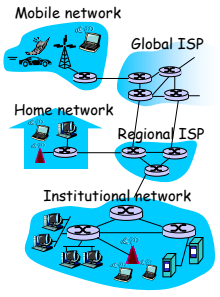
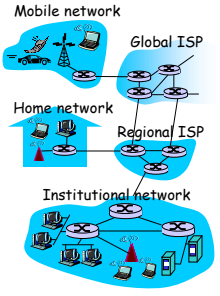
What's the Internet?

- connected computing devices: *hosts = end systems*
  - running *network apps*
- *communication links*
  - fiber, copper, radio
  - transmission rate = *bandwidth*
- *routers:* forward packets



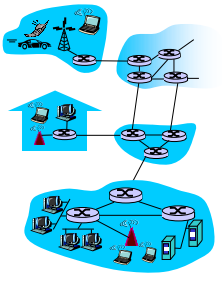
What's the Internet?

- *Protocols* control sending and receiving
  - TCP, IP, HTTP, Ethernet
- *Internet:* "network of networks"
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet? Service view:

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



What's a protocol?

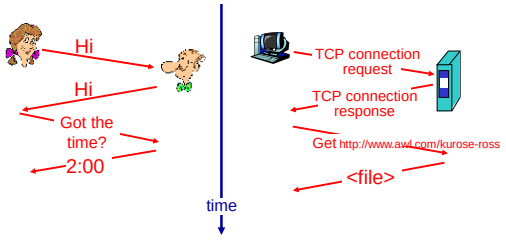
human protocols:
- "what's the time?"
- "I have a question"
- introductions

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

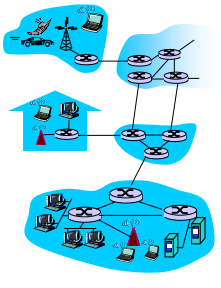
What's a protocol?

a human protocol and a computer network protocol:



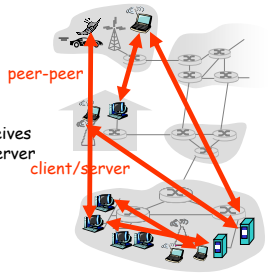
A closer look at network structure:

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



The network edge:

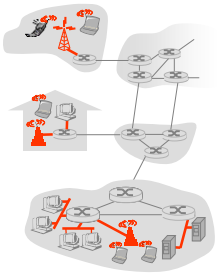
- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at "edge of network"
- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- peer-peer model:
  - minimal (or no) use of dedicated servers
  -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



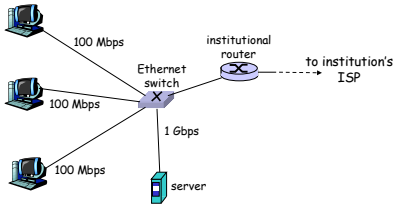
Access networks and physical media

Q: How to connect end systems to edge router?

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



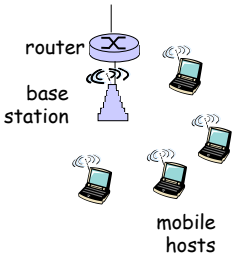
Ethernet Internet access



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

Wireless access networks

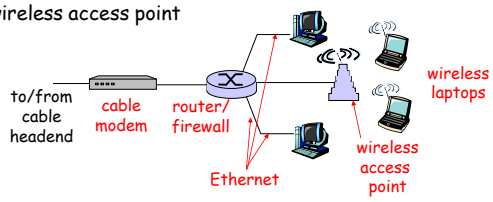
- *wireless* access network
  - via base station aka "access point"
- wireless LANs:
  - 802.11
- wider-area wireless access
  - provided by telco operator
  - 3G, 4G



Home networks

Typical home network components:

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



Physical Media

- physical link: what lies between transmitter & receiver
- guided media (cables):
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

Twisted Pair (TP)

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

Physical Media: coax, fiber

Coaxial cable:
- two concentric copper conductors

Fiber optic cable:
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gpbs)
- low error rate
- repeaters spaced far apart
- immune to electromaanetic noise

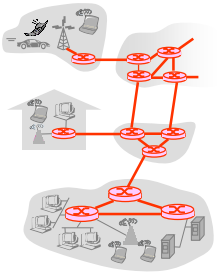
Physical media: radio

- 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 Mbps channels
- LAN (e.g., WiFi)
  - 11Mbps, 54 Mbps
- wide-area (cellular)
  - 3G, 4G
- satellite
  - 270 msec end-end delay
  - geosynchronous versus low altitude

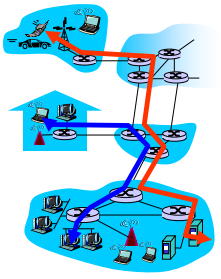
The Network Core

- mesh of interconnected routers
- *Two main principles:*
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



Network Core: Circuit Switching

- link bandwidth, switch capacity reserved for call
- no sharing
- Guaranteed performance
- call setup required

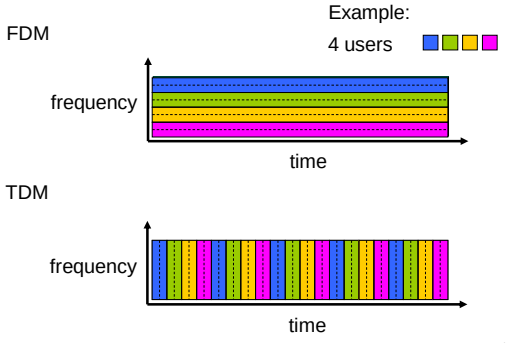


Network Core: Circuit Switching

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



Network Core: Packet Switching

data stream divided into *packets*

- packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

resource contention:

- demand can exceed capacity
- congestion: packets queue
- store and forward: packets move one hop at a time

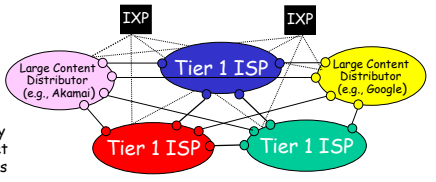
Packet switching

- great for bursty data
  - resource sharing
  - simpler, no call setup
- congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- How to provide quality of service?
  - bandwidth guarantees for audio/video apps
  - still an unsolved problem

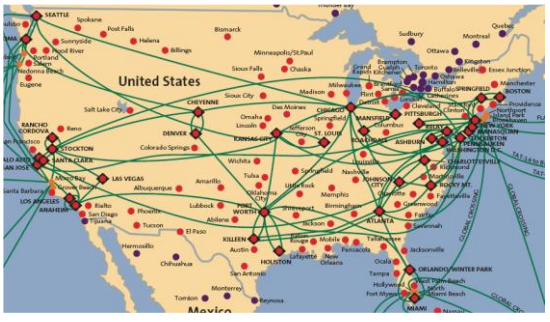
Internet structure: network of networks

- roughly hierarchical
- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Verizon, Sprint, AT&T, Qwest, Level3), national & international coverage
  - large content distributors (Google, Akamai, Microsoft)
  - treat each other as equals

Tier-1 ISPs & Content Distributors, interconnect (peer) privately … or at Internet Exchange Points IXPs



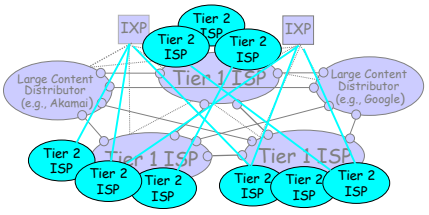
Tier-1 ISP: e.g., Sprint



Internet structure: network of networks

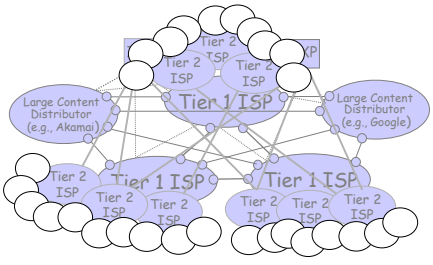
"tier-2" ISPs: smaller (often regional) ISPs

- connect to one or more tier-1 *(provider)* ISPs
  - each tier-1 has many tier-2 *customer nets*
  - tier 2 pays tier 1 provider
- tier-2 nets sometimes peer directly with each other (bypassing tier 1) , or at IXP



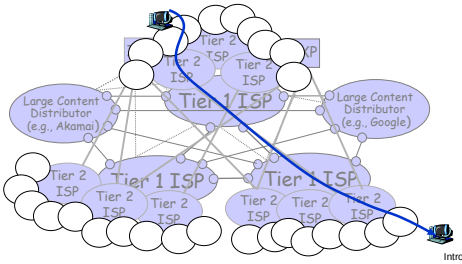
Internet structure: network of networks

- "Tier-3" ISPs, local ISPs
- customer of tier 1 or tier 2 network
  - last hop ("access") network (closest to end systems)



Internet structure: network of networks

- a packet passes through *many* networks from source host to destination host



Protocol "Layers"

Networks are complex, with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

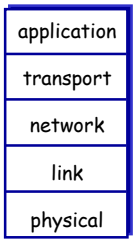
Question:

Is there any hope of *organizing* structure of network?

Or at least our discussion of networks?

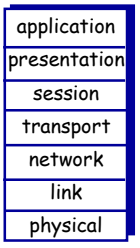
Internet protocol stack

- application: supporting network applications
  - FTP, SMTP, HTTP
- transport: process-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)
- physical: bits "on the wire"



ISO/OSI reference model

- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed,* must be implemented in application



Encapsulation