

Introduction

Illustration

Circuit Switching in a Telephone Network

Many paths are possible, but only one path is selected per call.

Once a call is established, all communication takes place on this path, or circuit. A circuit is dedicated to this call for the duration of the call.

The circuit stays active, even if no one is speaking.

Telephone Network

There are many, many circuits, but a finite number. During peak periods, some calls may be denied.

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Network Core: Circuit Switching

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 (FDMA)
 - ❖ time division (TDMA)
 - ❖ code division (CDMA)

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Circuit Switching: FDM and TDM

Example: 4 users

FDM

frequency

time

simultaneously

TDM

frequency

time

concurrently

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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!

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Network Core: Packet Switching

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*

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

Bandwidth division into "pieces"

~~Dedicated allocation~~

~~Resource reservation~~

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Illustration

Packet Switching in a Data Network

Many paths may be used for a single communication as individual packets are routed to a destination.

No fixed path is established. Packets are routed according to the best path available at the time.

Prior to transmission, each communication is broken into packets which are addressed and numbered.

Internet

Source address	Destination address	Sequence number
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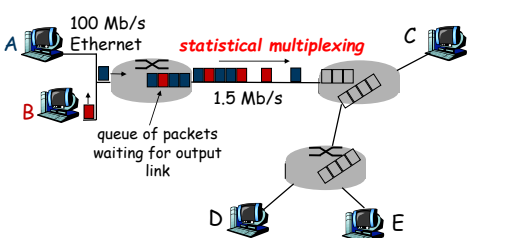
At the destination, packets may be reassembled into order according to their sequence number.

During peak periods, communication may be delayed, but not denied.

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Packet Switching: Statistical Multiplexing

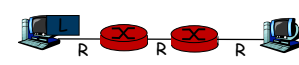


Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand **statistical multiplexing**.
TDM: each host gets same slot in revolving TDM frame.

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Packet-switching: store-and-forward



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

Example:

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

} more on delay shortly ...

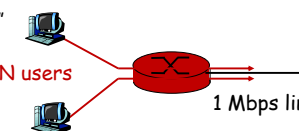
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Packet switching vs. circuit switching

Packet switching allows more users to use network!

- 1 Mb/s link
- each user:
 - ✦ 100 kb/s when "active"
 - ✦ active 10% of time
- **circuit-switching:**
 - ✦ 10 users
- **packet switching:**
 - ✦ with 35 users, probability > 10 active at same time is less than .0004



Q: how did we get value 0.0004?

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Packet switching vs. circuit switching

Is packet switching a "slam dunk winner?"

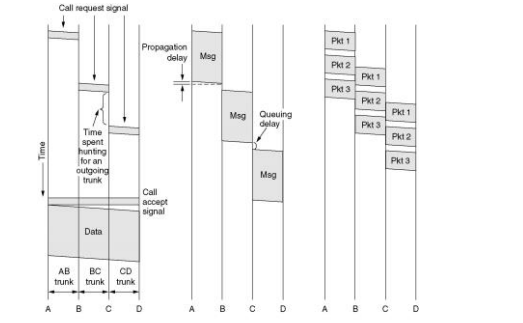
- great for bursty data
 - ✦ resource sharing
 - ✦ simpler, no call setup
- **excessive congestion:** packet delay and loss
 - ✦ protocols needed for reliable data transfer, congestion control
- **Q: How to provide circuit-like behavior?**
 - ✦ bandwidth guarantees needed for audio/video apps
 - ✦ still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

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

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Timing of Events in Switching



(a) Circuit switching (b) Message switching (c) Packet switching

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Introduction

Circuit vs. Packet Switching

- **Advantages of packet switching**
 - ✦ Efficient for bursty data
 - ✦ Easy to provide bandwidth on demand with variable rates
- **Disadvantages of packet switching**
 - ✦ Variable delays
 - ✦ Difficult to provide QoS assurances (Best-effort service)
 - ✦ Packets can arrive out-of-order

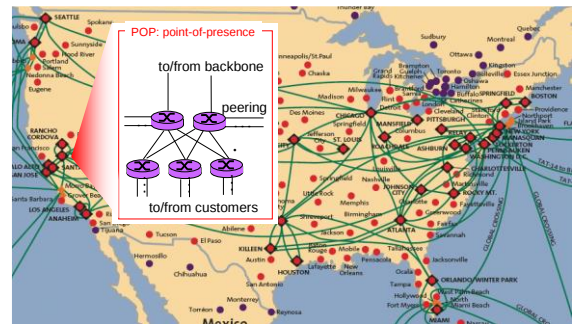
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Internet structure: network of networks

- roughly hierarchical
- at center: "tier-1" ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
 - ❖ treat each other as equals



Tier-1 ISP: e.g., Sprint

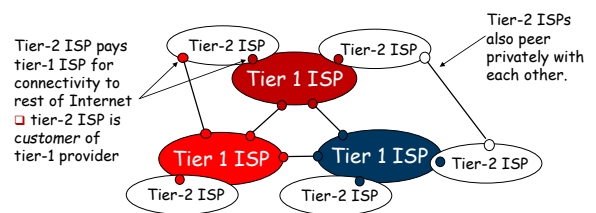


Tier 1 Networks

Name	AS number
Qwest	209
Verizon Business	701
Sprint	1239
TeliaSonera International Carrier	1299
NTT Communications	2914
Tinet	3257
Level 3 Communications (L3)	3356
Global Crossing (GBLX)	3549
Savvis	3561
AT&T	7018
Tata Communications	6453

Internet structure: network of networks

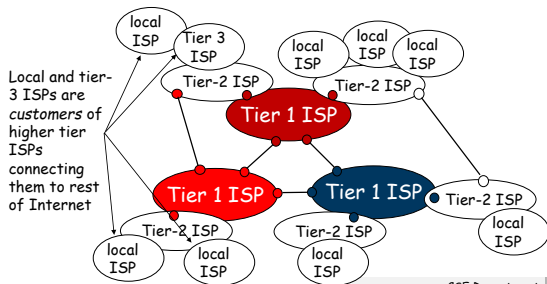
- "Tier-2" ISPs: smaller (often regional) ISPs
 - ❖ Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



Internet structure: network of networks

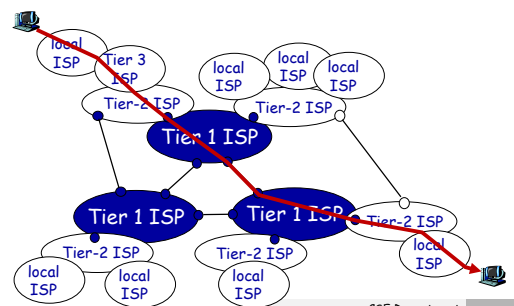
"Tier-3" ISPs and local ISPs

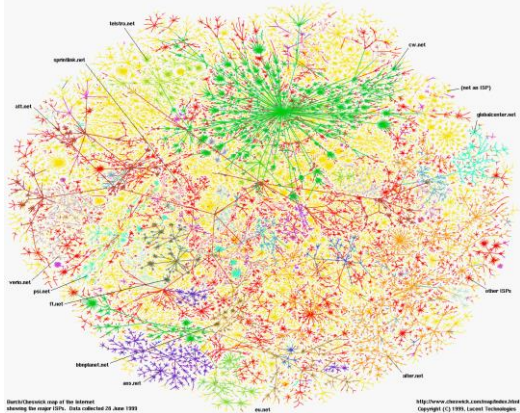
- ❖ last hop ("access") network (closest to end systems)



Internet structure: network of networks

a packet passes through many networks!





Chapter 1: roadmap

- What is the Internet?
- Network edge
 - ❖ end systems, access networks, links
- Network core
 - ❖ circuit switching, packet switching, network structure
- Delay, loss and throughput in packet-switched networks
- Protocol layers, service models
- Networks under attack: security
- History

Why Different Delays?



<http://www.sjtu.edu.cn>



<http://www.korea-dpr.com/>



Discussion!

Distance matters

Is it the only reason?

If not, any insights?

How do loss and delay occur?

packets *queue* in router buffers

- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn

