
Networked Communication

What *are* networks and protocols?

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A solid blue vertical bar is positioned on the right side of the slide, extending from the top of the content area to the bottom.

- What's the Internet?
- What's a protocol?
- Network edge
- Hosts, access network, physical media
- Network core
- Security
- Protocol layers, service models



After this lecture and associated assignment, you will be able to:

- Follow the key elements of our course and describe its structure (lecture, exercises, exams)
- State the goals of this course
- Describe what 'the Internet' and 'a Protocol' are on a high level
- Know key-terminology in terms of access and core networks
- Describe key characteristics of network access mod
- Describe the basics of packet forwarding
- Calculate the latency and bandwidth for example topologies using the terminology of the lecture



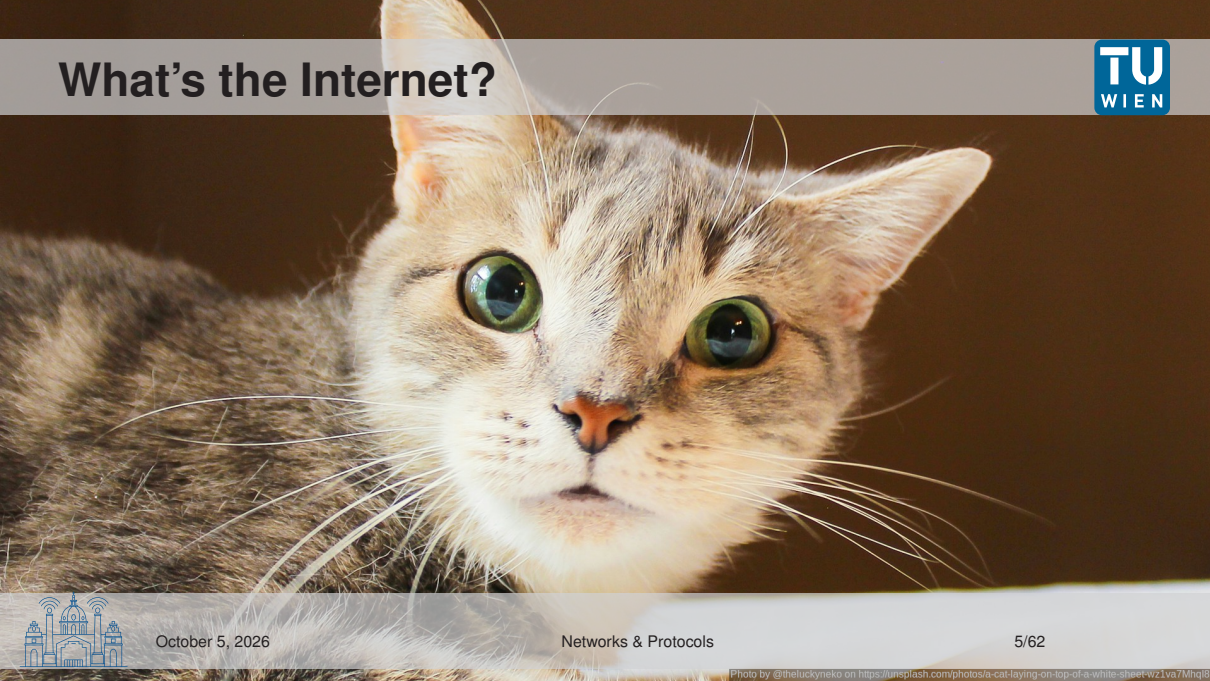
Goals:

Get “feel”, “big picture”, Introduction of terminology

- More depth and detail later in course
- Approach:
 - Use Internet as example



What's the Internet?



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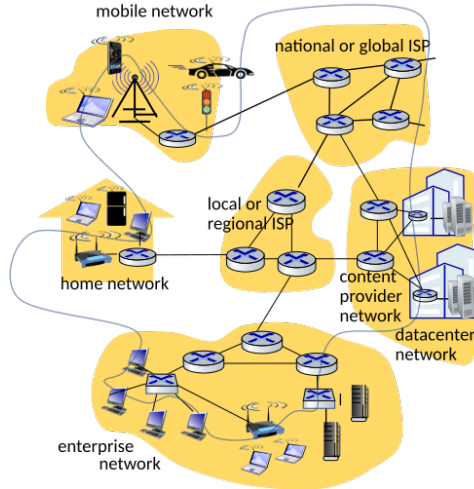
The Internet: A “Nuts and Bolts” View

Billions of connected computing **devices**:

- **Hosts:**
 - End systems
 - Running network apps at Internet’s “edge”
- **Packet switches:**
 - Forward packets (chunks of data)
 - Routers, switches
- **Communication links:**
 - Transmit packets
 - Fiber, copper, radio, satellite
- **Networks:**
 - Collection of hosts, routers, switches, and links
 - Managed by an organization



An example “Internet”



“Fun” Internet-connected devices



Amazon Echo



Internet refrigerator



IP picture frame



Pacemaker & Monitor



Tweet-a-watt:
monitor energy use
bikes



Security Camera



Slingbox: remote
control cable TV



Web-enabled toaster +
weather forecaster



cars



AR devices



scooters



Internet phones



Gaming devices



sensorized
bed
mattress



Fitbit



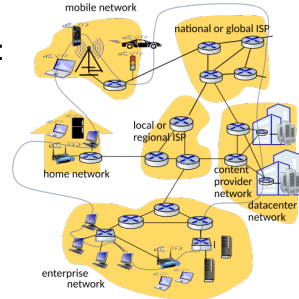
diapers

Others?



The Internet: A “Services” View

- **Infrastructure** that provides services to applications:
 - Web
 - Streaming video
 - Multimedia conferencing
 - E-mail, E-commerce
 - Games
 - Social media
 - Inter-connected appliances
 - ...
- Provides **programming interfaces** to distributed applications:
 - “Hooks” allow apps to send & receive, i.e., connect to the Internet and use it as a transport service
 - Provides service options, analogous to a postal service



What's a protocol?



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What's a Protocol?

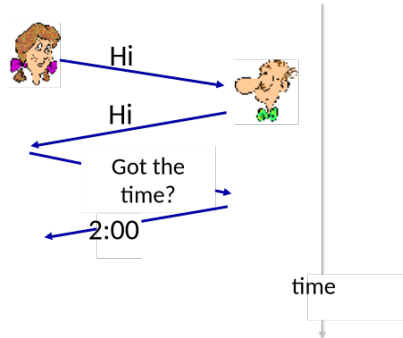
Definitions for:

- Message composition to express semantics
- Message decomposition to extract semantics
- Valid states of communicating entities
- Actions taken based on state and received semantics



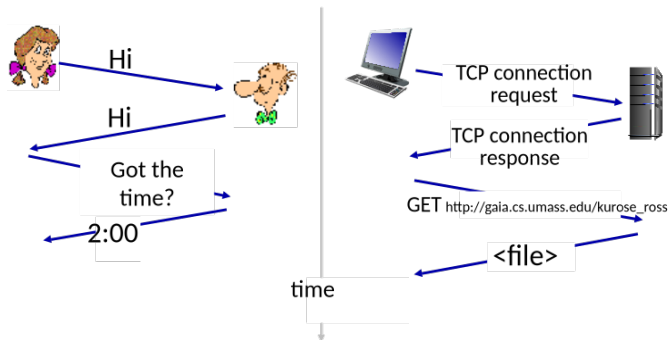
What's a Protocol?

A human protocol:



What's a Protocol?

A human protocol and a network protocol:



What's a Protocol?

- Human protocols:
 - “What’s the time?”
 - “I have a question”
 - Introductions, greetings, ...
- Network protocols:
 - Computers (devices) rather than humans
 - All communication activity in the Internet is governed by protocols

Protocols define the format and order of messages sent and received among communication entities, and actions taken for message transmission and upon message receipt.

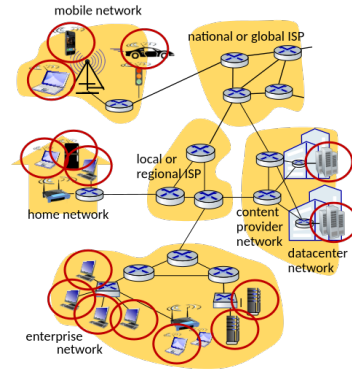




A Closer Look at Internet Structure

Network edge:

- Hosts: clients and servers
- Servers are often in data centers



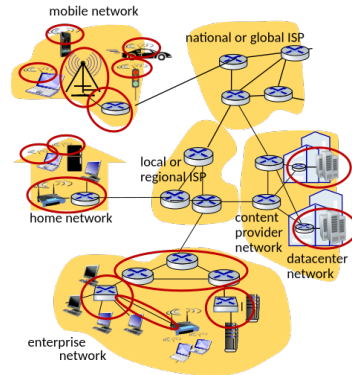
A Closer Look at Internet Structure

Network edge:

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Access networks, physical media

- Wired communication links
- Wireless communication links



A Closer Look at Internet Structure

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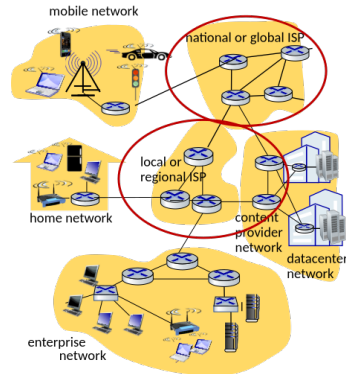
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Access networks, physical media

- Wired communication links
- Wireless communication links

Network core

- Interconnected routers
- Network of networks

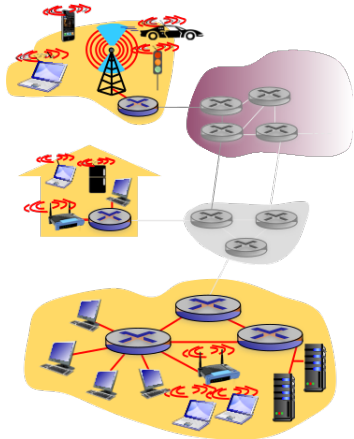


Q: How to connect end systems to an edge router?

- Residential access networks
- Institutional access networks (schools, companies)
- Mobile access networks

Keep in mind:

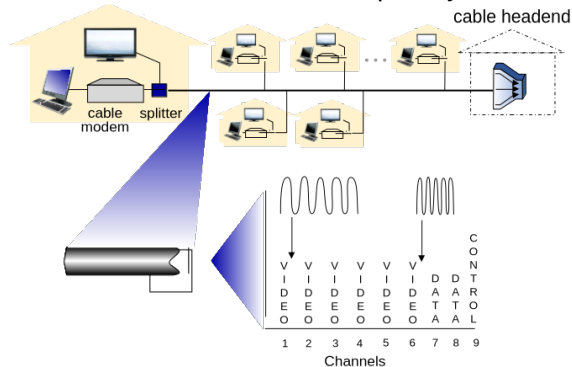
- Bandwidth (bits per second) of access network?
- Shared or dedicated?



Access Networks: Cable-based Access

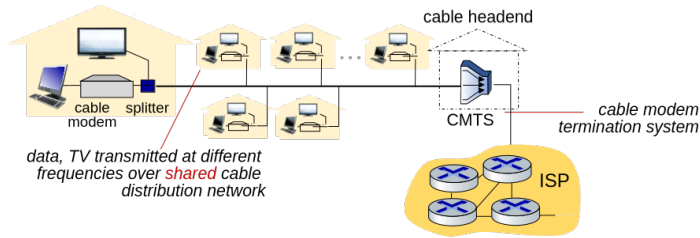
Frequency division multiplexing (FDM):

Different channels transmitted in different frequency bands



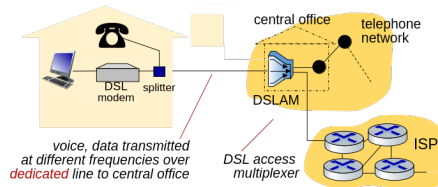
Access Networks: Cable-based Access

- HFC: Hybrid fiber coax
 - Asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
- Network of cable, fiber attaches homes to ISP router
 - Homes share access network to cable headend



Access Networks: Digital Subscriber Line

- 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
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

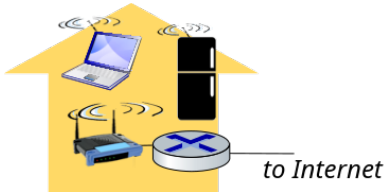


Shared *wireless* access network connects end system to router

- Via base station, a.k.a “access point”

Wireless local area networks (LAN)

- Typically with or around building ($\sim 30\text{m}$)
- 802.11b/g/n (WiFi): 11, 54, 450, ... Mbps bandwidth

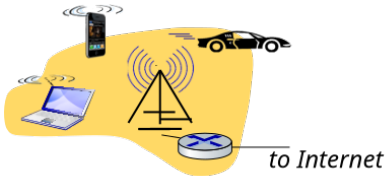


Shared *wireless* access network connects end system to router

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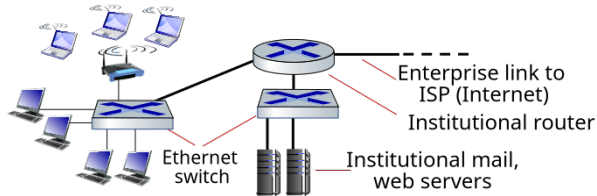
Wide-area cellular access networks

- Provided by mobile/cellular network operator (~ 10 's km)
- 10's Mbps, up to 1 Gbps bandwidth
- LTE/5G cellular networks



Access Networks: Enterprise Networks

- Companies, universities, etc.
- Mix of wired and wireless link technologies
- Mix of switches and routers (we'll cover the differences shortly)
 - Ethernet: Wired access at 100 Mbps, 1 Gbps, 10 Gbps, ...
 - WiFi: Wireless access points at 11, 54, 450, ... Mbps

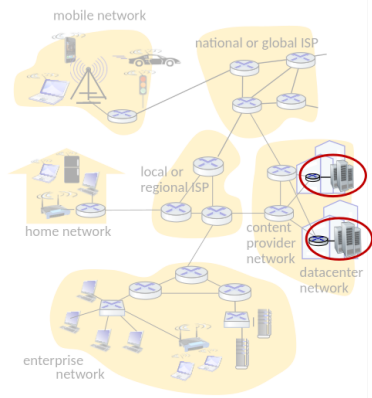


Access Networks: Data Center Networks

- High bandwidth links (10s to 100s Gbps) connect hundreds of thousands of servers together, and to the Internet



Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)



Hosts



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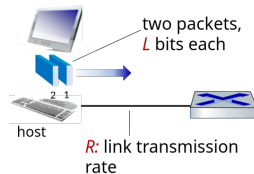
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Sending side:

- Breaks application message into smaller chunks, known as *packets*, of length L bits
- Transmits packets into access network at transmission rate R
 - Link transmission rate, a.k.a., *link capacity* or *link bandwidth*

$$\begin{array}{lcl} \text{Packet} & \text{time needed} & \\ \text{transmission} & = \text{to transmit } L \text{ bit} & = \frac{L(\text{bits})}{R(\text{bits/sec})} \\ \text{delay} & \text{packet into link} & \end{array}$$



Links: Physical Media



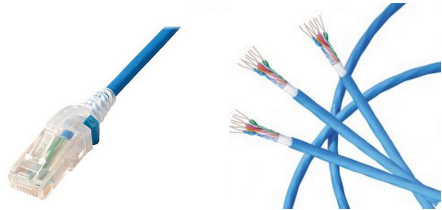
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- **Bit:**
 - Propagates between transceiver/receiver pairs
- **Physical link:**
 - What lies between transmitter and receiver
- **Guided media:**
 - Signal propagates in solid media: copper, fiber, coax
- **Unguided media:**
 - Signal propagates freely, e.g., radio
- **Twisted Pair (TP):**
 - Two insulated copper wires
 - Category 5: 100 Mbps, 1 Gbps Ethernet
 - Category 6: 10 Gbps Ethernet



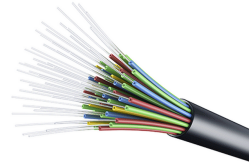
■ Coaxial cable:

- Two concentric copper conductors
- Bidirectional
- Broadband:
 - Multiple frequency channels on cable
 - 100's of Mbps per channel



■ Fiber optic cable:

- Glass fiber carrying light pulses, each pulse is a bit
- High-speed operation
 - 1000's of Gbps point-to-point transmission
- Low error rate:
 - Repeaters spaced far apart
 - Immune to electromagnetic noise



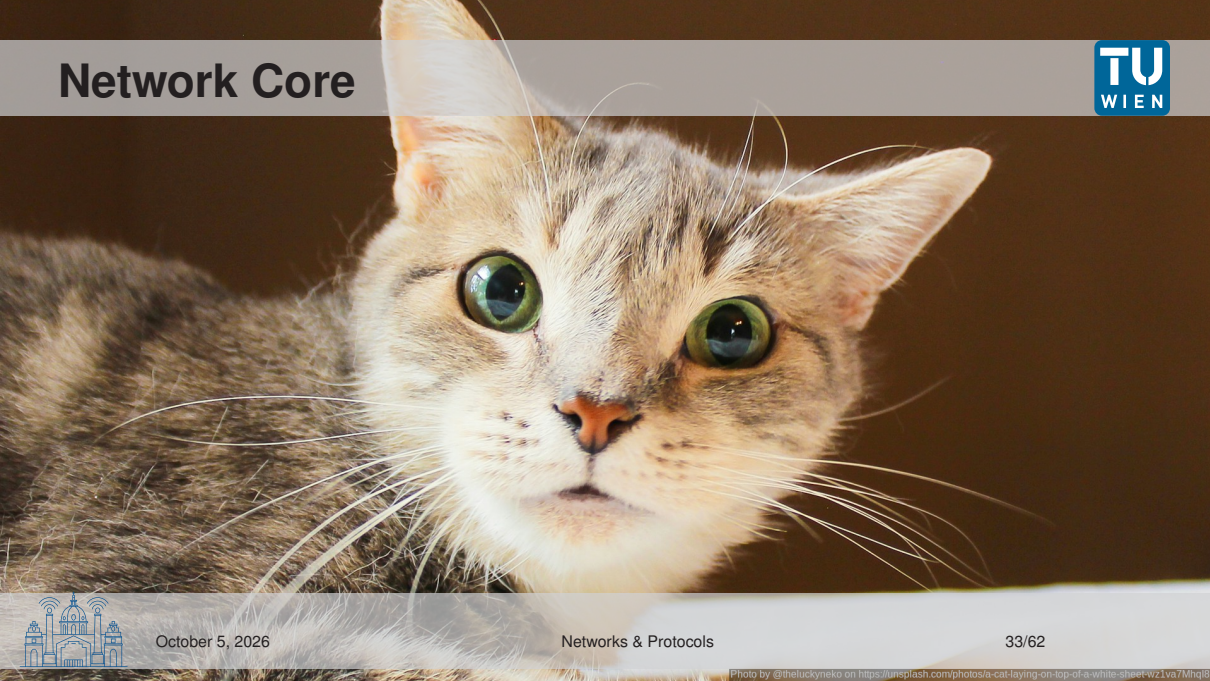
■ Wireless radio:

- Signal carried in various “bands” in electromagnetic spectrum
- No physical “wire”
- Broadcast, “half-duplex” (sender to receiver)
- Propagation environment effects:
 - Reflection
 - Obstruction by objects
 - Inference / noise

■ Radio link types:

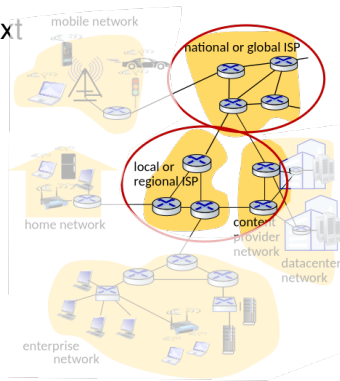
- Wireless LAN (WiFi)
 - <40 Gbps; 10's of meters
- Wide-area (e.g., 4G/5G cellular)
 - <10's Gbps (4G) over 10 Km
- Bluetooth: Cable replacement
 - Short distances, limited rates
- Terrestrial microwave
 - Point-to-point; 45 Mbps channels
- Satellite
 - Up to < 1 Gbps (Starlink) downlink
 - 270 msec end-end delay (geostationary)





The Network Core

- Mesh of interconnected routers
- Network forwards packets from one router to the next
- Across links on path from source to destination

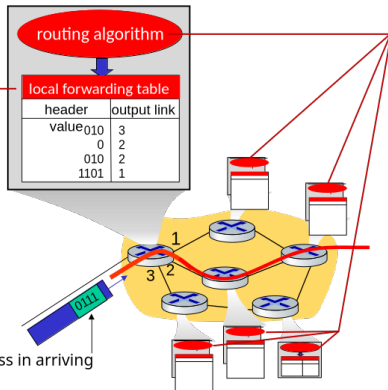


Two Key Network-core Functions

Forwarding:

- A.k.a. “switching”
- **Local** action: move arriving packets from router's input link to appropriate router output link

Destination address in arriving packet's header



Routing:

- **Global** action: determine source-destination paths for packet
- Routing algorithms used



Routing

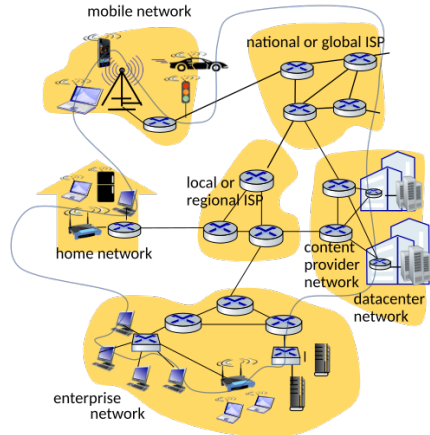


Forwarding



Internet structure: A “Network of Networks”

- Hosts connect to Internet via access Internet Service Providers (ISPs)
- Access ISPs in turn must be interconnected
 - So that any two hosts (anywhere!) can send packets to each other
- Resulting network of networks is very complex
 - Evolution driven by **economics**, **national policies**

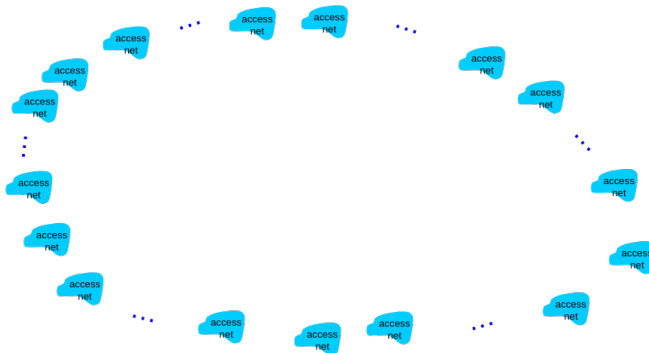


Let's take a stepwise approach to describe current Internet structure



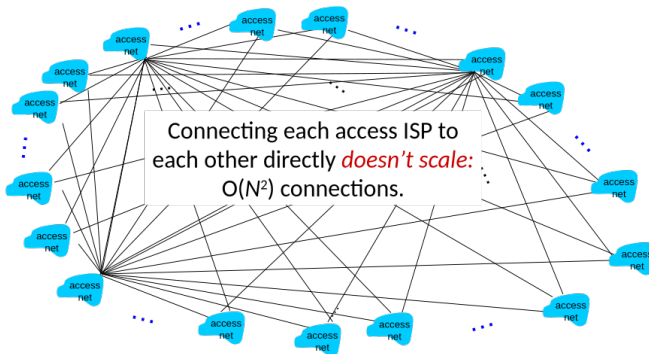
Internet structure: A “Network of Networks”

Given millions of access ISPs: how to connect them together?



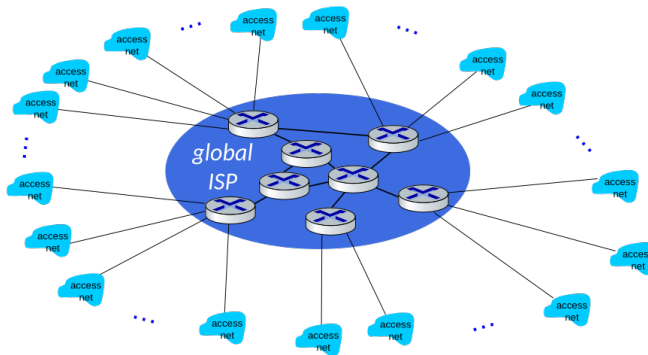
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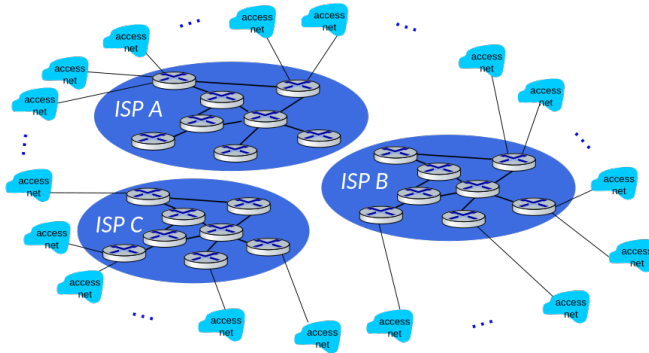
Internet structure: A “Network of Networks”

Given millions of access ISPs: connect all to one global ISP?



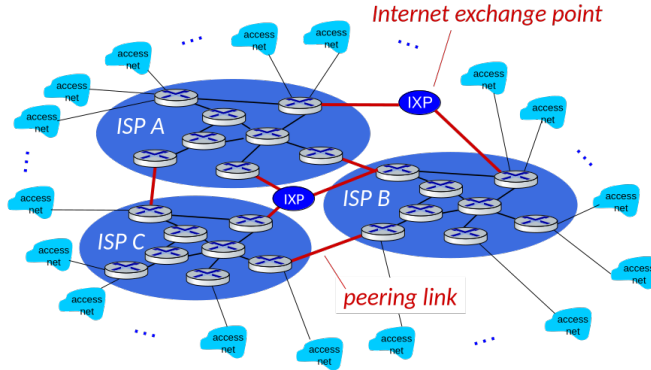
Internet structure: A “Network of Networks”

If the business is viable, here will be competitors...



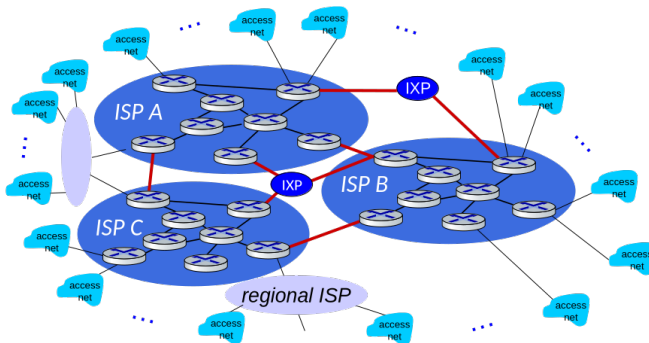
Internet structure: A “Network of Networks”

... that need to be interconnected, via private peering or Internet Exchange Points (IXPs)



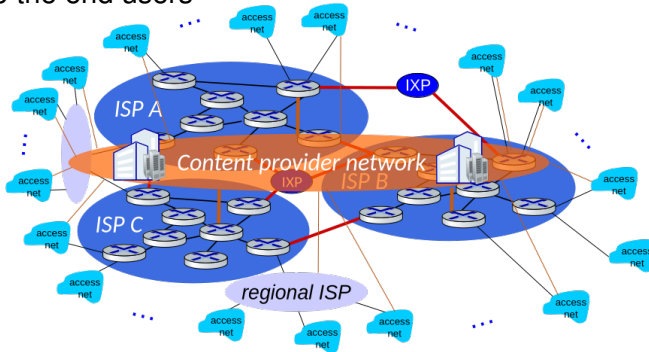
Internet structure: A “Network of Networks”

Also regional ISPs will emerge to connect access networks to ISPs



Internet structure: A “Network of Networks”

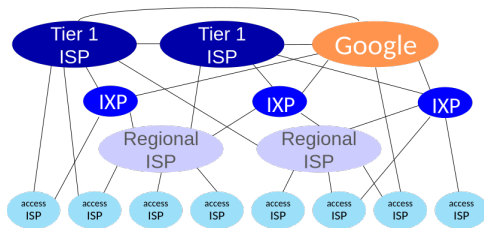
Lastly, private companies may run their own network to bring services and content close to the end users



Internet structure: A “Network of Networks”

At “center”: small number of well-connected networks

- “Tier-1” commercial ISPs (e.g.: Lumen, Arelion, Cogent, NTT, ...) with national & international coverage
- Content provider networks (e.g.: Google, Facebook): private networks that connect its data centers to Internet, often bypassing Tier-1 & regional networks





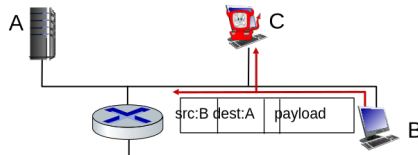
- Internet not originally designed with (much) security in mind
 - Original vision: “a group of mutually trusting users attached to a transparent network”
 - Internet protocol designers playing “catch-up”
 - Security considerations in all layers!
- We now need to think about:
 - How bad guys can attack computer networks
 - How we can defend networks against attacks
 - How to design architectures that are immune to attacks



Bad Guys: Packet Interception

Packet “sniffing”

- Broadcast media (shared Ethernet, wireless)
- Promiscuous network interface reads / records all packets, including passwords passing by

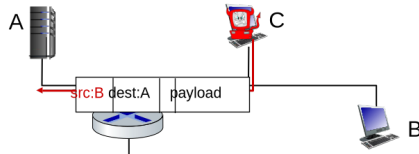


Wireshark software is a (free) packet-sniffer



Bad Guys: Fake Identity

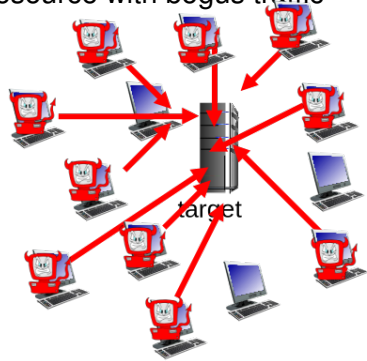
IP Spooting: Injection of packet with false source address



Bad Guys: Denial of Service

Denial of Service (DoS): Attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

- Select target
- Compromise a lot of hosts (c.f. “botnet”)
- Send packets from hosts to target



- **Authentication:** Proving you are who you say you are
 - Cellular networks provides hardware identity via SIM card; no such hardware assist in traditional Internet
- **Confidentiality:** Via encryption
- **Integrity checks:** Digital signatures prevent/detect tampering
- **Access restrictions:** Password-protected VPNs
- **Firewalls:** Specialized “middleboxes” in access and core networks:
 - Off-by-default: filter incoming packets to restrict senders, receivers, applications
 - Detecting/reacting to DOS attacks



Protocol Layers, Service Models



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Protocol “Layers” & Reference Models

Networks are complex, with many “pieces”:

- Hosts
- Routers
- Links of various media
- Applications
- Protocols
- Hardware, software

Question: Is there any hope of *organizing* the structure of the networks?

- And / or our *discussion* of networks?



Why Layering?

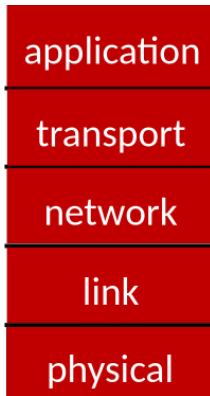
Approach to designing / discussing complex systems:

- Explicit structure allows identification, relationship of system's pieces
 - Layered *reference model* for discussion
- Modularization eases maintenance, updating of system
 - Change in layer's service implementation: transparent to rest of system
 - E.g., change in gate procedure doesn't affect rest of system

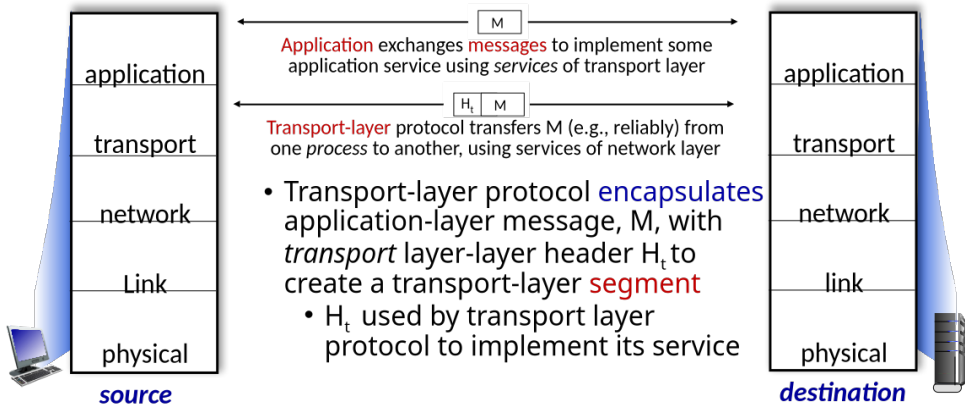


Layered Internet Protocol Stack

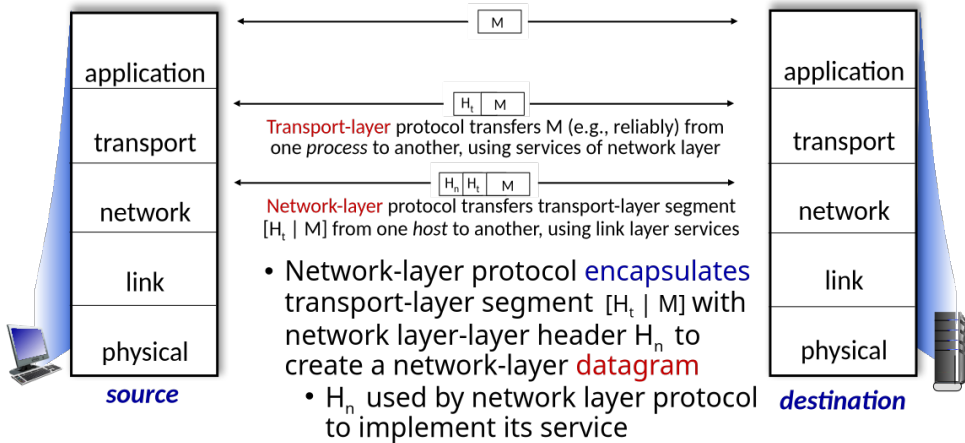
- **Application:** Supporting network applications
 - HTTP, IMAP, SMTP, DNS
- **Transport:** Process-to-process data transfer
 - UDP, TCP
- **Network:** Routing of datagrams from source to destination
 - IP, routing protocols
- **Link:** Forwarding of frames between neighboring network elements
 - Ethernet, 802.11 (WiFi), PPP
- **Physical:** Bits “on the wire”



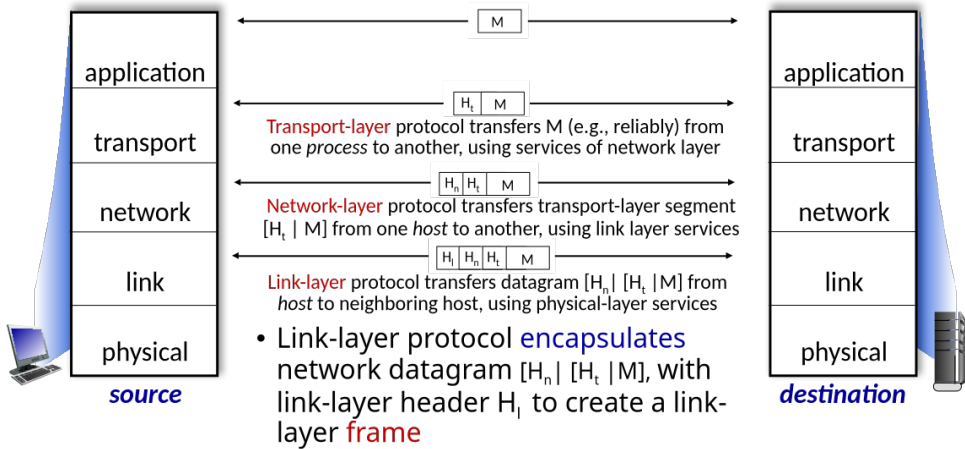
Services, layering, and encapsulation



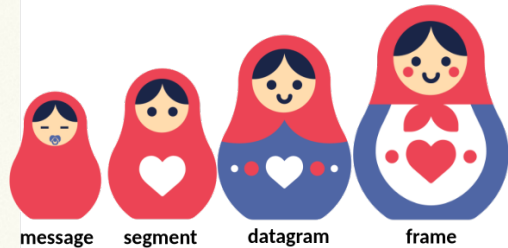
Services, layering, and encapsulation



Services, layering, and encapsulation



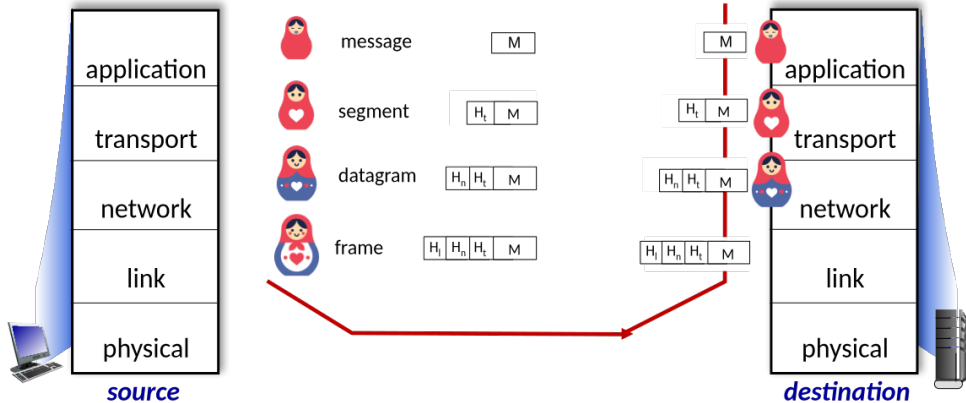
Matryoska dolls (stacking dolls)



Credit: <https://dribbble.com/shots/7182188-Babushka-Boi>



Services, layering, and encapsulation



Encapsulation: An End-to-End View

