Introduction

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COMP 429

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The use of computer networks has changed over time

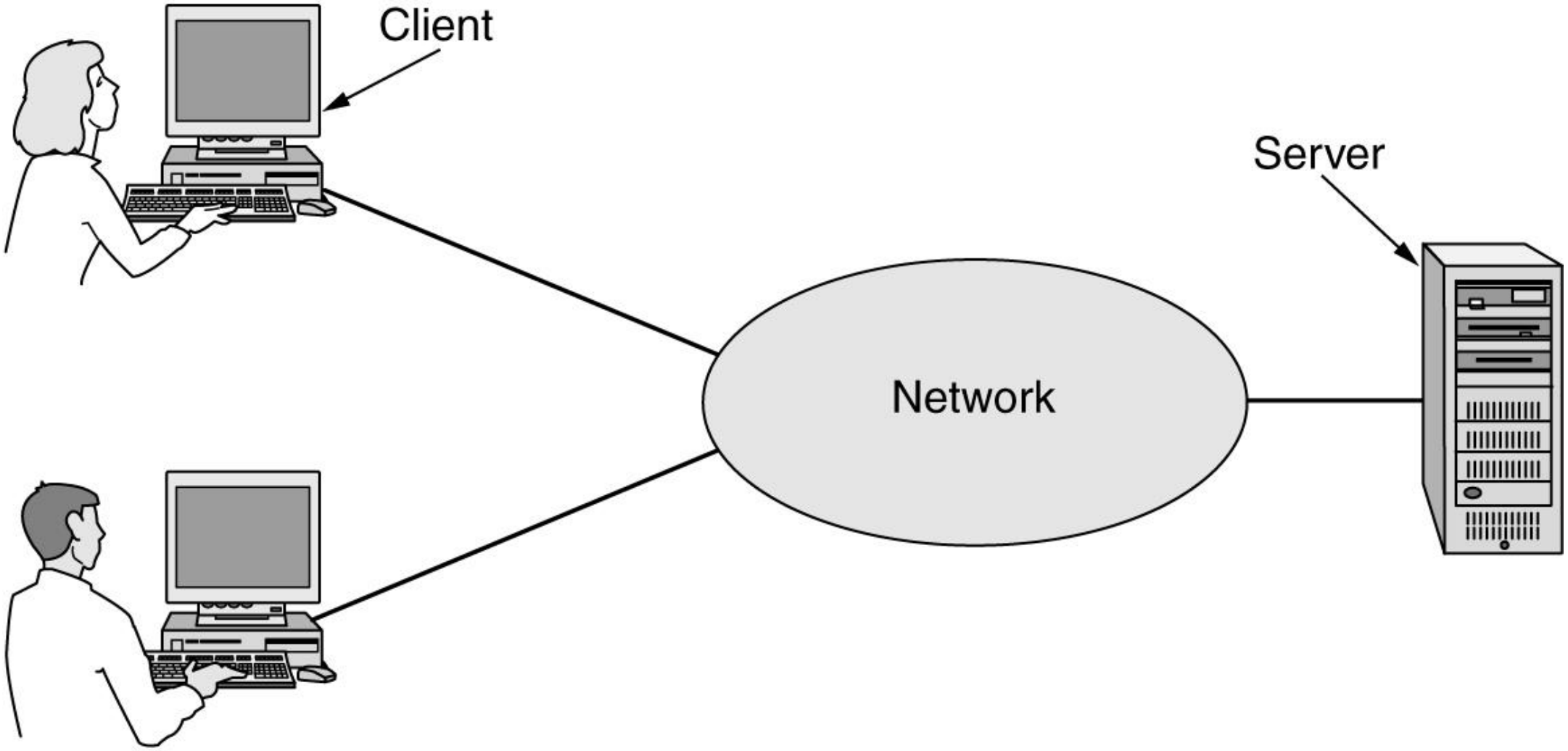
- Old Model
  - A single computer serving the business needs
  - Think: one large computer everyone SSH's into
- New Model
  - A large number of interconnected systems (computer networks) serving many different business needs
  - Think: Canvas, gmail, SafariBooks, OneDrive, etc…
- Computer Network
  - A collection of interconnected, autonomous computing devices
  - The most famous being… the Internet (capital I)
  - Aside: What does internet stand for?

The way we access information has changed over time as well

- Websites on computers
- Then on mobile phones
- Then onto apps on the mobile phones
- News, television, movies (lately) have moved online
  - News is often shared on social media
  - With algorithms determining what news you should see
  - *Based on the data collected on the users*
  - Hmm
- Online Libraries
  - What is an encyclopedia?
- Aside: where do you get your information from?

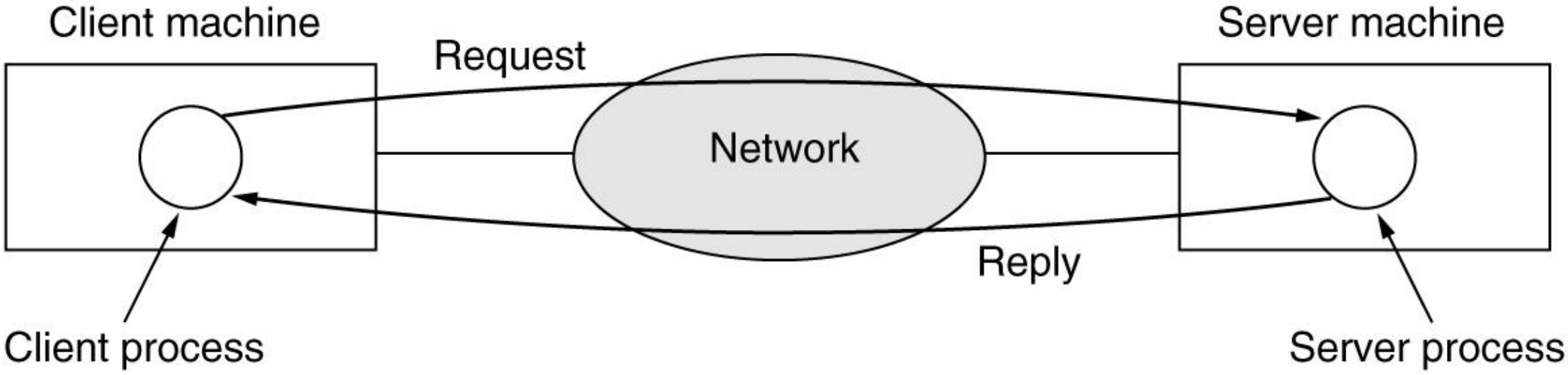
Much of the Internet is accessed through the client-server model

- Client and server communicating over a network



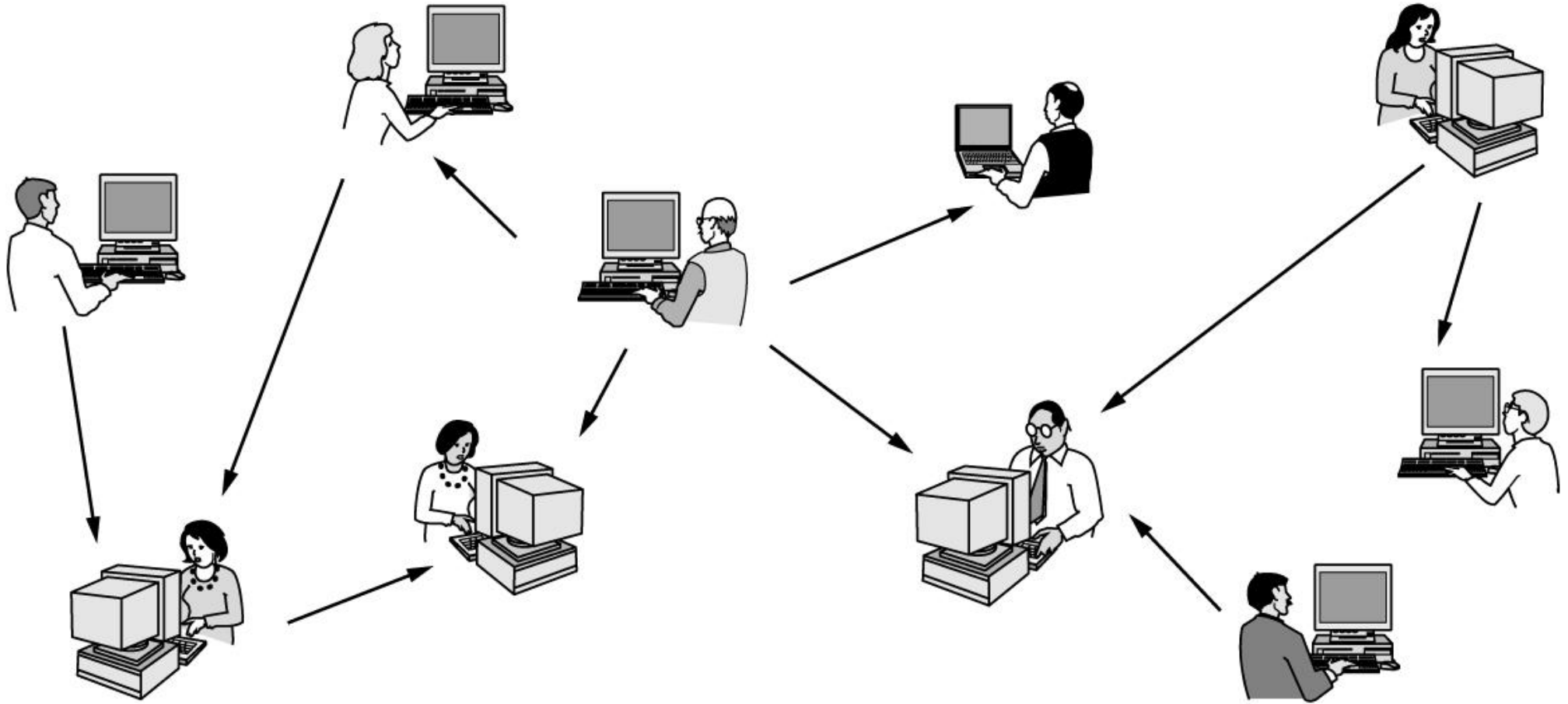
Client-server model which uses a request and response protocol of communication

- Client **requests** information from the server that hosts information
- The server **responds** to the information request
- One server may handle 100,000+ requests
- They may be near or far



Other models do exist, such as peer-to-peer (P2P)

- There are no fixed clients or servers
- Originally used for piracy (napster in 2000s, bit torrent)
- But have many legal uses today (matrix, windows update)



Person to person communication is a large portion of the Internet

- Email was originally a popular alternative to the telephone
  - Who likes calling places anyway?
  - Eventually images and media made its way into email
- Instant Messaging
  - AIM, ICQ, UNIX talk
  - Poll: how many different apps do you have on your phone to talk to people?
- Chat Programs
  - IRC, Discord, Slack, Mattermost, Matrix, Teams
- Online Classes
  - Nice to take an 8am class without a commute
  - May be helpful for those who do not live in big cities

E-commerce was a big deal

- Web things started with e, eBay, eToys, eSports?
- Provides an online shopping experience
- Companies can charge for online tech support
- Access your financial information easily
- Corporate jargon
  - B2C – ordering books online (amazon)
  - B2B – car manufacturer ordering parts
  - G2C – paying for your car registration (DMV)
  - C2C – selling your garbage on craigslist
  - P2P – File sharing, skype

Entertainment has taken on new forms

- Personal music collections curated through illegal downloads
- Cable TV has become Streaming
- Radio has turned into podcasts
- Children think they will be YouTubers when they grow up
- Some small things we don’t think about
  - All of the above is moved around via networking in our house
  - Between devices wirelessly, to displays over wires, speakers that are WiFi connected or Bluetooth (all still networking)
- Games – MMO, FPS, lots of bandwidth
- Future
  - Interactive TV? Metaverse?

Internet of Things (IoT) all of the things!

- Imagine a world where your egg carton sends you a notification to get more eggs
- Ubiquitous Computing
  - This was predicted in 1991
  - Security systems with door/window alarms
  - “Smart” all the things
    - Oven, gas, electricity, stupid doorbells that spy on you, smoke detectors
- Future
  - Maybe the shower will shame you for using too much water in California
  - Your bed will track your sleep (and maybe your weight…)
  - Insurance companies will want all the data (they already do)
- All enabled by small, cheap, wireless networked devices
- Engineering Aside: why were doorbells first?

There are many different types of Computer Networks

- Mobile Broadband
  - Provides **connectivity** to the Internet
  - Ex: Your ISP
- Data Centers
  - House the **data** we use/access
  - Ex: Netflix, Google
- Transit Networks
  - **Connect** access networks to data centers
  - Ex: Level 3, AT&T
- Enterprise Networks
  - **Campus**, **office**, or other organizations
  - Ex: CSUCI

The popularity of the Internet is due to its immense size

- Think: Costco has so much stuff so things are cheap
- Would tech advance as much as it has without the vast size of the Internet? Is it a good thing for society?
- When IBM was #1, there was a #2 company named “Digital Equipment Corporation) and in 1977 said
  - “There is no reason for any individual to have a computer in his home”
  - They no longer exist
- There are several billion daily users of the Internet, that’s crazy

Mobile and Wireless Access Networks are in every home

- People want their network access in the land, sea and air.
- We have laptops, tablets, smart phones (all mobile devices)

- Fixed wireless vs. Mobile wireless
  - You're not usually moving with your laptop (fixed to a seat)
  - You may be driving or moving with your phone (mobile)

- Has proven very useful for fleets of trucks, taxis, delivery vehicles, etc.

- Sensor networks are an entire area of research

Content Delivery Providers have had to scale with the popularity of the Internet

- Anything in networking should ask the question: does it scale?

- Due to the growth of cloud computing
  - Mostly in that companies want to provide fast access to data
    - Imagine if your stream was buffering? Do people know what buffering is anymore?
  - Scale, throughput, and energy use are huge concerns here

- Because distance is key for low latency, many companies run their own CDN (Content Delivery Network) in many places
  - Google, Facebook, Netflix, etc.
  - Others provide the service for smaller companies: Akami, Cloudflare, etc

How does data get from the Data Center Networks to your ISP network? Transit Networks

- I think we are starting to see the idea of “interconnected networks” now

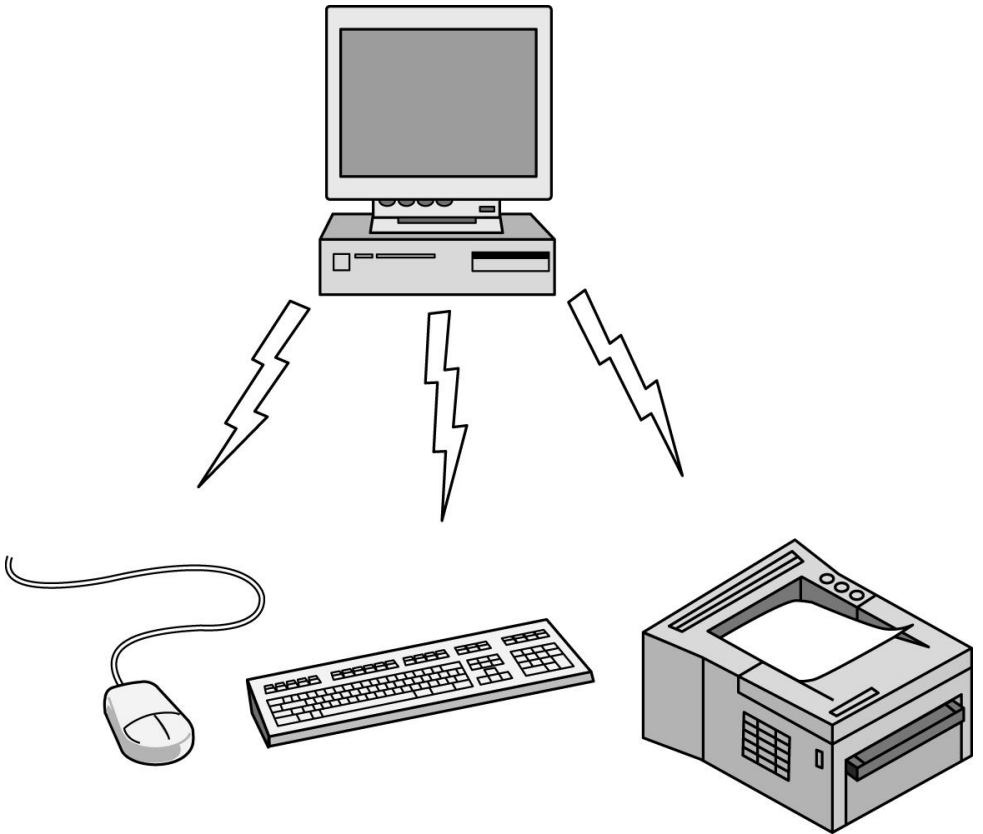
- Transit network (or backbone)
  - Where your traffic goes between your ISP and the data centers
  - ISPs work very hard to build these connections
  - It *was* very profitable to run a backbone: as everyone needs to pay to get their data transmitted
  - Now ISPs are creating their own backbones as they grow very large
- Much is being consolidated in a way due to
  - Cloud hosting (all in a few locations)
  - Large CDNs

Enterprise networking has gone full circle

- Every employee has a computer
  - Access company resources
  - Physical things can be shared: networked printers, conference rooms
  - Information can be shared: storage, datalakes, etc.
  - IP phones
  - Interactions with customers
  - VPN breaks down the “tyranny of geography”
- Powerful computer servers maintained by IT
  - Users used to connect to a centralized server to do work
  - Then got their own machines
  - Now back to connecting to a centralized location to do work (the cloud)
  - Full circle

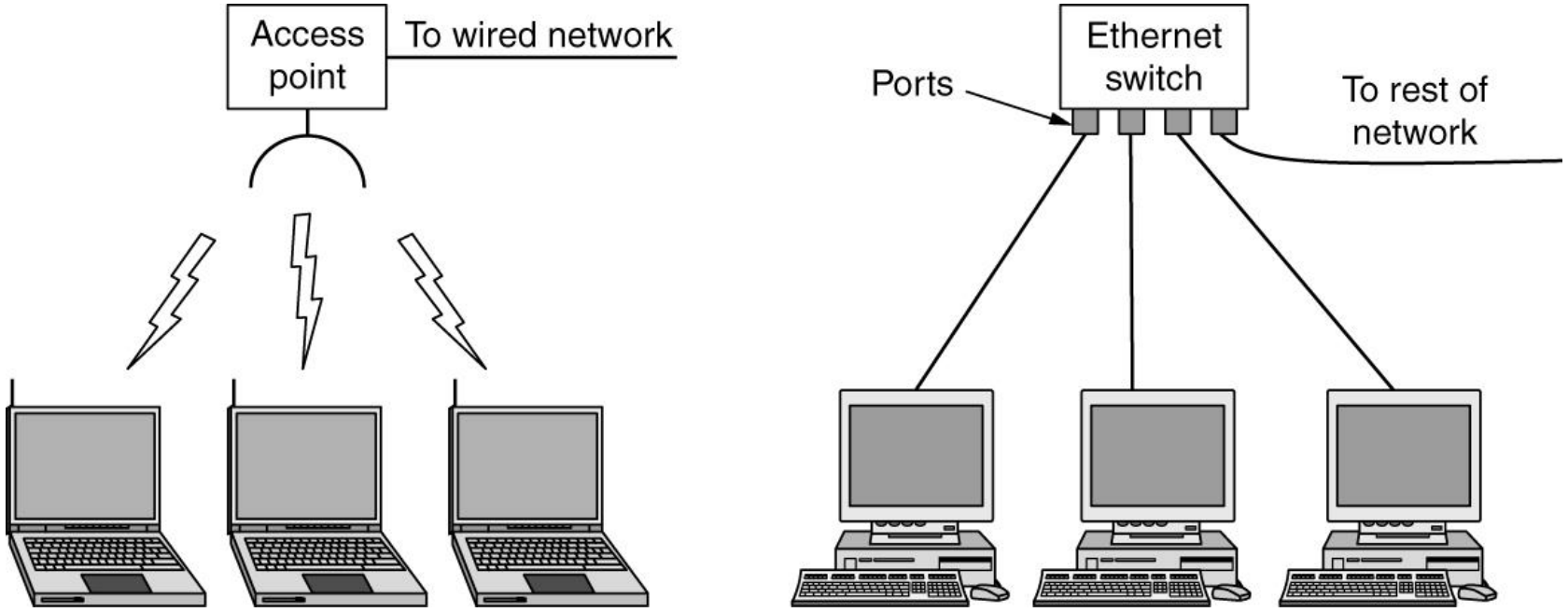
Let’s consider the technology behind networking (from local to global) starting with PAN

- PAN – personal area network
- An often overlooked, underappreciated network
- Still a network though! Often wireless



The local area network (LAN) is a private network usually in a single building

- This lab has its own isolated LAN (cut off from everything else so we can break things)
- Your home is its own LAN as well, private to you
  - Generally Wireless with either a wireless router, access point/base station, or mesh network
  - Aside: what is your home setup?

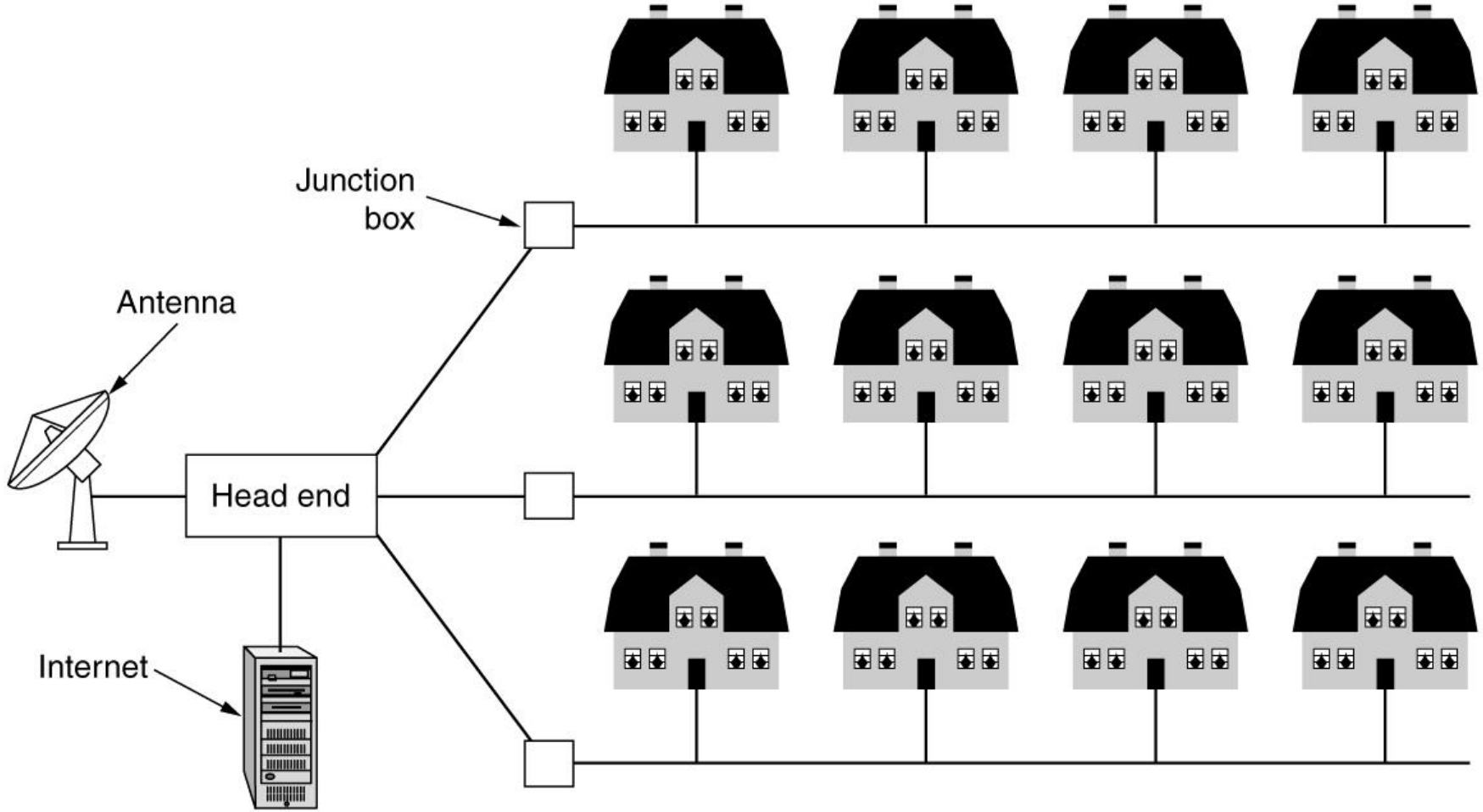


We consider a home network a type of LAN managed by non-technical users (not IT)

- Previously it may have been a few devices and a laptop
- Now
  - Computers, phones, thermostats, doorbells, light bulbs, TVs, speakers, spy devices (alexa and such)
- Security/reliability have higher stakes
  - Microphones in your home
  - Cameras in the baby room (that can be hacked)
  - Anything with an app likely reaches out the Internet and back
  - What if the smart lock fails?
- Profit margins are low because we want cheap stuff
  - Aside: was reliability and security considered in this equation?

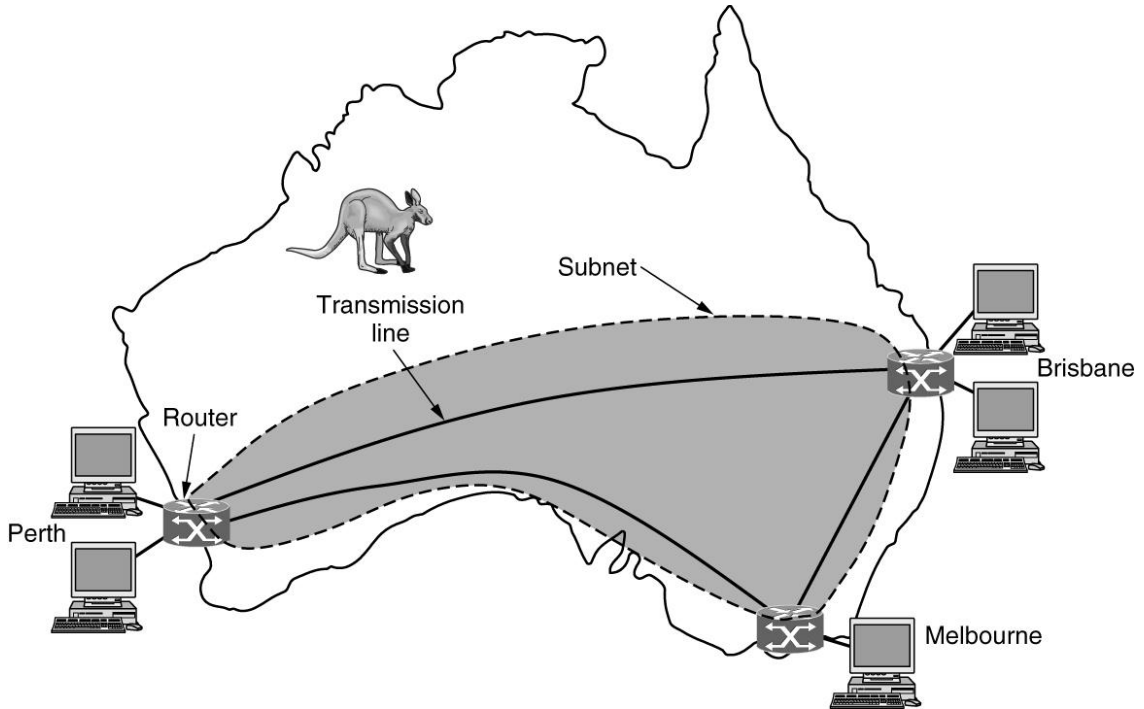
Metropolitan Area Networks cover a vast area (such as a city)

- Often from the old cable TV infrastructure
- Does your modem connect through coax?

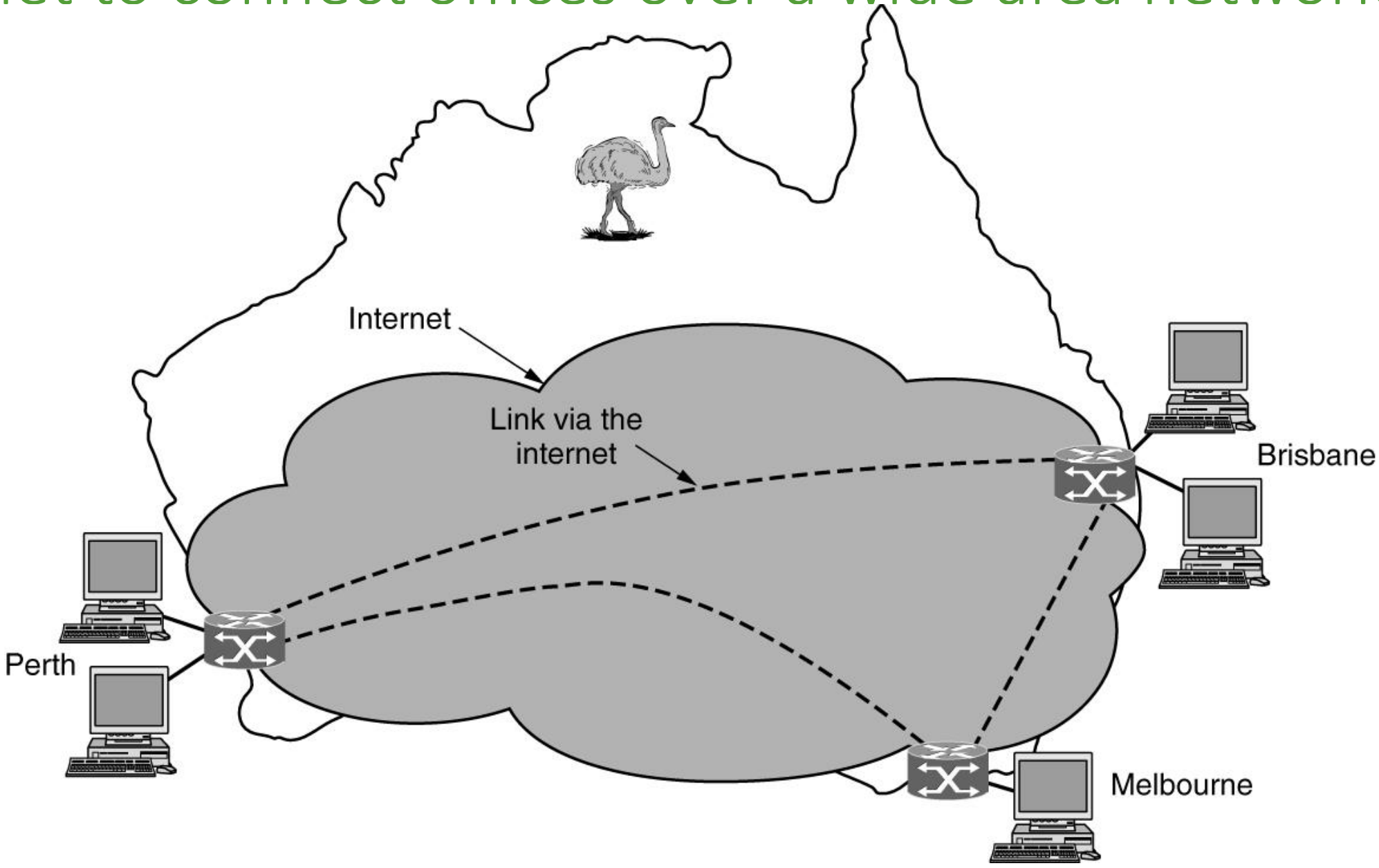


Wide Area Networks (WANs) connect an entire country, continent, or multiple continents

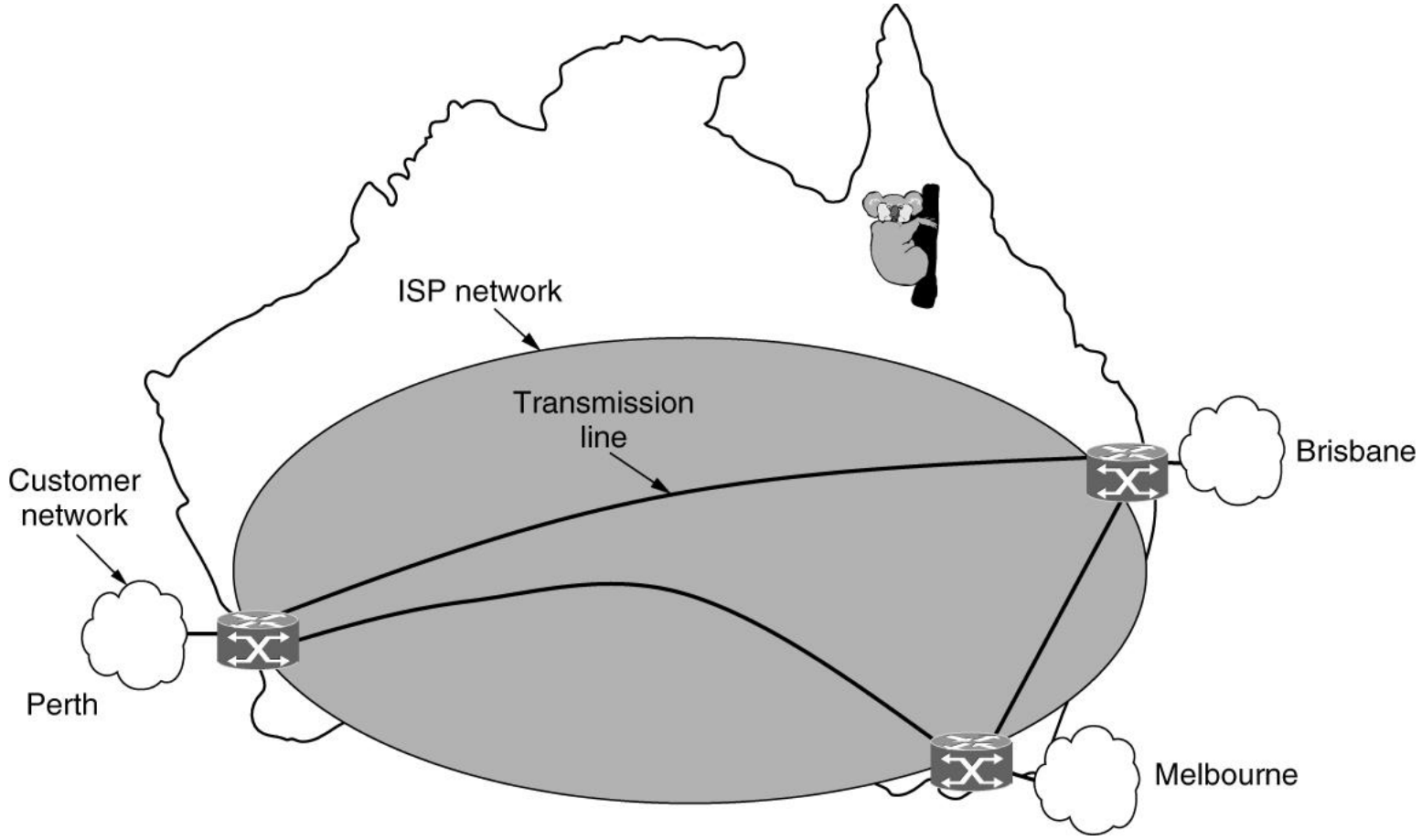
- Routers along the way determine which way data should go based on forwarding algorithms
- We call the network of routers that forward packets a subnet
- It would be expensive to create this network yourself



A company can lease dedicated transmission lines via the Internet to connect offices over a wide area network



A company can also buy Internet connectivity from an ISP to connect their offices



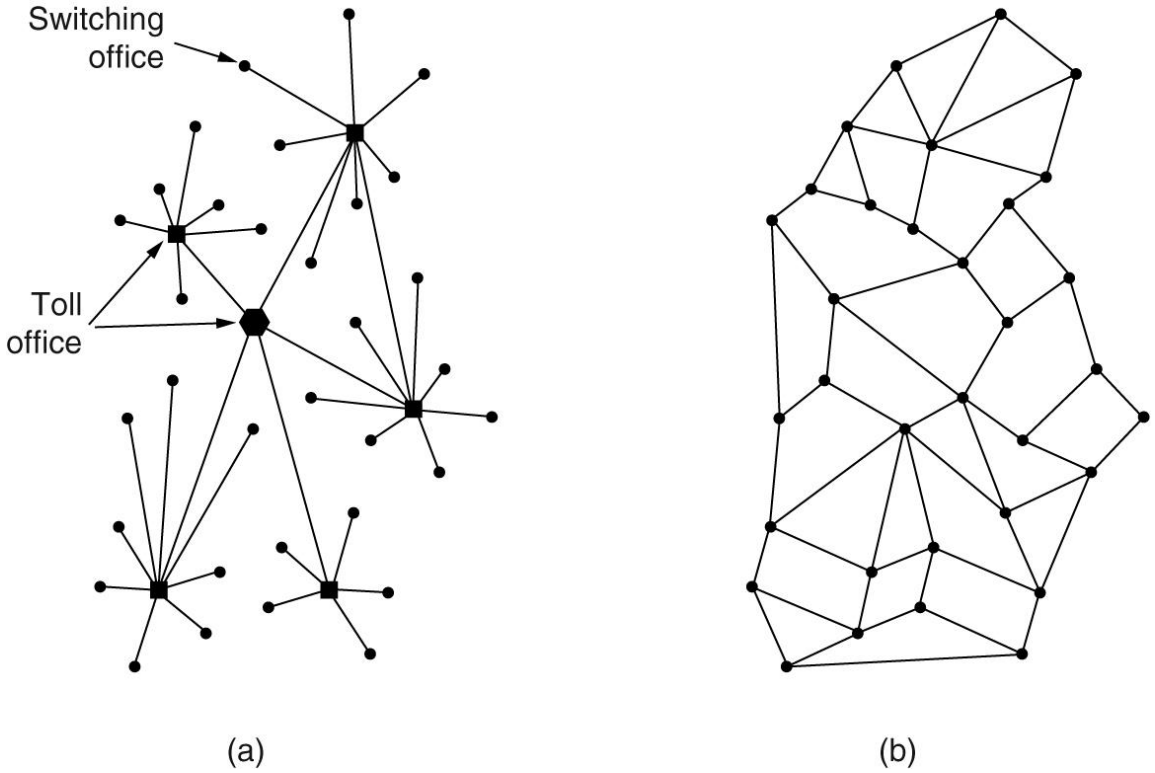
Internetworks are a collection of interconnected networks

- For example, the campus network (Enterprise) will connect to its ISP (Broadband access) which will connect to Google (Data Center) via an Internet eXchange center (Transit Network)
- We call this particular internetwork the Internet

- internet without capital I is a generic collection of interconnected networks.

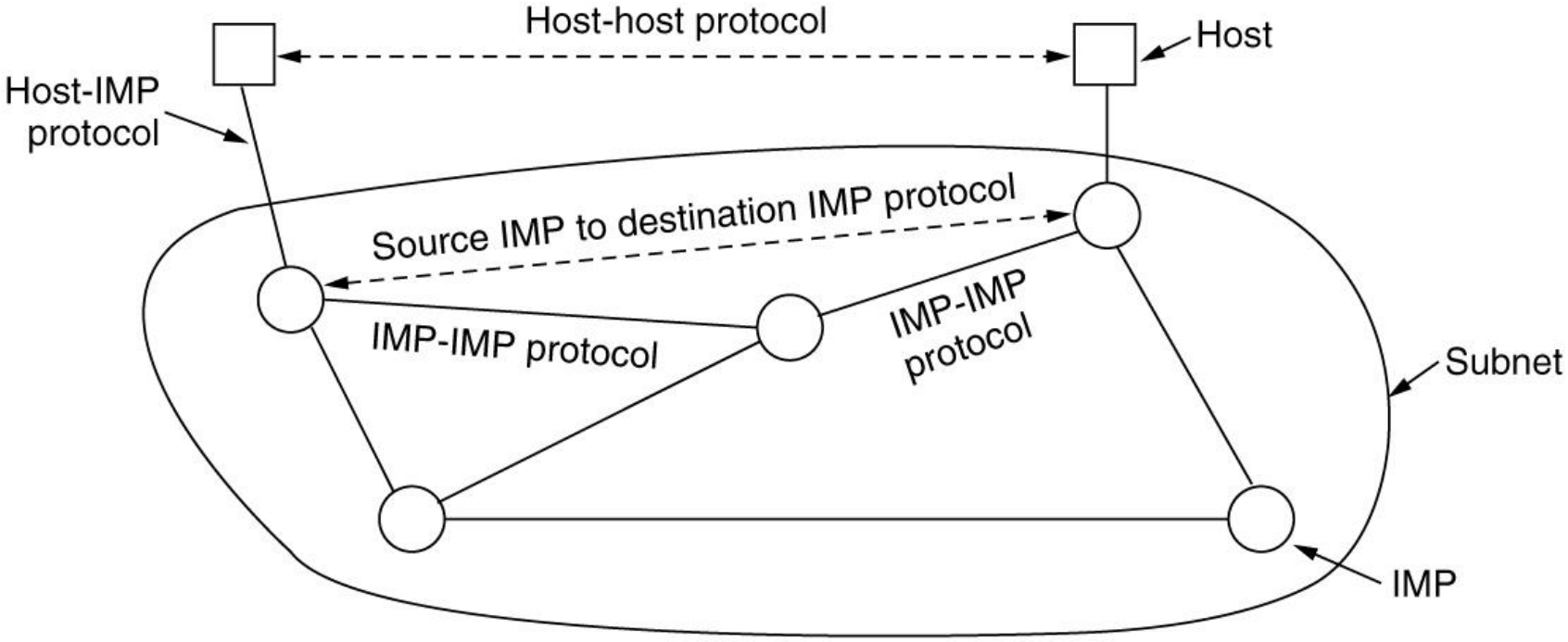
The Internet came to be because the DoD said yes and the AT&T said no

- The Internet is special in that no single organization planned or owns it
- In the 1950s during the Cold War (after sputnik)
  - DoD had a need
  - A system that can survive a nuclear attack



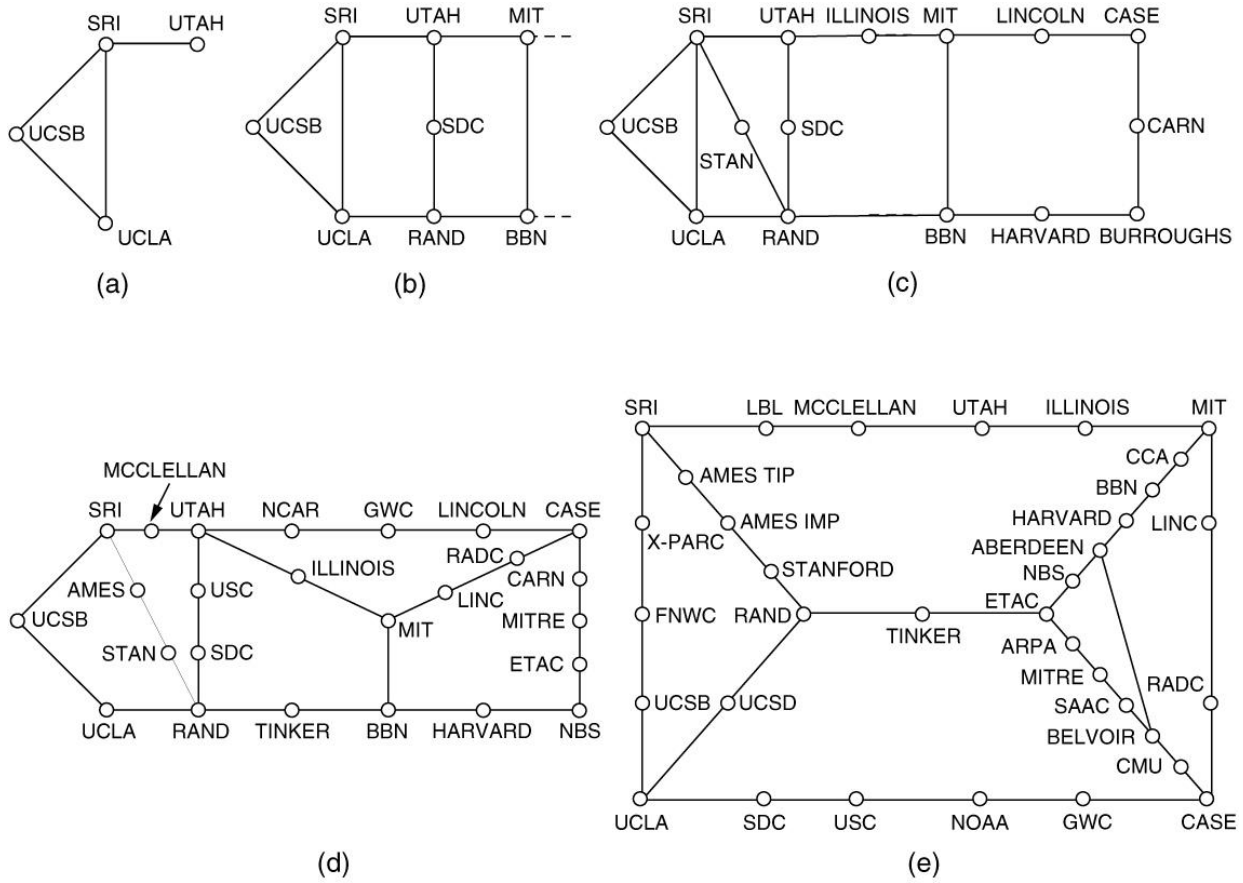
The RAND corporation thought that digital could traverse farther and allow for the decentralized links we saw in the previous diagram

- AT&T said it was impossible
- ARPA (Advanced Research Projects Agency) was then tasked to create a centralized location for defense work
- The birth of ARPANET



UCLA, UCSB, SRI, and U of Utah all had a large number of ARPA contracts

- Hence why they were chosen for the experimental network



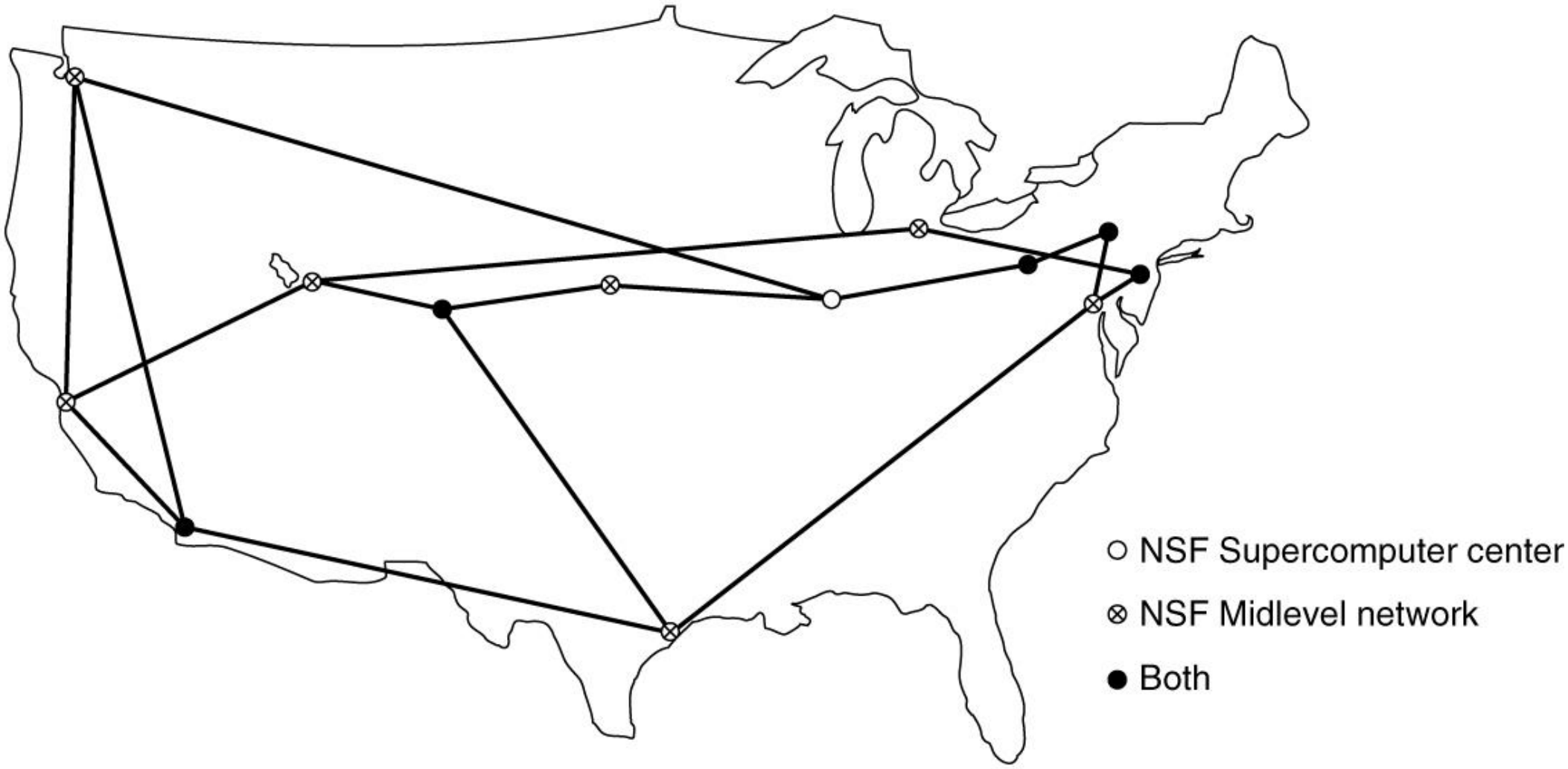
- Growth of the number of nodes on ARPANET. (a) December 1969. (b) July 1970. (c) March 1971. (d) April 1972. (e) September 1972.

Timing is everything

- When ARPANET was launched in 1969 there were some other interesting things happening at universities and laboratories
- UNIX was being developed at Bell Labs
- Universities began purchasing their third generation computers

- NSF created a new network for universities that wasn’t associated directly with the DoD
- Europe had gone through something similar and produced EuropaNET and EBONE
- By the 1990s we had the World Wide Web (www)

NSFNET was a backbone network connecting both coasts

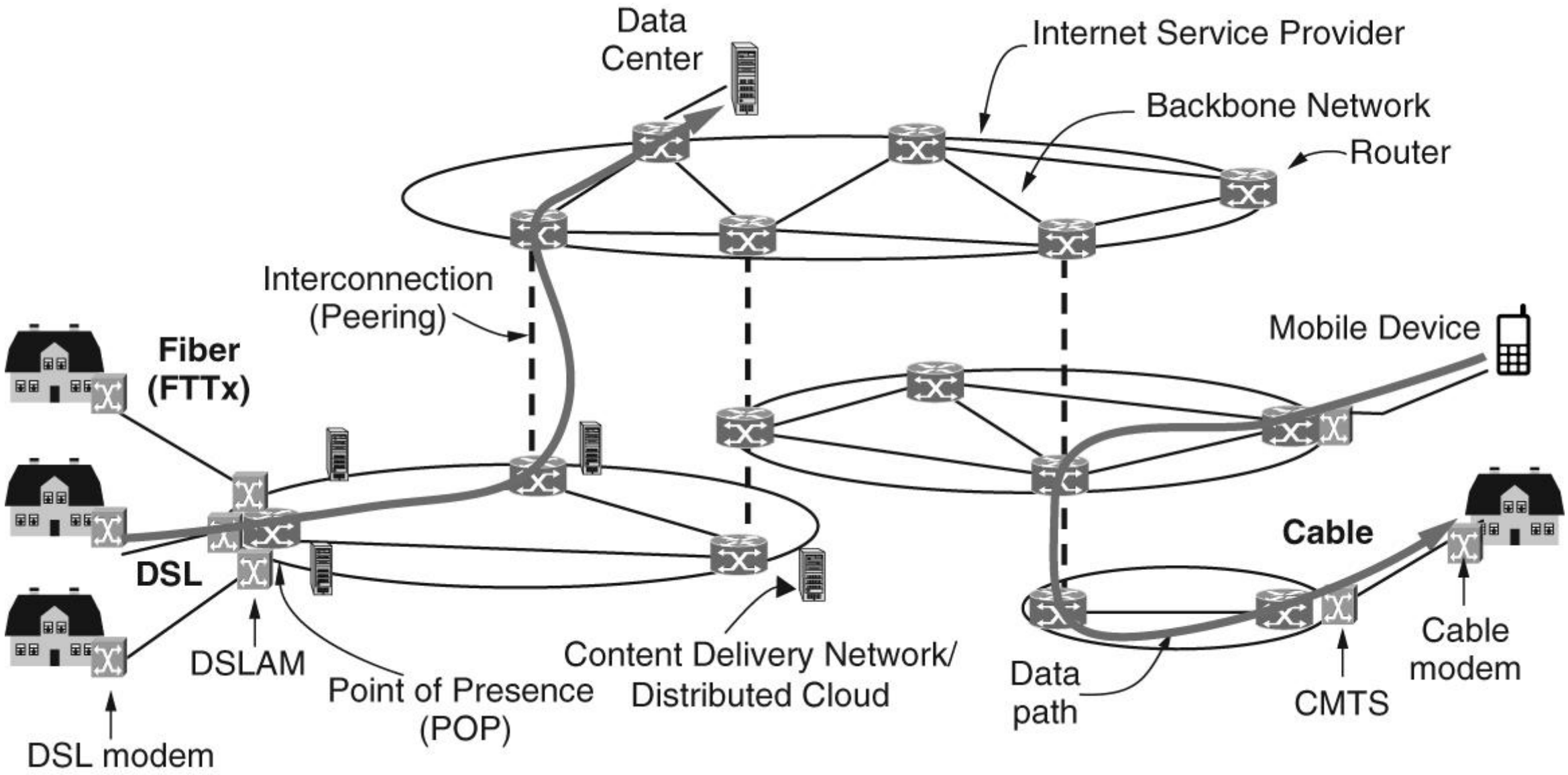


So what does the Internet look like today?

- Cable TV infrastructure connects most users to the Internet
  - The last of the analog
  - Good thing everyone watched TV though, thanks for that
- Everything passed that is digital
- HFC (Hybrid Fibre-Coaxial) greatly increases the speeds over the old coax lines

- We refer to the entrance point into your ISP network as the POP
  - Point Of Presence

The Internet

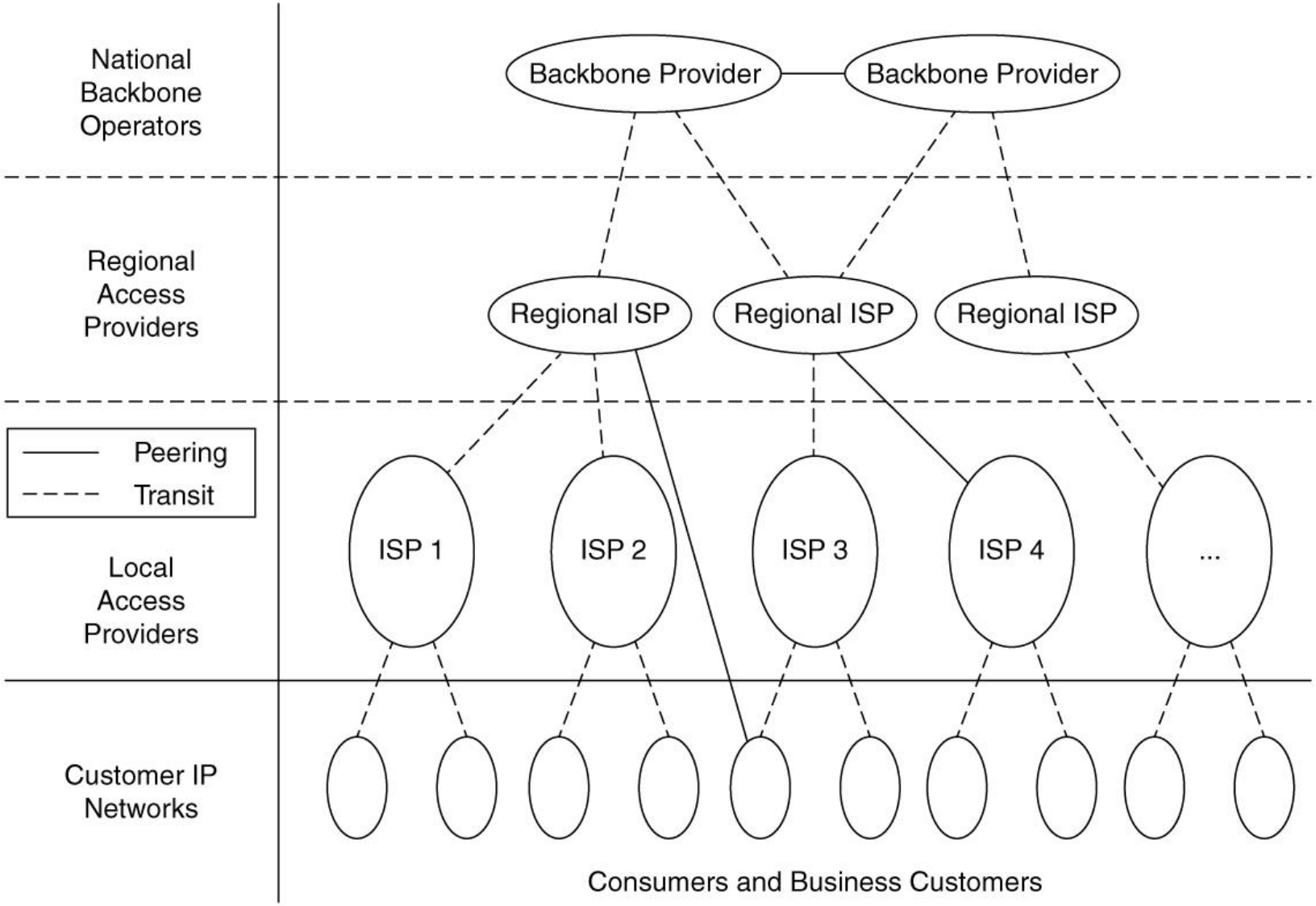


ISPs operate on the backbone

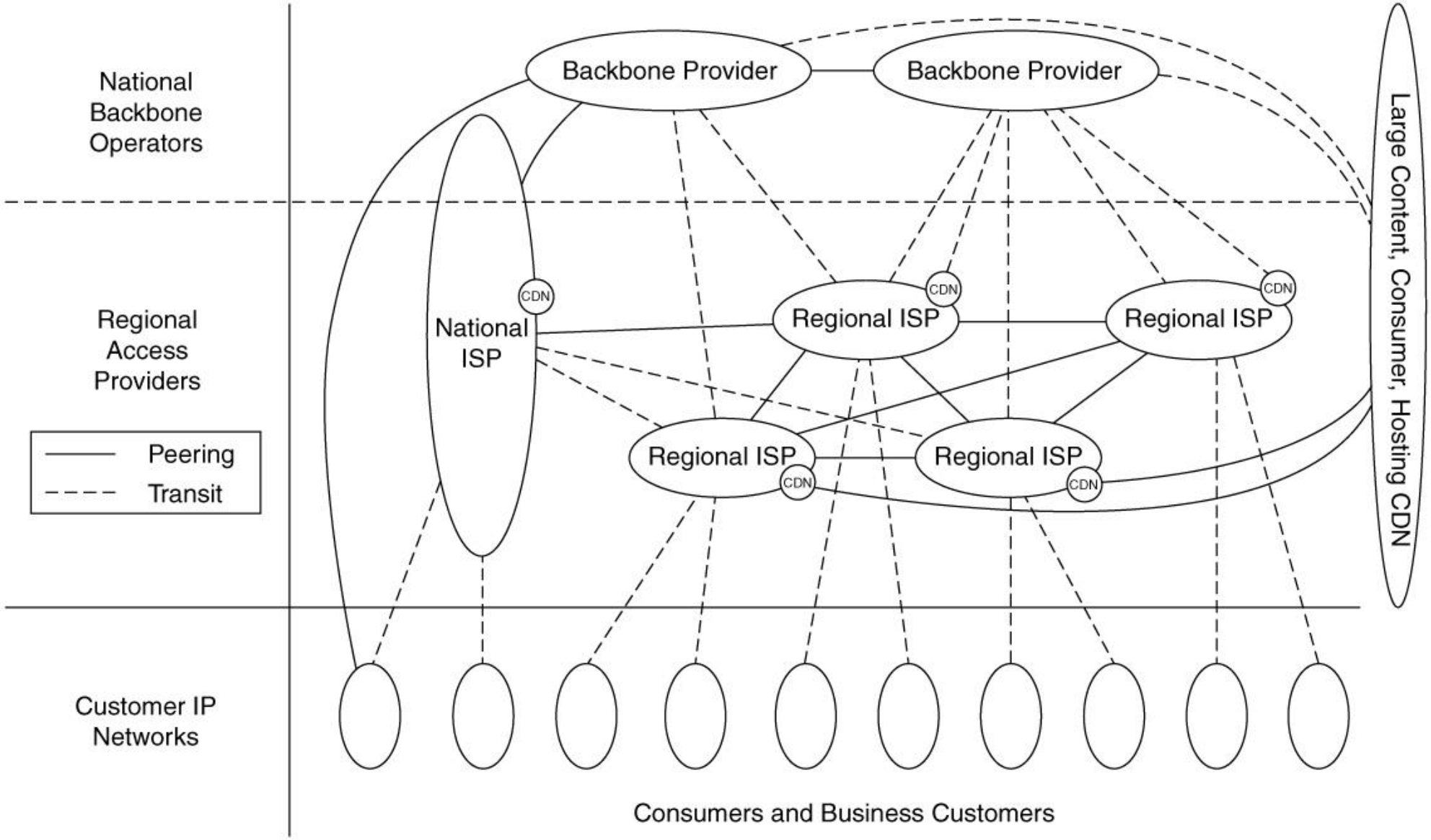
- ISPs talk to other ISPs at IXP (Internet eXchange Points) through **peering**
  - These are essentially giant buildings full of fibre optic connected routers owned by different ISPs
  - AmsterdamIX hosts 800 ISPs serving 4000 gigabits *per second* (4 terabytes per second)

- Oddly enough, data doesn't often travel the shortest path
  - It takes the cheapest (since ISPs rent from backbones)
  - Or the least congested (congestion leads to data loss)

An outdated hierarchical view of the Internet



A modern view of the Internet



Distance is what drove this change

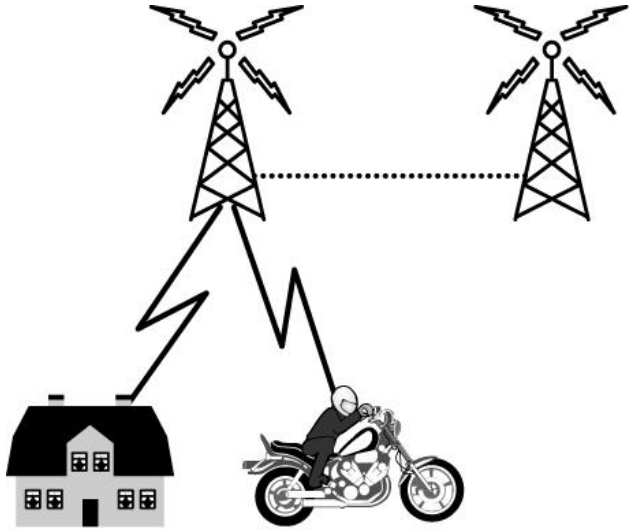
- Latency (the time it takes for traffic to get to a data center and back) is greatly reduced by increasing the number of data centers
- Amazon, twitch, Google, FB, Netflix all operate data centers throughout the US
- Sometimes these are built next to Dams to use the water for cooling AND power

- This caused the hierarchy to flatten

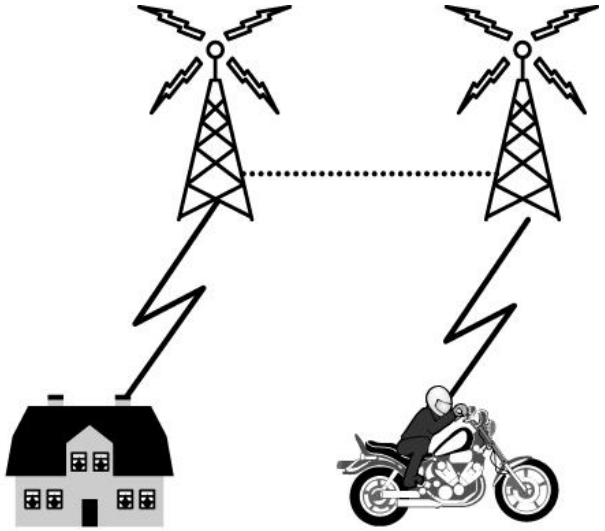
Now there is a whole new complicated way to connect to the Internet: truly mobile devices

- 65% of the world population has a mobile network subscription
- In 2018, > 50% of the traffic was coming from mobile networks

- They have unique challenges that we may cover in the future



(a)



(b)

A network protocol defines how these devices talk to each other

- The design goals behind a protocol are
- Reliability
  - Recover from errors, failures
- Resource allocation
  - Sharing access to common, limited resources
- Evolvability
  - Allow of change over time
- Security
  - Defending the network against various attacks

Reliability – operate correctly even if comprised of unreliable things

- The Internet is regarded as “best effort”
  - It tries really hard but cannot guarantee results (like a capstone student
- There are mechanisms to handle this unreliability (it is not a bad thing)
- Error detection/correction
  - Use codes and redundant information to detect flipped bits or missing information
- Routing
  - Find a working path through a potentially very large network

Resource allocation – the big question: does it scale?

- There may be little traffic in your local neighborhood, but in the city there is a lot of traffic
  - Somehow the roads are almost the same width?
  - Scale!
- Networks, like traffic, is a very dynamic environment and must handle change in scale rapidly and on demand
  - Statistical multiplexing means sharing based on demand
- Flow control
  - How much data should an application send?
- Congestion
  - The overloading of a network

Evolvability

- Since the Internet has grown so quickly, engineers often try to future-proof their protocols

- Ethernet cables were created with extra pairs of wires
  - Likely because of how much it sucks to rewire a building

- There are only 4 billion IP addresses in IPv4
  - This is less than the population of the planet

- Protocols need to assume massive scale is possible
- We will see how *protocol layering* helps solve this problem shortly

Security is all about CIA (not CYA, but maybe that too)

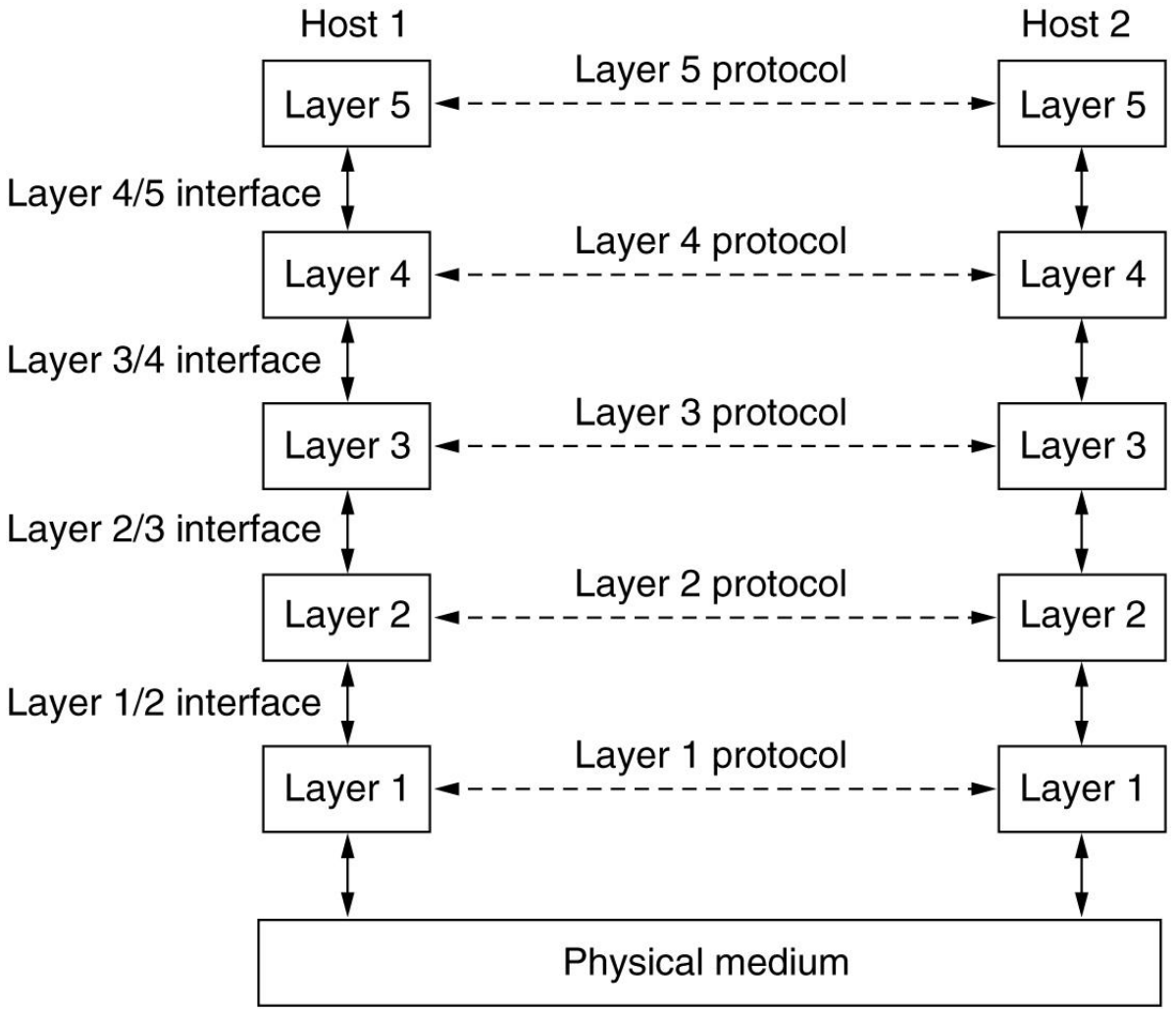
- Confidentiality
  - Can only the intended recipient read this?
- Integrity
  - Was the message altered in any way?
- Authenticity
  - Do we truly know who sent this message?

- Most things are protected with very strong math algorithms, but even that can't stop humans from being bad at security
- We'll spend time on this at the end of the semester

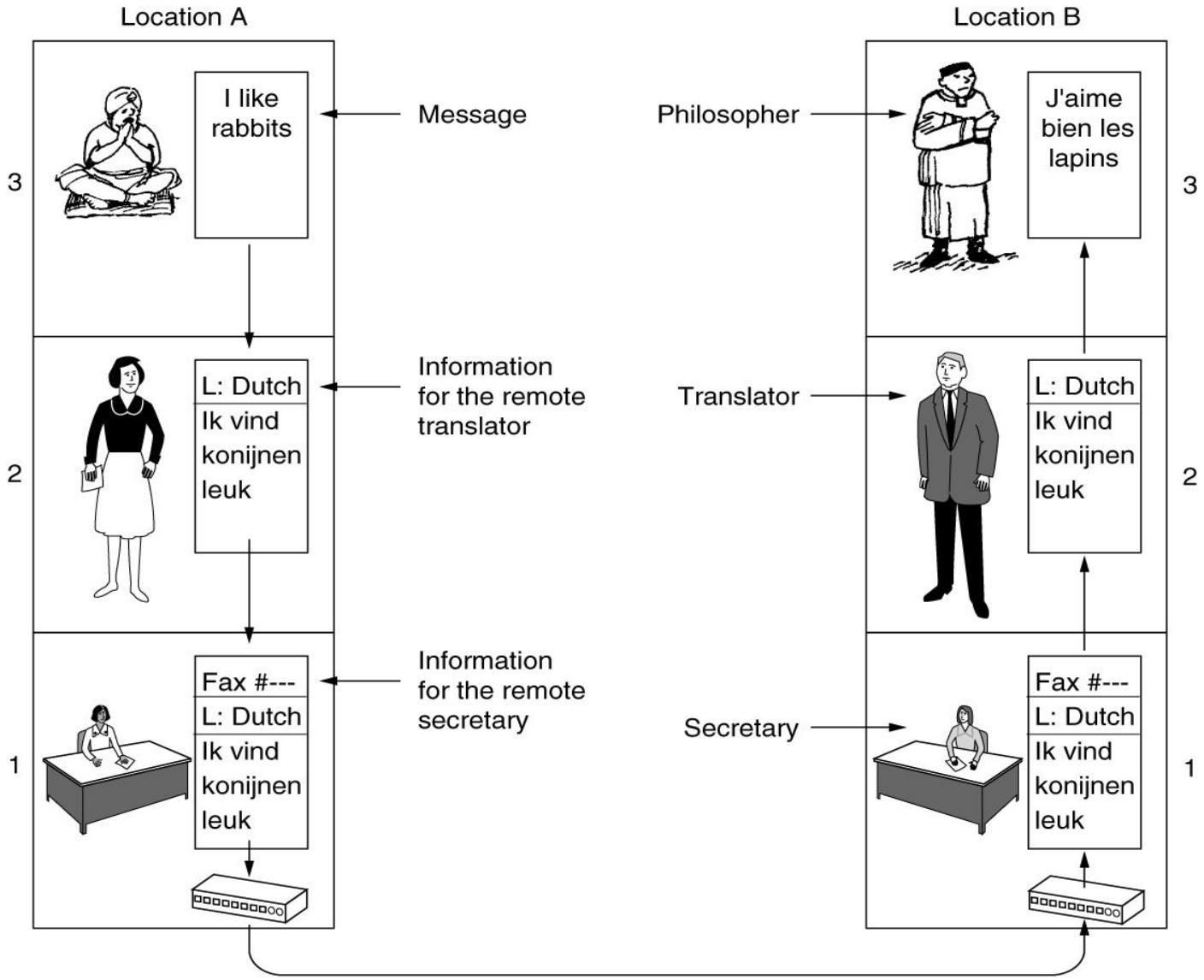
Protocol Layering reduces the complexity of solving all of these design considerations at once

- The purpose of layering is to provide a service to a higher layer while shielding that layer away from the details of how it was implemented
- Protocol
  - An agreement between communicating parties on how the communication shall proceed
  - Protocols are very important and violations can lead to awkward moments

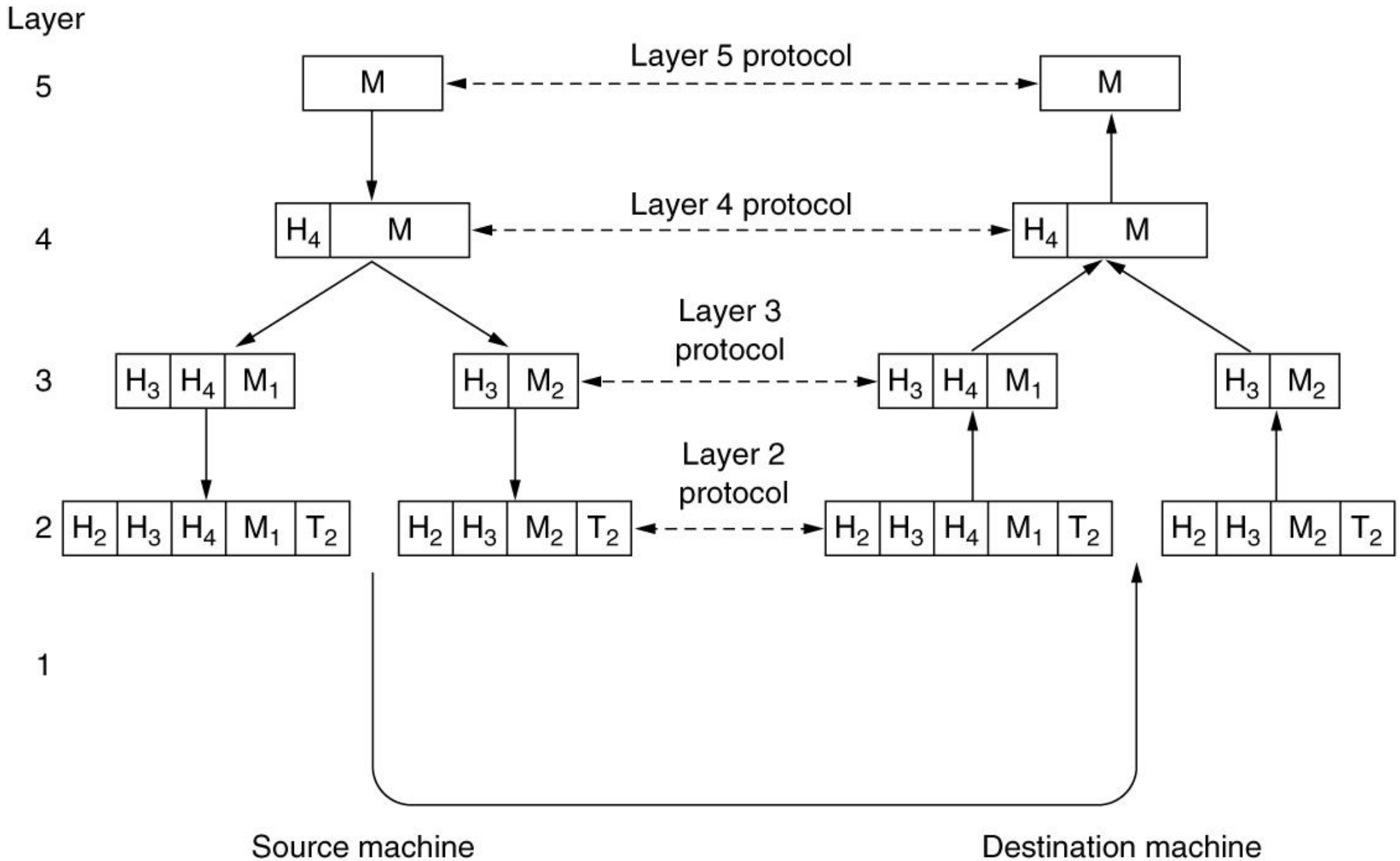
In networking, we solve the problems at each layer from software application down to the physical medium



Each layer adds an additional information or “header” information to the message

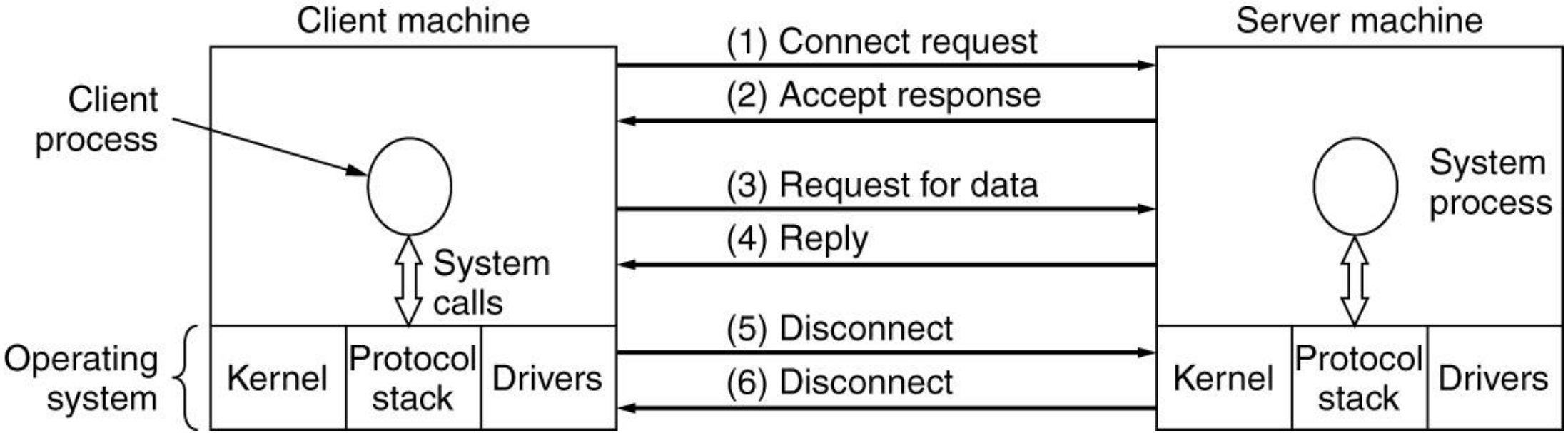


Headers attached to a message (formal)

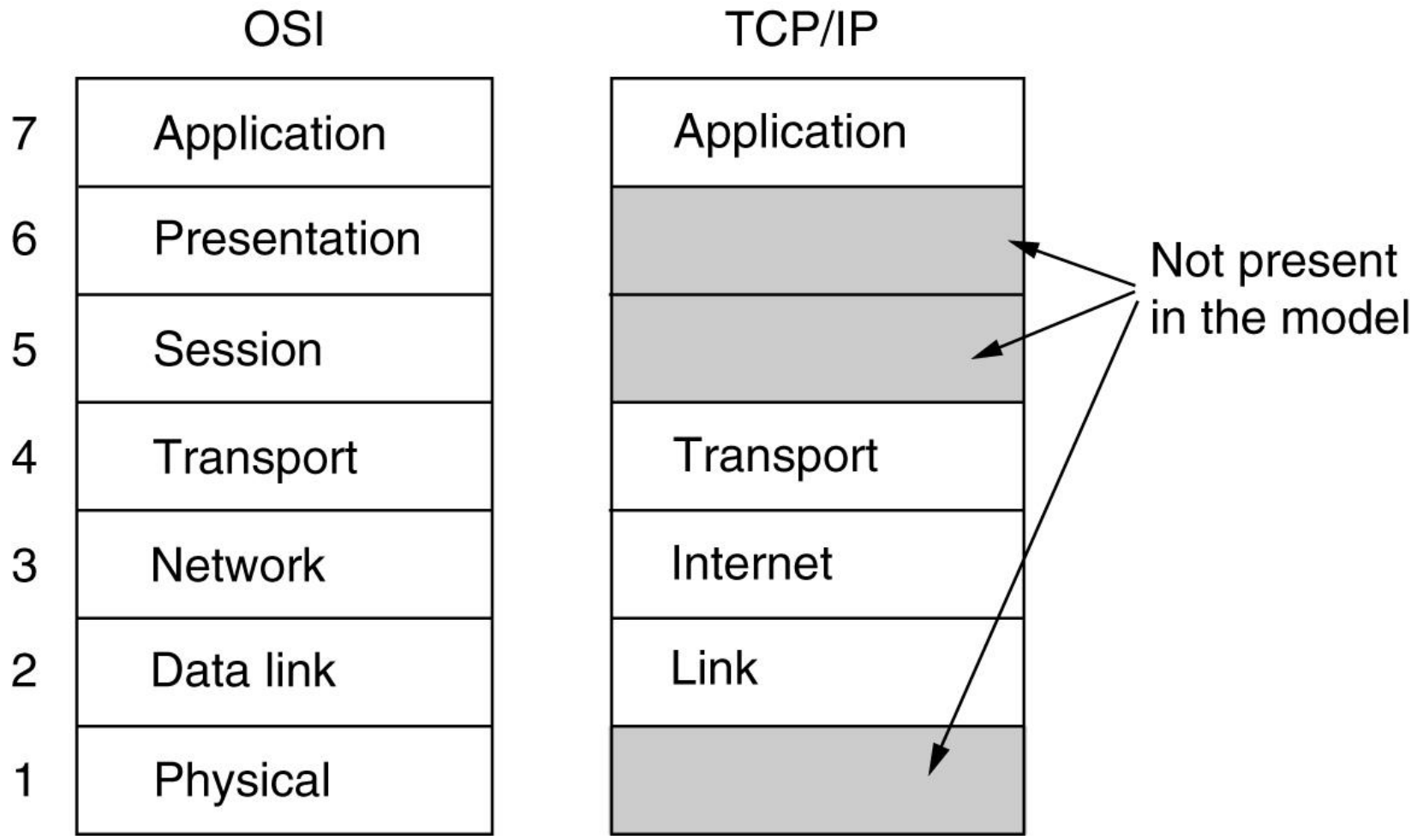


How a client and server may communicate over the Internet

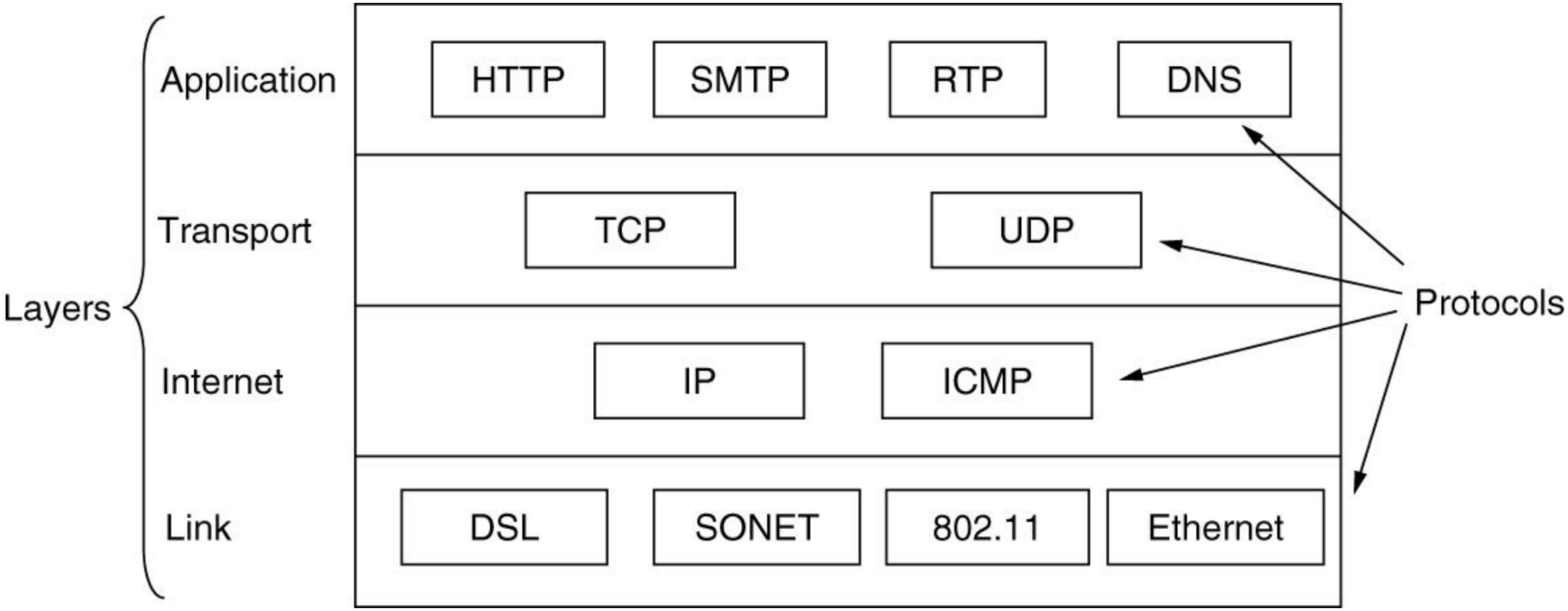
- In a connection-oriented client-server model, we typically have an interaction as shown below:



So what are all these protocol layers then? Well, it depends on who you ask



Various applications listed in the TCP/IP layering model

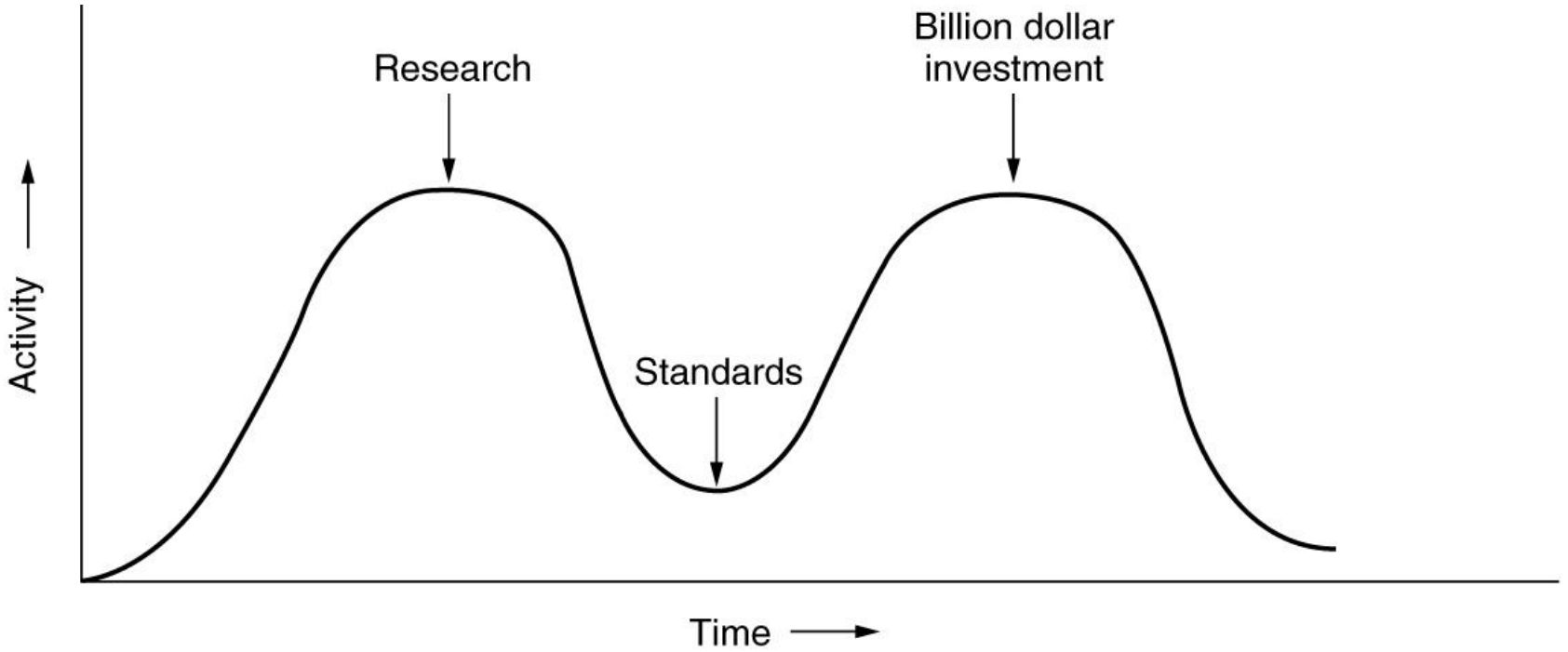


The issues with the models comes down to

- Bad timing
  - TCP/IP was already in wide spread use, there was no going back
- Bad design
  - Both models are flawed in some way
  - They are not generalized
  - The link layer is not really a layer in the normal sense of the term
  - There are data link and physical link layers…
- Bad implementations
  - Initial implementations were huge, unwieldy, and slow
- Bad politics
  - Blame the governments

Standards should be written between the two elephants

- They must come AFTER research has been done and things are figured out
- They must come BEFORE rich companies decide to do whatever they want



The model we will use (and the book too)

- 5 layer model with a separate data and physical link layer
- Application
  - Web browser, discord client, SSH
- Transport
  - Which application needs the message?
- Network
  - Where does the message route to?
- Link
  - How do messages get between two devices?
- Physical
  - What is the physics behind copper, fiber, radio?