CS2105

An *Awesome* Introduction to Computer Networks

Lecture 1: Introduction

NUS National University of Singapore | Department of Computer Science, School of Computing

Course Instructors

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What is CS2105 About?

- Discussion of fundamental **concepts** and **principles** behind computer networking
  - Using the Internet as a case study
- Introduction to networking tools and networked application programming
  - Programming with Python, Java, or C++

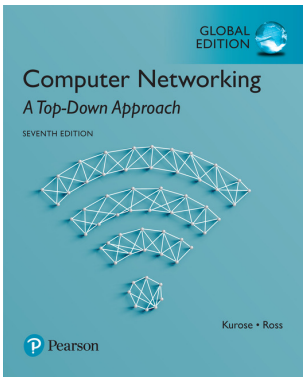
What you will NOT learn in CS2105

- How to configure hardware, e.g. router
  - This is covered in CS3103 Computer Networks Practice - perform hands-on experiments in subnetting, DHCP, DNS, RIP, OSPF, TCP handshaking and congestion mechanism
- Mobile and wireless networks
  - This is covered in CS4222 Wireless Networking

Textbook

Computer Networking: A Top-Down Approach: Global Edition, 7/E

Authors : Kurose
Ross
Publisher : Pearson
ISBN : 9781292153599



Available at **NUS Campus bookstore**

Acknowledgement:
Most of the lecture slides are adopted from slides of this textbook.

Contact Hours

- Lectures
  - Every Monday 2 - 4pm @ ICube Auditorium
  - 2 hours per session
  - week 8 lecture reserved for midterm test
- Tutorials
  - Start from week 3.
  - 1 hour per session
  - No tutorial in week 8 ☺
- Consultation
  - Email me or Wai Kay to make arrangement

Assessments

- CA (50%)
  - Tutorial attendance/participation - 5%
  - Individual programming assignments - 25%
  - Mid-term test (week 8 lecture time: Mon, 7 Oct 2019, 2:10 - 3:30pm) - 20%
- Final Exam (50%)
  - Mon, 2 Dec 2019, 5 - 7pm

Notes and Tips

- Why CS2105 can be **easy**
  - You use and interact with the Internet constantly
  - Many of the concepts are intuitive and based on very practical design considerations
  - There are very few equations!
- Why CS2105 can be **tough**
  - Many concepts are covered
  - Programming!

Lecture 1: Introduction

After this class, you are expected to:

- understand the basic terms, including host, packet, protocol, throughput, store-and-forward, and autonomous system.
- know about the logical (five protocol layers) and physical (a network of ASes) architecture of the Internet.
- understand the different components of end-to-end delay and their relations to bandwidth, packet size, distance, propagation speed, and queue size.

Lecture 1: Roadmap

1.1 What is the Internet?

1.2 Network Edge

1.3 Network Core

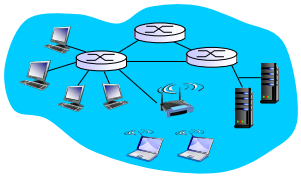
1.4 Delay, Loss and Throughput in Networks

1.5 Protocol Layers and Service Models

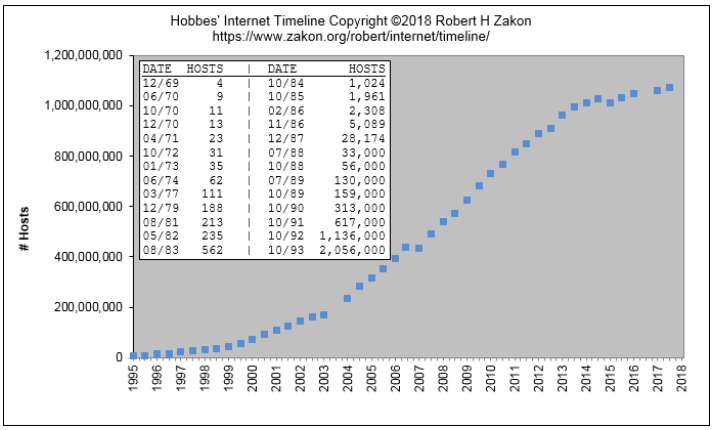
Kurose Textbook, Chapter 1
(Some slides are taken from the book)

Internet: "nuts and bolts" View

- The Internet is a network of connected computing devices (e.g. PC, server, laptop, smartphone)
  - such devices are known as *hosts* or *end systems*.
  - they run network applications (e.g. WhatsApp, browser).
  - they communicate over links.



Growth of Internet Hosts



DATE	HOSTS	DATE	HOSTS
12/69	4	10/84	1,024
06/70	9	10/85	1,961
10/70	11	02/86	2,308
12/70	13	11/86	5,089
04/71	23	12/87	28,174
10/72	31	07/88	33,000
01/73	35	10/88	56,000
06/74	62	07/89	130,000
03/77	111	10/89	159,000
12/79	188	10/90	313,000
08/81	213	10/91	617,000
05/82	235	10/92	1,136,000
08/83	562	10/93	2,056,000

"Fun" Internet-connected Devices


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


Web-enabled toaster + weather forecaster


Tweet-a-watt: monitor energy use


Internet refrigerator


Slingbox: watch, control cable TV remotely


sensorized, bed mattress


Internet phones

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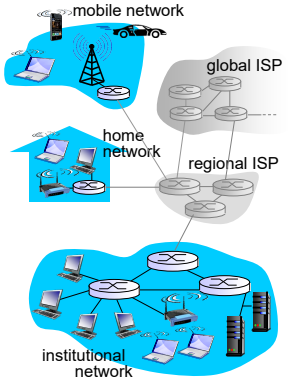
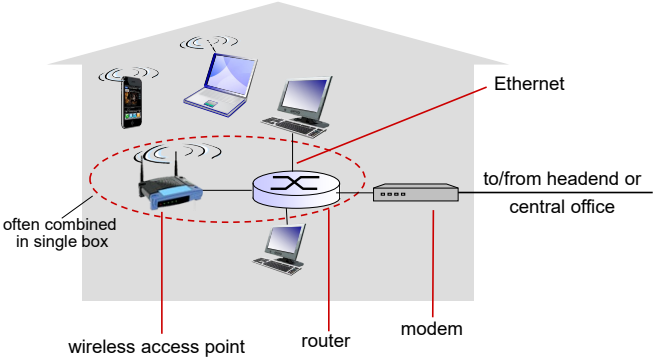
Access Networks

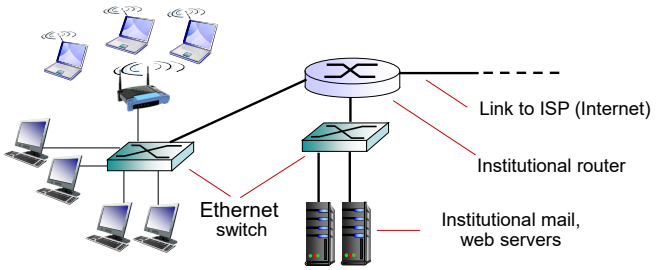
- Hosts access the Internet through *access network*.
  - Residential access networks
  - Institutional access networks (school, company)
  - Mobile access networks



Home Networks



Enterprise Access Networks (Ethernet)



- Typically used in companies, universities, etc.
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- Today, hosts typically connect to Ethernet switch

Wireless Access Networks

- Wireless access network connects hosts to router
  - via base station aka "access point"

Wireless LANs:

- within building (100 ft)
- 802.11b/g/n/ac (Wi-Fi)

Wide-area wireless access

- 3G, 4G
- provided by telco (cellular) operator, 10's km

Physical Media

- Hosts connect to the access network over different physical media.
  - Guided media:
    - signals propagate in solid media

Twisted pair cable

Coaxial cable

Fiber optic cable

  - Unguided media:
    - signals propagate freely, e.g., radio

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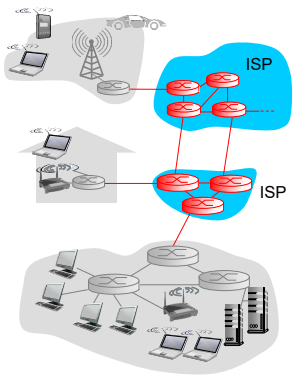
The Network Core

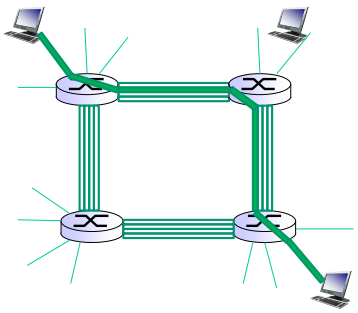
- A mesh of interconnected routers
- The fundamental question: how is data transmitted through net?
  - Circuit switching: dedicated circuit per call
  - Packet switching: data sent thru net in discrete "chunks"



Circuit Switching

End-end resources allocated to and reserved for "call" between source & dest:

- call setup required
- circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- commonly used in traditional telephone networks
- divide link bandwidth into "pieces"
  - frequency division
  - time division

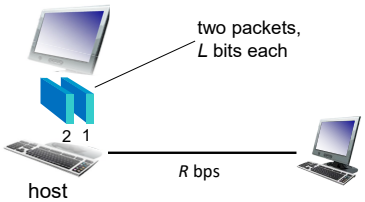


In above diagram, each link has four circuits. A "call" gets 2nd circuit in top link and 1st circuit in right link.

Packet Switching

Host sending function:

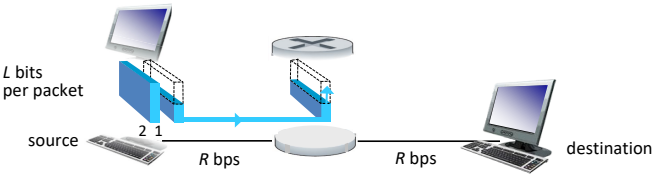
- breaks application message into smaller chunks, known as *packets*, of length *L* bits
- transmits packets onto the link at *transmission rate R*
  - link transmission rate is aka *link capacity* or *link bandwidth*



$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Packet-switching: store-and-forward

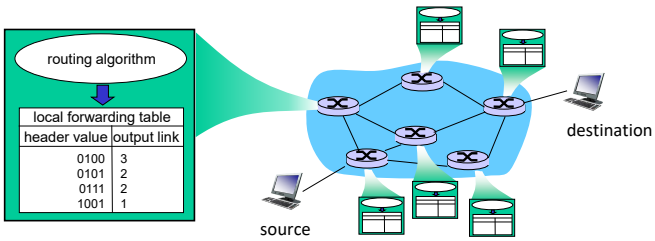
- Packets are passed from one router to the next, across links on path from source to destination.
- *Store and forward:* entire packet must arrive at a router before it can be transmitted on the next link.



End-to-end delay = 2*L/R* (assuming no other delay)

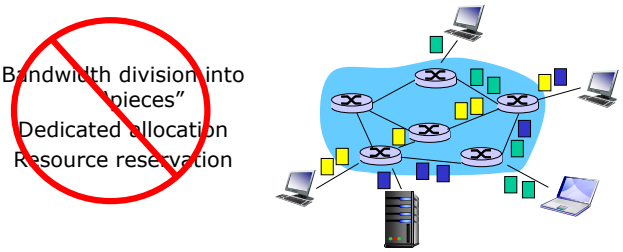
Routing and Addressing

- Routers determine source-destination route taken by packets.
  - Routing algorithms
- Addressing: each packet needs to carry source and destination information



Packet Switching

- The Internet is a packet switching network
- User A, B … 's packets *share* network resources
- Resources are used on demand
- Excessive congestion is possible

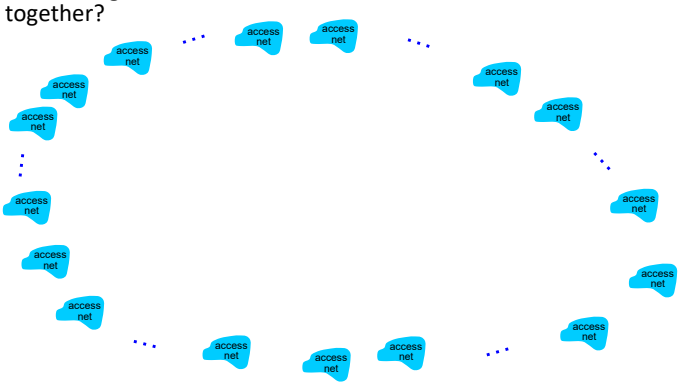


Internet Structure: Network of Networks

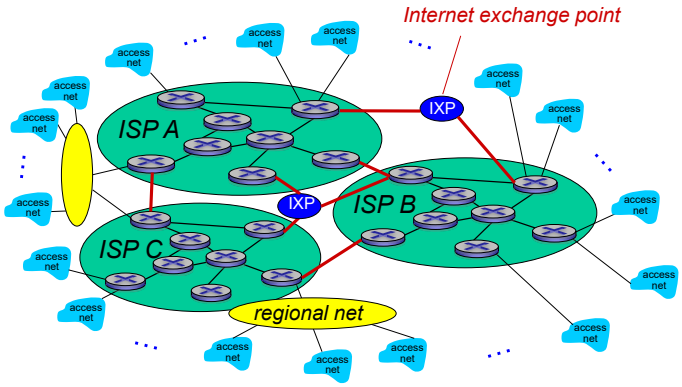
- Hosts connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs
- Access ISPs in turn must be interconnected.
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies
- Therefore, the Internet is a "network-of-networks", organized into autonomous systems (AS), each is owned by an organization.

Internet Structure: Network of Networks

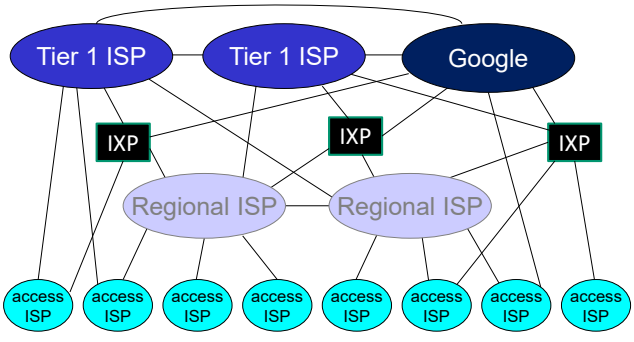
Question: given *millions* of access nets, how to connect them together?



Internet Structure: Network of Networks



Internet Structure: Network of Networks



Who Runs the Internet?

- IP address & Internet Naming administered by Network Information Centre (NIC)
  - Refer to: www.sgnic.net.sg; www.apnic.org
- The Internet Society (ISOC) - Provides leadership in Internet related standards, education, and policy around the world.
- The Internet Architecture Board (IAB) - Authority to issue and update technical standards regarding Internet protocols.
- Internet Engineering Task Force (IETF) - Protocol engineering, development and standardization arm of the IAB.
  - Internet standards are published as RFCs (Request For Comments)
    - Refer to: www.ietf.org; for RFCs: http://www.ietf.org/rfc.html

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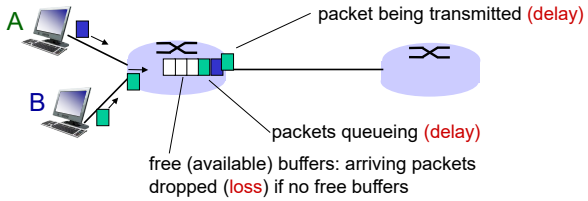
Recall: Packet Switching Network

- To send a packet in a packet switching network,
  1. Sender transmit a packet onto the link as a sequence of bits.
  2. Bits are propagated to the next node (e.g. a router) on the link.
  3. Router stores, processes and forwards the packet to the next link.
  4. Steps 2 & 3 repeat till the packet arrives at the receiver.

How do Delay and Loss Occur?

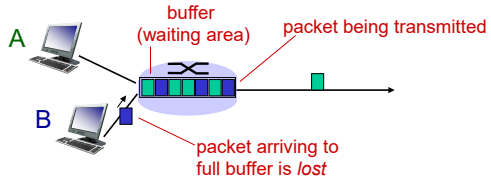
- Packets *queue* in router buffers
  - wait for turn to be sent out one by one



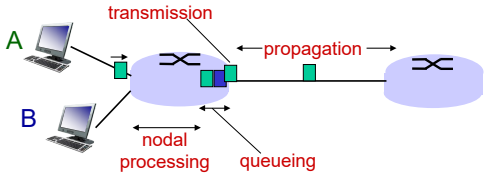
Q: What if packet arrival rate exceeds departure rate?

Packet Loss

- Queue (aka buffer) of a router has finite capacity.
- Packet arriving to full queue will be dropped (aka lost).
- Lost packet may be retransmitted by previous node, by source host, or not at all.



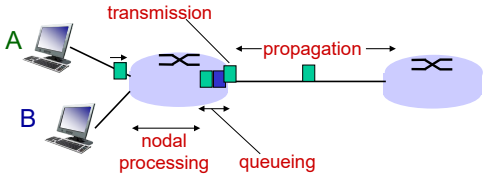
Four Sources of Packet Delay



d_{proc}: nodal processing
- check bit errors
- determine output link
- typically < msec

d_{queue}: queuing delay
- time waiting in the queue for transmission
- depends on congestion level of router

Four Sources of Packet Delay



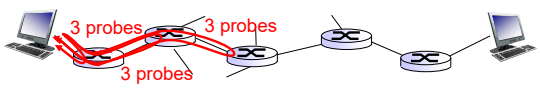
d_{trans}: transmission delay
- L: packet length (bits)
- R: link *bandwidth (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay
- d: length of physical link
- s: propagation speed in medium (~2×10^8 m/sec)
- $d_{prop} = d/s$

End-to-end Packet Delay

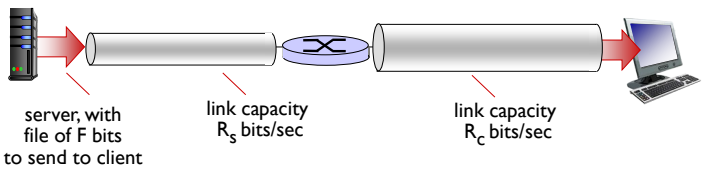
- End-to-end packet delay is the time taken for a packet to travel from source to destination. It consists of:
  - transmission delay
  - propagation delay
  - processing delay
  - queueing delay

traceroute program displays the route (path) from source to destination and measures the delay from source to each router along the end-end Internet path.



Throughput

- Throughput: how many bits can be transmitted per unit time.
  - Throughput is measured for end-to-end communication.
  - Link capacity (bandwidth) is meant for a specific link.



Metric Units

- 1 byte = 8 bits

Exp.	Explicit	Prefix	Exp.	Explicit	Prefix
10^{-3}	0.001	milli	10^{3}	1,000	Kilo
10^{-6}	0.000001	micro	10^{6}	1,000,000	Mega
10^{-9}	0.000000001	nano	10^{9}	1,000,000,000	Giga
10^{-12}	0.000000000001	pico	10^{12}	1,000,000,000,000	Tera
10^{-15}	0.000000000000001	femto	10^{15}	1,000,000,000,000,000	Peta
10^{-18}	0.000000000000000001	atto	10^{18}	1,000,000,000,000,000,000	Exa
10^{-21}	0.000000000000000000001	zepto	10^{21}	1,000,000,000,000,000,000,000	Zetta
10^{-24}	0.000000000000000000000001	yocto	10^{24}	1,000,000,000,000,000,000,000,000	Yotta

The principal metric prefixes

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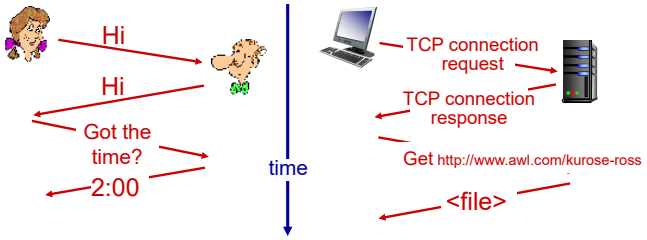
Internet: a Service View

- The Internet supports various kinds of network applications:
  - Web, VoIP, email, games, e-commerce, social nets, …
- Network applications exchange messages and communicate among peers according to protocols.

What's a Protocol?

a human protocol and a computer network protocol:



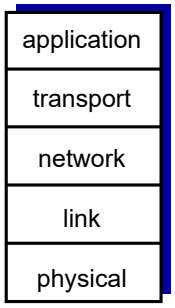
Protocols define format and order of messages exchanged and the actions taken after messages are sent or received.

Protocol "Layers"

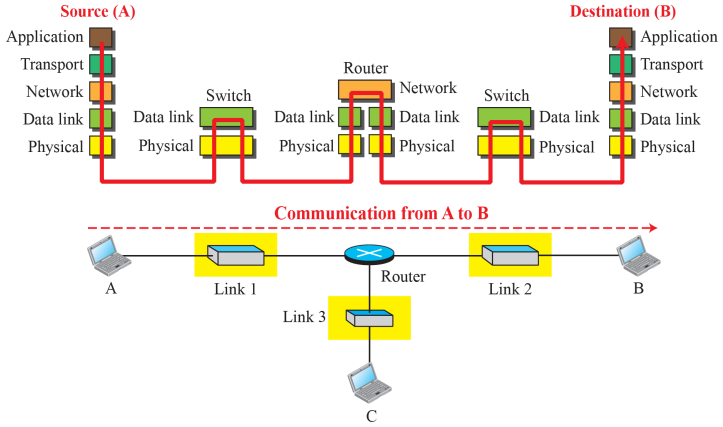
- Protocols in the Internet are logically organized into "layers" according to their purposes.
  - Each layer provides a service
  - Simple interfaces between layers
  - Hide details from each other
- Layering is a common CS trick to deal with large and complex systems.
  - Explicit structure allows identification, relationship of complex system's pieces
  - Modularization eases maintenance, updating of system
    - E.g. change of implementation of one layer's service is transparent to rest of system

Internet Protocol Stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *transport:* process-to-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- *physical:* bits "on the wire"



Example



ISO/OSI reference model (FYI)

- Theoretical model – not in use
- Two additional layers not present in Internet Protocol Stack
  - *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
  - *session:* synchronization, checkpointing, recovery of data exchange

Lecture 1: Summary

covered a "ton" of material!
- Internet overview
- Network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- Performance: loss, delay, throughput
- What's a protocol?
- Layering, service models

you now have:
- Context, overview, "feel" of networking
- More depth, detail *to follow!*