中国科学院大学
University of Chinese Academy of Sciences

CS101

网络思维-2

连通性，协议栈

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提纲

- 网络思维概述
- 名词术语
- 网页编程

- 连通性
  - 名字空间
  - 网络拓扑
- 协议栈
  - 分组交换
  - Web over Internet

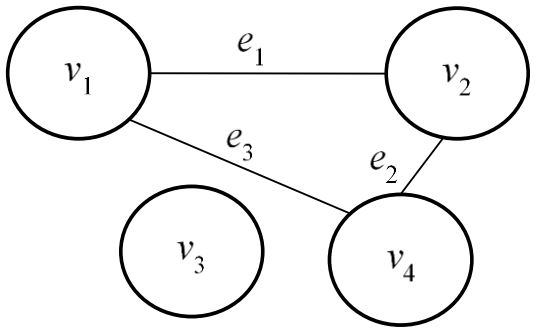
- 网络效应与职业素养

课件中包含教科书未包括的素材引用，特此致谢

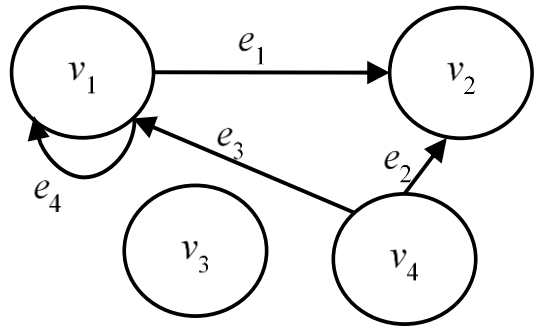
1. Connectivity (连通性，互联互通)

- 连通性往往用一个图表示
  - Often expressed as a graph $G =< V, E >$ of two sets
    - Set of nodes (vertices): $V = \{v_1, v_2, \ldots, v_n\}$
    - Set of edges (links): $E = \{e_1, e_2, \ldots, e_m\}$
- Connectivity studies *naming* and *topology* problems
  - Naming: How to name the nodes of a network? How to find a specific node? How to refer to a specific node? 如何命名网络的节点、发现节点、指向节点？
  - How are the nodes interconnected? Does the network structure change over time? 网络拓扑如何变化？

- Undirected
- $V = \{v_1, v_2, v_3, v_4\}$
- $E = \{e_1, e_2, e_3\}$
- Directed
- $V = \{v_1, v_2, v_3, v_4\}$
- $E = \{e_1, e_2, e_3, e_4\}$



undirected graph



directed graph

1.1 Naming 命名与名字空间

- Every network has one or more **namespaces**
  - Consisting of all names specified by a naming scheme
    - Naming scheme: a function mapping a legitimate string to a node or an edge
    - 一个名字是一个合规字符串

1.1 Naming 命名与名字空间

- Every network has one or more **namespaces**
  - Consisting of all names specified by a naming scheme
    - Naming scheme: a function mapping a legitimate string to a node or an edge
  - Specified by a standards body 命名方法往往由志愿者社区标准确定
    - Institute of Electrical and Electronics Engineers (IEEE) 国际电气与电子工程师协会
    - Internet Engineering Task Force (IETF) 国际互联网工程任务组
    - World Wide Web Consortium (W3C) 万维网联盟

Namespace	Instance	Remark on naming schemes
Personal name	Joan Smith	Personal names in a country
WeChat user	中关村民	Any legitimate string per WeChat standard
URL	cs101.ucas.edu.cn/中文/	Universal Resource Locator of a webpage
Internet site	www.ict.ac.cn	Any domain name by IETF standards
Email address	zxu@ict.ac.cn	userName@domainName
IP address	159.226.97.84	Internet Protocol address per IETF standards
Phone number	189-6666-8888	11 decimal digits by Telcom provider standards
MAC address	00-1E-C9-43-24-42	12 hexadecimal digits per IEEE standards

命名涉及的三个概念

- 名字（name）是最广的概念，指代某个实体（entity）
  - 实体往往是网络中的节点，也可以是边
  - 例如，同学们用Go语言编程时使用的变量名　studentGender := 0
- 地址（address）是可直接用于访问所指代实体的名字
  - 例如，采用地址运算符获得的地址　&studentRank
  - 例如，汇编语言程序看见的内存地址
  - 不是地址的名字需要转换出地址才能直接访问实体
- 标识符（identifier，ID）是可唯一标识所指代实体的名字
  - 在某个范围内唯一
  - 例如，一个自然人的身份证号
  - 例如，万维网网址 URL

Naming issues and considerations

- *Uniqueness*. Does a name map to a unique node? 唯一性
  - The email address namespace enjoys uniqueness, but the namespace of personal names of a country's population does not have uniqueness. There may be multiple persons named Joan Smith, causing *name conflicts*, which in turn may lead to wrong connections.

  - 可与身份证号比较（教科书242页）

Namespace	Name (a legitimate string)	Uniqueness
Personal name 自然人姓名	Joan Smith	?
WeChat user 微信用户名	中关村民	?
URL 万维网网址	cs101.ucas.edu.cn/中文/	?
Internet site 因特网域名	www.ict.ac.cn	?
Email address 电子邮件地址	zxu@ict.ac.cn	?
IP address IP地址	159.226.97.84	?
Phone number 手机号码	189-6666-8888	?
MAC address MAC地址	00-1E-C9-43-24-42	?

Naming issues and considerations

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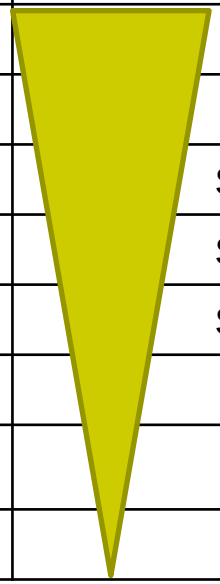
  - The email address namespace enjoys uniqueness, but the namespace of personal names of a country's population does not have uniqueness. There may be multiple persons named Joan Smith, causing *name conflicts*, which in turn may lead to wrong connections.

Namespace	Name (a legitimate string)	Uniqueness
Personal name	Joan Smith	No
WeChat user	中关村民	No
URL	cs101.ucas.edu.cn/中文/	Yes
Internet site	www.ict.ac.cn	Yes
Email address	zxu@ict.ac.cn	Yes
IP address	159.226.97.84	Yes
Phone number	189-6666-8888	Yes
MAC address	00-1E-C9-43-24-42	Yes

Naming issues and considerations

- *Friendliness*. Are the names user-friendly, i.e., understandable by humans?
  用户友好性：是否对人（用户）友好，便于用户理解？
  - The eight name schemes in Table have roughly decreasing user friendliness
  - "Joan Smith" is much more understandable than "00-1E-C9-43-24-42", which is the name of the network interface circuitry in a computer, also called MAC address

Namespace	Name (a legitimate string)	User Friendliness
Personal name	Joan Smith	Yes
WeChat user	中关村民	Mostly Yes
URL	cs101.ucas.edu.cn/中文/	Somewhat friendly
Internet site	www.ict.ac.cn	Somewhat friendly
Email address	zxu@ict.ac.cn	Somewhat friendly
IP address	159.226.97.84	No
Phone number	189-6666-8888	No
MAC address	00-1E-C9-43-24-42	No



Naming issues and considerations

- *Autonomy*. Can a user create or change a name on his own? 自主性
  - Autonomy has the advantage of convenience, but may lead to chaos
  - One may change a URL, but Web links to the old URL become invalid
  - Creating or modifying a name may need to go through a centralized process
    - Involving an authority of name registry

Namespace	Name (a legitimate string)	Autonomy
Personal name	Joan Smith	?
WeChat user	中关村民	?
URL	cs101.ucas.edu.cn/中文/	?
Internet site	www.ict.ac.cn	?
Email address	zxu@ict.ac.cn	?
IP address	159.226.97.84	?
Phone number	189-6666-8888	?
MAC address	00-1E-C9-43-24-42	?

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  - Creating or modifying a name may need to go through a centralized process
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Namespace	Name (a legitimate string)	Autonomy
Personal name	Joan Smith	Yes
WeChat user	中关村民	Mostly Yes
URL	cs101.ucas.edu.cn/中文/	Hierarchically Centralized
Internet site	www.ict.ac.cn	Hierarchically Centralized
Email address	zxu@ict.ac.cn	Hierarchically Centralized
IP address	159.226.97.84	Hierarchically Centralized
Phone number	189-6666-8888	Choose from a centralized pool
MAC address	00-1E-C9-43-24-42	Hierarchically Centralized

Naming issues and considerations

- *Name conversion*. An entity can have two namespaces.
  - The Internet site with domain name www.ict.ac.cn and IP address 159.226.97.84
  - The Domain Name System (**DNS**) converts a domain name to its IP address
    DNS将互联网域名转换为IP地址
    - **http://www.ict.ac.cn → http://159.226.97.84**

- Two types of IP addresses are used today **两类IP地址**
  - **IPv4 addresses** use **32 bits** and can generate 2^{32} different IP addresses
    - Each IPv4 address is organized as a 4-field format xxx.xxx.xxx.xxx such as 159.226.97.84
      IPv4地址通常写成“.”区分开的4个字段，每个从0到255
    - Each field is a decimal number from 0 to 255 159.266.97.84是非法的

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      IPv4地址通常写成“.”区分开的4个字段
    - Each field is a decimal number from 0 to 255 159.266.97.84是非法的
  - **IPv6 addresses** use **128 bits** and can generate 2^{128} different IP addresses
  - *** Each IPv6 address is an 8-field format (colon-hexadecimal form)
    xxxx:xxxx:xxxx:xxxx:xxxx:xxxx:xxxx:xxxx
    such as 2001:0db8:85a3:0000:0000:8a2e:0370:7334
  - ***IPv6地址通常写成“:”区分开的8个字段，每个包含4个Hex数

Naming issues and considerations

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  - The Internet site with domain name www.ict.ac.cn has an IP address 159.226.97.84
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  - **IPv6 addresses** use **128 bits** and can generate 2^{128} different IP addresses
    - *** such as 2001:0db8:85a3:0000:0000:8a2e:0370:7334
- IPv4 addresses exhaustion occurred as of November 2019
  - There are $2^{128-32} = 2^{96}$ times as many IPv6 addresses as IPv4 addresses
  - 2019年11月，全球IPv4地址已穷尽

万维网网址 URL

- Uniform Resource Locator 入门知识

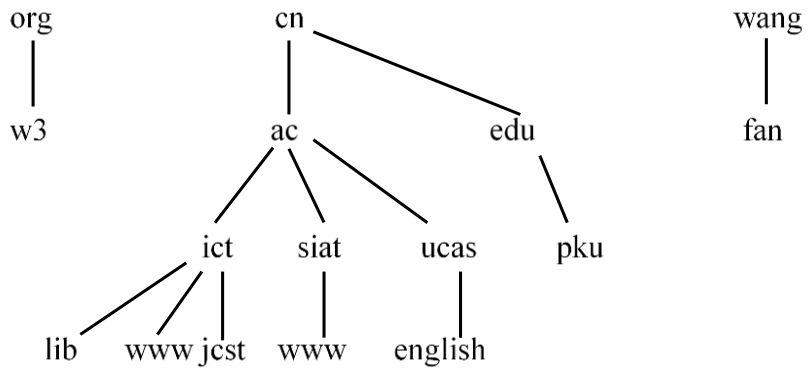
http :// cs101.ucas.edu.cn /中文/

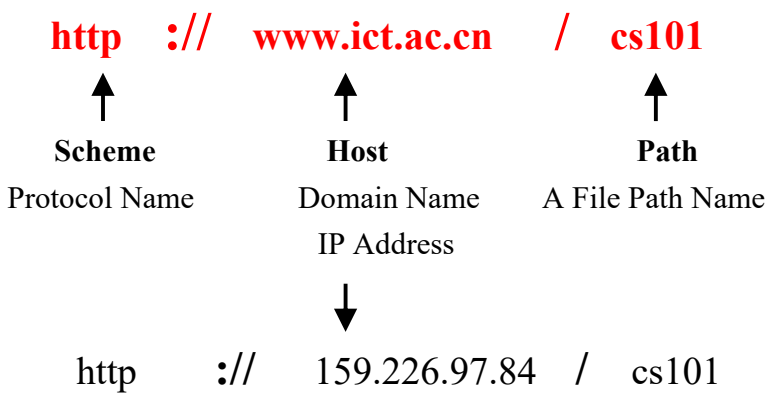
协议 网站（域名或IP地址） 路径

- 其他协议：
  - file：访问本计算机的文件
  - ftp：访问互联网上任意计算机的文件
  - https：安全地访问Web资源
  - mailto：访问电子邮件地址

Domain name hierarchy and URL

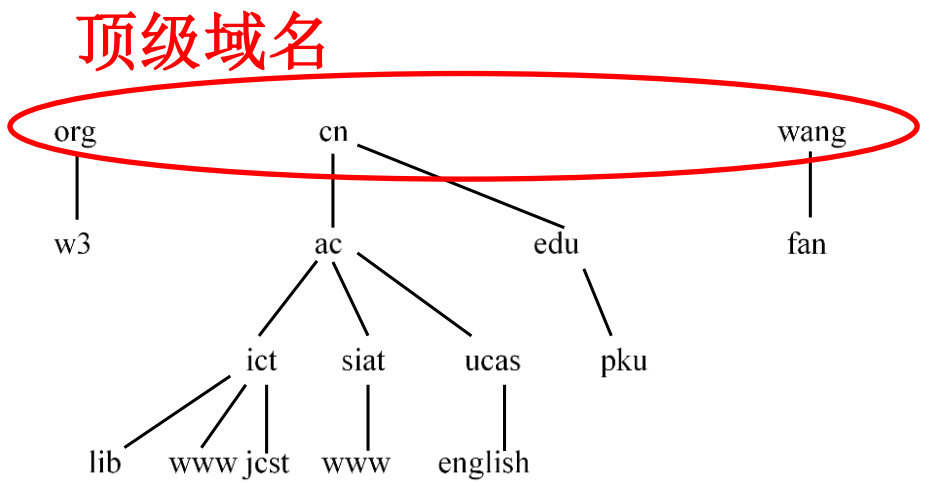
- 给定域名树，What is the URL of the homepage 首页 of the following institutions?
  - Fan Wang
  - Journal of Computer Science and Technology
  - Peking University
  - Shenzhen Institute of Advanced Technology
  - The World Wide Web Consortium
  - The University of Chinese Academy of Sciences
- Check your answers by accessing the URLs

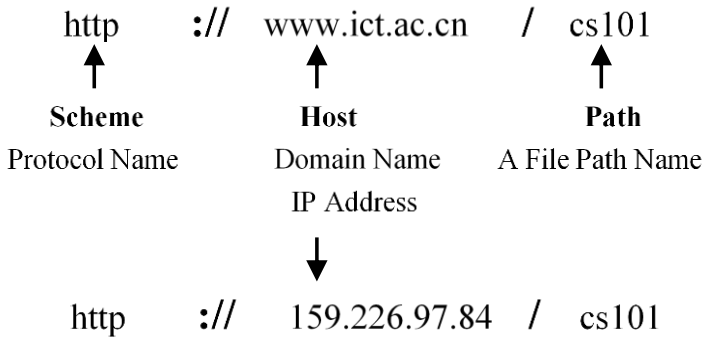




Domain name hierarchy and URL

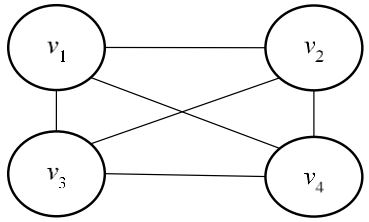
- What is the URL of the homepage of each of the following institutions? What is the top-level domain?
  - http://fan.wang/ — wang — .wang
  - http://jcst.ict.ac.cn/ — cn — .cn
  - http://pku.edu.cn/ — cn — .cn
  - http://www.siat.ac.cn/ — cn — .cn
  - http://w3.org/ — org — .org
  - http://English.ucas.ac.cn — cn — .cn



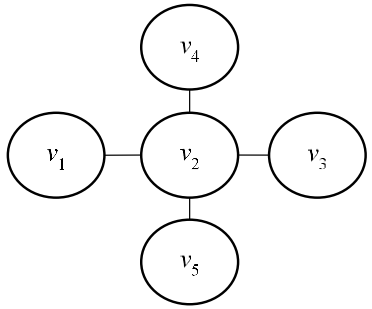


1.2 Topology 网络拓扑

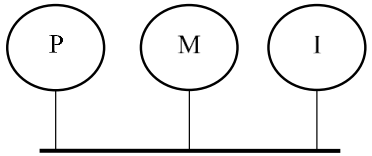
- Three types of networks 静态网络、动态网络、演化网络
  - A **static network** does not change nodes and edges
  - A **dynamic network** does not change nodes; may change edges
    - At one moment, the bus connects the processor (P) and the memory (M)
    - At the next moment, the bus connects the memory (M) and an input device (I)
      - The bus supports a *shared-media network*, while the crossbar supports a *switching network*
        总线：一对一、一对多（广播）；交叉开关：多对多
  - An **Evolutionary network** change both nodes and edges over time
    - Internet, WWW



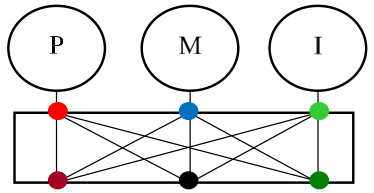
(a) A fully connected graph



(b) A star network



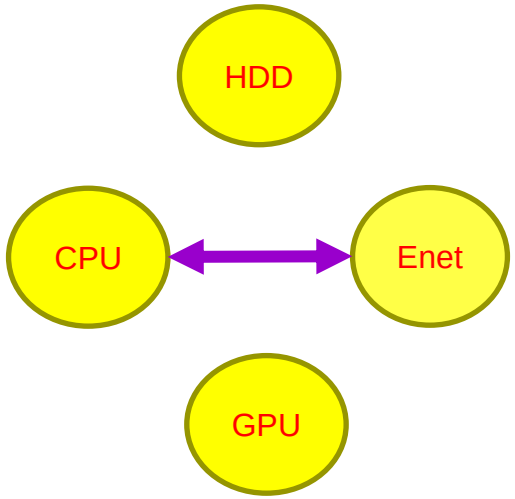
Nodes connected by (c) a bus

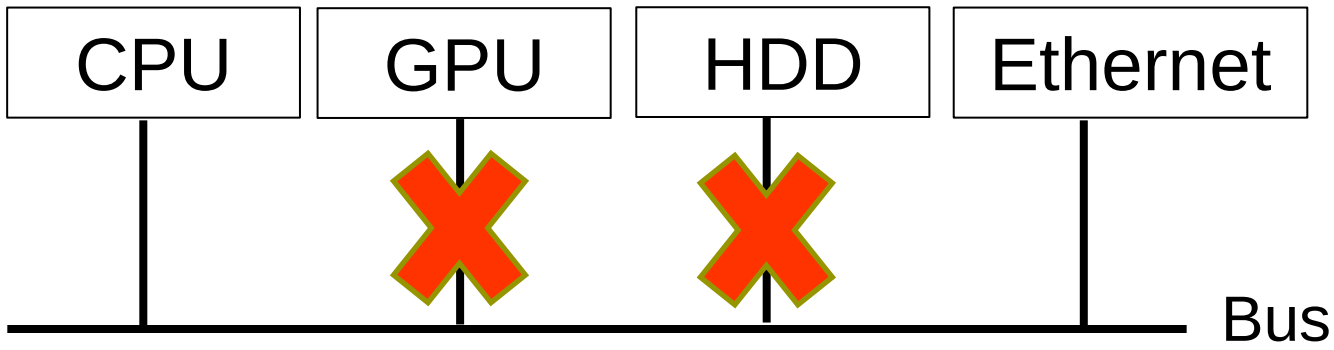


(d) a crossbar switch

How does a dynamic network work?

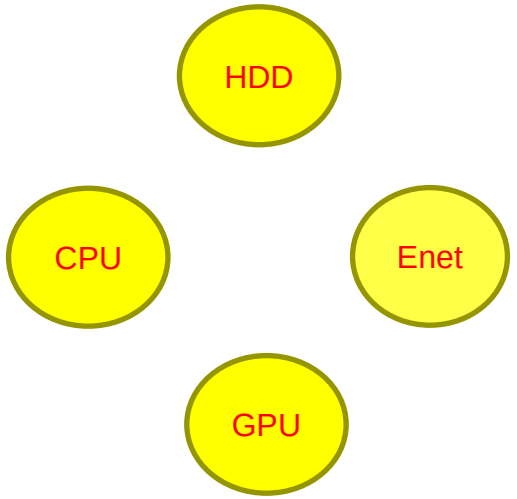
- Bus arbitration　总线仲裁例子
  - Time interval 1: CPU connects to Ethernet

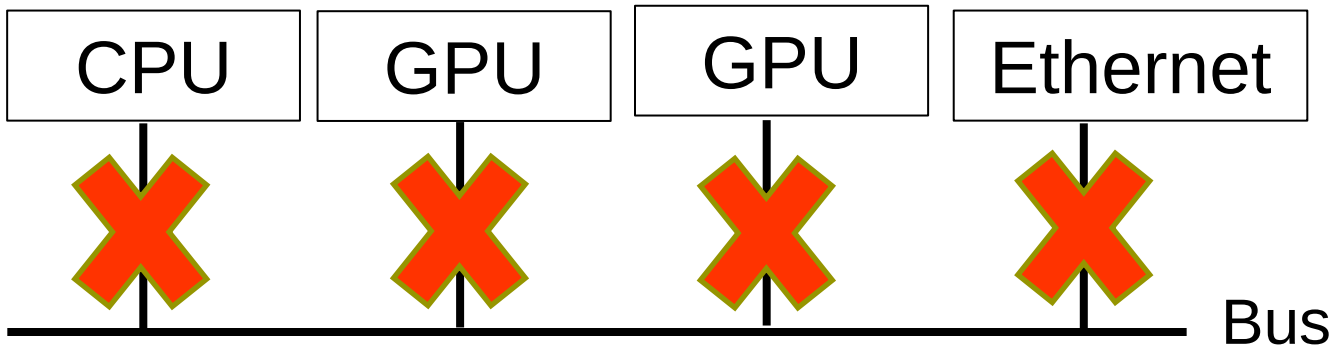




How does a dynamic network work?

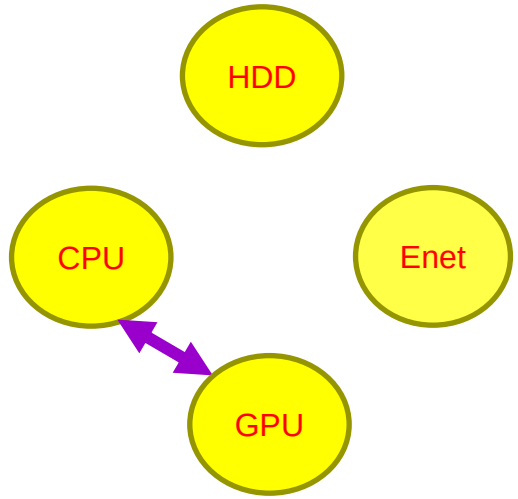
- Bus arbitration
  - Time interval 1: CPU connects to Ethernet
  - End of interval 1: Bus arbitration operation
    - Switch to a new connection

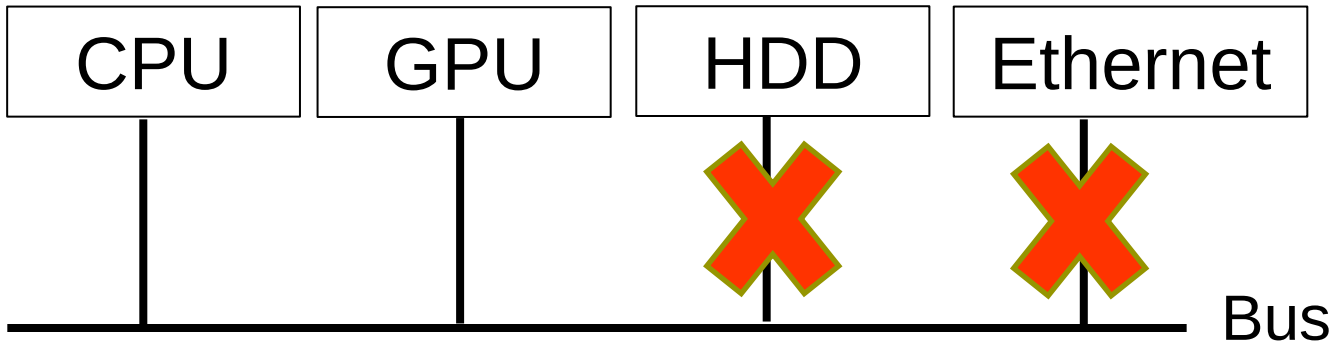




How does a dynamic network work?

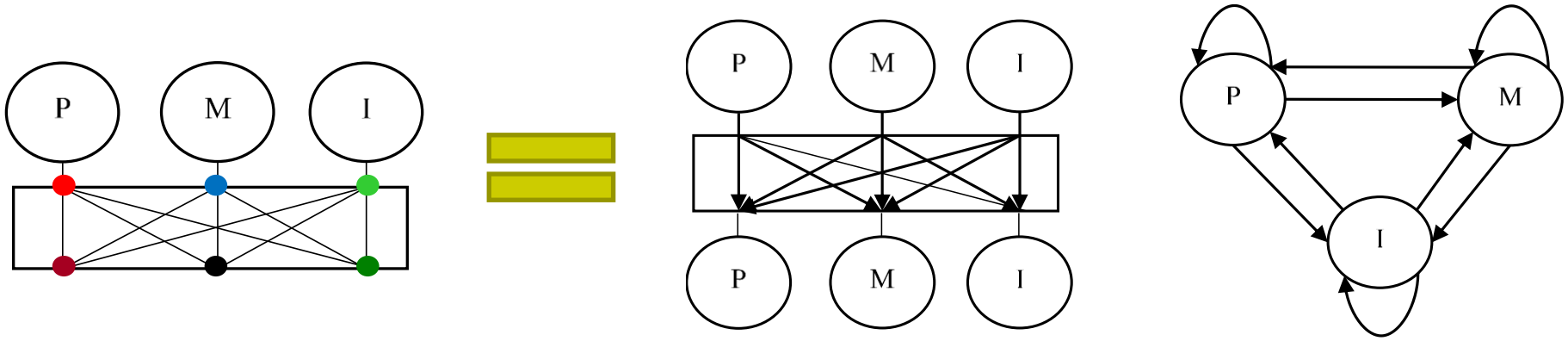
- Bus arbitration
  - Time interval 1: CPU connects to Ethernet
  - End of interval 1: Bus arbitration operation
    - Switch to a new connection
  - Time interval 2: CPU connects to GPU





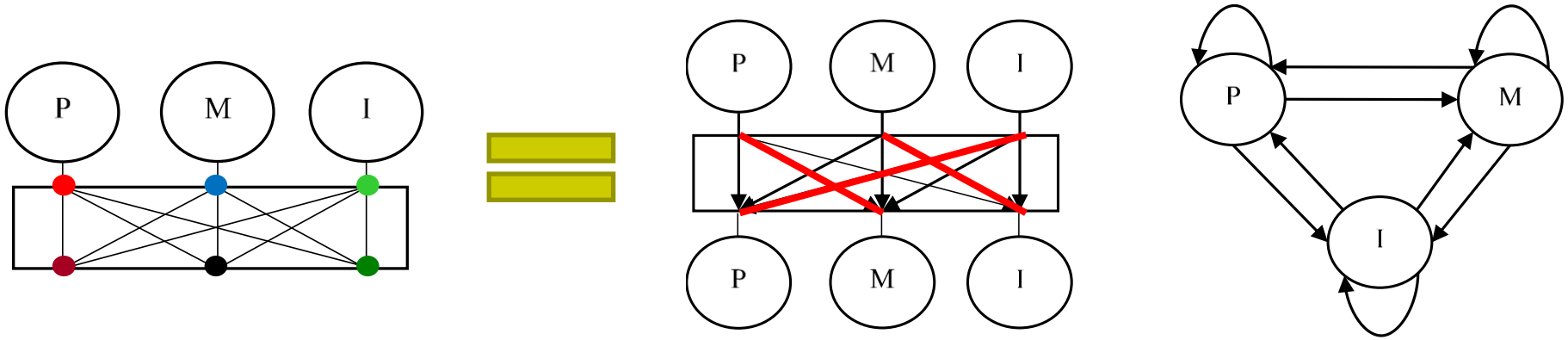
Switch 交换机 交叉开关，比总线成本更高

- All nodes of the network are dynamically connected
  - Switch = dynamic fully-connected network



Switch 交换机 交叉开关（crossbar switch）

- All nodes of the network are dynamically connected
  - Switch = dynamic fully-connected network
- Can be configured to realize any connection
  - Interval 1: Permutation, {P→M, M→I, I→P}　　置换



Switch 交换机 交叉开关

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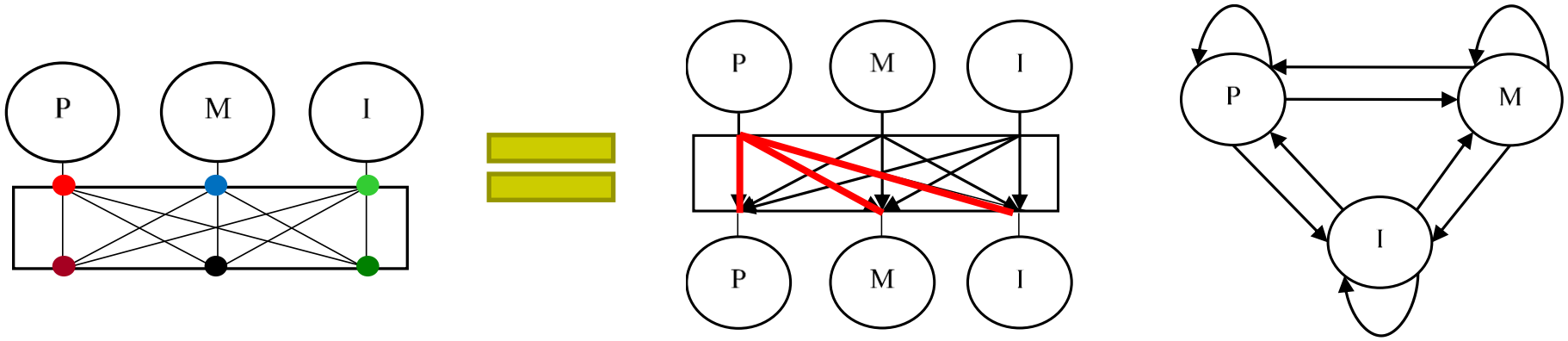
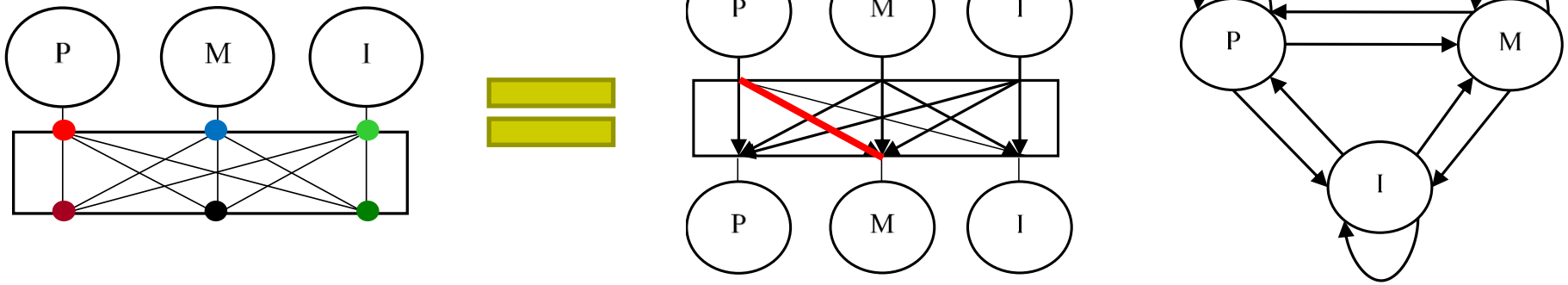
- Can be configured to realize any connection
  - Interval 1: Permutation, {P→M, M→I, I→P}
  - Interval 2: Broadcast, {P→P, P→M, P→I}　　广播



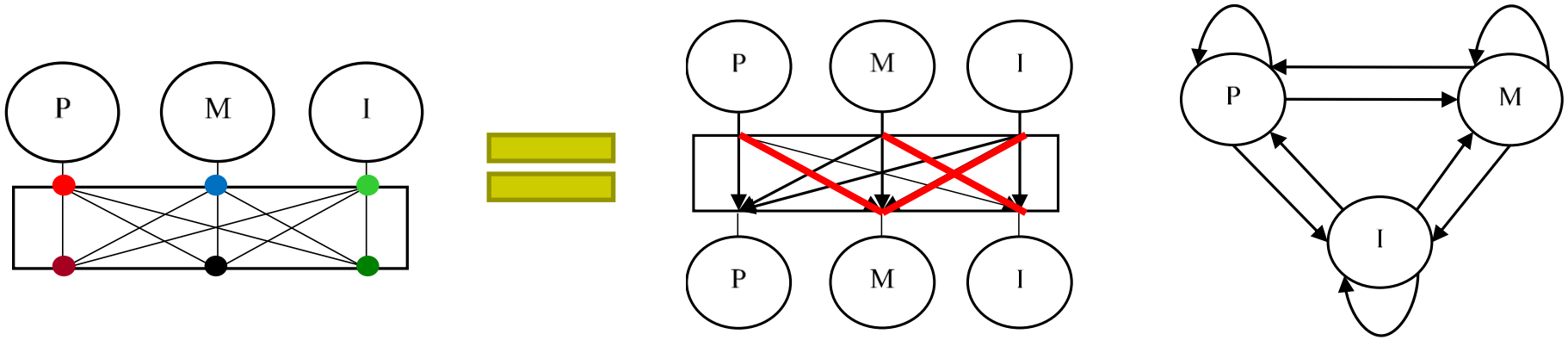
Switch 交换机 交叉开关

- All nodes of the network are dynamically connected
  - Switch = dynamic fully-connected network
- Can be configured to realize any connection
  - Interval 1: Permutation, {P→M, M→I, I→P}
  - Interval 2: Broadcast, {P→P, P→M, P→I}
  - Interval 3: Point-to-point, {P→M} 点到点



Switch 交换机 交叉开关；可实现任意连通？

- All nodes of the network are dynamically connected
  - Switch = dynamic fully-connected network
- Can be configured to realize any connection
  - Interval 4: {P→M, M→I, I→M}　　不行！
  - 可实现任意**无冲突连通**



课堂小测验

- 姓名：　　学号：

- 关于连通性，请指出下述哪一个断言是正确的（）

A. 一个IPv4地址有32比特，可指称2^{32}个互联网节点
B. DNS将IP地址转换为互联网域名
C. cs101.ucas.edu.cn的顶级域名是cs101
D. 总线是静态网络

2. Protocol stack 协议栈

- A network uses a protocol stack to communicate messages
  - A set of layers of protocols
  - We focus on one stack
- Key terms
  - Message and packet
    消息 **vs.** 分组（包、数据包）
    - Packet is part of a message
  - Circuit switching
    versus packet switching
    线路交换 **vs.** 分组交换
  - The Web over Internet stack
    - HTTP
    - TCP
    - IP
    - Ethernet or WiFi
    - Wired or wireless

互联网协议栈
The Web over Internet Stack

Layer	Protocol	Purpose
Application Layer Layer 5	HTTP	Access hypertext resources on a Web server from a Web client
Transport Layer Layer 4	TCP	Reliably transfer packets between two Internet hosts
Network Layer Layer 3	IP	Transfer packets between two Internet hosts in the best-effort way
Data Link Layer Layer 2	Ethernet, WiFi	Reliably transfer packets between two homogeneously connected devices
Physical Layer Layer 1	Wired or wireless, electrical or optical, cables or waveforms	Provide physical communication channels Transfer signals of individual bits

2.1 线路交换与分组交换（包交换）

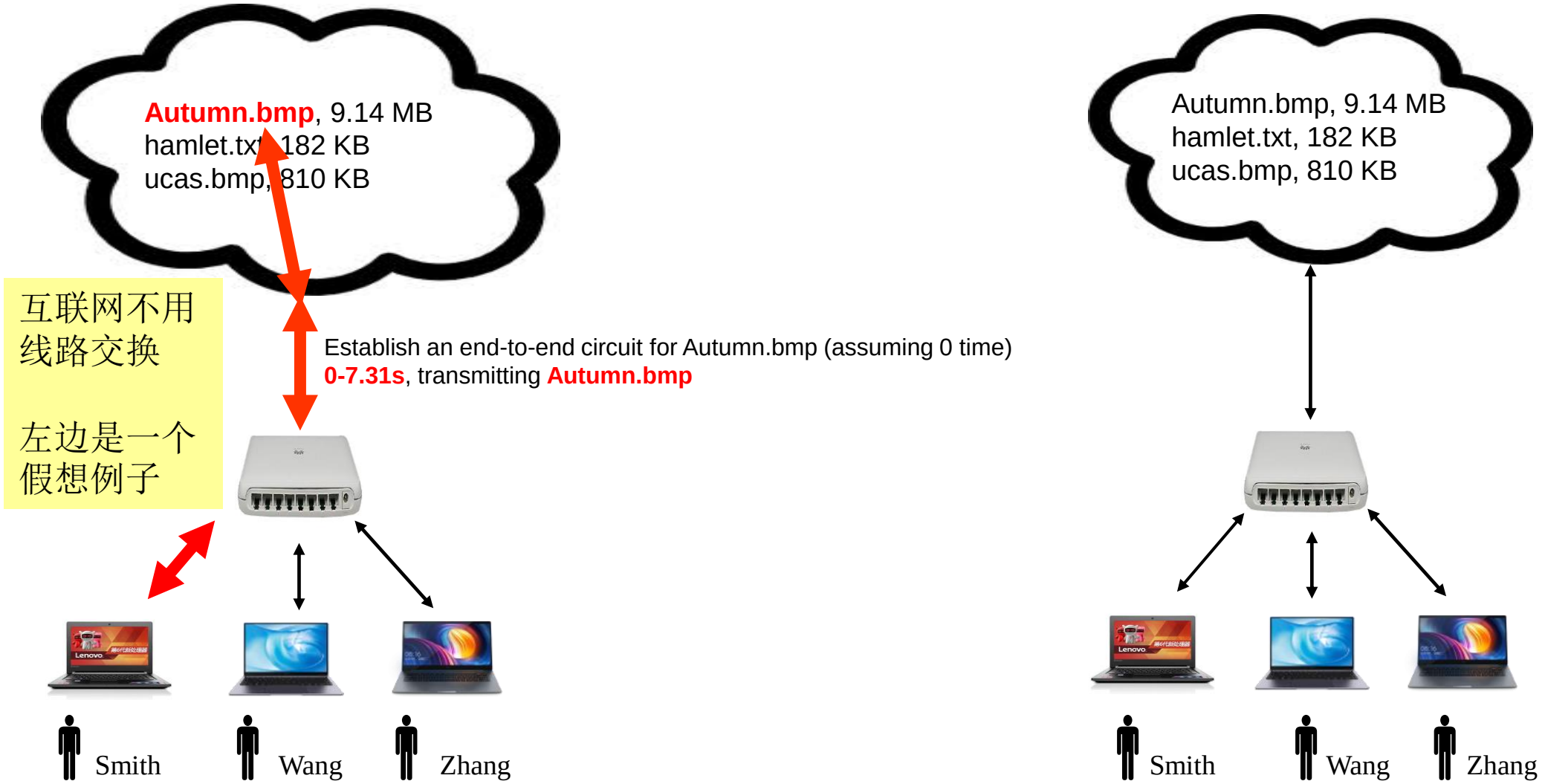
- 两种主要的通信方法
  - 传统的电话通信采用线路交换，计算机网络采用分组交换
- 线路交换（circuit switching）
  - 假设A与B要通话
    - 建立一条从A到B的物理线路
    - 在整个通话时间，这条物理线路一直被A和B的会话独占
    - 传统电话通信采用的线路交换技术使用了上百年，质量好，但通信线路效率低（2%）

线路交换与分组交换

- 两种主要的通信方法
  - 传统的电话通信采用线路交换，计算机网络采用分组交换
- 线路交换（circuit switching）
  - 假设A与B要通话
    - 建立一条从A到B的物理线路
    - 在整个通话时间，这条物理线路一直被A和B的会话独占
- 分组交换（packet switching）
  - 假设A要送一条消息给B
    - 将消息拆成很多小单元，称为“包”或“分组”（packet）
    - 通信线路每个时刻只在传输一个包
    - 但在1秒钟的时段内，通信线路传递来自多个用户的多个消息的多个包
      - 100个用户感受到：多条消息同时在一条物理线路上传播

Circuit switch vs. packet switch

Assumptions for both systems: (1) 10 Mbps; (2) all three tasks start at 0; (3) ignore all overheads



Circuit switch vs. packet switch

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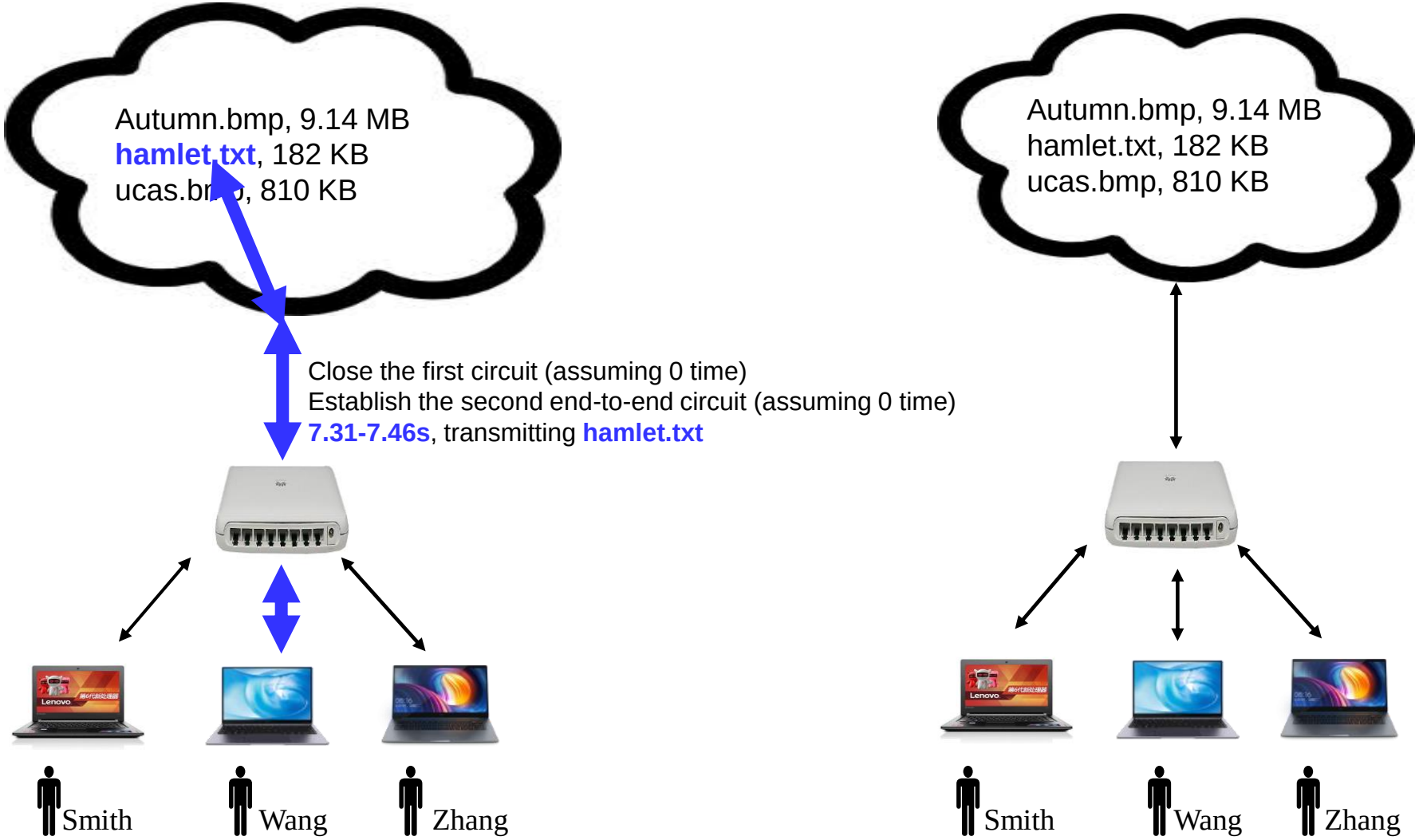

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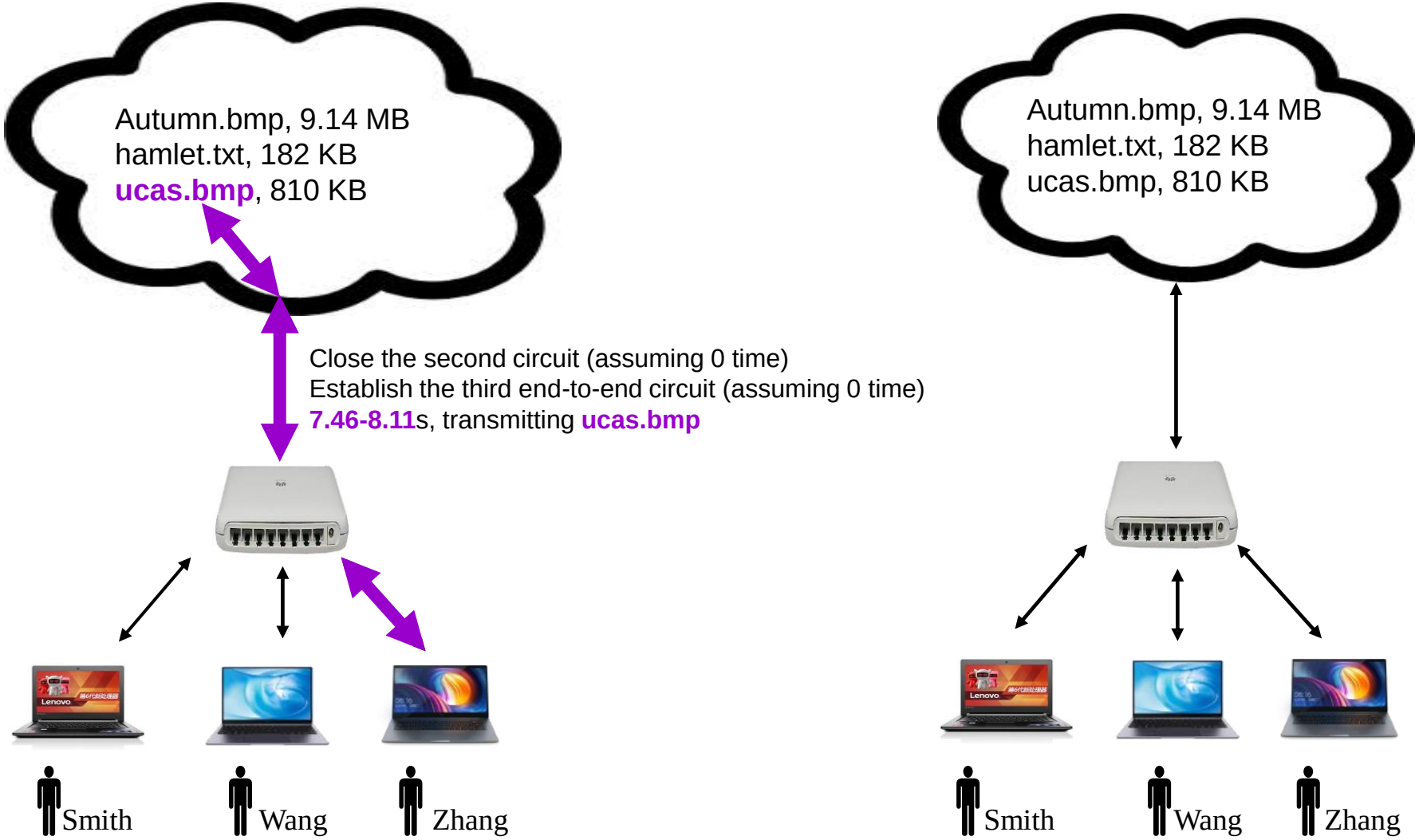

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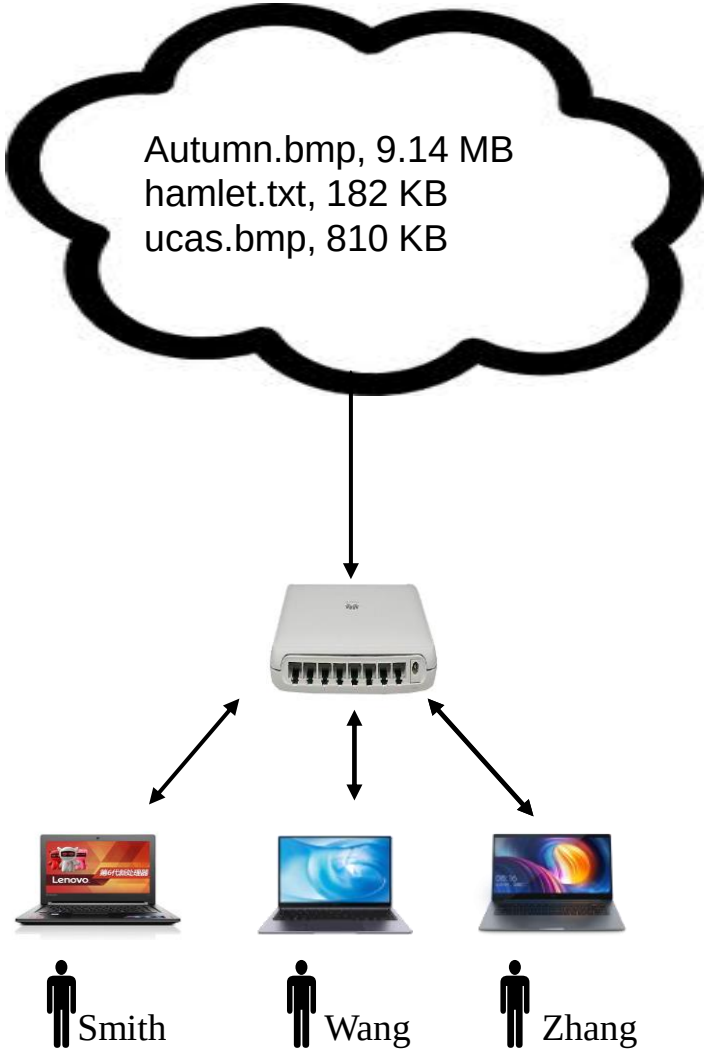
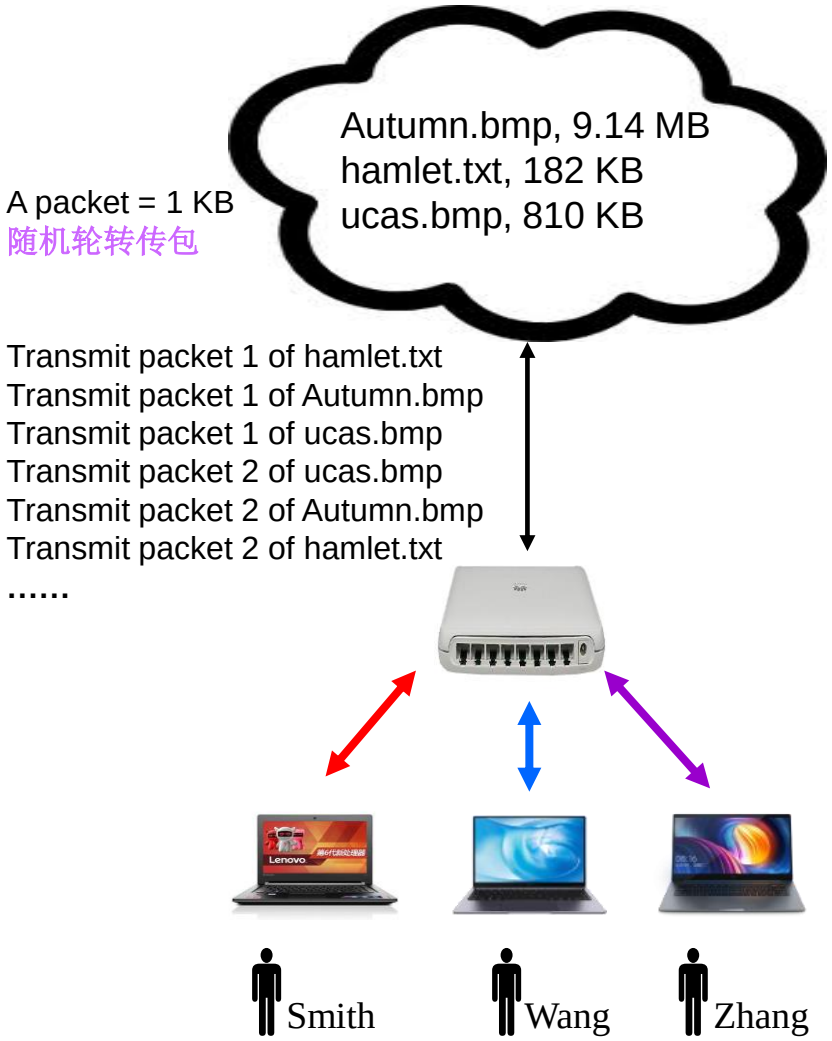


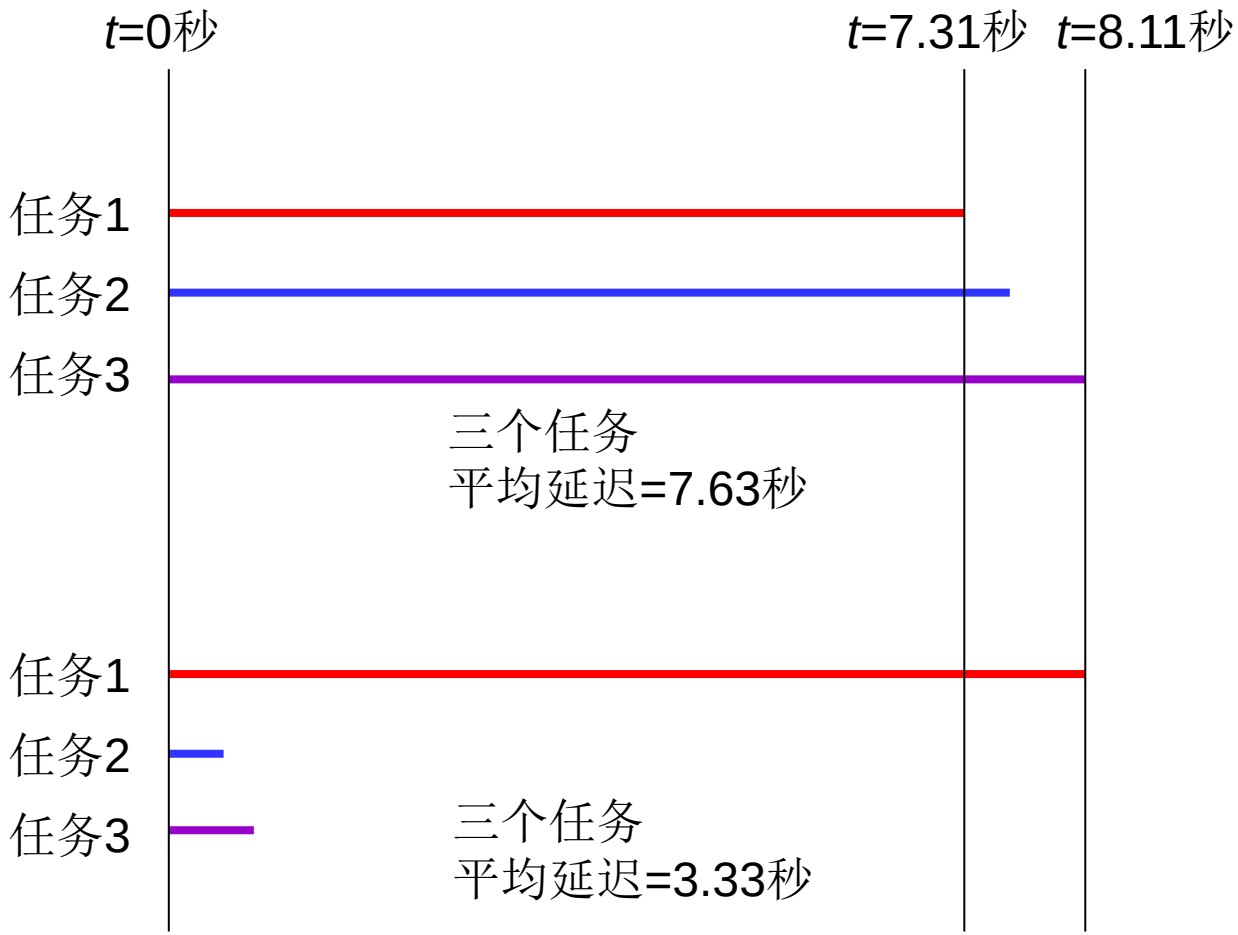
A packet = 1 KB
随机轮转传包



假设三个下载任务使用10 Mbps带宽资源

分组交换平均延迟更小，且任务1没有阻塞其他任务

Circuit switch
线路交换



Packet switch
分组交换

包格式 A packet has two parts
header and body

- Packet body is the payload data 包体是载荷数据
- Packet header holds various metadata 包头是3类元数据
  - **Addresses** of source and destination nodes 地址
  - Error check information, e.g., Cyclic Redundancy Check (CRC) 查错
  - Other information, e.g., control information 其他信息
  - Part of header may come after body
- Think of post mail
  - Body = Letter 包体 = 信
  - Header = Envelop 包头 = 信封

Format of an Ethernet packet 以太网帧

7 bytes	1 byte	6 bytes	6 bytes	2 bytes	46-1500 bytes	4 bytes
Preamble	Frame Delimiter	Destination MAC Address	Source MAC Address	Type	Data (Payload)	CRC

以太网的帧格式 对比 WiFi的帧格式

字节数		包头				包体	总计
		地址	查错	其他	小计		
以太网 802.3	最小包	12	4	10	26	46	72
	最大包	12	4	10	26	1500	1538
WiFi 802.11	最小包	24	4	6	34	0	34
	最大包	24	4	6	34	2312	2346

以太网 (IEEE 802.3) 帧格式

7 bytes	1 byte	6 bytes	6 bytes	2 bytes	46-1500 bytes	4 bytes
Preamble	Frame Delimiter	Destination MAC Address	Source MAC Address	Type	Data (Payload)	CRC

WiFi (IEEE 802.11) 帧格式

2 bytes	2 bytes	6 bytes	6 bytes	6 bytes	2 bytes	6 bytes	0-2312 bytes	4 bytes
Frame Control	Duration	Address 1	Address 2	Address 3	Sequence	Address 4	Data (Payload)	CRC

2.2 Protocol stack 协议栈

- A network uses a protocol stack to communicate messages
  - A set of layers of protocols
  - We focus on one stack
- Key terms
  - Message and packet
    消息 vs. 分组（包、数据包）
    - a message is divided into one or more packets
  - Circuit switching versus packet switching
    线路交换 vs. 分组交换
  - The Web over Internet stack
    - HTTP
    - TCP
    - **IP (Internet Protocol)**
    - Ethernet or WiFi
    - Wired or wireless

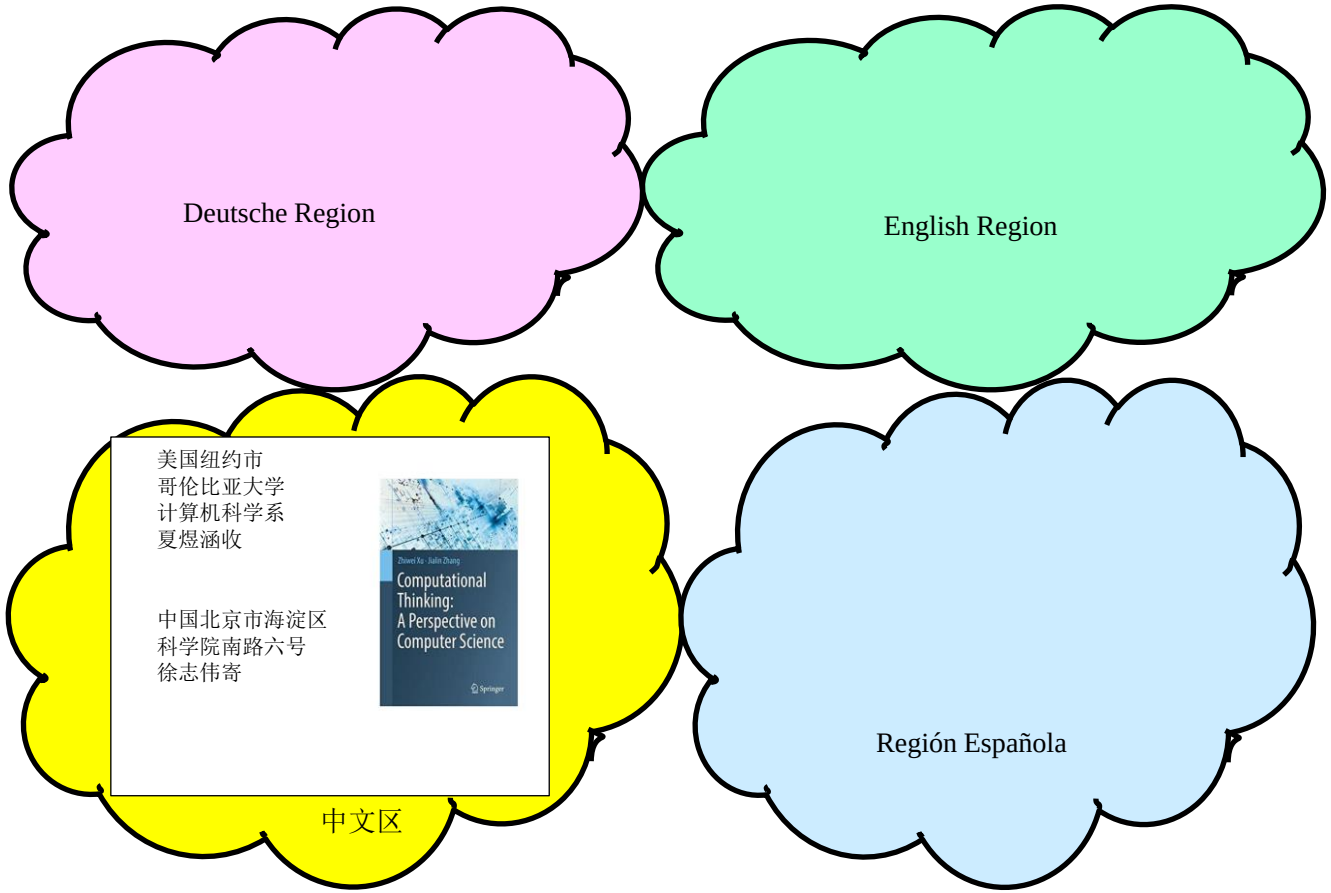
互联网协议栈

The Web over Internet Stack

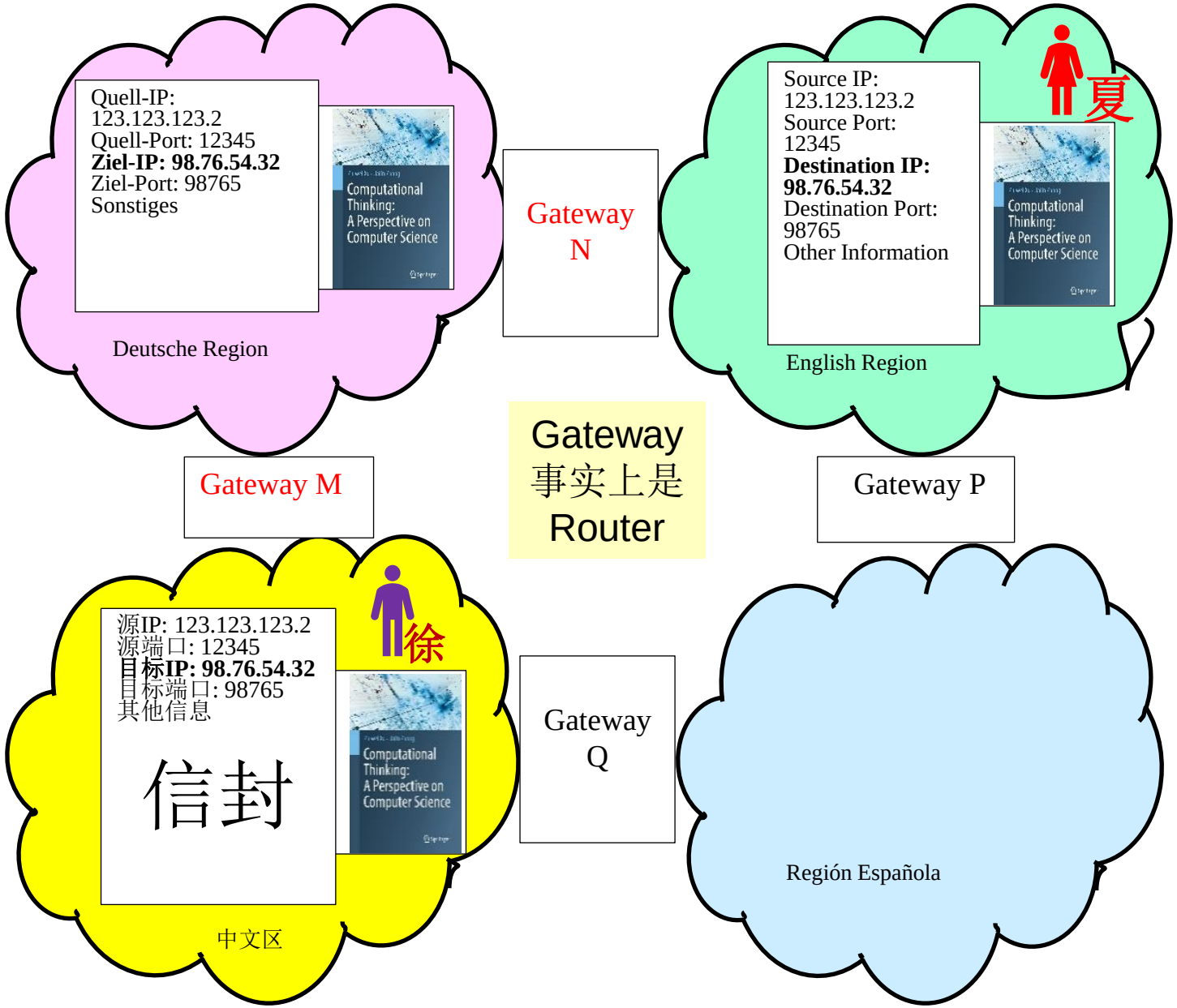
Layer	Protocol	Purpose
Application Layer Layer 5	HTTP	Access hypertext resources on a Web server from a Web client
Transport Layer Layer 4	TCP	Reliably transfer **TCP packets** between two Internet hosts
Network Layer Layer 3	IP	Transfer IP datagrams **数据报** Between two Internet hosts in a best-effort way
Data Link Layer Layer 2	Ethernet, WiFi	Reliably transfer **frames 帧** between two homogeneously connected devices
Physical Layer Layer 1	Wired or wireless, electrical or optical, cables or waveforms	Provide physical communication channels Transfer signals of individual **bits 比特**

为什么需要IP？

- 邮局示例：徐志伟送新书图片给夏煜涵
  - 明信片方式不能解决异构网络问题

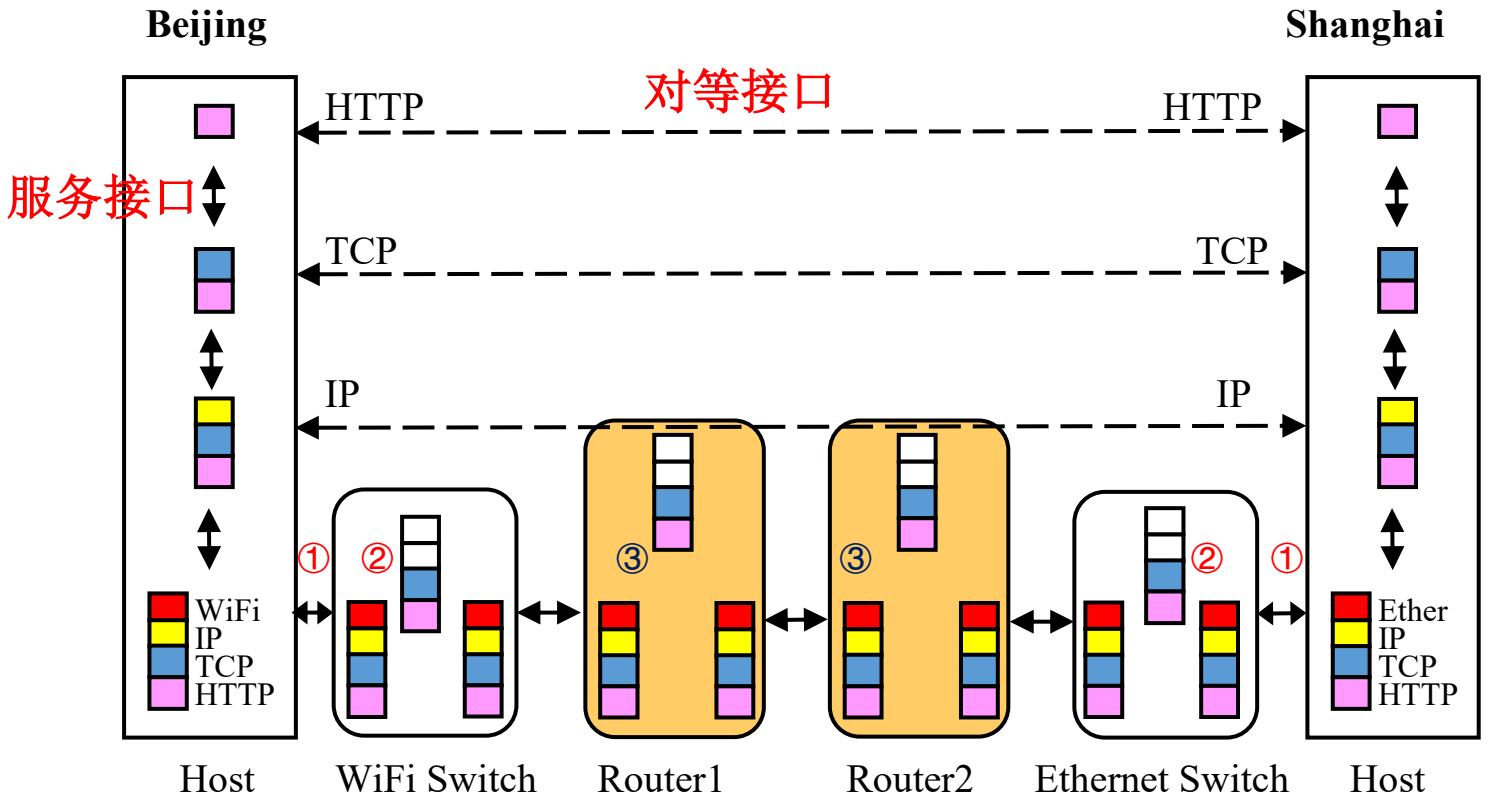


信件方式能够解决异构网络问题



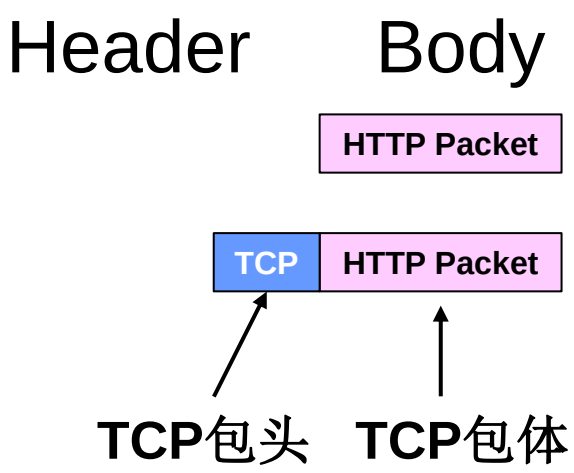
HTTP GET request and response messages

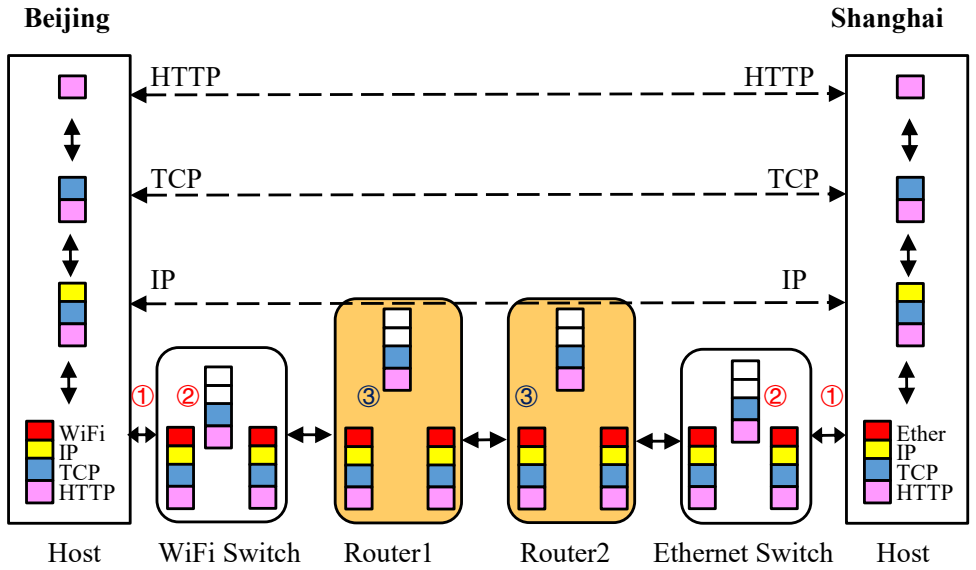
- Request message: http://www.shanghaitech.edu.cn/
  - Sent to the server as a stream of packets
- Response message: the contents of the home page
  - Sent from the server as a stream of packets



How is the response message communicated

- Response message, i.e., the contents of the home page, is divided into a number of packets, i.e., slices of the message
  - Each HTTP packet is turned into an Ethernet packet as follows 打包
    - HTTP packet (**pink**) is handed to the TCP layer as the body of a TCP packet
    - TCP layer adds a TCP header (**blue**) to form a TCP packet
    - The TCP packet is handed over to the IP layer as the IP packet body
    - The IP layer adds an IP header (**yellow**) to form an IP packet
    - Finally, the IP packet is handed over to the data link (Ethernet) layer as the Ethernet packet body
    - The Ethernet layer adds an Ethernet header (**red**) to form an Ethernet packet





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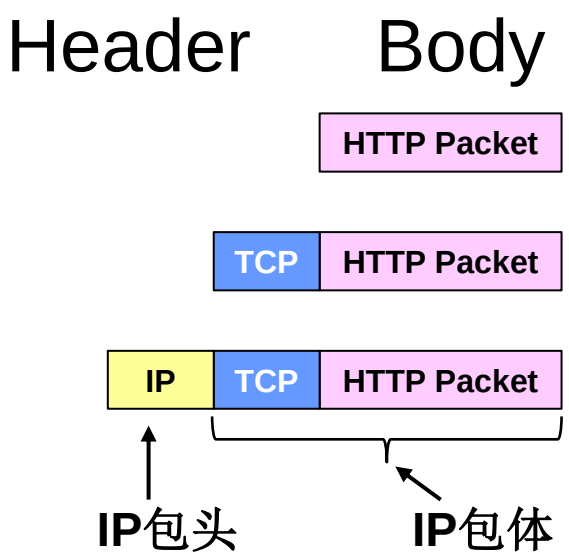

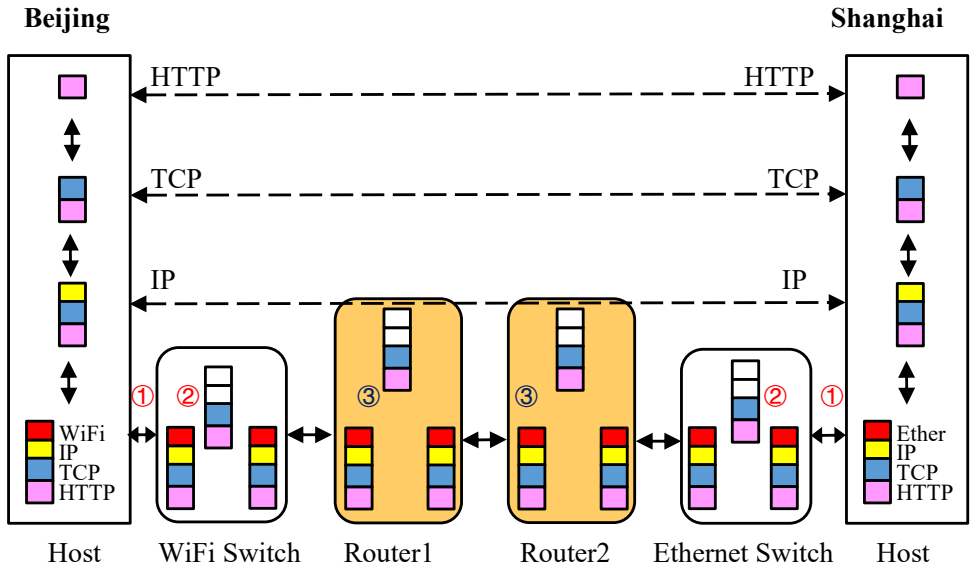

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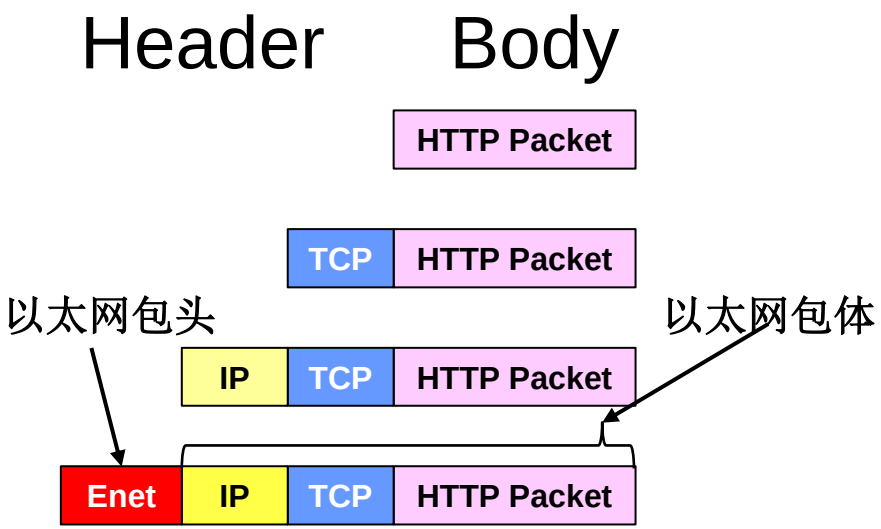
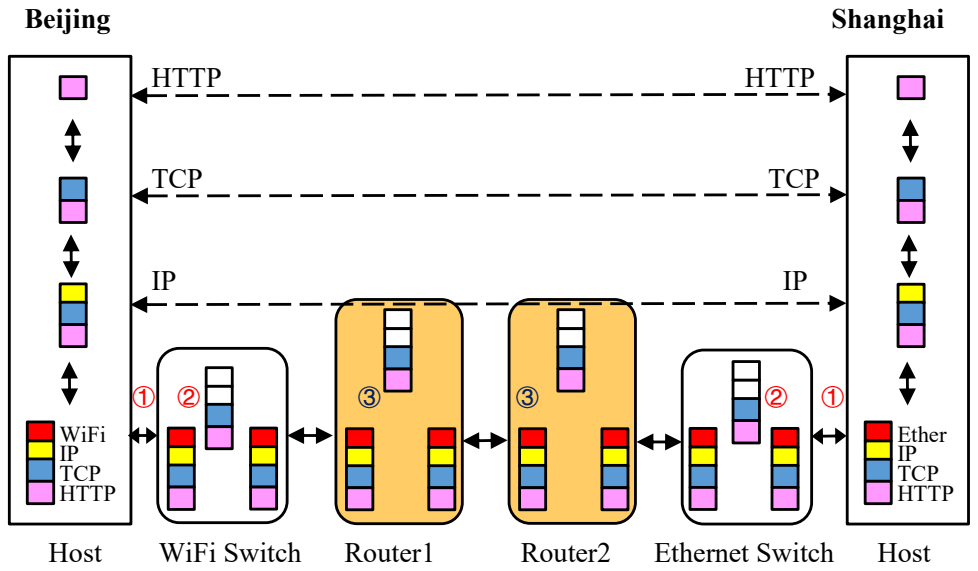
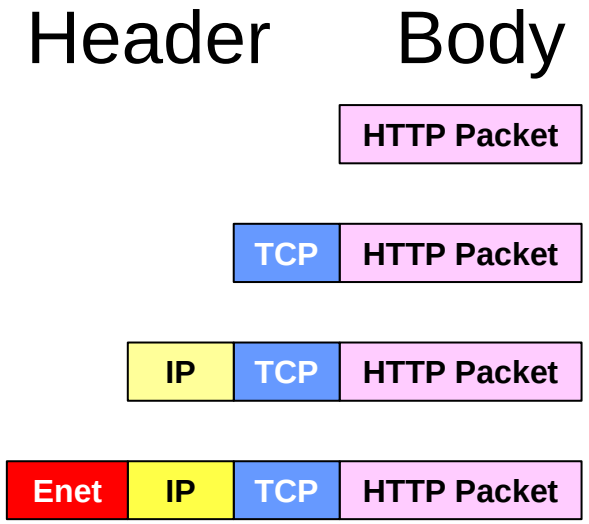
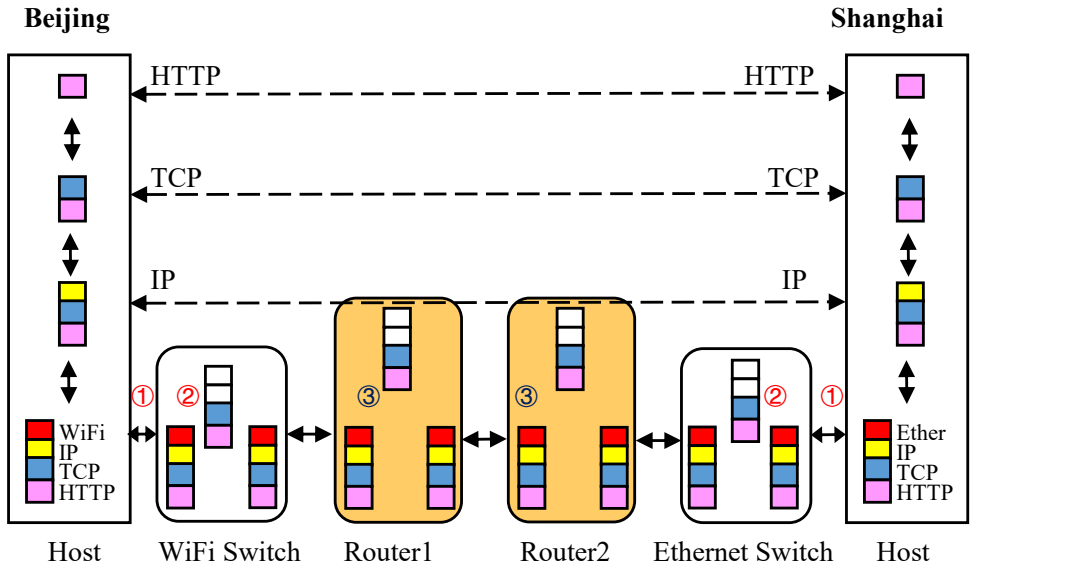




How is the response message communicated

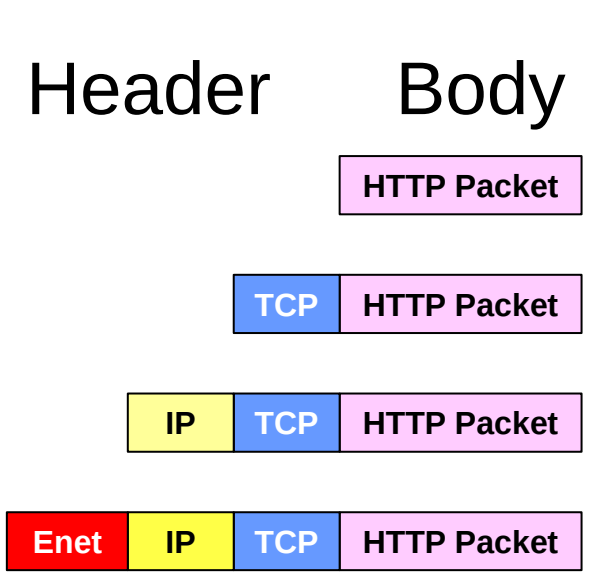
- Each HTTP packet is communicated as follows 传输
  - ① The server host sends an HTTP packet, wrapped as an Ethernet packet, to the Ethernet switch
  - ② The switch opens the packet to reveal the Ethernet and the IP headers, and then adds a new header to form a new Ethernet packet
  - ③ When the packet arrives at Router2, the router opens the packet to reveal both the Ethernet and the IP headers and then form a new Ethernet packet by reformatting the packet and adding a new Ethernet header
  - Similar steps take place at Router1 (③) and the WiFi Switch (②), and then a WiFi packet arrives at the laptop computer host (①)

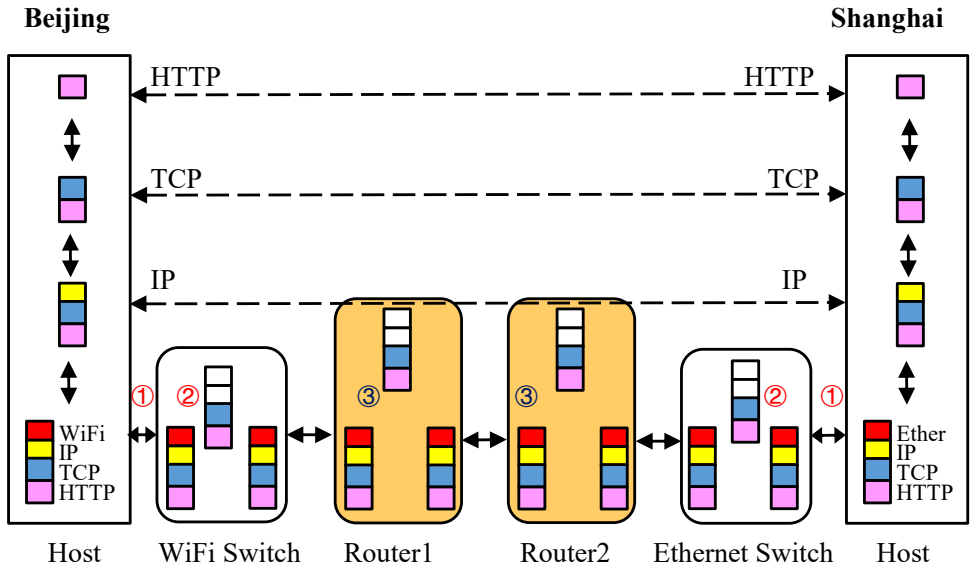




How is the response message communicated

- Each HTTP packet is communicated as follows 解包
  - After a WiFi packet arrives at the laptop computer host in Beijing, it is unpacked by the host (the laptop computer) to reveal
    - the IP packet,
    - the TCP packet, and finally
    - the HTTP packet, i.e., a slice of the message





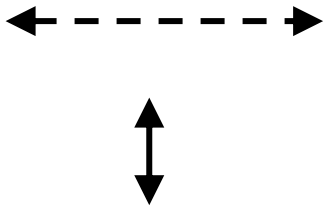
Does Zhang need to worry about TCP/IP and Ethernet when surfing the Web?

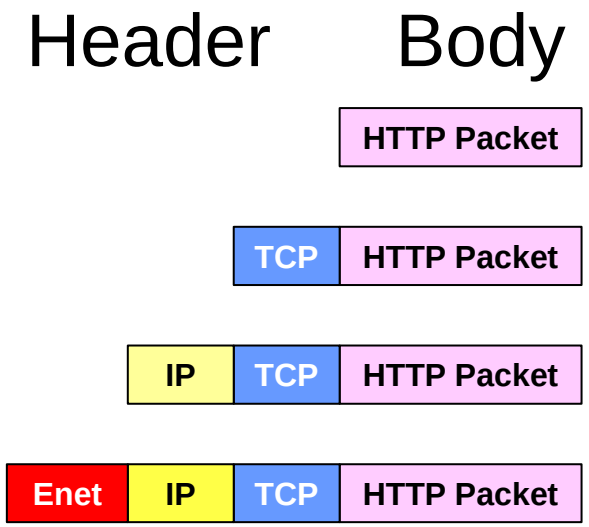
张蕾访问上海科大网站时，需要操心TCP/IP与以太网吗？

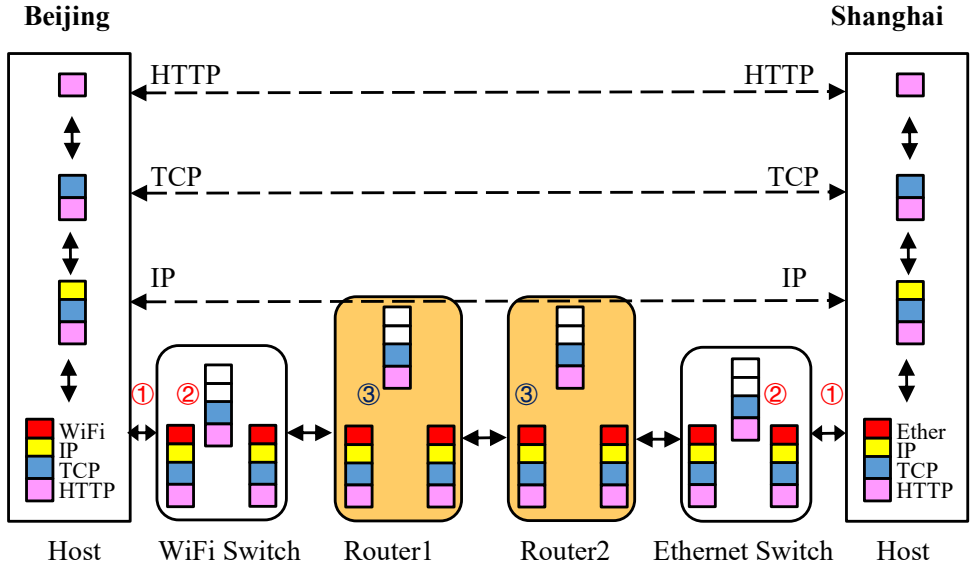
- No! A user only needs to know the peering interface HTTP
- Two types of interfaces
  - Peering interface for user

  对等接口
  - Service interfaces for implementation

  服务接口



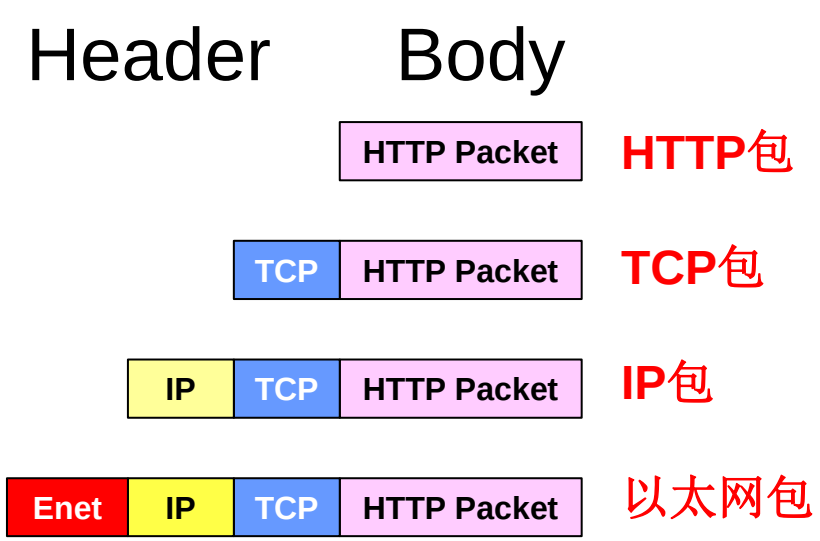


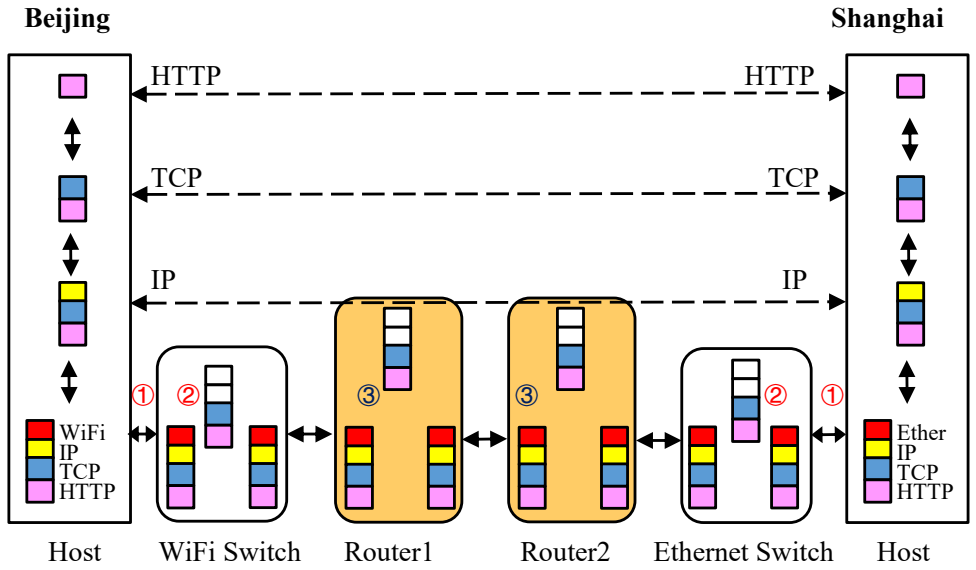


Can one send an upper layer packet without also sending a lower layer packet?

能否只传HTTP包不传IP包

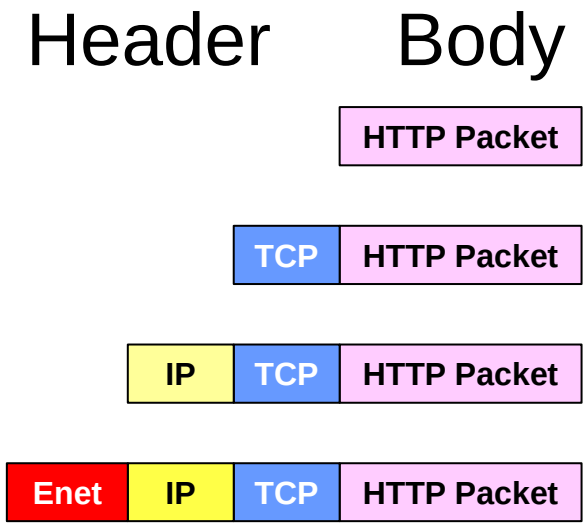
- Can the Web server in Shanghai send an HTTP packet to Zhang's Web browser in Beijing, without also sending an Ethernet frame?
- No! 不能只传上层数据包(如TCP包)，而不传下层包(IP包、以太网包)
  - Any information at the HTTP layer is wrapped in a data link layer packet, and eventually wrapped in a physical layer packet
  - One cannot send a high layer packet without also sending a packet of every layer below
  - When a packet enters a network, it is in a data link layer format and travels as wired and/or wireless signals

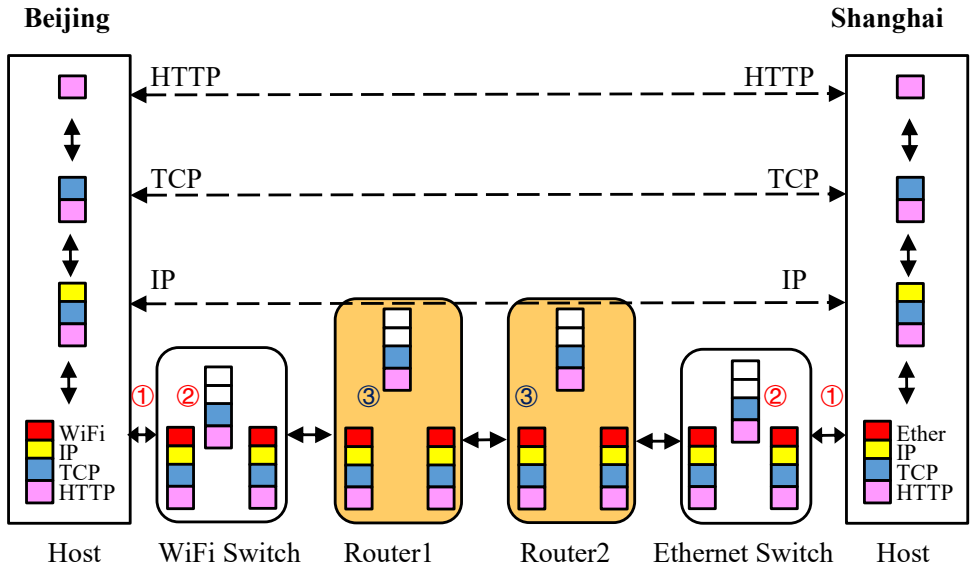




What is actually sent over the network hardware?

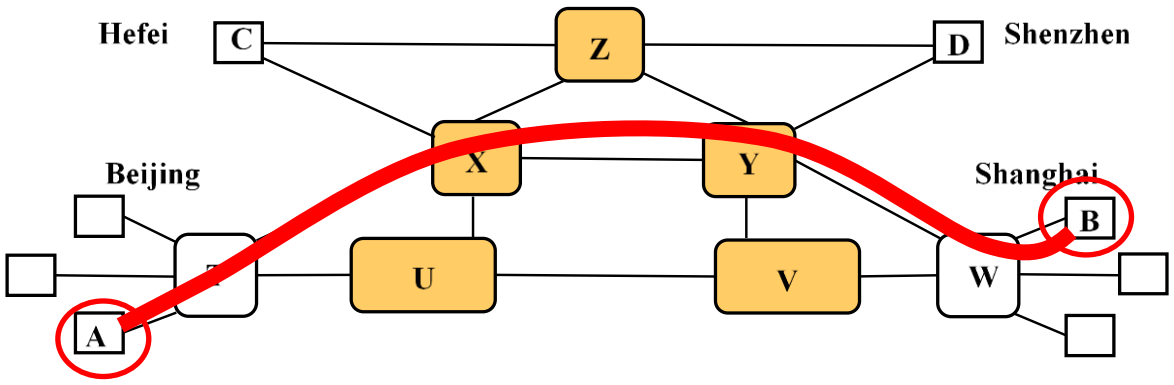
- Bit string of 0‘s and 1’s
  任何数据包最终在物理层作为比特流传递，即一串0或1信号 （电、光）
- Any packet is eventually encapsulated as one or more physical layer packets, which travel as wired or wireless signals
  - A physical layer packet is sent through electrical cables, electromagnetic waveforms or optical fibers, in a bit string of 0‘s and 1’s
  - A 0 may be represented as a LOW voltage pulse or a LIGHTOFF state, while a 1 may be represented as a HIGH voltage pulse or a LIGHTON state





Do all packets travel through the same physical path?
从A到B的一条消息的数据包必然通过同一条通路吗？

- A message is sent from host A to host B
  - Do all packets of the message travel through the same physical path from host A to host B?
  - Not necessarily. Internet has built-in redundancy 不一定。互联网有冗余通路
    - Possible physical paths for a 99-packet message from A to B
      - 1st packet of the message travels along the physical path **A-T-X-Y-W-B**
      - 49th packet traverses path **A-T-U-V-W-B**
        - Arriving at B before 1st packet
      - 99th packet traverses path **A-T-X-Z-Y-W-B**
    - Complete message is reassembled from the packets by their numbers



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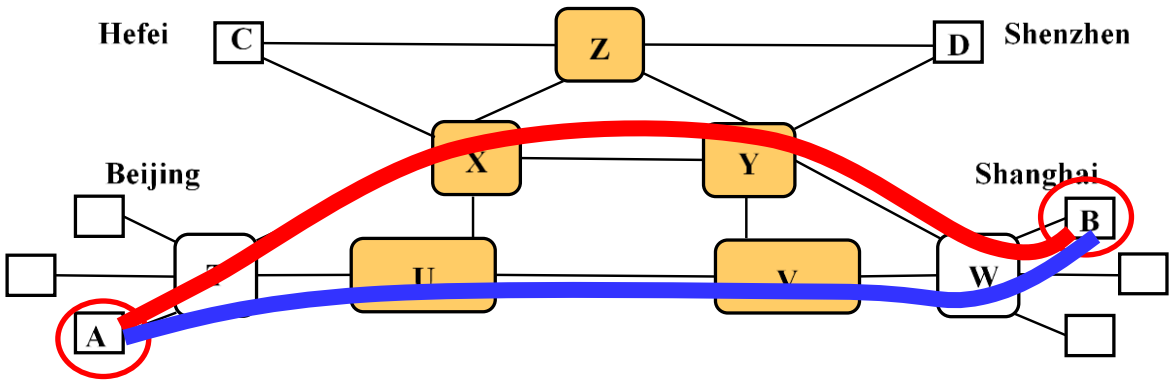

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