NETWORKS

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Before we dive in…

After this week, if you have a technology question feel free to contact me.

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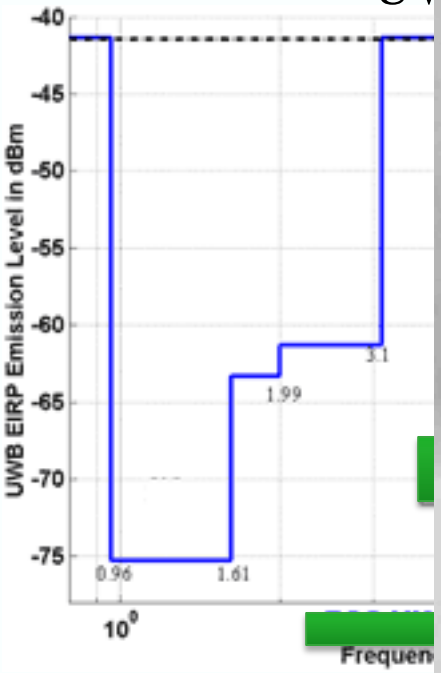
What is this?

Hush-a-phone

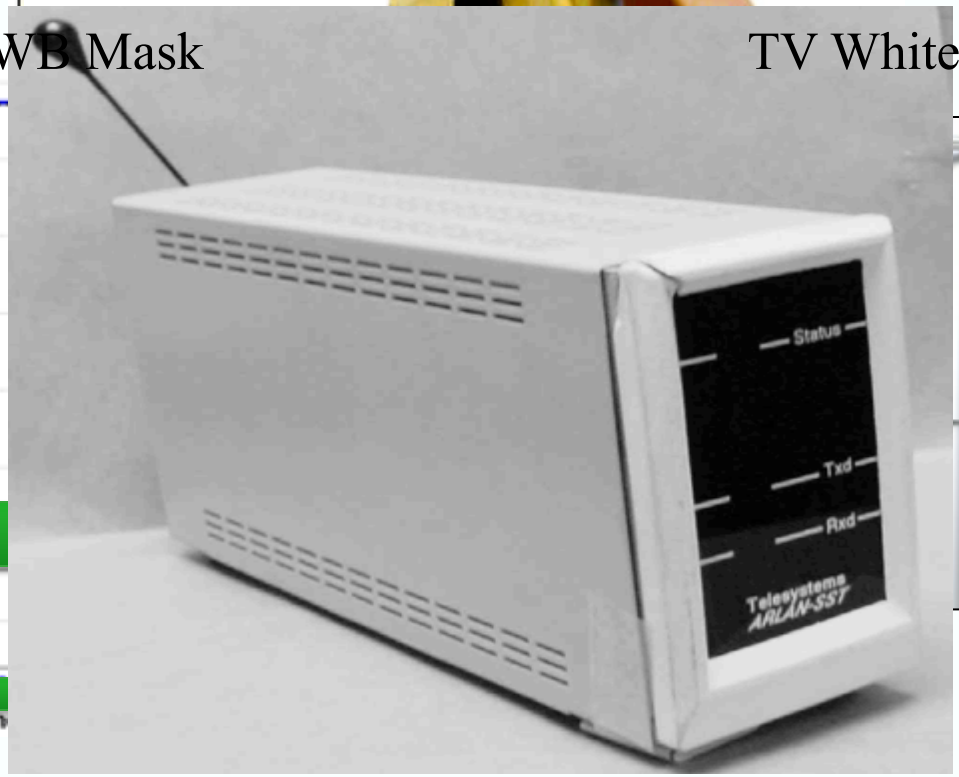
Carterphone

First certified WLAN

UWB Mask

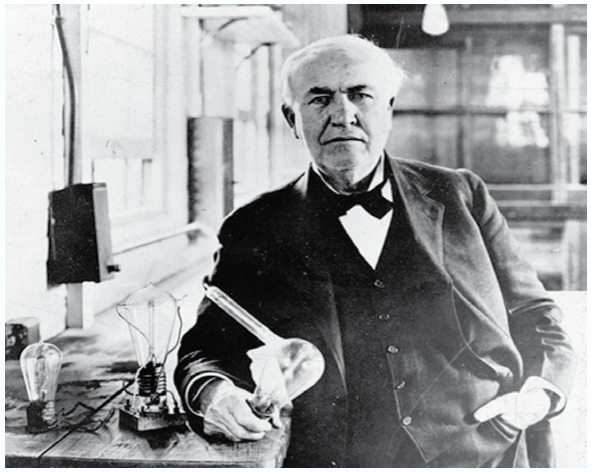


TV Whitespace Device

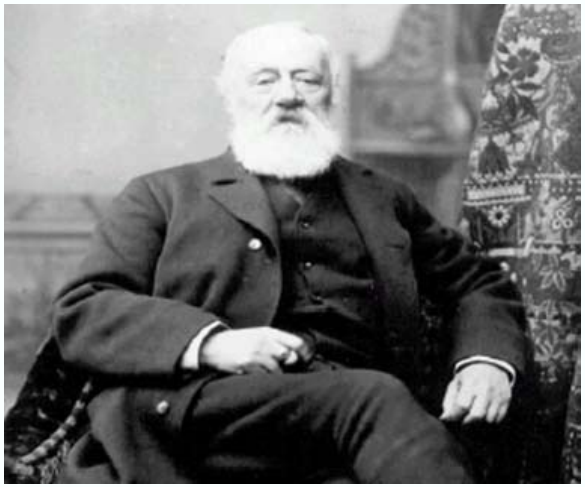


Why policy matters – incumbents will fight innovation

Edison



Bell



Same wires and service for 100+ years

Keeping the lights on

Providing dialtone

Finely honed machine

Engine of innovation

WHY DID ONE INNOVATE?

Goals and Outline

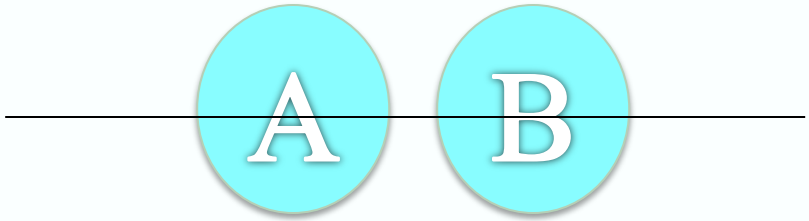
- Gain a basic understanding of networked systems
  - Understand what aspects matter with **any** network
- Learn the concepts used to describe networks
  - Basic network terminology
  - Power grids
    - Electricity basics, power grids and Smart grids
  - Communications networks
    - Internet, Broadband and Wireless
- Observations on networks and network policy
- Extra slides
  - Recent network technology
  - Internet Interconnection

Networked Systems

What is a network?

A Set of Connected Objects

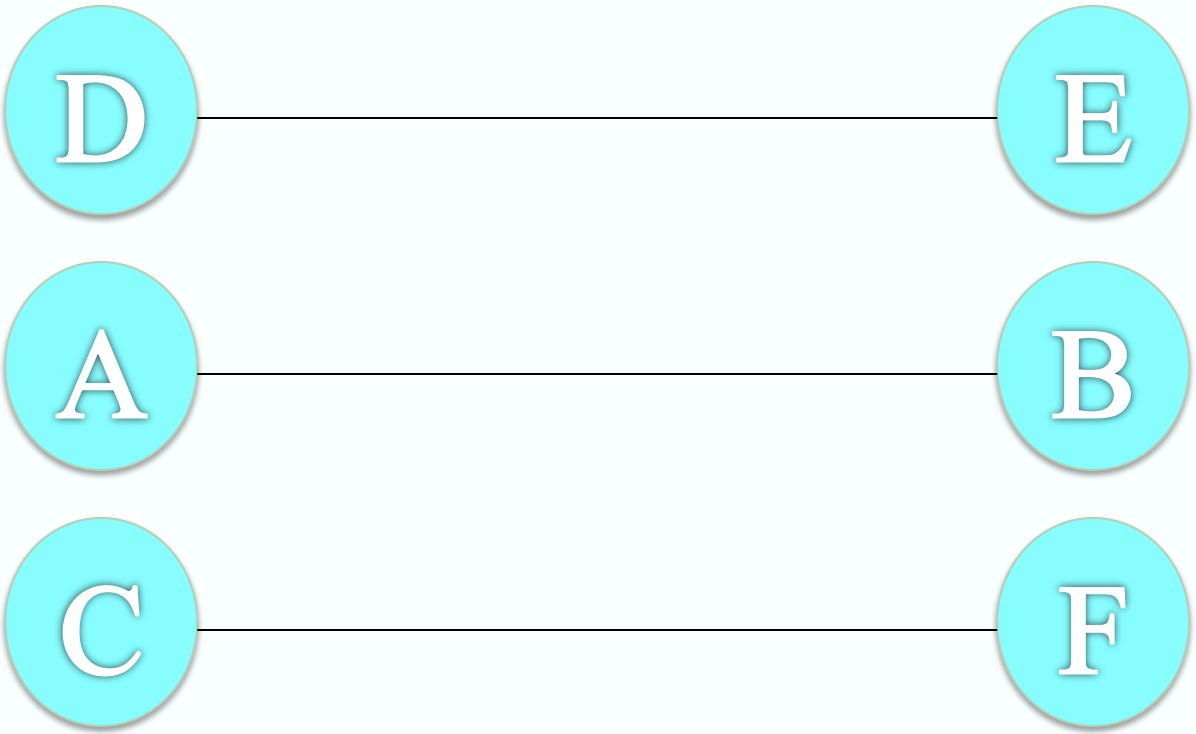
A Simple Network



Nodes and Links can combine to form complex systems

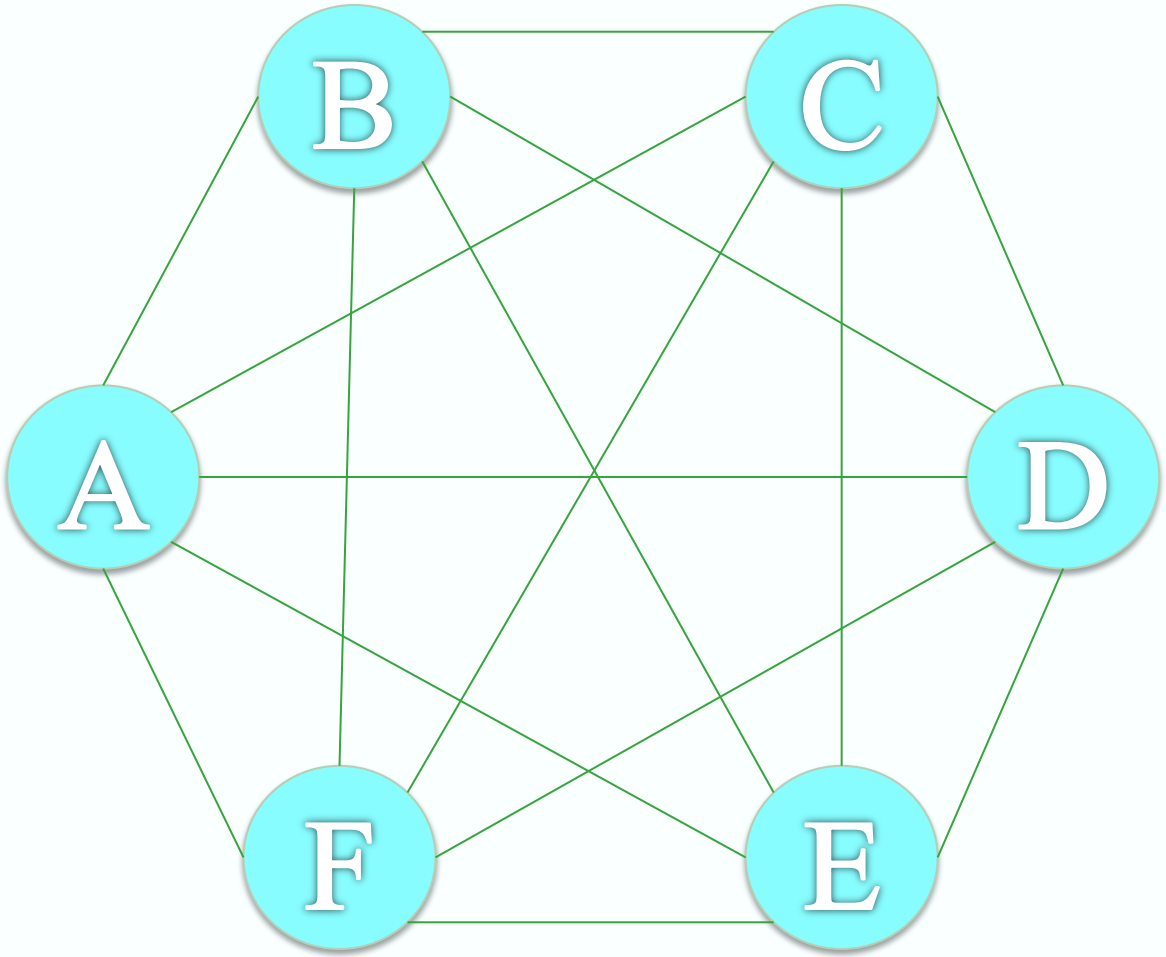
- We worry about the:
  - Connectivity, Reliability, Functionality…
  - How to build, finance, maintain, update and price

Simple Networks



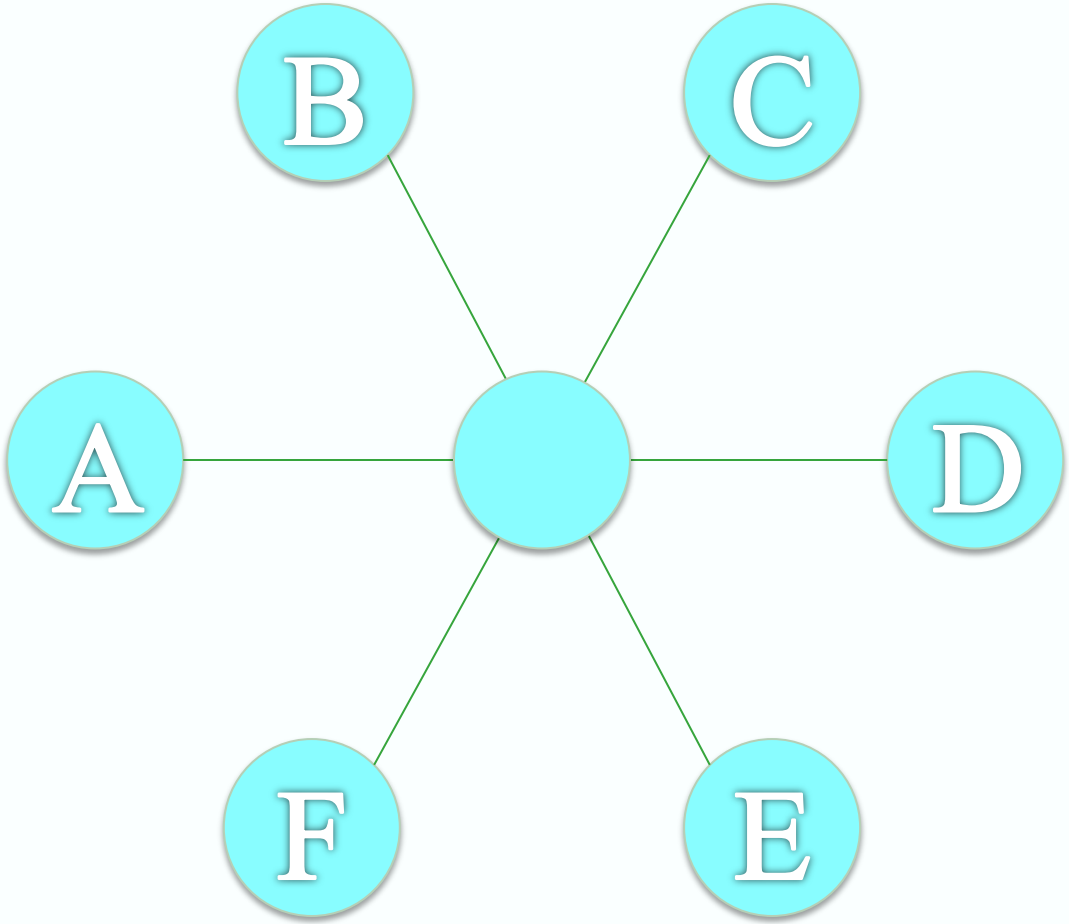
- Not very practical:
  - Connectivity?
  - Cost?

Mesh Network



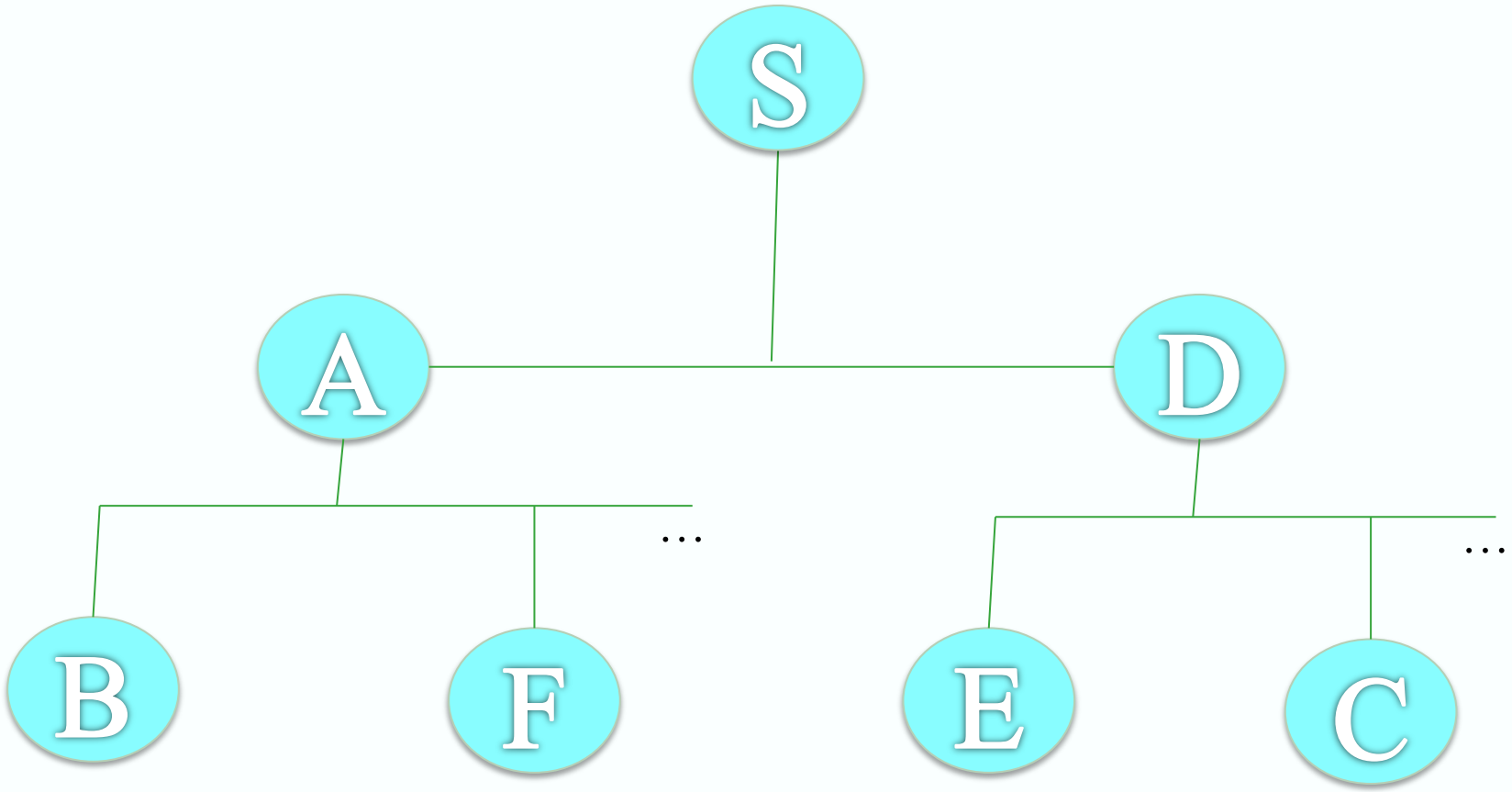
- Great connectivity, but not very practical:
  - Cost?
  - Scale?

Star (or spoke-and-hub) Network

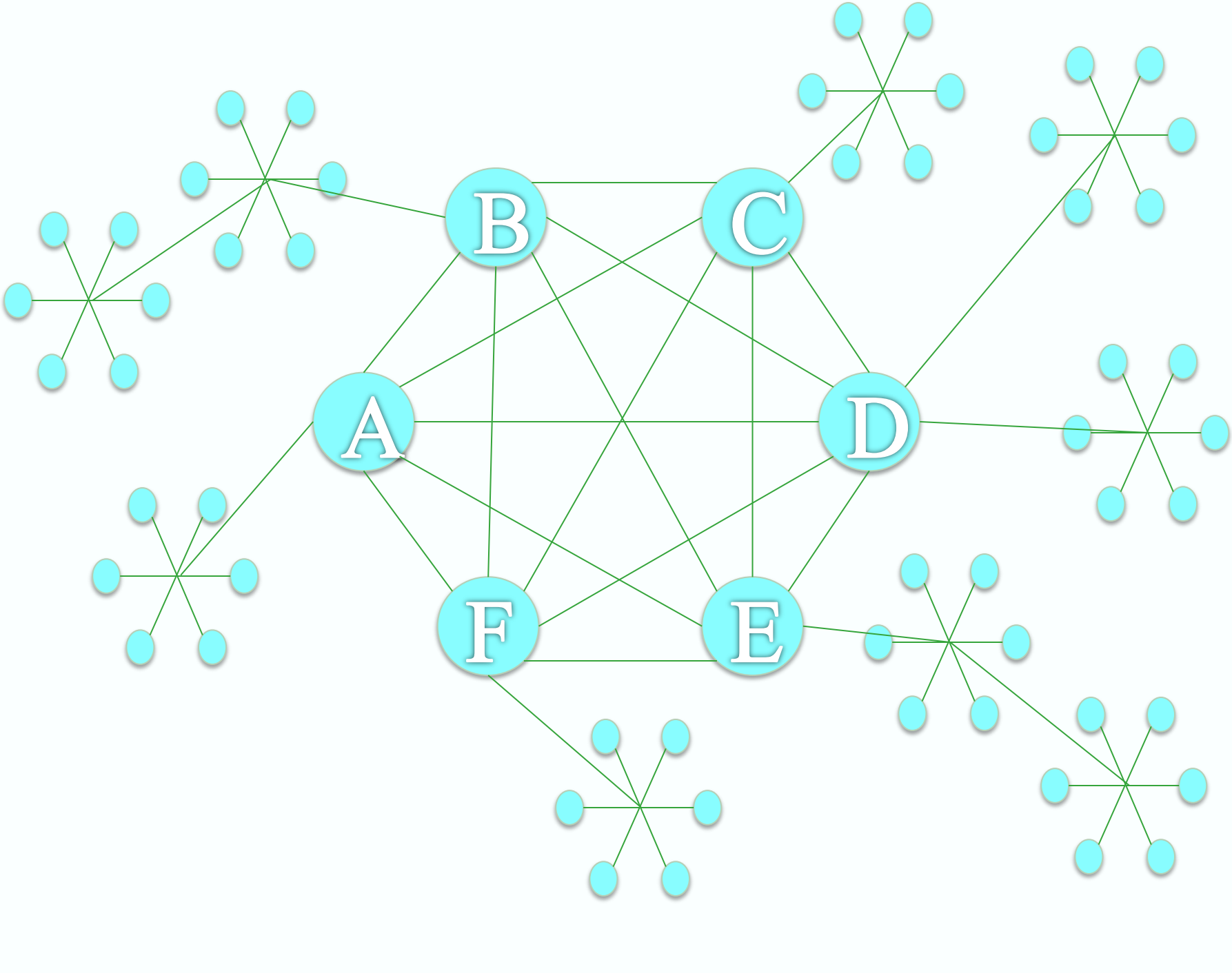


- Good connectivity
- But bottlenecks exist and require connection to other resources

Bus Network



- Again, good connectivity but bottlenecks exist and require connection to other resources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C
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Source: http://www.bluegreenalliance.org/blog/image/mapoftheweek.blogspot.com.jpg

Networks

- Things to consider for any network

  f{Connectivity, Ubiquity, Functionality, Reliability, Quality of Service, Security/Privacy, Scalability, Adoption, Adaptability…}

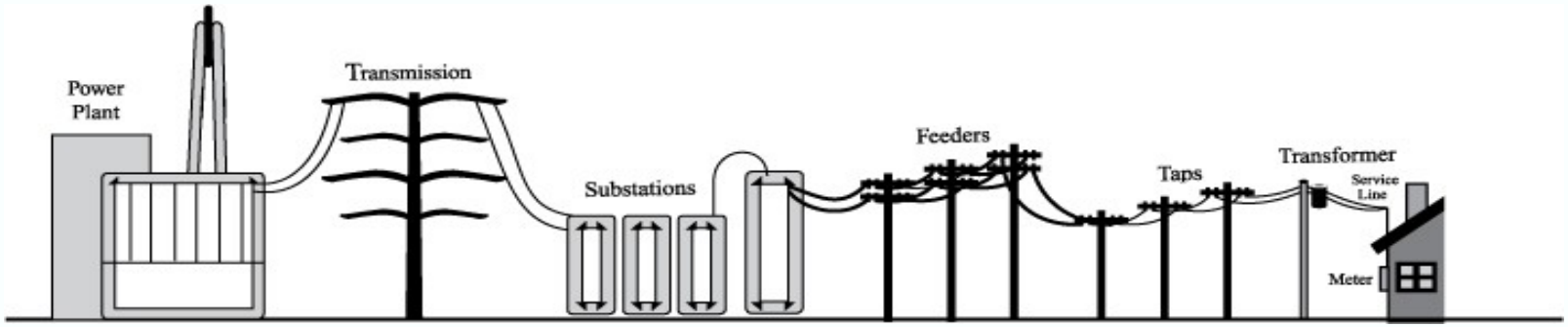
- Services
  - The complex set of tasks concerning the production and distribution of the "good"
- Technology innovation means…
  - Better, Faster, Cheaper
  - But also…
    - Impacts investment and economics
    - Accelerates timescales
    - Creates policy uncertainty
    - Unsettles (or locks in) the incumbent
    - Impacts the consumer

Power Grids

Electricity Fundamentals

Electricity Fundamentals

- Generation - first process in the delivery of electricity
- Plant - facility that generates electric power (may be distributed)
- Transmission - bulk transfer of electricity from plant to substation
- Substation - provides switching, protection and transforms voltage
- Distribution - transfer between substations and customers
- Transformer - steps voltage from low to high OR high to low
- Service Line
- Meter



Electricity Fundamentals

- Current - measure of the flow of charge (think water flow) - I
- Resistance - opposition to electric current (size of the pipe) - R
- Voltage - electromotive force (think water pressure) - V

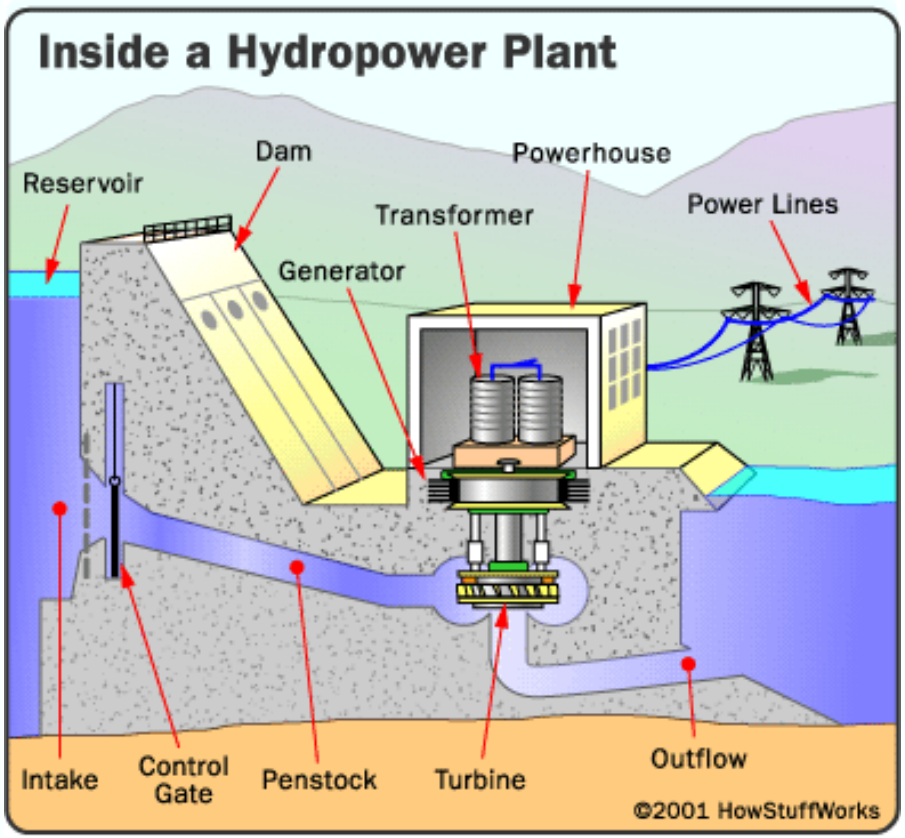
$$V = IR$$

- Power - the "work" and equals voltage times current - W
- Energy - power across time – kWh

BTW, it's the CURRENT that kills you.

Generation

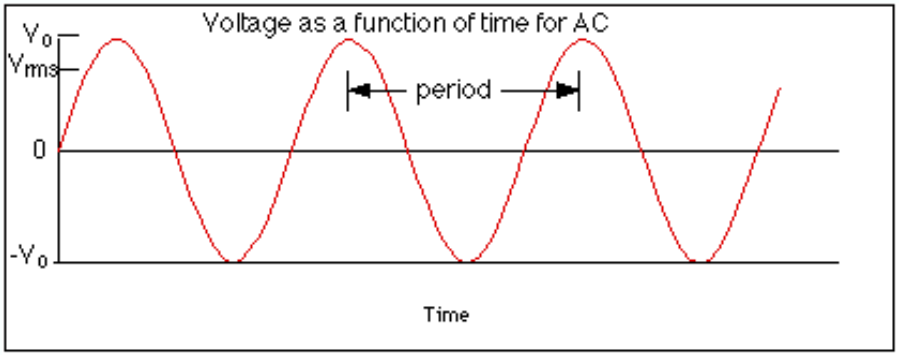
- Generation starts at a power plant or might be locally generated (residential solar)
- At the center of most power plant is a spinning electrical generator (often a turbine)
- Coal, Gas, Nuclear, Hydro, Wind



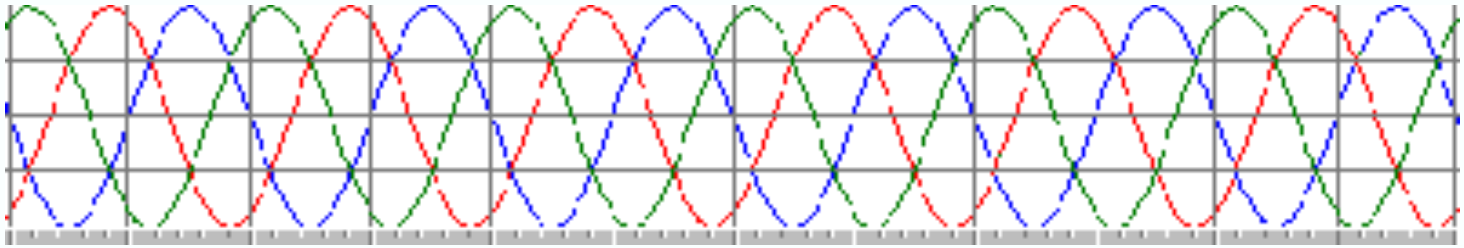
AC Power

Alternating Current (AC) power

- Single phase AC power (residential)
  - Voltage oscillates between +170 Volts and – 170 Volts (Vrms=120 V)
  - Frequency of oscillation is 60 times a second (60 Hz)
  - Current flows back and forth



- Three phase AC power (as it leaves the plant)
  - 3 live wires, plus the ground wire
  - Current on wires are offset in time (at different phases)



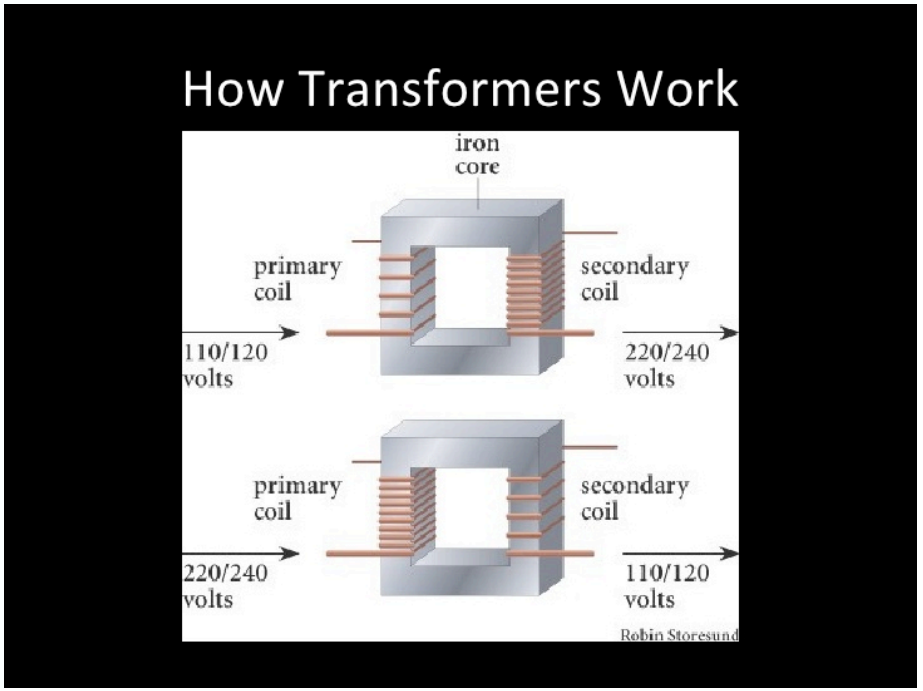
Transmission Substation

- At generation, the voltage is generally 3-25 kVs
- However to be efficiently transmitted over long distances the voltage must be much higher
- So the transmission substation transformer converts the power to a much higher voltage (e.g., 132 kV)
- Then power is transmitted to substations on thick insulated cables held high on pylons

Transformer - steps up or down voltage

Step up

Step down



Distribution Grid

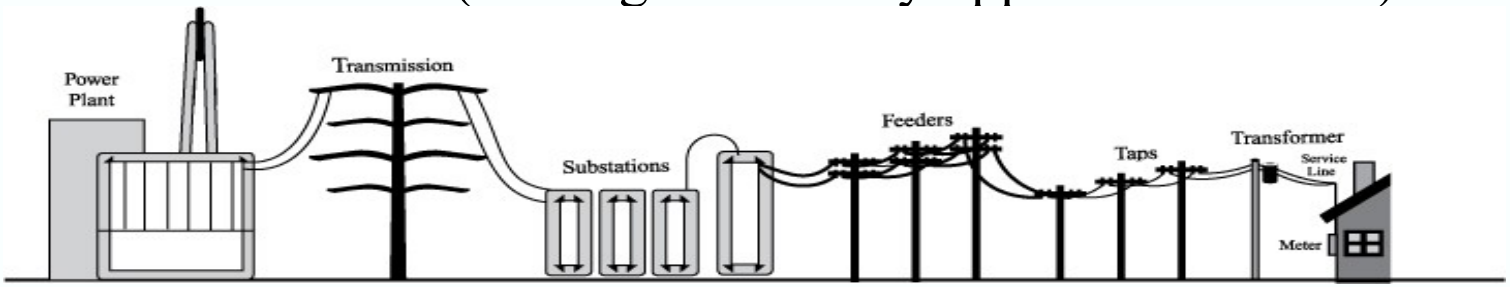
- After traveling through the high voltage transmission segment of the grid, the power is stepped down for distribution (often done in stages) to e.g., 7200V
- Also spreads the power out across a bus and provides switching and circuit breaking and regulator banks conditions the power

In the home…

- Only need a single phase, which is accomplished using taps
- Transformer at house or on the pole (7200V to 240V)
- Three wires from the transformer – two live wires (120V, out of phase) and a ground, allowing for the use of 120V and 240V appliances

More Electricity Fundamentals

- Power is measured in Watts (W)
  - Voltage * Current
- Energy is Power (W) * Time (h)
  - kilowatt hour (kWh) - kilowatt (1000W) for an hour
  - 10,000 (100 W) bulbs for an hour - 1 megawatt hour (MWh)
- Why a grid?
  - To connect – not really practical for most of us to self generate
  - To move – electric energy moves at about the speed of light
  - To be efficient
    - Large power plants are more efficient than small (economies of scale)
    - Things didn't start out large
  - Transmission is efficient (although efficiency opportunities exist)

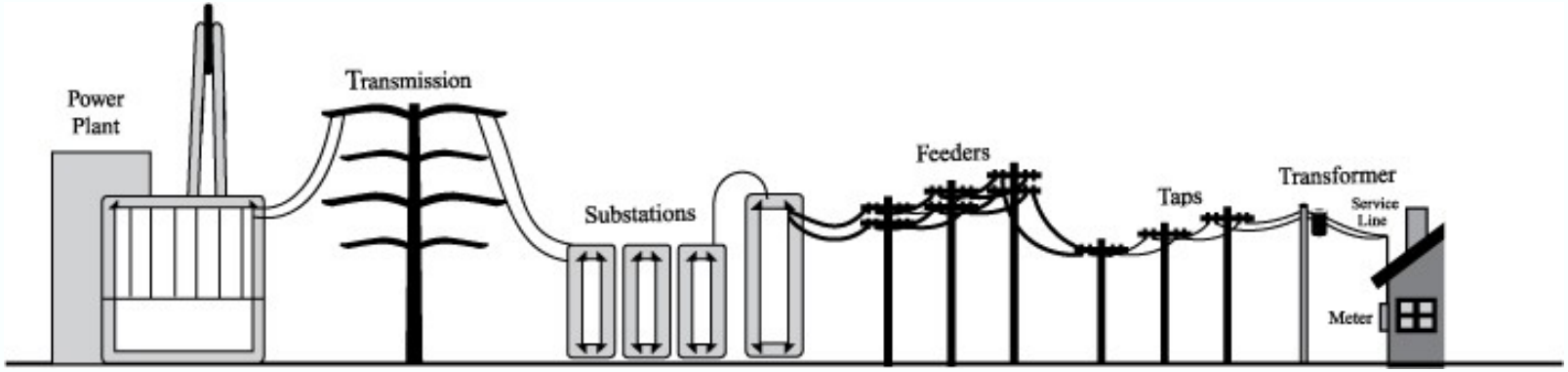


Traditional Power Grid

Has served us well, but…

- Aging
- Inefficient (peak power generators)
- Limited operational data
- Limited user control
- Limited real-time data
- Limited energy storage
- One-way binary demand response
- Reactive outage management
- Remains robust

Very reminiscent of the telecommunications networks of the 1990s



Can we improve *reliability* and *efficiency,* increase *innovation* and *investment*?

DoE's Definition of a Smart Grid

A fully *automated* power delivery network that monitors and controls every customer and node, ensuring a two-way flow of *electricity and information* between the power plant and the appliance, and all points in between. Its *distributed* intelligence, coupled with broadband communications and automated control systems, enables *real-time market transactions* and seamless interfaces among people, buildings, industrial plants, generation facilities, and the electric network.

My definition:

Evolving the grid with sensing, computing and communications to improve the use, efficiency, reliability, economics, and production of energy

Smart Grid

Might include…

- Smart meters
  - A digital electric meter likely equipped with (wireless) communications technology, allowing companies and customers to better manage use of energy
    - automatic meter reading (AMR) – automation first step towards "smart"
    - advanced metering infrastructure (AMI) – two way, fully set of features (e.g., pricing aware usage, time shifting use, prepay)

Smart Grid (continued)

Might include…

- Smart generation
  - Alternative Generation
  - Distributed Generation (DG)
- Smart data and measurement
  - Demand side management
    - Demand Response (DR) – Utilities control devices inside the customer premise; Allow reducing or shifting of power use away from peak demand periods
  - Phasor Measurement Units
    - wide-area measurement system (WAMS) for quality control
  - Fault detection and tolerance
- Smart pricing
- Smart appliances
- More…

Smart Grids Offer:

- Combining electrical and data infrastructures
- Real-time distribution & customer data
- Energy storage devices
- Local power generation
- Flexible demand response
- Real-time price signals
- Smart distribution system and processes

Considerations:

- Consumer – What does it mean to them?
- Market - Who will make money and how?
- Regulation - How will regulatory compacts change?
- Utility – What changes and justifying a business case?

Current State of Smart Grid

Moving slowly

- Interesting to consider
  - Intelligence in (and control of) generation, distribution and edge
  - Physical and logical interconnection
  - Regulatory impact (of the fed/state/local div?)
- At the Federal level (e.g., FERC, NIST and DoE)
  - Regulation and rates
  - Standards, deployment, health, privacy and security concerns
  - R&D and funding (slowing)
- At the state and local level
  - Regulation and rates
  - Deployment, health, privacy and security concerns
  - Deployment and debate

Smart Grid Observations

- The electric power industry has been *slow* to adopt many aspects of the smart grid (e.g., distributed operations)
  - Uncertainty on setting the incentives correctly
  - Very similar to the transition of the PSTN to the Internet
  - However, PSTN was an underlay for the Internet; no clear that power grid has analogy
- Lessons to be learned from the Internet
  - Intelligence at the edge
  - Distributed and open design
  - Architecture matter (getting the security right)
- Could hold great change and value for consumers
  - Not guaranteed, AND is now being deployed
  - MY OPINION -Will not deliver on its promises

Communication Network Concepts

Communication Network Concepts

- Next we consider these network concepts/trends
  - Evolution of Voice
  - Circuit Switching - Packet Routing - Software Defined
  - Centralized to Distributed Control (?)
  - Closed to Open Architectures (?)
  - Higher Data Rates and Lower Latency
  - New Service Architectures
  - Mobility

Voice

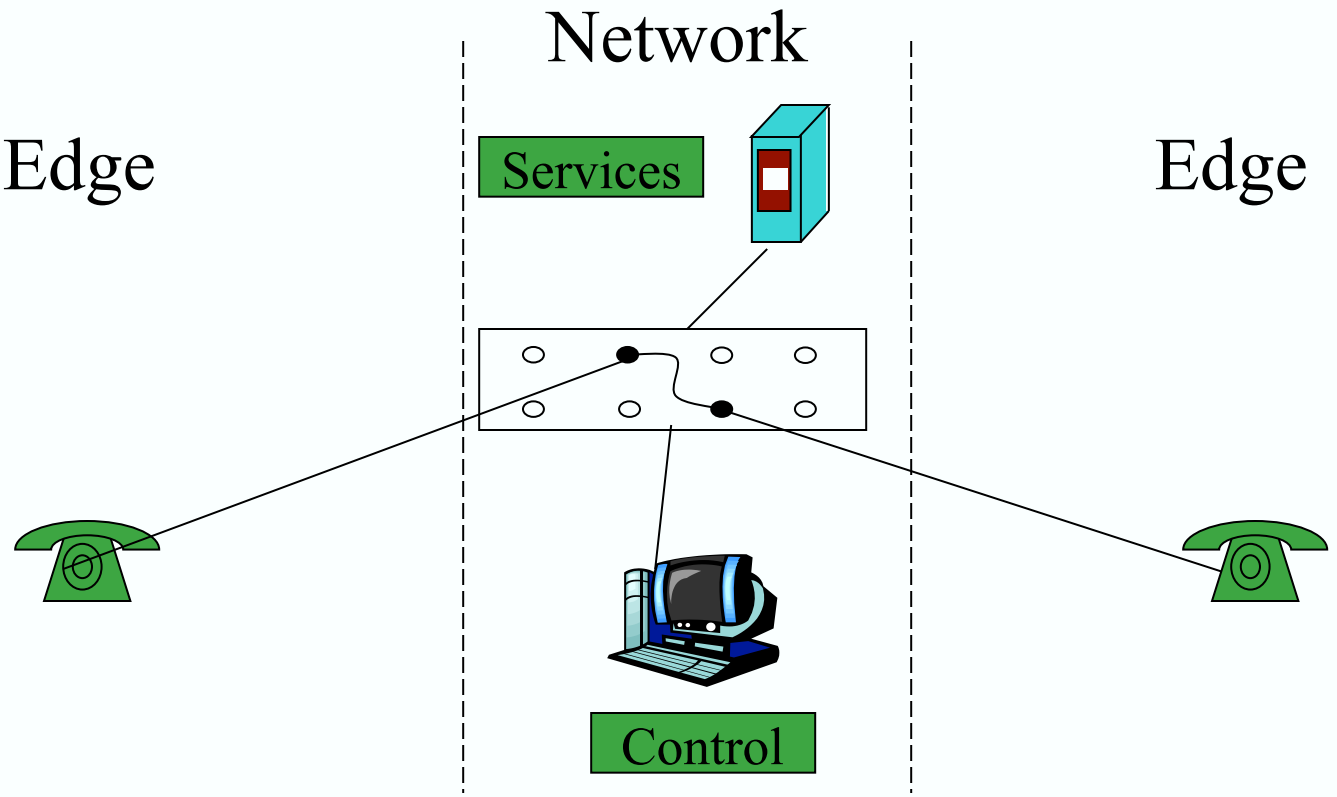
Evolution of Voice

- Voice evolves from THE application, to mobile, to AN application, to just another API…
  - Voice = Device = Network
  - Voice = Mobile
  - Simple end device replaced by computing platforms (wireline and wireless)
  - Becomes an application
  - With the role of new application suites (e.g., HTML5 w WebRTC), voice is little more than a plug in (impacts numerous)

Closed and Centralized

Traditional Communications and Power Grid Networks

- Circuit switching (and some VoIP), Grid (old and new)
- "Dumb" devices and "Intelligent" core
- Services created and maintained inside the network

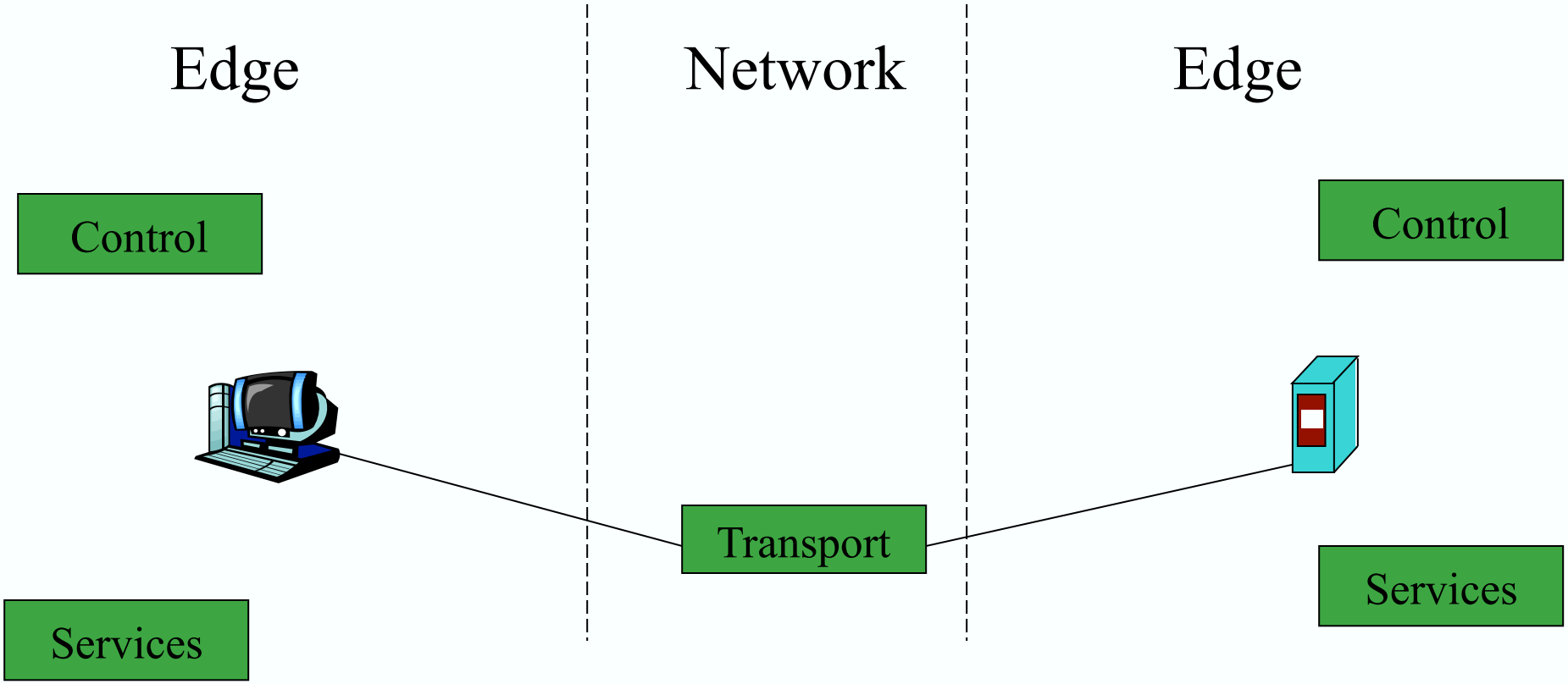


What do you think this means for revenue and innovation?

Open and Distributed

Internet

- Packet forwarding
- “Dumb” core and “Intelligent” devices
- Services created at the edge of the network



What is bandwidth?

- In simple terms, bandwidth is just a measure of *how much information* can be (or is being) transmitted
  - The larger the bandwidth, the more information that can be transmitted in a given amount of time
  - Bandwidth is measured in bits per second (bps, b/s)
  - Think gallons per minute (a volume, not a speed)
  - Broadband
    - Defined until 2009 as 200Kb/s, now ~ 4 Mb/s, soon Gb/s
- To simplify:
  - Voice requires narrow bandwidth (narrowband)
  - Most webpages and still images require more bandwidth
  - Video requires broad bandwidth (broadband)

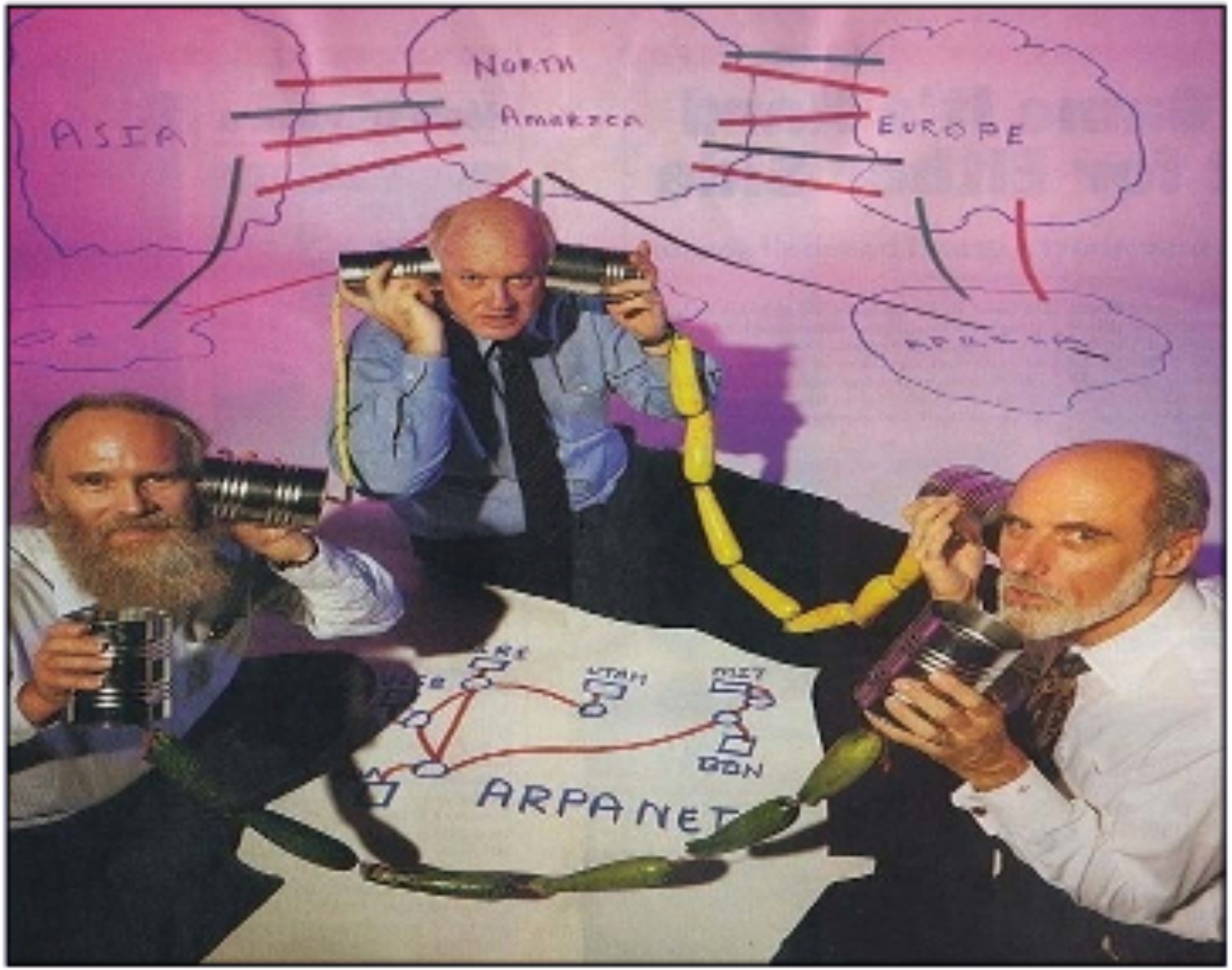
Latency and Quality

- Latency and Quality of Service (QoS)
  - Latency ~ *delay*
    - The time it takes a packet to travel from source to destination
  - It may
    - Occur anywhere along the path
    - Be short-term or long-term
  - Causes of latency
    - Network *not adequately designed or upgraded*
    - Growth in *user traffic*
    - When certain users are "*bandwidth hogs*"
  - *Low latency* is critical in voice and "*real-time*" applications, but not for all apps
  - Together latency and bandwidth define user experience

Internet, Broadband and Wireless

How does the Internet work?

Ah…



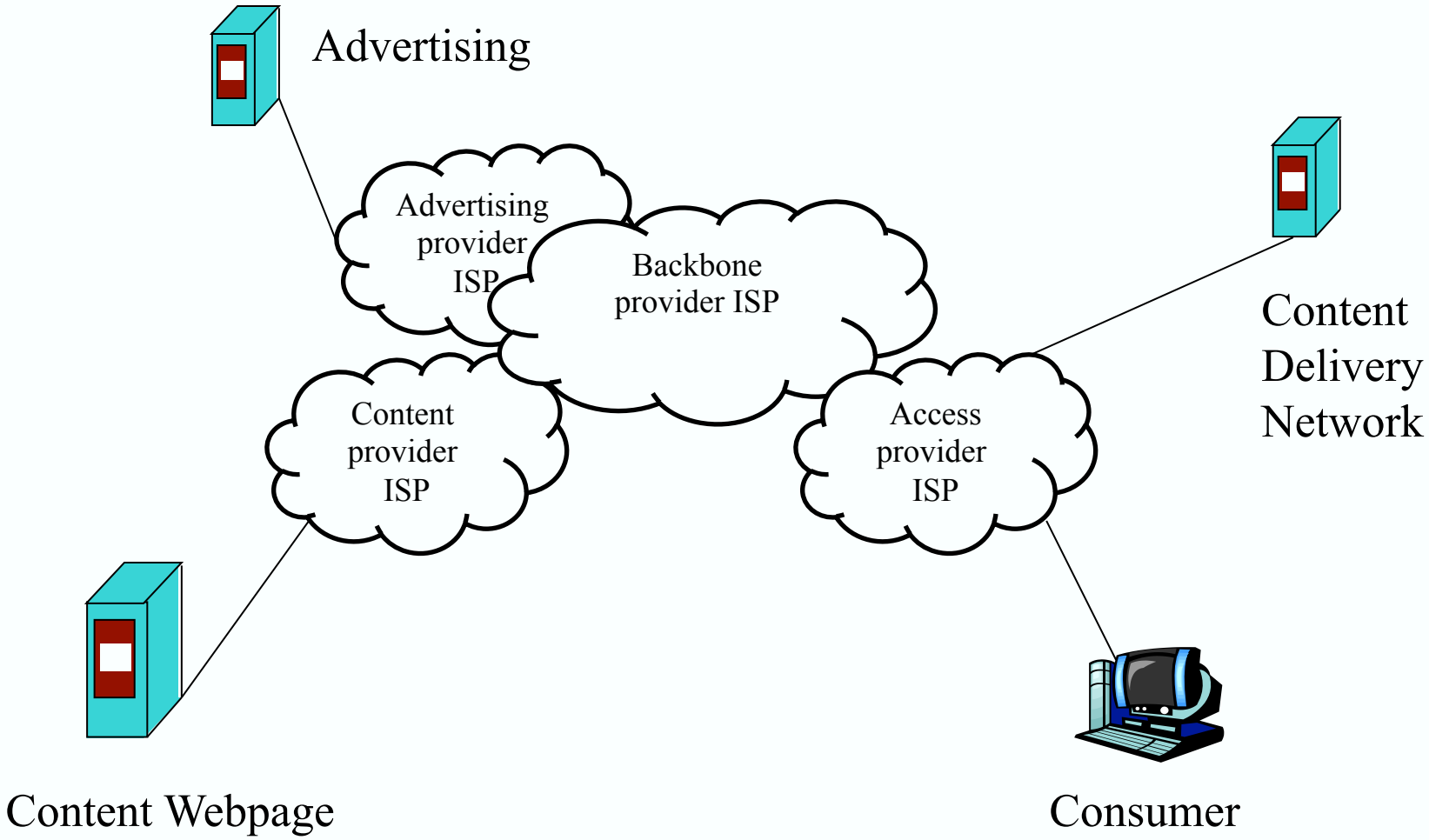
Defining the Internet

- What problems did the creators of the Internet solve?
  - They figured out how to connect disparate networks
  - A *network-of-networks*
- A set of protocols and operations is the *glue (TCP/IP)*
  - Globally interconnected through *packet networks and addresses*
- Supports a broad set of *underlying* technologies
  - Copper pair, cable, fiber, wireless
- Supports a broad set of *applications*
  - Web, Email, VoIP, Video, Gaming, File sharing
- Provides the infrastructure for the World Wide Web
  - The WWW runs on top of the Internet
- Has been an engine of innovation

Operation

- The operation of the Internet is a deceptively simple concept
  - Content is *broken up into small packets* and labeled with *addressing* information
  - Packets sent individually across the network
    - *Routers* use address information to determine best path to forward to toward destination
  - At the destination, related packets are *reassembled* to reconstitute the content
  - Mostly a *best effort service - no guarantees*
- This is a gross simplification
  - Based on complex technical and business designs

Internet Operation



Operation

- Business relationships in the Internet
  - *Business agreements* between parts of the networks
    - Based on Peering and Transit
    - Contracts not regulations
- Entities
  - Network providers
  - Customers (ISPs and Users)
  - Data Centers (housing servers, computing, storage)
  - Content Distribution Networks (to optimize content)
- No direct payment among all parties
  - Therefore *difficult (but possible) to provide guarantees* across the Internet

Broadband Infrastructure

- **Backbone**: The *collection of large connections* that carry communications among networks
- Some of the Large Backbone (Tier I) Networks:
  - Level 3 Communications
  - NTT Communications
- Providing *peering and transit* (and other services) to other ISPs
  - Traditionally Tier II service providers connect (and pay) to the Tier I providers, but now often connect directly to others
- Interconnection opportunities has changed this traditional hierarchical model

Broadband Infrastructure

- **Access Networks**: "Last mile" technologies that rely on the backbone to provide connections to the rest of the Internet
  - Ethernet
  - Digital Subscriber Line
  - Cable Broadband
  - Wireless Broadband – fixed and cellular
  - Fiber to the Home
- Each of these platforms is undergoing an *evolution* to provide additional capacity
  - Many face the challenges that has emerged from changes in the traffic patterns they are supporting
- Power of the access networks influence on interconnection

Asymmetry

- Most access networks use *asymmetric* links, meaning that the uplink data rate is significantly less than the downlink rate
  - Many forms of communications need to operate in *both* directions, but most broadband networks are asymmetric
  - Big downlink is great for video, which now dominates the Internet
  - The rise of higher uplink traffic volumes has caused problems for asymmetric access networks
  - We should not expect traffic patterns to remain the same (we know that they are currently changing)

The Wireless Revolution

Wireless access

- What is *happening in the wireless access space*?
  - New standards and technologies rolling out
    - LTE (4G and soon 5G) and 802.11 (ac, af, ax)
    - MIMO, Software Defined and Cognitive Radio
  - Programmable devices
  - Reallocation of spectrum for commercial use
  - New concepts for spectrum management and usage
    - Dynamic spectrum access - TV white space
    - Wireless networks within other services (smart grid)
    - Receiver standards
    - New auction models

Observations

Network Observations

- The emergence of the IP-based broadband network was *disruptive* to the traditional telephone industry (in at least three ways)
  - Shifted *intelligence* and hence control of *service creation* from inside the network to the edge ("Intelligent Network" – key PSTN service asset)
  - Provided a much more *powerful platform* that is capable of handling not just voice but a rich combination of content
  - *Undermined* traditional cost/pricing, jurisdictional and regulatory models
- Second round of disruption is underway with Cloud and SW Defined
- *Open* architectures facilitate service creation and creates opportunities for *rapid innovation*
  - Customers at the edge not only *consume* services and content but increasingly *create* them as well
  - Despite trend toward openness, services and content offered by platform providers inevitably raises issues of *interoperability, interconnection and potential discrimination*
  - *Proprietary* approaches, while offering short term advantages, can lead to long term disadvantages including vendor lock-in

Network Observations

- Internet is a complex ecosystem of interconnected networks
  - Driven by technology, investment, policy, consumers and business (some of which are multi-stakeholder processes)
  - The Internet continues to evolve in unpredictable ways and policy will lag technology
- Continued growth in wireless, smart grid, and fiber networks
  - Key element in economic growth far beyond the network itself
  - Power and communications are core to almost everything we do
- Enlightened policy approaches
  - Provide incentives for investment, innovation, “ities” improvements
  - Opportunities for technological development
  - Regulators have an important part to play and understanding the technical issues is key

What else?

Take Away

- We are growing ever move dependent on networks
- Many complex and interdependent parts
- Networks are enabling new service models
  - Smart Grid, M2M, Mobile, Cloud, EaaS
  - Networks supporting national priorities (health, education …)
- A balancing act
  - Connectivity, Ubiquity, Reliability, Quality (of Service), Security/Privacy, Control, Scalability, Cost/Price, Adoption
- Policies impact how networks evolve and vice versa
- Technology will continue to outpace policy
- Regulatory caution is warranted
  - Unintended consequences abound
- Technology awareness helps inform policy decisions

Contact Information

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First set of extra slides

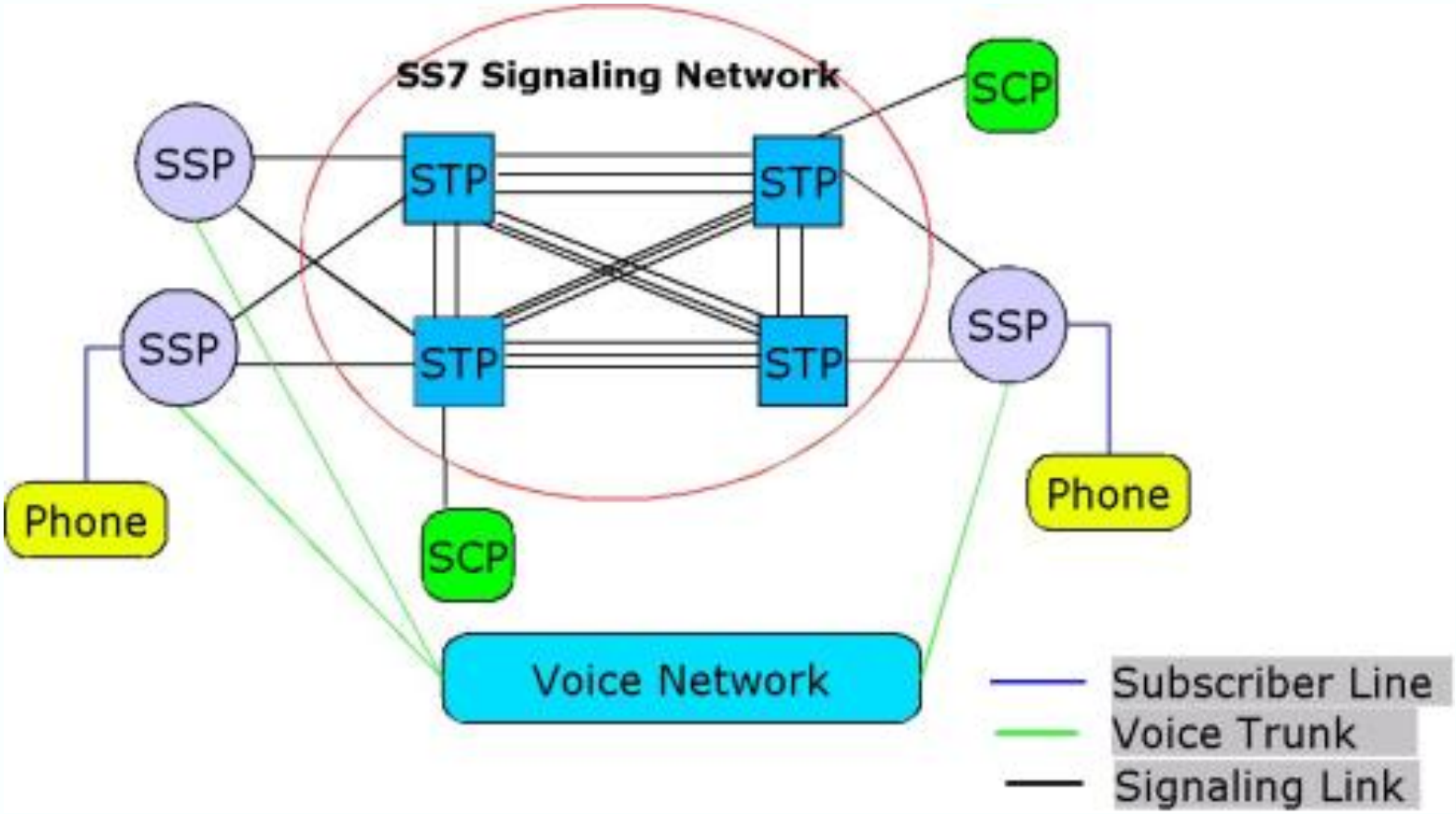
Trends

Evolution of Voice

- Voice evolves from THE application, to AN application, to just another API…
  - Voice = Device
  - Voice = mobile
  - Simple end device replaced by computing platforms (next slide)
  - Becomes an application
  - With the role of new application suites (e.g., HTML5 w WebRTC), voice is little more than a plug in (impacts numerous)

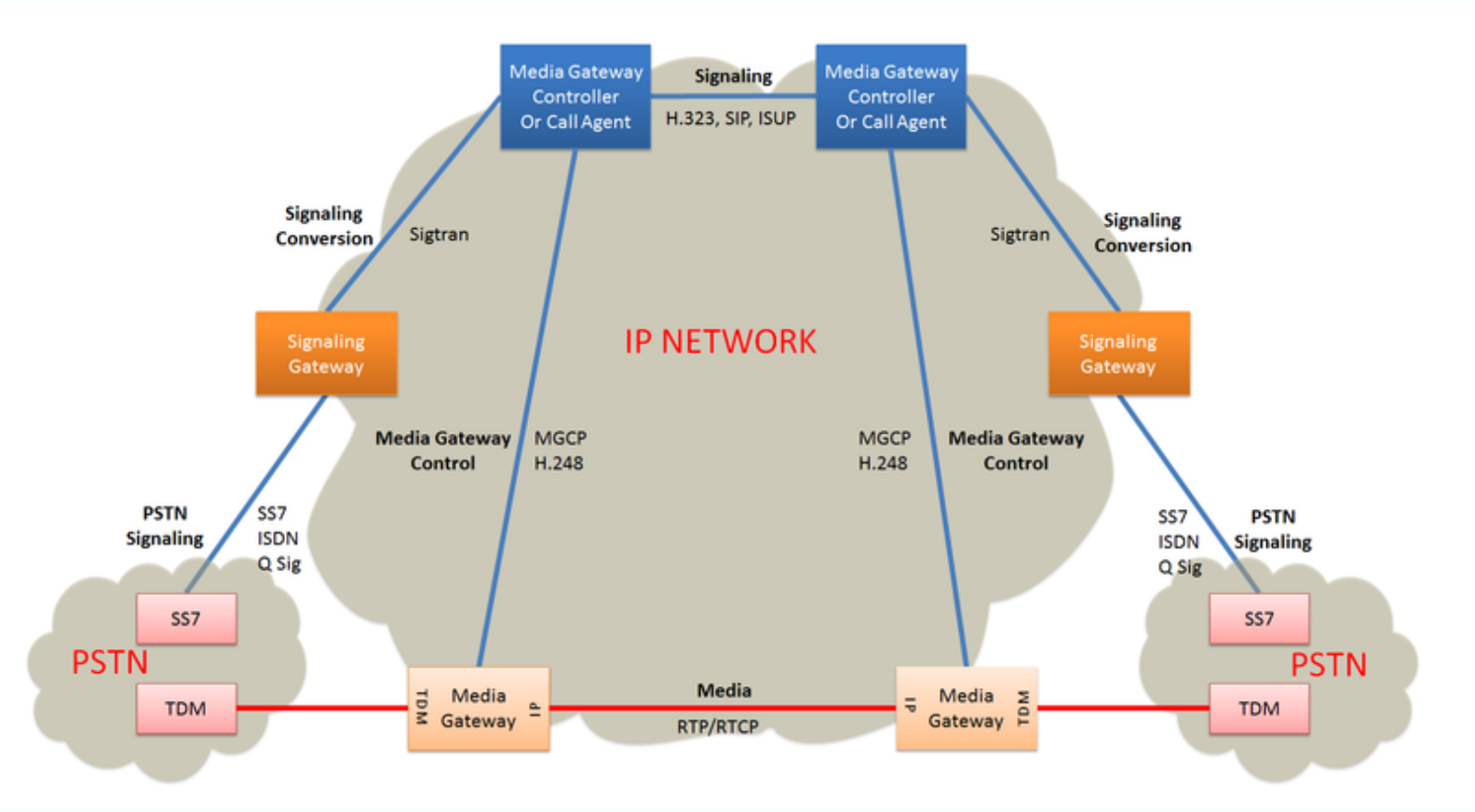
Trends

Evolution of Voice



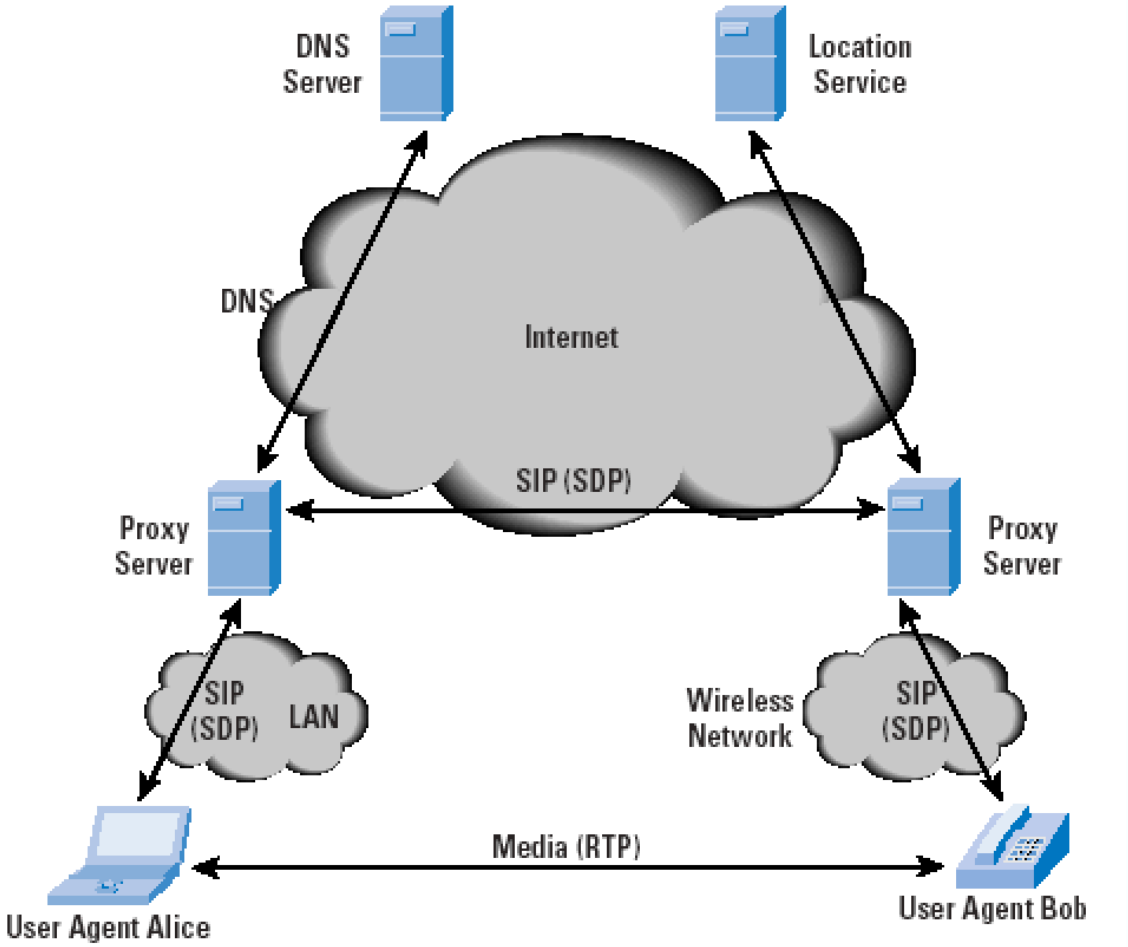
Trends

Evolution of Voice



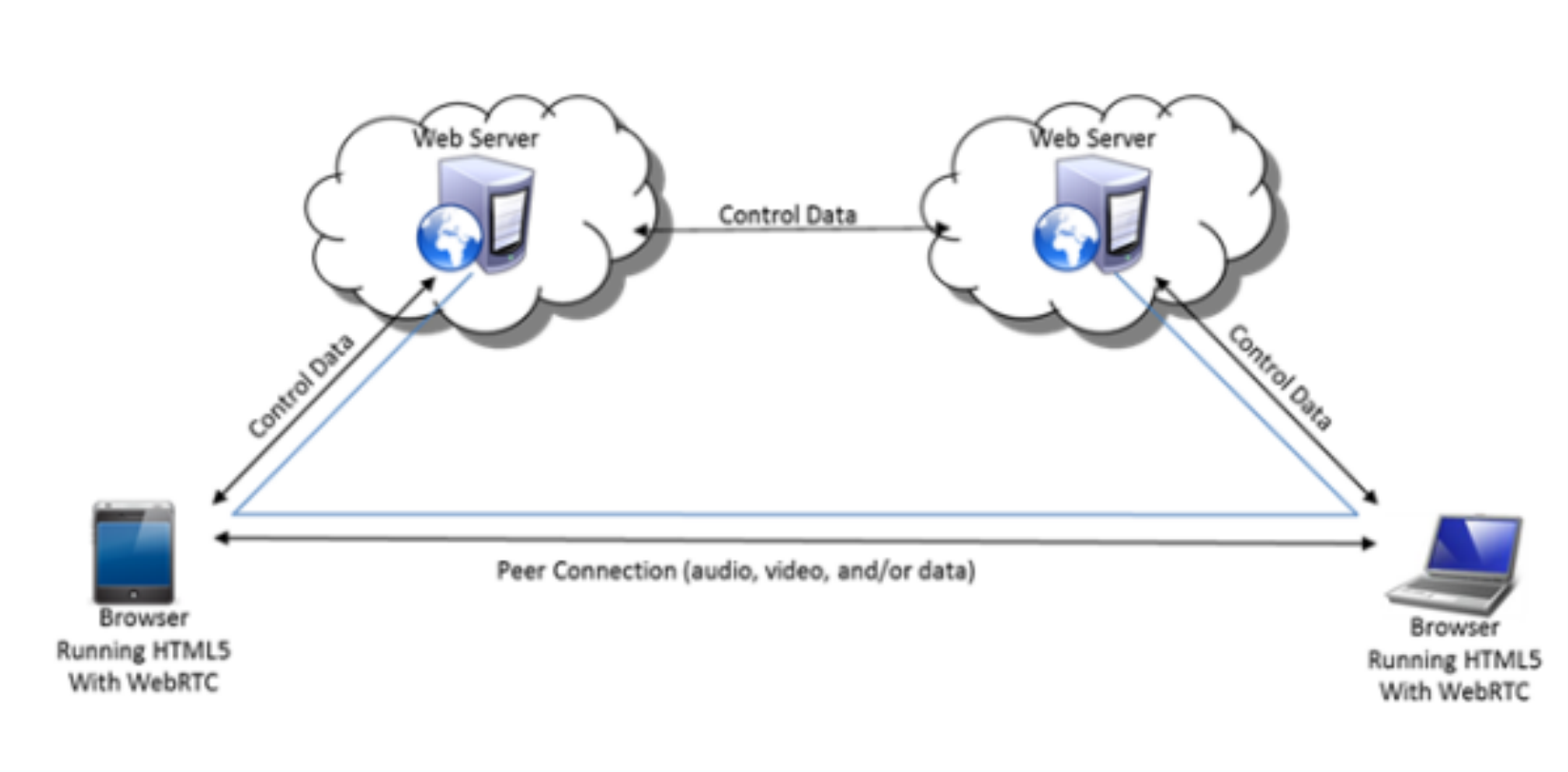
Trends

Evolution of Voice



Trends

Evolution of Voice

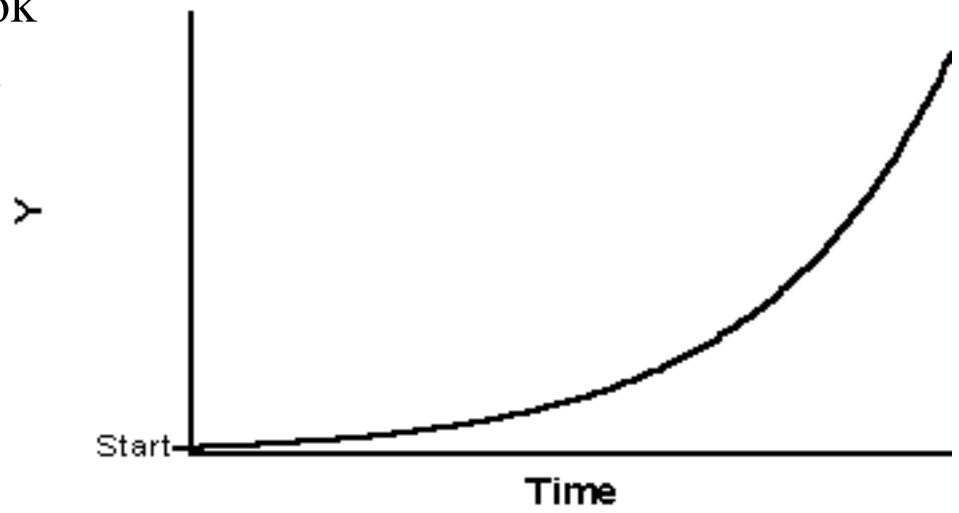


Trends

Infrastructure Growth

- Mobile, Fiber, Cable and Metro Ethernet all have strong growth projections
- LTE explosion; WiFi continues as offload
- Broadband access and wireless backhaul drive fiber and Metro Ethernet
- Hybrid fiber wireless architecture

I could add some charts that look like this and that have little real data or meaning



Trends

Web, html5 and apps

- Incredible innovation in how the web is used
  - Web as innovation engine on top of the Internet
- Traditional webspace developed in HTML
  - Battle between apps environment and HTML5
  - Wired – html5
  - Wireless – apps
- Regardless, the result – growth in traffic and infrastructure

VS

Trends

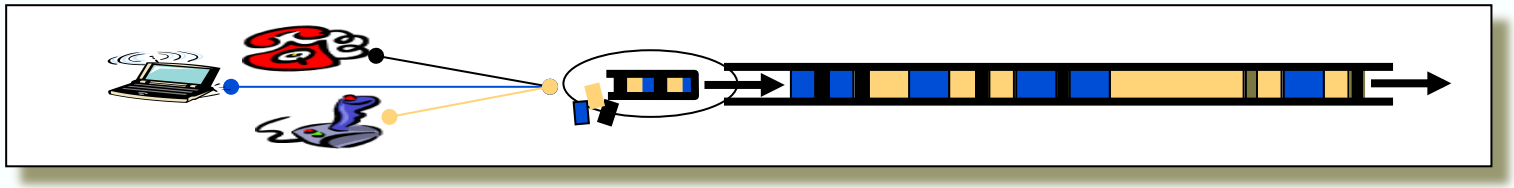
Continued convergence

- Voice, video and data
- Devices become “smart(er)”, embedding APIs and computes
  - Computer as new end device
  - Mobile becomes smartphone
  - TV becomes smart TV
- Network re-stratifies
  - We had a QoS tuned network for voice (the telephone network)
  - We moved to a “best effort” Internet
  - Then an Internet with overlay channels (DOCSIS for voice)
  - Then the once “best effort” Internet stratifies

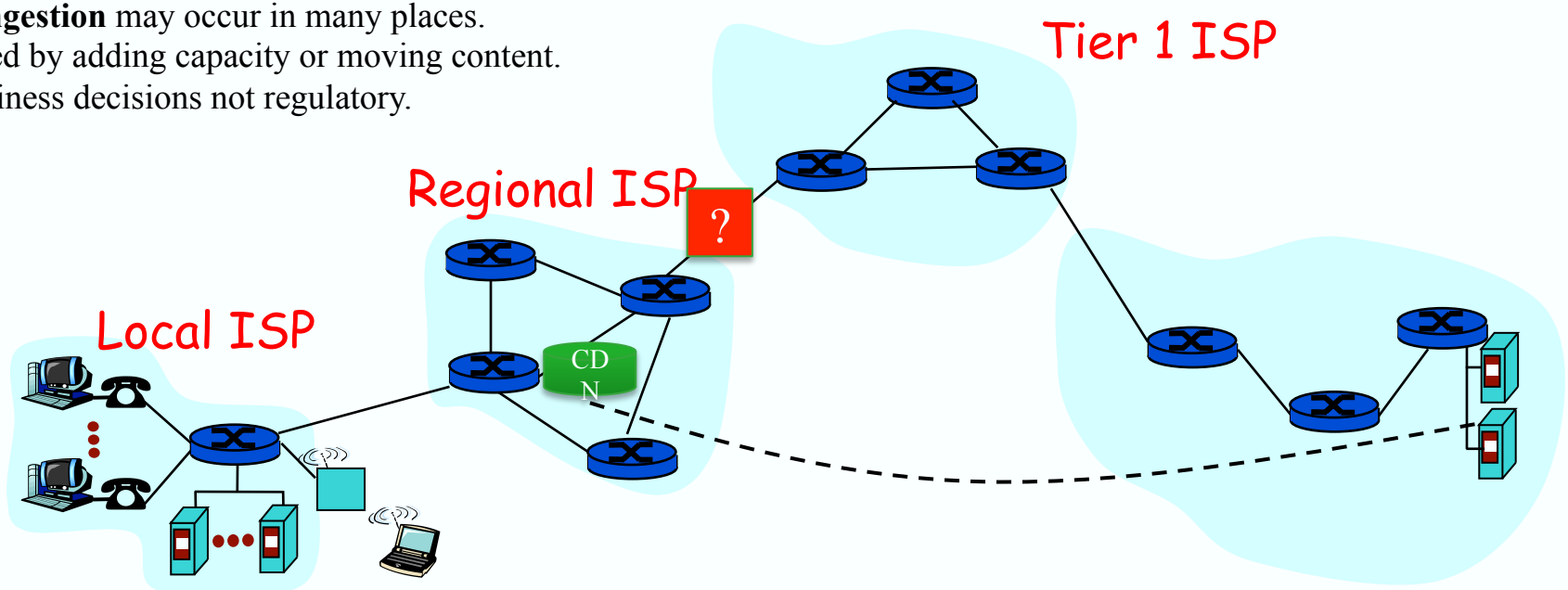
Trends

Video and other traffic

- Video and broadband go hand-in-hand, one driving the other
- OTT video accounts for the majority of Internet traffic
- It has changed the design and operation of the network
  - Strained the network and its interconnections

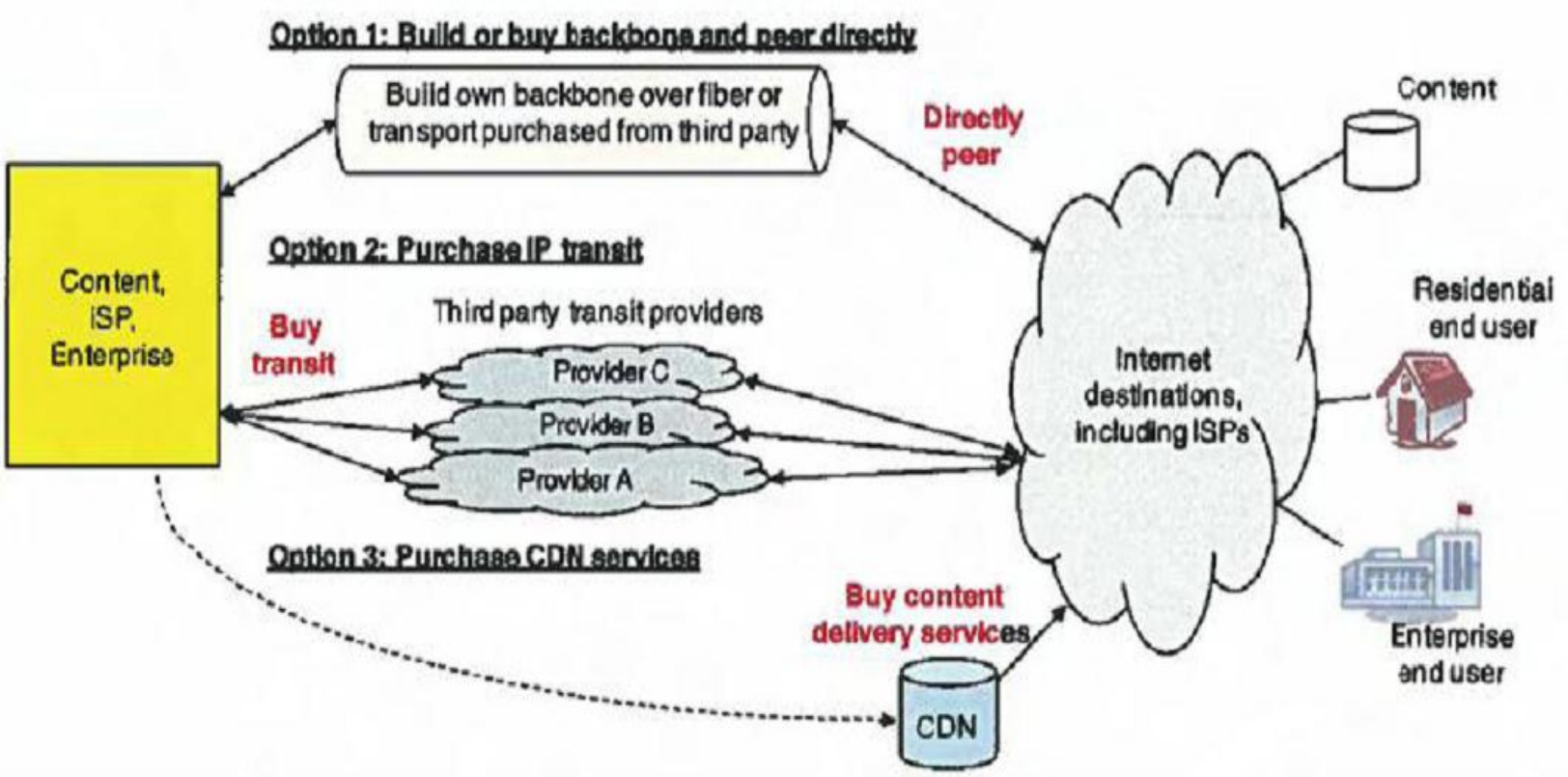


Congestion may occur in many places.
Fixed by adding capacity or moving content.
Business decisions not regulatory.



Trends

Video and other traffic



Source: Level 3 declaration in FCC docket IB 11-78

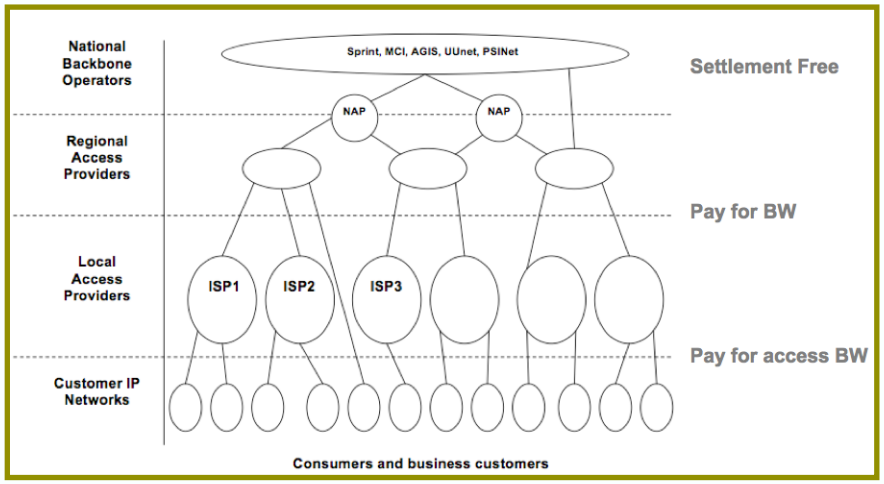
Trends

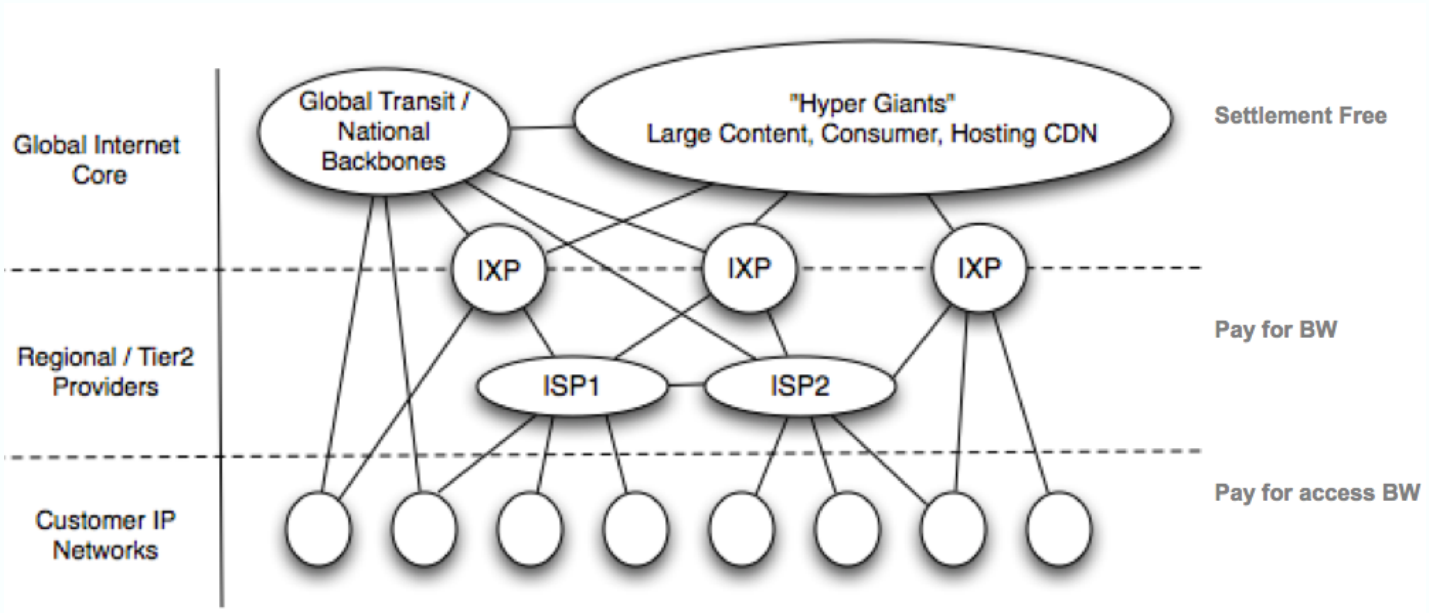
IoT (Internet of Things) and M2M

- IoT - (any and all) objects having unique network identifiers
  - Any store item, anything in your office or home, …
- M2M – machine to machine communications
  - Think meter reader, car, home appliance, factory equipment, …
- The need for infrastructure
- Most of these connections will be wireless
  - Hanging off of -a broadband connection, wireless interface (low or high BW) or LTE
- Again, I could add a chart here speculating to the anticipated growth but it would be complete speculation
  - Let's just say something exponentially increasing over time
  - It will happen and that it will be big

Trends

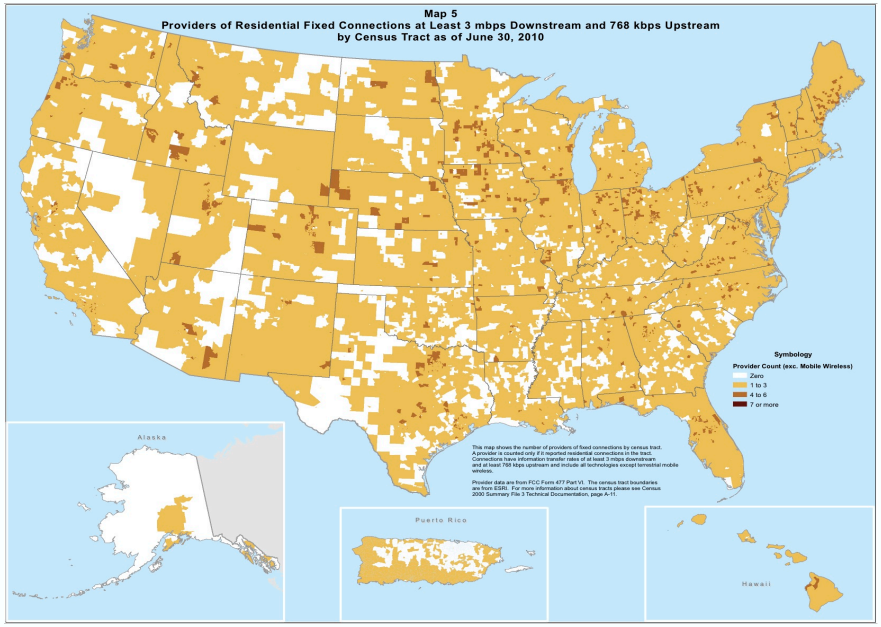
The core of the Internet evolves

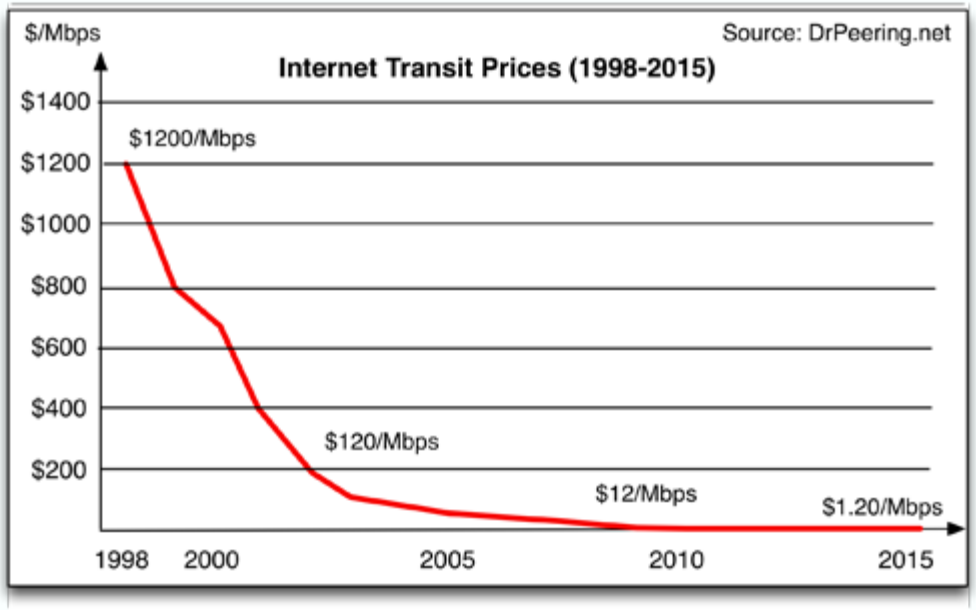




Trends

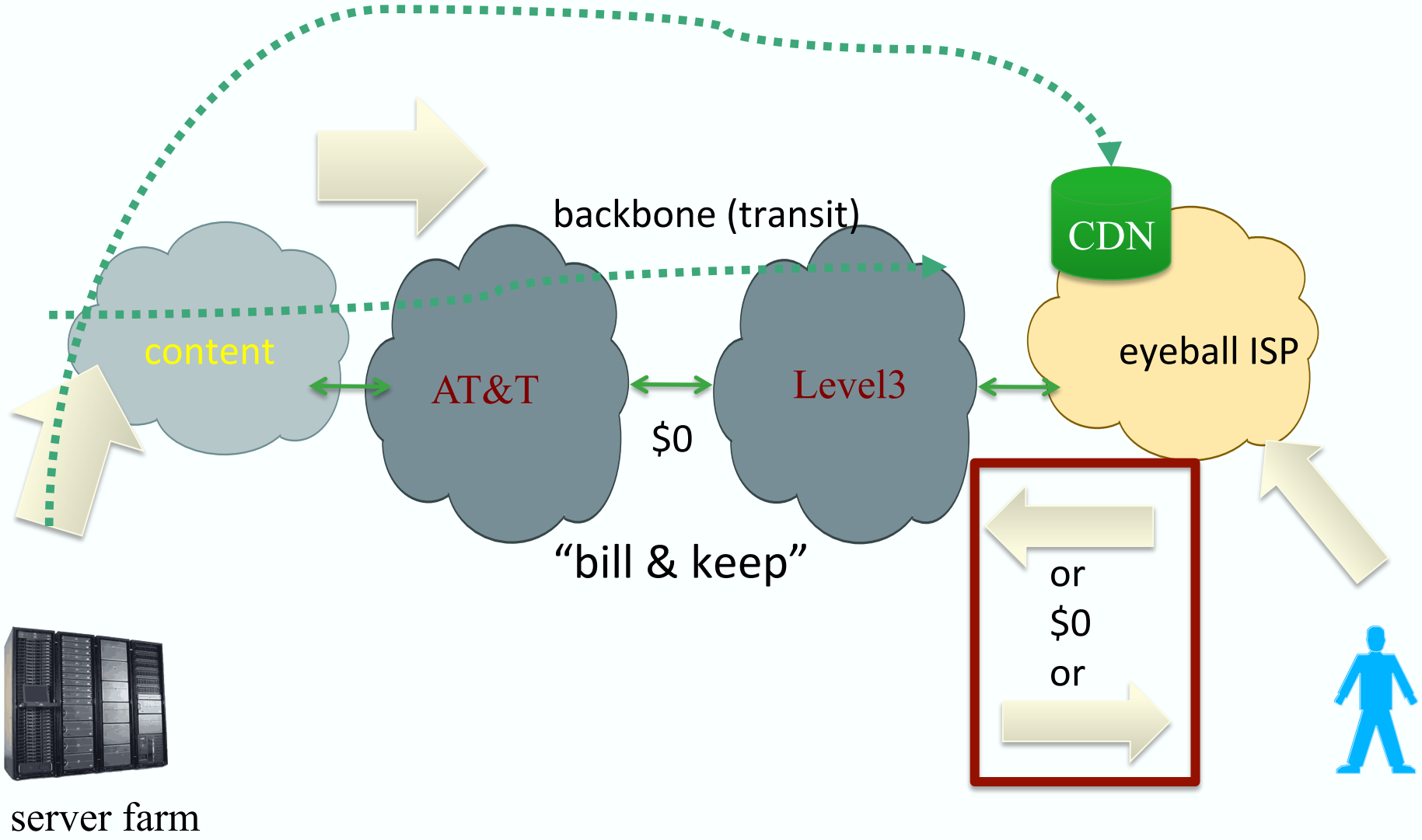
The Internet evolves





Trends

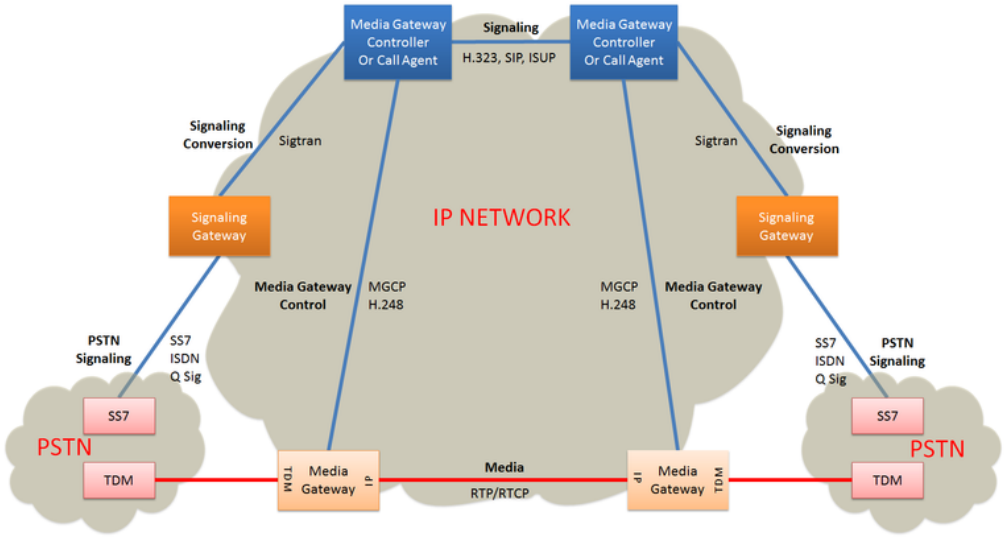
The Internet evolves

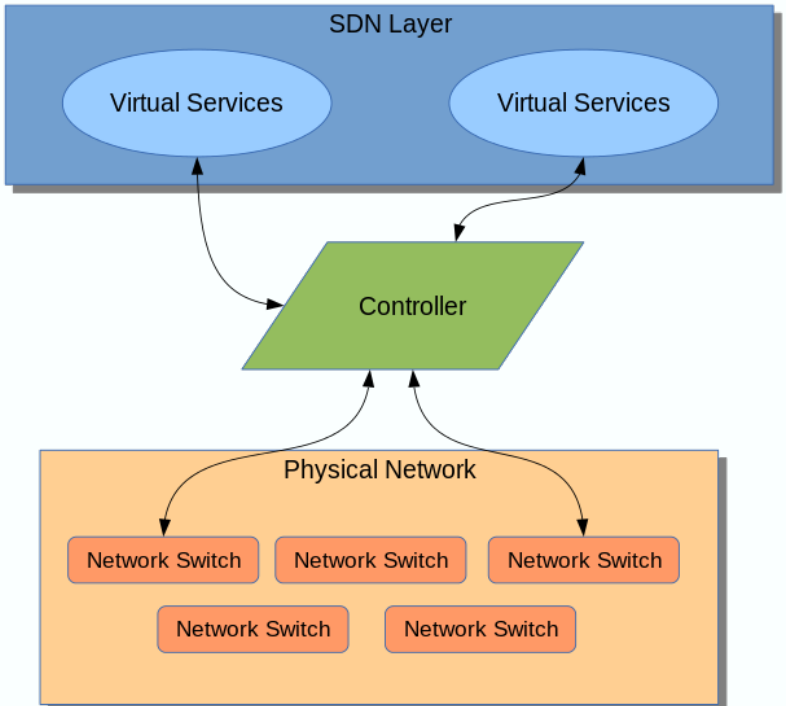


Trends

Software Defined Networks

- Equipment continues to decompose
- Devices evolve to scale better (density, cost, performance)
  - Decoupling the control plane from the data plane
  - Think SS7/AIN, Softswitch (gateway/controller), SDN, C-RAN





Trends

Software Defined Networking

- SDN decouples the control plane from underlying hardware
  - Remotely controlling heterogeneous equipment
- Allows for the administration of the network through abstractions of the device functionality
  - For example, the admin can communicate with an SDN protocol to a controller (to create the abstraction)
  - The controller can then deal with the underlining device operation (and likely, its proprietary nature)
- Threat to many in industry and all are scrambling
  - Create their own vision of SDN
  - Difficult choice of self cannibalizing (Huawei threat)
- One flavor of SDN is OpenFlow

Trends

Clouds, Software as a Service, "X" as a Service

- Many parts and much misunderstanding
  - Generally, the Cloud is synonymous with the Internet, and the core concept is a distributed computing and service platform
  - Cloud services are the functions obtained through the Internet and include applications, computing, storage, hosting, network capacity … including SaaS, PaaS and IaaS. Often viewed as moving from CAPEX to OPEX
- **SaaS** – "Software" aaS: Applications execute in the Internet
  - Typically available via the browser:, Google Apps, Salesforce.com (use the app)
  - Shrink-wrap software has given way to services – less local hardware needed
- **PaaS** – "Platform"aaS: Apps hosted on the platform in the Internet
  - Salesforce.com, Amazon E2C, Microsoft Azure (customer loads apps)
- **IaaS** – "Infrastructure"aaS: Compute resources (CPU, memory, storage, bandwidth) provided in an as-needed, pay-as-you-go model.
  - Such as VMs with hypervisors maintaining dynamic resources.
  - Amazon S3 (customer loads their OS, apps…)

Trends

Back office software evolves

- Many challenges in maintaining traditional BSS / OSS systems (beyond cost, lock-in and capability)
  - Toward Web, SAAS - no longer tied to network or device
- BSS/OSS as a service and borrowing from other trends
- M&A strains products and services (particularly in non traditional environments)
  - Example: Level 3 experience
  - Example solution:
    - Salesforce and other tools are driving fundamental change in business software
      - Impact on BSS systems and Oracle

Trends

Big Data Analytics

- Data sets with sizes beyond the tools typically used to the obtain, store, manipulate, assess and share data
- You pick the size
  - tera, peta, exa, zetta, yotta…
- Big data requires huge storage, tools, networks … infrastructure!

Trends

Regulatory Uncertainty

- Many FCC initiatives are inline with CWA – adoption, USF reform, NBP, Open Internet…
- Funding for rural BB builds
- Unclear where Open Internet will come out
- Strain in the backbone will continue
  - As described earlier

Trends

- Evolution of Voice
- Growth in Mobile, Cable, Fiber and Metro Ethernet
- Radical increase in traffic – video
- Internet, web and market evolves
- Continued convergence (packetizing of the world)
- Software Defined Networking
- Network virtualization
- Cloud - Software as a Service (SaaS) and “X”aaS
- Evolution of the back office software
- Big data analytics
- Regulatory uncertainty
- And many more…

What is

- cloud computing?
- deep packet inspection?
- overlay?
- peer-to-peer?
- network management?
- privacy?
- anonymity?

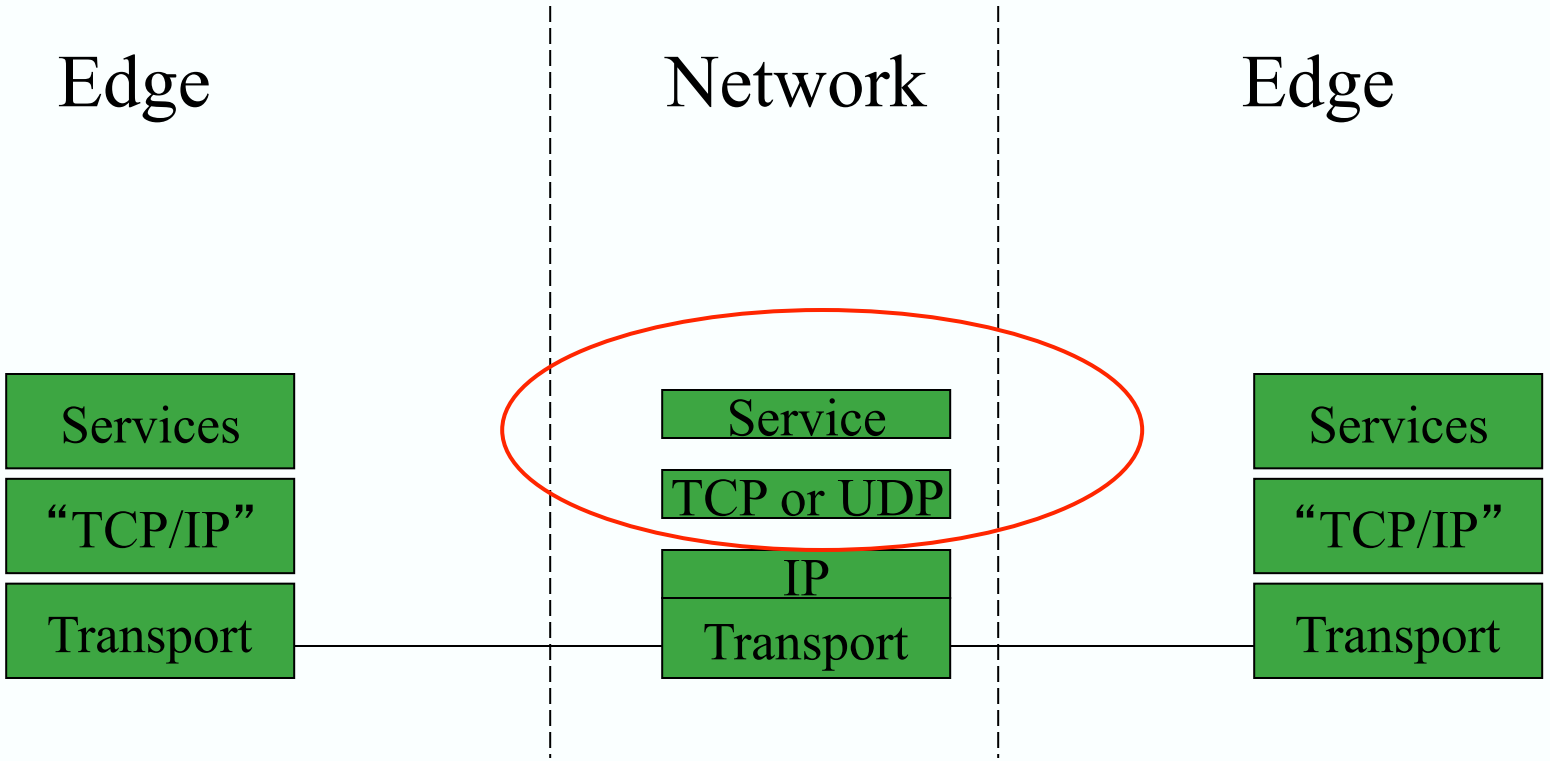
Cloud Computing

- What is *cloud computing*?
  - Computing where services are in the network
    - Not really occurring "in" the network! Just another edge.
  - Takes advantage of infrastructure to reallocate computing and storage
    - To the user, it shouldn't matter where the computing occurs
- A sub-concept is *utility computing*
  - Customers pay for discreet computing resources
- Amazon Web Services (AWS)
  - Elastic Compute Cloud (EC2) - hourly computing
  - Simple Storage Service (S3) - utility storage
  - Other AWS services - CloudFront, SimpleDB, SQS…

Deep Packet Inspection

- What is deep packet inspection (aka DPI)?
- Rather than looking only at the header info of a packet (e.g., address), DPI examines further into the packet.
  - Looks at such items as port information and content
- Very commonly used for security reasons within a network
  - Search for Malware, Spam, Attacks, online behavior …
- Potential uses of DPI
  - Security, Data mining, Ad injection, Censorship, Traffic shaping
- Concerns
  - Privacy and Discrimination

Packet Inspection



The Internet Model

Peer to Peer

- What is *peer-to-peer* (P2P)?
- First consider - what is the client/server model?
  - The familiar model (contacting a web server, email server)
- Unlike the client server model, P2P may use of many connections to facilitate data exchange.
  - P2P is really less about an application (e.g., distribution of video content) and more about a network design choice.
- What makes P2P a problem is that many forms flood the network with connections, thereby consuming resources.
  - Exacerbated by the asymmetry of the access networks.
- It's important to keep in mind that P2P has legitimate uses.

Network Management

Network Neutrality

- What is *Network Neutrality* (Open Internet)?
  - Impartial treatment of packets (without regard to source, destination, content …)
- An important distinction between:
  - Network management
  - Discrimination against a competitor
- There are several reasons networks seek to manage data:
  - To reduce operational costs
  - To deliver time-sensitive data more promptly
  - To manage congestion
  - To provide security
  - To discriminate against a competitor

Managing the Network

- Network protocols (i.e., TCP) are designed to *slow down as congestion* occurs.
- Some network providers might respond to network exhaust by *dropping packets*.
  - Where a router might randomly drop packets.
- Some network providers may *shape* traffic.
  - Employing *treatments* (next slide) that differentiate among different traffic types.
- Of course, this raises questions like:
  - Who should decide when this happens?
  - Who should decide on what traffic?

Managing the Network

- Traffic shaping might be based on:
  - *Source or Destination address*
  - *Port address*
    - Associated with the application
  - "*type of service*" field
    - Which can be used to indicate packet sensitivity
  - *Content*
    - Encryption complicates this
  - Other factors (security, usage …)
  - Some *combination* of these factors

Managing the Network

- Traffic Management "Treatments" can reduce to
  - *Preventing* access altogether
  - *Dropping* packets/connections when resources are constrained (e.g., RED, TCP reset)
  - Reducing latency by *preferring* some packets
- Future Management Techniques
  - *Pricing* (usage based pricing)

Managing the Network

- Monitoring by the end user
  - A means of *detecting* discriminatory management
- Is there a way for users to monitor the network to *detect improper network management*?
  - What if end users monitored their own experiences and shared data?
  - What if this data was integrated to provide data on the behavior of the network?
- Work is underway on this topic

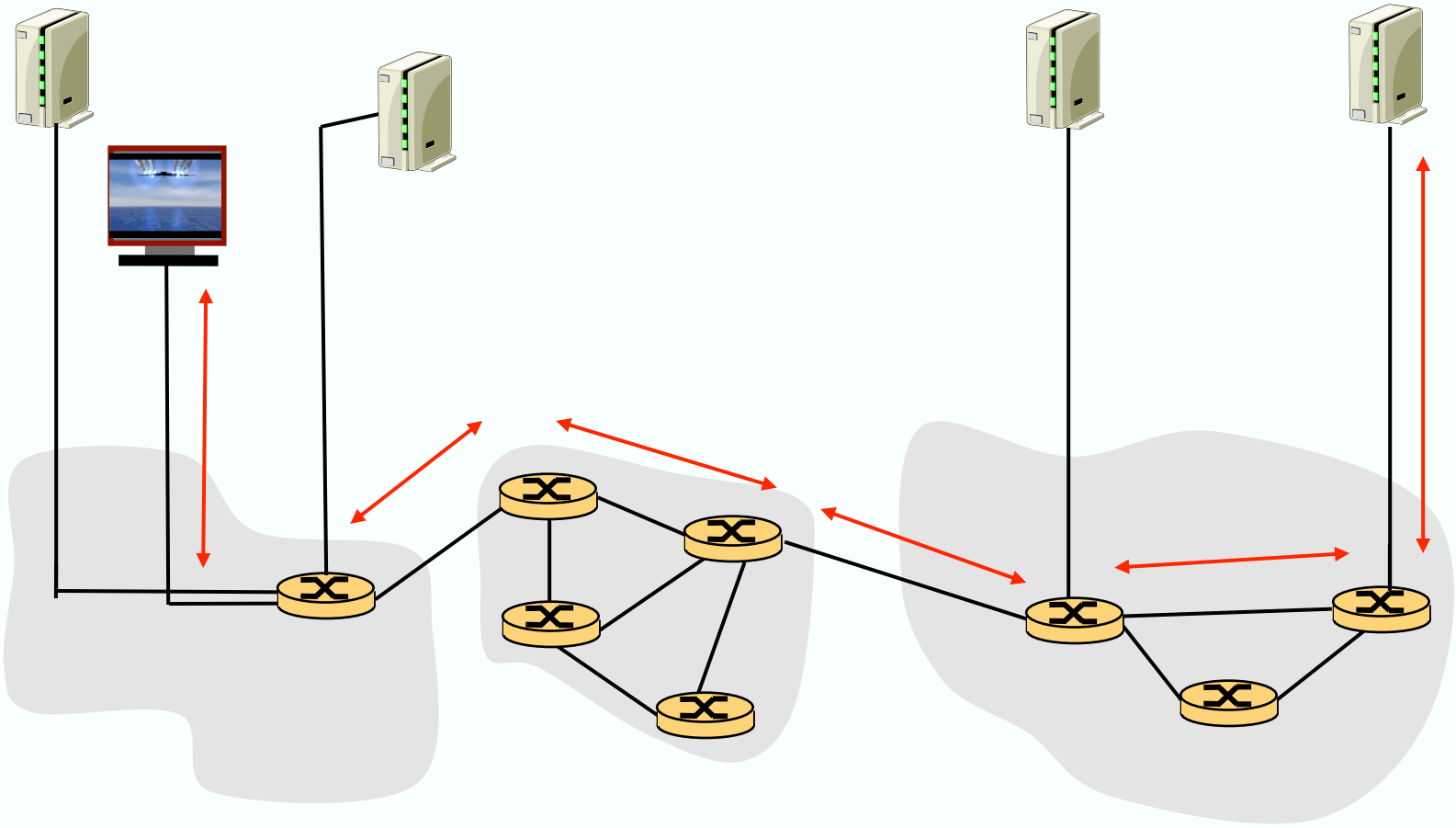
Managing the Network

- Network Neutrality raises very interesting network questions
  - Are there any network management practices that are acceptable to all parties?
  - Are content distribution networks a violation of network neutrality?
  - May a user request that their content be differentiated?
  - Are priority services allowed to preempt other services?
  - And more

Overlay Networks

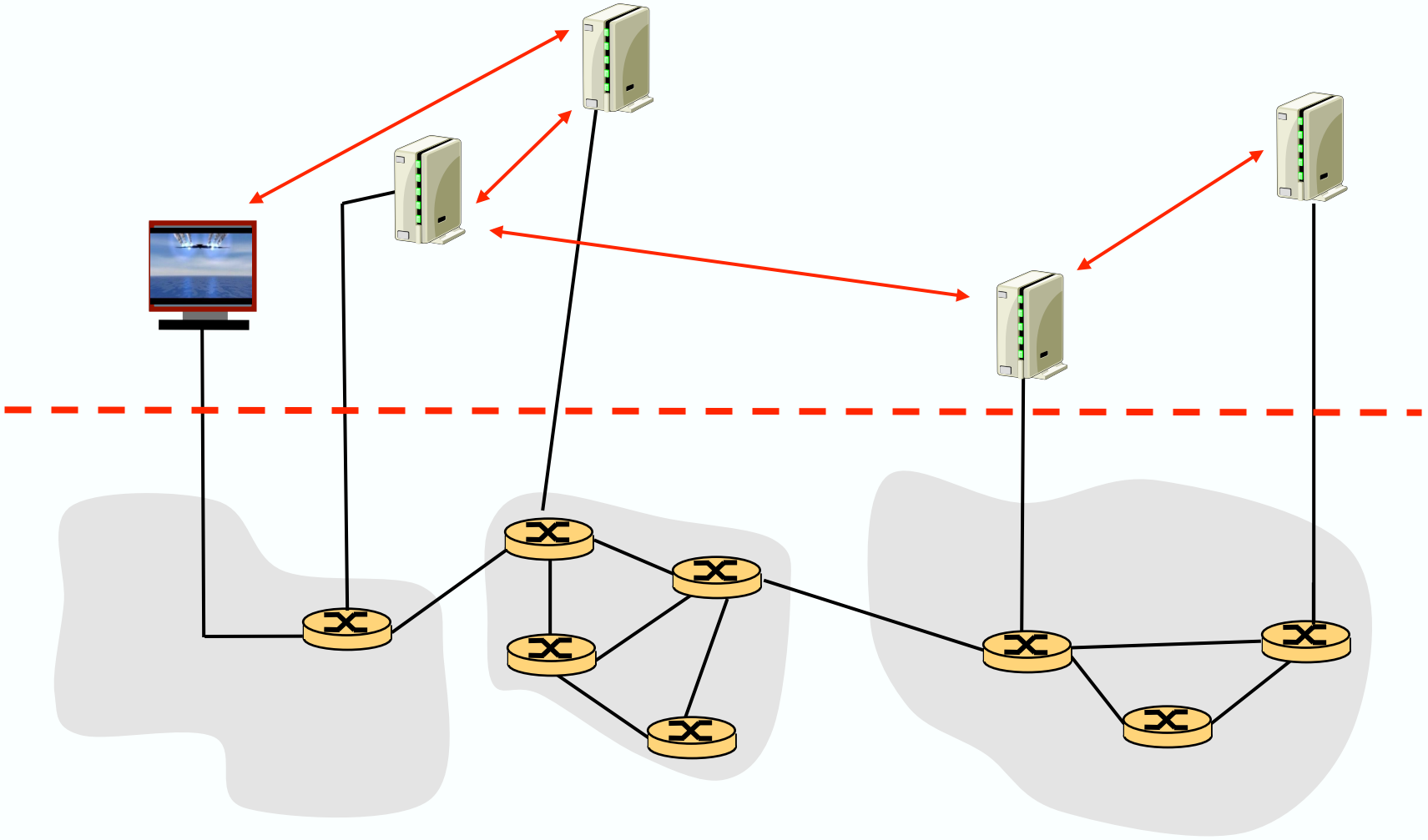
- What is an *overlay network*?
- In simple terms, a network built on top of other networks
- Many versions of this exist
  - *Could argue that Dial-up Internet access* is an overlay network
    - With common carrier non-discrimination obligation
  - *Peer-to-peer* networks are often an overlay network
  - *VPNs* (virtual private networks) are a type of overlay network
- Currently a hot topic within the network research community

Traditional network model



Slide adapted from Jennifer Rexford's networking course slides

Overlay network model



Slide adapted from Jennifer Rexford's networking course slides

Peer-to-Peer Networks: Napster

Shawn Fanning, Northeastern freshman

- Napster history: the rise
  - January 1999: Napster version 1.0
  - May 1999: company founded
  - September 1999: first lawsuits
  - 2000: 80 million users
- Napster history: the fall
  - Mid 2001: out of business due to lawsuits
  - Mid 2001: dozens of P2P alternatives that were harder to touch, though these have gradually been constrained
  - 2003: growth of pay services like iTunes
- Napster history: the resurrection
  - 2003: Napster reconstituted as a pay service

Slide adapted from Jennifer Rexford's networking course slides

Peer-to-Peer Networks

- Napster had an Achilles' heal
  - Central directory
    - Single point of failure, Performance bottleneck, Copyright infringement
- So, later P2P systems were more distributed
- Many P2Ps systems evolved after Napster
  - Gnutella
  - KaZaA
  - BitTorrent -Distributed downloading
  - P4P - Network Providers use of P2P
- NOTE:P2P is no longer the dominate traffic on the net

Slide adapted from Jennifer Rexford's networking course slides

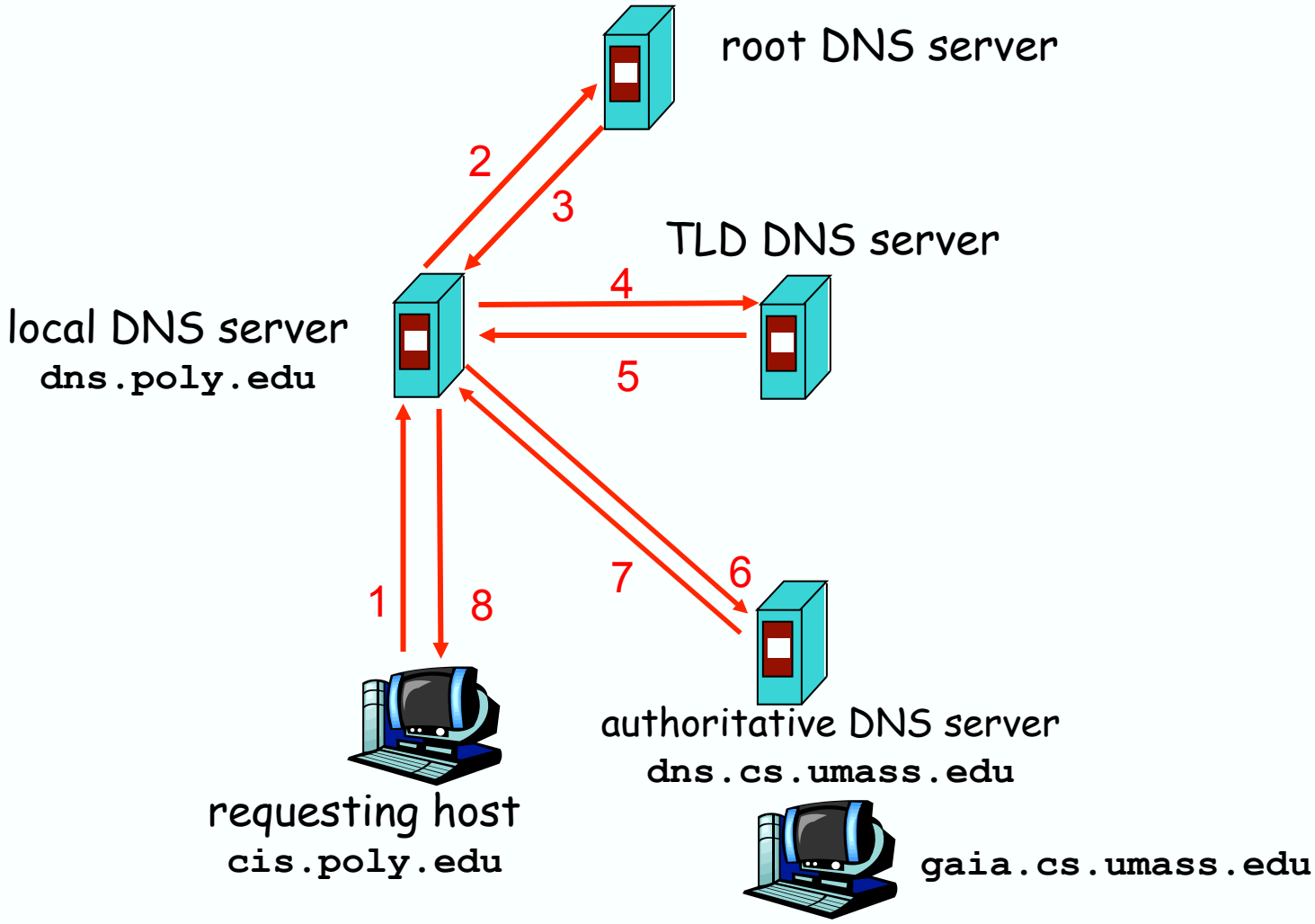
Privacy

- What is *privacy*?
  - Need to understand that this is a relative concept
    - Cultural, societal …
  - Can be instantiated in different ways
- What is *anonymity*?
  - Takes privacy to a different level
  - How can this be instantiated?
  - The TOR network
    - An overlay network - provides for anonymous web activities
    - Encrypted tunnels prevent linking of source and destination
  - Used for legit and illegitimate purposes

Many steps of web acess

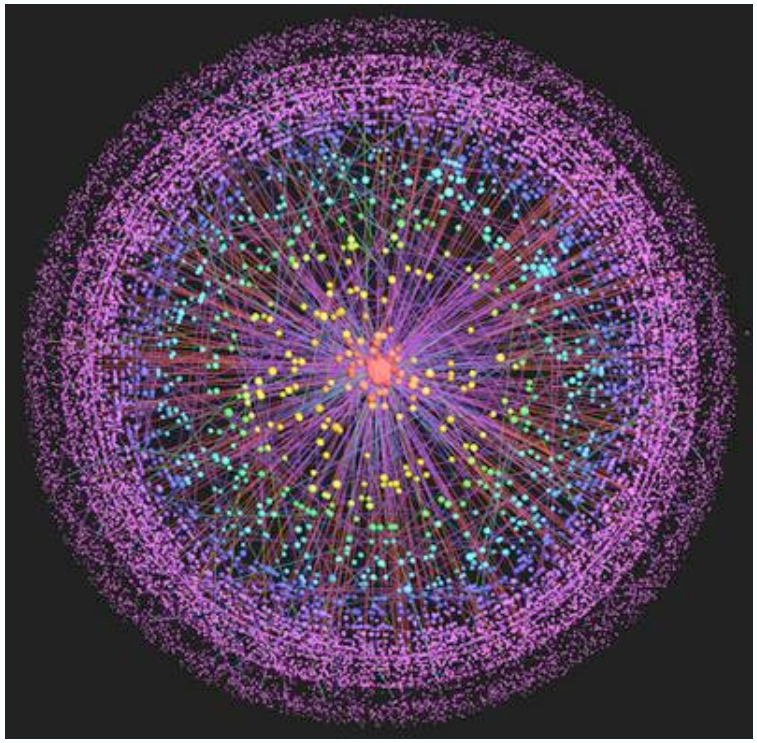
- Involving a variety of network elements
- DHCP - dynamic host configuration
- ARP - address resolution
- DNS - domain name
- TCP hand shake - sets up connection
- Get - request some web content
- Multiple possible iterations (DNS, TCP, Get)
- Just to get a webpage!

Example



Slide adapted from Jennifer Rexford's networking course slides

Second set of extra slides



Internet 101 and Interconnection

A number of these slides are borrowed from Computer Networking: A Top Down Approach Featuring the Internet, 3rd edition. Jim Kurose, Keith Ross

To start…

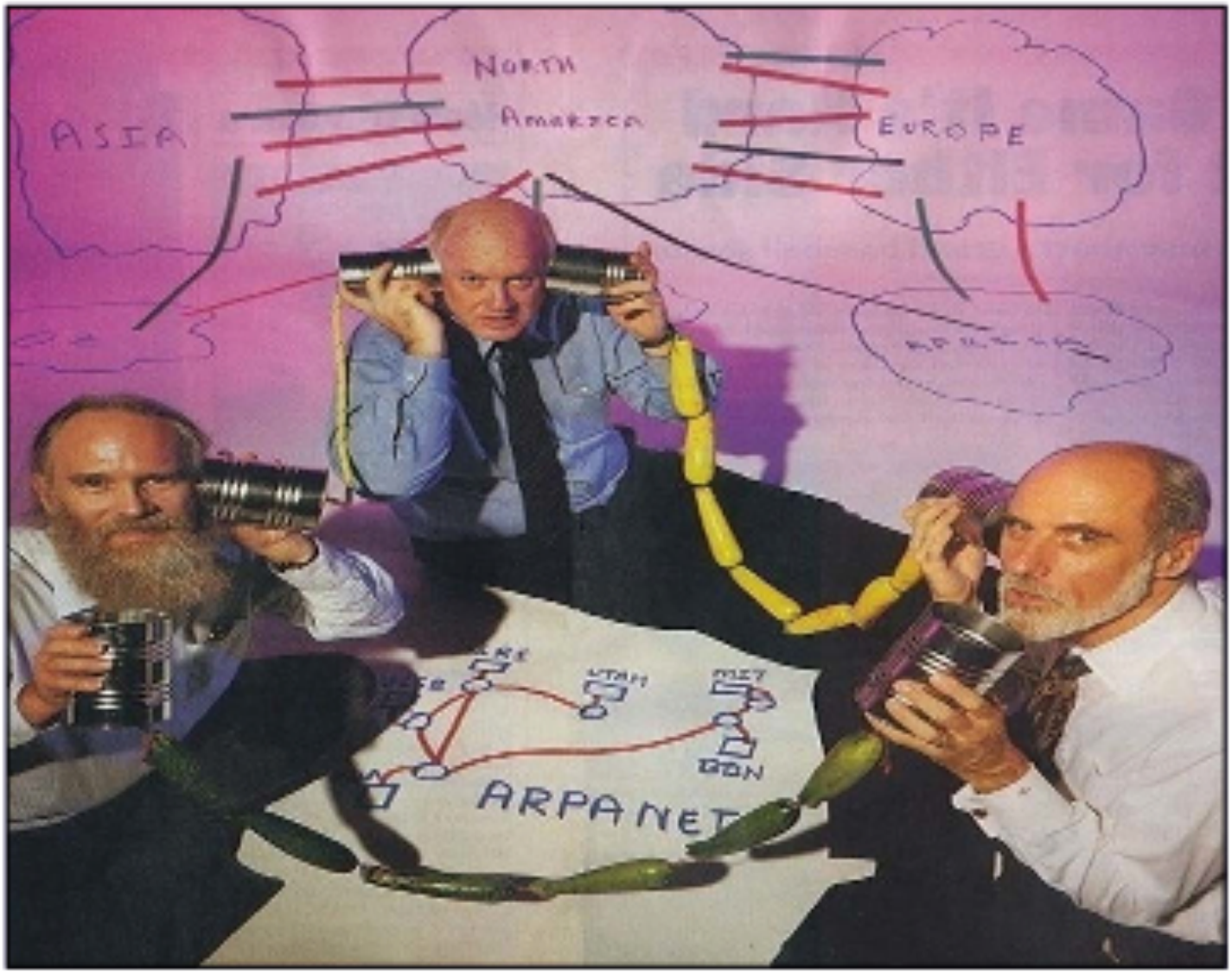
Outline

- Networking **overview**
- A brief **history** of Internet interconnection and its evolution
- Highlight the **implications** of this evolution

(Jumping ahead to the) **Implications**

- U.S. Internet intercxn is **unregulated** and continues to **evolve**
- Interconnection agreements under **heavy NDAs**
- **Video traffic** is the new disrupting factor
- "Eyeball" ISPs are flipping the **power structure** (e.g., money flows)
- Interconnection arrangements will continue to be under **stress**
- **Competitive** concerns may arise in parts of this ecosystem

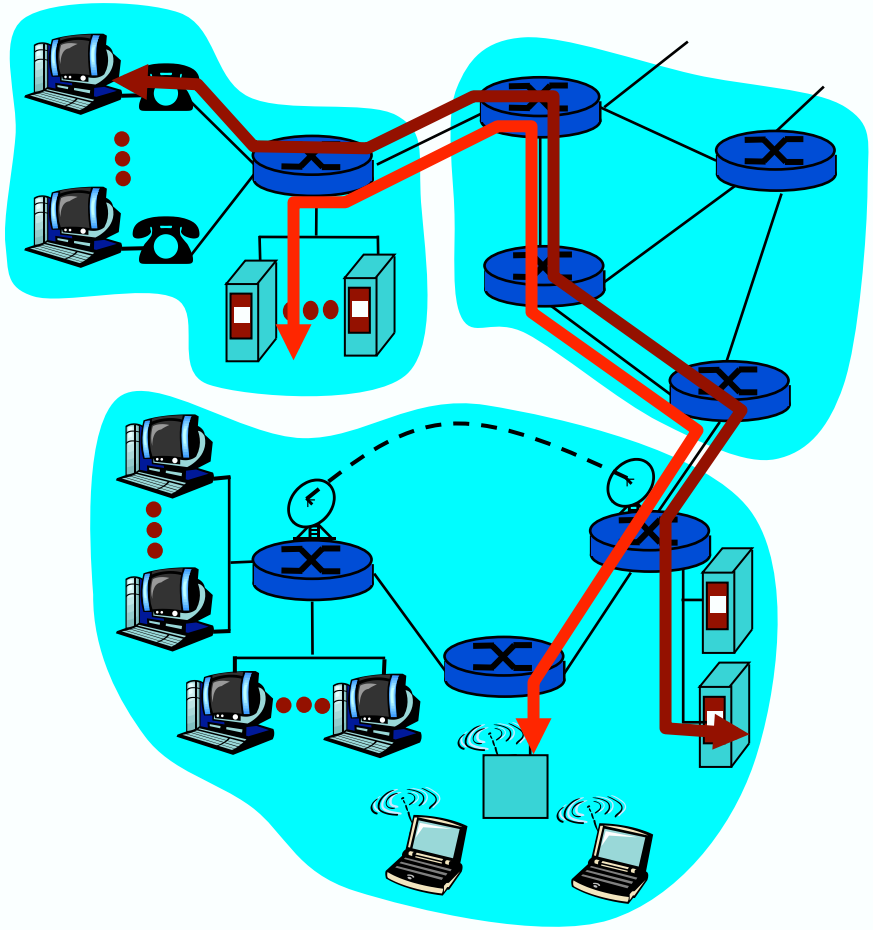
How does the Internet work?



All of this, without much regulation, and in only a few decades!

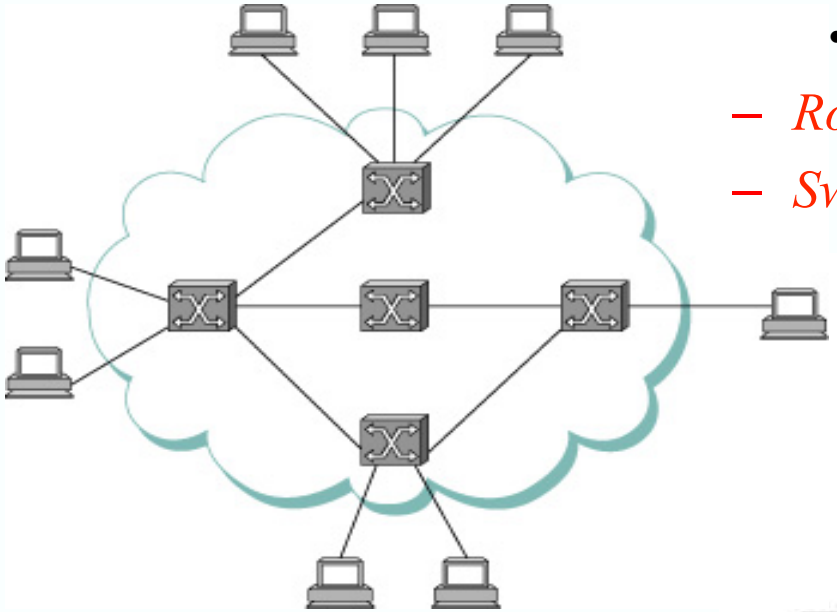
Network Types

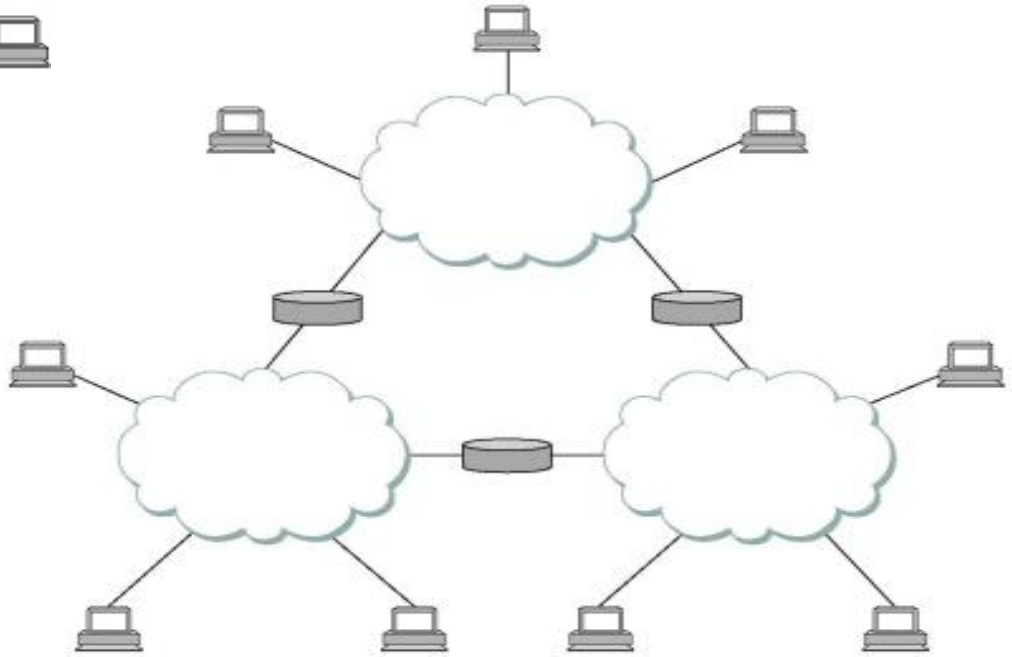
- A fundamental question: how is data transferred through the network?
  - Circuit switching
    - The telephone network
    - Dedicated circuit per call
      - No sharing
    - Call set up
    - Guaranteed quality of service
  - Packet switching
    - The Internet
    - Data forwarded as *packets*
      - Sharing
    - No call set up
    - No quality of service guarantee



Network Core: Packet Switching

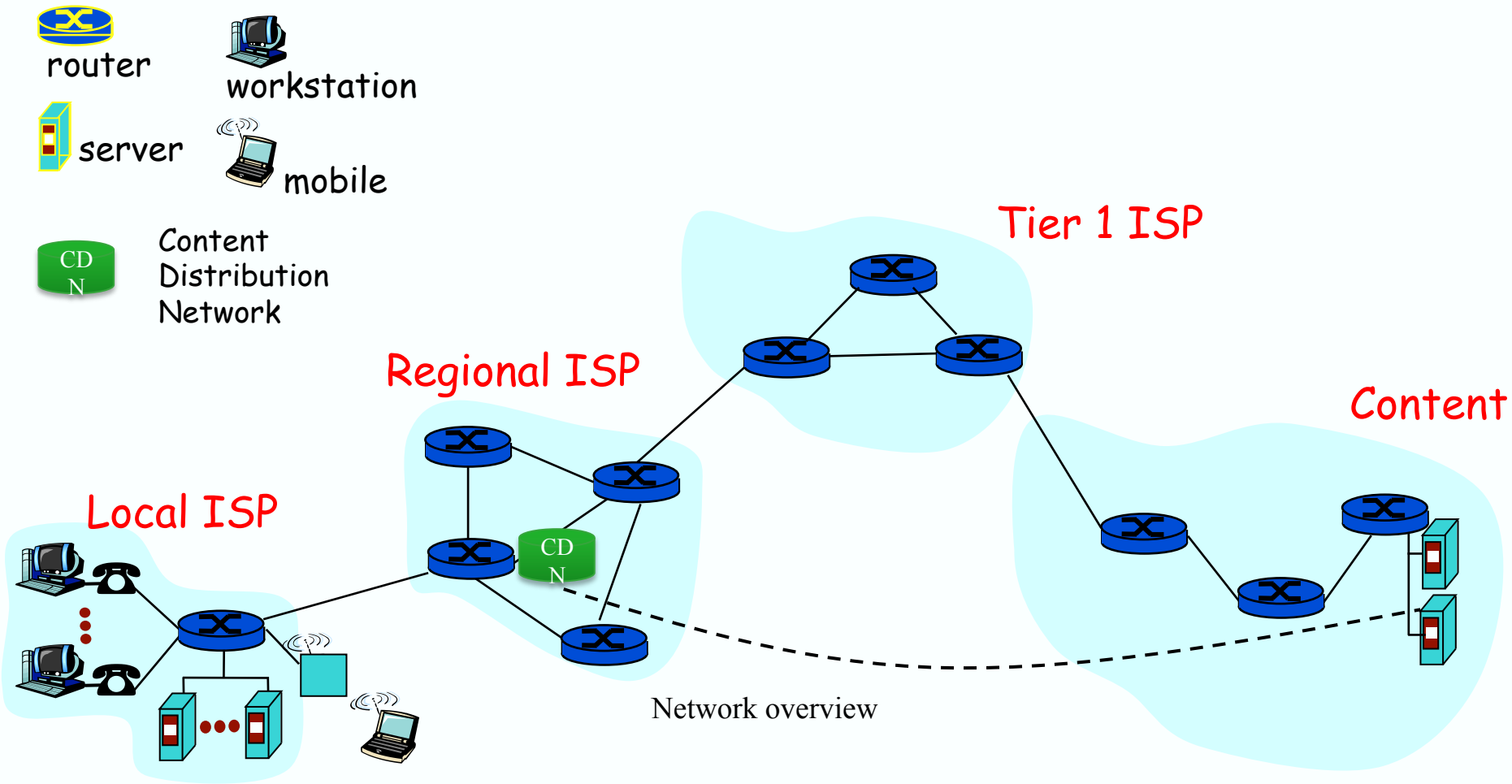
- Millions of connected computing devices:
  - *Hosts = your computer*
  - *Communication links =* fiber, copper, radio, satellite
    - transmission rate = ***bandwidth***
  - *Routers =* devices to forward packets
  - *Switches =* devices to move frames (local or far)





What's the Internet: "nuts and bolts"

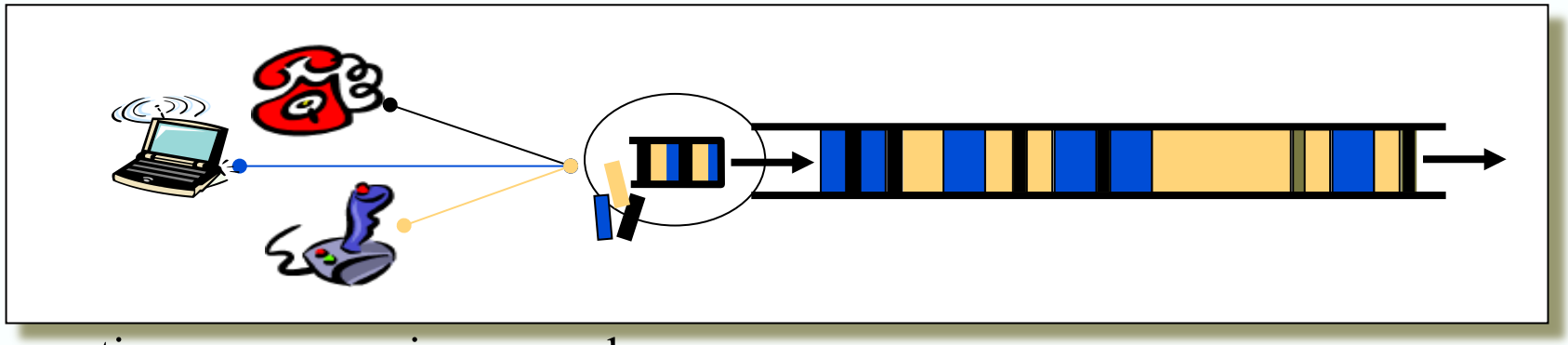
- *Internet:* "network of networks"
  - No one network directly connects to all of the Internet



The Internet

- Internet = **thousands** of interconnected networks
    - no one directly connects to everyone else
- Each network = **set of routers =** *Autonomous System (AS)*
  - ISP, large enterprise, education, content providers
  - Each AS "owns" set of IP addresses
- Routers **forward** traffic via neighboring routers
  - **Routing table** points to the correct next-hop neighbor router
  - Routers **announce routes** between neighbors

Congestion



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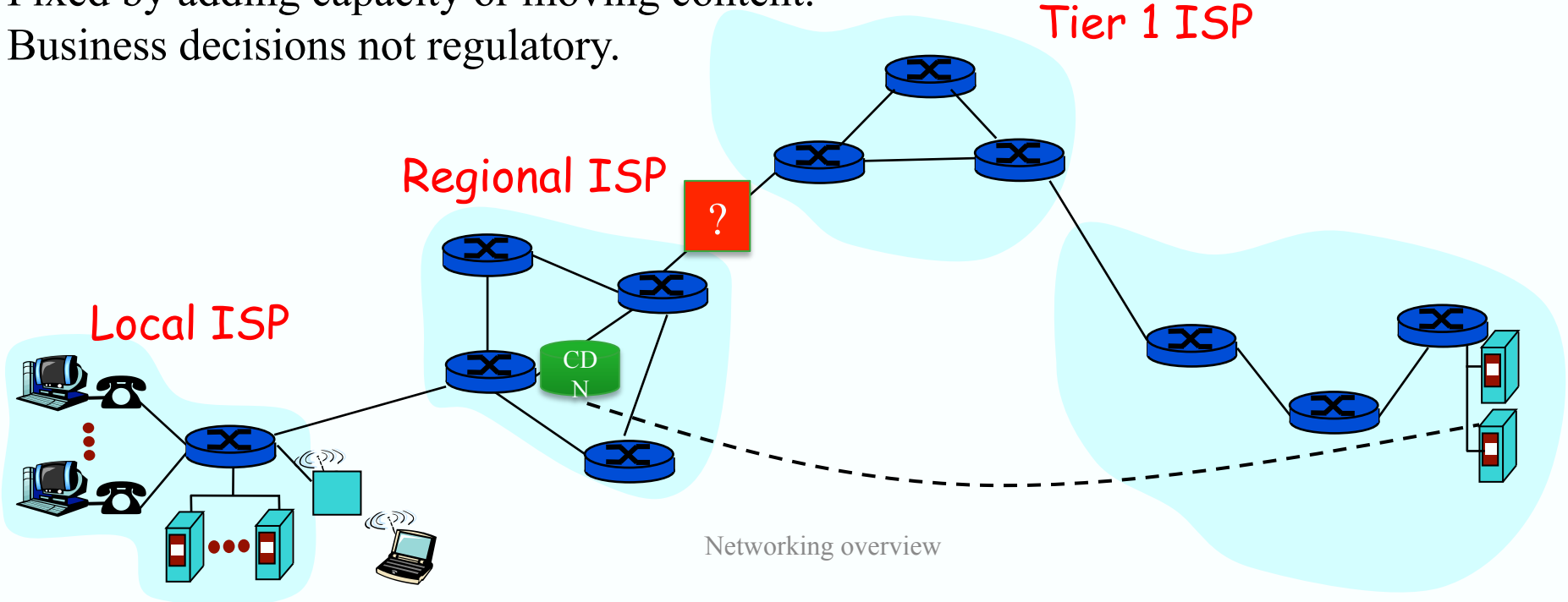
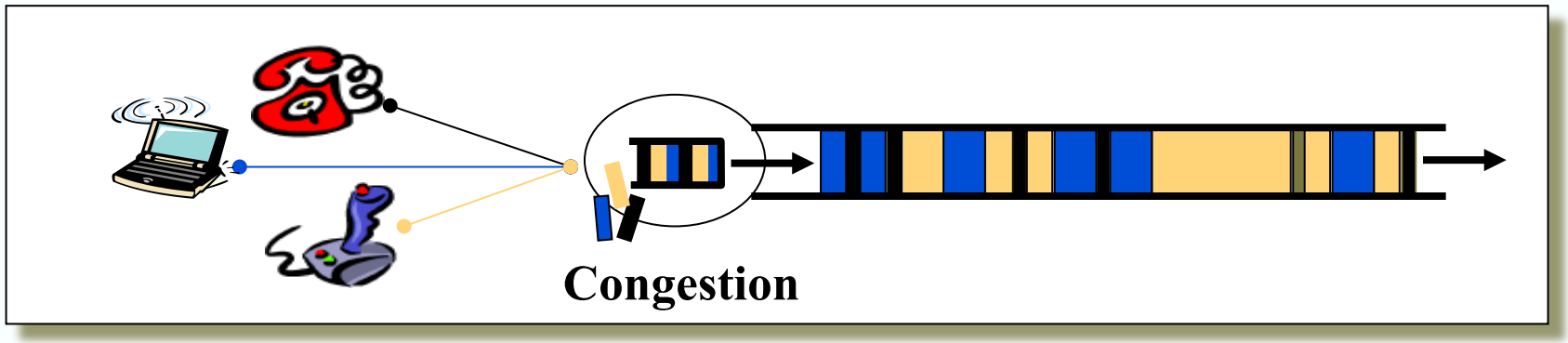
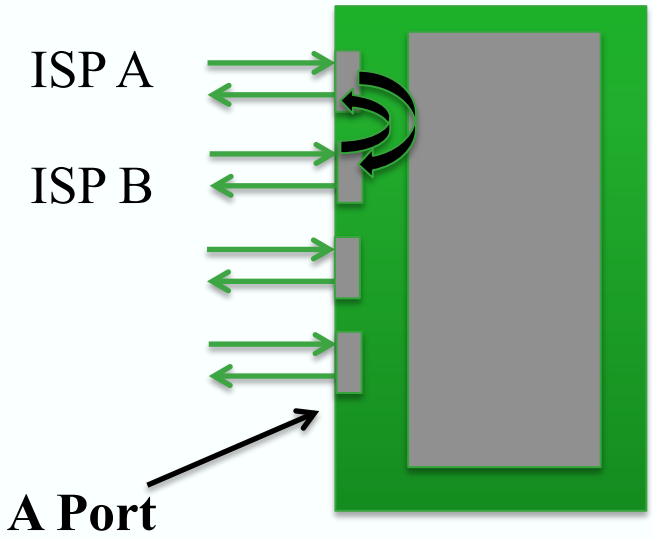
Fixed by adding capacity or moving content.
Business decisions not regulatory.



Switch Fabric



A Switch



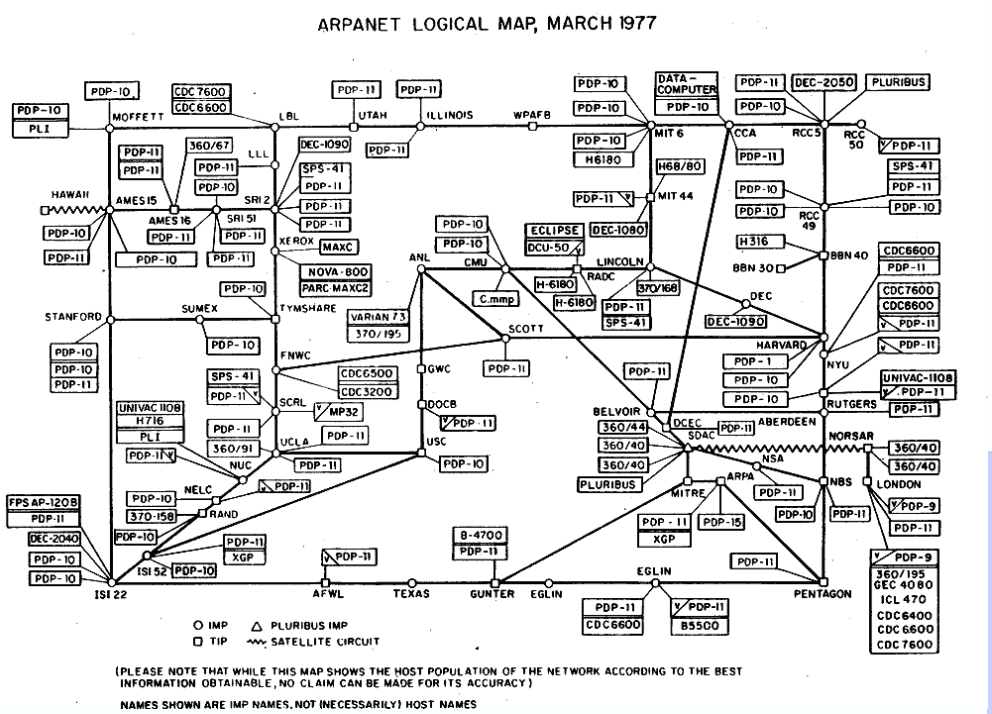
Two ISP might connect in this manner (peering or transit). Add ports as agreed upon.

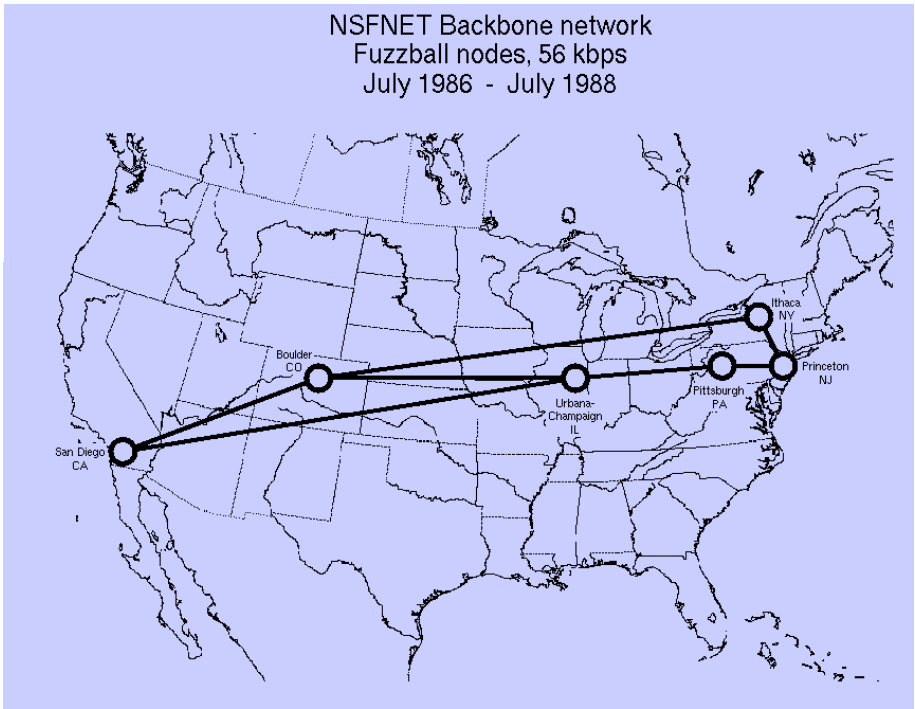
Many ISPs might come together at a switch in a multilateral peering arrangement.

The Internet

History

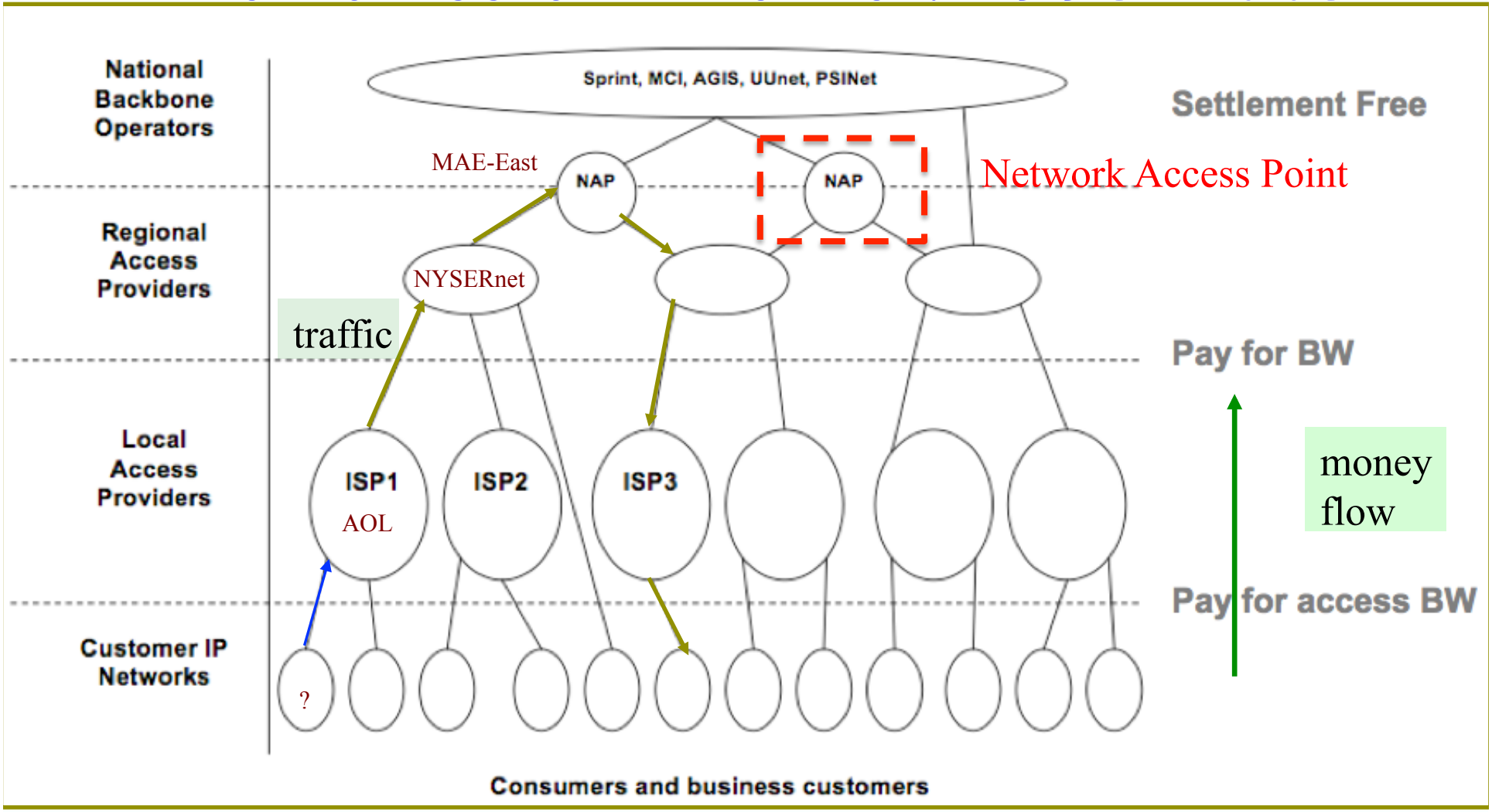
The NSFNET Internet





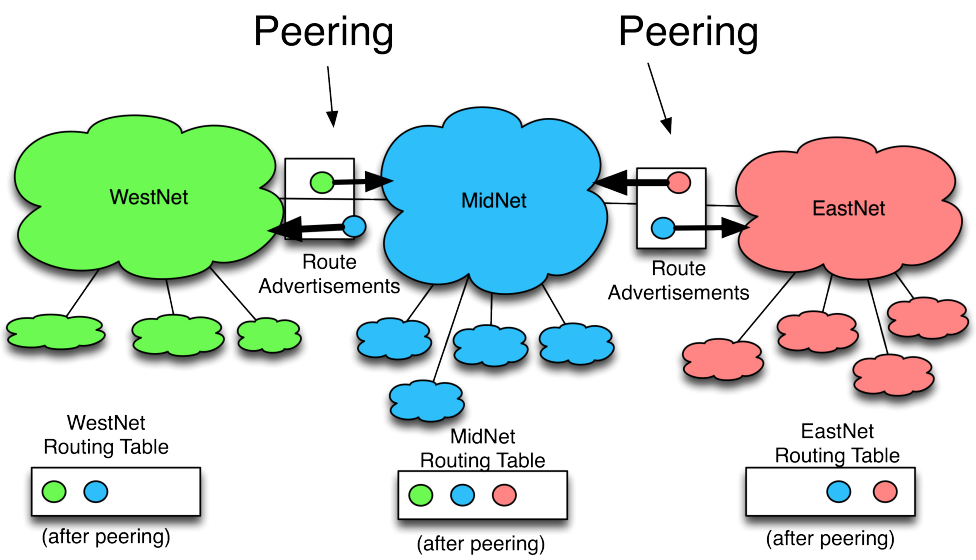
- ARPANET 1969 – 1990
- CSNET early 1980s
- NSFNET1985 -1995
- Commercialization – early 1990's

The "classic" Internet: 1993-2003



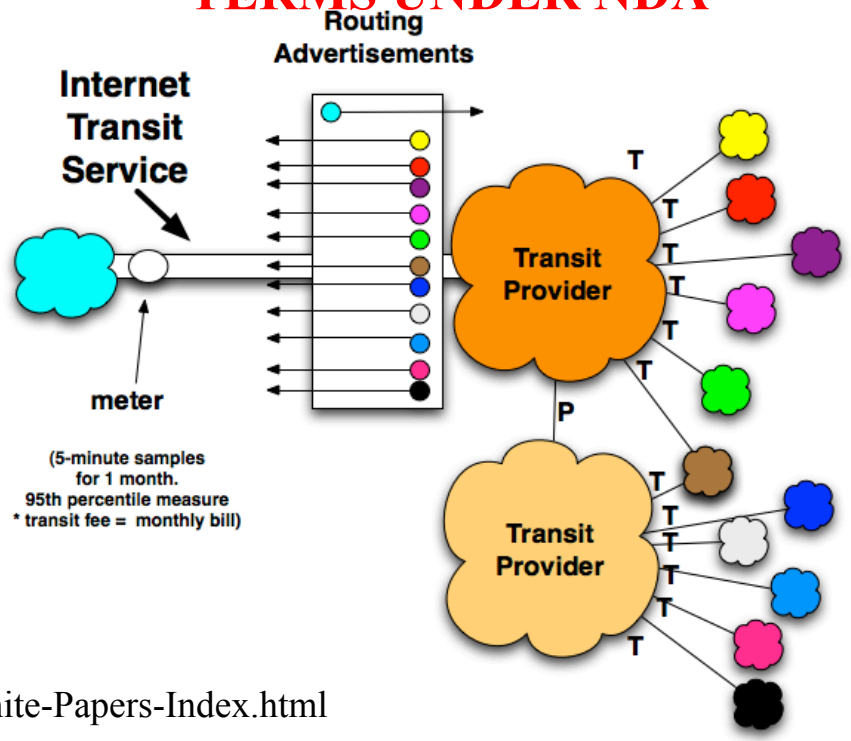
Craig Labovitz, "Internet Traffic and Content Consolidation", IETF

Peering versus Transit



Peering - a business relationship whereby ISPs reciprocally provide connectivity to each others' customers (not to the entire Internet and not to other peers)

TERMS UNDER NDA



Transit - a business relationship whereby *ISP A* provides access to the Internet for *ISP B* (advertises to the rest of the Internet how to reach *ISP B and passes B's packets to the Internet*)

Source: http://drpeering.net/white-papers/An-Internet-Peering-White-Papers-Index.html

The players & their roles

Role	**Examples**
End user	Residential … GM
“Eyeball” ISP (have the subscribers…)	Comcast, Verizon, AT&T… WISPs
Content & application hosting	GoDaddy
Content providers and aggregators	Netflix, YouTube, Vimeo
CDNs (content distribution networks)	Akamai, Limelight
IXPs (Internet Exchange Points)	Equinix
Transit ISPs	Verizon, Level 3, Tata

Some of the bigger changes since the (late) 1990's

Changes since the (late) 1990's

Internet eXchange Points (IXPs)

"Eyeball" ISP change

Transit pricing dropping

Denser interconnection

Content Distribution Networks (CDNs)

Radical increase in traffic (video …)

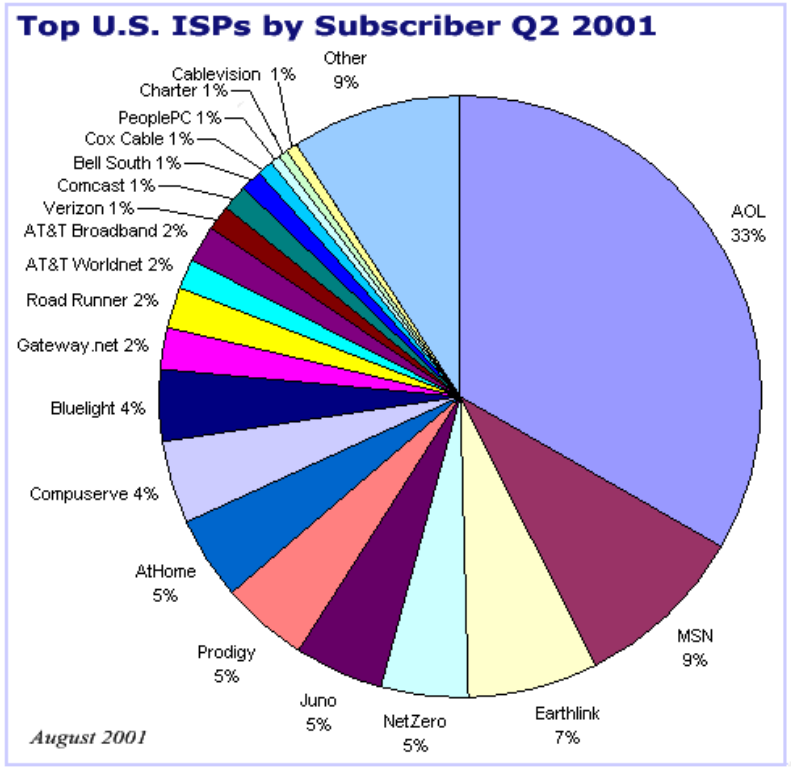
Growth of the mobile market

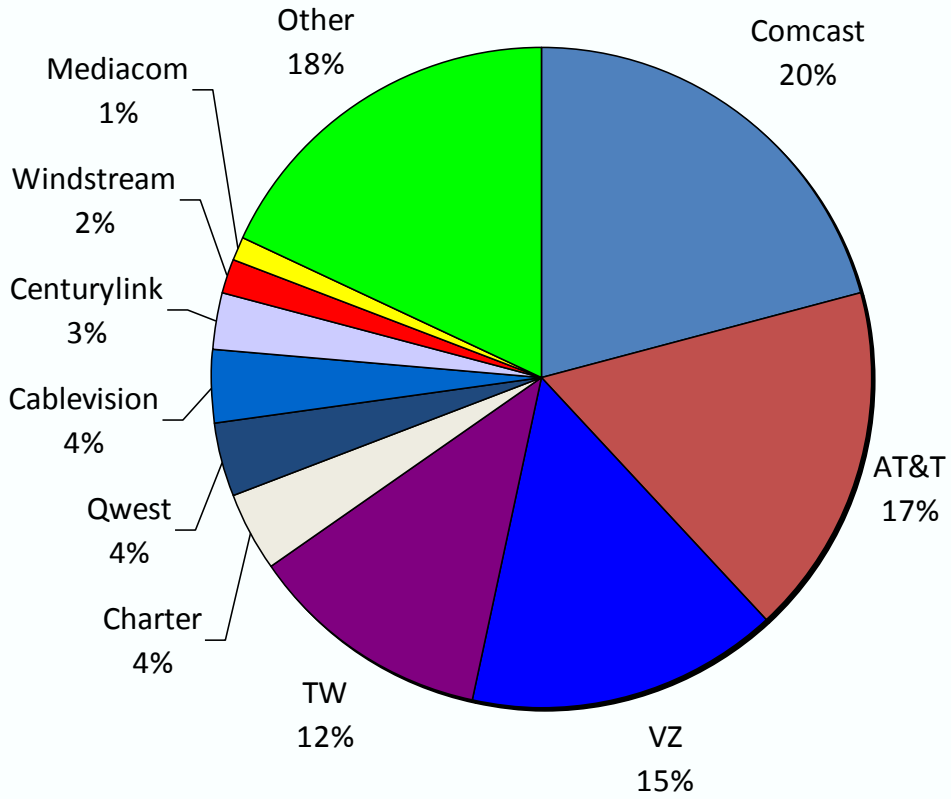
Role of IXPs

- IXP
  - Internet eXchange Points
  - As NAPs congested, IXPs emerged (including, most notably, overseas)
  - IXPs → public peering and private peering
  - IXPs
    - reduced tromboning
    - provided cost reductions
    - improved performance for some
    - occurred mostly without regulatory oversight

Eyeball ISPs: 2001 vs. 2010

This trend has increased





Market power: eye ball vs. transit

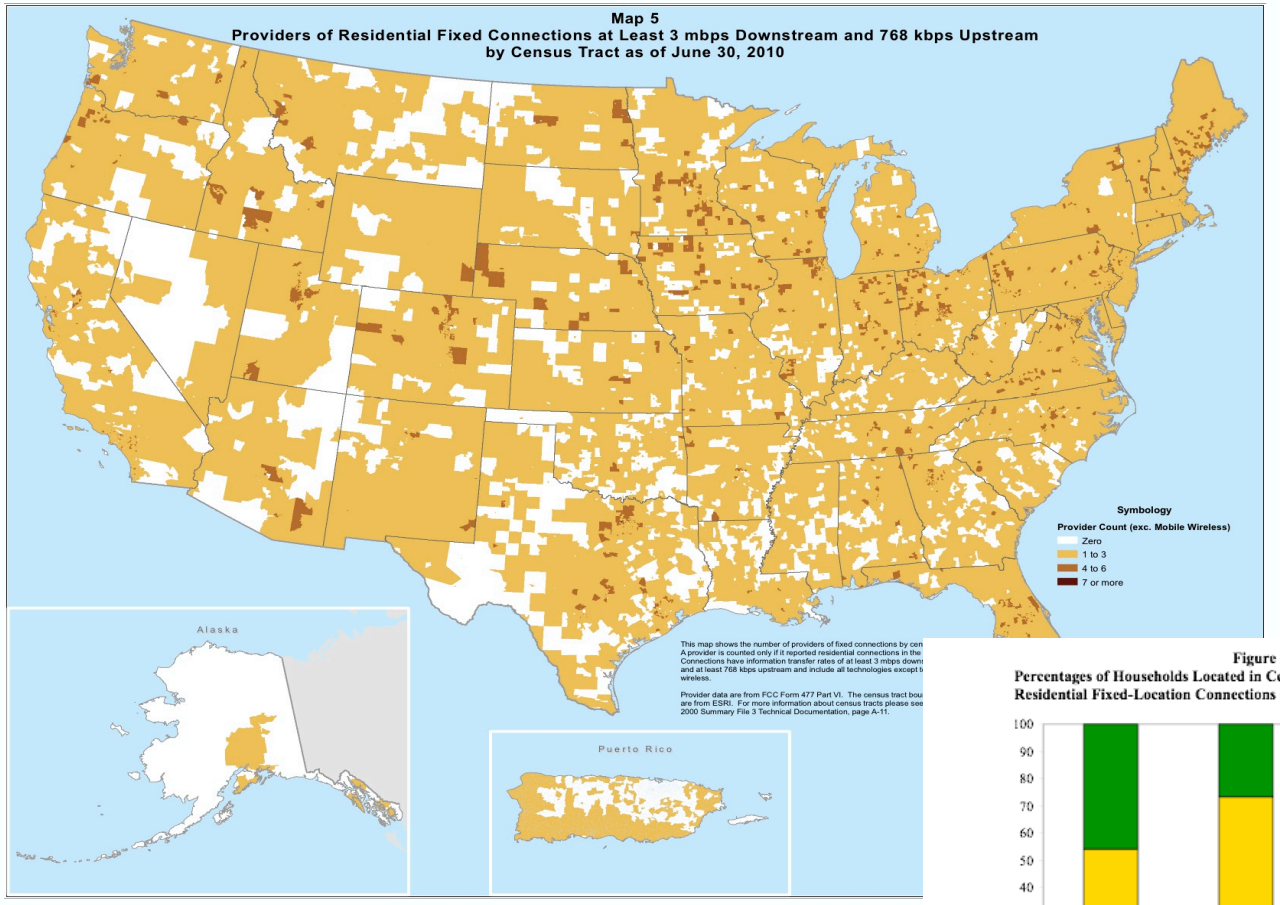
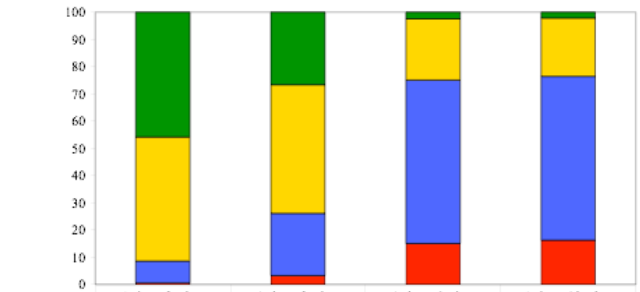


Figure 3(a)
Percentages of Households Located in Census Tracts Where Providers Report Residential Fixed-Location Connections of Various Speeds as of June 30, 2010



	At least 3 mbps downstream & over 200 kbps upstream	At least 3 mbps downstream & 768 kbps upstream	At least 6 mbps downstream & 1.5 mbps upstream	At least 10 mbps downstream & 1.5 mbps upstream
3+ Providers	46	27	2	2
2 Providers	46	47	22	21
1 Provider	8	23	60	60
0 Providers	1	3	15	16

Figures may not sum to 100% due to rounding.

- Tier 1 ISP: ~ 12 tier networks (~ equal)
- BB access ISP: only 0-2 choices

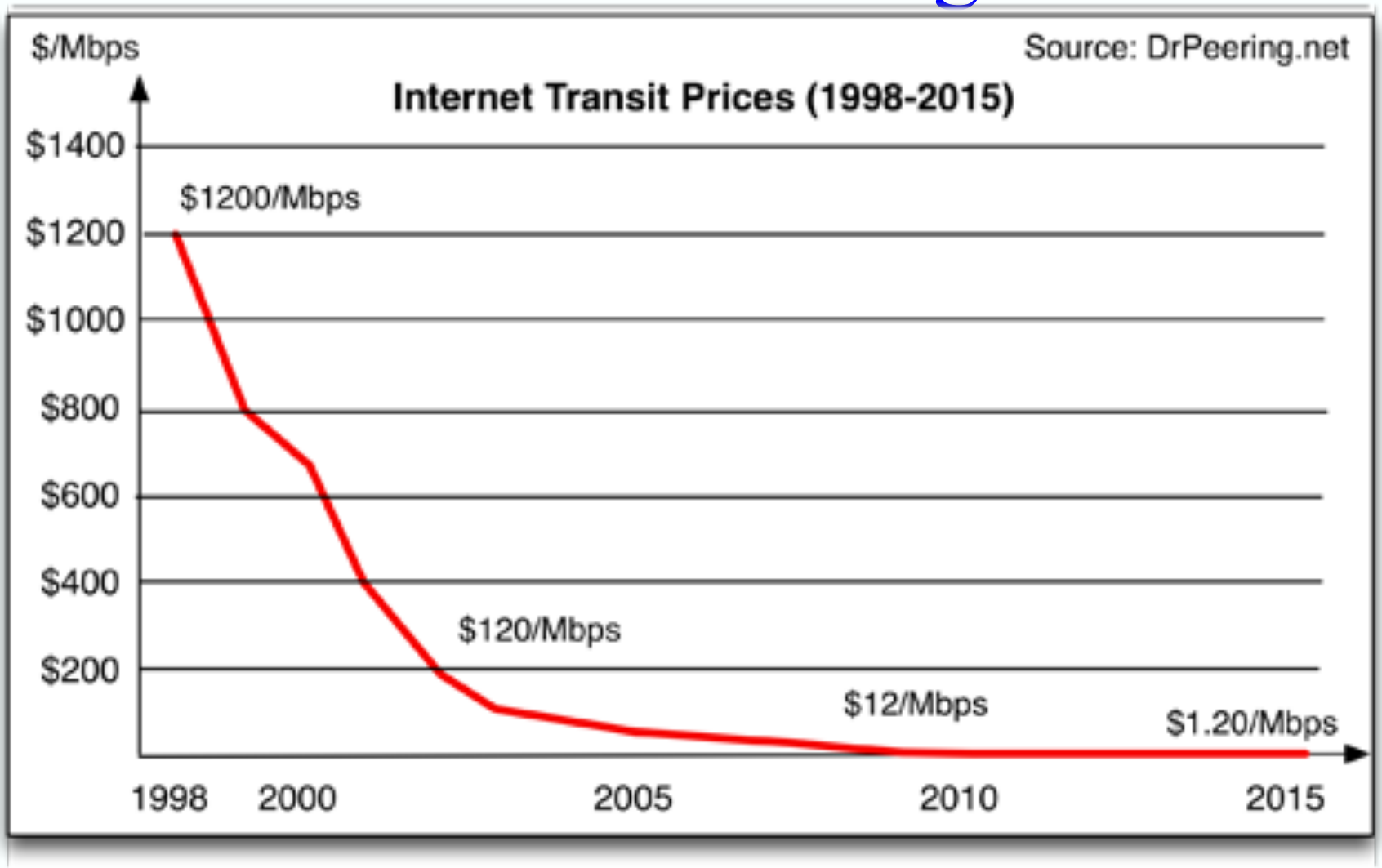
These charts are old but the trend stands

New Network Providers

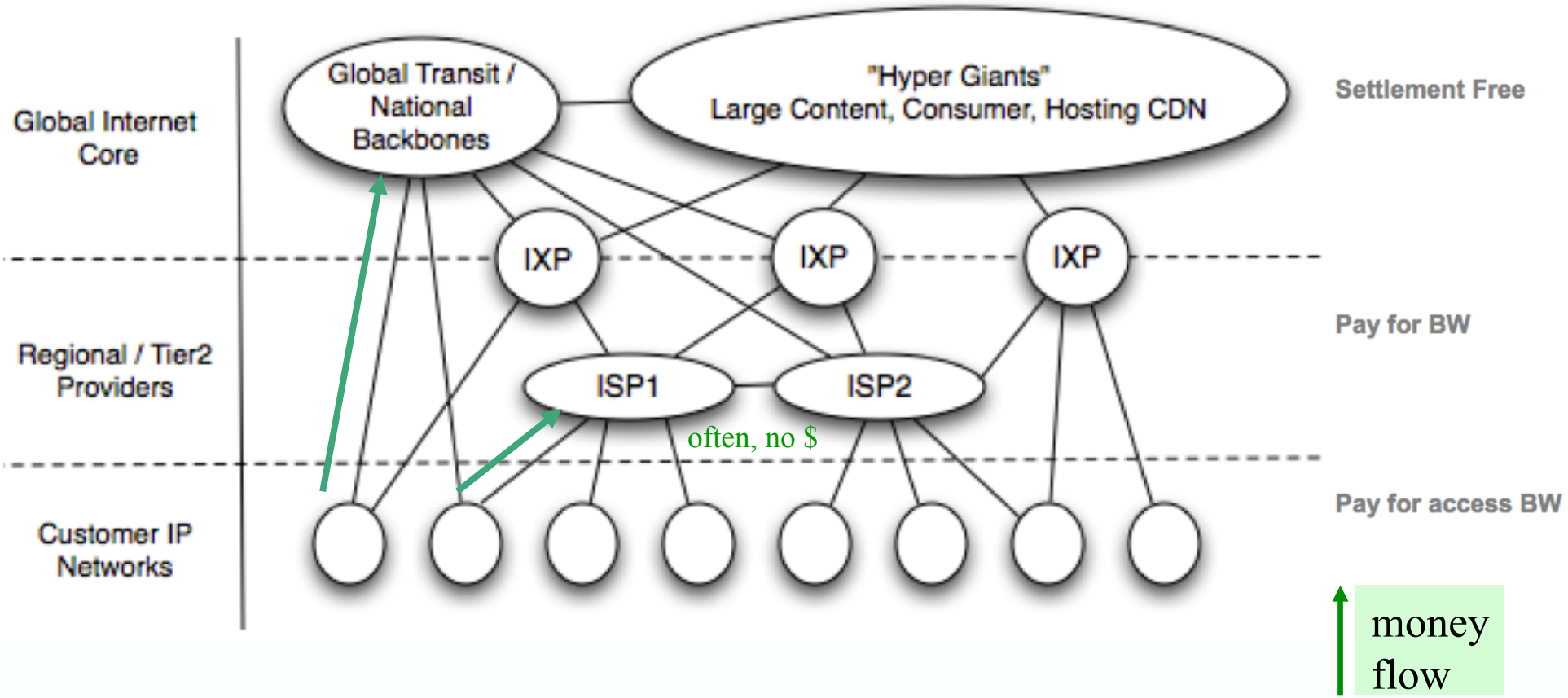
Top ISP 2007	Top ISP 2010	Top ISP 2013
Level 3	Level 3	Level 3
Global Crossing	Global Crossing	NTT
AT&T	Google	Teliasonera
Sprint	NTT	Inteliquent
NTT	Sprint	Cogent
Cogent	Comcast	Sprint
Verizon	Cogent	Tata

Many ways to measure the above; details are less important than the movement in the list

Transit Pricing

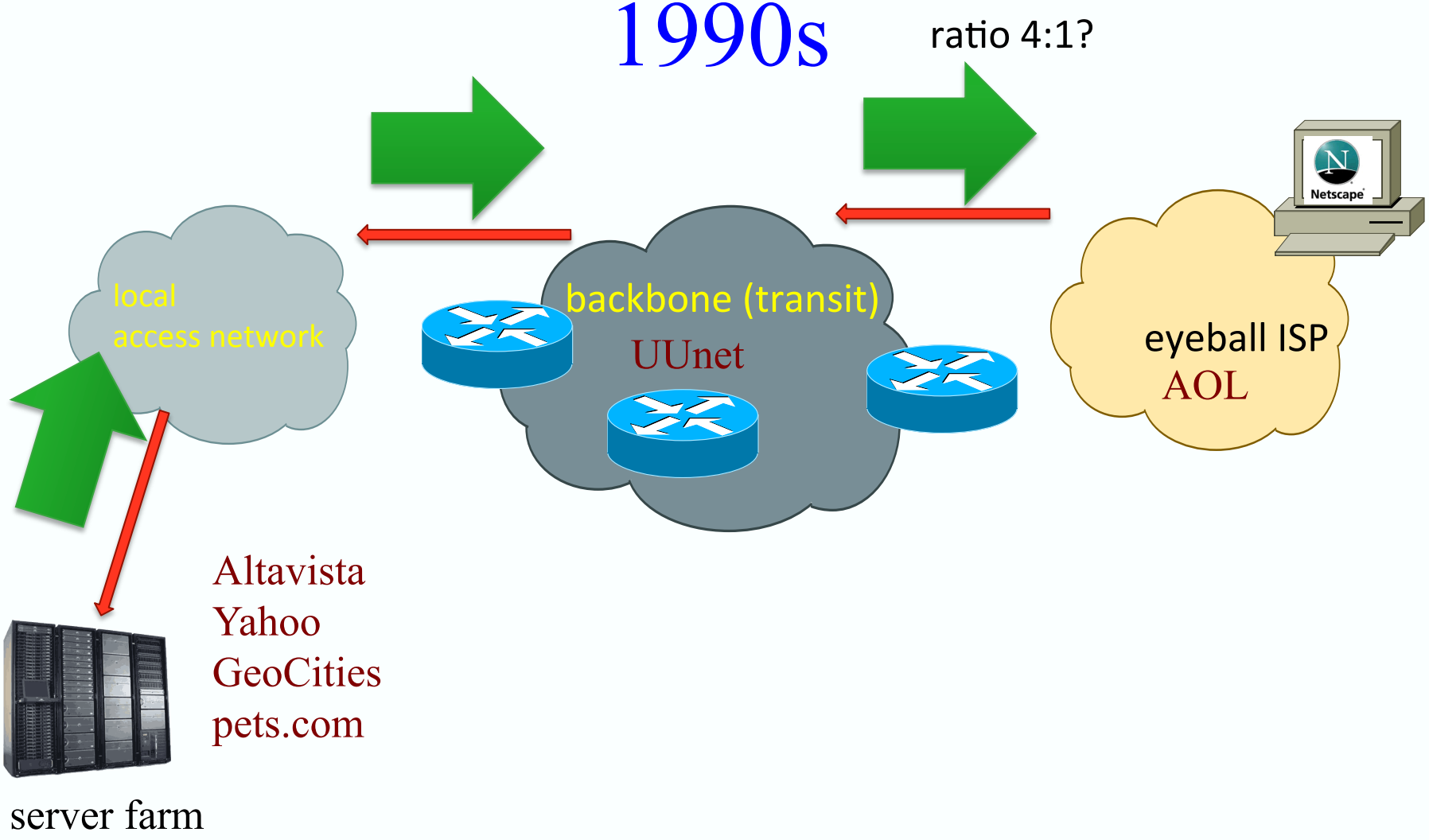


A Denser Internet



Craig Labovitz, "4", IETF March 2010.

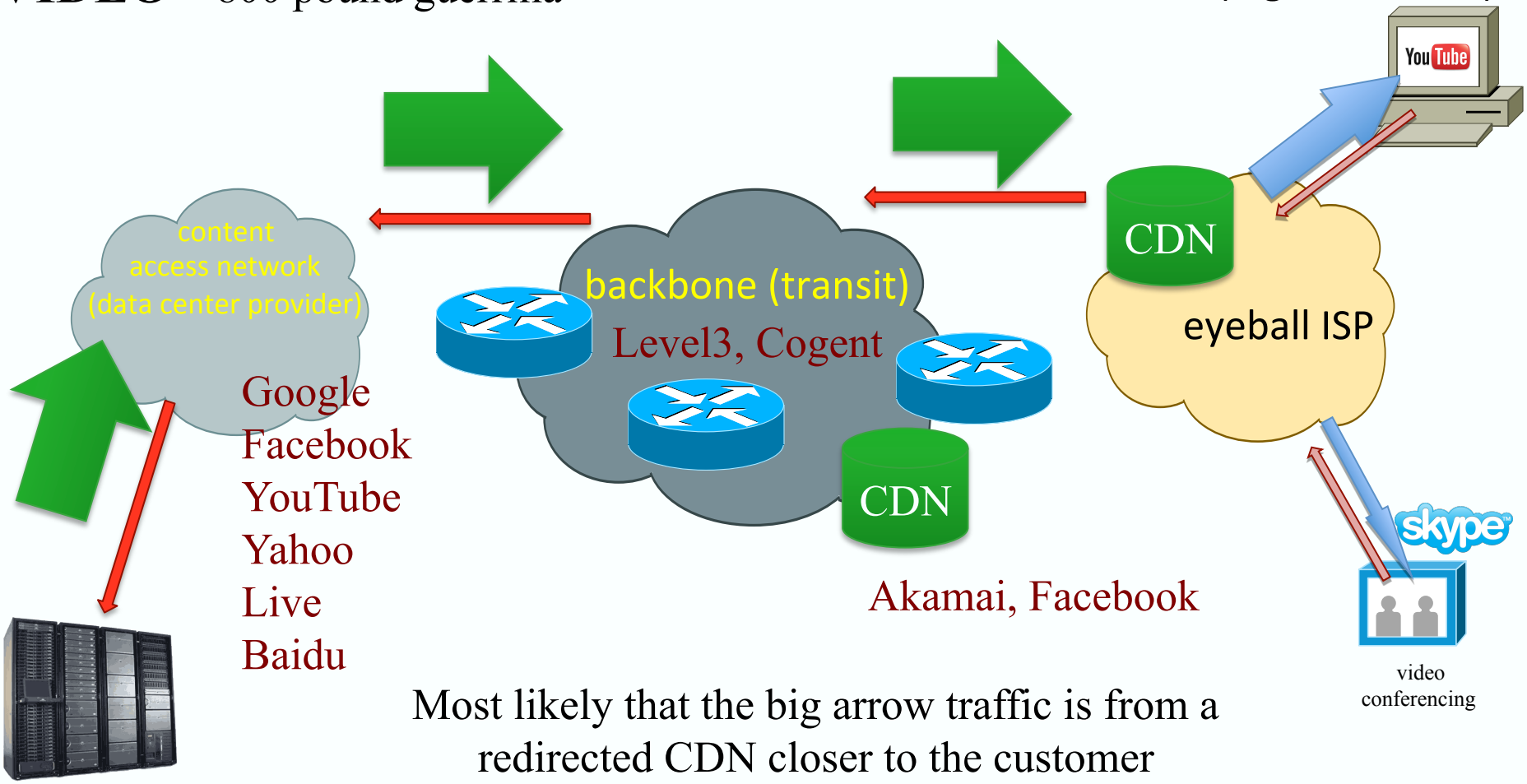
Internet Traffic Flows in the 1990s



Internet Traffic Flows 2010

VIDEO – 800 pound guerrilla

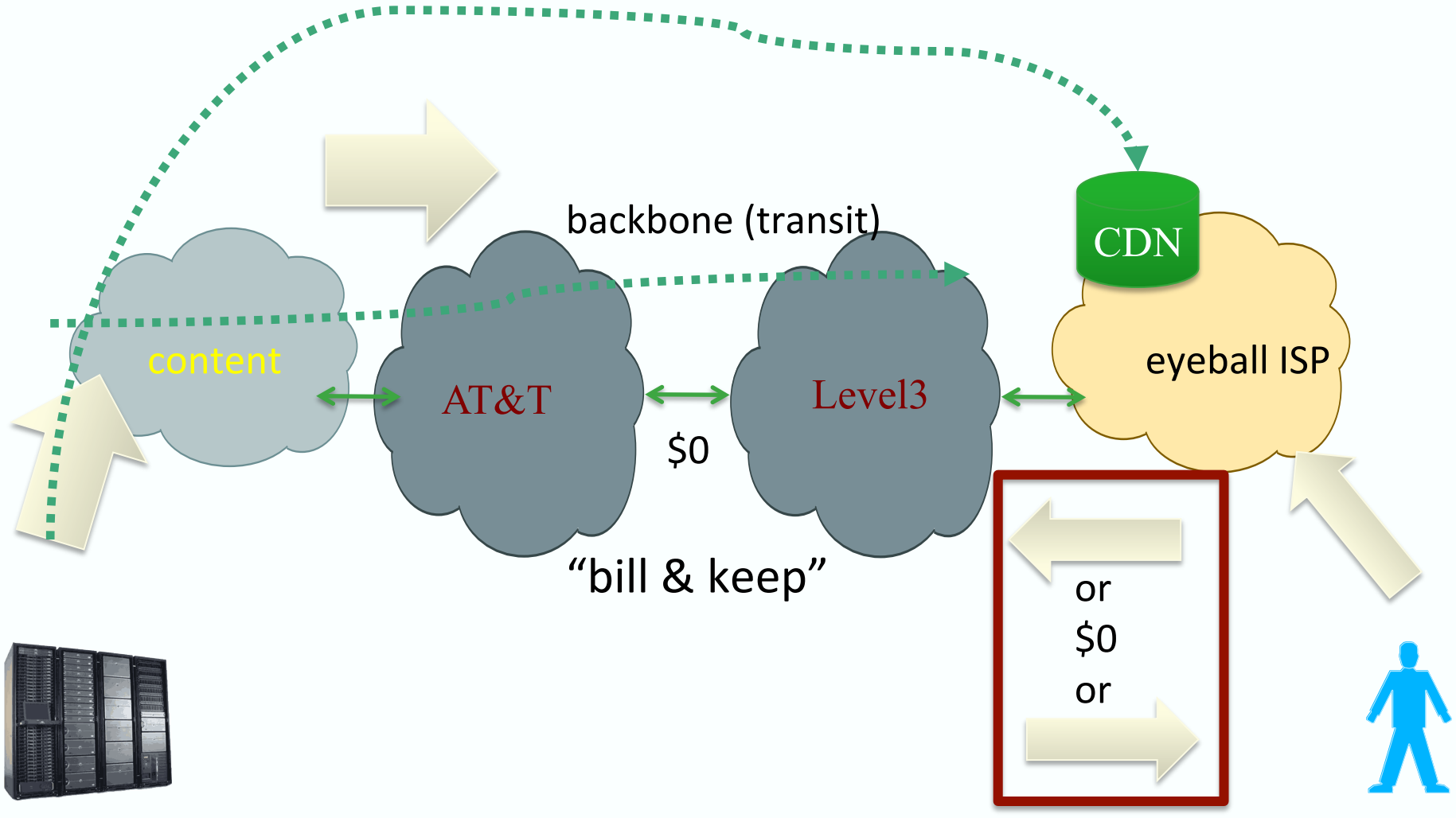
ratio 16:1 to 30:1 (higher/lower?)



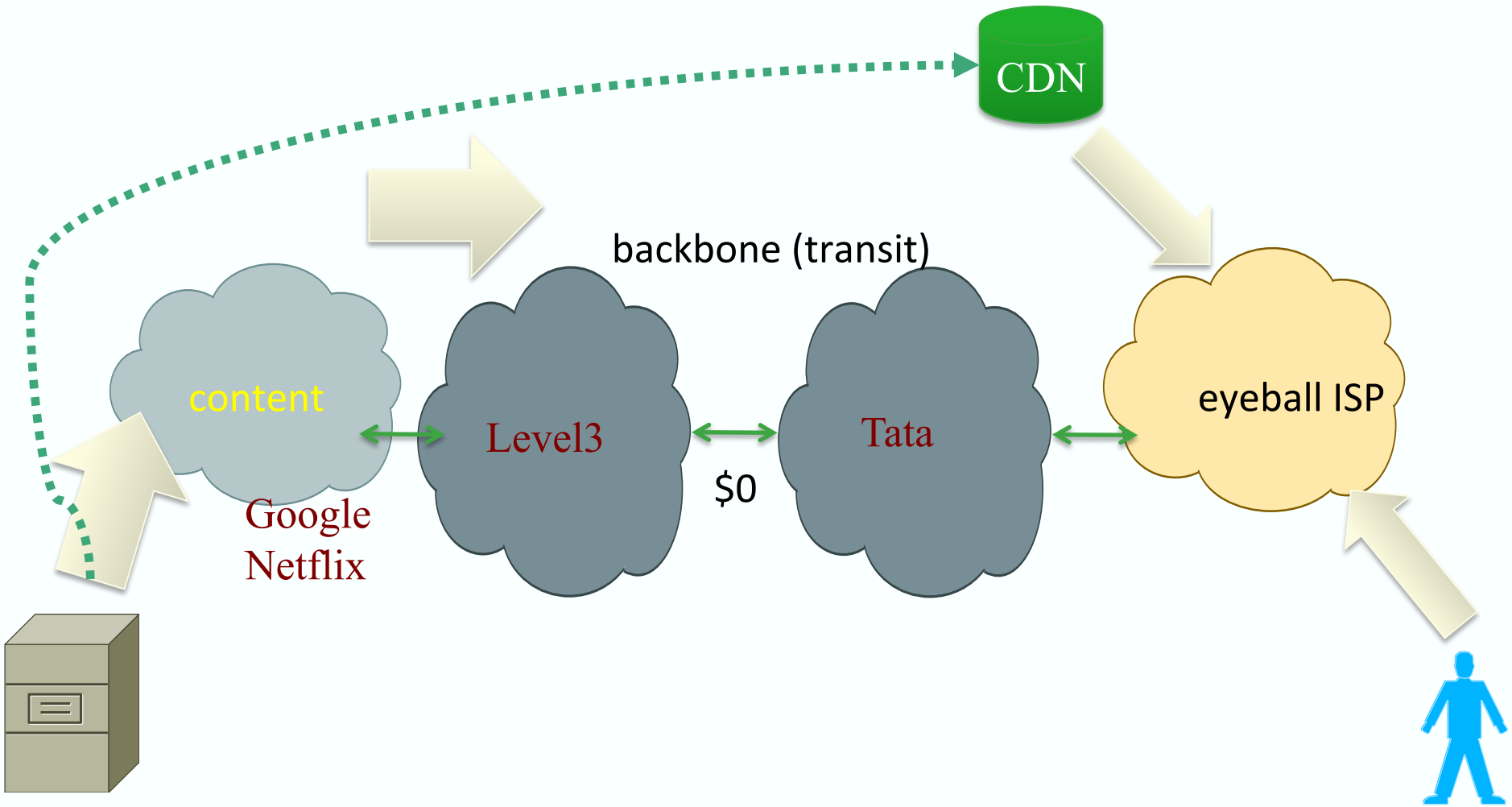
Most likely that the big arrow traffic is from a redirected CDN closer to the customer

Traffic is coming from fewer ASNs

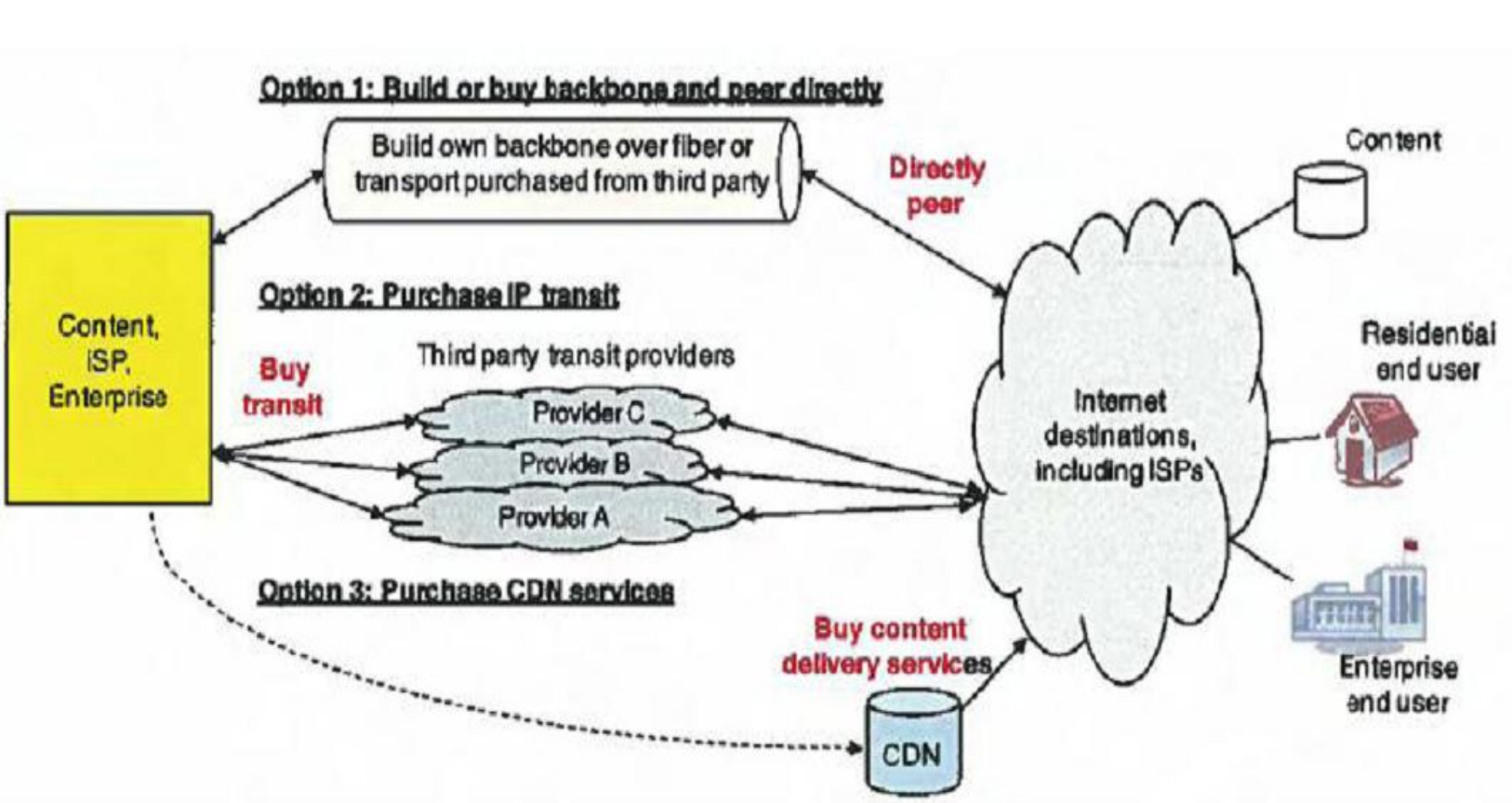
Money Flows Today (future?)



Future Internet Money Flows?



How to get Content to Customer



Source: Level 3 declaration in FCC docket IB 11-78

Who Pays Whom?

- Shared-cost peering (settlement-free interconnection)
  - Peering that is often done on a bill & keep basis - no payment
  - Typically used when both parties perceive a roughly equal exchange of value
- Paid peering (settlement-paid interconnection)
  - Agreement whereby ISPs agree to carry traffic for each other and for their respective customers, but with payment involved;
  - Offsets perceived differences in value received (*e.g.,* between a small regional ISP and a large national ISP)
- Perceived value
  - Traffic ratio (symmetric traffic often proxy for "roughly equal")
  - Traffic volume (Large ISP won't peer with small)
  - Specific content
  - Number and geographic spread of customers

Summary & Conclusion

- Peering
  - Fundamental to Internet architecture
  - A function of traffic + money
- 1990s – today
  - Traffic, money flows change
  - Denser and with different market power & traffic flows

- U.S. Internet Interconnect is **unregulated** and continues to **evolve**
- Interconnections agreements under **heavy NDAs**
- **Video traffic** is majorly disrupting things
- "Eyeball" ISPs are flipping the **power structure** (e.g., money flows)
- Interconnections arrangements will continue to be under **stress**
- **Competitive** concerns may arise in parts of this ecosystem

Additional Slides

Let's talk about Netflix and Comcast

What the public knows:

- Agreement reached; NetFlix connecting directly with Comcast at Equinix San Jose data center; NetFlix likely paying for the connection; None of this should be a surprise

What really happened:

- Invite them in to speak to you

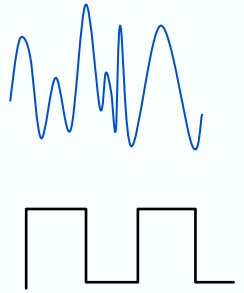
Bottom line

- These conflicts will continue; It isn't clear what regulators might be able to do to help; "Sunlight is said to be the best of disinfectants"

Extra extras!

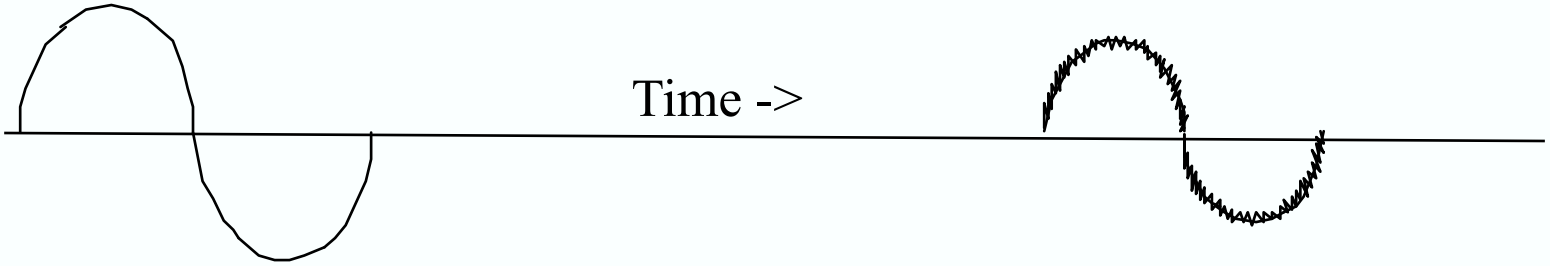
Analog versus Digital

- Analog – continuously varying
- Digital – discreet



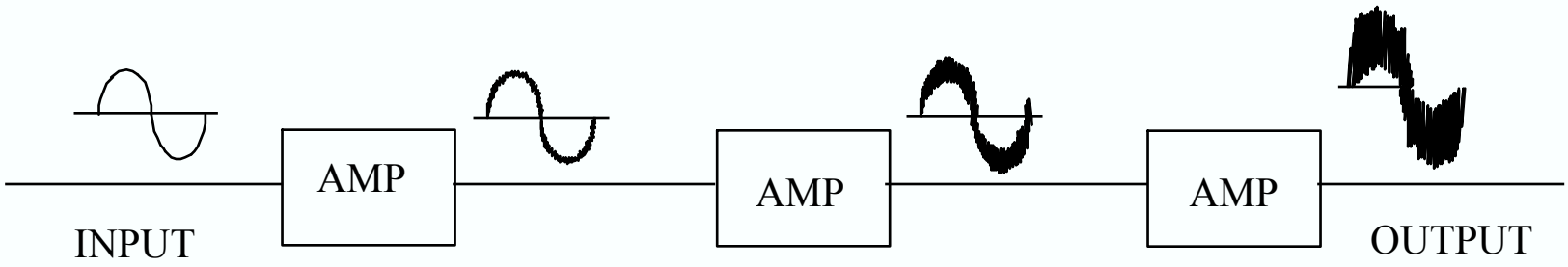
What happens to signals as they travel from sender to receiver?

Signals (analog or digital) degrade over time

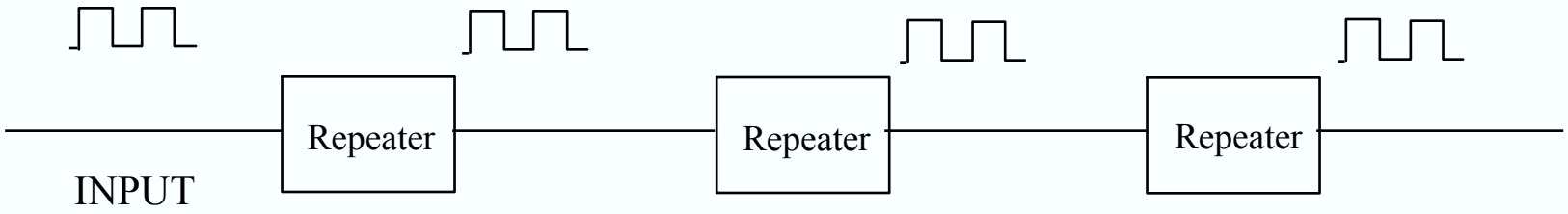


The Digital Revolution

- Why Digital?
  - Analog Amplification vs. Digital Regeneration



Analog Amplification: Noise Accumulates



Digital Regeneration: "Perfect" Signal is Regenerated

Other Advantages:

- Easy to *combine services* (multiplexing)
- Rapid *cost* declines / *performance* improvements

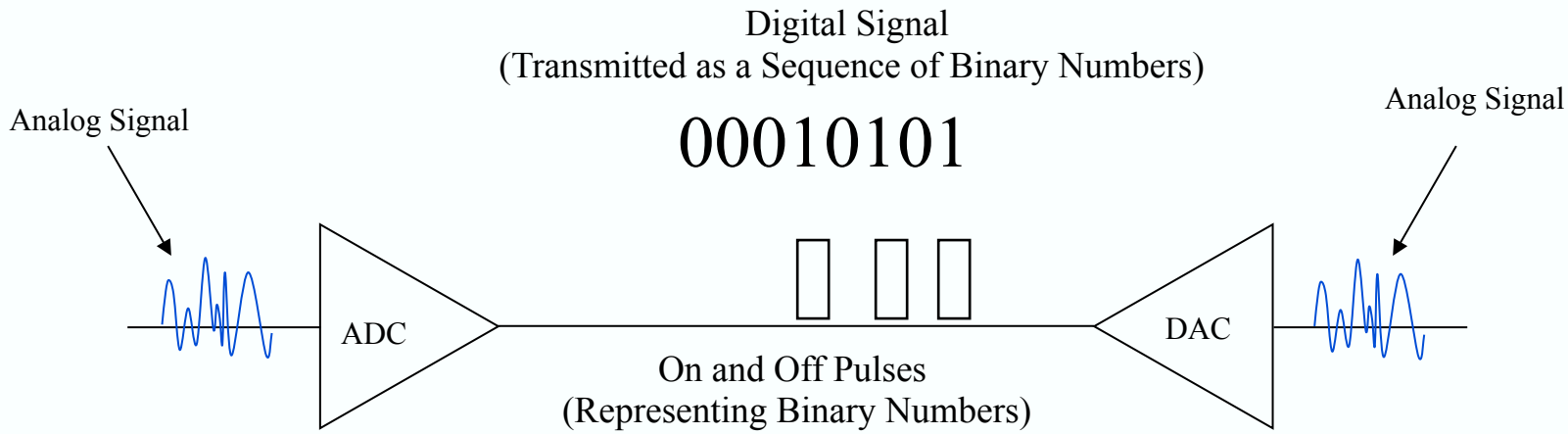
So how do we make analog signals (like voice) digital?

Through an analog to digital converter (ADC)

http://www.netbook.cs.purdue.edu/animations/convert%20analog%20to%20digital.html

The Digital Revolution

Analog to Digital and Digital to Analog Conversion



Digital to Digital (no conversion)