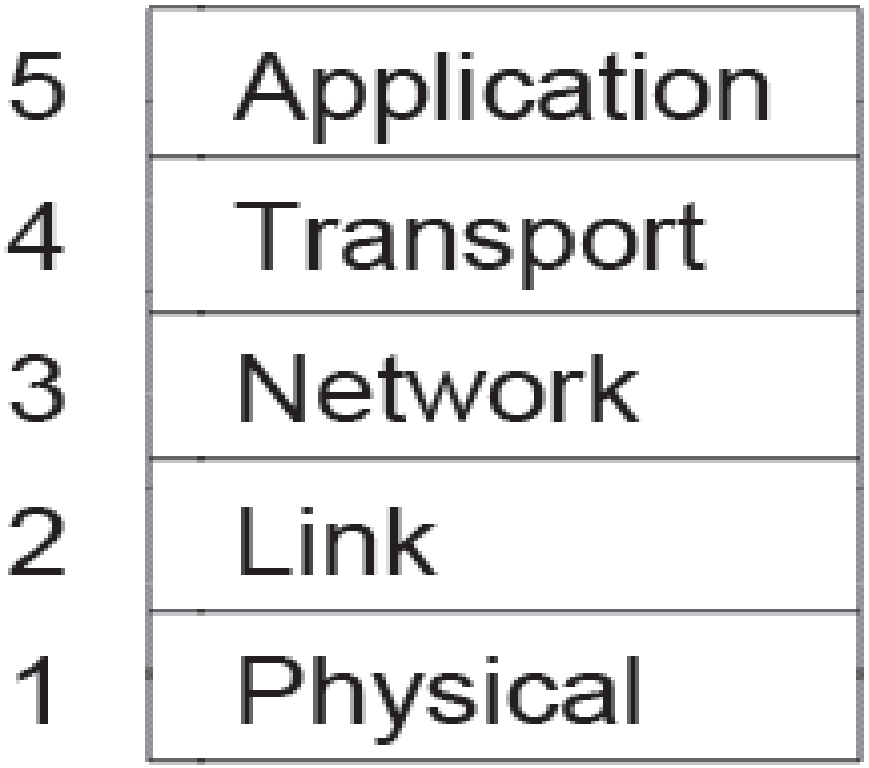
Protocols are shown in their respective layers



The TCP/IP reference model.

Model Used in this Book

It is based on the TCP/IP model but we call out the physical layer and look beyond Internet protocols.



Critique of OSI & TCP/IP

OSI:

+ Very influential model with clear concepts
− Models, protocols and adoption all bogged down by politics and complexity

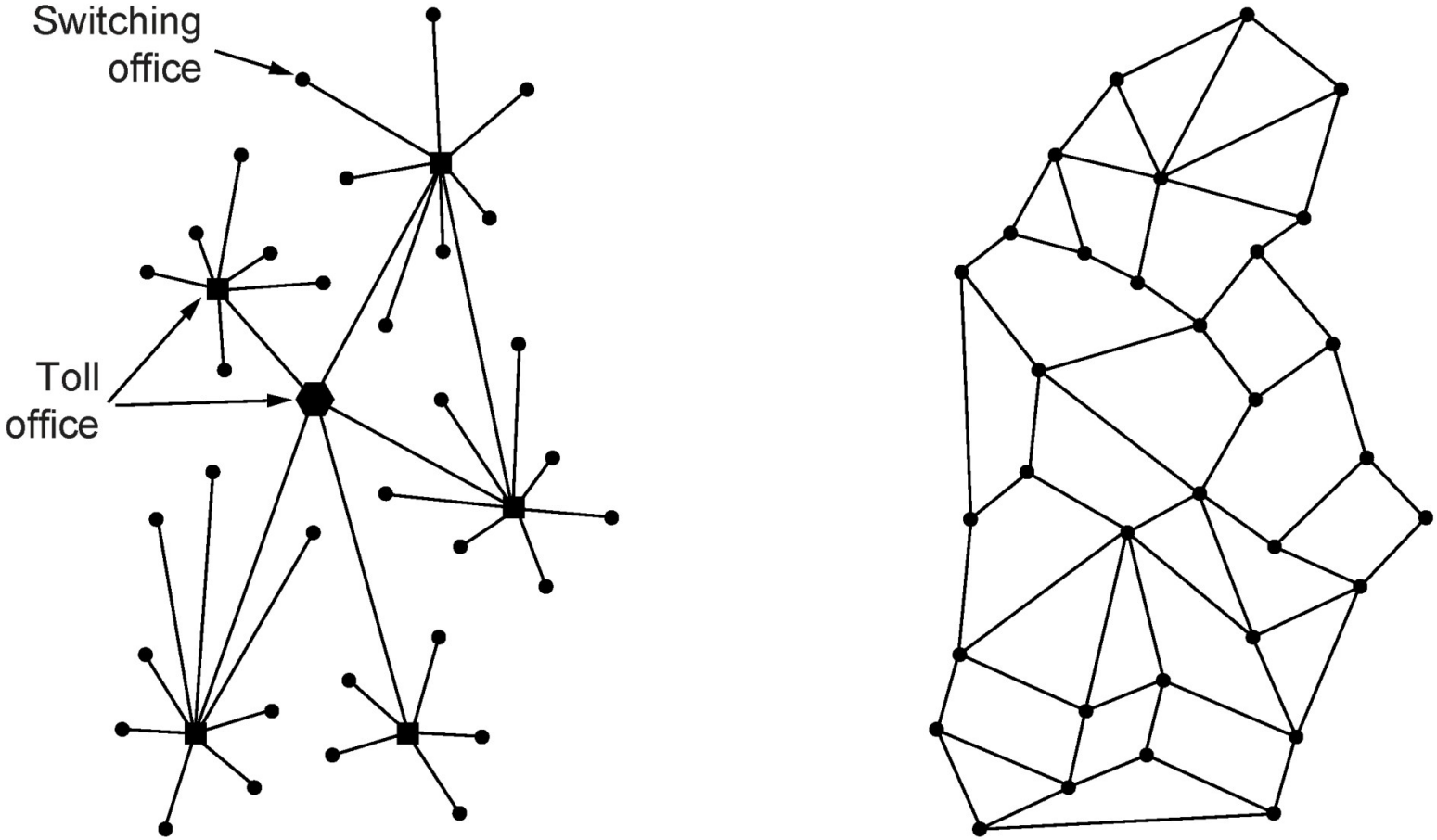
TCP/IP:

+ Very successful protocols that worked well and thrived
− Weak model derived after the fact from protocols

Example Networks

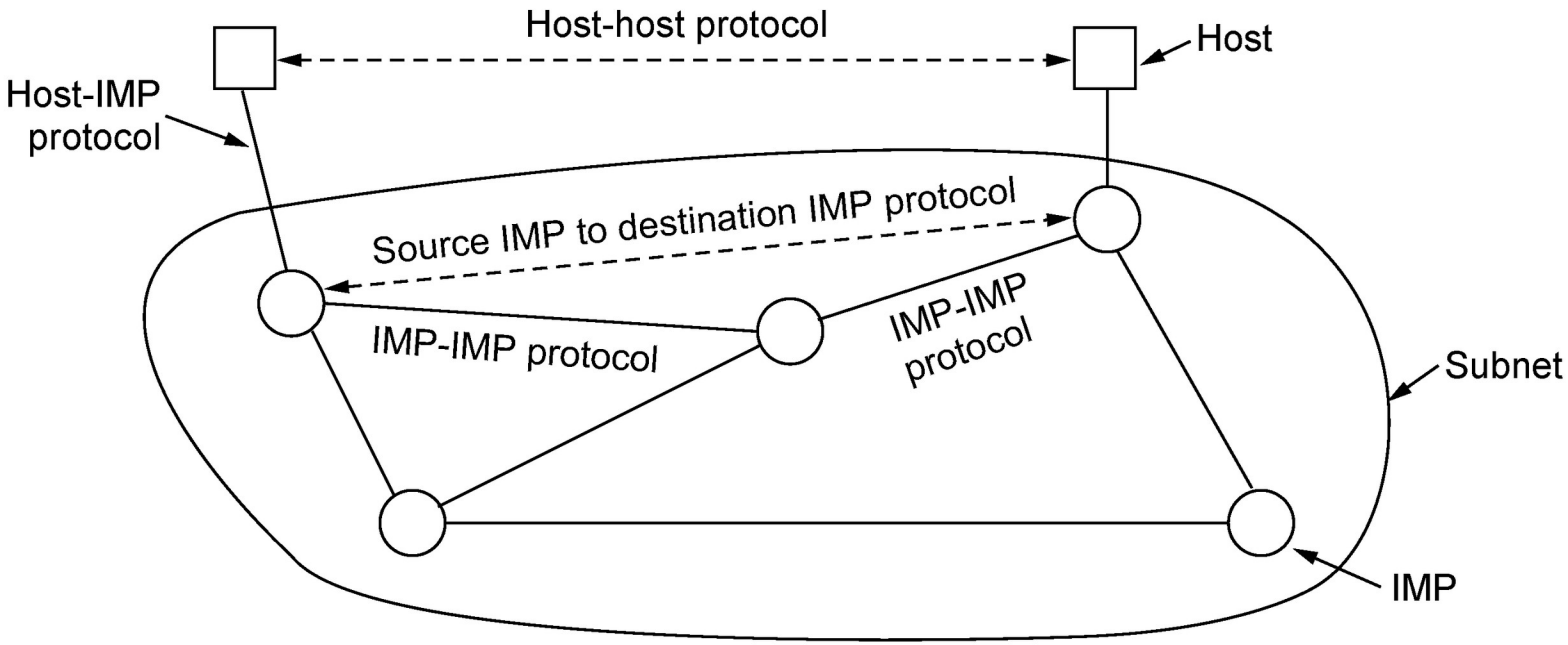
- The Internet »
- 3G mobile phone networks »
- Wireless LANs »
- RFID and sensor networks »

Internet



(a) Structure of the telephone system. (b) Baran's proposed distributed switching system.

Internet



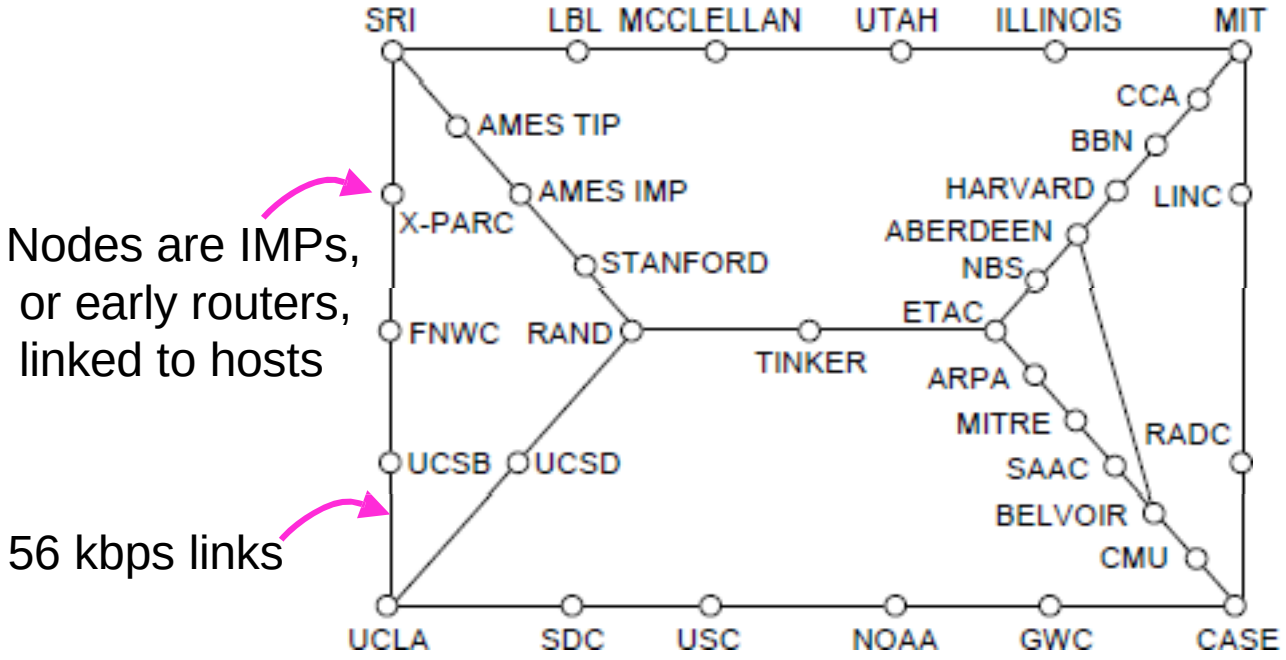
The original ARPANET design.

IMP: Interface message processors

Internet

- Before the Internet was the ARPANET, a decentralized, packet-switched network based on Baran's ideas.

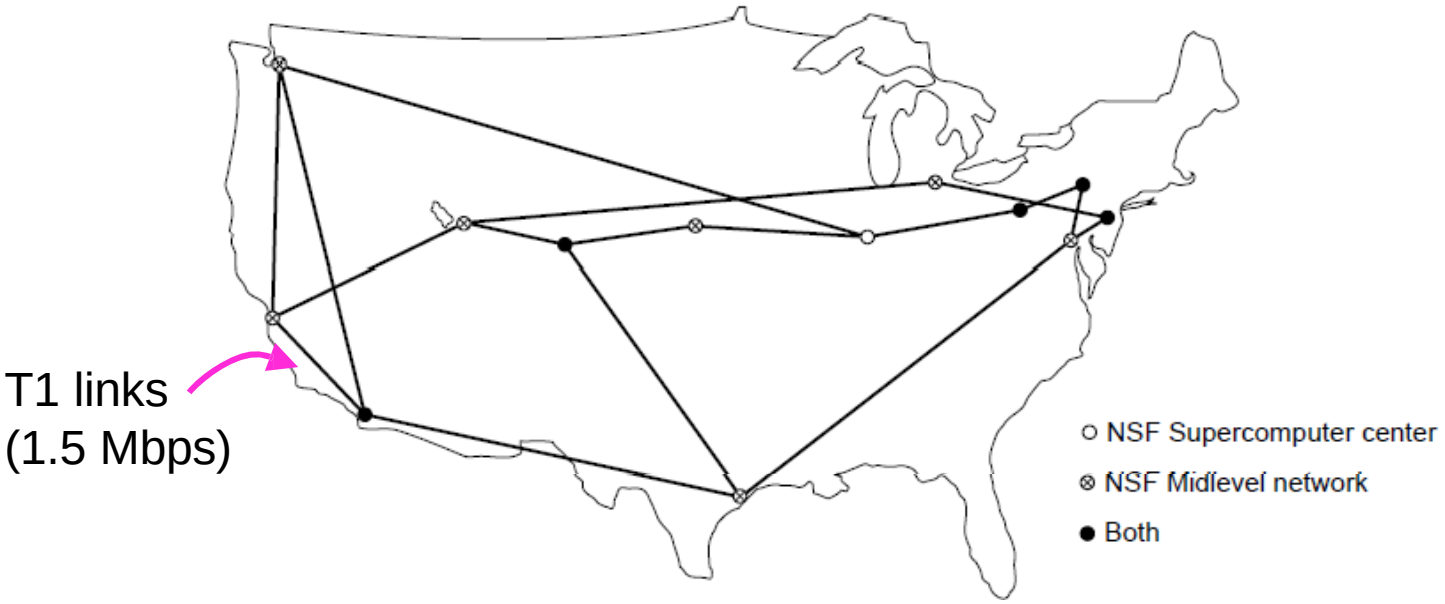
- DNS evolved (Domain name system)
  - A generalized distributed database system for storing varitety of information related to naming.



A
R

Internet

The early Internet used NSFNET (1985-1995) as its backbone; universities connected to get on the Internet



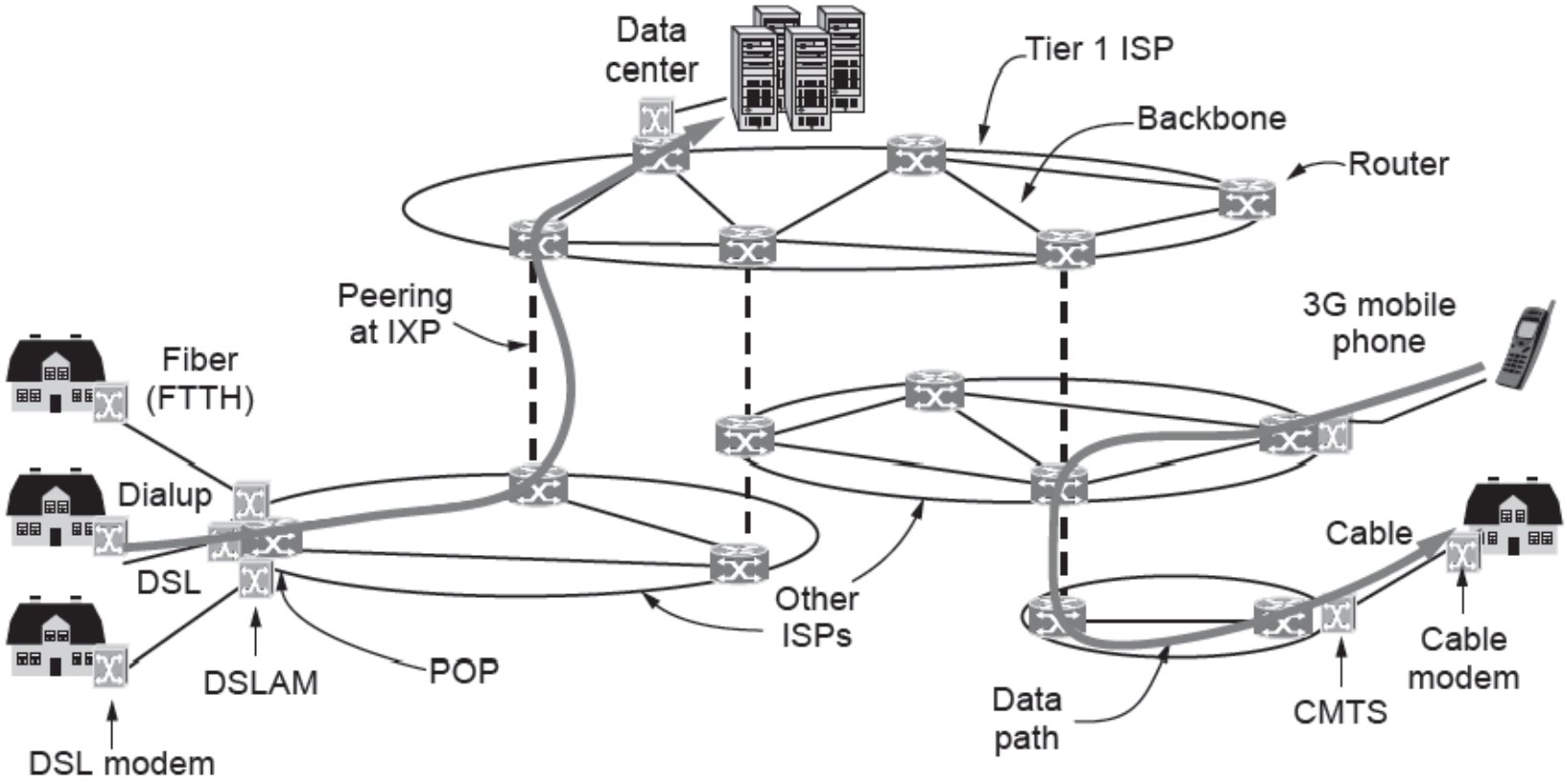
NSFNET topology in 1988

Internet

The modern Internet is more complex:

- ISP networks serve as the Internet backbone
- ISPs connect or peer to exchange traffic at IXPs
- Within each network routers switch packets
- Between networks, traffic exchange is set by business agreements
- Customers connect at the edge by many means
  - Cable, DSL, Fiber-to-the-Home, 3G/4G wireless, dialup
- Data centers concentrate many servers (“the cloud”)
- Most traffic is content from data centers (esp. video)
- The architecture continues to evolve

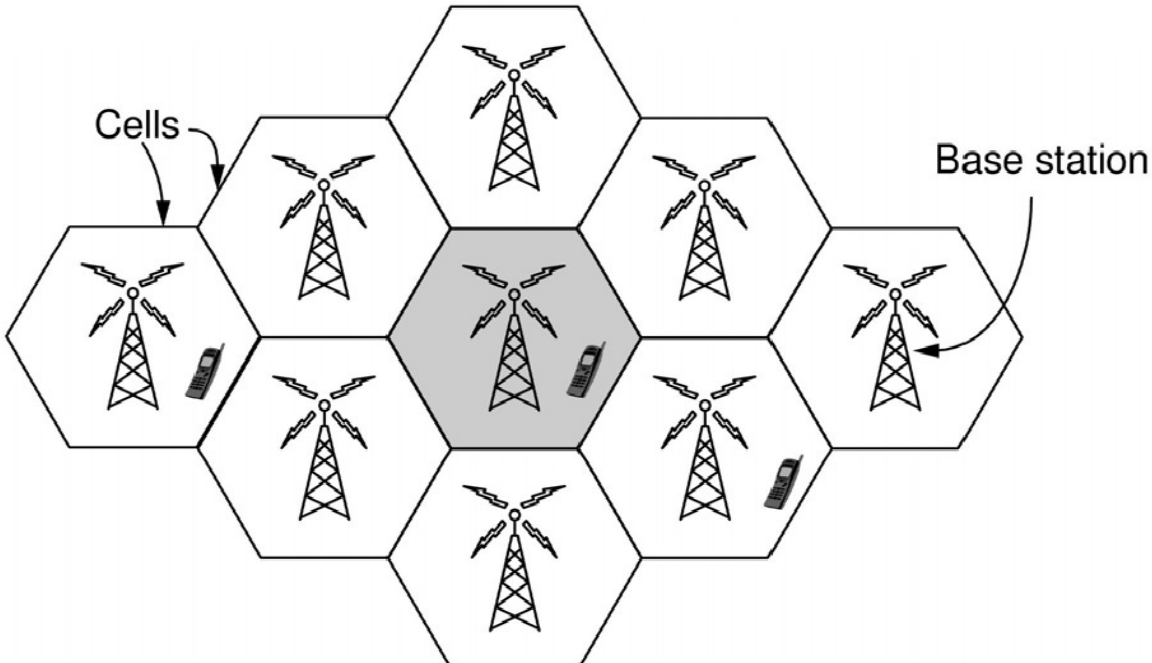
Internet (4)



Architecture of the Internet

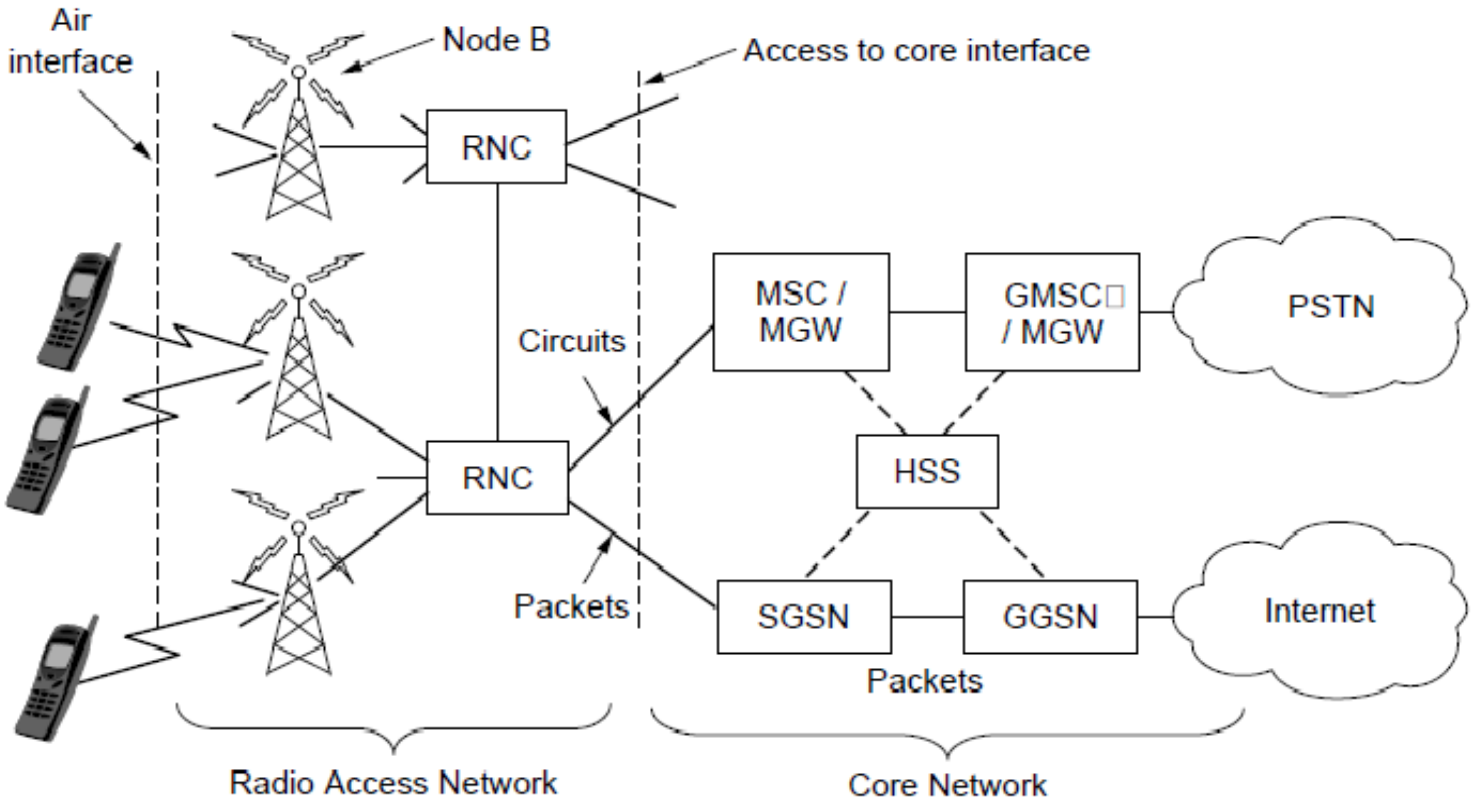
3G Mobile Phone Networks (1)

- 3G stands for third generation
- Evolved due to scarcity of spectrum
- 3G network is based on spatial cells; each cell provides wireless service to mobiles within it via a base station
- Coverage area is divided into cells.
- Within a cell, users are assigned channels which do not interfere with each other and do not cause much interference to adjacent cells.



3G Mobile Phone Networks (2)

Base stations connect to the core network to find other mobiles and send data to the phone network and Internet

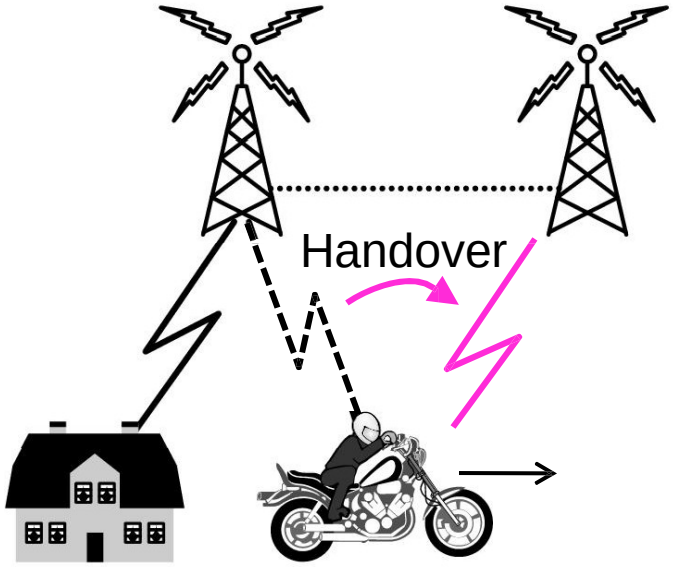


3G mobile networks

- Air interface
- It is based on UMTS (Universal Mobile Telecommunication System) or WCDMA (Wideband code division multiple access)
  - Can provide 14Mbps downlink and 6Mbps uplink
- Cellular base station together with the controller forms radio access network
- The controller node RNC (Radio Network Controller) controls the spectrum used.
- The rest of the mobile network carries traffic, which is called core network
  - MSC: mobile switching center
- Data services
  - GPRS General Packet Radio Service
  - SGSN: Serving GPRS support node
  - GGSN: Gateway GPRS support node
- SIM card
  - Subscriber Identify module (SIM)
- 4G
  - LTE (Long term evolution)
  - WiMAX
- It can support both connection oriented and connectionless

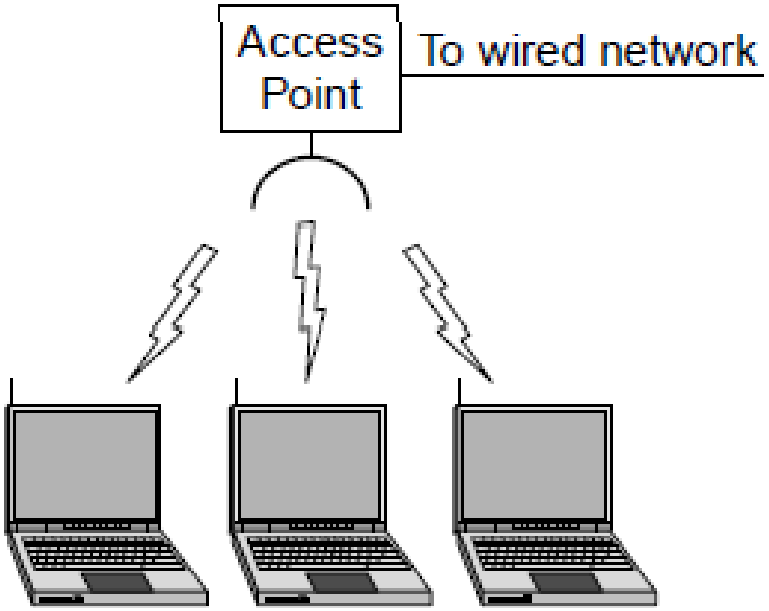
3G Mobile Phone Networks (3)

As mobiles move, base stations hand them off from one cell to the next, and the network tracks their location



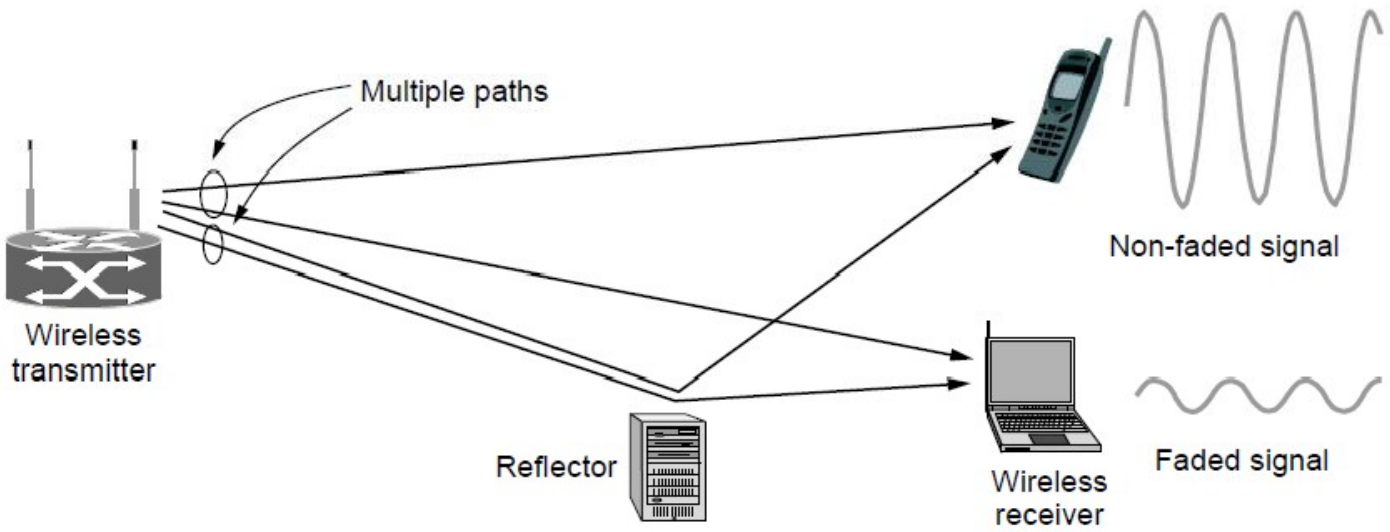
Wireless LANs (1)

In 802.11, clients communicate via an AP (Access Point) that is wired to the rest of the network.



Wireless LANs (2)

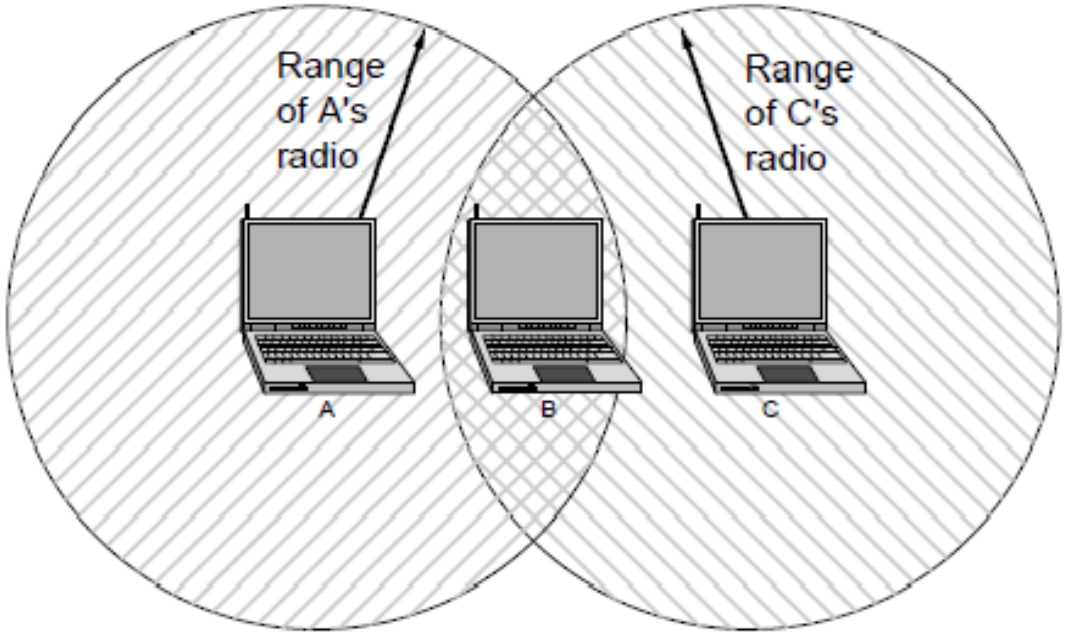
- Signals in the 2.4GHz ISM band vary in strength due to many effects, such as **multipath fading** due to reflections
  - requires complex transmission schemes, e.g., OFDM



Wireless LANs (3)

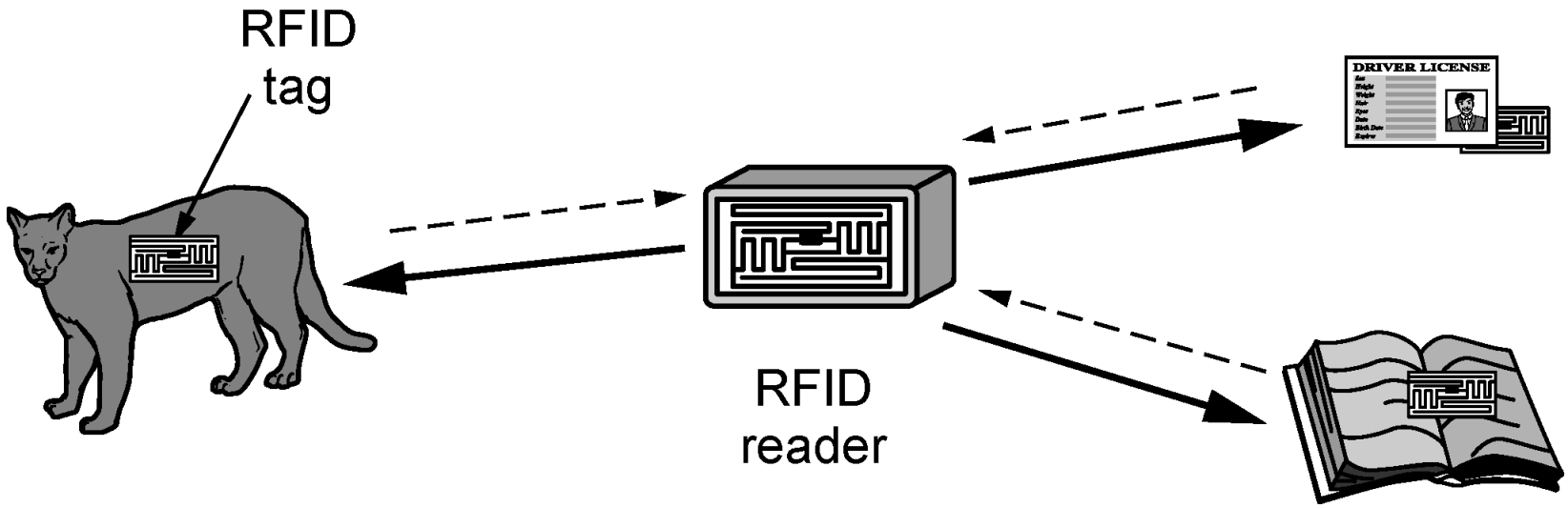
Radio broadcasts interfere with each other, and radio ranges may incompletely overlap

- CSMA (Carrier Sense Multiple Access) designs are used



RFID and Sensor Networks (1)

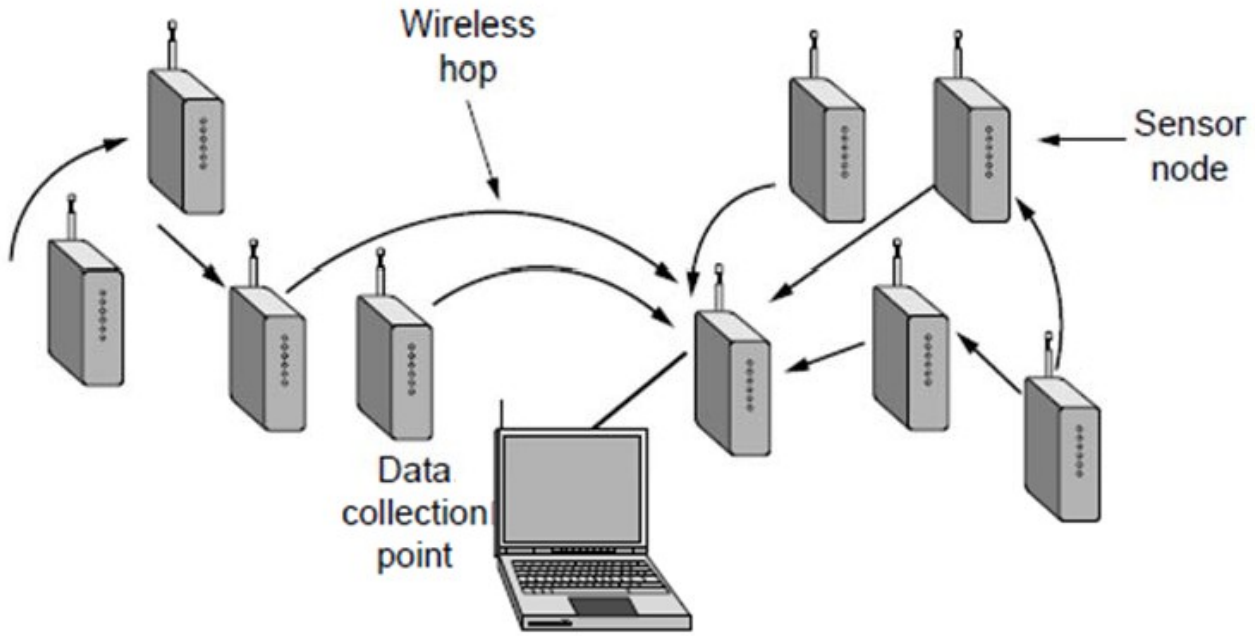
- RFID: **R**adio **F**requency **Identification**
- Passive UHF RFID networks everyday objects:
  - Tags (stickers with not even a battery) are placed on objects
  - Readers send signals that the tags reflect to communicate Tags communicate at distances of several meters
- HF RFID is short range, 1 meter
- LF RFID is used for animal tracking



RFID used t o network everyday objects.

RFID and Sensor Networks (2)

- Sensor networks spread small devices over an area:
  - Devices send sensed data to collector via wireless hops
  - Sensor nodes are small computers which has the temperature, pressure, vibration and other sensors.
  - They have batteries. They can also harvest energy from Sun
  - They can communicate with each other. One of the node can become hop.
  - Organized into a **multihop network**



Network Standardization

Standards define what is needed for interoperability

Some of the many standards bodies:

Body	Area	Examples
ITU	Telecommunications	G.992, ADSL H.264, MPEG4
IEEE	Communications	802.3, Ethernet 802.11, WiFi
IETF	Internet	RFC 2616, HTTP/1.1 RFC 1034/1035, DNS
W3C	Web	HTML5 standard CSS standard

ITU: International Telecommunications Union.
IRTF: Internet Research Task Force
IETF: Internet Engineering Task Force
iAB: Internet Architecture Board

Metric Units

- The main prefixes we use:

Prefix	Exp.	prefix	exp.
K(ilo)	10^3	m(illi)	10^{-3}
M(ega)	10^6	μ(micro)	10^{-6}
G(iga)	10^9	n(ano)	10^{-9}

- Use powers of 10 for rates, powers of 2 for storage
  - E.g., 1 Mbps = 1,000,000 bps, 1 KB = 1024 bytes
- "B" is for bytes, "b" is for bits

Exp.	Explicit	Prefix	Exp.	Explicit	Prefix
10^{-3}	0.001	milli	10^3	1,000	Kilo
10^{-6}	0.000001	micro	10^6	1,000,000	Mega
10^{-9}	0.000000001	nano	10^9	1,000,000,000	Giga
10^{-12}	0.000000000001	pico	10^{12}	1,000,000,000,000	Tera
10^{-15}	0.000000000000001	femto	10^{15}	1,000,000,000,000,000	Peta
10^{-18}	0.000000000000000001	atto	10^{18}	1,000,000,000,000,000, 000	Exa
10^{-21}	0.000000000000000000001	zepto	10^{21}	1,000,000,000,000,000,000,000	Zetta
10^{-24}	0.000000000000000000000001	yocto	10^{24}	1,000,000,000,000,000,000,000,000	Yotta

Summary

- Computer networks have many uses
  - Companies and individuals
- Networks can be divided into LANs, MANs, WANs and Internetworks.
- Wireless networks such as 3G and 802.11 LANs are becoming popular.
- Network software is built around protocols, the rules the processes communicate.
- Protocols are based on OSI or TCP/IP model
- TCP/IP
  - Link, network, transport and application layers
- Networks provide services
  - Connectionless best effort packet delivery
  - Connection oriented guaranteed delivery
- Well-known networks
  - Internet, the 3G mobile phone network, 802.11 LANs
- Internet is a collection of thousands of networks which employ TCP/IP stack
- New kinds of networks
  - Embedded sensor networks, networks based on sensor technology
- Standardization efforts
  - ITU-T, ISO, IEEE and IETF manage different parts of