Computer Networks

高艺
浙江大学计算机学院
2021秋冬

Computer Networks (计算机网络)

- Textbook:
  - 《Computer Networks》 Tanenbaum, Feamster, and Wetherall 2021. 6th.
  - 《Computer Networks》 Tanenbaum and Wetherall 2011. 5th. Prentice Hal PTR.
  - 《Computer Networking: A Top-Down Approach》 James Kurose and Keith Ross, 6th edition.

- 任课教师联系邮箱:
  - gaoyi@zju.edu.cn (邮件标题包含“COMNET21”)
- 助教: 李晔明（lym_sada@163.com）;

Computer Networks (计算机网络)

- 课程钉钉群
- 学在浙大

该群属于“浙江大学”内部群，仅组织内部成员可以加入，如果组织外部人员收到此分享，需要先申请加入该组织。

Computer Networks (计算机网络)

- References
  - Douglas Comer. "Internetworking with TCP/IP”, Volume 1,2,3, Prentice-Hall.
  - W. Richard Stevens, 1998. "Unix Network Programming Volume 1: Networking APIs: Sockets and XTI", Prentice-Hall.
  - Stephen T. Satchell and H.B.J. Clifford 2000. "Linux IP Stacks Commentary", Coriolis.
  - 《从创意到原型：物联网应用快速开发》, 科学出版社.
  - RFCs.

课程评分

- 平时成绩50%
  - 课程作业 7次
  - 课程实验 7-8次
  - 分组presentation
  - 出勤+quiz 3-4 次
- 期末考试50% (闭卷)

Presentation Topics (1): Internet

1. Network architecture
2. Network topology
3. Network measurement
4. Transport protocols

Presentation Topics (2): Wireless

5. Wireless PHY layer technologies
6. Wireless link quality estimation
7. Duty cycled MAC
8. Multihop wireless protocols

Presentation Topics (3): IoT

9. Bluetooth & BLE
10. RFID
11. LPWAN: NB-IoT, LoRaWAN
12. MQTT and COAP: protocols for IoT

Presentation Topics (4): Any other network-related topics

13. Network security
14. Data center network
15. Video QoE
16. Web page load time
17. Other topics.

Recent Trends

- **Trends: More powerful servers + Smarter clients**

- **Data Centers and Cloud Computing**
- **Mobile Internet**
- **Internet of Things**

Data centers

- Data centers are the base for cloud computing
  - Phone/laptop/desktop at client side
  - Data centers at the back end
- Data centers are huge
  - Google has more than 450,000 servers in 2006
  - Microsoft has “hundreds of thousands” servers
  - The growth rate is exponential

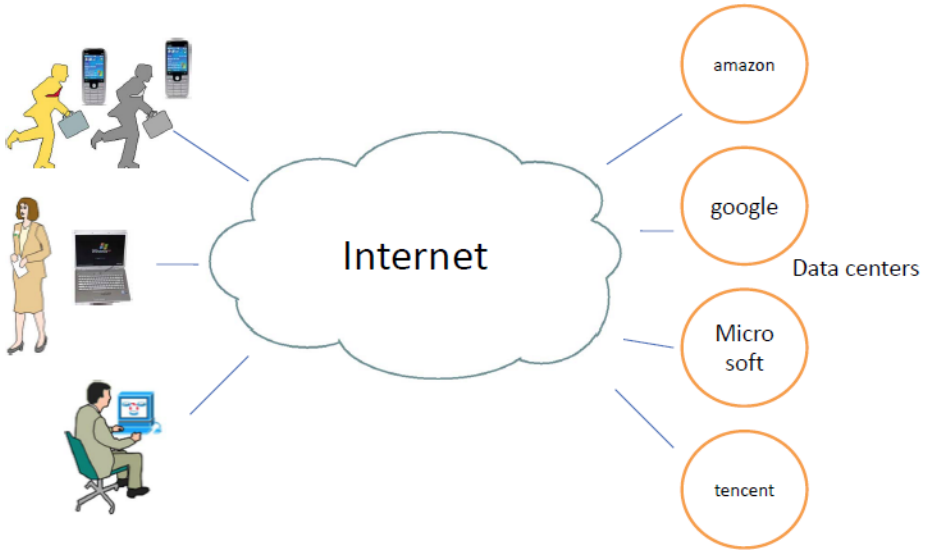
Cloud computing

- Cloud Computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services
- The services themselves have long been referred to as Software as a Service (SaaS)
- The data center hardware and software is what we will call a Cloud

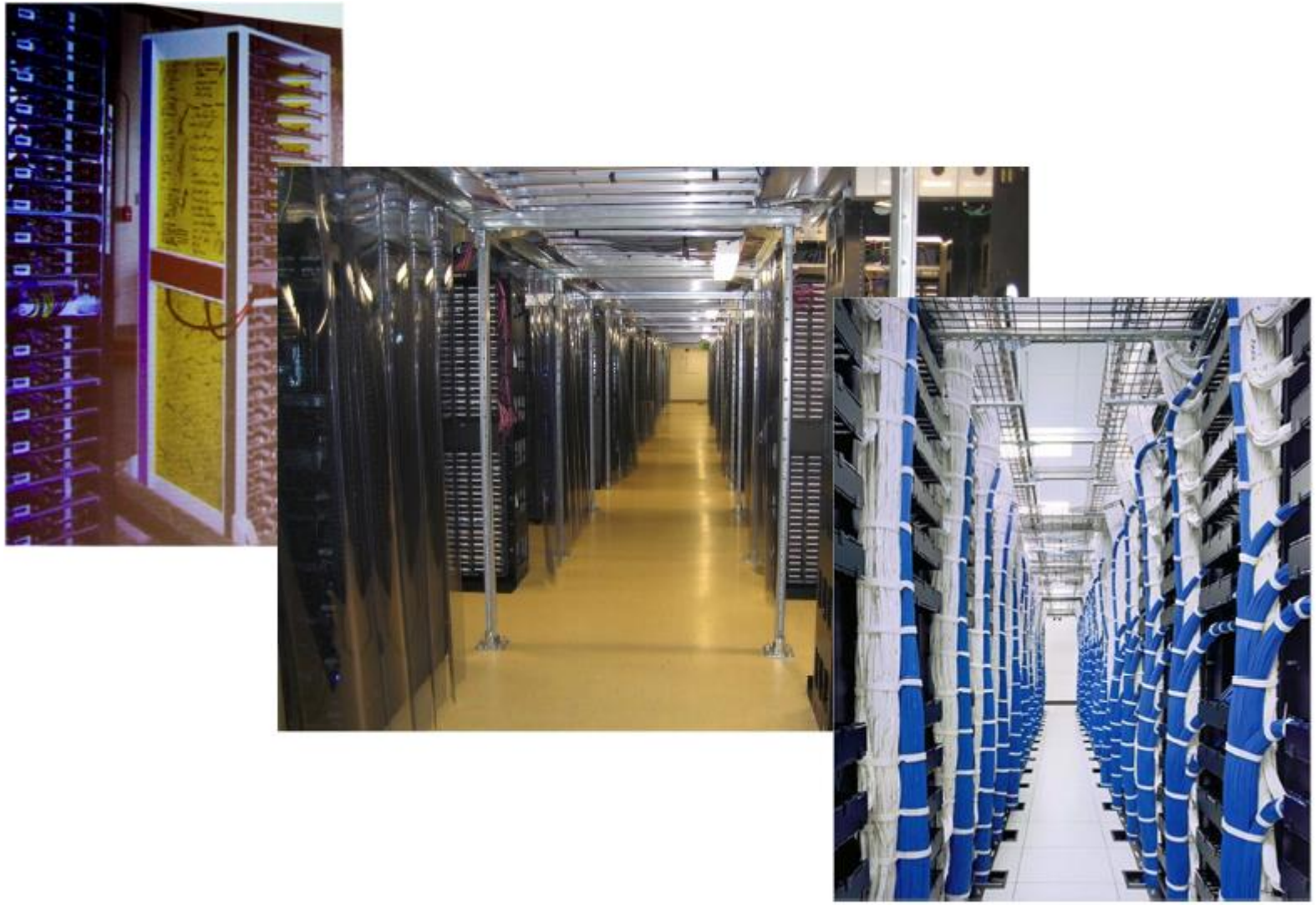
- From users' viewpoint
  - Pay-as-you-go
  - Device and location independent
  - High reliability and easy to scale
- From cloud service providers' viewpoint
  - Economics of scale
  - Resource sharing

Cloud computing

- Virtualization
- Lightweight container
- Serverless computing
- AI
- Data center



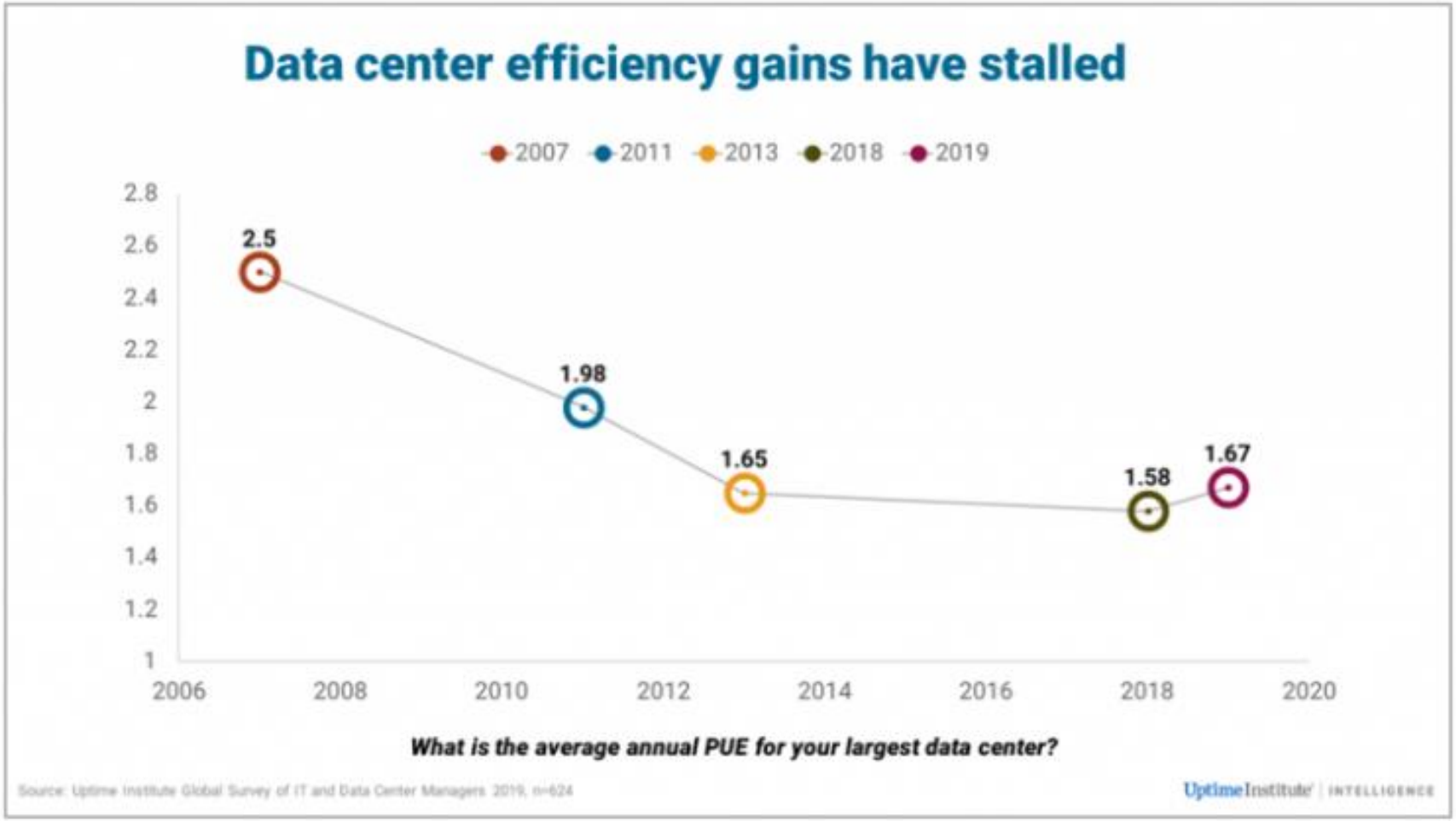

535
530
525



Data Centers

- Data centers are built from commodity devices instead of specially designed ones
- Driven by economical laws (performance-price ratio)
- Admit failures are common and use software to handle it

PUE


Data center efficiency gains have stalled
2007
2011
2013
2018
2019
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
2.5
1.98
1.65
1.58
1.67
2006
2008
2010
2012
2014
2016
2018
2020
What is the average annual PUE for your largest data center?
Source: Uptime Institute Global Survey of IT and Data Center Managers 2019, n=624
Uptime Institute | INTELLIGENCE

Data Centers

Data Centers

IoT (物联网)

- In 1974, the TCP/IP model (and its protocols) was invented.
  - **Vint Cerf** (&Robert Kahn)
  - ACM President, Turing Award 2004
  - One of the "Fathers of the Internet,"
  - Co-designer of the TCP/IP protocols and the architecture of the Internet.

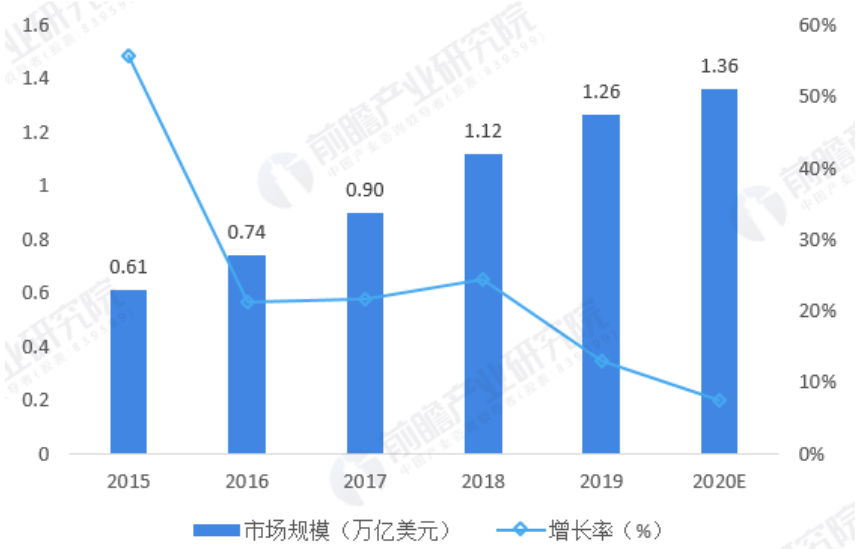
Vint Cerf @ TURC 2018

The future of IoT

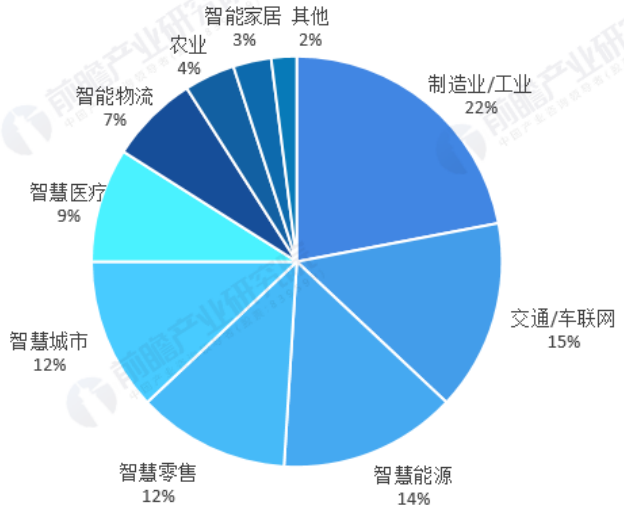
- **Vint Cerf:** Software arose as a way to compute solutions to business and engineering problems more quickly. But it has become ubiquitous across billions of devices – in our homes, cars, workplaces, and in continuous contact. This spread of automation has fueled a massive rise in productivity, but it has also sown the seeds of **vulnerabilities with bugs**, some innocuous, some serious, and some **fatal**. Are there remedies? Software is beginning to detect bugs and even produce bug-free software. Fault-tolerant infrastructure is emerging. And we will eventually find ways to test the innumerable combinations of devices that work together. I will explore these opportunities and challenges as the IoT tsunami continues largely unabated.

IoT

图表3：2015-2020年全球物联网行业市场规模情况(单位：万亿美元，%)



图表4：2020年全球物联网十大应用领域结构(单位：%)



资料来源：IOT Analytics 前瞻产业研究院整理

物联网学术来源

- 在学术界，研究主线复杂，来源并不单一
  - Pervasive computing (普适计算)
    - 利用广泛部署的微小计算设备，实现透明和智能的计算服务；
    - 前期研究主要集中在上下文感知
  - RFID (无线射频识别)
    - 1999年MIT提出；
    - 2008年射频标签技术市场规模达52.5亿美元
  - Wireless sensor network (无线传感器网络)
    - 大量微型化的计算设备自组织连接；
    - 将计算延伸到制造、运输、能源、环境等生产领域

RFID & backscatter

图1　美国国玺图章

图 2　带监听设备的图
音女雕

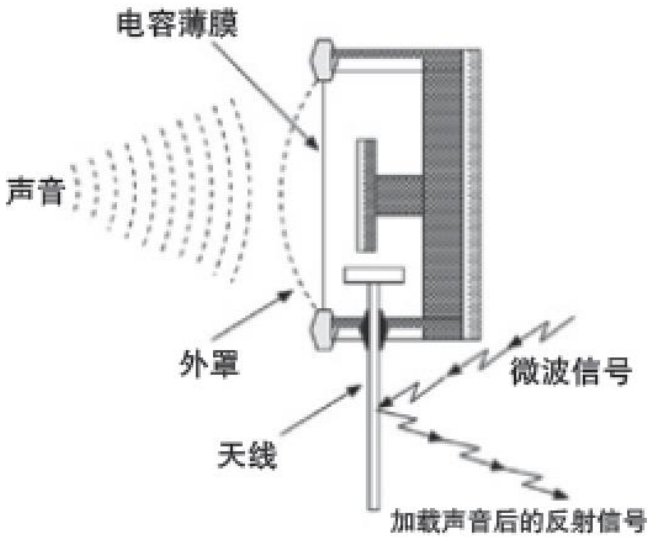
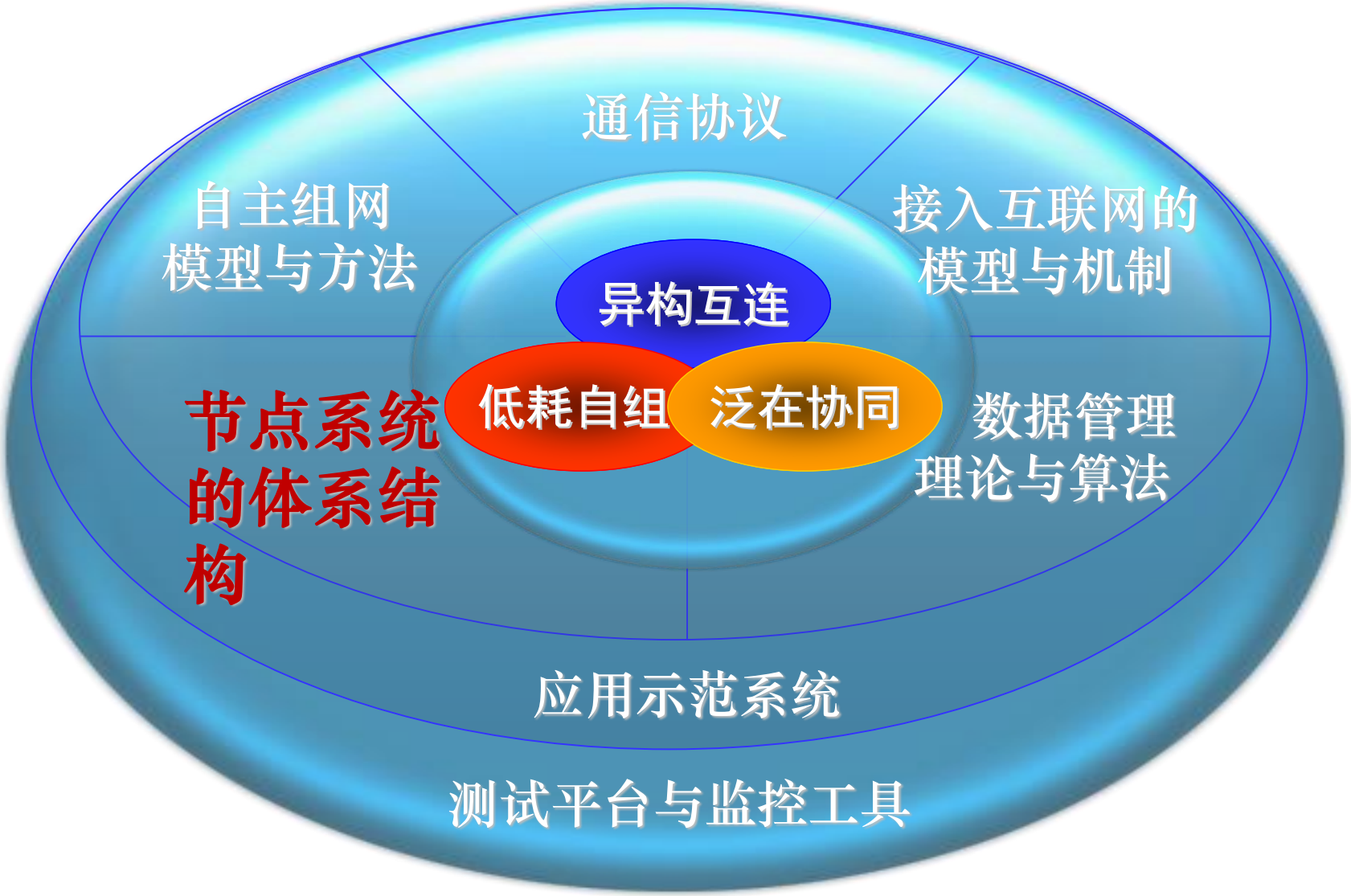
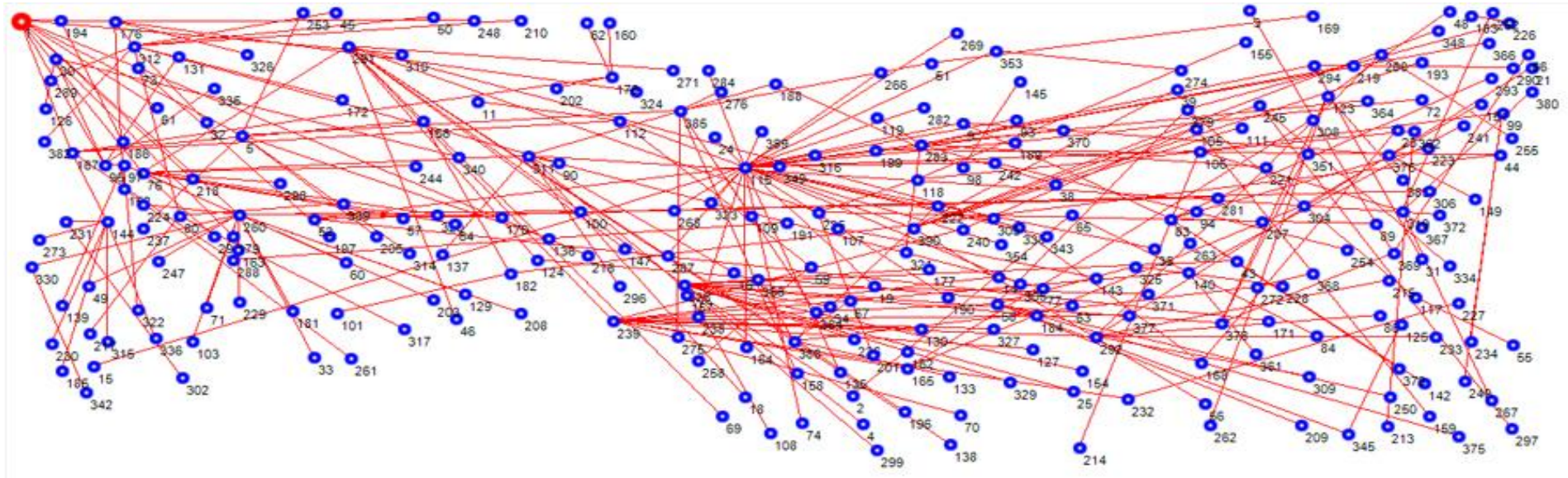


图3　设备原理图

973计划: 无线传感网络的基础理论及关键技术研究



无线传感器网络: GreenOrbs



无线传感器网络: CitySee

发展趋势

①电源技术：持续研究中…

- 电池供电 → 太阳能供电、无线充电、后向散射

②节点平台：**集成到开放**，组件更加丰富

- MicaZ, TelosB → Arduino, LinkIt One, Beagle Bone, …

③组网互联：多跳 → 单跳

- 多跳ZigBee → BLE，LoRa， NB-IoT

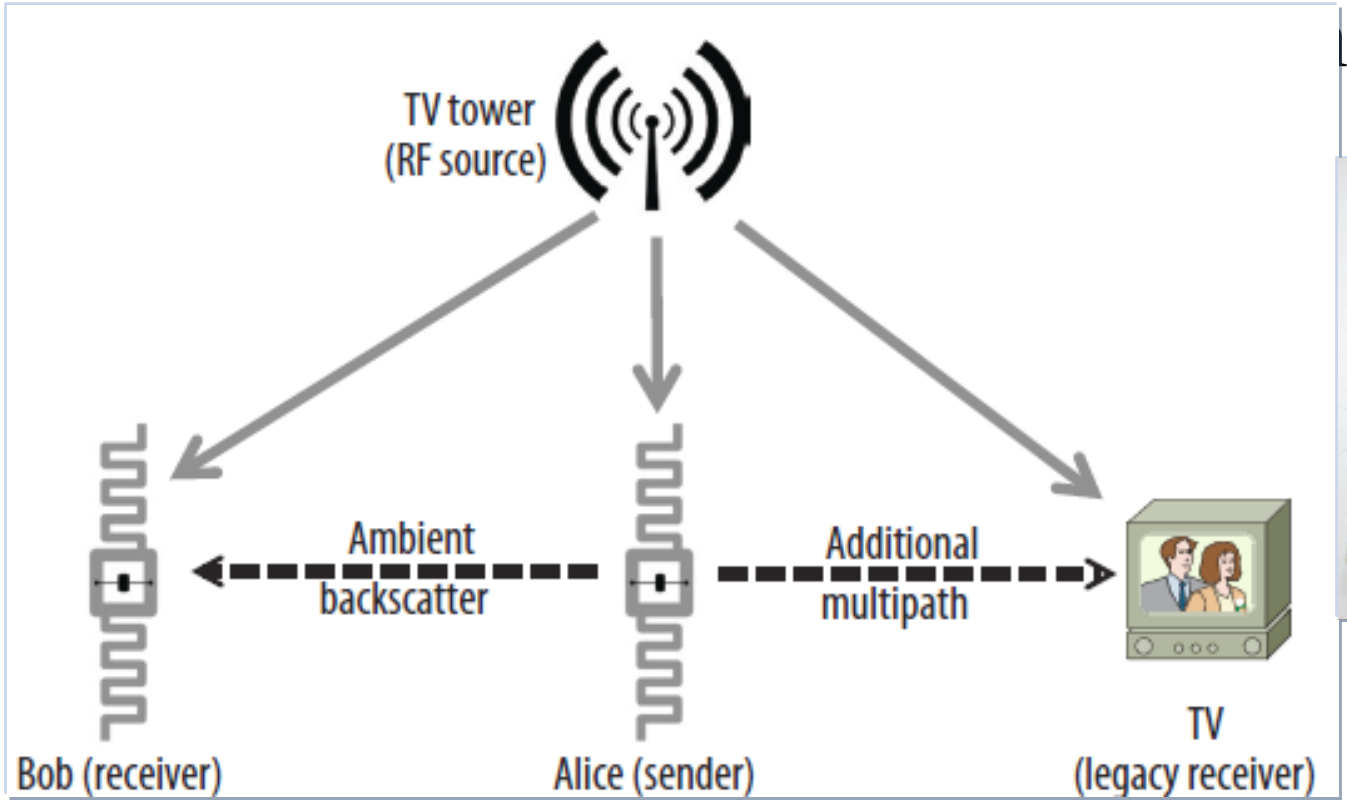
④智能感知：感知更加智能

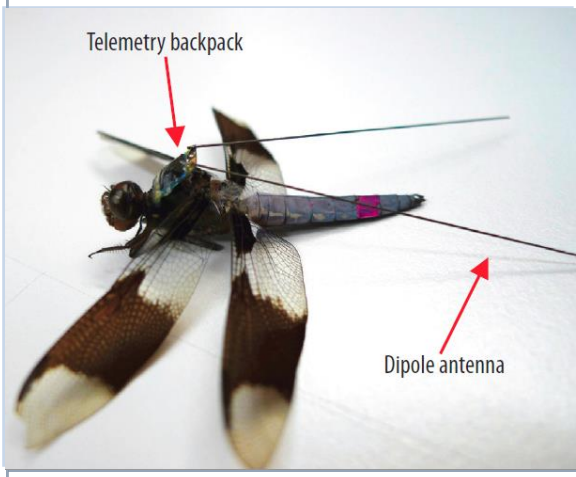
- 简单的温湿度、光照 → 精确手势识别、智能人机交互

⑤安全：多层次的安全保障

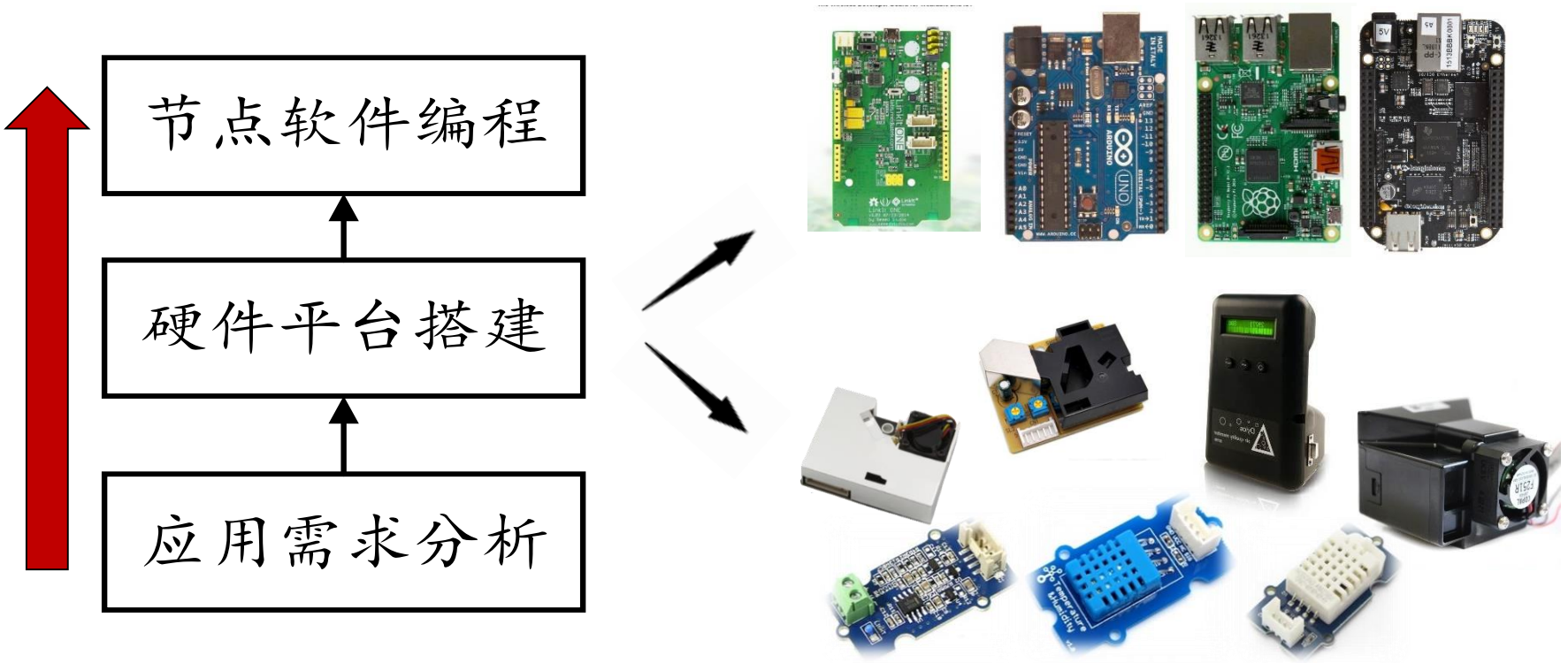
①电源技术: 后向散射 (华盛顿大学)

ckscatter





②节点平台:传统开发模型



②节点平台: TinyLink

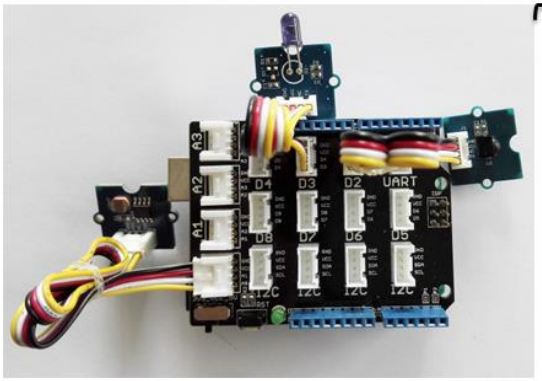
应用需求分析

节点软件编程

硬件平台搭建

```
void setup() {
  TL_WiFi.init();
  TL_WiFi.join("SSID", "PASSWORD");
  TL_Light.setMeasuringRange(1,30000,"LUX");
}
void loop() {
  TL_Light.read();
  TL_Soil_Humidity.read();
  ……
}
```

分析用户代码



TinyLink: a Holistic System for Rapid Development of IoT Applications, ACM MobiCom 2017.

③组网互联

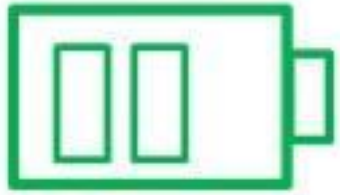

5G、LTE-V等
LPWA（低功率广覆盖）
（eMTC）
Wi-Fi
UWB
Bluetooth
ZigBee
NB-IoT，LoRa，Sigfox
网络性能要求
覆盖要求
短距离
长距离

③组网互联: NB-IoT

20dB+

超强覆盖

10年+



超低功耗

$1

超低成本

50K/Cell

超大连接

④智能感知: 智能语音助手

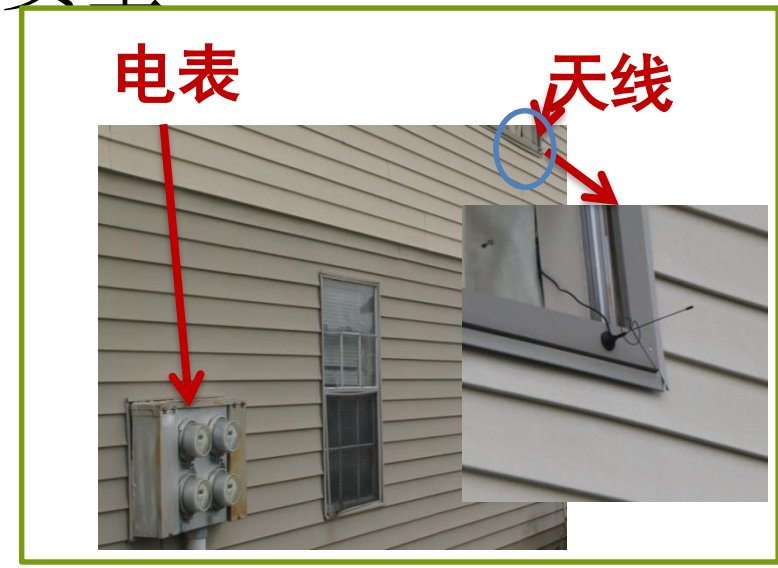
- Google Assistant
- Amazon Echo
- Apple Siri & HomeKit

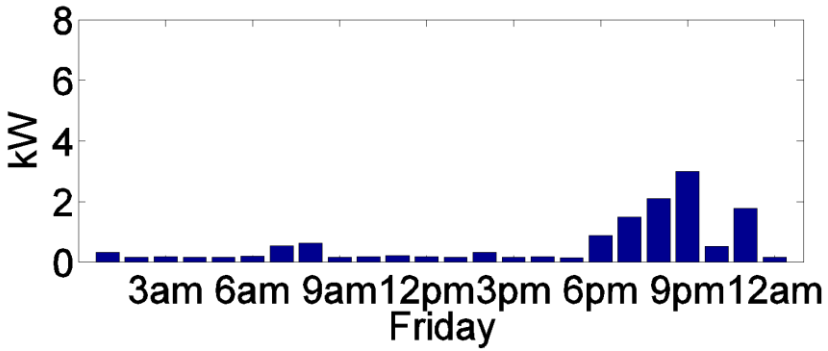
⑤物联网安全

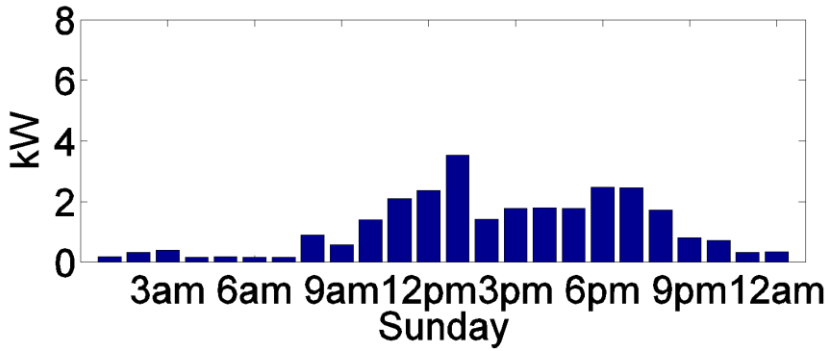
- **2016年6月18日，央视新闻：目前智能家庭摄像头泄露隐私已成为火热的生意，只要将被破解的IP地址输入播放软件，就可以实现偷窥，不被察觉。**

⑤物联网安全

- 智能电表系统——用户隐私安全
  - 无线表（AMR）
    - 47百万电表（2010）
    - 水表，气表，电表
  - 安全分析
    - 反工程→破解电表帐号及读数
    - 截获电表数据包→实时监视用电量
    - 发射假包→改变用电量统计







CHAPTER 1 INTRODUCTION

- Network Usage
- Types of Computer Networks
- Network Examples
- Network Protocols
- Network Standardization

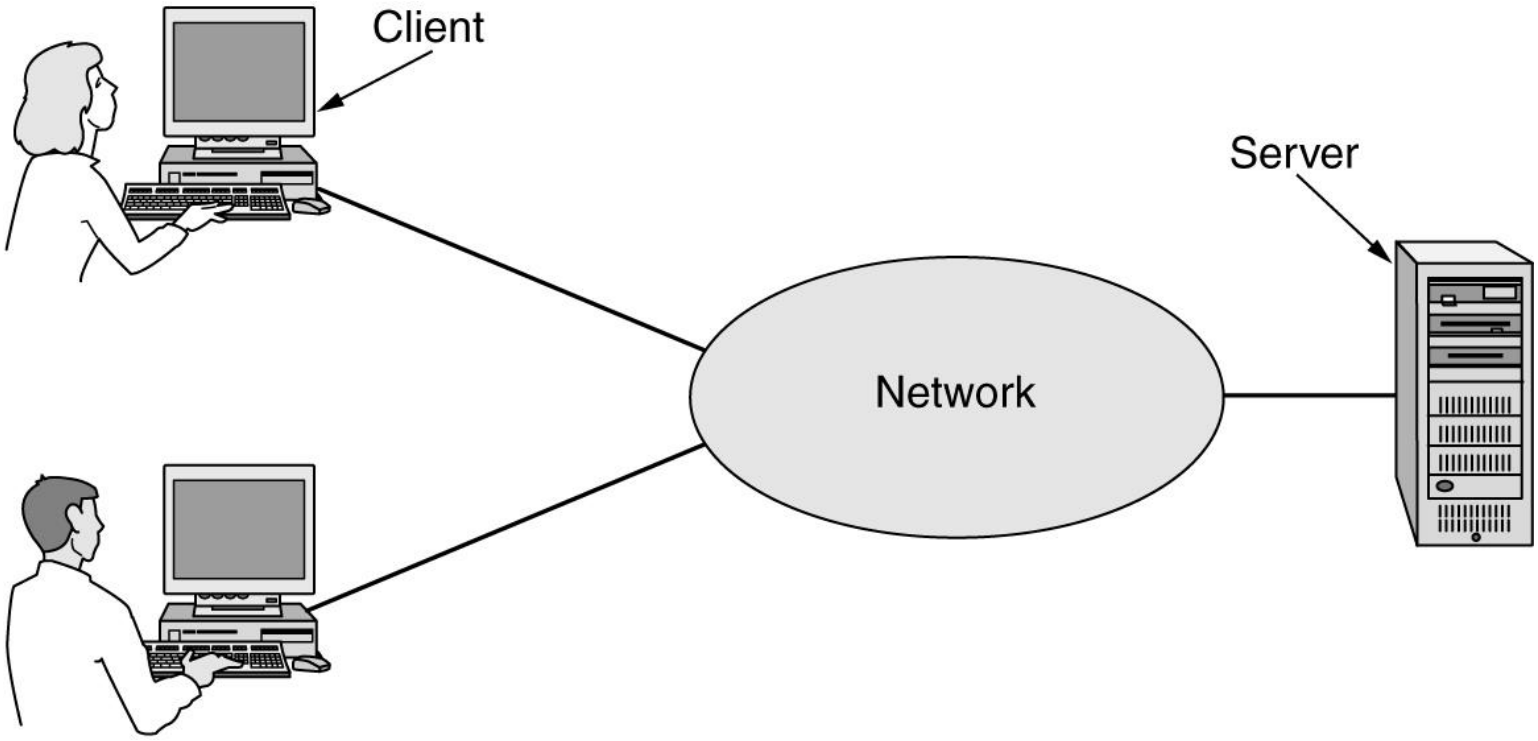
Computer Network

- In the old days, computer systems were highly centralized.
- Now, a large number of autonomous (自治) computers are interconnected to do the job → Computer network (计算机网络) → Distributed systems (分布式系统).
- Computer network v.s. distributed system
  - Computer network: a collection of interconnected, autonomous computing devices.
  - Distributed systems: a collection of autonomous computers appears to its users as a single coherent system. Coherence, model, implementation (middleware).

Access to Information (1 of 4)

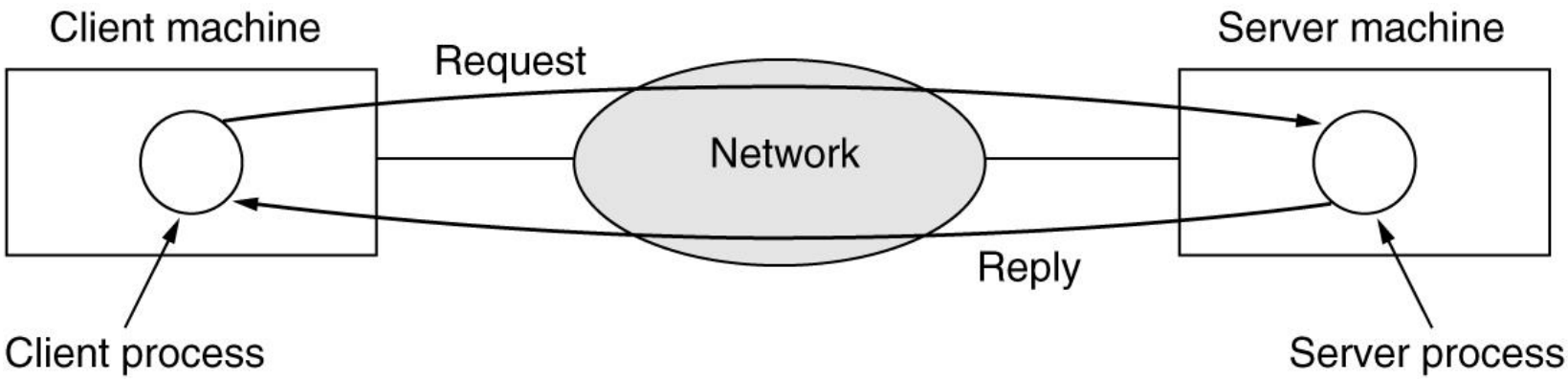
- Web browser and smart phones retrieve information from various Web sites
- Social media platforms support targeted behavioral advertising
- Online digital libraries and retail sites host digital content
- Client-server model forms the basis of network usage
- Web applications: Server generates Web pages in response to client requests
- Peer-to-peer communication: Individuals form a loose group to communicate with others in the group

Access to Information (2 of 4)



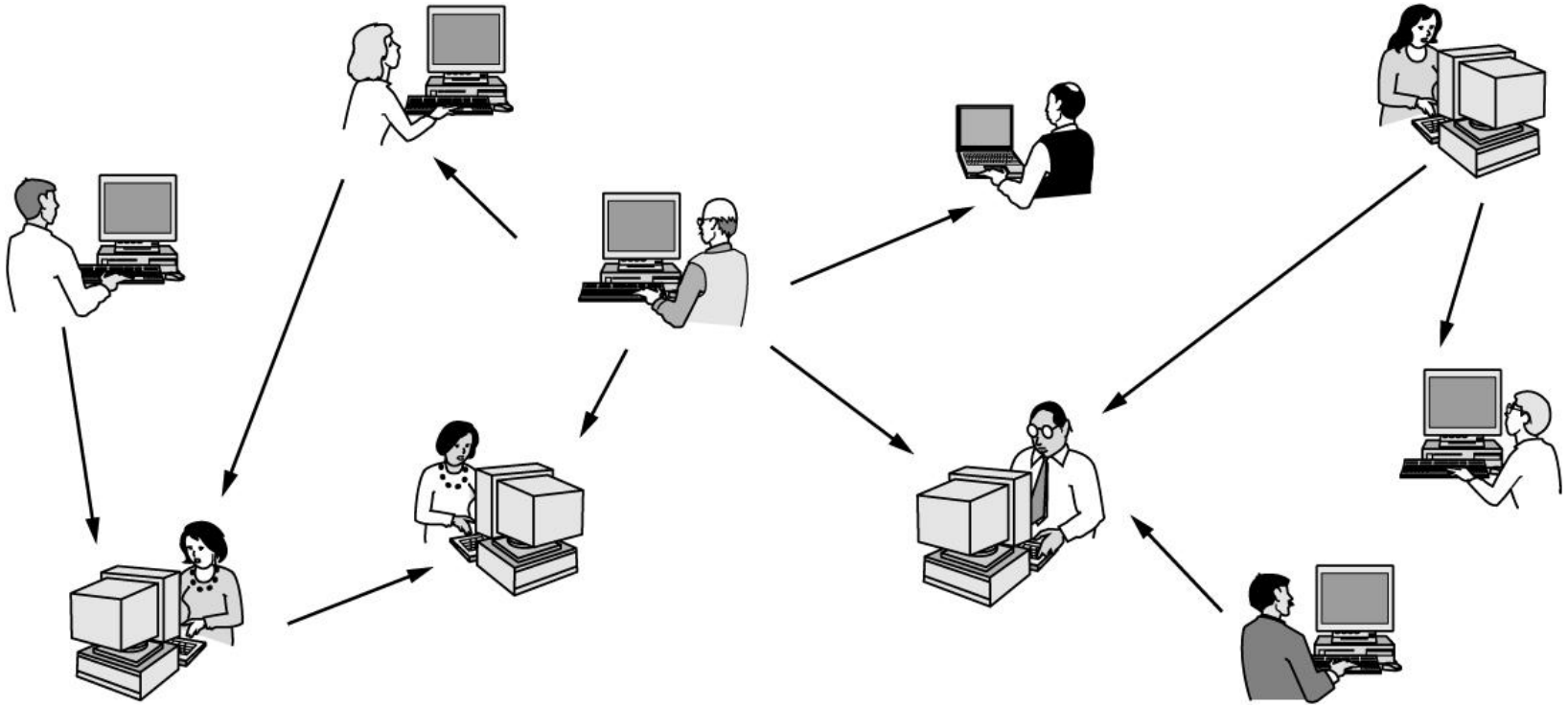
In the client-server model, a client explicitly requests information from a server that hosts that information.

Access to Information (3 of 4)



Communication takes the form of the client process sending a message over the network to the server process. The client process then waits for a reply message.

Access to Information (4 of 4)



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

Person-to-Person Communication

- Instant messaging
  - Allows two people to type messages at each other in real time
- Twitter multi-person messaging service
  - Allows people to send short messages to their circle of friends or other followers or the whole world
- Social network applications
  - Information flow driven by the relationships that people declare between each other
- Wiki content is a collaborative Web site the members of a community edit

Electronic Commerce (1 of 2)

- Online shopping and financial institution transactions follow client-server model
- Online auctions follow peer-to-peer model
  - Consumers act as buyers and sellers
  - Central server holds the database of products for sale

Electronic Commerce (2 of 2)

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

Some forms of e-commerce have acquired little tags based on the fact that ‘‘to’’ and ‘‘2’’ are pronounced the same.

Entertainment

- IPTV (IP Television) systems
  - TV shows based on IP technology instead of cable TV or radio transmissions
- Media streaming applications
  - Internet-provided radio stations, TV shows, and movies
  - Content usually moves wirelessly between devices
- Game playing using multi-person real-time simulation
- Virtual worlds provide a persistent setting
  - Thousands of users experience a shared reality with three-dimensional graphics

The Internet of Things

- Ubiquitous computing
  - Computing embedded in everyday life
  - Home security systems wired with door and window sensors
  - Sensors folded into a smart home monitor
  - Smart refrigerators
- IoT (Internet of Things)
  - Sensing and communication take place over the Internet
  - Poised to connect every electronic device to the Internet
- Power-line networks
  - Send information throughout the house over the electric wires

Types of Computer Networks

- Mobile and broadband access networks
  - Networks used to access the Internet
- Data-center networks
  - Networks that house data and applications
- Transit networks
  - Networks that connect access networks to data centers
- Enterprise networks
  - Networks used on campuses, in office buildings, or at other organizations

Broadband Access Networks

- Home network use
  - Listen to, look at, and create music, photos, and videos
  - Access information, communicate with other people, buy products and services
- Metcalfe's law
  - Explains how tremendous Internet popularity comes from its size
- Broadband access networks
  - Delivered to homes using copper, coaxial cable, or optical fiber
  - Broadband Internet speeds: gigabit per second to individual homes

Mobile and Wireless Access Networks (1 of 3)

- Wireless hotspots are based on the 802.11 standard
- Wireless networking and mobile computing
  - Related but not identical
- Smartphones combine aspects of mobile phones and mobile computers
- Text messaging or texting short message
- GPS (Global Positioning System): locates a device
- Geo-tagging: annotating photos and videos with the location where they were made

Mobile and Wireless Access Networks (2 of 3)

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

Although wireless networking and mobile computing are often related, they are not identical.

Mobile and Wireless Access Networks (3 of 3)

- M-commerce (mobile-commerce) uses mobile phones
- NFC (Near Field Communication)
  - Allows mobile device to act as an RFID smartcard and interact with a nearby reader for payment
- Sensor networks use nodes gathering and relaying information about the physical state of the world
  - Nodes may be embedded in familiar devices (cars or phones)
  - Nodes may be small, separate devices
  - Provide a wealth of data on behavior
  - Example: wireless parking meters

Content Provider Networks

- Data-center network
  - Internet services are served from ‘‘the cloud’’
  - Serves the increasingly growing demands of cloud computing
  - Moves large amounts of data between servers in the data center
  - Moves data between the data center and the rest of the Internet
- Data center network challenges
  - Network throughput and energy usage scaling
  - ‘‘Cross-section bandwidth”
- CDN (Content Delivery Network)
  - Large collection of servers, geographically distributed so content is close to the users requesting it

Transit Networks

- Transit network
  - Carry traffic between the content provider and the ISP (Internet Service Provider) when they are not directly connected
  - Typically charge both the ISP and the content provider for carrying traffic from end-to-end
  - Traditionally called backbone networks because they carry traffic between two endpoints
- Two trends
  - Consolidation of content in a handful of large content providers
  - Expansion of the footprint of individual access ISP networks

Enterprise Networks

- Allows resource sharing for devices and information
- VPNs (Virtual Private Networks)
  - Connect individual networks at different sites into one logical network
  - Act as a communication medium among employees
- Allows IP telephony or VoIP (Voice over IP)
  - Internet technology and computer networks for telephone calls
- Allows desktop sharing
  - Remote workers can see and interact with a computer screen
- Allows electronic business communication

NETWORK SCALE

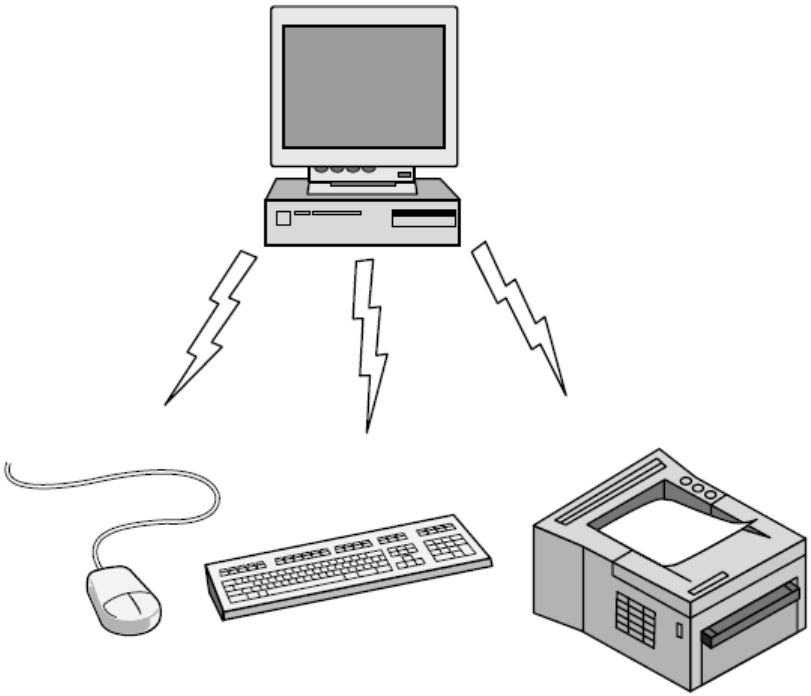
- Scale
  - Local area networks (LANs)
  - Metropolitan area networks (MANs not Men)
  - Wide area networks (WANs)
  - Inter-networks (internet vs. Internet)

Scale

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

PAN (个人局域网)

- PANs (Personal Area Networks) let device communicate over the range o a person.
- To connect a Bluetooth mouse a Bluetooth keyboard, a Bluetooth Printer with a computer.
- To connect a Bluetooth earphone with a mobile phone



LAN (局域网)

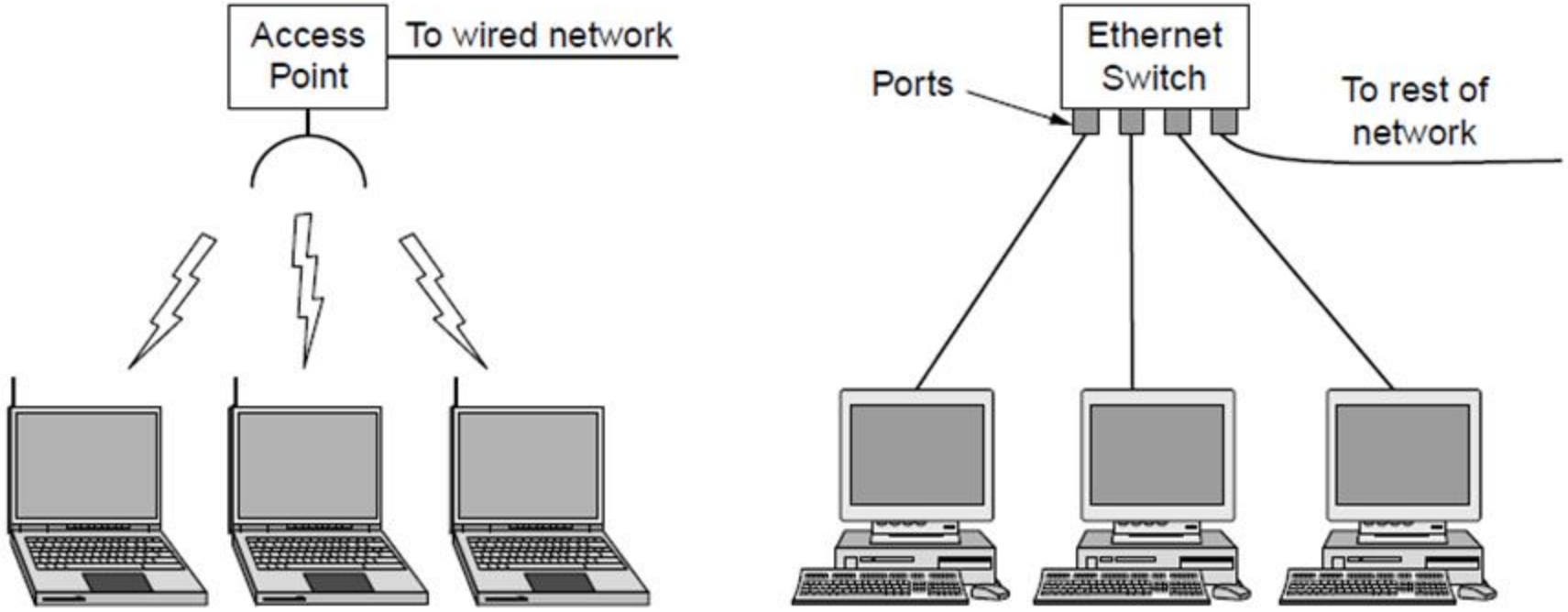
- LANs are privately-owned networks within a single building or campus of up to a few kilometers in size.
- LAN characteristics
  - The size is restricted → The worst-case transmission time is bounded and known in advance → Certain designs are possible and network management can be simplified.
  - Transmission technology →high speed → 10Gbps
  - Topology (physical and local): Bus, Ring, Star (Hub)

LAN

Wireless and wired LANs.

(a) 802.11.

(b) Switched Ethernet.



LAN

- Broadcast networks can be further divided into static and dynamic, depending on how the channel is allocated.
  - A typical static allocation would be to divide time into discrete intervals and use a round-robin algorithm, allowing each machine to broadcast only when its time slot comes up.
  - Dynamic allocation methods for a common channel are
    - either centralized (A single entity determines who goes next)
    - or decentralized. (Many algorithms are designed to bring order out of the potential chaos.)

LAN

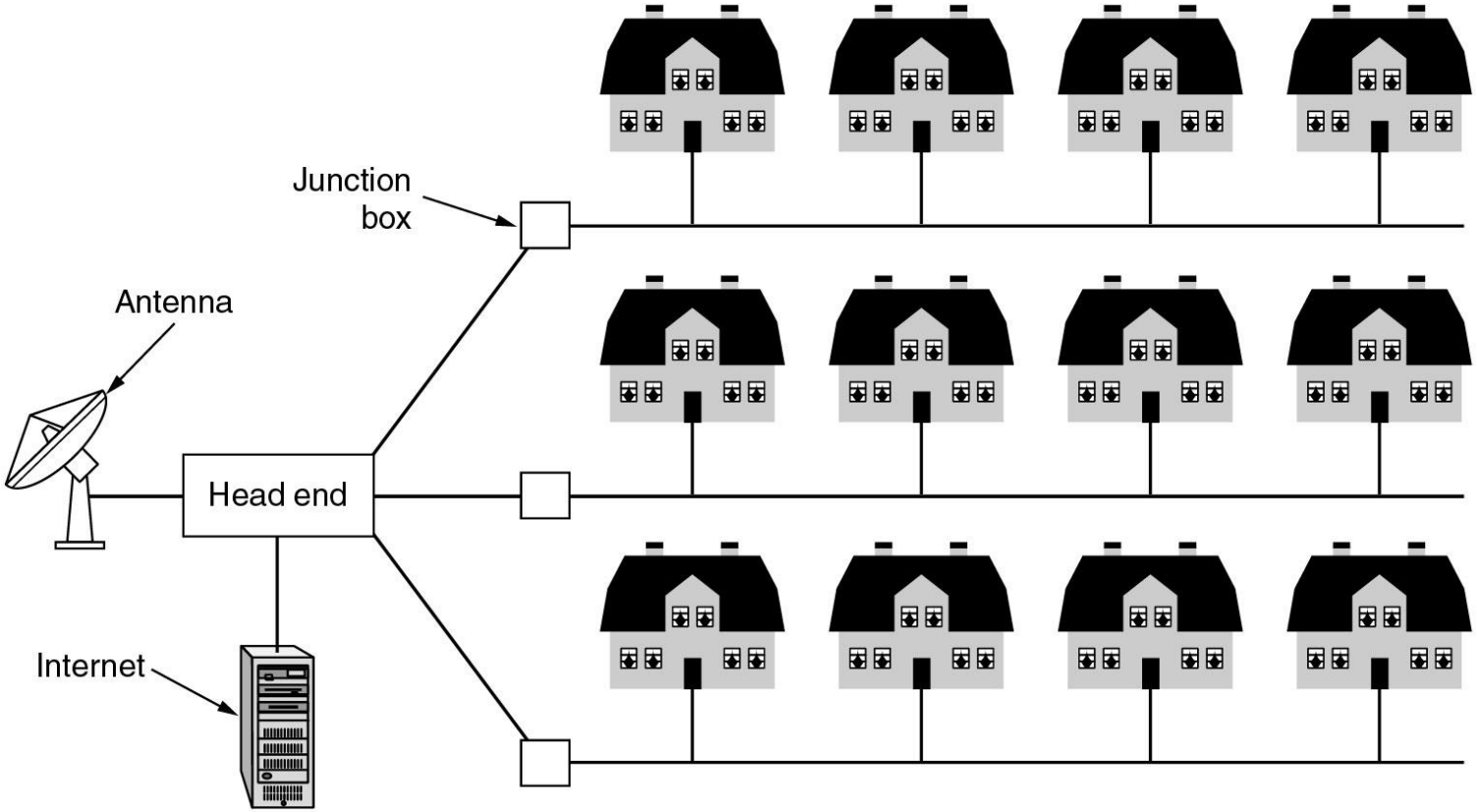
- Many home devices are capable of being networked:
  - Computers (desktop PC, PDA, shared peripherals)
  - Entertainment (TV, DVD, VCR, camera, stereo, MP3)
  - Telecommunications (telephone, cell phone, intercom, fax)
  - Appliances (microwave, fridge, clock, furnace, airco)
  - Telemetry (utility meter, burglar alarm, babycam).
- Requirements: easy to install, foolproof in operation, low price, sufficient capacity, to be expandable, secure and reliable.

MAN (城域网)

- A metropolitan area work, or, MAN (plural: MANs, not MEN) is basically a bigger version of a LAN and normally uses similar technology.
- Examples
  - A MAN can be based on cable TV (See the next slide)
  - IEEE 802.16 (WiMAX), NB-IoT
- A key aspect of MAN is that there is a broadcast medium to which all the computers are attached.

MAN

A metropolitan area network based on cable TV.

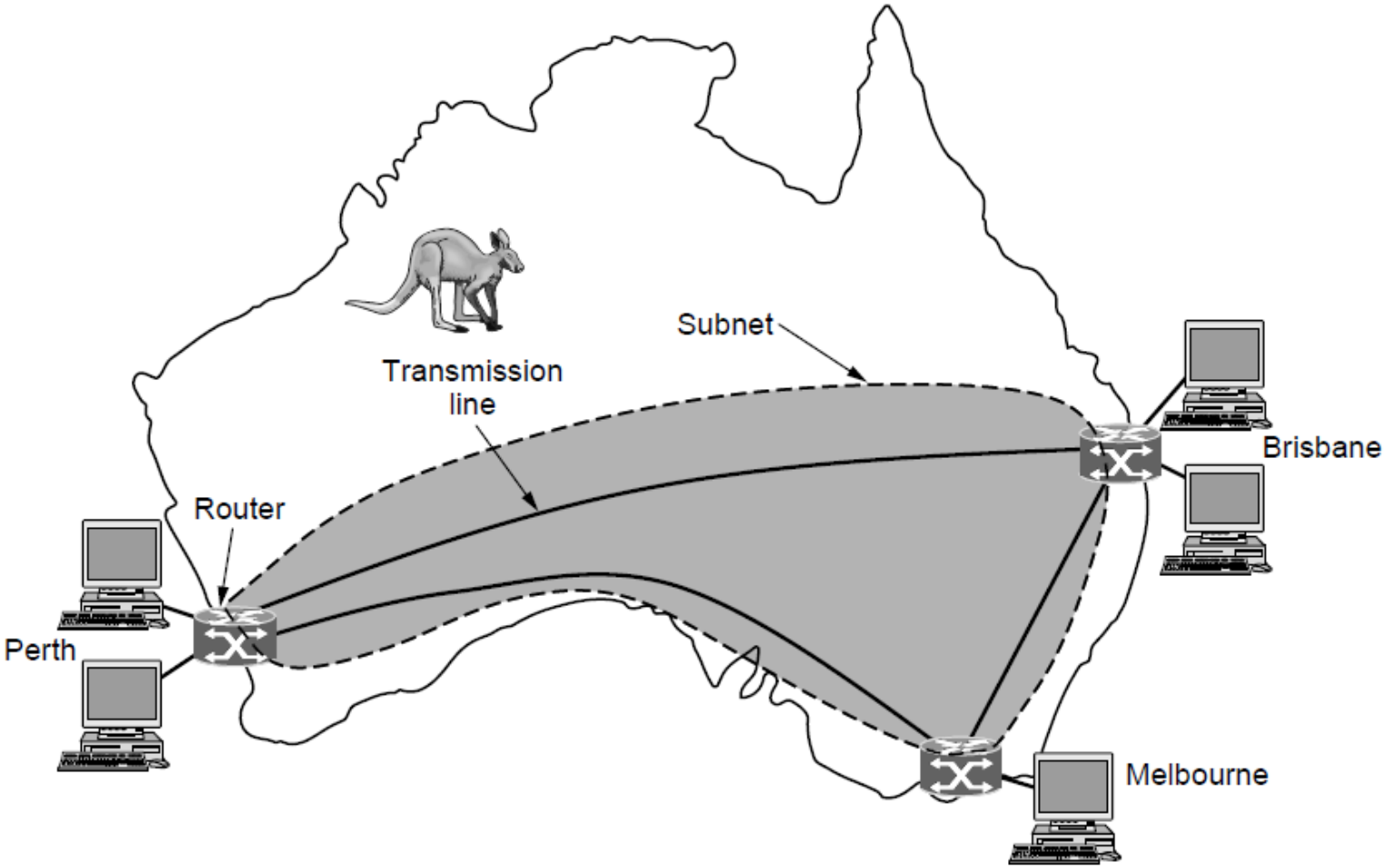


WAN (广域网)

- A WAN consists of a collection of machines intended for running user programs (hosts, end systems) and a pure communication subnet (subnet)
- The **subnet** consists of two distinct components:
  - Transmission lines (also called circuits, channels, or trunks) move bits between machines.
  - Switching elements (packet switching nodes, intermediate system, data switching exchanges, routers) are specialized computers used to connect three or more transmission lines. When data arrive on an incoming line, the switching element must choose an outgoing line to forward them on.

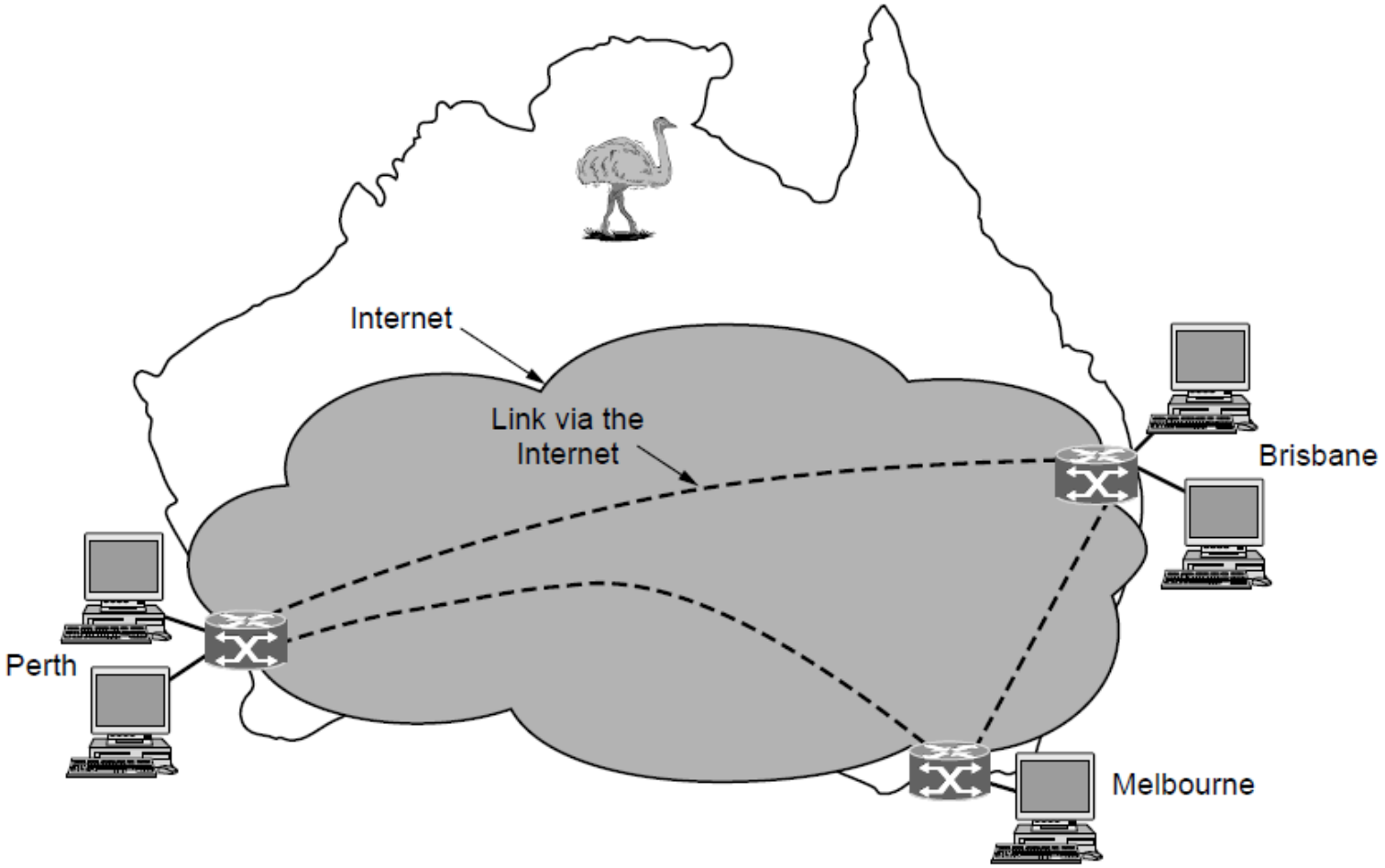
WAN

WAN that connects three branch offices in Australia



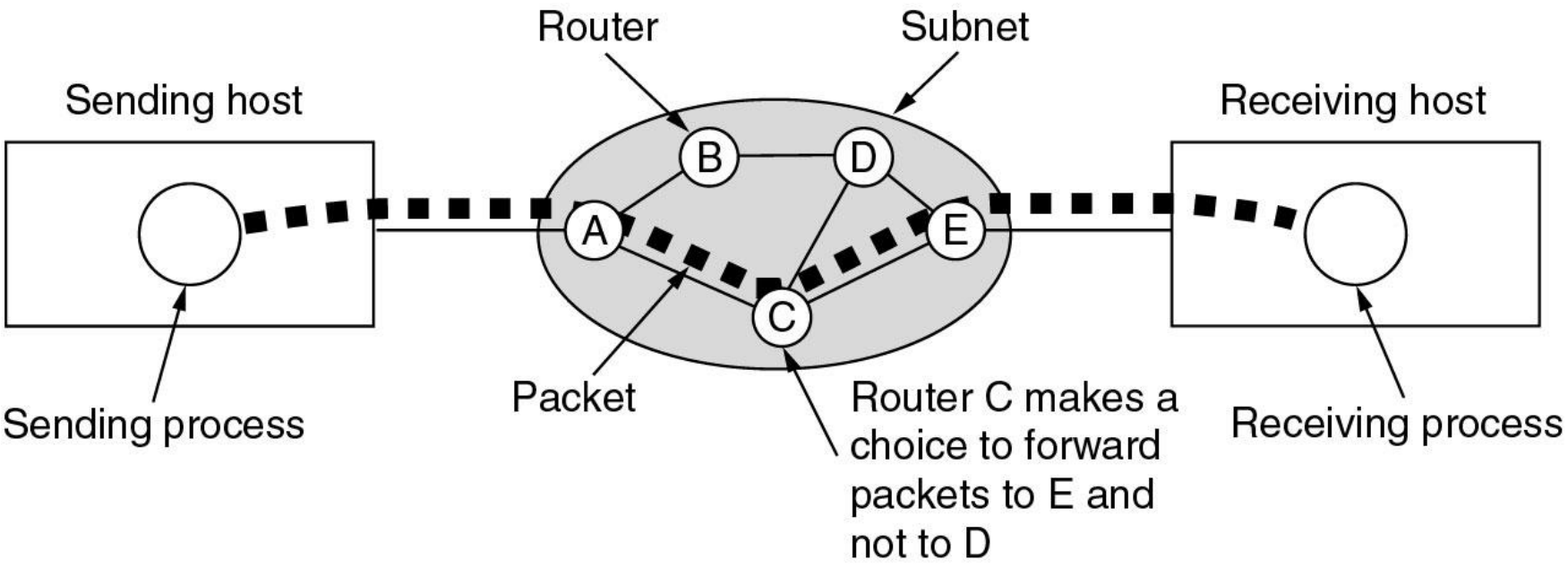
WAN

WAN using a virtual private network.



WAN

A stream of packets from sender to receiver.



Internet (互联网)

- An internetwork or just internet is a collection of interconnected networks. (internet vs Internet)
- A common form of internet is a collection of LANs connected by a WAN.
- Differences among WANs, subnets, networks, and internetworks.
  - WAN = subnet + hosts
  - Subset = transmission lines + switching elements
  - Network: e.g. LAN
  - Many interconnected networks → internetworks.
    - Different owners
    - Different technologies.

EXAMPLE NETWORKS

- **The Internet**
- Wireless LANs: 802.11
- Mobile networks

The Internet

- The ARPANET
- NSFNET
- Internet usage
- Architecture of the Internet

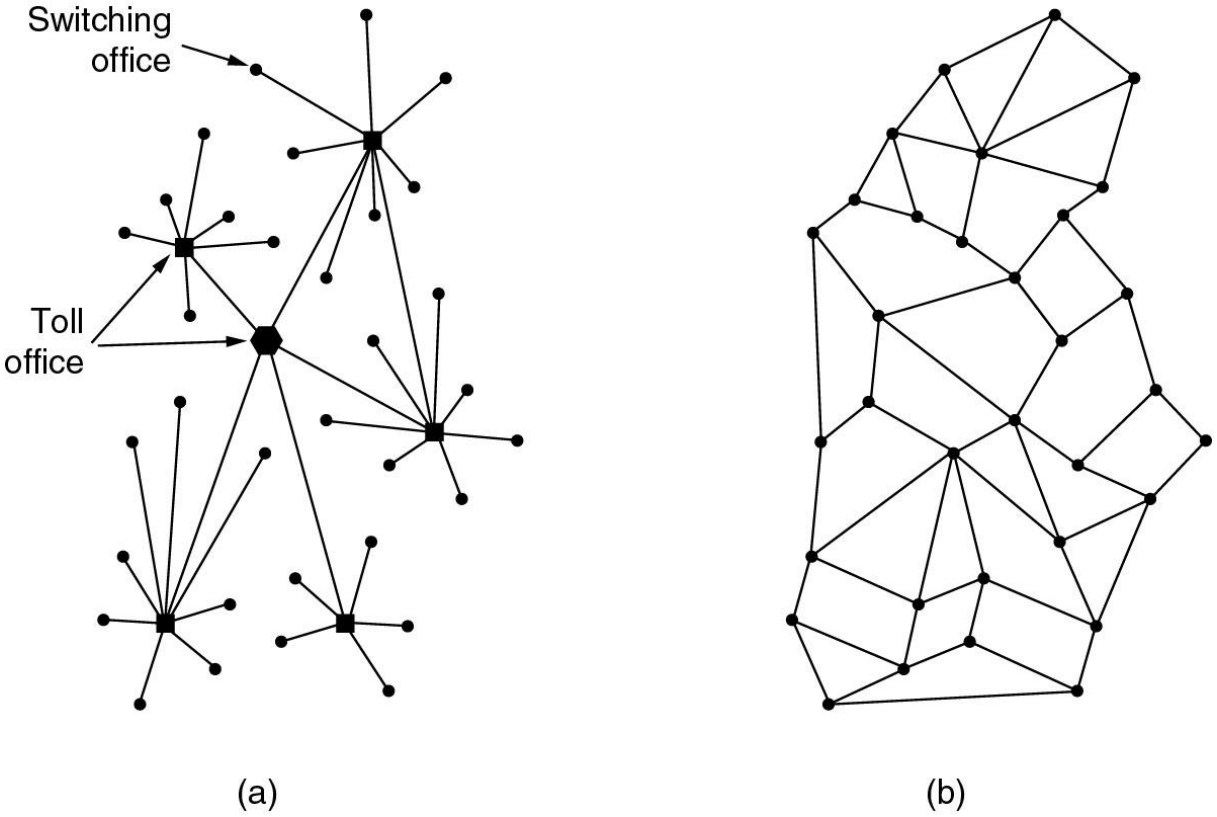
Example networks: The Internet: ARPANET

- In the late 1950s (at the height of the Cold War), the DoD wanted a command-and-control network that could survive a nuclear war.
- Around 1960, the DoD awarded a contract to the RAND Cooperation to find a solution.
  - **Paul Baran** came up with the highly distributed and fault-tolerant design.
  - Baran wrote several reports for the DoD describing his ideas in detail
  - Officials liked the concept and asked AT&T to build a prototype
  - **AT&T** dismissed Baran's ideas out of hand.

Example networks: The Internet: ARPANET

(a) Structure of the telephone system.

(b) Baran's proposed distributed switching system.

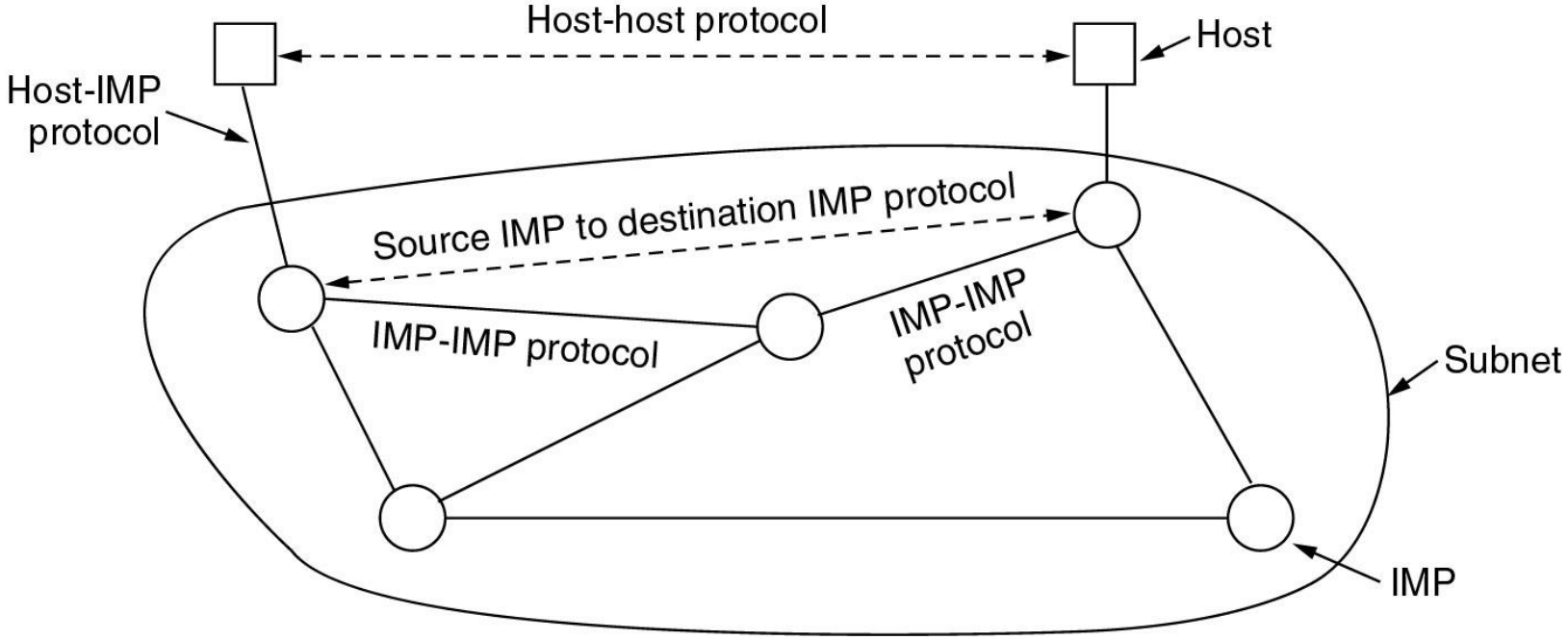


Example networks: The Internet: ARPANET

- In 1967, the attention of ARPA's then director, **Larry Roberts**, turned to networking.
- At the **SOSP** held in Gatlinburg, Tennessee in late 1967, Larry Roberts presented a somewhat vague paper about his idea.
- Another paper described a similar system that had not only been designed but actually implemented under the direction of **Donald Davies** at the National Physical Laboratory in England.
- Roberts came back and determined to build what later became known as the ARPANET.

Example networks: The Internet: ARPANET

- The original design ARPANET
  - The subnet would consist of minicomputers called IMP (Interface Message Processors) connected by 56-kbps transmission lines.
  - Hosts would be connected to IMPs by short wires.

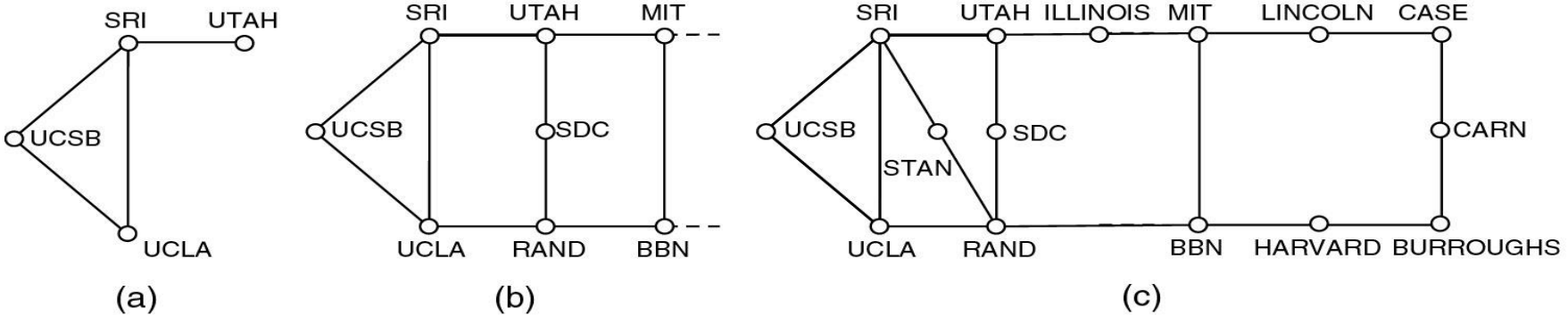


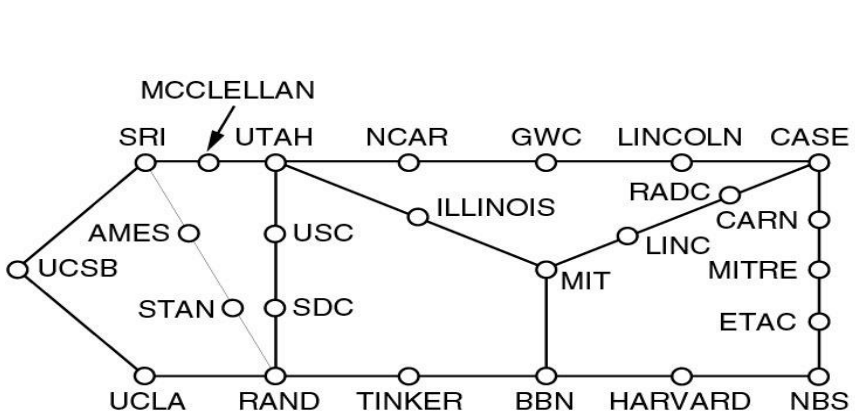
Example networks: The Internet: ARPANET

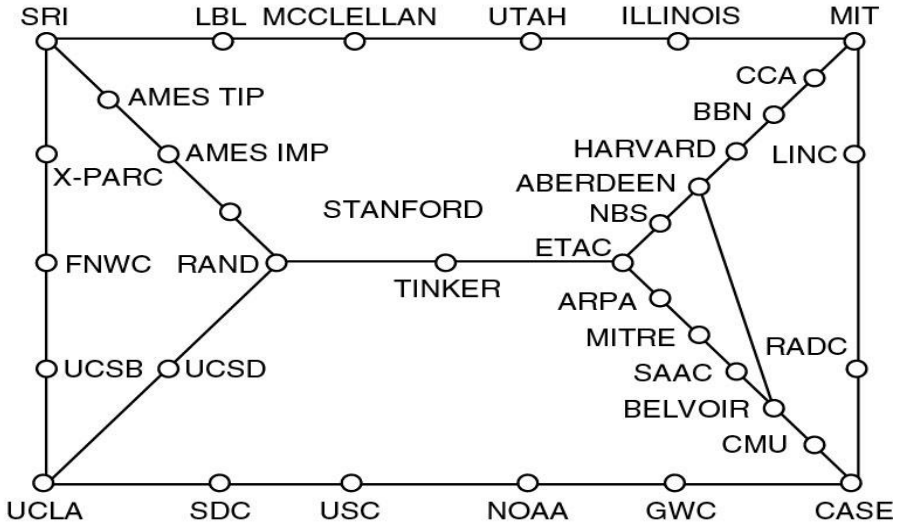
- In December 1968, ARPA selected and awarded BBN (a consulting firm in Cambridge, Massachusetts) a contract to build the subnet and write the subnet software.
- In the summer of 1969, Roberts convened a meeting of network researchers, mostly graduate students, at **Snowbird, Utah**.
  - No network expert and no grand design.
  - The graduate students had to figure out what to do on their own.
- In December 1969, an experimental network went on the air with four nodes: at UCLA, UCSB, SRI, and the University of Utah.

Example networks: The Internet: ARPANET

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







The Internet: ARPANET

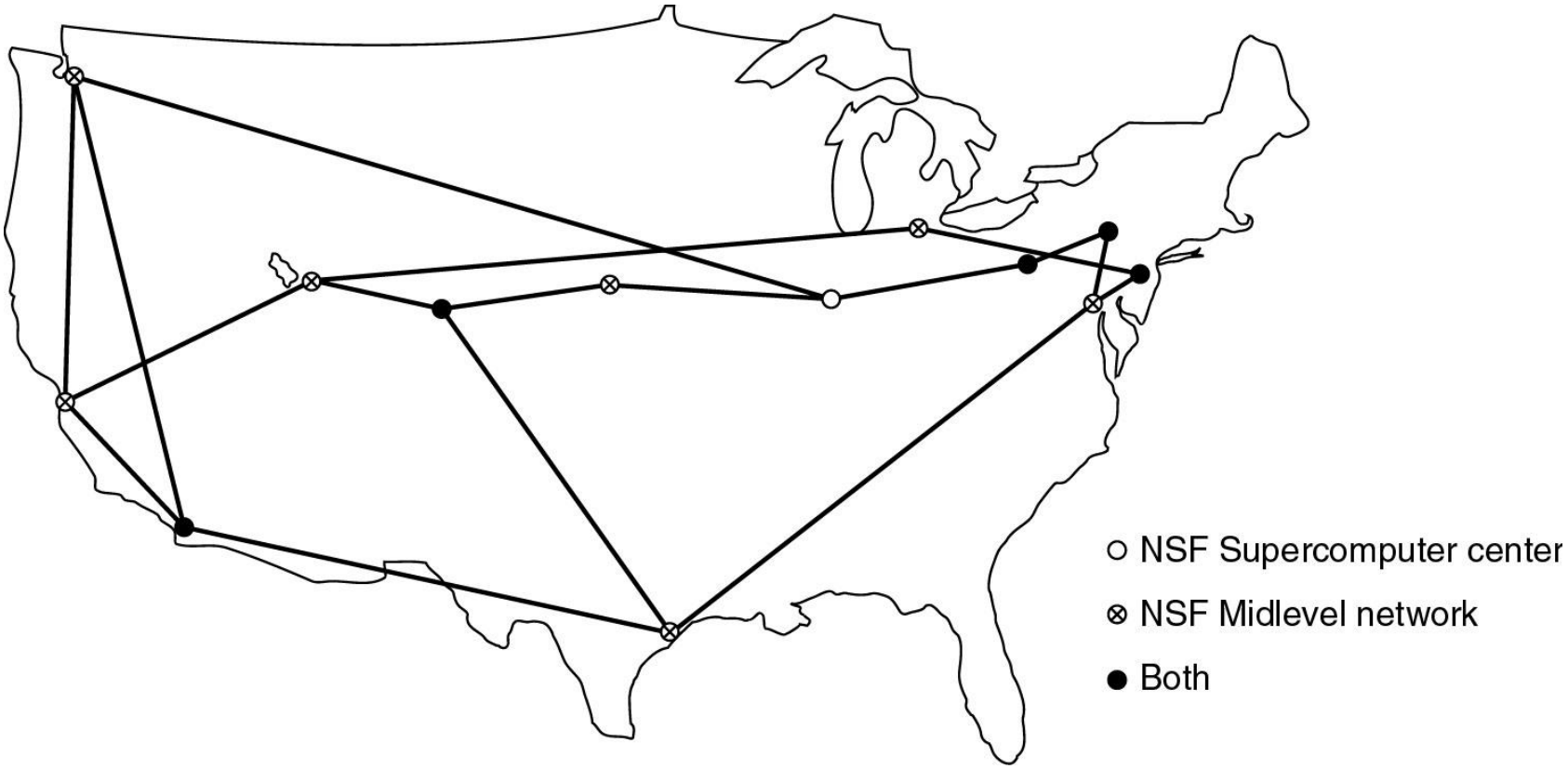
- In 1974, the TCP/IP model (and its protocols) was invented.
  - **Vint Cerf** (&Robert Kahn)
  - ACM President, Turing Award 2004
  - One of the "Fathers of the Internet,"
  - Co-designer of the TCP/IP protocols and the architecture of the Internet.
- During the 1980s, additional networks, especially LANs were connected to the ARPANET.
- DNS (Domain Name System)

Example networks: The Internet: NSFNET

- By the late 1970s, NSF saw the enormous impact the ARPANET was having on university research, allowing scientists across the country to share data and collaborate on research projects.
- NSFNET
  - One backbone network that connected six NSF super computer centers.
  - About 20 regional networks that connected to the backbone
  - ARPANET and NSFNET connected at CMU.

Example networks: The Internet: NSFNET

The NSFNET backbone in 1988.



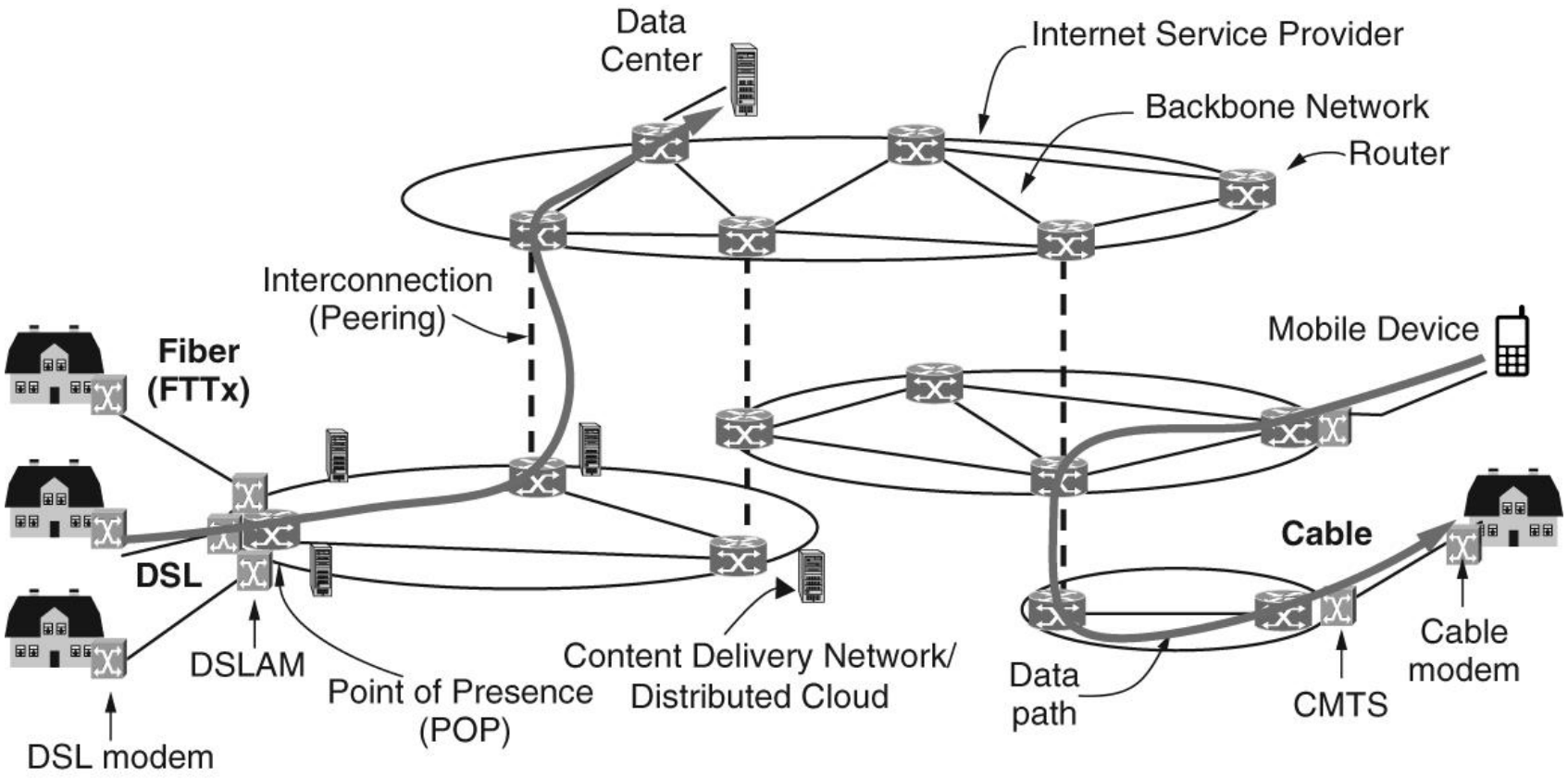
Example networks: The Internet: NSFNET

- NSFNET grew
  - 56kbps
    - NSFNET was overloaded from the word go.
  - 448kbps
    - Soon overwhelmed.
  - 1.5Mbps
  - 45Mbps (ANSNET, Advanced Networks and Services)
  - NSFNET → HEAVEN → many different commercial network operators

The Internet: Usage

- On January 1, 1983, the TCP/IP became the only official protocol.
- Up until the early 1990s, the applications: email, news, remote login file transfer.
- WWW and Internet.
  - **Tim Berners-Lee (Turing Award 2016)**
  - ***Anything Could Be Linked to Anything***
  - URI: Universal Resource Identifiers
  - HTTP: Hypertext Transfer Protocol
  - HTML: Hypertext Markup Language

Example networks: The Internet: The architecture



Wireless Networks (WiFi) (1 of 6)

- IEEE created a wireless LAN standard
  - Wireless LAN standard was dubbed 802.11
  - Common slang name for it is WiFi
  - 802.11 systems operate in unlicensed bands
  - Example: ISM (Industrial, Scientific, and Medical) bands defined by ITU-R
  - 802.11 radios compete with cordless phones, garage door openers, and microwave ovens
- 802.11 network modes: Ad hoc and access point (AP)
- Multipath fading causes received signals to fluctuate greatly

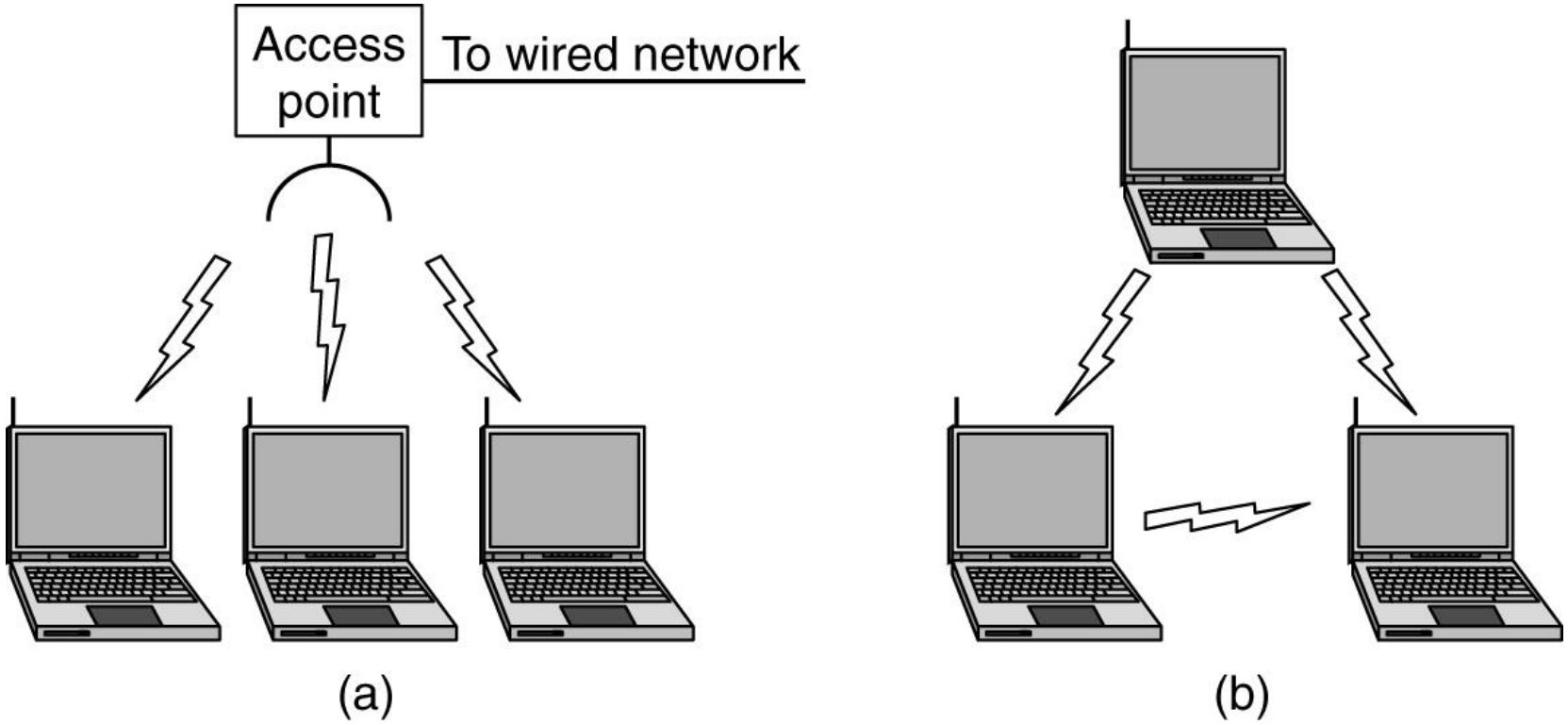
Wireless Networks (WiFi) (2 of 6)

- Path diversity overcomes variable wireless conditions
- Versions of 802.11
  - Original 802.11 ran at either 1 Mbps or 2 Mbps
  - 802.11b used spread spectrum for rates up to 11 Mbps
  - 802.11a/g rates were boosted to 54 mbps using OFDM (Orthogonal Frequency Division Multiplexing) modulation
  - 802.11ac can run at 3.5 Gbps
  - 802.11ad can run at 7 Gbps (only indoors within a single room)
- CSMA (Carrier Sense Multiple Access) scheme
  - Handles transmission collision

Wireless Networks (WiFi) (3 of 6)

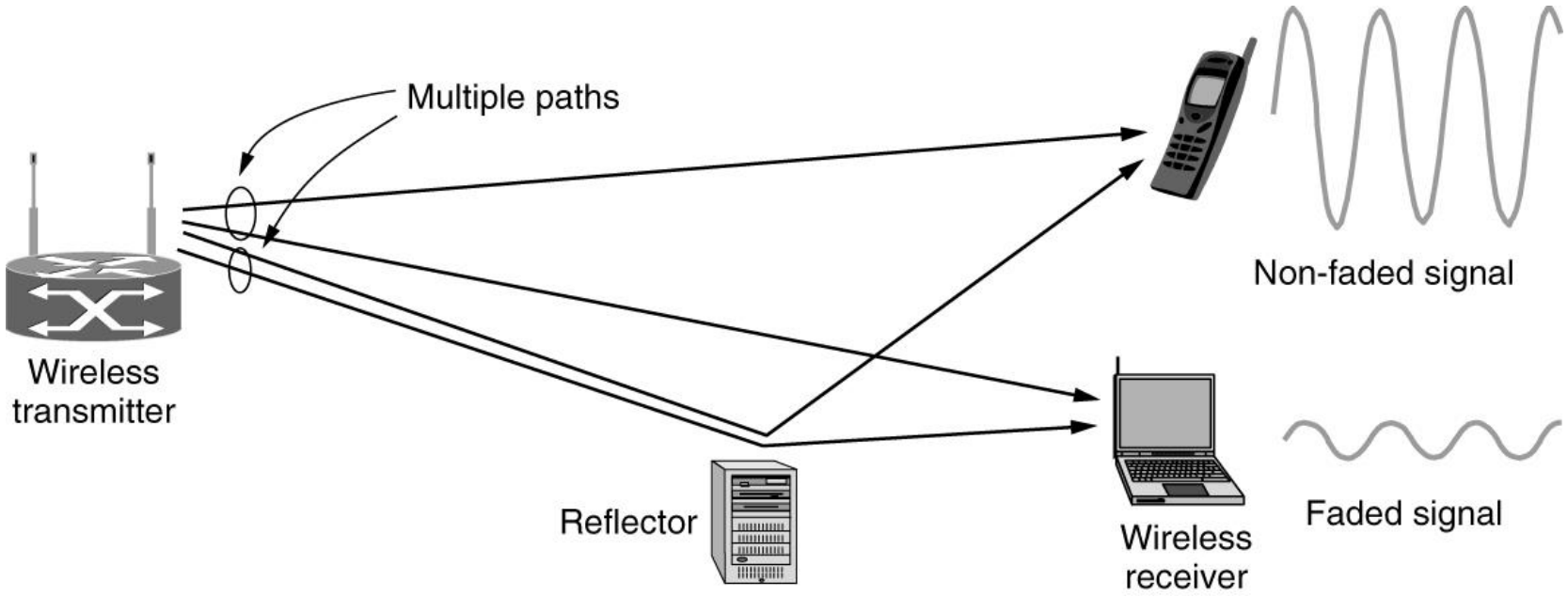
- 802.11 mobility
  - Of limited value compared to mobility in mobile phone networks
- 802.11 security
  - WEP (Wired Equivalent Privacy)
  - WEP replaced by WiFi Protected Access (initially called WPA)
  - WiFi Protected Access (WPA) replaced by WPA2 and 802.1X

Wireless Networks (WiFi) (4 of 6)



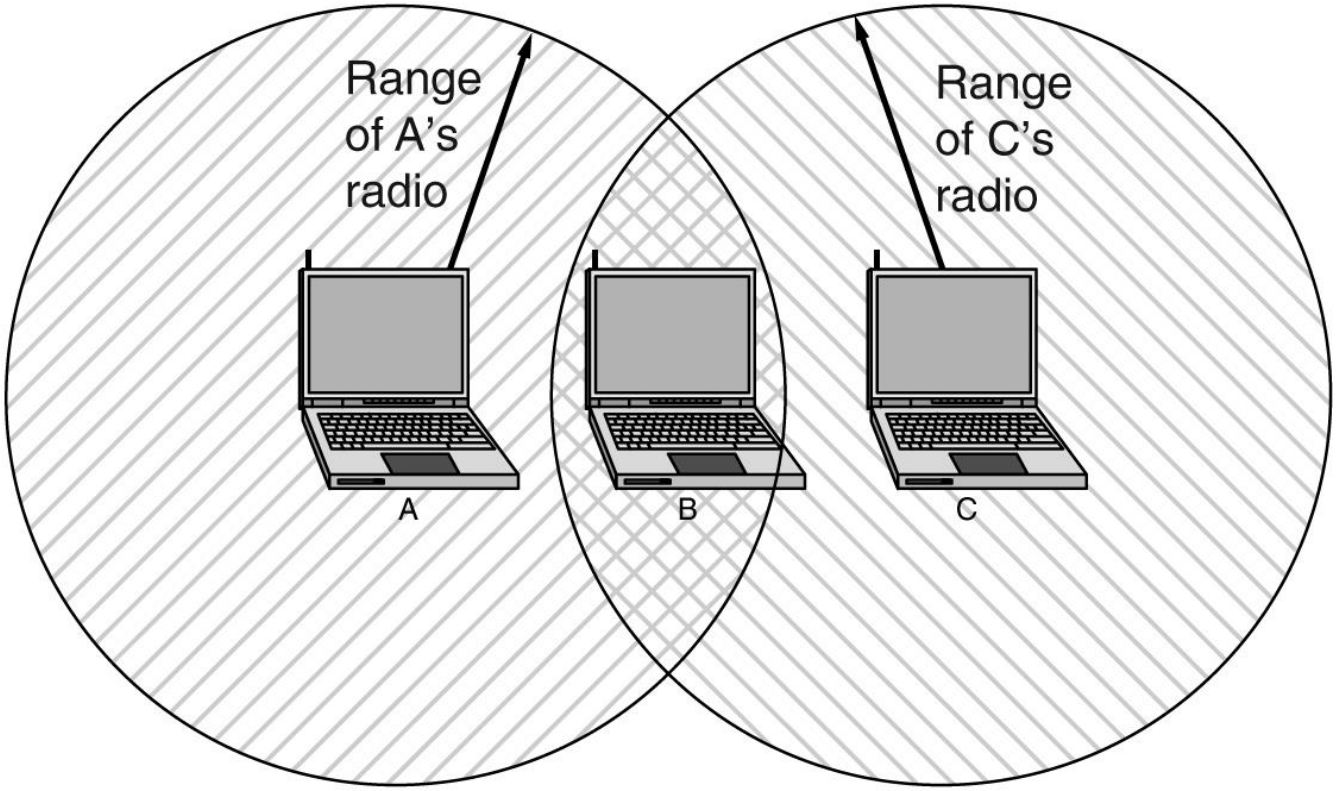
Access points connect to the wired network, and all communication between clients goes through the access point. In an ad hoc network, clients that are in radio range talk directly without an access point.

Wireless Networks (WiFi) (5 of 6)



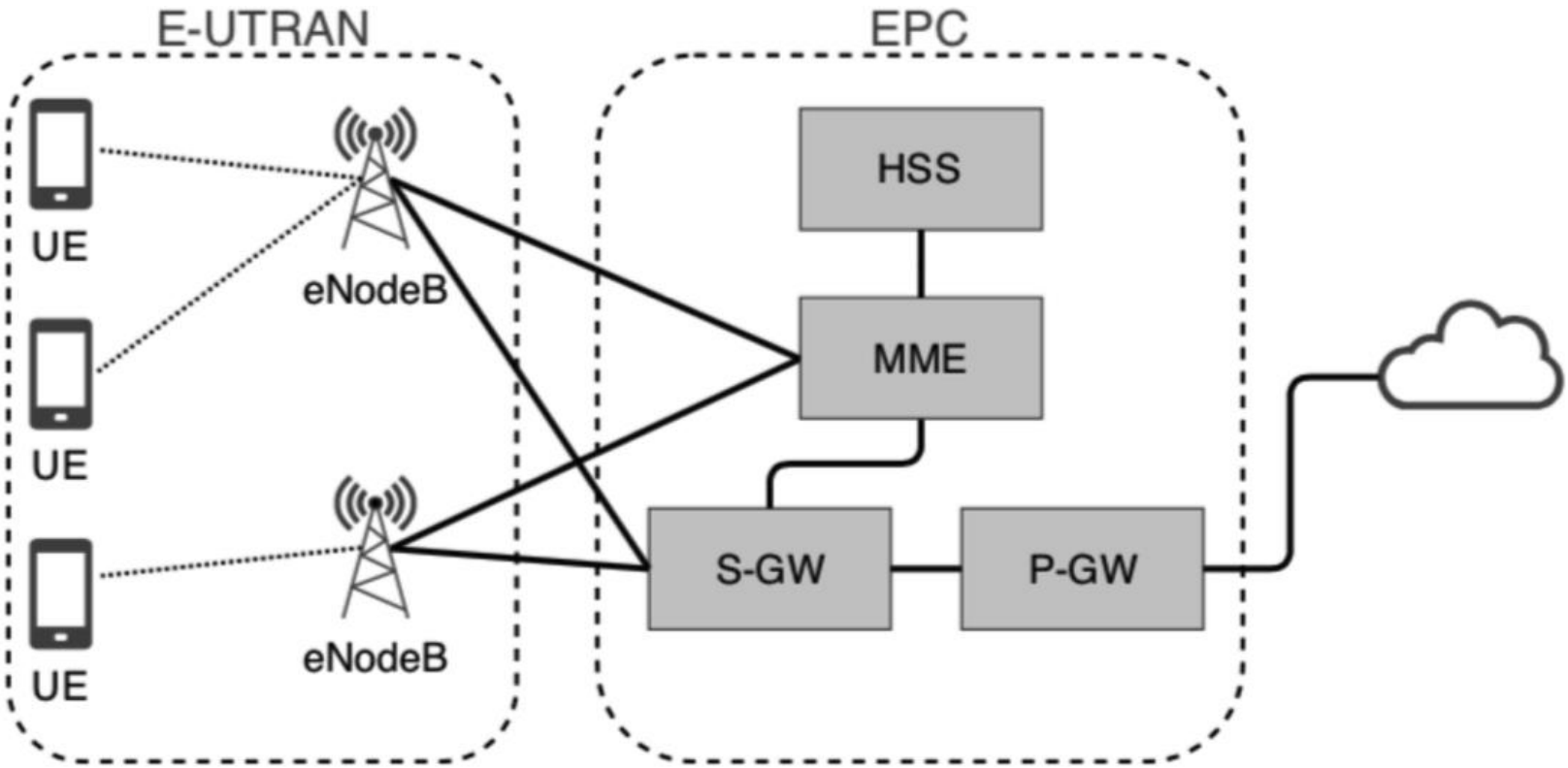
At the frequencies used for 802.11, radio signals can be reflected off solid objects so that multiple echoes of a transmission may reach a receiver along different paths. The echoes can cancel or reinforce each other, causing the received signal to fluctuate greatly – a phenomenon known as multipath fading.

Wireless Networks (WiFi) (6 of 6)



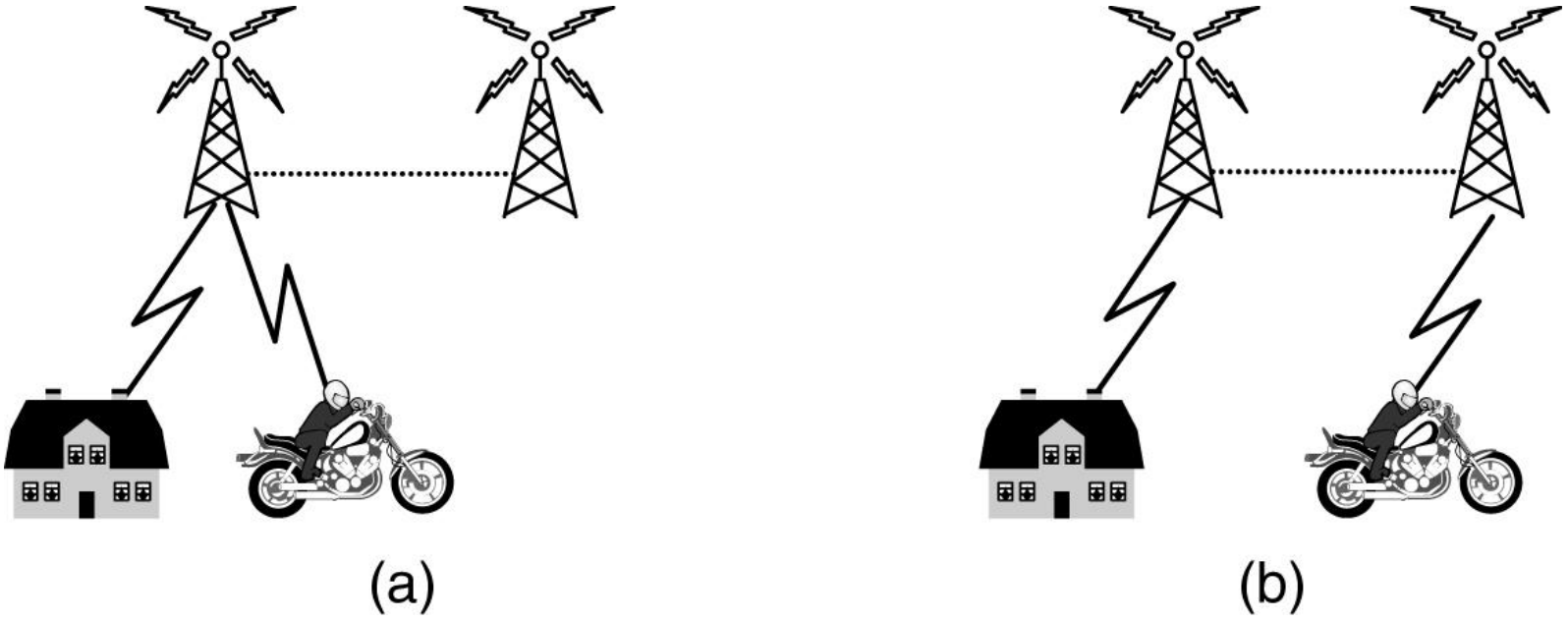
The range of a single radio may not cover the entire system.

Mobile Networks (1 of 6)



The architecture of the mobile phone network has several parts.

Mobile Networks (2 of 6)



When a user moves out of the range of one cellular base station and into the range of another one, the flow of data must be re-routed from the old to the new cell base station.

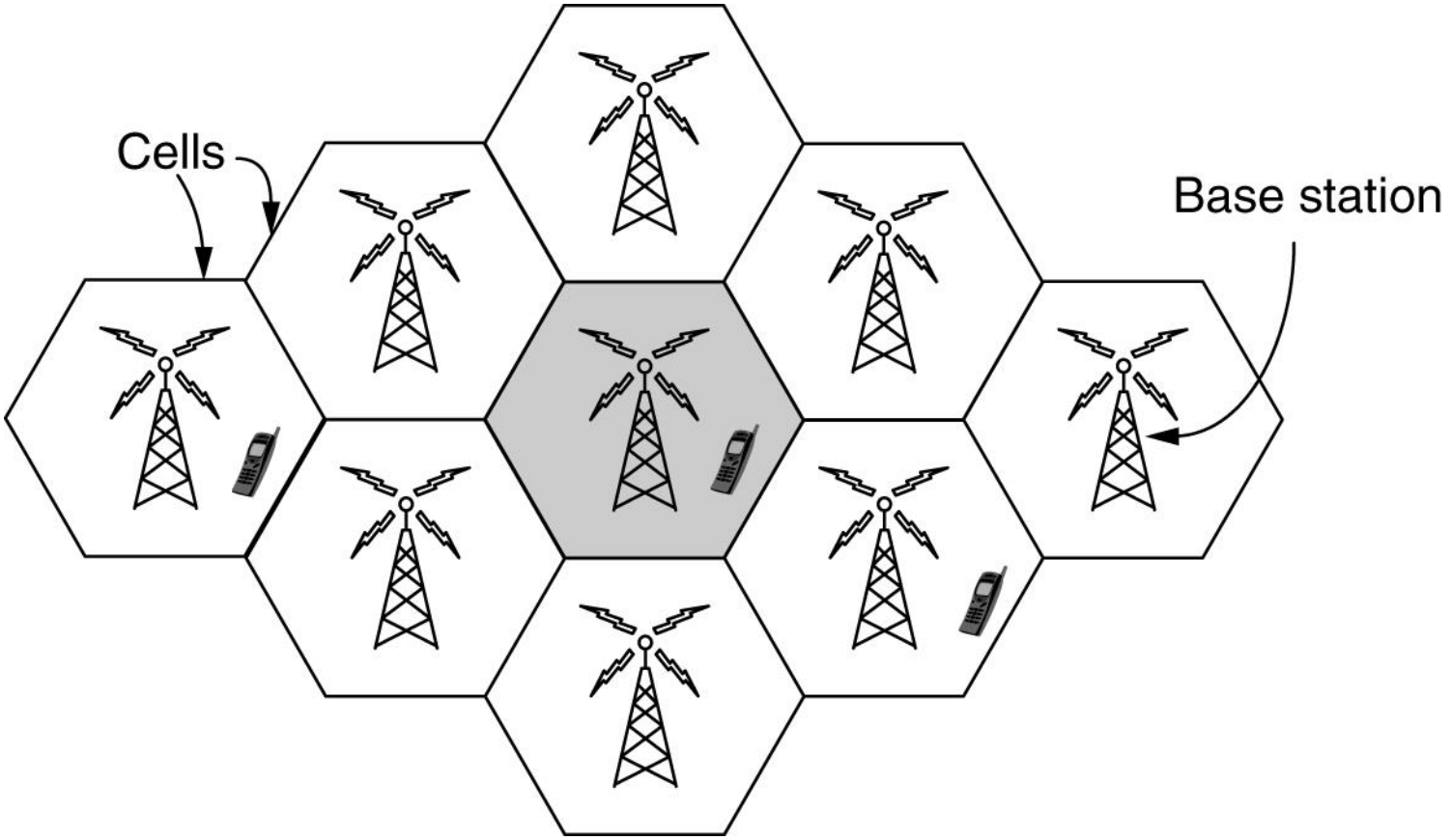
Mobile Networks (3 of 6)

- Packet switching comes from the Internet community
  - Connectionless networks
  - Every packet is routed independently
  - If some routers go down during a session, no harm will be done as long as the system can dynamically reconfigure itself
- Circuit switching comes from telephone companies
  - Connection-oriented networks
  - Caller must dial the called party's number and wait for a connection before talking or sending data
  - Route maintained until call is terminated
  - Can support quality of service more easily

Mobile Networks (4 of 6)

- First-generation mobile phone systems
  - Transmitted voice calls as continuously varying (analog) signals
  - AMPS (Advanced Mobile Phone System)
- Second-generation (2G) mobile phone systems
  - Transmitted voice calls in digital form to increase capacity, improve security, and offer text messaging
  - GSM (Global System for Mobile communications)
- Third generation (3G) offer digital voice and broadband digital data services
- Spectrum scarcity led to today's cellular network design

Mobile Networks (5 of 6)



To manage the radio interference between users, the coverage area is divided into cells.

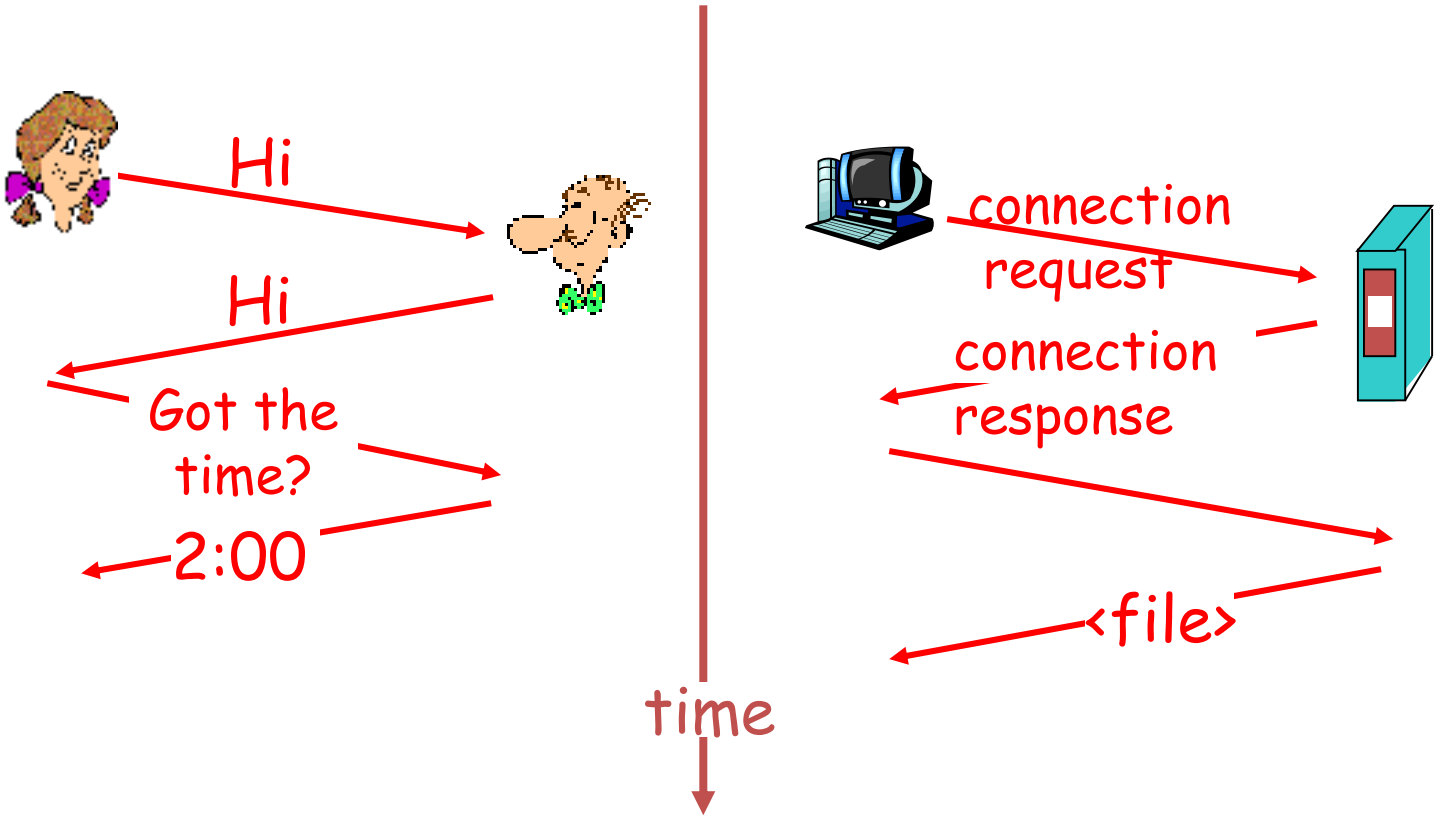
Mobile Networks (6 of 6)

- 4G
  - Later 4G known as LTE (Long Term Evolution) technology
  - Offers faster speeds
  - Emerged in the late 2000s
  - Quickly became the predominant mode of mobile Internet access in the late 2000s
  - Outpacing competitors like 802.16 (WiMiMax)
- 5G technologies are promising faster speeds
  - Up to 10 Gbps
  - Large-scale deployment in the early 2020s
- Main distinction: frequency spectrum they rely on

NETWORK PROTOCOLS

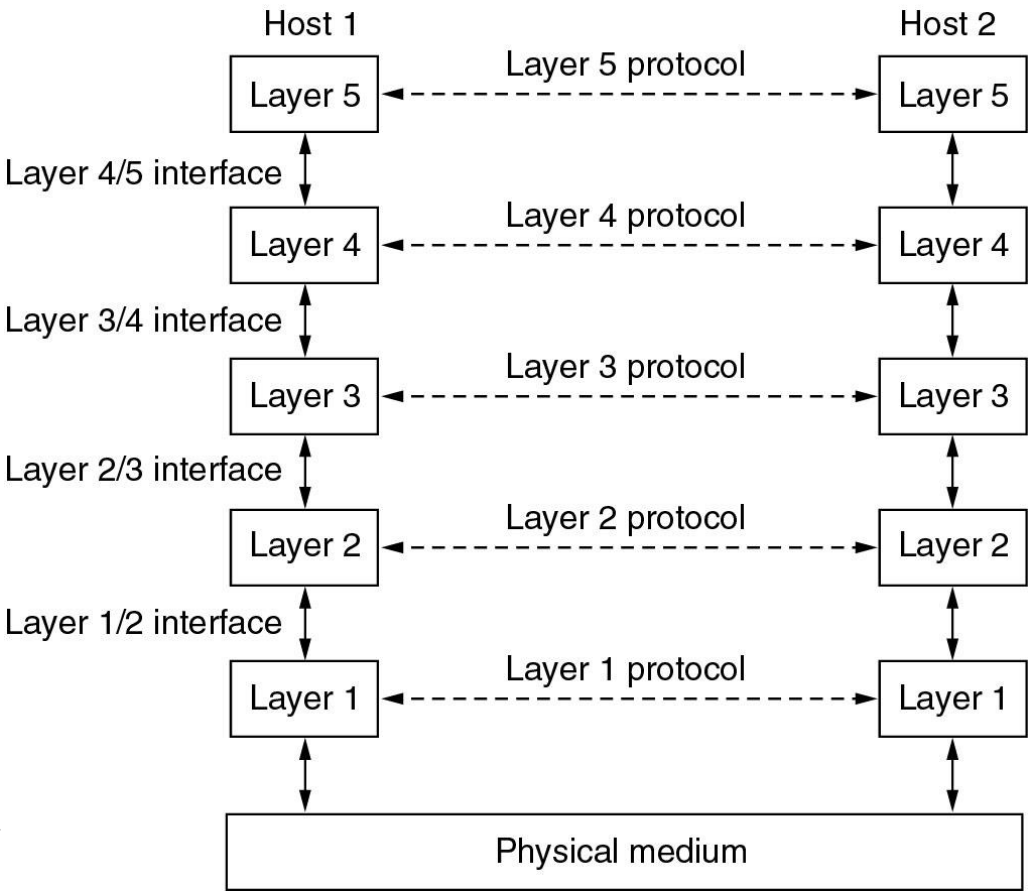
- Protocol Hierarchies
- Design Issues for the Layers
- Connection-Oriented and Connectionless Services
- Service Primitives
- The Relationship of Services to Protocols

Human protocol & network protocol



Network Software: Protocol hierarchies (协议层次结构)

- Layers, protocols, and interfaces.
  - The number of layers
  - The name of each layer
  - The function of each layer
  - The content of each layer



Network Software: Protocol hierarchies

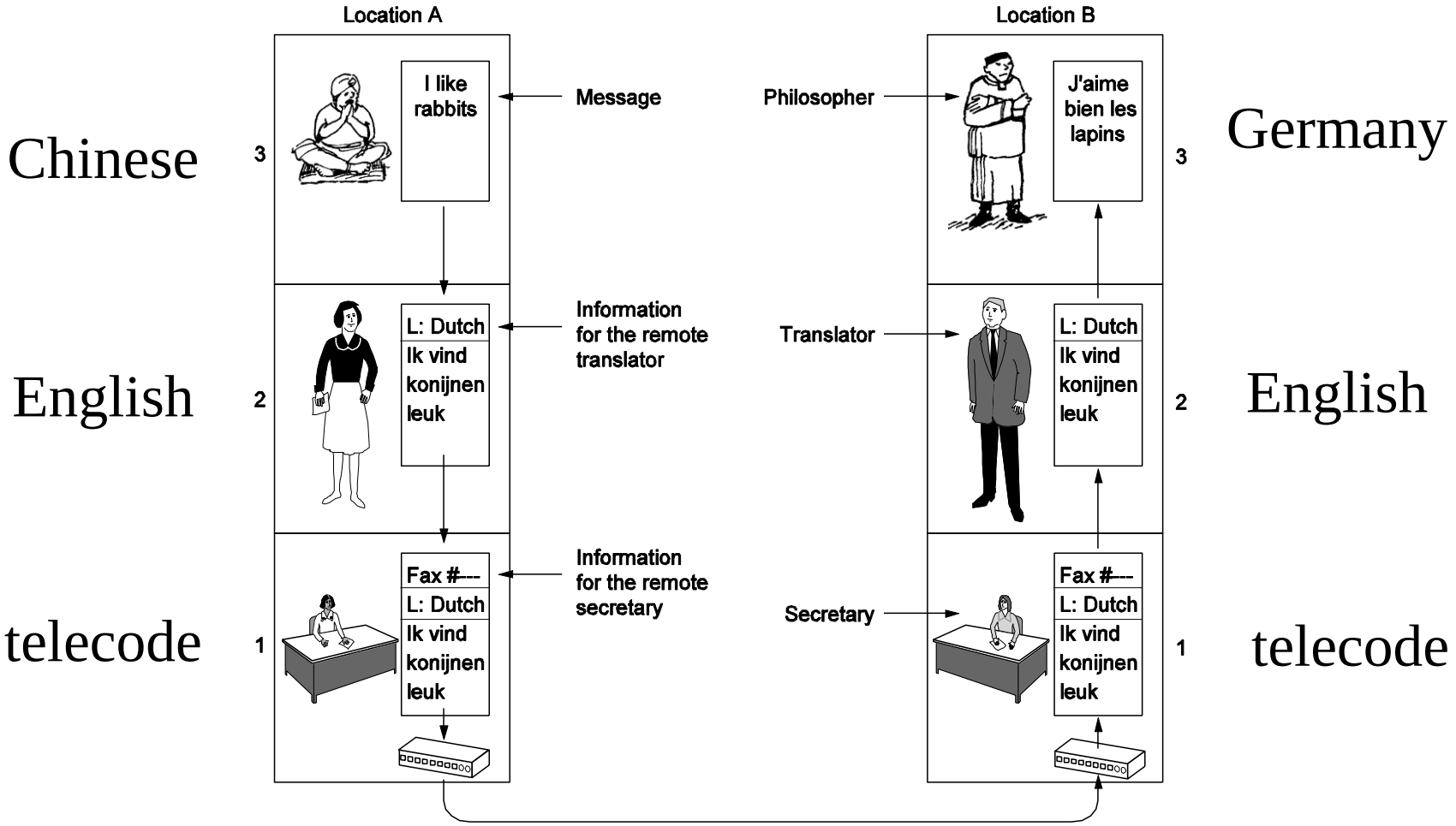
- A **protocol (协议)** is an agreement between the communicating parties on how communication is to proceed.
- The **peers** (对等实体) are the entities comprising the corresponding layers on different machines. The peers may be OS kernel, processes, hardware devices, or even human beings. It is the peers that communicate by using the protocol.
- Communication: actual and virtual.
- Service interfaces:
  - The interface defines which primitive operations and services the lower layer makes available to the upper one.
  - It is common that different hosts use different implementations.

Network Software: Protocol hierarchies

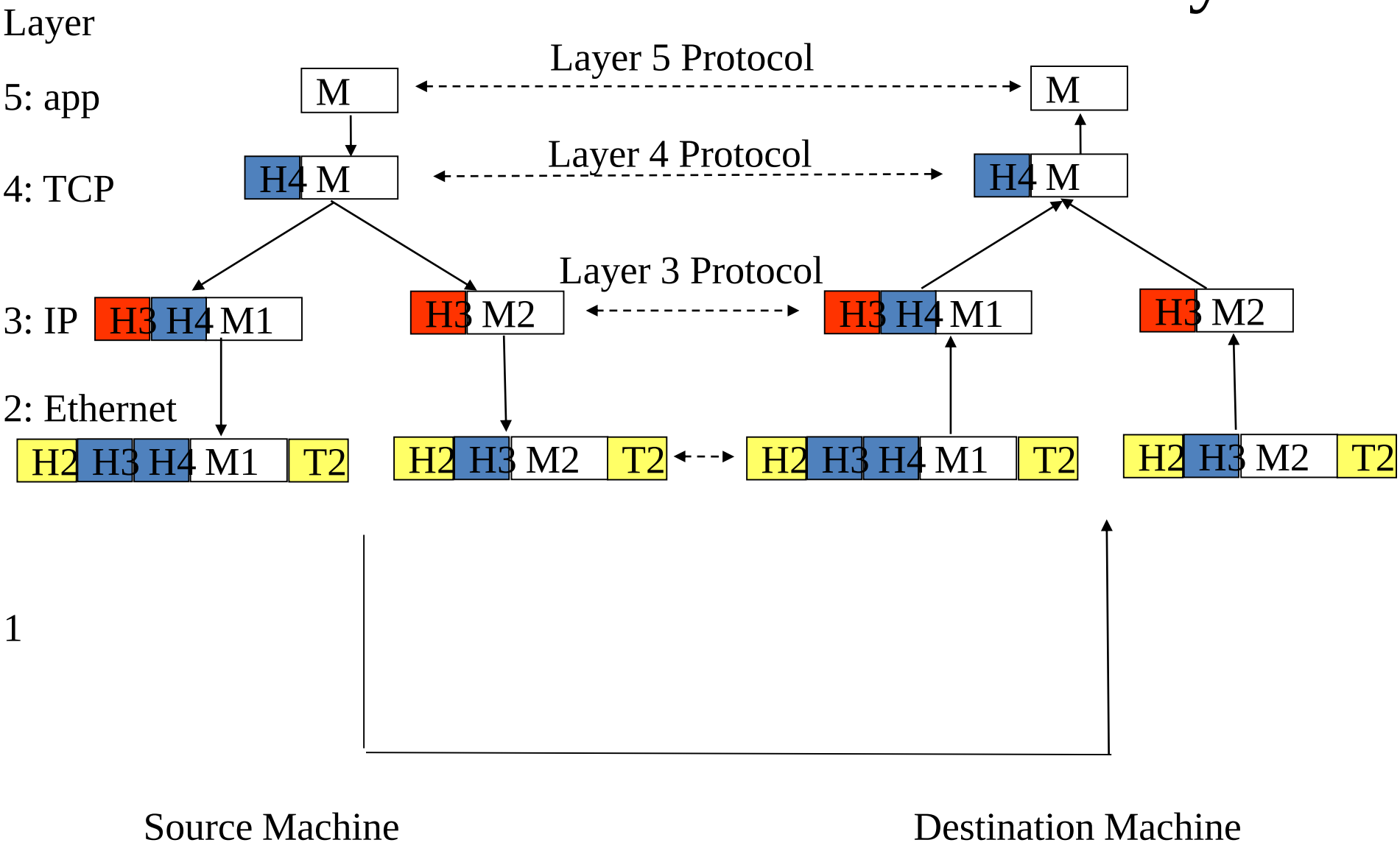
- A set of layers and protocols is called **a network architecture (网络体系结构).**
- A list of protocols used by a certain system, one protocol per layer, is called **a protocol stack**.
- The subjects of network architectures, protocol stack, and the protocol themselves are the principal topics of computer networks.

Network Software: Protocol hierarchies

The philosopher-translator-secretary architecture.



Virtual Communication in Peer Layer



Network Software: Layer design issues

- Addressing
- Channel control
  - simplex/duplex,
  - data channel/control channel
- Error control: Detection / correction
- Flow control: not to drown the poor receiver
- Disassembling / reassembling
- Multiplexing / demultiplexing
- Routing

Network Software: Service issues

- Two main types:
  - Connection-oriented service (面向连接的服务)
  - Connectionless service (无连接的服务)
- QoS (Quality of service) （服务质量）

	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

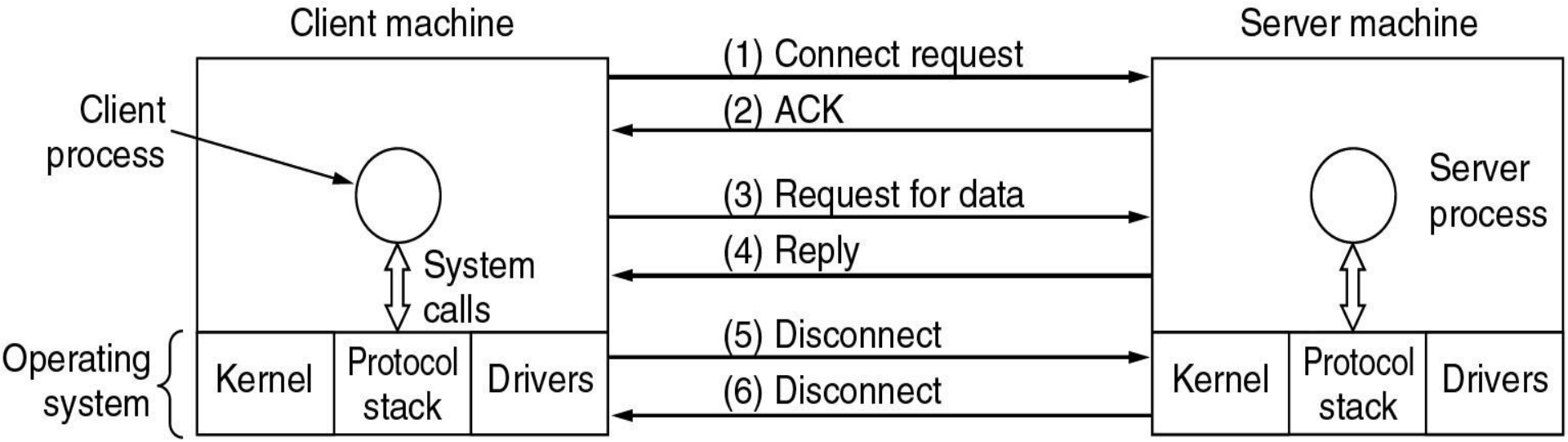
Network Software: Service primitives

Five service primitives for implementing a simple connection-oriented service.

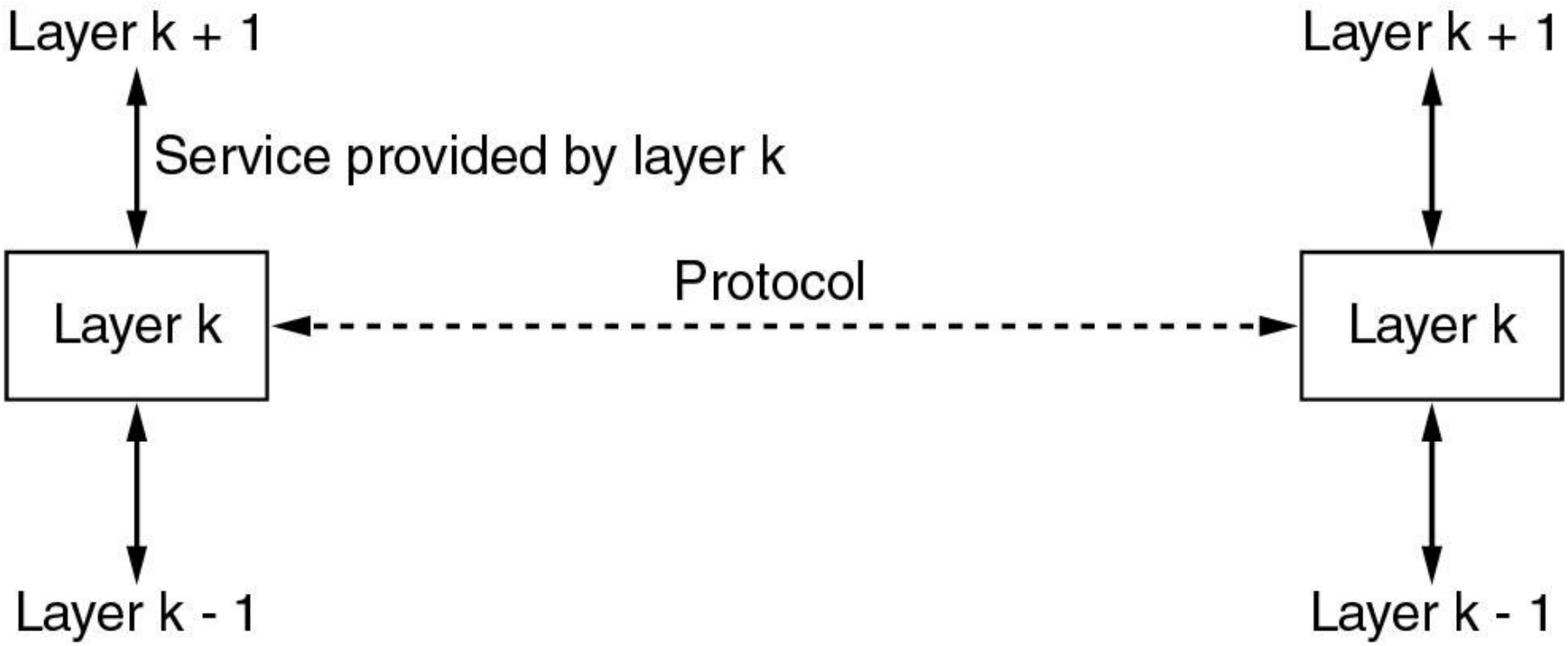
Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

Network Software: Service primitives

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



Network Software: Services / protocols



Network Software: Services / protocols

- **A service** is a set of primitives (operations) that a layer provides to the layer above it.

- **A 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.
  Ref: A protocol is an agreement between the communicating parties on how communication is to proceed

Network Software: Services / protocols

- An analogy with programming languages
  - A service is like an abstract data type or an object in an object-oriented language. It defines the operations that can be performed on an object but does not specify how these operations are implemented.
  - A protocol relates to the implementation of the service and as such is not visible to the user of the service.
- An analogy with programming
  - A service
  - An interface (C++, C#, Java)
  - A protocol

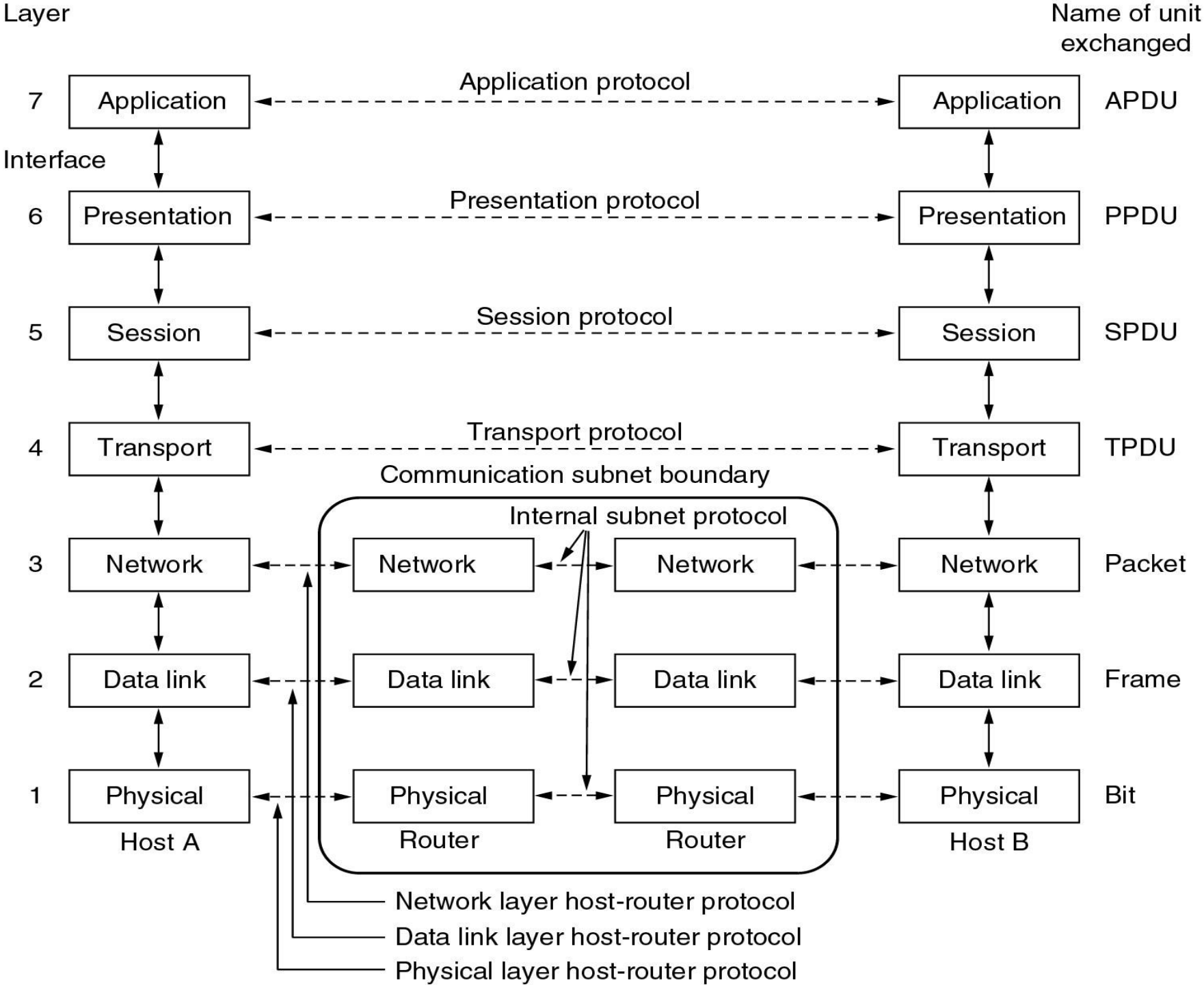
REFERENCE MODELS

- The OSI (Open Systems Interconnection) Reference Model
- The TCP/IP Reference Model
- A Comparison of OSI and TCP/IP
  - A Critique of the OSI Model and Protocols
  - A Critique of the TCP/IP Reference Model

Reference models: The OSI reference model

Design principles

1. A layer should be created where a ***different abstraction*** is needed.
2. Each layer should perform a ***well-defined function***.
3. The function of each layer should be chosen with an eye toward ***defining internationally standardized protocols***.
4. ***The layer boundaries*** should be chosen to minimize the information flow across the interfaces.
5. ***The number of layers*** should be
   - large enough that distinct functions need not be thrown together in the same layer out of necessity and
   - small enough that the architecture does not become unwieldy (笨拙).


Layer
Name of unit exchanged
7
Application
Application protocol
Application
APDU
Interface
6
Presentation
Presentation protocol
Presentation
PPDU
5
Session
Session protocol
Session
SPDU
4
Transport
Transport protocol
Transport
TPDU
Communication subnet boundary
Internal subnet protocol
3
Network
Network
Network
Network
Packet
2
Data link
Data link
Data link
Data link
Frame
1
Physical
Physical
Physical
Physical
Bit
Host A
Router
Router
Host B
Network layer host-router protocol
Data link layer host-router protocol
Physical layer host-router protocol

Reference models: The OSI reference model

Physical layer (物理层): Concerned with transmitting raw bits over a communication channel. The design issues deal with mechanical, electrical, and timing interfaces, and the physical transmission medium. Some typical questions:

- how many volts should be used to ***represent*** a 1 and how many for a 0, how many microseconds a bit lasts,
- whether transmission may proceed simultaneously in both ***directions***,
- how the initial ***connection*** is established and how it is torn down when both sides are finished,
- how many pins the network ***connector*** has and what each pin is used for.

Reference models: The OSI reference model

Data link layer (数据链路层): This layer is to take a raw transmission facility and transform it into a line that appears free of undetected transmission errors to the network layer. The design issues are:

- Framing: how to create and recognize ***frame boundaries***,
- Error detection, recovery: how to solve the problems caused by ***damaged, lost, and duplicate frames***,
- Flow control: how to keep a fast transmitter from ***drowning*** a slow receiver in data,
- MAC: how to control access to the ***shared channel*** (for broadcast networks).

Reference models: The OSI reference model

Network layer(网络层) : This layer is concerned with controlling the operation of the subnet. The design issues:

- how to ***route packets*** from source to destination:
- how to ***control congestion***.
- how to ***connect heterogeneous networks*** (different addressing, different maximum packet size, different protocols).

Reference models: The OSI reference model

Transport layer (传输层): To accept data from the session layer, split it up info smaller units if need be, pass these to the network layer, and ensure that the pieces all arrive correctly at the other end.

The design issues:

- Multiplexing: how to make the multiplexing transparent to the session layer,
- how to determine what types of service to provide the session layer,
- how to tell which messages belongs to which connection,
- how to regulate the flow of information.

Reference models: The OSI reference model

Session layer (会话层) : To allow users on different machines to establish sessions between them.

The design issues are:

- how to manage dialog control (对话控制),
- how to manage token,
- how to synchronize different sessions.

Reference models: The OSI reference model

Presentation layer (表示层): The presentation layer is concerned with the syntax and semantics of the information transmitted.

The design issues are:

- how to encode data in a standard agreed upon way,
- how to efficiently convert from the representation used inside the computer to the network standard representation and back.
- Big endian (most sig. appear first/smallest addr) vs. little endian (e.g. Intel x86)

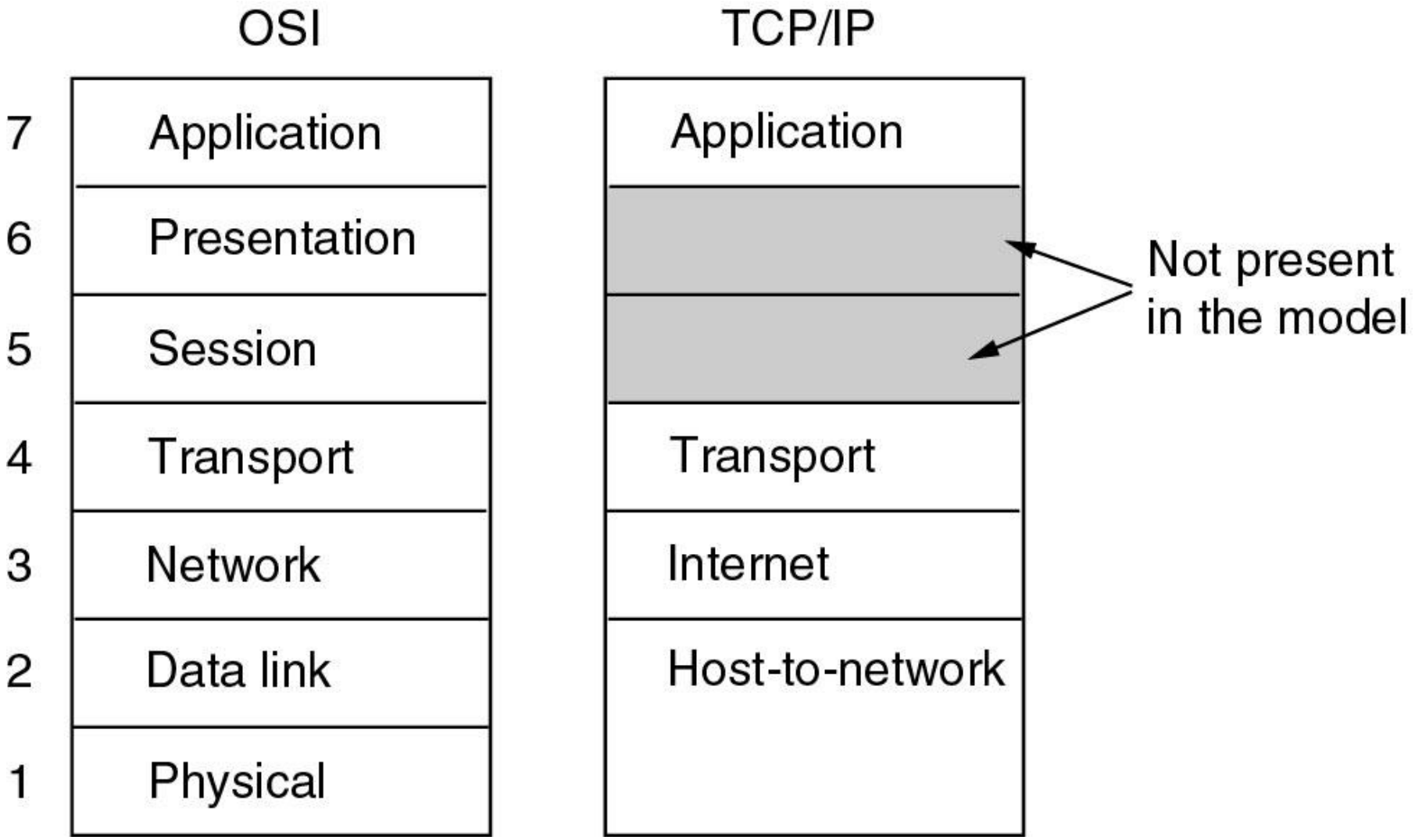
Reference models: The OSI reference model

Application layer(应用层): This layer contains a variety of protocols that are commonly needed.

Some application layer protocols:

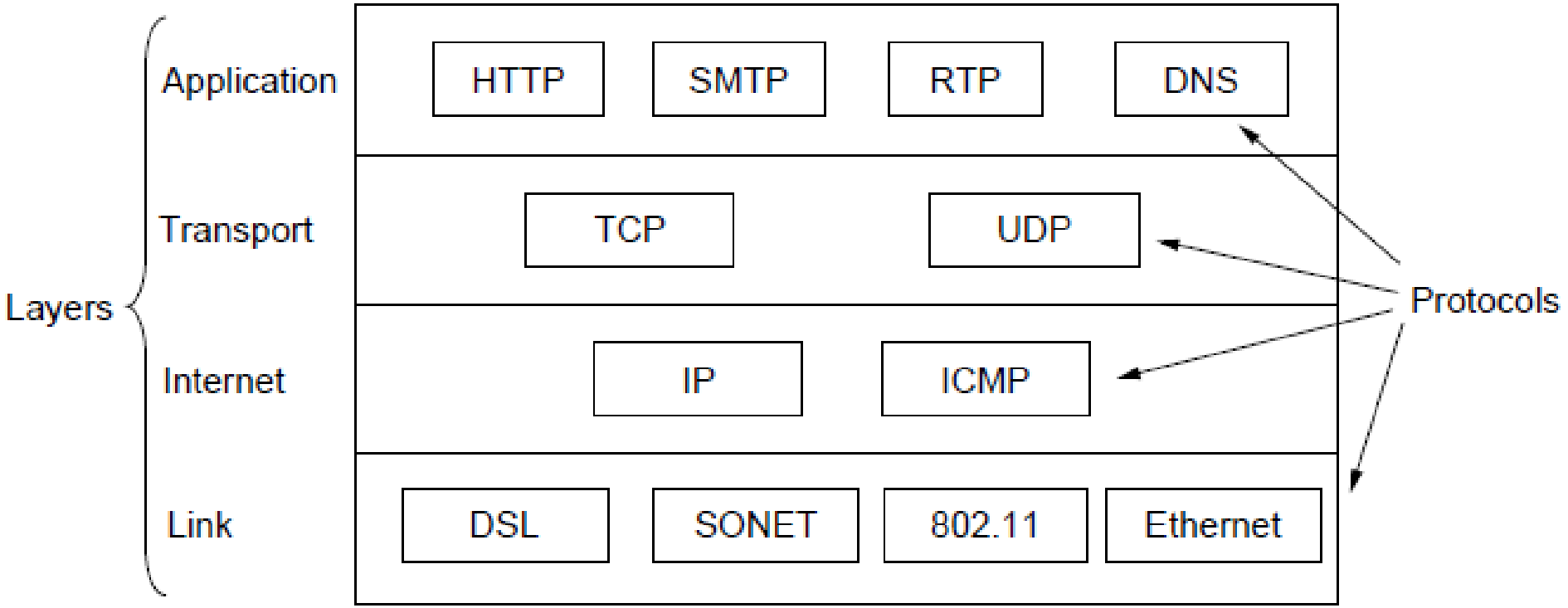
- http (WWW)
- telnet (network virtual terminal)
- ftp (file transfer protocol)
- DNS
- DHCP
- SMTP
- POP.

Reference models: The TCP/IP reference model



Reference models: The TCP/IP reference model

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



Reference models: The TCP/IP reference model

Host-to-network layer

- The host has to connect to the network using some protocol so it can send packets to it.
- The protocol is not defined and varies from host to host and network to network.
- Books and papers about the the TCP/IP model rarely discuss it.
- Possible connections
  - LAN → router → Internet
  - Dial-up → router → Internet
  - ADSL → router → Internet

Reference models: The TCP/IP reference model

Internet layer

- Its job is to permit hosts to inject packets into any network and have them travel independently to the destination (potentially on a different network).
- The internet layer defines an official packet format and protocol called IP (Internet Protocol).
- Some issues
  - Packet routing
  - Avoiding congestion
  - QoS

Reference models: The TCP/IP reference model

Transport Layer

- It is designed to allow peer entities on the source and destination hosts to carry on a conversation.
- Two end-end transport protocols
  - TCP: a reliable connection-oriented protocol
  - UDP: an unreliable, connectionless protocol

Reference models: The TCP/IP reference model

Application layer

- It contains all the higher-level protocols
- Some examples
  - HTTP
  - FTP
  - TFTP
  - SMTP
  - POP
  - DNS
  - NNTP
  - DHCP

Reference models: Comparison

Similarities for the OSI and TCP/IP reference models

- Protocol stack
- Layer functionality
- End-end service provider vs. end-end service user

Differences for the OSI and TCP/IP reference models

- Services/interfaces/protocols
  - The OSI makes the distinction explicit
  - The TCP/IP model did not originally clearly distinguish them

Reference models: Comparison

Differences for the OSI and TCP/IP reference models

- Which comes first? (Models/protocols):
  - OSI model first while TCP protocol first.
- 7 layer / 4 layers; (inter)network, transport, application layers common; the rest different.
- Connection-oriented vs connectionless comm.
  - OSI: Connection-oriented and connectionless communication in network layer
    connection-oriented in transport layer
  - TCP: connectionless communication in network layer
    connection-oriented and connectionless communication in transport layer.

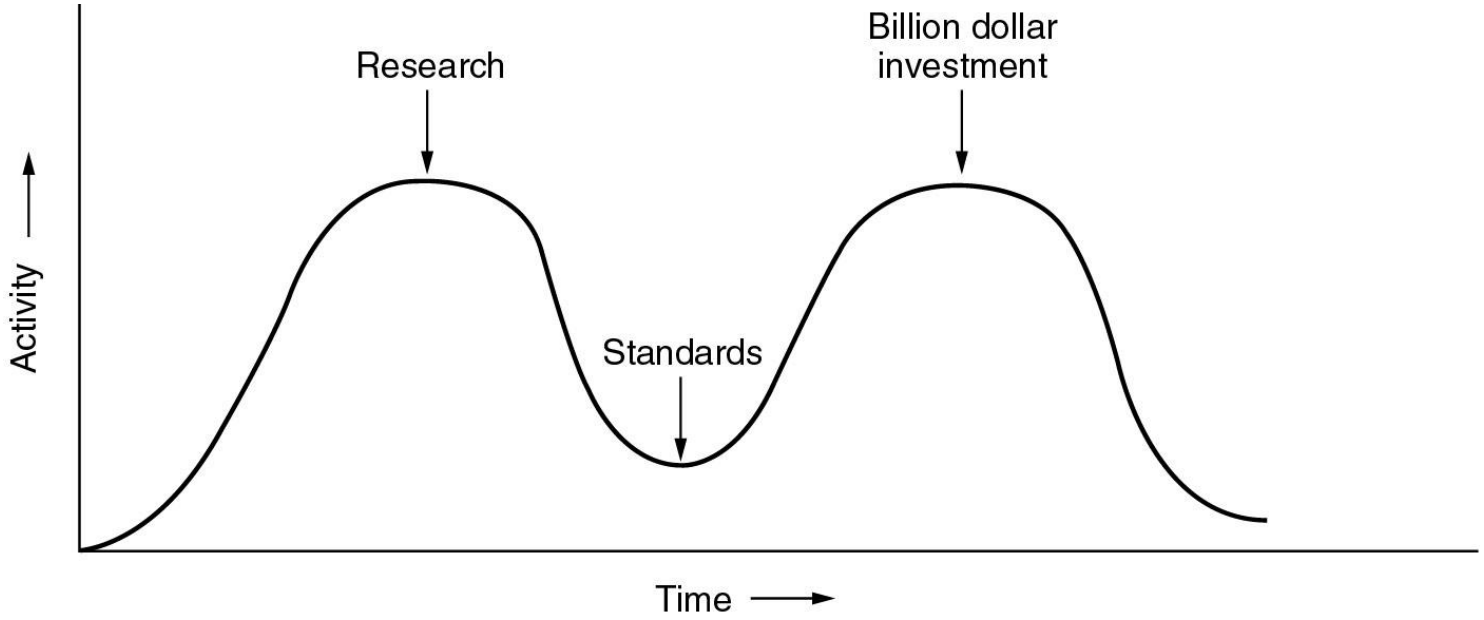
Reference models: A critique of the OSI model and protocols

Why OSI did not take over the world

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

Reference models: A critique of the OSI model and protocols

- Bad timing
  - The time at which a standard is established is absolutely critical to its success.
  - The first elephant represents a burst of research activity.
  - The second elephant represents the billion-dollar wave of investment hits.



Reference models: A critique of the OSI model and protocols

- Bad technology: Both the model and the protocols are flawed, extraordinarily complex, difficult to implement and inefficient in operation.
- Bad implementation: The initial implementations were huge, unwieldy, and slow.
- Bad politics: The OSI model was thought to be the creature of government bureaucrats.

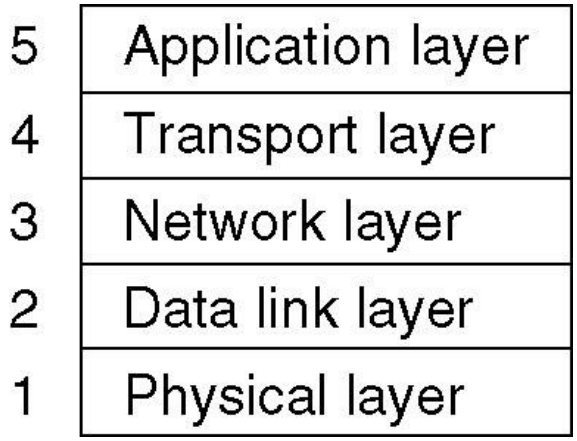
Reference models:
A critique of the TCP/IP model and protocols

Problems:

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

REFERENCE MODELS

The hybrid reference model



NETWORK STANDARDIZATION

- Why standardization?
  - Many network vendors and suppliers exist, each with its own ideas of how things should be done. Without coordination, there would be complete chaos, and users would get nothing done. The only way out is to agree on some network standards.
  - Standards increase the market for products adhering to the standard
- Standards fall into two categories:
  - De facto (Latin “from the fact”):
    - PC for small office and home / Unix for the CS
  - De jure (Latin “by law”)

Network standardization: ITU

- International Telecommunications Union
- Main sectors
  - Radio communications (ITU-R)
  - *Telecommunications Standardization (ITU-T)*
  - Development (ITU-D)

Network standardization: ISO & IEEE

- ISO (International Standards Organization, International Organization of Standardization)
- Members
  - national standards organizations of the 157 member countries. e.g. ANSI (美国)

- IEEE, Institute of Electrical and Electronic Engineers

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
802.12 ↓	Demand priority (Hewlett-Packard's AnyLAN)
802.13	Unlucky number. Nobody wanted it
802.14 ↓	Cable modems (defunct: an industry consortium got there first)
802.15 *	Personal area networks (Bluetooth)
802.16 *	Broadband wireless
802.17	Resilient packet ring

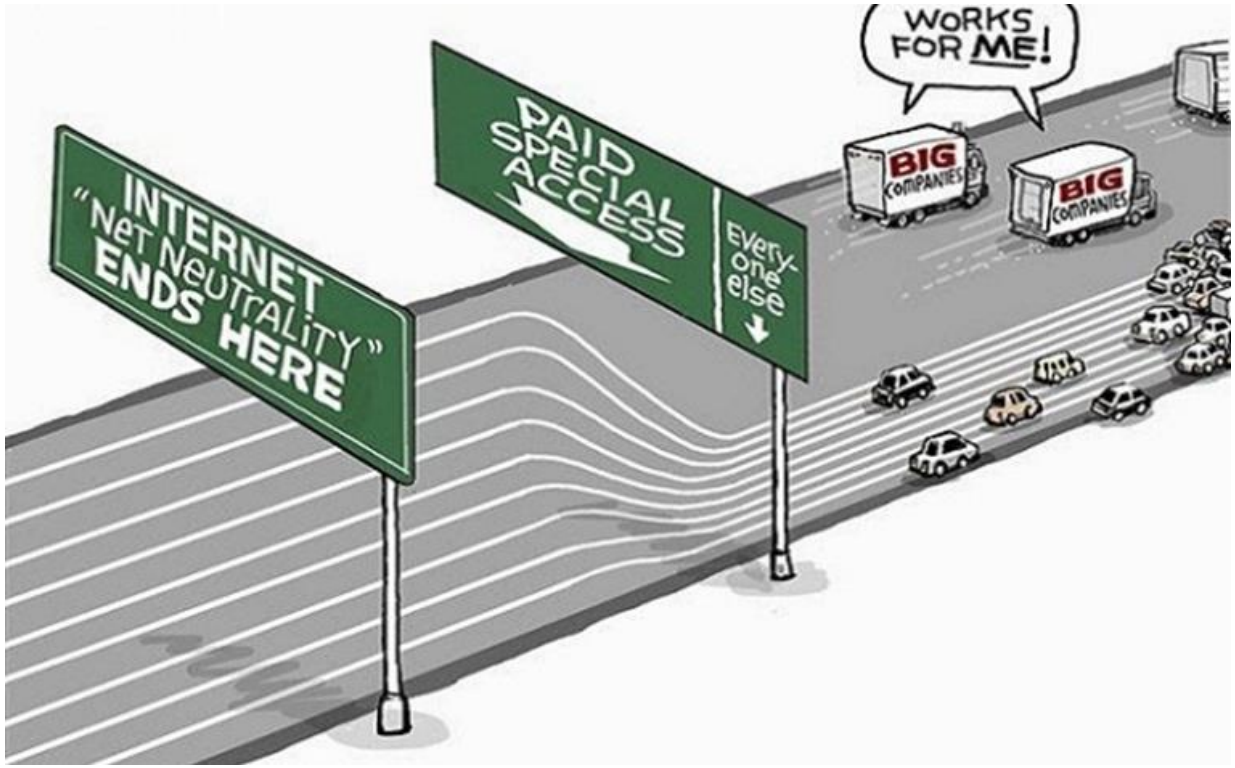
Network standardization: Internet

- In 1983, IAB (Internet Activities Board)
- Later, IAB(Internet Architecture Board)
- In 1989, IAB → IRTF + IETF
  - IRTF (Internet Research Task Force)
  - **IETF** (Internet Engineering Task Force)
    - Originated by DARPA for TCP/IP protocol development
    - **R**equest **f**or **C**omments (RFC)
    - e.g., www.ietf.org/rfc/rfc0793.txt = TCP

Social issues

- Contents on newsgroup or BBS
- Employee rights versus employer rights
- Government versus citizen's rights
- Profiling
- Anonymous messages
- Along with the good comes the bad. Life seems to be like that.
  - Junk email
  - Ill-informed, misleading, or downright wrong info.
  - Identity theft

Network Usage: Social issues



https://en.wikipedia.org/wiki/Net_Neutrality_(Last_Week_Tonight)

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

- 内存: 1kB = 2^10 bytes
- 网络: 1kB/s = 1000 bytes/second

Computer Networks

- All the abovementioned subjects deal with the essential of computing networking:
  - How to connect?
  - How to communicate?

- Textbook:
  - **[T]**《Computer Networks》 Tanenbaum and Wetherall 2011. 5th. Prentice Hal PTR.
  - **[J]**《Computer Networking: A Top-Down Approach》 James Kurose and Keith Ross, 6th edition.

Thanks for your attention!

Homework-1

1. Imagine that you have trained your St. Bernard, Bernie, to carry a box of three 8-mm tapes instead of a flask of brandy. (When your disk fills up, you consider that an emergency.) These tapes each contain 7 gigabytes. The dog can travel to your side, wherever you may be, at 18 km/hour. For what range of distances does Bernie have a higher data rate than a transmission line whose data rate (excluding overhead) is 150 Mbps? How does your answer change if (i) Bernie's speed is doubled; (ii) each tape capacity is doubled; (iii) the data rate of the transmission line is doubled.

2. What are two reasons for using layered protocols? What is one possible disadvantage of using layered protocols?

3. In some networks, the data link layer handles transmission errors by requesting that damaged frames be retransmitted. If the probability of a frame's being damaged is *p*, what is the mean number of transmissions required to send a frame? Assume that acknowledgements are never lost.

Homework-2

4. What is the main difference between TCP and UDP?

5. How long was a bit in the original 802.3 standard in meters? Use a transmission speed of 10 Mbps and assume the propagation speed in coax is 2/3 the speed of light in vacuum.

6. List one advantage and one disadvantage of having international standards for network protocols.

7. Which layers are common in the OSI model and TCP/IP model?