



南京大學

NANJING UNIVERSITY



Computer Networks

Wenzhong Li, Chen Tian

Nanjing University

Material with thanks to James F. Kurose, Mosharaf Chowdhury, and other colleagues.



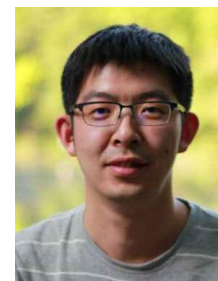
教学团队



- 李文中（一班）
- 研究方向：分布计算与并行处理、移动互联网、社交网络、大数据挖掘
- 个人主页：
<http://cs.nju.edu.cn/lwz/>



- 田臣（二班）
- 研究方向：数据中心网络、分布式系统、网络协议
- 个人主页：
<http://cs.nju.edu.cn/tianchen/index.htm>



- 郑嘉琦（三班）
- 研究方向：计算机网络及系统
- 个人主页：
<http://cs.nju.edu.cn/jzheng>

- 课程主页：<http://cs.nju.edu.cn/lwz/networks/>
- 课程QQ群：**972333708**（实验验收、作业提交、答疑）



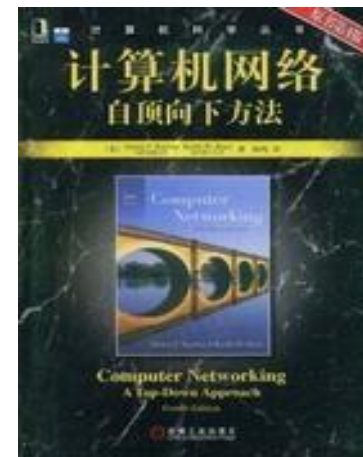
课程概况

- 课程名称： 计算机网络
- 课程编号： 22010050
- 授课方式： 课堂讲授+实验
 - 实验课每两周一次，共7-8次实验
- 课程考核
 - 平时成绩： 15%
 - 实验： 25%
 - 期末考试： 60%



参考书籍

- James F. Kurose, Keith W. Ross. 计算机网络—自顶向下方法 (8th). 机械工业出版社, 2022.
- William Stallings. 数据与计算机通信 (8th). 电子工业出版社





课程大纲

- Internet简介（教材第1章）
- 应用层（教材第2章）
- 传输层（教材第3章）
- 网络层（教材第4章、第5章）
- 链路层和无线网络（教材第6章，第7章）
- 网路安全（教材第8章）

- 作业习题：**以教材第8版为准**



南京大學

NANJING UNIVERSITY



Chapter 1. Introduction of Networking



Chapter 1. Introduction of Networking

- **Basic Concepts and Questions**
- Internet History
- Protocol Layers and Service Model
- Network Performance

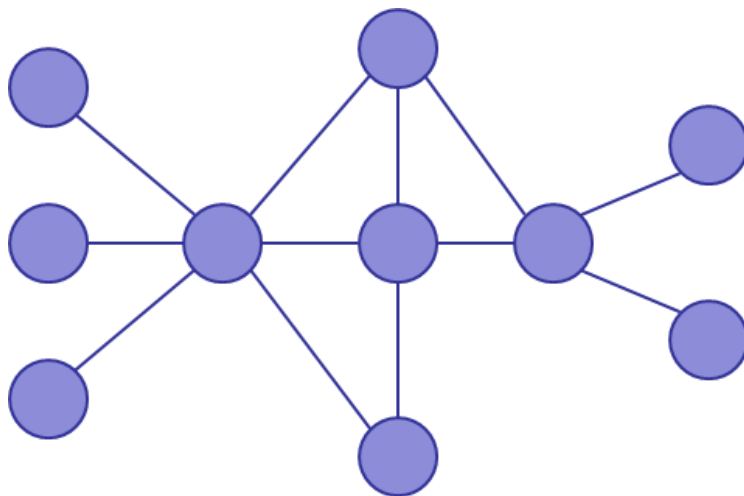


Concept: Internet



What is a network?

- A system of “links” that interconnect “nodes” in order to move “information” between nodes



- Yes, this is very vague



Different types of networks

- Internet
- Telephone network
- Wireless networks
- Optical networks
- Datacenter networks
- *Transportation networks*
- *Social networks*

We will focus primarily on *the Internet*



What is the Internet?

■ [WiKi]

- The Internet is the **global system** of **interconnected** mainframe, personal, and wireless computer networks that use the **Internet protocol suite** (TCP/IP) to link billions of devices worldwide.
- It is a **network of networks** that consists of millions of private, public, academic, business, and government networks of local to global scope, linked by a broad array of electronic, wireless, and optical networking technologies.



The Internet is transforming everything

- The way we do business
 - E-commerce, advertising, cloud-computing
- The way we have relationships
 - Facebook friends, E-mail, IM, virtual worlds
- The way we learn
 - Wikipedia, MOOCs, search engines
- The way we govern and view law
 - E-voting, censorship, copyright, cyber-attacks



MASSIVE Scale

- 3.5 Billion users (34% of world population)
- 1 Trillion websites
- 200 Billion emails sent per day
- 2 Billion smartphones
- 1.8 Billion Facebook users
- 4 Billion YouTube videos watched per day
- Routers that switch 10 Terabits/second
- Links that carry 100 Gigabits/second



Diversity in all dimensions

■ Technology

- Optical, wireless, satellite, copper

■ Endpoint devices

- From wearable devices and cell phones to datacenters and supercomputers

■ Applications

- Video streaming, social networking, file transfer, Skype, live TV, gaming, remote medicine, IM

■ Users

- Malicious, naïve, savvy, embarrassed, paranoid



The Internet is a lesson

- In how to reason through the design of a very complex system
 - What are our goals and constraints?
 - What's the right prioritization of goals?
 - How do we decompose a problem?
 - Who does what? How?
 - What are the interfaces between components?
 - What are the tradeoffs between design options?



Basic questions:

Q1: What is the Internet made of?

Q2: How to connect to the Internet?

Q3: How to transfer data in the network?

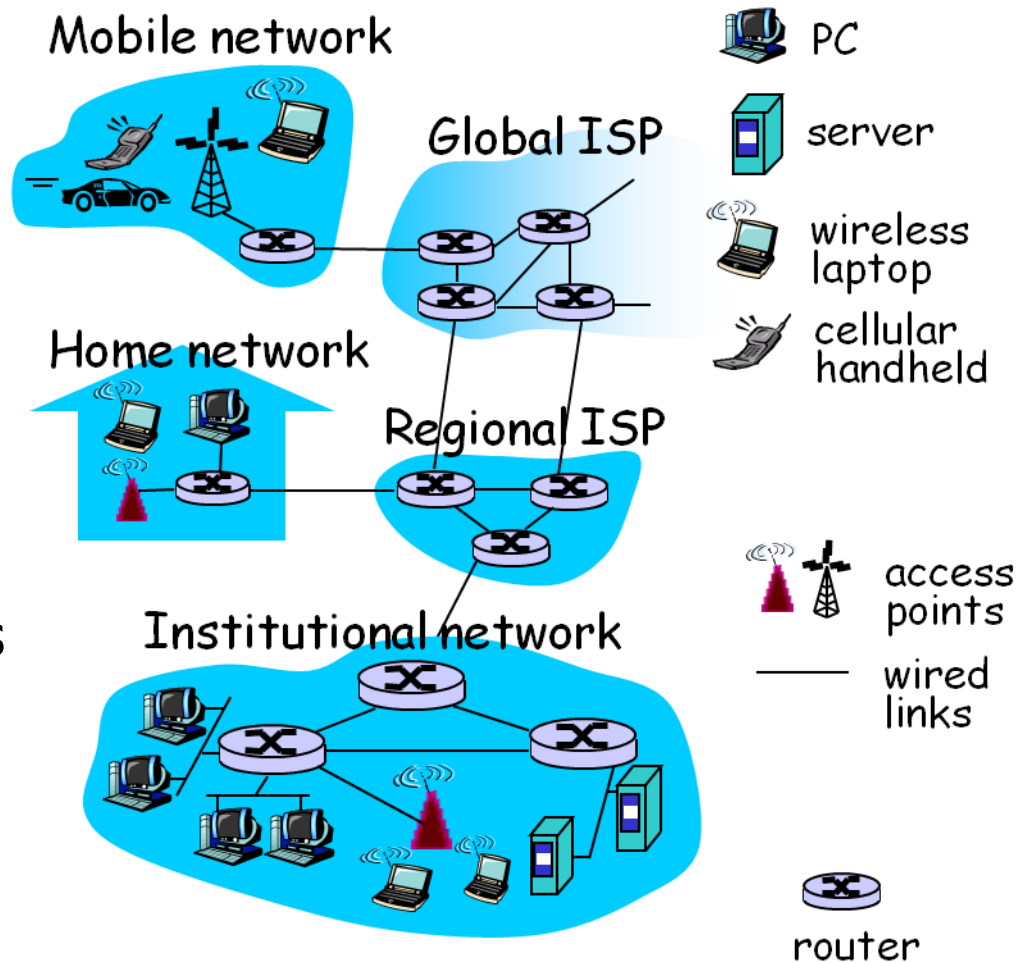


**Q1: What is the
Internet made of?**



Internet – component view

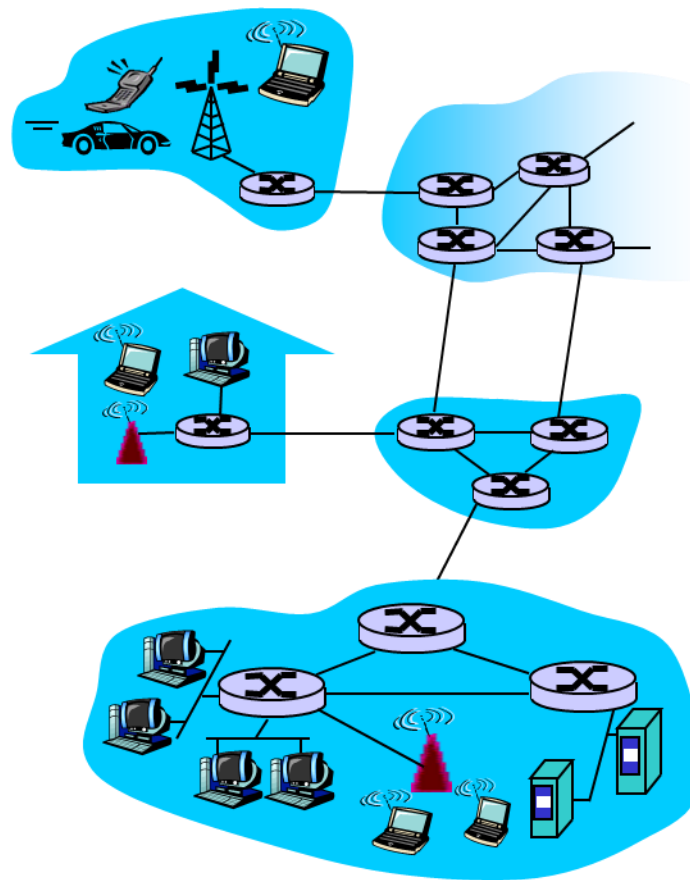
- Millions of connected computing devices
 - Hosts = **End systems**
 - Running network applications
- **Communication links**
 - Fiber, Copper, Radio, Satellite
 - Building physical networks
- **Routers**
 - Forward packets (chunks of data) between physical networks





Internet – service view

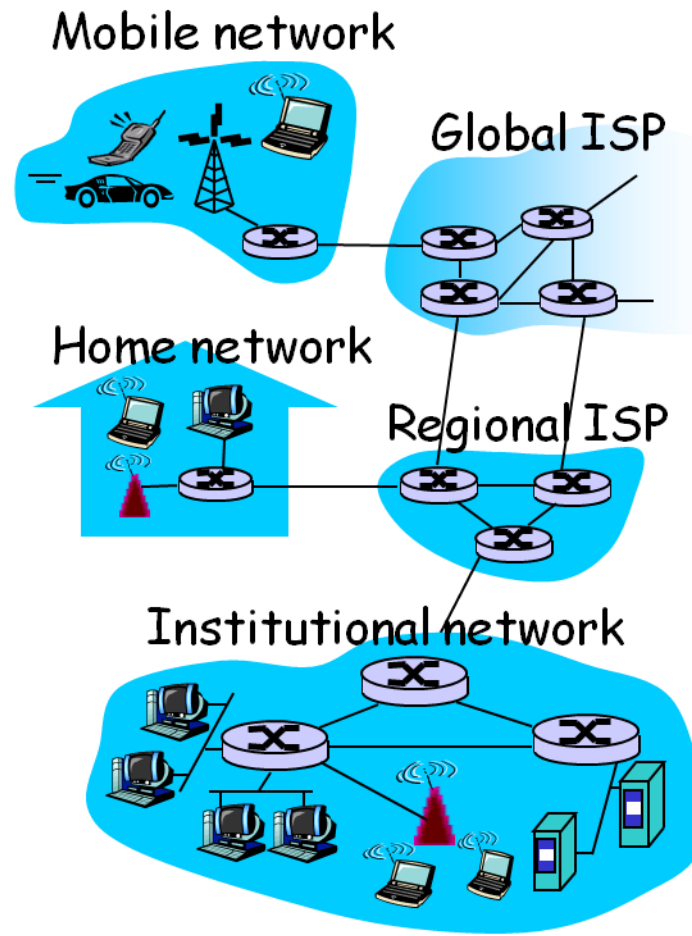
- Communication infrastructure
 - Enables distributed applications
 - Web, VoIP, email, online games, e-commerce, file sharing
- Communication services provided to Apps:
 - Reliable data delivery from source to destination
 - “best effort” (unreliable) data delivery
 - Guaranteed delay and throughput





Internet – protocols

- Network Protocols
 - Control sending, receiving of messages
 - e.g. HTTP, Skype; TCP, IP; PPP, Ethernet
- Internet standards
 - IETF: Internet Engineering Task Force
 - RFC: Request for comments
- Internet: “network of networks”
 - Public Internet versus private Intranet
 - Loosely hierarchical





What's a protocol?

human protocols:

- “what’s the time?”
- “I have a question”

... specific msgs sent

... specific actions taken when msgs received, or other events

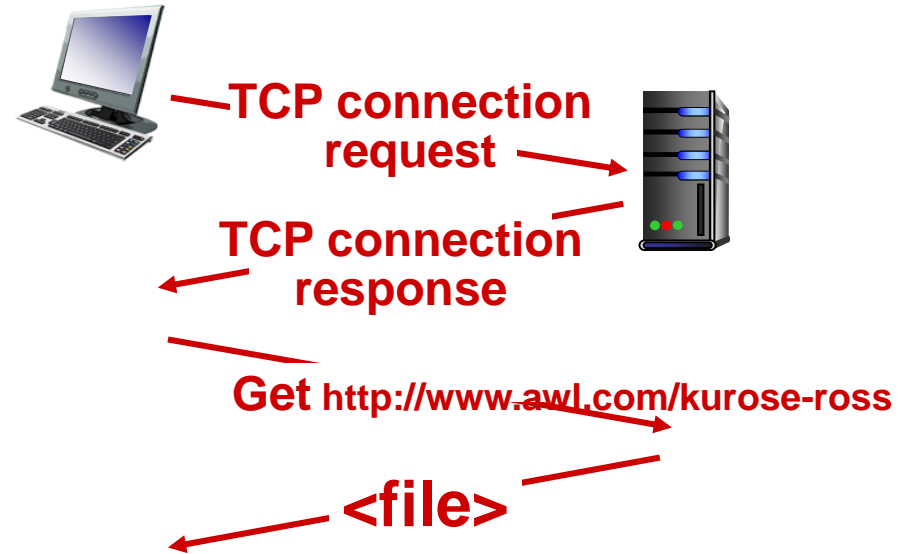
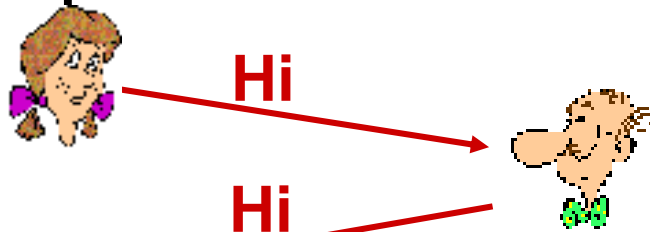
network protocols:

- 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



a human protocol and a computer network protocol:

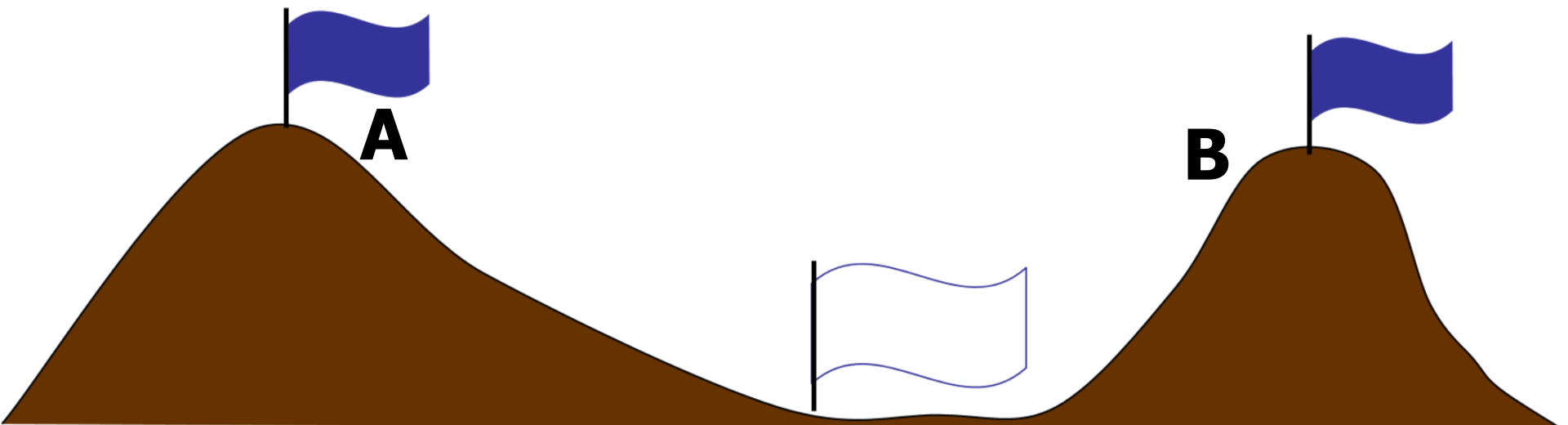




Reliability of communication

例子：蓝军-白军作战

- 占据东、西两个山顶的蓝军**A**和蓝军**B**与驻扎在山谷的白军作战。其力量对比是：单独的蓝军**A**或蓝军**B**打不过白军，但蓝军**A**和蓝军**B**协同作战则可战胜白军。
 - **A**和**B**可以派遣通信兵穿过白军营地向对方发送消息，但是通信兵有可能被白军截获。
 - 现蓝军**A**拟于次日正午向白军发起攻击。有什么方法能保证蓝军取得胜利？





明日正午进攻，如何？

收到“同意”

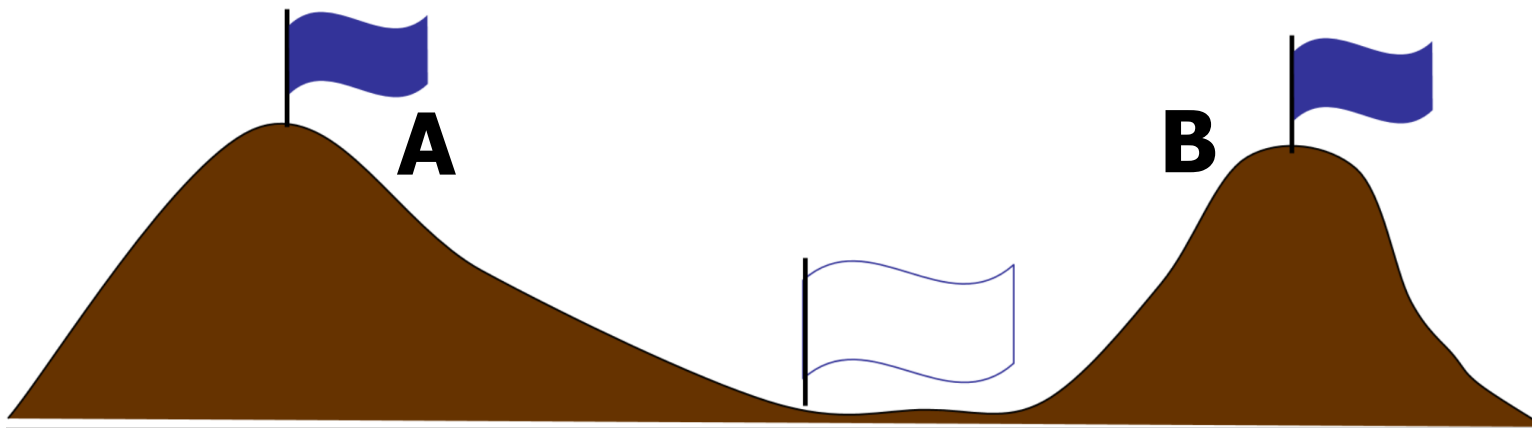
同意

收到：收到“同意”

...

这样的协议无法实现！
没有方法能保证蓝军100%取得胜利

...



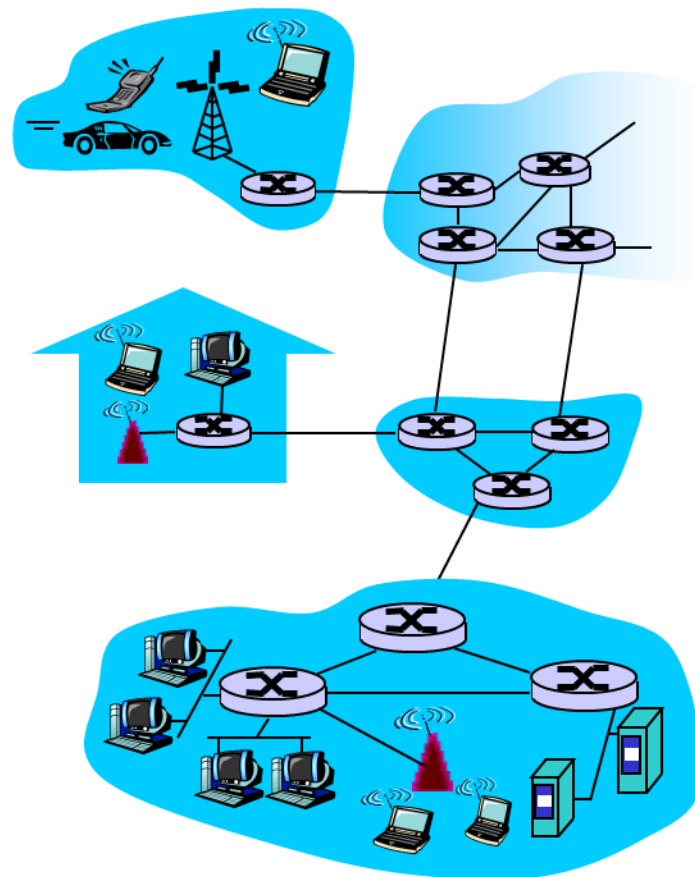


Q2: How to connect to the Internet?



Access Internet

- **Network edge**
 - Applications and hosts
- **Access networks**
 - Physical media
 - Wired and wireless communication links
- **Network core**
 - Interconnected routers
 - Network of networks





Network edge

- End systems (hosts)

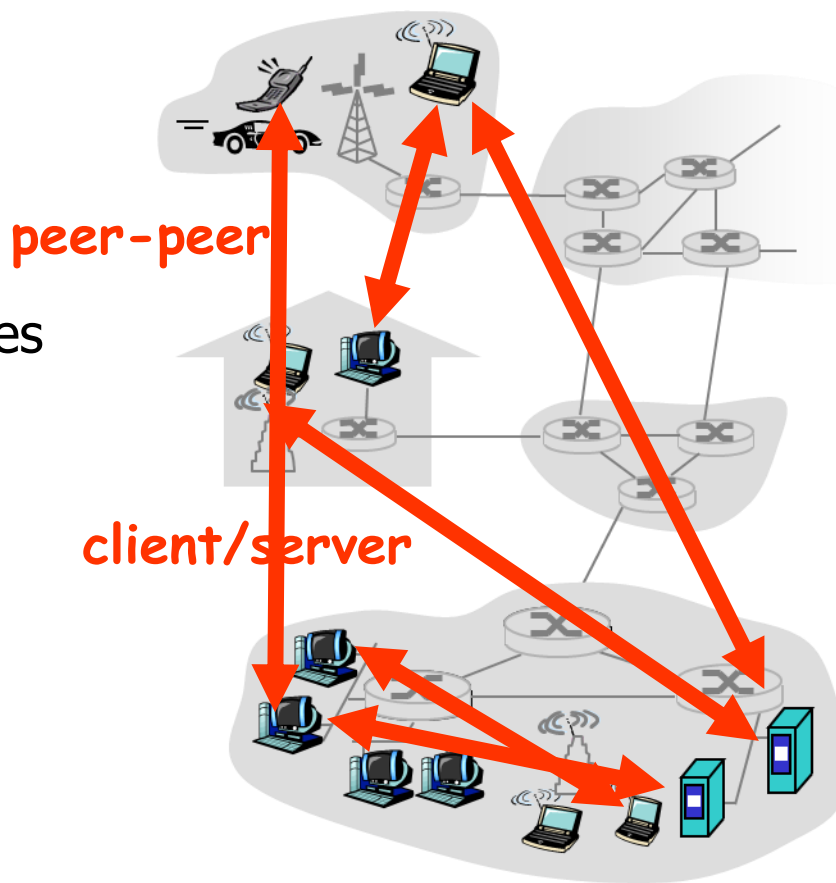
- Run application programs
- e.g. Web, Email

- Client/server model

- Client host requests, receives service from always-on server
- e.g. Web browser/server; Email client/server

- Peer-to-peer model

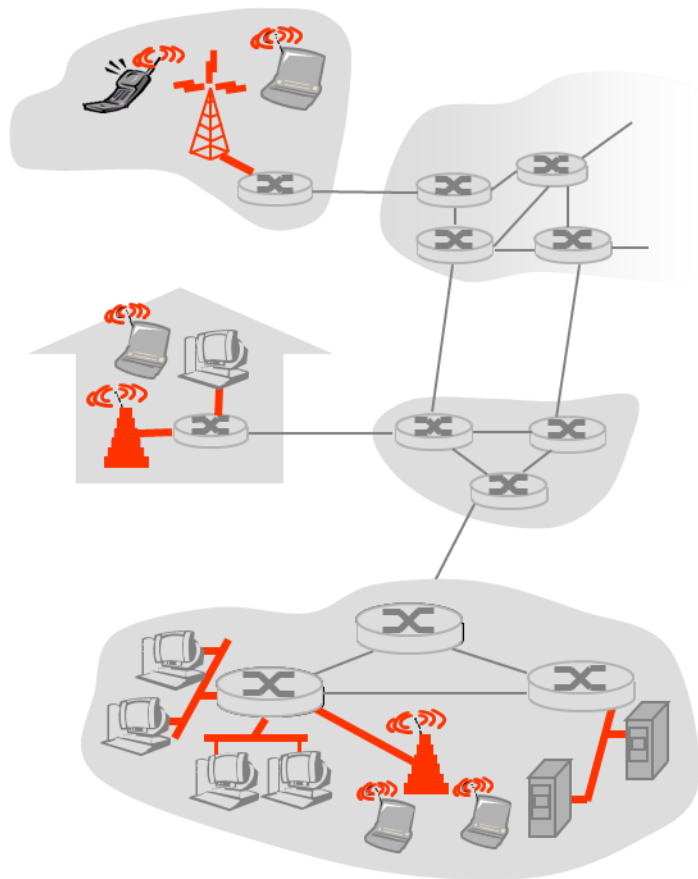
- Minimal (or no) use of dedicated servers
- e.g. Skype, BitTorrent





Access networks

- How to connect **end systems to edge router?**
 - Residential (Home) access networks
 - Institutional access networks (school, company)
 - Mobile access networks





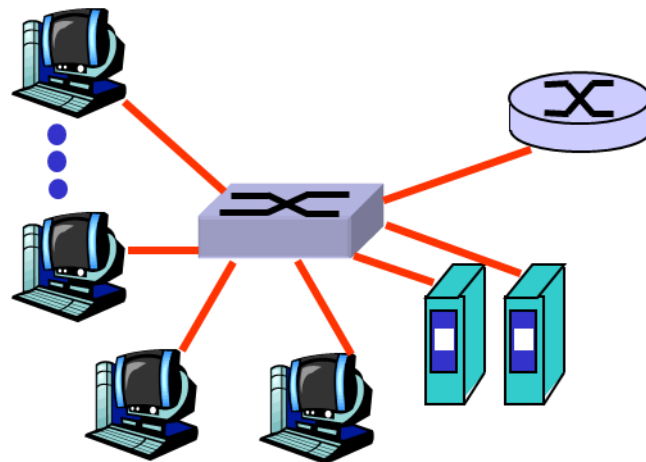
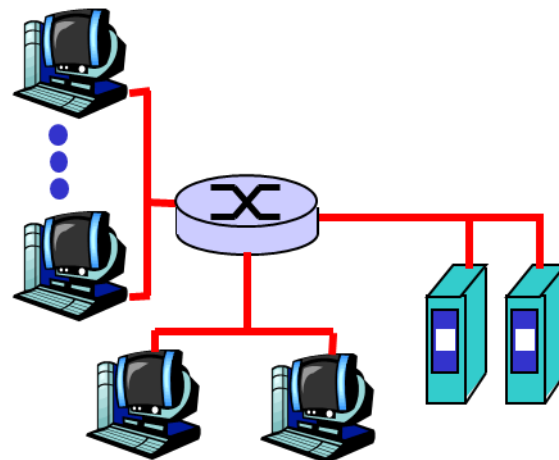
Residential access

- **Dialup via modem**
 - Up to 56Kbps direct access to router
- **DSL: digital subscriber line**
 - Deployment: telephone company
 - Up to 1 Mbps upstream, and 8 Mbps downstream
 - **Dedicated** physical line to telephone central office
- **HFC: hybrid fiber coax**
 - Asymmetric: up to 30Mbps downstream, 2 Mbps upstream
 - **Homes share** access to ISP router
 - Deployment: cable TV companies



Company access: Local Area Networks

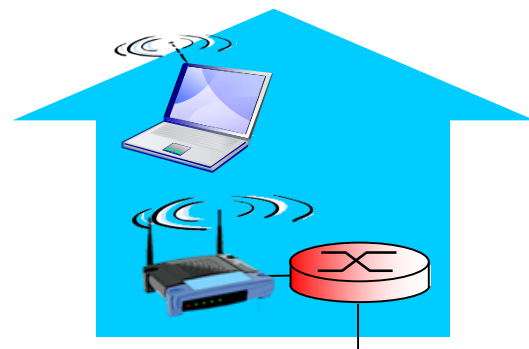
- Company/University **local area network** (LAN) connects end systems to edge router
- **Ethernet:**
 - 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
 - Modern configuration: end systems connect into backbone of Ethernet switches





Wireless access networks

- **Shared wireless media** connects end system to router
 - via base station, or “access point”
- **Wireless LANs:**
 - 802.11b/g (**WiFi**): 11 or 54 Mbps
- **Wider-area wireless access**
 - Provided by telecommunication operator, 10's Km
 - between 1 and 10 Mbps
 - 3G, 4G: LTE, WiMax



to Internet



to Internet



Physical media

- **bit:** propagates between transmitter/receiver pairs
- **physical link:** what lies between transmitter & receiver
- **guided media:**
 - signals propagate in solid media: copper, fiber, coax
- **unguided media:**
 - signals propagate freely, e.g., radio

twisted pair (TP)

- two insulated copper wires
 - Category 5: 100 Mbps, 1 Gpbs Ethernet
 - Category 6: 10Gbps





Physical media: coax, fiber

coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
 - multiple channels on cable



fiber optic cable:

- ❖ glass fiber carrying light pulses, each pulse a bit
- ❖ high-speed operation:
 - high-speed point-to-point transmission (e.g., 10' s-100' s Gpbs transmission rate)
- ❖ low error rate:
 - repeaters spaced far apart
 - immune to electromagnetic noise





Physical media: radio

- signal carried in electromagnetic spectrum
- no physical “wire”
- bidirectional
- propagation environment effects:
 - reflection
 - obstruction by objects
 - interference

radio link types:

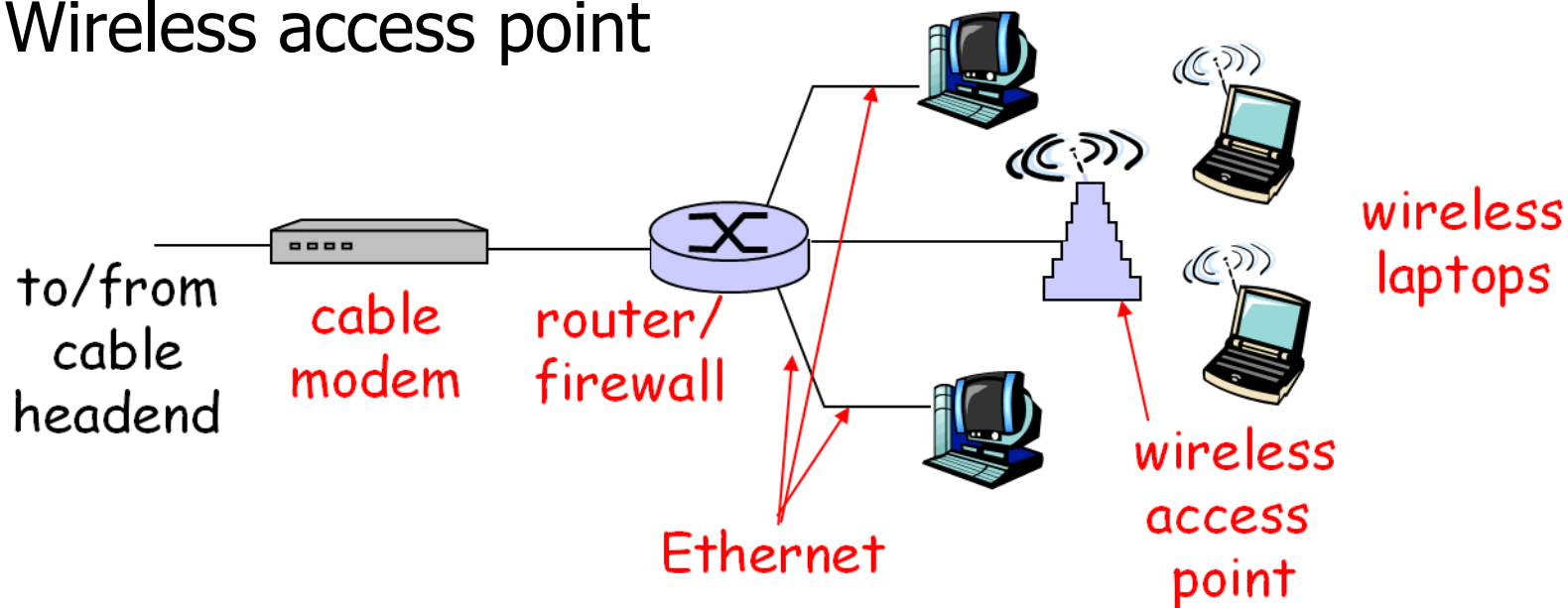
- ❖ **terrestrial microwave**
 - e.g. up to 45 Mbps channels
- ❖ **LAN (e.g., WiFi)**
 - 11 Mbps, 54 Mbps
- ❖ **wide-area (e.g., cellular)**
 - 3G cellular: ~ 1 Mbps
- ❖ **satellite**
 - Kbps to 45Mbps channel (or multiple smaller channels)
 - 270 msec end-end delay
 - geosynchronous versus low altitude



Example: a modern family

- A **home network** components:

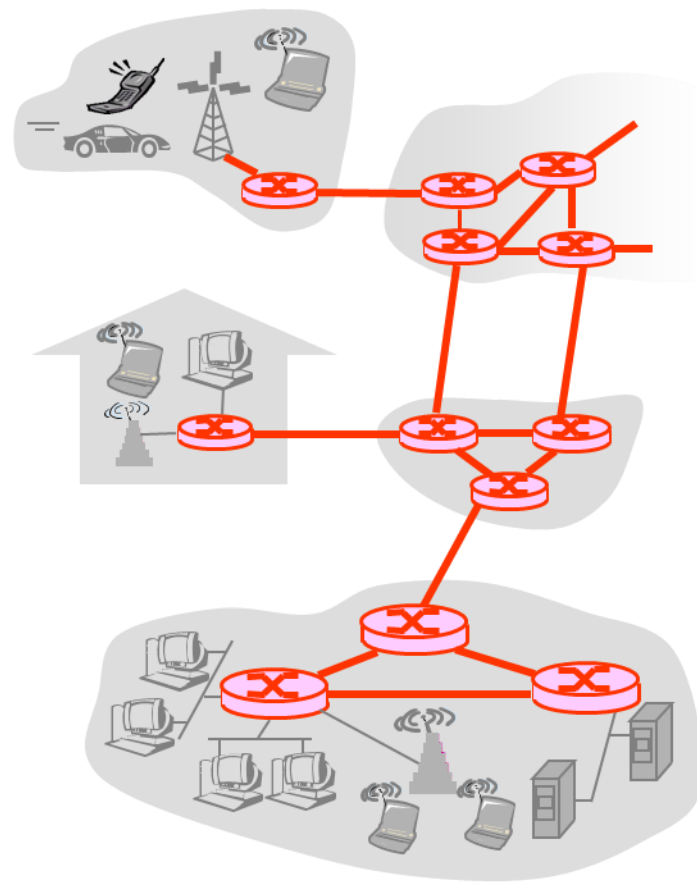
- DSL or cable modem
- Router/Firewall/NAT
- Ethernet switch
- Wireless access point





The network core

- Mesh of **interconnected routers**
- **Fundamental question**
 - How is data transferred through the net?
- **Circuit switching**
 - Dedicated circuit per call, e.g. telephone net
- **Packet-switching**
 - hosts break application-layer messages into packets
 - forward packets from one router to the next, across links on path from source to destination





■ 请归类：

- 属于网络边缘的是： _____
- 属于接入网络的是： _____
- 属于网络核心的是： _____

A 笔记本电脑； **B** 手机； **C** 路由器；

D 双绞线； **E** 智能家具； **F** 无线路由器；

G 服务器； **H** 同轴电缆； **I** 光纤； **J** 交换机



■ 请归类:

- 属于网络边缘的是: A B E G
- 属于接入网络的是: D F H I
- 属于网络核心的是: C J

A 笔记本电脑; **B** 手机; **C** 路由器;

D 双绞线; **E** 智能家具; **F** 无线路由器;

G 服务器; **H** 同轴电缆; **I** 光纤; **J** 交换机



**Q3: How to transfer
data in the network?**

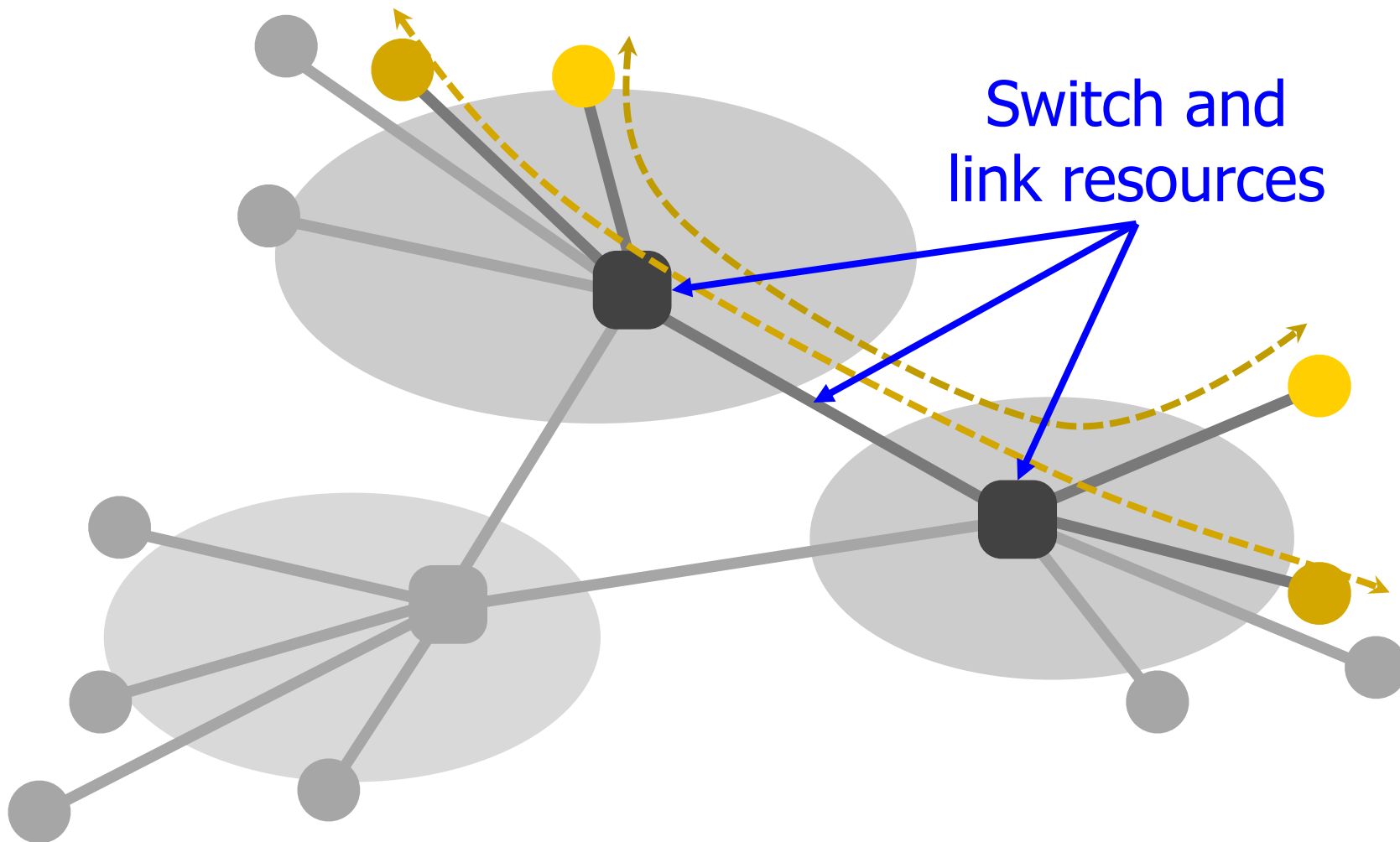


Switched networks

- End-systems and networks connected by switches instead of directly connecting them
- Allows us to scale
 - For example, directly connecting N nodes to each other would require N^2 links!



When do we need to share the network?





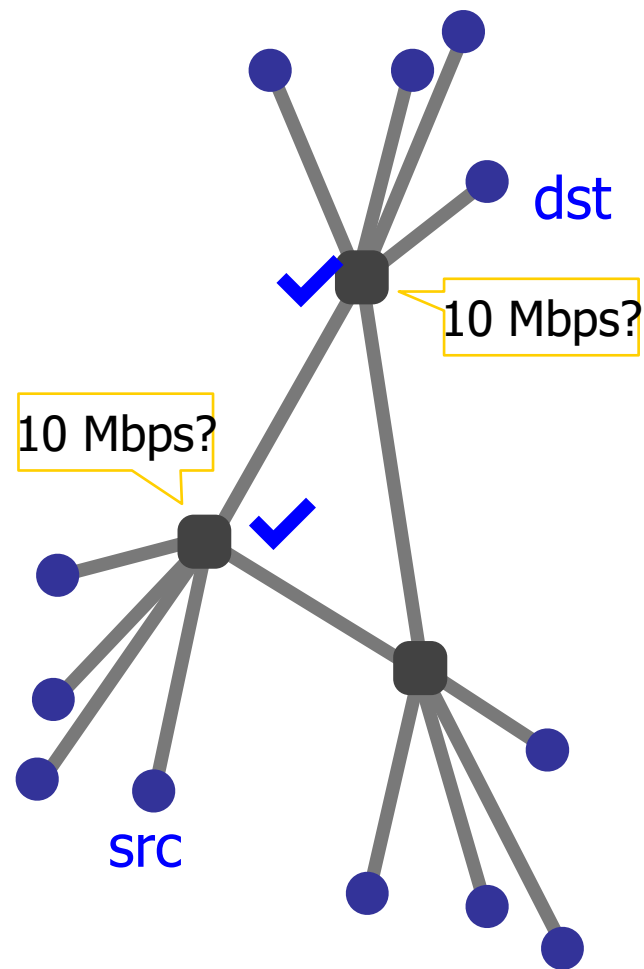
Two ways to share switched networks

- **Circuit switching**
 - Resource reserved per connection
 - Admission control: per connection
- **Packet switching**
 - Packets treated independently, on-demand
 - Admission control: per packet
- **Hybrid: virtual circuits**
 - Emulating circuit switching with packets (see text)



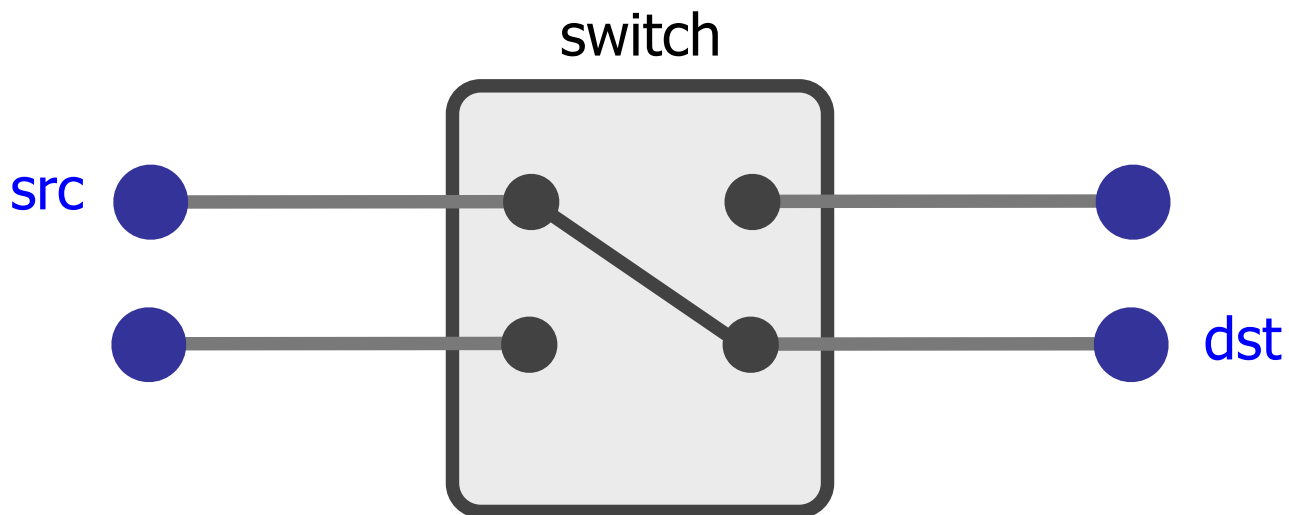
Circuit switching

1. **src** sends reservation request to **dst**
2. Switches create circuit *after* admission control
3. **src** sends data
4. **src** sends teardown request





Circuit switching



- Reservation establishes a "circuit" within a switch



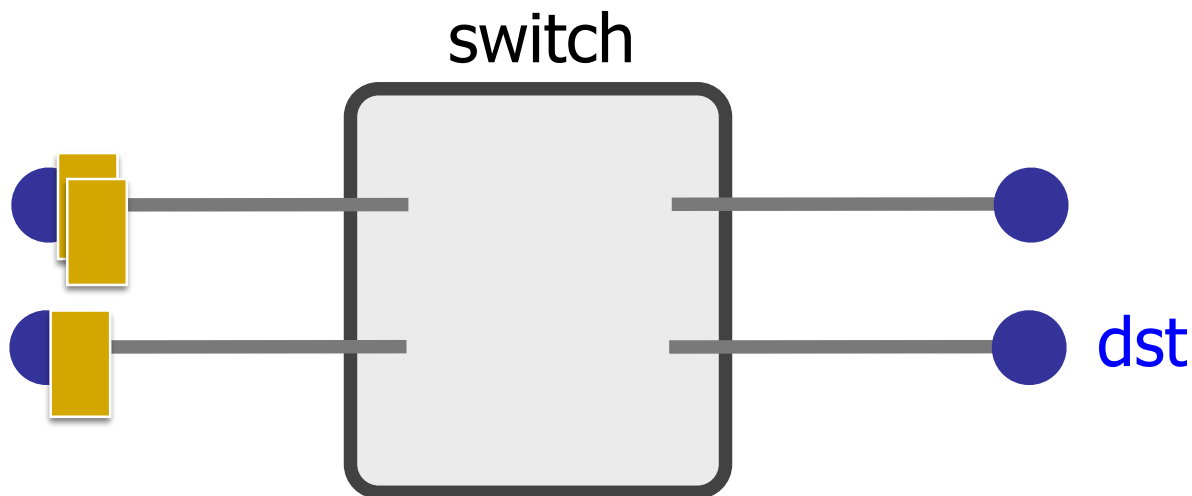
Circuit switching

- Pros
 - Predictable performance
 - Simple/fast switching (once circuit established)

- Cons
 - Complexity of circuit setup/teardown
 - Dedicated resources: Inefficient when traffic is bursty
 - Circuit setup adds delay
 - Switch fails → its circuit(s) fails



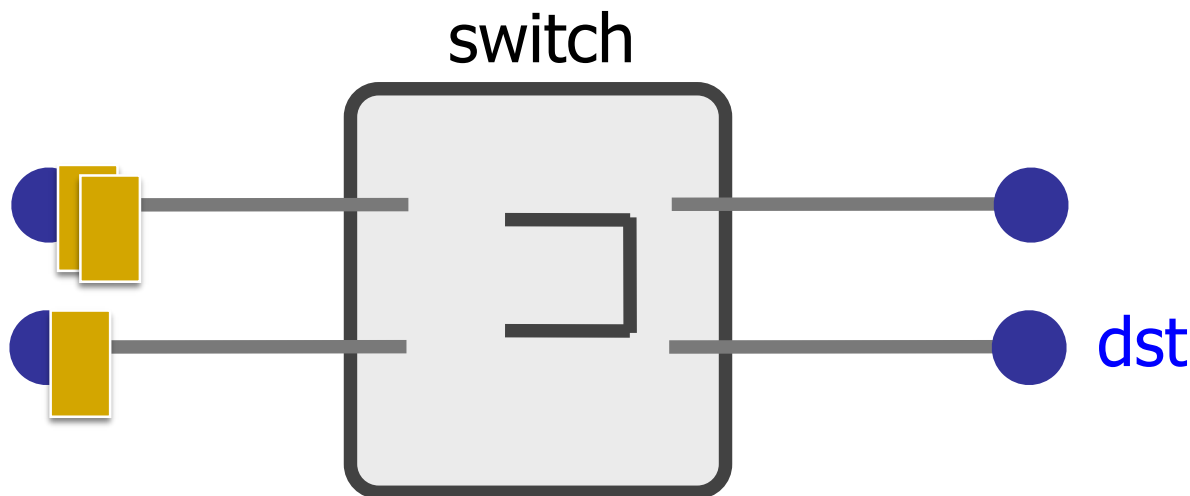
Packet switching



- Each packet contains destination (**dst**)
- Each packet treated independently



Packet switching

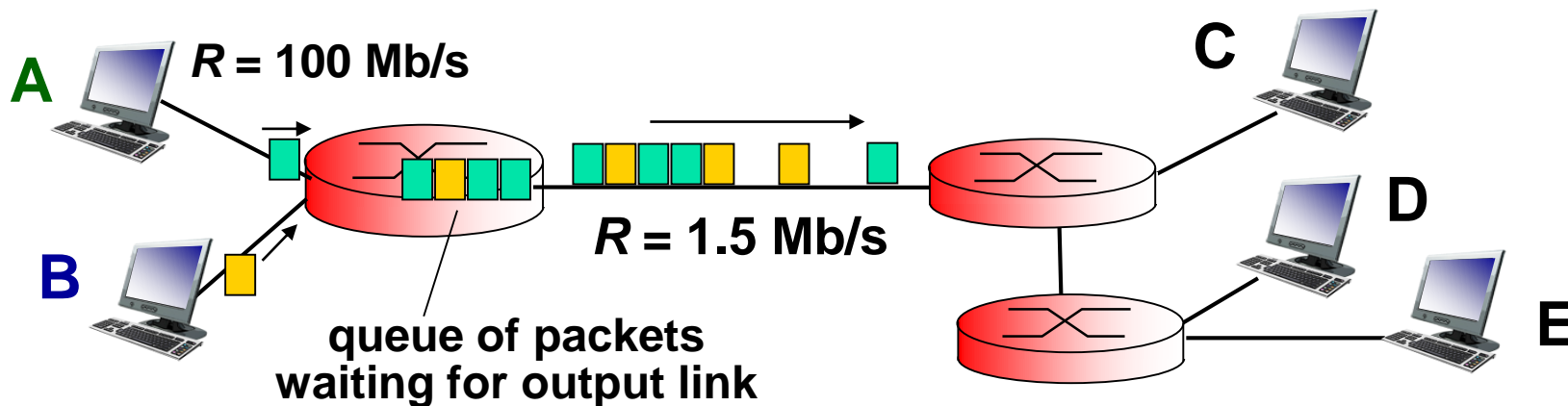


- Each packet contains destination (**dst**)
- Each packet treated independently
- **With buffers to absolve transient overloads**

Store and forward: packets move one hop at a time, stored (queued) at switches



Packet Switching: queueing delay, loss



■ Resource contention

- aggregate (burst-up) resource demand can exceed amount available

■ Congestion:

- packets will queue, wait for link use
- packets can be dropped (lost) if no memory to store them



Packet switching

■ Pros

- Efficient use of network resources
- Simpler to implement
- Robust: can “route around trouble”

■ Cons

- Unpredictable performance
- Requires buffer management and congestion control



Statistical multiplexing

- Statistical Multiplexing (统计多路复用): **Link bandwidth shared on demand** (按需共享)
- Allowing more demands than the network can handle
 - Hoping that not all demands are required at the same time
 - Results in unpredictability
 - Works well except for the extreme cases



Example: Statistical Multiplexing

Example:

- **N users share one link (10Mbps)**
 - **Each user requires 1Mbps**
 - **Each user: active 10%, idle 90%.**
- How many users are supported?**

Circuit Switching:

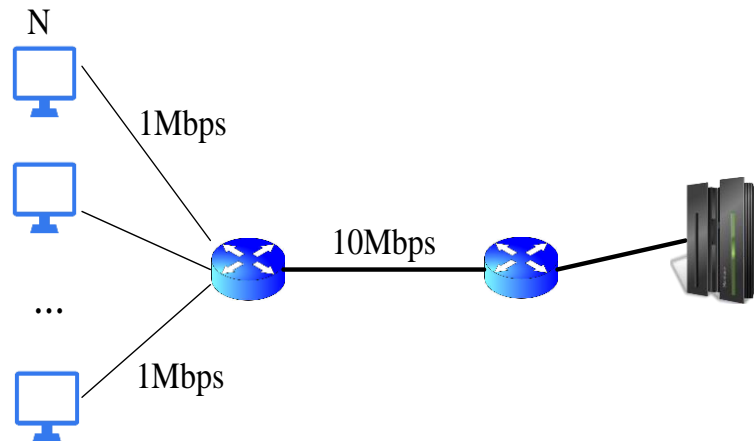
$N = 10\text{Mbps} / 1\text{Mbps} = 10$ users

Statistical Multiplexing:

Assume $N = 35$,

$\text{Prob}\{\text{active user} > 10\} \leq 0.0004$,

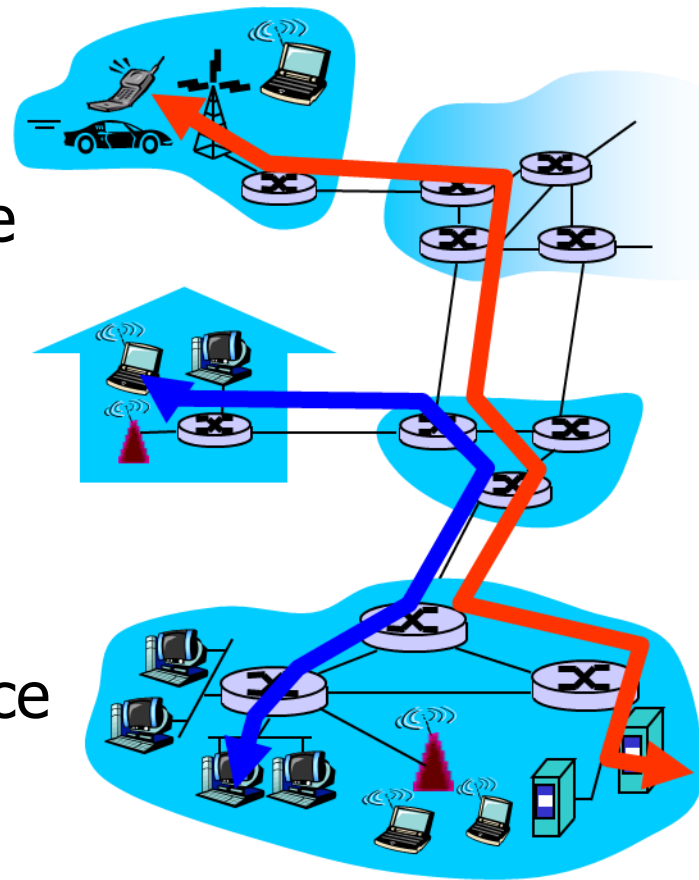
So for $N = 35$, with probability 0.9996 a user have bandwidth larger than 1Mbps.





Virtual Circuit

- **Circuit Switching + Packet Switching**
 - Routes or main cross roads are fixed
 - Resources shared, congestion control needed
 - Resources can be **preserved**, leading to different performance
 - Connection setup/teardown needed





Comparison

	电路交换	数据报分组交换	虚电路分组交换
传输通路	专用	非专用	非专用
连续性	连续传输	分组传输	分组传输
带宽	固定	动态使用	动态使用
路由	固定	动态	固定
时延	实时（只有呼叫建立时延）	分组传输时延	分组传输时延+呼叫建立时延
扩展性	差（接入用户有上限）	好（用户数量可动态扩充）	较好（用户数量动态，由拥塞控制来保证服务质量）



南京大學

NANJING UNIVERSITY



Thank You !