Chapter 2 Application Layer

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Computer Networking: A Top-Down Approach

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Application layer: overview

- Principles of network applications
- Web and HTTP
- E-mail, SMTP, IMAP
- The Domain Name System DNS

- P2P applications
- video streaming and content distribution networks
- socket programming with UDP and TCP



Application layer: overview

Our goals:

- conceptual and implementation aspects of application-layer protocols
 - transport-layer service models
 - client-server paradigm
 - peer-to-peer paradigm

- learn about protocols by examining popular application-layer protocols and infrastructure
 - HTTP
 - SMTP, IMAP
 - DNS
 - video streaming systems, CDNs
- programming network applications
 - socket API

Some network apps

- social networking
- Web
- text messaging
- e-mail
- multi-user network games
- streaming stored video (YouTube, Hulu, Netflix)
- P2P file sharing

- voice over IP (e.g., Skype)
- real-time video conferencing (e.g., Zoom)
- Internet search
- remote login
- • •

Q: your favorites?

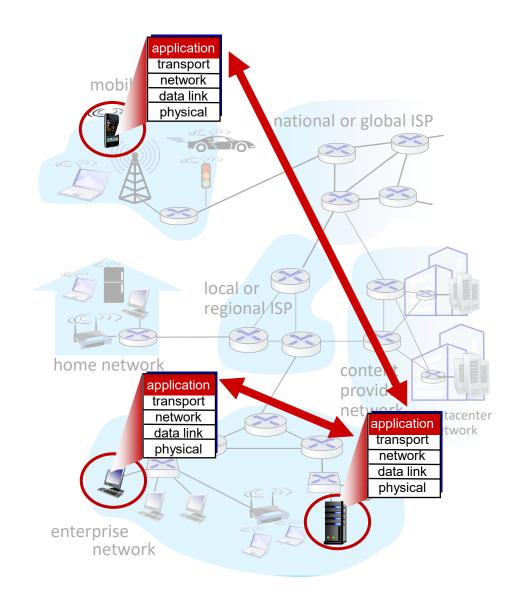
Creating a network app

write programs that:

- run on (different) end systems
- communicate over network
- e.g., web server software communicates with browser software

no need to write software for network-core devices

- network-core devices do not run user applications
- applications on end systems allows for rapid app development, propagation





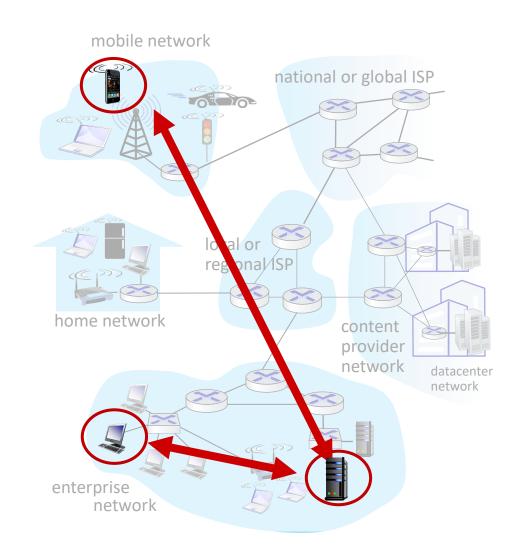
Client-server paradigm

server:

- always-on host
- permanent IP address
- often in data centers, for scaling

clients:

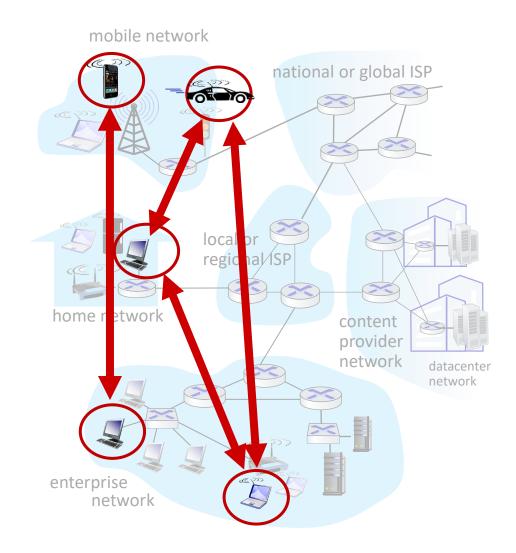
- contact, communicate with server
- may be intermittently connected
- may have dynamic IP addresses
- do not communicate directly with each other
- examples: HTTP, IMAP, FTP





Peer-peer architecture

- no always-on server
- arbitrary end systems directly communicate
- peers request service from other peers, provide service in return to other peers
 - self scalability new peers bring new service capacity, as well as new service demands
- peers are intermittently connected and change IP addresses
 - complex management
- example: P2P file sharing [BitTorrent]



Processes communicating

- process: program running
 within a host
- within same host, two processes communicate using inter-process communication (defined by OS)
- processes in different hosts communicate by exchanging messages

clients, servers

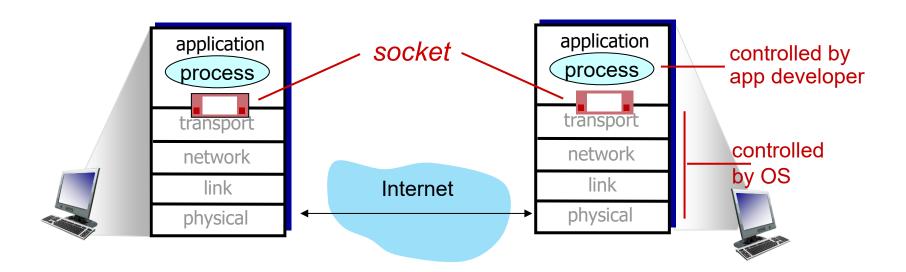
client process: process that initiates communication

server process: process that waits to be contacted

 note: applications with P2P architectures have client processes & server processes

Sockets

- process sends/receives messages to/from its socket
- socket analogous to door
 - sending process shoves message out door
 - sending process relies on transport infrastructure on other side of door to deliver message to socket at receiving process
 - two sockets involved: one on each side



Addressing processes

- to receive messages, process must have *identifier*
- host device has unique 32-bit
 IP address
- Q: does IP address of host on which process runs suffice for identifying the process?
 - A: no, many processes can be running on same host

- identifier includes both IP address and port numbers associated with process on host.
- example port numbers:
 - HTTP server: 80
 - mail server: 25
- to send HTTP message to gaia.cs.umass.edu web server:
 - IP address: 128.119.245.12
 - port number: 80
- more shortly...

An application-layer protocol defines:

- types of messages exchanged,
 - e.g., request, response
- message syntax:
 - what fields in messages & how fields are delineated
- message semantics
 - meaning of information in fields
- rules for when and how processes send & respond to messages

open protocols:

- defined in RFCs, everyone has access to protocol definition
- allows for interoperability
- e.g., HTTP, SMTP

proprietary protocols:

e.g., Skype, Zoom

What transport service does an app need?

data integrity

- some apps (e.g., file transfer, web transactions) require
 100% reliable data transfer
- other apps (e.g., audio) can tolerate some loss

timing

 some apps (e.g., Internet telephony, interactive games) require low delay to be "effective"

throughput

- some apps (e.g., multimedia) require minimum amount of throughput to be "effective"
- other apps ("elastic apps")
 make use of whatever
 throughput they get

security

encryption, data integrity,

Transport service requirements: common apps

application	data loss	throughput	time sensitive?
file transfer/download	no loss	elastic	no
e-mail	no loss	elastic	no
Web documents	no loss	elastic	no
real-time audio/video	loss-tolerant	audio: 5Kbps-1Mbps video:10Kbps-5Mbps	yes, 10's msec
streaming audio/video	loss-tolerant	same as above	yes, few secs
interactive games	loss-tolerant	Kbps+	yes, 10's msec
text messaging	no loss	elastic	yes and no

Internet transport protocols services

TCP service:

- reliable transport between sending and receiving process
- *flow control:* sender won't overwhelm receiver
- congestion control: throttle sender when network overloaded
- connection-oriented: setup required between client and server processes
- does not provide: timing, minimum throughput guarantee, security

UDP service:

- unreliable data transfer
 between sending and receiving process
- does not provide: reliability, flow control, congestion control, timing, throughput guarantee, security, or connection setup.

Q: why bother? Why is there a UDP?

Internet applications, and transport protocols

application	application layer protocol	transport protocol
file transfer/download	FTP [RFC 959]	TCP
e-mail	SMTP [RFC 5321]	TCP
Web documents	HTTP [RFC 7230, 9110]	ТСР
Internet telephony	SIP [RFC 3261], RTP [RFC	TCP or UDP
	3550], or proprietary	
streaming audio/video	HTTP [RFC 7230], DASH	ТСР
interactive games	WOW, FPS (proprietary)	UDP or TCP

Securing TCP

Vanilla TCP & UDP sockets:

- no encryption
- cleartext passwords sent into socket traverse Internet in cleartext (!)

Transport Layer Security (TLS)

- provides encrypted TCP connections
- data integrity
- end-point authentication

TLS implemented in application layer

- apps use TLS libraries, that use TCP in turn
- cleartext sent into "socket" traverse Internet encrypted
- more: Chapter 8