计算机网络技术的发展历史与趋势

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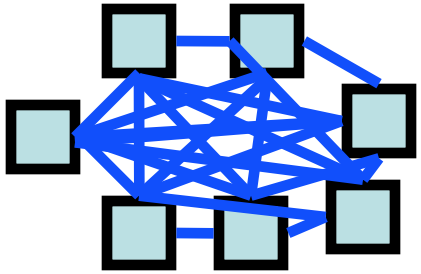
什么是计算机网络？

- 什么是网络？
  - ✓把一系列节点通过线路连接起来的系统
  - ✓例如：铁路网，公路网，电话网，计算机网络
- 什么是计算机网络？
  - ✓一种移动信息的通信网络
  - ✓节点是计算机

最简单的计算机网络

如果节点数大于2

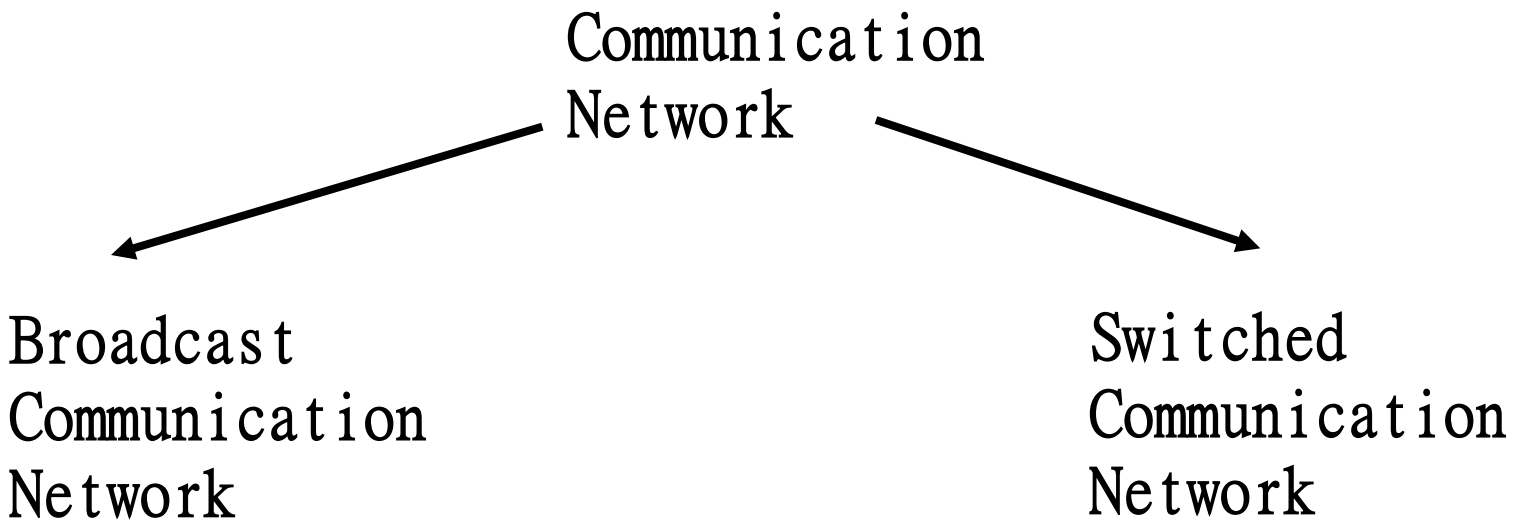
- … But what if we want more hosts?



Wires for everybody!

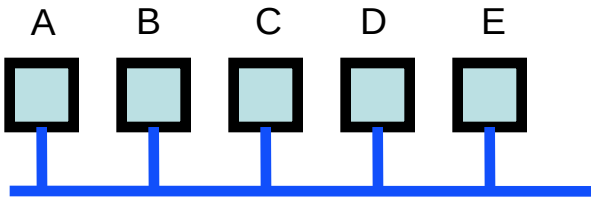
- Scalability?

A Taxonomy of Communication Networks



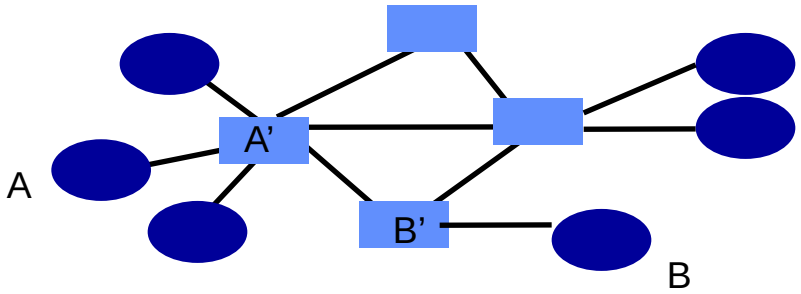
Broadcast vs. Switched

- Broadcast communication networks
  - ✓ Information transmitted by any node is received by every other node in the network
  - ✓ Problem: coordinate the access of all nodes to the shared communication medium (Multiple Access Problem)



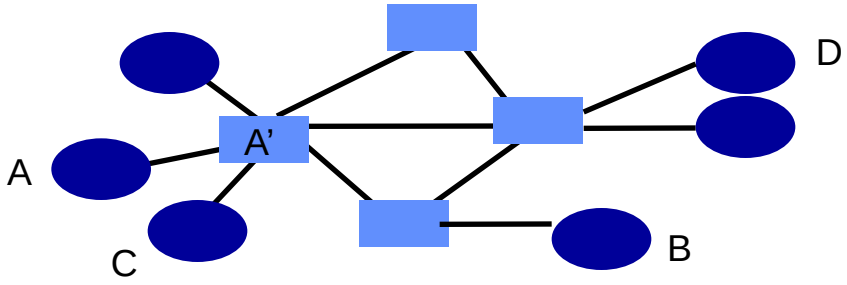
Broadcast vs. Switched (Cont.)

- Switched communication networks
  - ✓ Information is transmitted to a sub-set of designated nodes
    - ➢ Example: WAN
  - ✓ Problem: how to forward information to intended node(s)



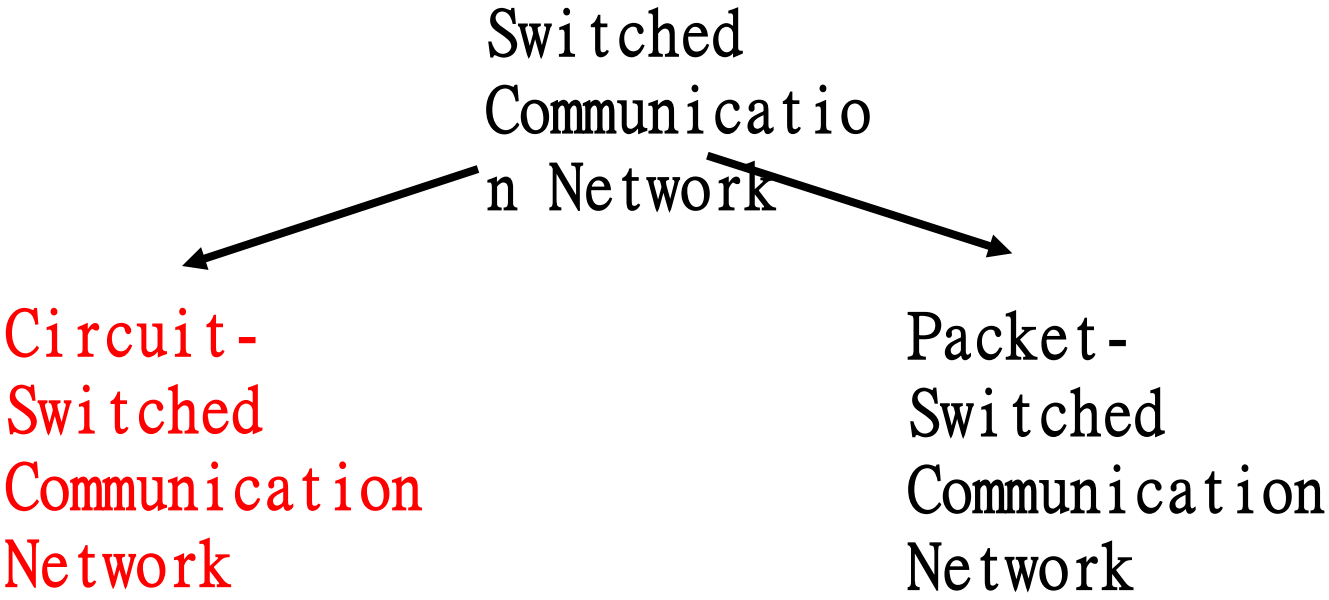
Multiplexing in Switched Network

- Need to share network resources



  - ✓ Conversation 1: A->B
  - ✓ Conversation 2: C->D
- How?
  - ✓ Con. 1 gets the forwarding resource of A' sometimes
  - ✓ Con. 2 gets the forwarding resource of A' sometimes

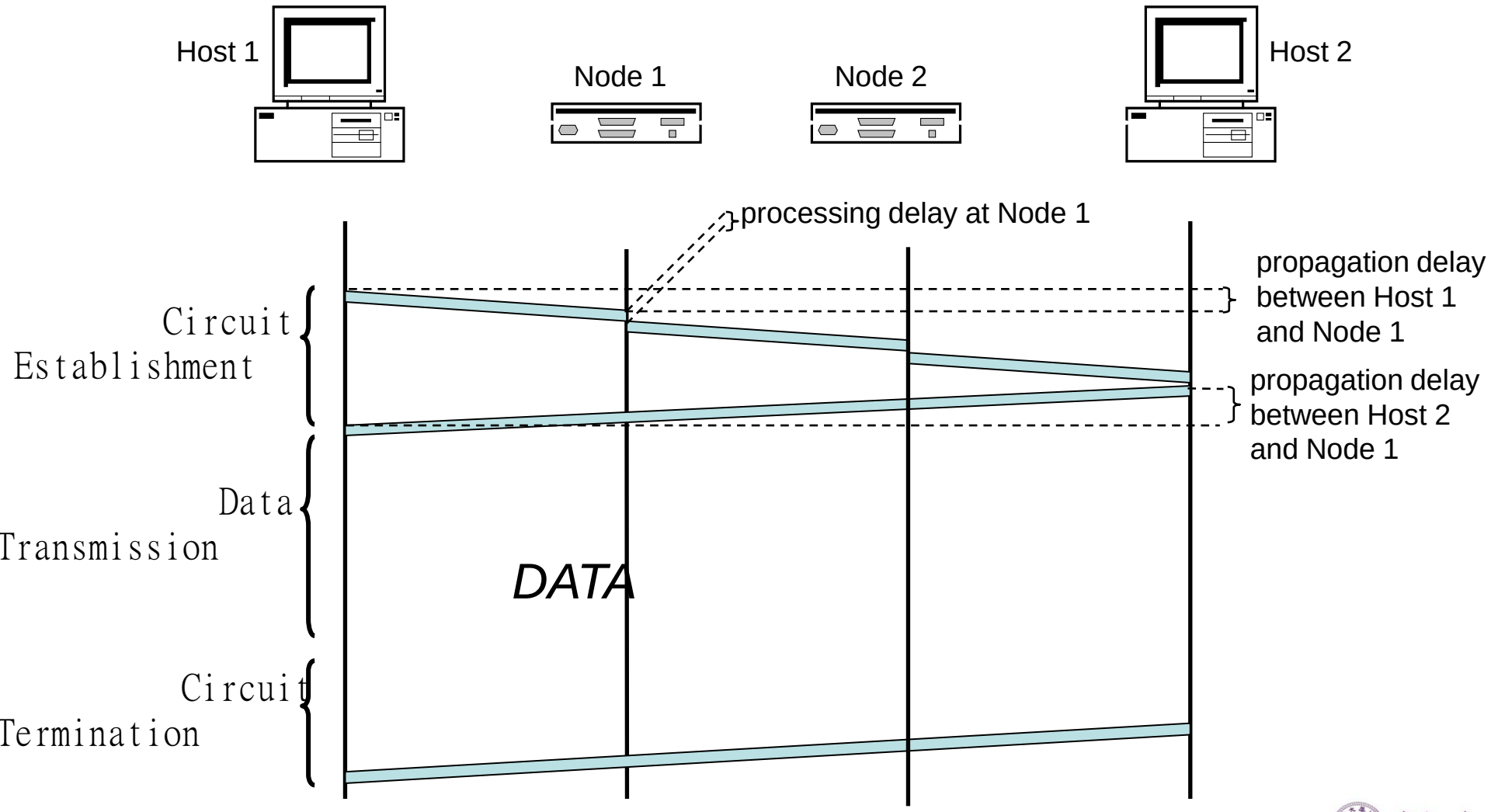
Taxonomy of Switched Communication Networks



Circuit Switching

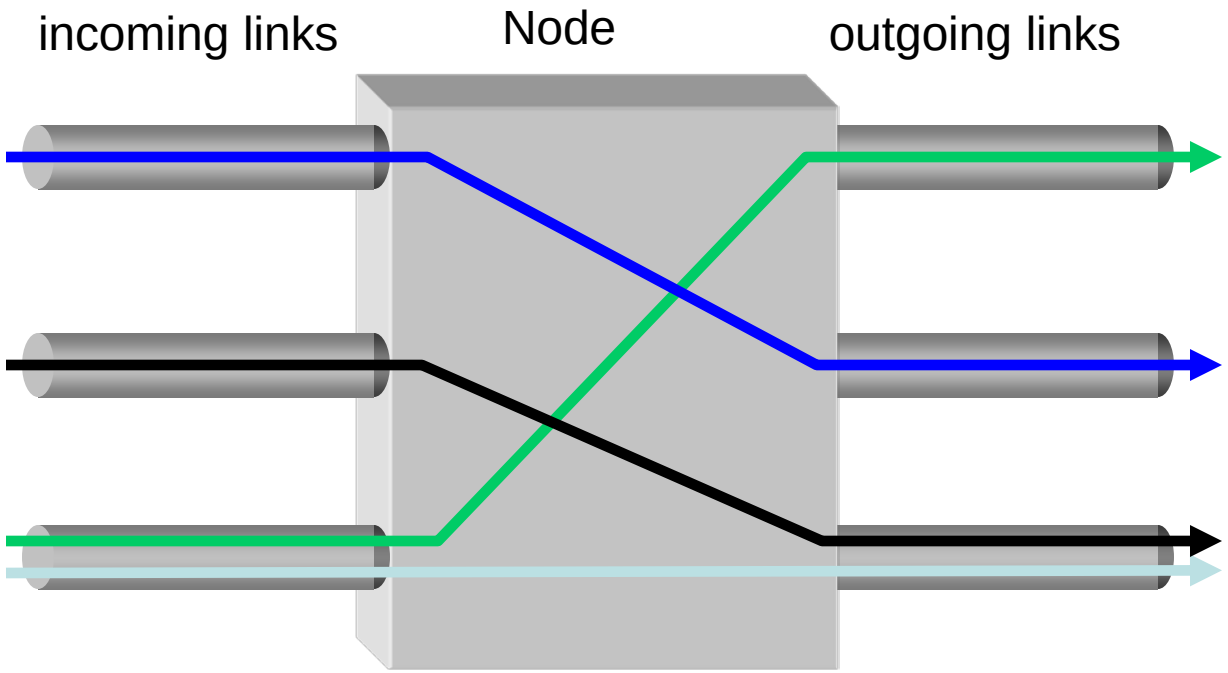
- Source first establishes a connection (circuit) to the destination
- Source sends the data over the circuit
  - ✓ Then the connection is torn down
- Example: telephony network
  - ✓ Early versions: human-mediated switches
  - ✓ Later versions: end-to-end electrical connection

Timing in Circuit Switching



Circuit Switching

- A node (switch) in a circuit switching network

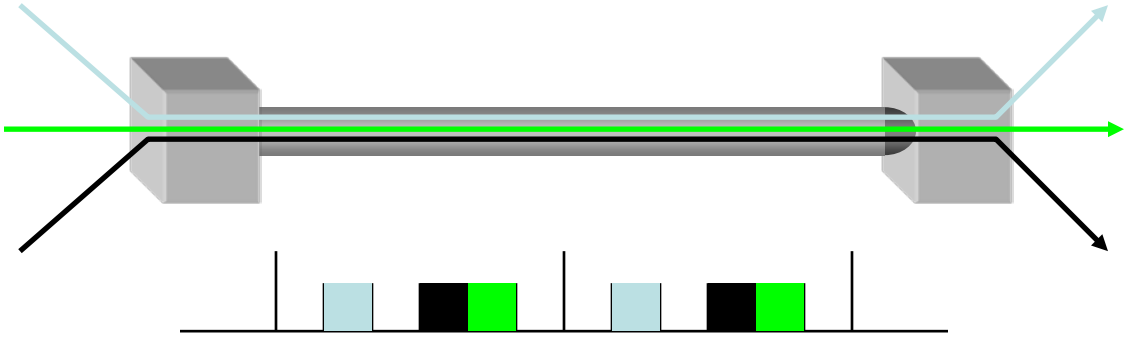


Circuit Switching (Cont.)

- What about many connections?
  - ✓ Many wires
    - ➢ E.g., those big 200-pair cables you sometimes see

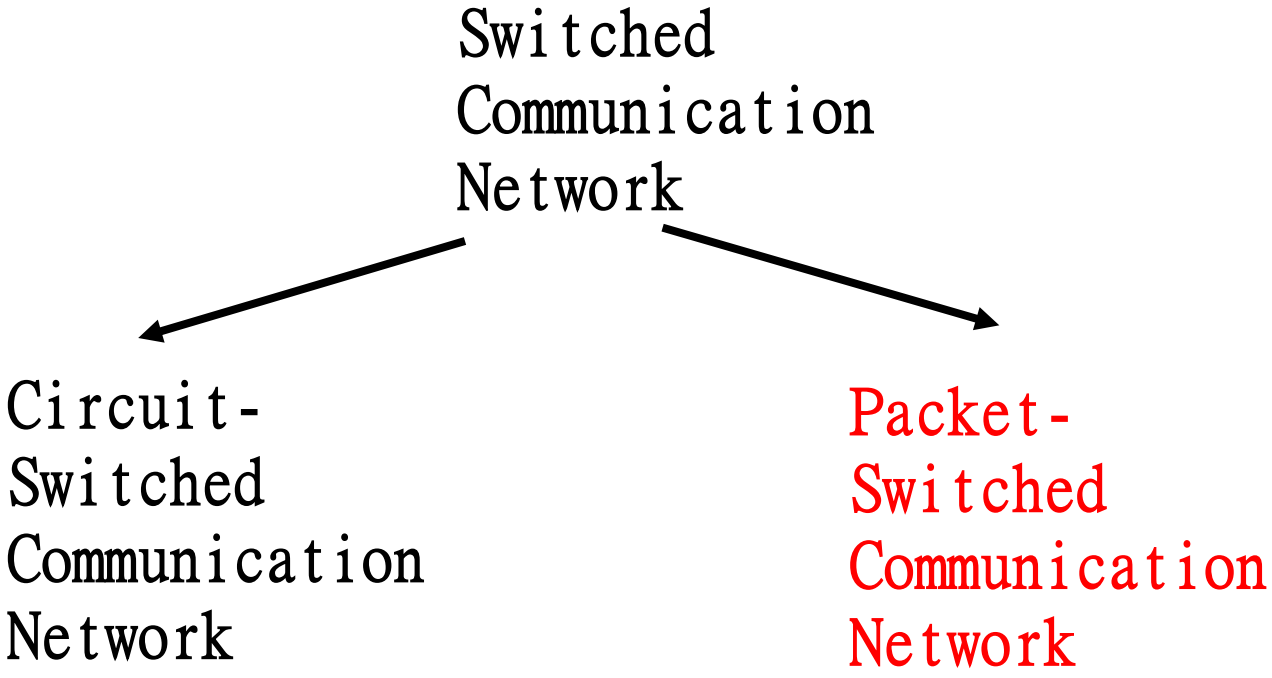
- A more practical approach is to multiplex multiple circuits over a single "fast" wire

Circuit Switching: Multiplexing/Demultiplexing



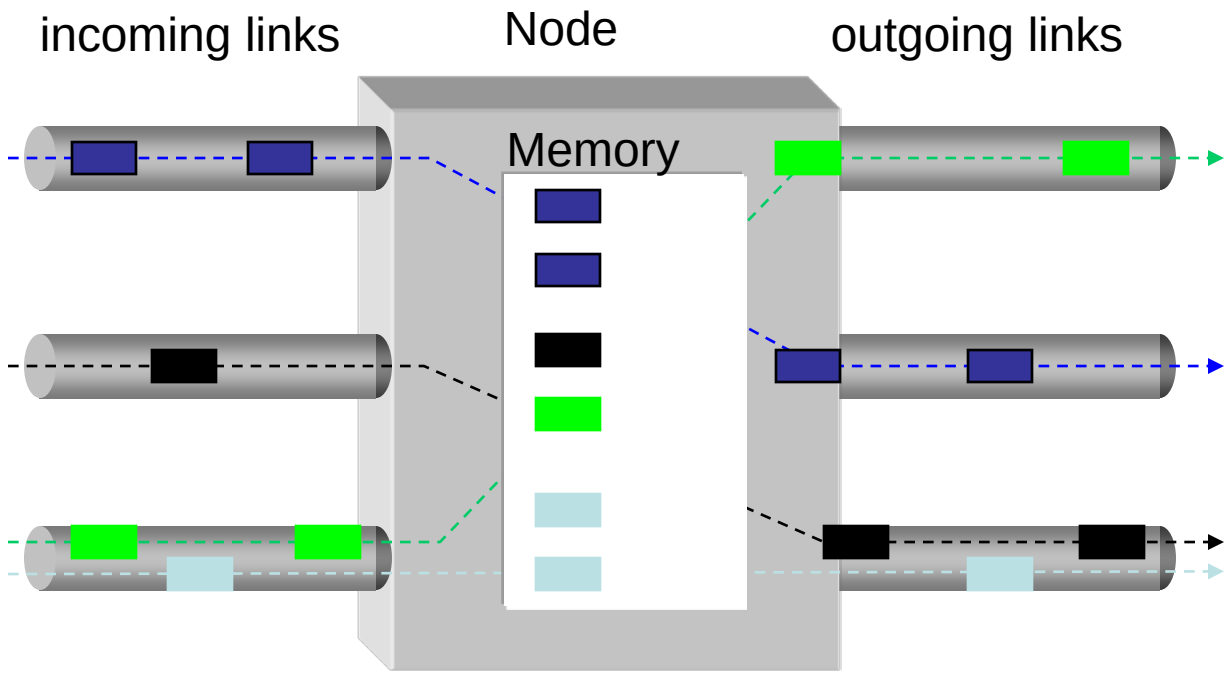
- Time divided in frames and frames divided in slots
- Relative slot position inside a frame determines which conversation the data belongs to
- Needs synchronization between sender and receiver
- In case of non-permanent conversations
  - ✓ Needs to dynamically bind a slot to a conservation

A Taxonomy of Communication Networks

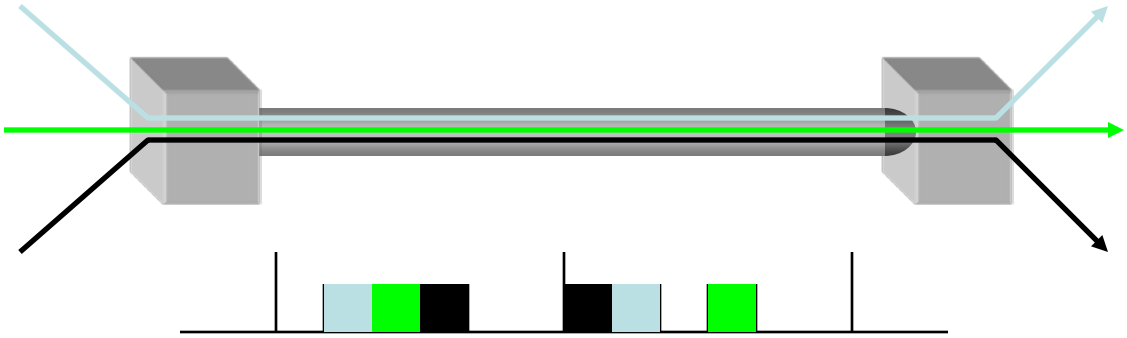


Packet Switching

- Data divided into multiple packets
- At each node the entire packet is received, stored, and then forwarded to the next node
  - ✓ Store-and-Forward Networks



Packet Switching (Cont.)

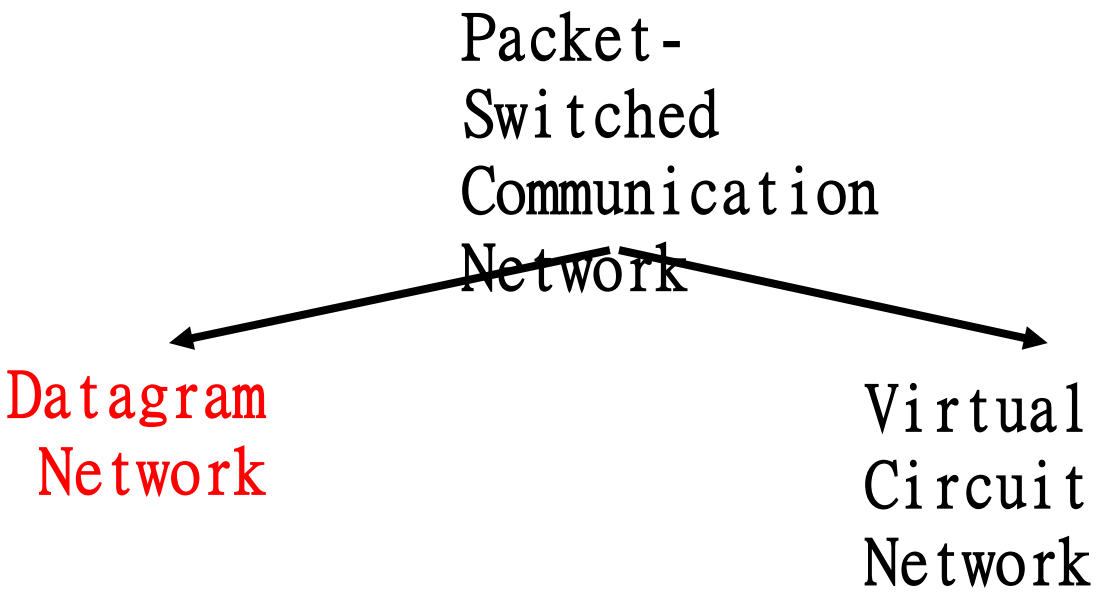


- Data from any conversation can be transmitted at any given time
- How to tell them apart?
  - ✓ Use meta-data (header) to describe packet

Packet-Switching vs. Circuit-Switching

- Advantage of packet-switching over circuit switching
  - ✓ Efficient bandwidth usage
- Disadvantage
  - ✓ More complex routers
  - ✓ Harder to provide good network services (e.g., delay and bandwidth guarantees)
- In practice they are combined
  - ✓ IP over SONET, IP over Frame Relay

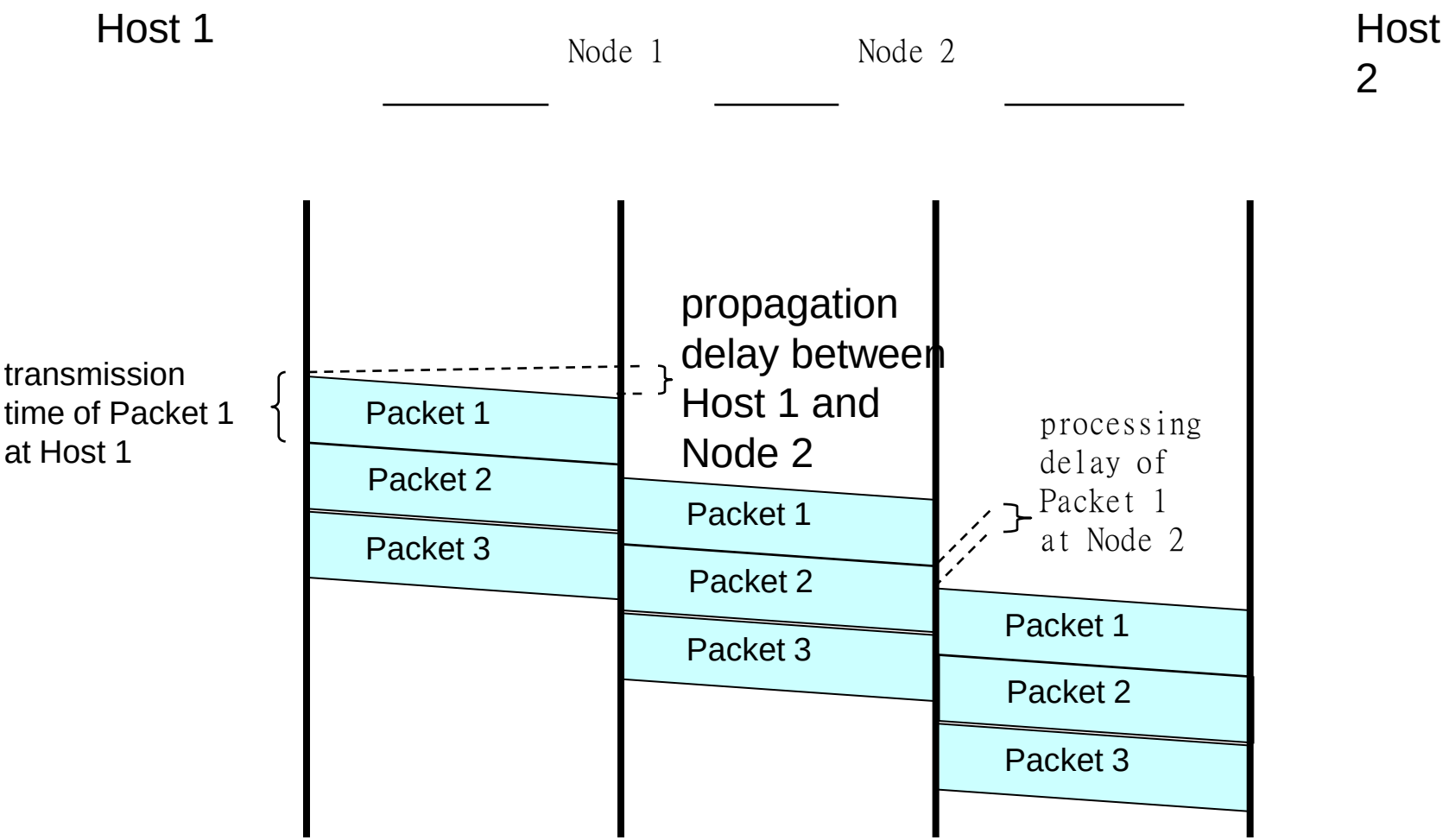
A Taxonomy of Communication Networks



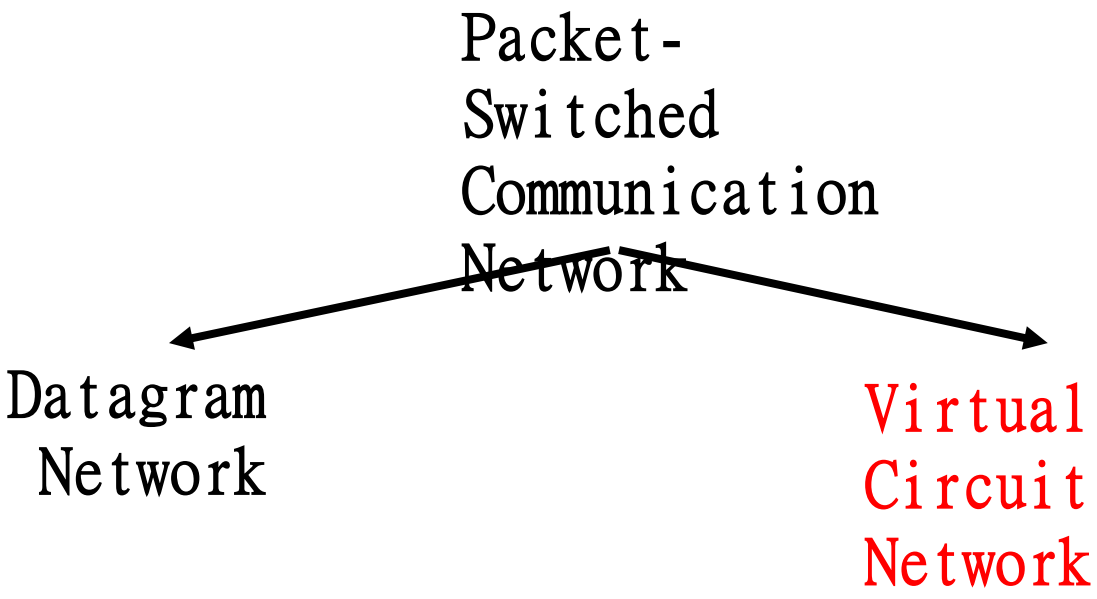
Datagram Packet Switching

- Each packet is independently switched
  - ✓ Outgoing link of the packet is determined by the switching node in per-packet granularity
- No pre-allocated (reserved) path in advance
  - ✓ The paths for packets from the same conversation can be different
- Example: IP networks

Timing of Datagram Packet Switching



A Taxonomy of Communication Networks



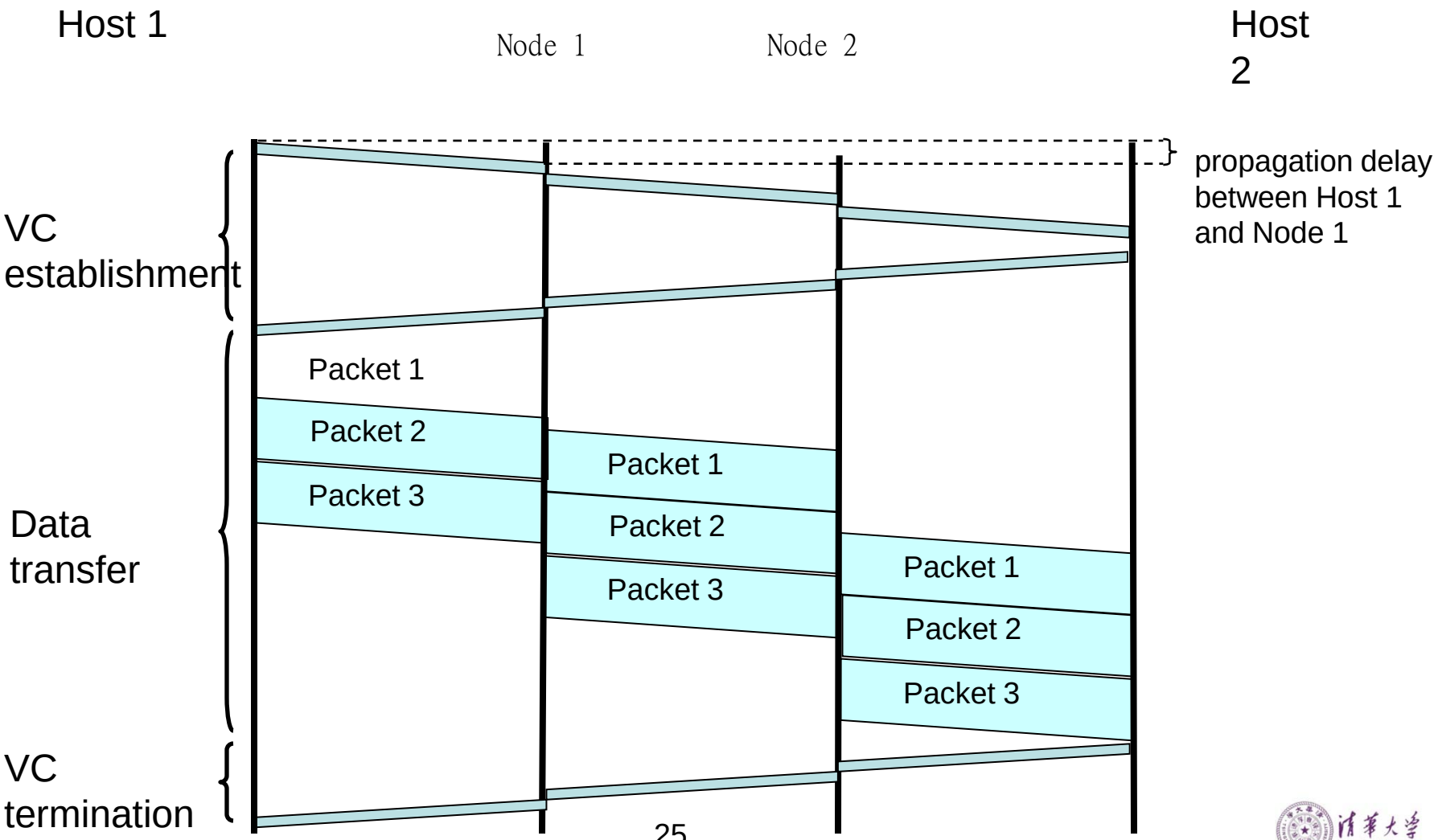
Virtual-Circuit Packet Switching

- Hybrid of circuit switching and packet switching
  - ✓ Data is transmitted as packets
  - ✓ All packets from one conversation are sent along a pre-established path (=virtual circuit)
- Guarantees in-sequence delivery of packets within a virtual circuit
- **However**: Packets from different virtual circuits may be interleaved
- Example: ATM networks

Virtual-Circuit Packet Switching (Cont.)

- Communication with virtual circuits takes place in three phases
  - ✓ VC establishment
  - ✓ Data transfer
  - ✓ VC disconnect

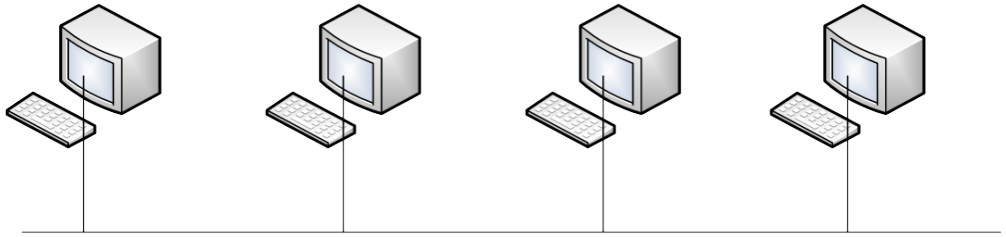
Timing of Virtual-Circuit Packet Switching



Circuit Switching vs. Virtual-Circuit Packet Switching

- Both establish a path before data transfer
  - ✓ Guarantee in-sequence packet delivery
- Difference
  - ✓ Whether using packet (header)
  - ✓ Resource multiplexing
    - ➢ The reserved slot for a circuit in circuit switching cannot be used by other circuits
    - ➢ But no slot reservation in virtual-circuit packet switching

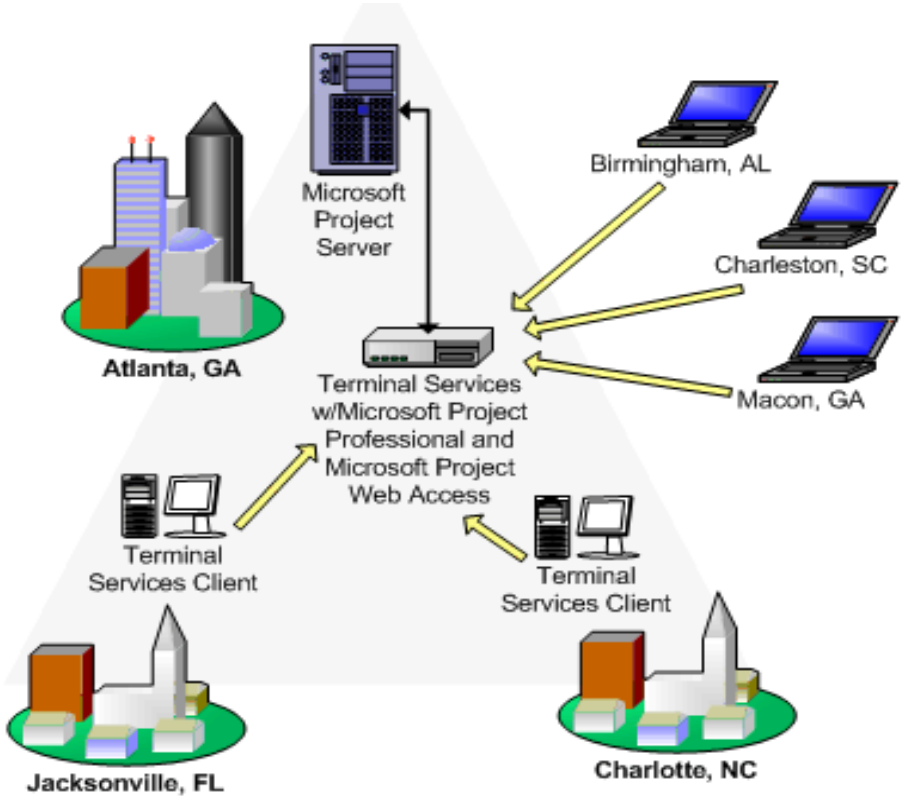
计算机网络的技术选择：局域网



LAN

Broadcast communication network

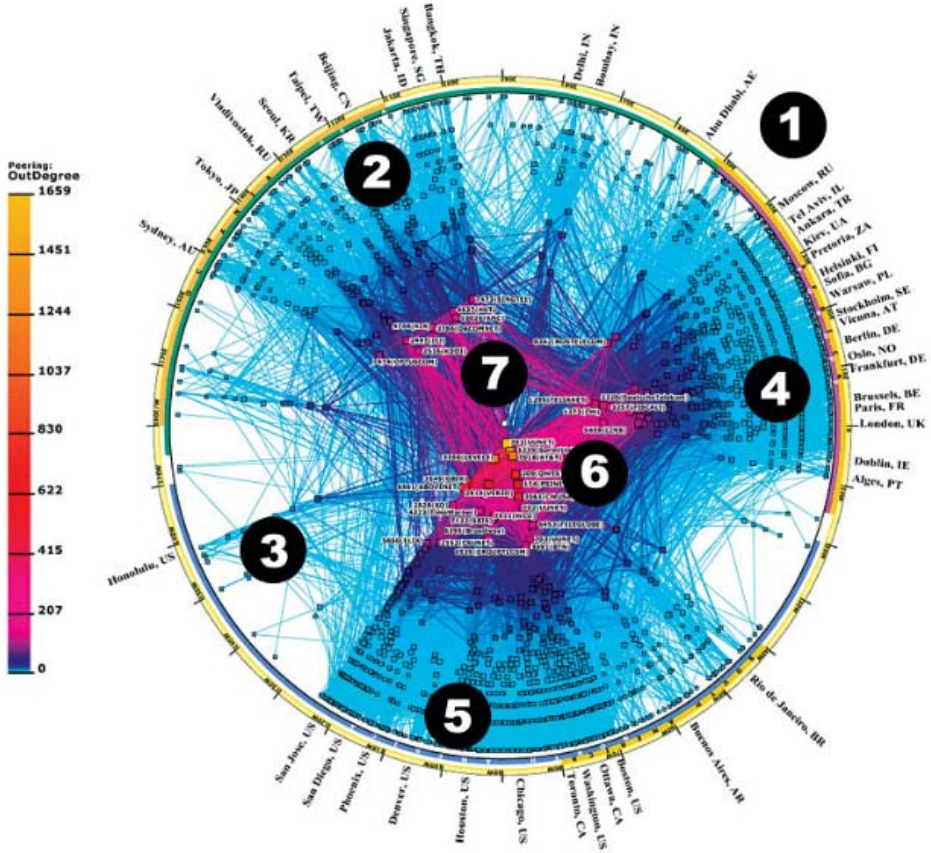
计算机网络的技术选择：广域网



WAN

datagram packet switching communication network

覆盖全球的计算机网络-互联网



Today’s Internet

互联网的定义

- Public, global-scale, general-purpose, heterogeneous-technologies, computer network
- Internet Protocol
  - ✓ Open standard: Internet Engineering Task Force (IETF) as standard body (http://www.ietf.org)
  - ✓ Technical basis for other types of networks
    - ➢ Intranet: enterprise IP network
- Driven by the research community

互联网的发展历史

- ARPANET
  - ✓ 1969, built by DARPA
  - ✓ Started as a research project for the military, < 100 computers , 56 kbps
  - ✓ Mid of 70's, using TCP/IP
  - ✓ 1983, ARPANET and MILNET split
- NSFNET
  - ✓ NSF builds NSFNET in 1986
  - ✓ Links 6 Supercomputer centers
  - ✓ 1.5 Mbps, 10,000 computers
  - ✓ Replaces ARPANET as the backbone of Internet

互联网的发展历史（Cont.）

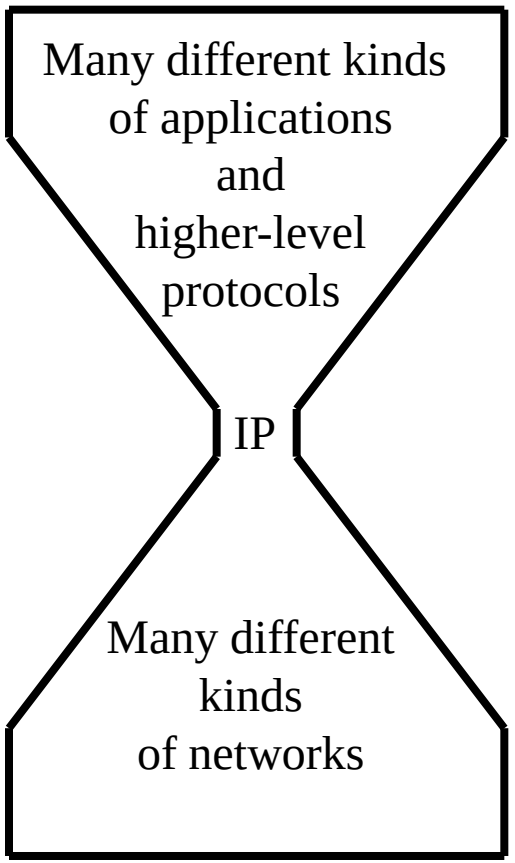
- 1990
  - ✓ NSFNET moves to 45 Mbps, 16 mid-level networks
- 1994
  - ✓ NSF backbone dismantled, multiple private backbones
- 1994
  - ✓ Birth of WWW
- 2005
  - ✓ Backbones run at 10 Gbps
  - ✓ >300 millions users from allover the world
- Today
  - ✓ Backbone speed reaches 1T Gbps
  - ✓ >3.3 billion users in the world, among which 0.72 billion from China

互联网提供的服务的变迁

- Shared access to computing resources
  - ✓ Telnet (1970's)
- Shared access to data/files
  - ✓ FTP, NFS (1980's)
- Communication medium over which people interact
  - ✓ Email (1980's), Instant messaging, IP Telephony (2000's)
- A medium for information dissemination
  - ✓ WWW (1990's), Audio, video (2000's)
- A cyber for social activities
  - ✓ Social network: Facebook (2009)
- Today: Serving for real economics
  - ✓ 滴滴出行, 阿里巴巴 (2014-)

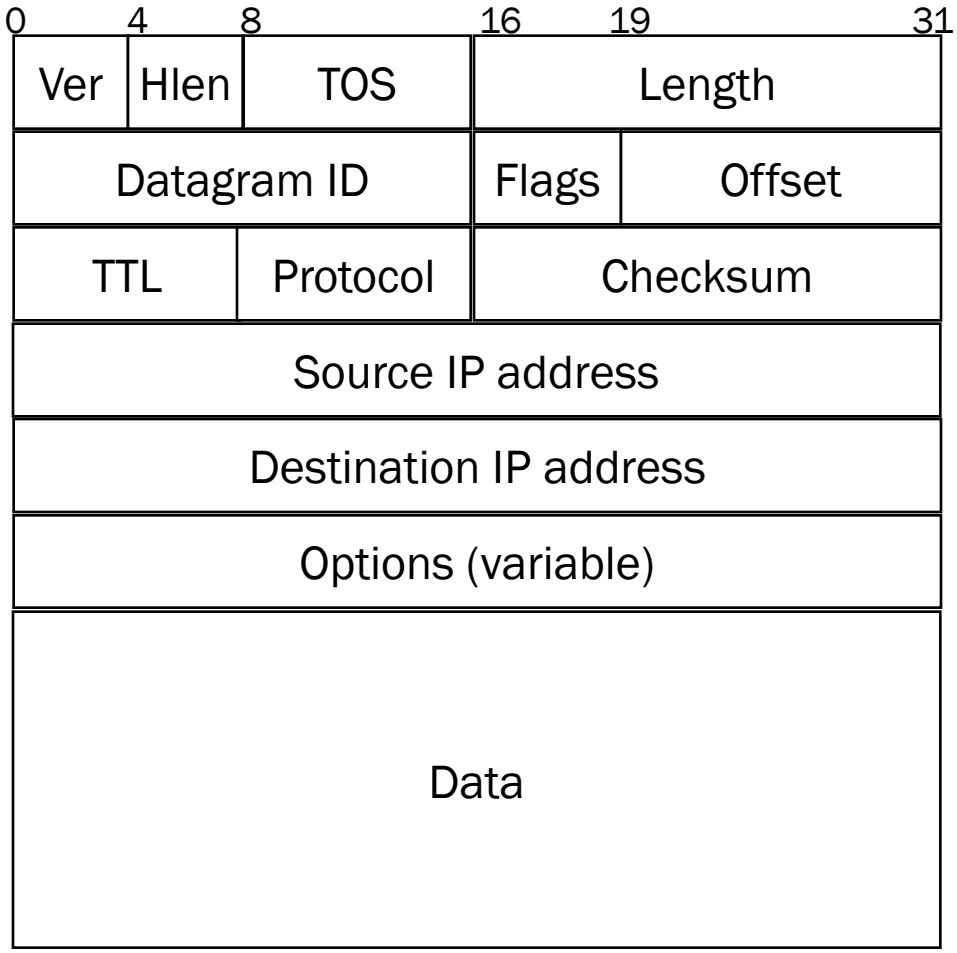
互联网成功的核心：IP协议

- IP is the most successful protocol ever developed
- Keys to success:
  - ✓ simple enough to implement on top of any physical network
    - ➢ e.g., two tin cans and a string.
  - ✓ rich enough to serve as the base for implementations of more complicated protocols and applications.
    - ➢ The IP designers never dreamed of something like the Web.
  - ✓ "rough consensus and working code"
    - ➢ resulted in solid implementable specs.



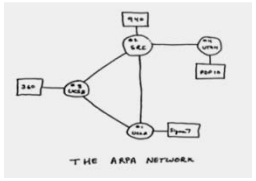
The "Hourglass Model",
Dave Clark, MIT

互联网成功的核心：IP协议



VER	IP version
HL	Header length (in 32-bit words)
TOS	Type of service (unused)
Length	Datagram length (max 64K B)
ID	Unique datagram identifier
Flags	xxM (more fragmented packets)
Offset	Fragment offset
TTL	Time to Live
Protocol	Higher level protocol (e.g., TCP)

互联网技术发展的里程碑事件

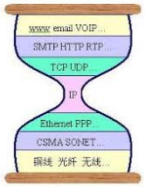


1969年

ARPNET

(从无到有)

- 军事应用
- 科学计算



1974年

TCP/IP

(解决异构互联问题)

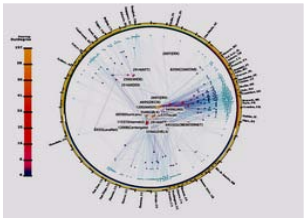
- 广域互联
- 文件共享
- 电子邮件

1991年

WWW

(解决易用性问题)

- 即时通信
- 在线搜索
- 视频传输
- 社交网络



1998年

IPv6

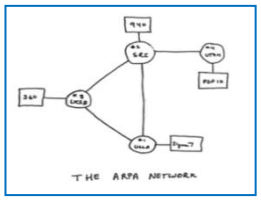
(解决规模爆炸问题)

- 更多用户
- 移动网络
- 网络安全
- 组播通信

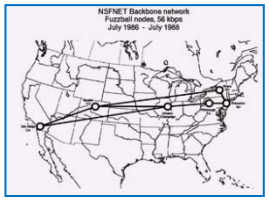
2017年

？ ？ ？

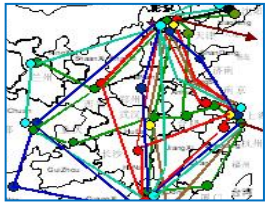
互联网正在逐步发展成为网络空间



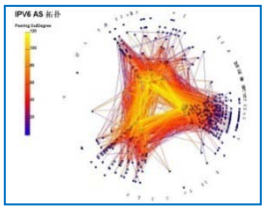
4个节点



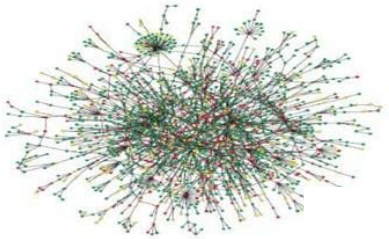
11个节点



突破1亿台



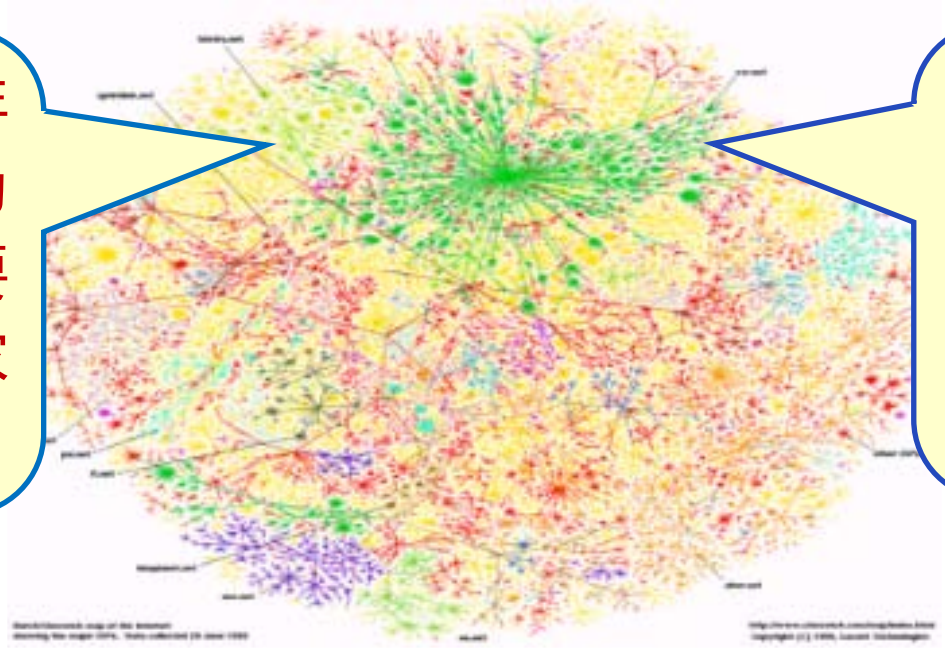
近50亿台



近1000亿台

1969年 1971年 1996年 2015年 **2020年**

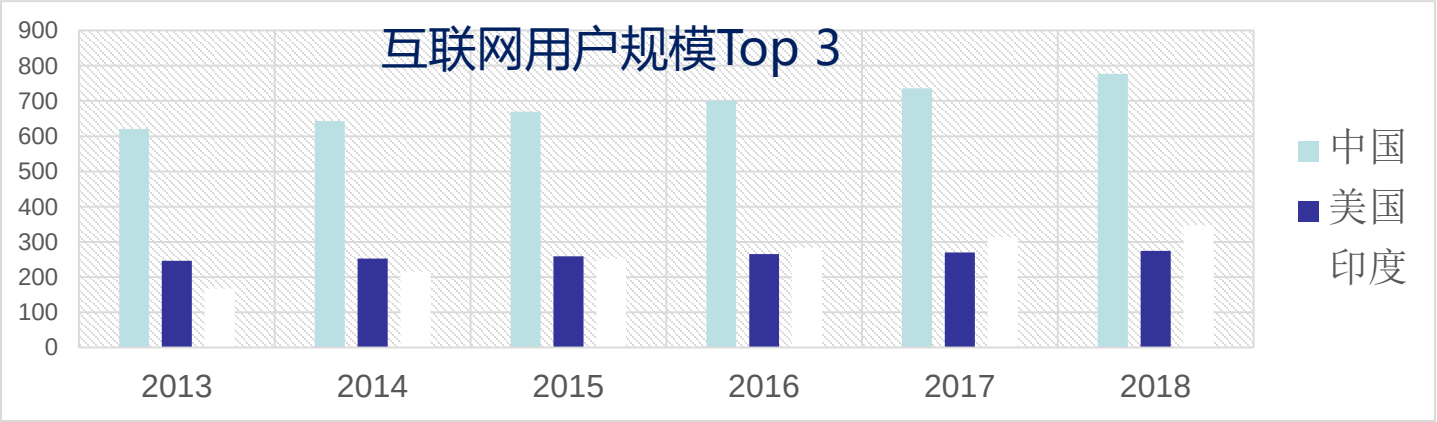
互联网经过40年的发展，已成为人类社会的重要基础设施和国家的重要战略资源



正在发展成为继陆、海、空和太空之后的人类第五疆域：网络空间(Cyberspace)

互联网对民生的影响

- 中国是互联网用户最多的国家，互联网用户数7.1亿，占全球22%，是美国2.5倍
  - 微　　信： 2016年用户超过6亿
  - 网络购物： 2015年用户达到3.61亿
  - 滴滴打车： 2015年用户突破2.5亿



- 梅特卡夫定律：
  - 网络的价值与用户数量的平方成正比 $V=K\times N^2$，N为用户数量

互联网对经济的影响

- 中国面临艰难的经济转型，互联网承担着产业升级重任
  - 2015年网络购物交易：3.8万亿元，电子商务市场：18.2万亿元
  - 中国制造2025计划：互联网发展由“消费型”向 “生产型”转变
  - 2025年中国互联网经济占GDP比重达22%

互联网+

推动移动互联网、云计算、大数据、物联网等与现代制造业结合，促进电子商务、工业互联网和互联网金融健康发展，引导互联网企业拓展国际市场。

互联网对国家主权的影响

- 缺少自主核心技术以及与西方发达国家存在意识形态差异，中国对网络空间掌控能力有更强的危机感
  - 截止2016年5月，国际互联网标准化组织（IETF）发布了7889项标准，中国牵头的只有84项，占比1.06%
  - 全球13台DNS根服务器：10台在美国，2台在欧洲，1台在日本

2016年4月19日，重要讲话：
互联网核心技术是我们最大的“命门”，核心技术受制于人是我们最大的隐患，核心技术的根源问题是基础研究问题。

问题与挑战

面对工业互联网、物联网、车联网等新兴应用，现有互联网面临实时性、安全性、扩展性、管控性等挑战。

- 实时性
- 安全性
- 扩展性
- 管控性

2009~2013年，因为网络传输延时，美国陆基导弹防御系统三次拦截试验均未成功

网络延时增加会导致互联网内容提供商的巨大利润损失

Aberdeen Group
A Harte-Hanks Company
延迟增加1s，网页访问**降低11%**

amazon
延迟增加100ms，销量**降低1%**

bing
延迟增加0.5s,利润**降低1.2%**

清华大学 Tsinghua University

问题与挑战

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- 实时性
- 安全性
- 扩展性
- 管控性

2013年06月曝光的**“斯诺登”事件**表明，美国在全球进行网络和电话监控，**严重危害我国的国家安全**。

2016年9月，**物联网设备（145000台照相机）发起的DDoS网络攻击流量已达1.5Tbps。**

问题与挑战

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实时性

安全性

扩展性

管控性

IPv4的地址空间为2^{32}个(约10^9)

剧增10^{27}倍

IPv6的地址空间为2^{128}个(约10^{36})

与IPv4比，IPv6地址空间**剧增10^{27}倍**，网络寻址面临严峻挑战！

2015年，我国**有232部**电视剧播放**超10亿次，存在大量重复传输。**

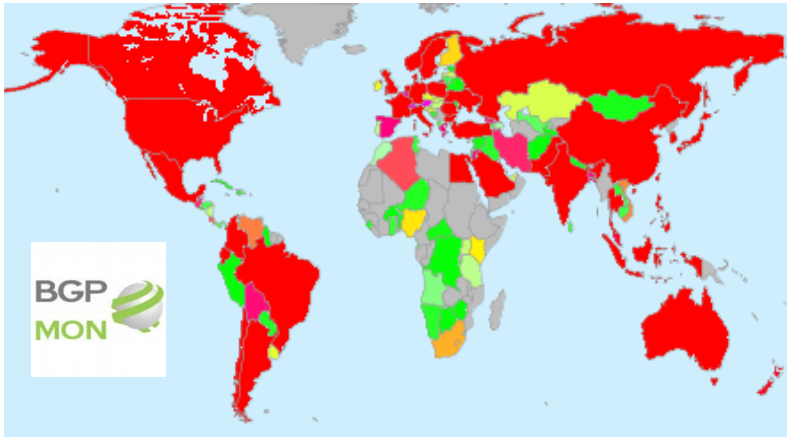
排名	网络电视剧名称	网络播放量（亿次）
1	芈月传	**238.22**
2	花千骨	196.17
3	武媚娘传奇	129.17
4	琅琊榜	111.99
5	古剑奇谭	97.78
6	甄嬛传	94.59
7	何以笙箫默	88.61
8	大秧歌	78.99

数据来源：www.laikan.me/p/252

问题与挑战

面对工业互联网、物联网、车联网等新兴应用，现有互联网面临实时性、安全性、扩展性、管控性等挑战。

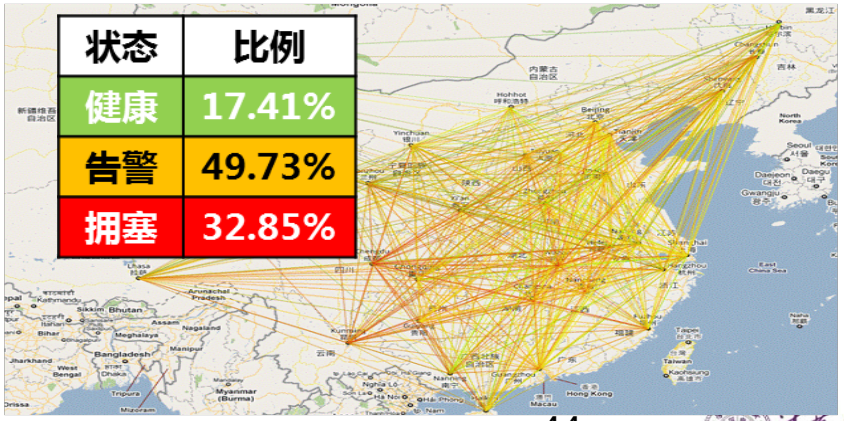
- 实时性
- 安全性
- 扩展性
- 管控性



2010.4.8，因中国电信误配置，导致全球15%的IP地址无法访问。

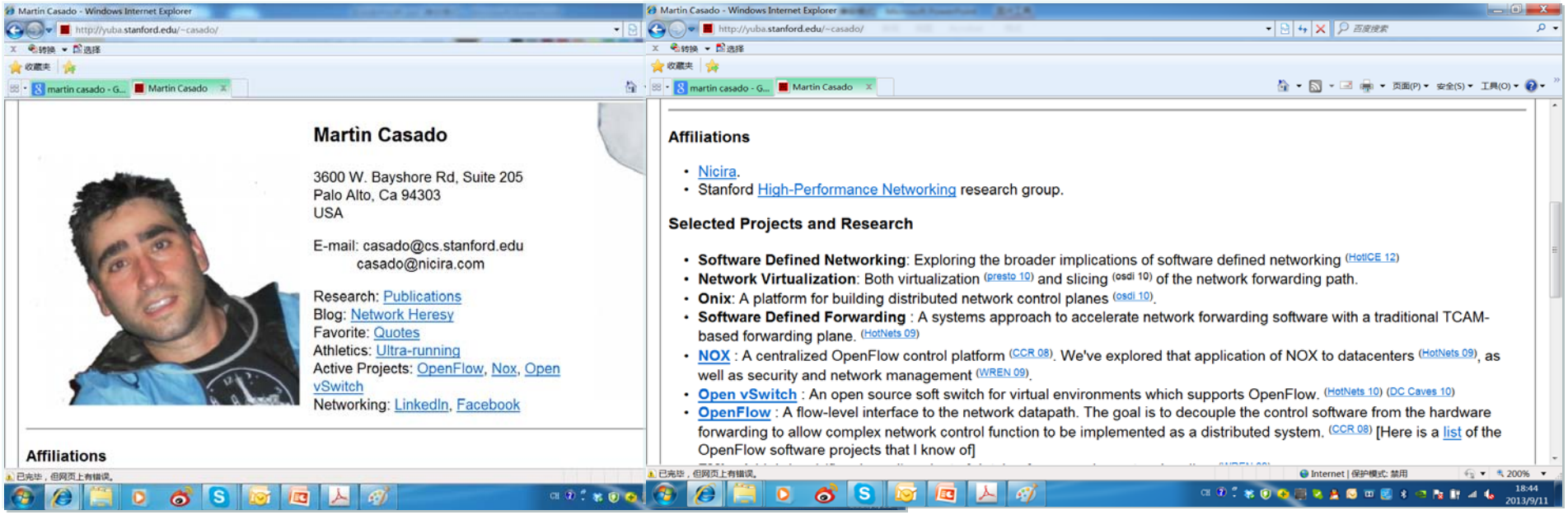
我国ISP之间仅有17.4%链路处于延迟的健康状态。

状态	比例
健康	17.41%
告警	49.73%
拥塞	32.85%



软件定义网络（SDN）：
一个从大学孕育的重大产业创新

Martin Casado



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Palo Alto, Ca 94303
USA

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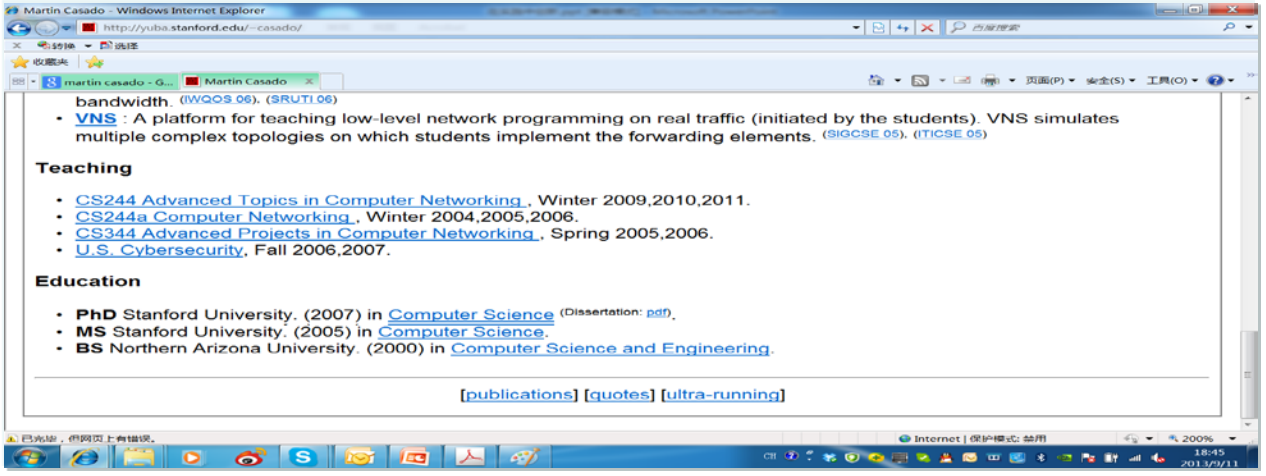
Research: Publications
Blog: Network Heresy
Favorite: Quotes
Athletics: Ultra-running
Active Projects: OpenFlow, Nox, Open vSwitch
Networking: LinkedIn, Facebook

Affiliations

- Nicira.
- Stanford High-Performance Networking research group.

Selected Projects and Research

- **Software Defined Networking**: Exploring the broader implications of software defined networking (HotICE 12)
- **Network Virtualization**: Both virtualization (presto 10) and slicing (osdi 10) of the network forwarding path.
- **Onix**: A platform for building distributed network control planes (osdi 10).
- **Software Defined Forwarding** : A systems approach to accelerate network forwarding software with a traditional TCAM-based forwarding plane. (HotNets 09)
- **NOX** : A centralized OpenFlow control platform (CCR 08). We've explored that application of NOX to datacenters (HotNets 09), as well as security and network management (WREN 09).
- **Open vSwitch** : An open source soft switch for virtual environments which supports OpenFlow. (HotNets 10) (DC Caves 10)
- **OpenFlow** : A flow-level interface to the network datapath. The goal is to decouple the control software from the hardware forwarding to allow complex network control function to be implemented as a distributed system. (CCR 08) [Here is a list of the OpenFlow software projects that I know of]



bandwidth. (IWQOS 06). (SRUTI 06)
- **VNS** : A platform for teaching low-level network programming on real traffic (initiated by the students). VNS simulates multiple complex topologies on which students implement the forwarding elements. (SIGCSE 05). (ITICSE 05)

Teaching

- CS244 Advanced Topics in Computer Networking , Winter 2009,2010,2011.
- CS244a Computer Networking , Winter 2004,2005,2006.
- CS344 Advanced Projects in Computer Networking , Spring 2005,2006.
- U.S. Cybersecurity, Fall 2006,2007.

Education

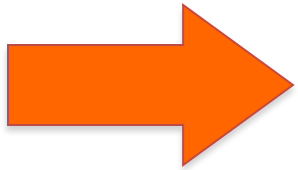
- **PhD** Stanford University. (2007) in Computer Science (Dissertation: pdf).
- **MS** Stanford University. (2005) in Computer Science.
- **BS** Northern Arizona University. (2000) in Computer Science and Engineering.

[publications] [quotes] [ultra-running]

清華大學 Tsinghua University

软件定义网络SDN


专有网络功能
（IETF定义）
专用控制平面
（设备商实现）
专用硬件
（设备商实现）




自定义
网络功能
自定义
网络功能
自定义
网络功能
开放接口
控制平面
（网络操
作系统）
控制平面
（网络操
作系统）
控制平面
（网络操
作系统）
开放接口
商用芯片

SDN所引起的巨大关注

- ONF联盟：Open Network Foundation
  - ✓几百家家企业和科研单位参加
- 学术界
  - ✓SIGOCMM 、NSDI、OSDI
- 创业公司
  - ✓ Nicira：2012年8月以12.6亿美元被VMWare公司收购
  - ✓ Big Switch：2013年3月获得Intel公司4500万美元注资
  - ✓ Contrail Systems：2012年12月成立仅2天即被Juniper公司以1.76亿美元收购
  - ✓ Embrane：2011年获得2700 万美元融资

几点启示和寄语

- 计算机技术（包括计算机网络技术）正在经历前所未有的技术变革，新技术层叠不穷，创新机会众多
- 大学是孕育新技术、推动产业发展的重要基地，而计算机网络技术更是一直有这样的传统
- 在本科阶段要掌握好基础知识，将来不管是从事科研工作、还是投身工业界，都将终身受用
- 在本科阶段学有余力的前提下，可以进老师的实验室，提前接触、了解前沿技术，投身到创新浪潮中

谢谢！