CS2505
Network Computing

Prof. Cormac J. Sreenan

Instructor Details

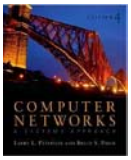
- Email
  - For Prof. Sreenan: cjs@cs.ucc.ie
  - Always put CS2505 in "Subject" line of message
  - Always send from cs.ucc.ie to avoid being labelled as spam
- Office Hours
  - For Prof. Sreenan: normally Mondays 3-4pm, or by appointment. Room 1-75

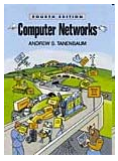
Course Information

- CS2505 is a 5-credit module
  - 24 lectures plus practical laboratory sessions
  - Two lectures per week (Period 2 only)
- Assessment
  - Summer Exam. 80%
  - Lab. assignments 20%
- Course website
  - www.cs.ucc.ie/~cjs/teach/CS2505
  - Lecture notes added as the course progresses; also lab. details

Textbooks

- Required to purchase:
  - J. Kurose & K. Ross, "Computer Networking", Addison-Wesley Pub.
  - Latest edition is 5th (2009) but older editions should be sufficient
- Other good books (in library):
  - L. Peterson and B. Davie. "Computer Networks: A Systems Approach". Morgan Kaufmann Pub. 4th Edition (2007)
  - A. Tanenbaum, "Computer Networks", Prentice Hall Pub. 4th edition (2002)





Course Overview

- Networking Basics
- Application layer
- Transport layer
- Network Management

Part 1: Introduction

Our goal:

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

Overview:

- what's the Internet?
- what's a protocol?
- network edge; hosts, access net, physical media
- network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- security
- protocol layers, service models
- history

Part 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge
- end systems, access networks, links

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

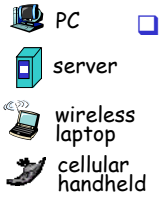
1.4 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

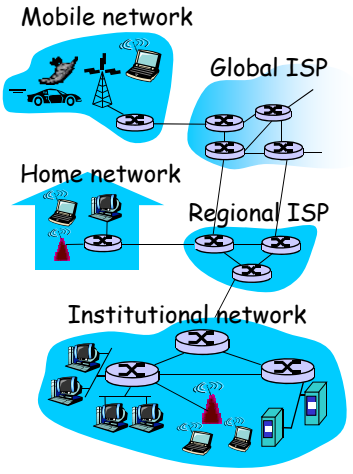
1.6 Networks under attack: security

1.7 History

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



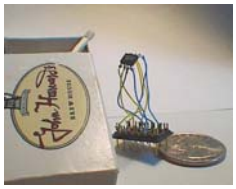
- millions of connected computing devices: *hosts = end systems*
  - running *network apps*
- *communication links*
  - fibre, copper, radio, satellite
  - transmission rate = *bandwidth*
- *routers:* forward packets (chunks of data)



"Cool" internet appliances

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

Web-enabled toaster + weather forecaster

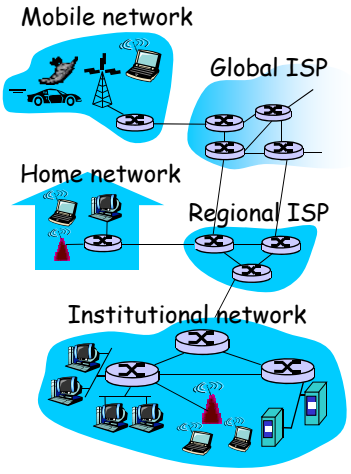


World's smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html

Internet phones

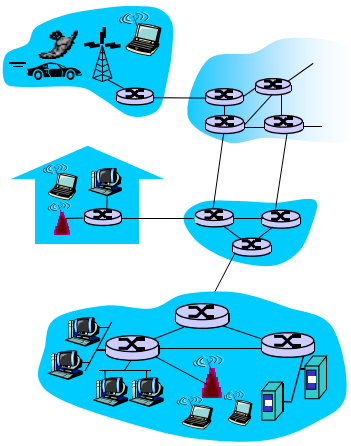
What's the Internet: "nuts and bolts" view

- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, Ethernet
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- communication *infrastructure* enables distributed applications:
  - Web, VoIP, email, games, e-commerce, file sharing
- communication services provided to apps:
  - reliable data delivery from source to destination
  - "best effort" (unreliable) data delivery



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

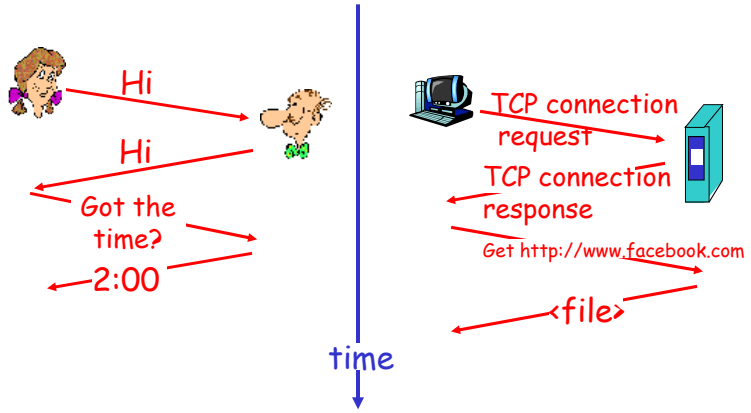
network protocols:

- 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?

Part 1: roadmap

1.1 What *is* the Internet?

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

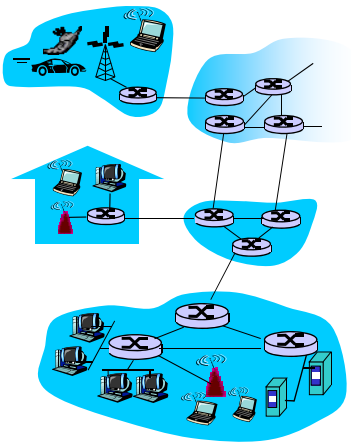
1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

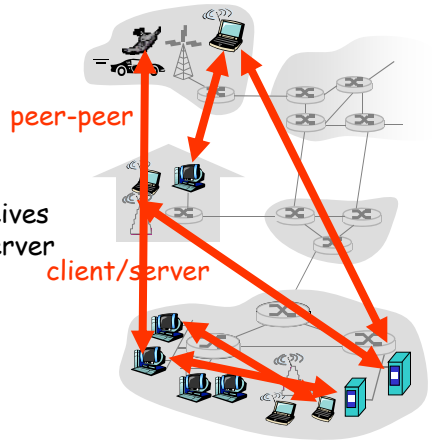
A closer look at network structure:

- network edge: applications and hosts
- access networks, physical media: wired, wireless communication links
- network core:
  - interconnected routers
  - network of networks



The network edge:

- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at "edge of network"
- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent



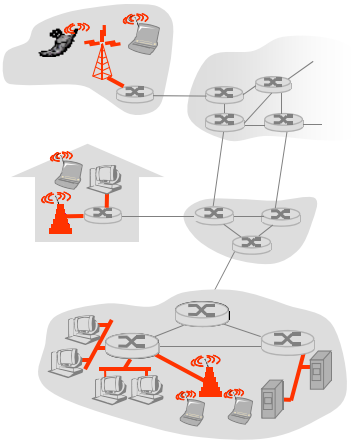
Access networks and physical media

Q: How to connect end systems to edge router?

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

Keep in mind:

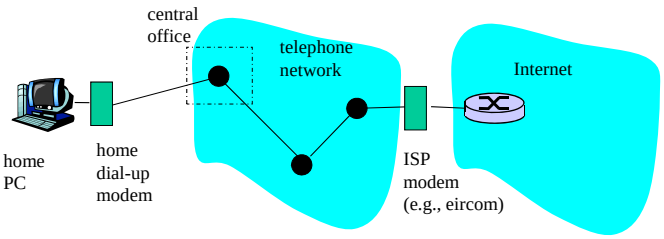
- bandwidth (bits per second) of access network?
- shared or dedicated?



Bandwidth

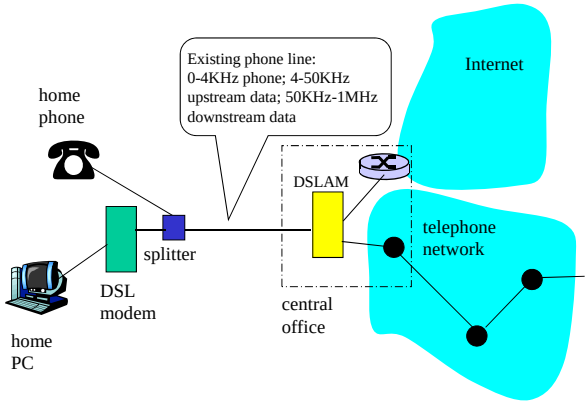
- Amount of data that can be transmitted per time unit
  - Example: 10 Mega bits per second (Mb/s or Mbps) or 100 Kilo bits per second (Kb/s)
  - Also called data rate or capacity
- Notation
  - distinguish between bits (b) and bytes (B)
  - One byte = 8 bits; bytes sometimes called octets
  - Kb/s = 10^3 bits per second; Mb/s = 10^6 bits per second

Dial-up Modem



- Uses existing telephony infrastructure
  - Home is connected to central office
- up to 56Kb/s direct access to router (often less)
- Can't surf and phone at same time: not "always on"

Digital Subscriber Line (DSL)



- Also uses existing telephone infrastructure
- up to 3.5 Mb/s upstream (today typically < 1 Mb/s)
- up to 24 Mb/s downstream (today typically < 8 Mb/s)
- dedicated physical line to telephone central office

Residential access: cable modems

- Does not use telephone infrastructure
  - Instead uses cable TV infrastructure
- HFC: hybrid fibre coax
  - asymmetric: up to 30Mb/s downstream, 2 Mb/s upstream
- network of cable and fibre attaches homes to ISP router
  - homes share access to router
  - unlike DSL, which has dedicated access

Residential access: cable modems

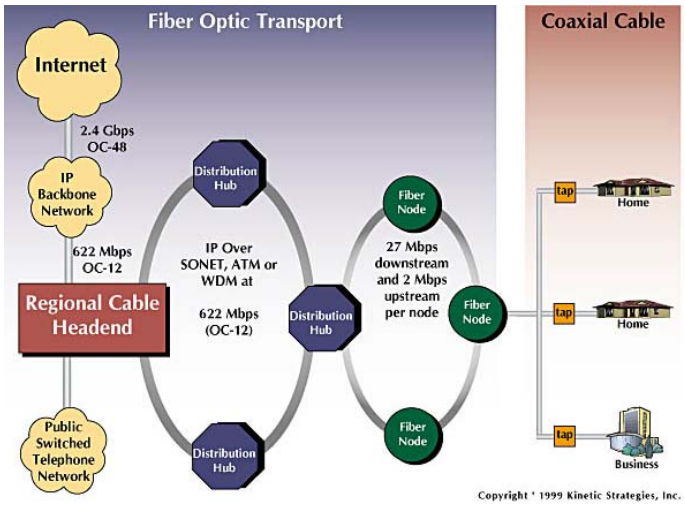
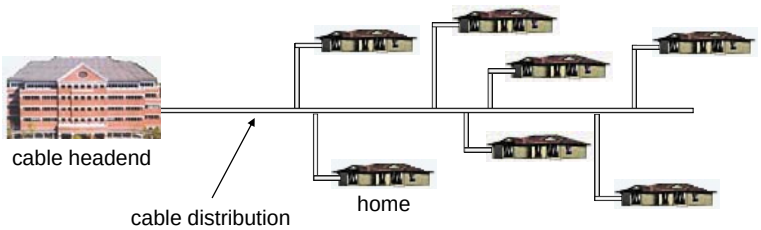


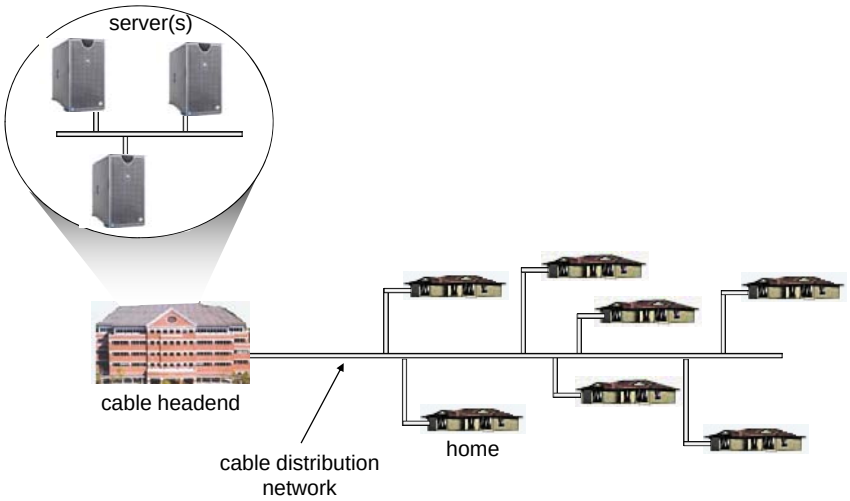
Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

Cable Network Architecture: Overview

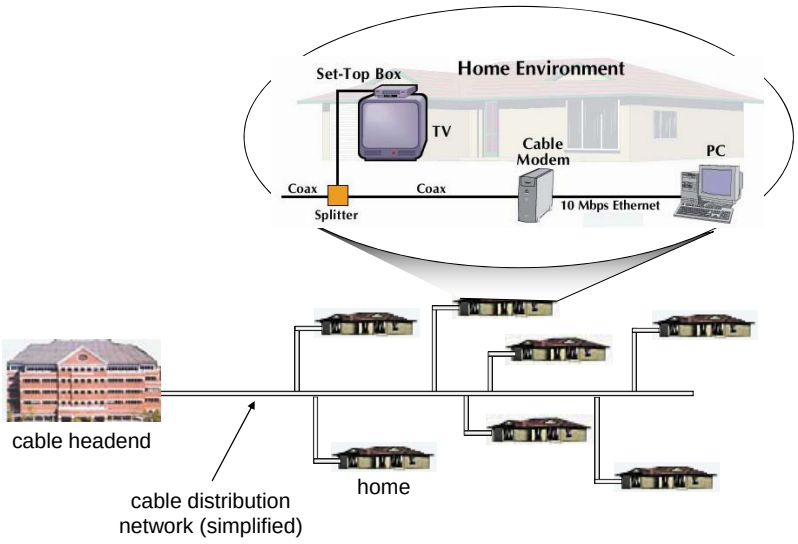
Typically 500 to 5,000 homes



Cable Network Architecture: Overview

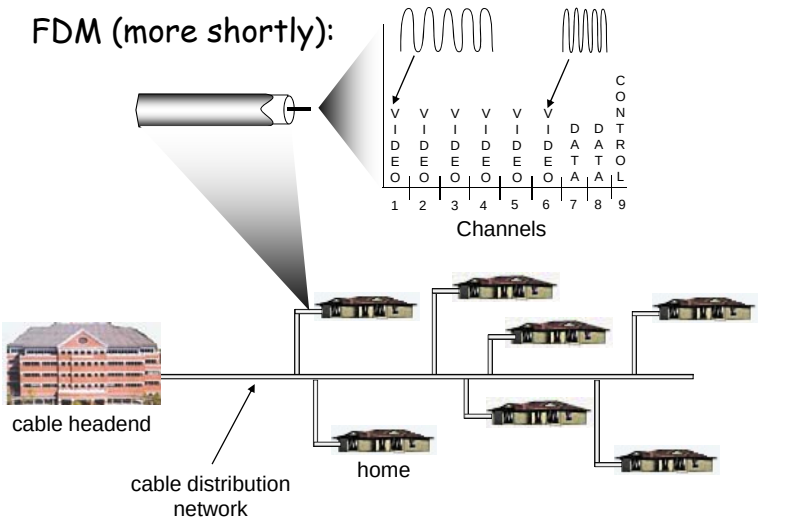


Cable Network Architecture: Overview

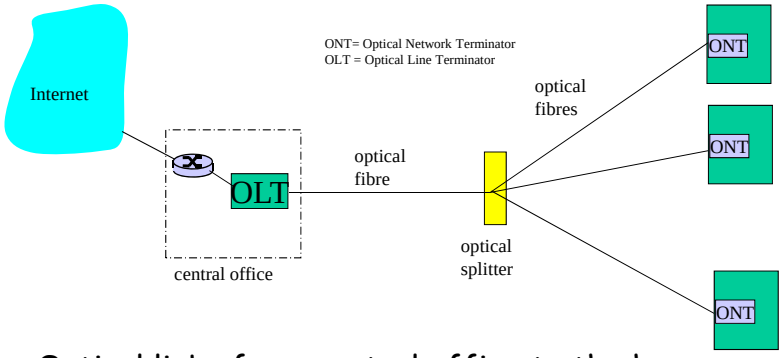


Cable Network Architecture: Overview

FDM (more shortly):

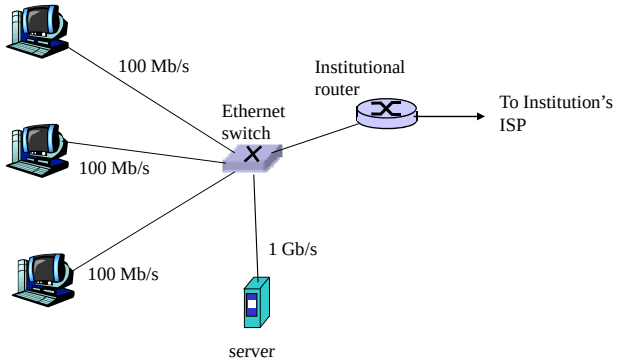


Fibre to the Home



- Optical links from central office to the home
- Two competing optical technologies:
  - Passive Optical network (PON)
  - Active Optical Network (PAN)
- Much higher Internet rates; fibre also carries television and phone services

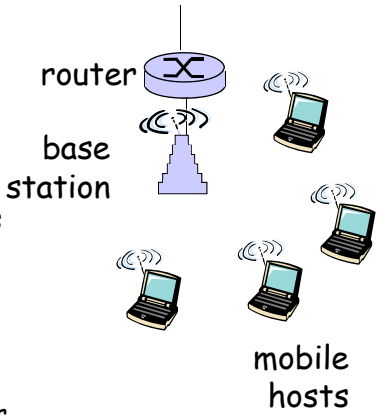
Ethernet Internet access



- Typically used in companies, universities, etc
- 10 Mb/s, 100Mb/s, 1Gb/s, 10Gb/s Ethernet
- Today, end systems typically connect into Ethernet switch

Wireless access networks

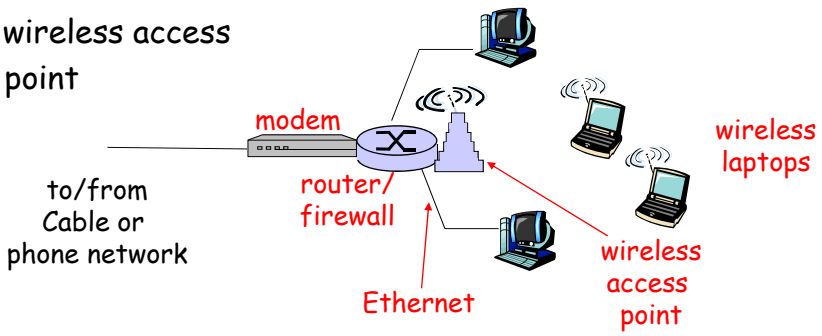
- shared *wireless* access network connects end system to router
  - via base station aka "access point"
- wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mb/s
- wider-area wireless access
  - provided by telco operator
  - Up to 2Mb/s over 3G cellular system
  - 100 Mb/s to 1 Gb/s in 4G cellular systems



Home networks

Typical home network components:

- DSL or cable modem
- router/firewall/NAT
- Ethernet
- wireless access point



Physical Media

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

Twisted Pair (TP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mb/s Ethernet
  - Category 5: 100Mb/s Ethernet

Physical Media: coax, fibre

Coaxial cable:

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

fibre optic cable:

- glass fibre carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10-100 Gps)
- low error rate: repeaters spaced far apart ; immune to electromagnetic noise

Physical media: radio

- 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 Mb/s channels
- LAN (e.g., Wifi)
  - 11Mb/s, 54 Mb/s
- wide-area (e.g., cellular)
  - 3G cellular: ~ 2 Mb/s
- satellite
  - Kb/s to 45Mb/s channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

Part 1: roadmap

1.1 What *is* the Internet?

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

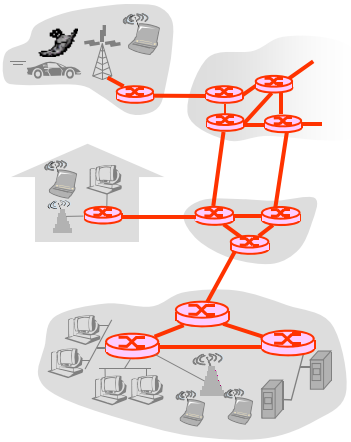
1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

The Network Core

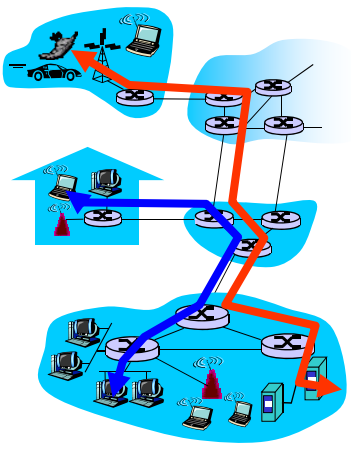
- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



Network Core: Circuit Switching

End-end resources reserved for "call"

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



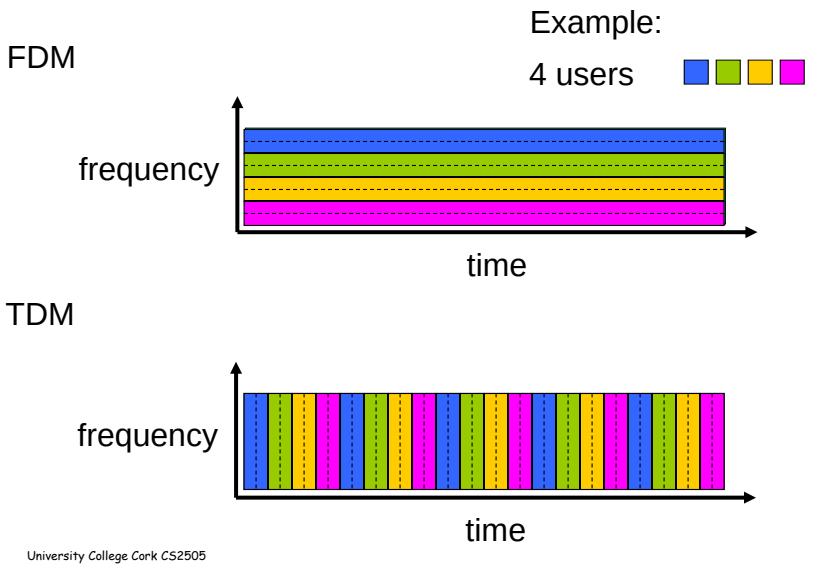
Network Core: Circuit Switching

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
  - time division

Circuit Switching: FDM and TDM



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 Mb/s
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Let's work it out!

Network Core: Packet Switching

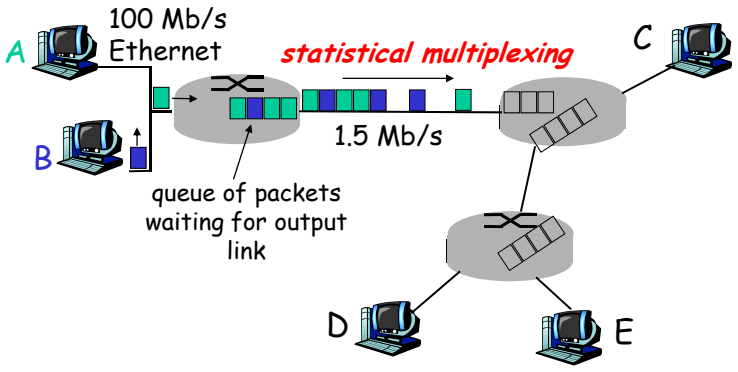
each end-end data stream divided into *packets*

- 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

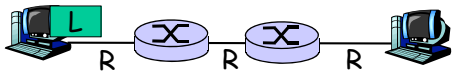
Packet Switching: Statistical Multiplexing



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 b/s
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- delay = 3 L/R (assuming zero propagation delay)

more on delay shortly …

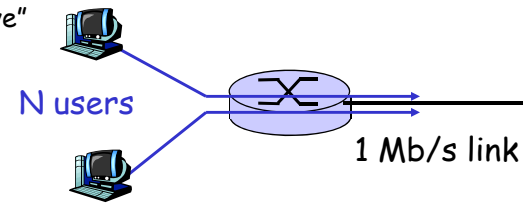
Example:

- L = 7.5 Mbits
- R = 1.5 Mb/s
- transmission delay = 15 sec

Packet switching versus 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:*
  - At least 10; depends on probability of users being active at same time



Packet switching versus circuit switching

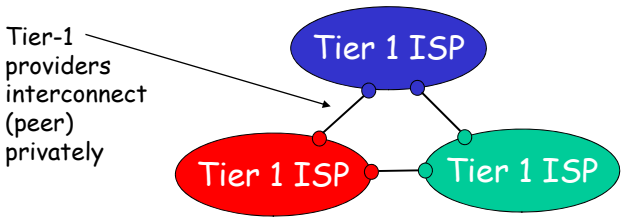
Is packet switching a clear winner?

- 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

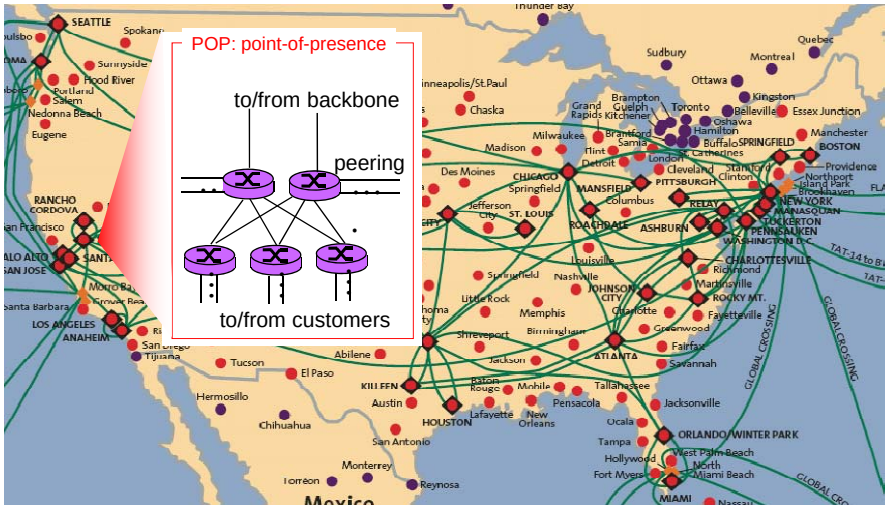
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

Internet structure: network of networks

- roughly hierarchical
- at center: "tier-1" ISPs (e.g., Global Crossing, Level 3, Sprint, AT&T), national/international coverage
  - treat each other as equals

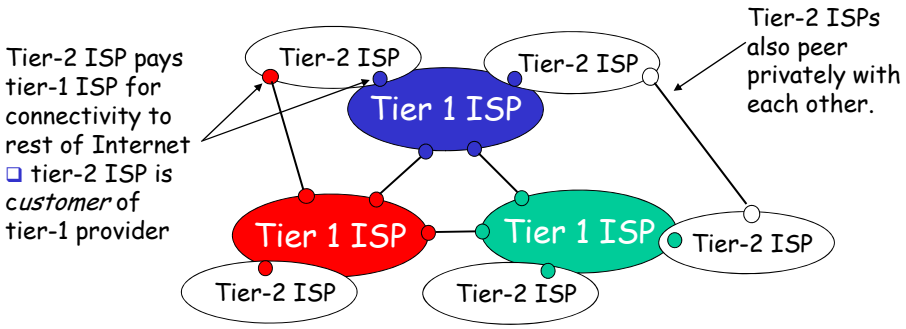


Tier-1 ISP: e.g., Sprint



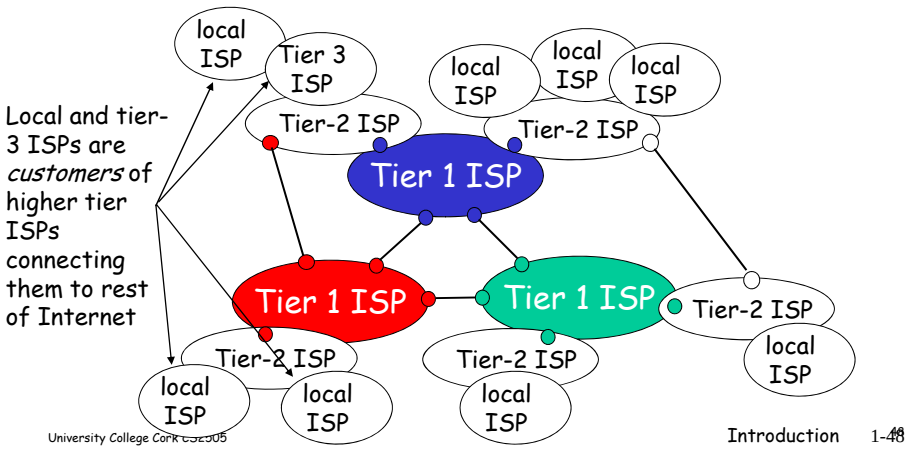
Internet structure: network of networks

- "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!