# Computer Networks and Applications

## COMP 3331/COMP 9331

## Week 1

# Introduction to Computer Networks

Reading Guide: Chapter 1, Sections 1.1 - 1.7

# Acknowledgment

- Majority of lecture slides are from the author's lecture slide set
  - Enhancements + additional material

# 1. Introduction

*Goals:*

- get "feel" and terminology
- defer depth and detail to *later* in course
- understand concepts using the Internet as example

# 1. Introduction: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers

1.6 networks under attack: security

1.7 history

Self study

Hobbe's Internet Timeline - http://www.zakon.org/robert/internet/timeline/

# Quiz: What is the Internet?

**A**. One single homogenous network

**B**. An interconnection of different computer networks

**C**. An infrastructure that provides services to networked applications

**D**. Something else (be prepared to discuss)

# "Fun" Internet-connected devices

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

Web-enabled toaster +
weather forecaster


Tweet-a-watt:
monitor energy use

Internet
refrigerator

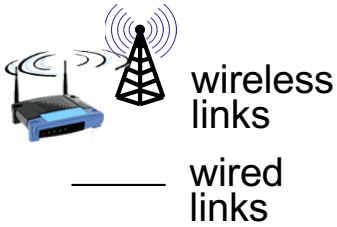
Slingbox: watch,
control cable TV remotely

sensorized,
bed
mattress

Internet phones

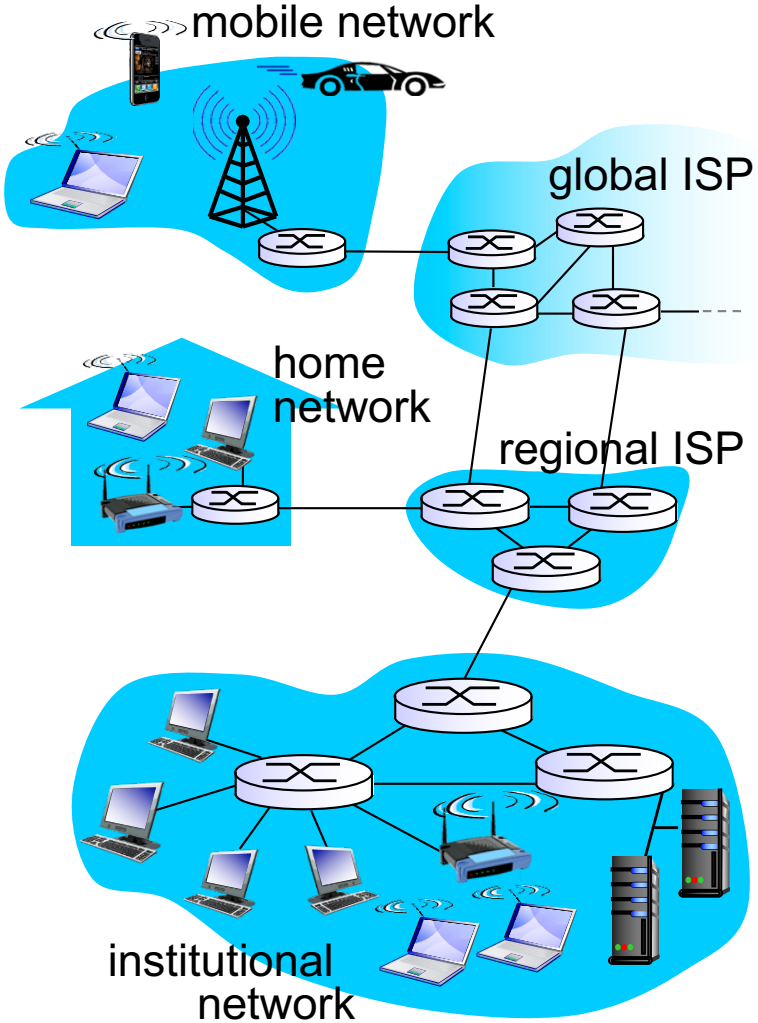
# What's the Internet: "nuts and bolts" view


- millions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*



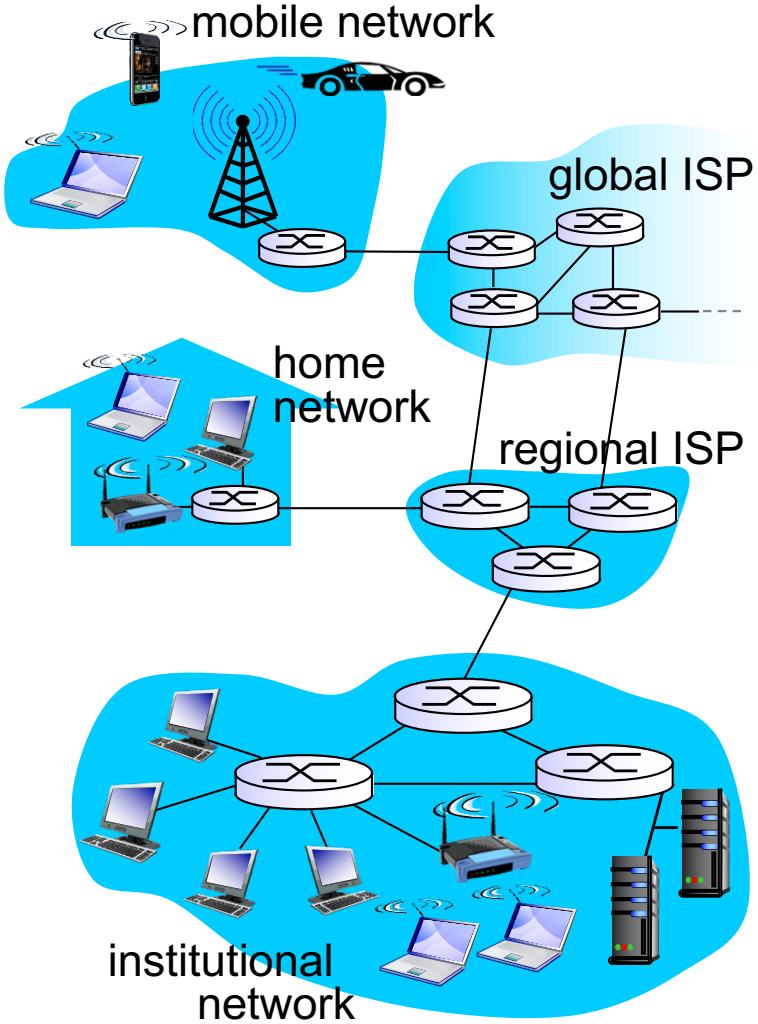

- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*


- *Packet switches:* forward packets (chunks of data)
  - *routers* and *switches*



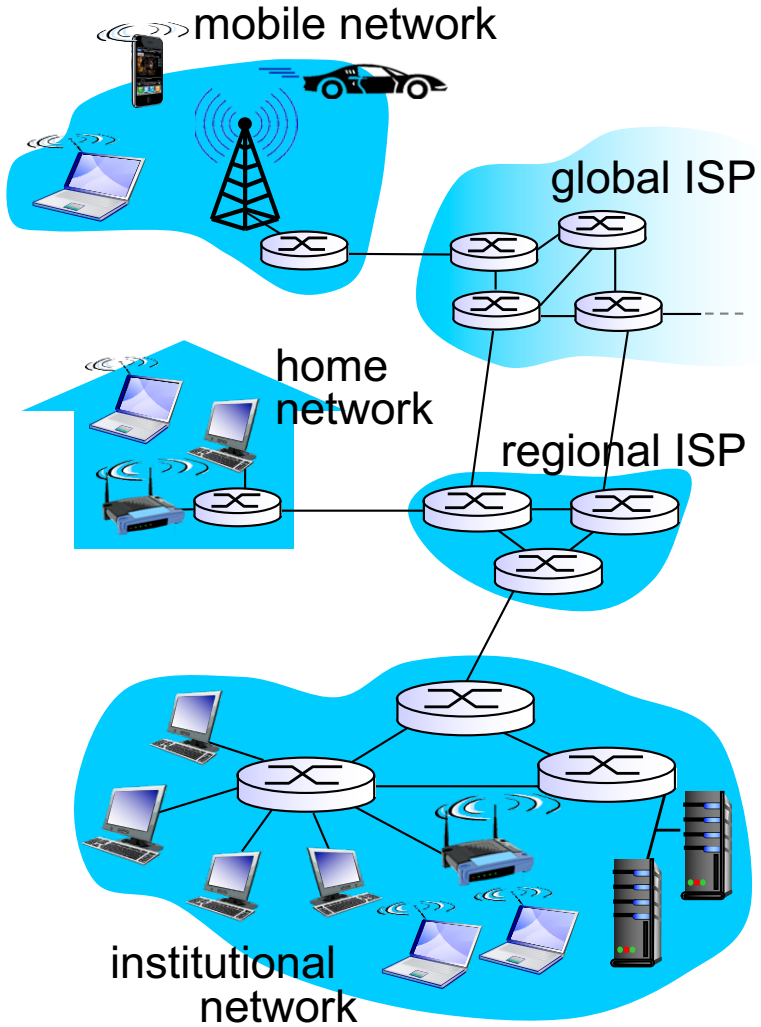
# What's the Internet: "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



# What's the Internet: a service view

- *Infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, …
- *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - provides service options, analogous to postal service

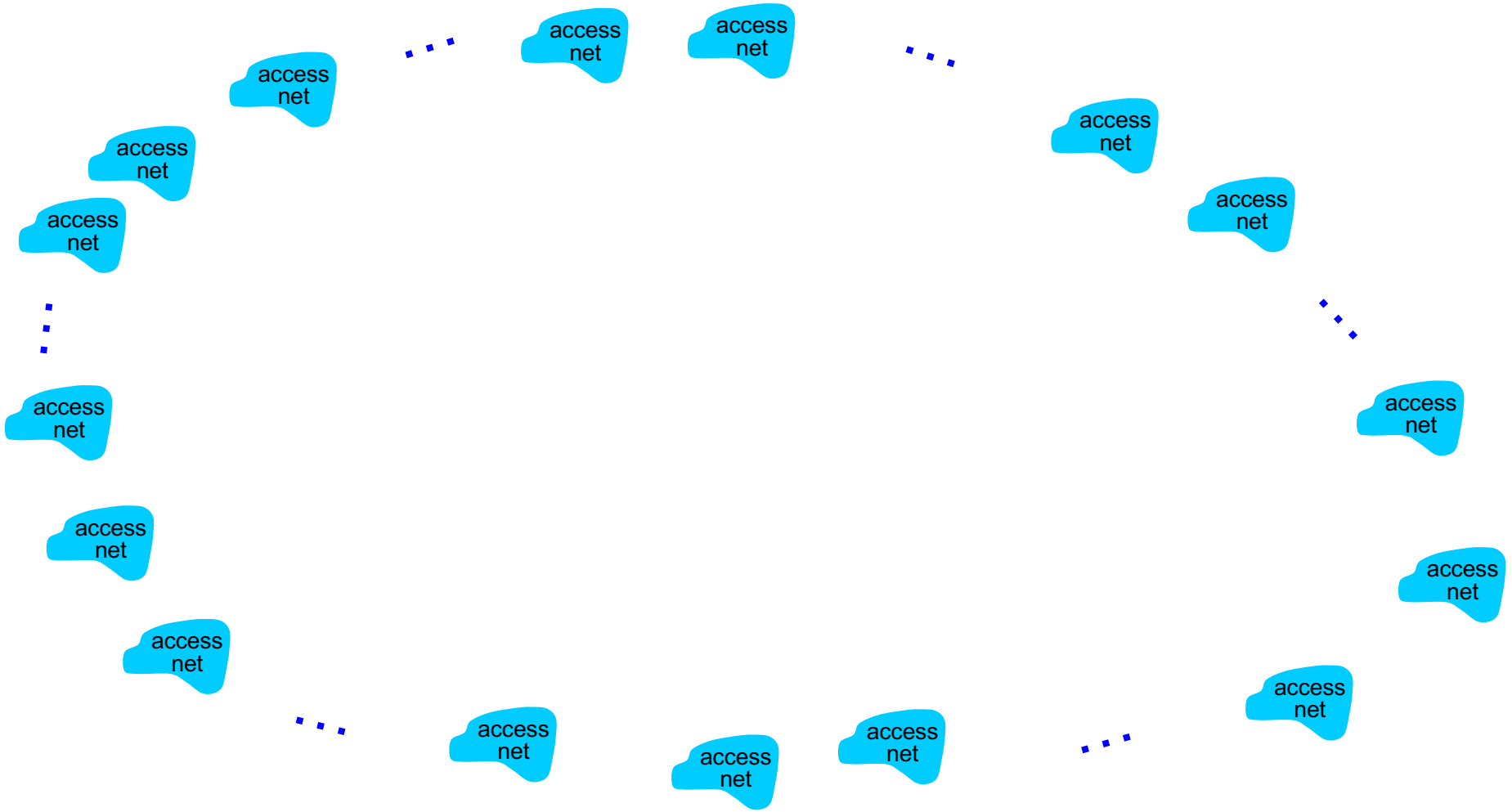


# Internet structure: network of networks

- End systems connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs
- Access ISPs in turn must be interconnected.
  - So that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies
- Let's take a stepwise approach to describe current Internet structure

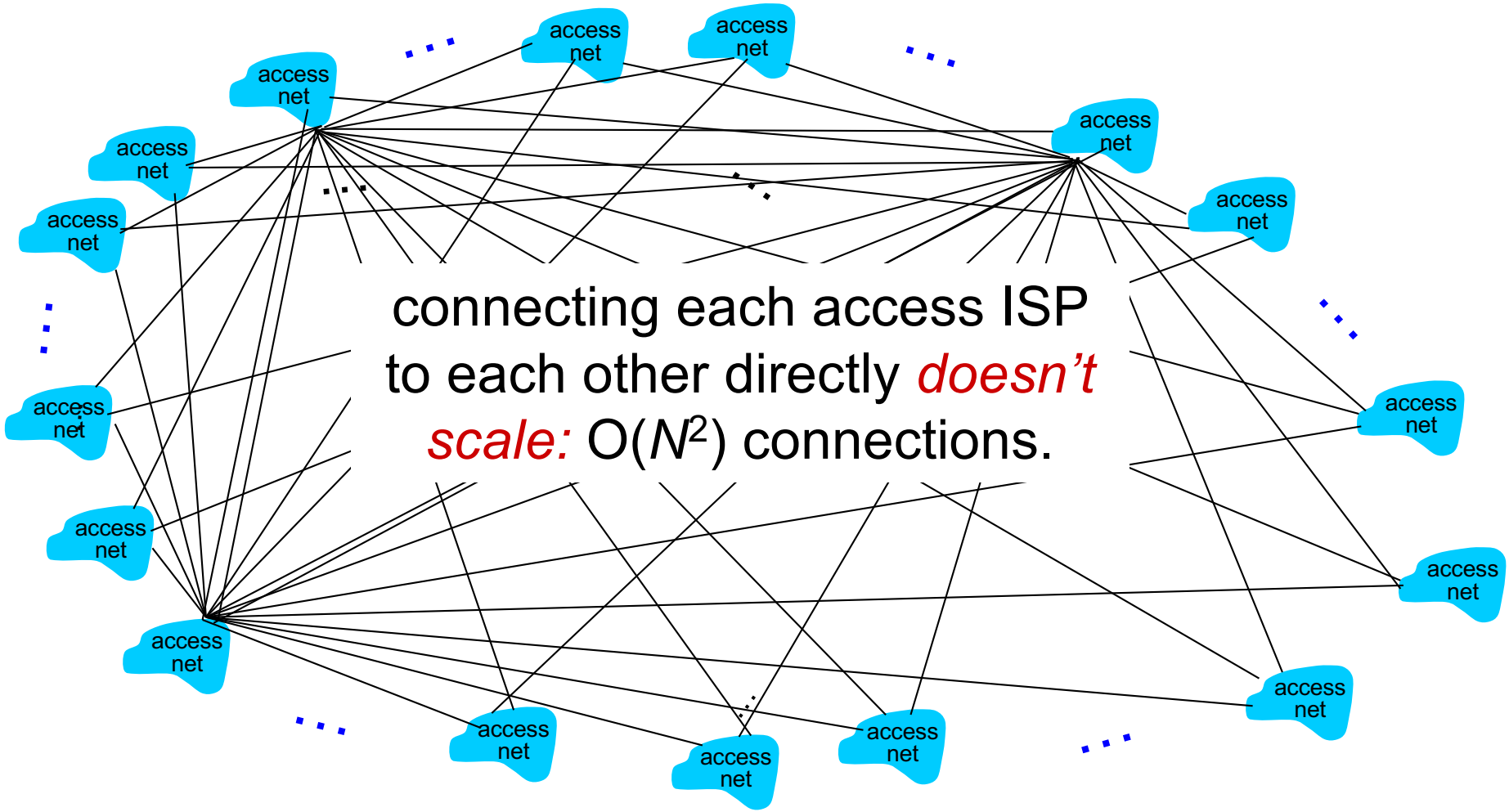
# Internet structure: network of networks

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



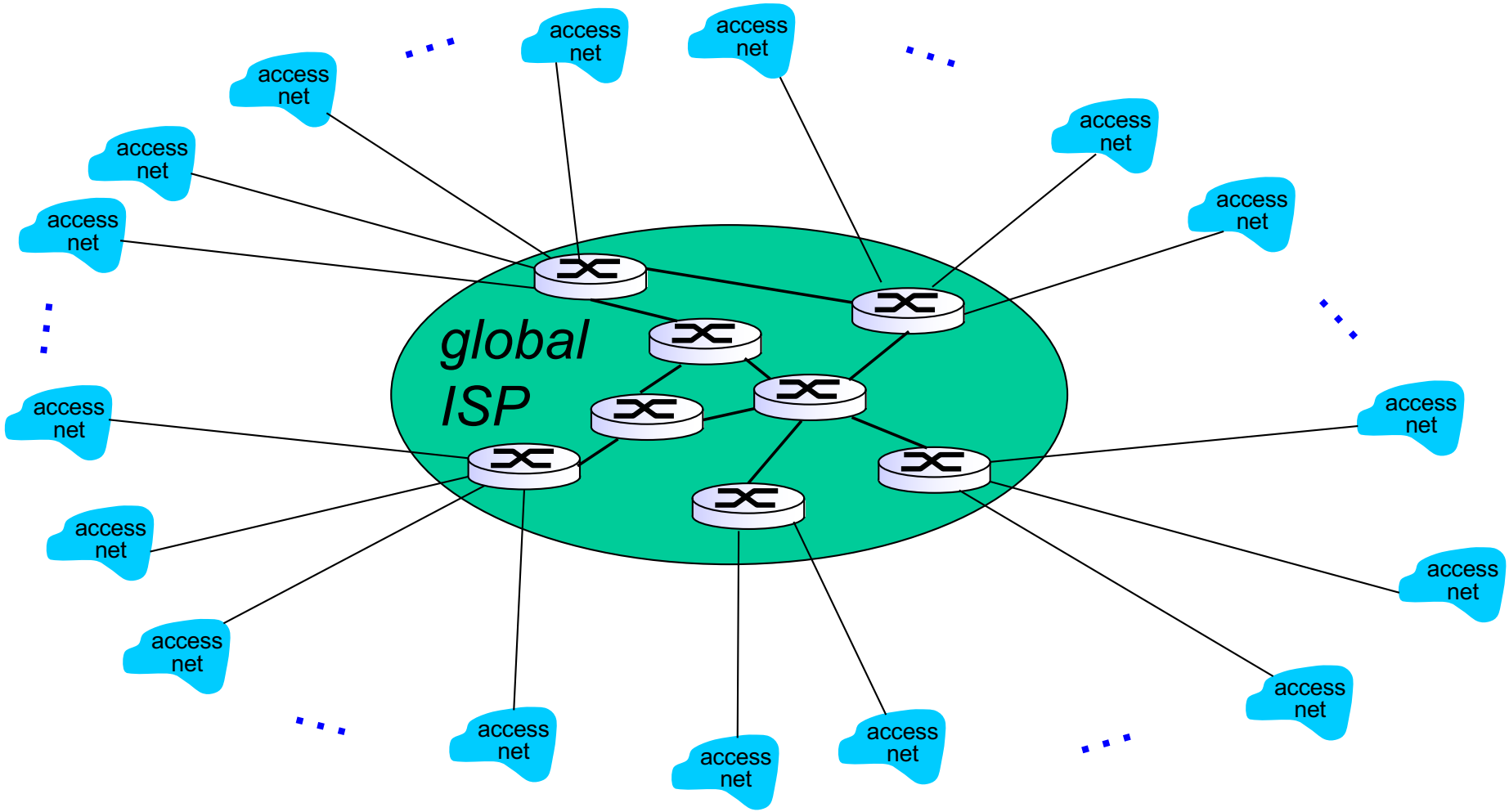
# Internet structure: network of networks

*Option: connect each access ISP to every other access ISP?*



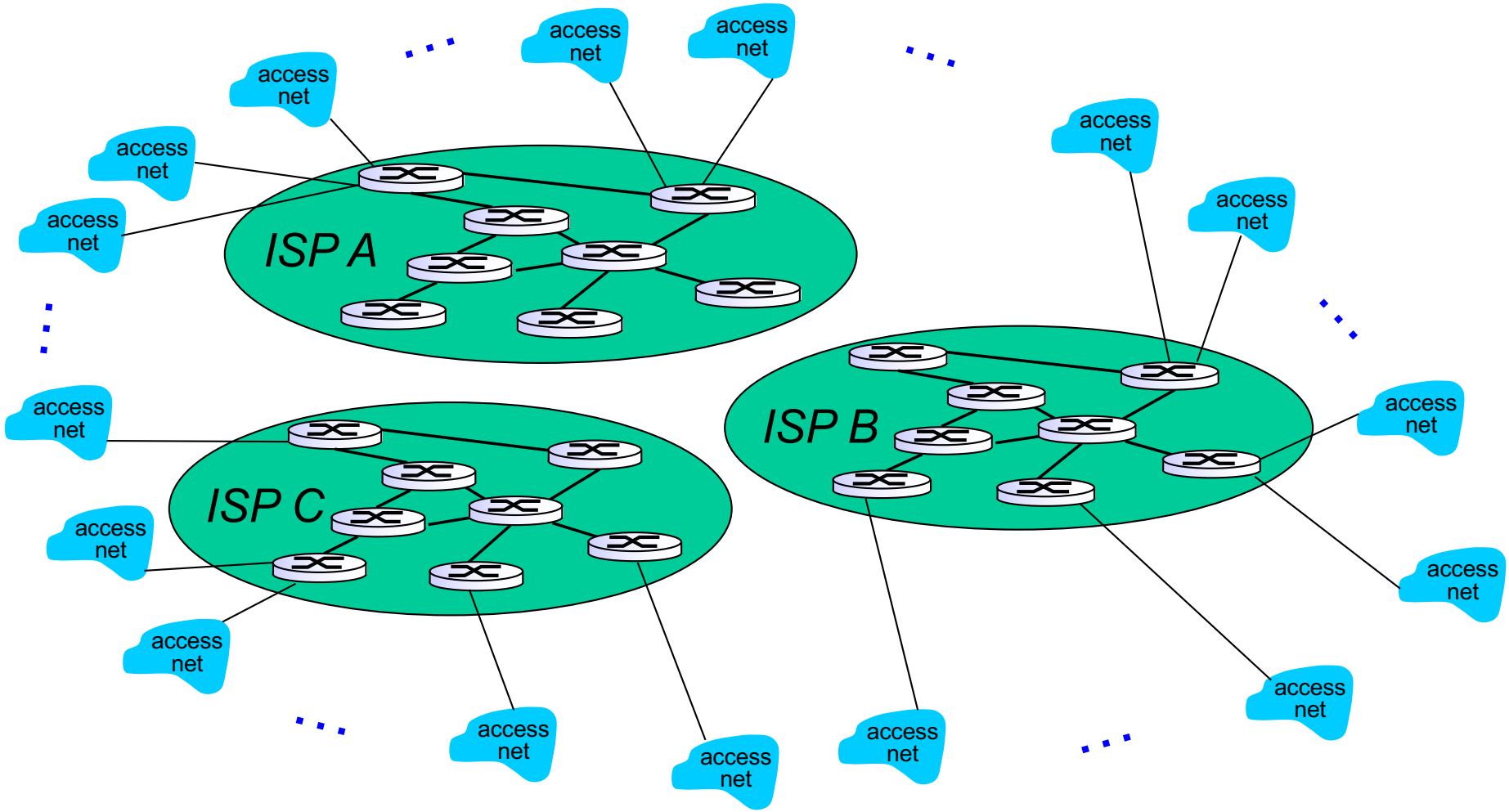
# Internet structure: network of networks

*Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.*



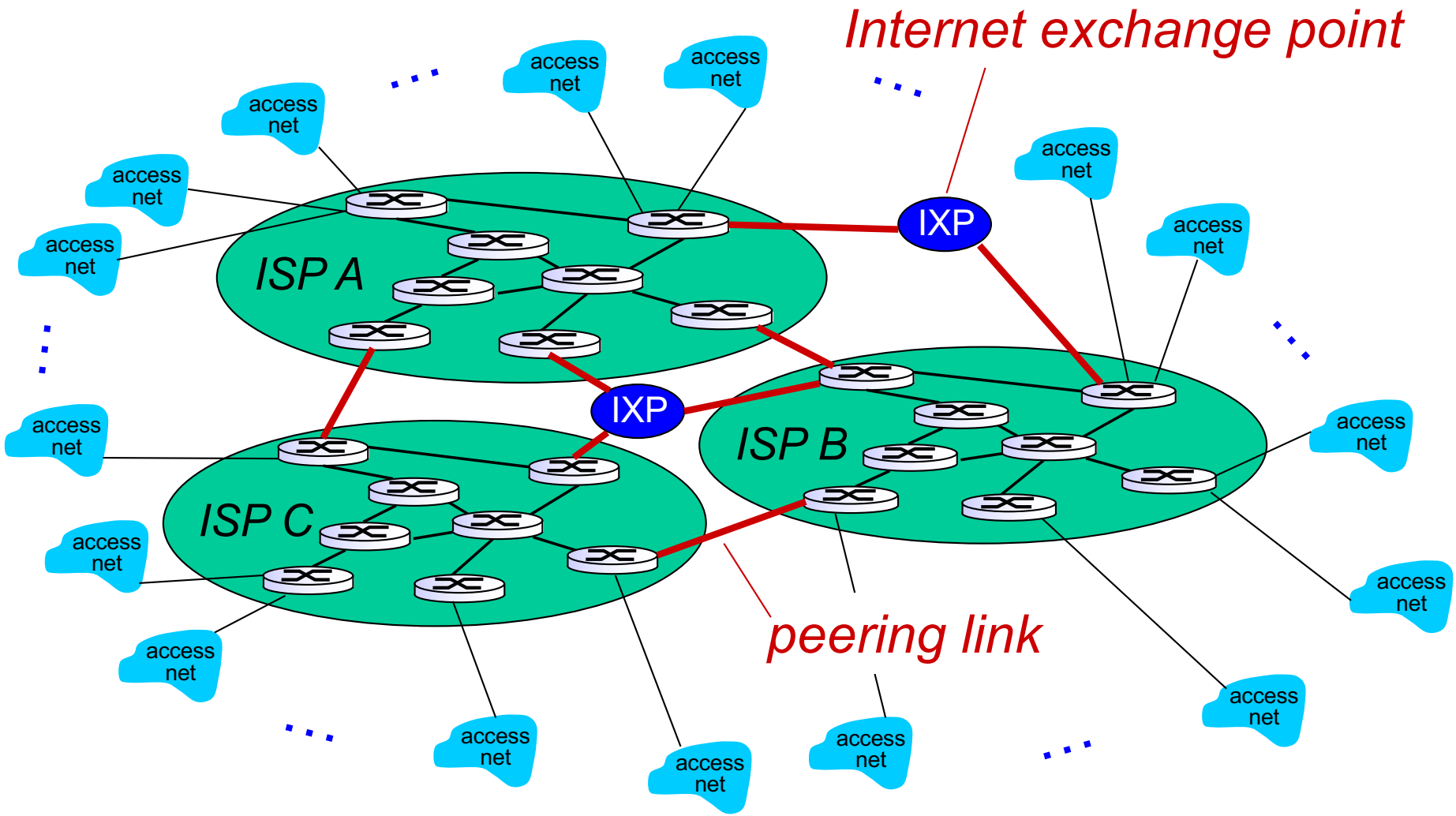
# Internet structure: network of networks

But if one global ISP is viable business, there will be competitors ….



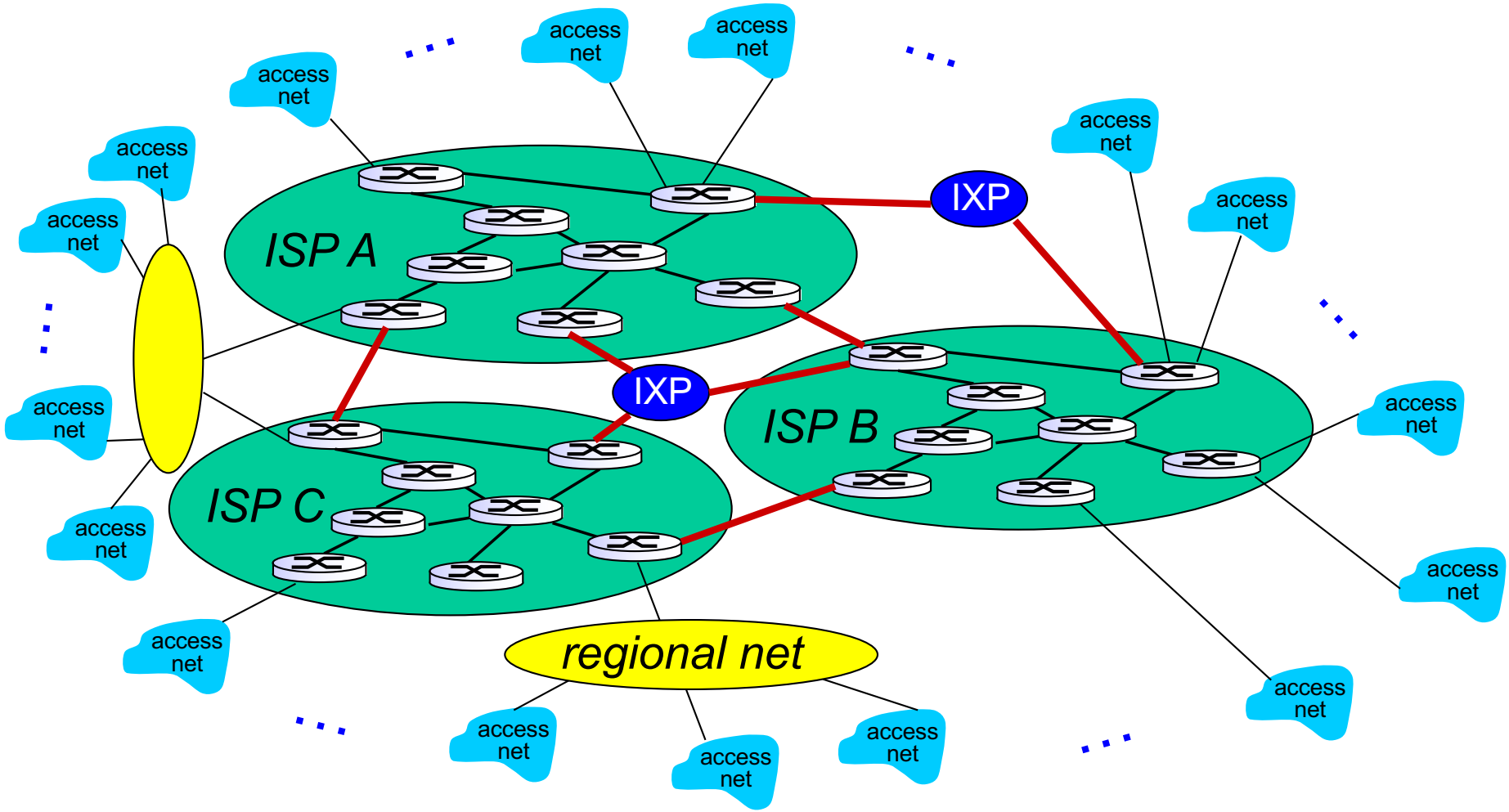
# Internet structure: network of networks

But if one global ISP is viable business, there will be competitors …. which must be interconnected



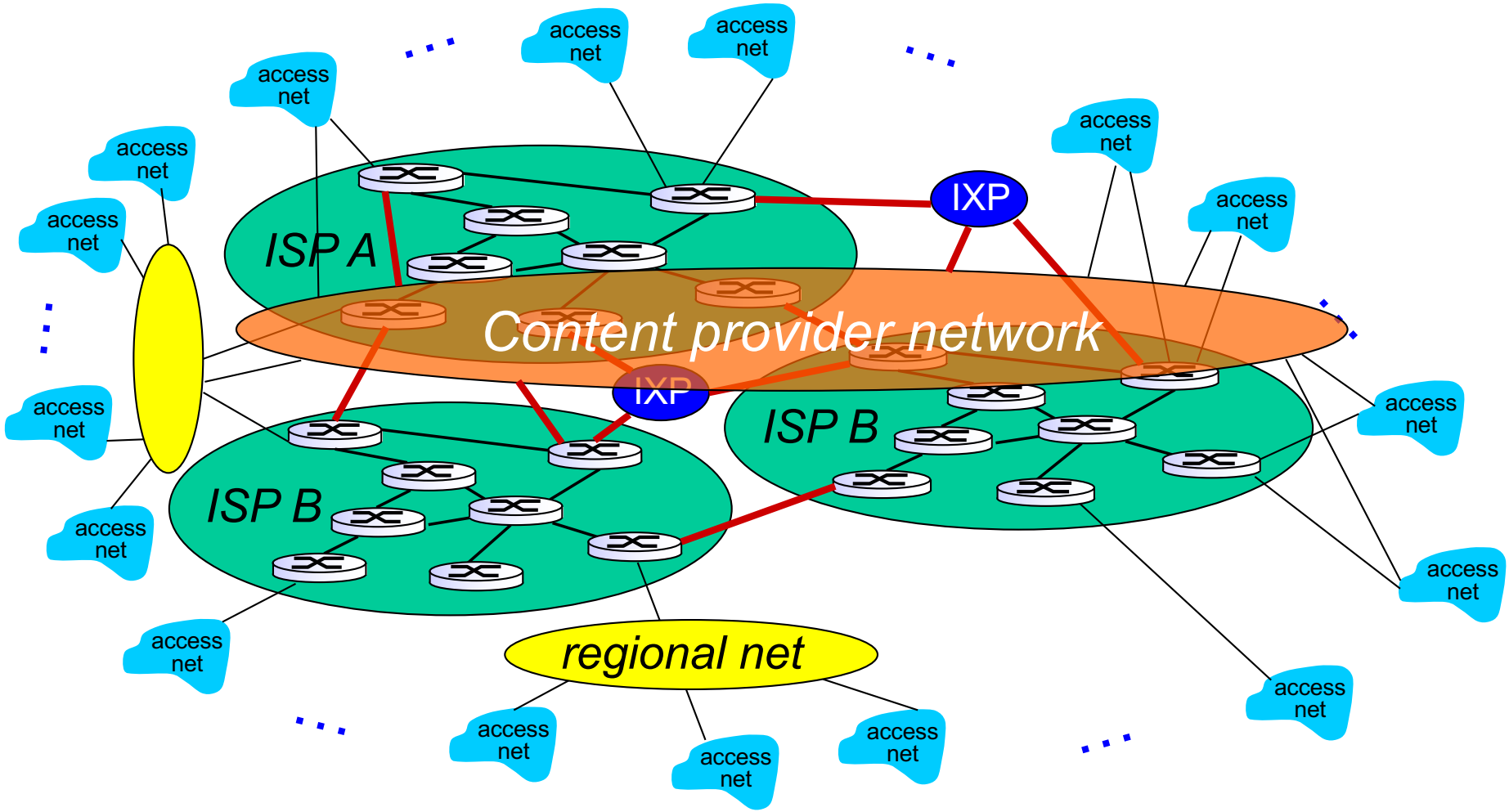
# Internet structure: network of networks

… and regional networks may arise to connect access nets to ISPS

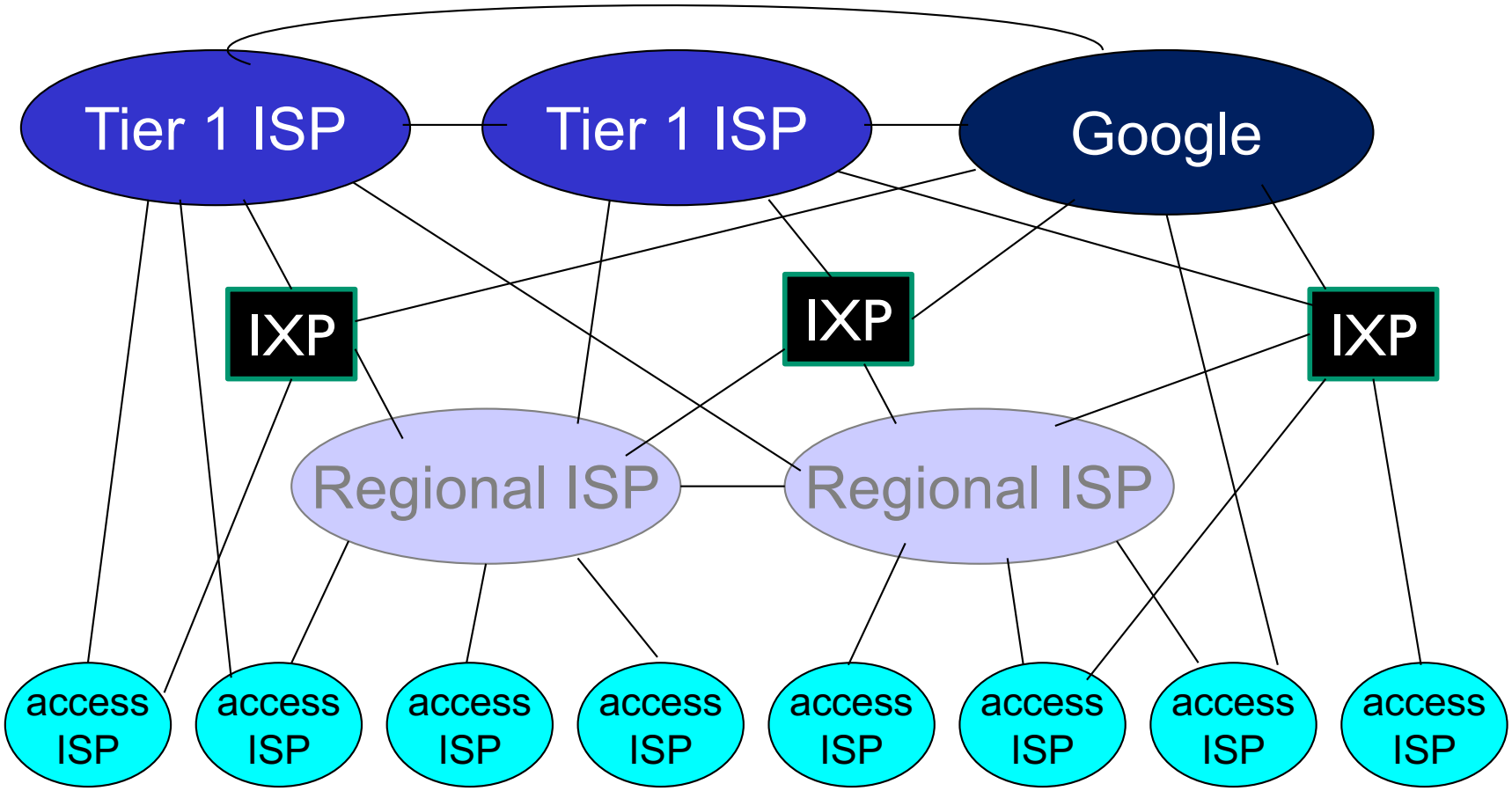


# Internet structure: network of networks

… and content provider networks (e.g., Google, Microsoft, Akamai ) may run their own network, to bring services, content close to end users

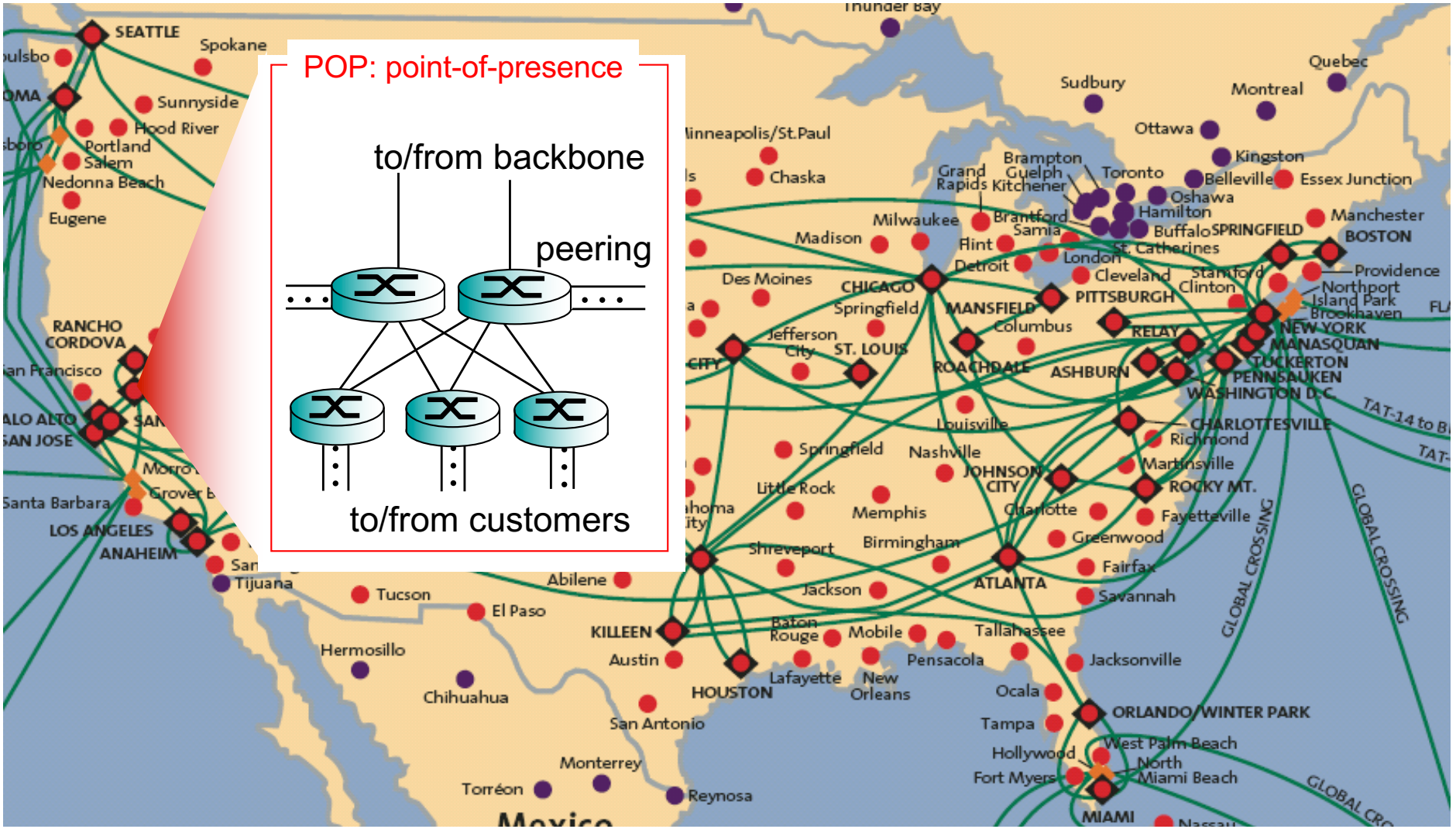


# Internet structure: network of networks



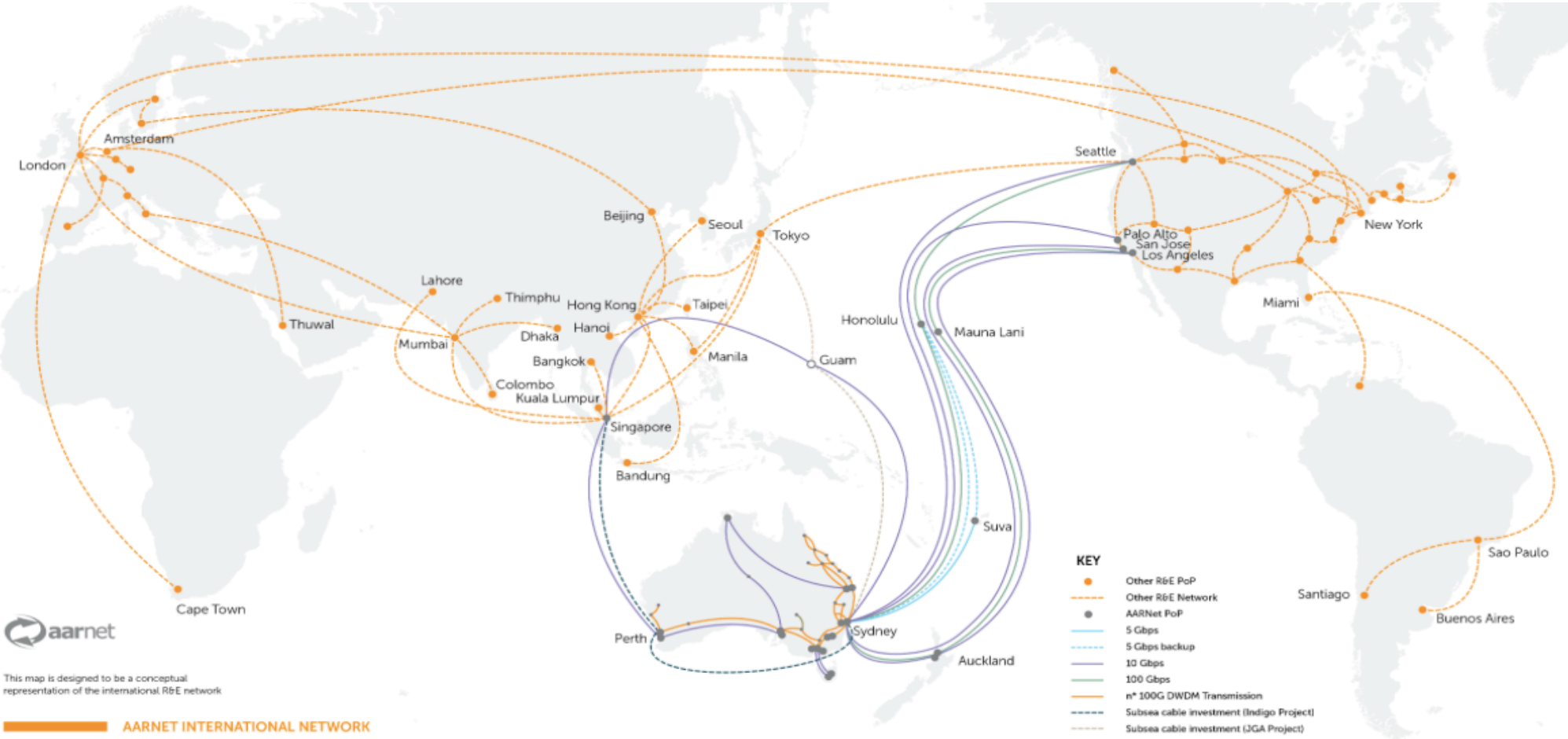

- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT, Orange, Deutsche Telekom), national & international coverage
  - content provider network (e.g., Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

# Tier-1 ISP: e.g., Sprint



# AARNET: Australia's Academic and Research Network

- https://www.aarnet.edu.au
- https://www.submarinecablemap.com



# What's a protocol?

*human protocols:*

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

… specific msgs sent

… specific actions taken when msgs received, or other events

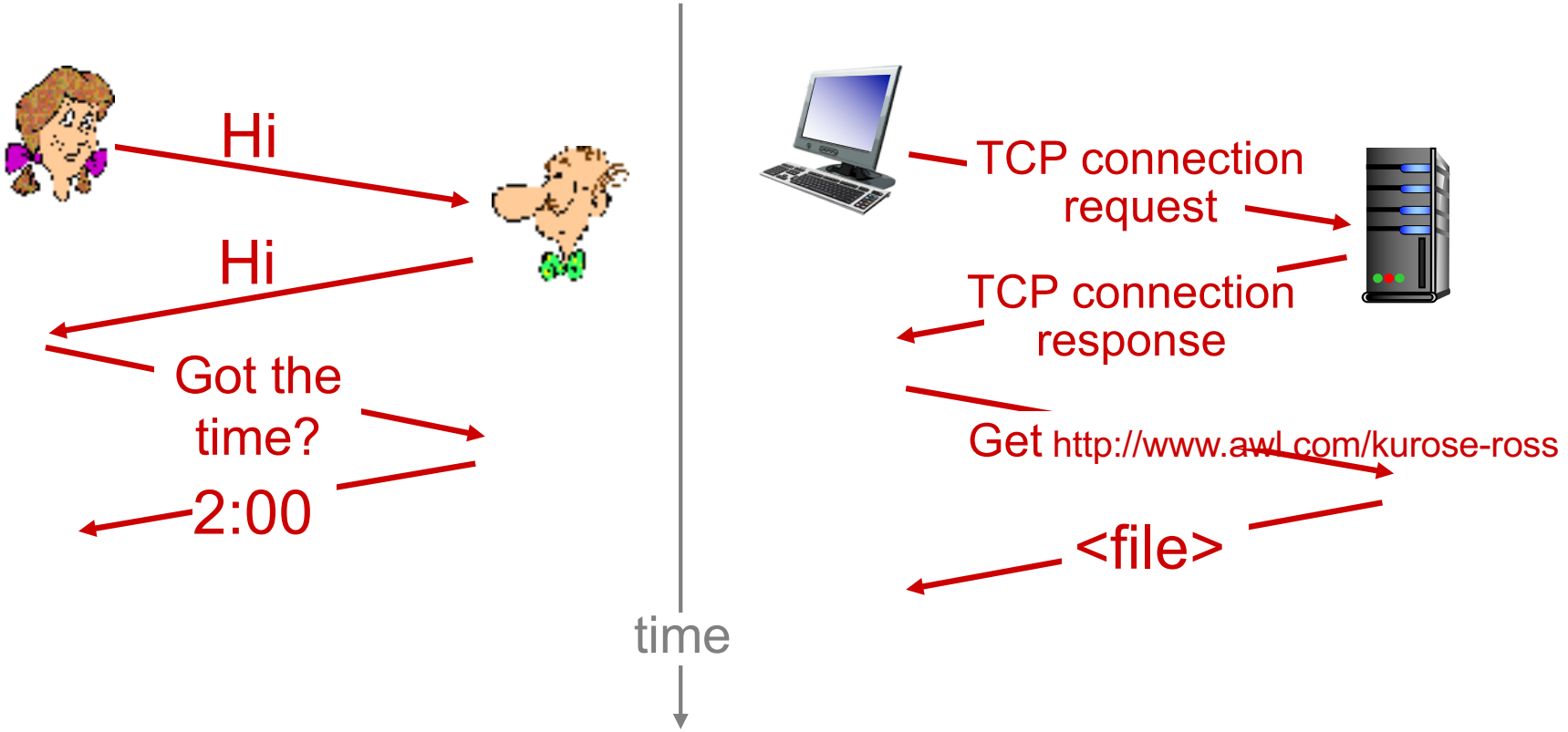
*network protocols:*

- machines rather than humans
- 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?

a human protocol and a computer network protocol:




*Q:* other human protocols?

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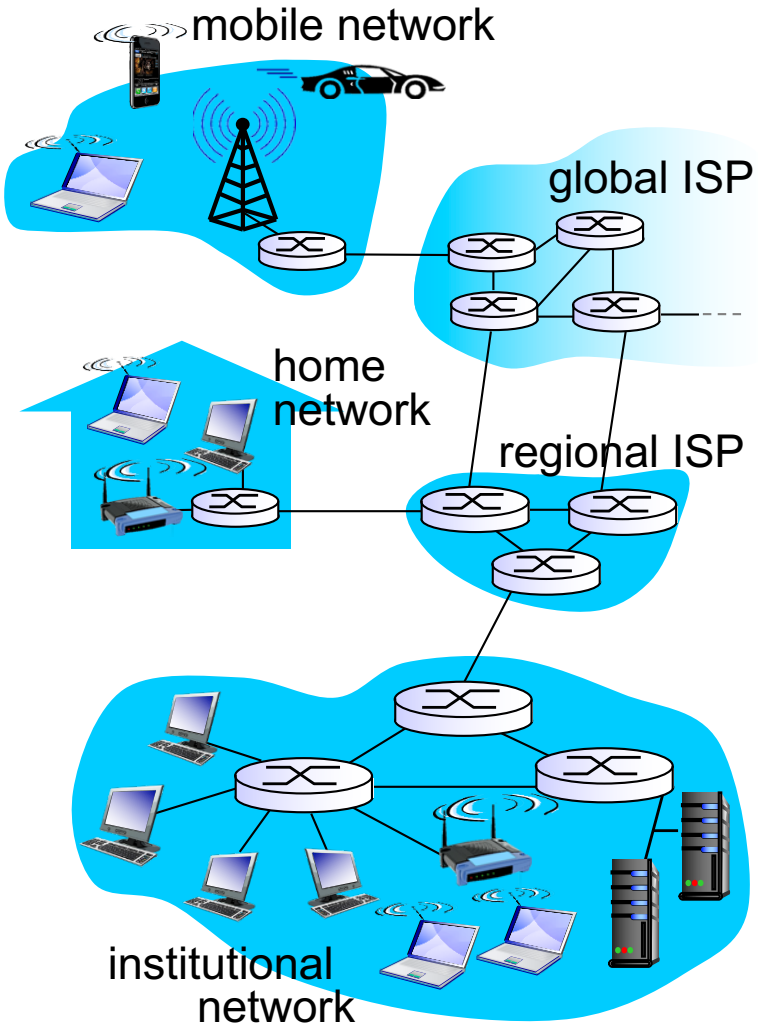
Self study

# A closer look at network structure:

- *network edge:*
  - hosts: clients and servers
  - servers often in data centers
- *access networks, physical media:* wired, wireless communication links
- *network core:*
  - interconnected routers
  - network of networks



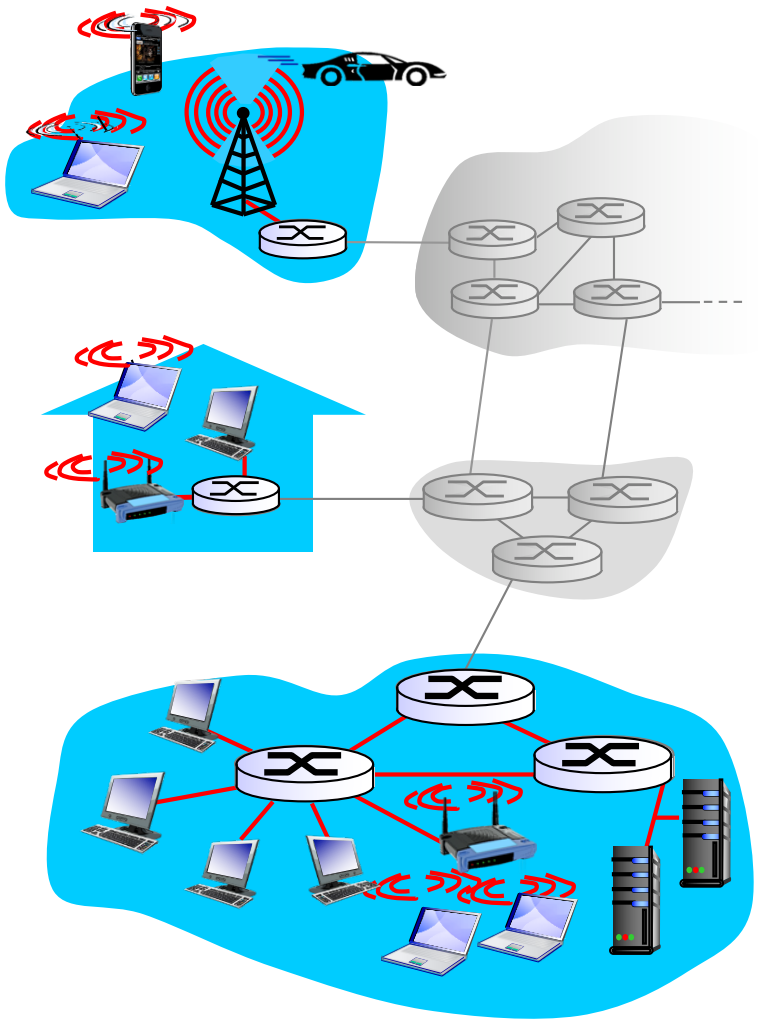
# Access networks and physical media

*Q: How to connect end systems to edge router?*

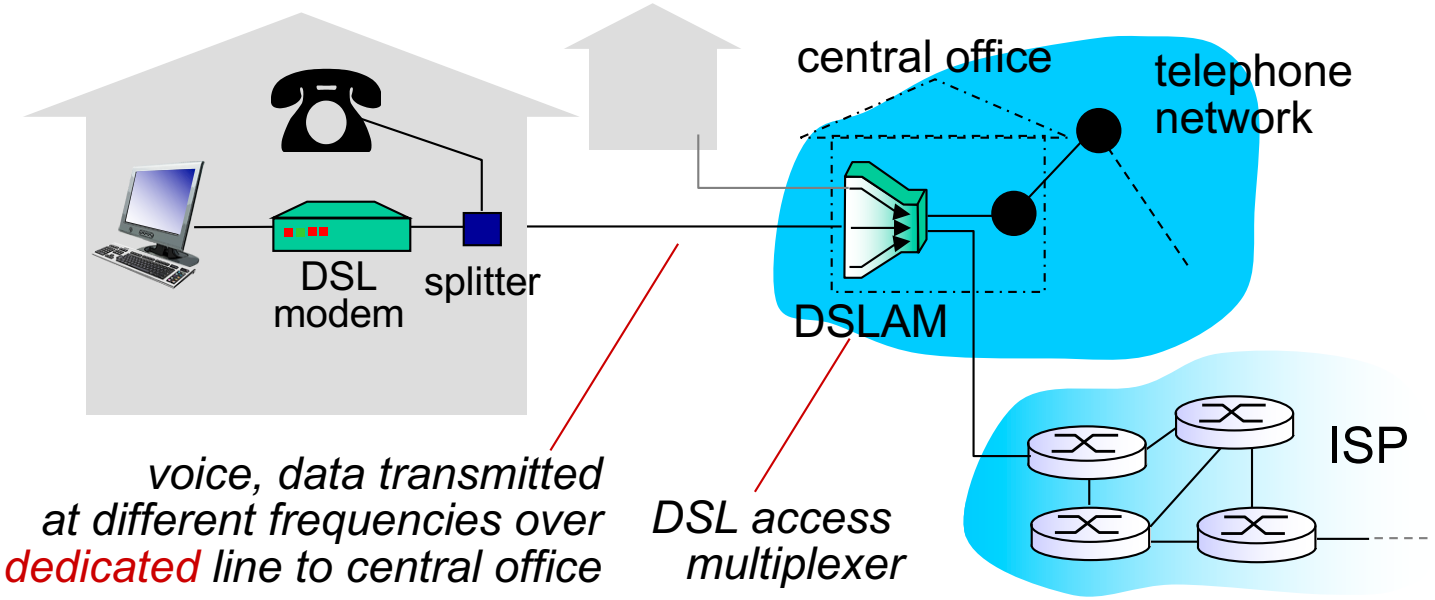
- residential access nets
- institutional access networks (school, company)
- mobile access networks

*keep in mind:*

- bandwidth (bits per second) of access network?
- shared or dedicated?

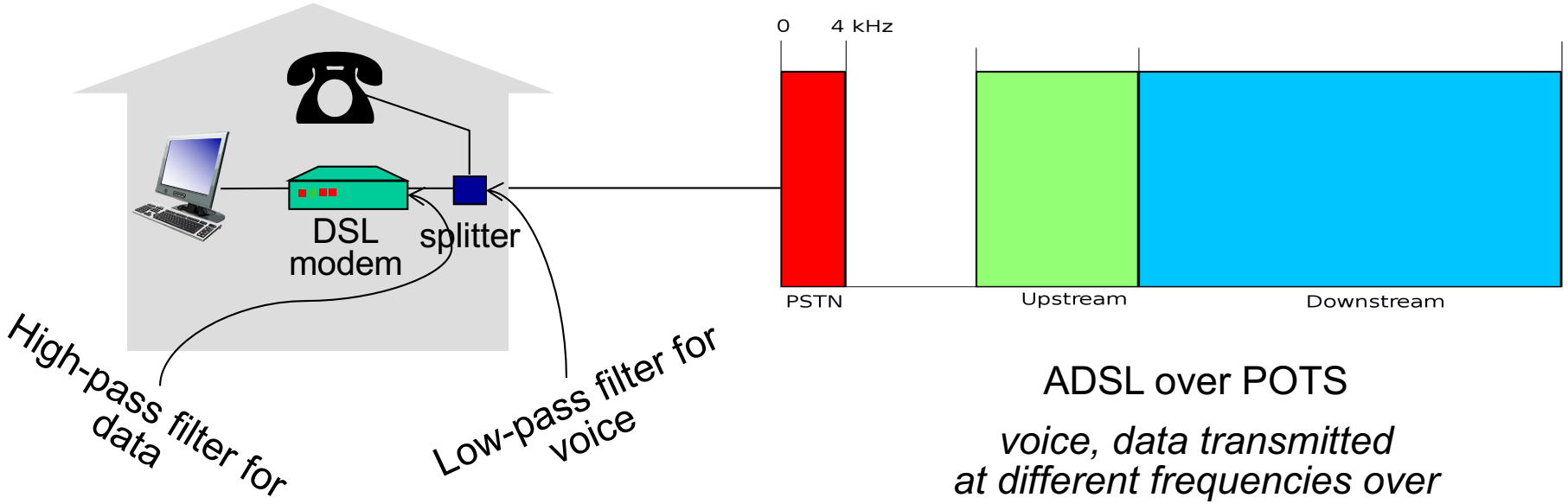


# Access net: digital subscriber line (DSL)




- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

# Access net: digital subscriber line (DSL)

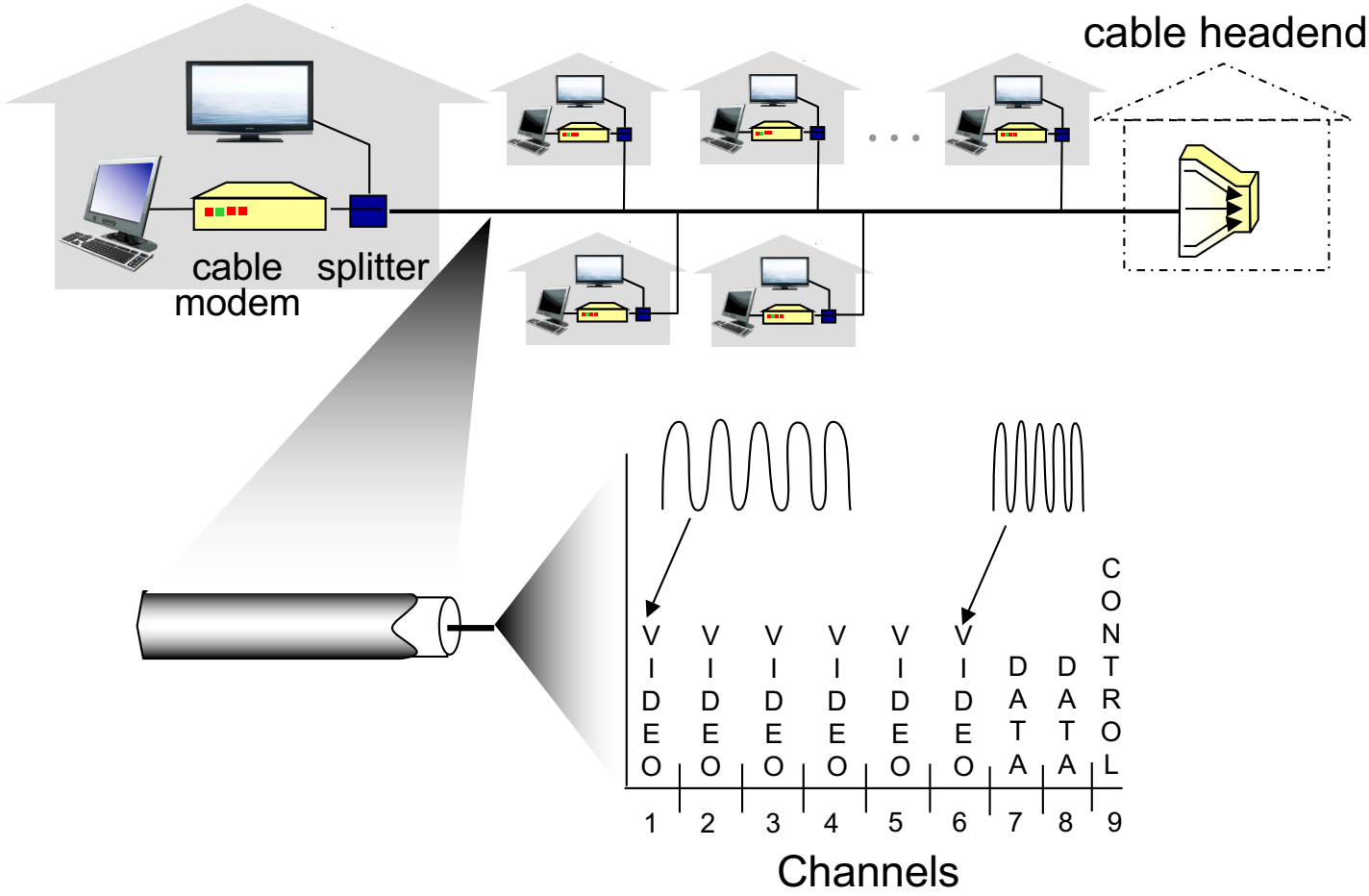



ADSL over POTS

*voice, data transmitted at different frequencies over dedicated line to central office*

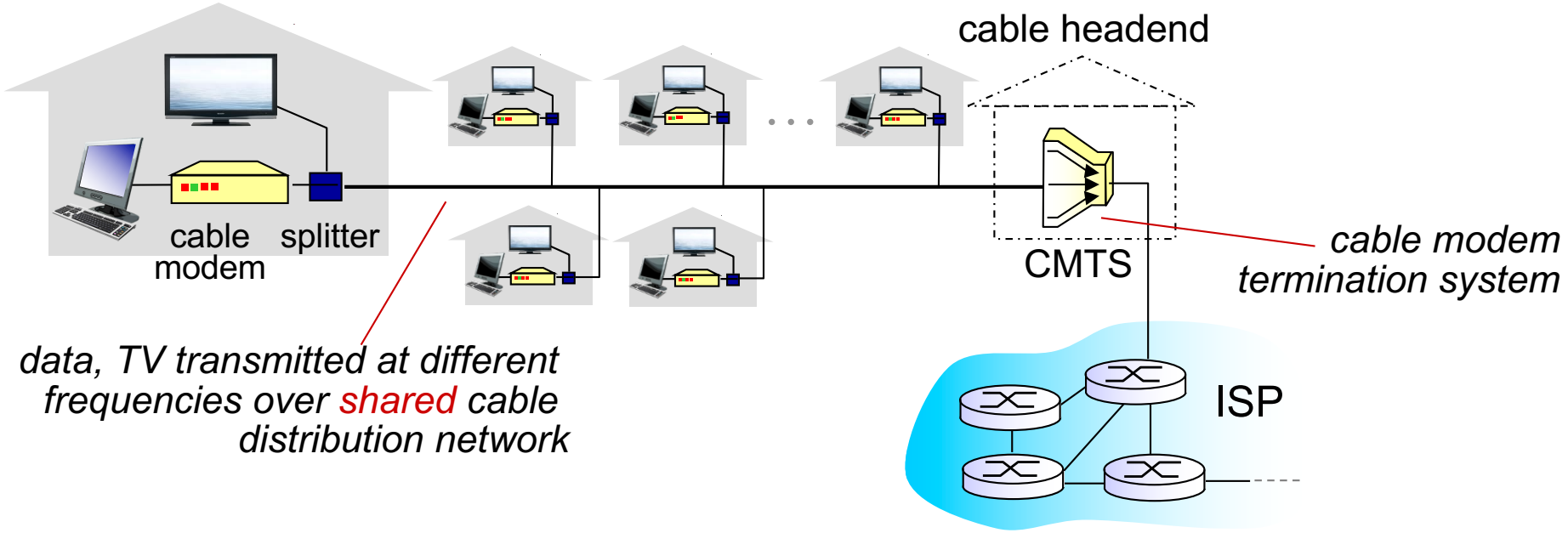
- Different data rates for upload and download (ADSL)
  - < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
  - < 24 Mbps downstream transmission rate (typically < 10 Mbps)

# Access net: cable network




*frequency division multiplexing:* different channels transmitted in different frequency bands

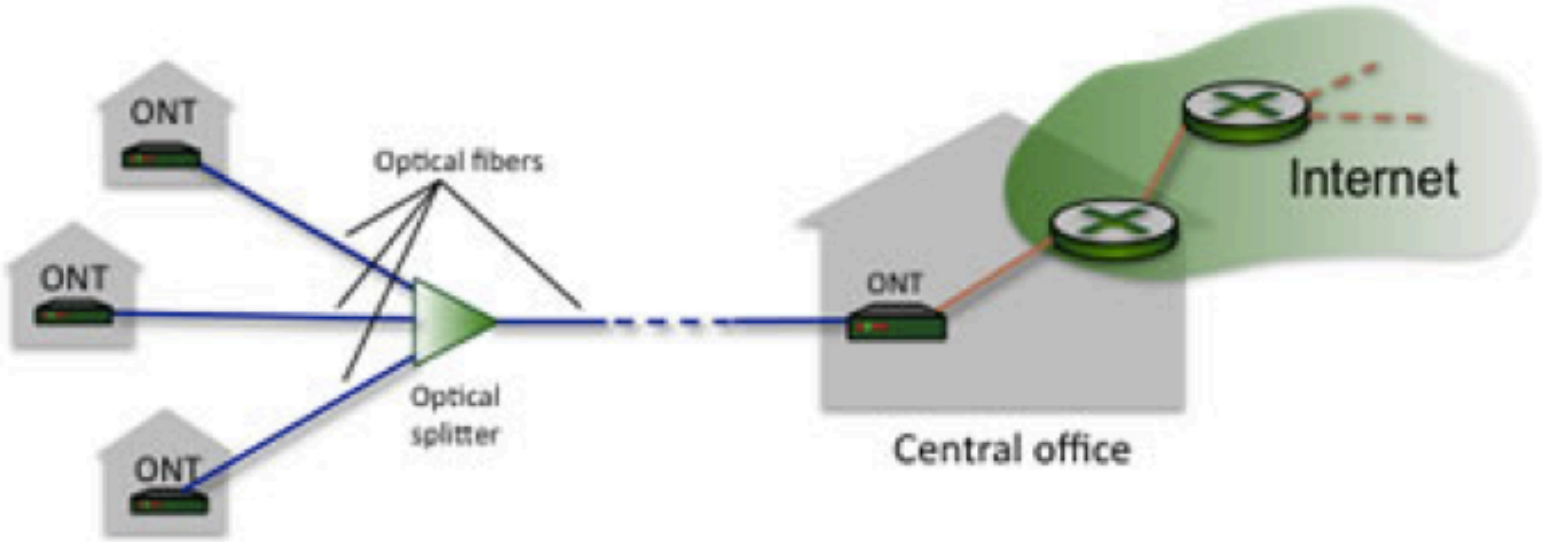
# Access net: cable network



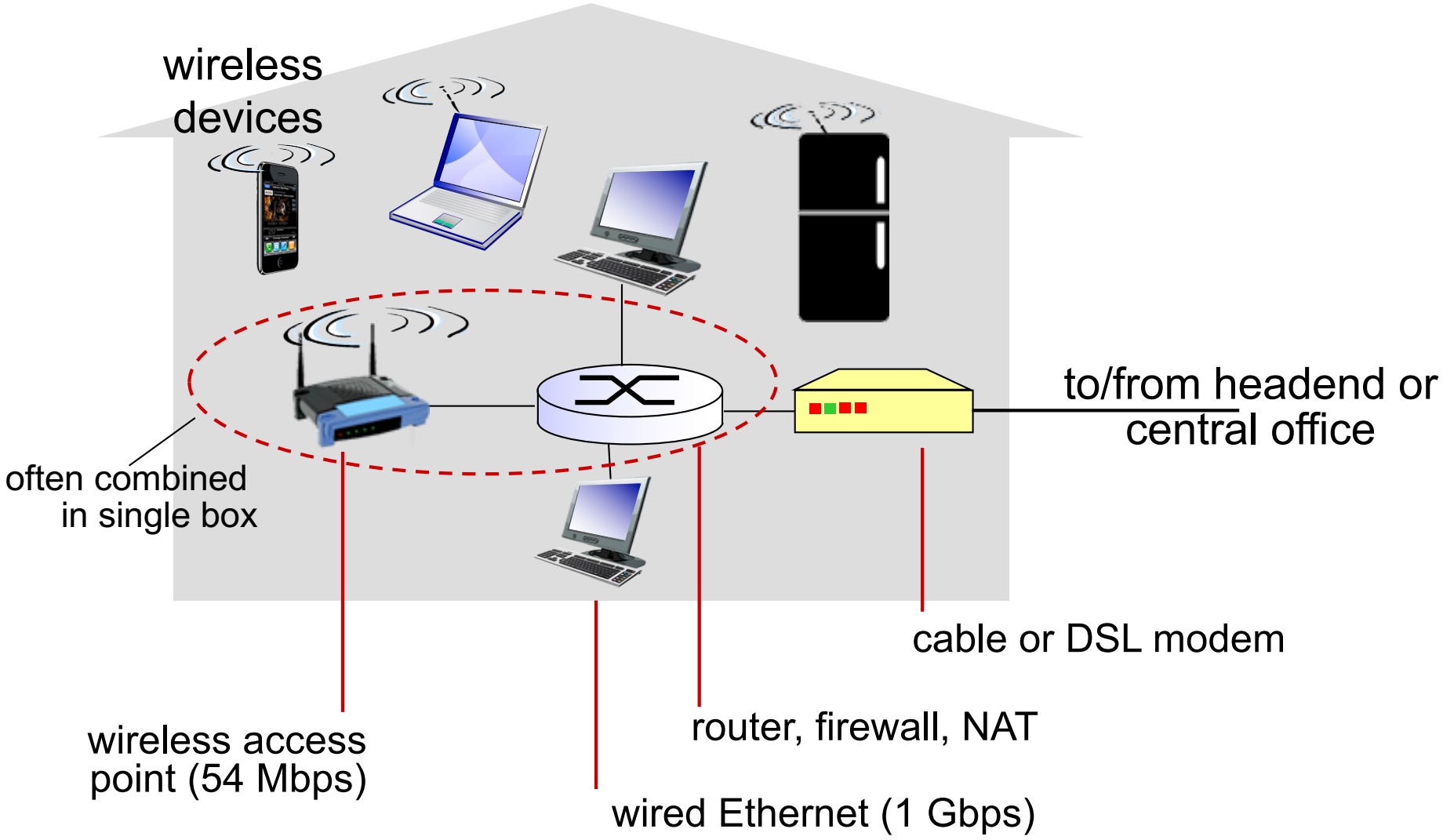

- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend
  - unlike DSL, which has dedicated access to central office

# Fiber to the home (FTTH)

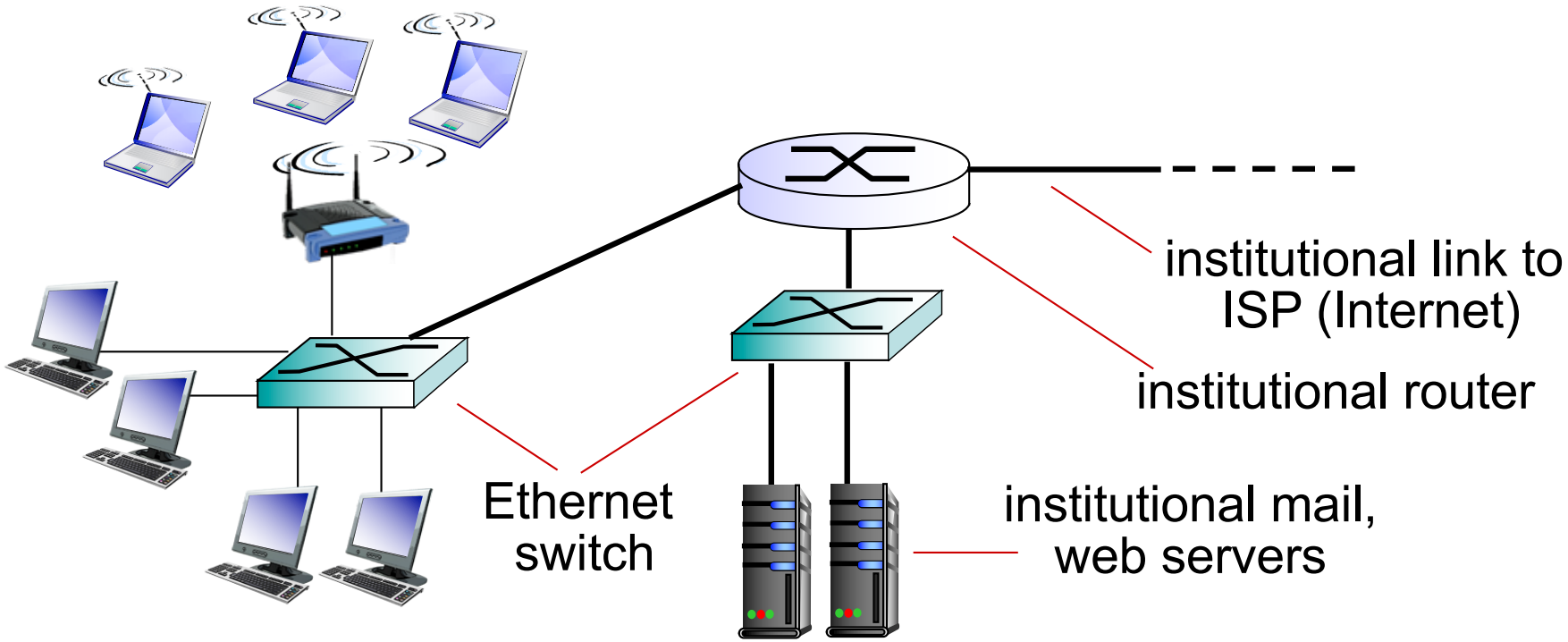
- Fully optical fiber path all the way to the home
  - e.g., Verizon FIOS, Google, NBN
  - ~30 Mbps to 1Gbps
- Active (like switched Ethernet) or passive optical



# Access net: home network



# Enterprise access networks (Ethernet)



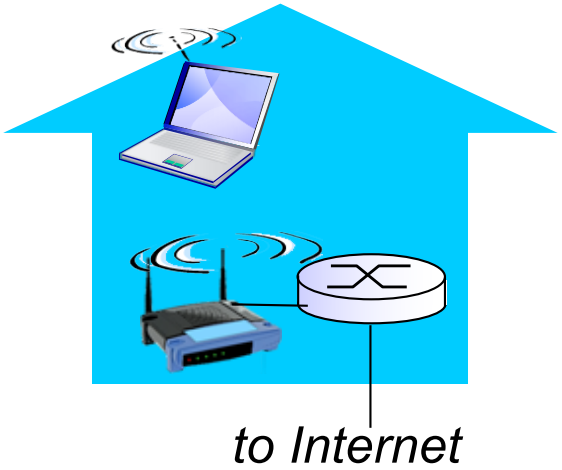

- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

# Wireless access networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"

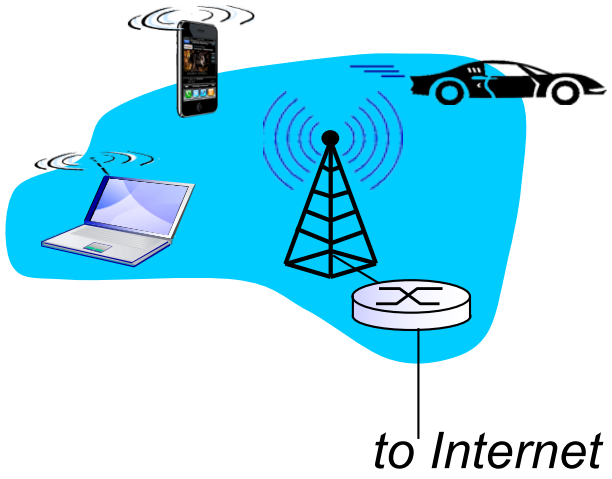
*wireless LANs:*

- within building (100 ft)
- 802.11b/g/n (WiFi): 11, 54, 300 Mbps transmission rate
- 802.11ac: 1 Gpbs(2.4GHz) + 4.34Gbps (5GHz)



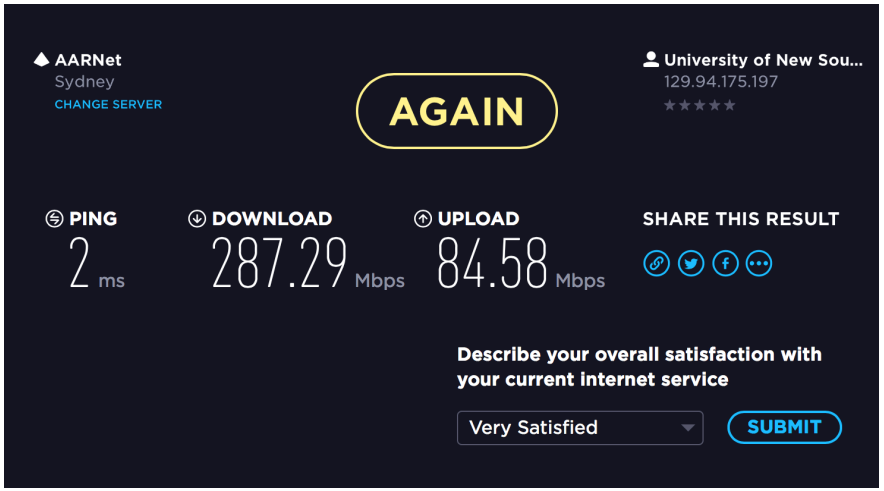

wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE



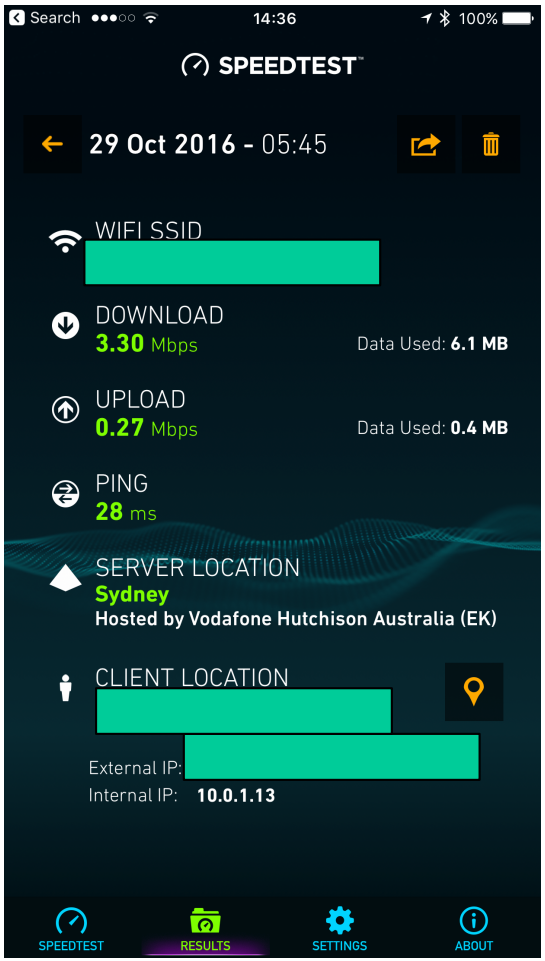
# Sample results

Wired Network at CSE

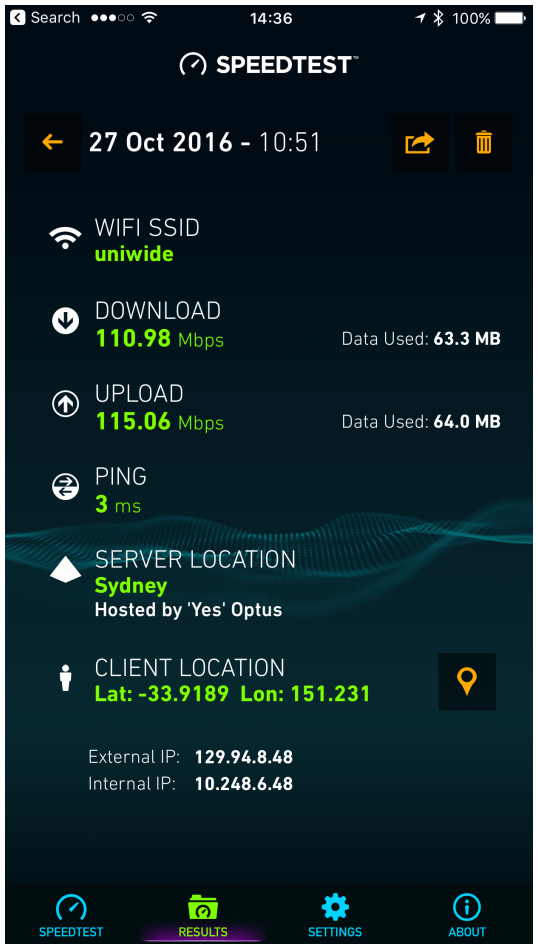


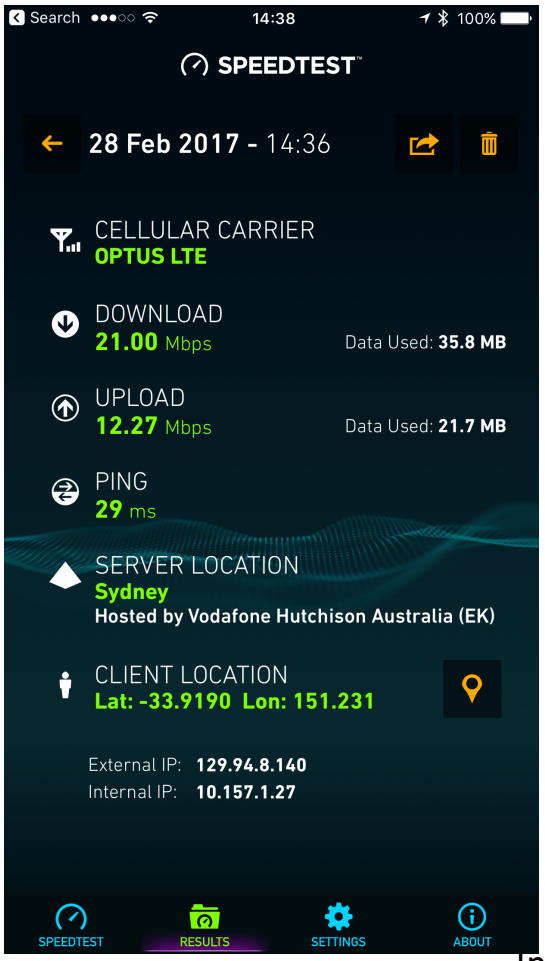

## Can you explain the differences?

Home wireless




Uniwide




4G Network

# Physical media

Self Study

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

# Physical media: twisted pair, coax, fiber

Self Study

*twisted pair (TP)*

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gpbs Ethernet
  - Category 6: 10Gbps

*coaxial cable:*

- two concentric copper conductors
- 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 Gpbs transmission rate)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise

# Physical media: radio

Self Study

- signal carried in electromagnetic spectrum, i.e., no physical "wire"
- 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, 450 Mbps, Gbps
- wide-area (e.g., cellular)
  - 4G cellular: ~ 10 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low earth-orbiting (LEO)

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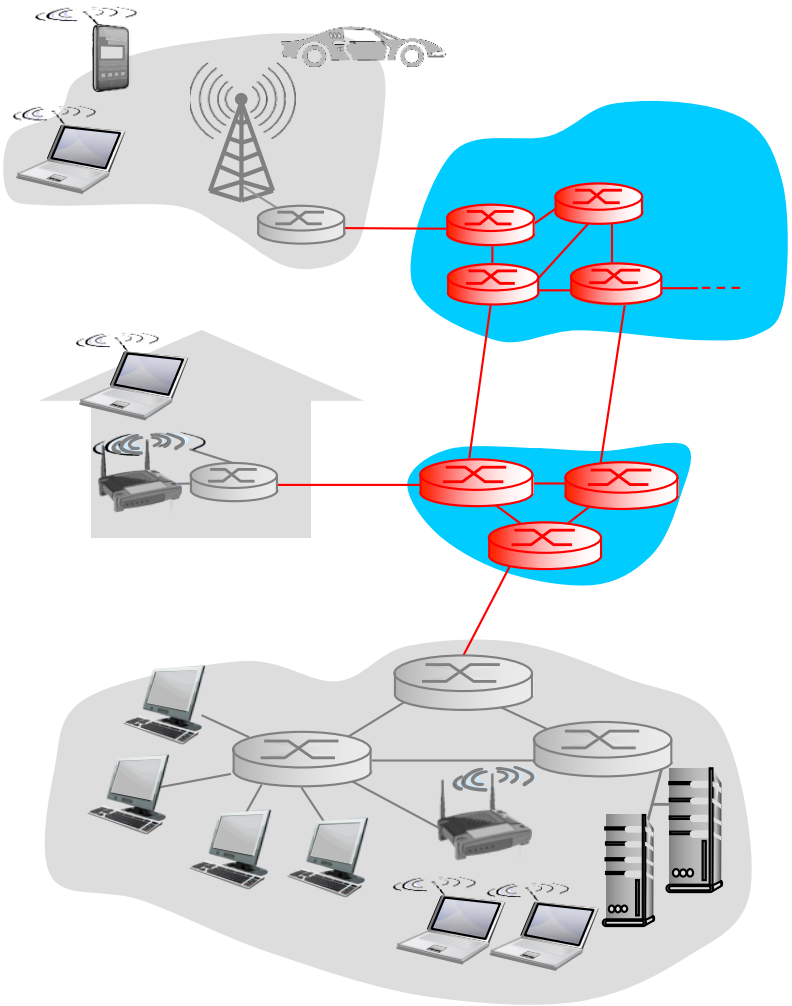
Self study

# The network core

- mesh of interconnected routers/switches
- Two forms of switched networks:
  - Circuit switching: used in the legacy telephone networks


  - Packet switching: used in the Internet

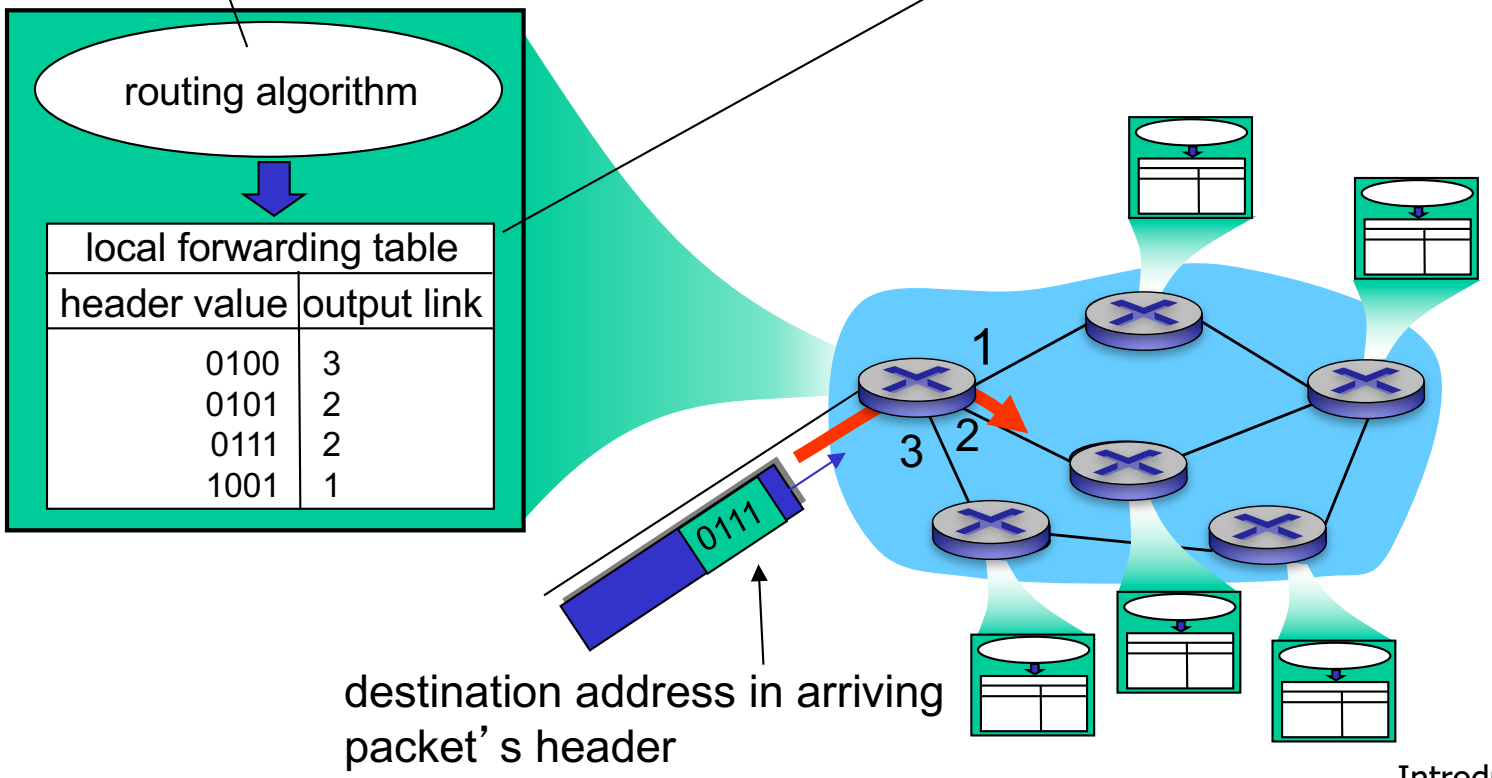


# Two key network-core functions

*routing:* determines source-destination route taken by packets

- *routing algorithms*

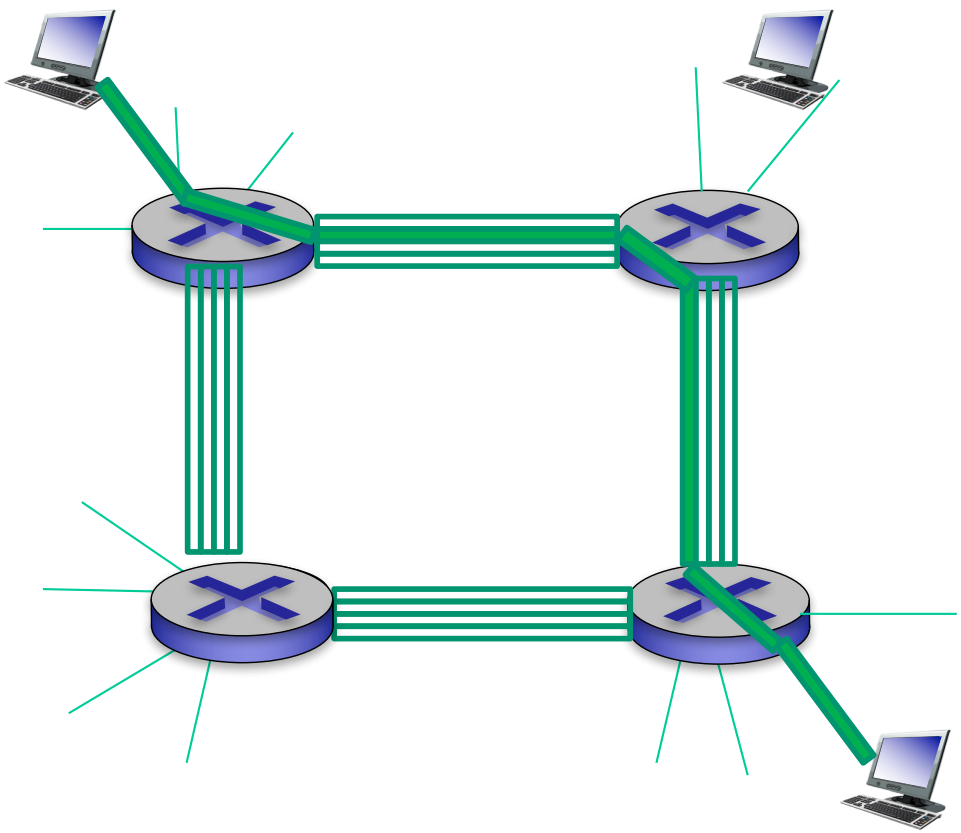
*forwarding:* move packets from router's input to appropriate router output



# Circuit Switching

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

- in diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- commonly used in traditional telephone networks

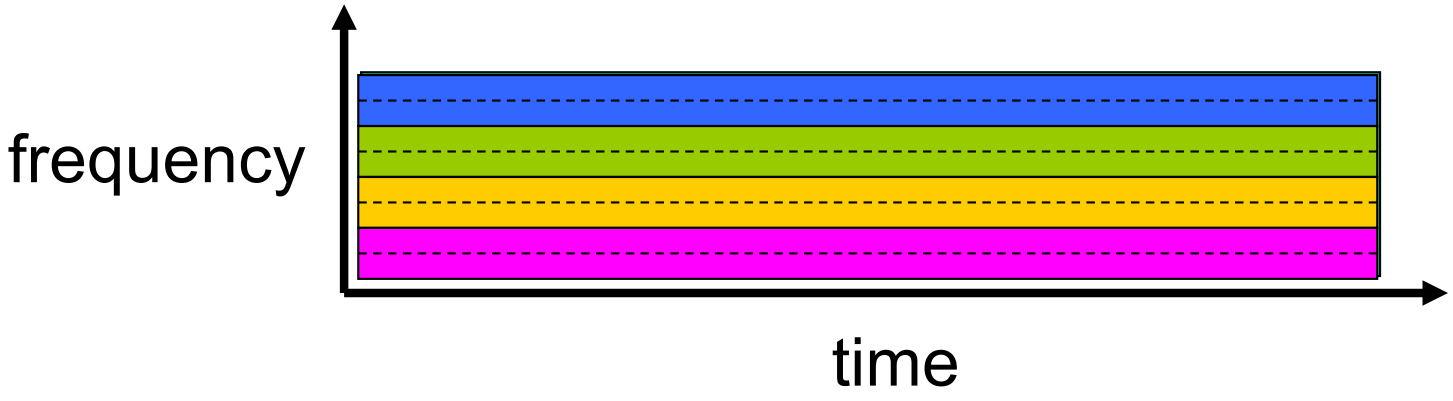


# Circuit switching: FDM versus TDM

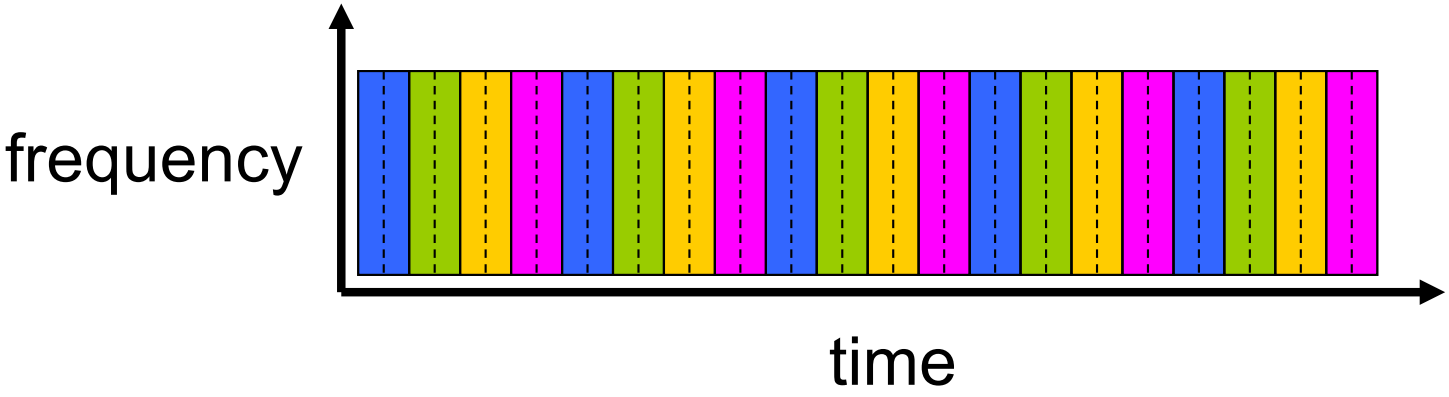
Example:

4 users

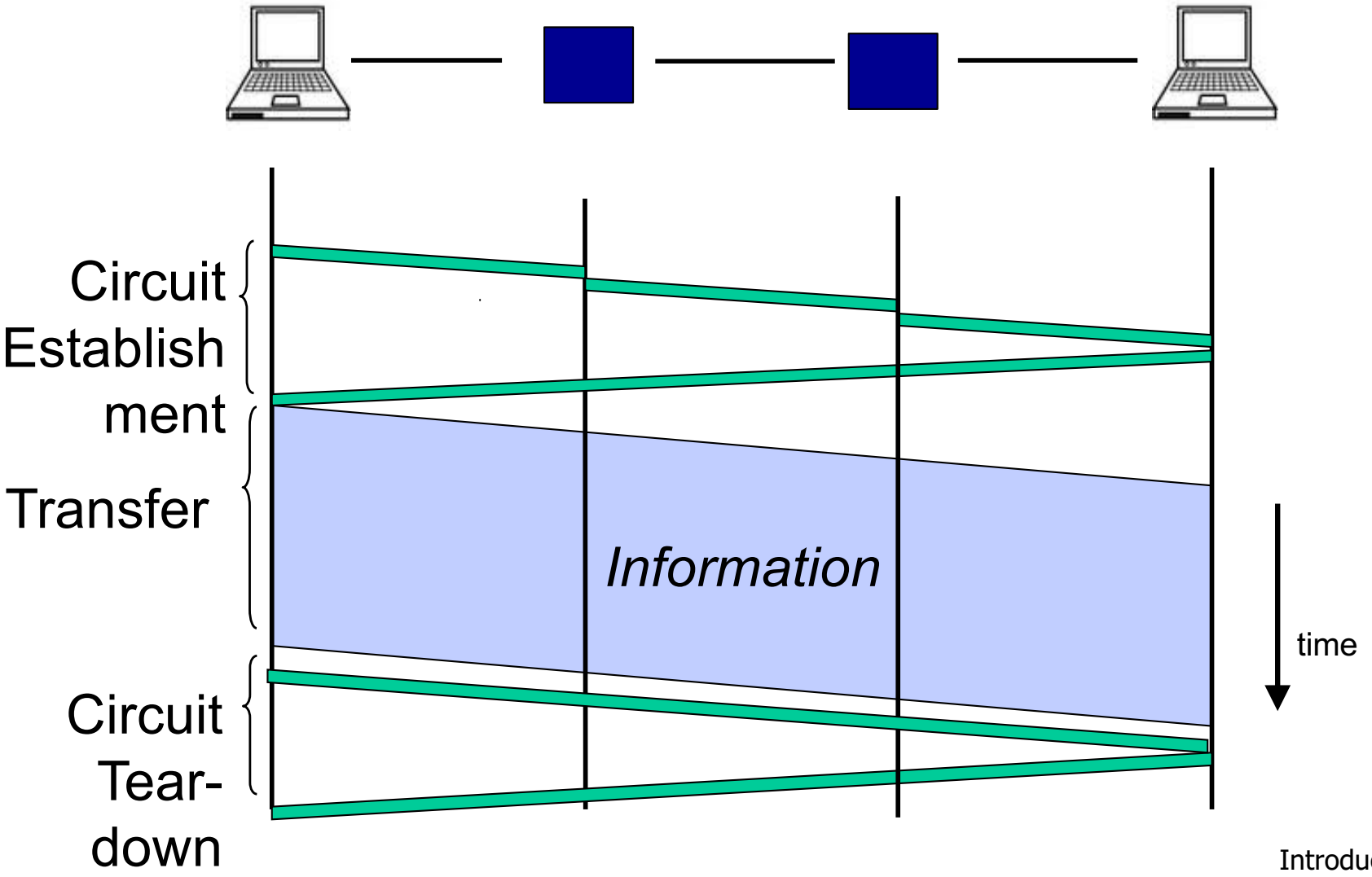
FDM




TDM



# Timing in Circuit Switching



# Quiz: What are the pros and cons of circuit switching? Let's discuss ..

- Pros:

- Cons:

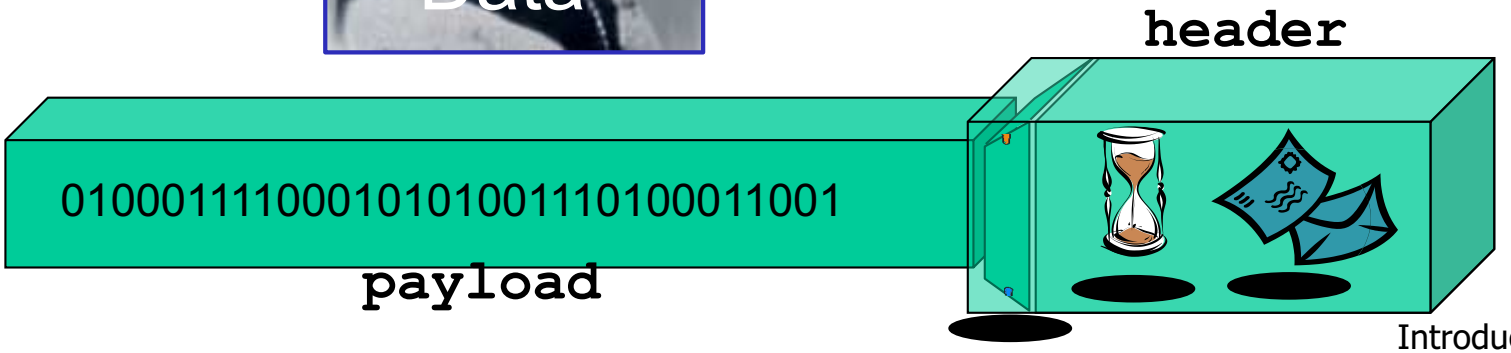
# Why circuit switching is not feasible?

- Inefficient
  - Computer communications tends to be very bursty. For example viewing a sequence of web pages
  - Dedicated circuit cannot be used or shared in periods of silence
  - Cannot adopt to network dynamics
- Fixed data rate
  - Computers communicate at very diverse rates. For example viewing a video vs using telnet or web browsing
  - Fixed data rate is not useful
- Connection state maintenance
  - Requires per communication state to be maintained that is a considerable overhead
  - Not scalabale

# Packet Switching

- Data is sent as chunks of formatted bits (Packets)
- Packets consist of a "header" and "payload"


1. Internet Address
2. Age (TTL)
3. Checksum to protect header



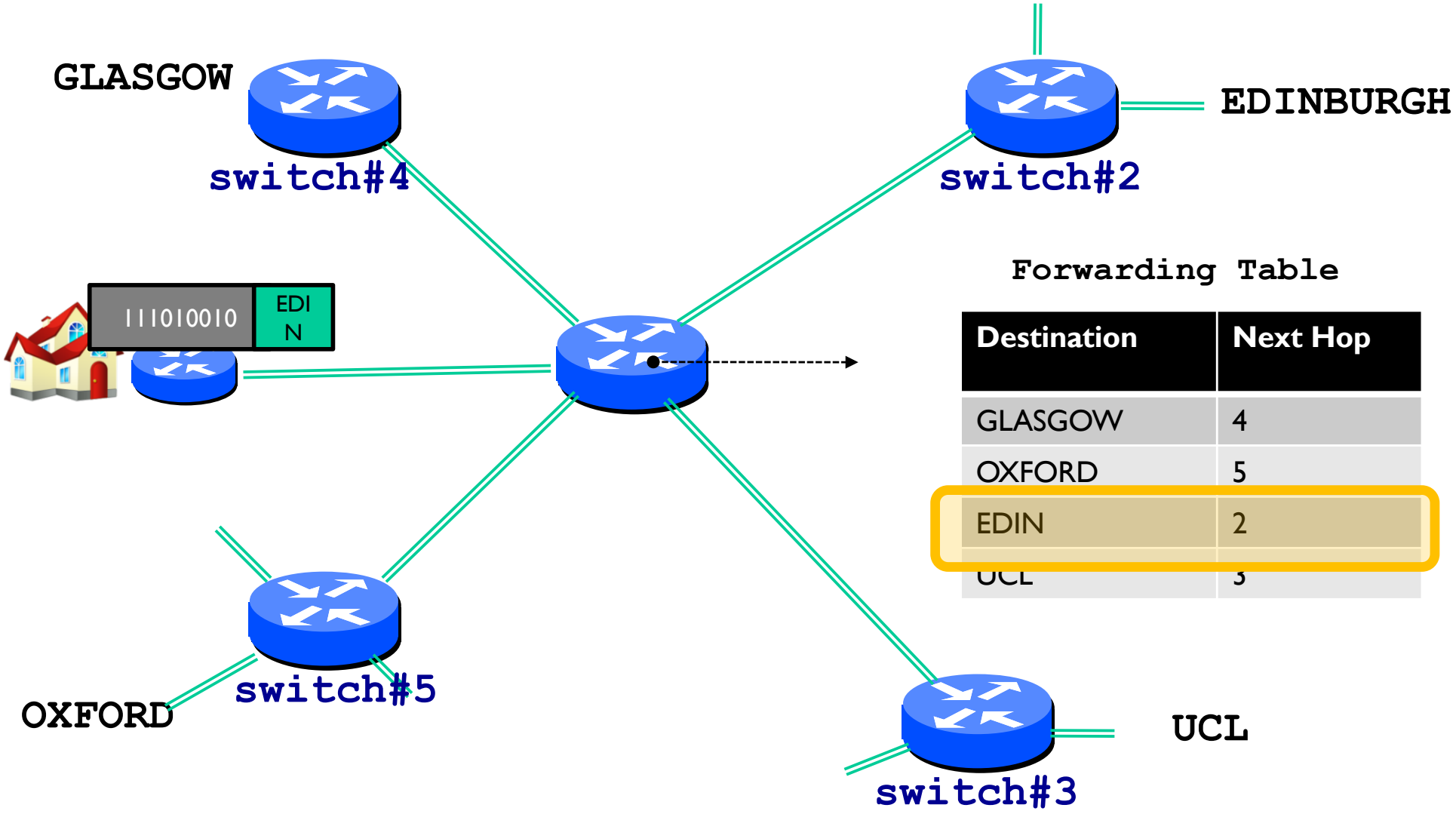
# Packet Switching

- Data is sent as chunks of formatted bits (Packets)
- Packets consist of a “header” and “payload”
  - payload is the data being carried
  - header holds instructions to the network for how to handle packet (think of the header as an API)

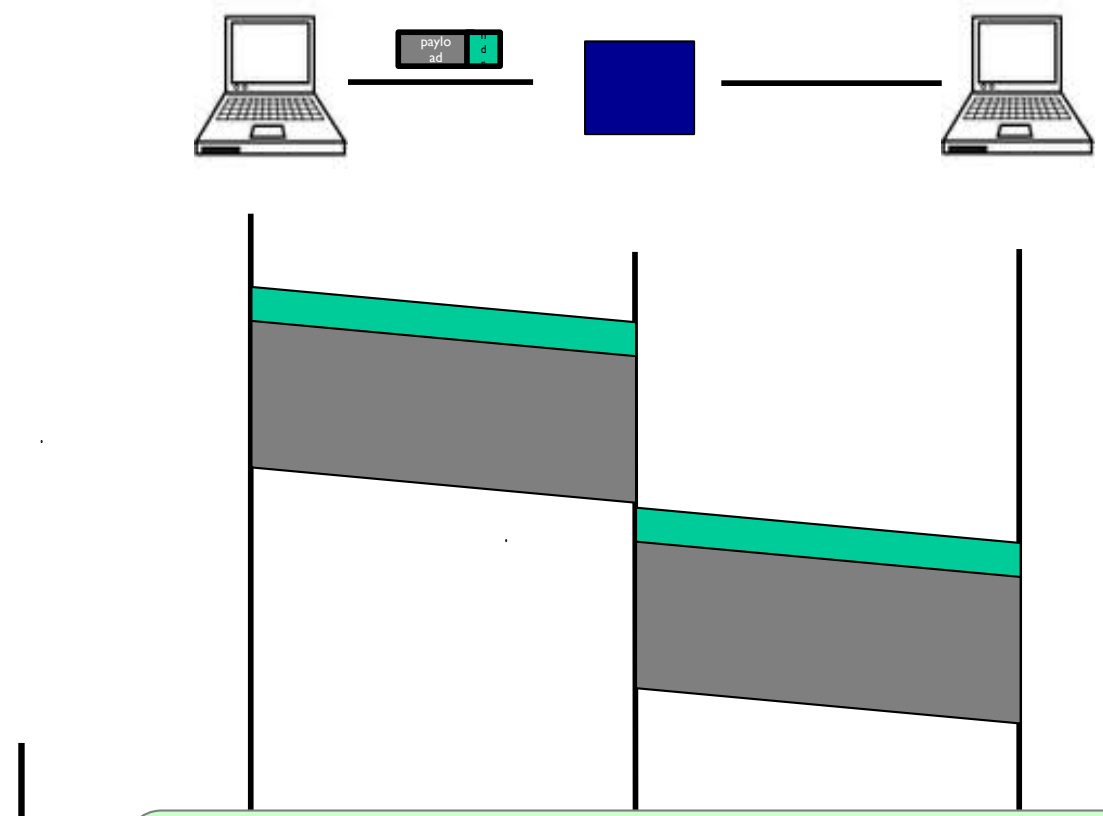
# Packet Switching

- Data is sent as chunks of formatted bits (Packets)
- Packets consist of a "header" and "payload"
- Switches "forward" packets based on their headers

# Switches forward packets



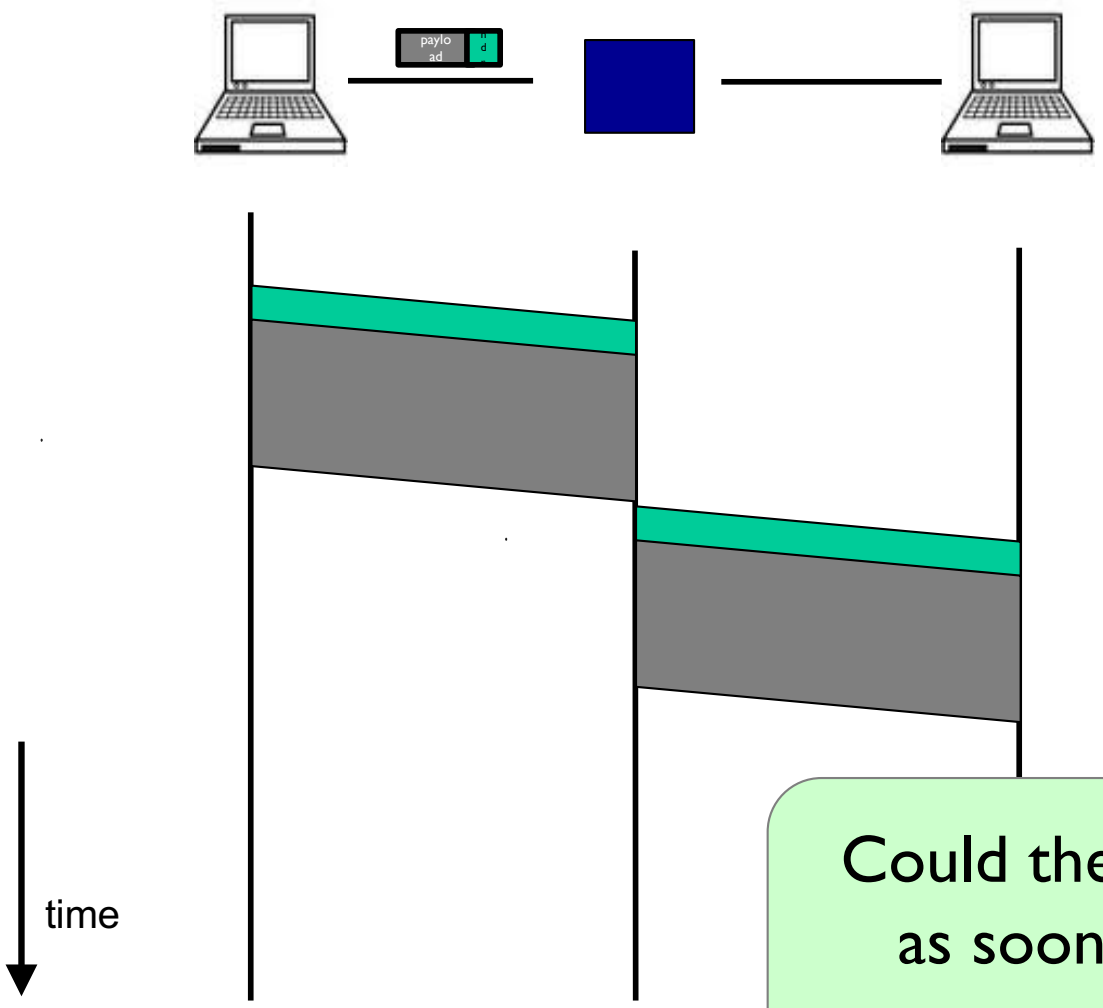
# Timing in Packet Switching




What about the time to process the packet at the switch?

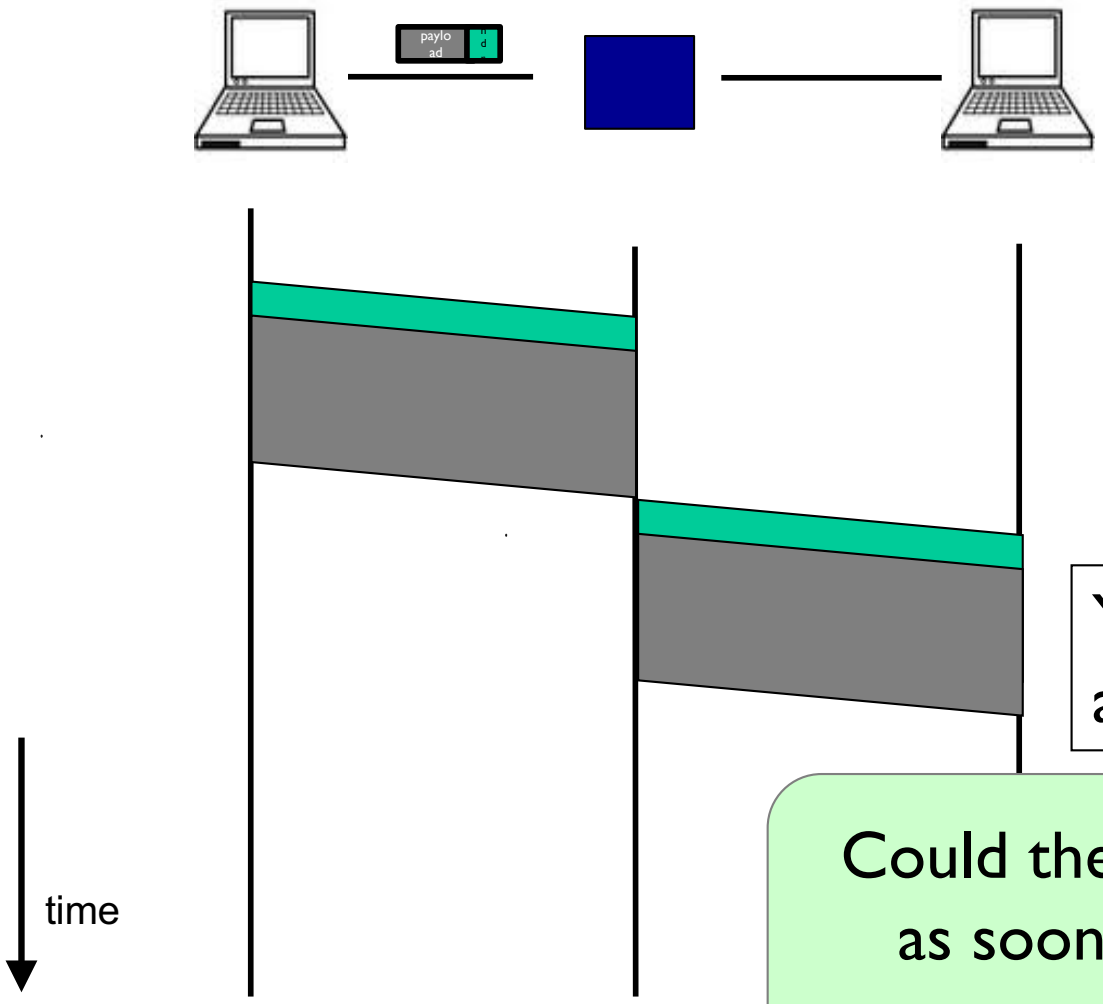
- We'll assume it's relatively negligible (mostly true)

# Timing in Packet Switching




Could the switch start transmitting as soon as it has processed the header?

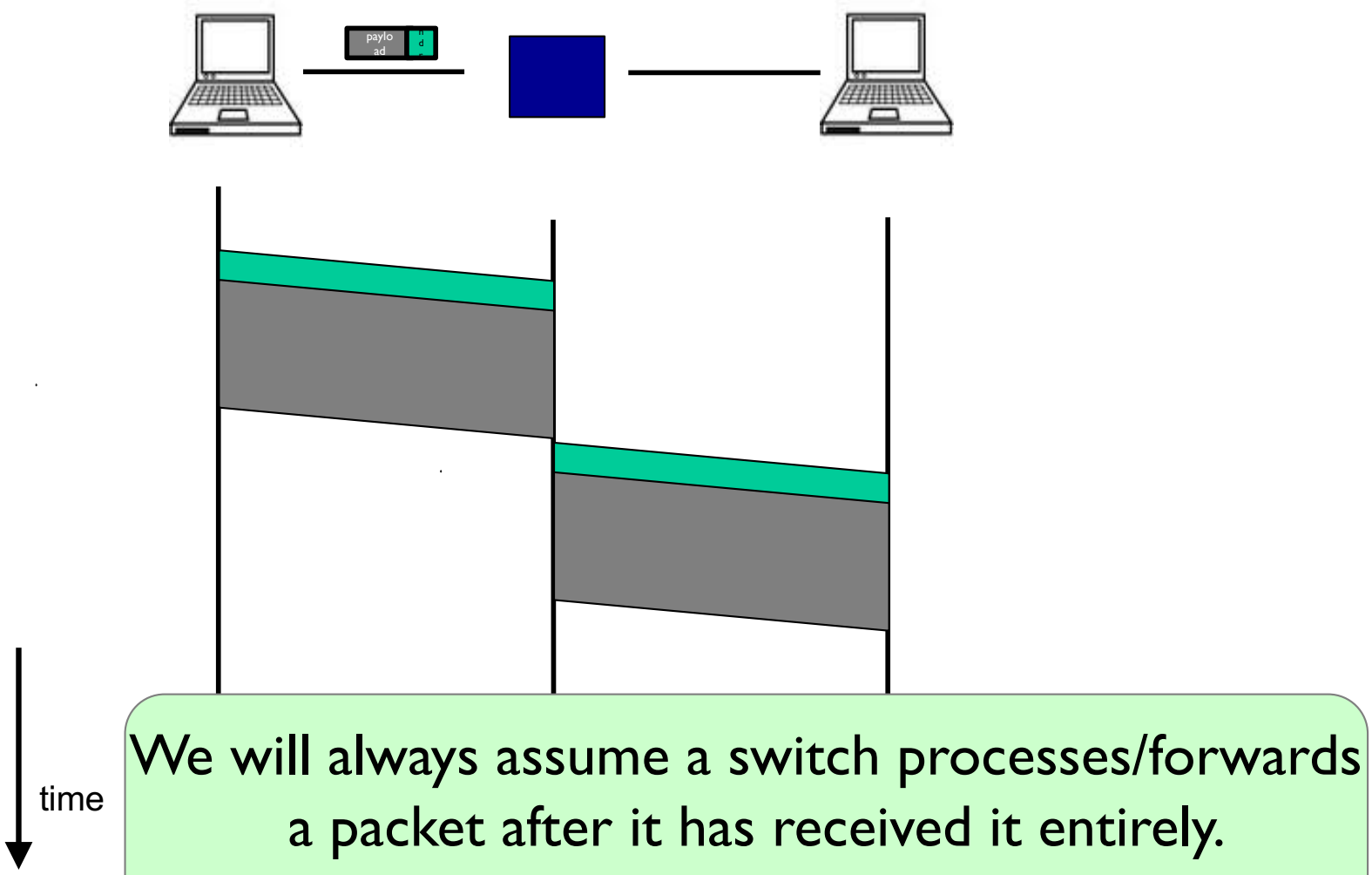
# Timing in Packet Switching




Yes! This would be called a "cut through" switch

Could the switch start transmitting as soon as it has processed the header?

# Timing in Packet Switching




We will always assume a switch processes/forwards a packet after it has received it entirely.
This is called "store and forward" switching

# Packet Switching

- Data is sent as chunks of formatted bits (Packets)
- Packets consist of a "header" and "payload"
- Switches "forward" packets based on their headers

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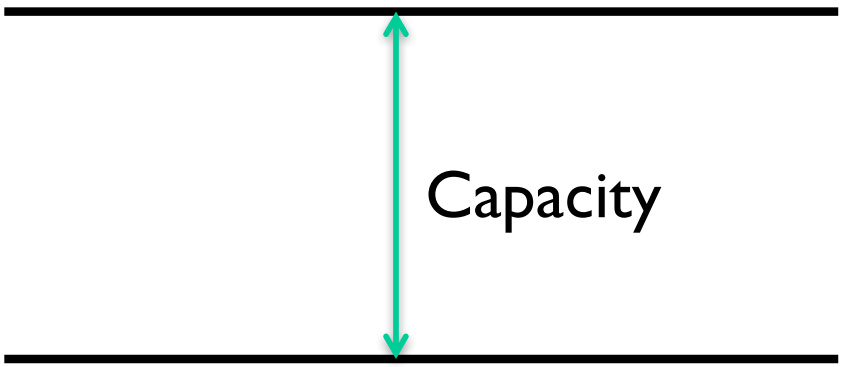
- Each packet travels independently
  - no notion of packets belonging to a "circuit"

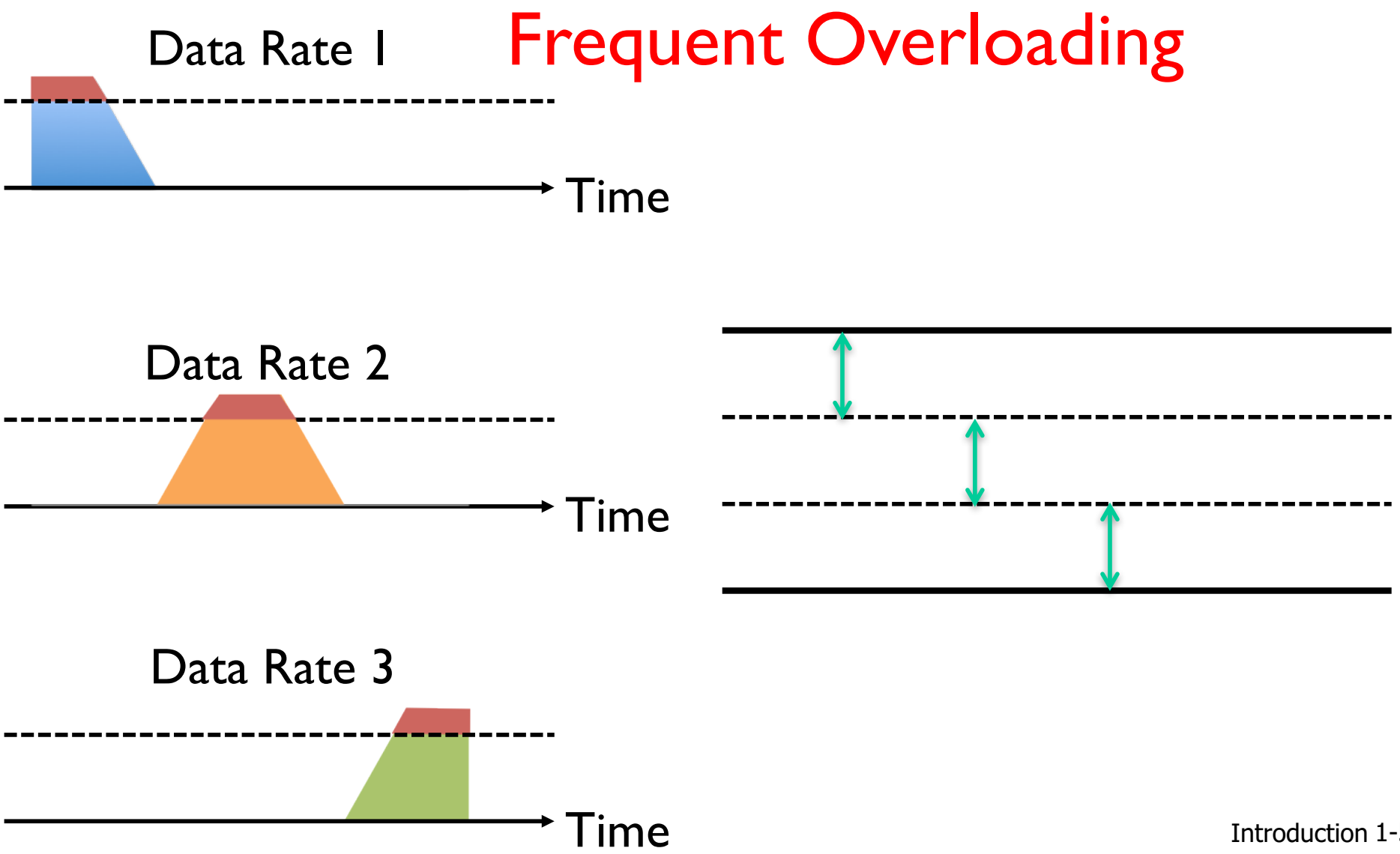
# Packet Switching

- Data is sent as chunks of formatted bits (Packets)
- Packets consist of a "header" and "payload"
- Switches "forward" packets based on their headers
- Each packet travels independently
- No link resources are reserved in advance. Instead packet switching leverages statistical multiplexing

# Three Flows with Bursty Traffic

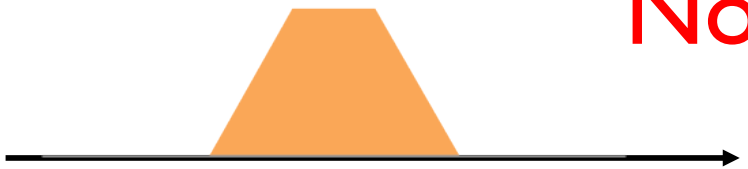



# When Each Flow Gets 1/3rd of Capacity



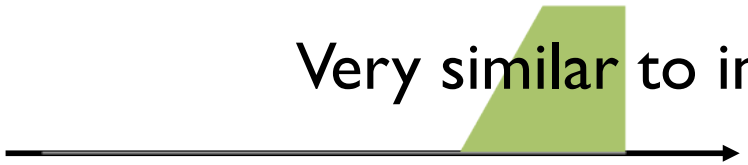
# When Flows Share Total Capacity


No Overloading

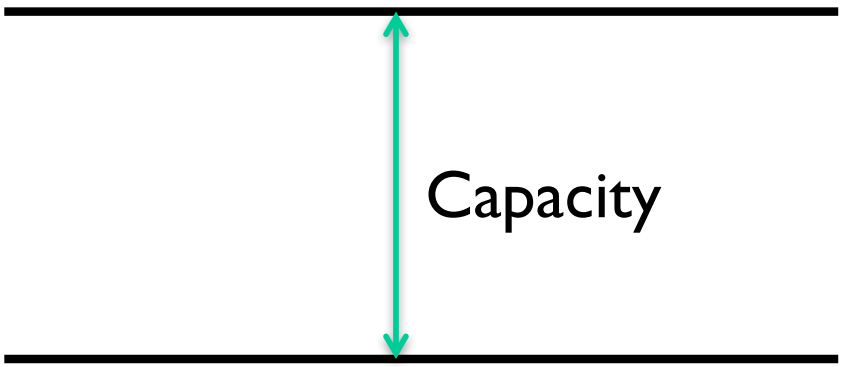



Statistical multiplexing relies on the assumption that not all flows burst at the same time.

Very similar to insurance, and has same failure case



# Three Flows with Bursty Traffic

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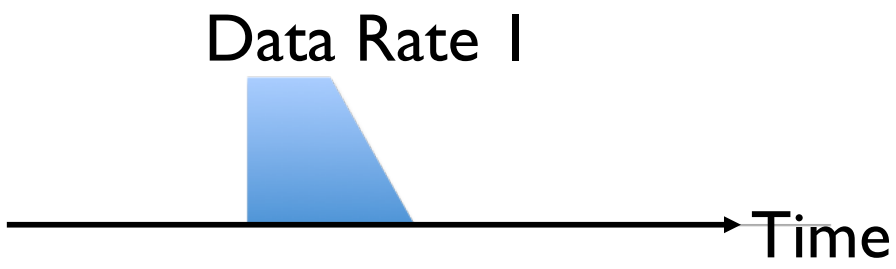
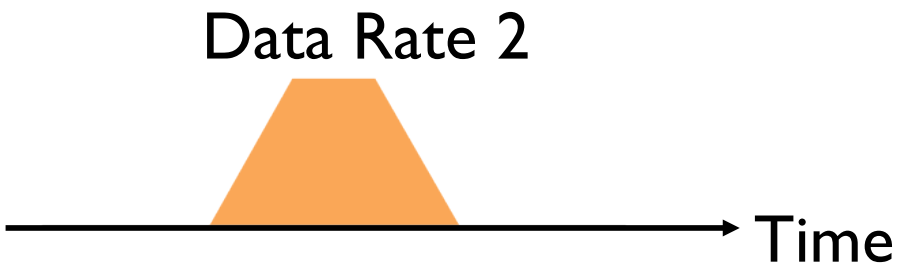
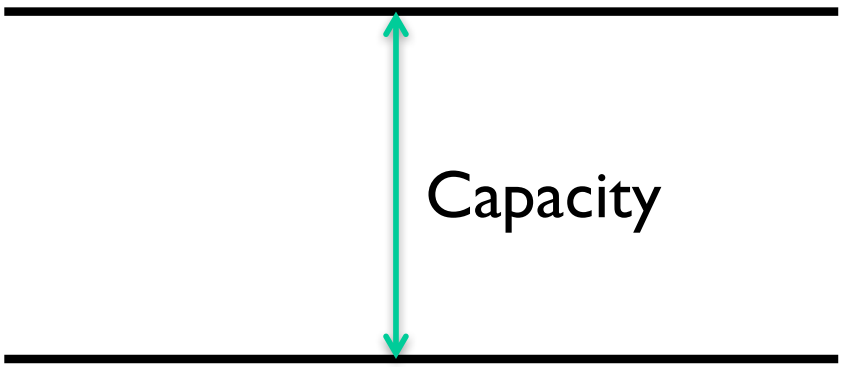
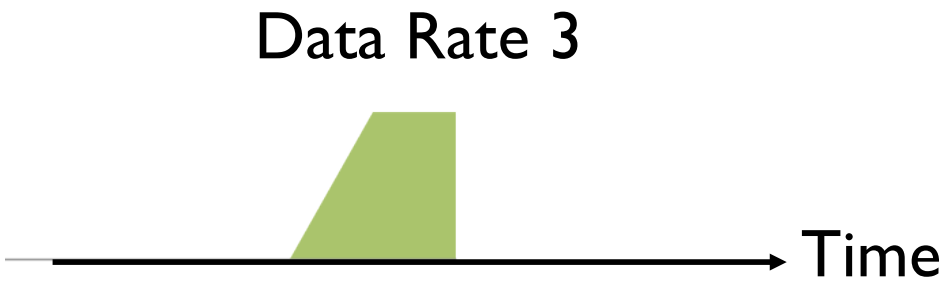


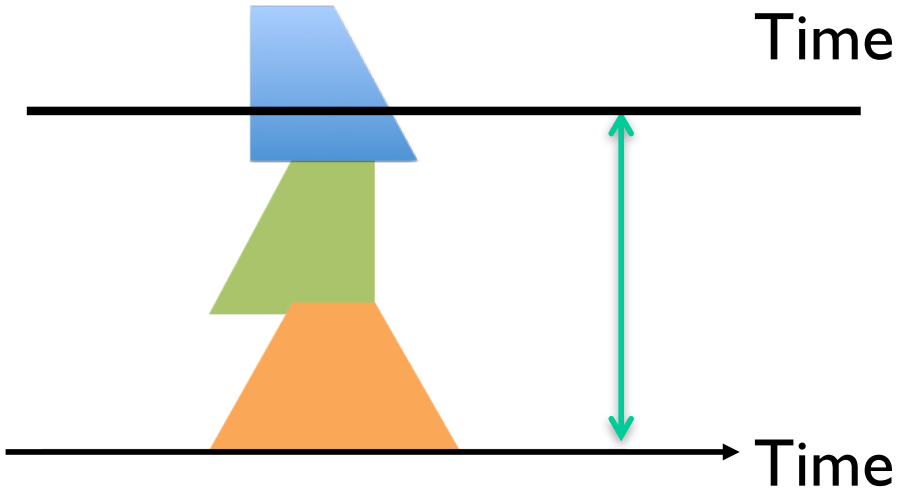



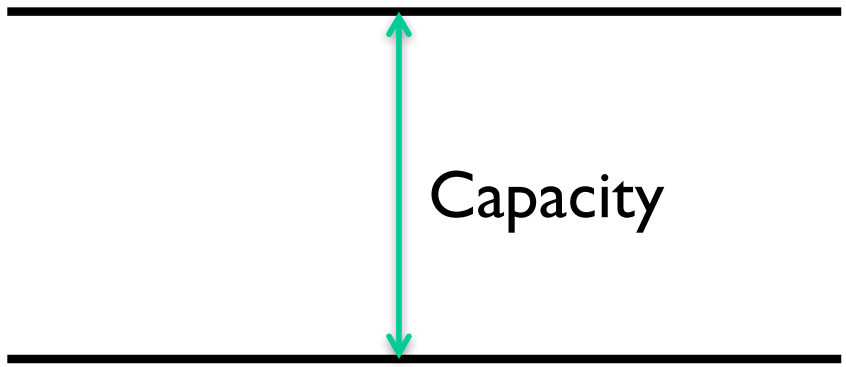



# Three Flows with Bursty Traffic

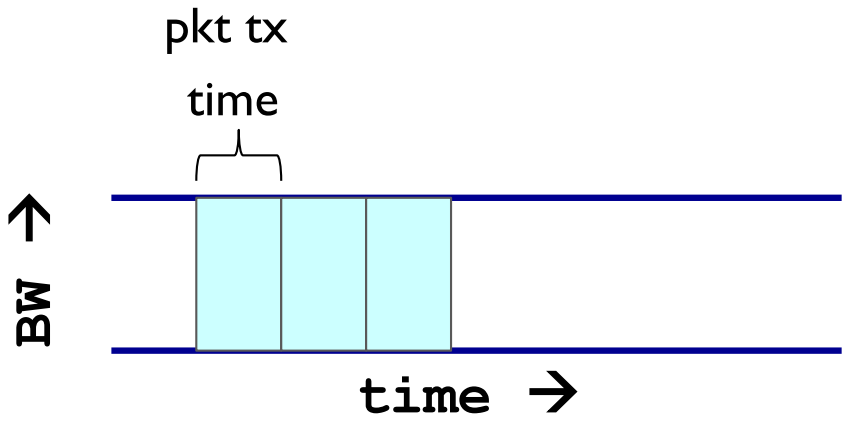
Data Rate 1+2+3 >> Capacity



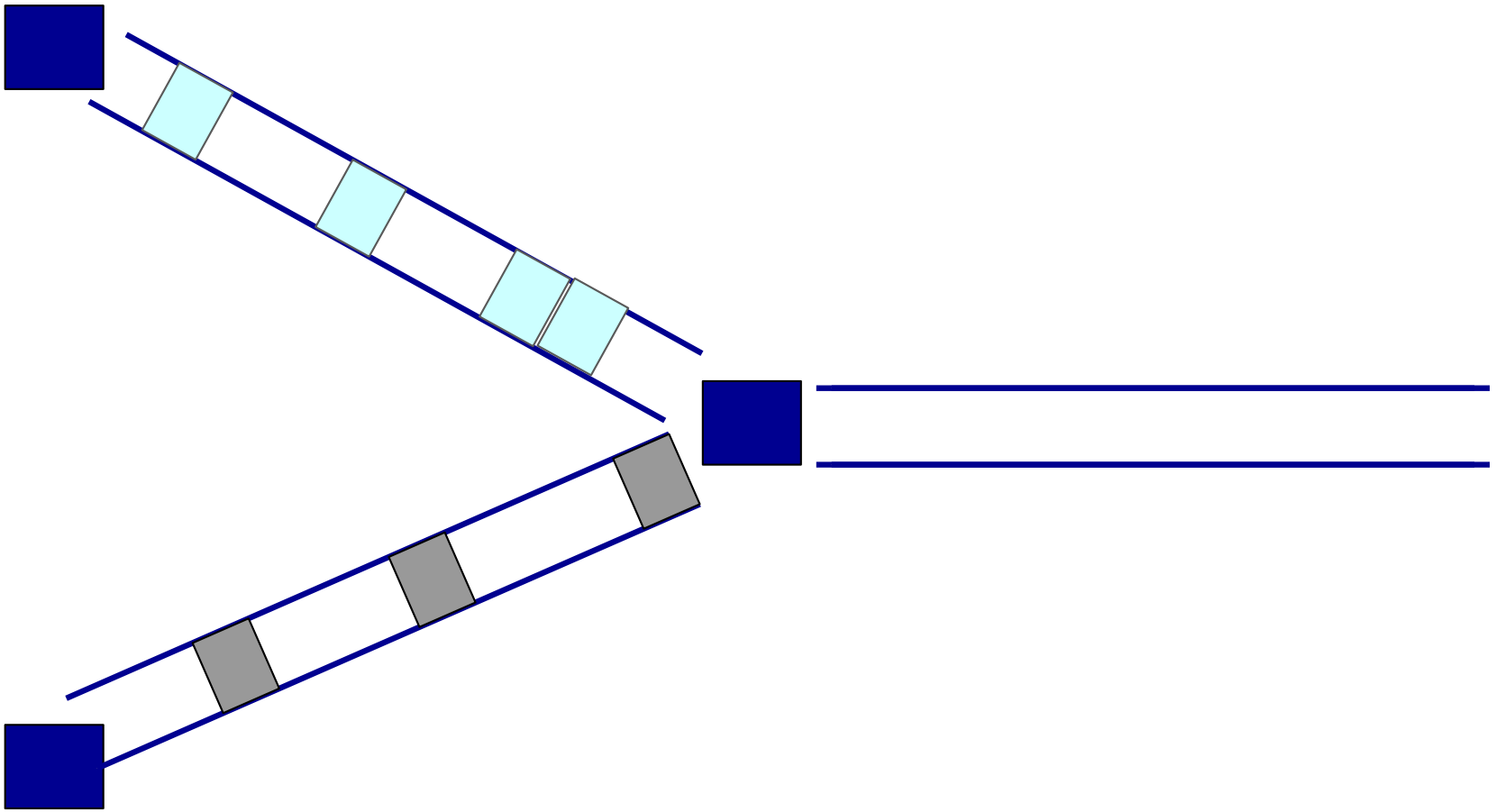




What do we do under overload?

# Statistical multiplexing: pipe view



# Statistical multiplexing: pipe view



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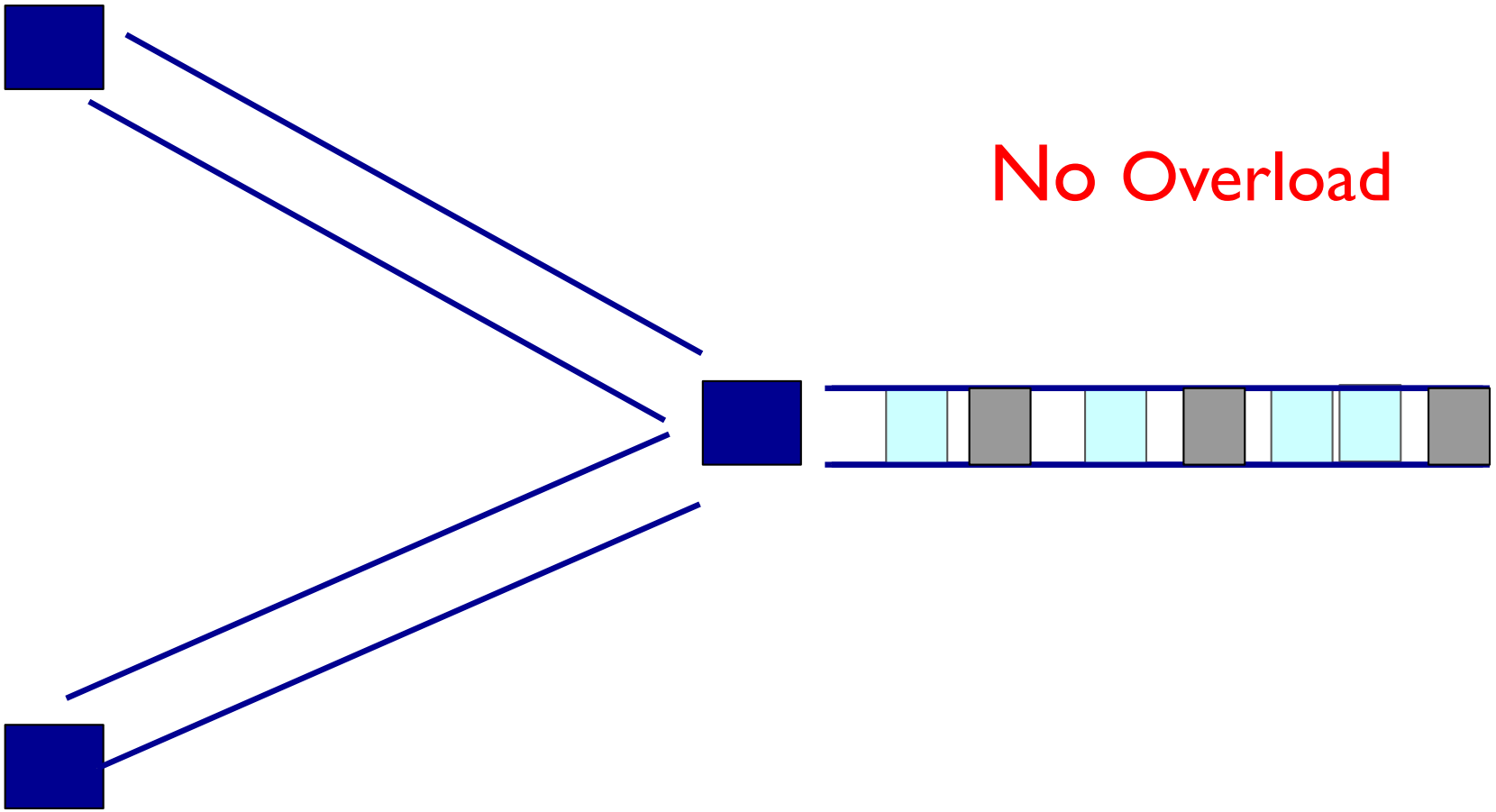
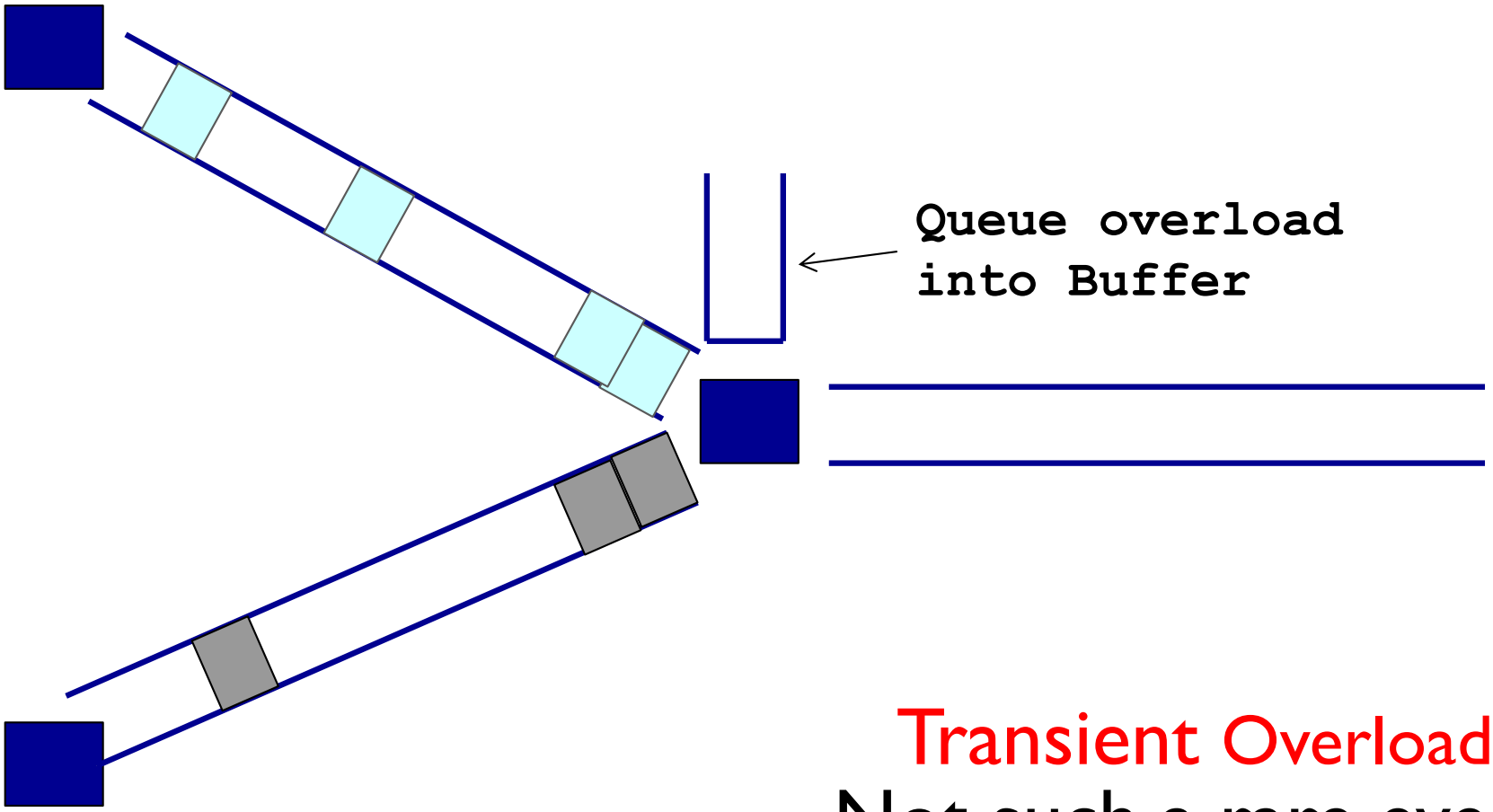


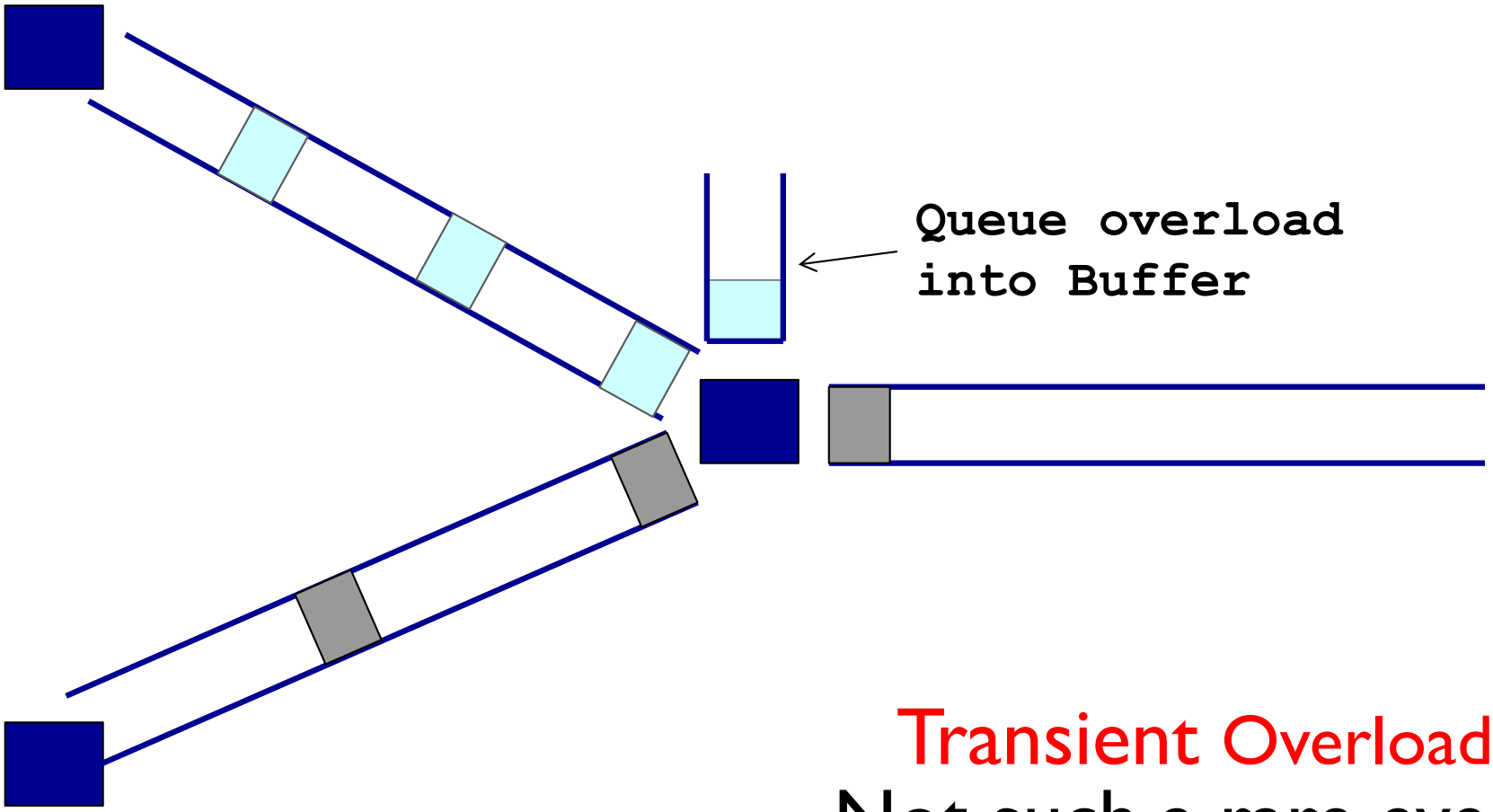
# Statistical multiplexing: pipe view




Transient Overload

Not such a rare event

# Statistical multiplexing: pipe view

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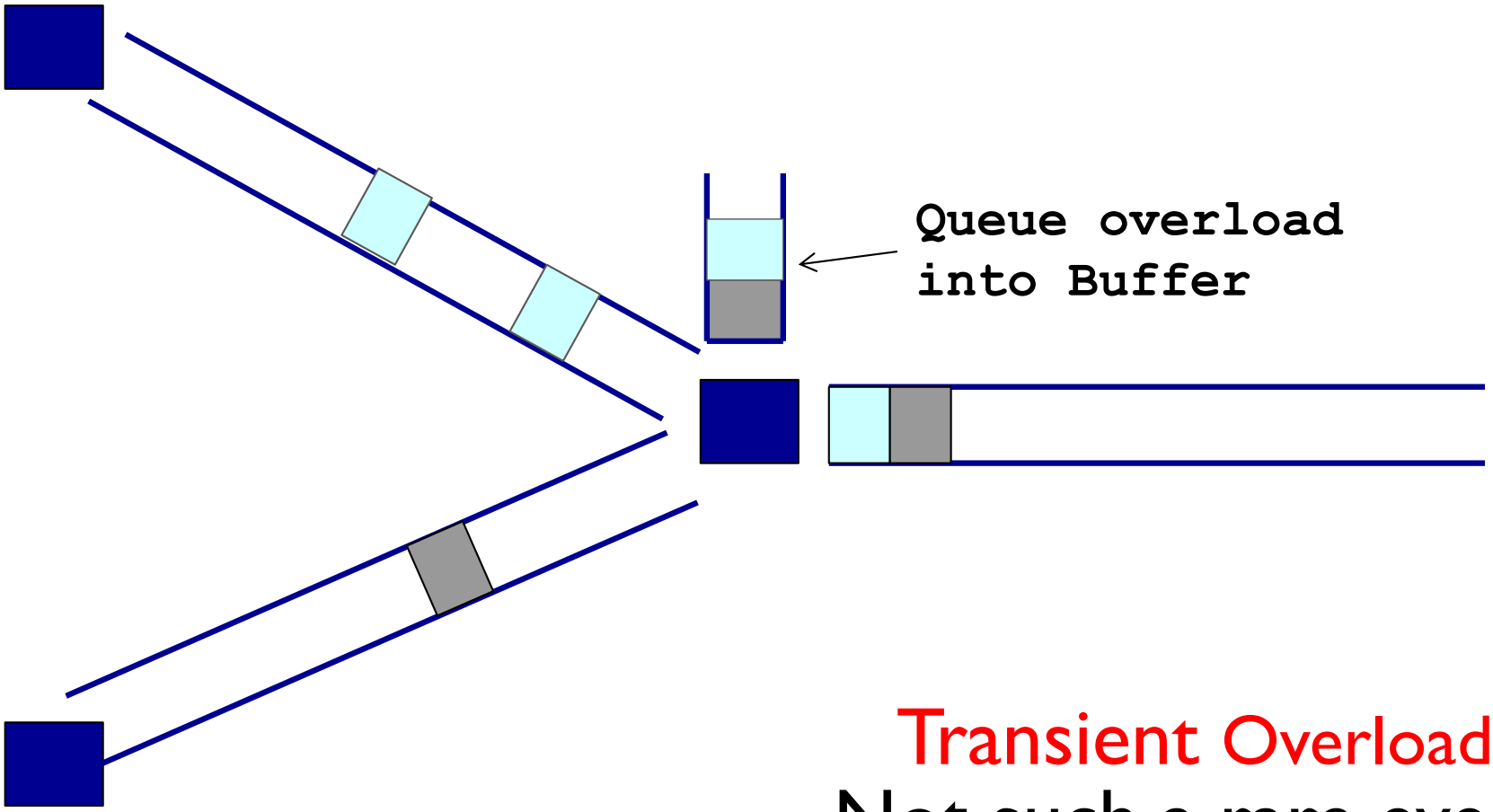


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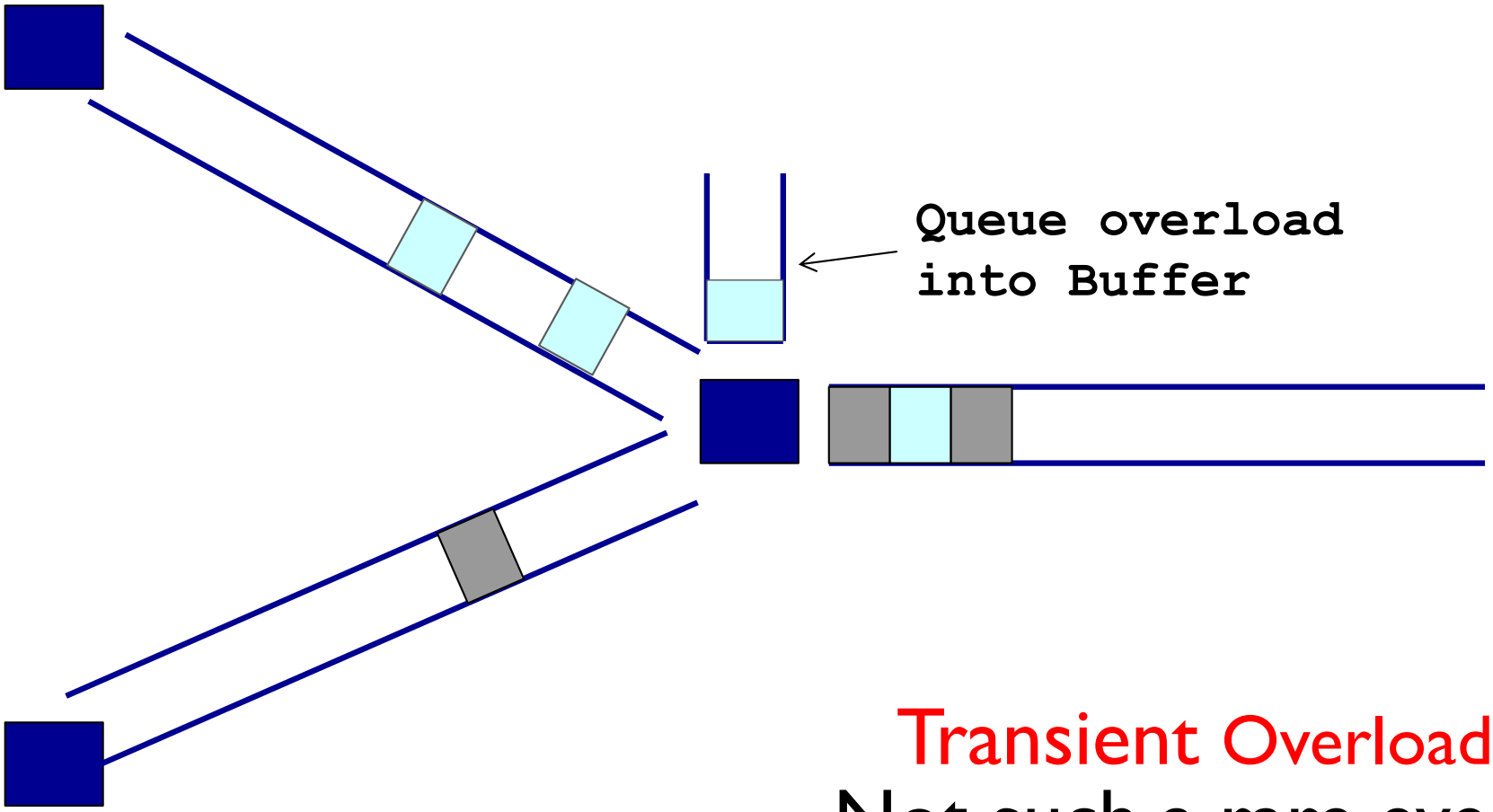


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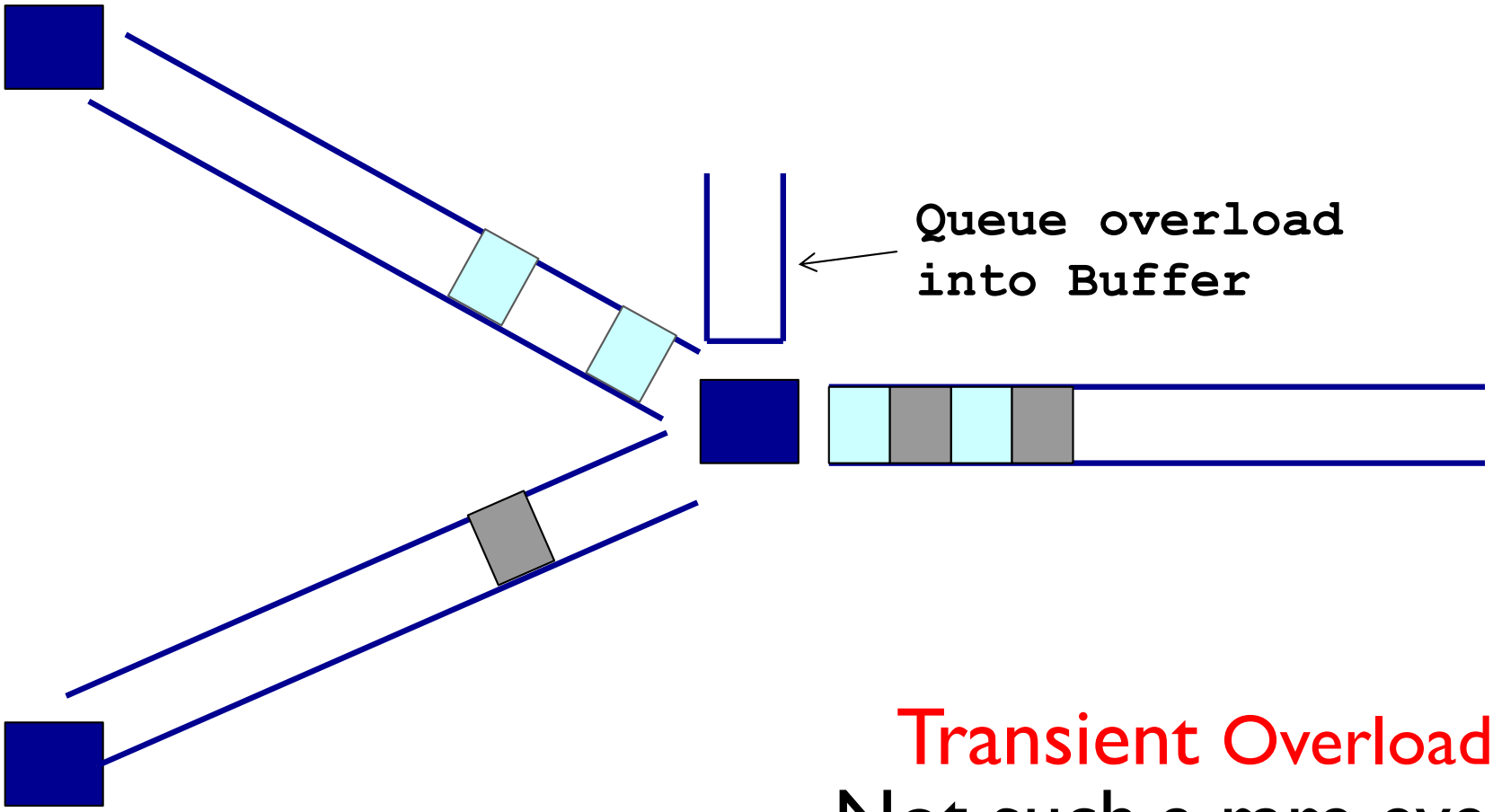


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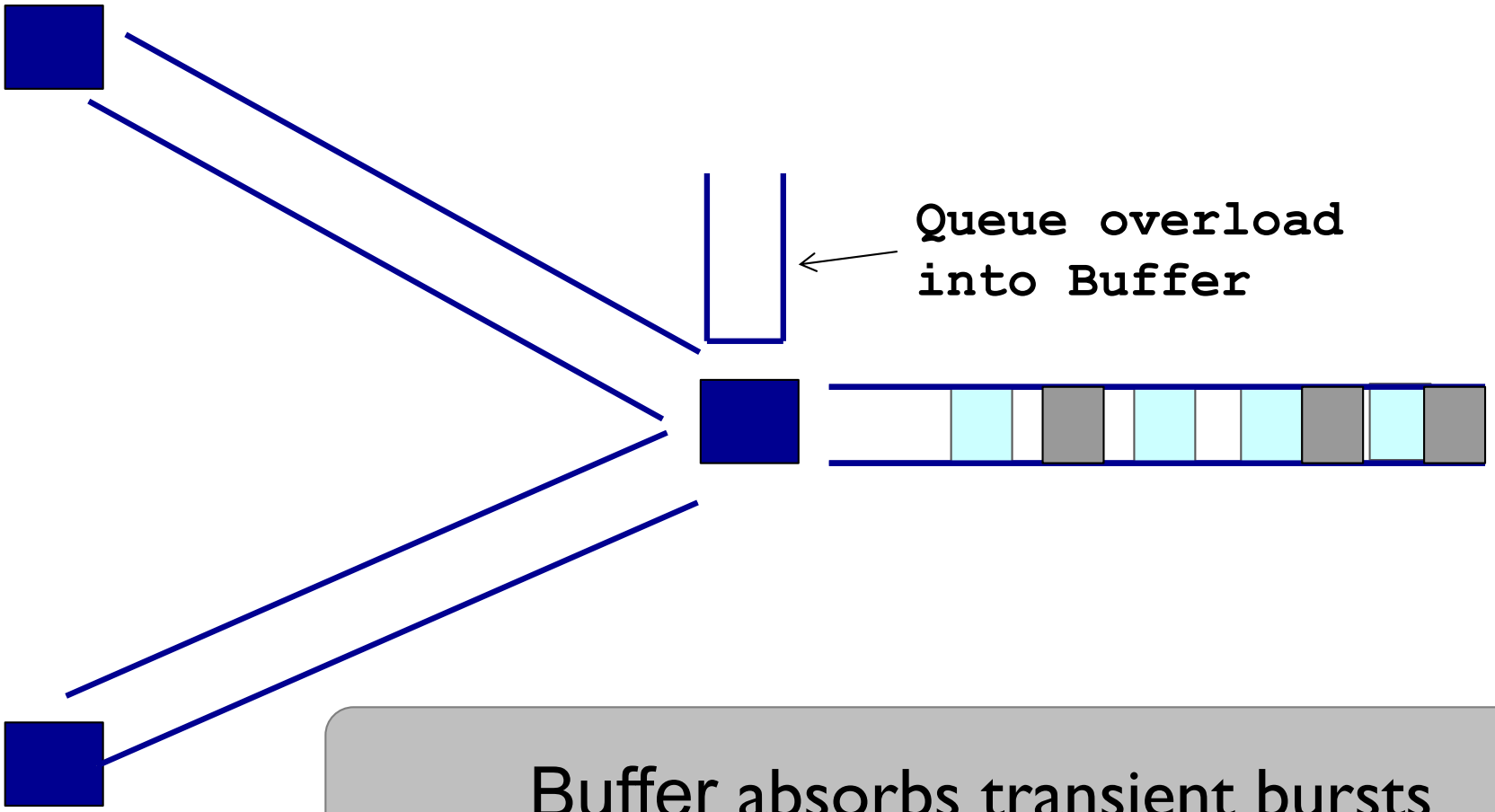
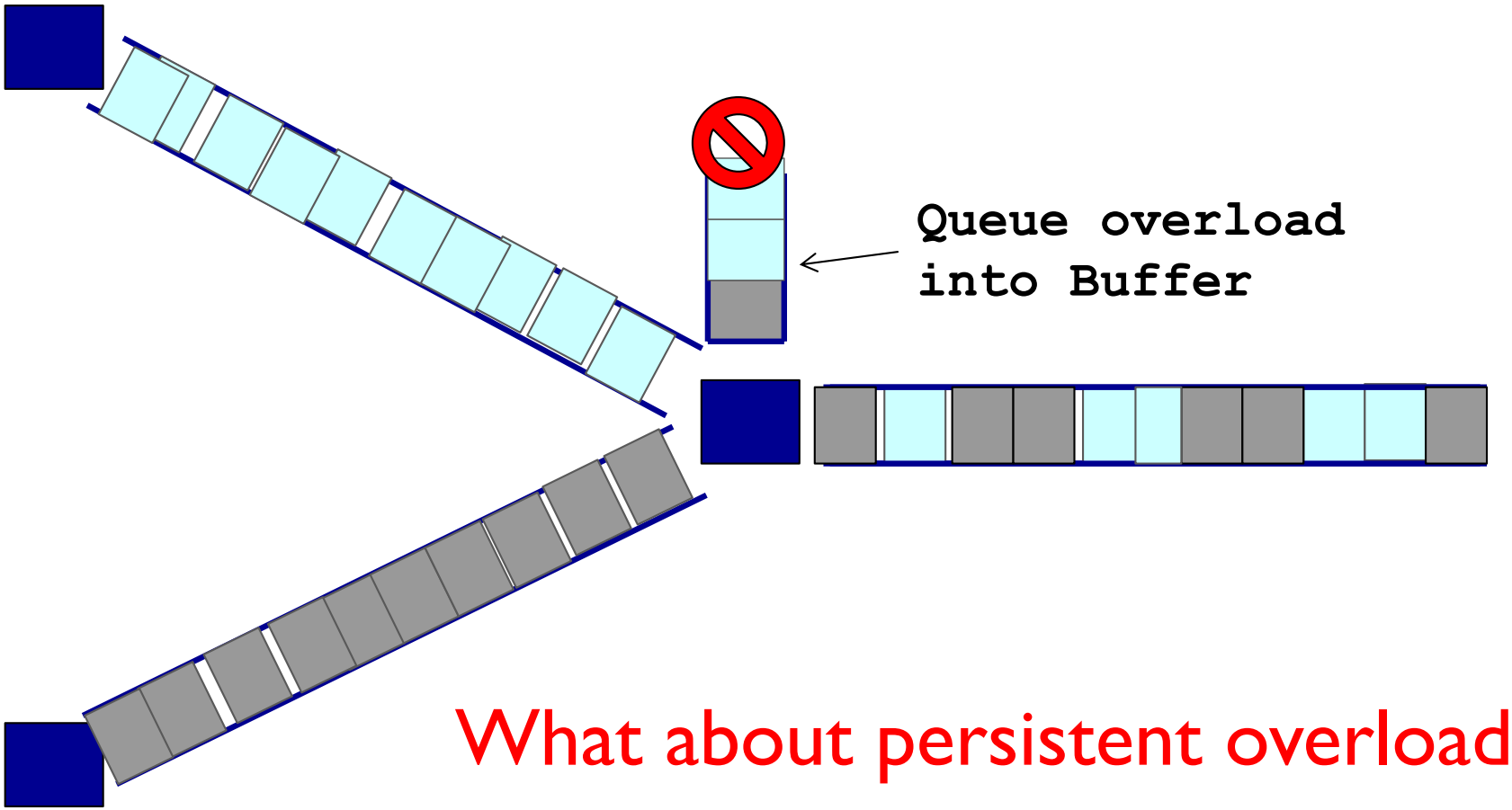



Buffer absorbs transient bursts

# Statistical multiplexing: pipe view




What about persistent overload?

Will eventually drop packets

# Quiz: What are the pros and cons of packet switching? Let's discuss ..

- Pros:

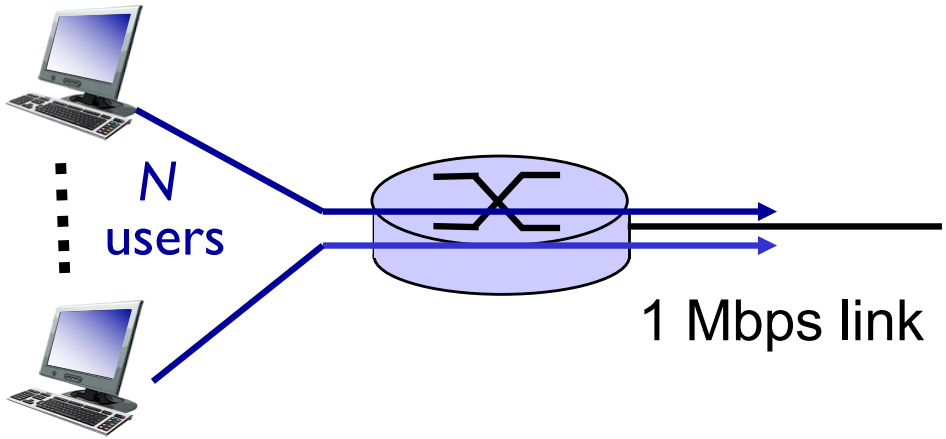
- Cons:

# Packet switching versus circuit switching

*packet switching allows more users to use network!*

example:

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time




❖ *circuit-switching:*

- 10 users

❖ *packet switching:*

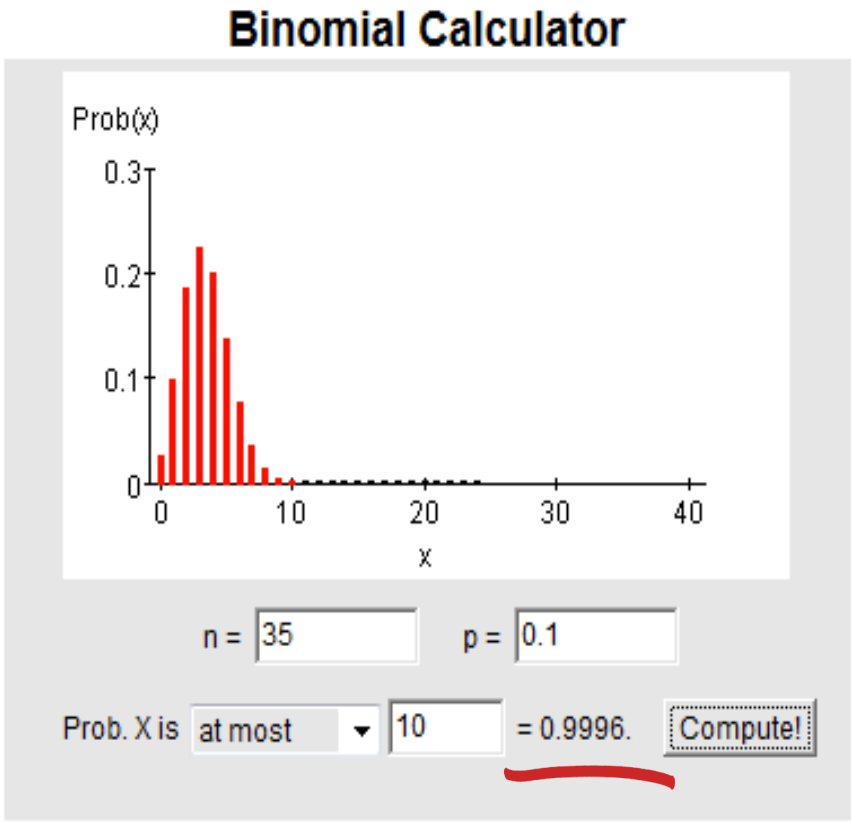
- with 35 users, probability > 10 active at same time is less than .0004 *

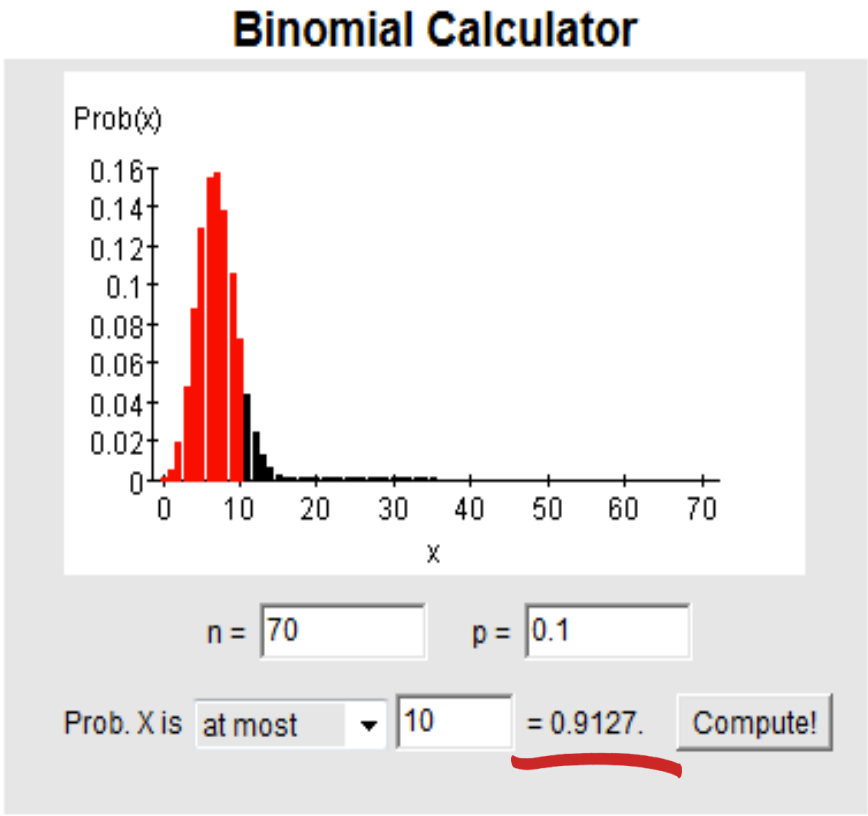
*Q:* how did we get value 0.0004?

*Q:* what happens if > 35 users say 70?

**Hint: Bernoulli Trials and Binomial Distribution**

# Statistical Multiplexing Gain (SMG)




SMG: 35/10=3.5

SMG: 70/10=7

# Packet switching versus circuit switching

is packet switching a "slam dunk winner?"

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: 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

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

# 1. Introduction: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

Self study