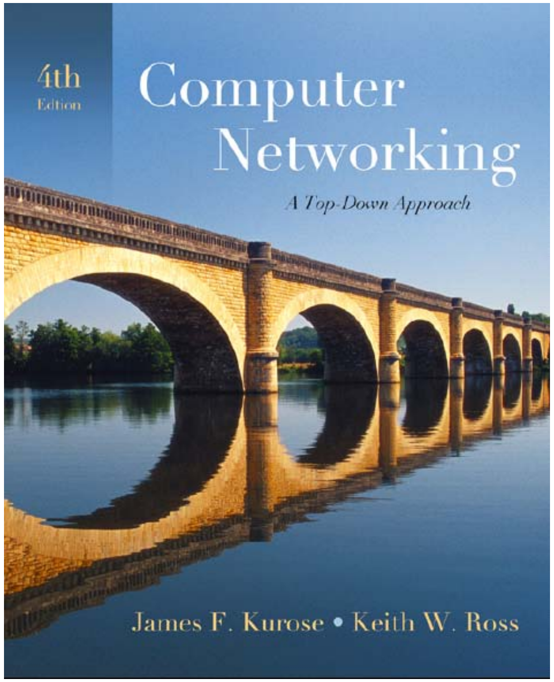
第一章
計算機網路與網際網路
Chapter 1
Introduction



Computer Networking: A Top Down Approach,
4th edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2007.

Chapter 1: Introduction

Our goal:

- get "feel" and terminology
- more depth, detail *later* in course
- approach:
  - use Internet as example

Overview:

- 什麼是網際網路（Internet）?
- 什麼是協定（Protocol）?
- 網路的邊際（network edge）
- 網路的核心（network core）
- 網路效能（performance）
  - 封包遺失（loss）
  - 延遲（delay）
  - 產出量（throughput）
- 安全（security）
- 協定分層（protocol layers）, service models
- 網路的歷史（history）

Chapter 1: roadmap

1.1 What *is* the Internet?什麼是網際網路？

1.2 Network edge
- end systems, access networks, links

1.3 Network core
- circuit switching, packet switching, network structure

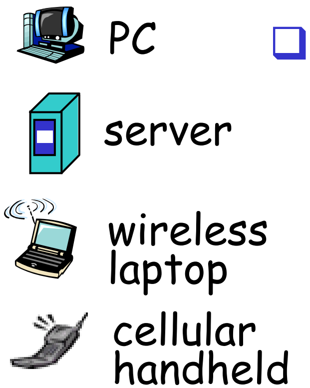
1.4 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

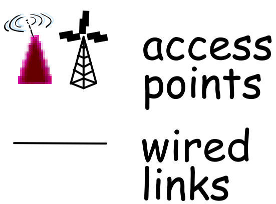
1.6 Networks under attack: security

1.7 History

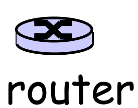
什麼是網際網路？從基本元素來看



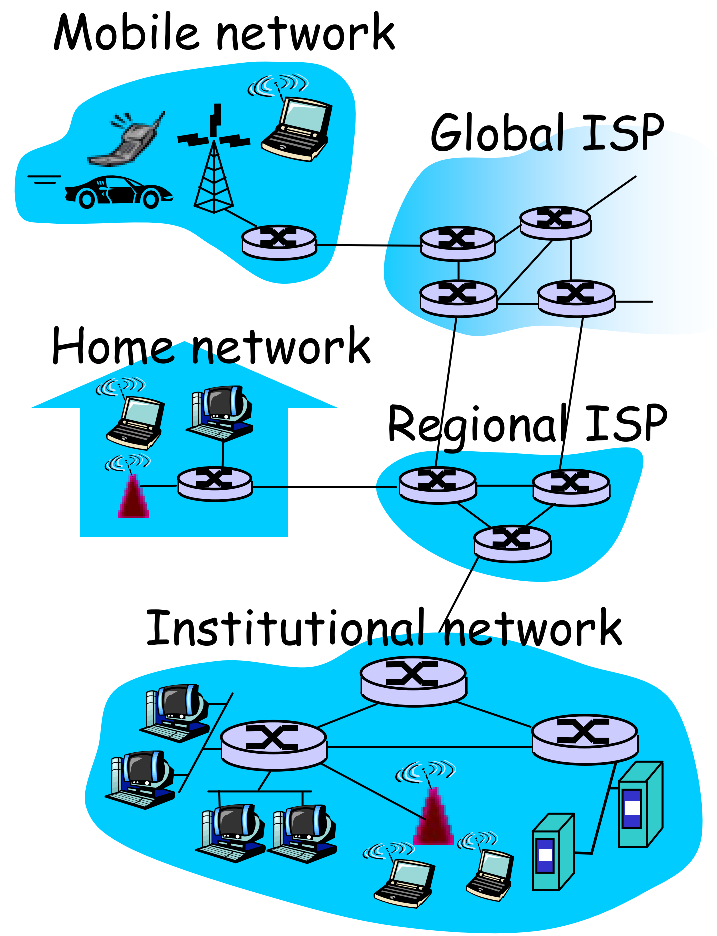
- millions of connected computing devices: 主機（終端系統）*hosts = end systems*
  - 執行應用程式 running *network apps*



- *communication links*
  - 光纖、纜線、衛星...
  - 頻寬（bandwidth）? transmission rate = *bandwidth*



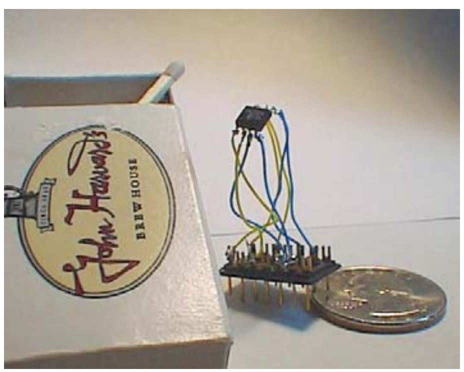
- 路由器（Routers）: forward packets (chunks of data)



“Cool” internet appliances

IP picture frame
http://www.ceiva.com/

Web-enabled toaster +
weather forecaster



World’s smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html

Internet phones

What's a protocol（通訊協定）?

human protocols:
人類的通訊協定

- "what' s the time?"
- "I have a question"
- introductions

... specific msgs sent

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

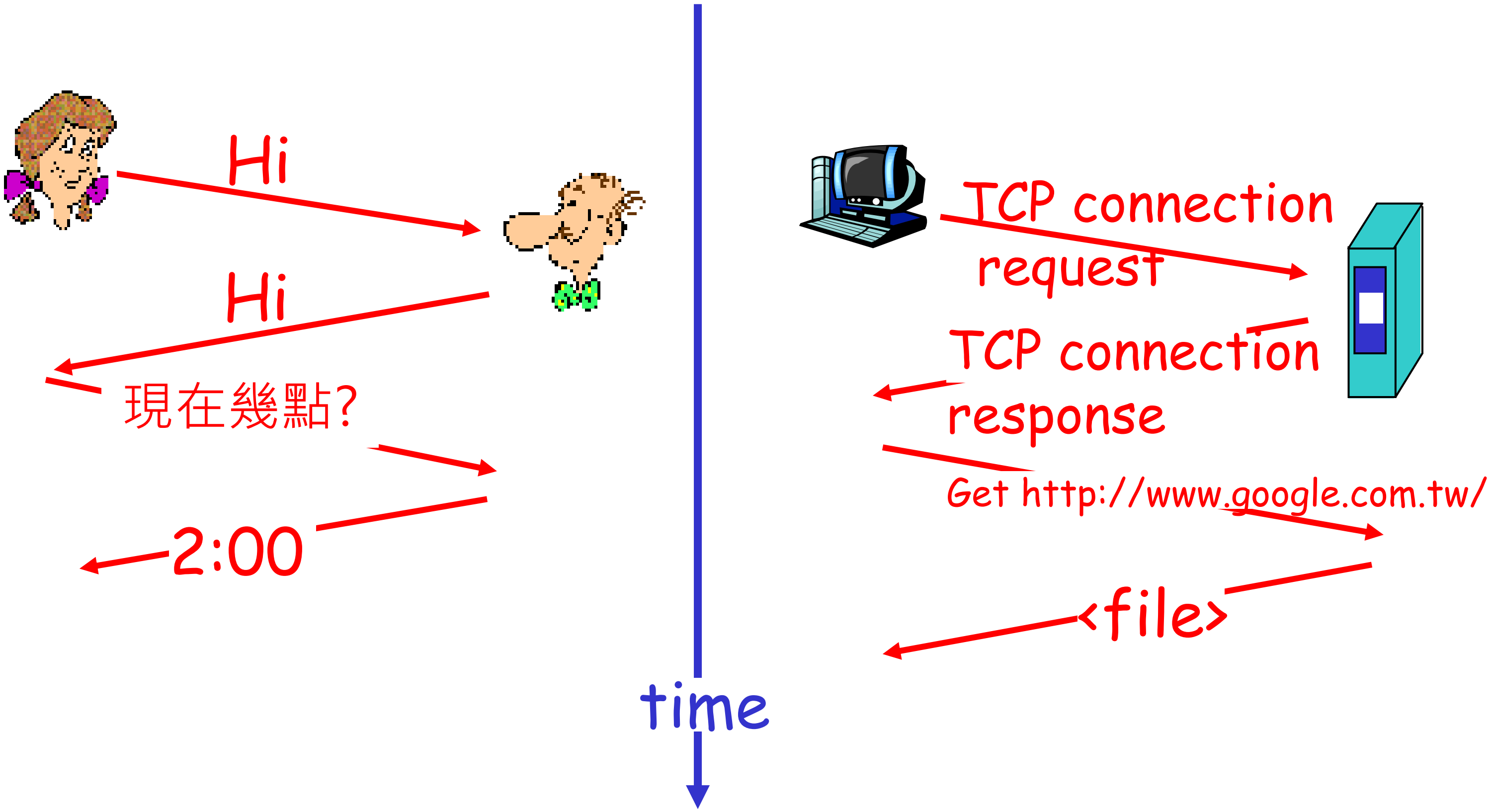
network protocols:
網路通訊協定

- machines rather than humans （no ambiguous）
- 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

What's a protocol（通訊協定）?

人類協定與電腦網路協定的異同



Q: Other human protocols?
有沒有其它的人類協定？

Chapter 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge 網路邊際

- end systems, access networks, links
- 終端系統、接取網路、鏈結

1.3 Network core

- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

1.6 Networks under attack: security

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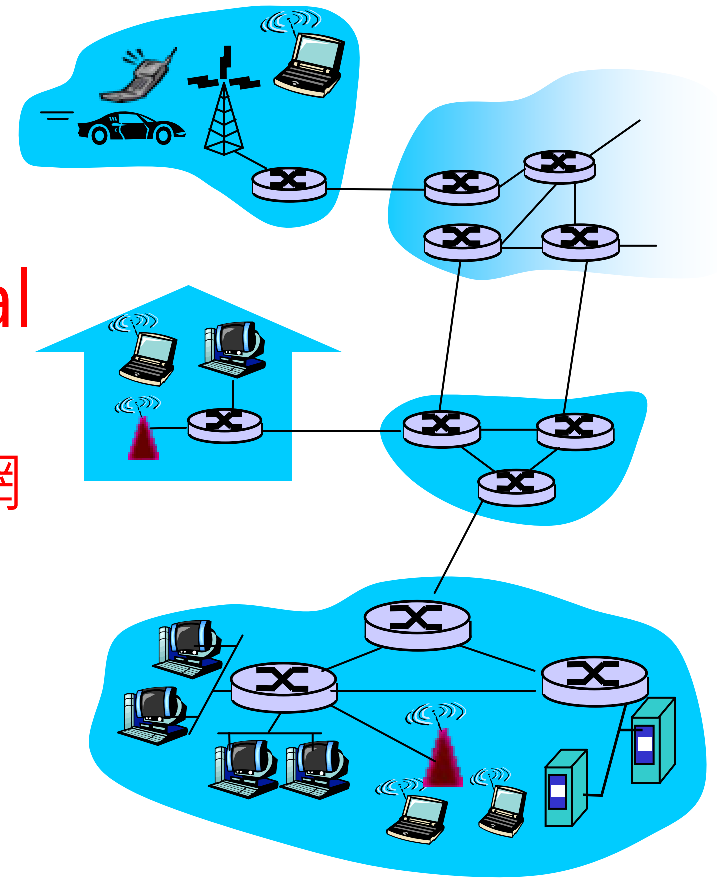
A closer look at network structure: 細看網路架構

- network edge: applications and hosts（應用程式及主機）
- access networks, physical media: wired, wireless communication links（網路連線）
- network core: 網路核心
  - interconnected routers
  - network of networks



Network edge: reliable data transfer service
可信賴的傳輸服務

Goal: data transfer between end systems

- *handshaking:* setup (prepare for) data transfer ahead of time
  - Hello, hello back human protocol
  - *set up "state"* in two communicating hosts
- TCP - Transmission Control Protocol
  - Internet's reliable data transfer service

補充：
TCP service [RFC 793]

- *reliable, in-order* byte-stream data transfer
  - loss: acknowledgements and retransmissions
- *flow control:*
  - sender won't overwhelm receiver
- *congestion control:*
  - senders "slow down sending rate" when network congested

Network edge: best effort (unreliable) data transfer service 盡力而為的服務模式

Goal: data transfer between end systems

- same as before!

- UDP - User Datagram Protocol [RFC 768]:
  - connectionless
  - unreliable data transfer
  - no flow control
  - no congestion control

App's using TCP:

- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

App's using UDP:

- streaming media, teleconferencing, DNS, Internet telephony

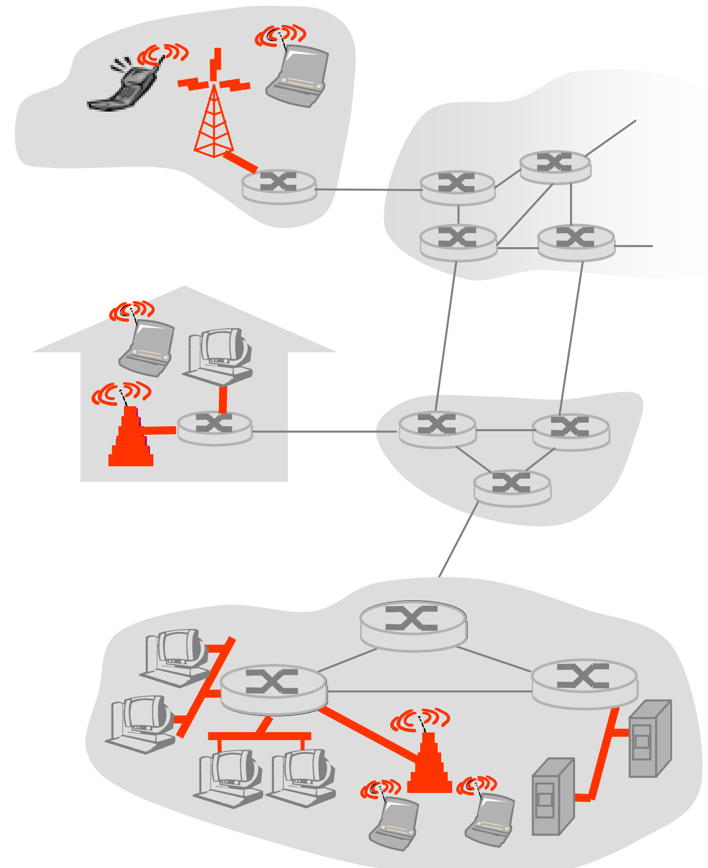
Access networks and physical media
連接網路與實體媒介

Q: How to connect end systems to edge router?

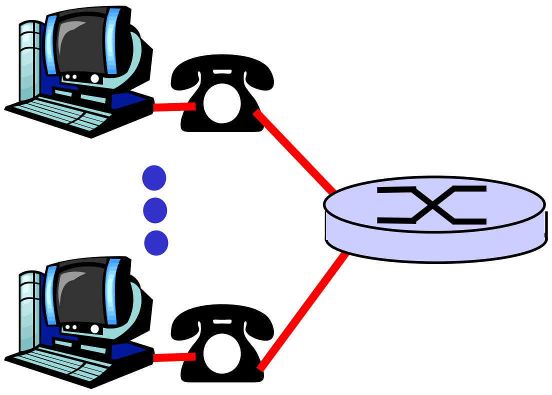
- residential access nets
- institutional access networks (school, company)
- mobile access networks

Keep in mind:

- bandwidth (bits per second) of access network? 頻寬有多大？
- shared or dedicated? 共用或專用？



Residential access: point to point access



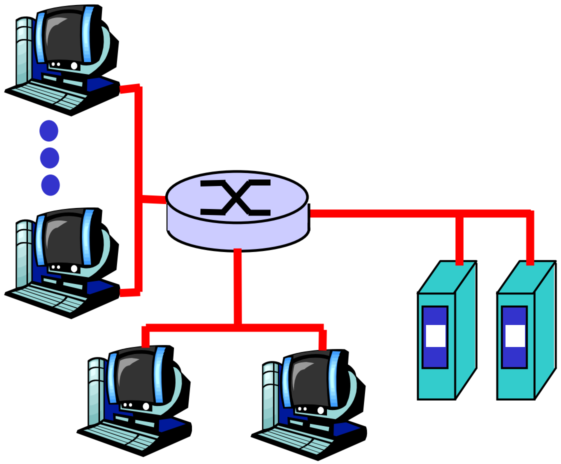
- Dialup via modem 透過數據機撥接
  - up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: can't be "always on"
- DSL: digital subscriber line 數位用戶專線
  - deployment: telephone company (typically)
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1 Mbps)
  - dedicated physical line to telephone central office
  - ADSL（Asymmetric Digital Subscriber Line ）

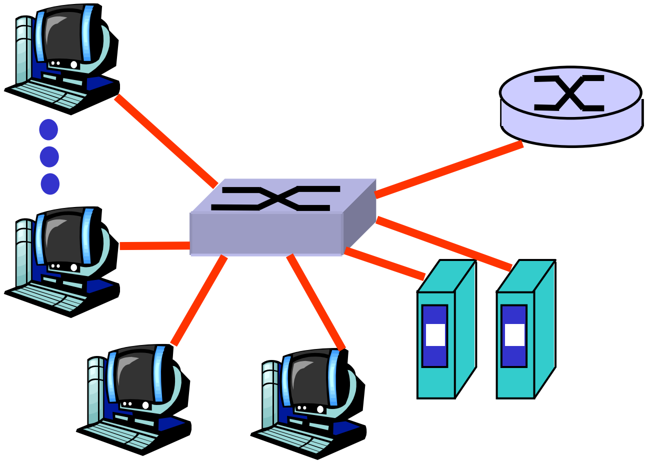
Residential access: cable modems

- HFC: hybrid fiber-coaxial cable 混合光纖同軸電纜
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - homes share access to router 共享
- deployment: available via cable TV companies

Company access: local area networks

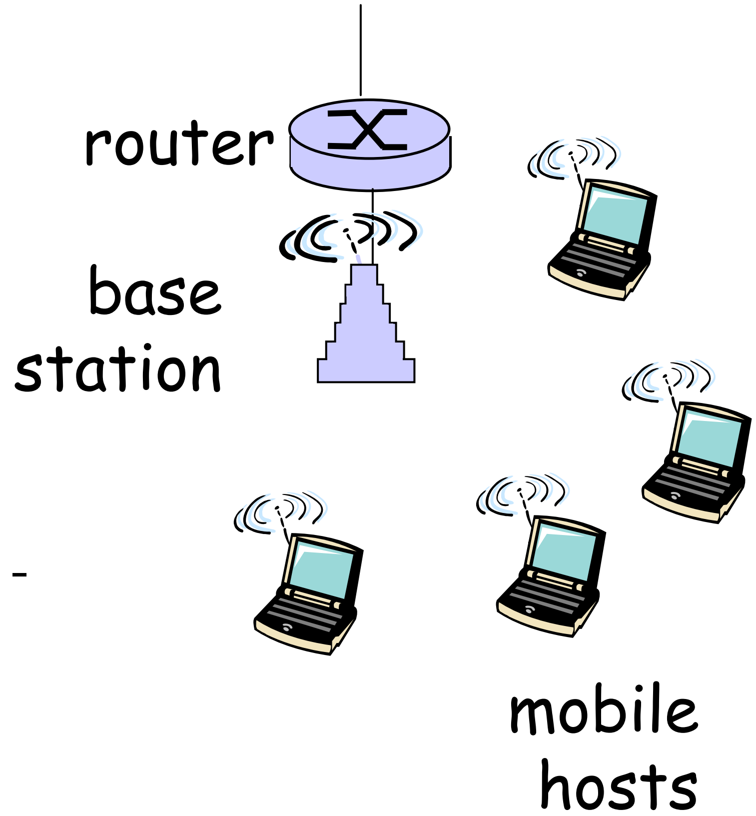
- company/univ local area network (LAN 區域網路) connects end system to edge router
- Ethernet: 乙太網路
  - 10 Mbps, 100Mbps, 1Gbps, 10Gbps Ethernet
  - modern configuration: end systems connect into *Ethernet switch*
- LANs: chapter 5





Wireless access networks 無線網路

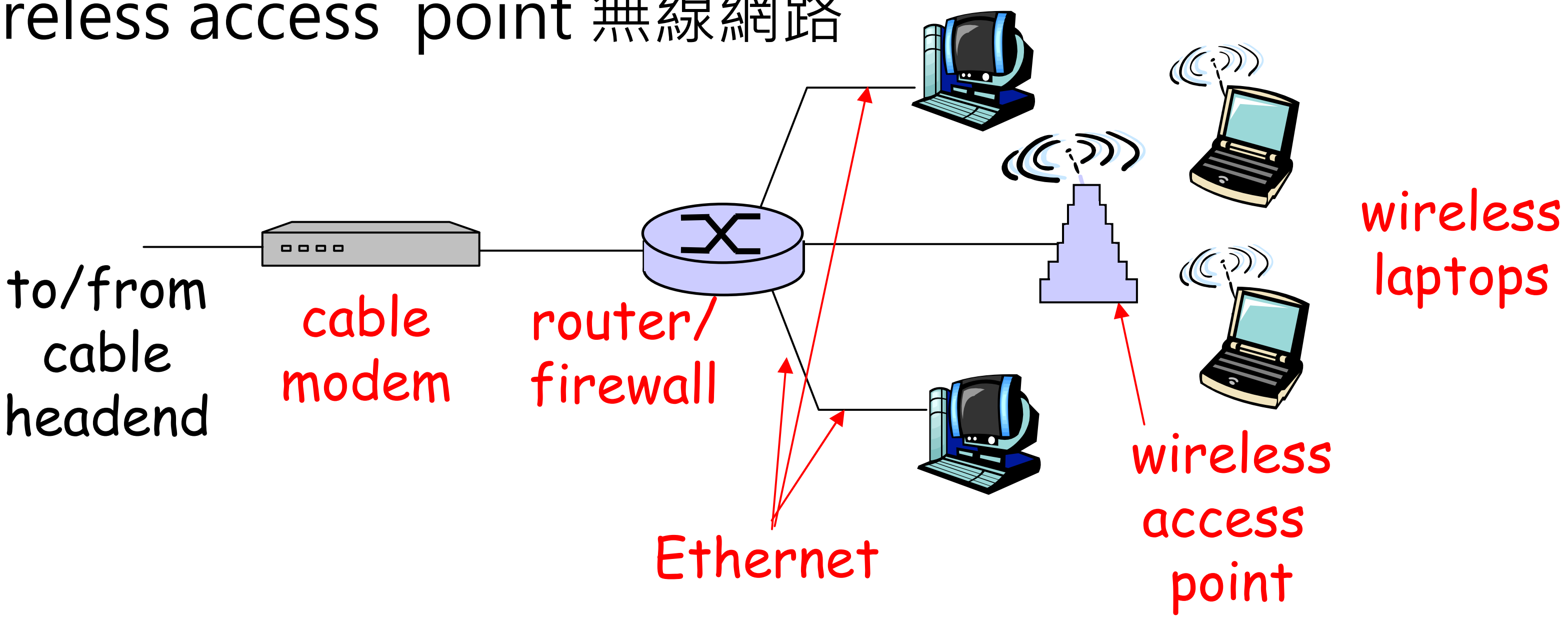
- shared *wireless* access network connects end system to router
  - via base station 基地台 aka "access point（AP）"
- wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mbps
- wide-area wireless access
  - provided by telecom operator
  - ~1Mbps over cellular system (EVDO - Evolution-Data Optimized, HSDPA - High-Speed Downlink Packet)
  - next up (?): 5-10Mbps, WiMAX IEEE 802.16(10's Mbps) over wide area



Home networks 家庭網路

Typical home network components:

- DSL or cable modem 數據機
- router/firewall/NAT 路由器、防火牆、IP 分享器
- Ethernet 乙太網路
- wireless access point 無線網路



Physical Media 實體媒介

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

Twisted Pair (TP) 雙絞線

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps Ethernet

Twisted Pair (TP) 雙絞線

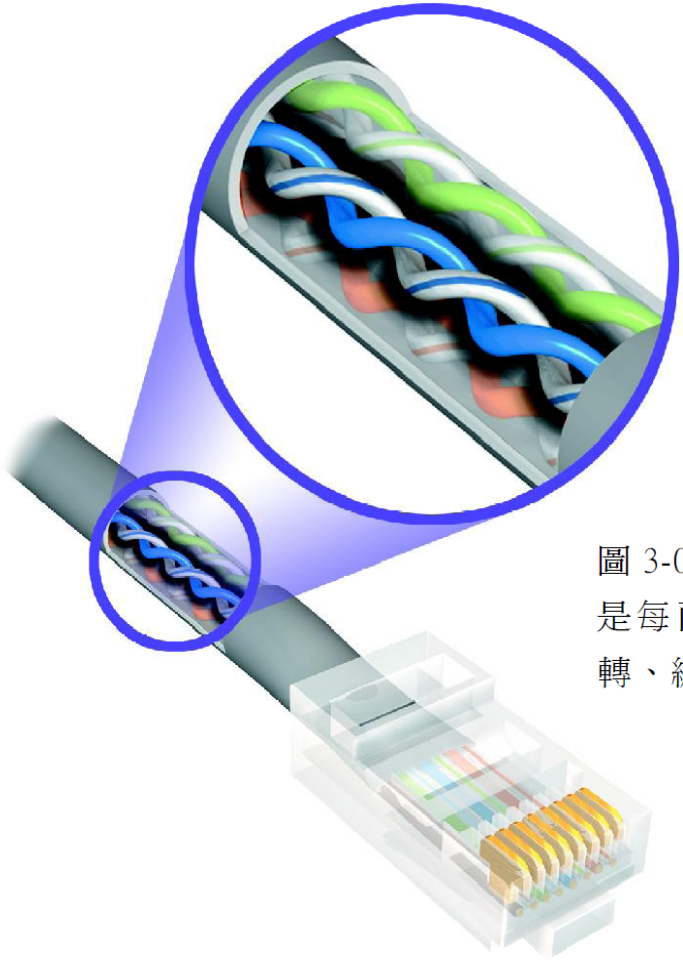
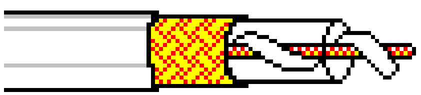


圖 3-03　雙絞線的特色是每兩條芯線相互旋轉、纏繞在一起

Physical Media: coax, fiber 同軸電纜、光纖

Coaxial cable:

- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channels on cable
  - HFC



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 Gps)
- low error rate: repeaters spaced far apart ; immune to ele oise

Physical media: radio 無線電

- 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)
  - 11Mbps, 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

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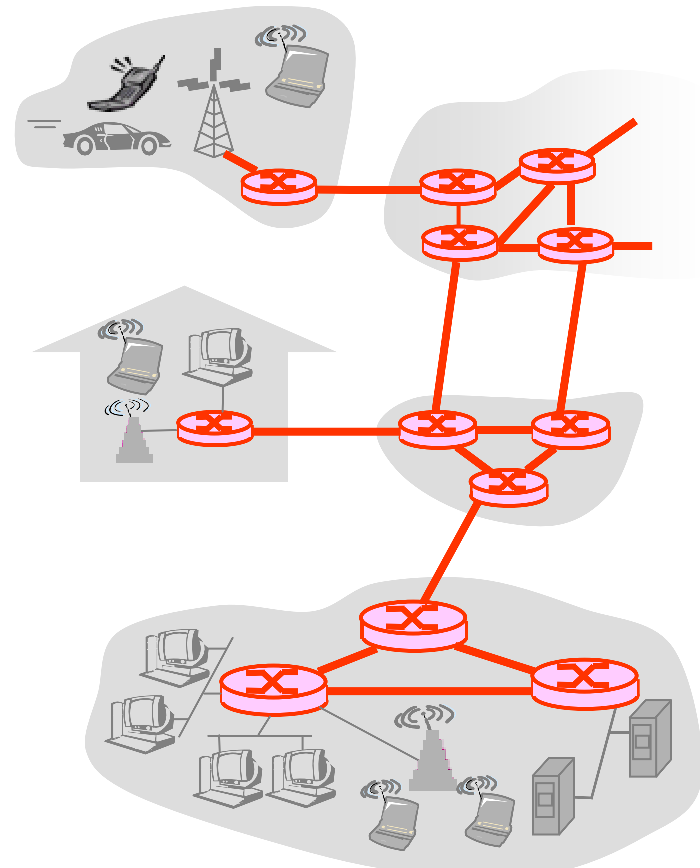
The Network Core 網路核心

- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: 電路交換 dedicated circuit per call: telephone net
  - packet-switching: 封包交換 data sent thru net in discrete "chunks"

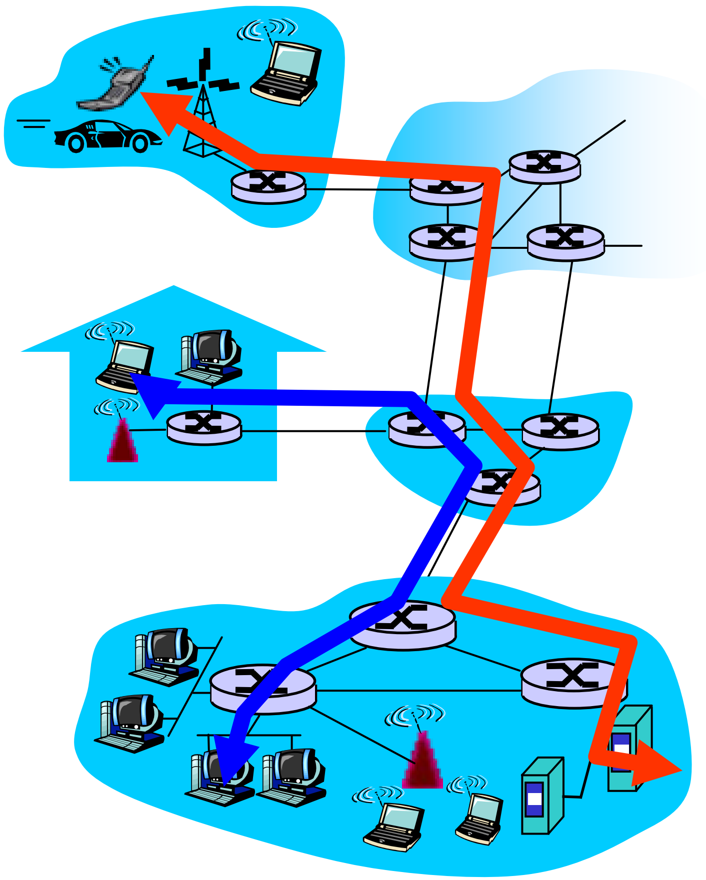


Network Core: Circuit Switching
網路核心：電路交換

End-end resources reserved for "call"

資源保留

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required



Network Core: Circuit Switching
網路核心：電路交換

network resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*

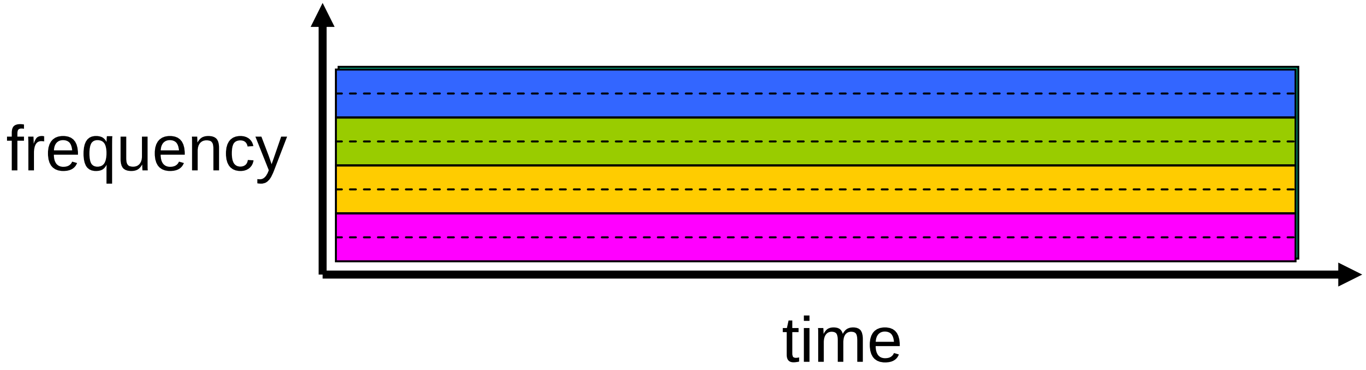
- dividing link bandwidth into "pieces"
  - frequency division
  - time division

Circuit Switching: FDM and TDM

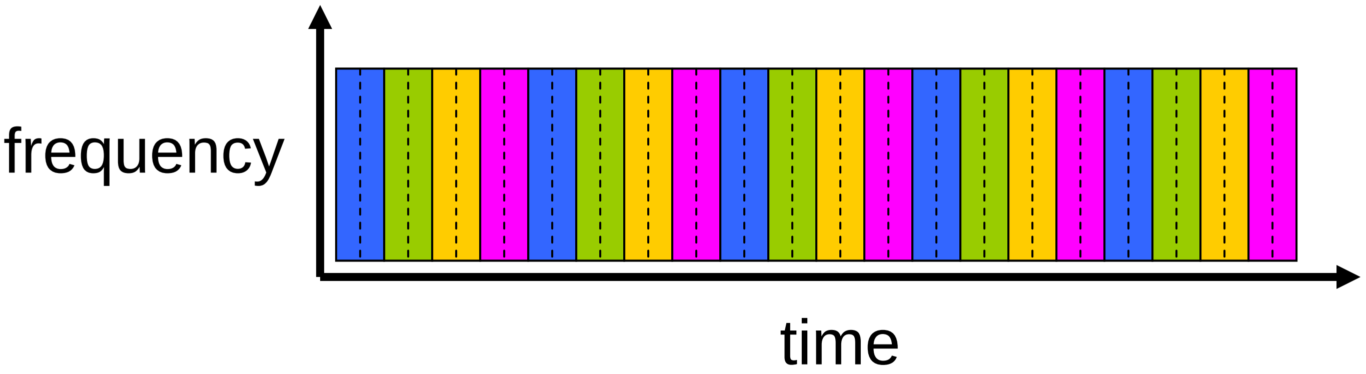
Example:

4 users

FDM : circuit=frequency



TDM : circuit=time slot



Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Let's work it out!

ANS：10.5 sec

Network Core: Packet Switching
網路核心：封包交換

each end-end data stream divided into *packets*

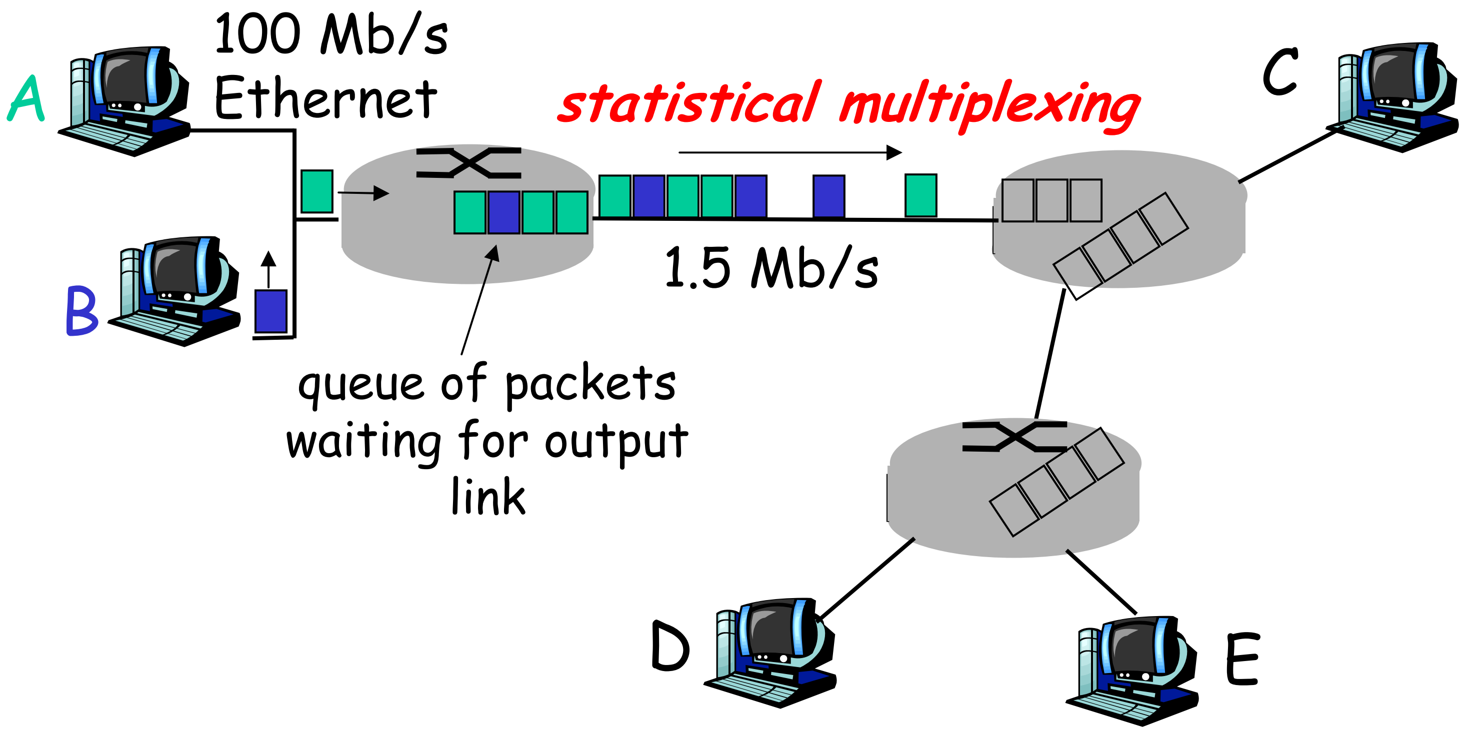
- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

Bandwidth division into "pieces"
Dedicated allocation
Resource reservation

resource contention:

- aggregate resource demand can exceed amount available
- congestion: packets queue, wait for link use
- store and forward: packets move one hop at a time
  - Node receives complete packet before forwarding

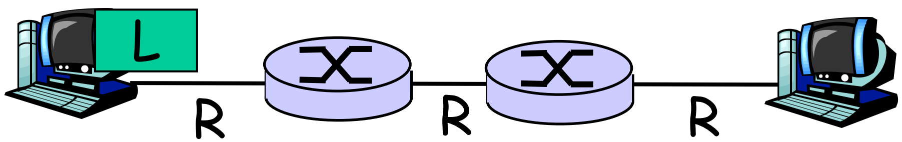
Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand ➔ ***statistical multiplexing***.

TDM: each host gets same slot in revolving TDM frame.

Packet-switching: store-and-forward



- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps 傳輸時間
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link 先收完再送
- delay = 3L/R (assuming zero propagation delay)

more on delay shortly …

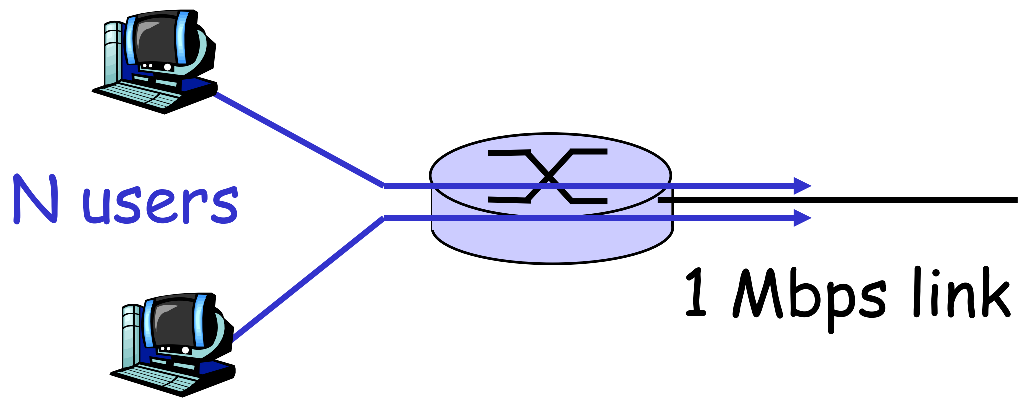
Example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- transmission delay = 15 sec

Packet switching versus circuit switching

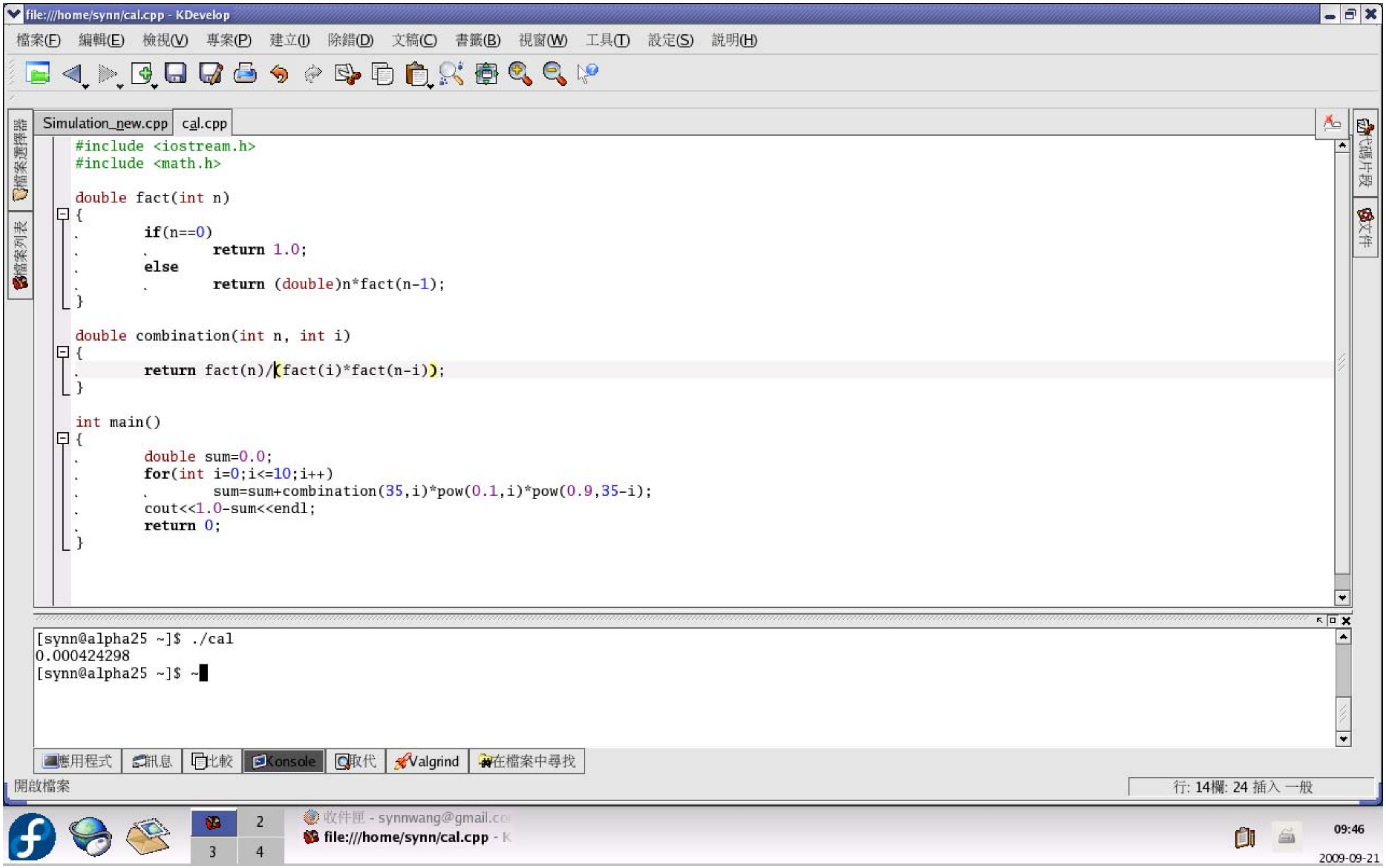
Packet switching allows more users to use network!
封包交換使更多使用者使用網路

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time
- *circuit-switching:*
  - 10 users (1M/100k=10)
- *packet switching:*
  - with 35 users, probability > 10 active at same time is about .0004



Q: how did we get value 0.0004?

Packet switching versus circuit switching



Packet switching versus circuit switching

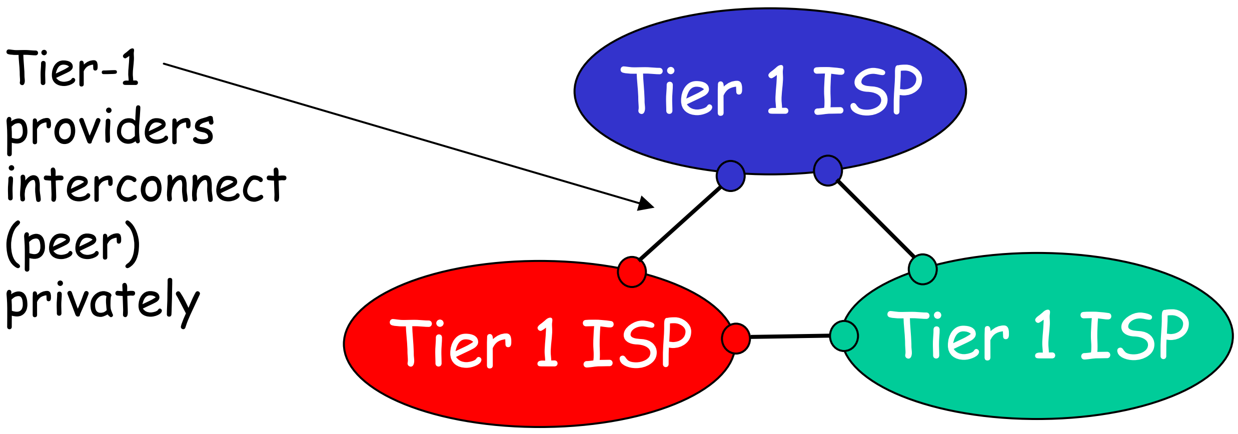
Is packet switching a "slam dunk winner?"

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 7)

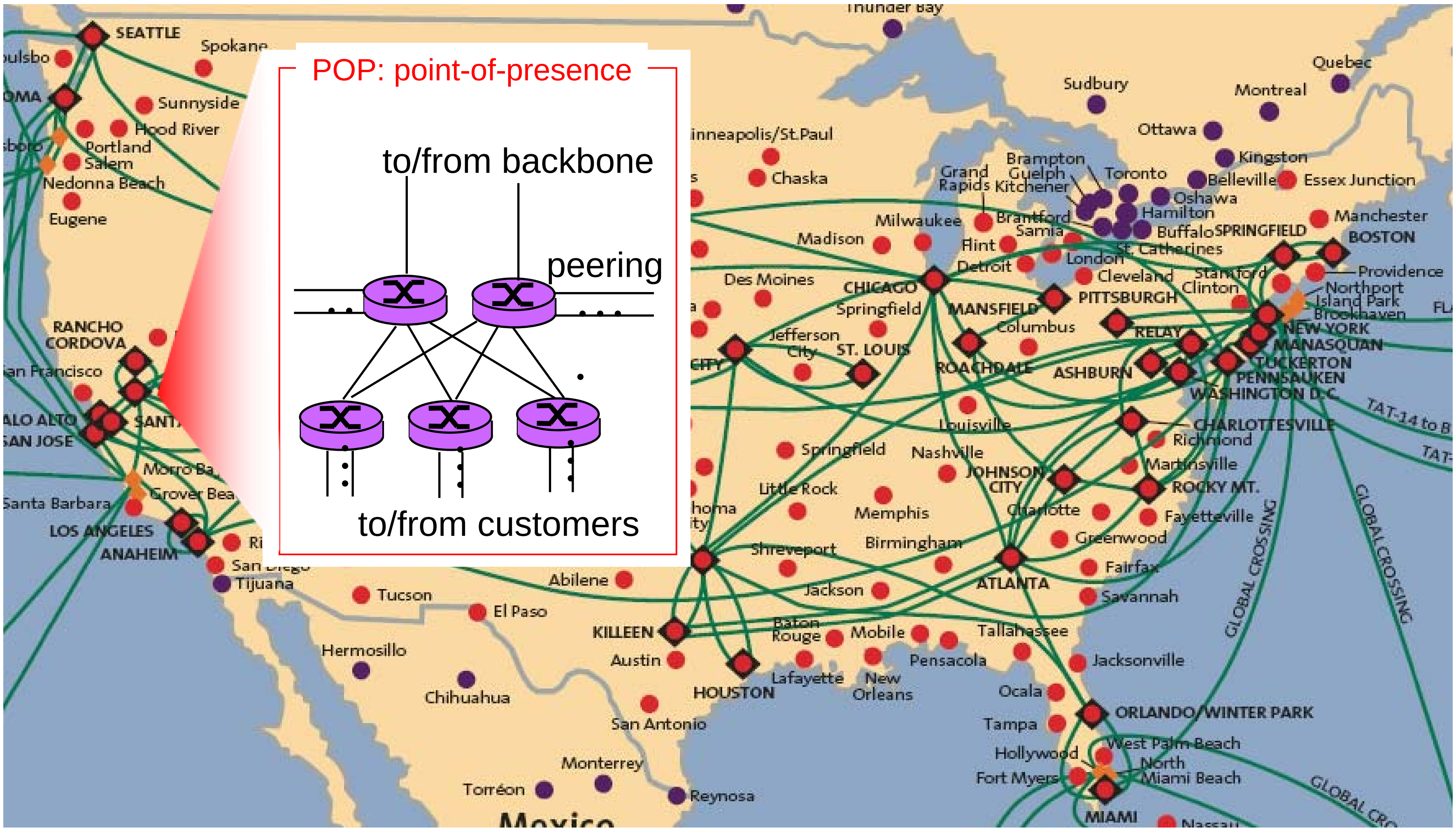
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

Internet structure: network of networks 網際網路架構：網路的網路...

- roughly hierarchical 階層式架構
- at center: “tier-1 第一層” ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
  - treat each other as equals

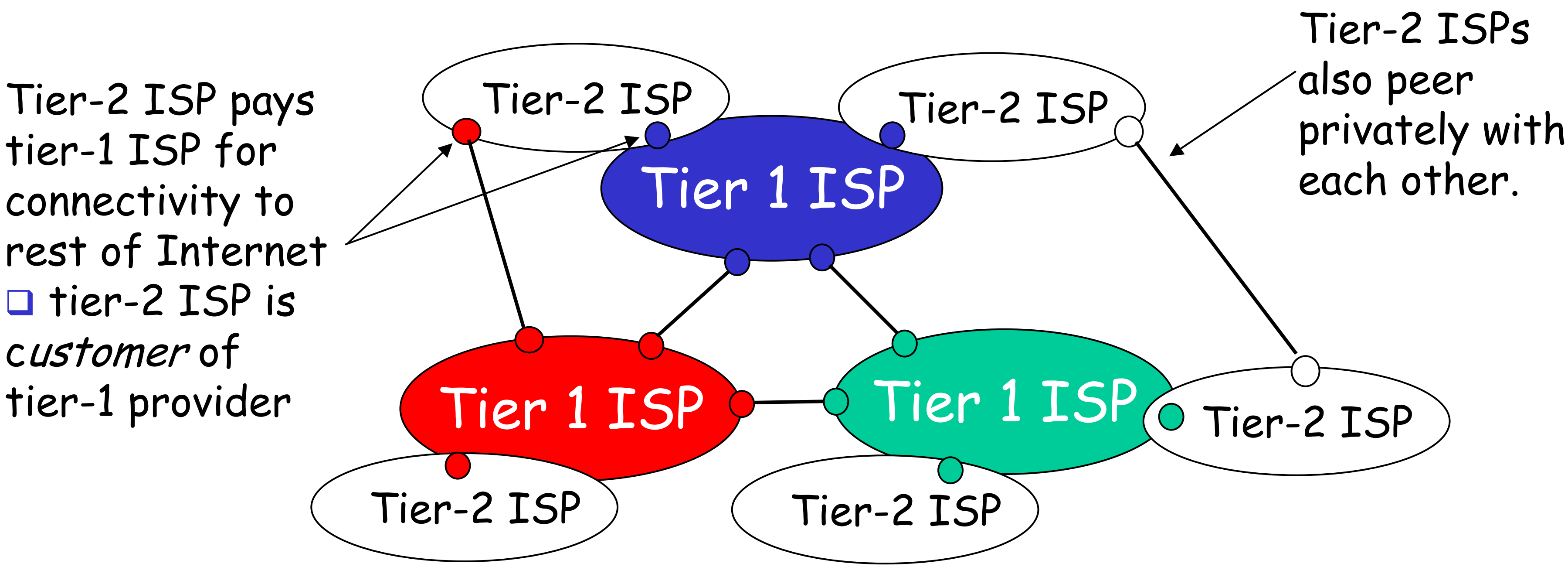


Tier-1 ISP: e.g., Sprint



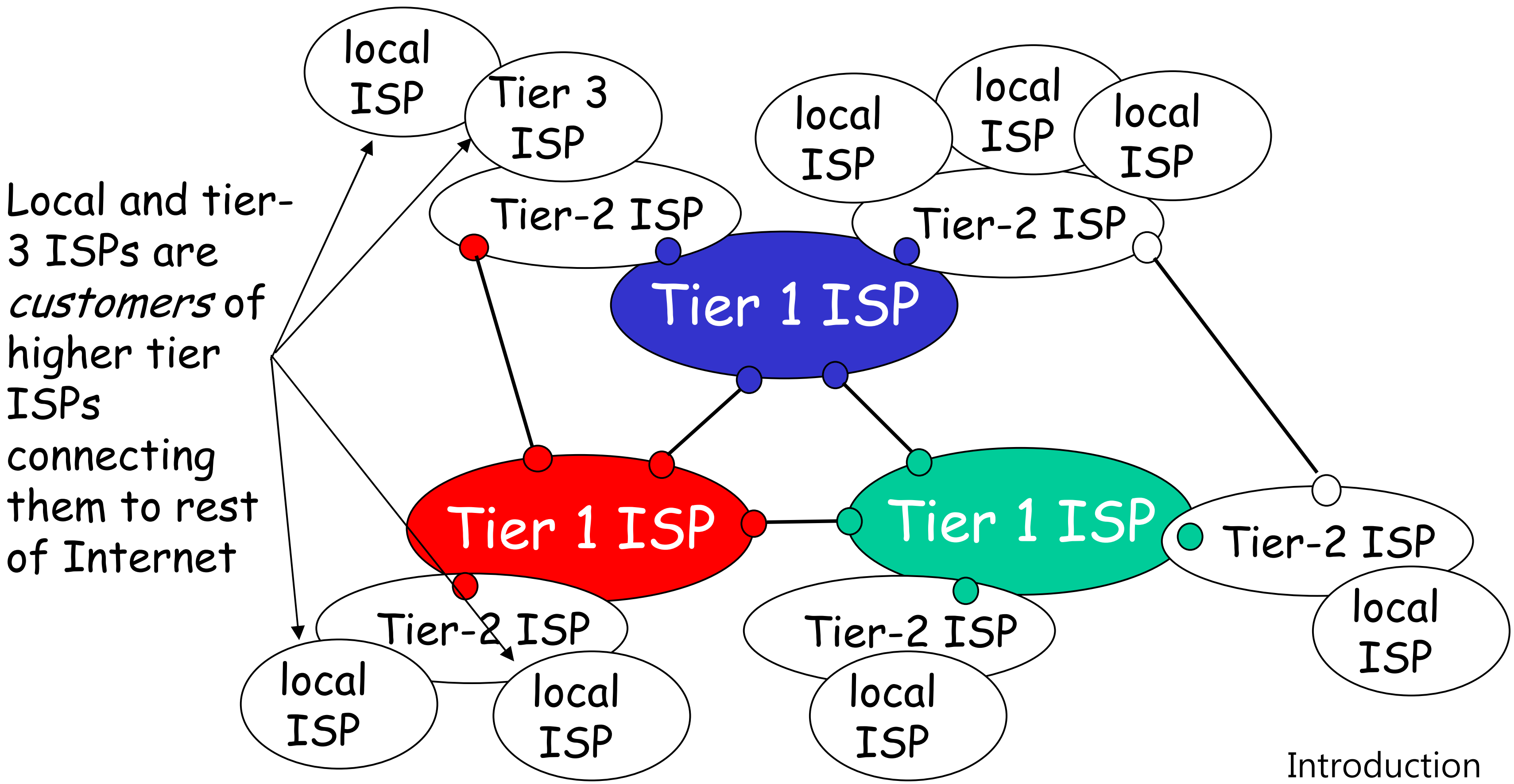
Internet structure: network of networks

- "Tier-2 第二層" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



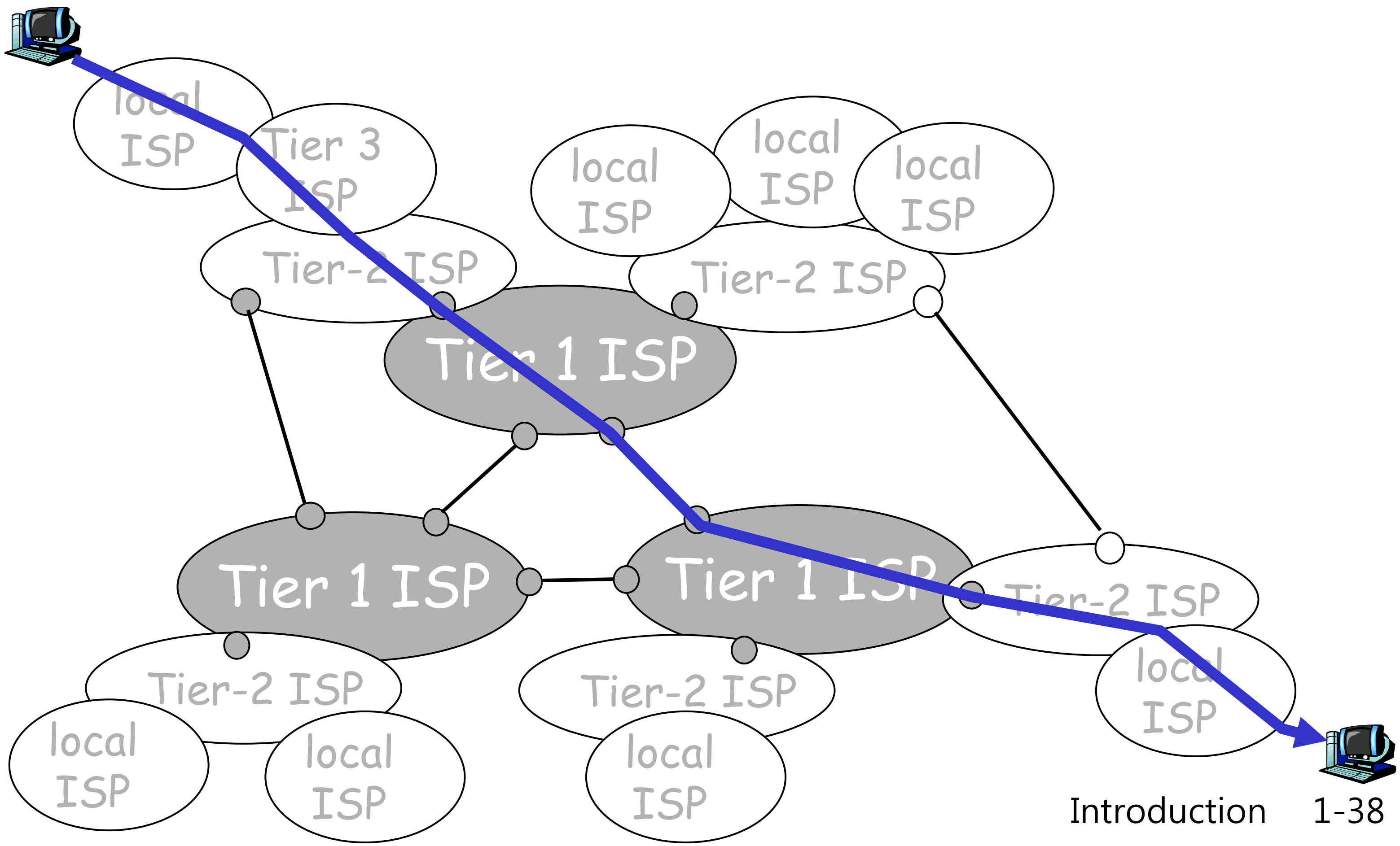
Internet structure: network of networks

- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)



Internet structure: network of networks

- a packet passes through many networks!
- 透過多個網路傳輸封包



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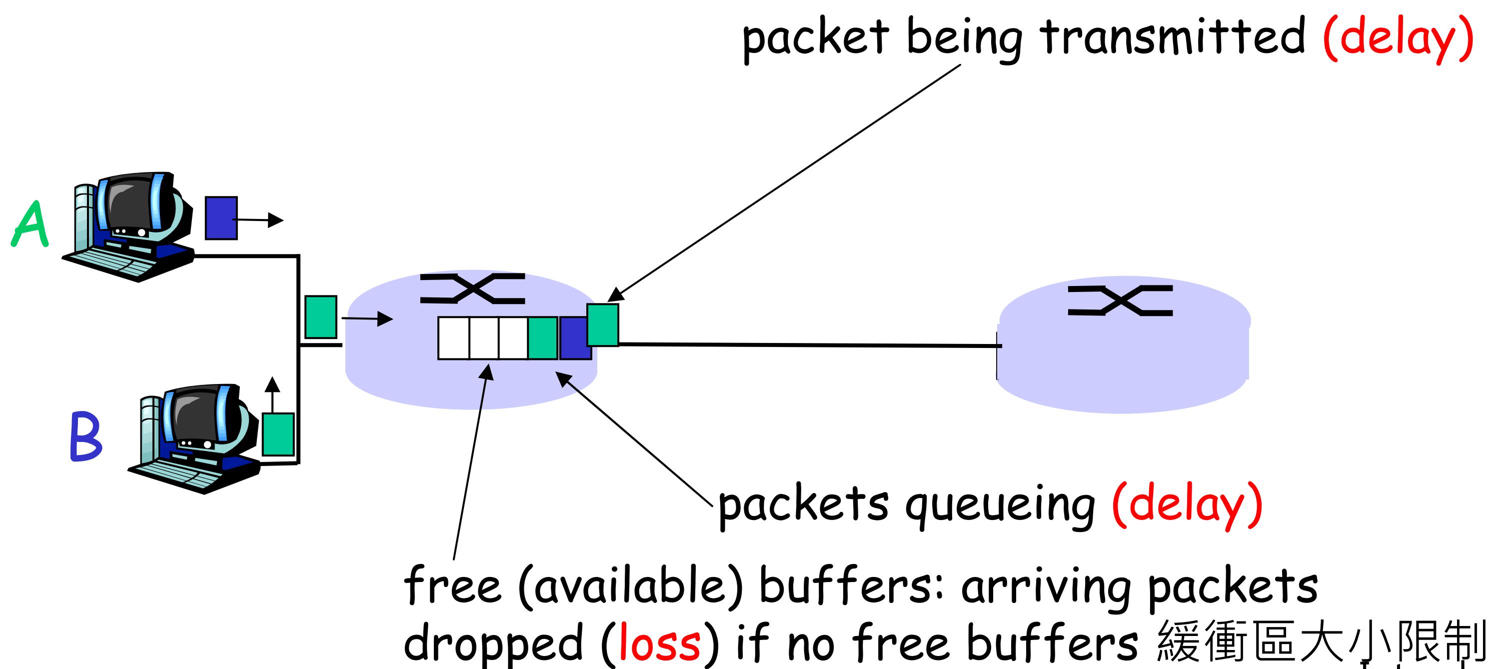
How do loss 遺失 and delay 延遲 occur?

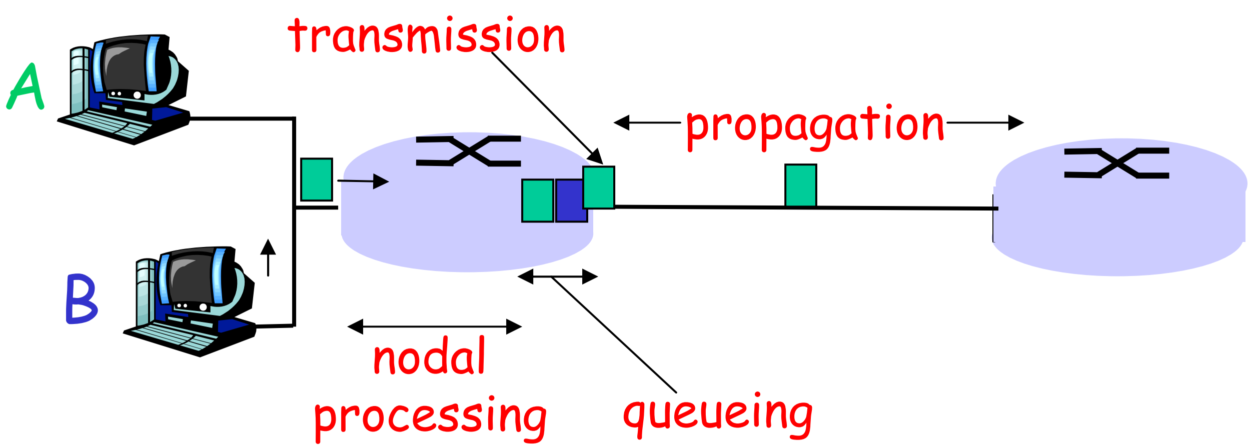
packets *queue* in router buffers

- packet arrival rate to link exceeds output link capacity 到達速率大於處理速率
- packets queue, wait for turn 封包排隊



Four sources of packet delay
封包延遲的四個來源

- 1. nodal processing:
  節點的訊號處理
  - check bit errors
  - determine output link
- 2. queueing
  等待被處理的時間
  - time waiting at output link for transmission
  - depends on congestion level of router



Delay in packet-switched networks

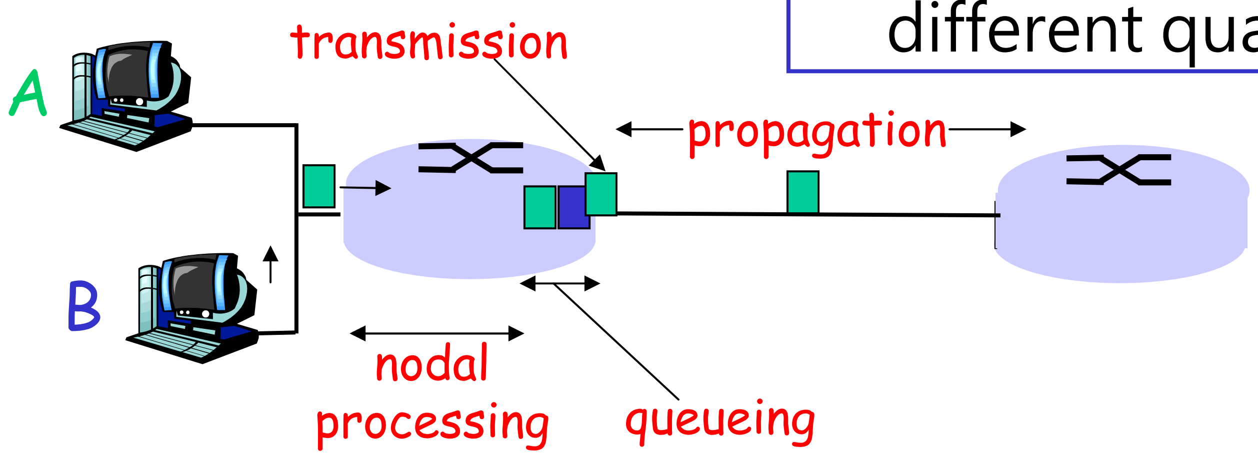
3. Transmission delay:傳輸延遲
（由機器送至傳輸媒介上）

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

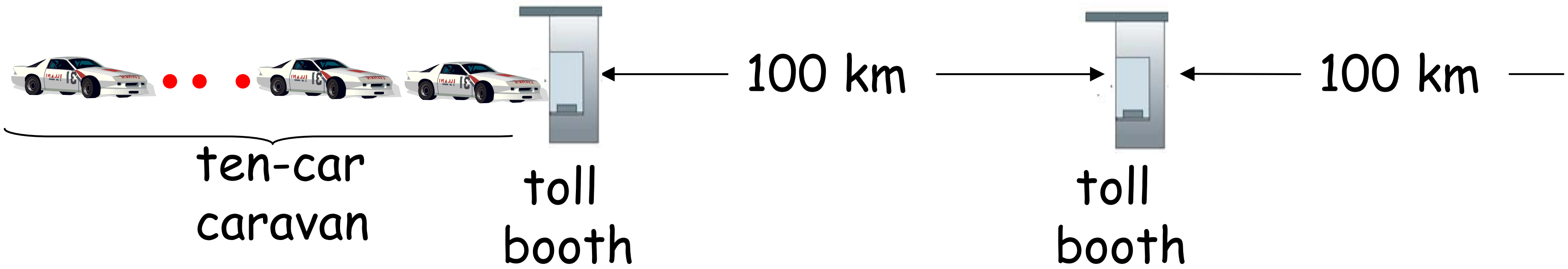
4. Propagation delay: 傳播延遲
（在傳輸媒介上傳輸的時間）

- d = length of physical link
- s = propagation speed in medium (~2x10^8 m/sec)
光速或電子傳輸速度
- propagation delay = d/s

Note: s and R are *very* different quantities!



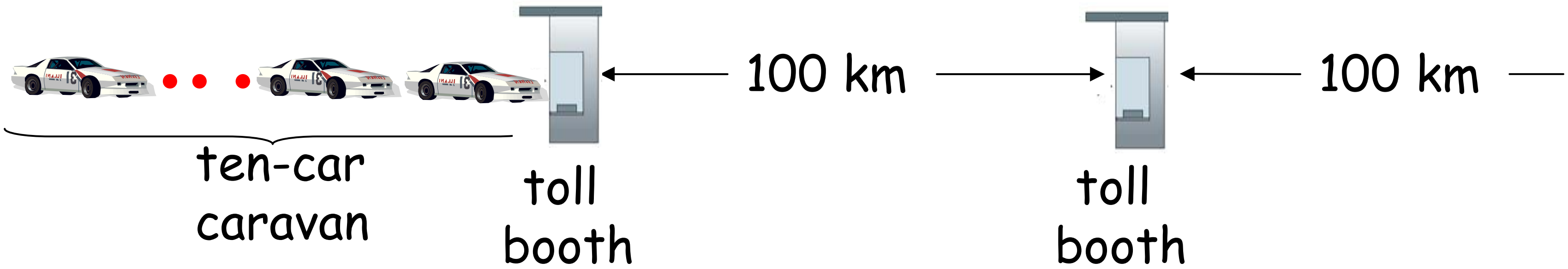
Caravan analogy 以車隊來類比



- cars "propagate" at 100 km/hr 車速
- toll booth takes 12 sec to service car (transmission time) 每12秒處理一輛車
- car~bit; caravan ~ packet 車=bit；車隊=封包
- Q: How long until caravan is lined up before 2nd toll booth?

- Time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- A: 62 minutes

Caravan analogy (more)



- Cars now "propagate" at
  1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?
- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
  - See Ethernet applet at AWL Web site

Nodal delay

$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

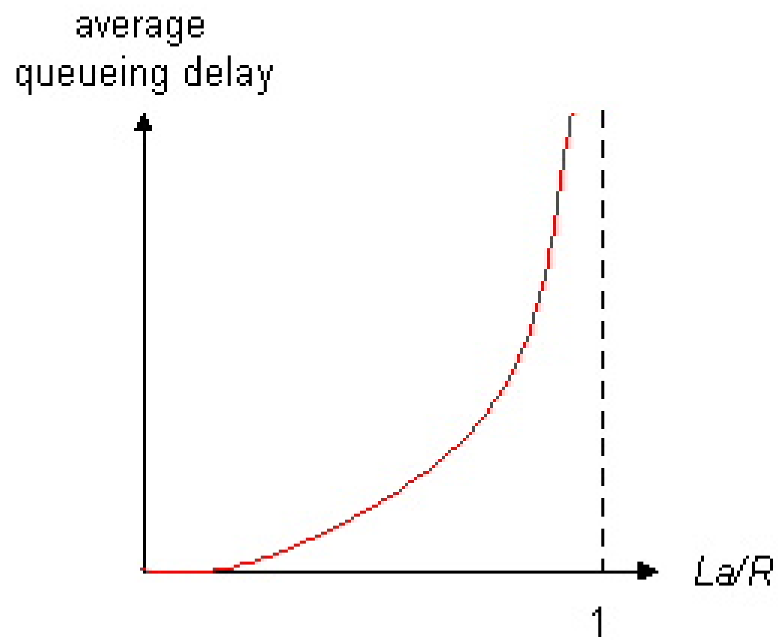
- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay和流量有關
  - depends on congestion
- d_{trans} = transmission delay 和封包大小、頻寬有關
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay 和傳輸媒體、傳輸距離有關
  - a few microsecs to hundreds of msecs

Queueing delay (revisited)

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate

traffic intensity = La/R

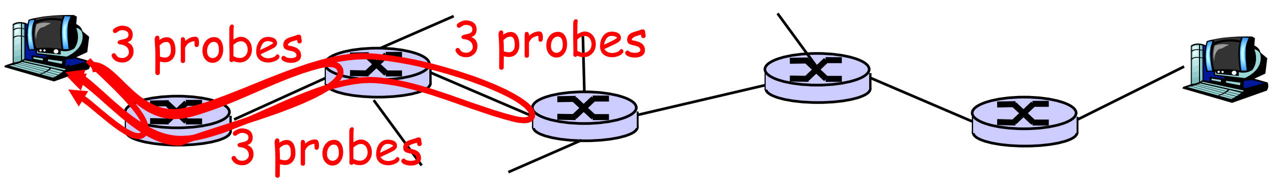
流量強度的定義



- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- Traceroute program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.



"Real" Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

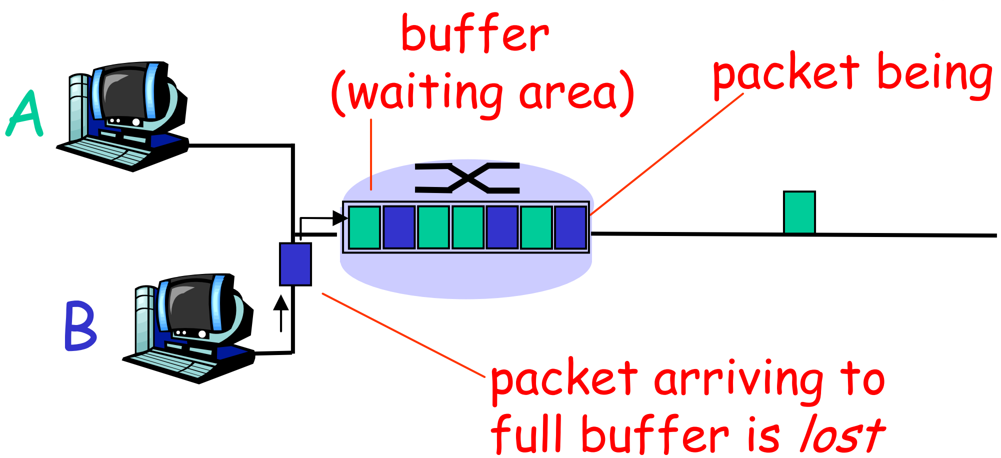
```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link

* means no response (probe lost, router not replying)

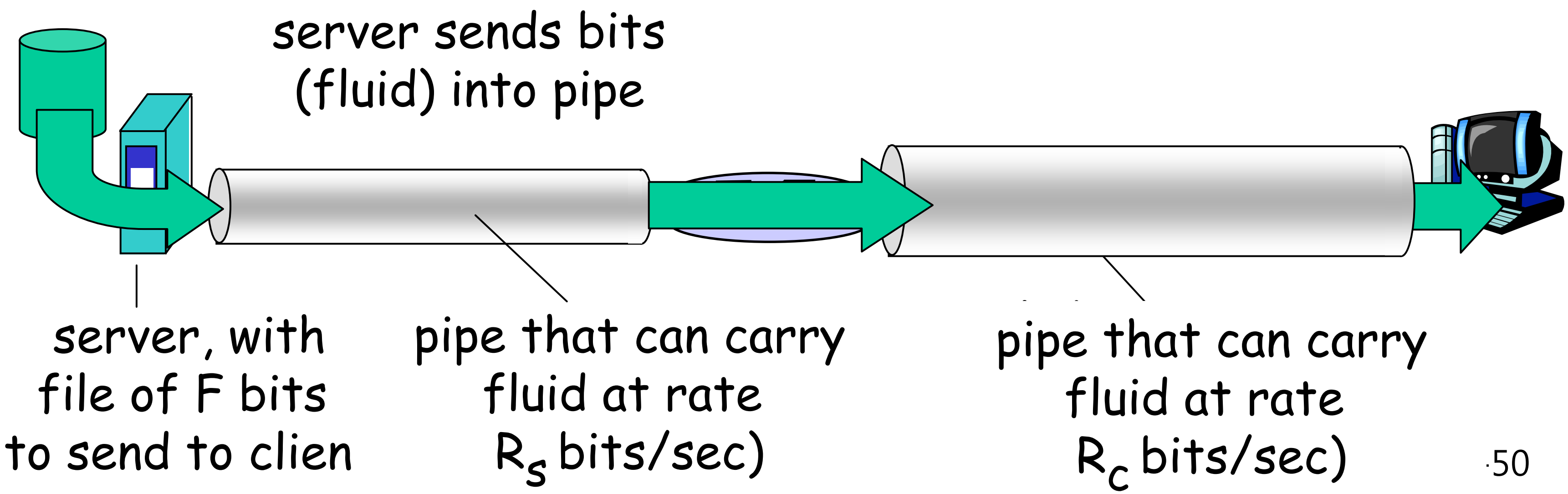
Packet loss 封包遺失

- queue (aka buffer) preceding link in buffer has finite capacity 緩衝區容量有限制
- packet arriving to full queue dropped (aka lost) 緩衝區沒有足夠容量時則丟棄封包
- lost packet may be retransmitted（重傳） by previous node, by source end system, or not at all



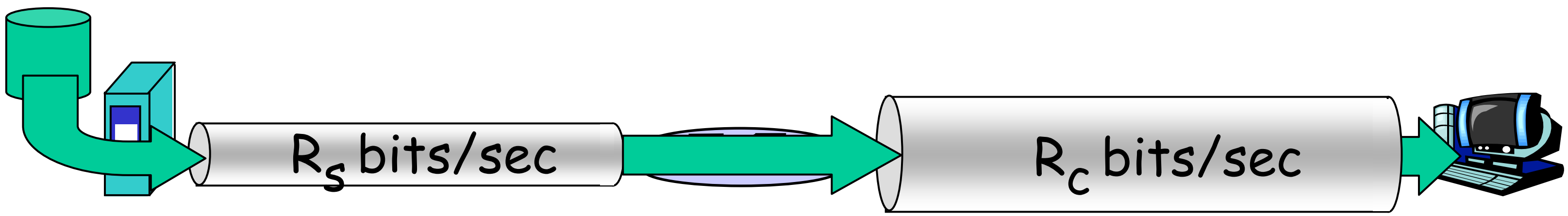
Throughput 產出量

- *throughput:* rate (bits/time unit) at which bits transferred between sender/receiver 每單位時間傳送的bit數量
  - *Instantaneous:* rate at given point in time 瞬間
  - *Average:* rate over long(er) period of time 平均

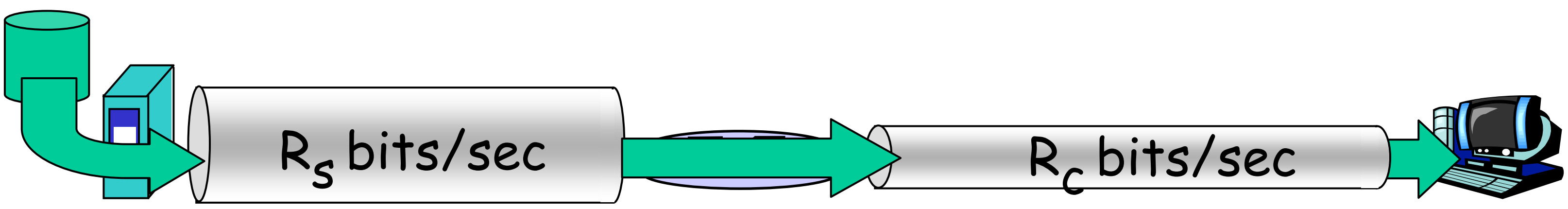


Throughput (more) 瓶頸連結

- $R_s < R_c$ What is average end-end throughput? R_s



- $R_s > R_c$ What is average end-end throughput? R_c

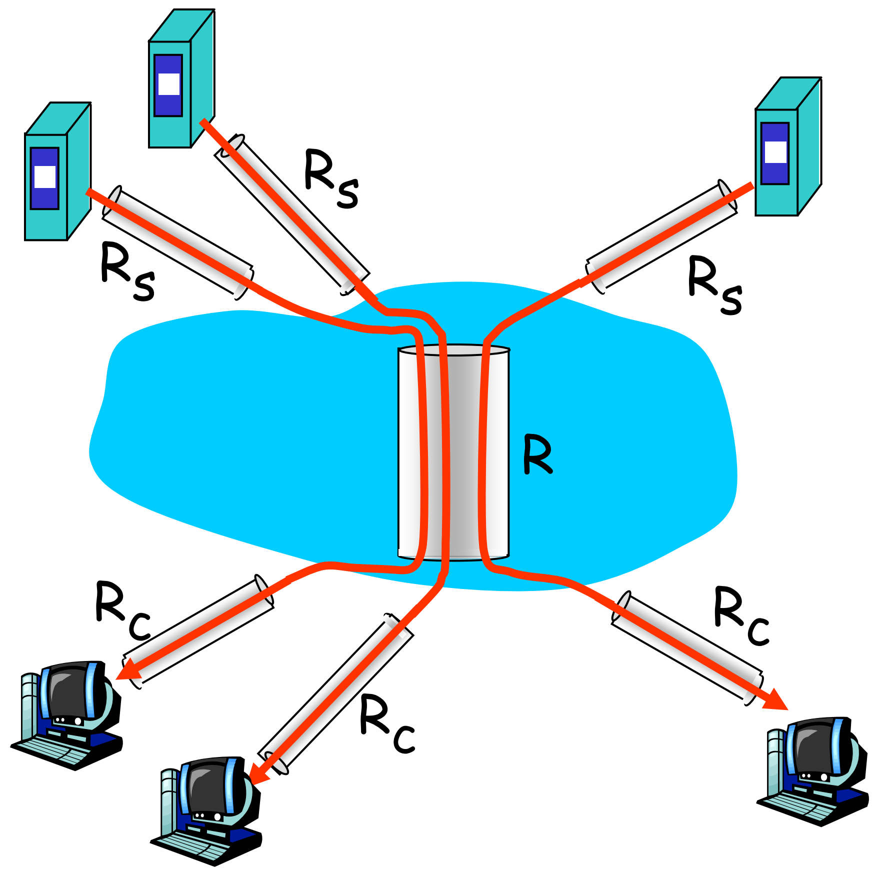


bottleneck link

link on end-end path that constrains end-end throughput=min{Rc , Rs}

Throughput: Internet scenario 網際網路的實際狀況

- per-connection end-end throughput: $\min(R_c, R_s, R/10)$
  R為link上的頻寬（傳輸速率）
- in practice: R_c or R_s is often bottleneck



10 connections (fairly) share backbone bottleneck link R bits/sec