Chapter 1

Introduction

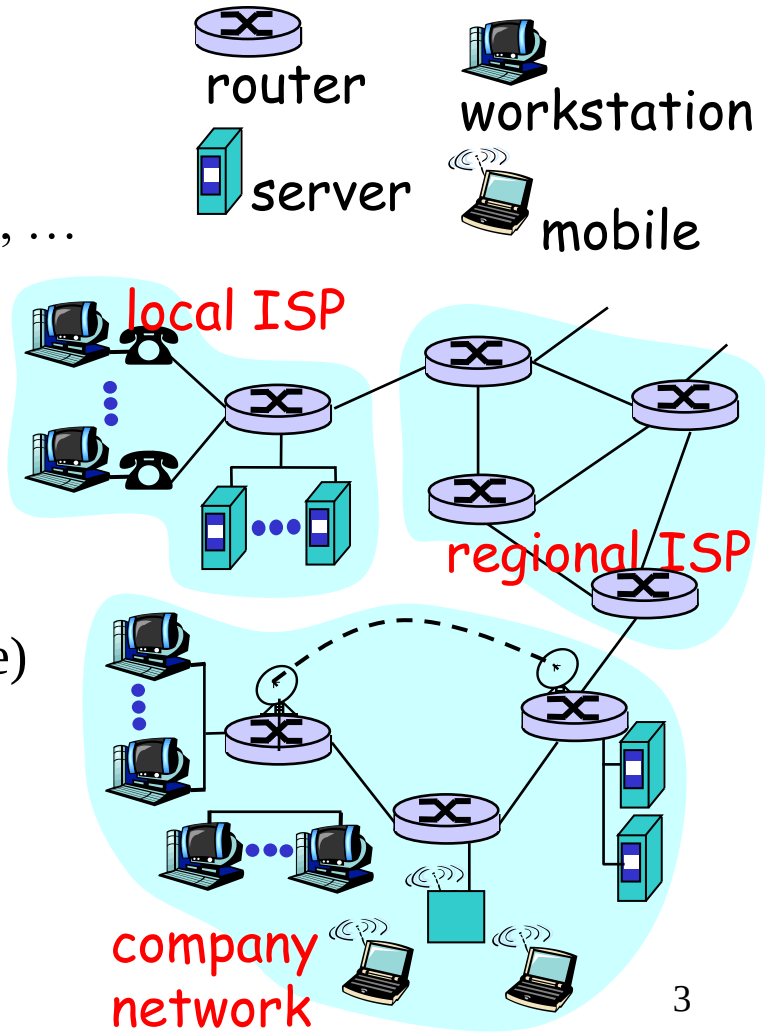
1.0 Technology Revolution

- 18th Century Mechanical systems
- 19th Century Steam Engine
- 20th Century Information
  - gathering
  - distribution
  - processing
  - creating
- 21st Century Networks

  Human-to-Human, Machine-to-Machine

What is a Computer Network

- **A set of communication elements connected by communication links**
  - Communication elements
    - Computers, printers, mobile phones, …
    - Routers, switches, ...
  - Communication links
    - optic fiber
    - coaxial cable
    - twisted pair
    - wireless (radio, microwave, satellite)
  - Topologies
    - Ring, Star, Bus, Tree, Mesh



What is a Computer Network

- **A software/hardware infrastructure**
  - Share resources
    - data, files, computing power, video,…
  - Information highway
    - communication between geographically dispersed users
  - Electronic Society
    - Cyberspace
    - Virtual global nation

Introduction

- **Computer Network**
  - an *interconnected* collection of *autonomous* computers
    - ☞*Internet:* "network of networks"
      - loosely hierarchical
      - public Internet versus private intranet
    - ☞WWW a distributed systems run on the top of Internet
- **Distributed System**
  - *High degree of cohesiveness and transparency*
  - A software system built on top of a network

1.1 Uses of Computer Networks

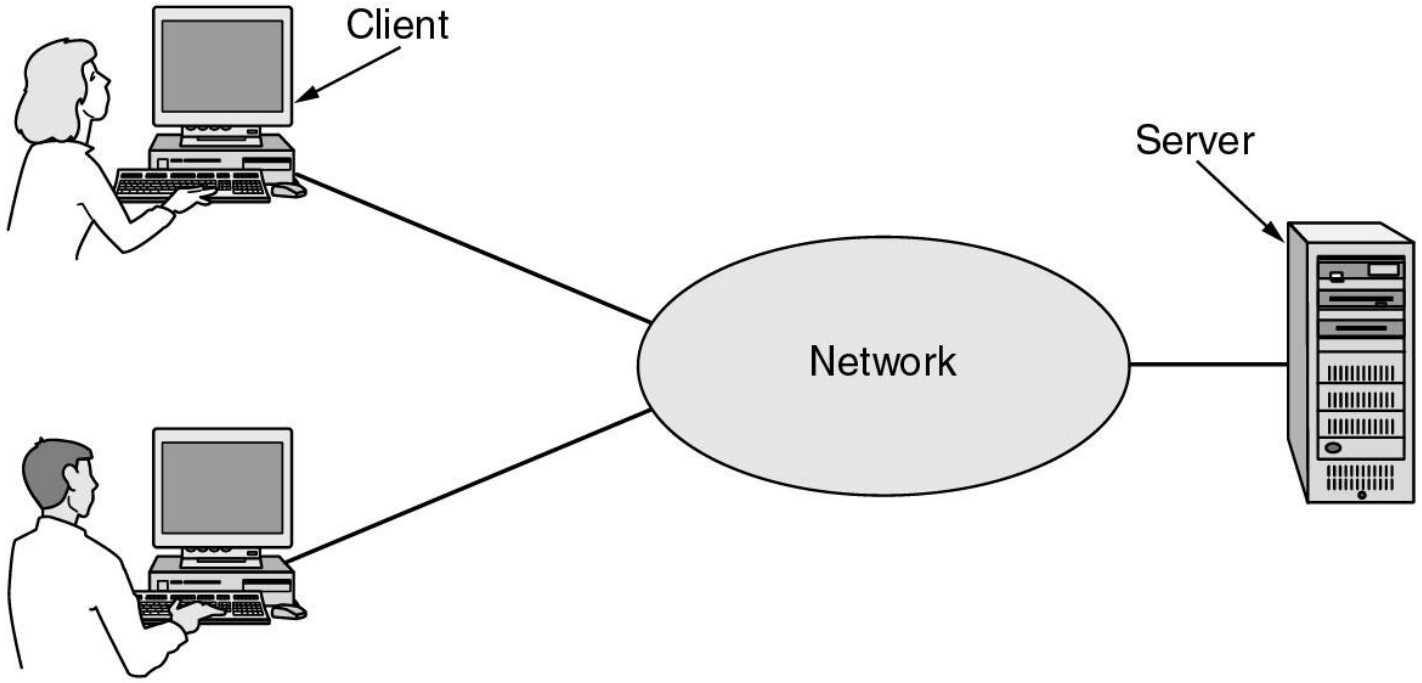
- Business Applications
- Home Applications
- Mobile Users
- Social Issues

Business Applications of Networks

a. Resource sharing (hardware, software, information, …)

b. Providing communication medium (e-mail, videoconferenceing)

c. Doing business electronically (B2B, B2C, e-commerce)



A network with two clients and one server.

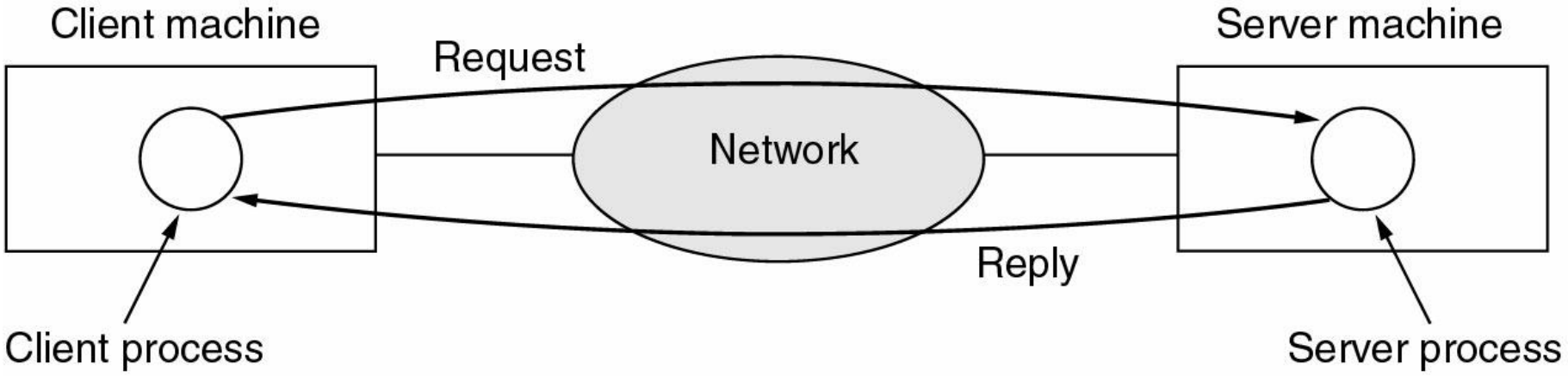
Goals of Networks for Companies

- Resource sharing: equipment, programs, data
- high reliability
  - replicated data
  - hardware
- Saving money
  - mainframe: 10 times faster, but 1000 times more expensive than PC
  - client-server model
- Scalability
  - mainframe: replace a larger one
  - client-server model: add more servers
- Communication medium for separated employees

Business Applications of Networks (2)

a. Two processes are involved

b. A communication network is needed



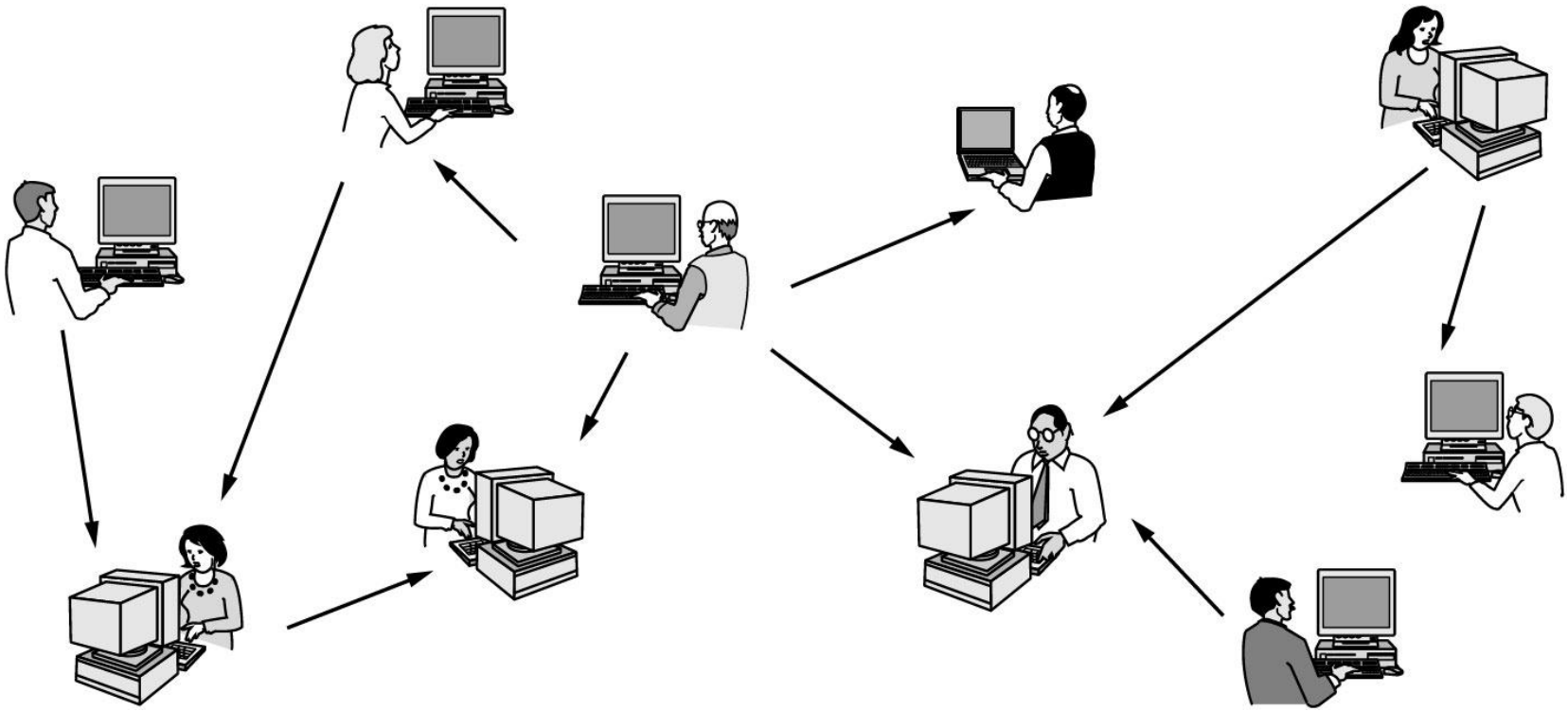
The client-server model involves requests and replies.

Home Network Applications

- Access to remote information
- Person-to-person communication
- Interactive entertainment
- Electronic commerce

- Networks for People
  - Access to remote information
    - e.g.: financial, shopping, customized newspapers, on-line digital library, WWW
  - Person-to-person communication
    - email, video conference, newsgroup
  - Interactive entertainment
    - VOD, interactive movies or TVs, game playing

Home Network Applications (2)



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

Home Network Applications (3)

Tag	Full name	Example
B2C	Business-to-consumer	Ordering books on-line
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 on-line
P2P	Peer-to-peer	Music sharing

Some forms of e-commerce.

Mobile Network Users

Wireless	Mobile	Applications
No	No	Desktop computers in offices
No	Yes	A notebook computer used in a hotel room
Yes	NO	Networks in older, unwired buildings
Yes	Yes	Store inventory with a handheld computer

Combinations of wireless networks and mobile computing.

Social Issues

- Network neutrality
- Digital Millennium Copyright Act
- Profiling users
- Phishing

Network Hardware

- Personal area networks
- Local area networks
- Metropolitan area networks
- Wide are networks
- The internet

Network Hardware

Types of transmission technology

- Broadcast links
- Point-to-point links

Network Hardware

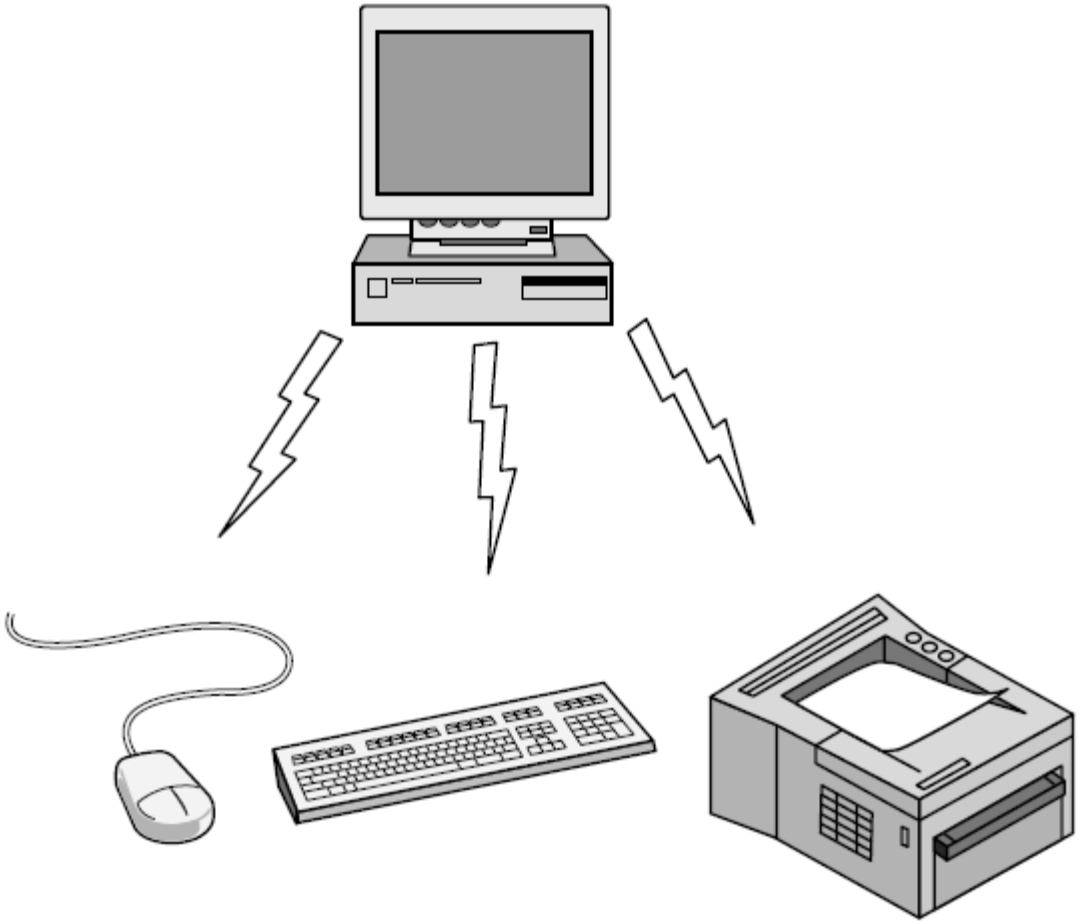
- Broadcast networks
  - single communication channel shared by all machines
  - broadcasting or multicasting (via packets)
    - broadcasting: a special code in address field
    - multicasting: reserve one bit to indicate multicasting, the remaining n-1address bits can hold a group number. Each machine can subscribe to any groups
  - used by localized networks (or satellites)
- point-to-point networks
  - many hops
  - routing algorithms: multiple routes are possible
  - used by large networks

Network Hardware

Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	Local area network
100 m	Building	
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1000 km	Continent	
10,000 km	Planet	The Internet

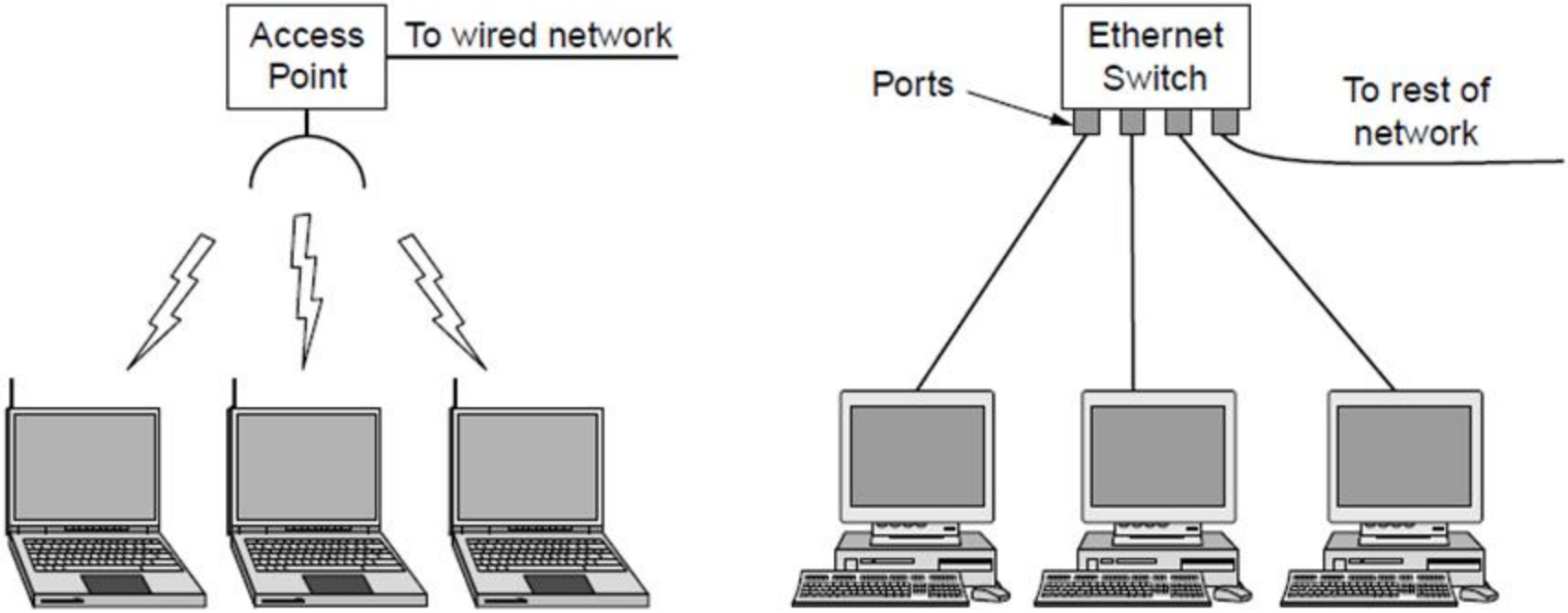
Classification of interconnected processors by scale.

Personal Area Network



Bluetooth PAN configuration

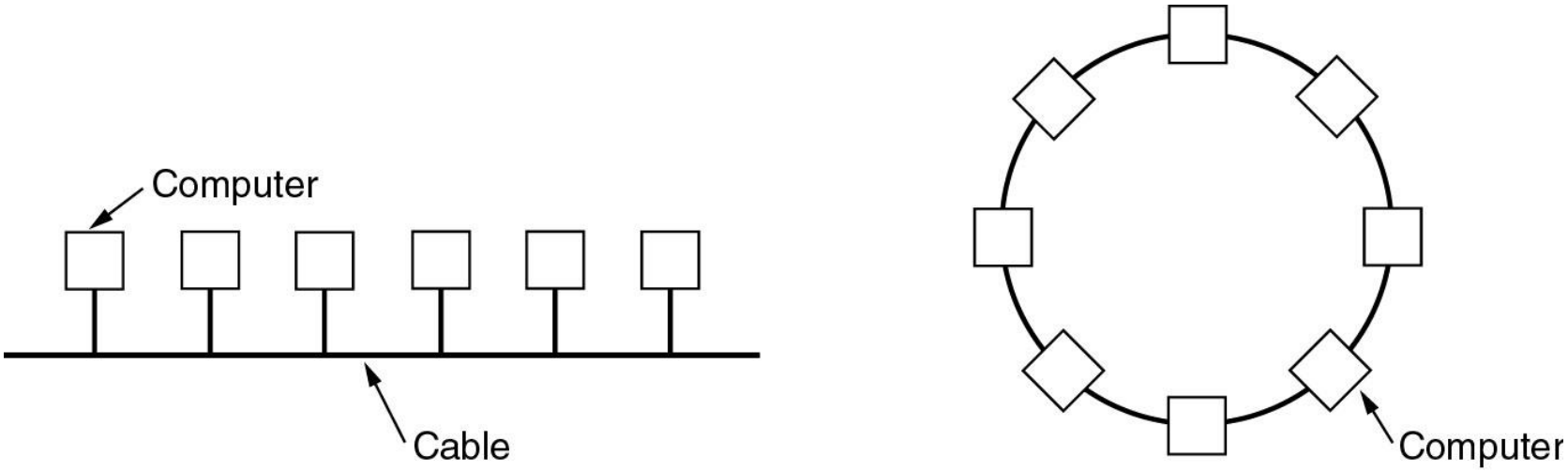
Local Area Networks



Wireless and wired LANs. (a) 802.11. (b) Switched Ethernet.

Local Area Networks (LANs)

- Characterics of LANs: (a) privated-owned, (b) small size, (c) transmission technology, (d) topology
- Ethernets are most popular (up to 10 Gb/s)



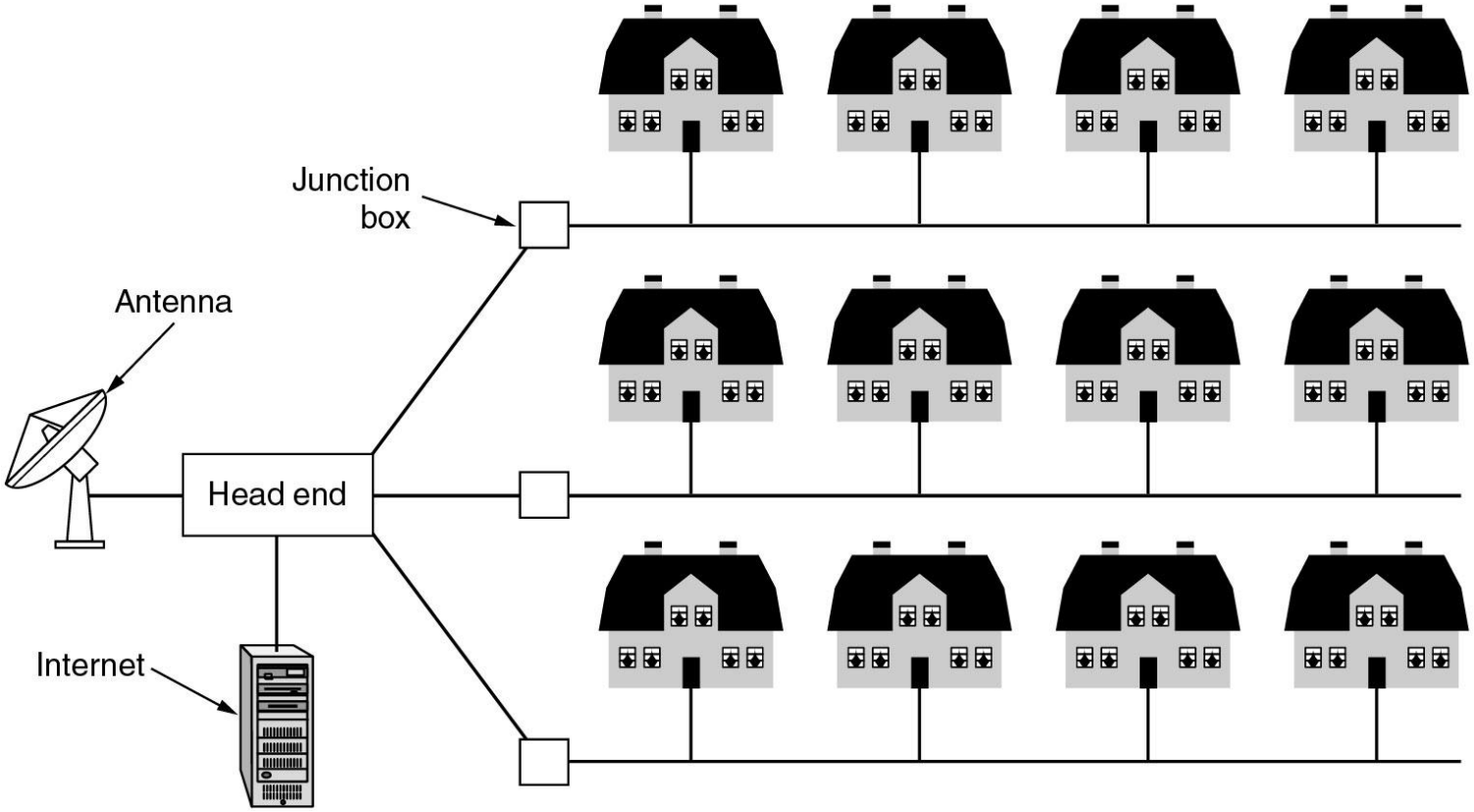
Four broadcast networks

(a) Bus 802.3
(b) Ring 802.5
(c) Token Ring 802.4
(d) Wireless LAN 802.11

Local Area Networks

- Characteristics
  - small size
  - transmission technology
    - single cable (single channel)
    - 10Mbps ~ 10Gb/s
    - 10Gb/s : 10,000,000.000 bps
  - topology:
    - bus
      - Ethernet (IEEE 802.3): 10 or 100 Mbps (10Gb/s)
    - ring
      - IBM token ring (IEEE 802.5): 4 or 16 Mbps
    - Wireless broadcast
- Channel allocation of broadcast networks
  - static: each machine has an allocated time slot
  - dynamic

Metropolitan Area Networks

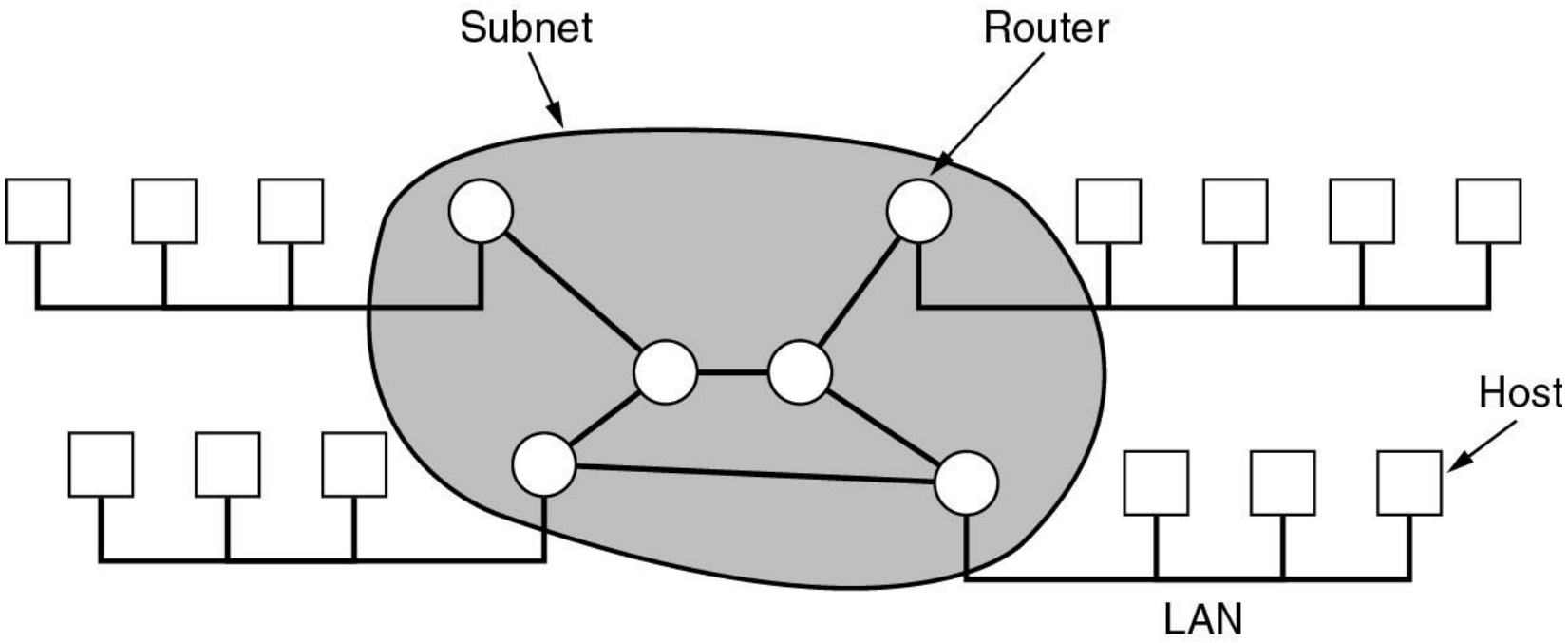


A metropolitan area network based on cable TV.

Wide Area Networks (WANs)

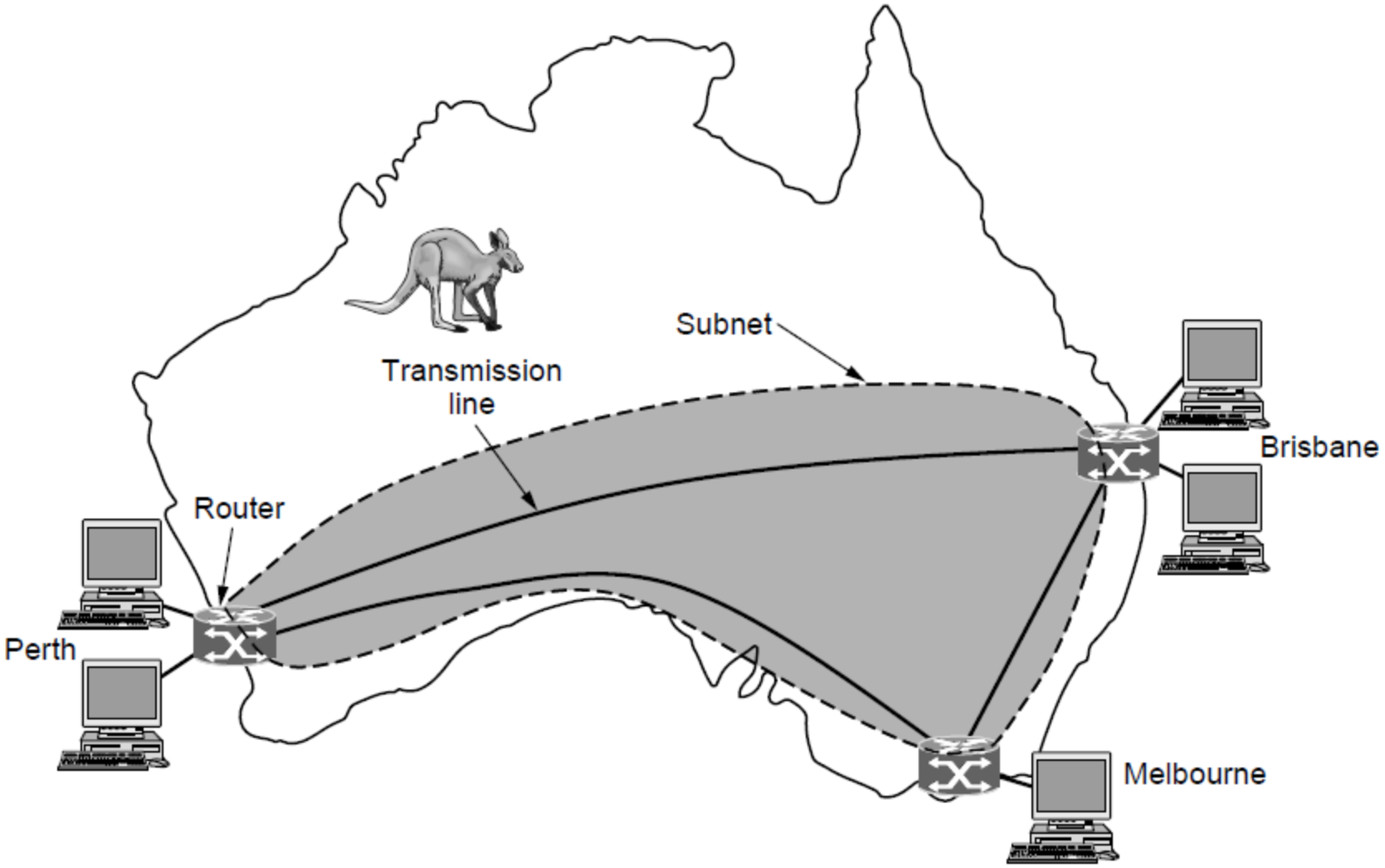
·WANs are **point-to-point** networks

·WANs consist of two distinct components:
transmission lines (copper, fiber, microwave) and **switches** (electronics, optics)
⇨ **Store-and-forward** or **packet-switched** subnet



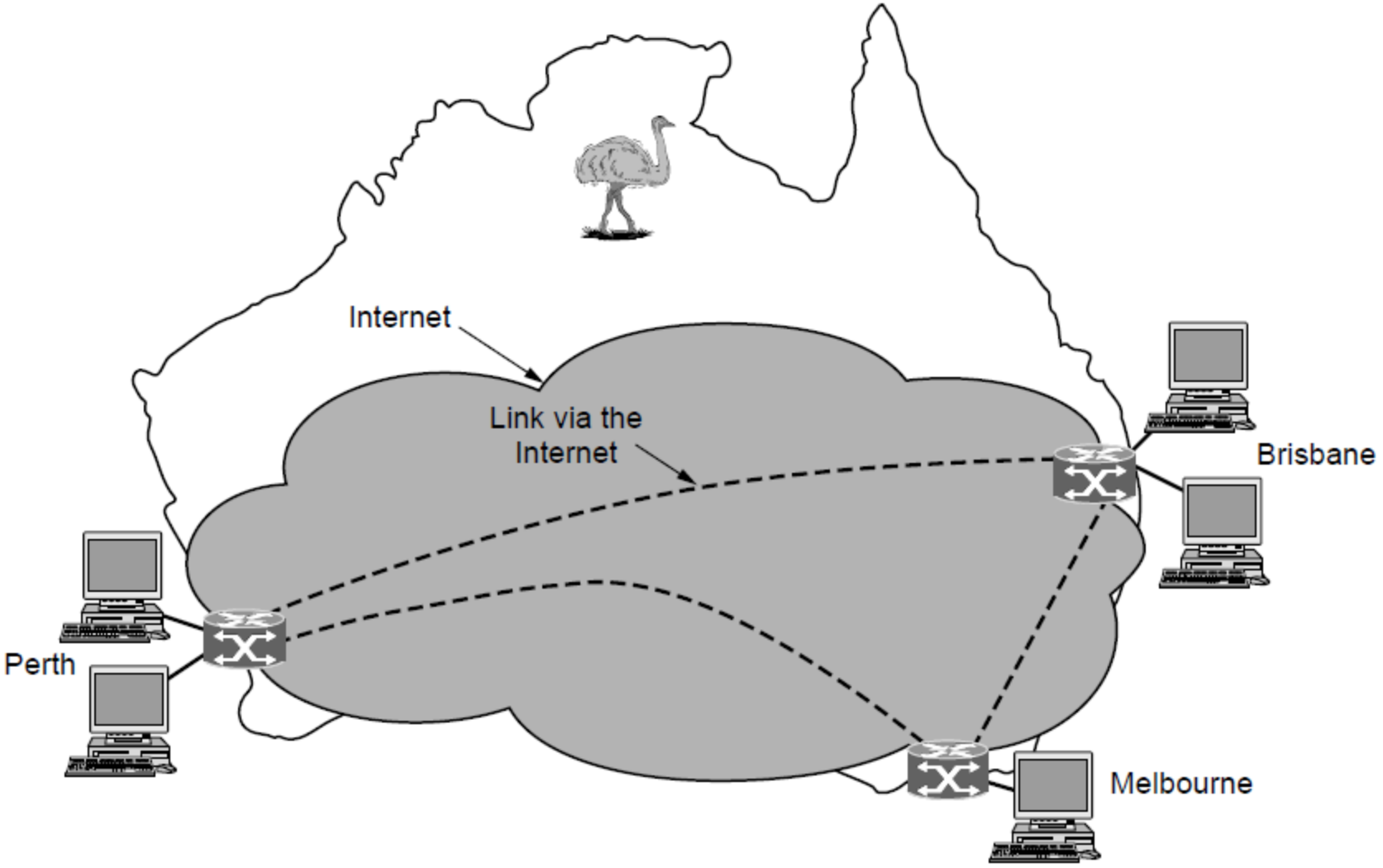
Relation between hosts on LANs and the subnet.

Wide Area Networks



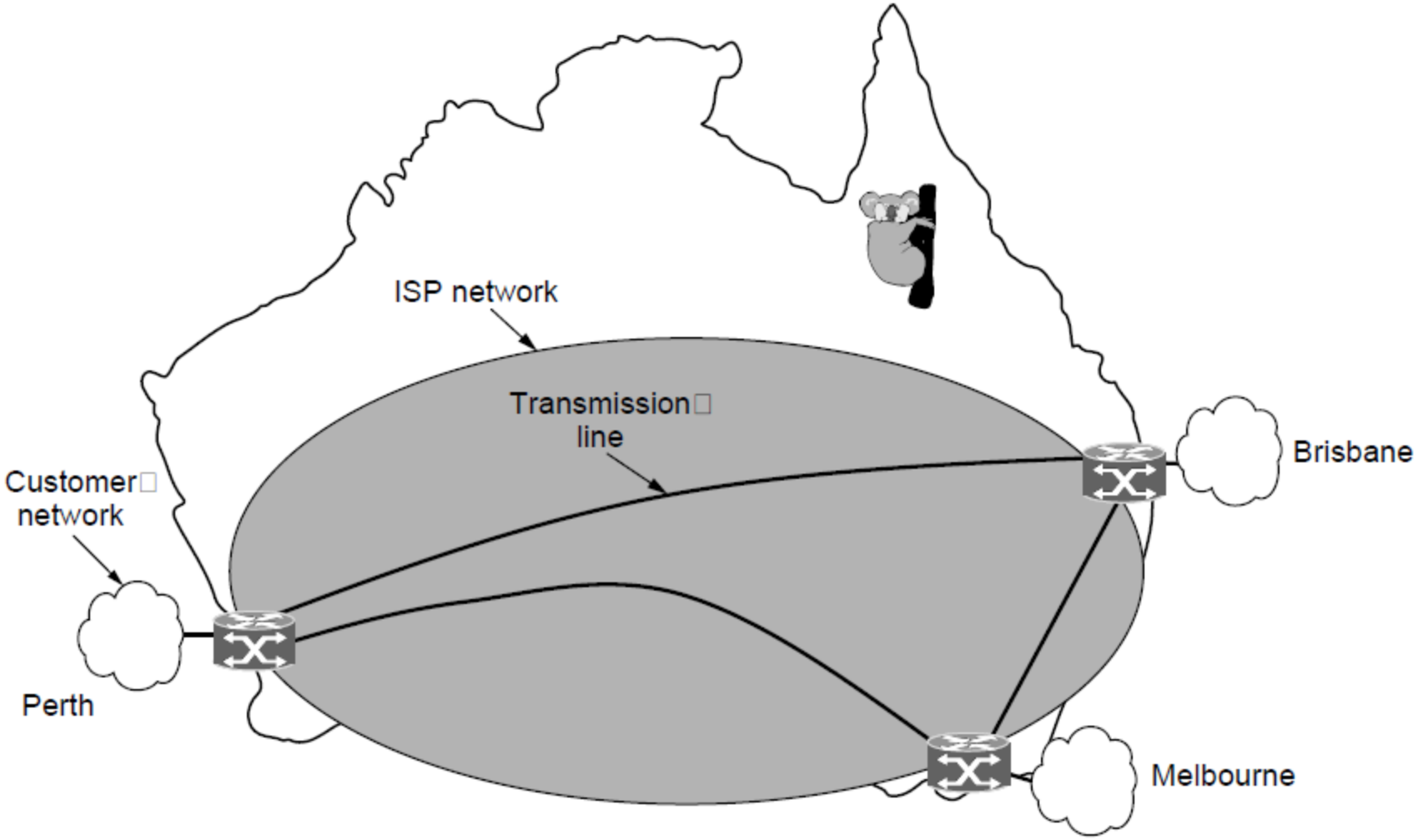
WAN that connects three branch offices in Australia

Wide Area Networks



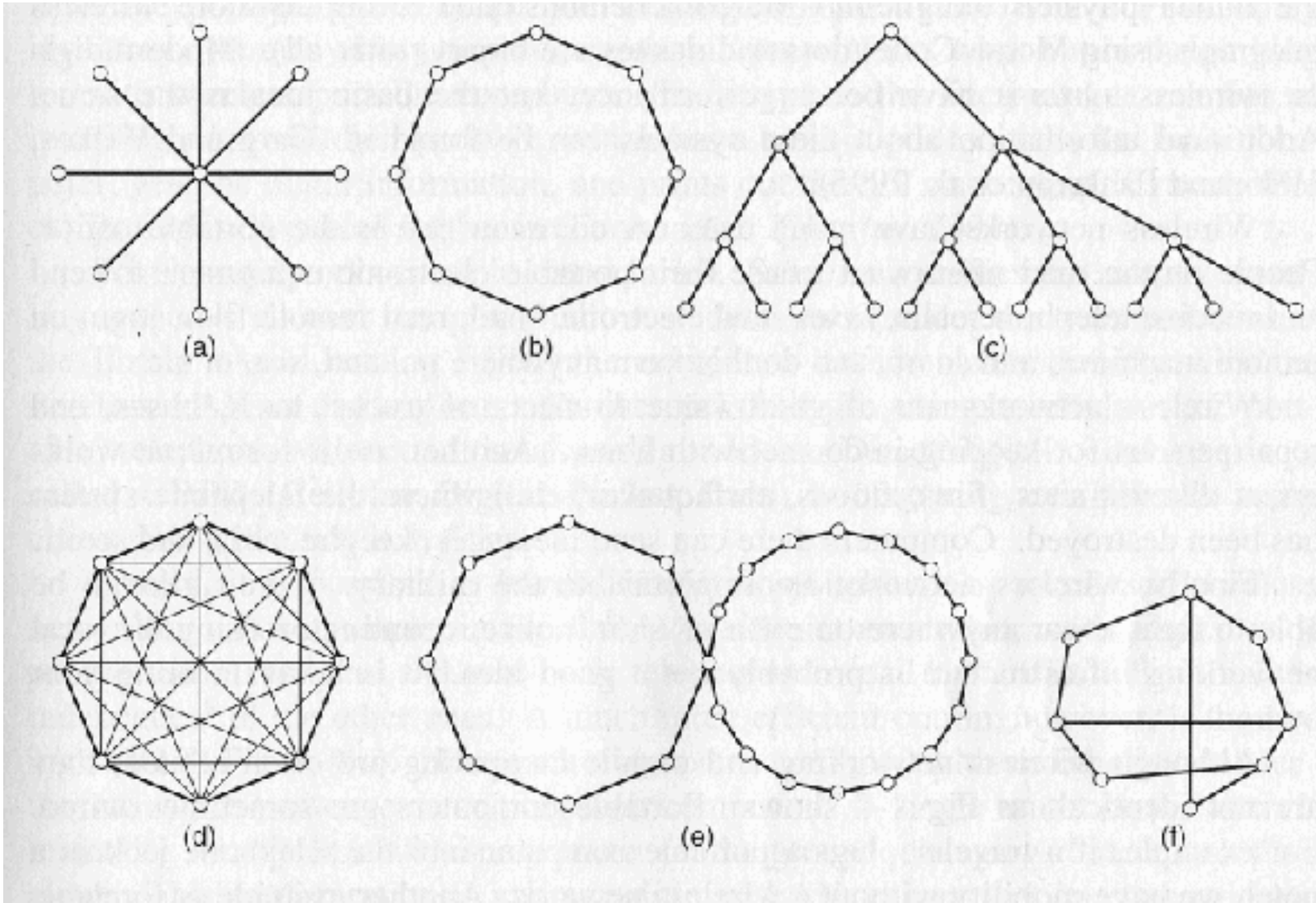
WAN using a virtual private network.

Wide Area Networks



WAN using an ISP network.

Network Topology

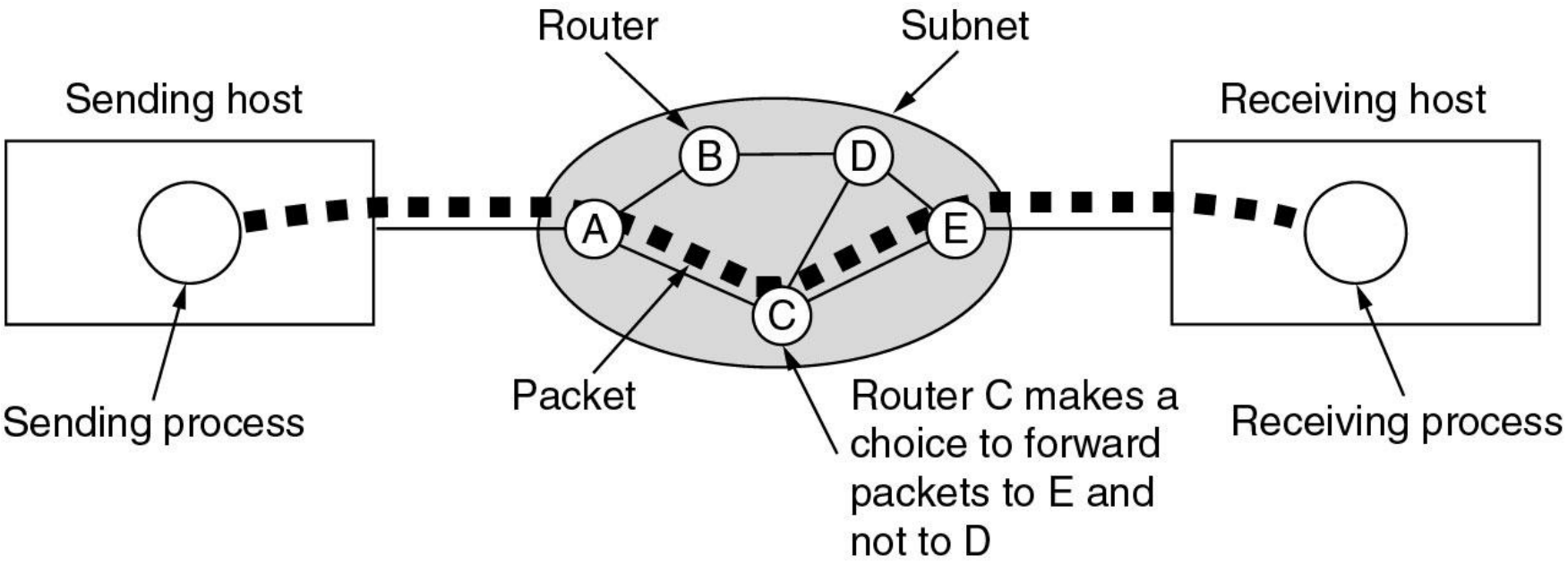


Subnet (WANs)

Subnet (WANs) is consists of two components:

- transmission lines (circuits, channels, trunks)
  - move bits between machines
- switching elements
  - connect transmission lines
  - Router: also called packet switching nodes, intermediate systems, and data switching exchanges
  - Operate in store-and-forward, or packet-switched mode.

Wide Area Networks (2)



- Routing decisions are made locally·
- How A makes that decision is called the routing algorithm.
  ⇨ Will be studied in detail in Chapter 6.

A stream of packets from sender to receiver. (virtual- circuit)

9/17 End

Network Software

- Protocol Hierarchies (Layer structure)
- Design Issues for the Layers
- Connection-Oriented and Connectionless Services
- Service Primitives
- The Relationship of Services to Protocols

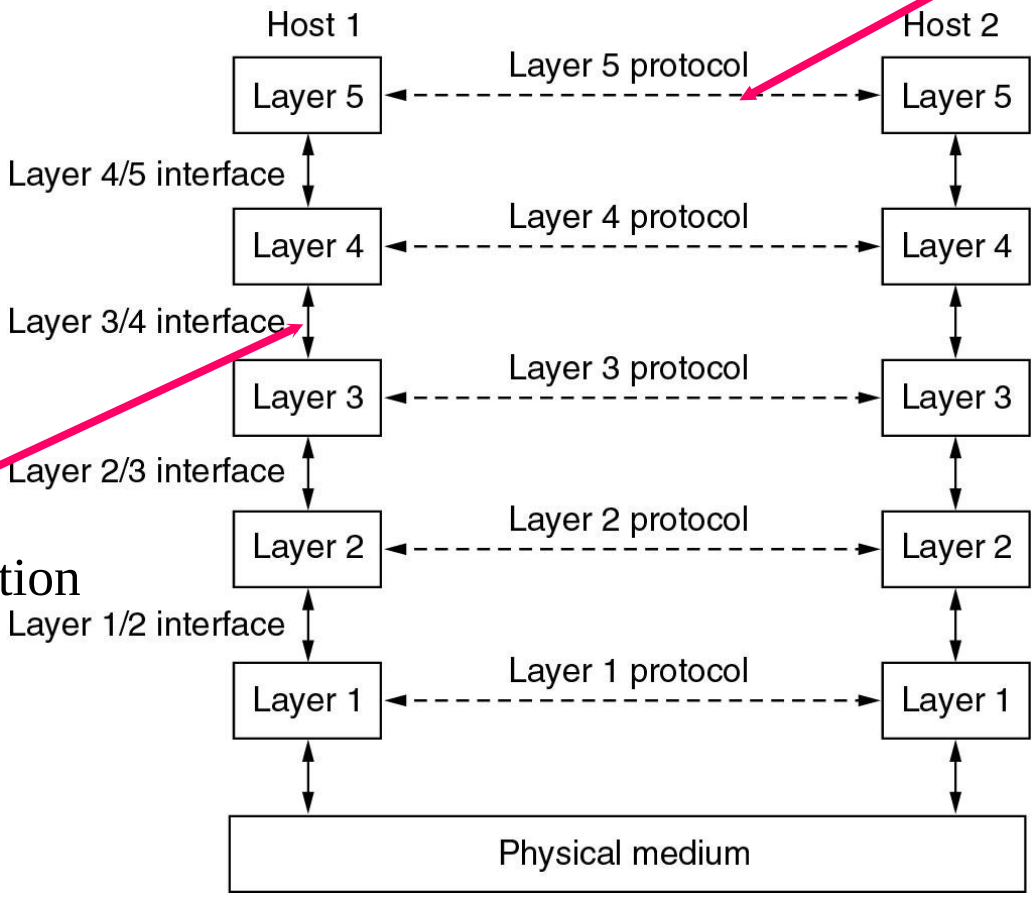
Network Software

Protocol Hierarchies

- a series of **layers** (levels)
- lower layer provides service to higher layers
- **protocol**:
  - an agreement between the communication parties on how communication is to proceed
- **Peers**:
  - the corresponding layers on different machines.
- **Network architecture**: a set of layers and protocols
- **Protocol stack**:
  - a list of protocols used by a certain system, one protocol per layer

Network Software

Protocol Hierarchies



Virtual Communication

→ **Peer**

Physical Communication

Layers, protocols, and interfaces.

Network Architecture: A set of layers and protocols

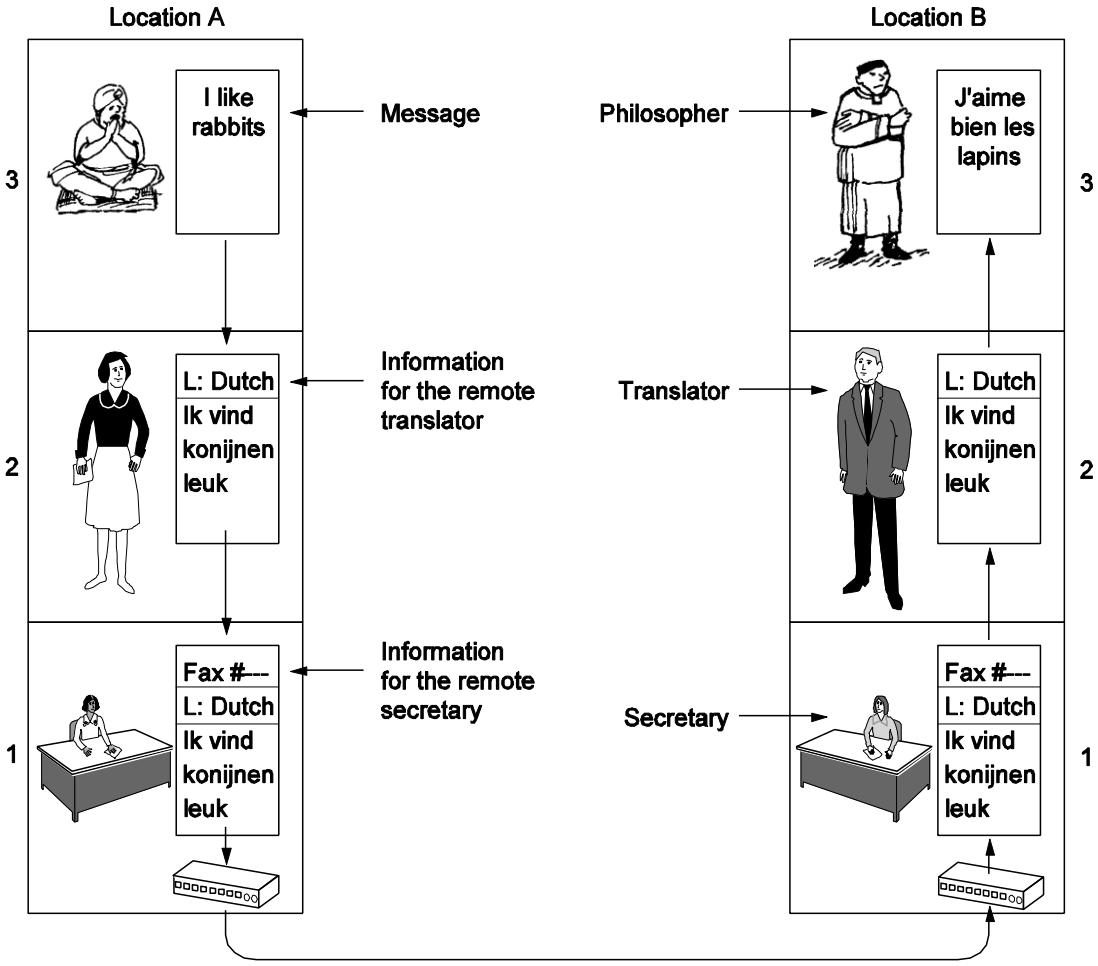
Protocol Stack: A list of protocols used by a certain system, one protocol per layer.

Network Software

◆ Layering

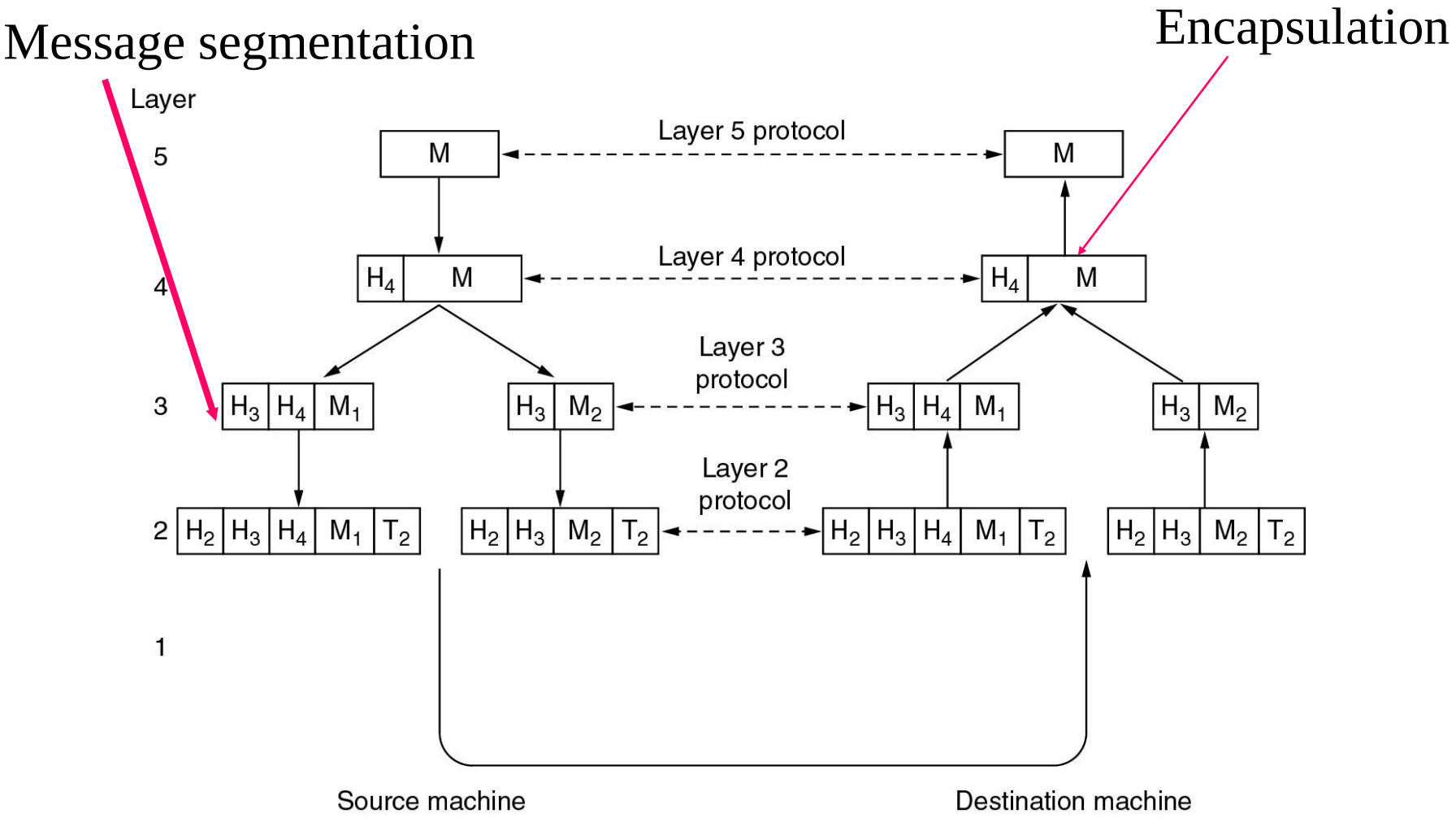
- ➪ To make things simple: modularization container
- ➪ Different layer has different functions
- ➪ Create layer boundary such that
  - ● **description of services can be small**
  - ● **number of interactions across boundary are minimized**
  - ● **potential for interface standardized**
- ➪ Different level of abstraction in the handling of data (e.g., syntax, semantics)
- ➪ Provide appropriate services to upper layer
- ➪ Use service primitives of lower layer

Protocol Hierarchies



The philosopher-translator-secretary architecture.

Protocol Hierarchies



Example information flow supporting virtual communication in layer 5.

Design Issues for the Layers

- Addressing (telephone number, e-mail address, IP address,…)
- Error Control (error correction codes, ARQ, HARQ,…)
- Flow Control (feedback-based, rate-based)
- Multiplexing (gathering several small messages with the same destination into a single large message or vice versa → Demultiplexing)
- Routing (directing traffic to the destination)

Design Issues for Layers

- Identify senders and receivers
  - multiple computers and processes: addressing
- Data transfer
  - simplex, half-duplex, full-duplex communication
  - # of logical channels per connections, priorities
- Error control
  - error detection
  - error correction
- Sequencing of pieces

Design Issues for Layers

- Flow control
  - feedback from the receiver
  - agreed upon transmission rate
- Length of messages
  - long messages: disassemble, transmit, and reassmeble messages
  - short messages: gather several small messages
- Multiplexing and Demultiplexing
  - when expensive to set up a separate connection
  - needed in physical layer
- Routing: split over two or more layers
  - High level: London -> France or Germany -> Rome
  - Low level: many available circuits

Connection-Oriented and Connectionless Services

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

Six different types of service.

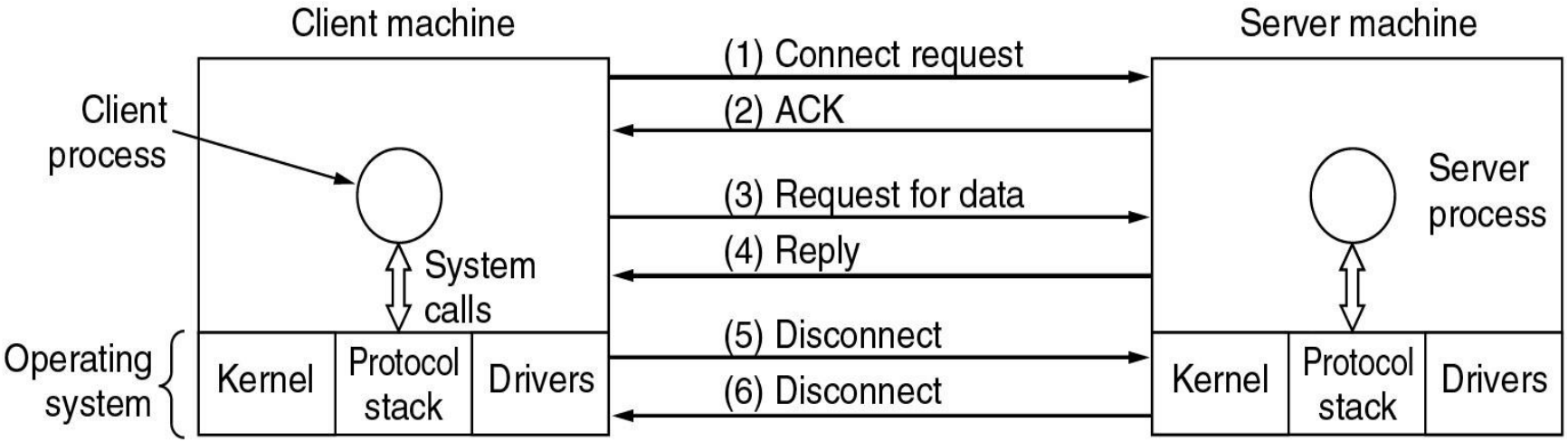
Service Primitives (operations) (1)

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

Six service primitives that provide a simple connection-oriented service

Service Primitives (2)

If the protocol stack is located in the operating system, the primitives are normally system calls.



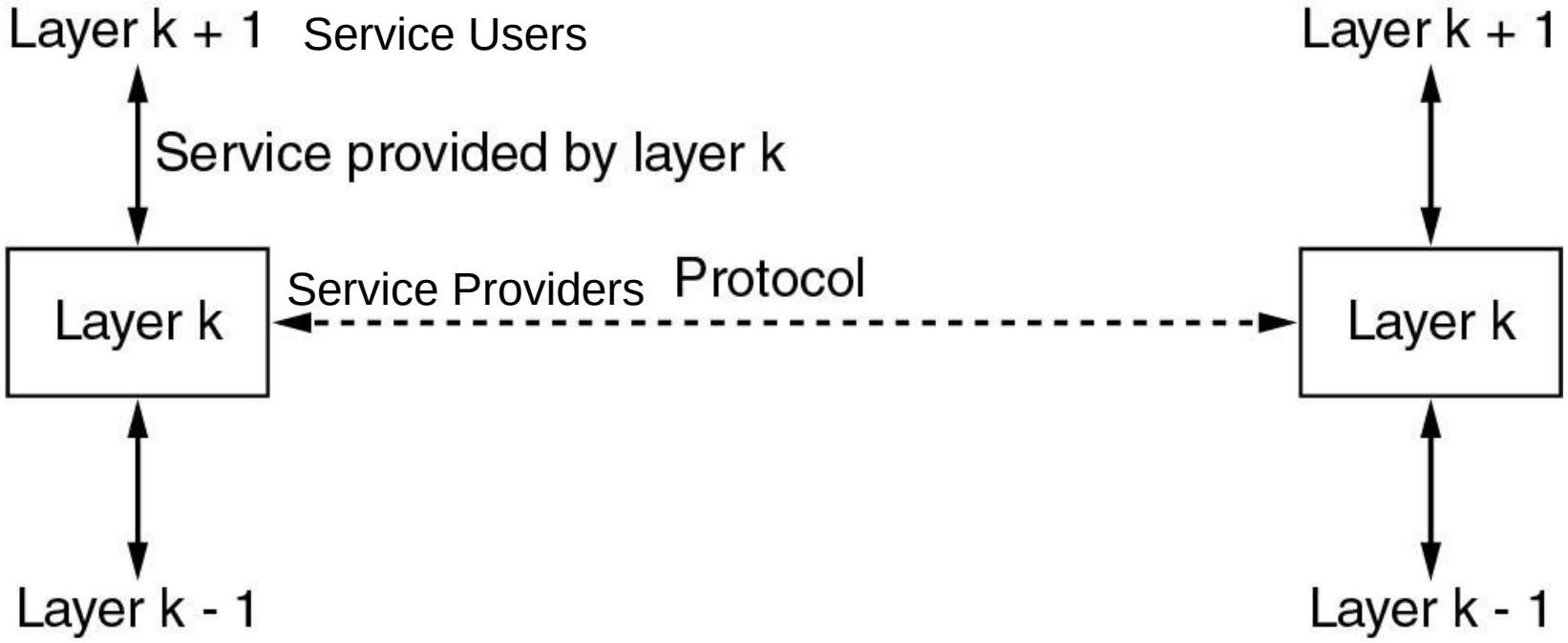
Packets sent in a simple client-server interaction on a connection-oriented network.

Services to Protocols Relationship

- The service defines what operations the layer is prepared to perform on behalf of its users
- A service is a set of primitives that a layer provides to the layer above it.
- A protocol is a set of rules governing the format and meaning of the packets which are exchanged by the peer entities in the same layer.

⇨ Services related to the interfaces between layers;

⇨ Protocols related to the packets sent between peer entities on different machine.



The relationship between a service and a protocol.

Reference Models

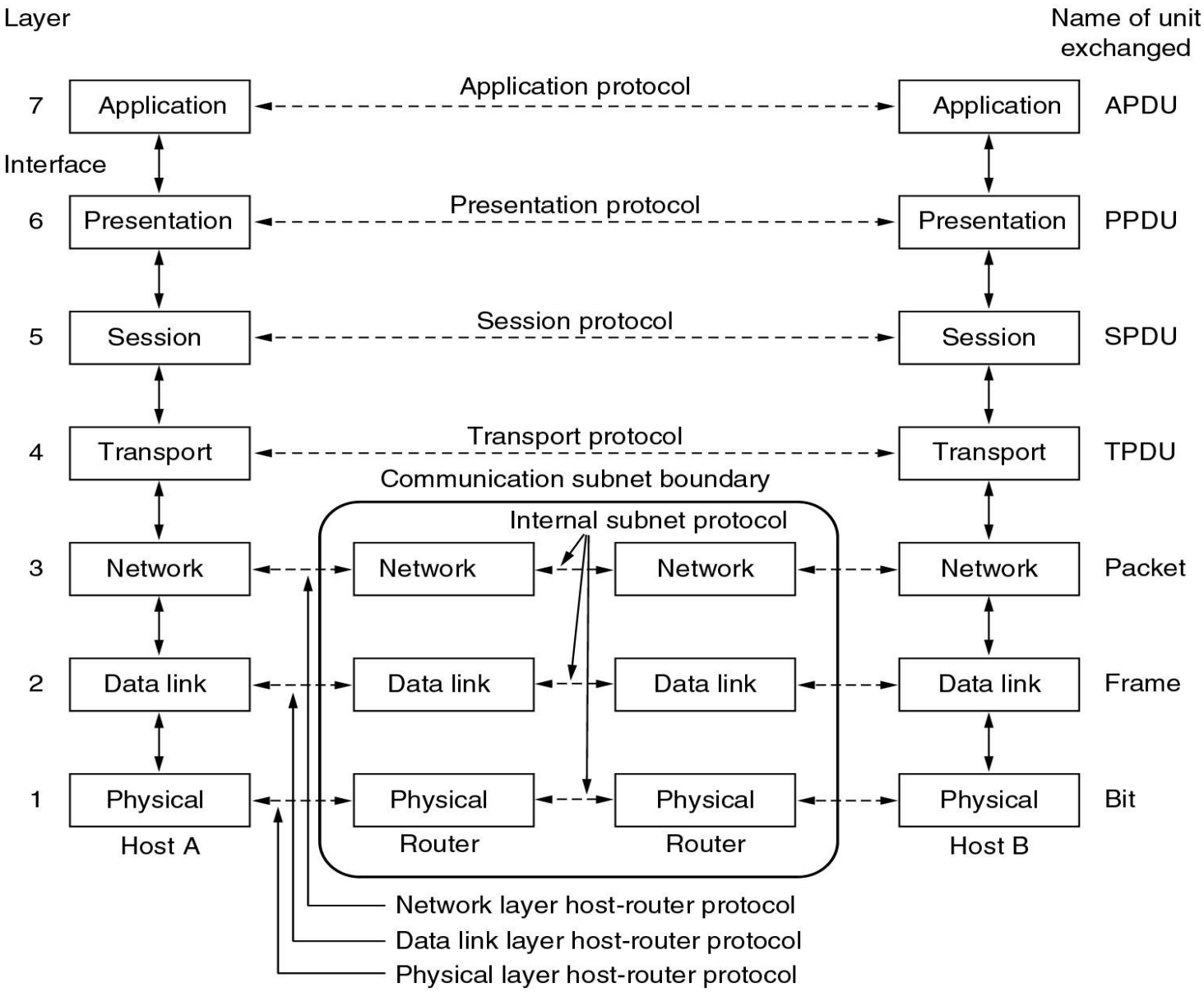
- OSI reference model
- TCP/IP reference model
- Model used for this text
- Comparison of OSI and TCP/IP
- Critique of OSI model and protocols
- Critique of the TCP/IP model

The design principle of the OSI reference model

- A layer should be created where a different abstraction is needed
- Each layer should perform a well defined function
- The function of each layer can be chosen as an international standard
- The layer boundaries should be chosen to minimize the information flow across the interfaces
- The number of layers should be not too large or not too small (optimum)

Reference Models

The OSI reference model.



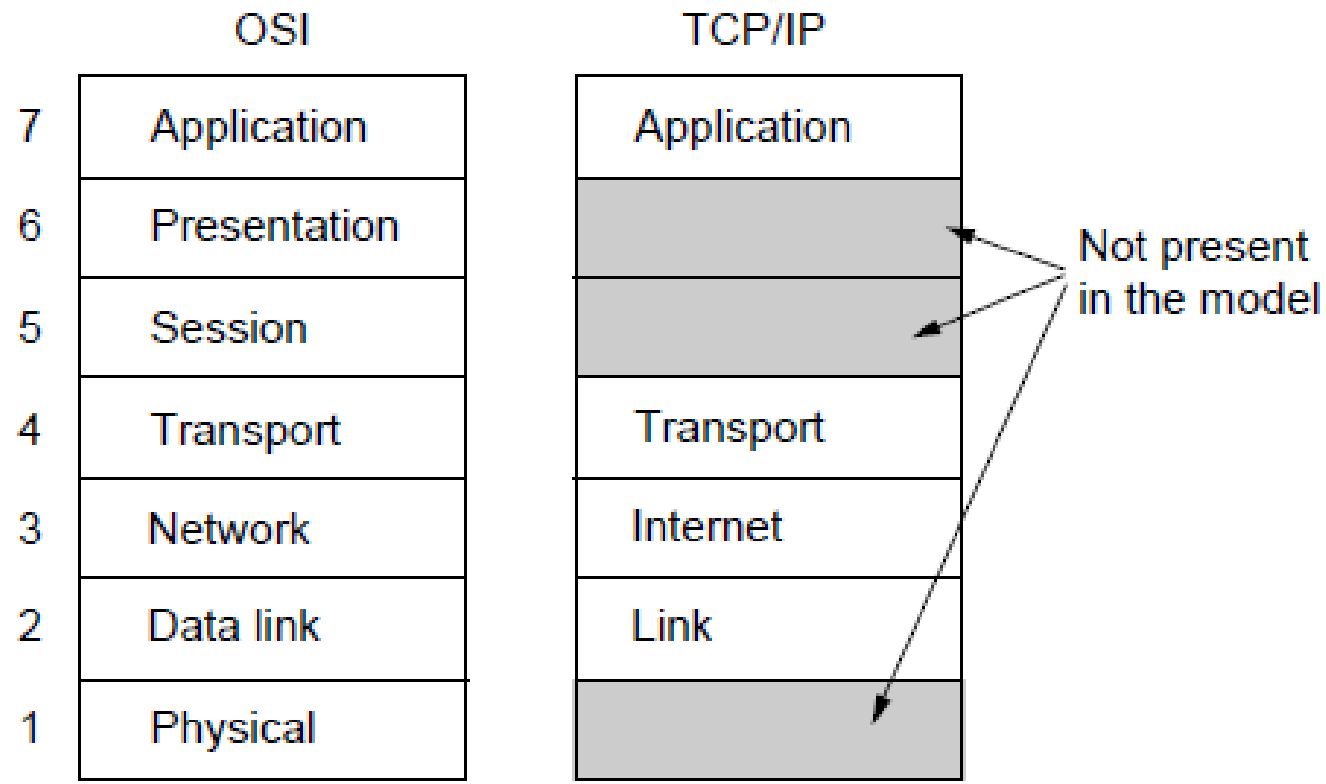
The functions of the seven layers

- The physical layer is concerned with transmitting raw bits over a communication channel
- The data link layer performs flow control and also transforms a raw transmission facility into a line that appears error free (ARQ)
- The network layer controls the operation of the subnet, e.g. routing, flow control, internetworking,…
- The transport layer performs assembling and disassembling, isolates the upper layers from the changes in the network hardware, and determines the type of services
- The session layer establishes sessions (dialog control, …)
- The presentation layer is concerned with the syntax and semantics
- The application layer contains a variety of commonly used protocols (e.g. Hyper Text Transfer Protocol for WWW, file transfer, e-mail, network news,…)

The TCP/IP Reference Models Layers

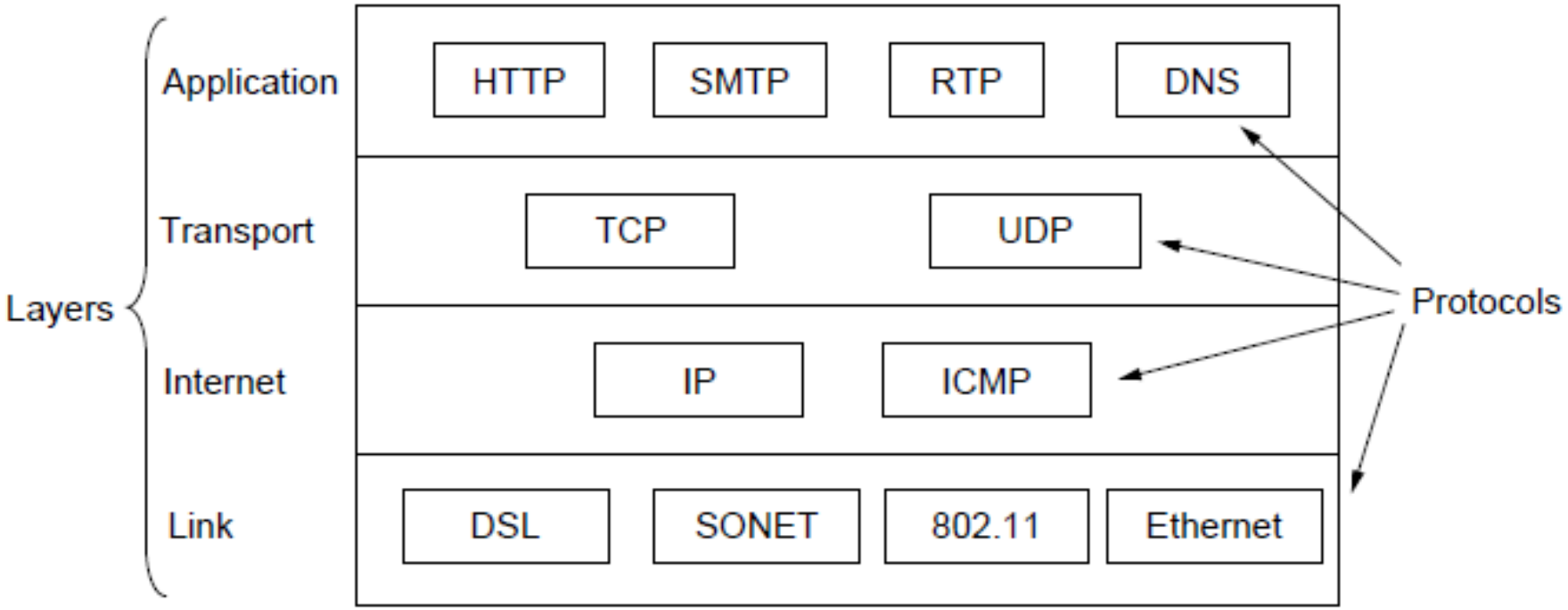
- Link layer
- Internet layer
- Transport layer
- Application layer

The TCP/IP Reference Model (1)



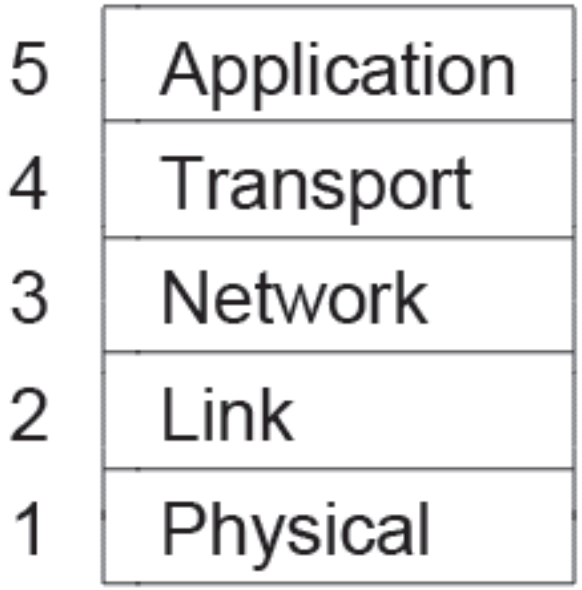
The TCP/IP reference model

The TCP/IP Reference Model (2)



The TCP/IP reference model with some protocols we will study

The Model Used in this Book



The reference model used in this book.

Comparing OSI and TCP/IP Models

Concepts central to the OSI model

- Services: defines layer's semantics
- Interfaces: tells the processes above it how to access it.
- Protocols

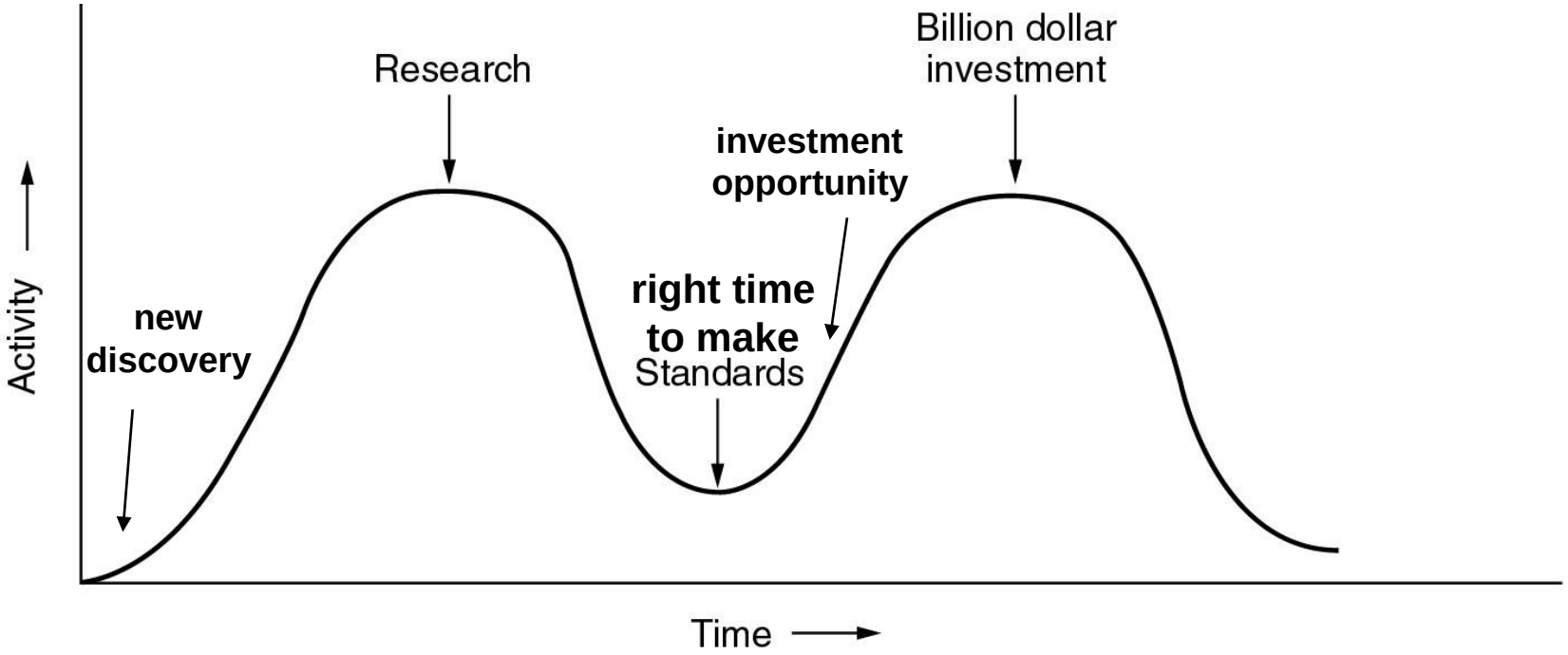
Probably the biggest contribution of the OSI model is to make the distinction between these three concepts explicit.

A Critique of the OSI Model and Protocols

Why OSI did not take over the world

- Bad timing
- Bad technology
- Bad implementations
- Bad politics

Bad Timing



The apocalypse of the two elephants.

Bad Technology

- The choice of seven layers was political
  - session and presentation layers are nearly empty
  - Data and network layers are overfull
- The OSI model is extraordinarily complex
- Some functions e.g. addressing, flow control, error control reappear again and again

Bad Implementations

- Huge, Unwieldy, and Slow

Bad Politics

- Bureaucrats involved too much (European telecommunication ministries, community, us government)

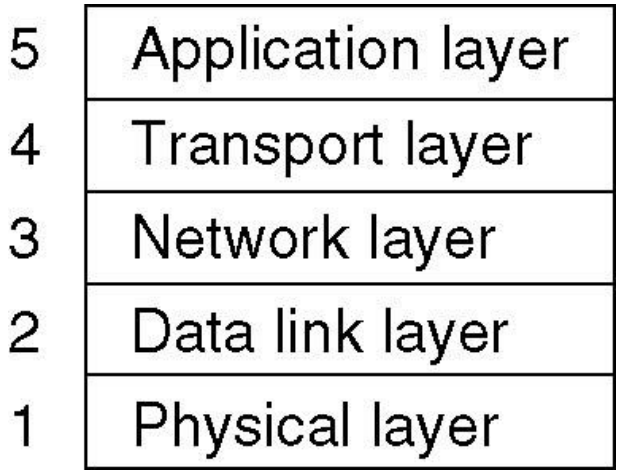
A Critique of the TCP/IP Reference Model

Problems:

- Service, interface, and protocol not distinguished
- Not a general model
- Host-to-network “layer” not really a layer (is an interface)
- No mention of physical and data link layers
- Minor protocols deeply entrenched, hard to replace

  (The virtual terminal protocol, TELNET, was designed for mechanical teletype terminal)

Hybrid Model

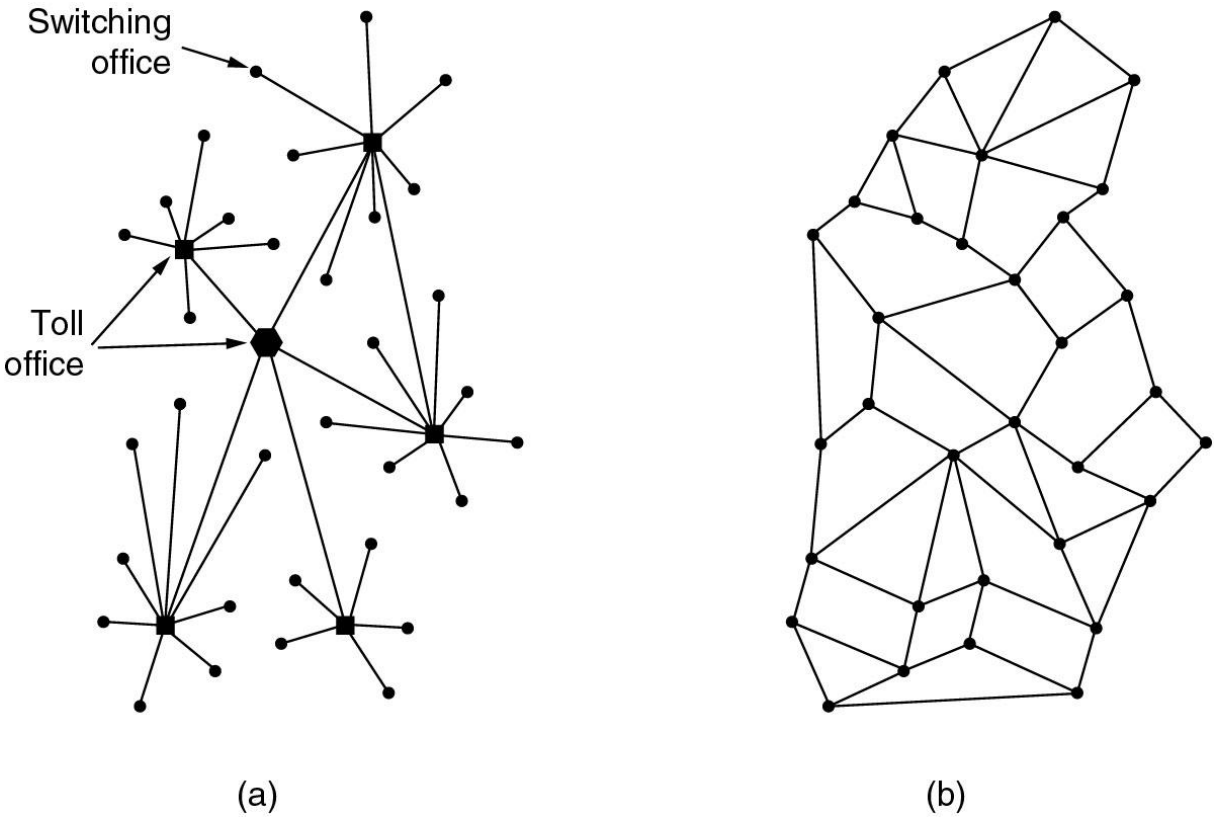


The hybrid reference model to be used in this book.

Example Networks

- Internet
- ARPANET
- NSFNET
- Third-generation mobile phone networks
- Wireless LANs: 802.11
- RFID and sensor networks

The ARPANET



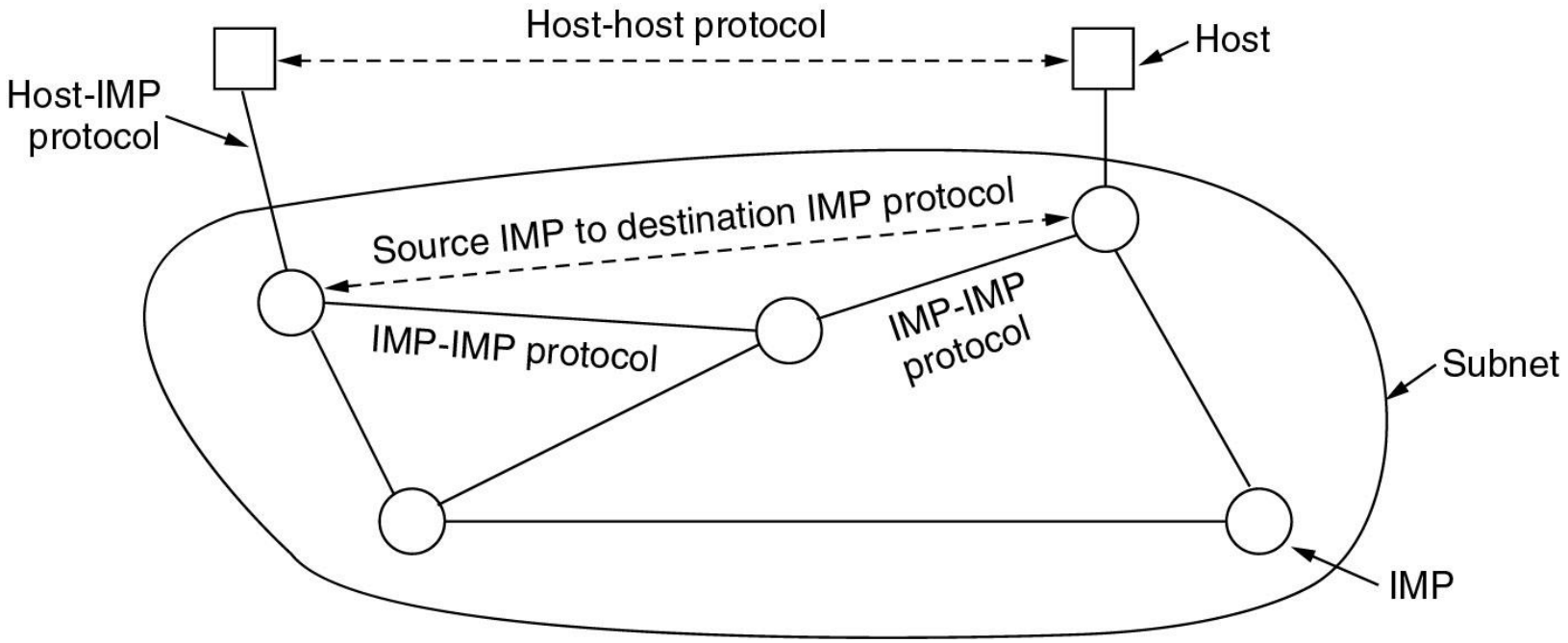
(a) Structure of the telephone system.

(b) Baran's proposed distributed switching system.

ARPANET (1969-1989)

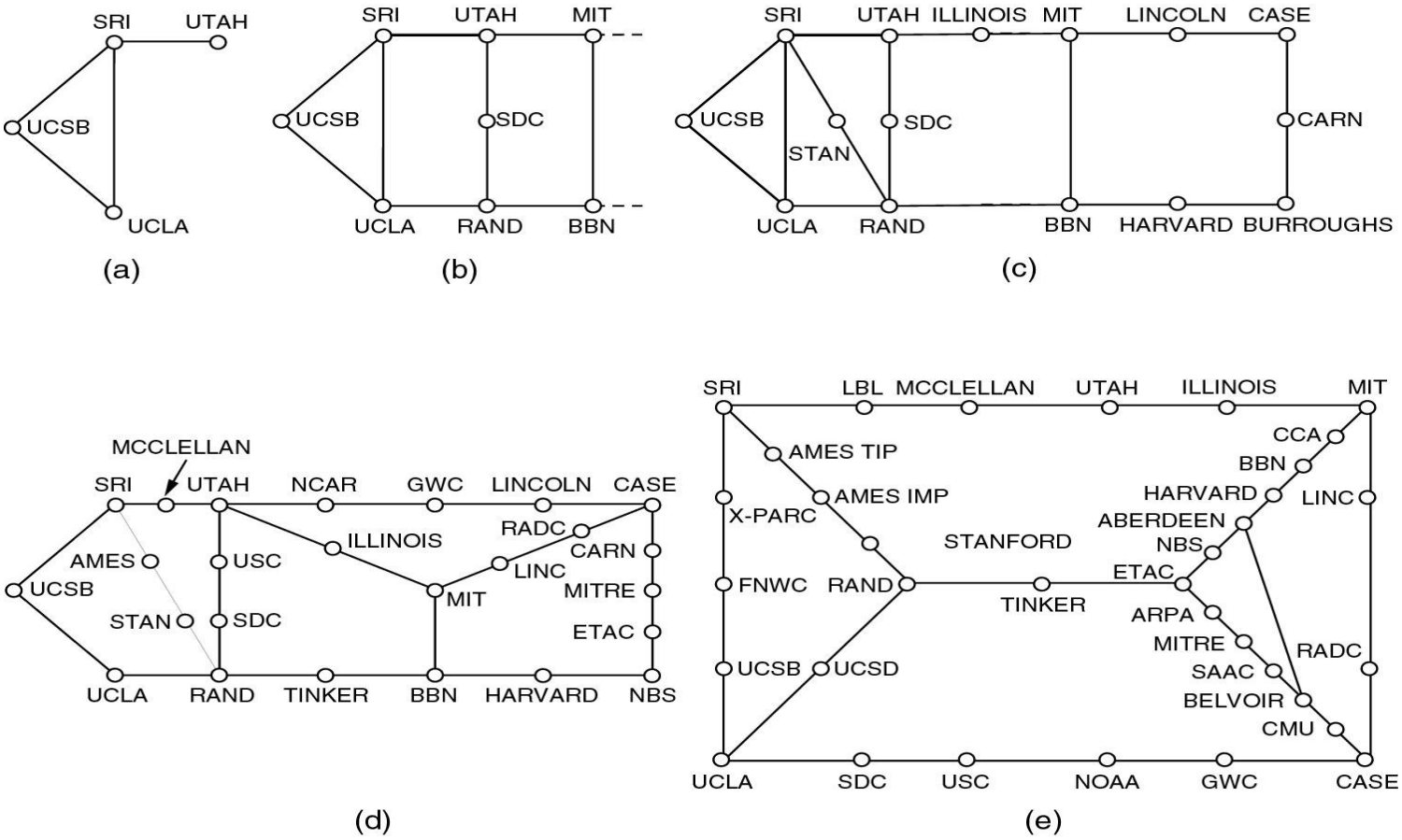
- Original backbone of Internet
- Wide area network around which TCP/IP was developed
- Funding from Advanced Research Project Agency
- Initial speed 50 Kbps

The ARPANET (2)



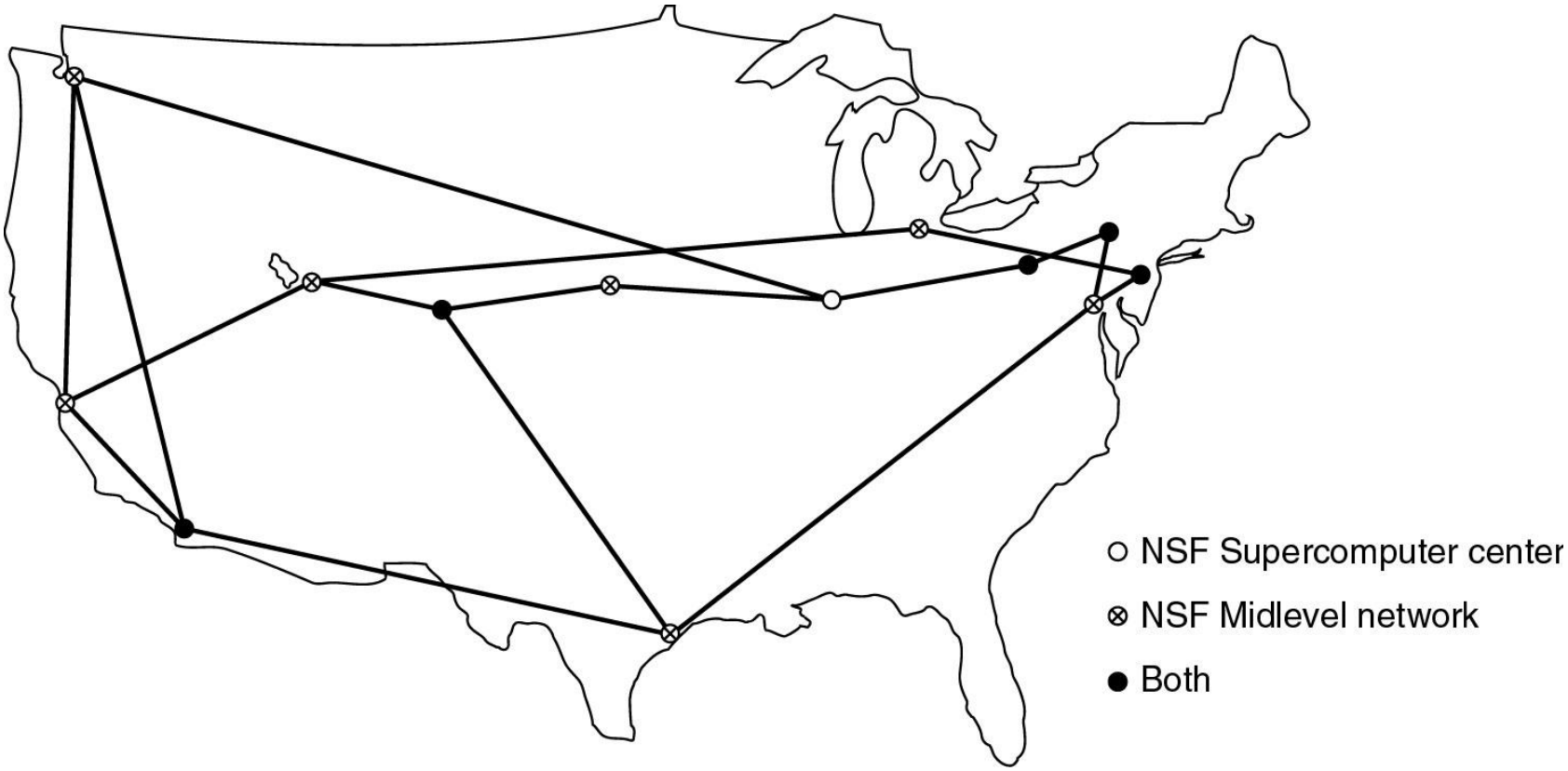
The original ARPANET design.

The ARPANET (3)



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

NSFNET

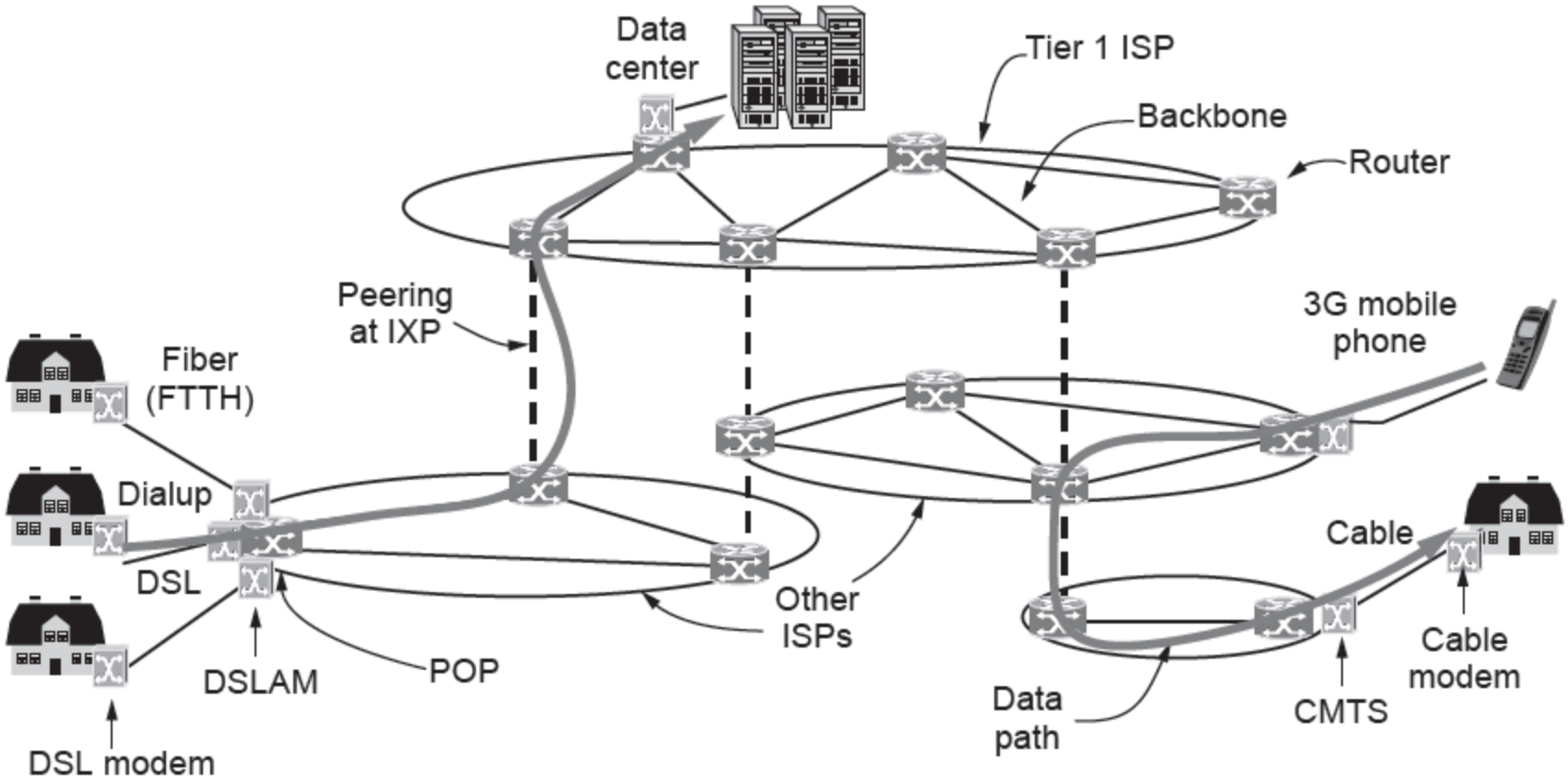


The NSFNET backbone in 1988.

NSFNET (1987-1992)

- Funded by National Science Foundation
- Motivation: Internet backbone to connect all scientists and engineers
- Introduced Internet hierarchy
  - Wide area backbone spanning geographic U.S.
  - Many mid-level (regional) networks that attach to backbone
  - Campus networks at lowest level
- Initial speed 1.544 Mbps

Architecture of the Internet



Overview of the Internet architecture

Internet Usage

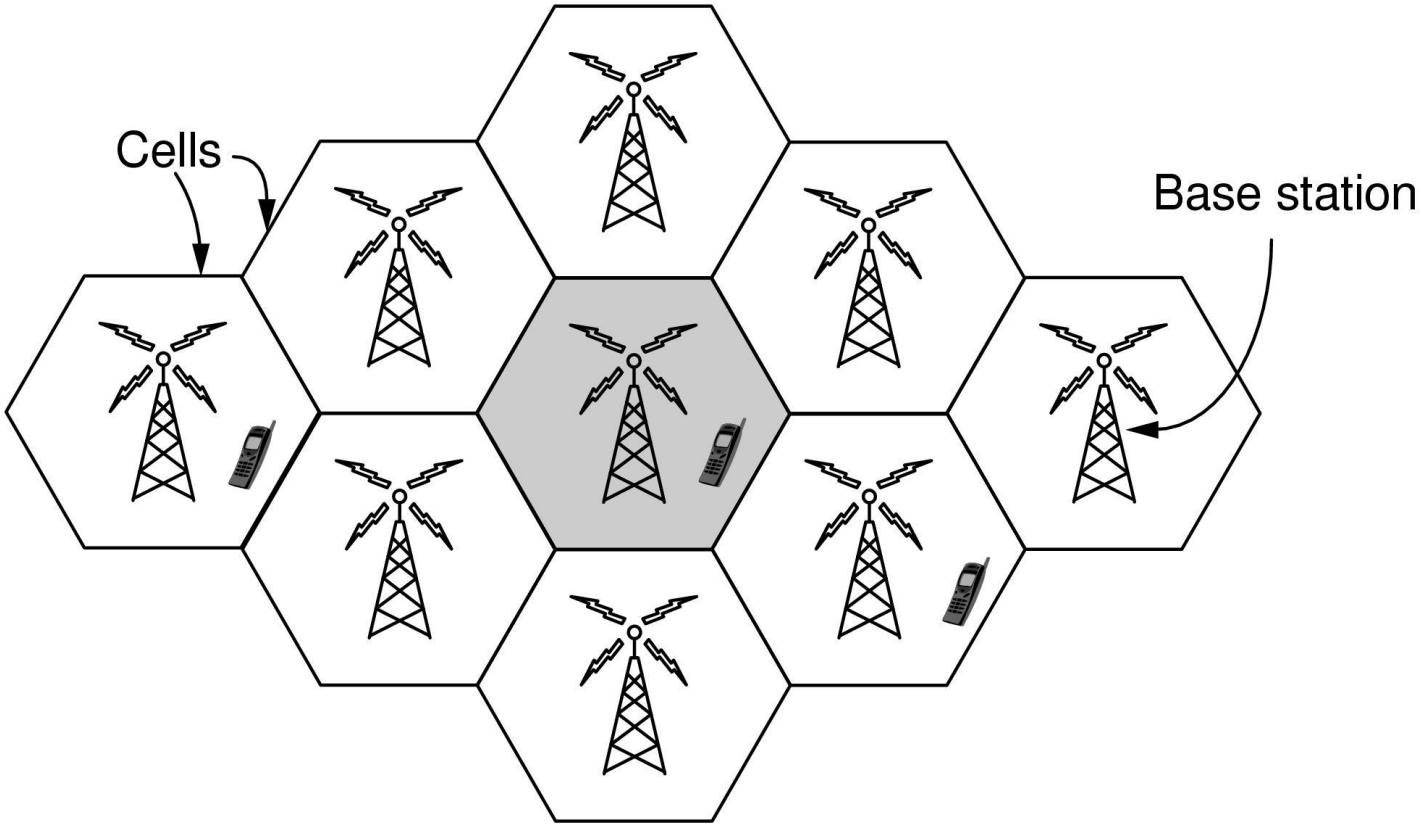
Traditional applications (1970 – 1990)

- E-mail
- News
- Remote login
- File transfer

World Wide Web changed all that and brought millions of new, nonacademic users.

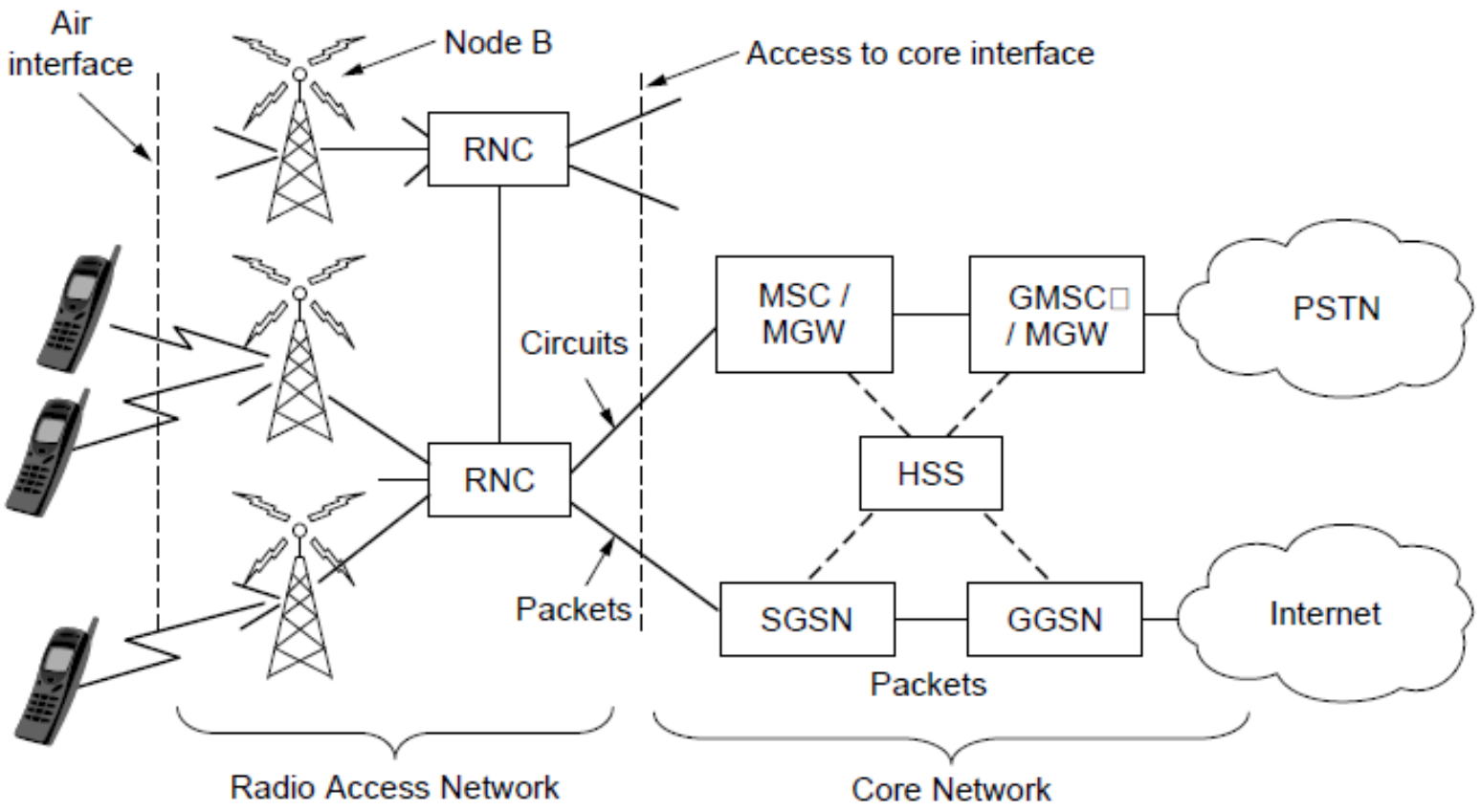
Internet Service Providers (ISP) offer individual users at home the ability to call up one of their machines and connect to the Internet to access all kinds of services.

Third-Generation Mobile Phone Networks (1)



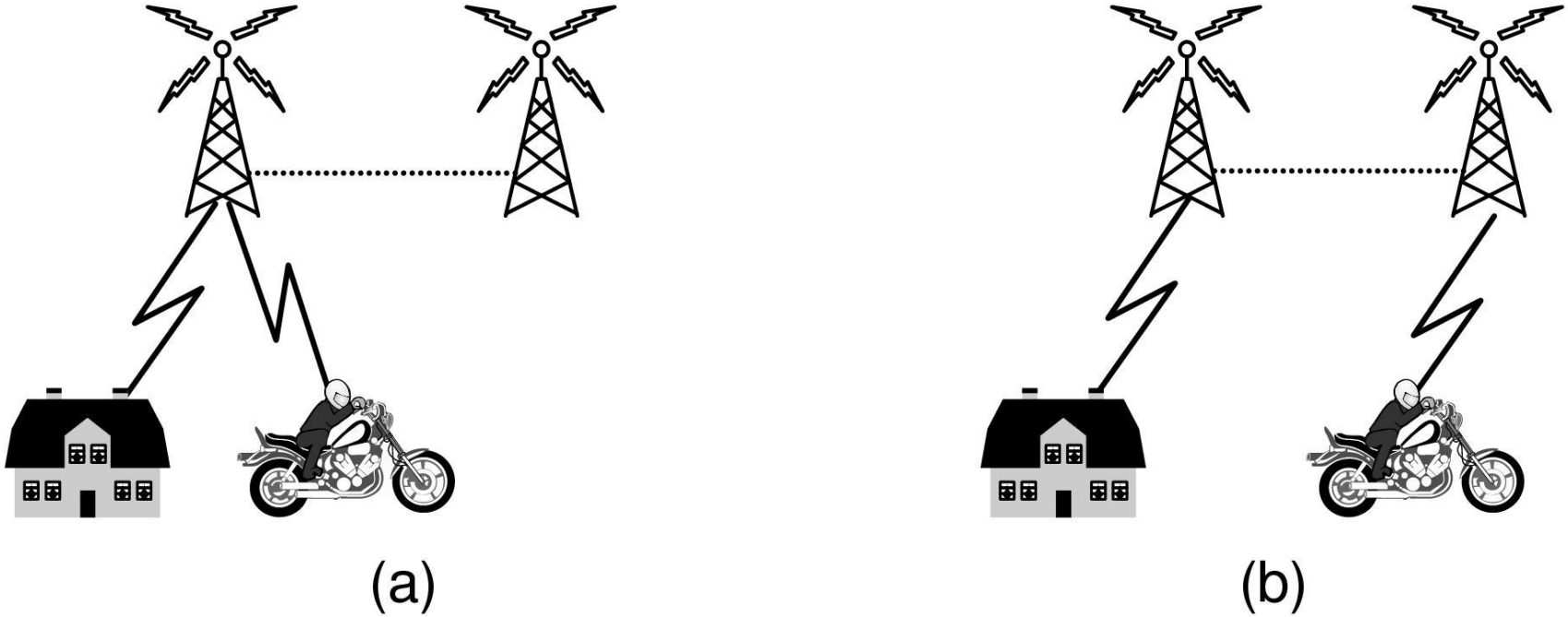
Cellular design of mobile phone networks

Third-Generation Mobile Phone Networks (2)



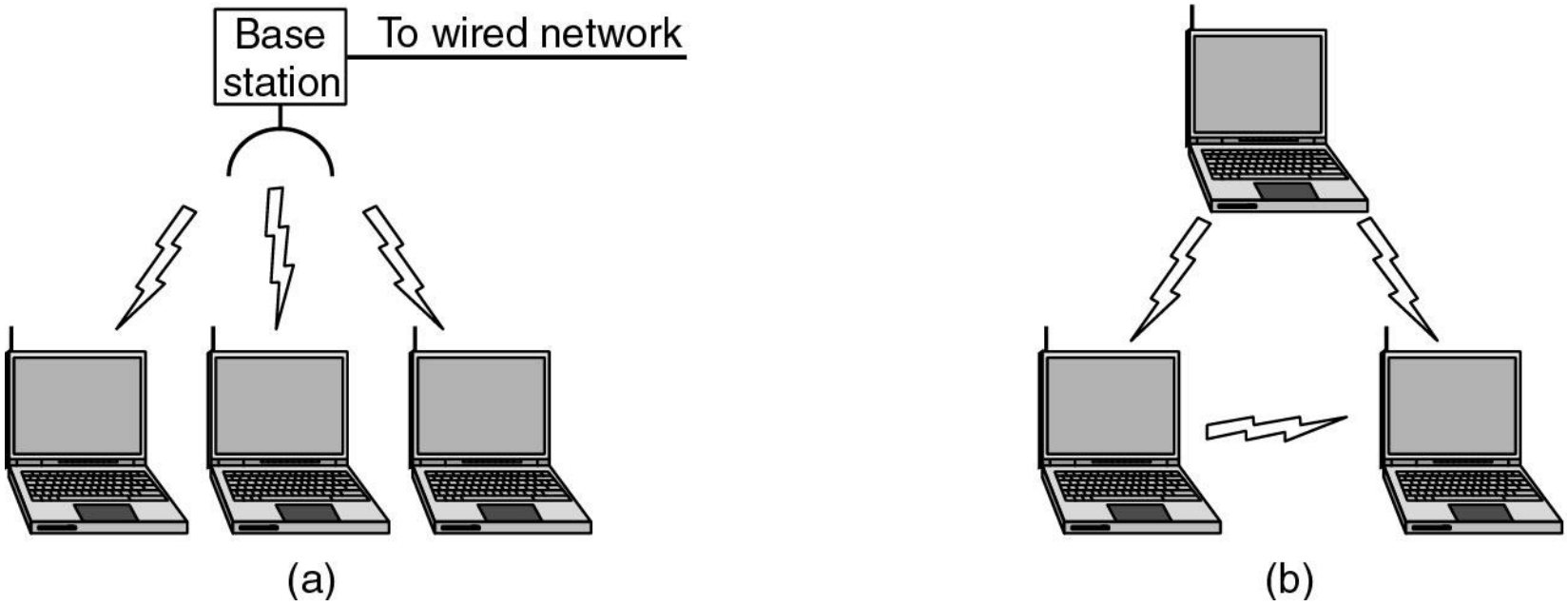
Architecture of the UMTS 3G mobile phone network.

Third-Generation Mobile Phone Networks (3)



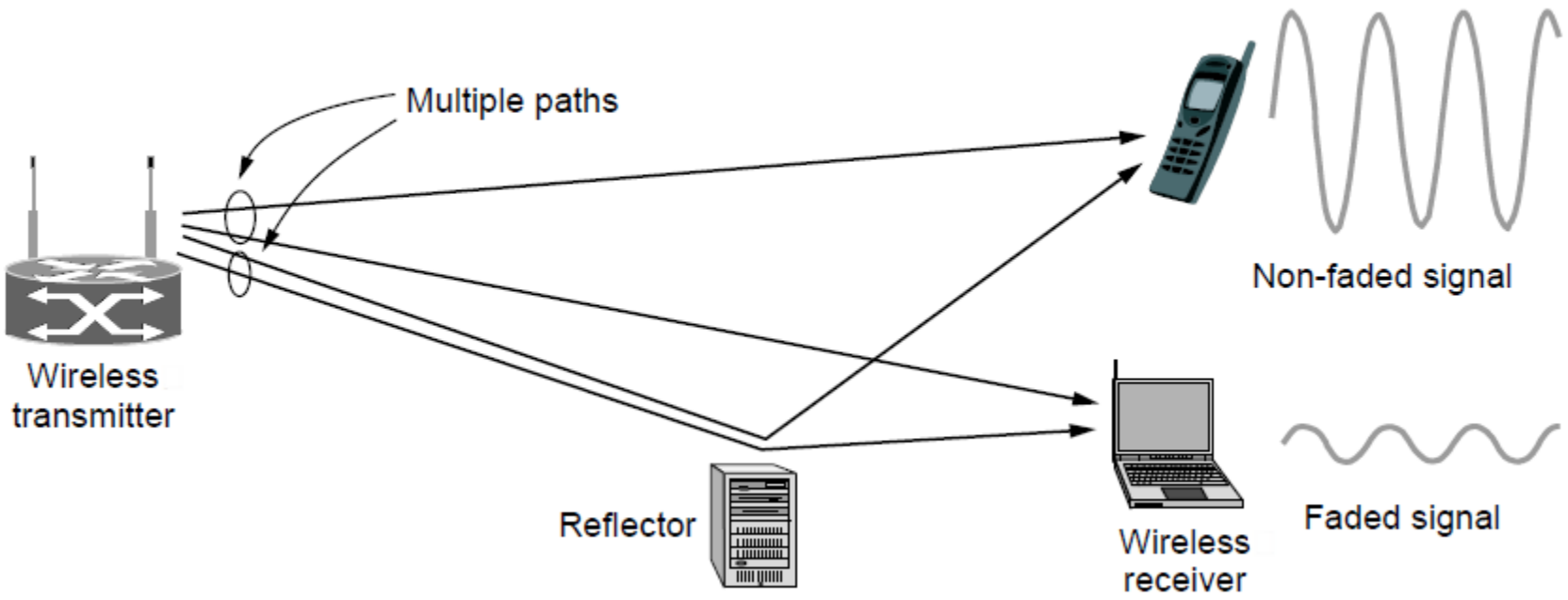
Mobile phone handover (a) before, (b) after.

Wireless LANs



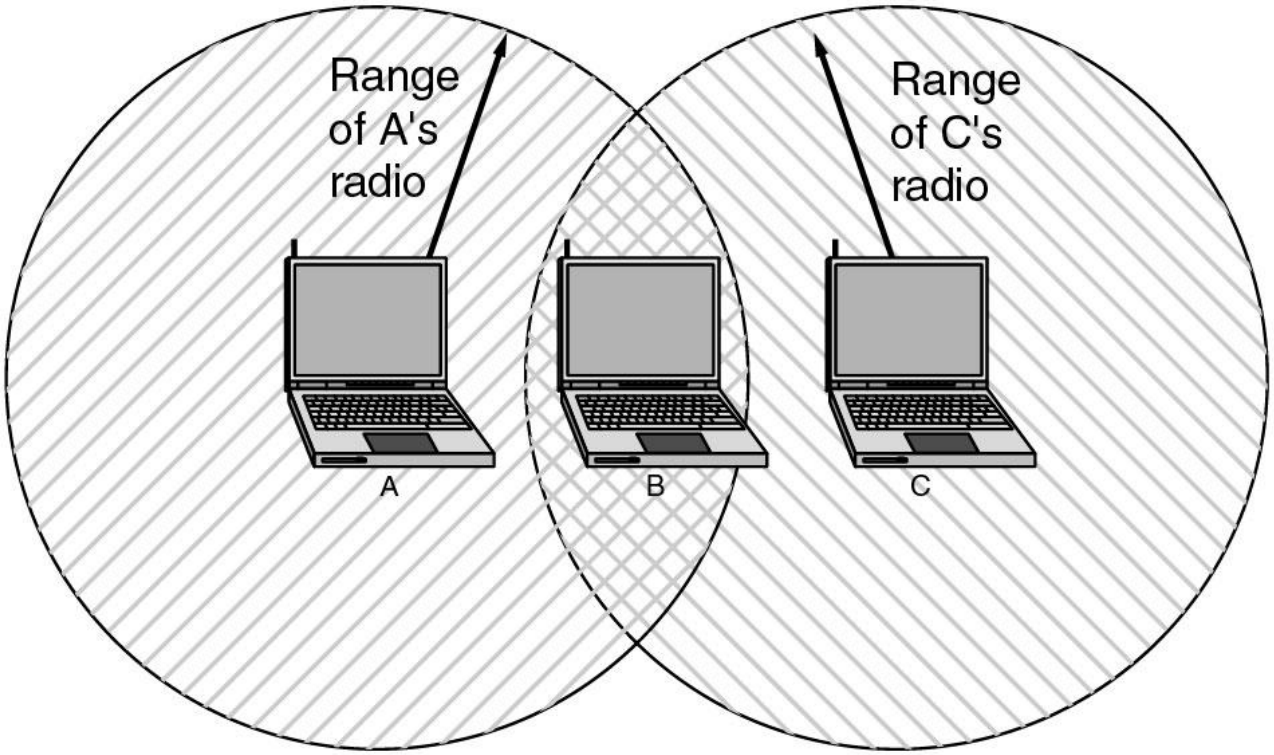
(a) Wireless networking with a base station.
(b) Ad hoc networking.

Wireless LANs: 802.11 (1)



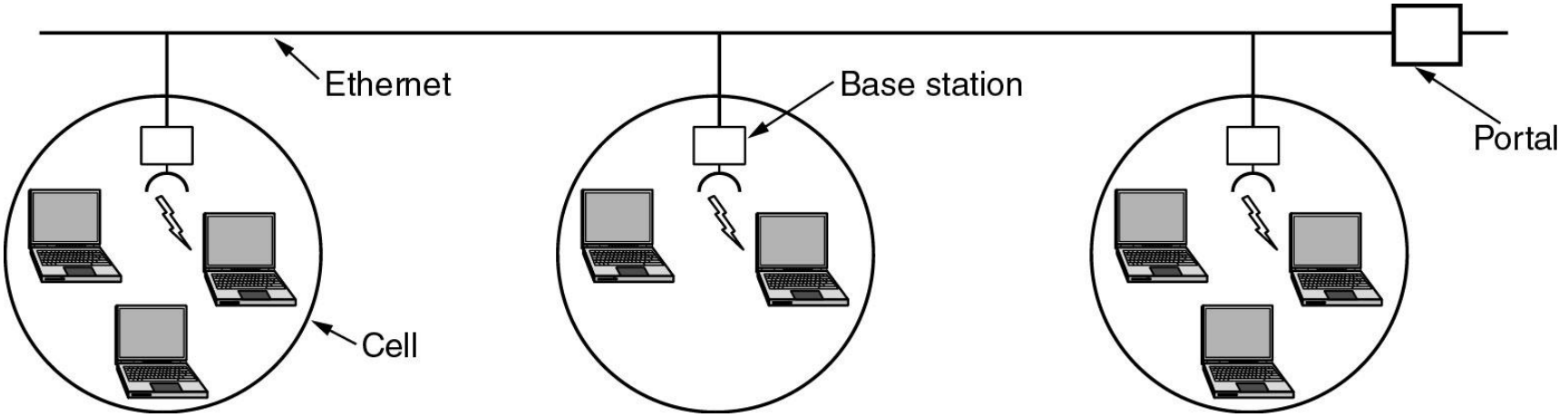
Multipath fading

Wireless LANs (2)



The range of a single radio may not cover the entire system.

Wireless LANs (3)



A multicell 802.11 network.

Network Standardization

- Who's Who in the Telecommunications World
- Who's Who in the International Standards World
- Who's Who in the Internet Standards World

Standard Organizations

- **Telecommunication**
  - International Telecommunication Union (ITU)
    - Telecommunications Standardization Sector (ITU-T)
- **International Standard**
  - International Standards Organization (ISO)
    - ANSI (USA), ETSI (Europe)
    - BSI (Great Britain)
    - AFNOR(France)
      - **IEEE**
- **Internet Standard**
  - Internet Activities Board (IAB, 1983)
  - Internet Research Task Force (IRTF)
  - Internet Engineering Task Force (IETF)
  - Request for Comments (RFC)
    - http://cache2.cis.nctu.edu.tw/Documents/rfc/
    - ftp://ftp.merit.edu/internet/documents/rfc/
      - Internet Draft Standard
      - Internet Standard

ITU

- Main sectors
  - Radiocommunications
  - Telecommunications Standardization
  - Development
- Classes of Members
  - National governments
  - Sector members
  - Associate members
  - Regulatory agencies

Network Standardization

- Who's Who in telecommunications
- Who's Who in international standards
- Who's Who in internet standards

Who's Who in International Standards (1)

Number	Topic
802.1	Overview and architecture of LANs
802.2 ↓	Logical link control
802.3 *	Ethernet
802.4 ↓	Token bus (was briefly used in manufacturing plants)
802.5	Token ring (IBM's entry into the LAN world)
802.6 ↓	Dual queue dual bus (early metropolitan area network)
802.7 ↓	Technical advisory group on broadband technologies
802.8 †	Technical advisory group on fiber optic technologies
802.9 ↓	Isochronous LANs (for real-time applications)
802.10 ↓	Virtual LANs and security
802.11 *	Wireless LANs (WiFi)
802.12 ↓	Demand priority (Hewlett-Packard's AnyLAN)

The 802 working groups. The important ones are marked with *. The ones marked with ↓ are hibernating. The one marked with † gave up and disbanded itself.

Metric Units

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

The principal metric prefixes.

History of Networking

- 1969: ARPANET
- 1970's: ALOHA, Ethernet, DECNet, SNA
- 1980's: Proliferation of LAN (Ethernet, Token Ring)
- 1987: High speed LAN/MAN (FDDI), BISDN (ATM)
- 1990: High speed WAN (NSFNET, 45 Mbps)
- 1993: High speed Ethernet (Fast Ethernet, EtherSwitch)
- 1996: Interent II (622Mbps)
- 1998: Gigabit Ethernet

History of Taiwan's Network

- **TANET**
  - 1991/12: 64Kbps
  - 1992/12: 256Kbps
  - 1994/10: 512Kbps
  - 1995/12: T1
  - 1997/5: T3
  - Current Status:
    - T3 to USA by the end of 1998 (Policy routing enforced)
    - T3 backbone around the island
    - Add a T3 from MOE to CCU
    - Internet II (1999/6)
- **HiNet (1994), SeedNet(數位聯合股份公司)**