Introduction

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What is a network?

- **Carrier of information between connected entities**

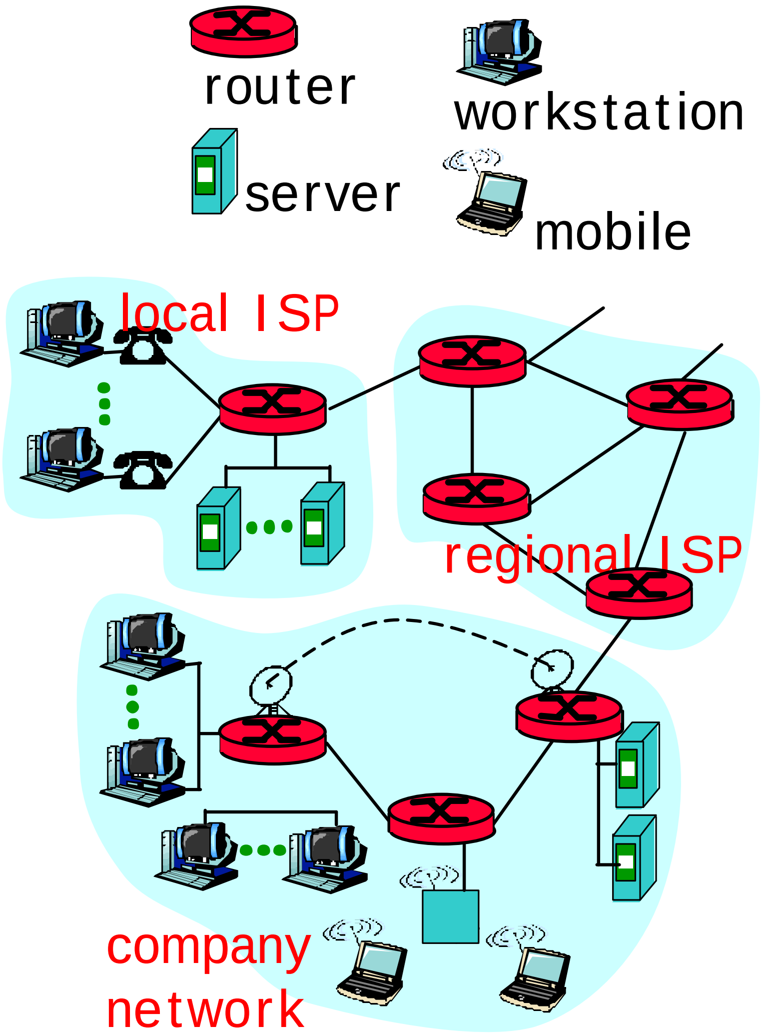
- **What does a network consist of?**
  - **End hosts connected to the network**
  - **Routers/switches that move data through the network**
  - **Physical links that carry information**
    - **E.g. Ethernet, FDDI, ATM, Token Ring**
  - **Applications that communicate with each other to provide services**
    - **E-Mail, File Transfer, Web Browser**

What is an internetwork?

- **A set of connected networks is called an internetwork.**
- **The *Internet* is a specific example of an internetwork.**
  - **The Internet is characterized by the use of a common network protocol (IP).**
- **An internetwork need NOT be connected to the *Internet***

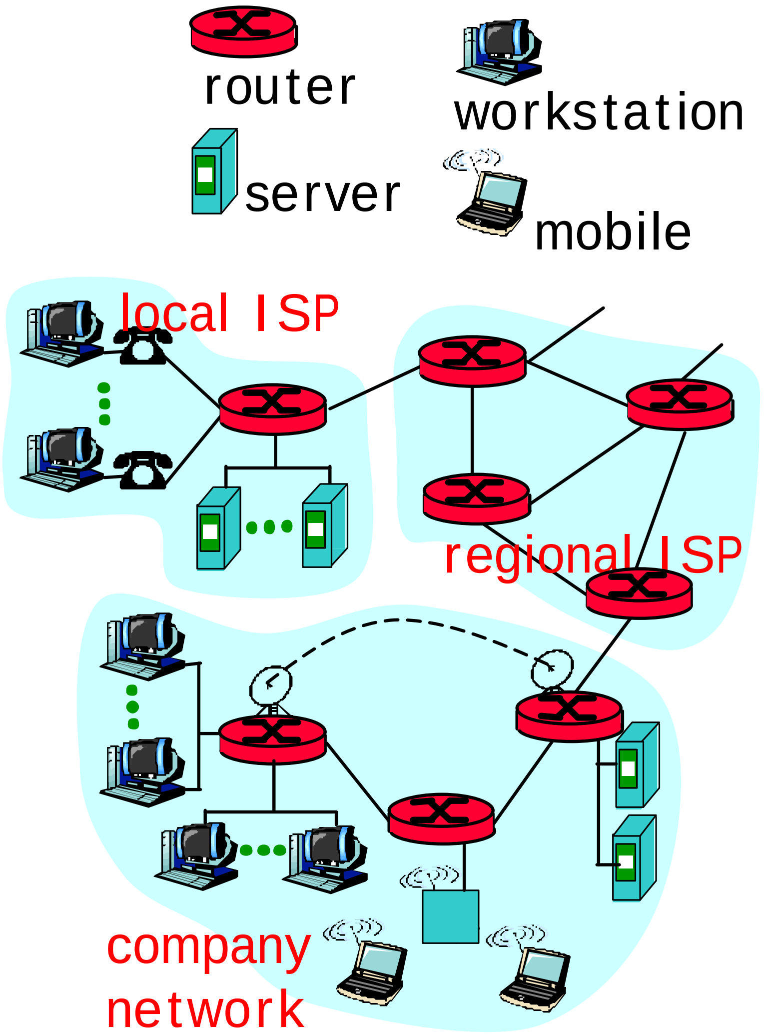
Internet: Components

- ***Network edge:***
  - millions of connected computing devices running ***network apps***
  - pc's workstations, servers
  - PDA's phones, toasters
- ***Network core:***
  - ***routers:*** forward packets (chunks) of data thru network
- ***Media:***
  - ***communication links:*** fiber, copper, radio, satellite



Internet: Components

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



Internet: Services

- **communication *infrastructure* enables distributed applications:**
  - **WWW, email, games, e-commerce, database., voting,**
  - **more?**
- **communication services provided:**
  - **connectionless**
  - **connection-oriented**
- **cyberspace [Gibson]:**

  “a consensual hallucination experienced daily by billions of operators, in every nation, ..."

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

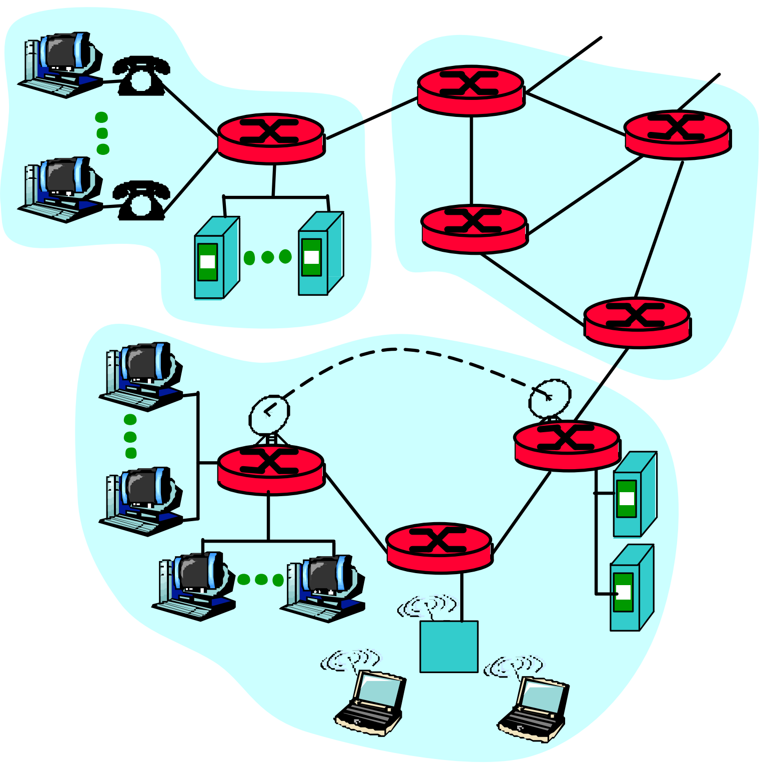
network protocols:

- 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

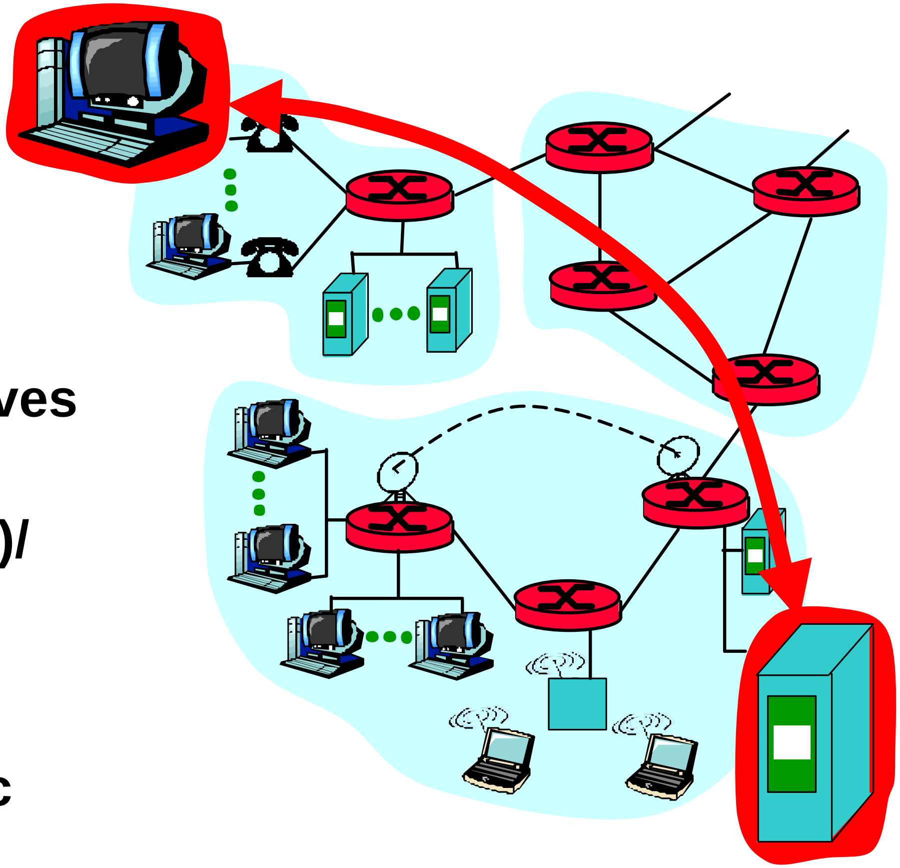
A closer look at network structure

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



The Network Edge

- **end systems (hosts):**
  - run application programs
  - e.g., WWW, email
  - at “edge of network”
- **client/server model**
  - client host requests, receives service from server
  - e.g., WWW client (browser)/ server; email client/server
- **peer-peer model:**
  - host interaction symmetric
  - e.g.: teleconferencing



Network edge: connection-oriented service

Goal: **data transfer between end sys.**

- ***handshaking:*** **setup (prepare for) data transfer ahead of time**
  - ***set up "state"*** **in two communicating hosts**
- **TCP - Transmission Control Protocol**
  - **Internet's connection-oriented service**

TCP service [RFC 793]

- ***reliable, in-order*** **byte-stream data transfer**
  - **loss: acknowledgements and retransmissions**
- ***flow control:***
  - **sender won't overwhelm receiver**
- ***congestion control:***
  - **senders "slow down sending rate" when network congested**

Network edge: connectionless service

Goal: **data transfer between end systems**

- **same as before!**

- **UDP - User Datagram Protocol [RFC 768]: Internet's connectionless service**
  - **unreliable data transfer**
  - **no flow control**
  - **no congestion control**

App's using TCP:

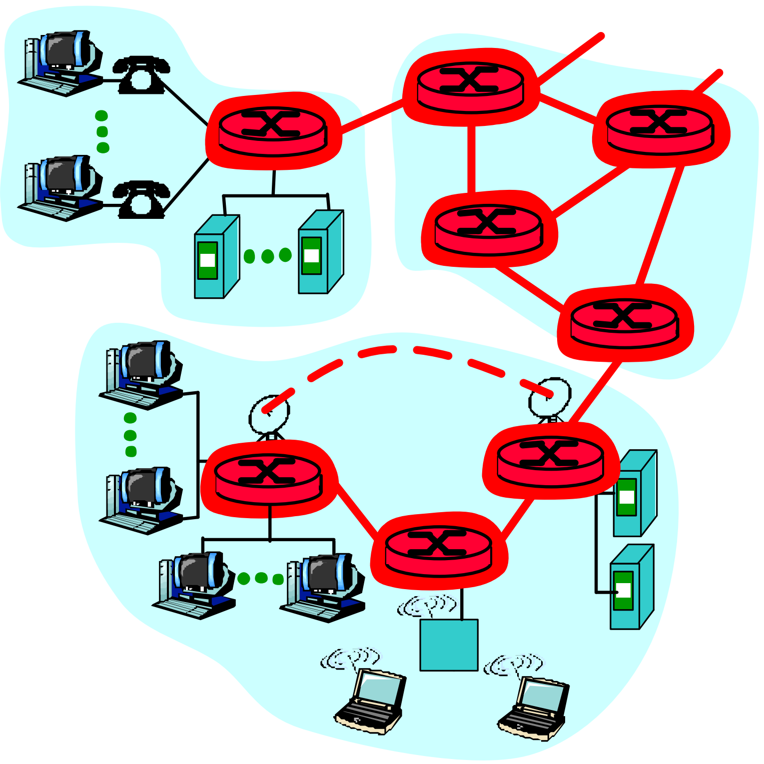
- **HTTP (WWW), FTP (file transfer), Telnet (remote login), SMTP (email)**

App's using UDP:

- **streaming media, teleconferencing, Internet telephony**

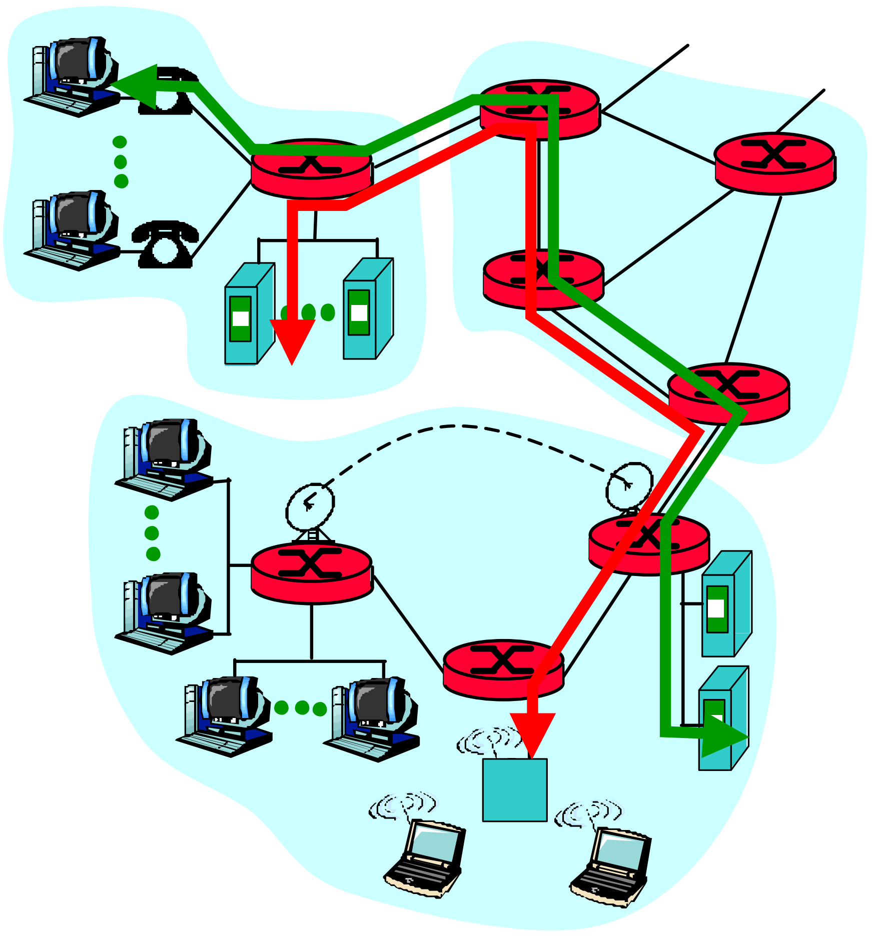
The Network Core

- 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

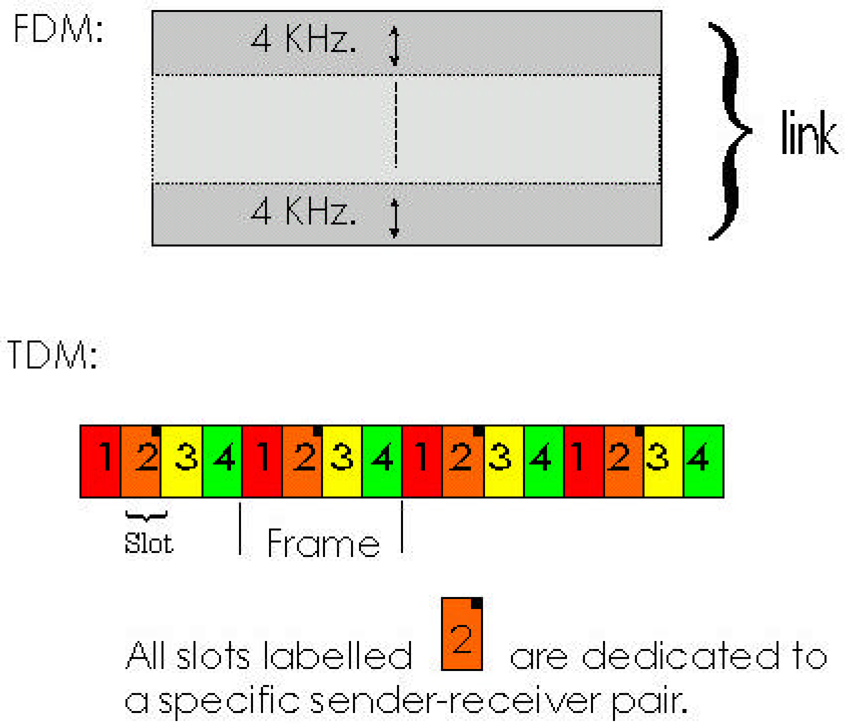
End-end resources reserved for "call"



- **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**



Network Core: Packet Switching

each end-end data stream divided into *packets*

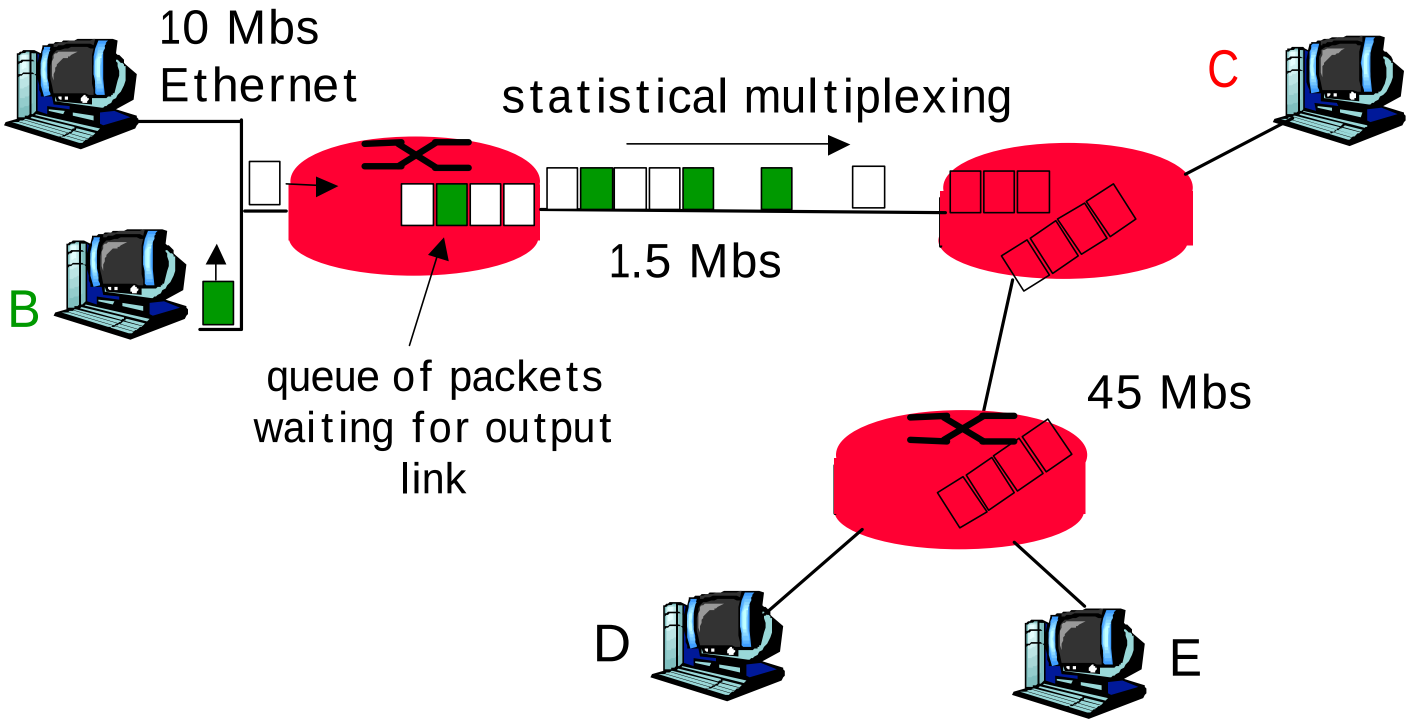
- **user A, B packets *share* network resources**
- **each packet uses full link bandwidth**
- **resources used *as needed*,**

Bandwidth division into "pieces"
Dedicated allocation
Resource reservation

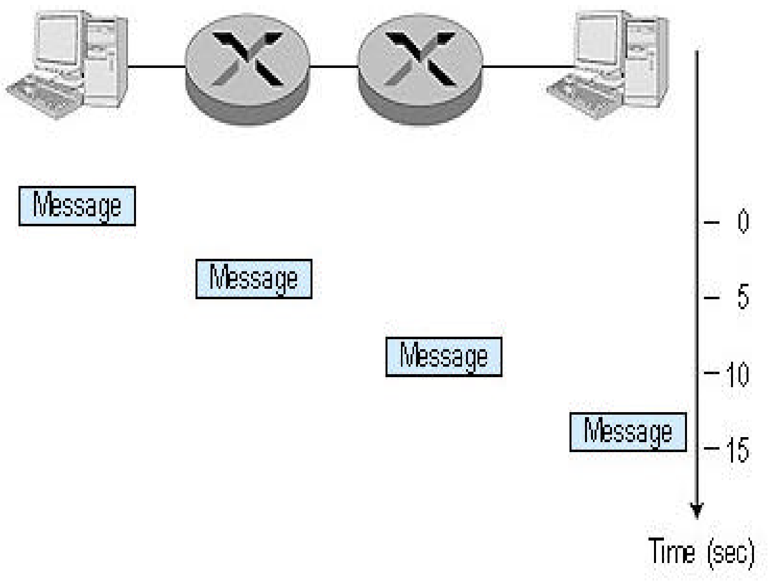
resource contention:

- **aggregate resource demand can exceed amount available**
- **congestion: packets queue, wait for link use**
- **store and forward: packets move one hop at a time**
  - **transmit over link**
  - **wait turn at next link**

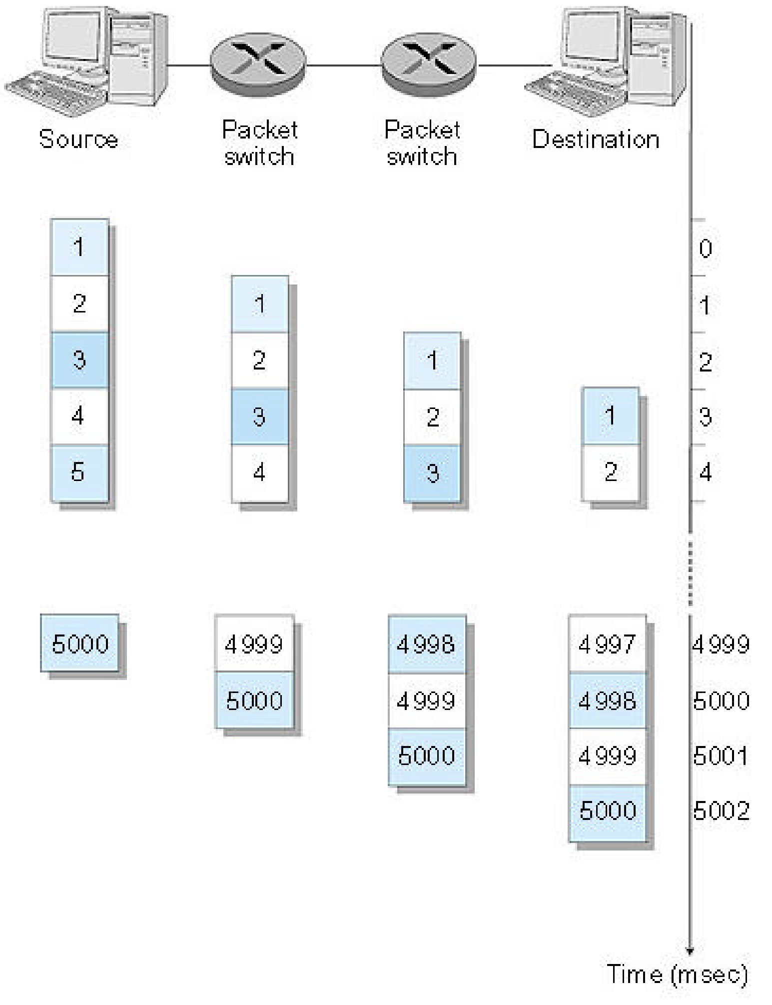
Network Core: Packet Switching



Network Core: Packet Switching



Message Switching



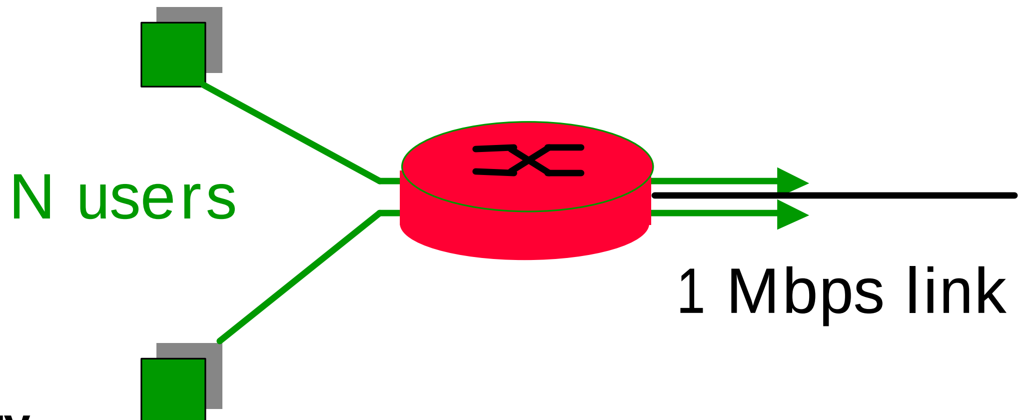
Segmented Packet Switching

Packet switching versus circuit switching

Packet switching allows more users to use network!

- **1 Mbit link**
- **each user:**
  - **100Kbps when "active"**
  - **active 10% of time**

- **circuit-switching:**
  - **10 users**
- **packet switching:**
  - **with 35 users, probability > 10 active less that .004**



Packet switching versus circuit switching

Is packet switching the "ultimate solution"

- **Great for bursty data**
  - **resource sharing**
  - **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

Packet-switched networks: routing

- ***Goal:*** **move packets among routers from source to destination**
- **datagram network:**
  - ***destination address*** **determines next hop**
  - **routes may change during session**
  - **analogy: driving, asking directions**
- **virtual circuit network:**
  - **each packet carries tag (virtual circuit ID), tag determines next hop**
  - **fixed path determined at *call setup time*, remains fixed thru call**
  - **routers maintain per-call state**

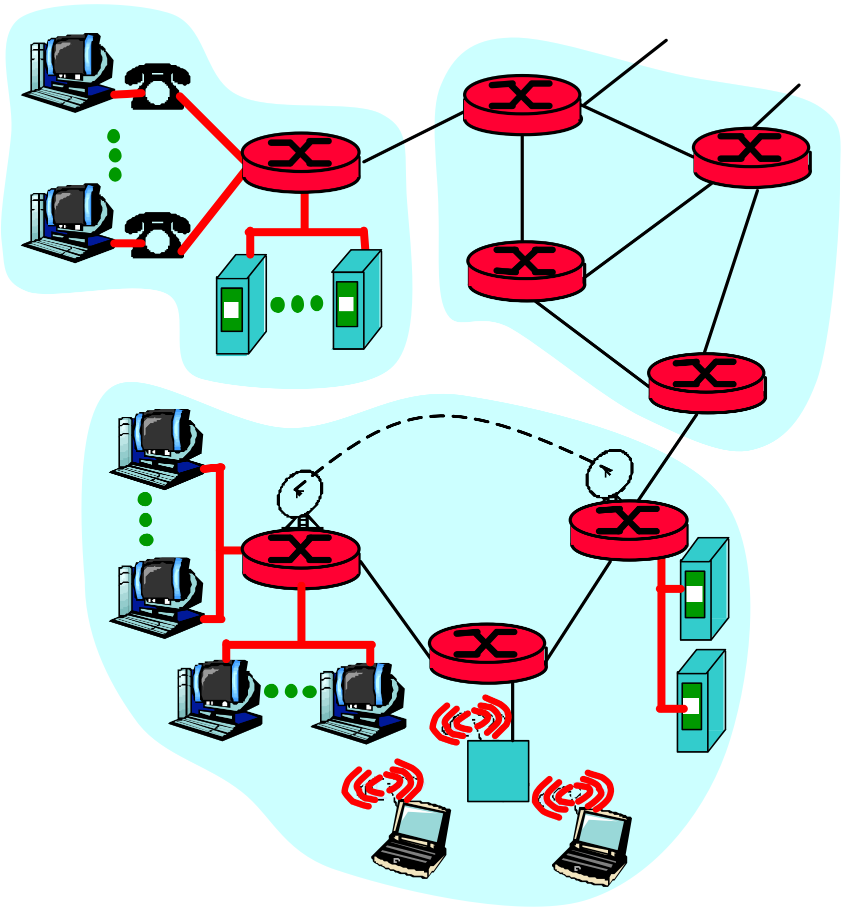
Access networks and physical media

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

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

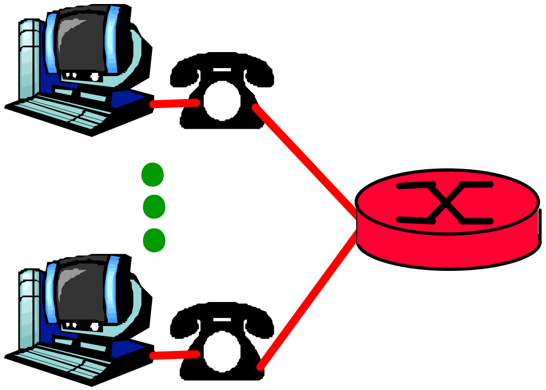
Keep in mind:

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



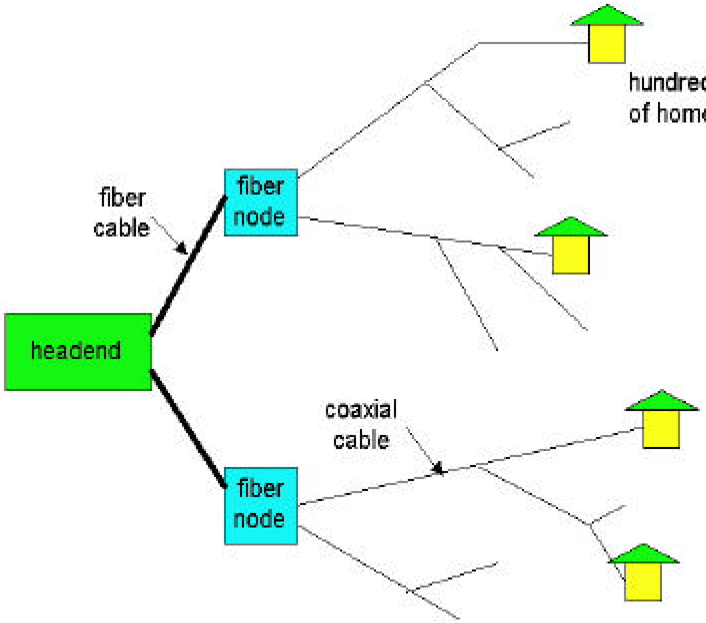
Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (conceptually)
- ISDN: integrated services digital network: 128Kbps all-digital connect to router
- ADSL: asymmetric digital subscriber line
  - up to 1 Mbps home-to-router
  - up to 8 Mbps router-to-home



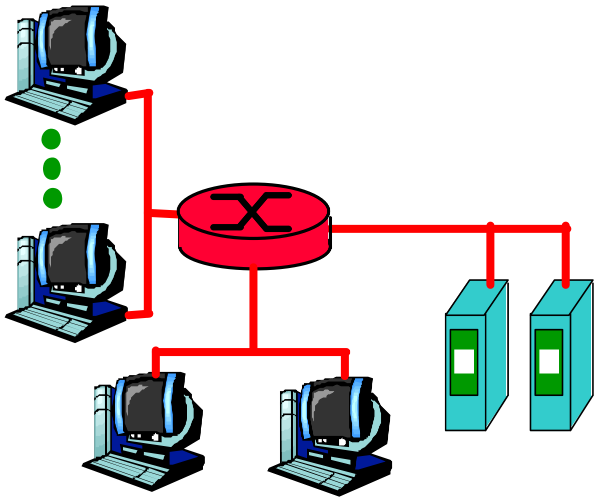
Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 10Mbps upstream, 1 Mbps downstream
- network of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning
- deployment: available via cable companies, e.g., MediaOne



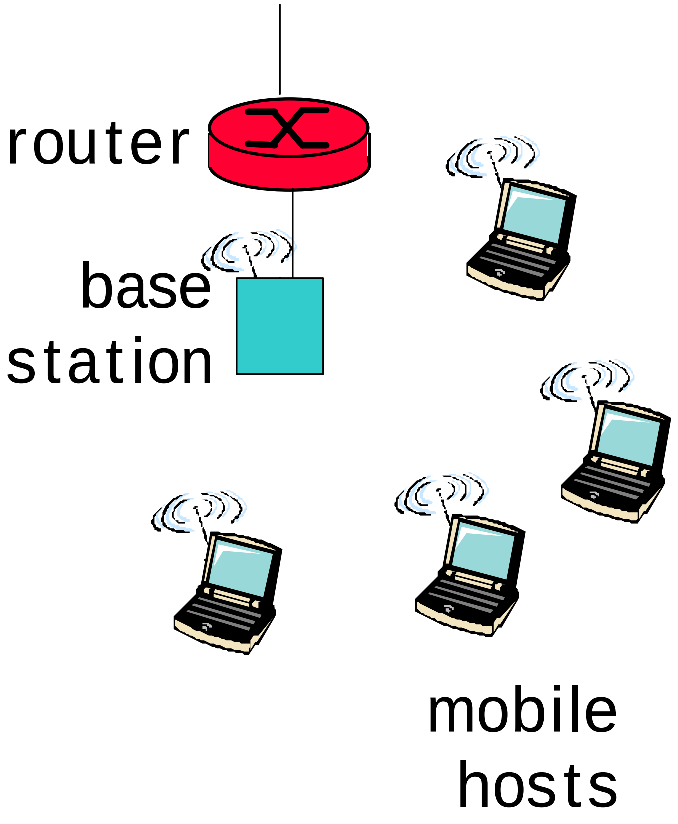
Institutional access: local area networks

- company/univ **local area network** (LAN) connects end system to edge router
- **Ethernet:**
  - shared or dedicated cable connects end system and router
  - 10 Mbs, 100Mbps, Gigabit Ethernet
- **deployment:** institutions, home LANs soon



Wireless access networks

- **shared *wireless* access network connects end system to router**
- **wireless LANs:**
  - **radio spectrum replaces wire**
  - **e.g., Lucent Wavelan 10 Mbps**
- **wider-area wireless access**
  - **CDPD: wireless access to ISP router via cellular network**



Physical Media

- **physical link:** transmitted data bit propagates across link
- **guided media:**
  - signals propagate in solid media: copper, fiber
- **unguided media:**
  - signals propagate freelye.g., radio

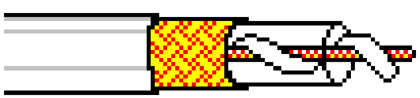
Twisted Pair (TP)

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

Physical Media: coax, fiber

Coaxial cable:

- wire (signal carrier) within a wire (shield)
  - baseband: single channel on cable
  - broadband: multiple channels on cable
- bidirectional
- common use in 10Mbs Ethernet



Fiber optic cable:

- glass fiber carrying light pulses
- high-speed operation:
  - 100Mbps Ethernet
  - high-speed point-to-point transmission (e.g., 5 Gbps)
- low error rate

Physical media: radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

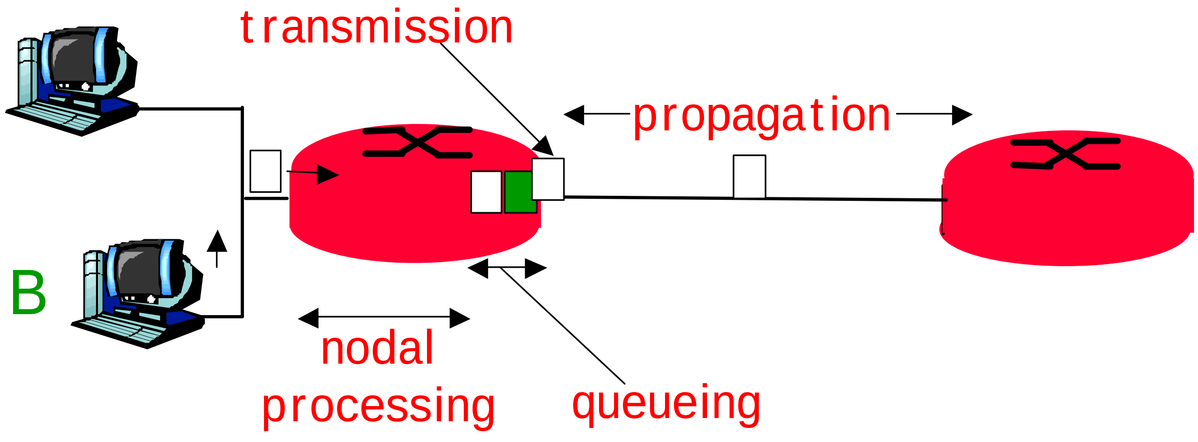
Radio link types:

- microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., waveLAN)
  - 2Mbps, 11Mbps
- wide-area (e.g., cellular)
  - e.g. CDPD, 10's Kbps
- satellite
  - up to 50Mbps channel (or multiple smaller channels)
  - 270 Msec end-end delay
  - geosynchronous versus LEOS

Delay in packet-switched networks

- packets experience delay on end-to-end path
- four sources of delay at each hop

- nodal processing:
  - check bit errors
  - determine output link
- queueing
  - time waiting at output link for transmission
  - depends on congestion level of router



Delay in packet-switched networks

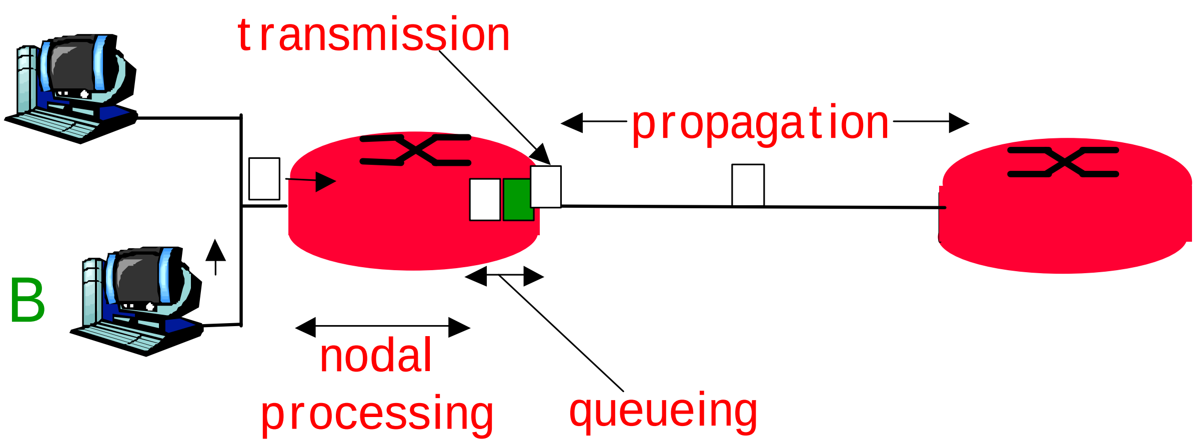
Transmission delay:

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

Propagation delay:

- d = length of physical link
- s = propagation speed in medium (~$2x10^8$ m/sec)
- propagation delay = d/s

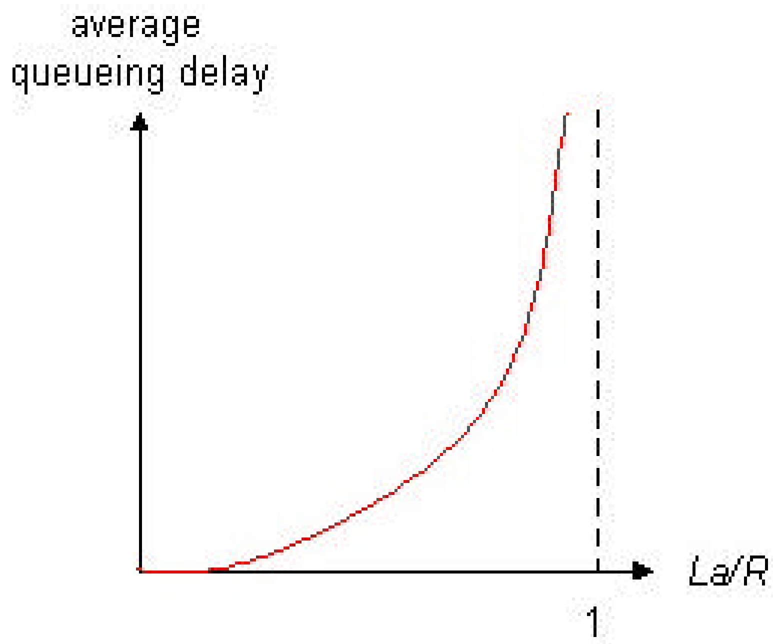
Note: s and R are *very* different quantitites!



Queuing delay (revisited)

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate

traffic intensity = La/R



- La/R ~ 0: average queuing delay small
- La/R <= 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

Protocol "Layers"

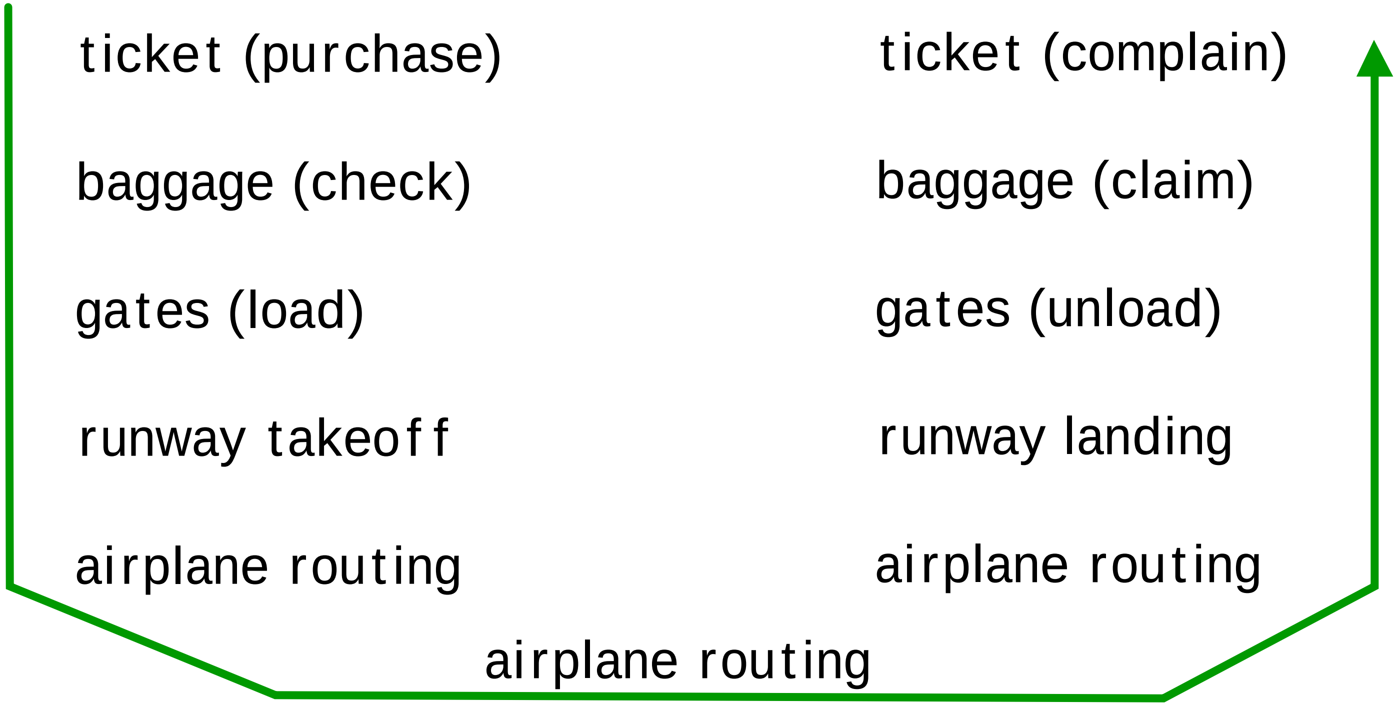
Networks are complex!

- **many "pieces":**
  - **hosts**
  - **routers**
  - **links of various media**
  - **applications**
  - **protocols**
  - **hardware, software**

Question:

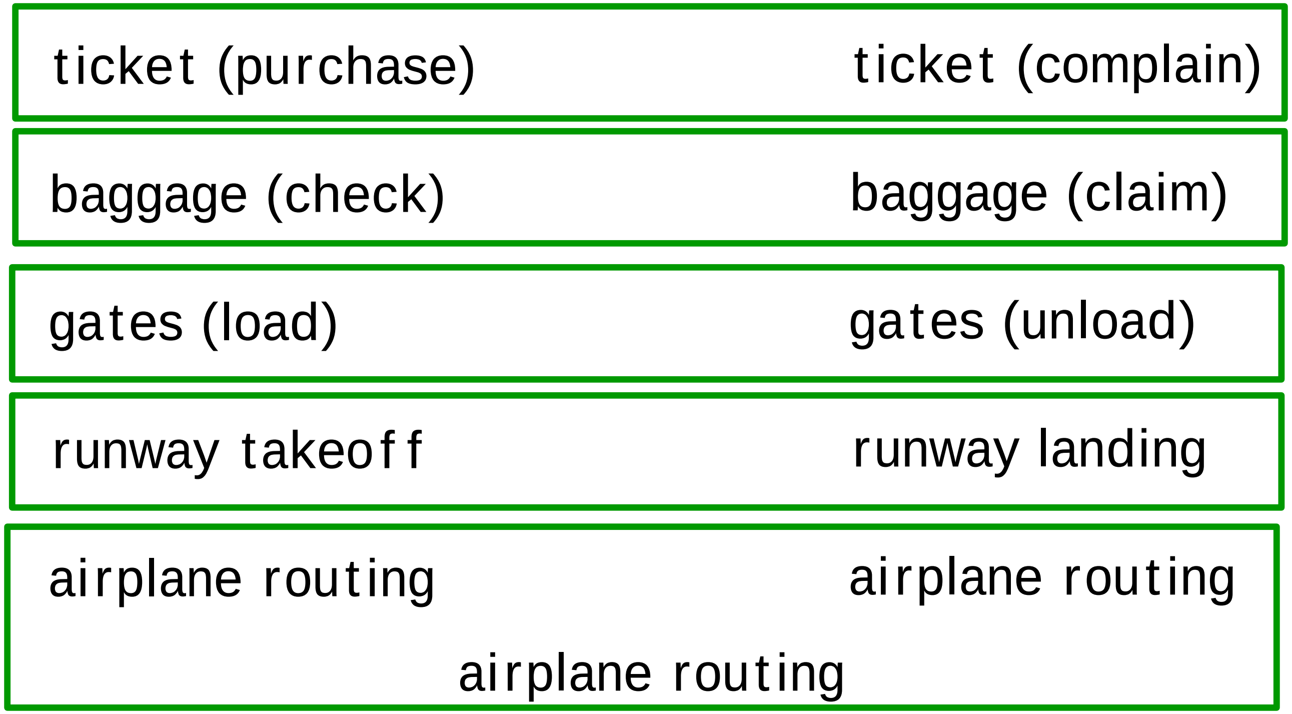
Is there any hope of *organizing* structure of network?

Organization of air travel



- **a series of steps**

Organization of air travel: a different view



Layers: **each layer implements a service**

- **via its own internal-layer actions**
- **relying on services provided by layer below**

Layered air travel: services

Counter-to-counter delivery of person+bags

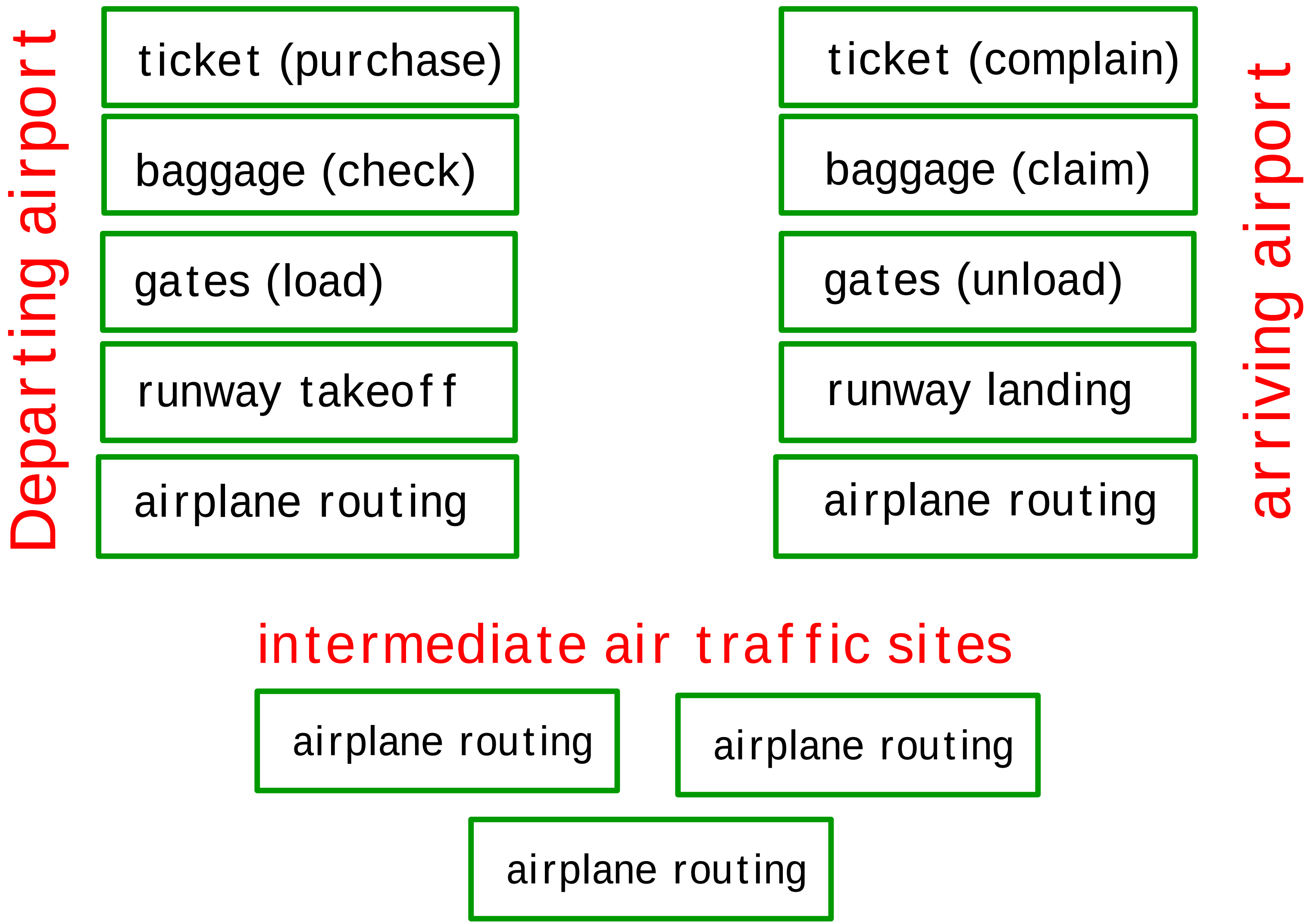
baggage-claim-to-baggage-claim delivery

people transfer: loading gate to arrival gate

runway-to-runway delivery of plane

airplane routing from source to destination

Distributed implementation of layer functionality



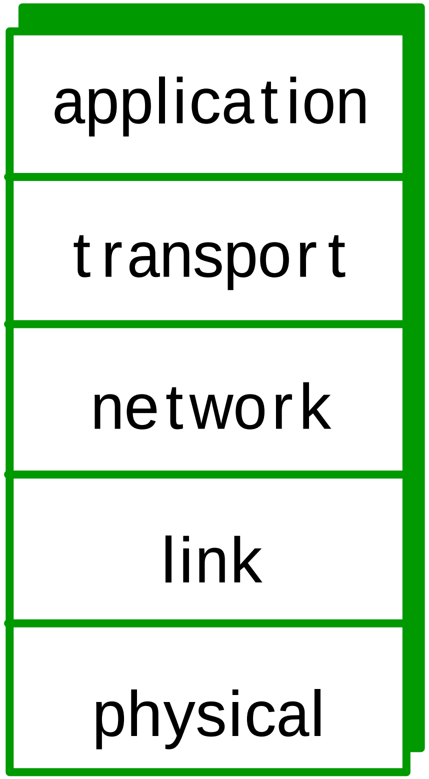
Why layering?

Dealing with complex systems:

- **explicit structure allows identification, relationship of complex system's pieces**
  - **layered reference model for discussion**
- **modularization eases maintenance, updating of system**
  - **change of implementation of layer's service transparent to rest of system**
  - **e.g., change in gate procedure doesn't affect rest of system**
- **layering considered harmful?**

Internet protocol stack

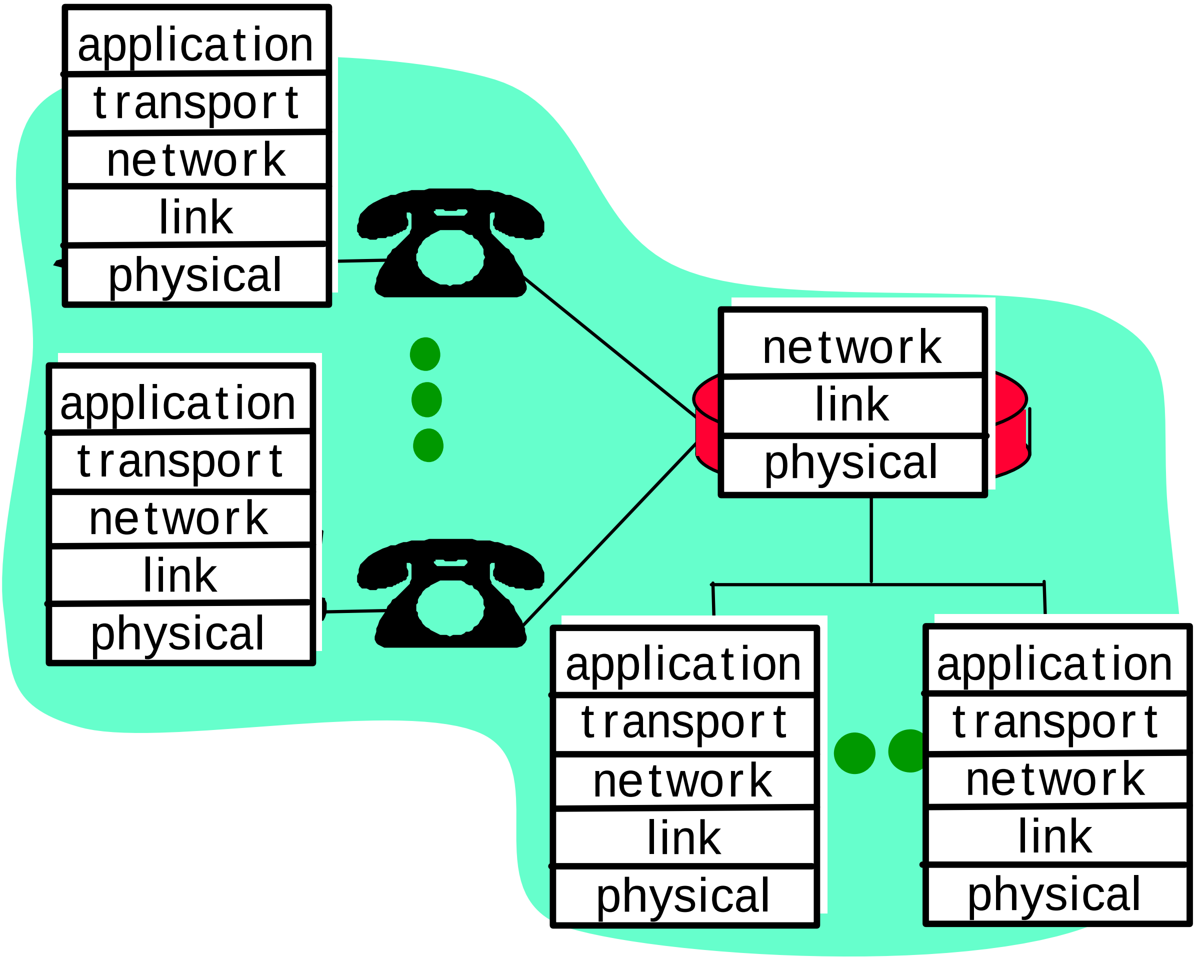
- **application:** **supporting network applications**
  - **ftp, smtp, http**
- **transport:** **process-process data transfer**
  - **tcp, udp**
- **network:** **routing of datagrams from source to destination**
  - **ip, routing protocols**
- **link:** **data transfer between neighboring network elements**
  - **ppp, ethernet**
- **physical:** **bits "on the wire"**



Layering: logical communication

Each layer:

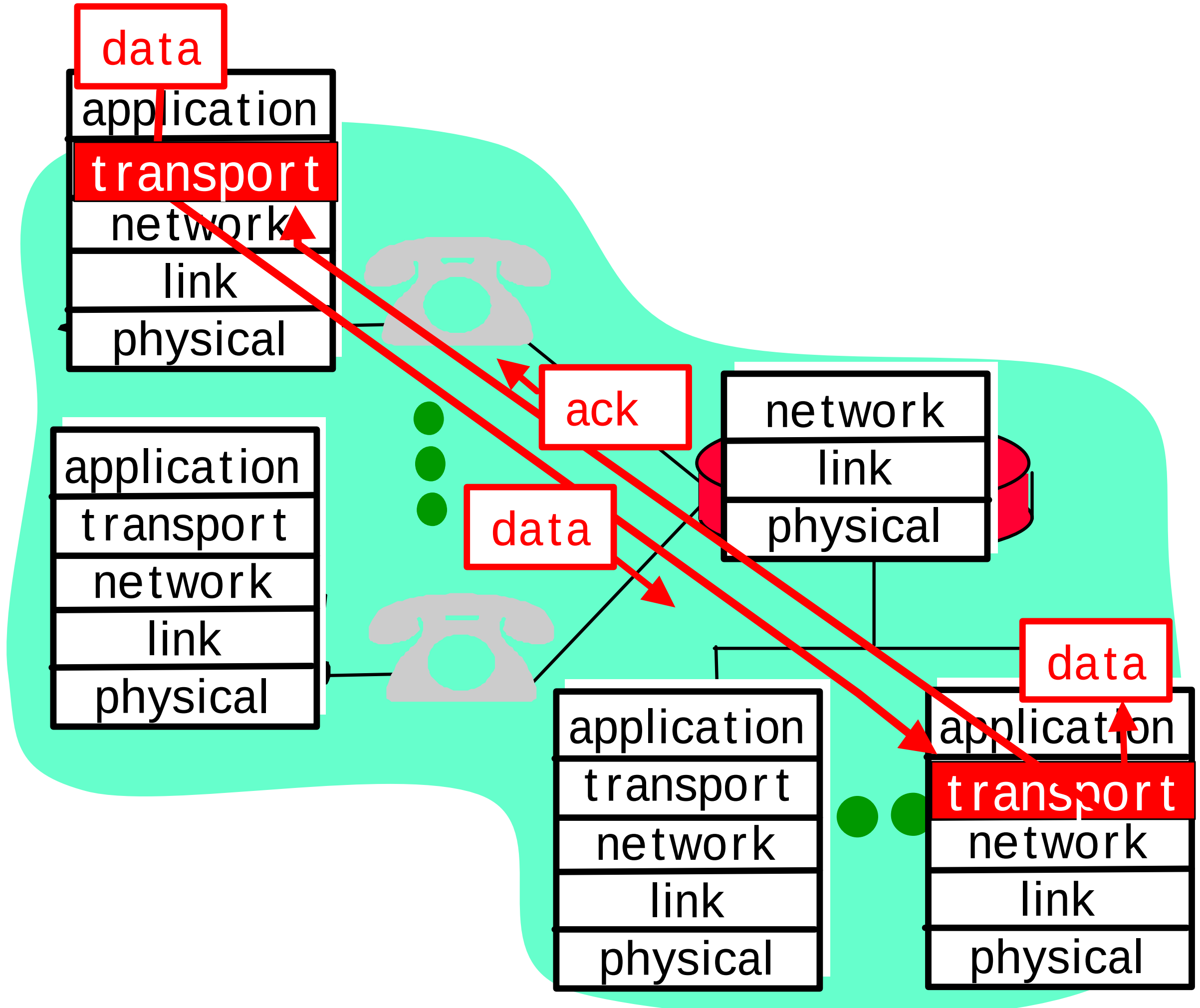
- **distributed**
- **“entities” implement layer functions at each node**
- **entities perform actions, exchange messages with peers**



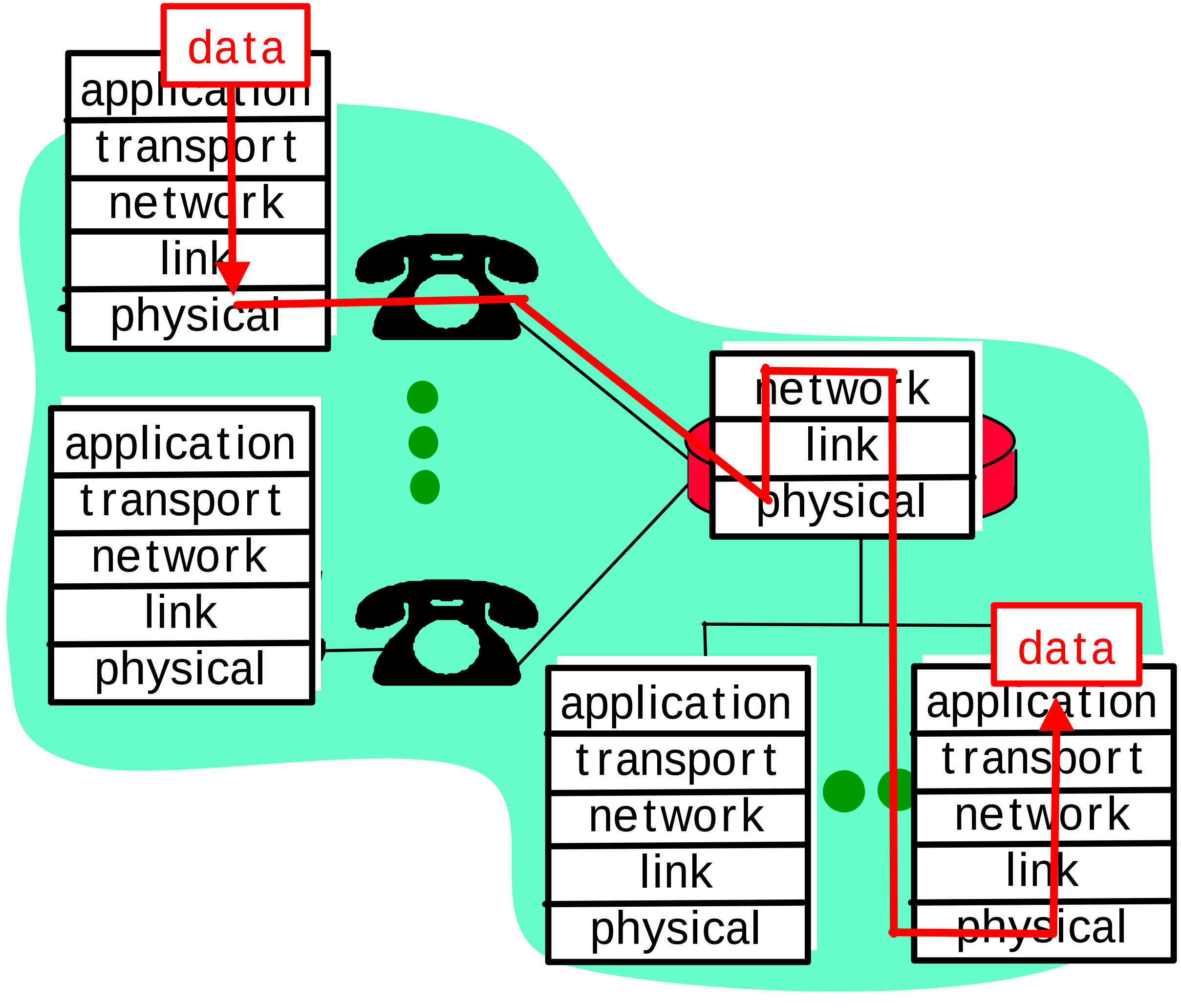
Layering: *logical* communication

E.g.: transport

- **take data from app**
- **add addressing, reliability check info to form "datagram"**
- **send datagram to peer**
- **wait for peer to ack receipt**
- **analogy: post office delivery to person**



Layering: physical communication



Protocol layering and data

Each layer takes data from above

- **adds header information to create new data unit**
- **passes new data unit to layer below**