COMPUTER NETWORKS

Chapter 01
Introduction (1)

Historic Review

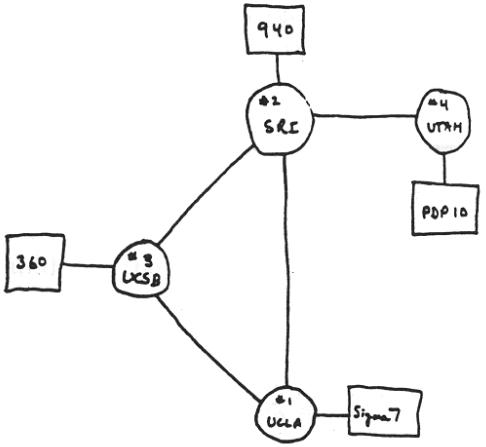
- ENIAC: 1946, the very first computer
- ARPANET: 1969, the very first computer network for advanced research project agent of defense department, USA.
- Internet: 1986
- National Information Infrastructure: 1993
- Commercialized Internet: 1995
- NGI: 1995, next generation internet
- I2: 1996, Internet2
- CNGI: Cernet2 + …

Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

- 1972:
  - ARPAnet public demonstration
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- early 70′s: proprietary architectures: DECnet, SNA, XNA
- late 70′s: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn′s internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today′s Internet architecture

Internet History

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control

- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet History

1990, 2000′s: commercialization, the Web, new apps

- Early 1990′s: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960′s]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990′s: commercialization of the Web

Late 1990′s – 2000′s:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Internet History

2007:

- ~500 million hosts
- Voice, Video over IP
- P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)
- more applications: YouTube, gaming
- wireless, mobility

Why Networking?

- The integration of computers and communication techniques:

  (1) communication network is the infrastructure for computer network;

  (2) computer progress facilitates telecommunication

  Computer Network = computer + communication

- Why networking?

  The needs for efficiently collecting, storing, processing, distributing and managing information

  The needs for changing manner of using computers

  The needs for changing manner of using networks

What is a computer network?

- Tanenbaum's definition

  Computer network - Interconnected collection of autonomous computers

- Our definition:

  A system that interconnecting multiple autonomous computers in different locations with communication equipment, trunks, and communication software(OS, protocols, etc.), for resource sharing, is so called computer network.

Differences between computer networks and distributed system

- Key distinction is that in a distributed system, the existence of multiple autonomous computers is transparent to users. It looks like a virtual machine with uniprocessor.
- With a network, users must explicitly log on to one machine, explicitly submit jobs remotely, explicitly move files around and handle network personally.

Important conclusion

- In effect, a distributed system is a software system build on top of network. The software gives it a high degree of cohesiveness and transparency. Thus the distinction between a network and a distributed system lies with the software (especially the operating system) rather than with the hardware.

Important conclusion

- The Internet is not a single network but a network of networks and the Web is a distributed system that runs on top of the Internet.

1.1 Use of Computer Networks

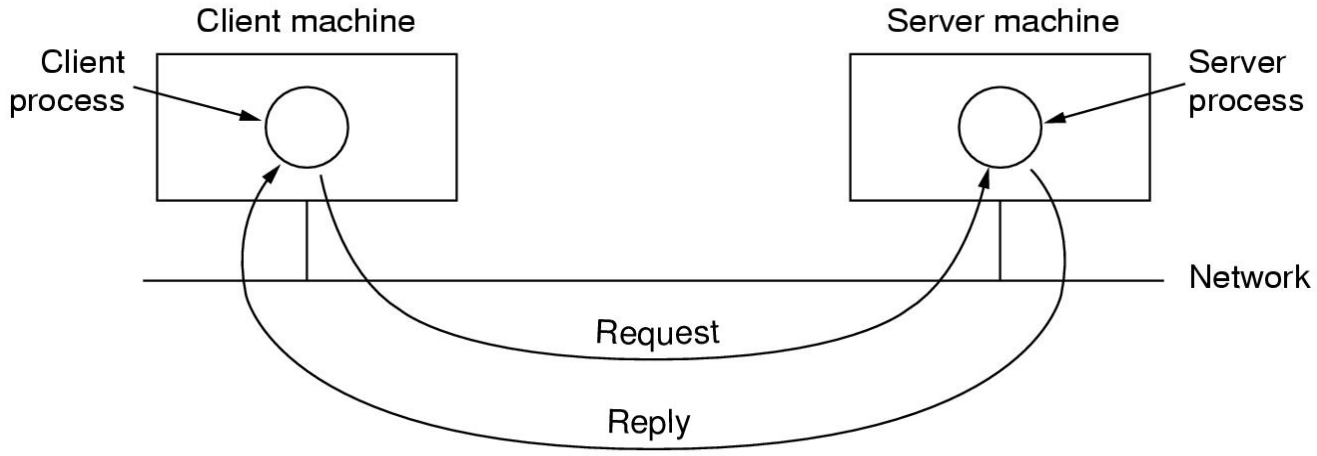
- Before we start to examine the technical issues in detail, it is worth devoting some time to pointing out why people are interested in computer networks and what they can be used for. After all, if nobody were interested in computer networks, few of them would be built. We will start with traditional uses at companies, then move on to home networking and recent developments regarding mobile users, and finish with social issues.

1.1.1 Business applications

Resource sharing, information sharing

High reliability

Saving money – client-server model



Scalability

Business Applications of Networks

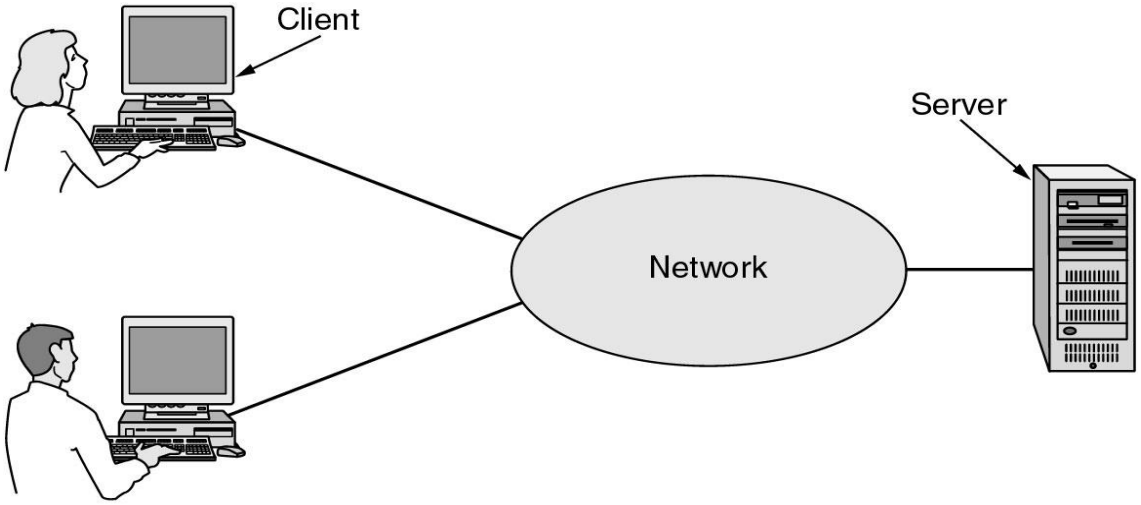


Fig. 1-1 A network with two clients and one server.

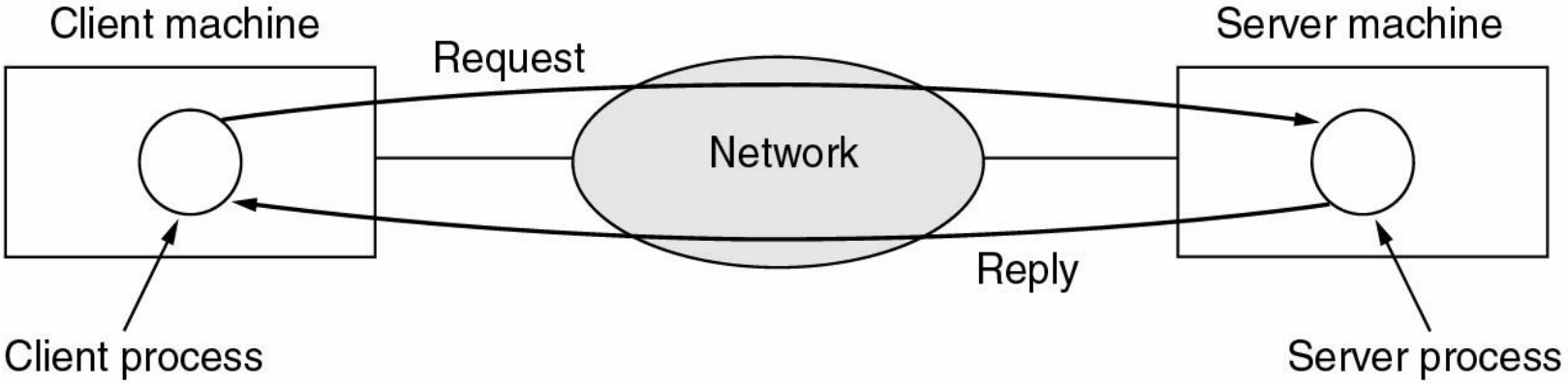


Fig. 1-2 The client-server model involves requests and replies

Business Applications of Networks

- A computer network can provide a powerful communication medium among employees.
  - e-mail (electronic mail)
  - IP telephony or Voice over IP(VoIP)
  - Videoconferencing
- doing business electronically with other companies, especially suppliers and customers.
  - This new model is called e-commerce (electronic commerce).

1.1.2 Home Network Applications

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

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	File sharing

Home Network Applications (2)

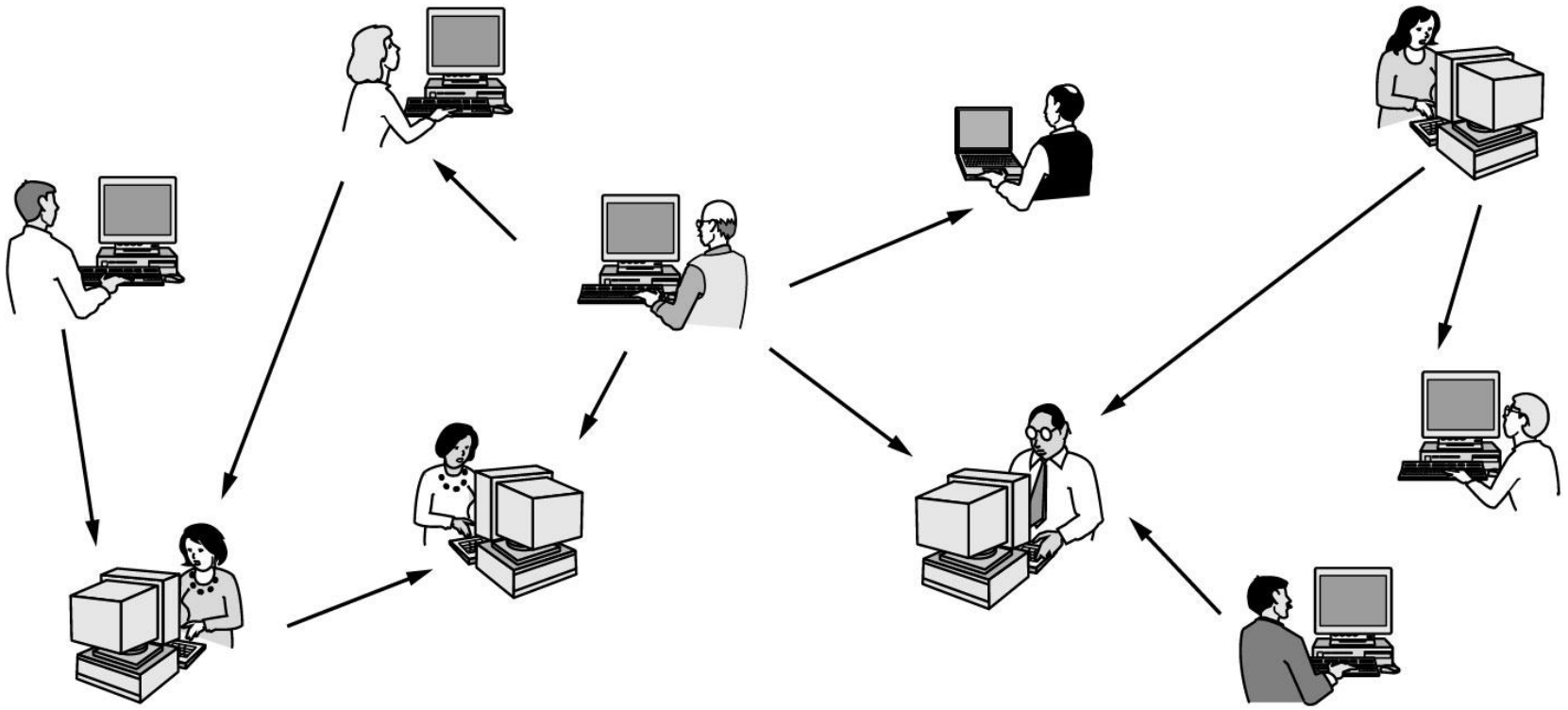


Fig. 1-3 In a peer-to-peer system there are no fixed clients and servers, such as BitTorrent, and PPlive, Skype…

Home Network Applications (3)

- Instant Messaging
  - Allow two people to type messages at each other in real time
- Twitter
  - Multi-person messaging service
- Social network
  - Between person-to-person communications and accessing information
  - Facebook
- Wiki
  - Groups of people can work together to create content
  - Wikipedia: an encyclopedia anyone can edit

Home Network Applications (4)

- IPTV(IP TeleVision)
  - Based on IP technology instead of cable TV or radio transmissions
- Game playing
  - Multiperson real-time simulation games
- Ubiquitous computing
  - Computing is embedded into everyday life
  - A technology called RFID (Radio Frequency IDentification) will push idea even further in the future. They may turn the real world into the Internet of things (IoT).

1.1.3 Mobile users

Wireless LAN

Fixed wireless and mobile wireless

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	Portable office; PDA for store inventory

Mobile phone: Text messaging or texting (Short Message Service), Smart phones, GPS (Global Positioning System)

m-commerce: mobile-commerce

Sensor networks

Wearable computers

Computer Networks Overview (1)

- **Hardware:** Talk just a bit about how you can configure a bunch of computers into a network:
  - Local Area Networks (LAN)
  - Metropolitan Area Networks (MAN)
  - Wide Area Networks (WAN)
  - Internetworks
- **Software:** This is what actually makes computer networks – not the hardware!

Computer Networks Overview(2)

- Protocols: describe *how* two communicating parties exchange information.
- Services: describe *what* a network offers to parties that want to communicate.
- Interfaces: describe *how* a client can make use of network services, i.e. how the services can be accessed.

Reference models: Describe how the OSI and Internet networks are organized.

1.2 Network Hardware

- **Two types of transmission technology are in widespread use: broadcast links and point-to-point links**
- **Broadcast network:** a single communication channel is shared by all computers, that is, sending a packet implies that all others receive it.
- **Multicasting:** transmission to a subnet of users
- **Point-to-point network:** Computers are connected in pairs, that is, sending a packet goes strictly from the sender to the receiver, possibly having to visit intermediate machines (*routing*).
- **Unicasting:** P2P with only one sender and one receiver

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

Fig. 1-6 Classification of interconnected processors by scale

1.2.1 Personal Area Networks(PAN)

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

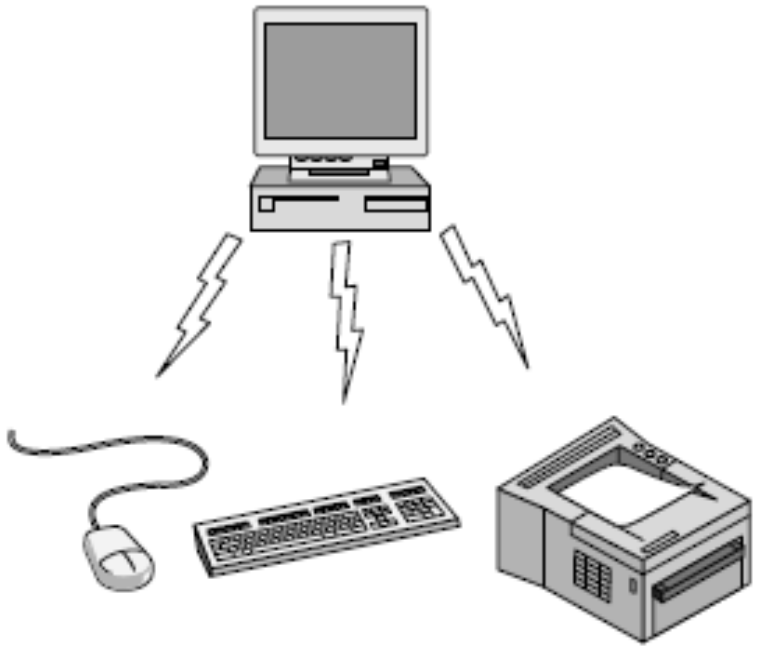
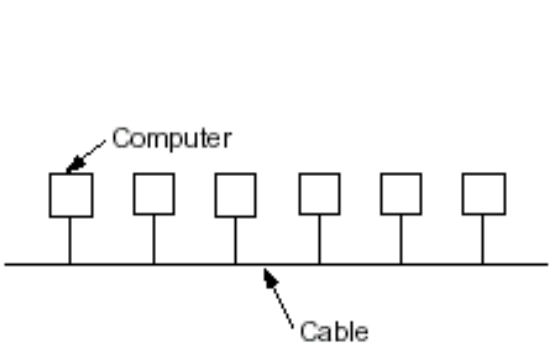
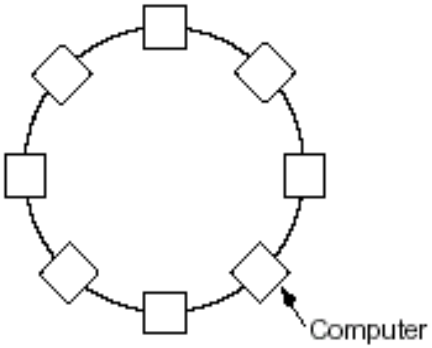


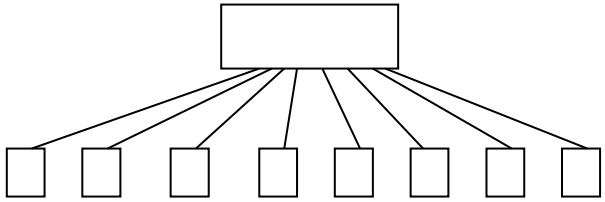
Fig. 1-7 Bluetooth PAN configuration.

1.2.2 Local Area Networks(LAN)

- Apart from scale, LANs distinguish themselves from other networks by (generally) using **broadcast** technology, and having simple **topologies**:







The Star

Fig. 1-7 Two broadcast networks. (a) Bus. (b) Ring.

- **Type (a) (Bus-based):** All computers are connected to the same wire. When one of them starts sending, the signal is propagated to all others. If two of them start sending at the same time, packets collide and rubbish is the result.
- **Type (b) (Token-based):** a token (which is just a small packet) *continuously* circulates along the ring. A sending computer:

  (1) waits until the token passes and removes it

  (2) sends its packet along the ring

  (3) waits until the packet returns

  (4) reinserts the token
- The star is the most commonly used today

Local Area Networks

- Connect devices in a home or office building
- Called enterprise network in a company

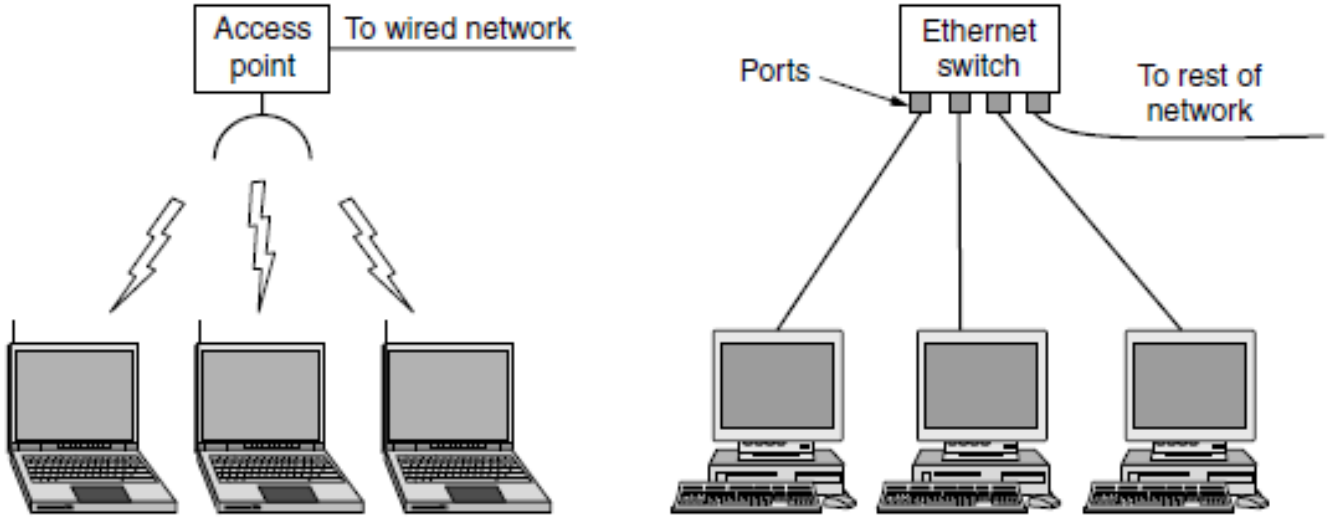


Figure 1-8. Wireless and wired LANs. (a) 802.11. (b) Switched Ethernet.

1.2.3 Metropolitan Area Networks (MAN)

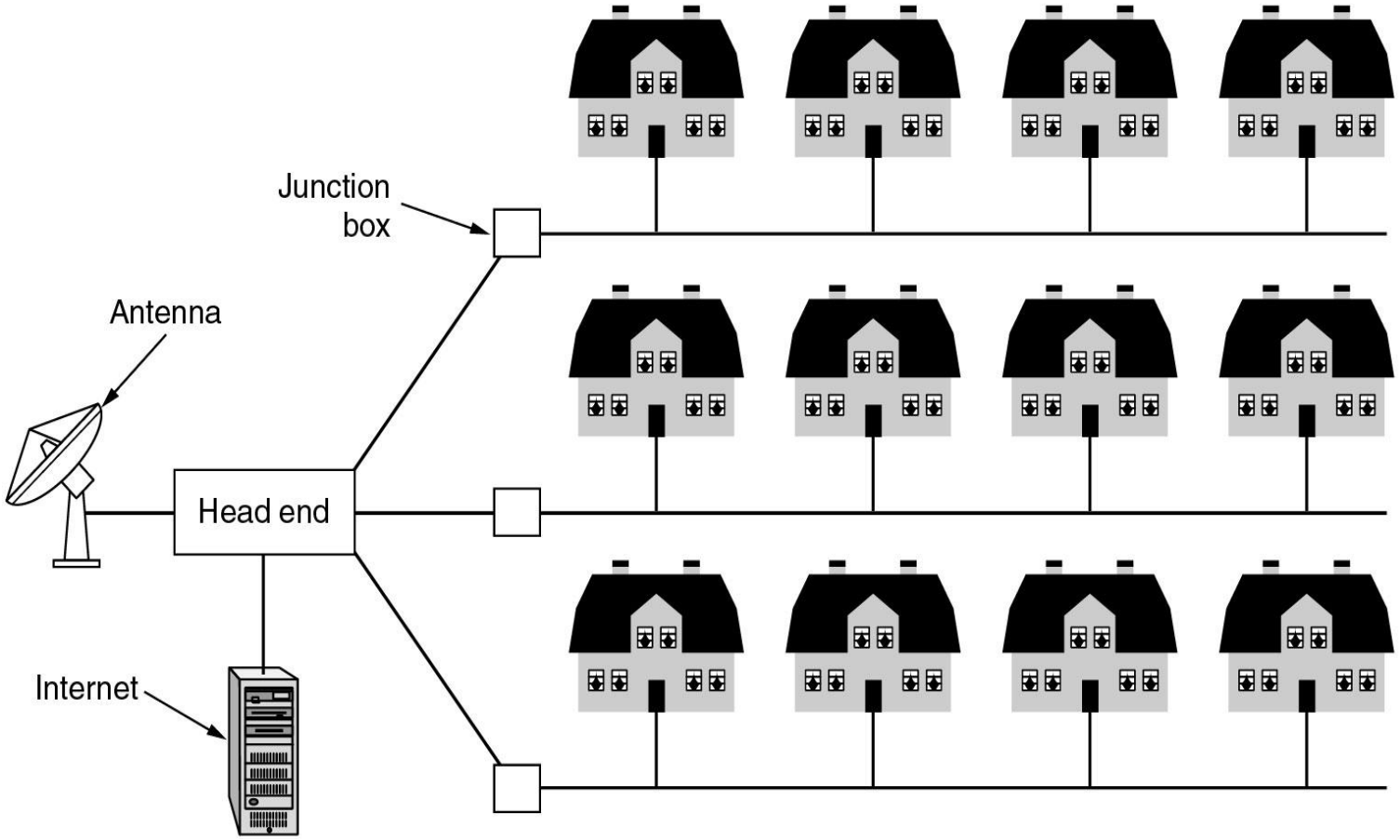


Fig. 1-8. A metropolitan area network based on cable TV.

1.2.4 Wide Area Networks (WAN)

- **Note:** LANs and MANs generally don't have any **switching elements**: the wire does all the work. This makes them extremely efficient, although harder to scale. Here's where WANs come in.

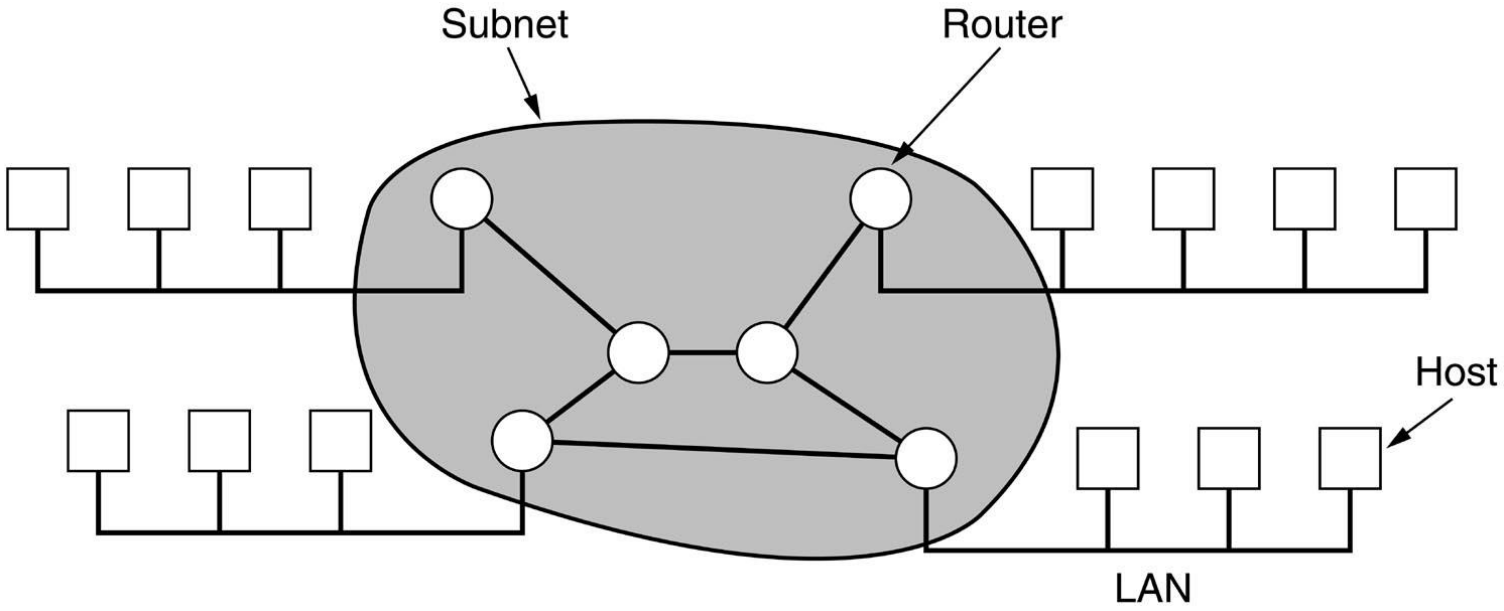


Fig. 1-9. Relation between hosts on LANs and the subnet

Wide Area Networks (2)

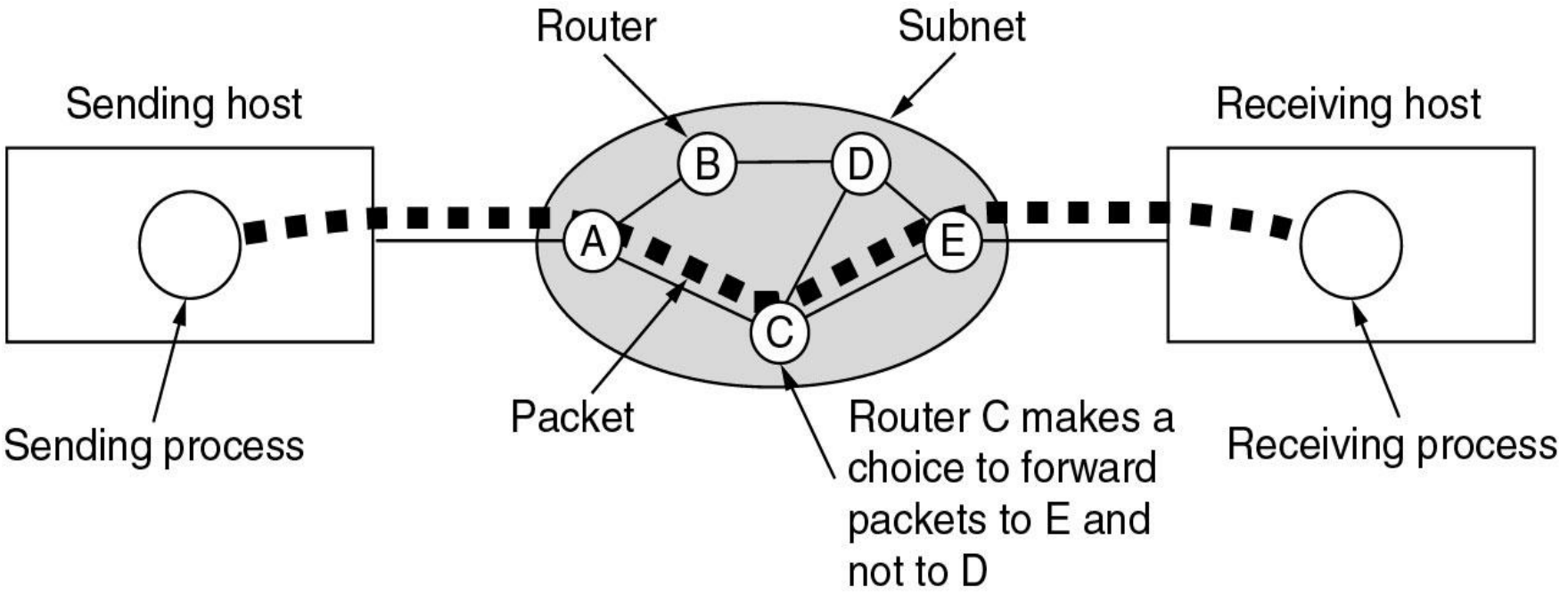


Fig. 1-10. A stream of packets from sender to receiver.

Wide Area Networks (3)

- In a WAN, **hosts** are connected to a **subnet**, which in turn consists of **routers** (switching elements) and **trunks**.
- Routers generally adhere to a **store-and-forward** principle: incoming packets are first buffered (stored), the router takes a decision on where the packet has to go, and forwards the packet across the selected output line.

Wide Area Networks

- Connect devices over a country
- Example WAN connecting three branch offices:

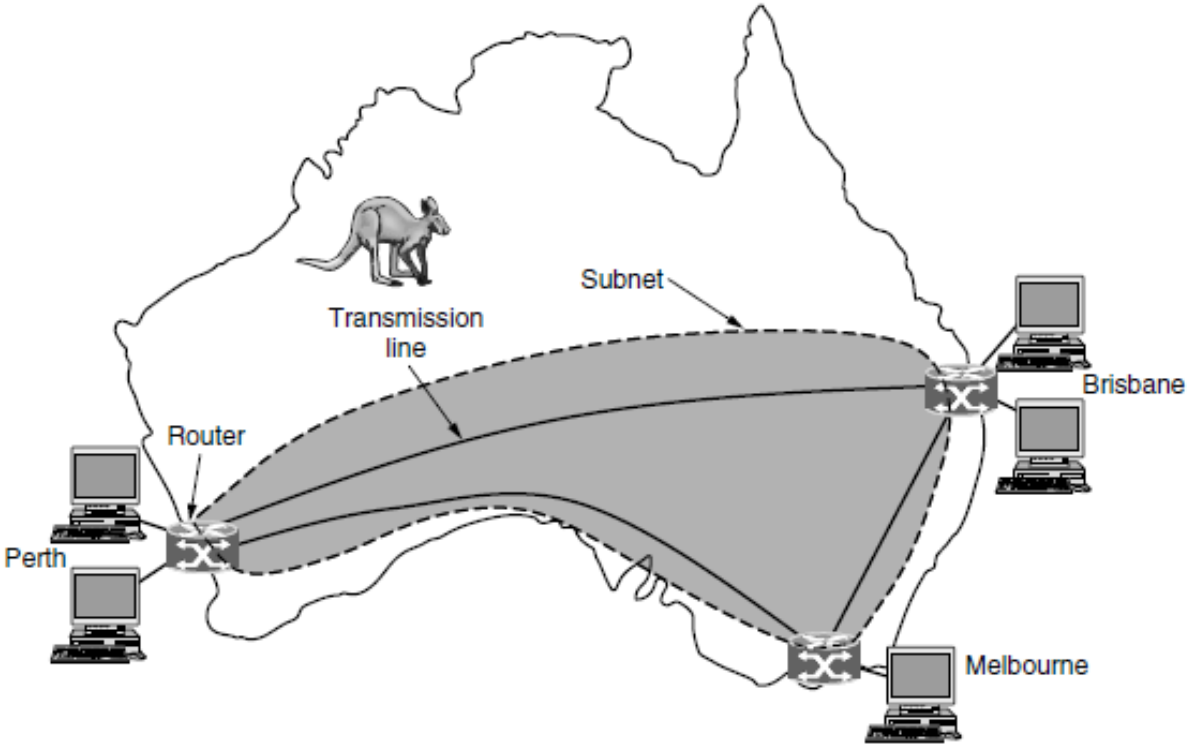


Figure 1-10. WAN that connects three branch offices in Australia.

Wide Area Networks

- An ISP (Internet Service Provider) network is also a WAN.
- Customers buy connectivity from the ISP to use it.

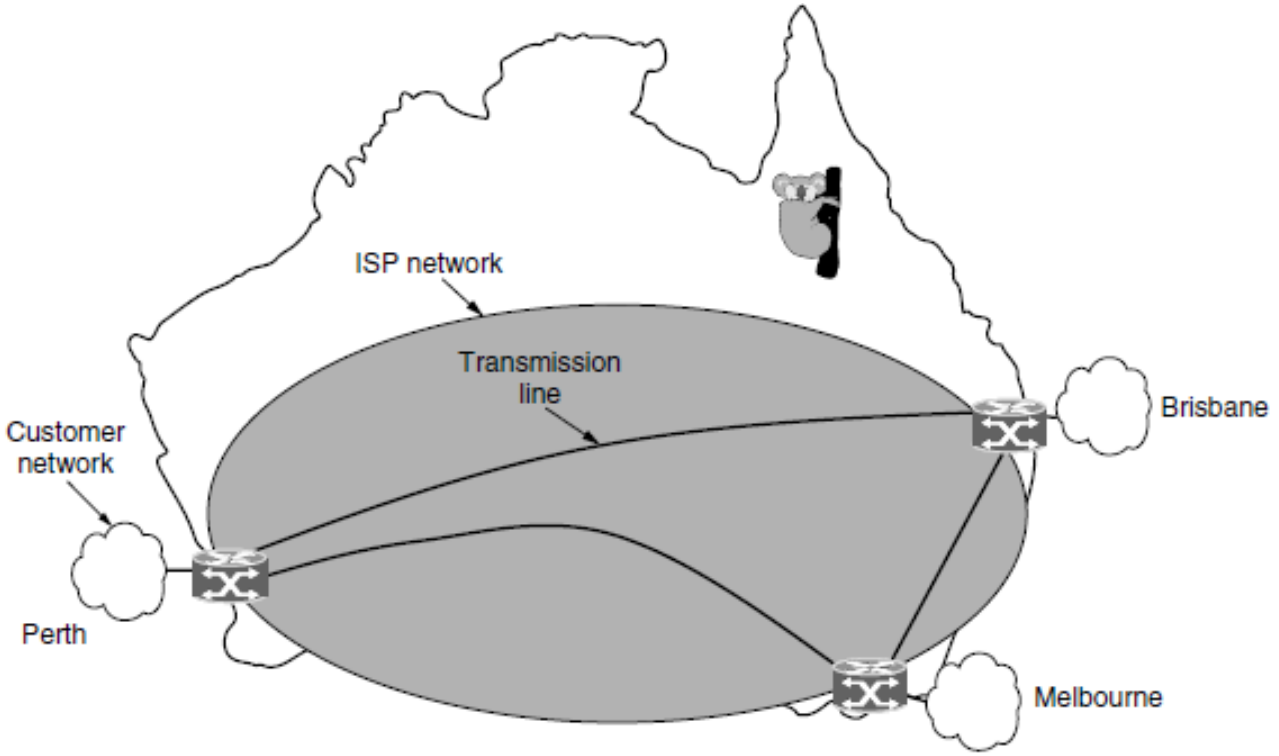


Figure 1-12. WAN using an ISP network.

Wide Area Networks

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

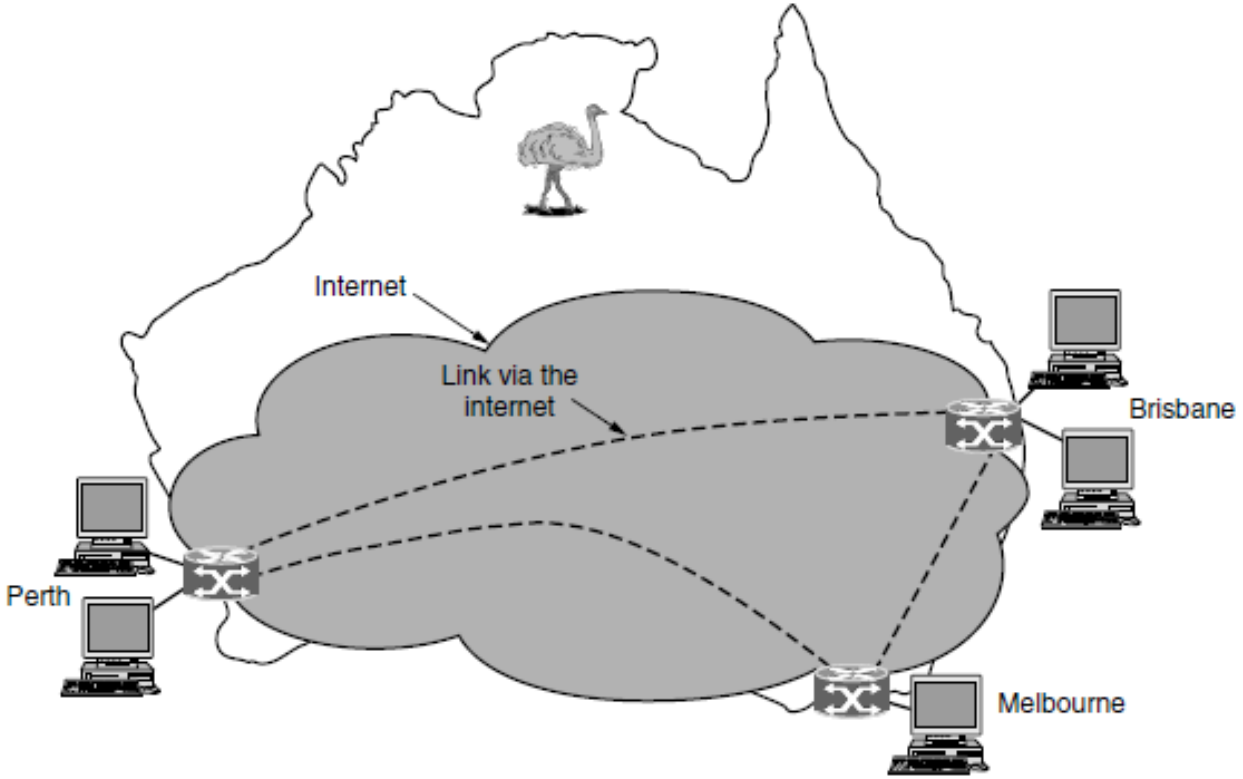


Figure 1-11. WAN using a virtual private network.

WAN consists of two subnets

- Resource subnet

  Includes computers, terminals, programs, etc.

  Responsible for information processing

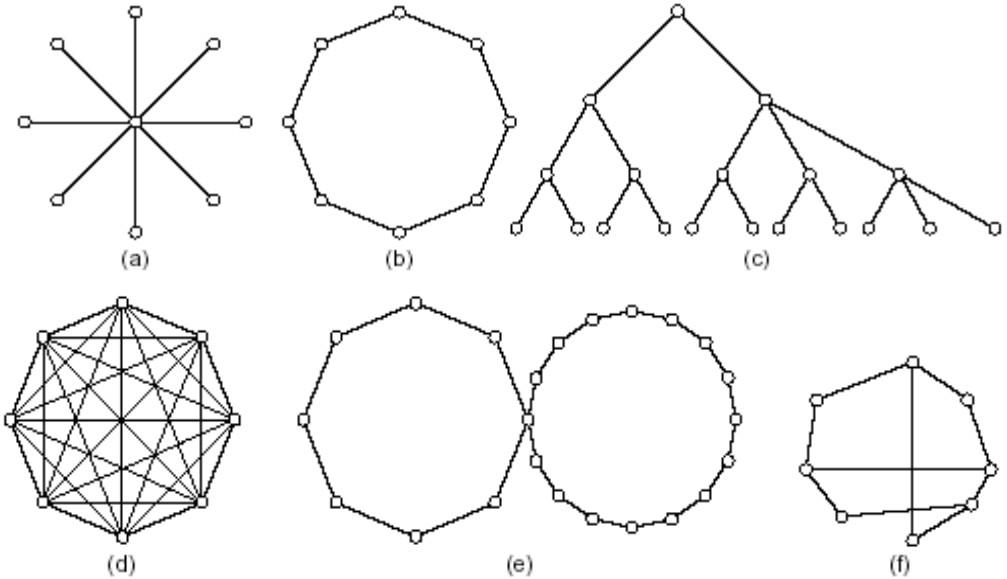
- Communication subnet:

  Includes transportation lines, switching elements(routers and switches, etc.)

  Responsible for information delivery and distribution

WAN Topologies

- **Note:** In contrast to LANs and MANs, the organization of a WAN in terms which hosts are interconnected is important



- **Observation:** Most often you'll see arbitrary topologies; the others are used in application-specific ways (mostly star, ring, and tree)

1.2.5 Internetworks (1)

- The assumption so far is that a network is **homogeneous**: there is hardly any variation in hardware and software. In practice, large networks can only be constructed by **interconnecting** different kinds of networks, **internet(work)**.
- **Heterogeneous**
  - hardware and software are variable

1.2.6 Internetworks (2)

- **Examples:**

  Connecting a collection of different kinds of LANs (bus-based to token-based) within a department.

  Connecting LANs to each other through a WAN (think of enterprise networks for multinationals). The WAN acts as a subnet.

  Connecting WANs to each other (the Internet).

1.3 Network Software

1.3.1. Protocol Hierarchies

- To reduce design complexity, most networks are organized as a series of layers, each layer offers certain services to its upper layer.
- Layer *n* on one machine carries on a conversation with layer *n* on another machine. The rules and conventions used in this conversation are collectively known as the layer *n* protocol.

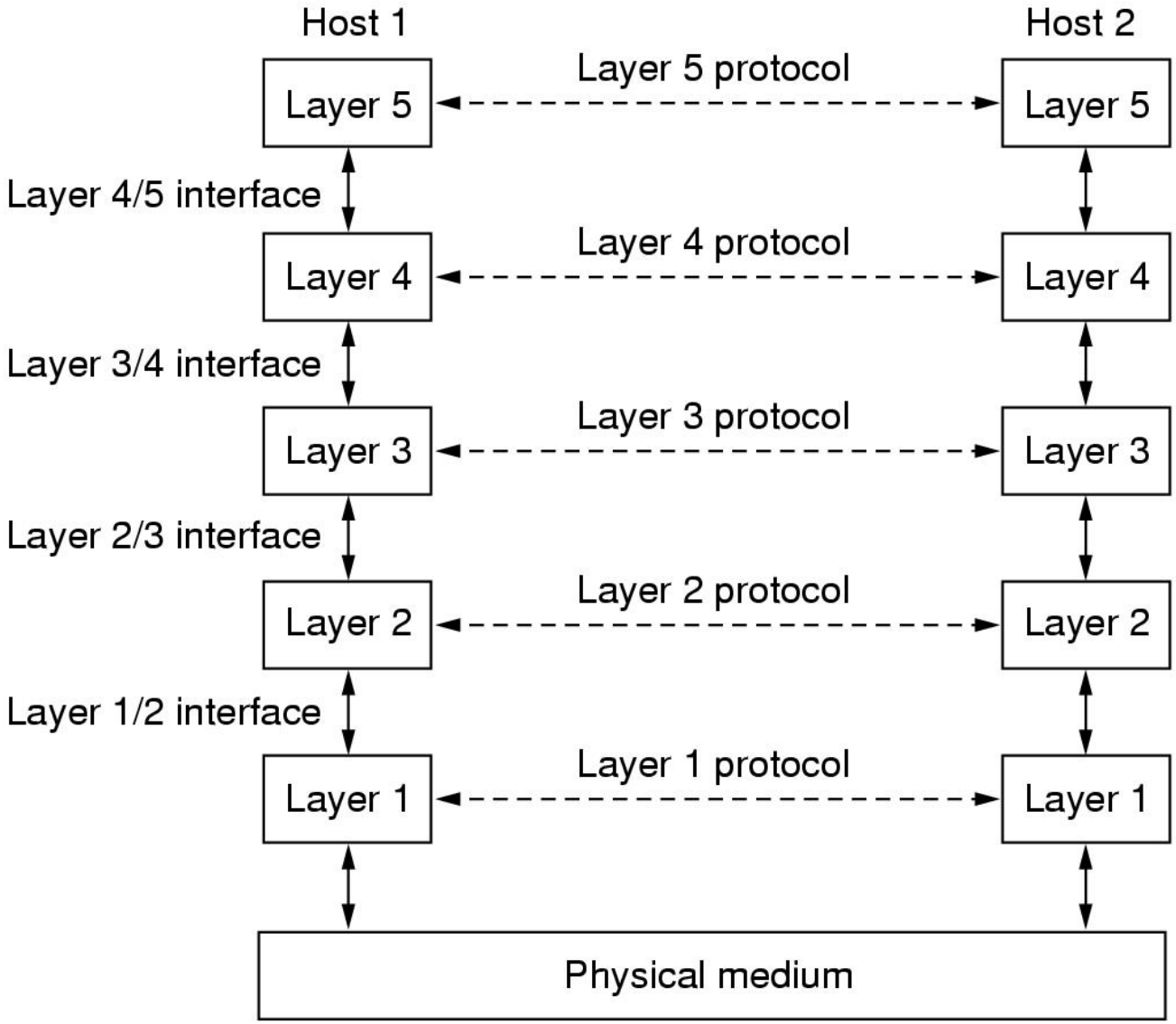


Fig.1.13 Layers, protocols, and interfaces

What's a protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific msgs sent

… specific actions taken when msgs received, or other events

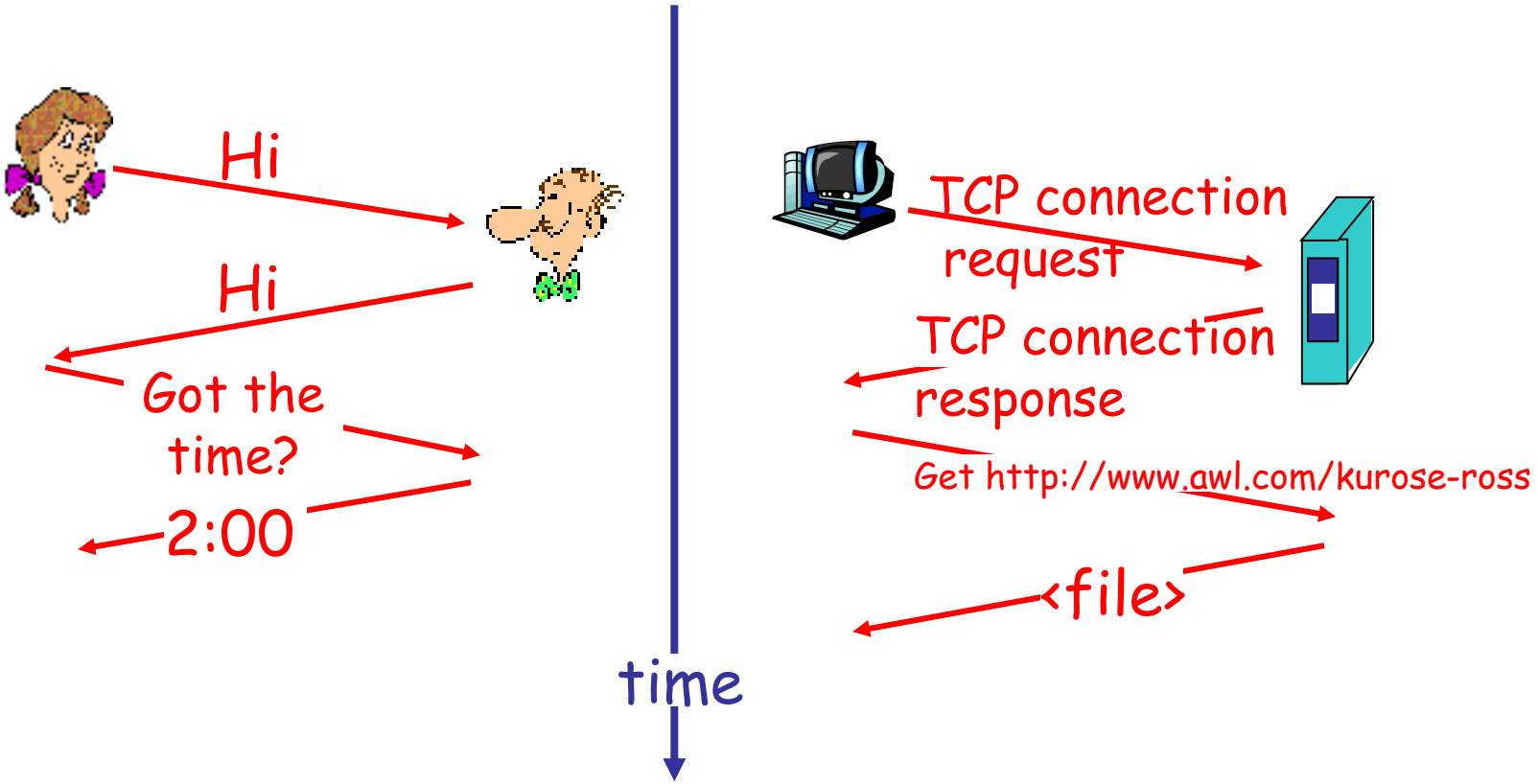
network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What's a protocol?

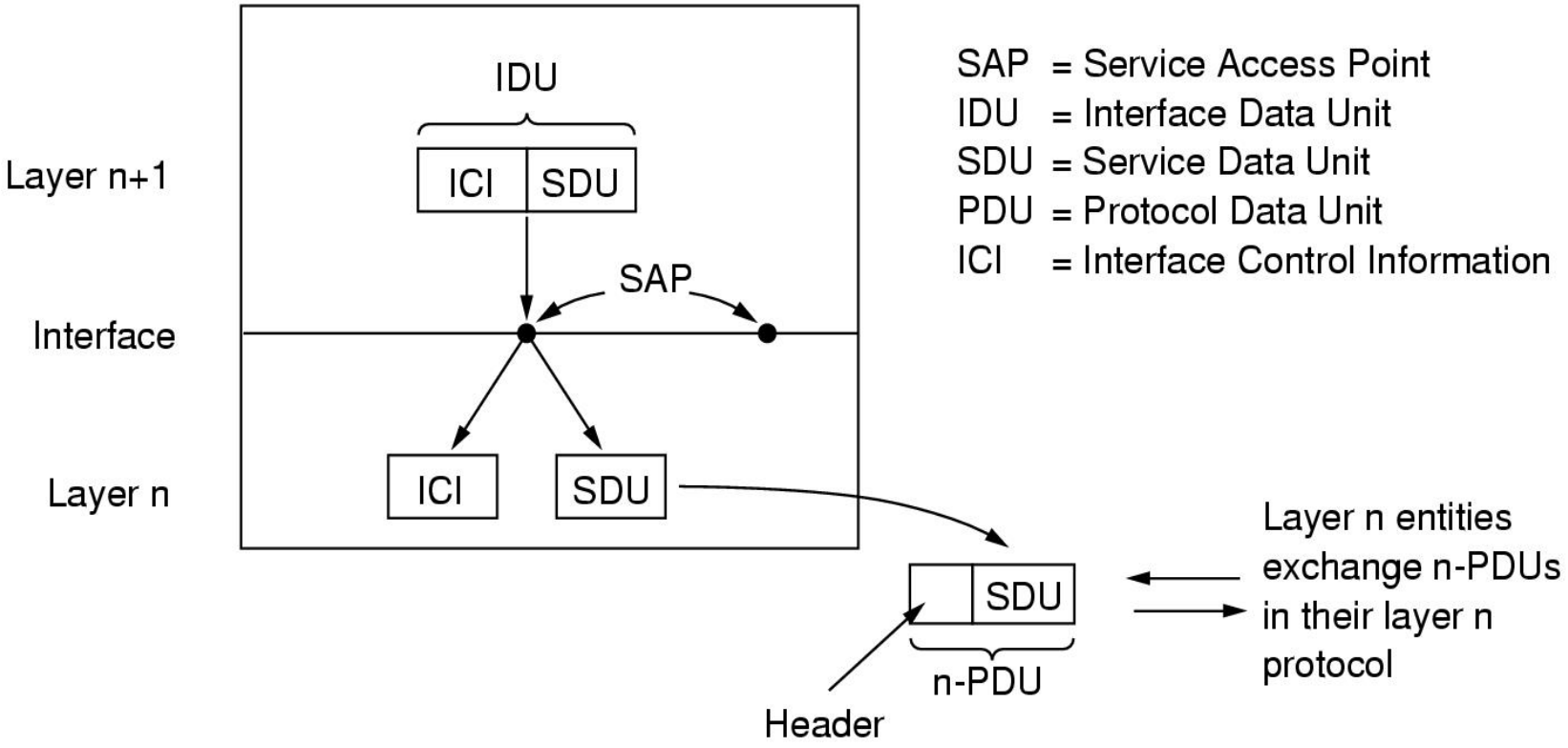
a human protocol and a computer network protocol:



Some terminologies (1)

- **Layers**
  - Networks are organized as a stack of layers or levels, each one built upon the one below it
- **Protocol**
  - An agreement between the communicating parties on how communication proceed
- **Peer**
  - The entities comprising the corresponding layers on different machines are called peers
- **Interface**
  - Defines which primitive operations and services the lower layer makes available to the upper one

Interfaces and Services



Relation between layers at an interface

- A **Service Access Point** is identified by an address, and forms the interface to a set of services.
- The **Service Data Unit** contains the data you want to send.
- The **Interface Control Information** contains info needed to send the SDU, e.g. number of bytes.
- The **Protocol Data Unit** is the data that is sent across the network, containing your SDU as well as protocol-specific data.

Some terminologies (2)

- **Network Architecture**
  - A set of layers and protocols, together with interfaces between layers, is called Network Architecture.
- **Protocol stack**
  - A list of protocols used by a certain system, one protocol per layer, is called a protocol stack.
- **protocol hierarchies**
  - Fundamental to *all* software that makes a computer network run, is the notion of **protocol hierarchies**: structuring the services that a network must offer in terms of **layers**.

Protocol "Layers"

Networks are complex!

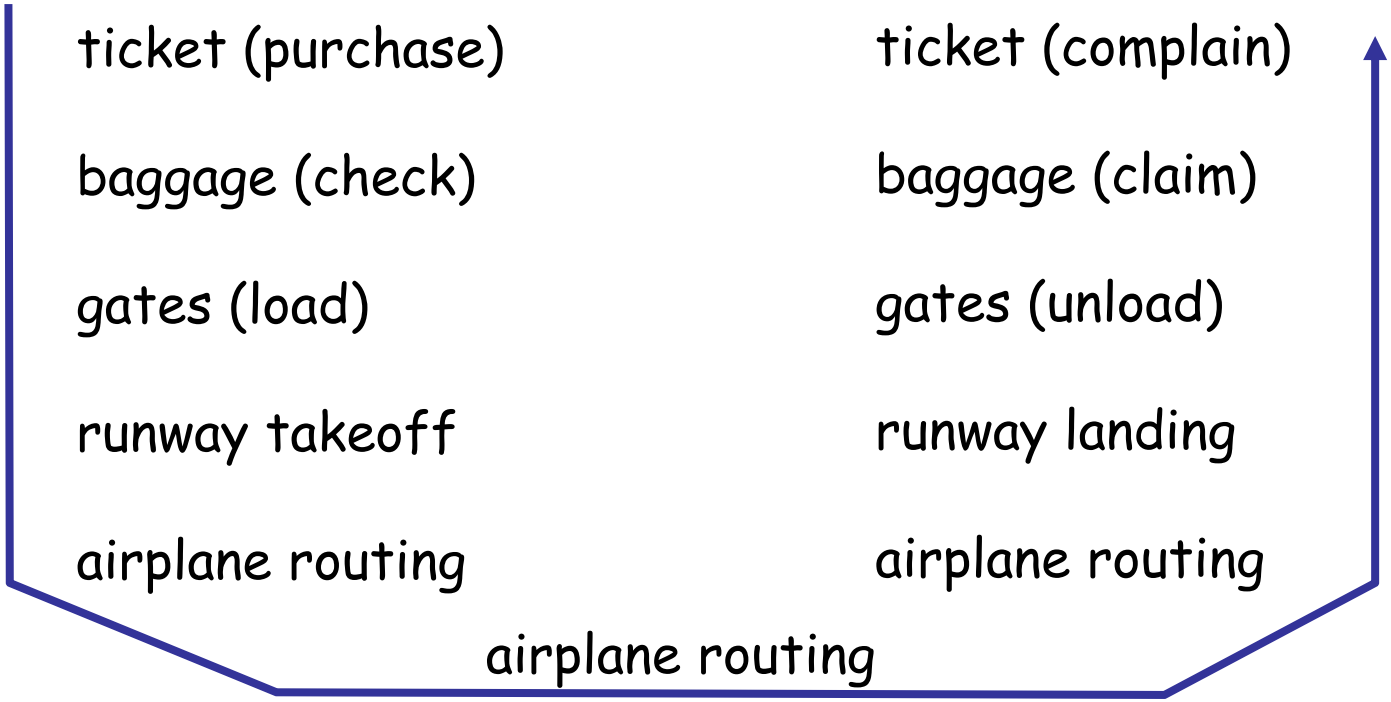
- many "pieces":
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

Question:

Is there any hope of *organizing* structure of network?

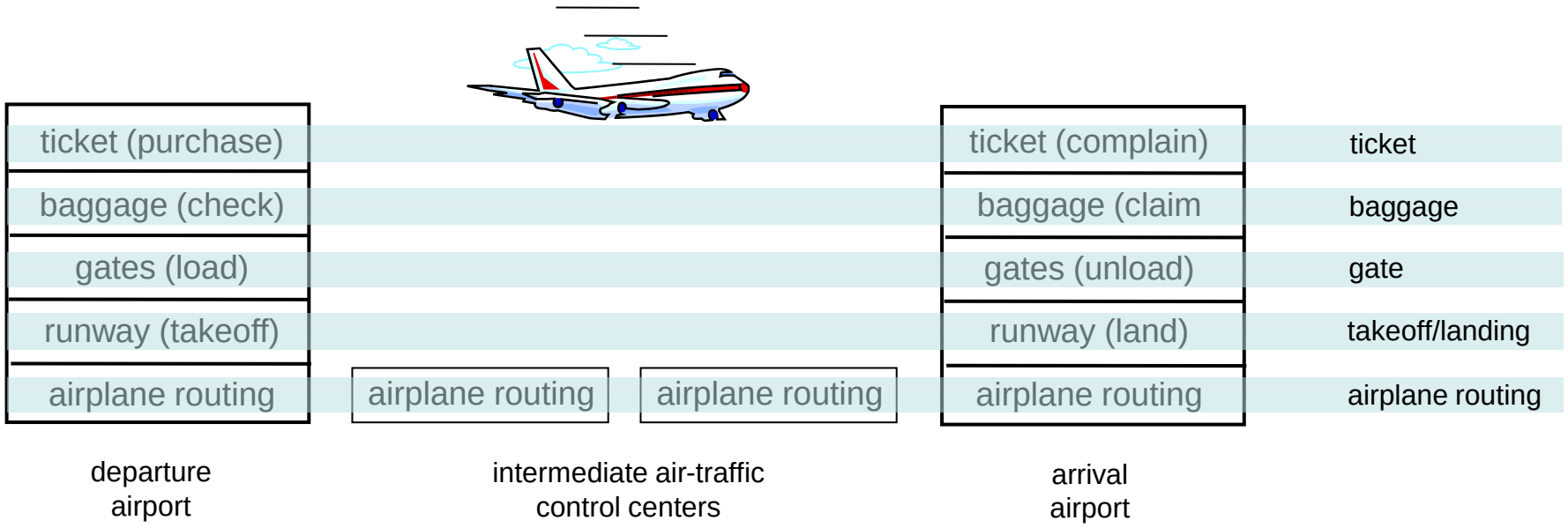
Or at least our discussion of networks?

Organization of air travel



- a series of steps

Layering of airline functionality



Layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below

Why layering?

Dealing with complex systems:

- explicit structure allows identification, relationship of complex system′s pieces
  - layered reference model for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer′s service transparent to rest of system
  - e.g., change in gate procedure doesn′t affect rest of system
- layering considered harmful?

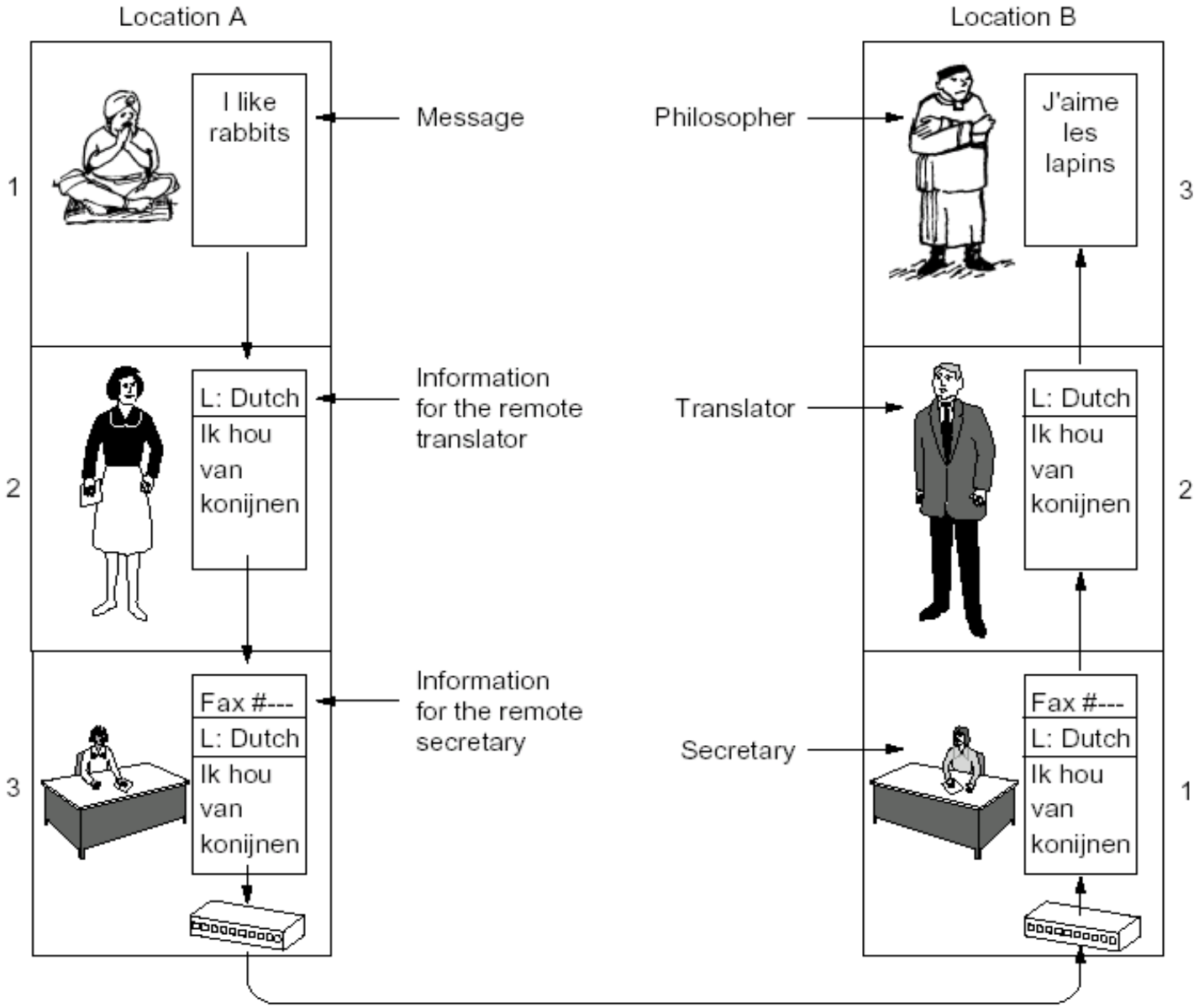


Fig.1.14 The philosopher – translator – secretary architecture

Layering: The Concepts (1)

- Two parties at different sites, but at the same level, always agree on how they will exchange information: specified in a **protocol**. Example: we all agree to speak Chinese (but use English on the sheets).
- In order for one party to send and receive information, it can only make use of the **communication services** offered by the layer directly underneath it.
- Example: The use of interpreters in negotiations between countries.

Layering: The Concepts (2)

- Services offered by a layer are always fully specified in terms of an **interface** that makes those services accessible.
  Example: phones have buttons that allow you to “dial” a number.
- **Protocol**: A set of rules and specifications for peer-to-peer virtual communication, it is “horizontal”.
- **Service**: A set of communication abilities and operations provided by lower layer to its higher layer, it is “vertical”.

Layering: An Example

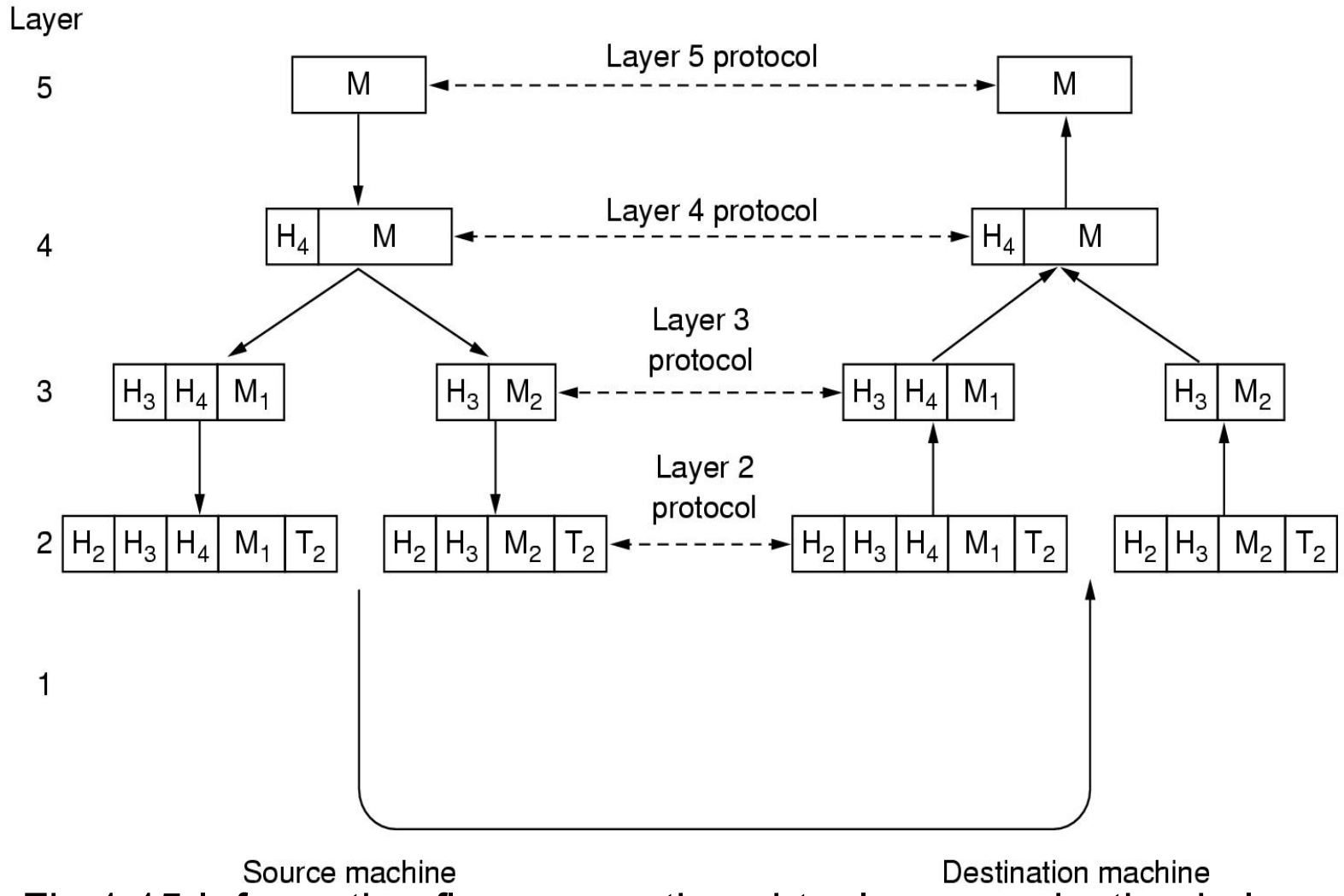


Fig.1.15 Information flow supporting virtual communication in layer 5

- **Observation:** In a protocol stack, Layer k puts its entire packet as **data** into a Layer k-1 packet, that is, the k-1 packet payload; the latter may add a header and/or a trailer.
- **Note:** It may even occur that Layer k data has to be split across several Layer k-1 packets, i.e., fragmentation. At the destination, reassembly is needed to recover Layer k data.

1.3.2 Design Issues for the Layers (1)

- **Addressing**
  - Mechanism for identifying senders and receivers: addressing to specify a party
- **Rules for data transfer**
  - Simplex communication, SDX
  - Half-duplex communication, HDX
  - Full-duplex communication, FDX
- **Error control**
  - Physical communication circuits are not perfect, so that error-detecting and error-correcting code are used. In addition, receiver must have some way of telling the sender which messages have been correctly received and which have not.

1.3.2 Design Issues for the Layers (2)

- **Sequencing**
  - Keep the messages order
- **Flow control**
  - Keep a fast sender from swamping a slow receiver with data
- **Disassembling and reassembling**
  - Allow all processes to accept arbitrarily long messages
- **Multiplexing**
  - Use the same connection for multiple, unrelated conversations
- **Routing**
  - Select a route from multiple paths between source and destination

1.3.3 Connection-oriented and Connectionless Services (1)

- **What is service?**
  - A set of communication abilities and operations provided by lower layer to its higher layer.
- **Connection-oriented Service**
  - Like the telephone model: you first **establish** a connection, then do a lot **communication**, and finally **release** the connection. Three phases.

Services: Connections or Not (2)

- **Connectionless:** Like the postal model: your data is put into some kind of envelope called packet, on which the destination address has been written. The envelope + contents (packet) is independently routed in communication subnet, until gets to the destination, and that’s it.

Services: Connections or Not (3)

- Each service can provide some quality:
  - *Is data delivered in the order it was sent?* With connections, this is generally the case.
  - *Is data transmission **reliable**?* Generally offered with connections, but not always with connectionless services. Reliability requires sending acknowledgements, so that performance may degrade.

Connection-Oriented and Connectionless Services (4)

- **Six different types of service**

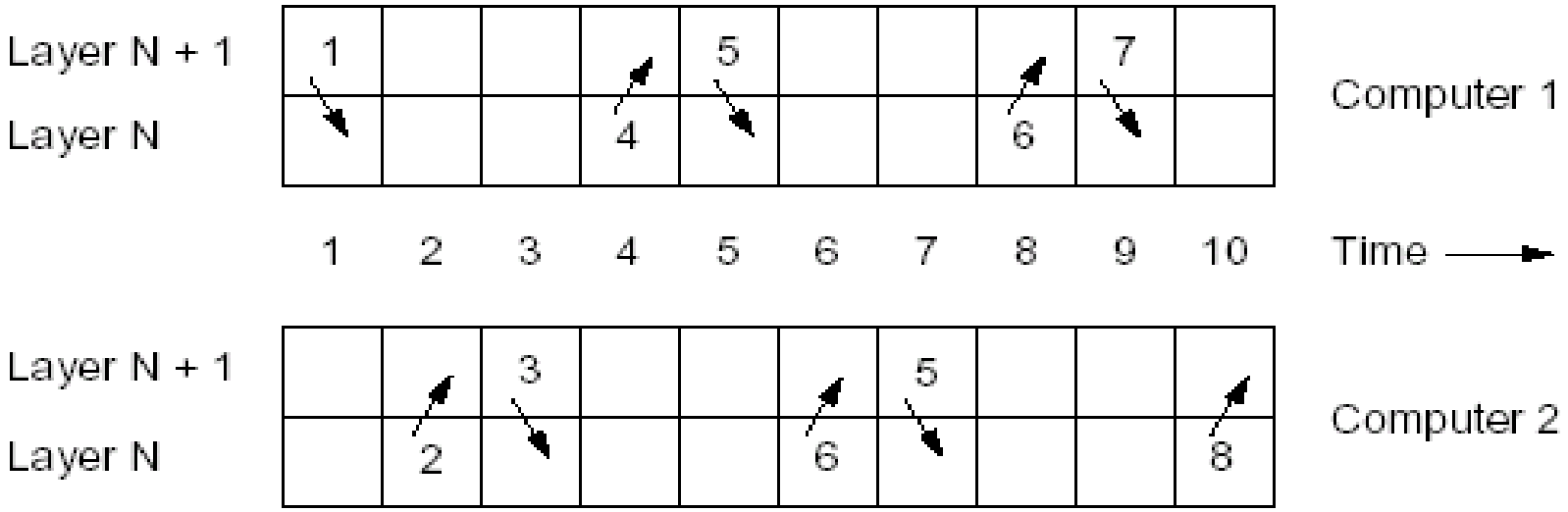
	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Remote login
	Unreliable connection	Digitized voice
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Registered mail
	Request-reply	Database query

1.3.4 Service Primitives

- Services are generally specified by a set of **primitives** (operations), which tell the service to perform some action or report on an action taken by a peer entity. Primitives are normally system calls.

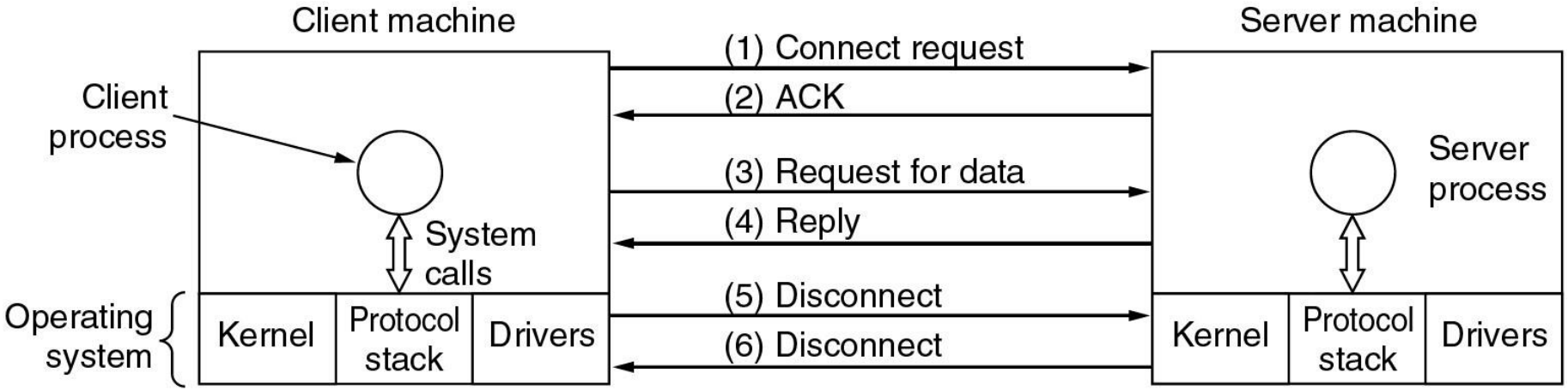
Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

1. CONNECT.request: request for establishing a connection (*dial a phone number*).
2. CONNECT.indication: signal the callee (*phone rings*).
3. CONNECT.response: reaction by callee to indication (*pick up the phone*).
4. CONNECT.confirm: tell caller whether call was accepted (*caller hears ringing stop*).
5. DATA.request: request data to be sent (*say something*)
6. DATA.indication: signal arrival of data (*callee hears you*)
7. DISCONNECT.request: request release of connection (*caller hangs up*)
8. DISCONNECT.indication: signal release of connection (*callee hears busy tone*)



Service Primitives (2)

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



1.3.5 The Relationship of Services to Protocols

- **Service**
  - is a set of primitives (operations) that a layer provides to the layer above it, defining what operations the layer is prepared to perform on behalf of its users, but nothing about how these operations are implemented.
- **Protocol**
  - is a set of rules governing the format and meaning of the packets, or messages that are exchanged by the peer entities within a layer. Entities use protocols to implement their service definitions.

1.3.5 The Relationship of Services to Protocols

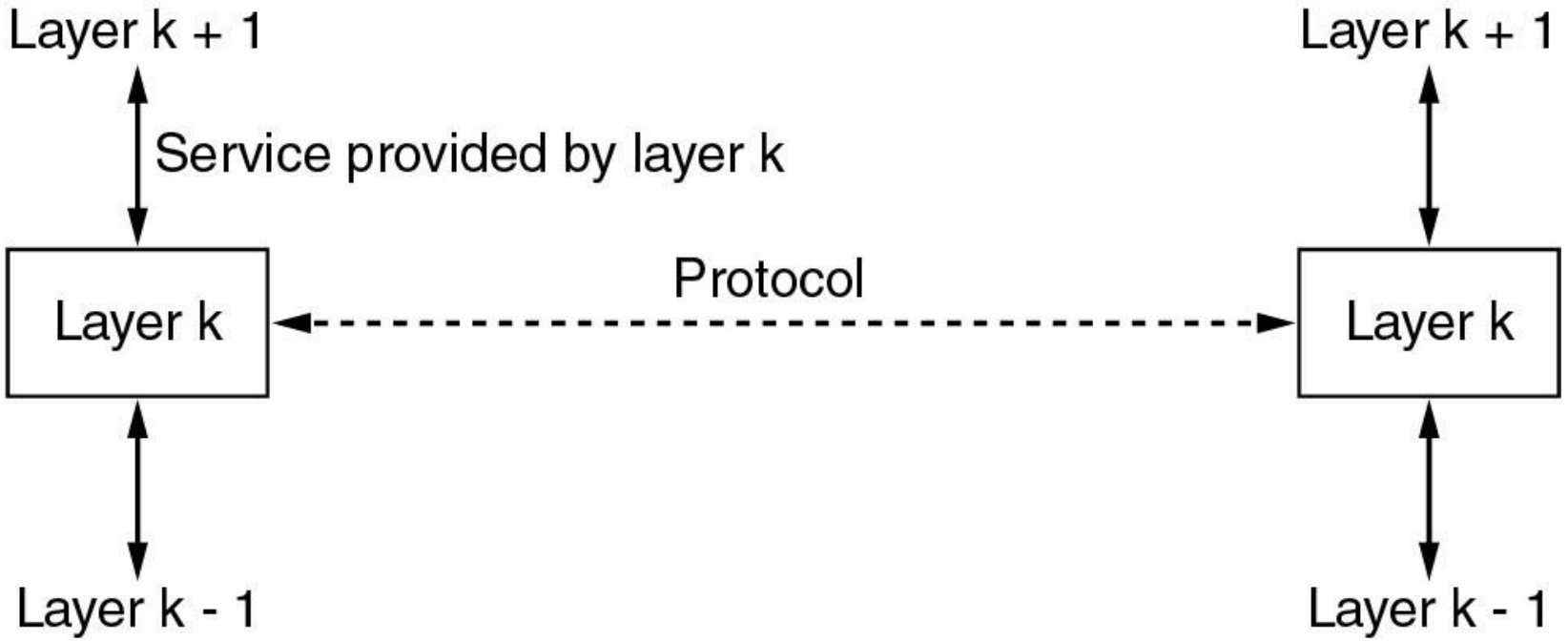


Fig. 1.19 The relationship between a service and a protocol

End of part 1