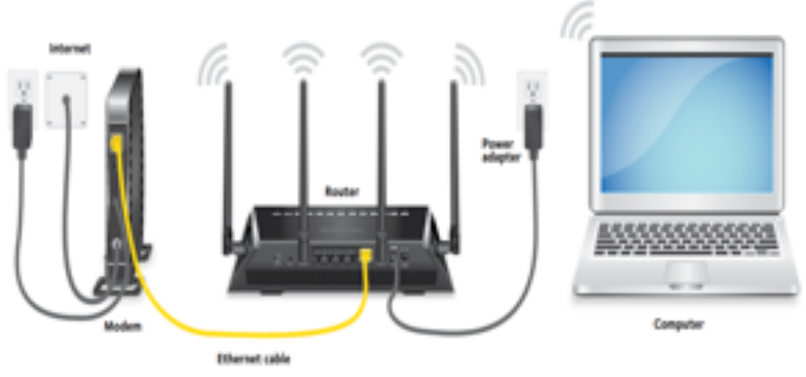
TCP/IP

The Physical Internet

A Network of Networks

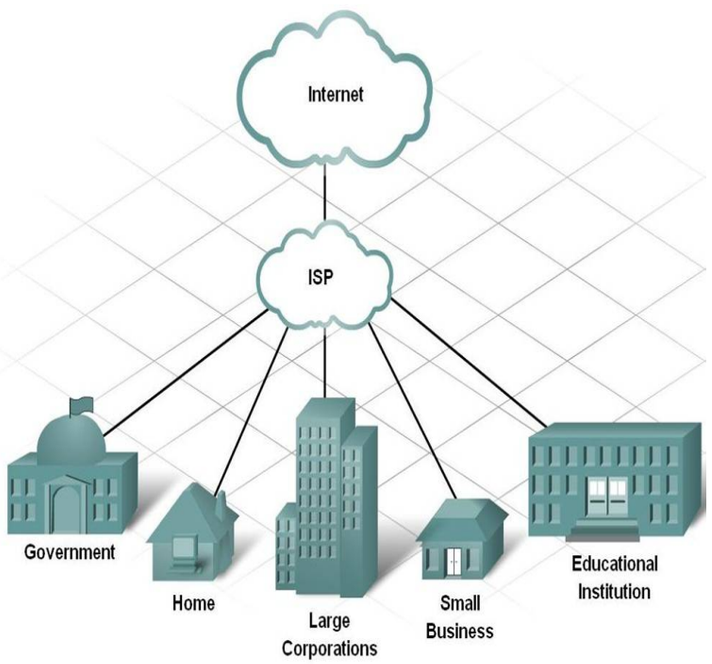
LAN

- However you connect your machine to your network
  - You are connected to everyone else on that network
  - We often call this a Local Area Network (LAN)
- To connect to the Internet
  - Connect a router in the network to a larger network
  - Most commonly an Internet Service Provider (ISP) network through a modem
- Router
  - Multiple devices can use the same connection
- Modem
  - Decodes signals from ISP



ISP Networks

- Connect customers to the Internet
- Maintain city and regional networks
- Addresses the last mile problem



https://bijanghayyoomi.files.wordpress.com/2010/08/picture20.jpg

http://oldforum.paradoxplaza.com/forum/showthread.php?837998-Underground-power-lines-and-capacity/page2

Tier 1 Networks

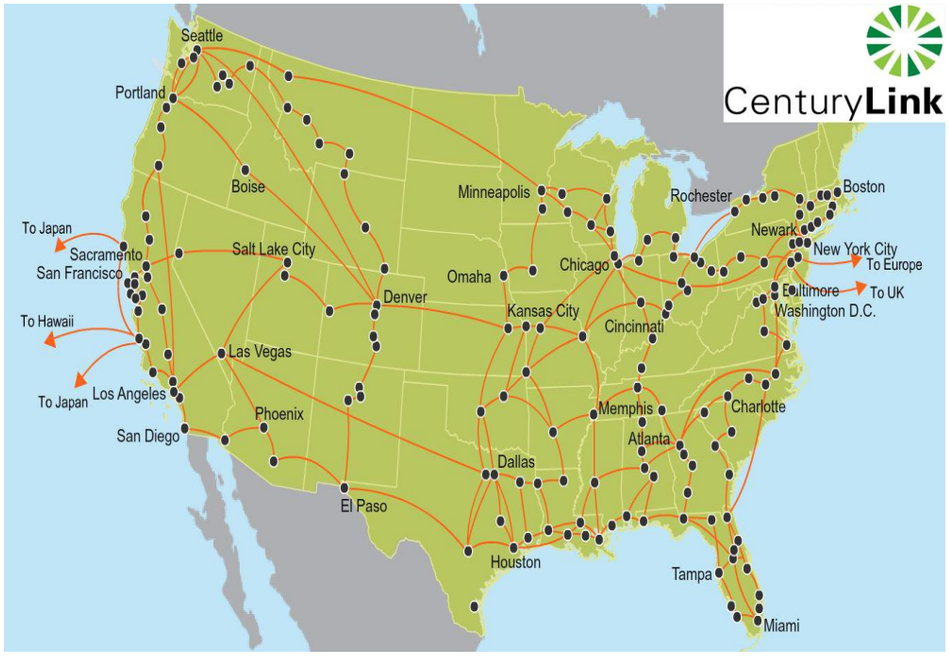
- A network that is connected to all other networks on the Internet without paying another network provider for access
- Maintain networks at the global scale
- ISP's pay for tier 1 access just like we pay ISPs
- Tier one networks form the backbone of the Internet
- Some tier 1 companies also offer ISP services to individuals in certain regions
- Often peer with each other allowing them to use each other's networks, thus increasing the overall speed and reliability of the Internet

Tier 1 Networks

AT&T

CenturyLink

Global Telcon & Communications



http://www.vootwerk.com/network.html

Level 3 Communications

NTT Communications

Verizon Enterprise Solutions

Zayo Group

(https://en.wikipedia.org/wiki/Tier_1_network for more)

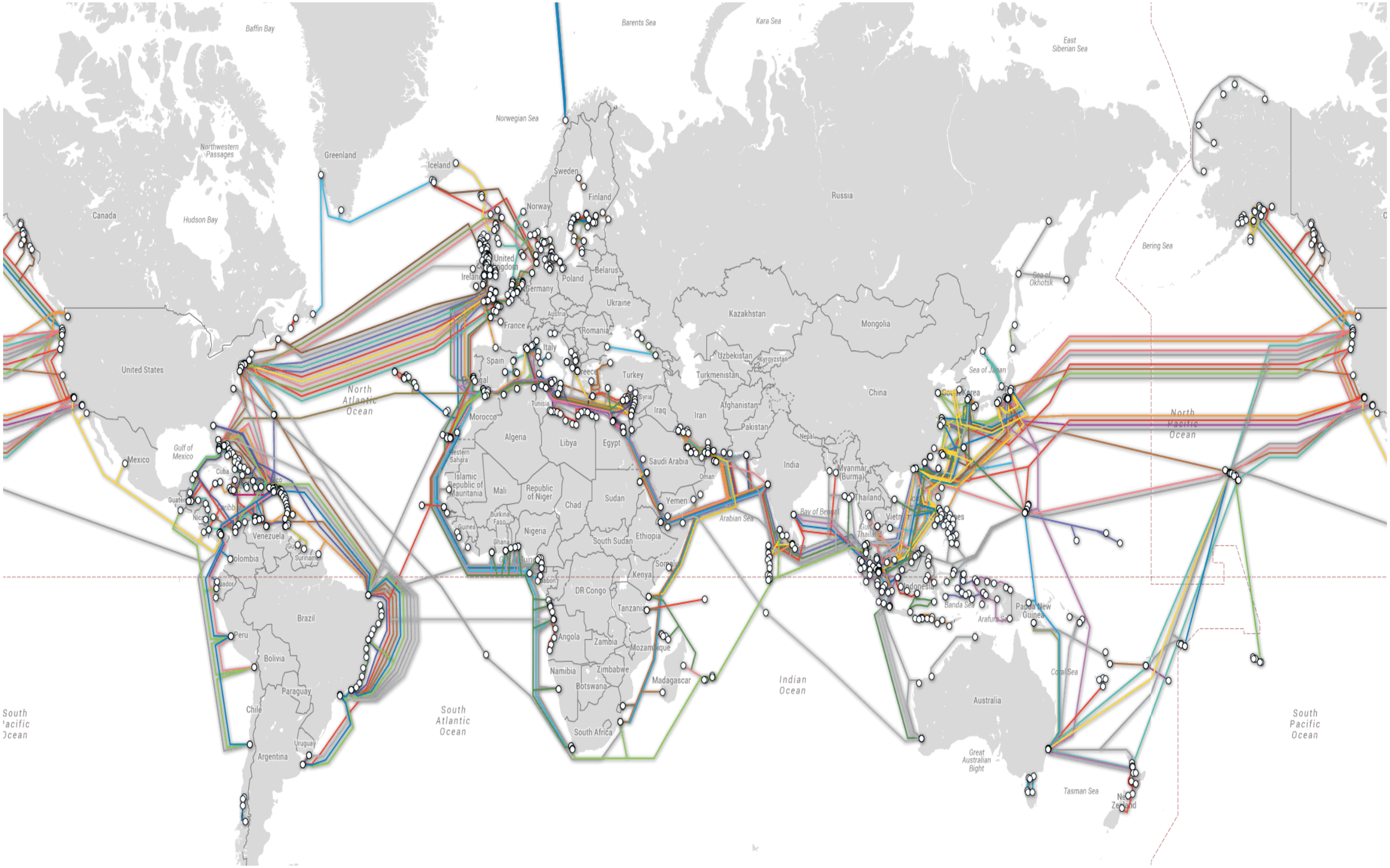
Internet Exchanges (IX)

- Tier 1 networks must connect to ISP networks and other Tier 1 networks
- These connections are made in Internet Exchanges
- 60 Hudson Street (pictured) houses one such IX in Manhattan

https://www.wired.com/2015/11/peter-garritano-where-the-internet-lives/

https://en.wikipedia.org/wiki/60_Hudson_Street

Cables Connect Continents



https://arstechnica.com/information-technology/2016/05/how-the-internet-works-submarine-cables-data-centres-last-mile/

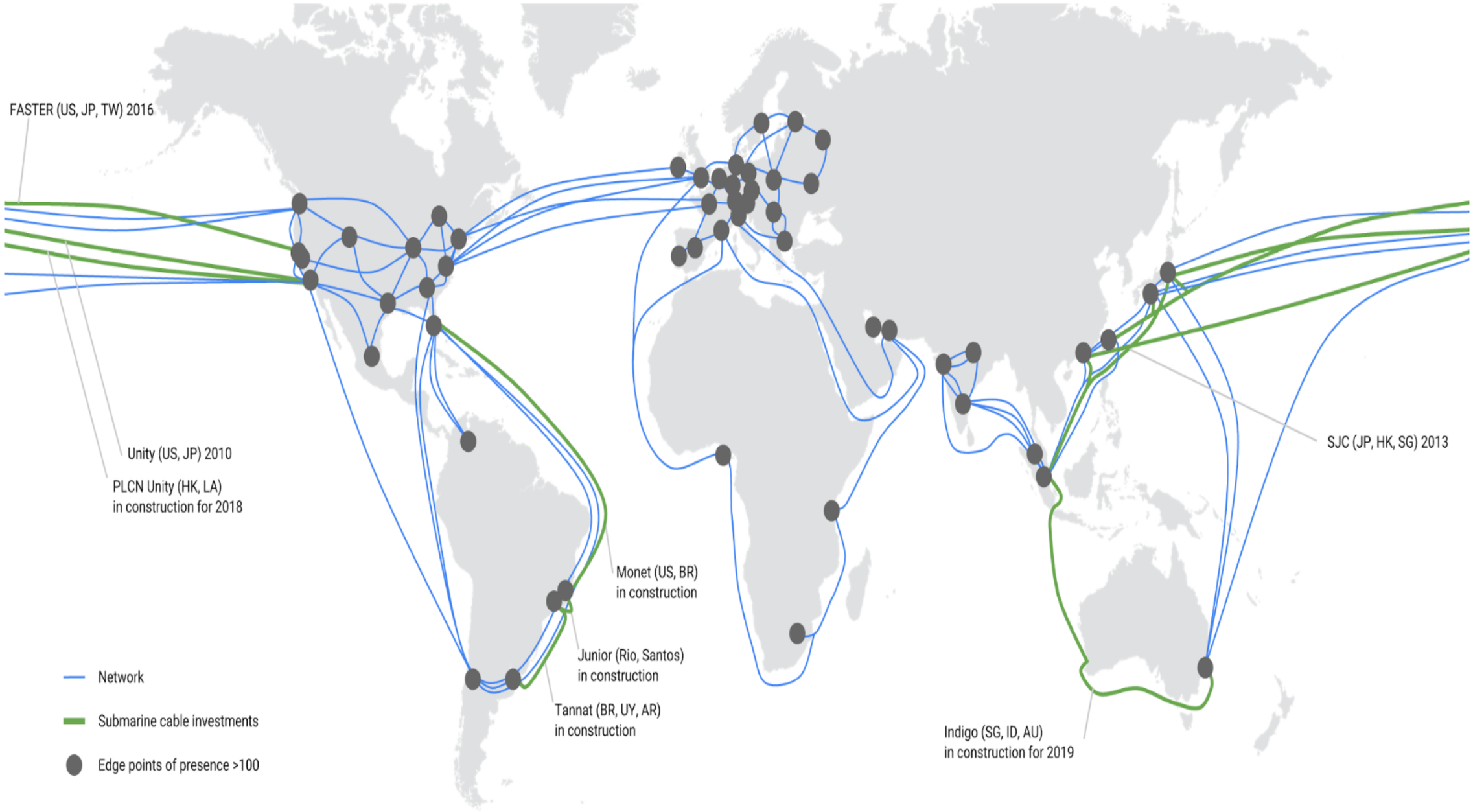
Data Centers Power Apps

http://americanbuildersquarterly.com/2015/yahoo/

http://imgur.com/gallery/7NPNf

Google Cloud Submarine Cable Investments

Google Cloud's well-provisioned global network is comprised of hundreds of thousands of miles of fiber optic cable and seven submarine cable investments



https://www.blog.google/topics/google-cloud/google-invests-indigo-undersea-cable-improve-cloud-infrastructure-southeast-asia/

The Physical Internet

How do we use these cables?

Internet Protocol

Internet Protocol (IP)

- *The Internet is a network of networks connected by cables*
- Now, how do these networks and devices communicate with each other?
  - Internet Protocol
    - Official standard for IPv4: https://tools.ietf.org/html/rfc760
  - Every device connected to the Internet has an IP address
    - Routers use this address to send data to its destination

Internet Protocol

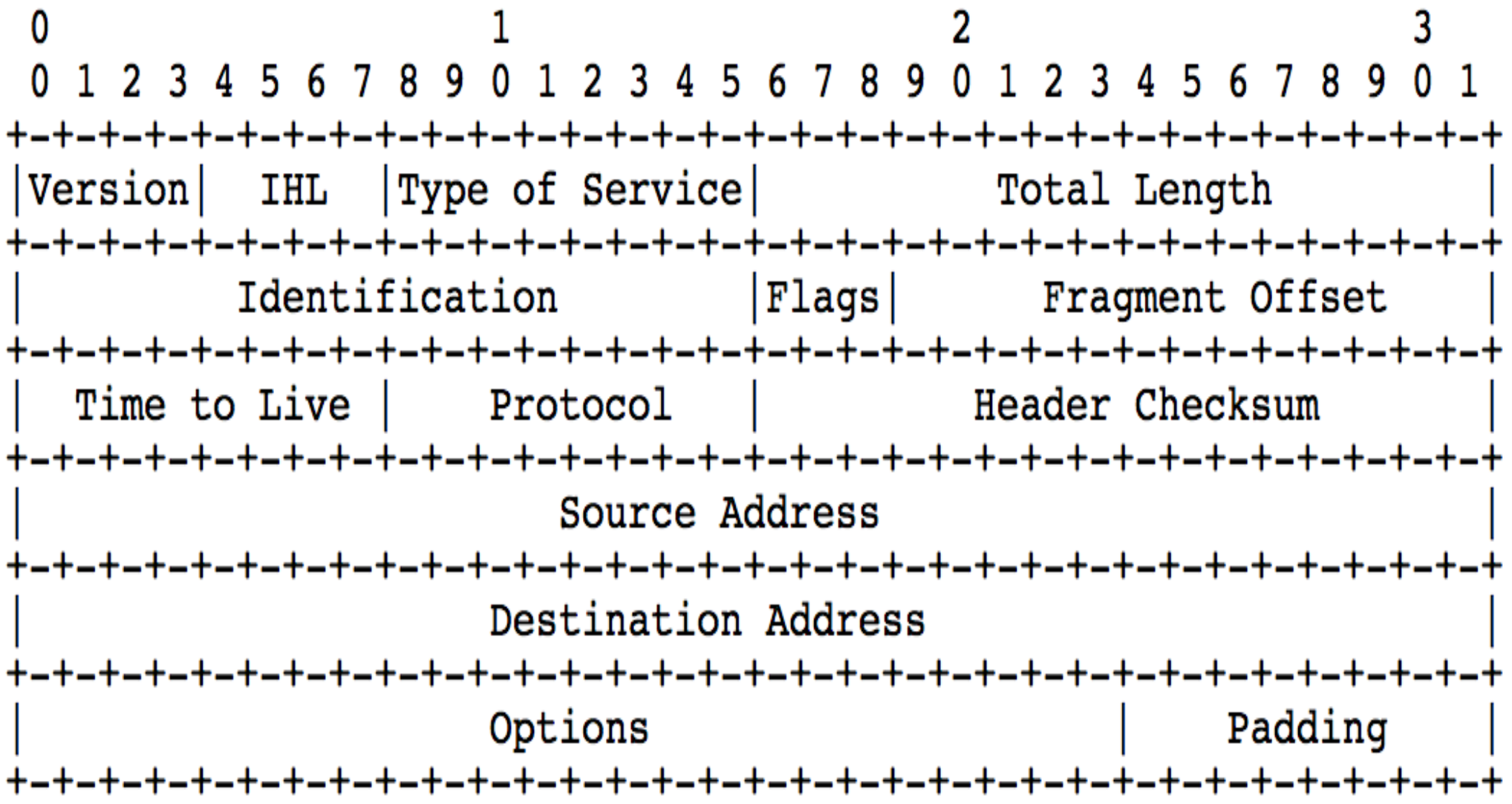
- Data is sent in packets/datagrams
  - Large messages are sent in multiple packets
- Each packet contains a header and a payload
- Header
  - Contains metadata about the packet
  - Most importantly, contains the source and destination IP addresses
- Payload
  - The data to be sent to the destination device
  - IP has no concern about the content of the payload
  - Payload often/always follows additional protocols agreed upon by the source and destination
    - Ex: TCP, UDP, HTTP[S]

IP

- Address of a machine on the Internet
  - Ex: 172.217.12.211
- Routers read the address and send it to the next step
- Often read a prefix
- IPs with a common prefix are related
- Two parts: Network, host
- Organizations will receive a prefix and own all IP's that start with that prefix
  - One of Google's ranges: 172.217.0.0-172.217.255.255
    - Network prefix: 172.217.x.x

IP

- IPv4 (8.8.4.4)
  - Consists of 4 numbers ranging from 0 to 255
  - How many total addresses?
    - 4 numbers, 8 bits each, 32 total bits, 2^32 total addresses
    - 4,294,967,296
  - A lot, but not enough
- IPv6 (2001:4860:4860:0000:0000:0000:0000:8844)
  - 128 bit addresses
  - 2^128 total addresses
    - 340,282,366,920,938,463,463,374,607,431,768,211,456
  - That should be enough
  - Used in conjunction with IPv4
  - Routers must be able to route both versions



Example Internet Datagram Header

Figure 4.

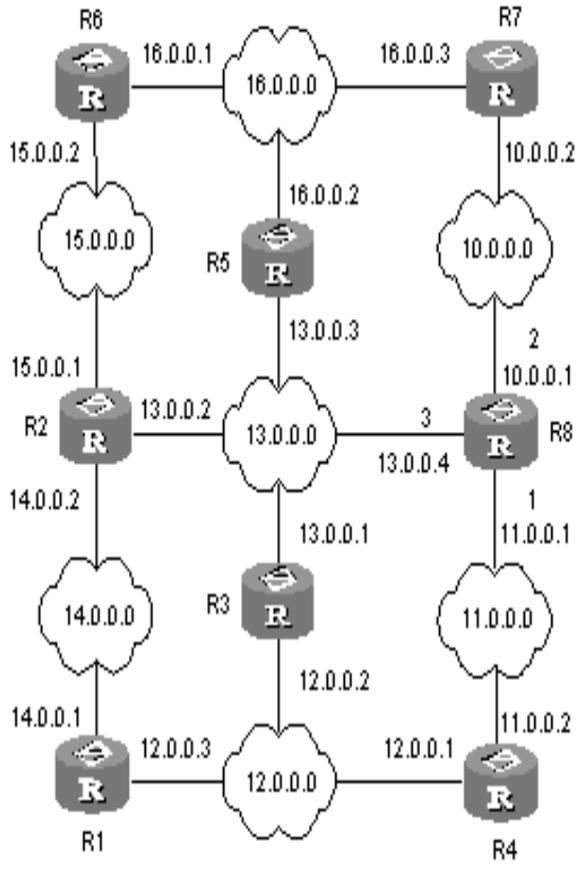
From the IPv4 official standard: https://tools.ietf.org/html/rfc791

Domain Name Service (DNS)

- We don’t want to remember IP address for all our favorite sites
- With DNS, we don’t have to
- DNS
  - Remember a Domain Name instead of an IP address
  - Domain Name: google.com
  - When you click a link, first a DNS request is made to get the IP address for that Domain Name
  - Then the IP address is used to make your request
- Can access sites directly by IP
  - http://172.217.6.228/
- Not all sites allow direct IP access
  - http://104.16.40.2/

Routing Through the Internet

- ISP and Tier 1 networks contain many routers to direct Internet traffic
  - These routers are made for speed!
  - To maximize speed, they are simple
- Router reads the destination IP address of a packet and sends it to the next router
  - Only knows the next step
  - No one needs to map the entire Internet
  - Routing tables can be updated



Routing table of router R8

Destination network	Next hop	Interface
10.0.0.0	10.0.0.1	2
11.0.0.0	11.0.0.1	1
12.0.0.0	11.0.0.2	1
13.0.0.0	13.0.0.4	3
14.0.0.0	13.0.0.2	3
15.0.0.0	13.0.0.2	3
16.0.0.0	10.0.0.2	2

https://superuser.com/questions/959242/how-is-next-hop-defined-in-routing-table

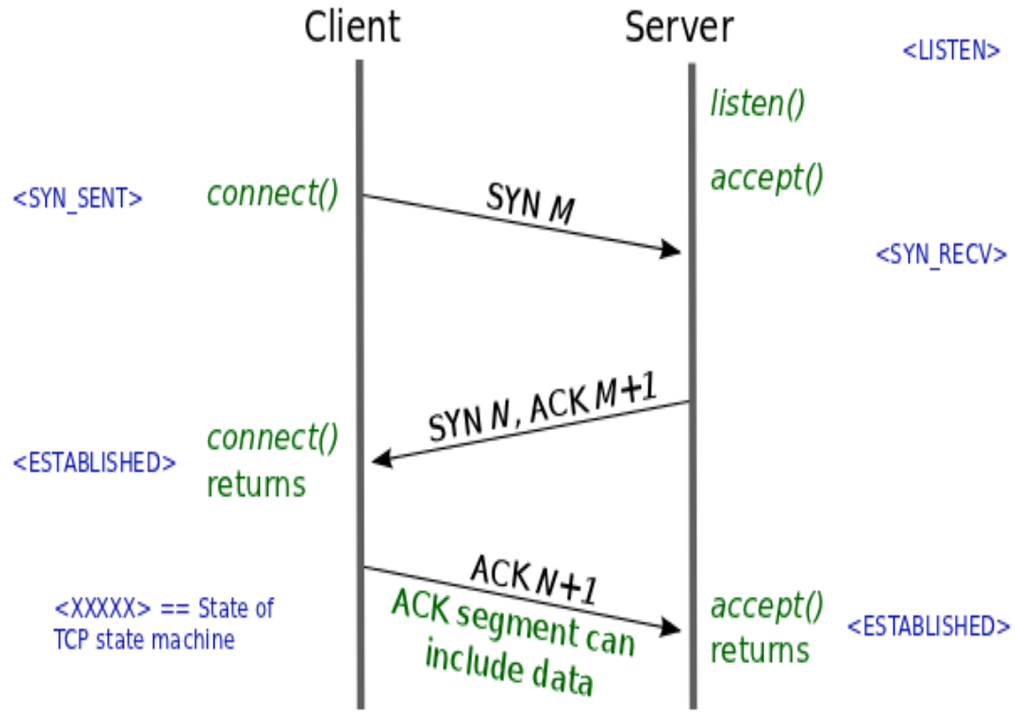
Transmission Control Protocol

Transmission Control Protocol (TCP)

- The Internet is unreliable
- Router sends a packet to its next step, then forgets about it
  - May have sent packets to a failed router
  - Cables may be cut
  - Regions can have power outages
  - Router never gets confirmation of delivery even if the packet made it to its destination
- Internet users (Browsers) and apps are responsible for reliability

TCP: Making a Connection

- 3-way handshake to confirm a connection
- SYN
  - Client sends a packet with a random number to the server
- SYN-ACK
  - Server acknowledges that it received the client's SYN by returning the random number+1
  - Also send another random number
- ACK
  - Client returns the server's random number plus 1
- After all three steps, both side have verified the connection



https://lwn.net/Articles/508865/

TCP: Transmitting Data

- When request/response is too large for a single packet
  - Receiver reassembles the packets on the other side of the connection
- Once a connection is established, send all the packets
- Packets can arrive out of order
  - Each packet contains a sequence number for reordering
  - If a sequence number is missing, request a resend
- Many streams simultaneously
  - TCP uses port numbers
  - Allows multiple programs to all use the Internet simultaneously
  - Connect to a port number/IP address combination (TCP/IP)

TCP: In code

- Use TCP sockets in your language of choice to listen for TCP connections on a chosen port

TCP/IP

- Much more coverage in **CSE489: Modern Networking Concepts**!
    - Covers these protocols, and many more, in great depth
- In CSE312, we assume TCP/IP just works
    - Use libraries to make TCP connections

TCP Socket Server Demo