CSMC 417

Computer Networks

Prof. Ashok K Agrawala

General

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- TA – Andrew Pachulski
  - Office Hours –
- Class Meets – Tu Th 9:30 – 10:45 CSIC 2117

Prerequisite

- Required Background
  - must have 351 and 330 (412 or 430 would be helpful)

- Expectations
  - Understand the basics of Computer Architecture
  - Experience in implementing non-trivial systems-type projects

  - Should know
    - Processor
    - Memory
    - Kernel vs. user process
  - Familiar with basic probability

Expectations – After the course

- Understand the fundamentals of networking protocols, including protocol layering, basic medium access including wireless protocols, routing, addressing, congestion control
- Understand the principles behind the Internet protocols and some application layer protocols such as http, ftp, and DNS, and a few peer-to-peer systems/protocols such as Gnutella and Chord.
- Understand some of the limitations of the current Internet and its service model
- Understand the causes behind network congestion, and explain the basic methods for alleviating congestion
- Design, implement, and test substantial parts of network protocols

Announcements

- Required Work
  - will require about the same amount of effort as 412
    - 412 a (slightly) harder project to debug
    - 417 project is (by design) more ambiguous
- Required Texts
  - *Computer Networks* **5th Edition**, Tanenbaum and Wetherall, Prentice Hall 2011. ISBN 0-13-212695-8
  - *TCP/IP Sockets in C: A Practical Guide for Programmers* **2nd Edition** by Jeff Donahoo and KenCalvert, Morgan Kaufmann, 2009. ISBN 978-0123745408

Other Material

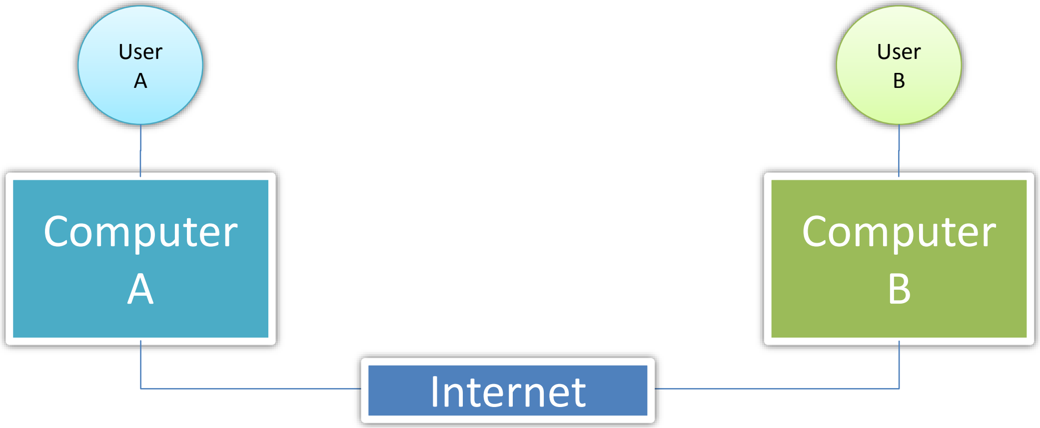
- Recommended Texts
  - *Computer Networking, 5e: A Top Down Approach Featuring the Internet* by Jim Kurose and Keith Ross, Addison-Wesley, (ISBN: 0-13-607967). The on-line version of this book is at http://www.awlonline.com/kurose-ross.
  - *Computer Networks: A Systems Approach* by Larry Peterson and Bruce Davie, MorganKaufman, 4rd Edition, 2007. ISBN 978-0123705488
  - *An Engineering Approach to Computer Networking*, by S. Keshav. Addison-Wesley,1997. ISBN 0-201-63442-2
  - *Computer Networking with Internet Protocols* by William Stallings, Prentice-Hall, 2004. ISBN 10: 0131410989
  - *TCP/IP Illustrated* volume 1 by W. Richard Stevens. Addison-Wesley. ISBN: 0-201- 63346-9.
- RFCs

Grading

- Final 30%
- In-Term Exam(s) 30%
- Programming Assignments 35%
- Class Participation 5%
  - Pop Quizzes

What is this course all about?

- Computer Networking
  - ???



Uses of Computer Networks

Computer networks are collections of autonomous computers, e.g., the Internet

They have many uses:

- Business Applications »
- Home Applications »
- Mobile Users »

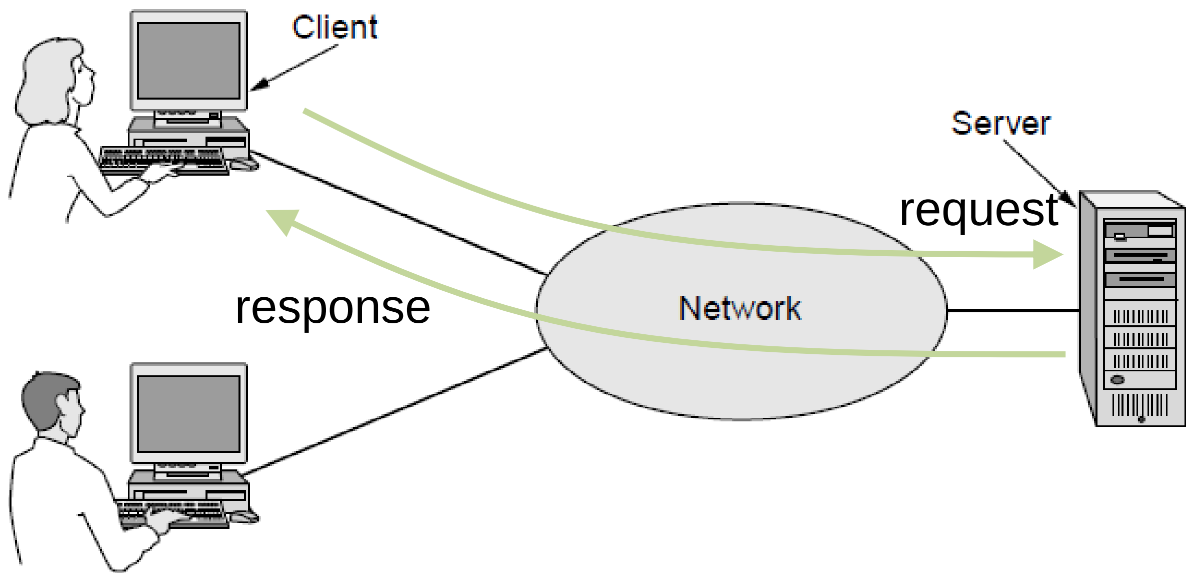
These uses raise:

- Social Issues »

This text covers networks for all of these uses

Business Applications

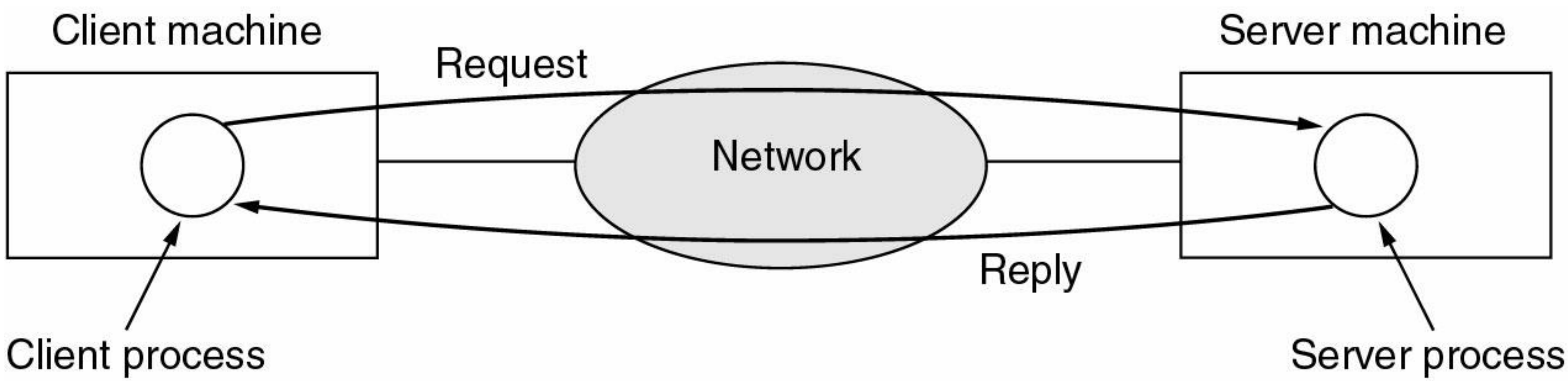
- Companies use networks and computers for resource sharing with the client-server model:



- Other popular uses are communication, e.g., email, VoIP, and e-commerce

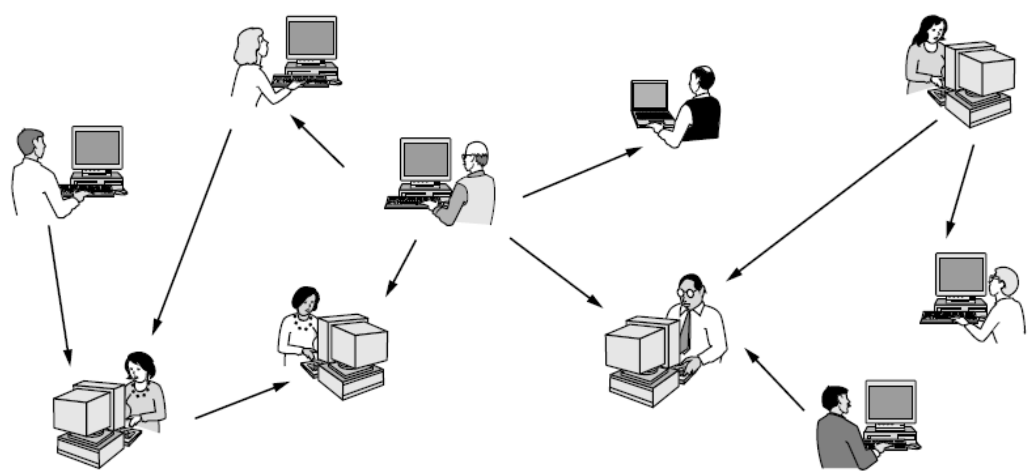
Business Applications of Networks (2)

- The client-server model involves requests and replies.



Home Applications

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



Home Network Applications (3)

- Some forms of e-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

Mobile Users

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

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

Social Issues

- Network neutrality – no network restrictions
- Content ownership, e.g., DMCA takedowns
- Anonymity and censorship
- Privacy, e.g., Web tracking and profiling
- Theft, e.g., botnets and phishing

Network Hardware

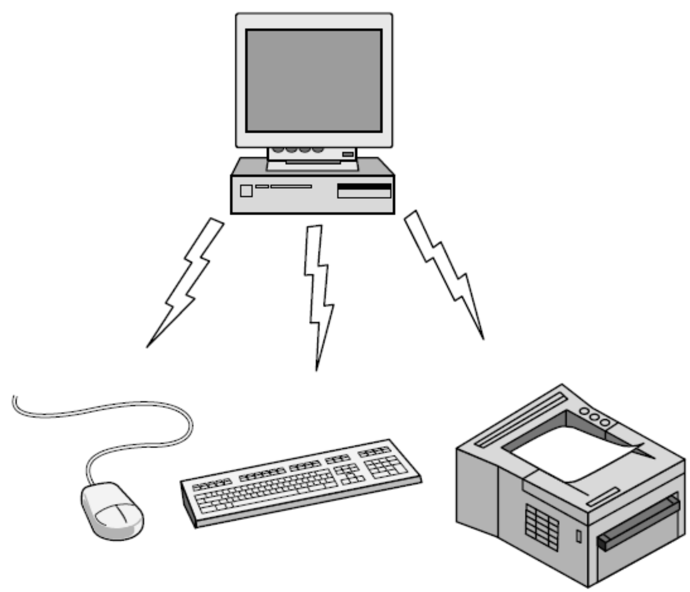
Networks can be classified by their scale:

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

Personal Area Network

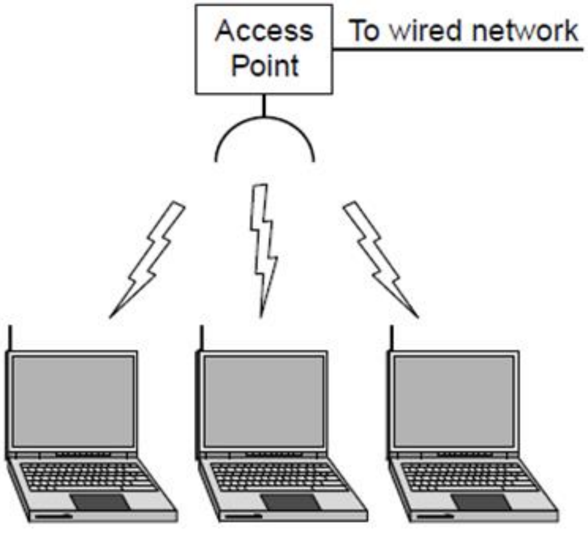
Connect devices over the range of a person

Example of a Bluetooth (wireless) PAN:

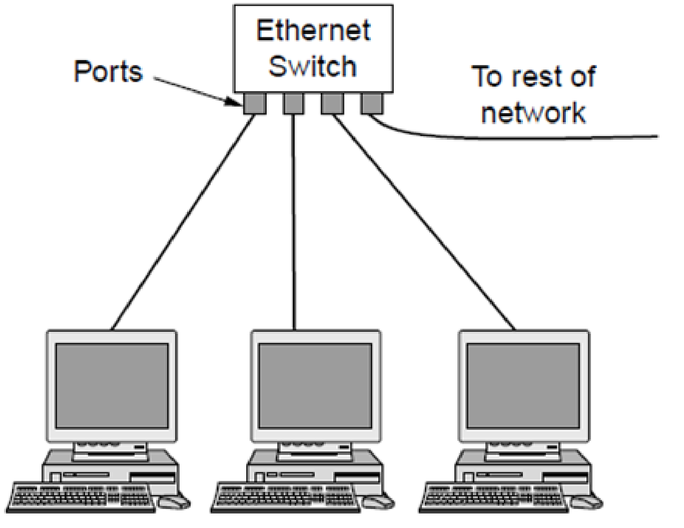


Local Area Networks

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

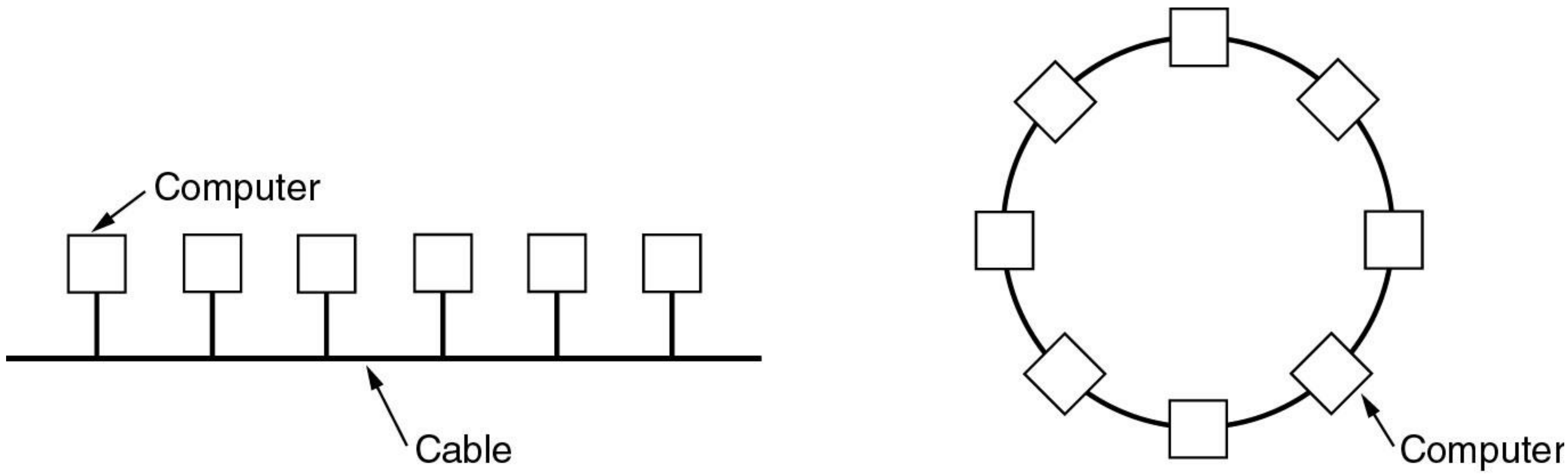


Wireless LAN with 802.11



Wired LAN with switched Ethernet

Local Area Networks



(a)

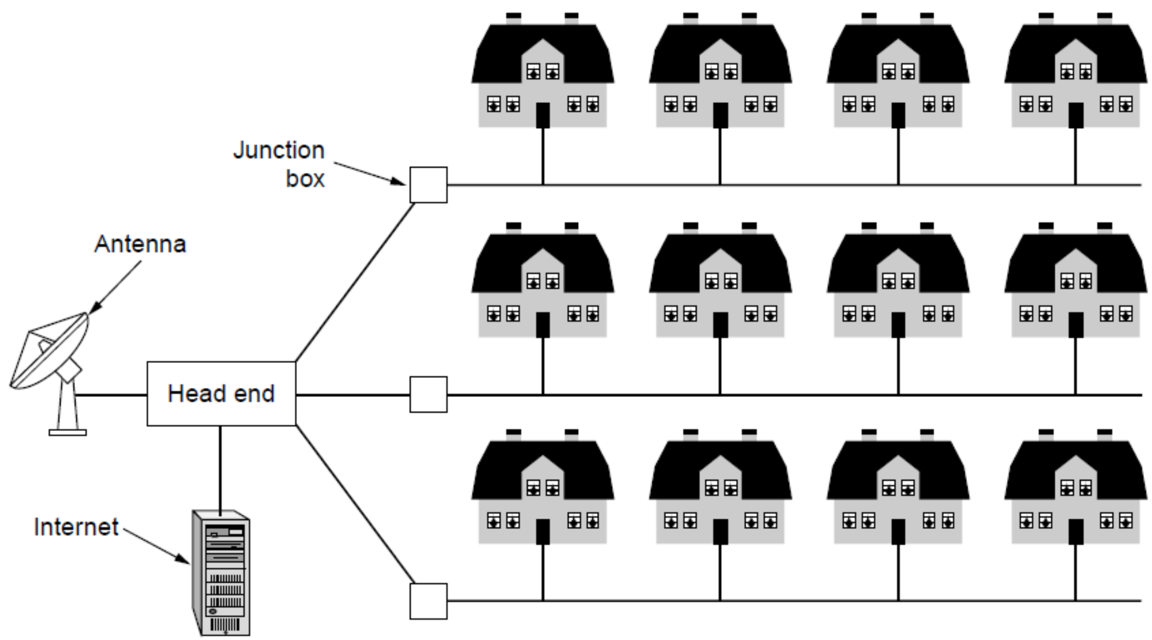
(b)

- Two broadcast networks
- (a) Bus
- (b) Ring

Metropolitan Area Networks

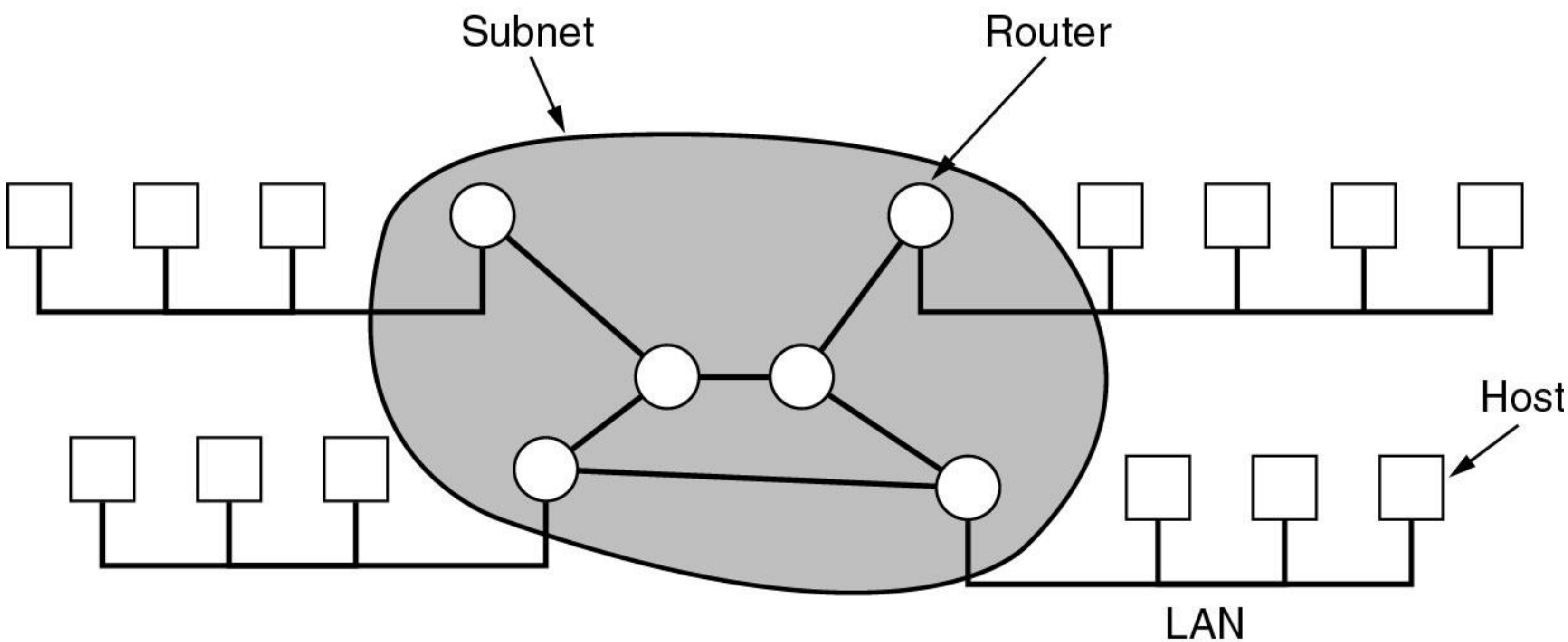
Connect devices over a metropolitan area

Example MAN based on cable TV:



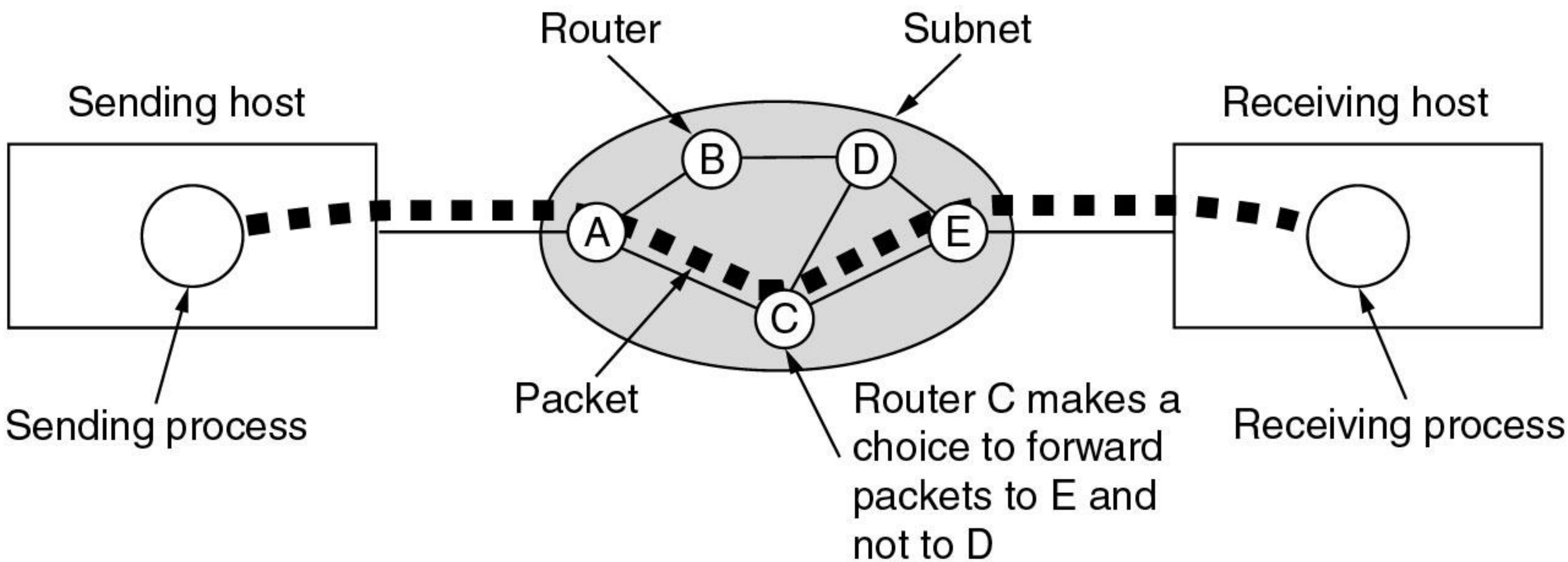
Wide Area Networks

- Relation between hosts on LANs and the subnet.



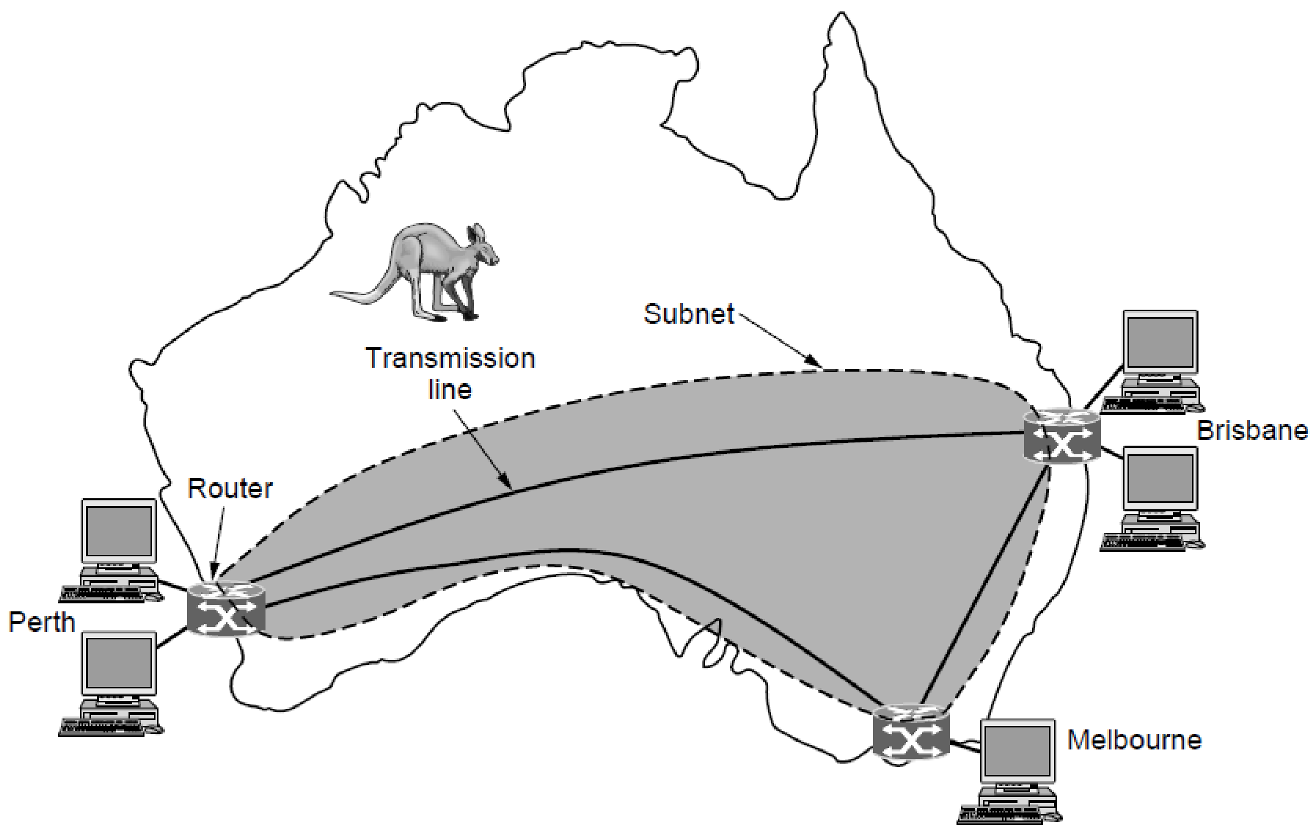
Wide Area Networks (2)

- A stream of packets from sender to receiver.



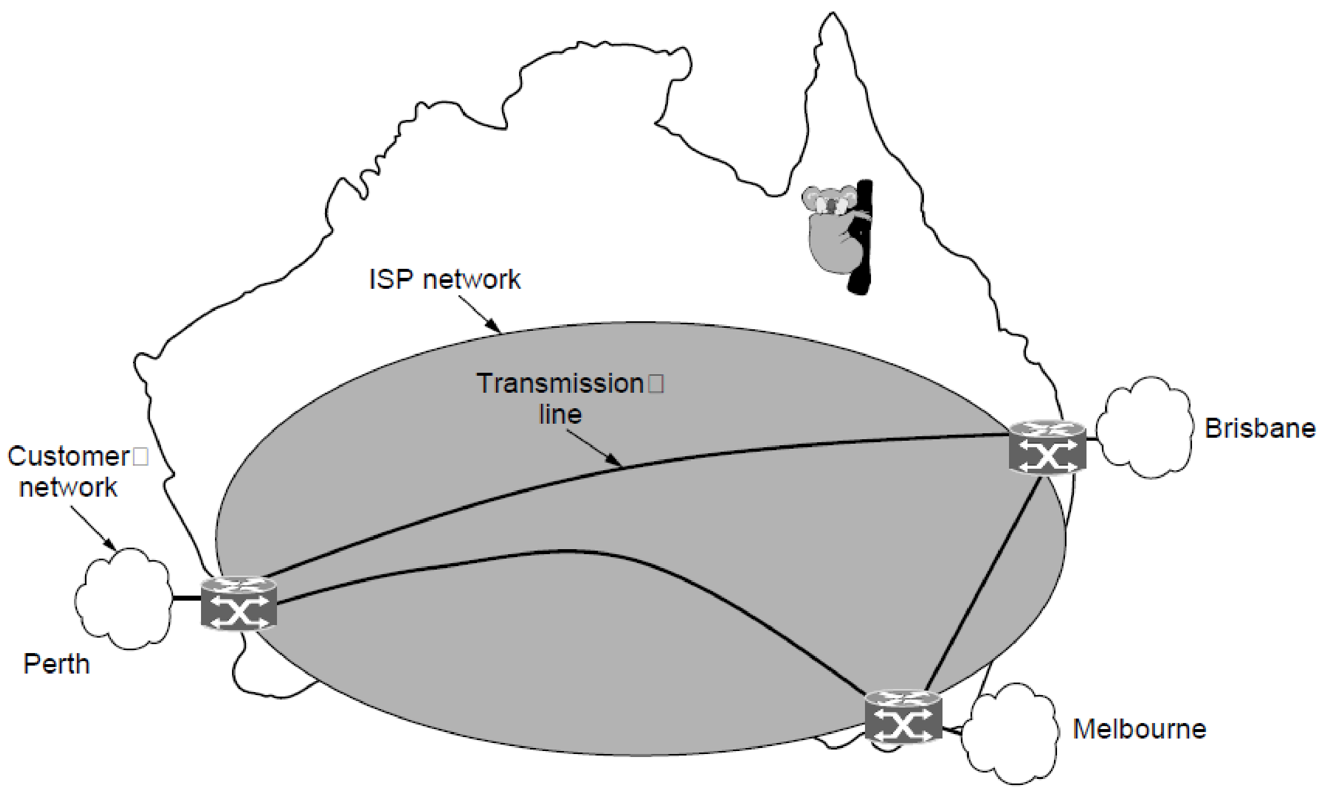
Wide Area Networks (1)

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



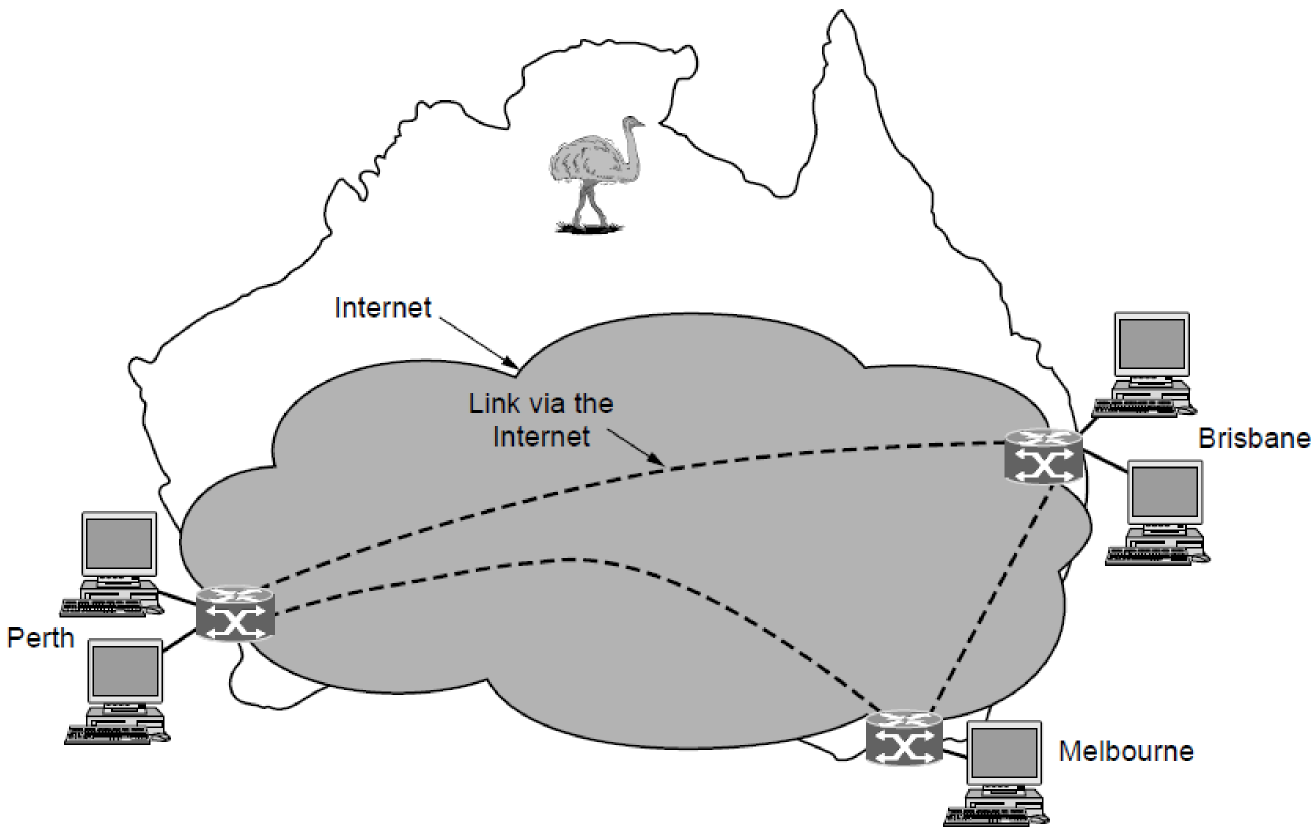
Wide Area Networks (2)

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



Wide Area Networks (3)

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



Broadcast Networks

- Types of transmission technology
- Broadcast links
- Point-to-point links

Broadcast Networks (2)

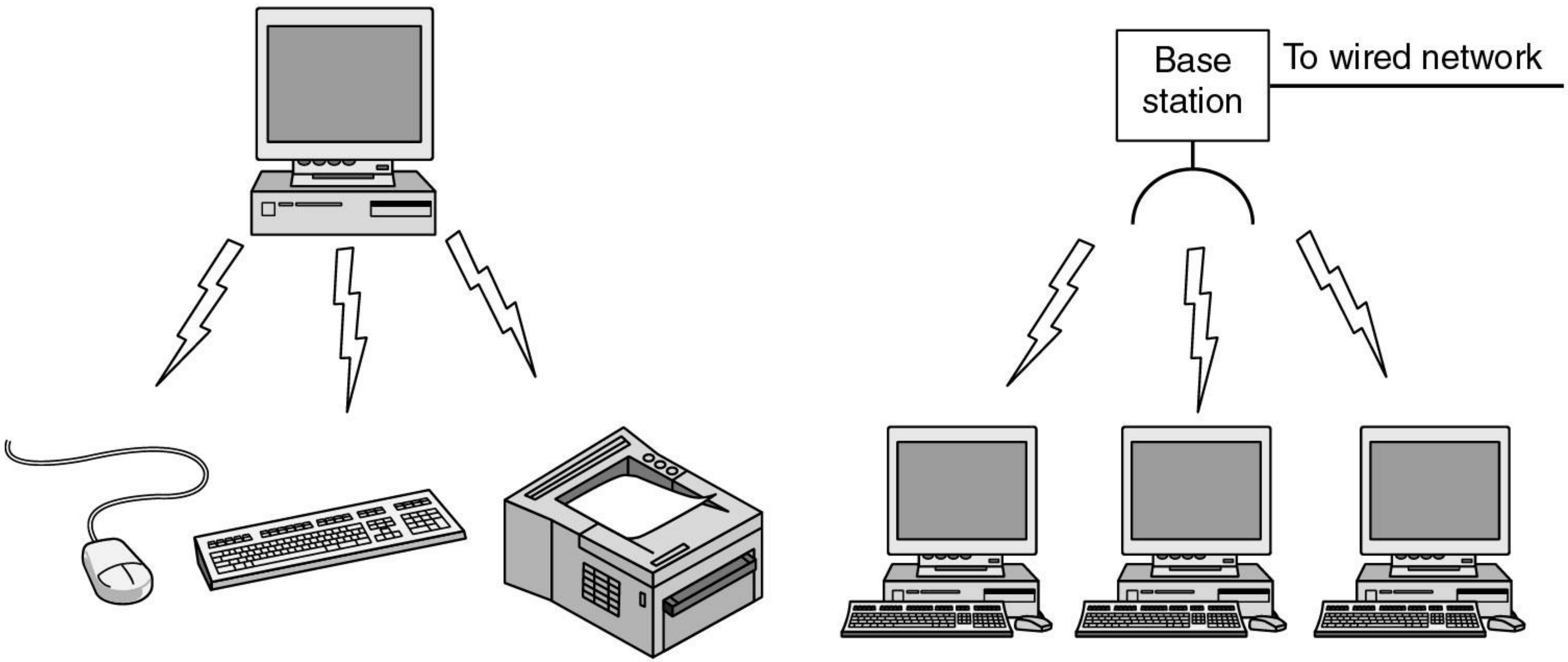
- Classification of interconnected processors by scale.

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

Wireless Networks

- Categories of wireless networks:
- System interconnection
- Wireless LANs
- Wireless WANs

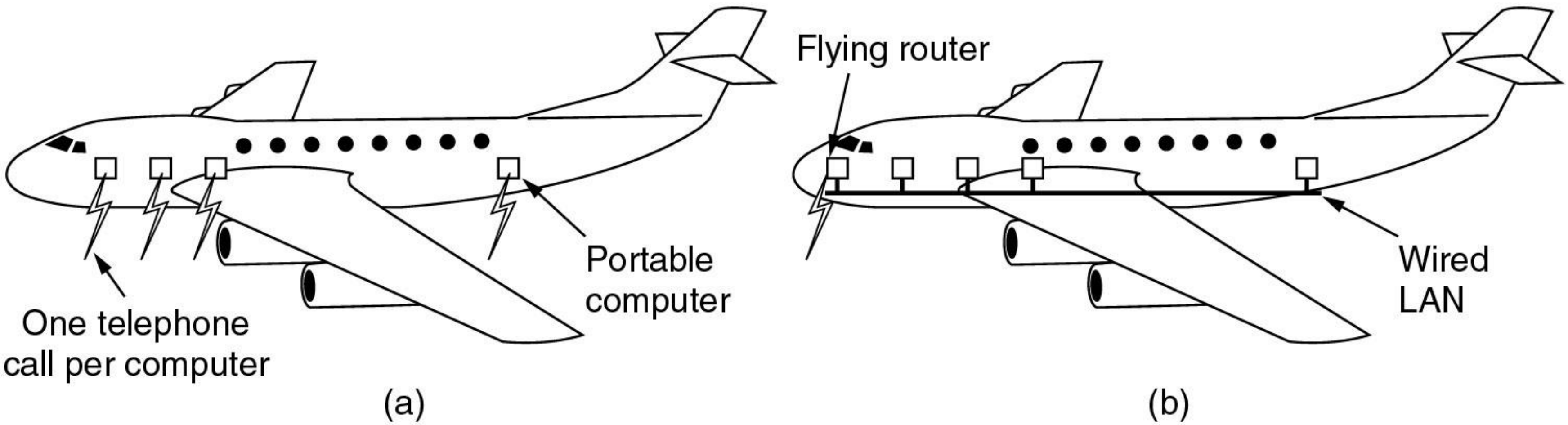
Wireless Networks (2)



(a) (b)

- (a) Bluetooth configuration
- (b) Wireless LAN

Wireless Networks (3)



- (a) Individual mobile computers
- (b) A flying LAN

Home Network Categories

- Computers (desktop PC, PDA, shared peripherals
- Entertainment (TV, DVD, VCR, camera, stereo, MP3)
- Telecomm (telephone, cell phone, intercom, fax)
- Appliances (microwave, fridge, clock, furnace, airco)
- Telemetry (utility meter, burglar alarm, babycam).

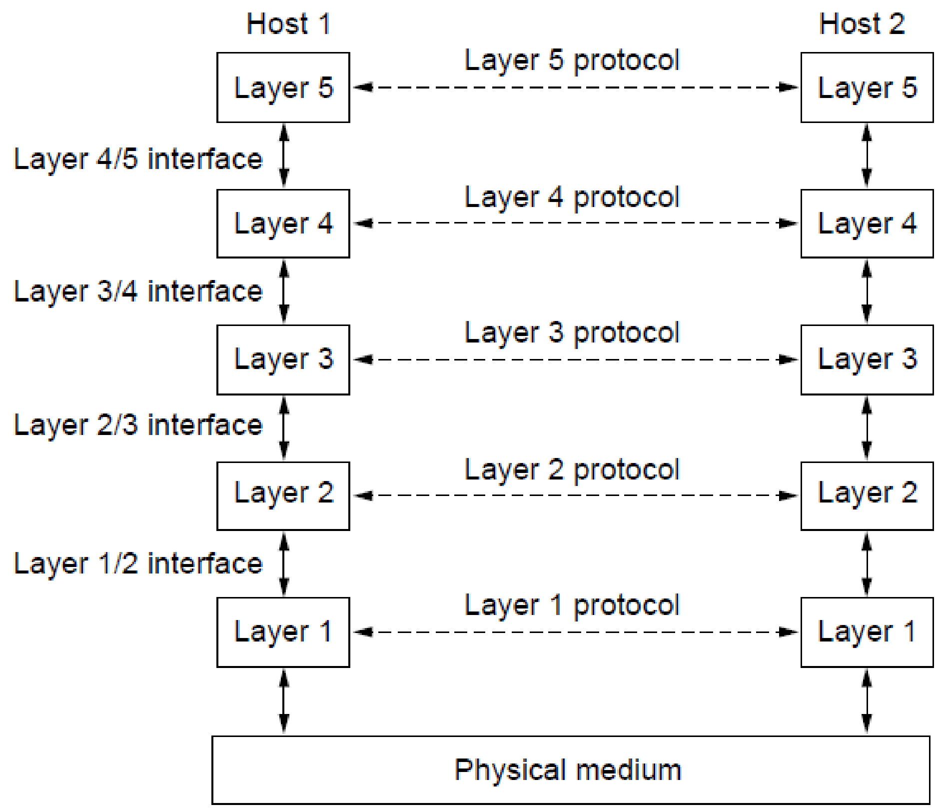
Network Software

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

Protocol Layers (1)

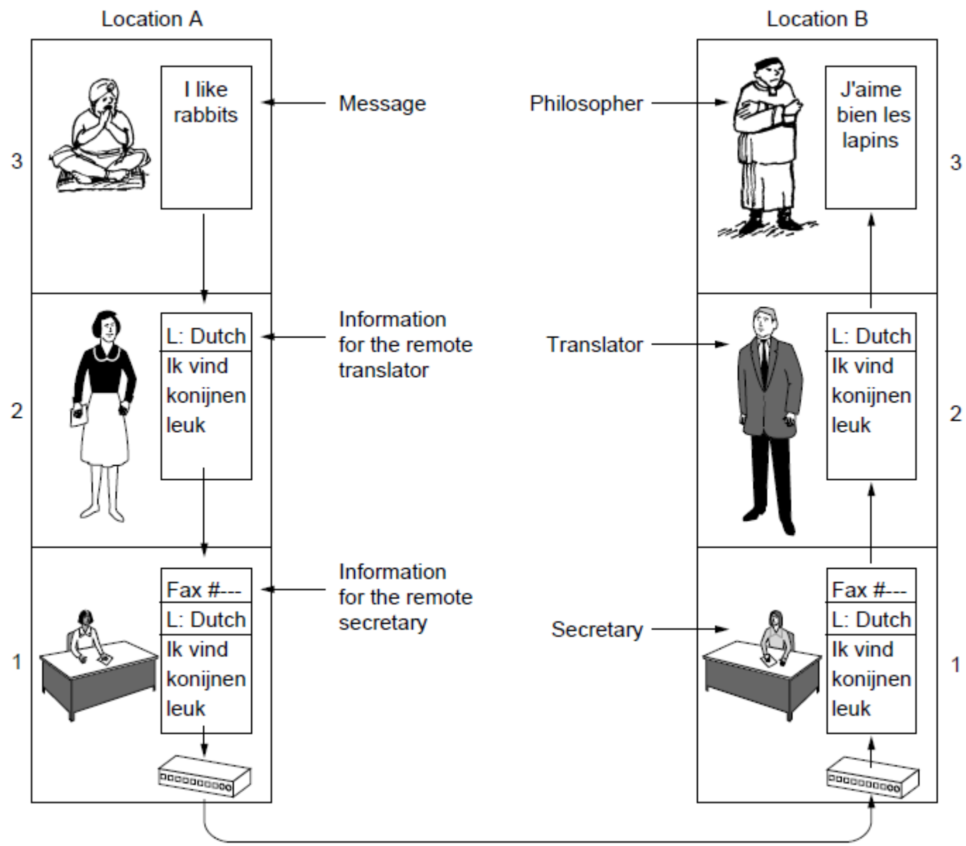
Protocol layering is the main structuring method used to divide up network functionality.

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



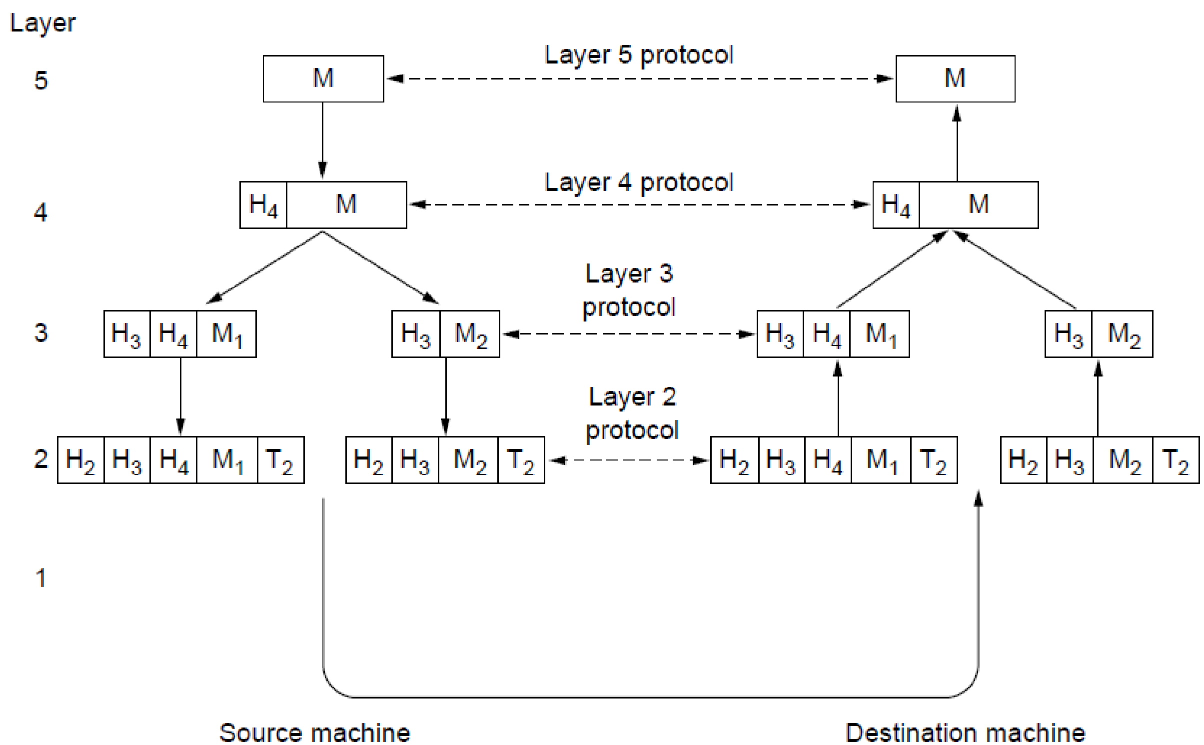
Protocol Layers (2)

- Example: the philosopher-translator-secretary architect
- Each pro different purpose



Protocol Layers (3)

- Each lower layer adds its own <u>header</u> (with control infor… …oves it on re…



- Layers may also split and join messages, etc.

Design Issues for the Layers

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

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

Connection-Oriented vs. Connectionless

- Service provided by a layer may be kinds of either:
  - Connection-oriented, must be set up for ongoing use (and torn down after use), e.g., phone call
  - Connectionless, messages are handled separately, e.g., postal delivery

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

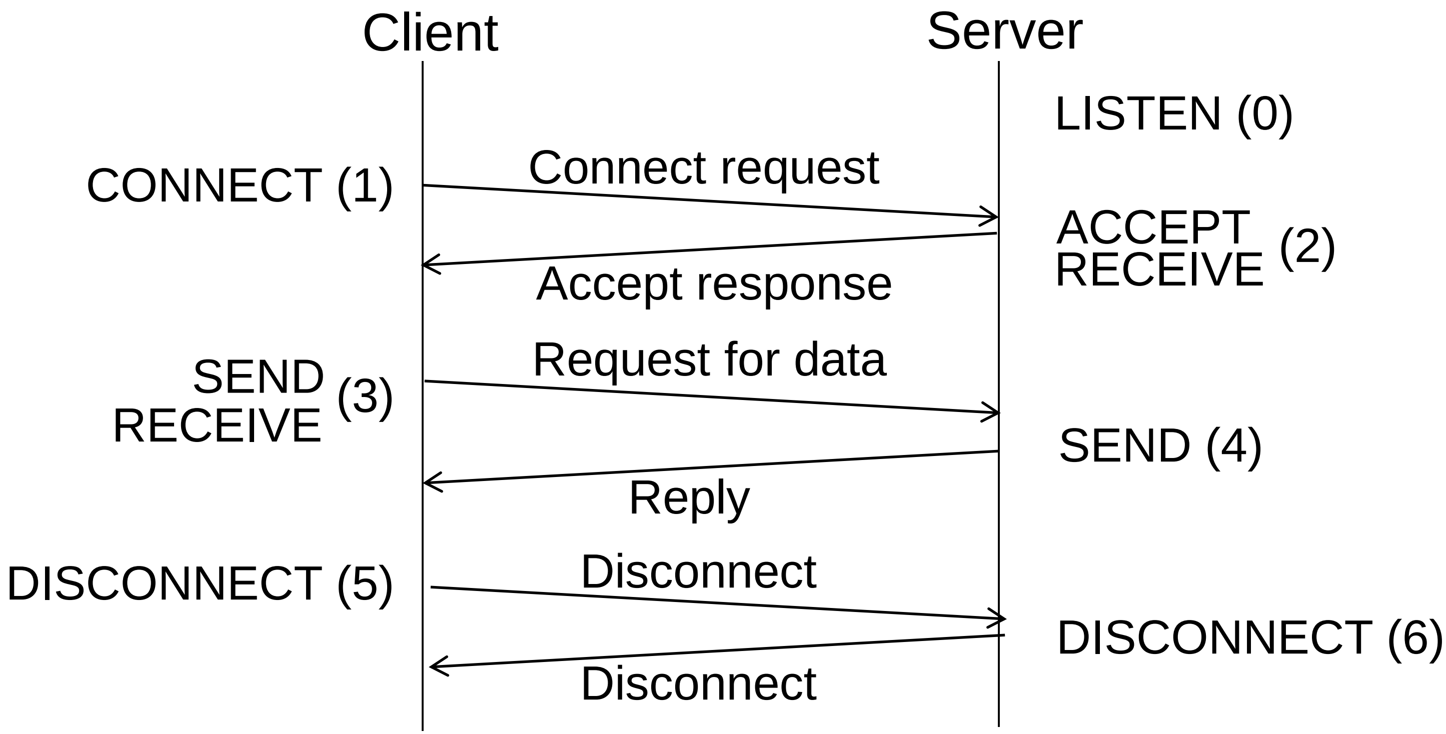
Service Primitives (1)

- A service is provided to the layer above as primitives
- Hypothetical example of service primitives that may provide a reliably byte stream (connection-oriented) service:

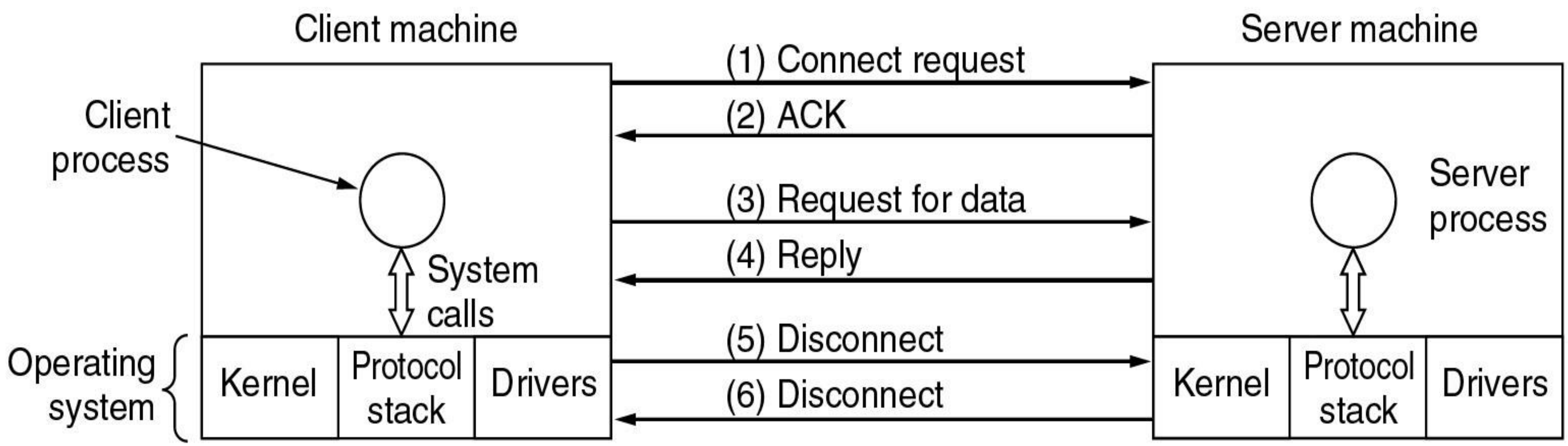
Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
ACCEPT	Accept an incoming connection from a peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

Service Primitives (2)

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



Service Primitives (2)

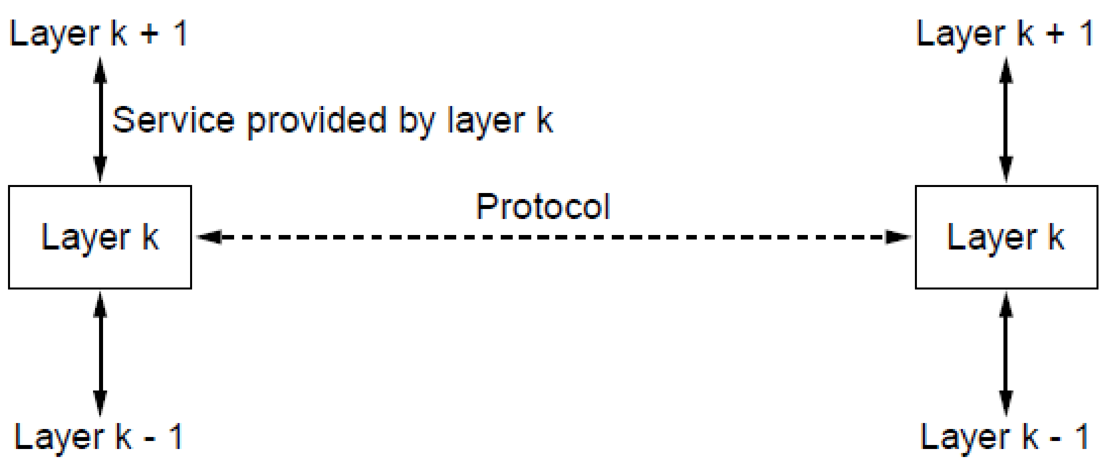


- Packets sent in a simple client-server interaction on a connection-oriented network.

Relationship of Services to Protocols

Recap:

- A layer provides a <u>service</u> to the one above [vertical]
- A layer talks to its peer using a <u>protocol</u> [horizontal]



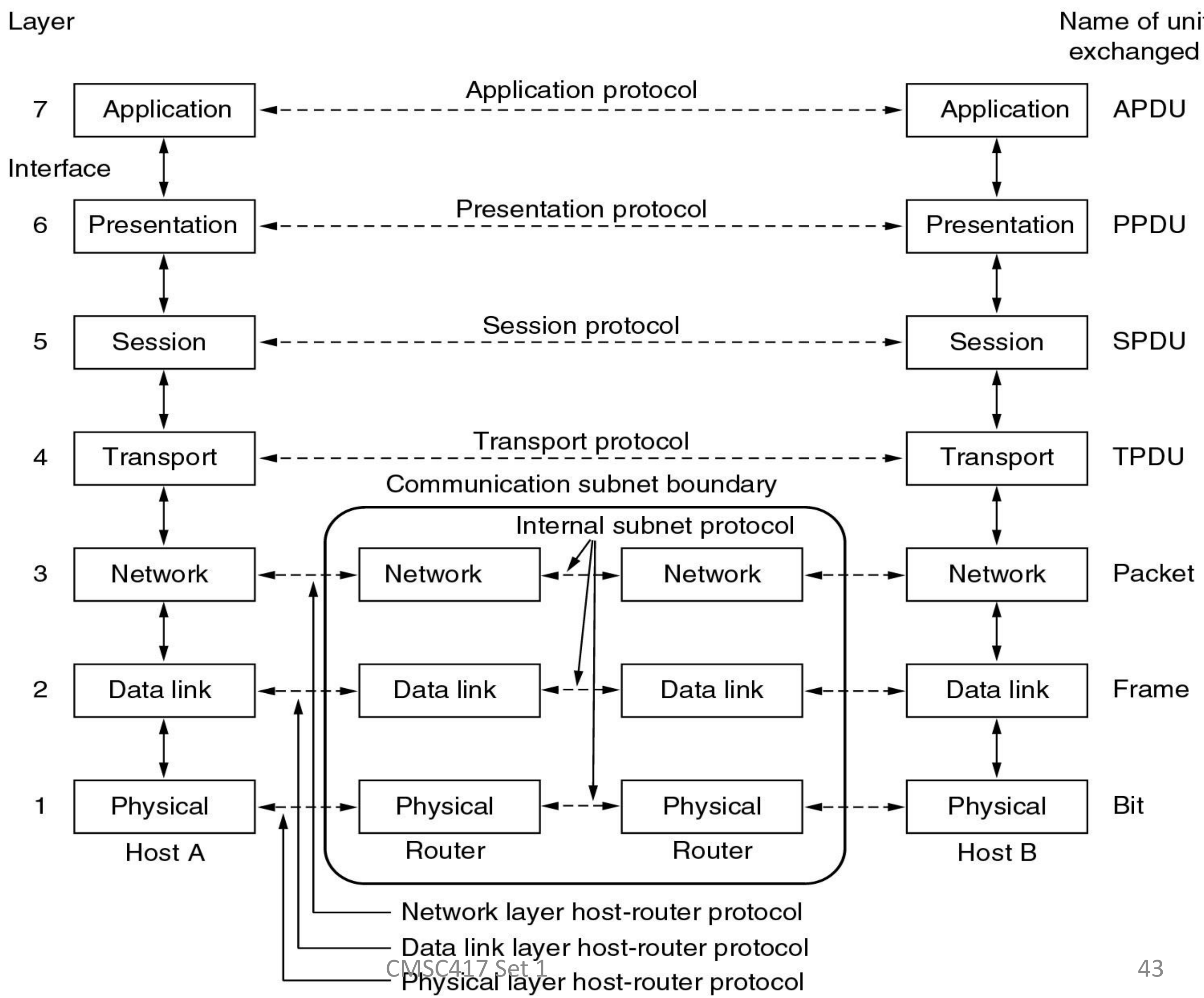
Reference Models

Reference models describe the layers in a network architecture

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

Reference Models

The OSI reference model.



OSI Reference Model

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

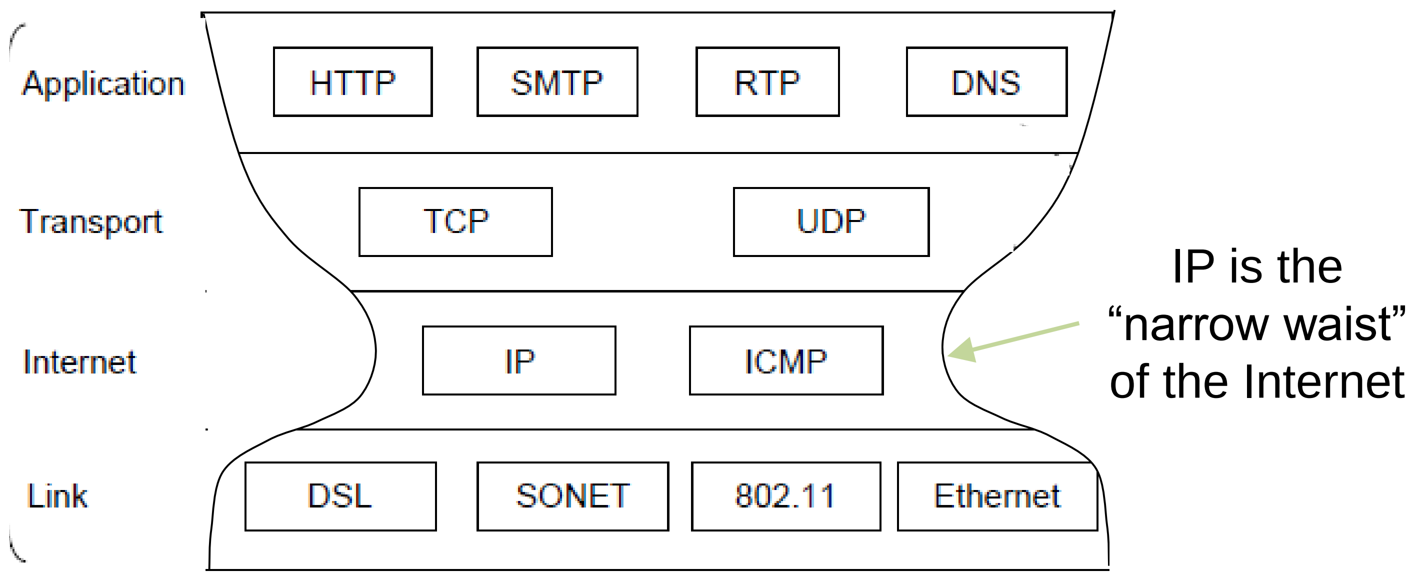
7	Application	– Provides functions needed by users
6	Presentation	– Converts different representations
5	Session	– Manages task dialogs
4	Transport	– Provides end-to-end delivery
3	Network	– Sends packets over multiple links
2	Data link	– Sends frames of information
1	Physical	– Sends bits as signals

The TCP/IP Reference Model Layers

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

TCP/IP Reference Model

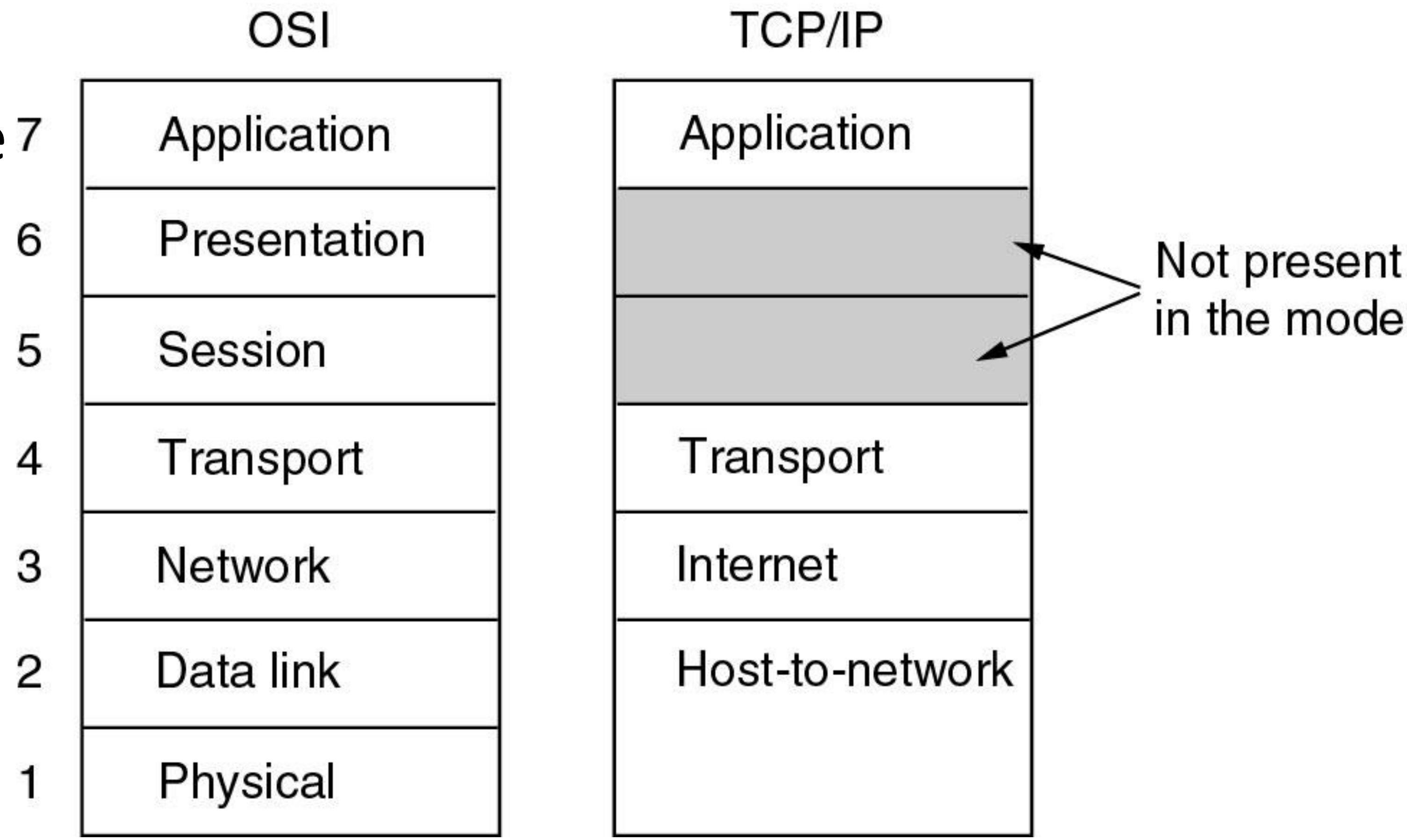
- A four layer model derived from experimentation; omits some OSI layers and uses the IP as the network



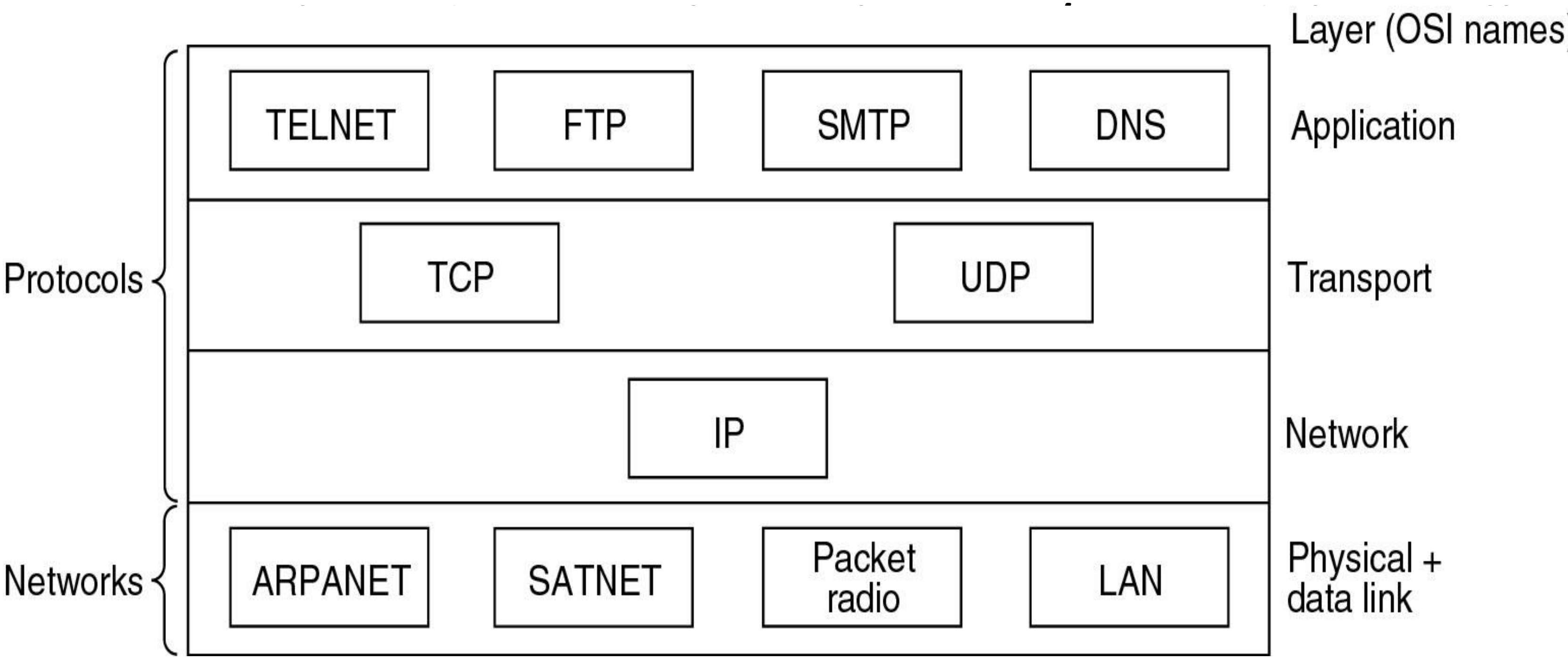
Protocols are shown in their respective layers

Reference Models (2)

- The



Reference Models (3)



Model Used in this Course

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

5	Application
4	Transport
3	Network
2	Link
1	Physical

Critique of OSI & TCP/IP

OSI:

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

TCP/IP:

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

Comparing OSI and TCP/IP Models

- Concepts central to the OSI model
- Services
- Interfaces
- Protocols

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

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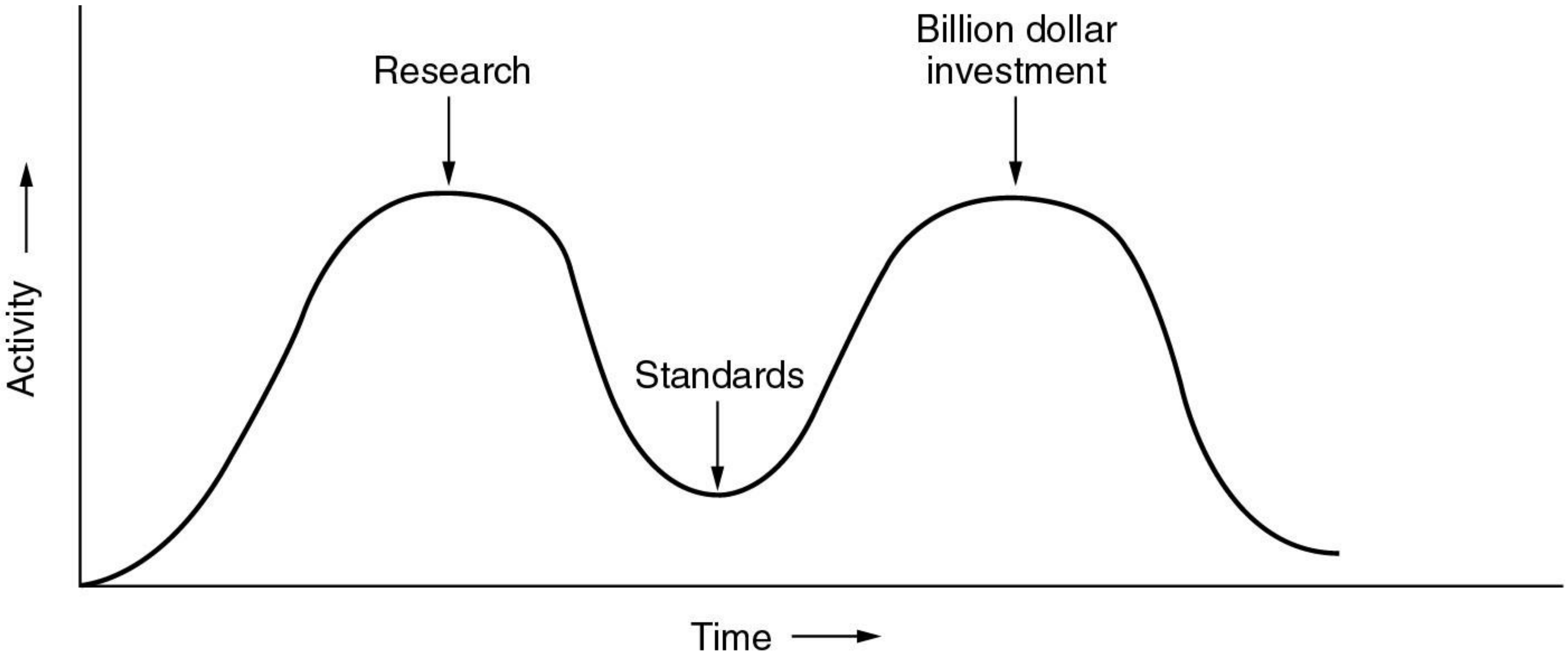


Research
Billion dollar
investment
Standards
Activity
Time

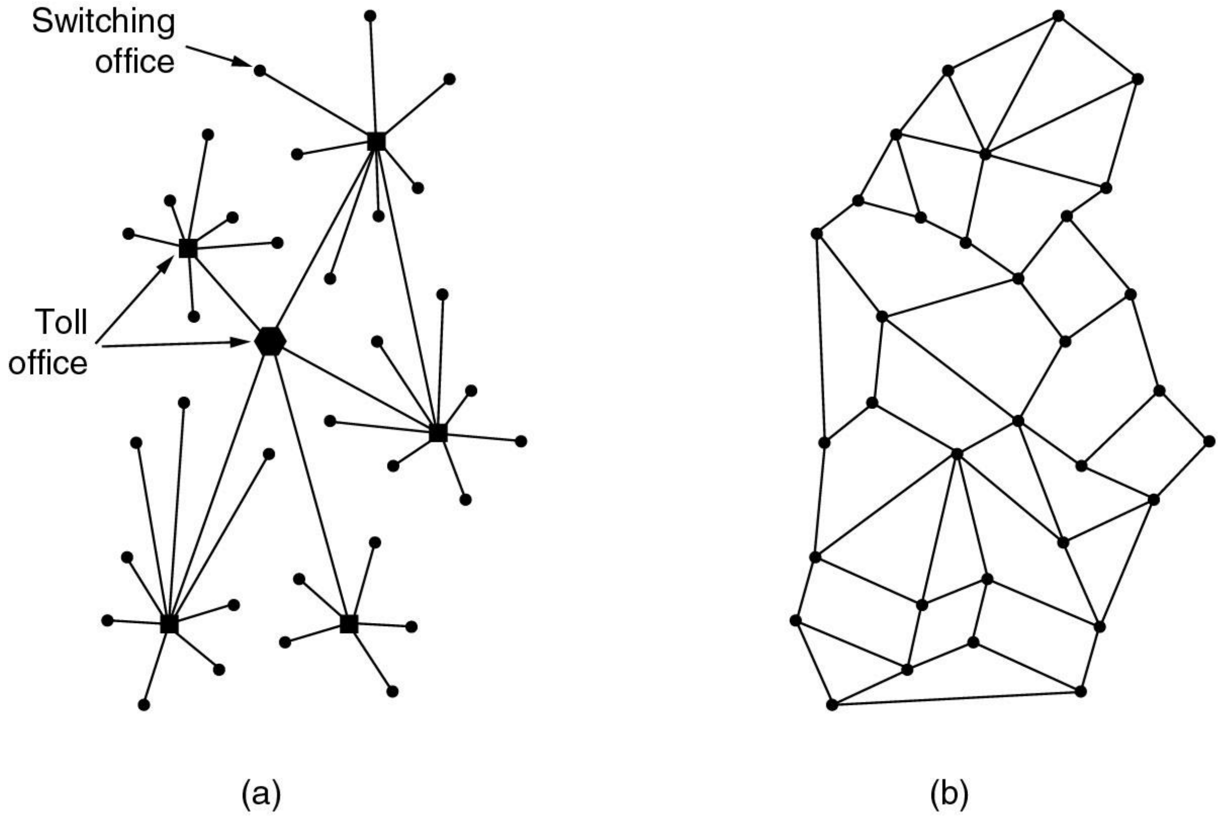
A Critique of the TCP/IP Reference Model

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

Example Networks

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

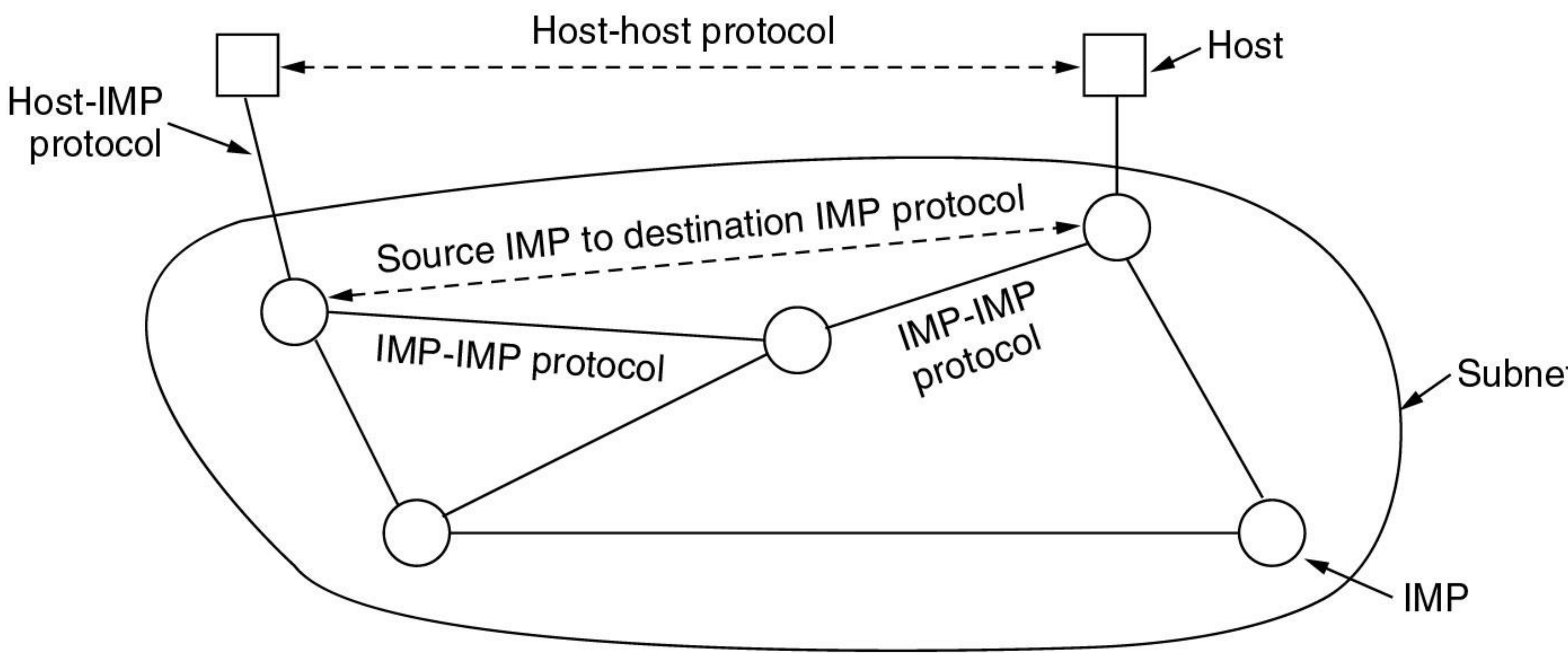
The ARPANET



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

The ARPANET (2)

- The original ARPANET design.



NSFNET

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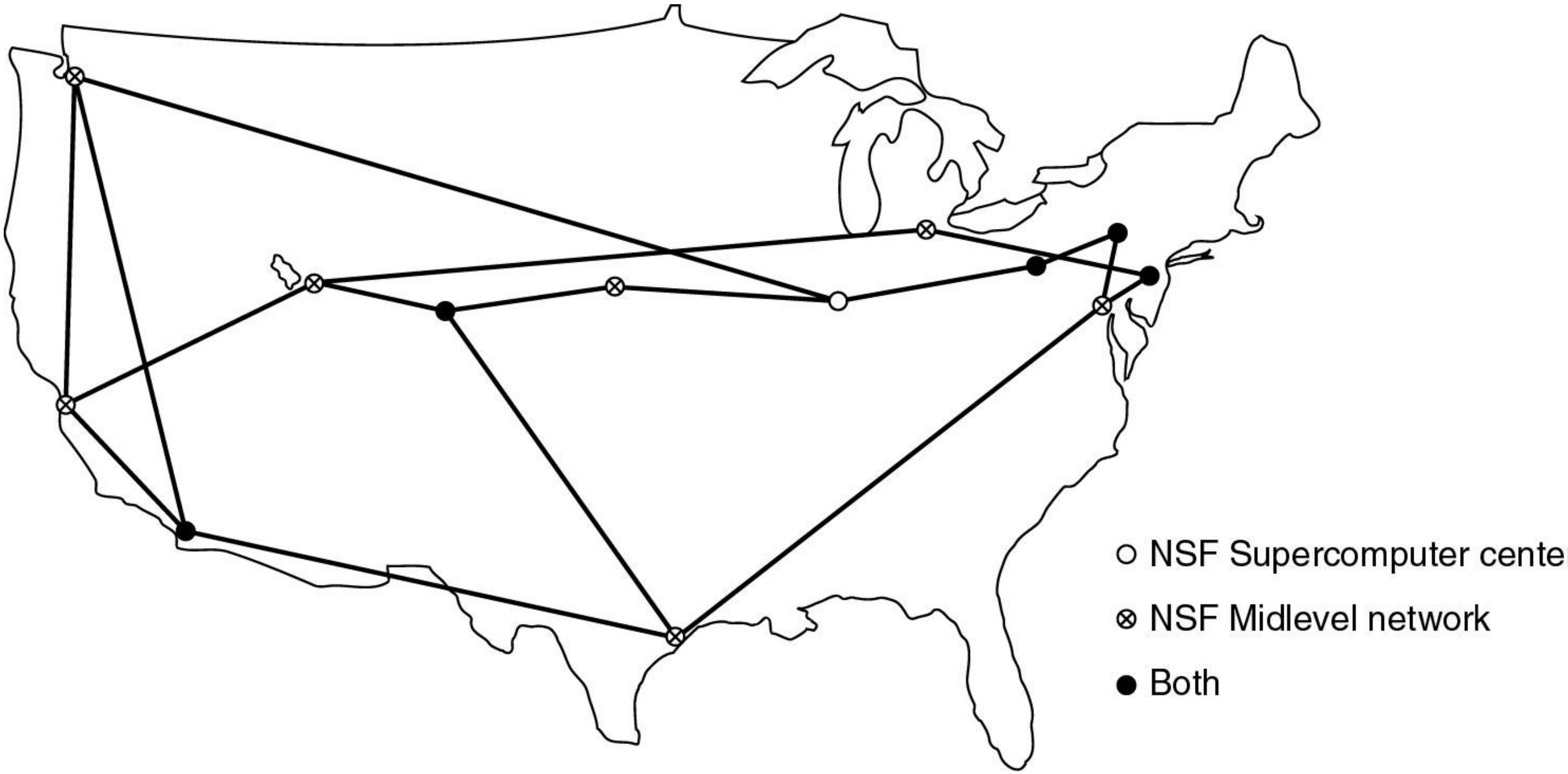
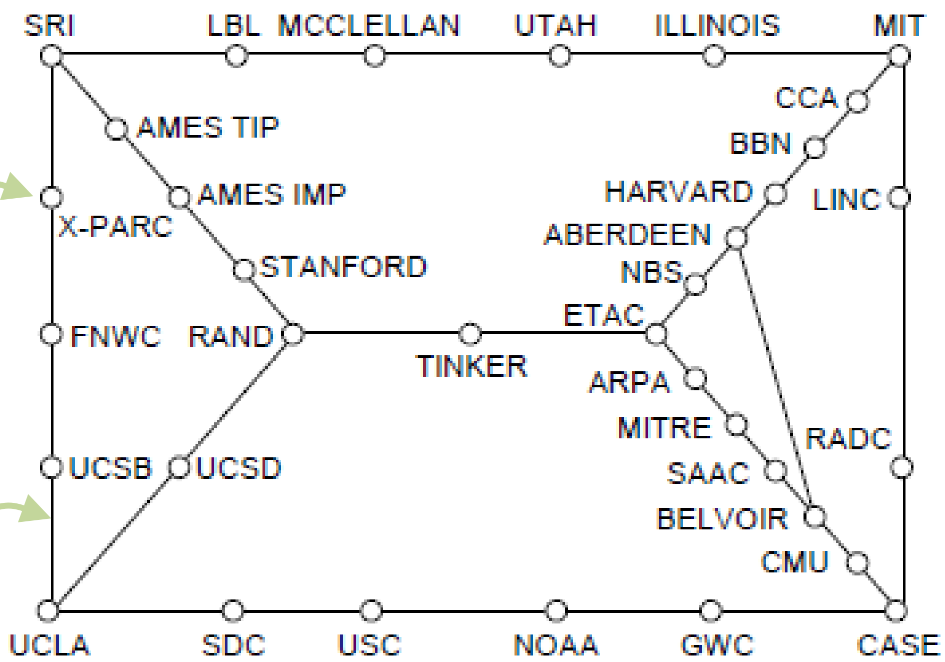


Internet (1)

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

Nodes are IMPs, or early routers, linked to hosts

56 kbps links

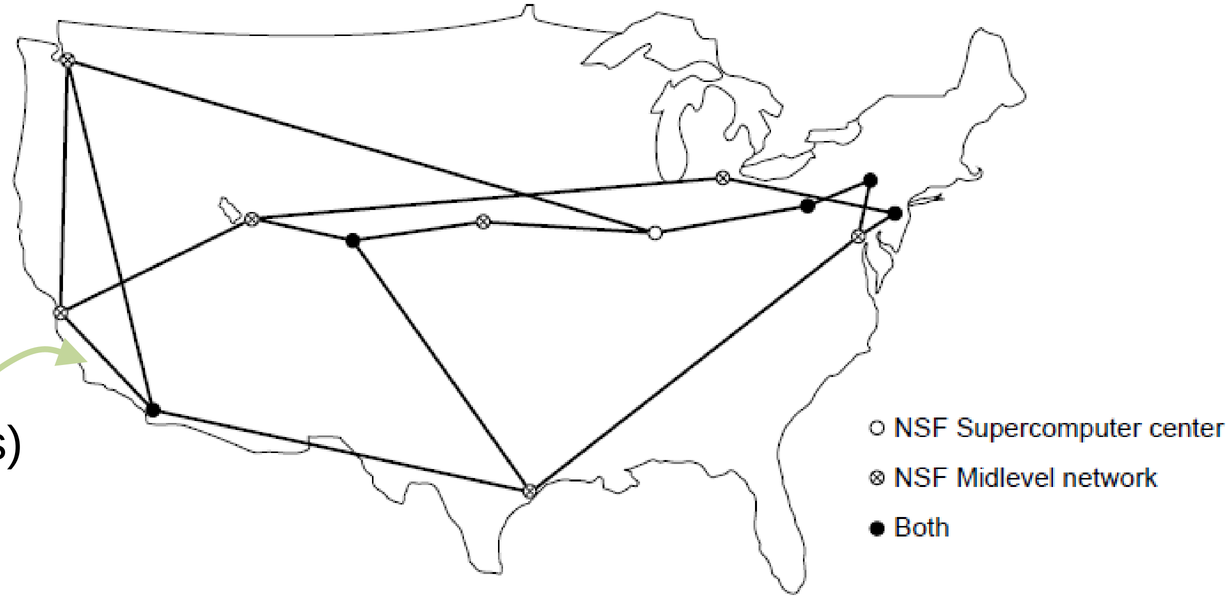


ARPANET topology in Sept 1972.

Internet (2)

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

T1 links
(1.5 Mbps)



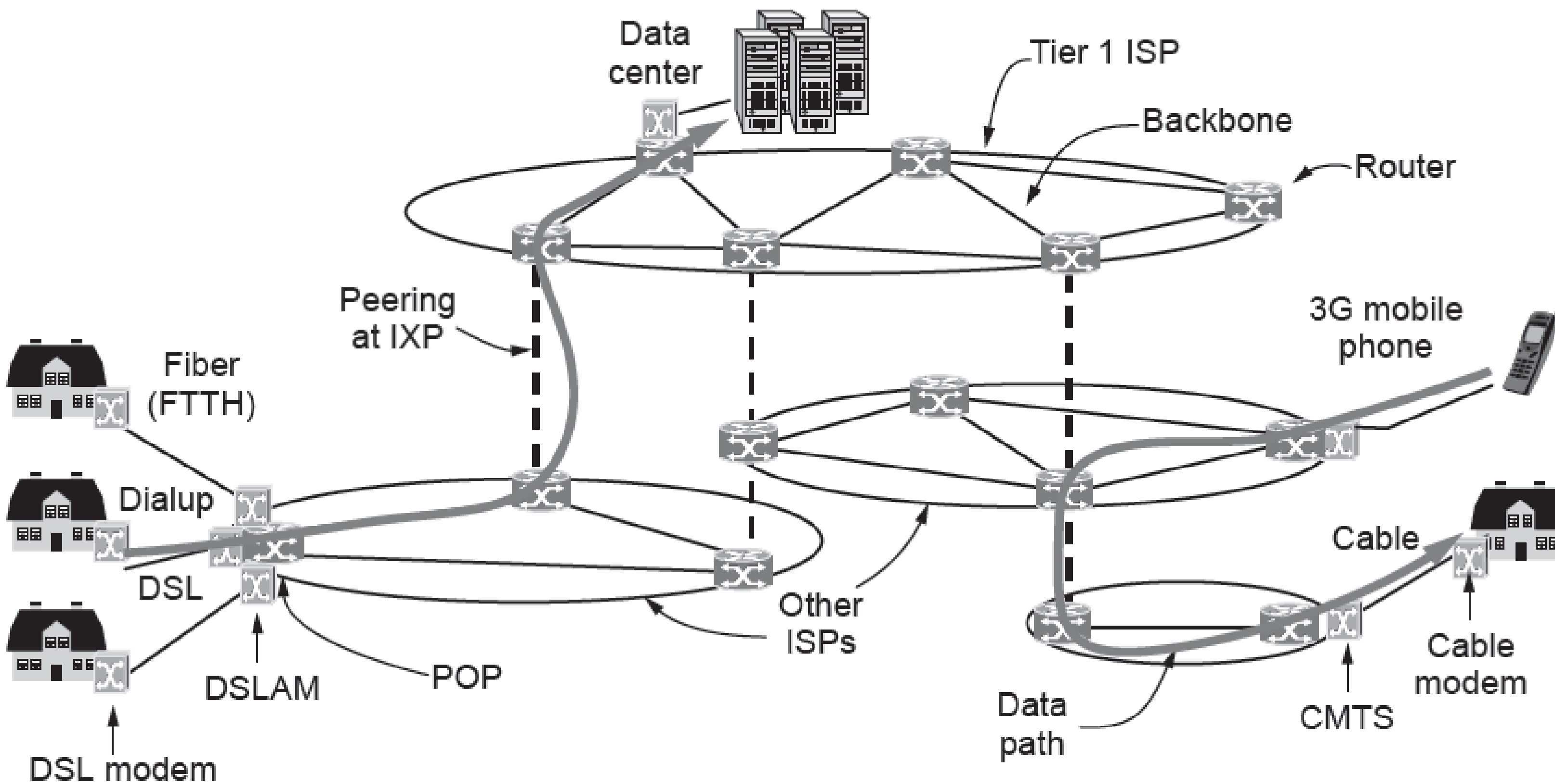
NSFNET topology in 1988

Internet (3)

The modern Internet is more complex:

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

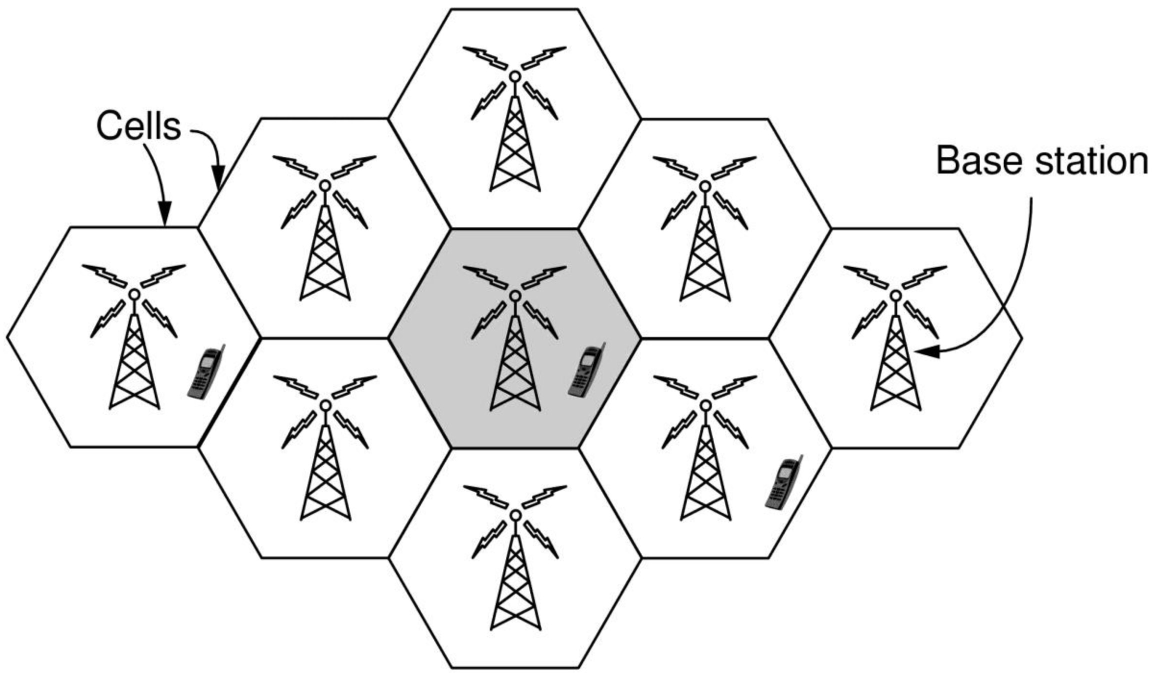
Internet (4)



Architecture of the Internet

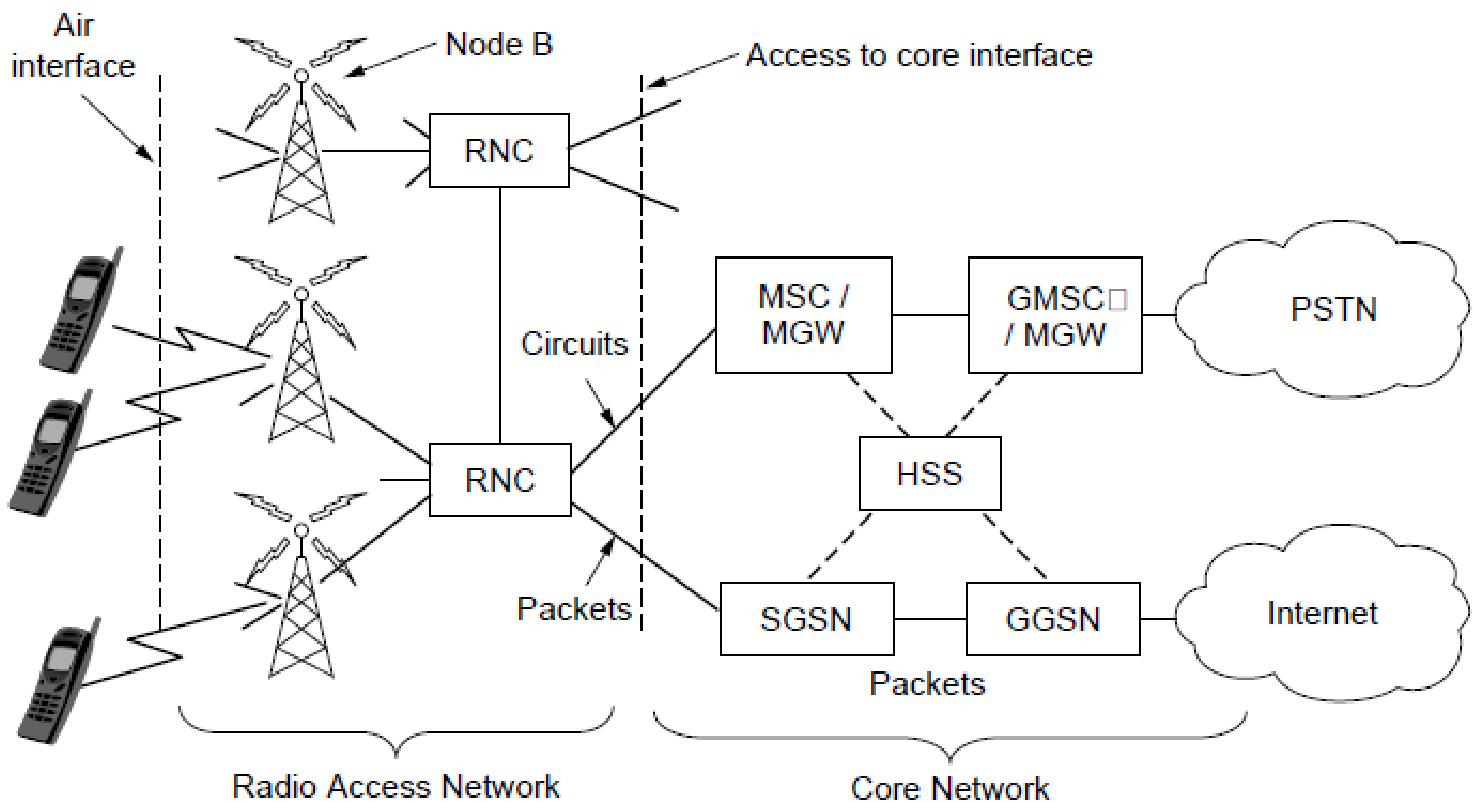
3G Mobile Phone Networks (1)

3G network is based on spatial cells; each cell provides wireless service to mobiles within it via a base station



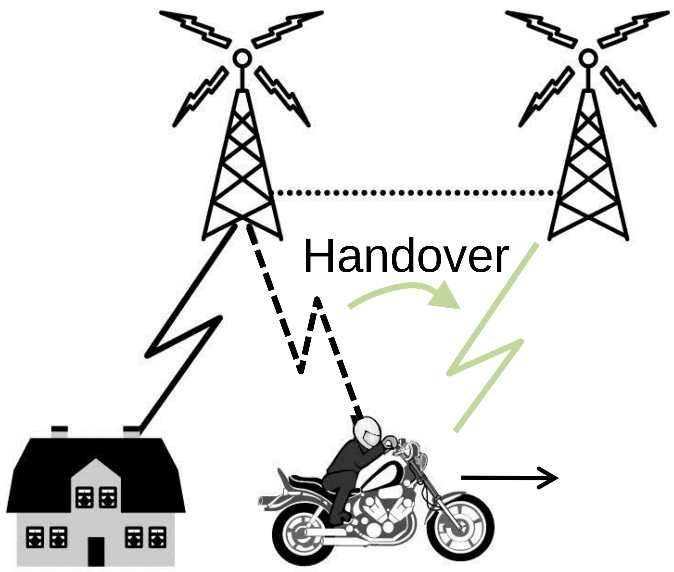
3G Mobile Phone Networks (2)

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



3G Mobile Phone Networks (3)

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

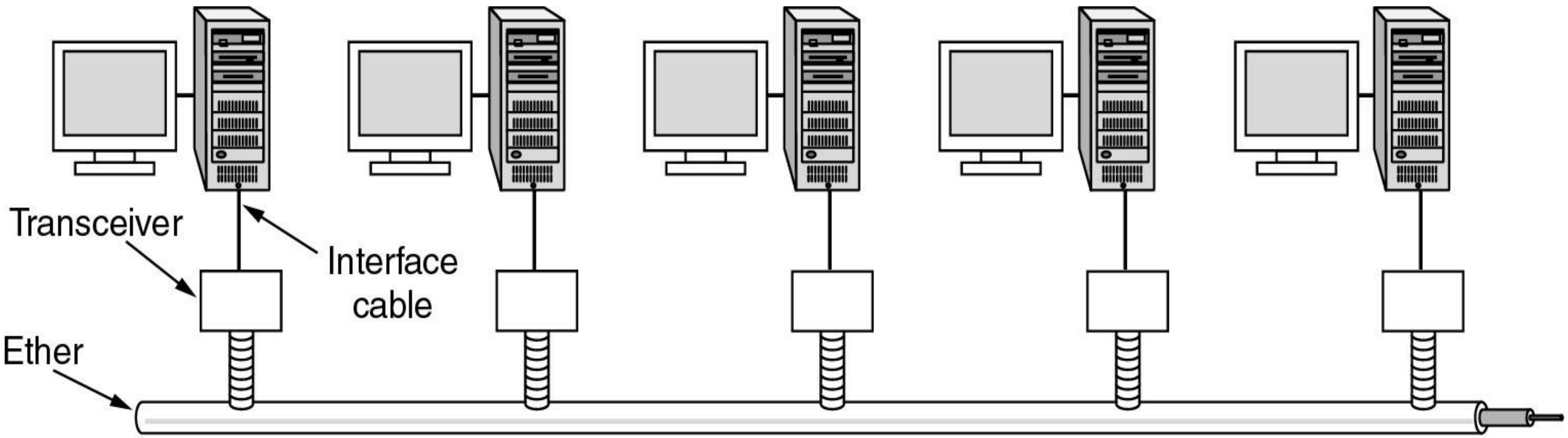


Fourth-Generation Mobile Phone Networks

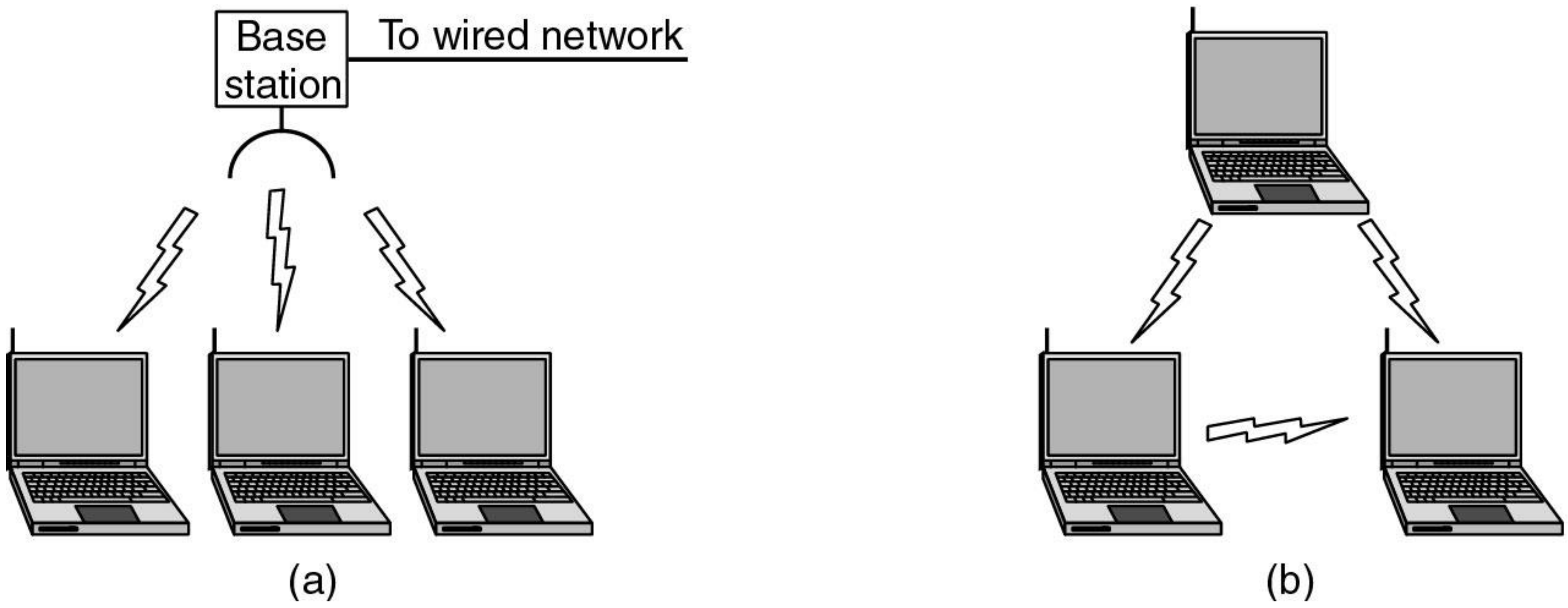
- Technologies
  - WiMAX
    - MAXWell Lab at UMd
  - LTE
- TDM Based
- Higher user level bandwidth

Ethernet

- Architecture of the original Ethernet.



Wireless LANs

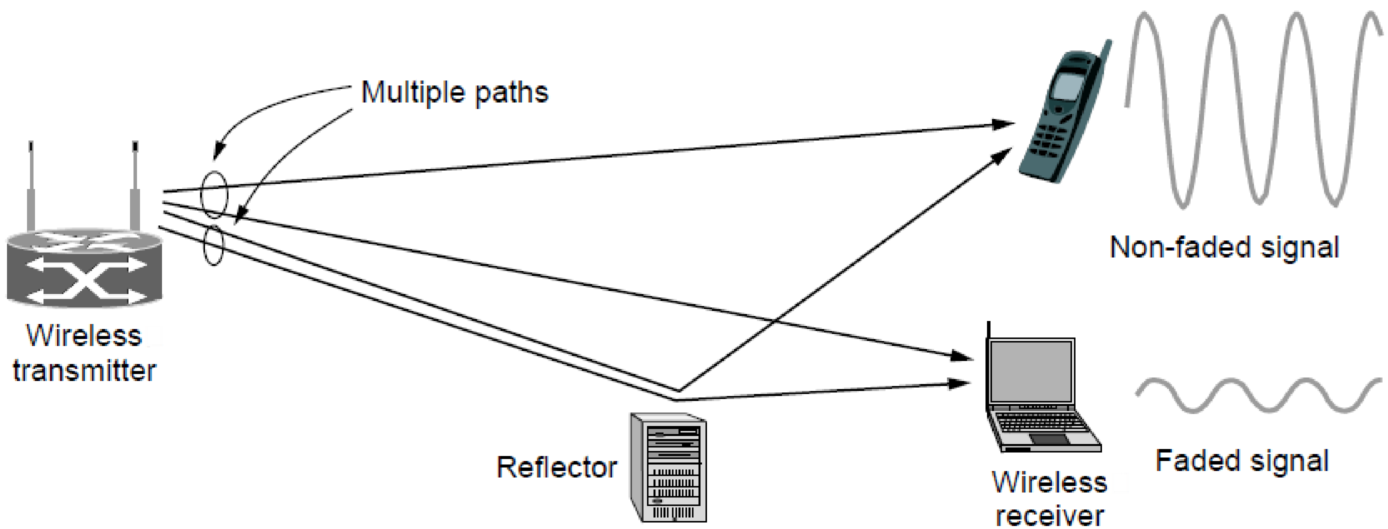


- (a) Wireless networking with a base station.
- (b) Ad hoc networking.

Wireless LANs (2)

Signals in the 2.4GHz ISM band vary in strength due to many effects, such as multipath fading due to reflections

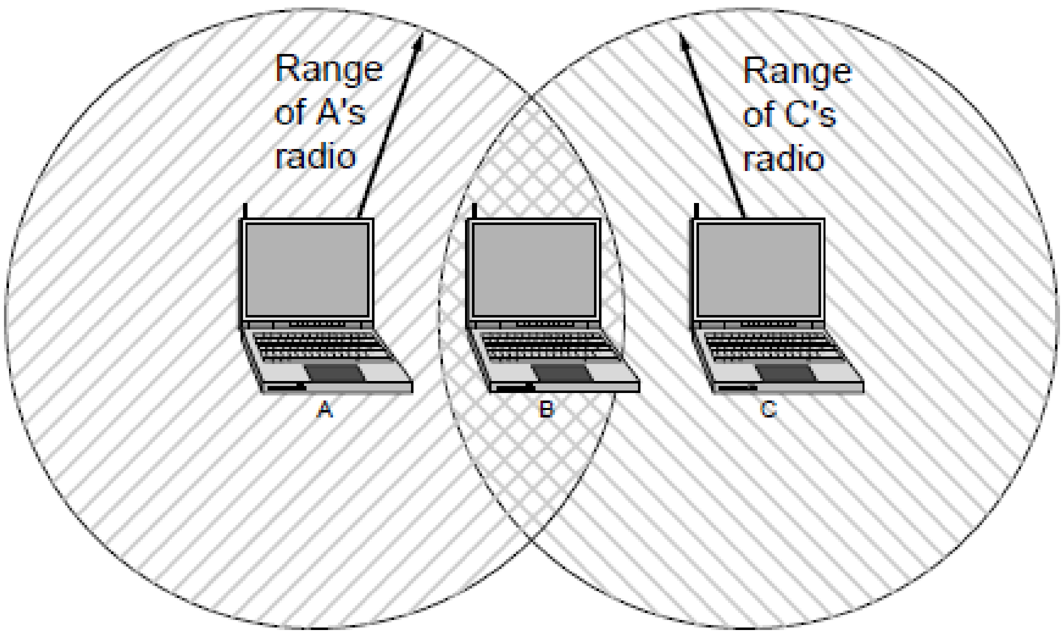
- requires complex transmission schemes, e.g., OFDM



Wireless LANs (3)

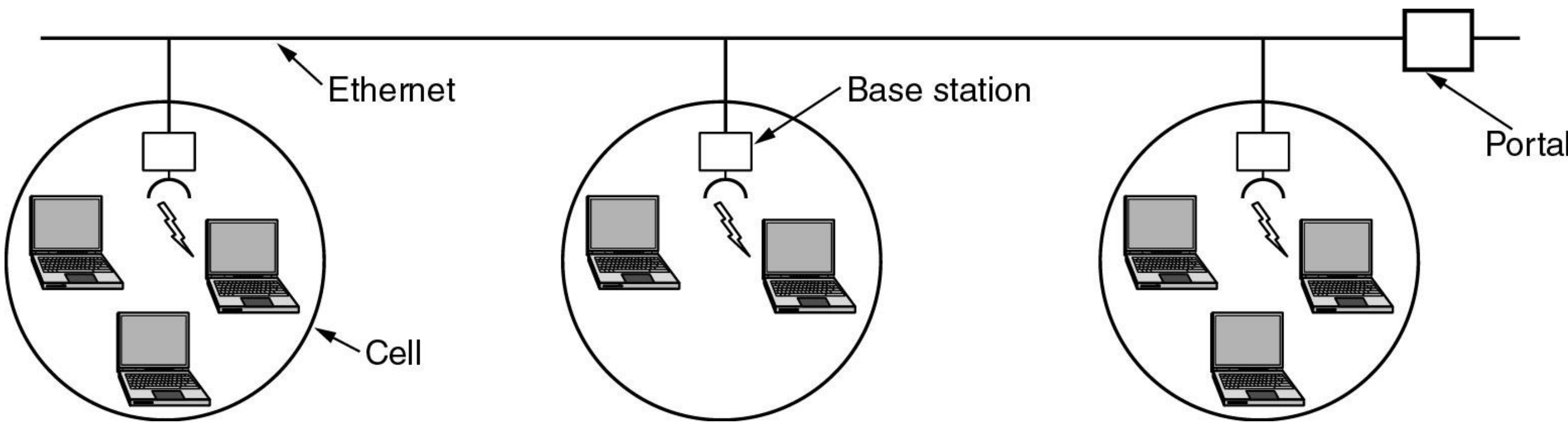
Radio broadcasts interfere with each other, and radio ranges may incompletely overlap

- CSMA (Carrier Sense Multiple Access) designs are



Wireless LANs (4)

- A multicell 802.11 network.



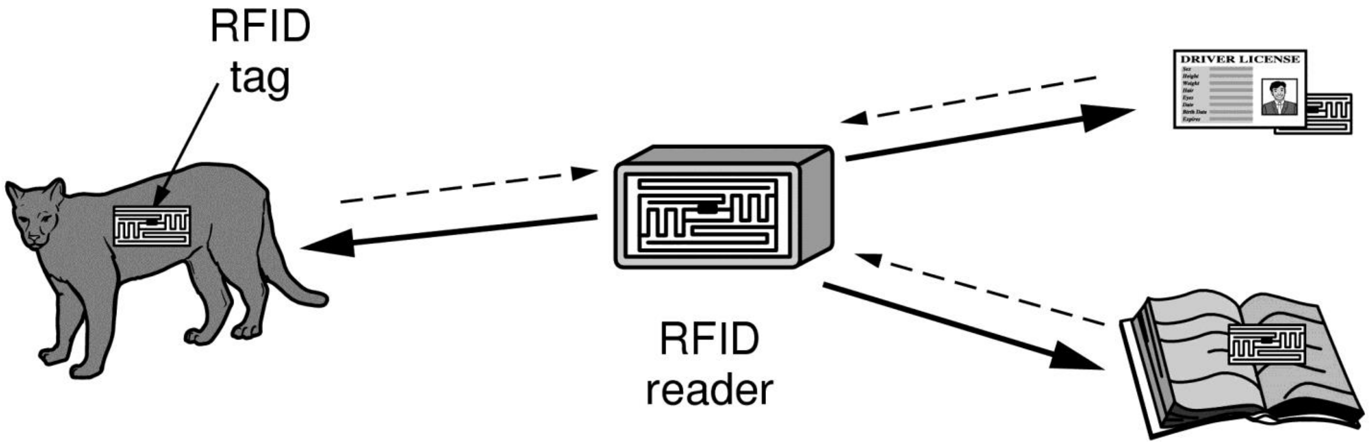
Ad hoc Networks

- Similar to Sensor Networks
- All nodes are equal
  - Some distinguished nodes may have servers/external connections
- Information moves from node to node

RFID and Sensor Networks (1)

Passive UHF RFID networks everyday objects:

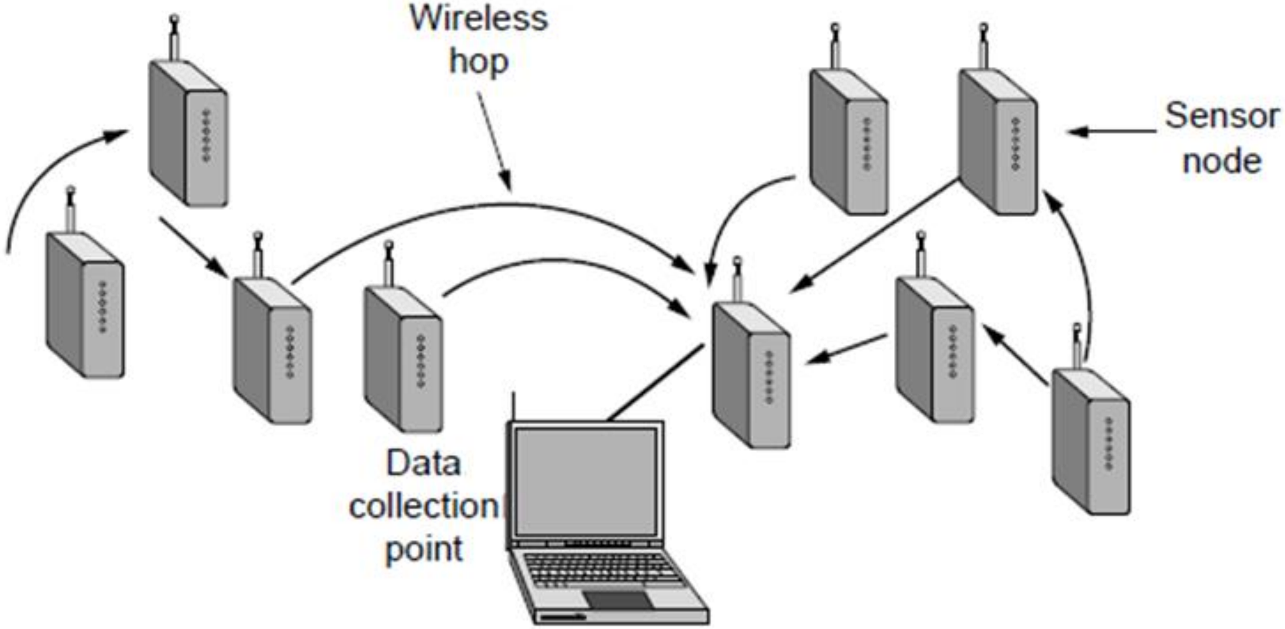
- Tags (stickers with not even a battery) are placed on objects
- Readers send signals that the tags reflect to communicate



RFID and Sensor Networks (2)

Sensor networks spread small devices over an area:

- Devices send sensed data to collector via wireless hops



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

Network Standardization

Standards define what is needed for <u>interoperability</u>

Some of the many standards bodies:

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

ITU

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

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.

Who's Who in International Standards (2)

802.13	Unlucky number; nobody wanted it
802.14 ↓	Cable modems (defunct: an industry consortium got there first)
802.15 *	Personal area networks (Bluetooth, Zigbee)
802.16 *	Broadband wireless (WiMAX)
802.17	Resilient packet ring
802.18	Technical advisory group on radio regulatory issues
802.19	Technical advisory group on coexistence of all these standards
802.20	Mobile broadband wireless (similar to 802.16e)
802.21	Media independent handoff (for roaming over technologies)
802.22	Wireless regional area network

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

The main prefixes we use:

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

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

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}	0.0000000000000000001	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.

Metric Units (1)

Exp.	Explicit	Prefix
10^{-3}	0.001	milli
10^{-6}	0.000001	micro
10^{-9}	0.000000001	nano
10^{-12}	0.000000000001	pico
10^{-15}	0.000000000000001	femto
10^{-18}	0.000000000000000001	atto
10^{-21}	0.000000000000000000001	zepto
10^{-24}	0.000000000000000000000001	yocto

The principal metric prefixes

Metric Units (2)

Exp.	Explicit	Prefix
10^3	1,000	Kilo
10^6	1,000,000	Mega
10^9	1,000,000,000	Giga
10^{12}	1,000,000,000,000	Tera
10^{15}	1,000,000,000,000,000	Peta
10^{18}	1,000,000,000,000,000,000	Exa
10^{21}	1,000,000,000,000,000,000,000	Zetta
10^{24}	1,000,000,000,000,000,000,000,000	Yotta

The principal metric prefixes