An Intro of Computer Networking

Problems, Principles and Solutions

- Problem, 问题
- Principle, 原理
- Solution, 方案

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2018 Spring

Outline

- Histories and Concepts
- Core Problems and Principles
- The current widely used solution: the Internet
  - That is, TCP/IP and Ethernet

- Outline, 提纲
- Concept, 概念
- TCP/IP, 核心网络协议
- Ethernet, 以太网
- The Internet, 互联网

Histories and Concepts

Communicating a piece of data between two locations geographically separated?

Before Computer Networking

- 550BC, **Postal Service**, by man on horses … …
- 150BC, **Smoke Signals**, by Chinese soldiers on the Great Wall
- 1150, **Carrier Pigeons**, … … (still used today?)

Entering electronic age

- 1876, **Telephone**, by Alexander Graham Bell
  - More then 4.16 billion people own mobile phones today
- 1920, **Commercial Radio**
  - More than 44, 000 Radio stations worldwide
- 1925, **TV**
  - 4 hours watching TC per day, my mum does!!

- Postal, 邮政
- Pigeon, 鸽子
- Telephone, 电话
- Commercial Radio, 商业 电台
- worldwide, 全球范围

Before computer networking

- 1965, **Email** (what? Before the Internet?)
  - MIT, users leave e-message in the Mainframe to who using the same computer

➢ Mainframe,
大型计算机

Try …… 'Communication through the ages' **Data Visualization and Infographics (数据可视化)**
@ https://www.atlassian.com/communication-through-the-ages-infographic

The Internet Age

- 1969, **the Internet**, …. ….
  - Starting as a US military project, ARPANET serves as the foundation for modern Internet as we know it.
- 1978, **Markup Languages**
  - HTML is just one type, and is the foundation of WWW (Web).
- 1990, **Search Engines**
  - **Google** really makes life better! But very sad ….
- 1994, **Wikis** (means 'fast' in Hawaiian)
  - https://www.wikipedia.org/ , make sure you try it!!!

- foundation, 基础
- Markup Language, 标记语言
- Search Engines, 搜索引擎
- Wikipedia, 维基百科

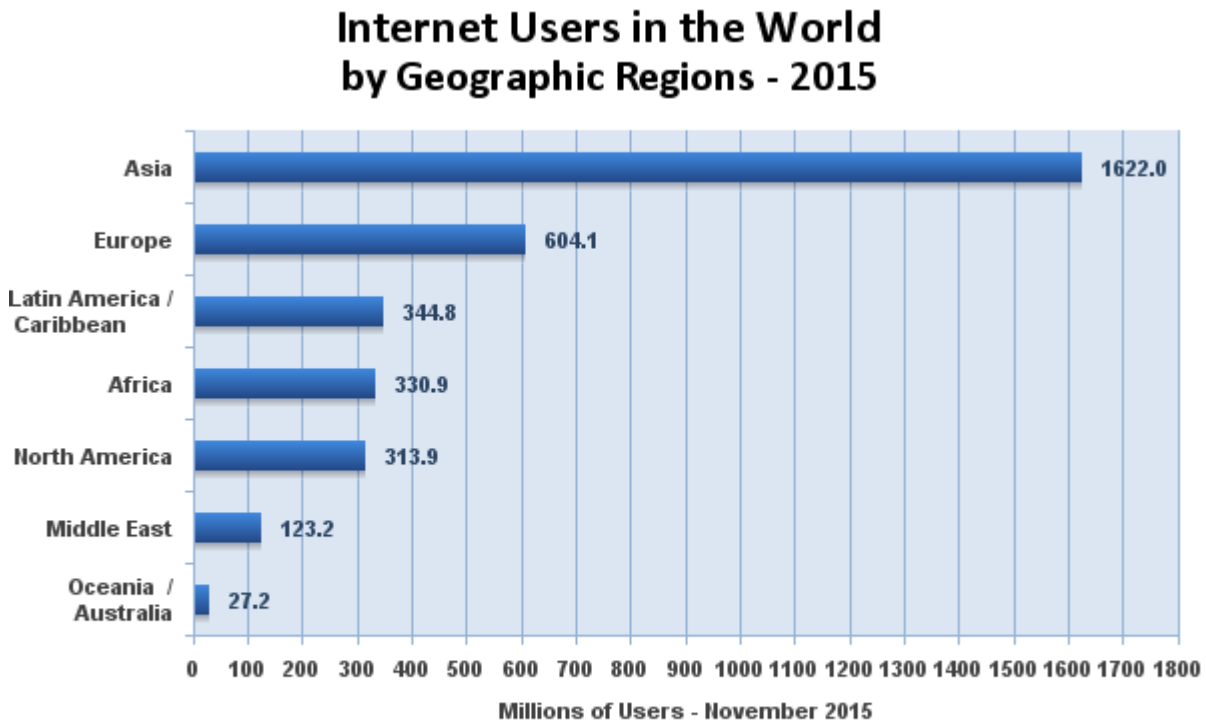
The Internet Age

- 1996, **Instant Messaging**, or IM for short
  - Gave us the wonderful world of emoticons
- 2002, **Social Networking**
  - MySpace, Facebook, … .. (中国呢？人人网 .. ..?)
- 2006, **Mirco-blogging**
  - Tweet, 微信, ...
- 2011, **Online Content Collaboration**
  - Enjoy the Cloud!

- Instant Messages, 即时通信
- Social Networking, 社交网络
- Mircoblogging, 微博
- Collaboration, 协作
- The Cloud, 云(计算)

How big is the Internet?

@http://www.internetworldstats.com/stats.htm

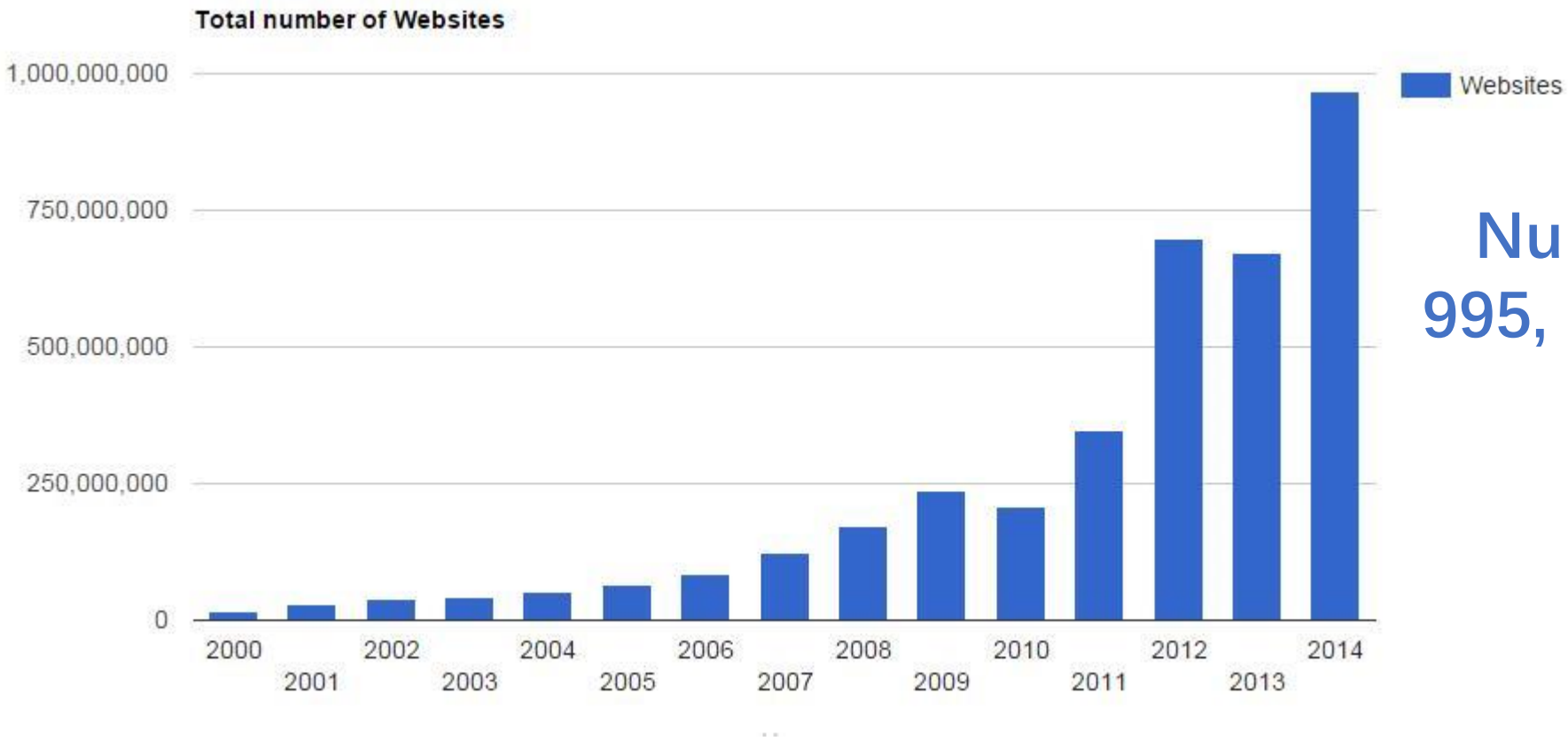


Source: Internet World Stats - www.internetworldstats.com/stats.htm
3,366,261,156 Internet users estimated for November 30, 2015

Number of internet users
3,366,261,156 at Nov 30, 2015
> 33 亿

How big is the Internet?

@http://www.internetlivestats.com/total-number-of-websites/



Number of websites
995, 152, 321 at Feb 27, 2016
约 10亿

How big is the Internet?

http://www.internetlivestats.com/one-second/

33,238 GB of Internet traffic in 1 second

53,068 Google searches in 1 second

117,717 YouTube videos viewed in 1 second

… …

So, what is the Internet?

Or, more fundamentally, Computer Networks

- A computer network facilitates networking devices and data links to connect geographically separated computers together, enabling sharing of network resources and **message transmission** by well-established network protocols and applications.

Dr. Chen's definition, might not be comprehensive.

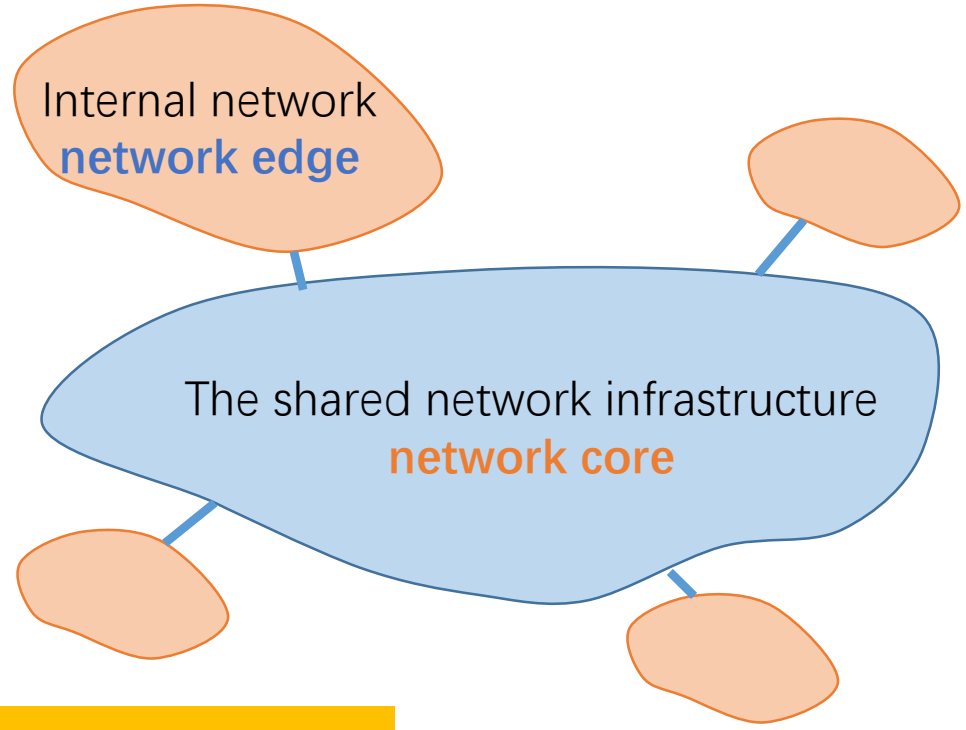
- The **best-known** computer network is the **Internet**.

- Facilitate, 利用
- Networking device, 组网设备
- Data link, 数据线路
- Well-established, 完善的
- Network protocol, 网络协议

Some facts of the Internet

Oh, …, it is shared and open connected

- Not built or controlled by a person, an organization, a nation … …
- No one knows the exact structure or topology; it is just like a cloud!
- But, the cloud is real and physically exists, full of **routers**, **switches**, **computers** and **cables** and **lines**.
- For an end user, she or he only understands her or his own network, known as internal or private network.
- All these internal networks connect to a shared network infrastructure, hence connecting each computer together.



- organization, 机构
- structure, 结构
- topology, 拓扑
- router, 路由器
- switch, 交换机
- Internal network, 内网

Access Networks

great diversity!!!

Up Link

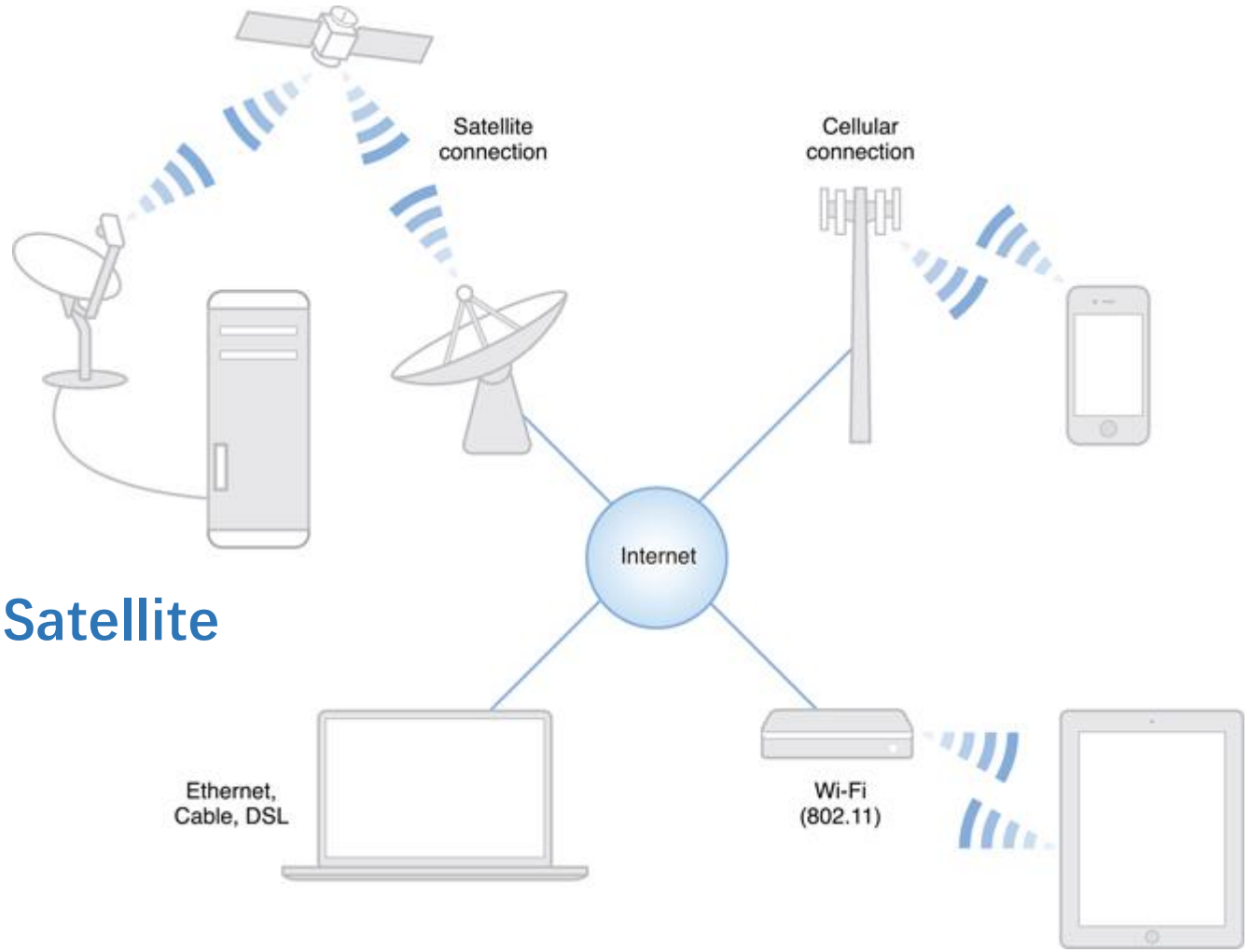
Down Link

Location:

- Home network
- Enterprise network
- Mobile network

Tech:

- DSL, Cable, FTTH, Dial-Up, and Satellite
- Ethernet and WiFi
- 3G, LTE (4G) and 5G



Hardware of the Internet

the real stuffs you can actually touch … …

- All call network devices, but they play quiet different roles.
  - Some resides in the network edge, used by end users, including
    - Computers (desktops, laptops, tablets, mobile phone, etc.), known as end systems or hosts.



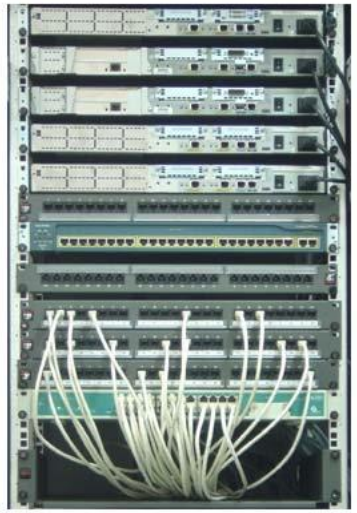

    - networking devices, repeaters, hubs, switches, routers, moderns, etc.


- Network device, 网络设备
- Desktop, 台式机器
- Laptop, 笔记本
- Tablet, 平板电脑
- Mobile/Smart phone, 移动、智能手机
- End systems or hosts, 终端系统、主机
- Repeater, 中继器
- Hub, 集线器
- modern, 猫，调制解调器

Hardware of the Internet

the real stuffs you can actually touch … …

- All call network devices, but they play quiet different roles.
  - Others resides in the network core, managed by network service providers.
    - Mainly, high-performance routers
    - File servers, Mail servers, DNS servers, … …

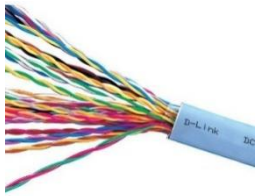


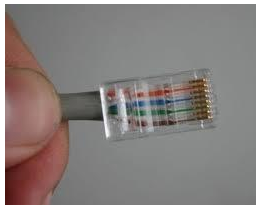
- Network Service Provider, 网络服务提供商
- High performance router, 高性能路由器
- File/Mail/DNS server, 文件，邮件，域名服务器

Hardware of the Internet

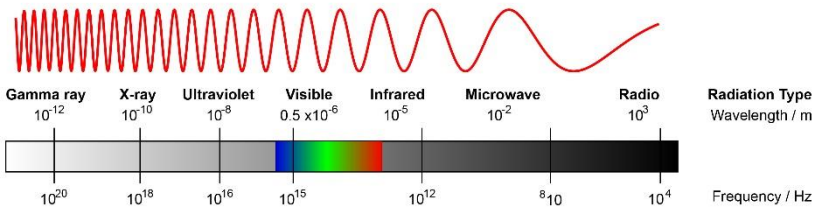
the real stuffs you can actually touch … …

- All mentioned devices need to be connected by data links or physical media, which can be
  - Wired, for example: twisted-pair copper wires, coaxial cables, fiber optics cables, … …





  - Or wireless, i.e., electromagnetic spectrum



- Physical media, 物理媒介
- Twisted-pair copper wire, 双绞线
- Coaxial cable, 同轴电缆
- Fiber optics cable, 光纤
- Electromagnetic spectrum, 电磁波

Hardware of the Internet

the real stuffs you can actually touch … …

- A network interface card (NIC) or controller is a hardware component that connects a network device to a computer network.
  - Old fashion NICs were commonly implemented on expansion cards that plugged into a computer bus.
  - Now, mostly are Motherboard integrated.

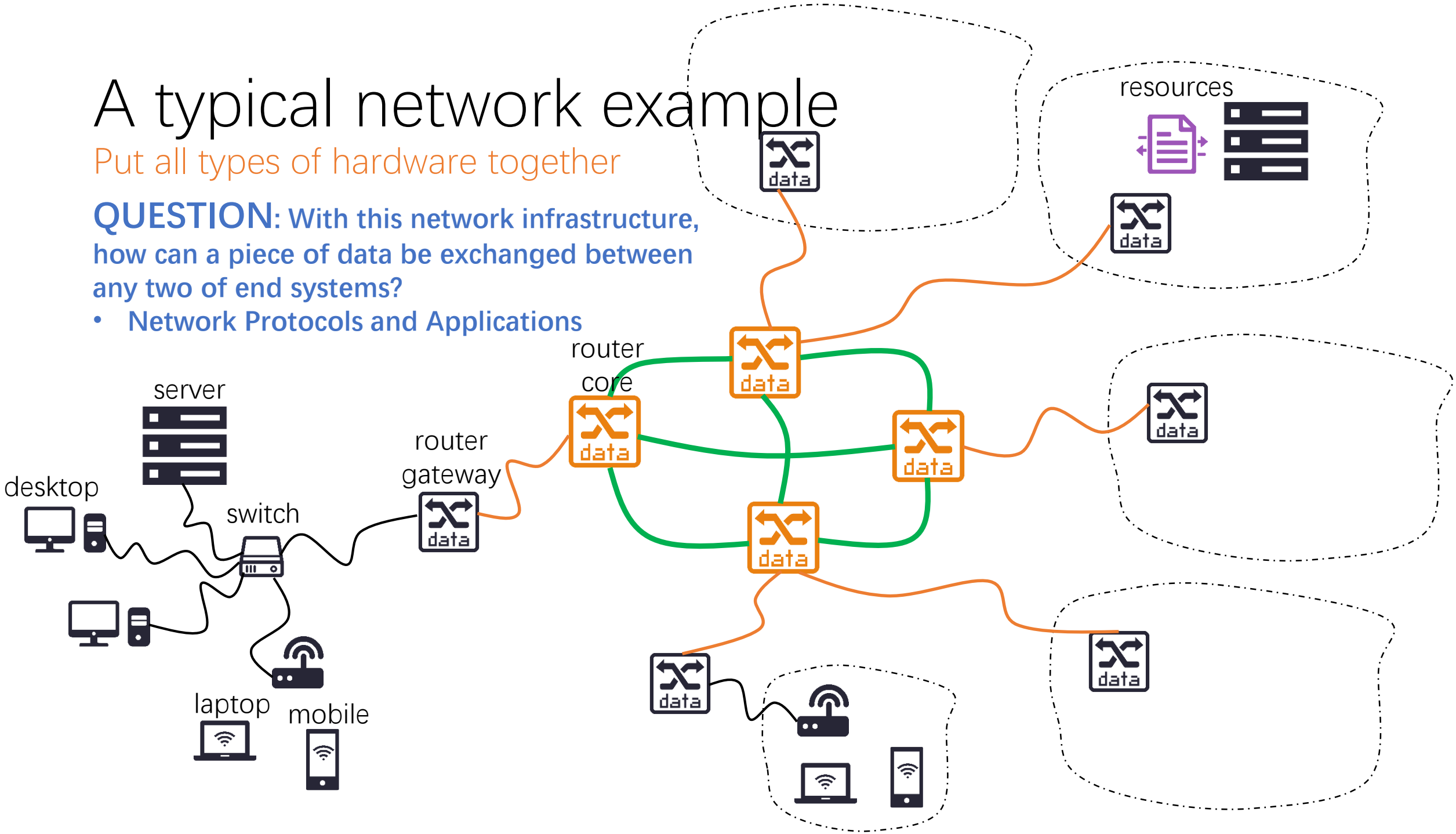
- Network interface card, 网卡
- Expansion card, 扩展网卡
- Plug into, 插入
- Computer bus, 计算机总线
- Motherboard Integrated, 主板集成

A typical network example

Put all types of hardware together

QUESTION: With this network infrastructure, how can a piece of data be exchanged between any two of end systems?

- **Network Protocols and Applications**

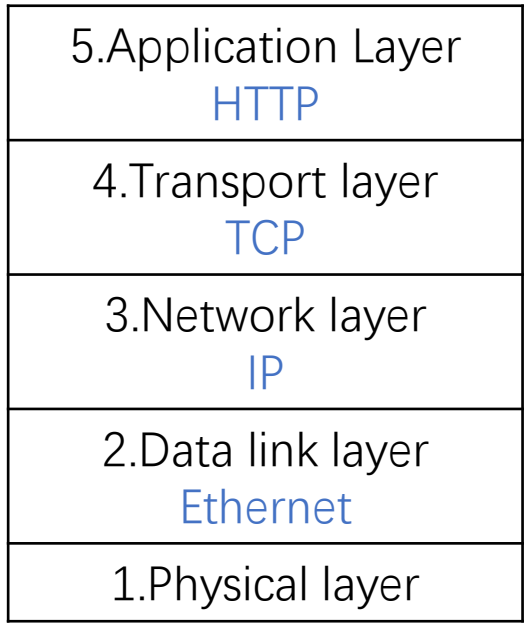


Software of the Internet

Protocols are what you have to master in this course

- A **network protocol** defines rules and conventions for communication between network devices. That is, it is the language talked by devices.
- Network protocols include mechanisms for devices to identify and make connections with each other, as well as formatting rules that specify how data is packaged into messages sent and received.
- We break a complex problem into a set of small ones to handle!! **(the layered architecture, divide and conquer, 分而治之)**
- Instead of having one protocol for achieving message transmission, we have a set of protocols in each layer!
  - HTTP, TCP, IP, ARP, DNS, …. ….

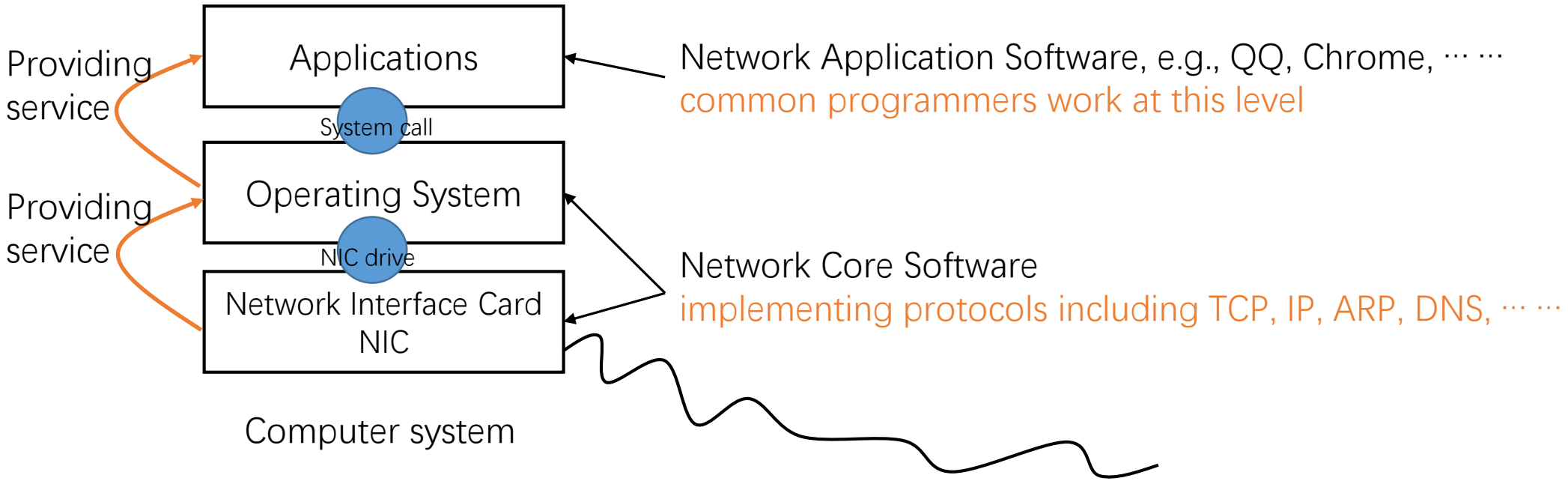
- Network protocol, 网络协议
- Mechanism, 机制



Network Stack

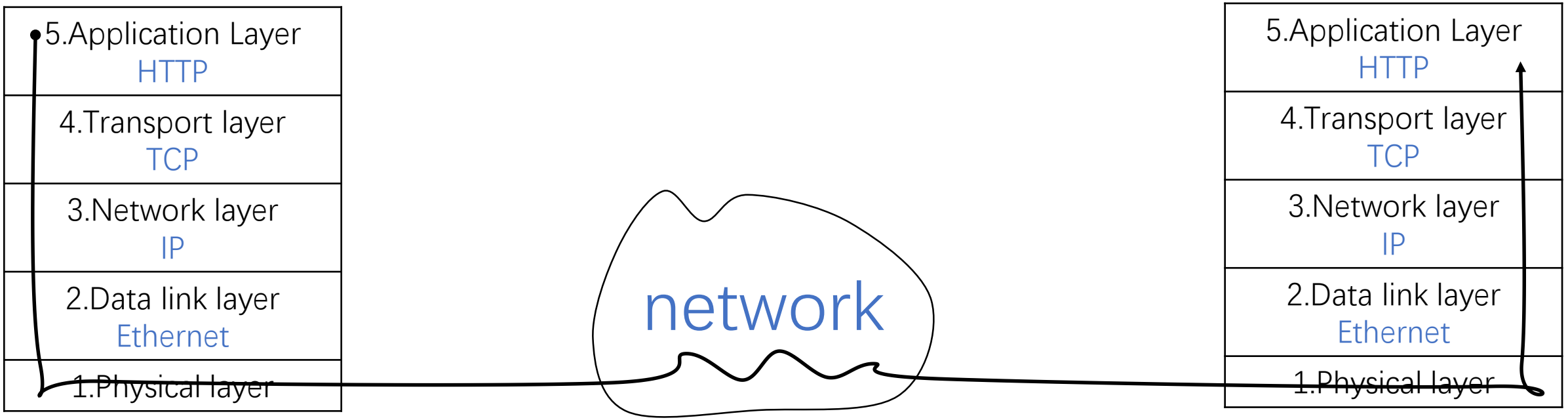
Software of the Internet

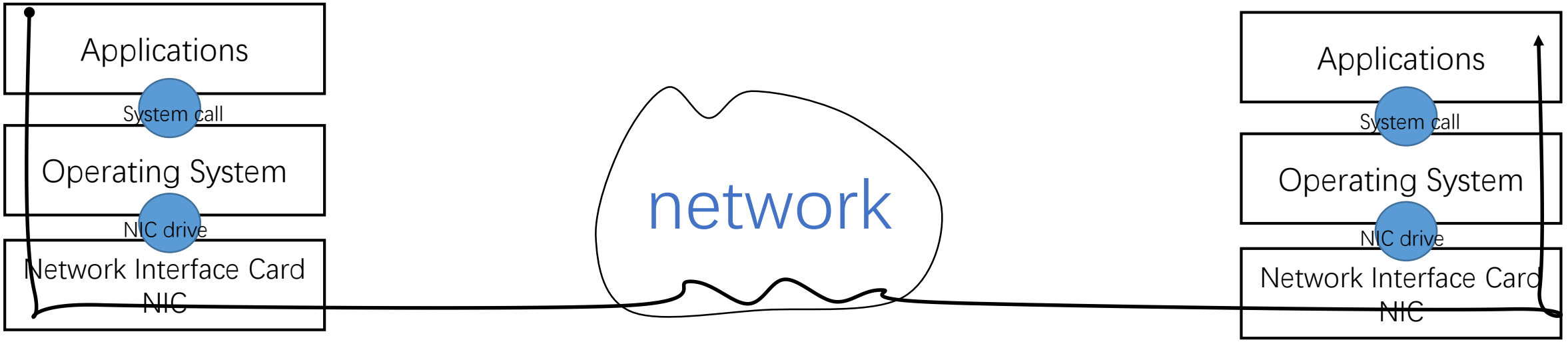
Protocols must be implemented as software somehow and somewhere



Network applications are directly used by end users, and must rely on the underlining network core software/protocols for data communication.

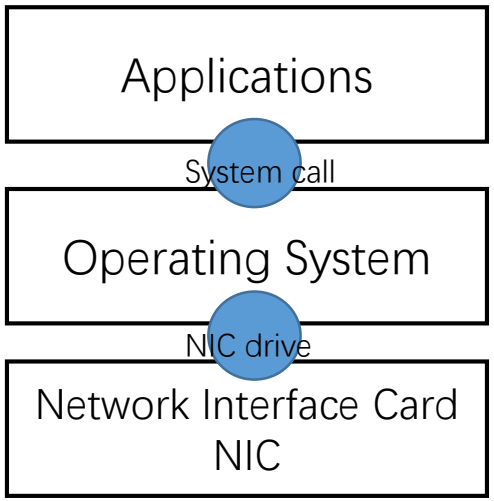
A close look of message transmission





Discussions: why layering?

5.Application Layer HTTP
4.Transport layer TCP
3.Network layer IP
2.Data link layer Ethernet
1.Physical layer

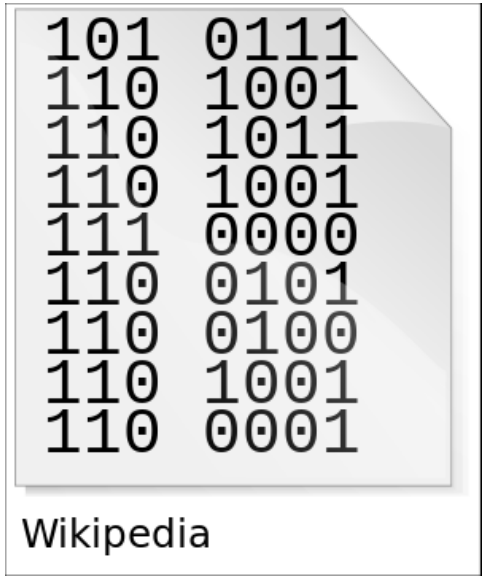


Information, Data, Messages and Packet

Basic terms

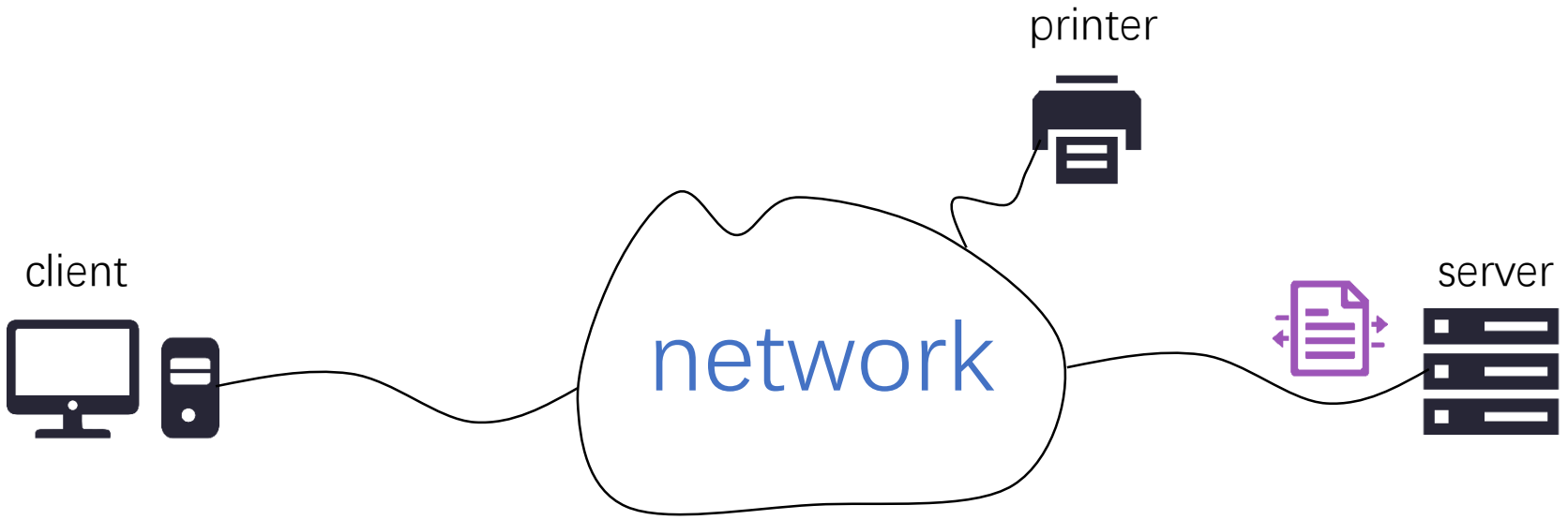
- In the computer world, Information or data is conveyed as the content of a message; a highly abstract form or nonce.
- Information can be encoded into various forms for transmission and interpretation.
  - **Binary system: {1010111 1101001} as bit streams**
- A message is a **discrete unit** of communication intended by the source for consumption by some recipient or group of recipients.
- A message may be delivered by various means, including carrier pigeon, computer network, etc.
- Data is packaged into messages when being sent and received.
  - So called **data packets**

- Information, 信息
- Message, 消息
- discrete, 离散
- consumption, 使用
- recipient, 接受者
- Binary system, 二进制系统
- Bit stream, 比特流
- Packet, 数据包



Message Transmission and Resource Sharing

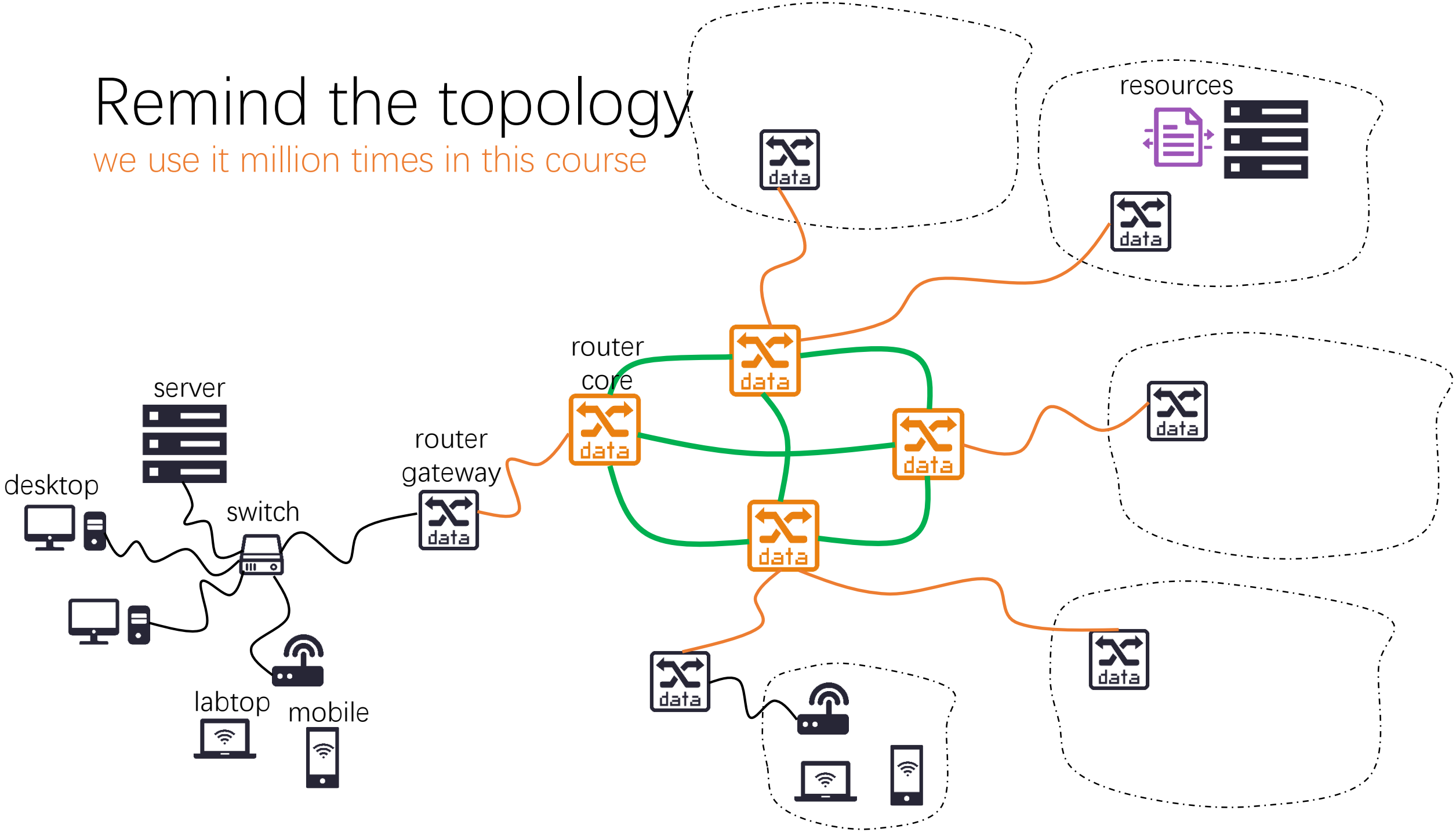
- Main purposes
  - Message transmission: transmit messages from one computer to another; this is the fundamental one!
  - Resource sharing: use resources (e.g. a printer) attached to the network.
- The client and server (C/S) computing or communication model



Core Problems and Basic Principles

Remind the topology

we use it million times in this course

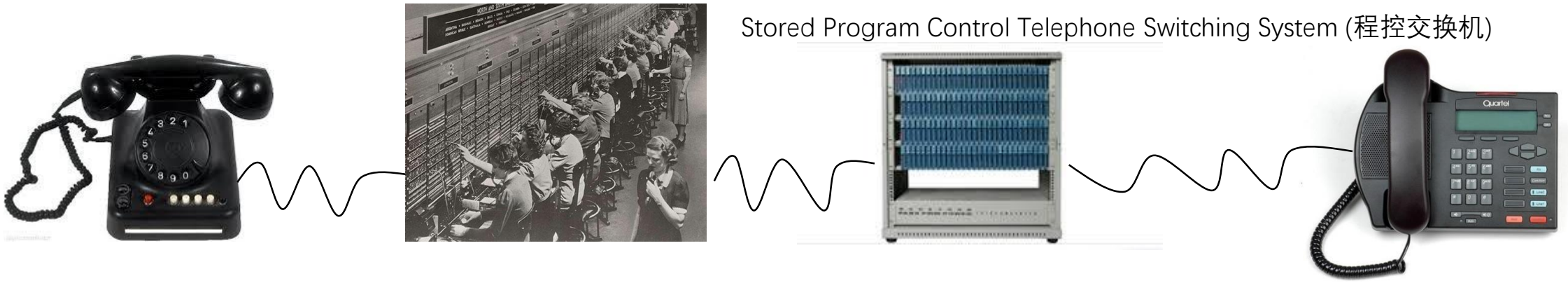


Problem 1: the Efficiency Problem

Sharing the network infrastructure efficiently

- FACTS: The network is a shared infrastructure, not controlled by a single entity and used by billion of users in the same time.
- QUESTION: in what way we can use the network most efficiently?
  - The ubiquitous telephone network might be a good example to learn.
    - What happens when you make a phone call to your parents?

➢ infrastructure, 基础设施

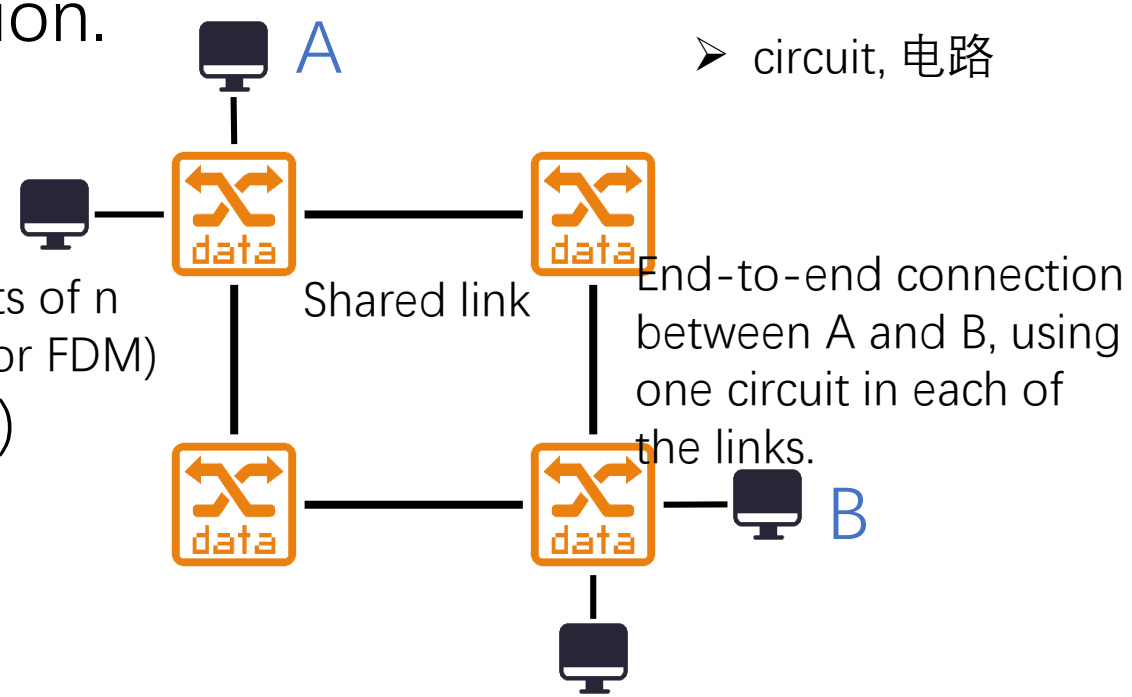


A dedicated connection must be established before you can talk to the person intended.

Circuit Switching: guaranteed rate transmission

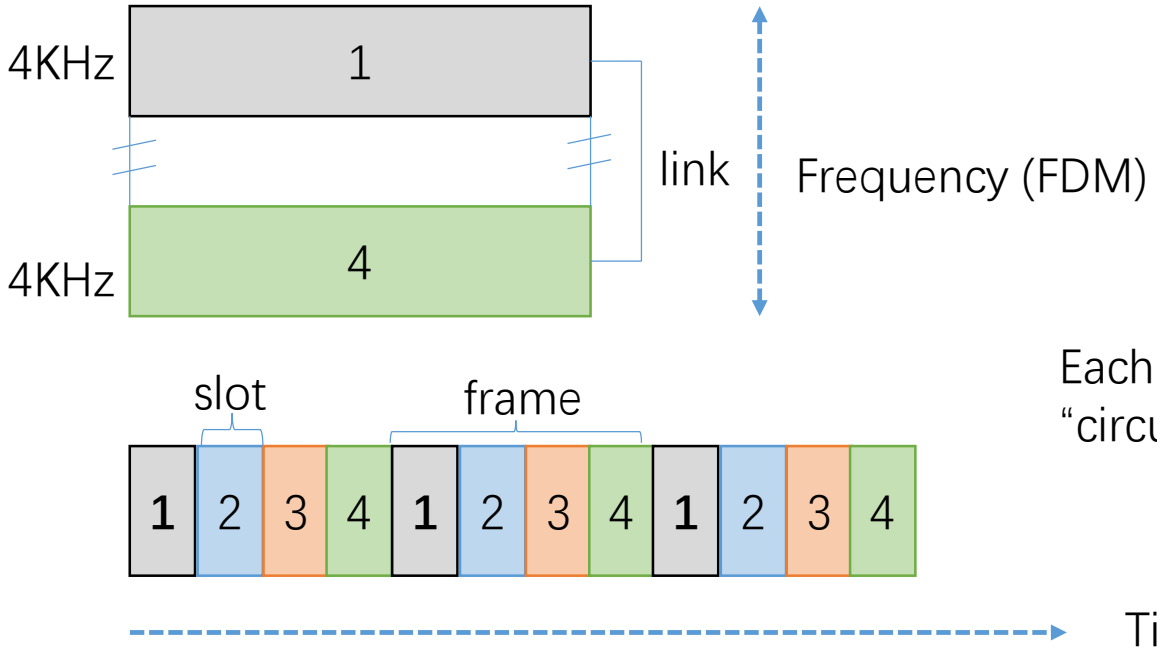
A bona fide connection must be reserved

- An end-to-end connection must be established before message transmission.
- Resources needed along a path (buffers, link transmissions rate) to provide communication are reserved for the duration of the communication session.
- This connection is called a circuit.
- A circuit in a link can be implemented by:
  - Frequency-Division Multiplexing (FDM)
  - Time-Division Multiplexing (TDM)

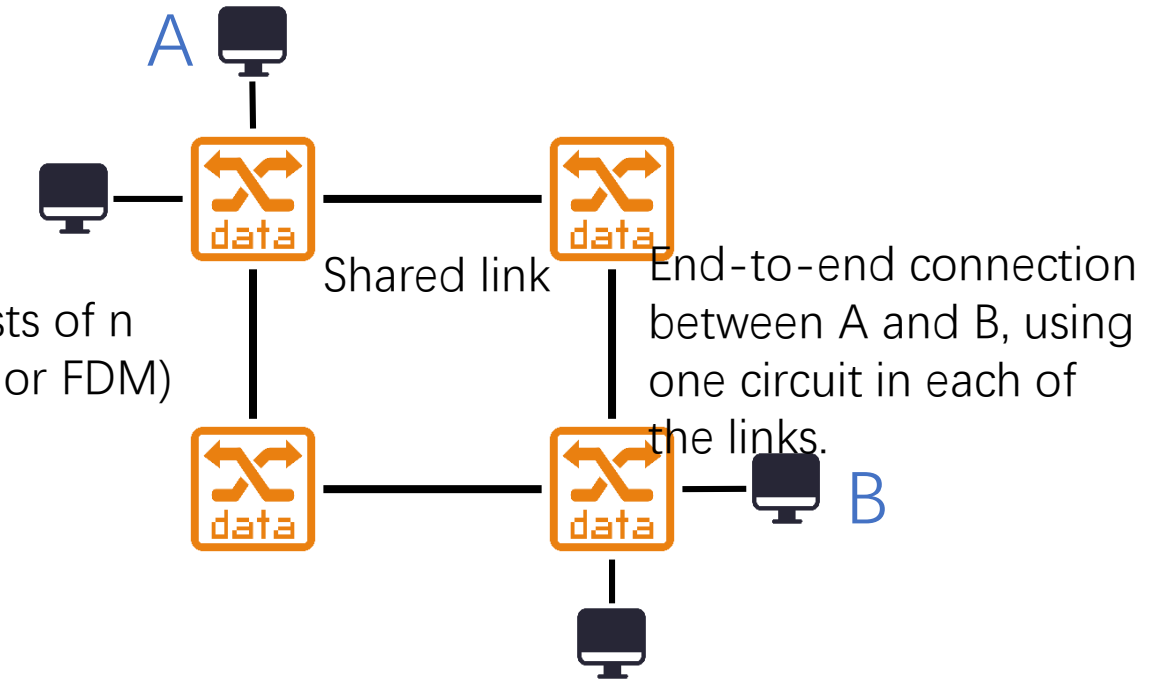


➢ circuit, 电路

Multiplexing in Circuit Switch Networks



Each link consists of n "circuits" (TDM or FDM)



With FDM, each circuit continuously gets a fraction of the bandwidth.
With TDM, each circuit gets all of the bandwidth periodically during brief intervals of time (that is, during slots).

The information source matters!!

Making Circuit Switch reasonable

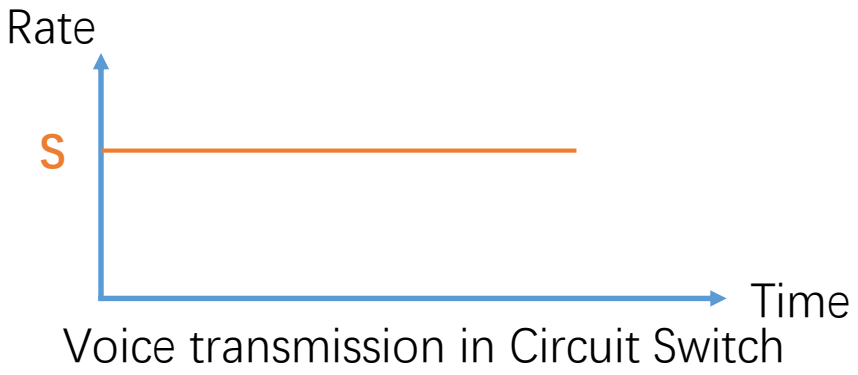
- Coding, transmitting, buffering and decoding is four necessary phrase in voice communication.
- Coding Speed S: b/s or bps (bit per second)
  - S = R * F, where F is the sampling frequency, and R is the number of bits for each sample value.
  - For sample, R = 8 bits, F = 8KHz, then S = 64Kbps!
- In analogy telephone system, if the voice is coding at 64Kbps, it must be send out at this constant rate!
- So, guaranteed rate transmission is an inherent requirement for voice communication in old analogy telephone system.
  - That make Circuit Switch, which set up a connection for reserving bandwidth, reasonable!

➢ analogy, 模拟

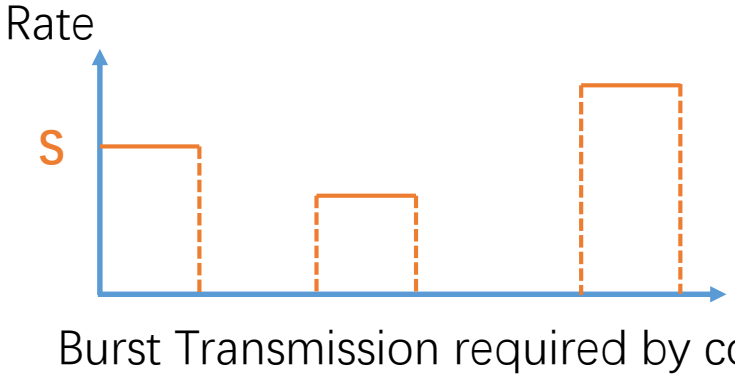
The information source matters!!

Computer sends data in a burst way

- Computer often buffers data, then want to send a bunch of data in a very short period!
  - Consider you start to send a video to you friend, but before that you does not need the network at all.
- So, as an info source, computer use the network in a burst way.
  - Most of the time, does not transmit any data, but,
  - when sending, requires a very high transmission rate (if possible)!!



Voice transmission in Circuit Switch



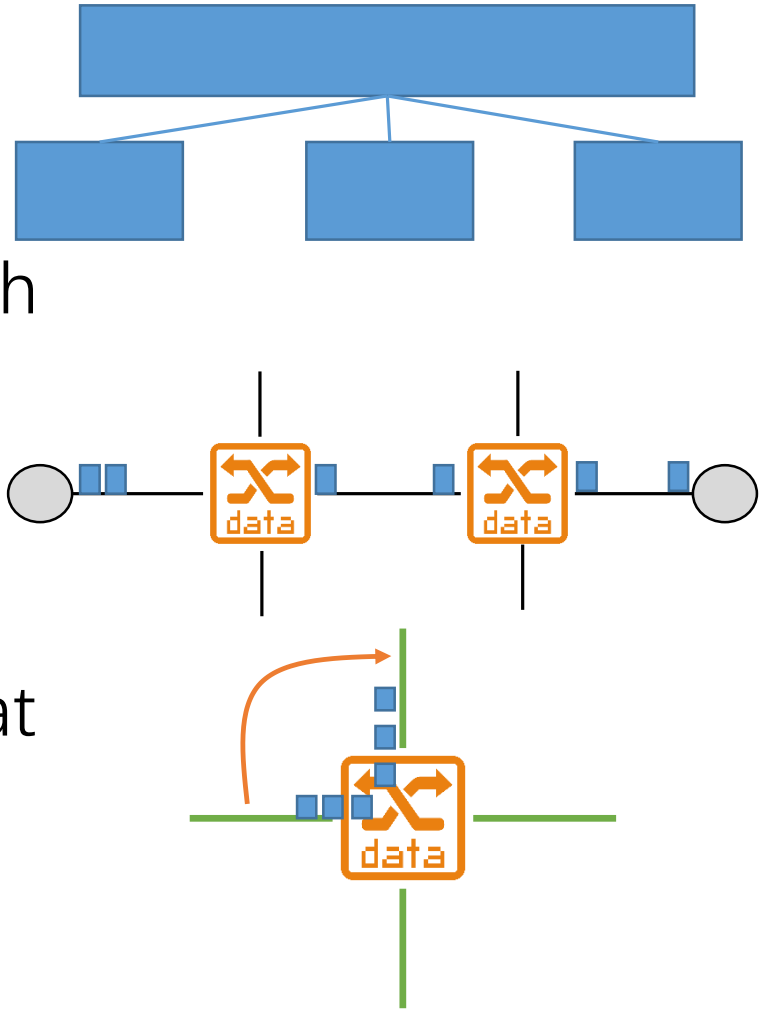
Burst Transmission required by computer

Reserve of bandwidth might be a waste!

Packet Switching: variable and unpredictable rate

Package data into chunks, and be sent out at a rate as high as possible

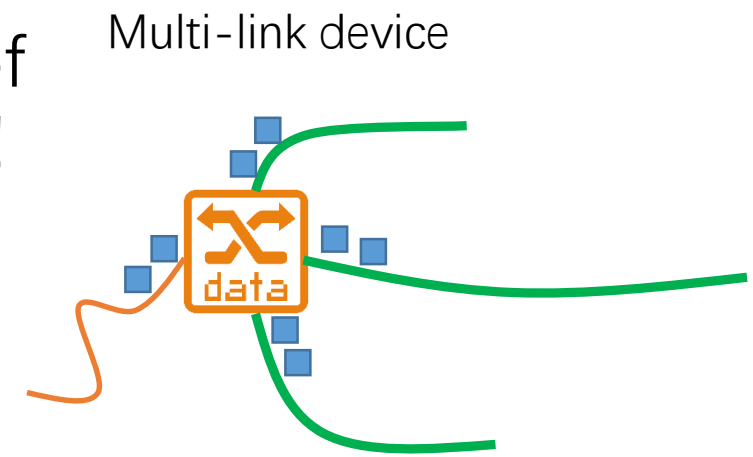
- Data is broken into chunks of data known as packet, and sent out at will (**connectionless**~).
- Along the path from the source to the destination, each of these packets travels through communication links and **packet-switches**.
- Packets are transmitted over each communication link at a rate equal to the full transmission of the link!!
- Each packet must be full received and buffered at each packet switch, and exam it destination, and then send out in another link of the switch.
  - Known as **store-and-forward (存储转发)**!!



More about Packet Switches

Core networking devices of computer network

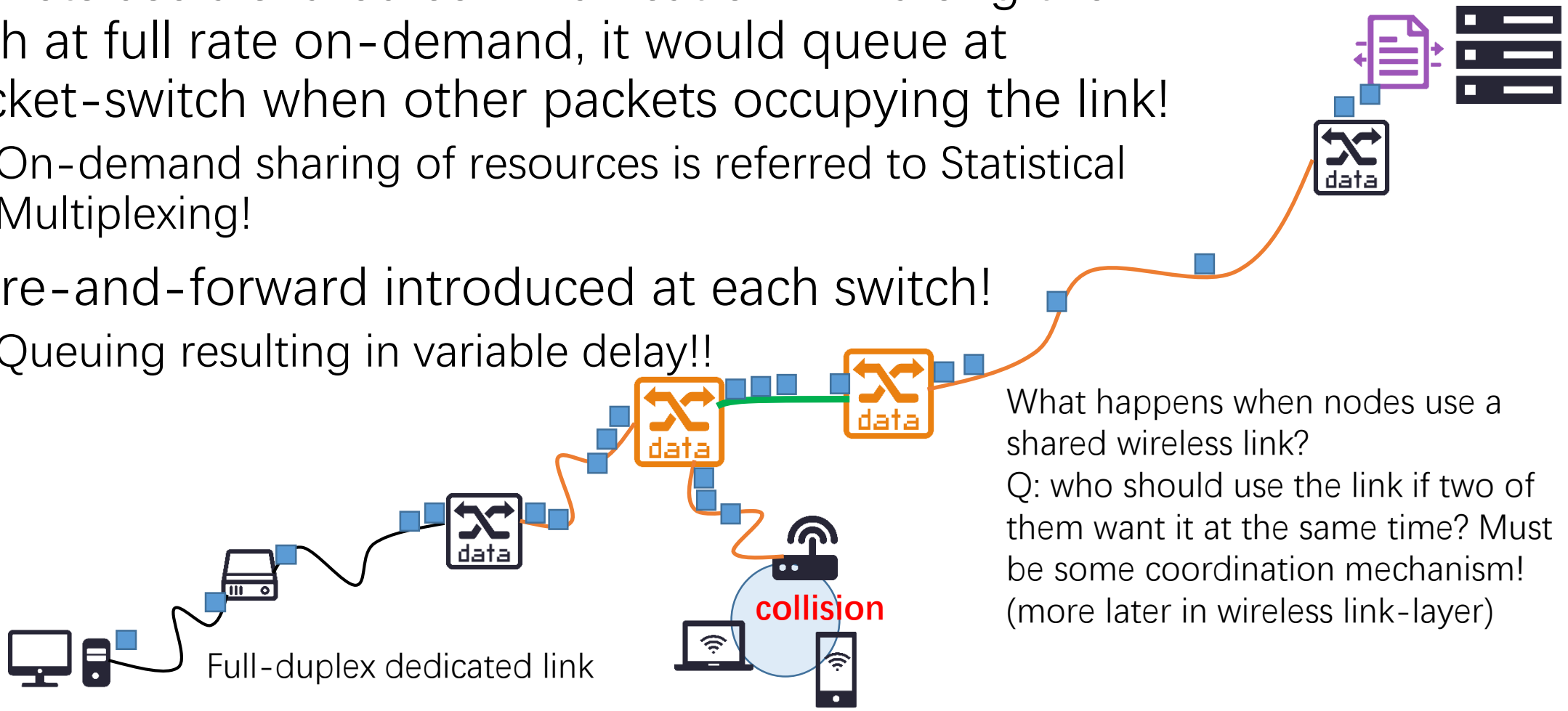
- Packet-Switches are multi-link devices, which contain input and output buffers in each link!
- A packet might be queue in the output buffer of a link, if the link is busy used by another packet!
- Store-and-forward in a switch (queue and process) introduces
  - Delays, and
  - Loss of packets
- There are two predominant types: routers and link-layer switches. (more later in the course)



Statistical Multiplexing in Packet Switching network

Queuing makes everything unpredictable

- Packets use a shared communication link along the path at full rate on-demand, it would queue at packet-switch when other packets occupying the link!
  - On-demand sharing of resources is referred to Statistical Multiplexing!
- Store-and-forward introduced at each switch!
  - Queuing resulting in variable delay!!



What happens when nodes use a shared wireless link?
Q: who should use the link if two of them want it at the same time? Must be some coordination mechanism! (more later in wireless link-layer)

Packet Switching vs. Circuit Switching

let us do some math

- Example @Section 1.3, page 31, V6
- 1Mbps Link, with 100Kbps rate for per user;
- User is only active 10 percent time (0.1 possibility);
- For TDM in circuit switching, 10 time slots of 100ms, each slot for one user excusive used;
  - Max support only 10 (10=1Mbps/100Kbps), simultaneous users.
- What about 35 users in packet switching?
  - The aggregate rate of data is equal to 1Mbps by simultaneous 10 users!
  - The binomial distribution (二项式概率分布)

Packet Switching vs. Circuit Switching

binomial distribution (35, 0.1)

- Probability mass function(概率质量函数):

$$f(k;n,p) = \Pr(X = k) = \binom{n}{k} p^k (1-p)^{n-k}$$

$$\binom{n}{k} = \frac{n!}{k!(n-k)!}$$

- Cumulative distribution function (累计分布函数):

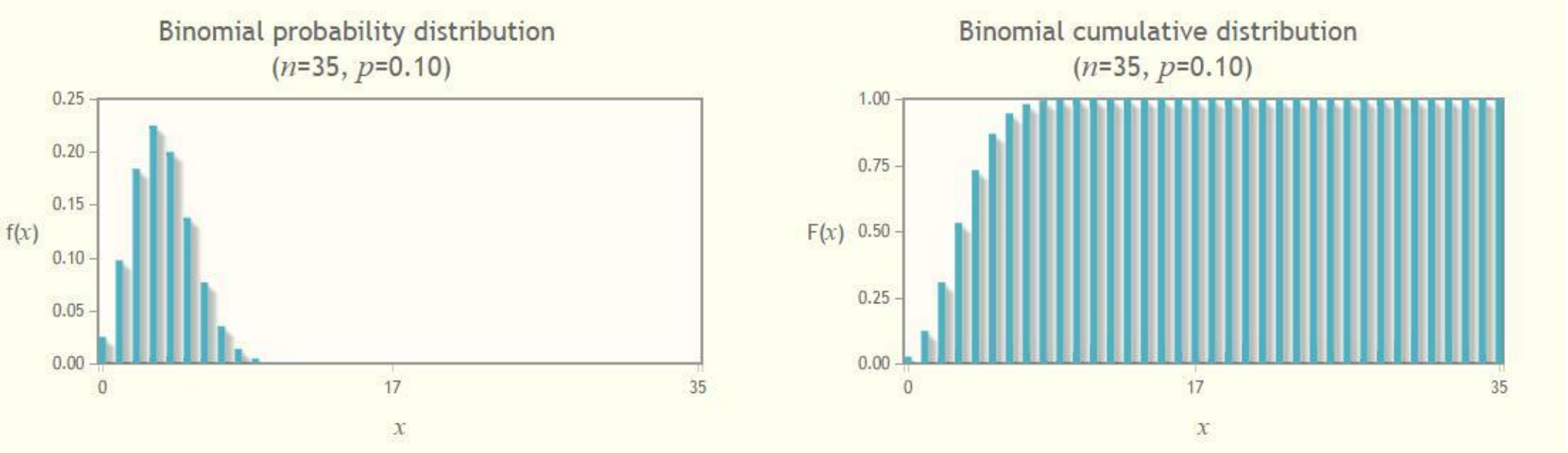
$$F(k;n,p) = \Pr(X \leq k) = \sum_{i=0}^{\lfloor k \rfloor} \binom{n}{i} p^i (1-p)^{n-i}$$

@http://www.di-mgt.com.au/binomial-calculator.html

Binomial distribution (n=35, p=0.1)			
	f(x)	F(x)	1 - F(x)
x	Pr[$X = x$]	Pr[$X \leq x$]	Pr[$X > x$]
0	0.0250	0.0250	0.9750
1	0.0973	0.1224	0.8776
2	0.1839	0.3063	0.6937
3	0.2247	0.5310	0.4690
4	0.1998	0.7307	0.2693
5	0.1376	0.8684	0.1316
6	0.0765	0.9448	0.0552
7	0.0352	0.9800	0.0200
8	0.0137	0.9937	0.0063
9	0.0046	0.9983	0.0017
10	0.0013	0.9996	0.0004
11	0.0003	0.9999	0.0001
12	0.0001	1.0000	0.0000
13	0.0000	1.0000	0.0000

Packet Switching vs. Circuit Switching

binomial distribution (35, 0.1)

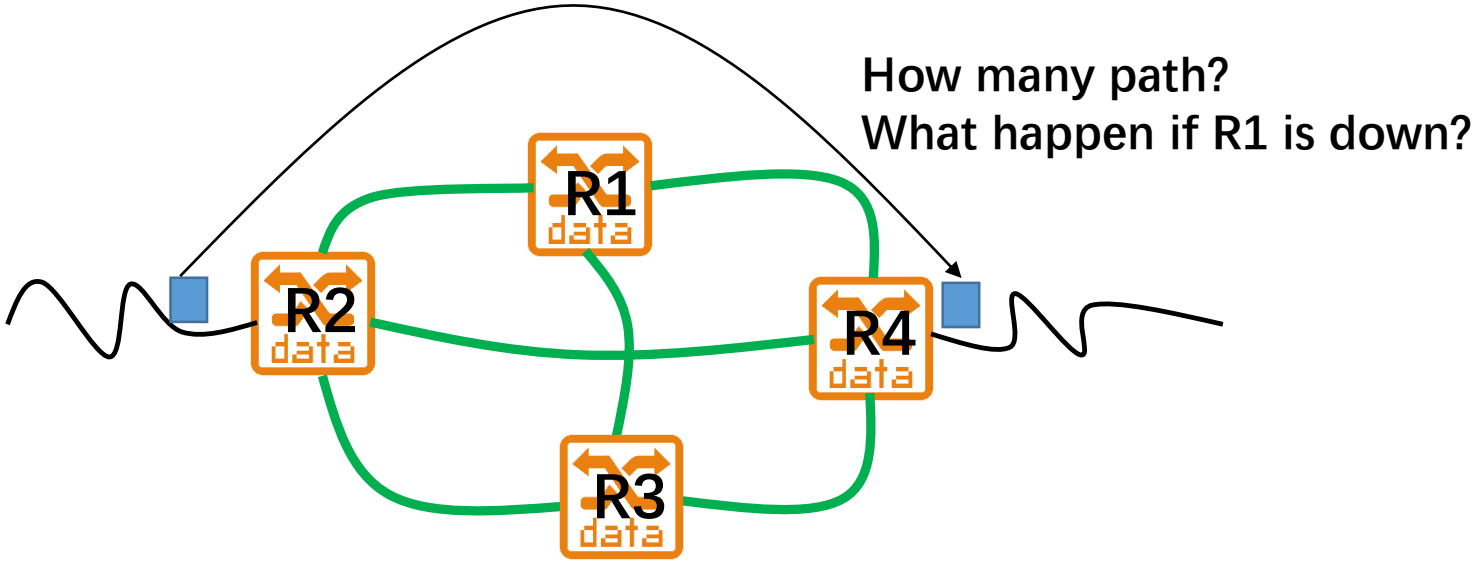


In this case, packet switching can support 35 users with 11 or more simultaneously users of 0.0004 probability.

Packet Switching vs Circuit Switching

With more considerations

Is packet switching only about efficiency of sharing?



Packet Switching is key to networking!!

Problem 2: the Reliable Problem

Oh, we make errors, so does the network

Why??

- FACTs: the network infrastructure is somewhat unreliable?
  - Bit errors
  - Packet loss (at network core and end systems)
  - Duplicate packets
  - Unordered arriving
- That is, only offering **best effort** service!
- QUESTION: in what way we can achieve reliable end-to-end data transmission? Keep in mind, network core (routers) is not controlled by end users (systems)!!
- Mechanisms must be employed in end systems at both sites, without help from the core!

- Reliable, 可靠的
- Best effort, 尽最大努力
- End-to-end, 端到端
  应用程序到应用程序

The end-to-end connection

Yes, connection is truly needed, even in Packet Switching; what? (:

- If reliable transmission is needed, connection must be established before sending out the first packet.
  - At least to confirm that the receiving node is online and ready!
  - This is known as Connection-Oriented Transport (面向连接的传输)
- Such a connect only shares transmission parameters at both ends, but not reserves any resource of the network; of course, it is very different from connection in Circuit Switching.
  - The network core know nothing about such a connection!
- Several mechanisms should be employed, to handle network errors.

Achieving the reliable transmission

Well, it is not a easy job!

- Error detection/correction code, 检错与纠错码
- Timeout & retransmission, 超时重传

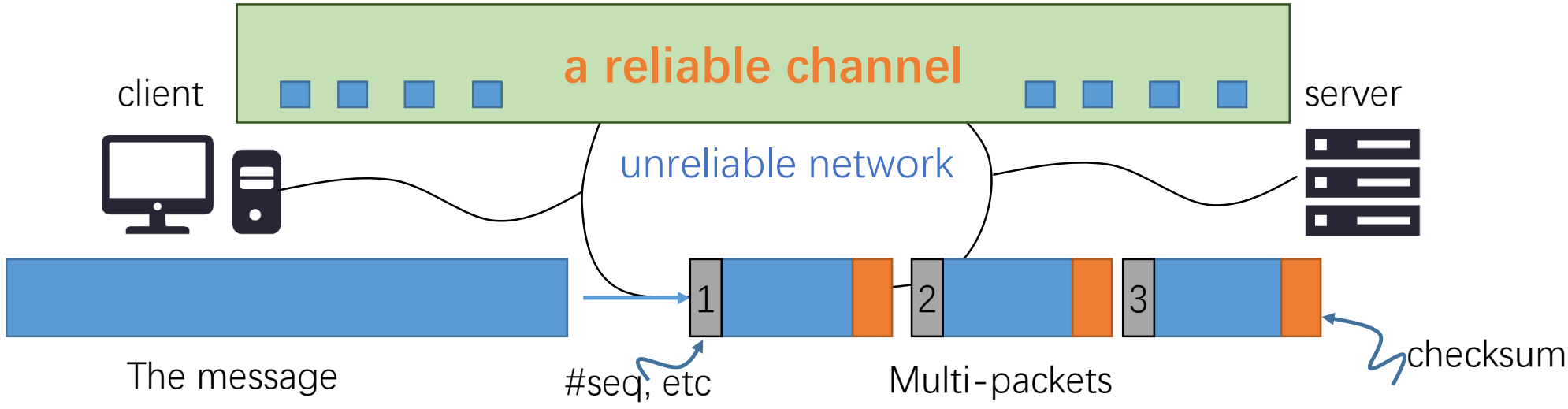
- For bit errors: error detection code and error correcting code.
  - Bit XOR case ~~ (011 -- 111 ?); Internet Checksum
- For packet loss: timeout and retransmission
- For unordered arriving and duplicate packet: sequence number in each packet belong to a message for identification.
- For un-match speed: control the send rate of the source, by the receiver telling the free buffer size to the sender; so called flow control (流量控制).
- If no one care about others, the network might be congested!
  - So, be nice; start sending at a low rate, probe the network, if good, increase the sending rate!
  - This is known as congestion control (拥塞控制).!

- Sequence number, 序列号
- Identification, 标识

Achieving the reliable transmission

Well, it is not a easy job!

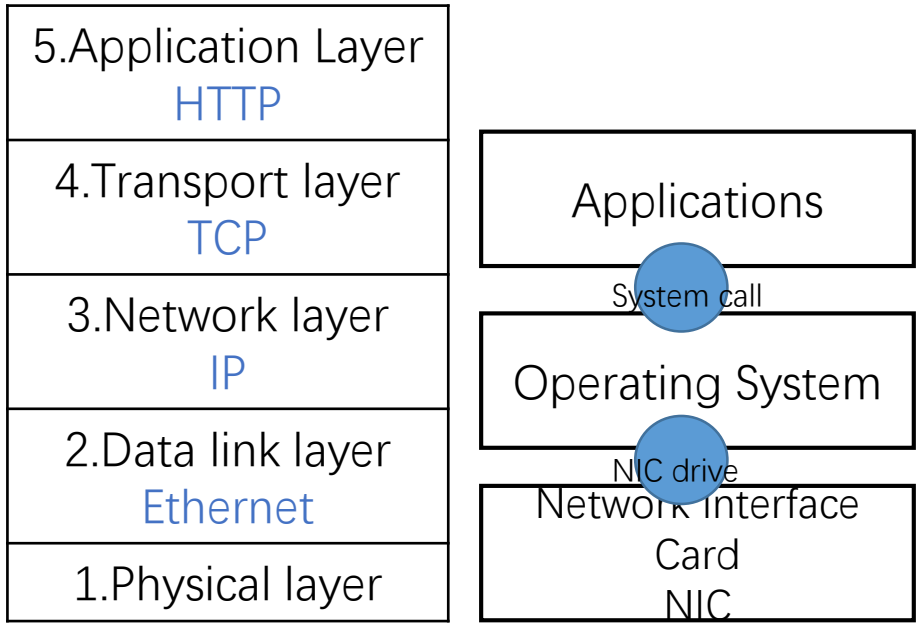
- Well, suppose the packet has been successfully arrive at the receiver, how can the sender know this fact?
  - The receiver should send acknowledgements (ACKs) back to the sender!!
  - Hopefully, this is the normal and most cases!
- All these are done by only maintain and exam a set of connection parameters at two communicating ends.



Problem 3: the Addressing Problem

In fact, we are facing a set of addressing or identification problems

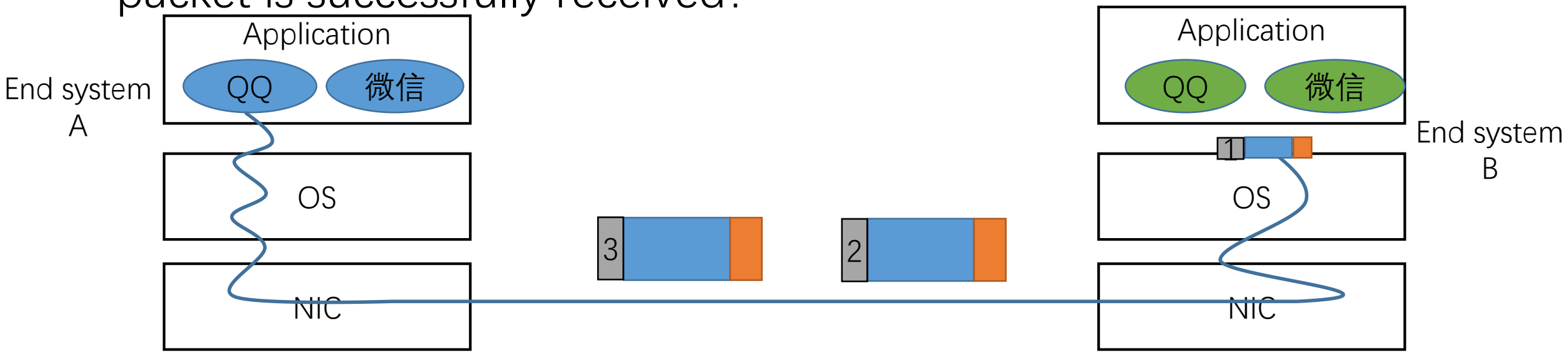
- Remind of you that we handle the message transmission problem in a layer architecture, with parts of the problem be solved in each layer!
- The addressing problem occurs in several layers.
  - Identifying the applications
  - Addressing the hosts in the network layer
  - Addressing the hosts in the data link layer



Identification of Applications

Certainly, we do not want QQ messages received by 微信

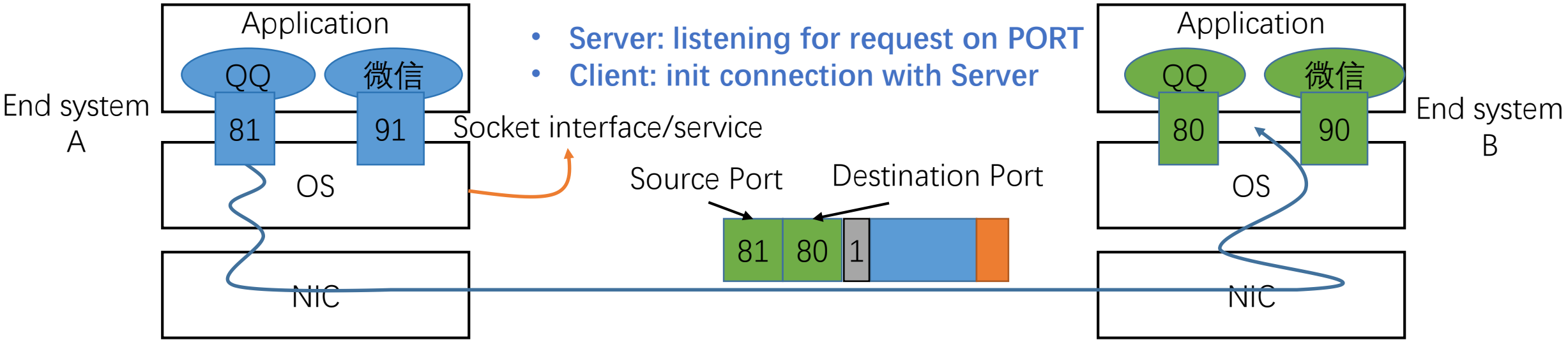
- FACTs: multiple application are running in a pair of communicating end systems; Message transmission is in fact one application from A sends a message to another corresponding application in B.
- QUESTION: how to identifying the intended application when a packet is successfully received?



Identification of Applications

In fact, it is the Socket to be identified

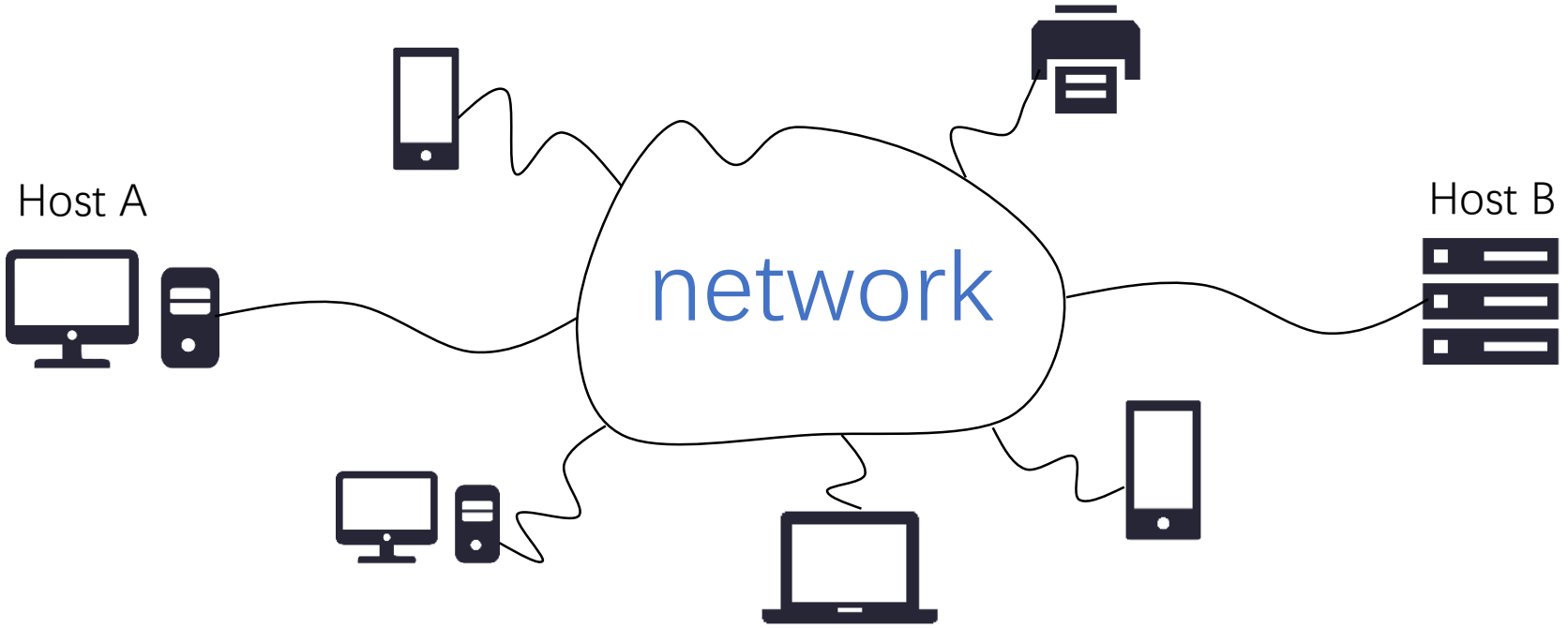
- An application can fork many processes, any process might send message using the network.
- To send a message, a process use the socket interface/service provided by the underling OS.
- Port numbers are used in both **ends** for identification of Sockets.



Identification of hosts (in the global network context)

Find the right one from vast number of computers is far from easy

- FACTs: There never would be only two computers connected to the network!! Billions of hosts~ ha, ha!!
- QUESTION: When a packet is sent out, which host is intended? Where is the destination host?

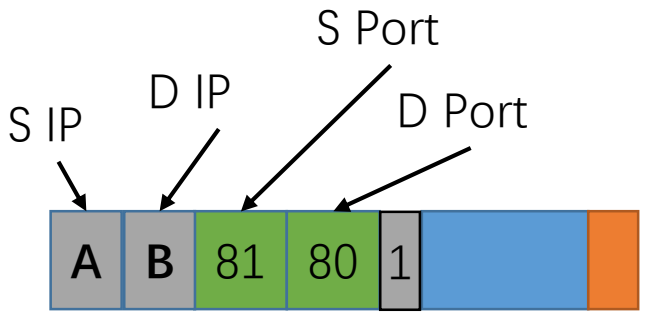


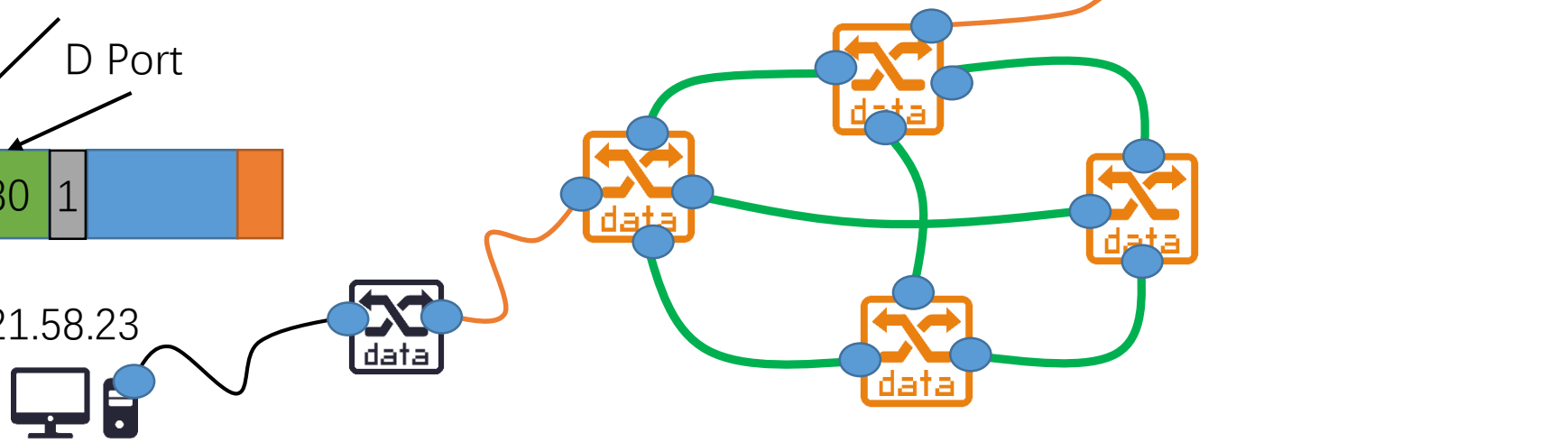
IP addressing of hosts (and routers)

We take the Internet as an example directly

- A host might have more than one NIC attached; Addressing is to give an IP address for each NIC.
- In the global network, each NIC's IP address must be unique!
- IP address: 32 bits, e.g. 159.121.58.23

IP Packet





The problem of 32bits IP addressing

Yes, we have run out of the IP address space

- Vint Cerf, one of the internet father admitted that their team has under estimate the size if the network at the beginning age.
- 42 Billions of IP addresses has been allocated, we are out of them from 2011/02/03!
- But, endless new devices want to connect to the Internet!! **How???**
- More about IP address, two sets
  - Reserved/private IP
  - Global IP

Reserved/private IP	Global IP
10.0.0.0 – 10.255.255.255	Others
100.64.0.0 – 100.127.255.255	
172.16.0.0 – 172.31.255.255	
192.168.0.0 – 192.168.255.255	

Identification of hosts (in the internal network context)

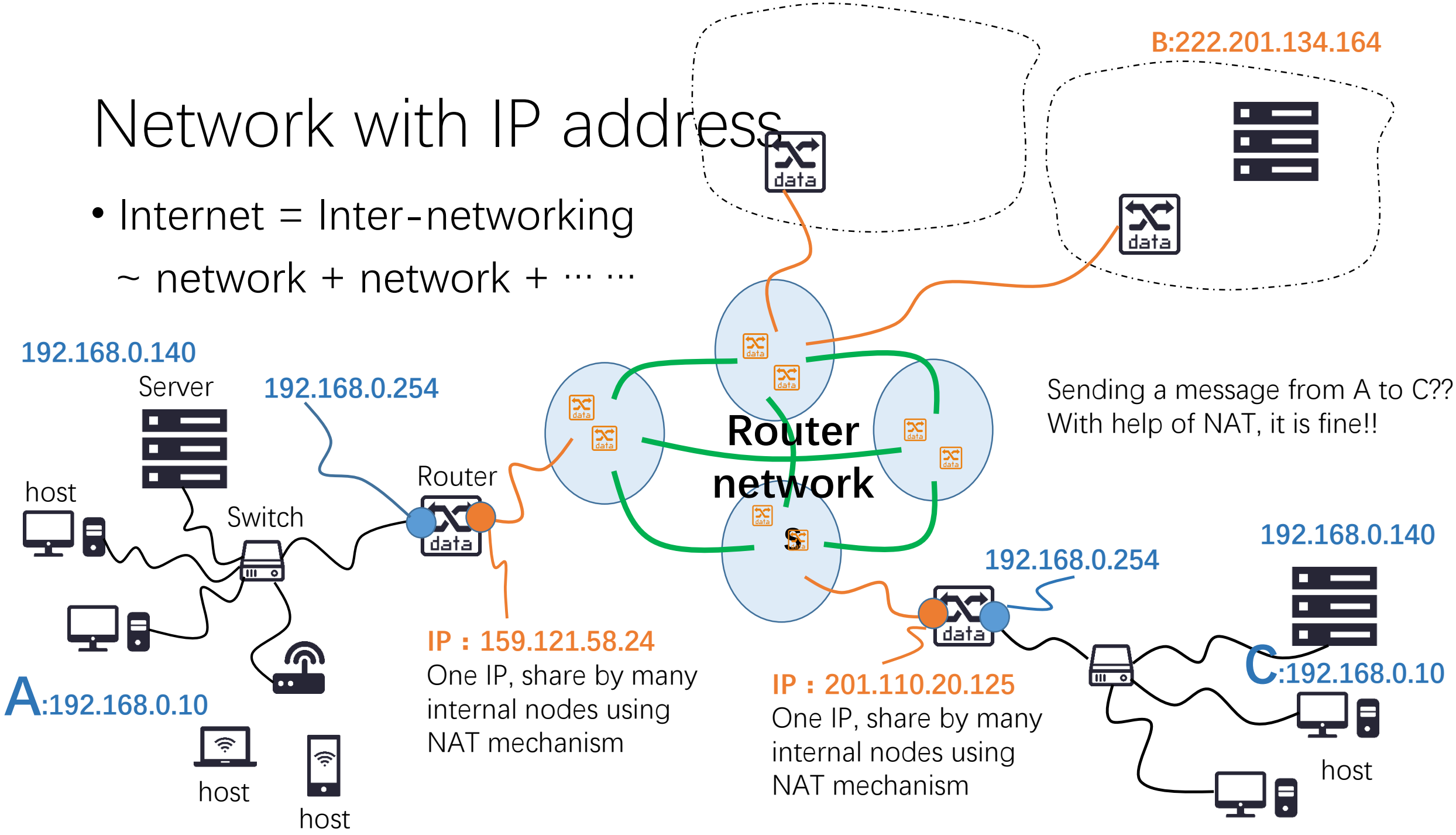
There are computers with the same IP addresses ~~

- A host commonly attached to an internal network constructed by his or her organization.
- The internal network is then connect to the network core via a **gateway router** for interconnection with others.
- A (new) host attached to an internal network is assigned with a unique private IP (e.g. 192.168.0.12), instead of a global one.
- Thus, there might be many host with the same IP address, but they has to be reside in their own internal context.
  - No visible from the outside
- **Network Address Translation (NAT)** mechanism is employed in the gateway router!
  - Enabling the end-to-end connection between two computers resides in their internal networks

Network with IP address

- Internet = Inter-networking

  ~ network + network + … …



Identification of hosts (in the link layer)

Why need two addresses for each host (again, it is the NIC)

- Linker layer provide communication service for devices connected to the same link; that is sharing of the link.
  - Point-to-point link: only two devices at each end of the link
  - Broadcast link: more than two devices share the link
- IP address is for moving an IP packet from one network to another until it reach its final destination.
- Link layer address is for moving a link layer packet within the link.
  - A link layer packet might not carry an IP packet;
  - Using an extra layer of address provide more flexible architecture for the network.

MAC addresses of hosts

- The link layer address of a NIC is known as MAC address.
- MAC is assign to NIC after manufacture, and intend to be globally unique.
  - 48bits, e.g. 44-45-53-54-00-00

- When A want to send an IP packet to B, it adds source MAC and destination MAC
- A：{S_MAC_A|D_MAC_R1|**192.168.0.10**|222.201.134.164|**81**|80|messgage|CRC}
- MAC_R1: is the MAC of default gateway 192.168.0.254
  - A user ARP protocol to ask : who owns 192.168.0.254, tell me your MAC?

Why use D_MAC_R1? Not D_MAC_C or D_MAC_B?

A close look at link layer switches

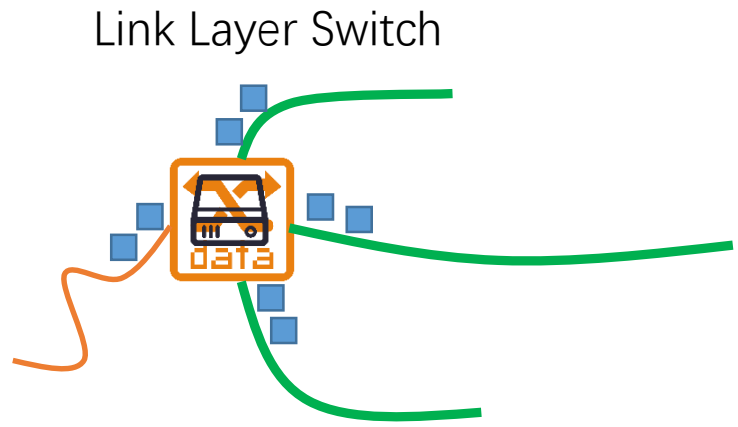
- Link layer packet:

  {**S_MAC_A|D_MAC_R1**|192.168.0.10|222.201.134.164|81|80|messgage|CRC}

- The Switch exams MAC {D_MAC_R1} against its switch table.

MAC	Interface
44-45-53-54-00-00	1
MAC_A	2
MAC_R1	3

- The switch table is self-learned.

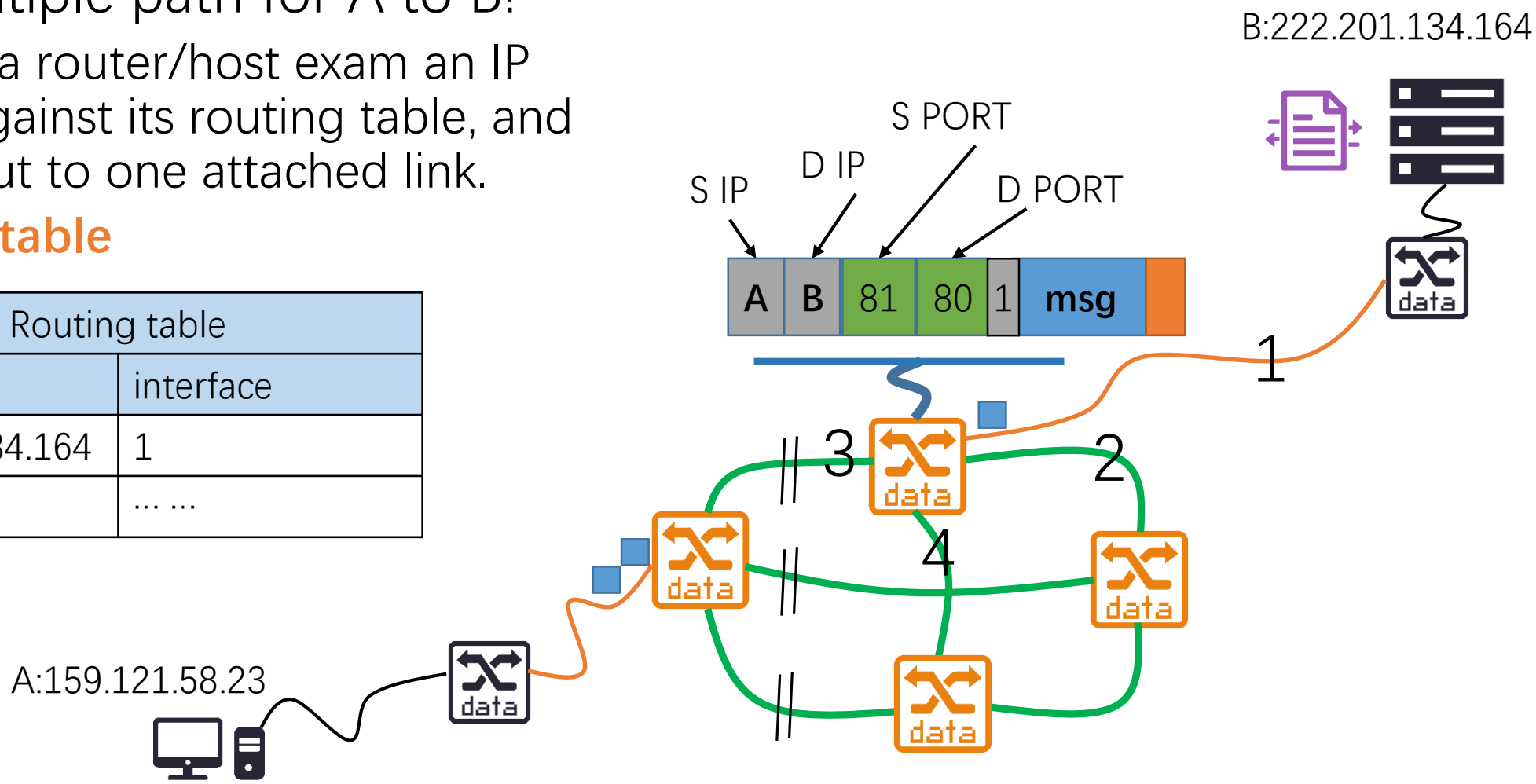


Problem 4: the Routing Problem

Finding the best way through

- FACTs: multiple path for A to B!
  - Routing: a router/host exam an IP packet against its routing table, and send it out to one attached link.
  - **Routing table**

Routing table	
D IP	interface
222.201.134.164	1
… …	… …



A close look at routers

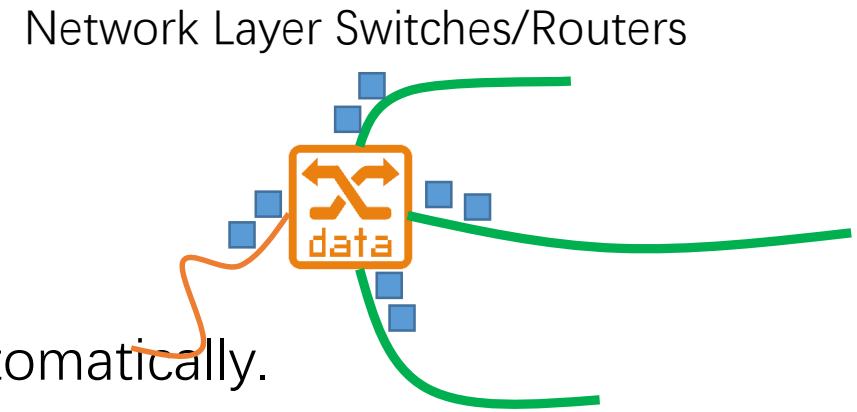
The network layer switches

- IP packet:

  {202.38.103.33|222.201.134.164|81|80|messgage|CRC}

- The router exams destination IP {222.201.134.164} against its routing table.

Routing table	
D IP	interface
222.201.134.164	1
… …	… …

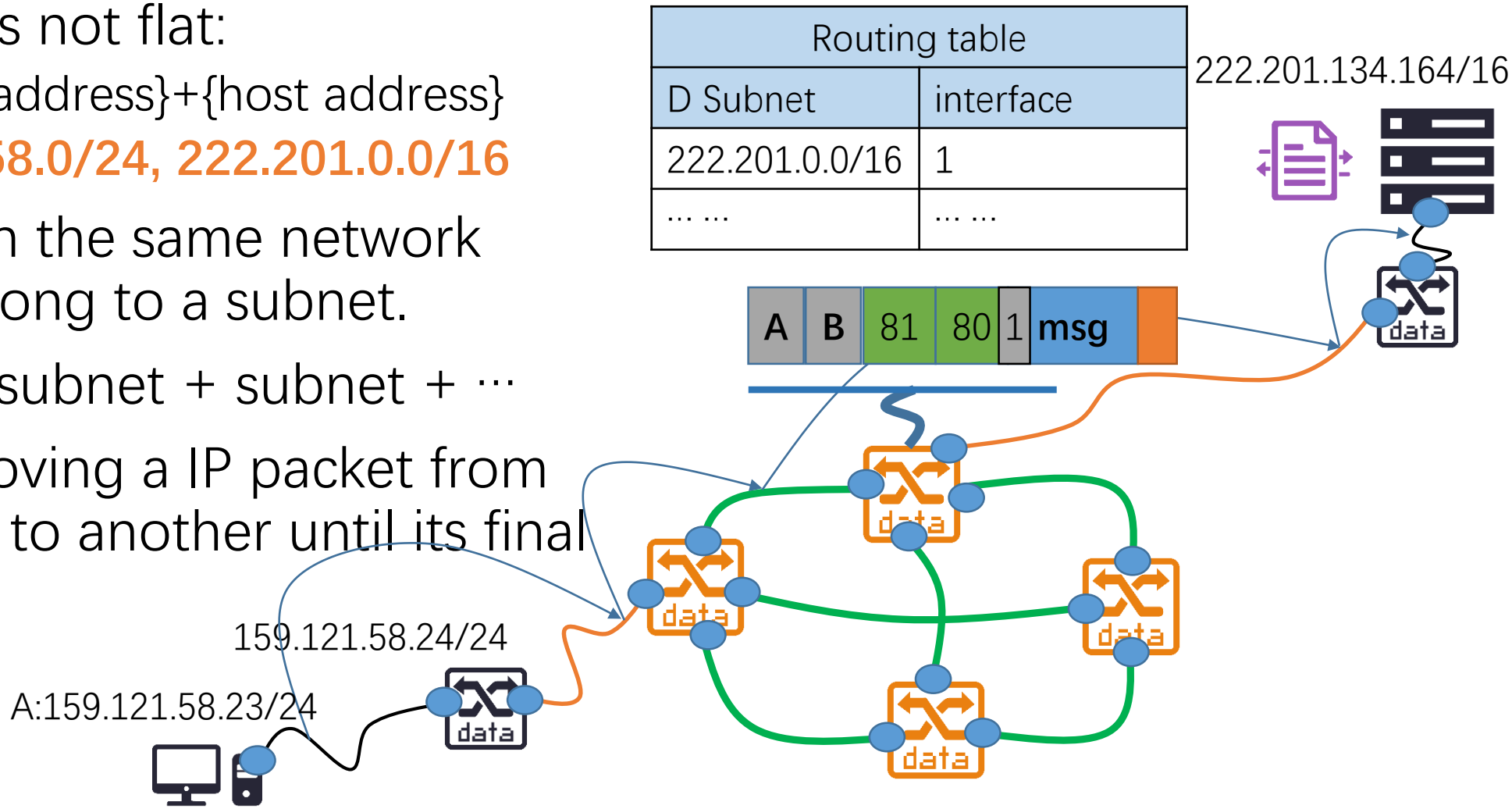


- The routing table is configured by Routing Algorithm automatically.
- Consider the size of Routing table, if IP is assign to hosts unorganized?
  - Hierarchical addressing and route aggregation (IP Subnets)

IP Subnets and Address/Route aggregation

Hierarchical IP addressing resulting in more efficient routing

- IP address is not flat:
  - {network address}+{host address}
  - **159.121.58.0/24, 222.201.0.0/16**
- All host with the same network address belong to a subnet.
- Network = subnet + subnet + …
- Routing: moving a IP packet from one subnet to another until its final destination.



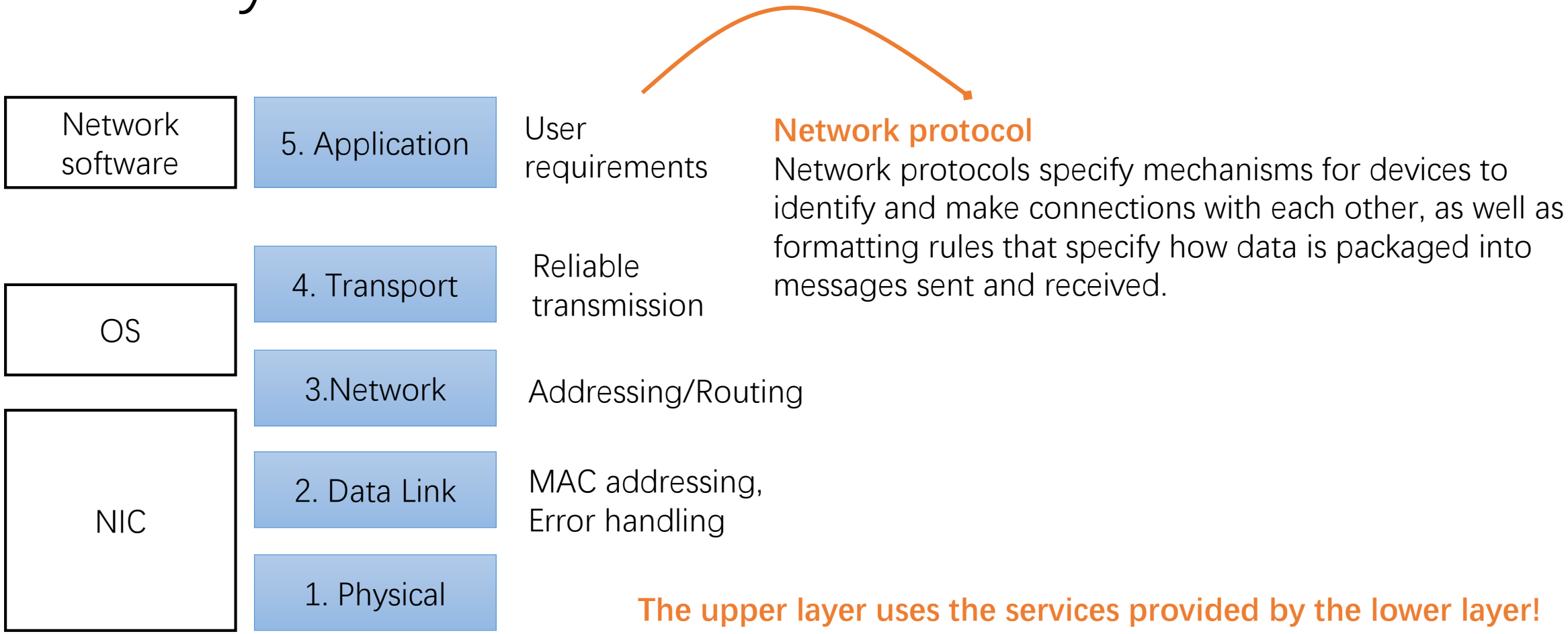
Problem 5: the vary requirements of end users

Many problem and principles cannot cover in this introductory talk.

However, please considering the requirements of online streaming video?

Connectionless: sometimes, unreliable transmission is tolerant!

The Layered architecture



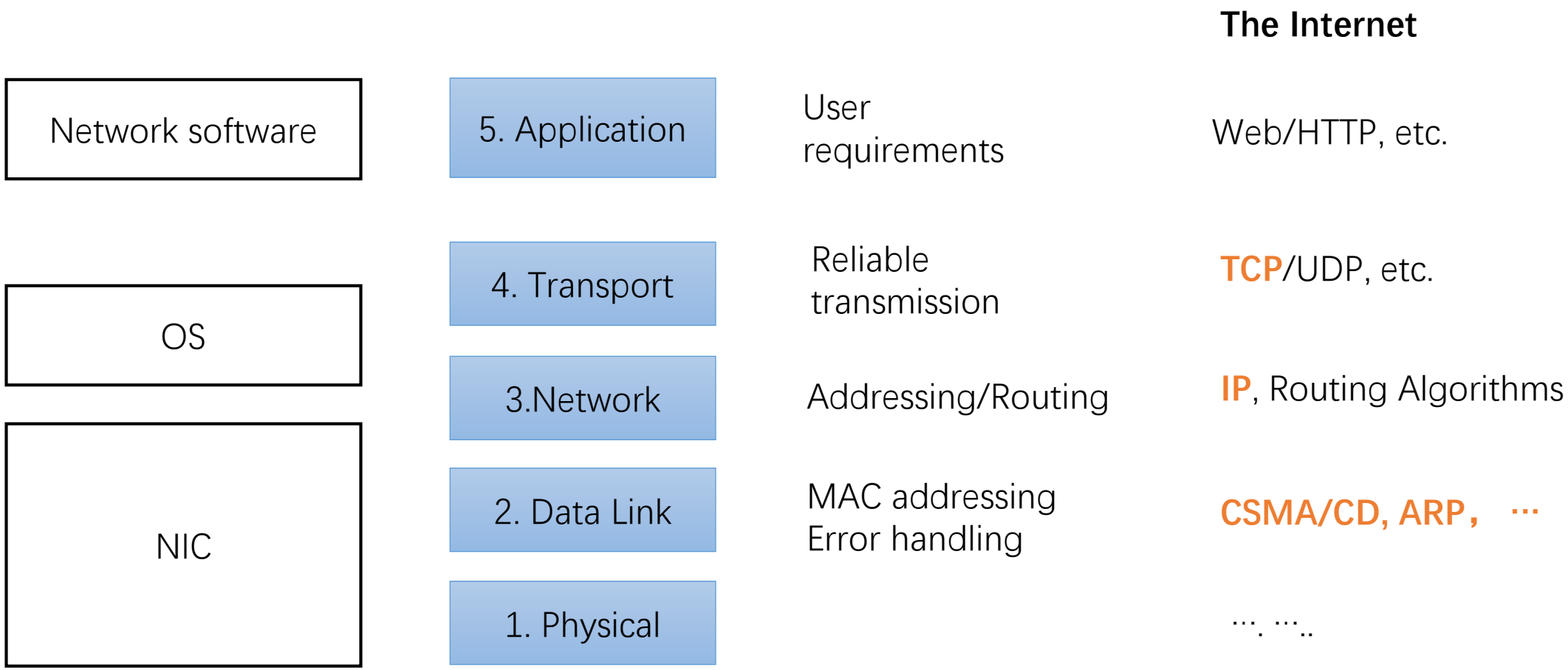
Network protocol

Network protocols specify mechanisms for devices to identify and make connections with each other, as well as formatting rules that specify how data is packaged into messages sent and received.

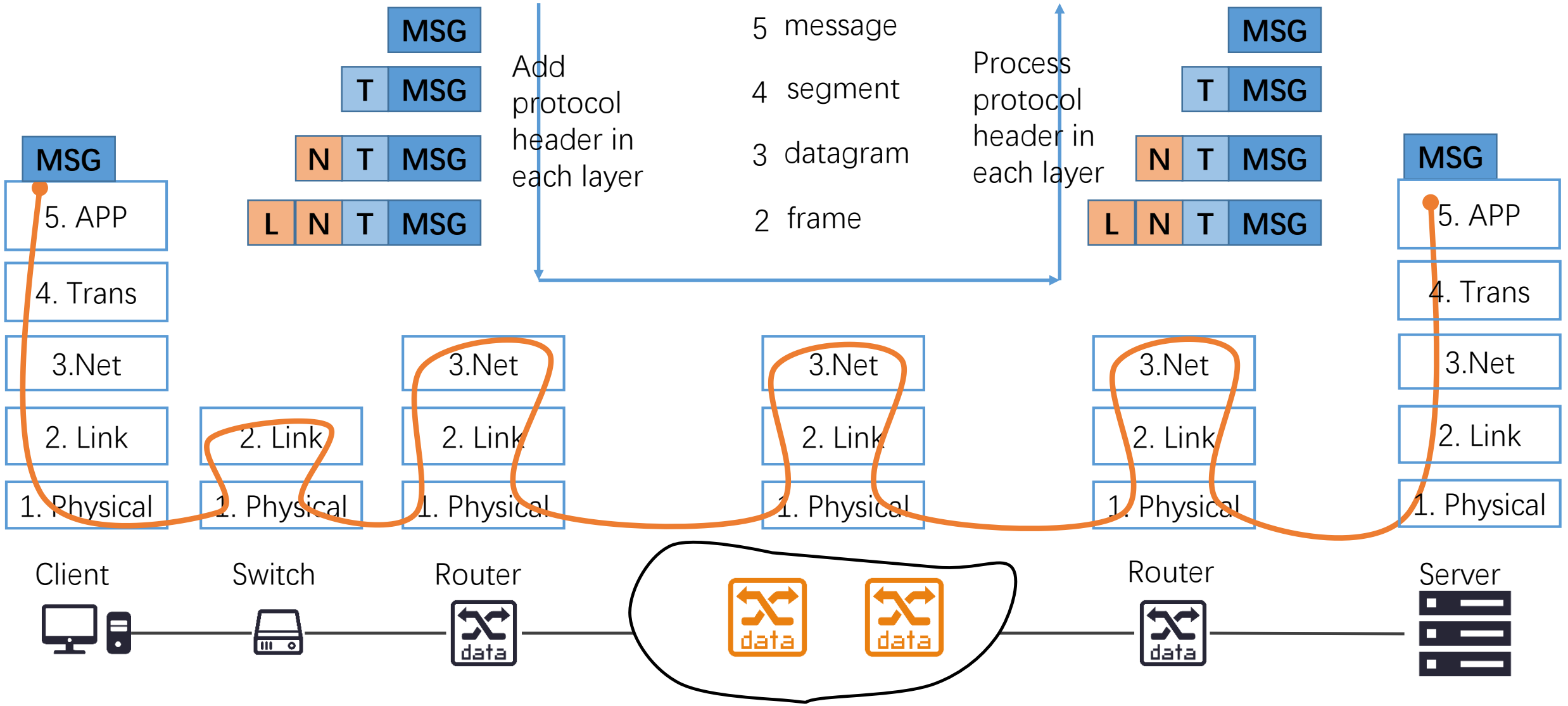
The upper layer uses the services provided by the lower layer!

Internet：TCP/IP + Ethernet

Internet and Ethernet



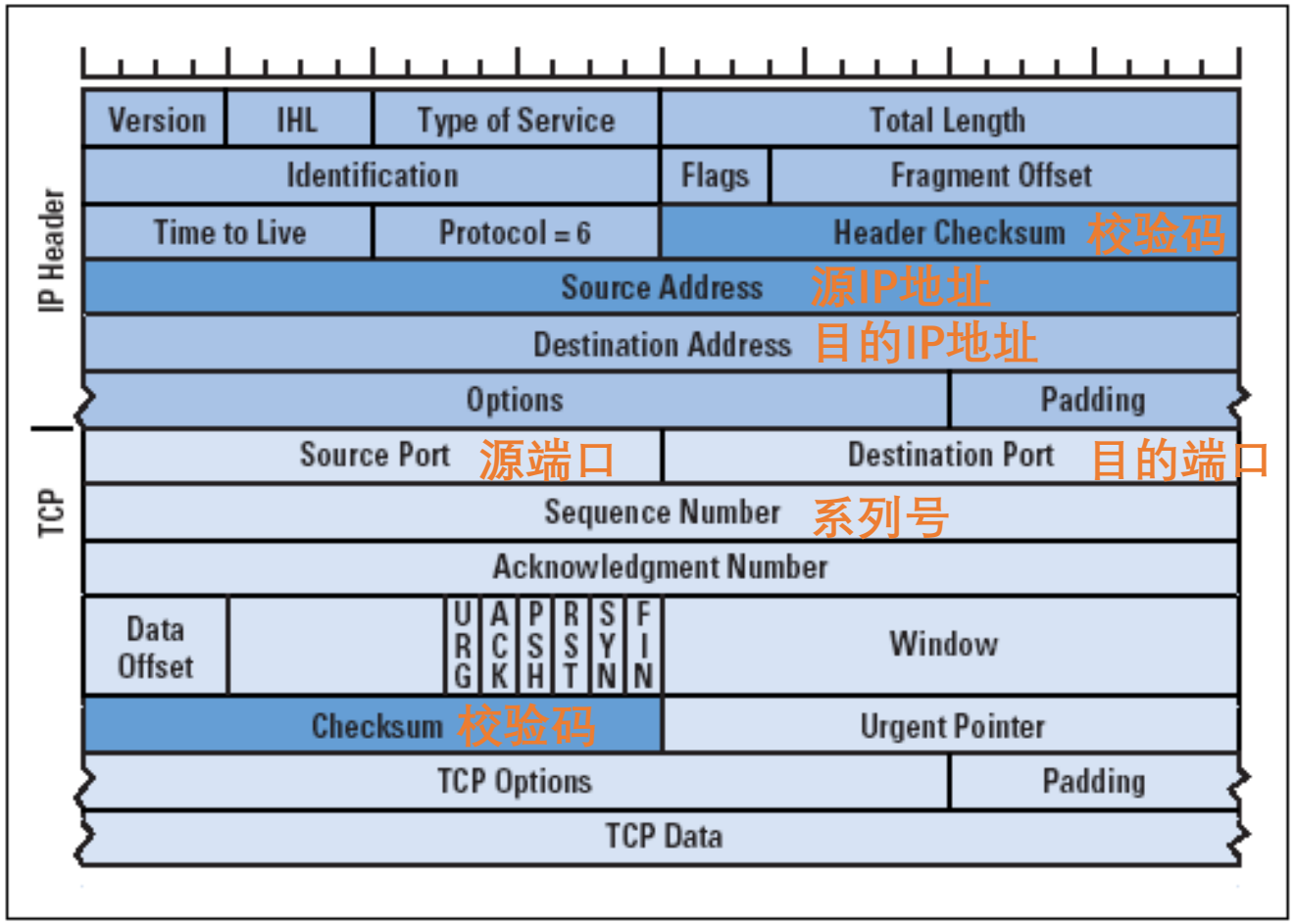
A detail exam of message transmission



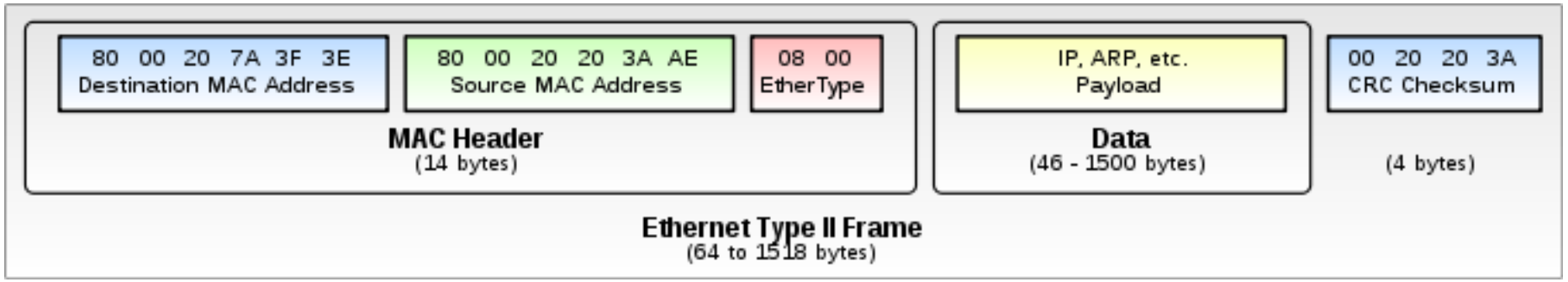
Internet: TCP/IP

- TCP/IP header

Figure 1: TCP/IP Header Fields Altered by NATs (Outgoing Packet)



Ethernet header



TCP/IP + Ethernet