

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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Goal is to better understand the following

$$\begin{aligned}
 f(t) = & \frac{1}{4} \frac{(k-2)\pi}{\sin \frac{(k-2)\delta}{2}} F_{\pi/2}^{-1} \left[F_1 \left\{ u + (k-2) \frac{u_s}{2} \right\} \right] \\
 & + \frac{1}{4} \frac{(k+2)\pi}{\sin \frac{(k+2)\delta}{2}} F_{\pi/2}^{-1} \left[F_2 \left\{ u + (k+2) \frac{u_s}{2} \right\} \right] \\
 & + \frac{1}{4} \frac{(k-2)\pi}{\sin \frac{(k-2)\delta}{2}} F_{\pi/2}^{-1} \left[F_3 \left\{ u - (k-2) \frac{u_s}{2} \right\} \right] \\
 & + \frac{1}{4} \frac{(k+2)\pi}{\sin \frac{(k+2)\delta}{2}} F_{\pi/2}^{-1} \left[F_4 \left\{ u - (k+2) \frac{u_s}{2} \right\} \right],
 \end{aligned}$$

where $F_1(u) = \text{rect} \left(\frac{u - u_1}{u_M} \right) \{ F_{\pi/2} [f(t)S(t)](u) \},$

$$F_2(u) = \text{rect} \left(\frac{u - u_2}{u_M} \right) \{ F_{\pi/2} [f(t)S(t)](u) \},$$

$$F_3(u) = \text{rect} \left(\frac{u + u_1}{u_M} \right) \{ F_{\pi/2} [f(t)S(t)](u) \},$$

$$F_4(u) = \text{rect} \left(\frac{u + u_2}{u_M} \right) \{ F_{\pi/2} [f(t)S(t)](u) \},$$

$$u_1 = (k-2) \frac{u_s}{2} + \frac{u_M}{2}, \text{ and } u_2 = k \frac{u_s}{2} + \frac{u_M}{2}.$$

Goals and Outline

- Gain a basic understanding of networked systems
 - What matters with any network?
- Learn the concepts used to describe networks
 - Basic network terminology
 - Internet, Broadband and Wireless
 - Electricity and Smart Grid
- Observations on networks and network policy
 - What are the trends and what do they mean?
- Extras

Take Away

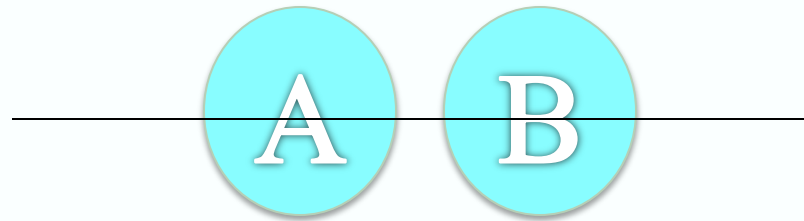
- We are growing ever more dependent on networks
- Networks are enabling new service models
- Many complex and interdependent parts
- Balancing
 - Connectivity, Ubiquity, Reliability, Quality (of Service), Security/Privacy, Control, Scalability, Cost/Price, Adoption
- Policies impact how networks evolve and vice versa
- Technology continues to outpace policy
- Technical knowledge helps inform policy decisions

Networked Systems

What is a network?

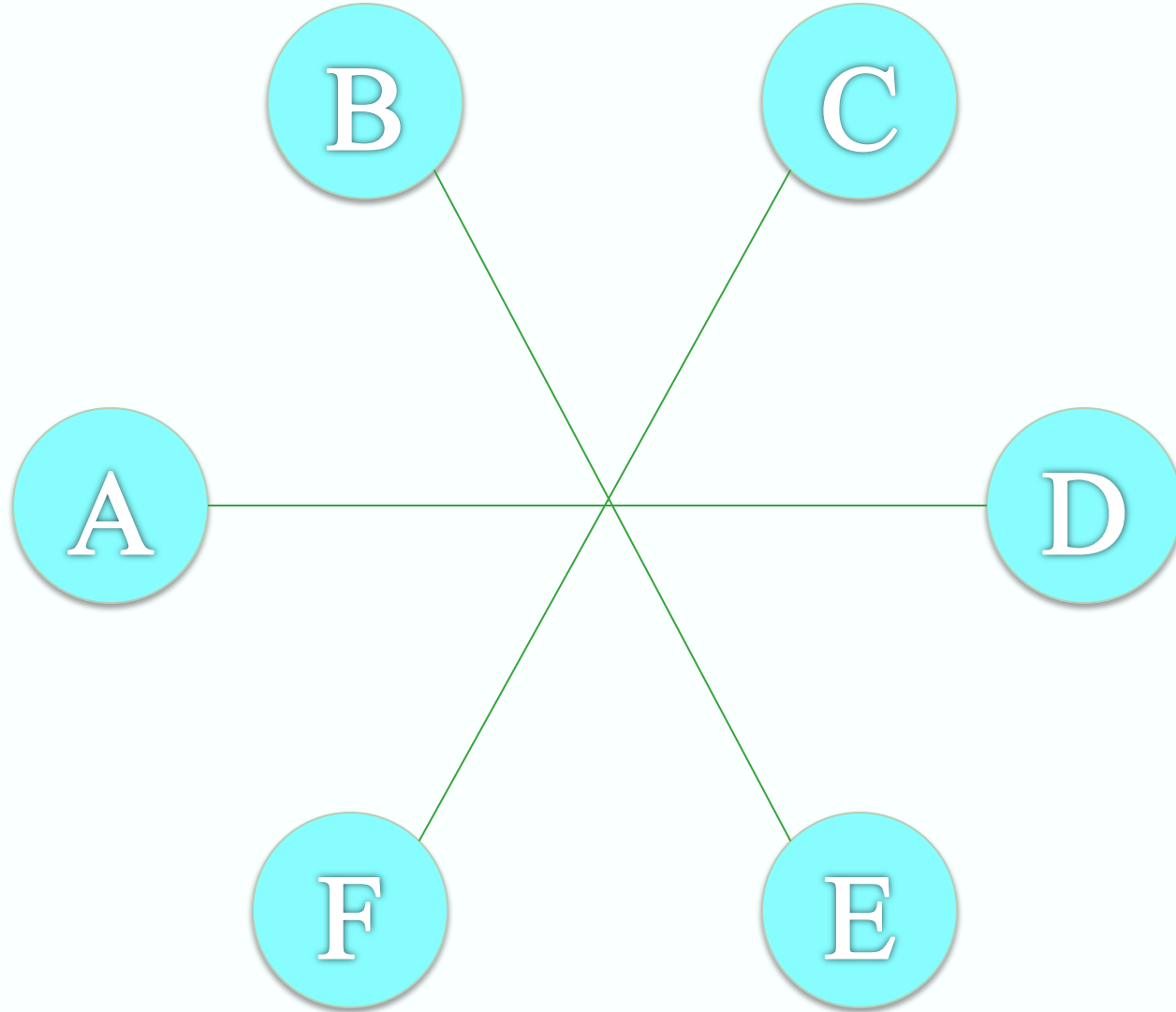
A Set of Connected Objects

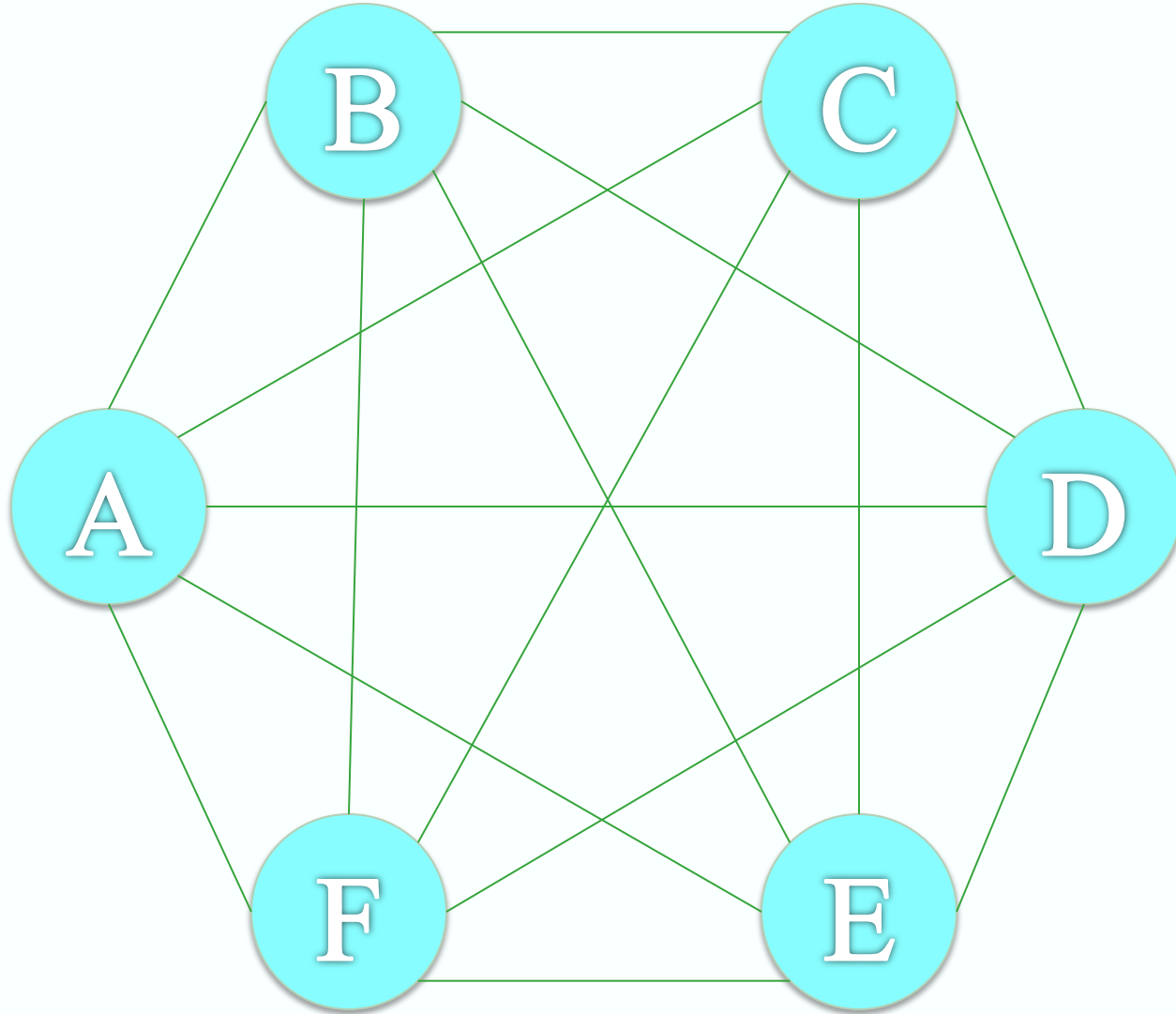
A Simple Network



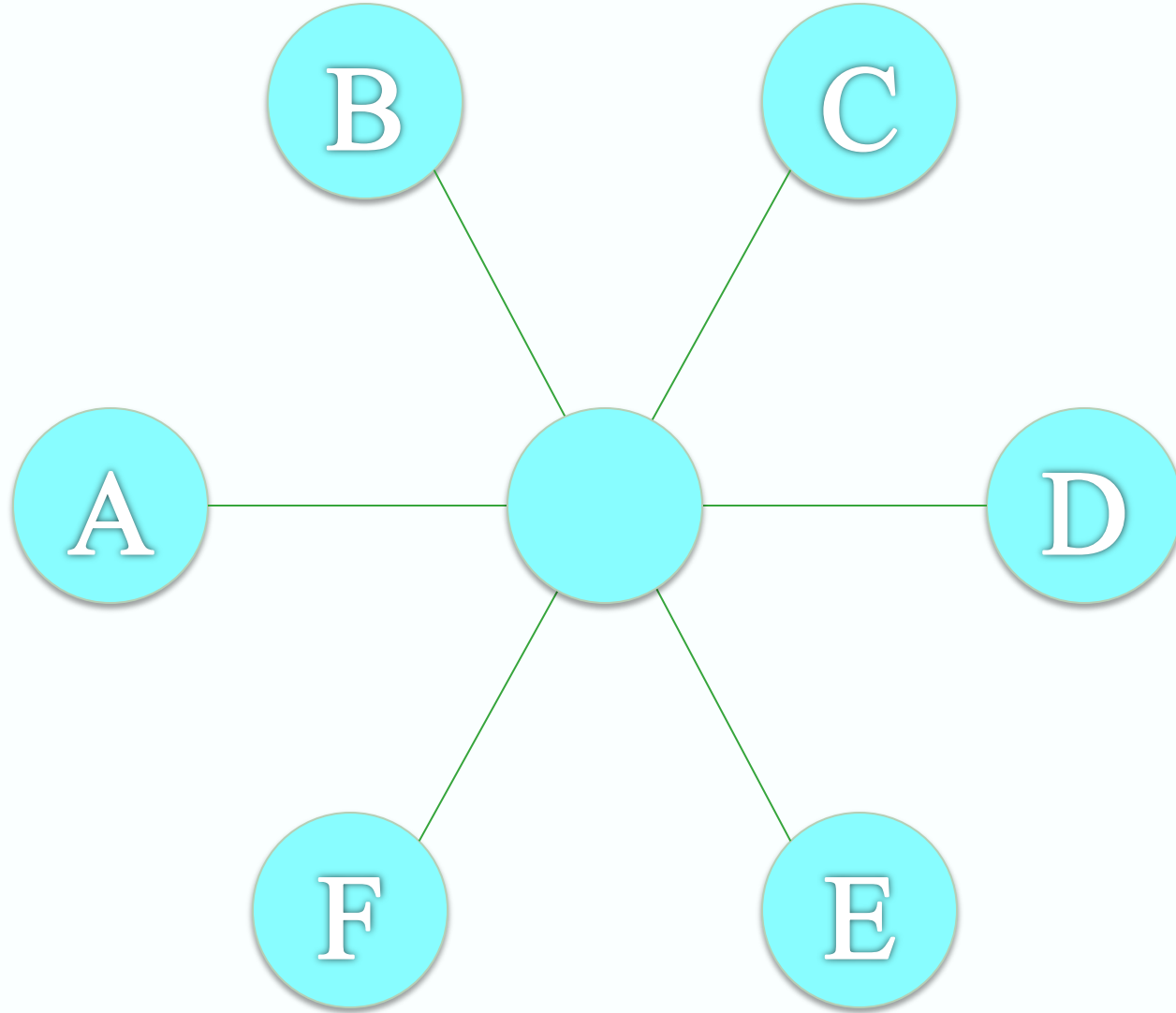
Nodes and Links can combine to form complex systems

Studied through - network theory, network science,
network engineering, network economics, network policy

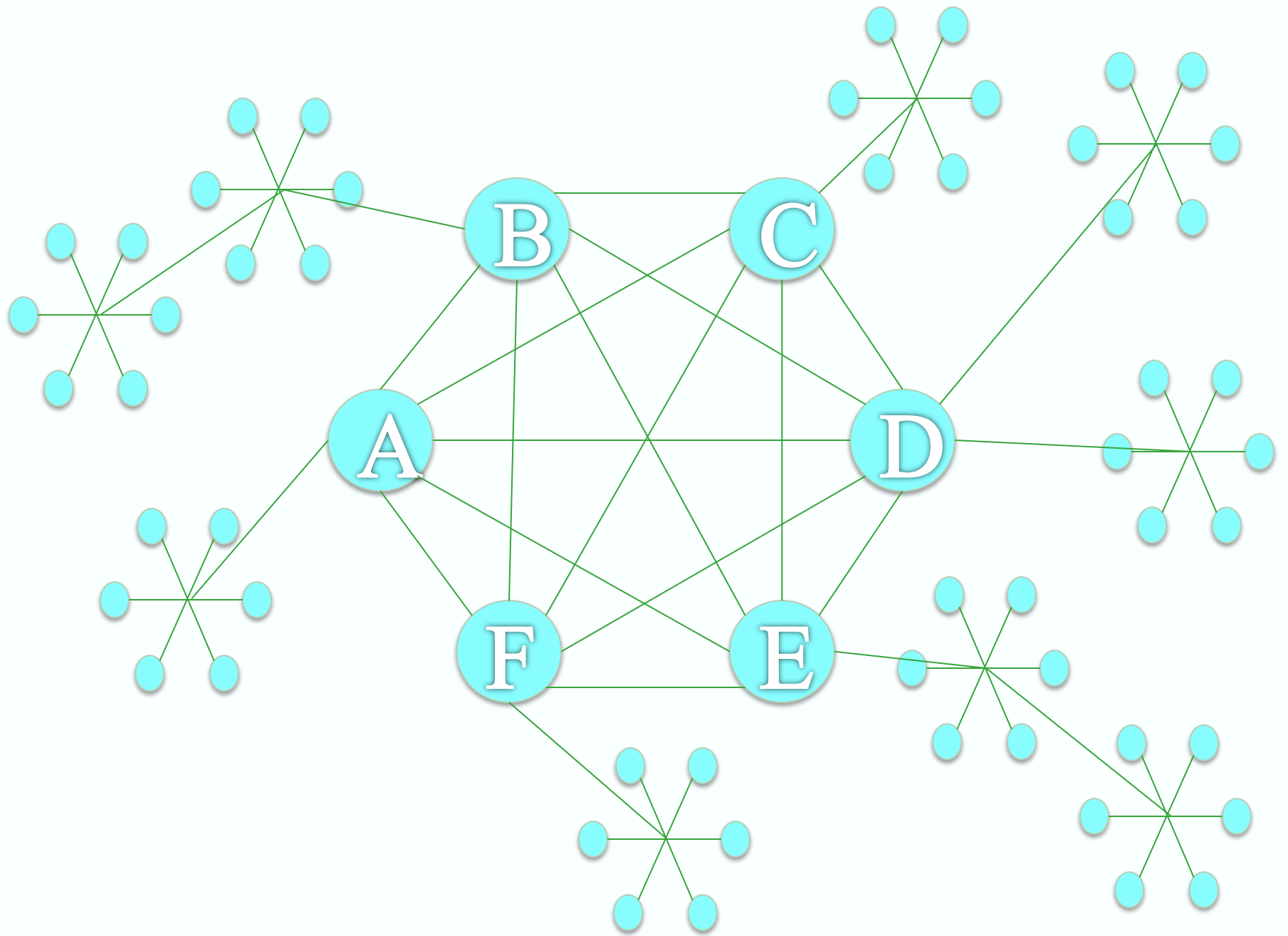




A Mesh Network



A Hub (and Spoke) Network





Networks

- Things we typically consider
 - How to build, finance, maintain, update and price the network
 - What services to offer and under what models
 - Connectivity, Ubiquity, Functionality, Reliability, Quality (of Service), Security/Privacy, Scalability, Adoption...
- Technology innovation means...
 - better, faster, cheaper
- But also...
 - Impacts investment
 - Changes the economics
 - Accelerates timescales
 - Creates policy uncertainty
 - Unsettles (or locks in) the incumbent
 - Impacts the consumer

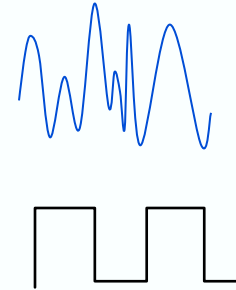
Network Concepts

Networks Concepts

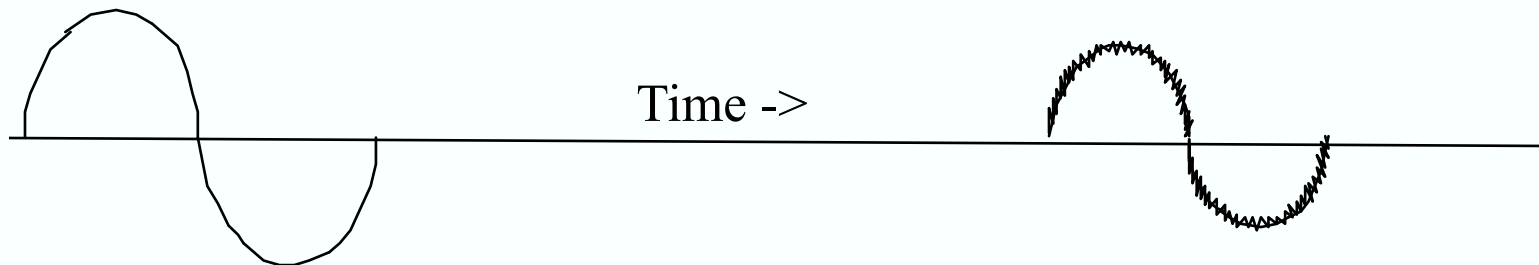
- We just discussed network traits
 - Connectivity, Ubiquity, Reliability, Functionality, Quality (of Service), Security/Privacy, Control, Scalability, Cost/Price, Adoption...
- Next we consider these network concepts/trends
 - Analog to Digital
 - Circuit Switching to Packet Routing
 - Centralized to Distributed Control (?)
 - Closed to Open Architectures (?)
 - New Services
 - Higher Data Rates and Lower Latency
 - Mobility

Analog versus Digital

- Analog – continuously varying
- Digital – discrete



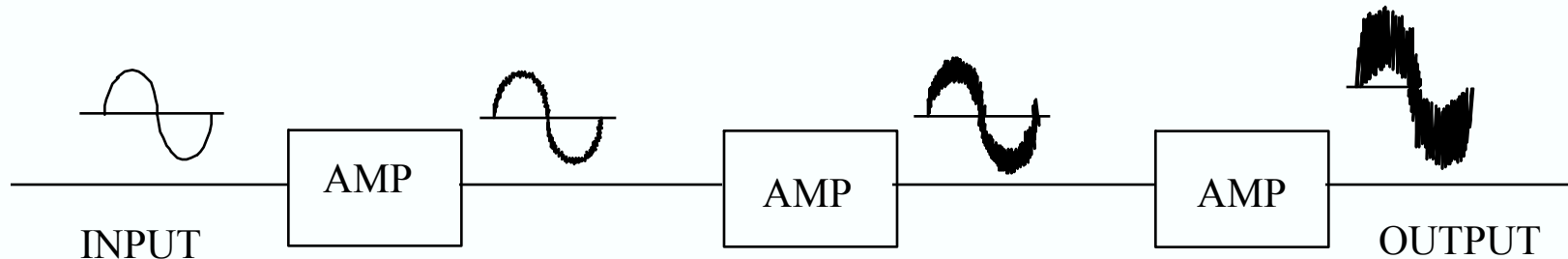
Signals Degrades



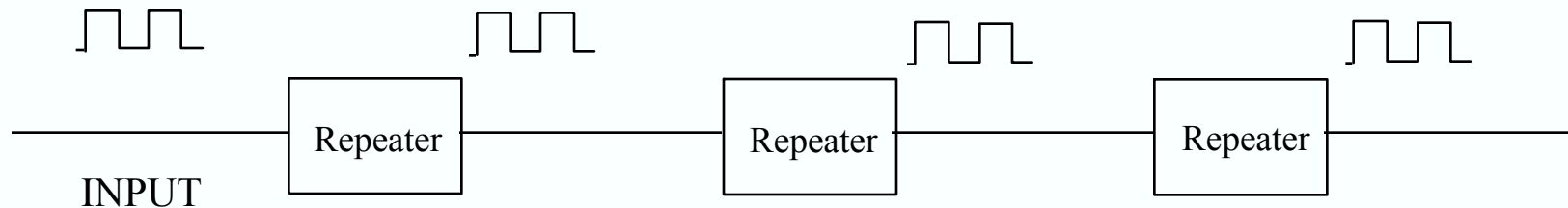
The Digital Revolution

- Why Digital?

- Analog Amplification vs. Digital Regeneration



Analog Amplification: Noise Accumulates



Digital Regeneration: “Perfect” Signal is Regenerated

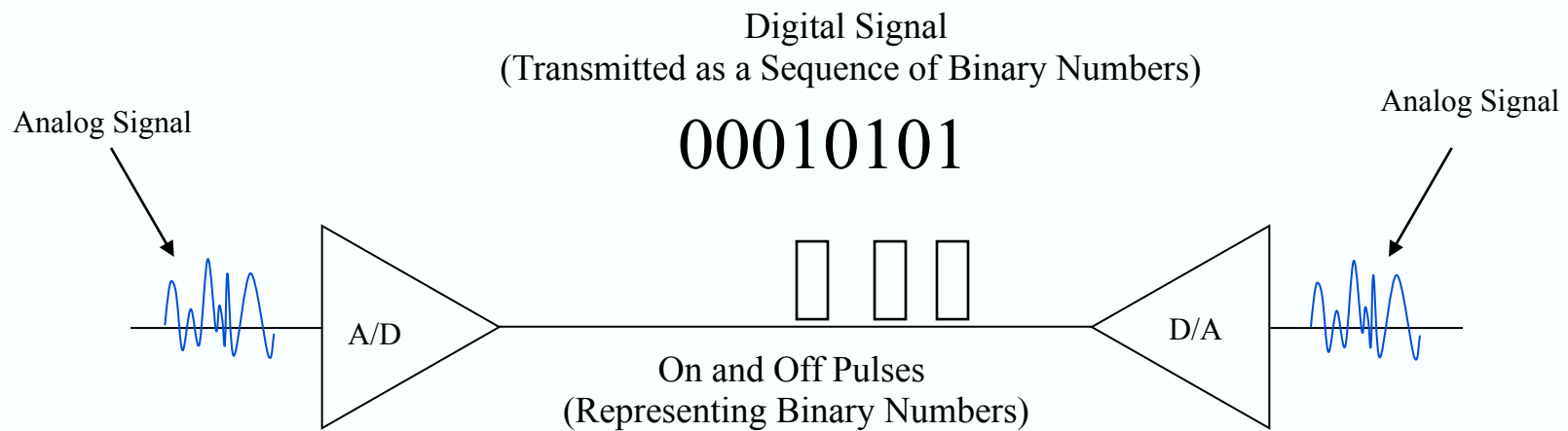
Other Advantages:

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

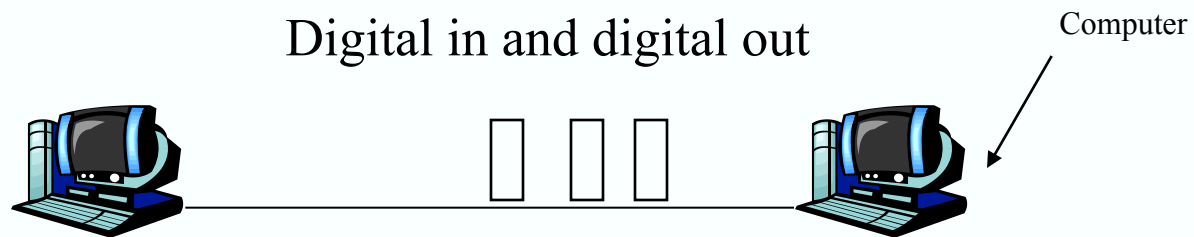
<http://www.netbook.cs.purdue.edu/animations/convert%20analog%20to%20digital.html>

The Digital Revolution

Analog to Digital and Digital to Analog Conversion



Digital to Digital (no conversion)

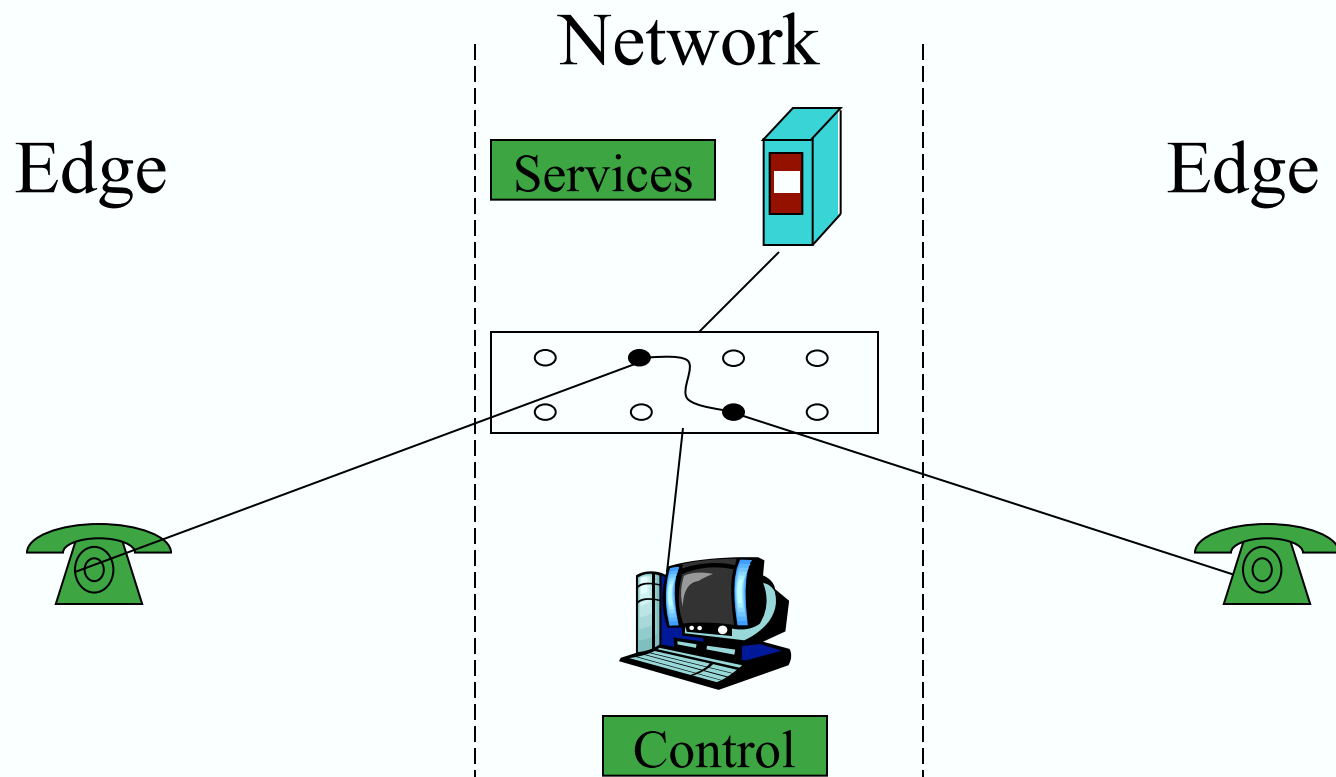


Centralized vs. Distributed

Closed and Centralized

Traditional Phone System (PSTN)

- Circuit switching (and even modern VoIP)
- “Dumb” devices and “Intelligent” core
- Services created and maintained inside the network

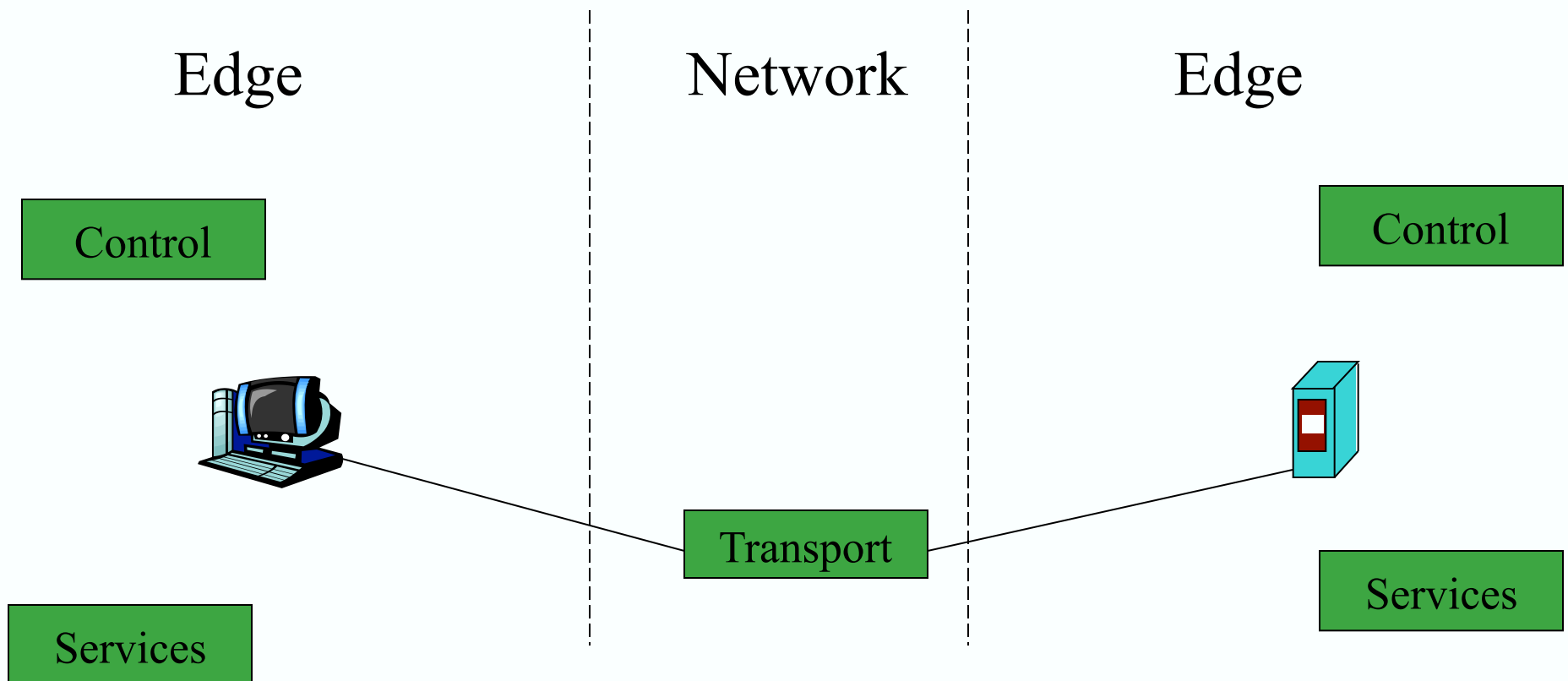


What do you think this means for revenues?

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
 - In digital, bandwidth is measured in bits per second
 - Think gallons per minute (volume, not speed)
 - Defined once at 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 \sim *delay*
 - Time it takes packets to travel from source to destination
 - Causes of latency
 - Network cannot handle the packets fast enough (*congestion*)
 - Too many consumers sharing access (under-provisioned)
 - When users are bandwidth “hogs”
 - *Low latency* is critical in voice and “*real-time*” applications (e.g., interactive video and gaming)
 - But not for all (or even most) Internet services
 - Together latency and bandwidth define user experience

Internet, Broadband and Wireless

Defining the Internet

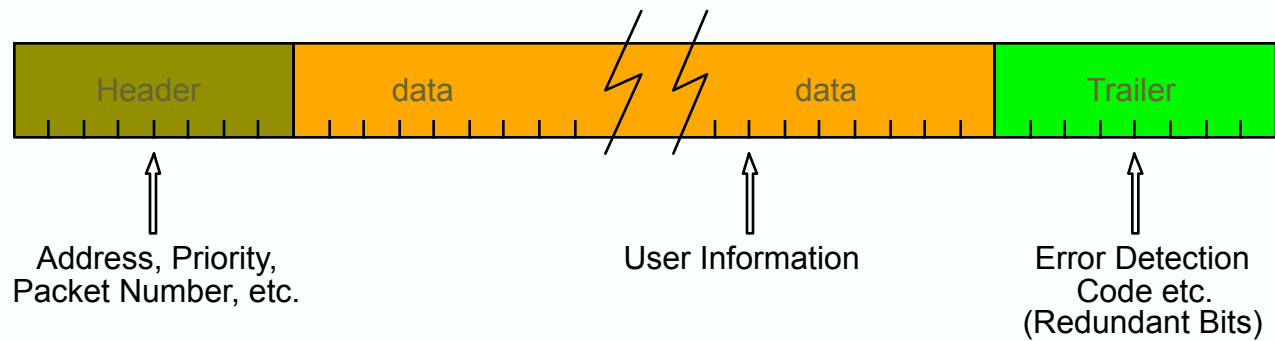
- What problems did the creators of the Internet solve?
 - They figured out how to connect disparate networks
 - *A network-of-networks*
- A set of protocols and operations is the *glue* (e.g., *TCP/IP*)
 - Globally interconnected through *packet networks*
- Supports a broad set of *underlying* technologies
 - 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
- Has been an engine of innovation (despite incumbents)

Operation

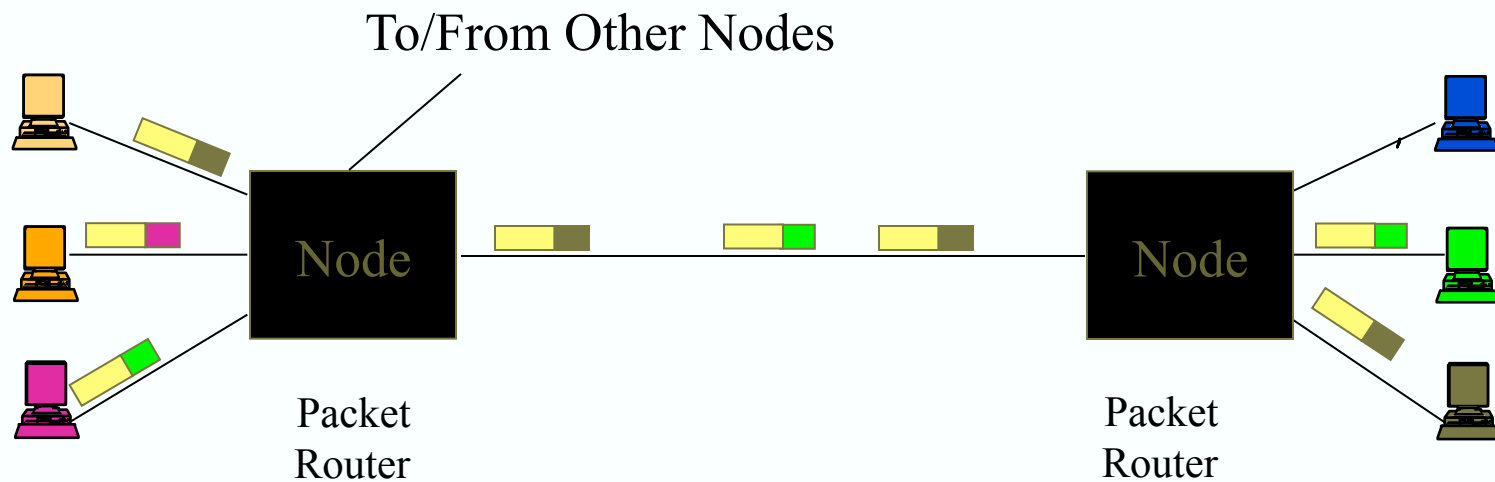
- The operation of the Internet is a deceptively simple concept
 - Content is *broken up into small packets* and labeled with *addressing* information
 - Address information is placed in the *packet header*
 - Packets sent individually across the network
 - *Routers* use address information to determine forwarding
 - 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

What's a packet?

- Packet



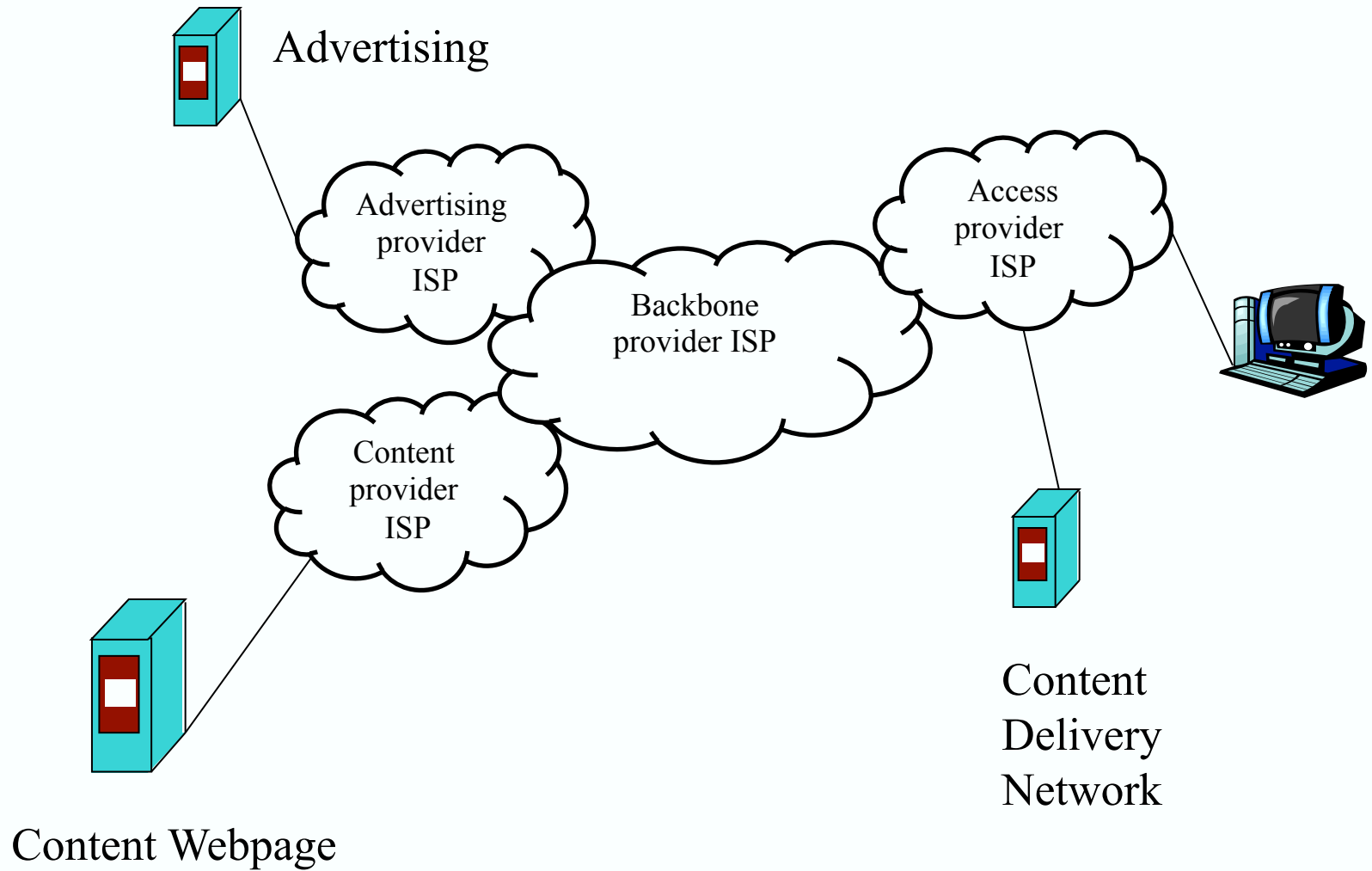
A Packet Routed Network



Operation

- Business Relationships in the Internet
 - *Business agreements* among the networks
 - Based on Peering and Transit (not regulations)
- Entities
 - Network providers
 - Customers (ISPs and Users)
 - Data Centers (housing servers, computing, storage)
 - Content Distribution Networks (to optimize content)
- No direct payment between all parties
 - Therefore *difficult to provide guarantees* across the Internet
- Let's walk through the following notional diagram of how the data flows among entities on the Internet

Internet Operation



Broadband Infrastructure

- **Backbone**: The *collection of large connections* that carry communications among networks
- Some of the Large Backbone (Tier I) Networks:
 - AT&T
 - 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

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
 - 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 technologies rolling out
 - LTE and 802.11 (e.g., af and n)
 - MIMO, Software Defined Radios 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

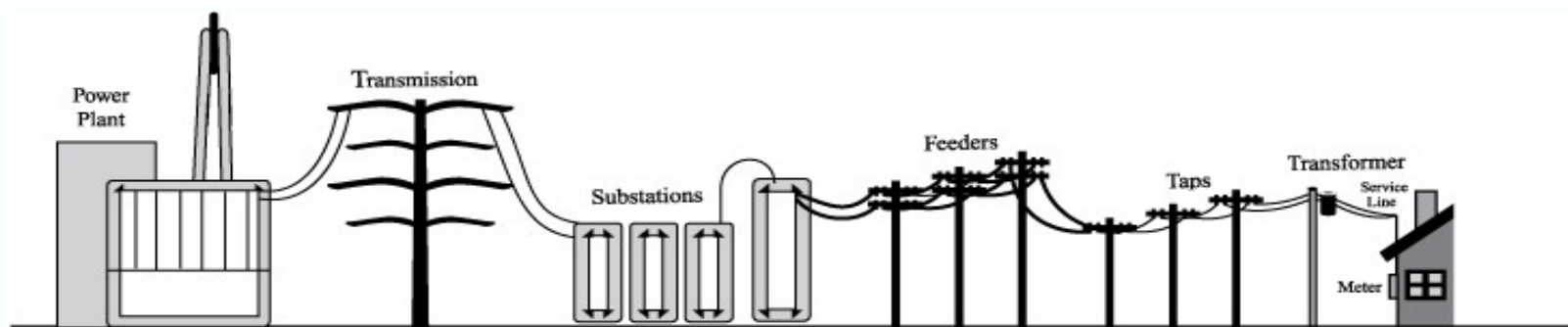
Smart Grids

What is a smart grid?

But first, what's wrong with what we have now?

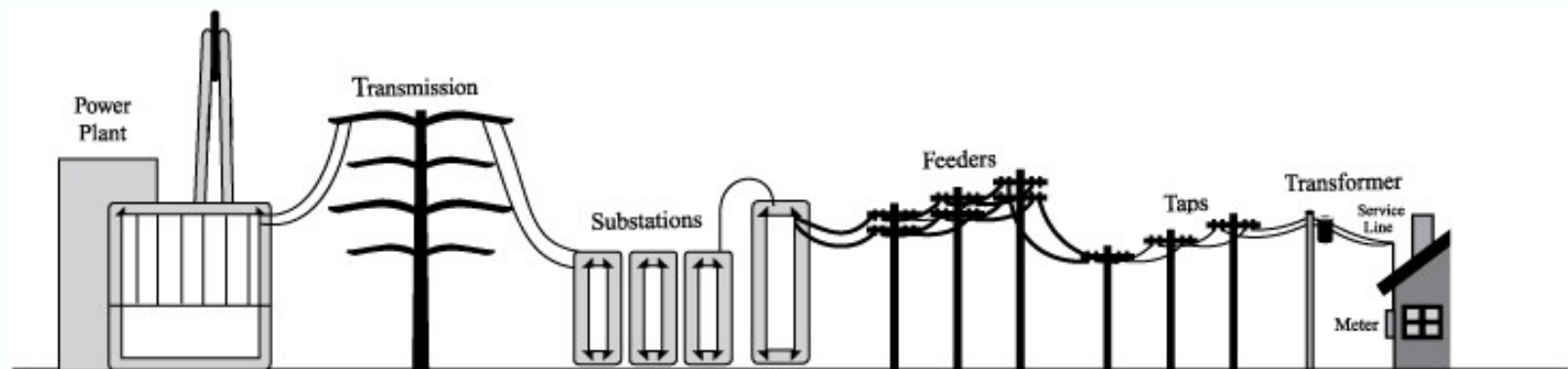
Electricity Fundamentals

- Voltage - electromotive force (think water pressure)
- Current - flow of electrons (think rate of water flow)
- Resistance - opposition to electric current (size of the pipe)
- Power - rate of energy conversion (voltage times current)
- Energy - power over time
- Generation - first process in the delivery of electricity
- Plant - facility that generates electric power
- Transmission - bulk transfer of electricity from plant to substation
- Substation - provides switching, protection and transforms voltage
- Distribution - transfer between substations and customers
- Transformer - generally steps voltage from high to low



Electricity Fundamentals

- Power is measured in Watts (W); it is the work
 - Power is 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 (MWh)
- Why a grid?
 - Electric energy moves at about the speed of light
 - Generation must meet Demand
 - Large power plants are more efficient than small (economies of scale)
 - Things didn't start this way
 - Transmission is efficient (although efficiency opportunities exist)

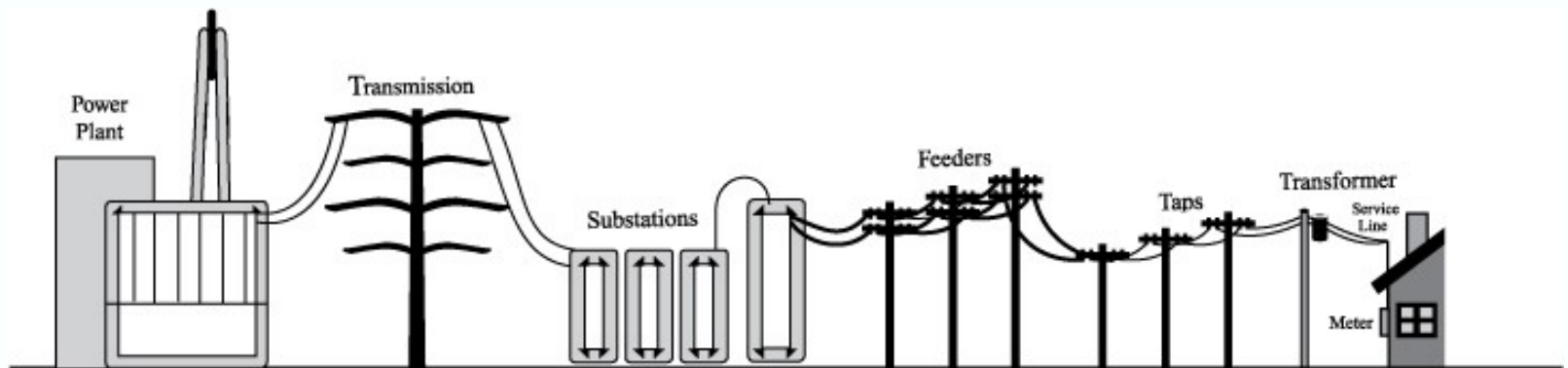


Traditional Power Grid

Has served us well, but...

- Aging
- Inefficient (distance, loss)
- Difficult to acquire data on operations
- Limited user control
- Remains robust
- Limited energy storage
- Central power generation
- One-way binary demand response
- Limited real-time data
- Reactive outage management

Very reminiscent of the telecommunications networks of the 1990s



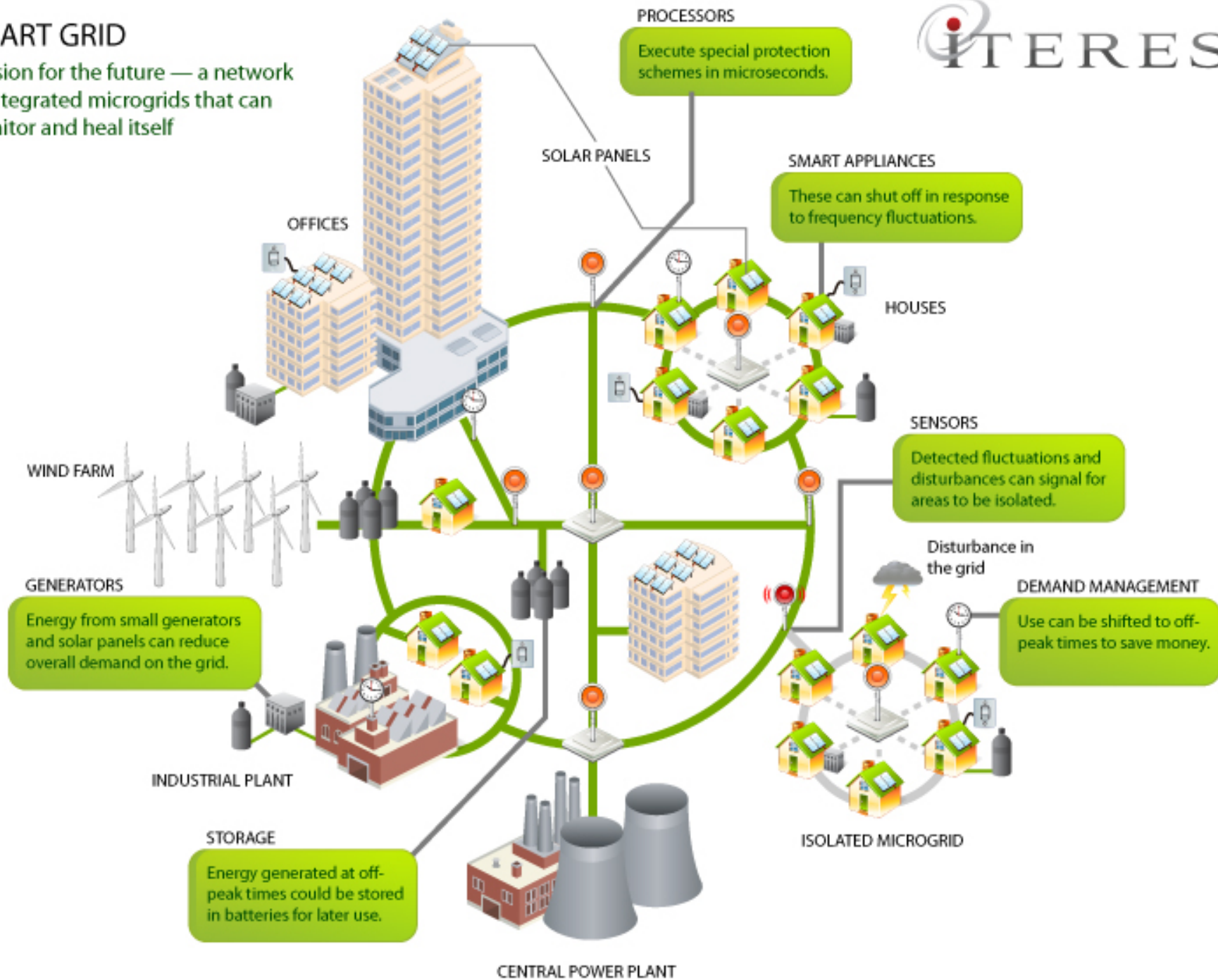
Can we improve *reliability* and *efficiency*, increase *innovation* and investment?

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.

SMART GRID

A vision for the future — a network of integrated microgrids that can monitor and heal itself



e?

Current State of Smart Grid

- Moving slowly but...
- Interesting to consider
 - Intelligence in (control of) generation, distribution and edge
 - Physical and logical interconnection
 - Regulatory impact (of the fed/state div?)
- At the Federal level (e.g., FERC, NIST and DoE)
 - Regulation and rates
 - Standards, deployment and security concerns
 - R&D and funding
- At the state and local level
 - Regulation and rates
 - Deployment and debate
- Lynn will have more to say here!

Observations

Smart Grid Observations

- The electric power industry has been *slow* to adopt many aspects of the smart grid (e.g., notion of distributed operations)
 - Uncertainty on setting the incentives correctly
 - Very similar to the transition of the PSTN to the Internet
- Lessons to be learned from the Internet
 - Intelligence at the edge
 - Distributed and open design
 - Architecture matter (getting the security right)
 - Energy doesn't have the alternative architecture of the early Internet
- Could hold great change and value for consumers
 - Not guaranteed, AND is now being deployed
 - May never deliver on all of its promises

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
- *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 (through 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
- 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, business and legal issues is key

What else?

Contact Information

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Take Away

- We are growing ever more dependent on networks
- Many complex and interdependent parts
- Networks are enabling new service models
 - Smart Grid
 - 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

Extras

What is

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

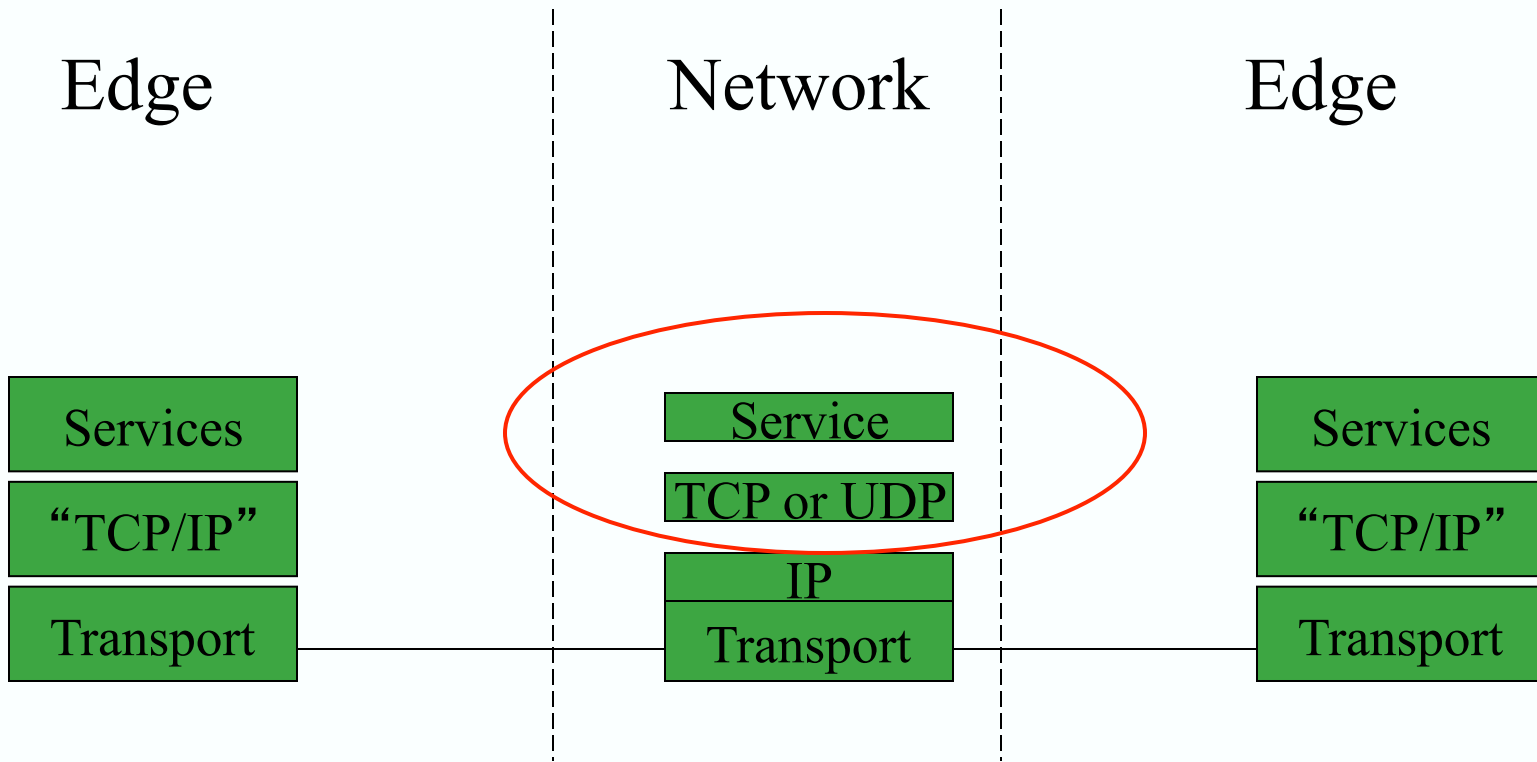
Cloud Computing

- 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
 - 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

Internet Developments

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* (aka network management)?
 - 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)
 - Emerging standards such as “*P4P*”

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

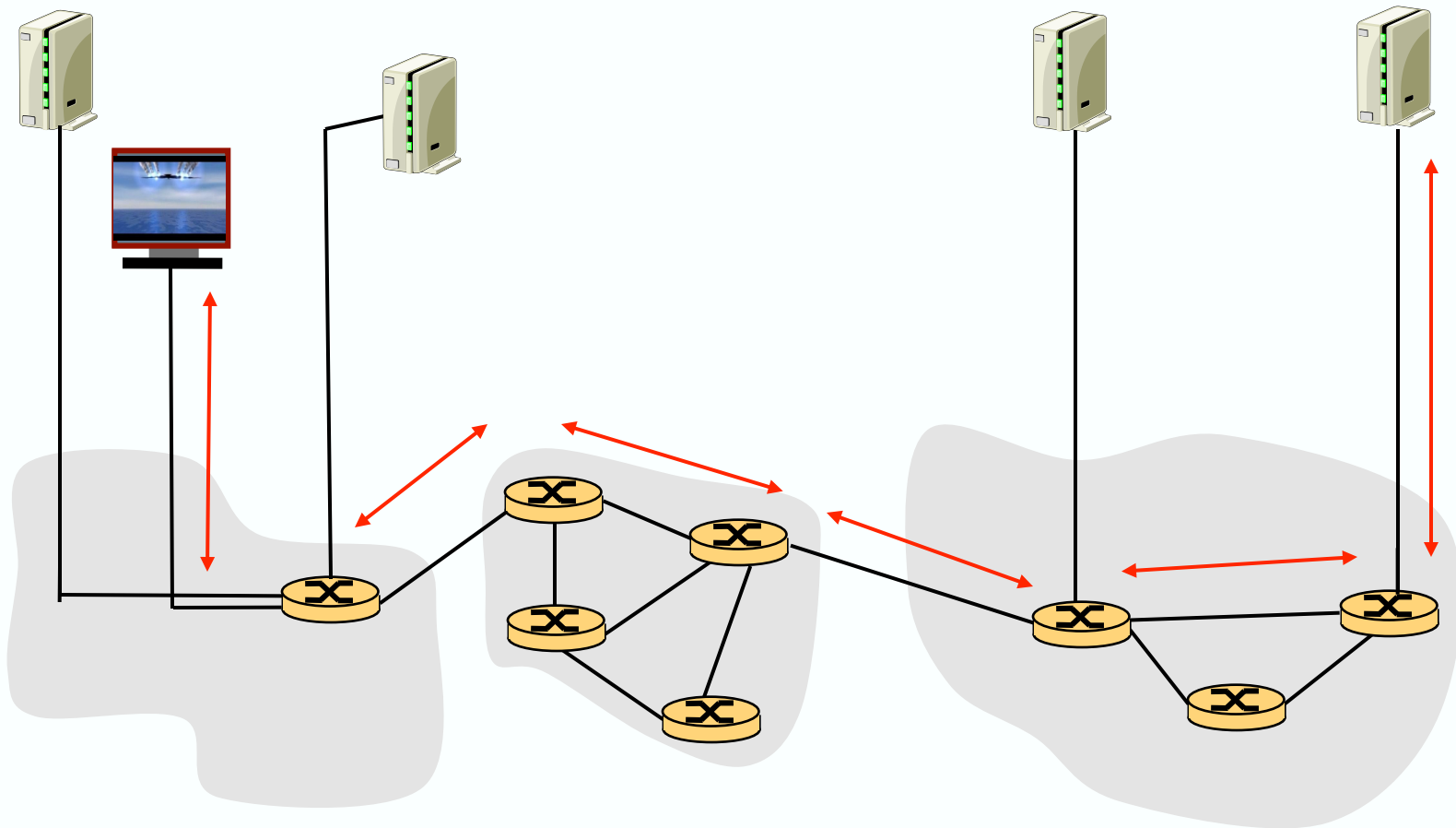
Managing the Network

- 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

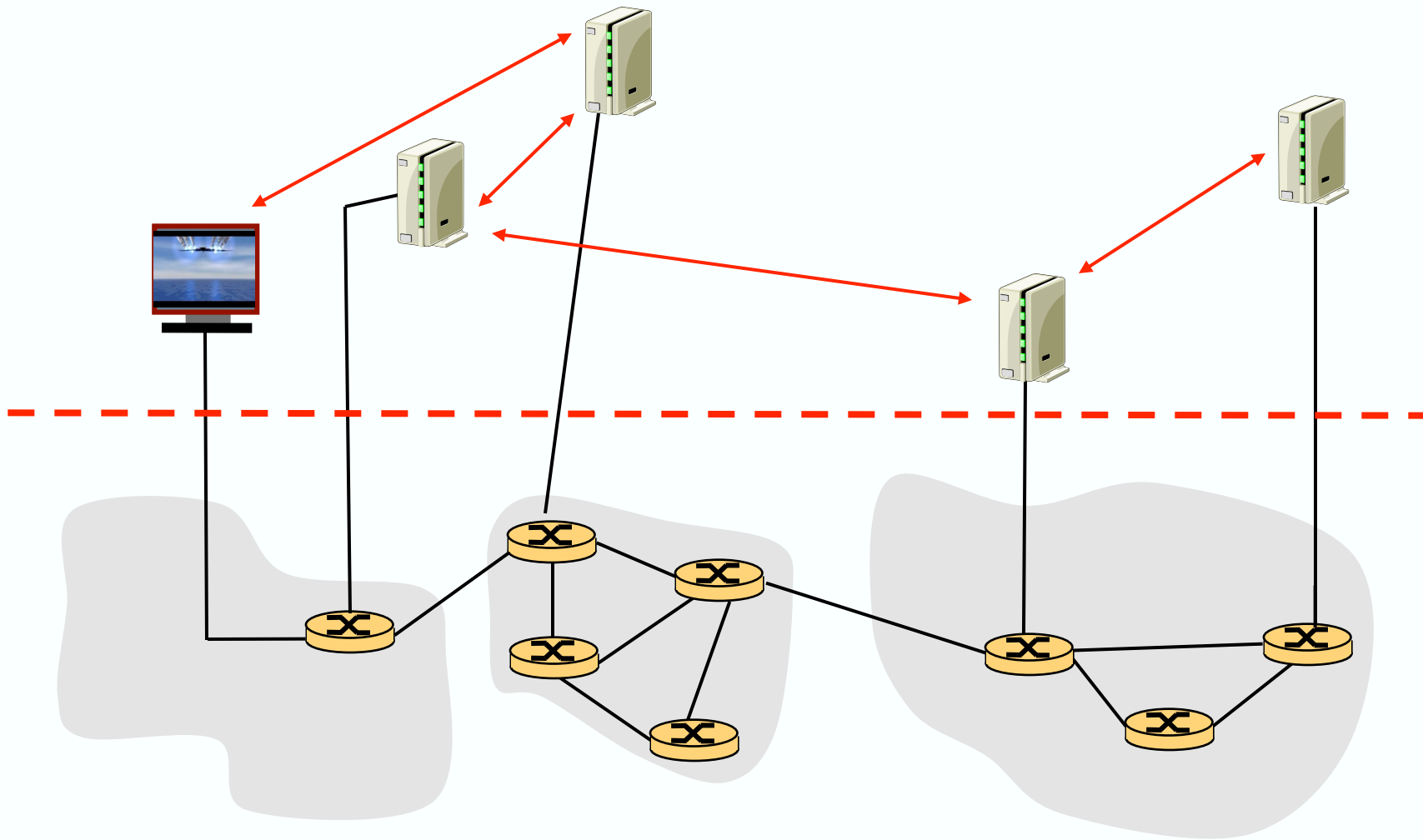
- What is an *overlay network*?
- In simple terms, a network built on top of other networks
- Many versions of this exist
 - *Could argue that Dial-up Internet access* is an overlay network
 - With common carrier non-discrimination obligation
 - *Peer-to-peer* networks are often an overlay network
 - *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

Traditional network model



Slide adapted from Jennifer Rexford's networking course slides

Peer-to-Peer Networks: Napster

- 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



**Shawn Fanning,
Northeastern freshman**

Peer-to-Peer Networks

- Napster had an Achilles' heel
 - 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 and anti-free-loading
 - 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

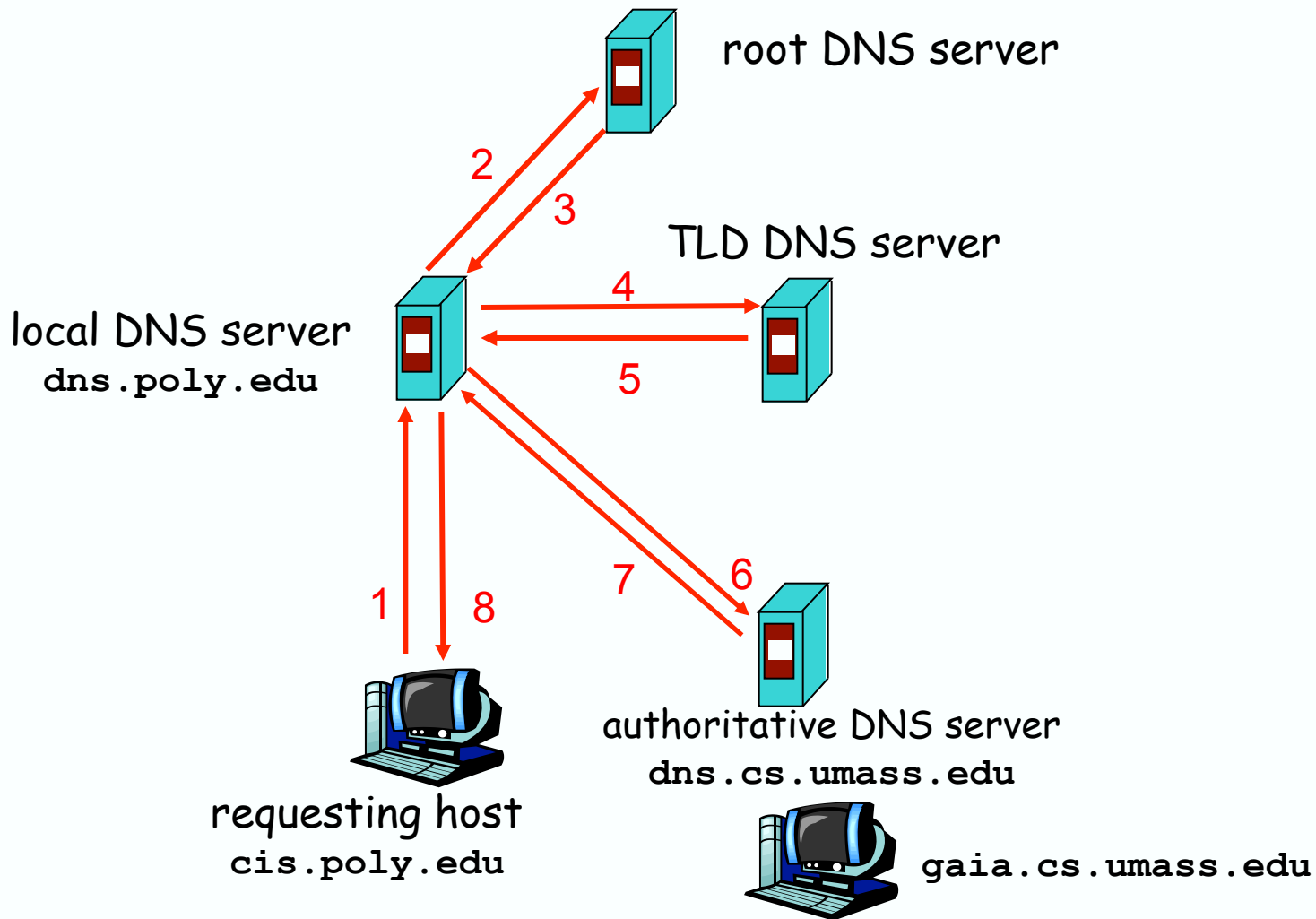
Privacy

- 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

- 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