

NETWORKS

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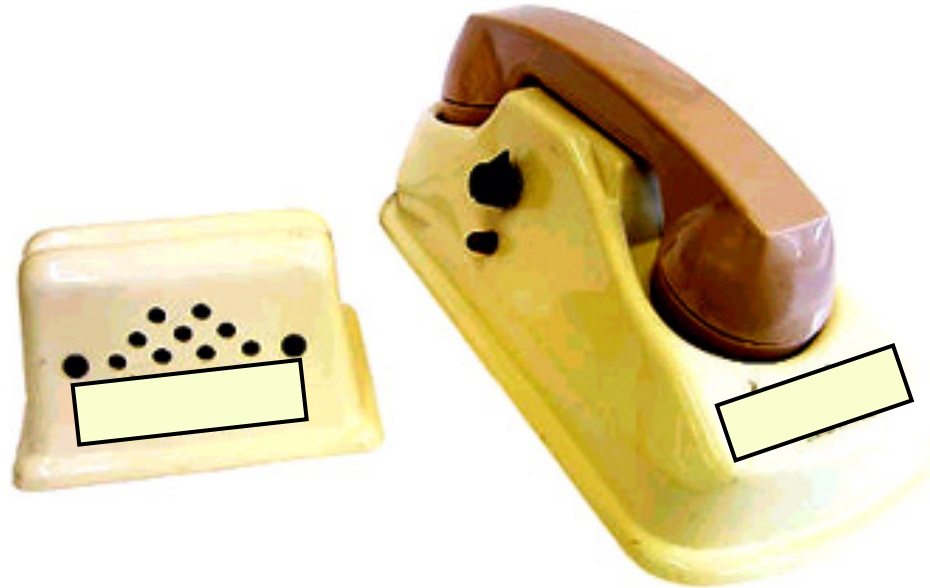
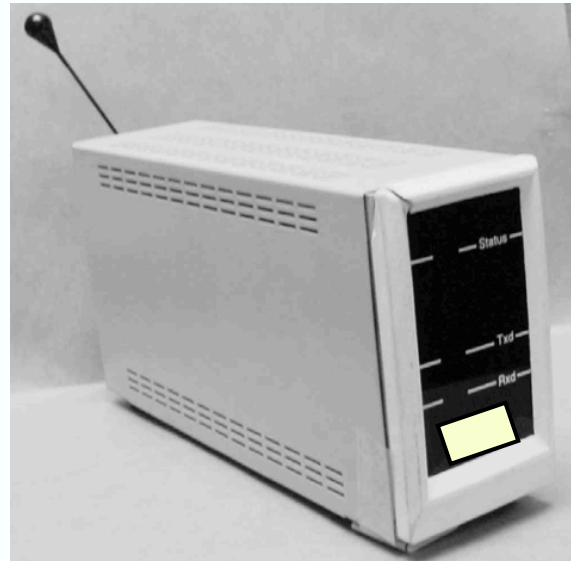
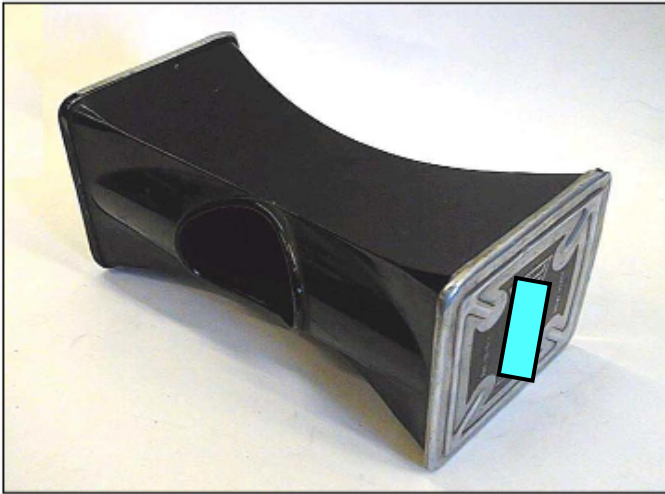
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Aspen, CO

Before we dive in...

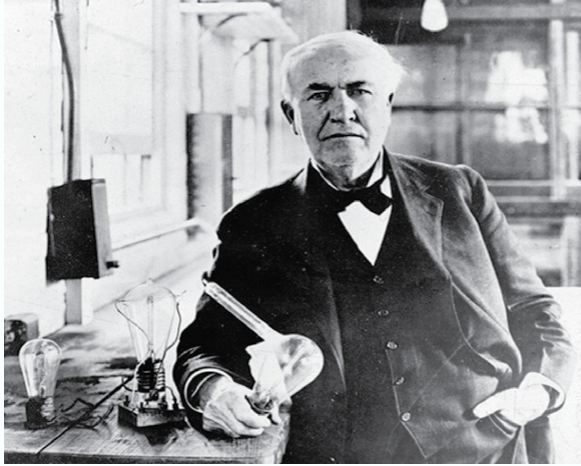
After this week, if you have a technology question feel free to contact me.

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Why technical policy matters

Edison



Bell



Same wires and service for 100+ years

Keeping the lights on

Providing dialtone

Finely honed machine

Engine of innovation

Comparing utilities...

Goals and Outline

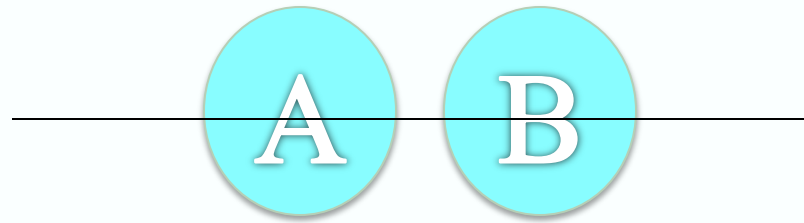
- Gain a basic understanding of networked systems
 - What matters with **any** network?
- Learn the concepts used to describe networks
 - Basic network terminology
 - Communications networks
 - Internet, Broadband and Wireless
 - Power grids
 - Electricity basics, power grids and Smart grids
- Observations on networks and network policy
- Extras (lunch or later tonight)
 - Recent network technology
 - Internet Interconnection

Networked Systems

What is a network?

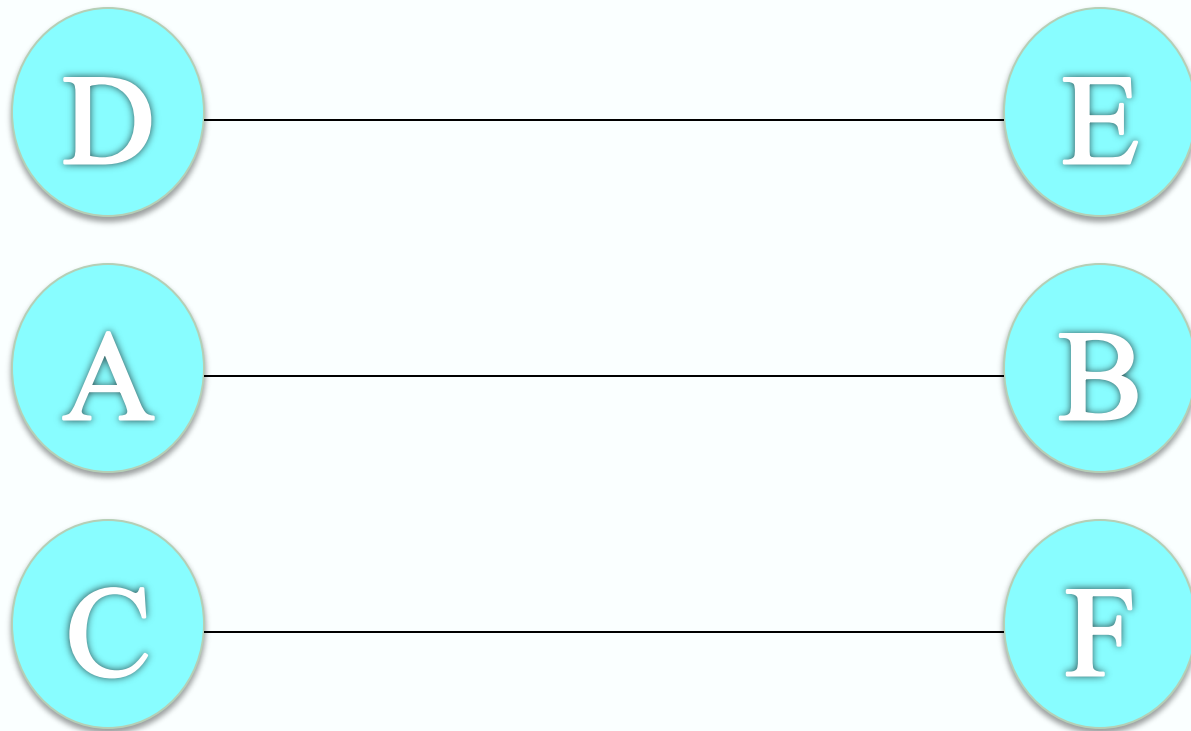
A Set of Connected Objects

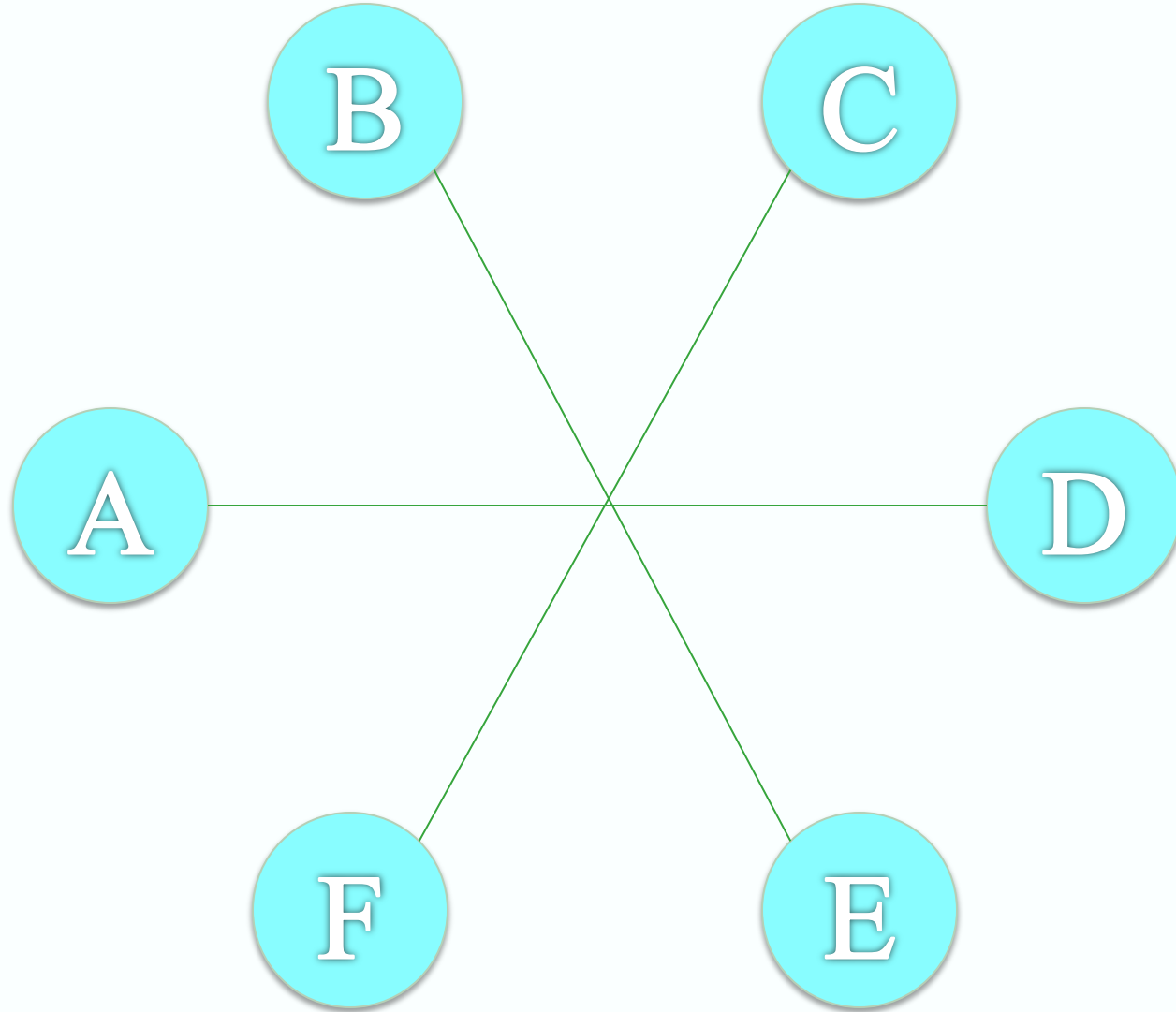
A Simple Network

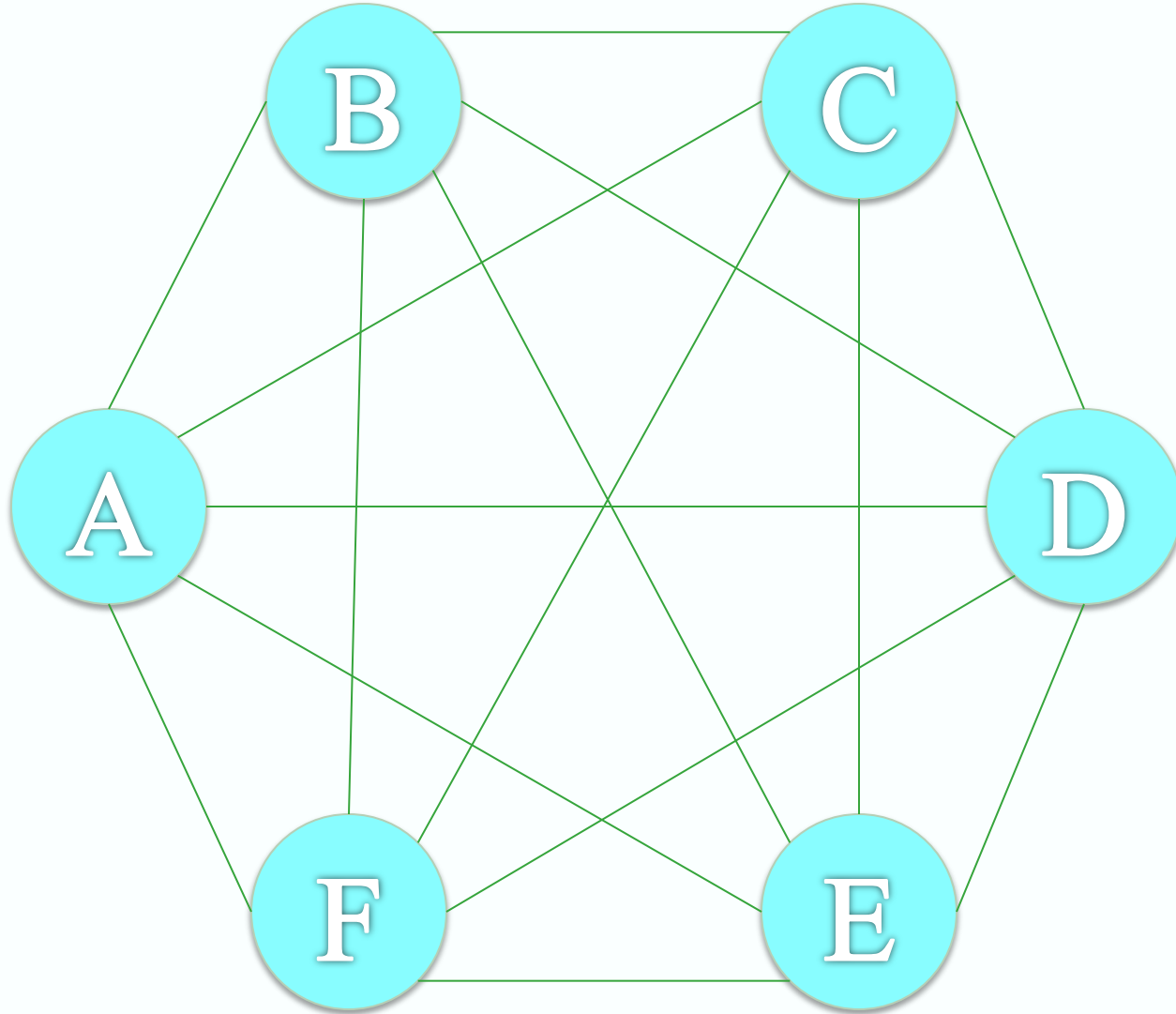


Nodes and Links can combine to form complex systems

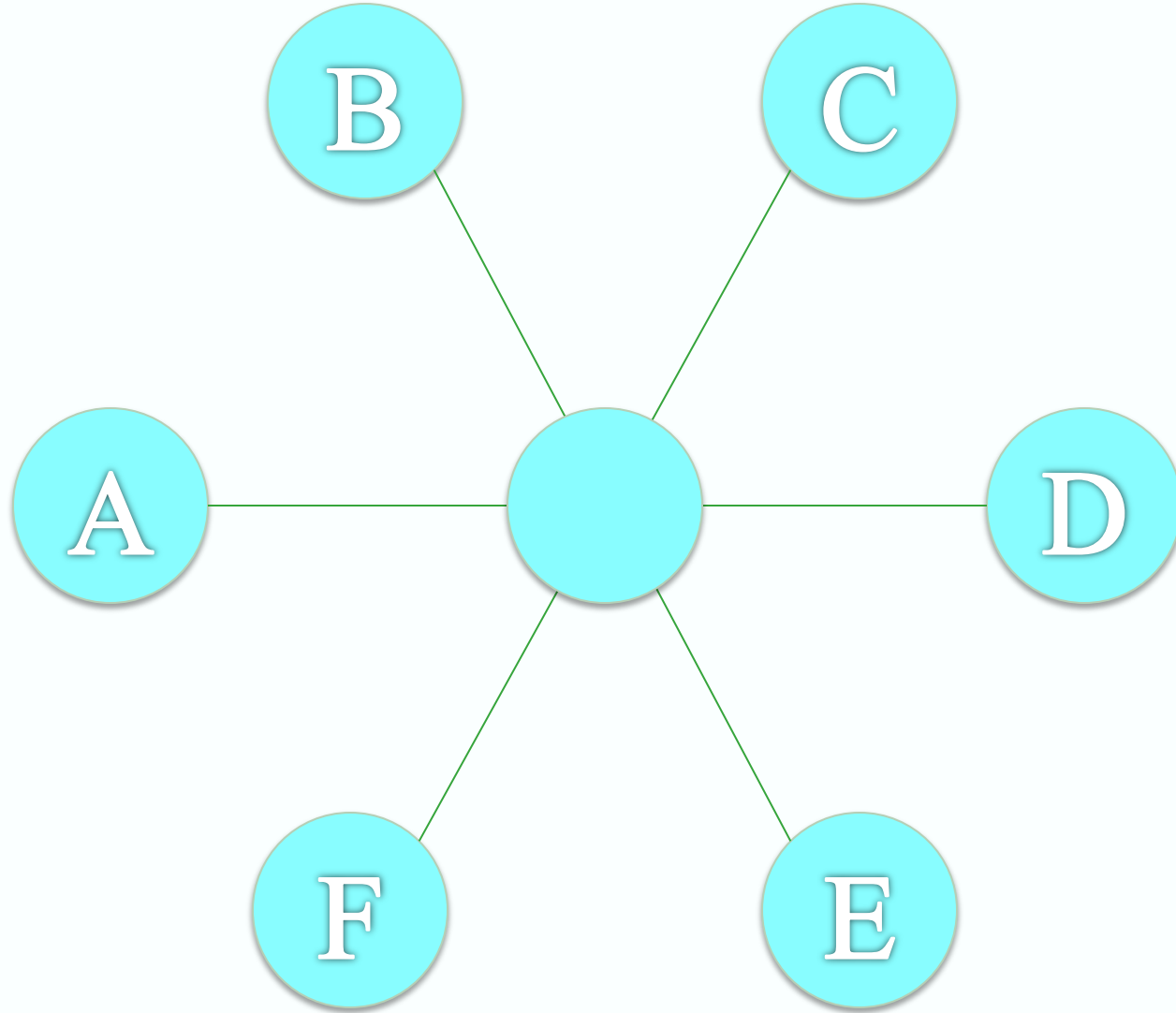
A Simple Network



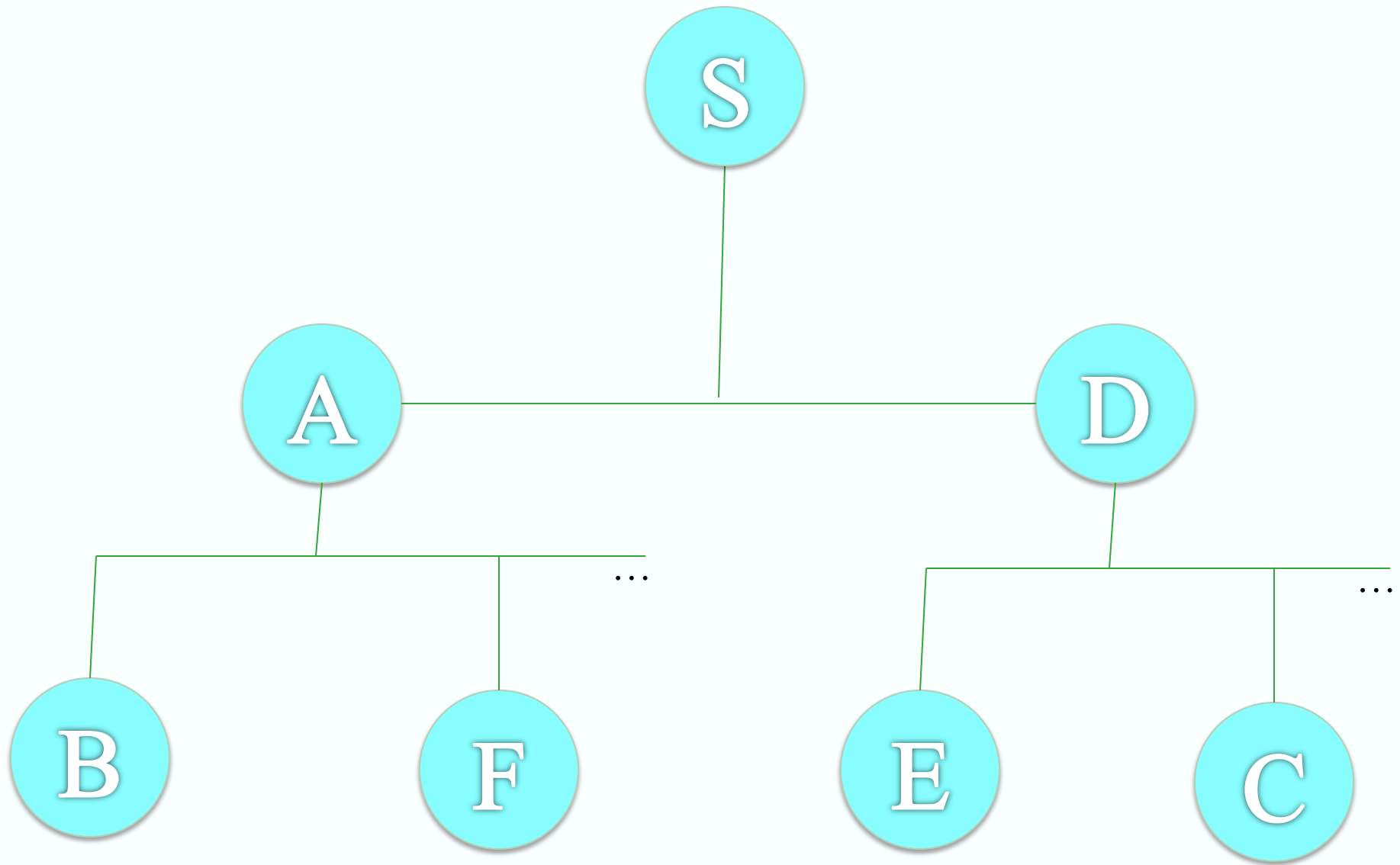




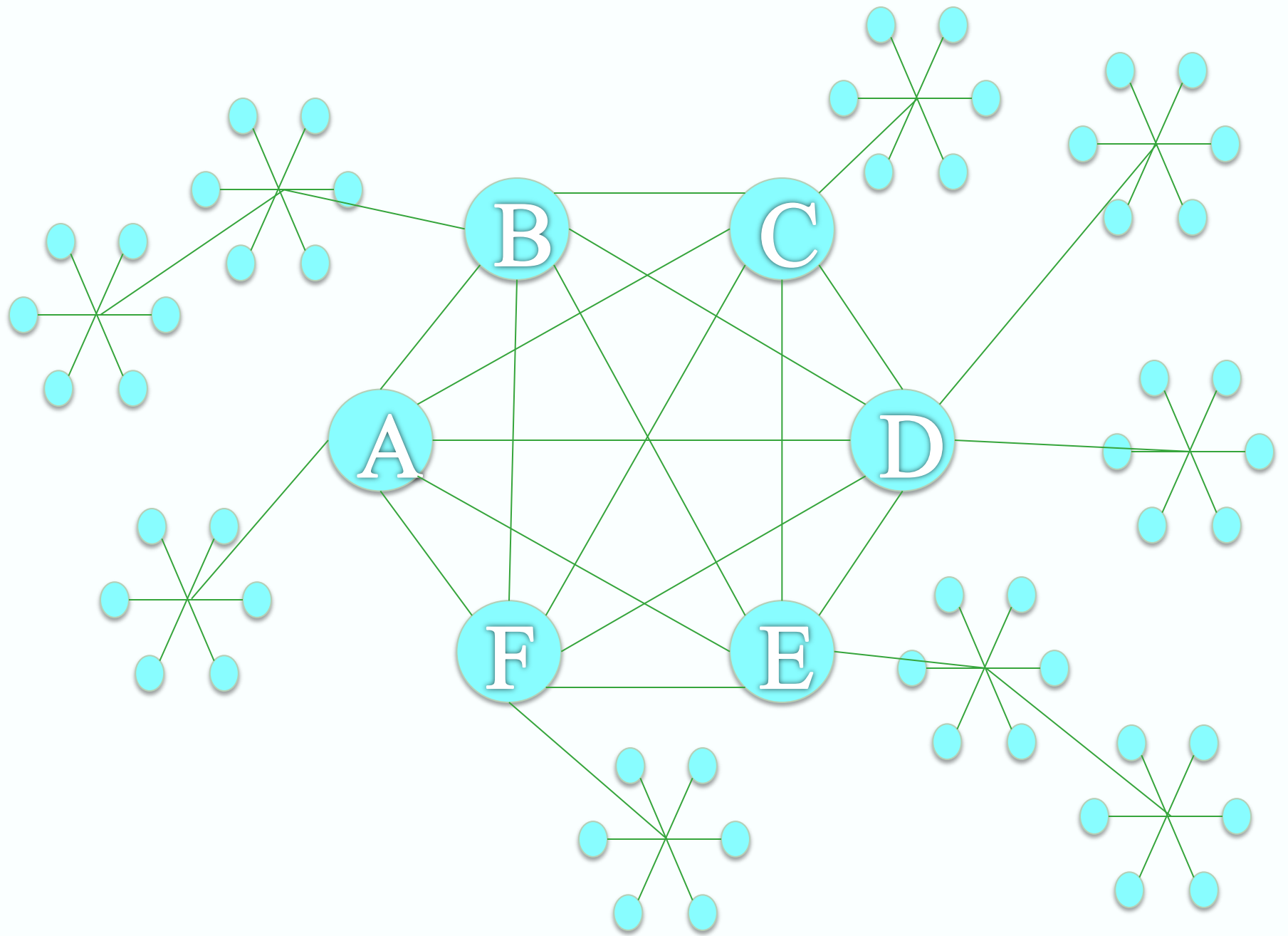
A Mesh Network



A Hub (and Spoke) Network



A Tree Network (bus)





Networks

- Things to consider for any network
 - How to build, finance, maintain, update and price the network
 - What services to offer and under what models
 - f{Connectivity, Ubiquity, Functionality, Reliability, Quality of Service, Security/Privacy, Scalability, Adoption...}
- 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

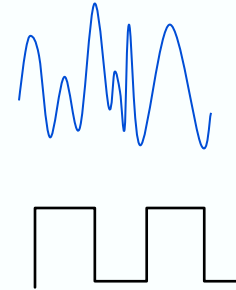
Communication Network Concepts

Communication Network Concepts

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

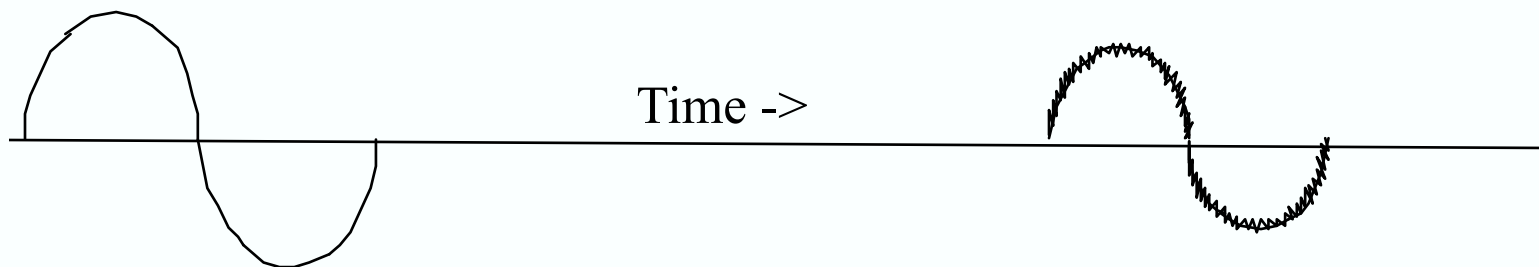
Analog versus Digital

- Analog – continuously varying
- Digital – discrete



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

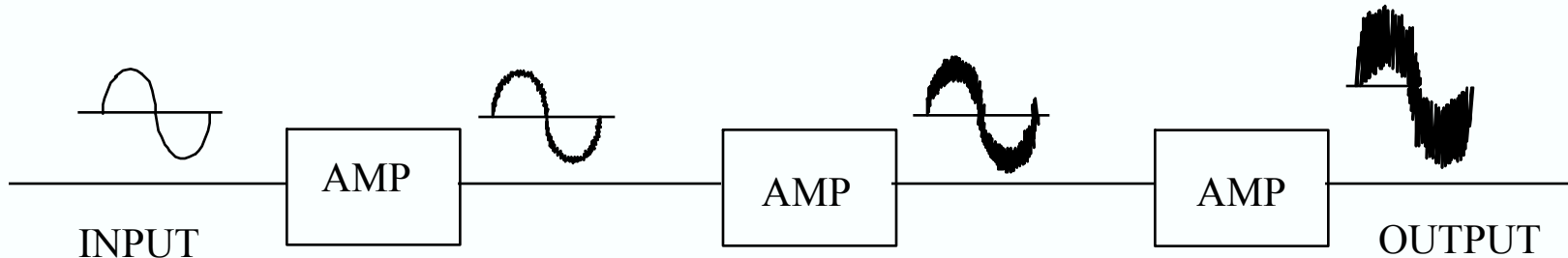
Signals (analog or digital) degrade over time



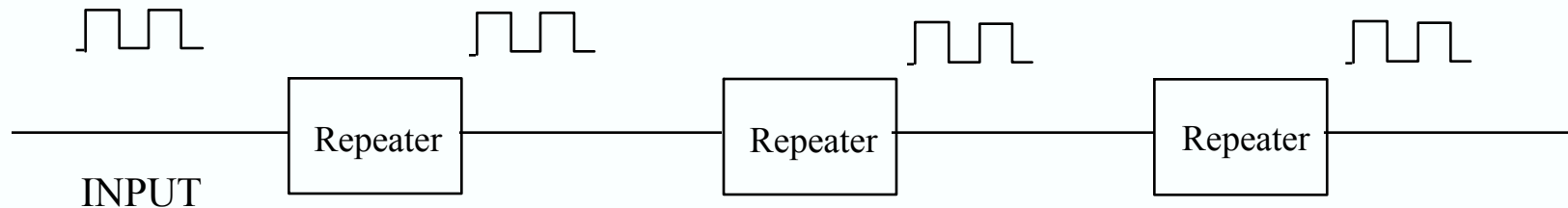
The Digital Revolution

- 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

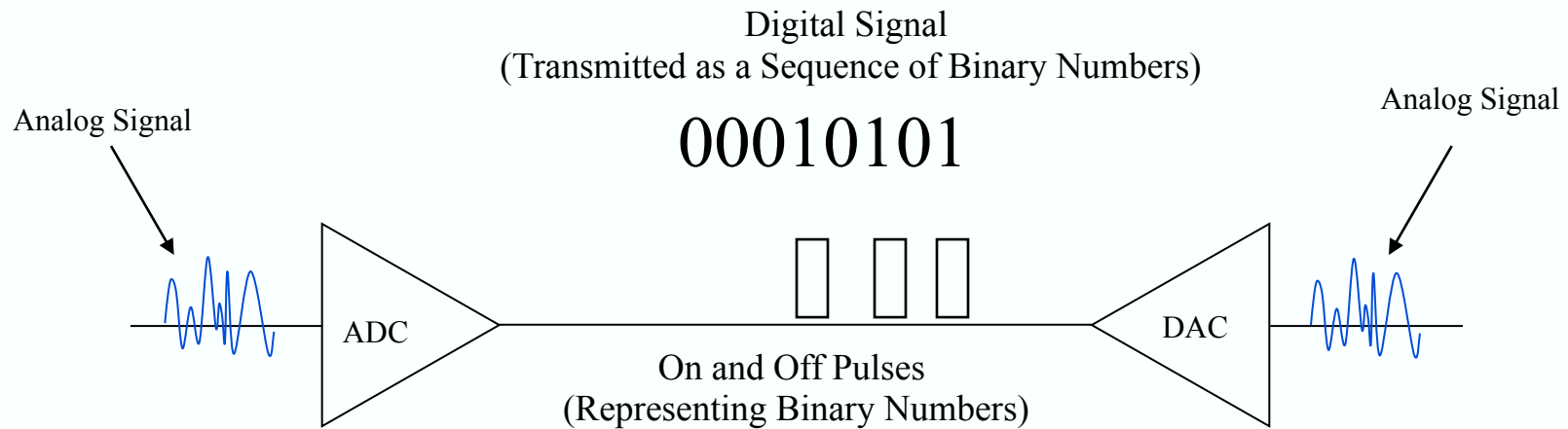
So how do we make analog signals (like voice) digital?

Through an analog to digital converter (ADC)

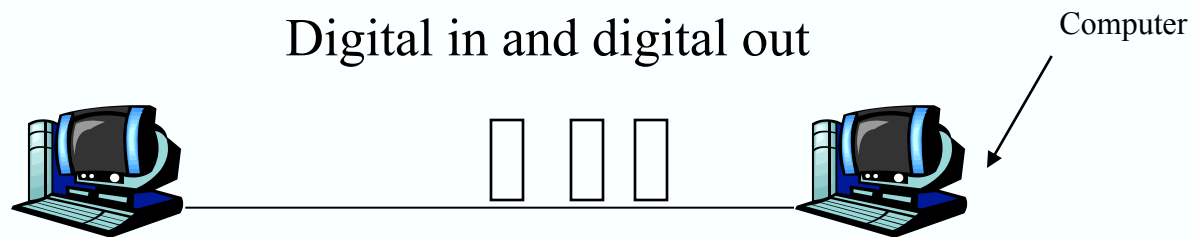
<http://www.netbook.cs.purdue.edu/animations/convert%20analog%20to%20digital.html>

The Digital Revolution

Analog to Digital and Digital to Analog Conversion



Digital to Digital (no conversion)

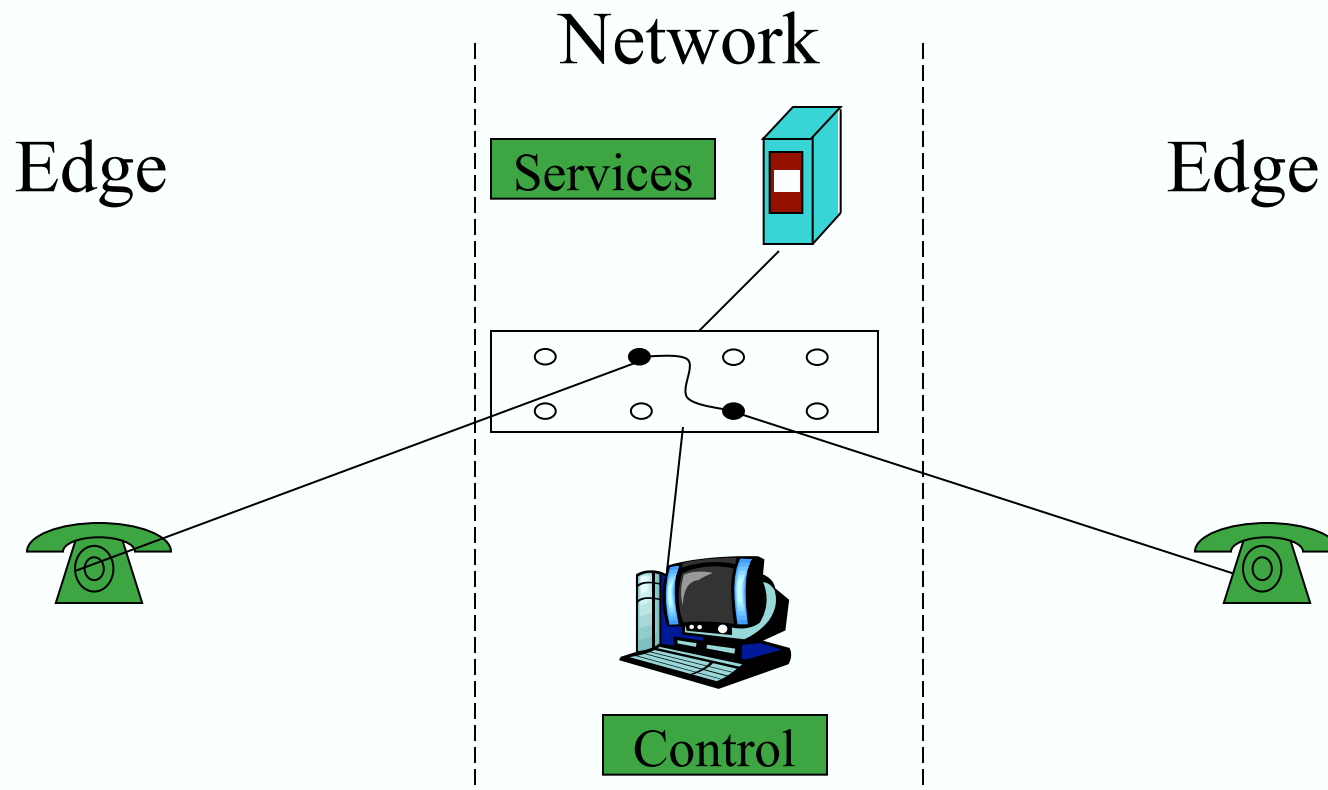


Centralized vs. Distributed

Closed and Centralized

Traditional Phone System (PSTN) – and the power grid

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

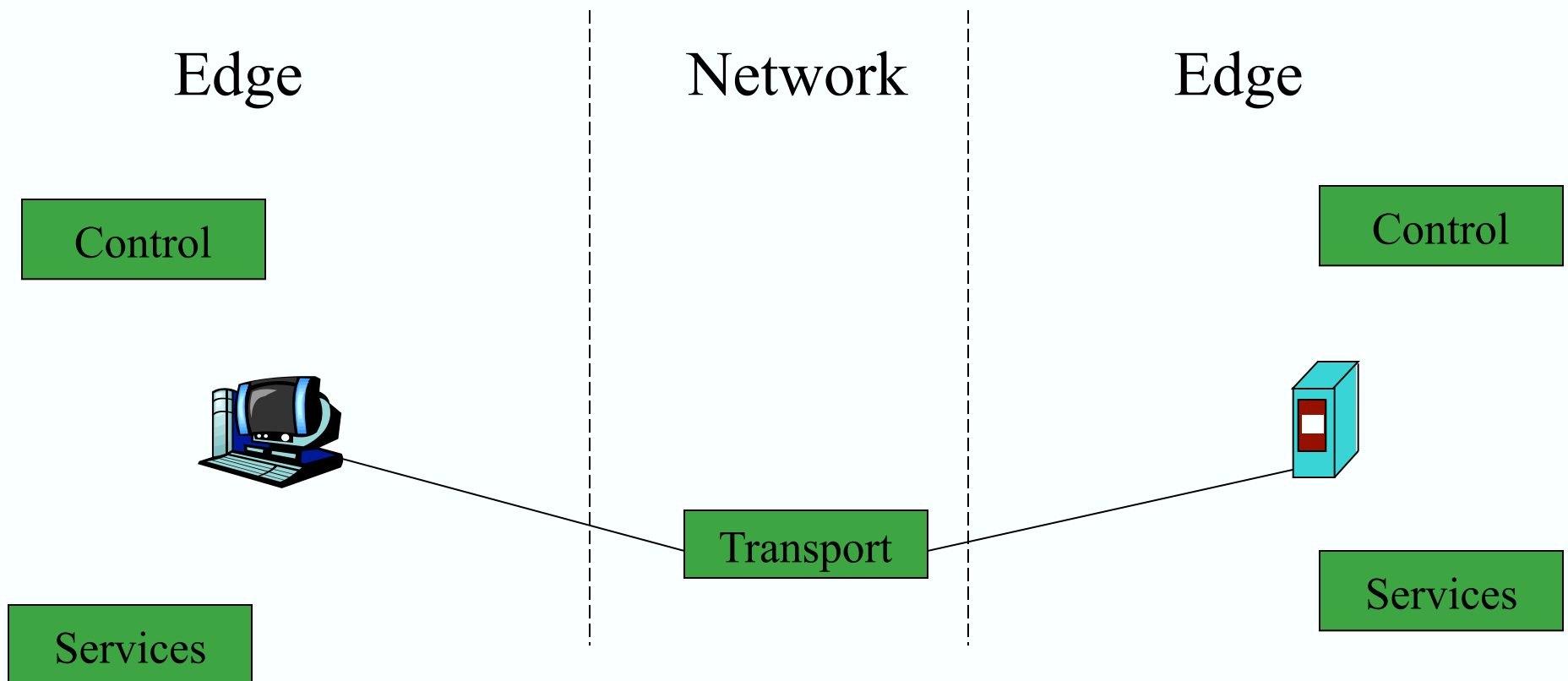


What do you think this means for revenue and innovation?

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
 - 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)

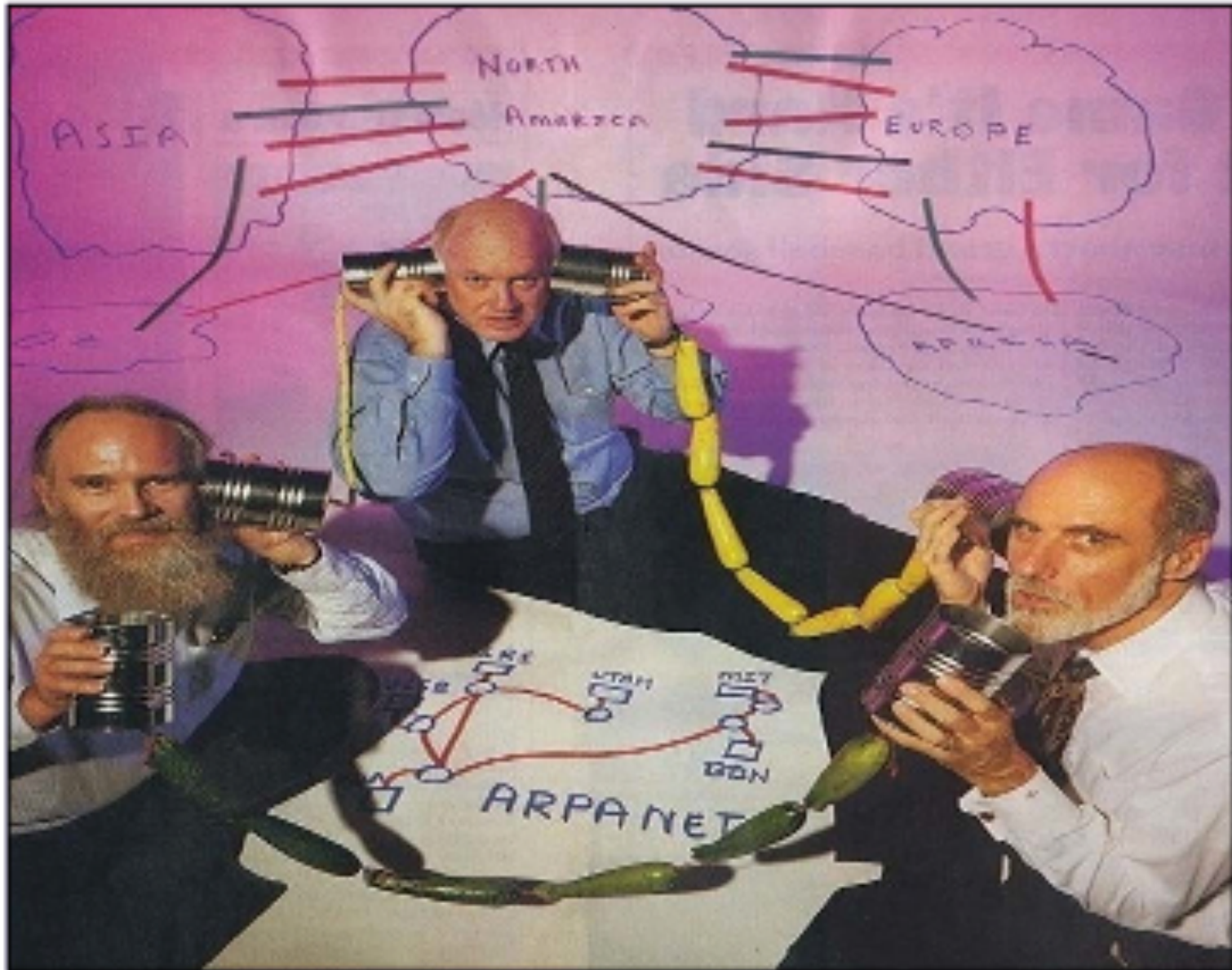
Latency and Quality

- 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

How does the Internet work?

Ah...



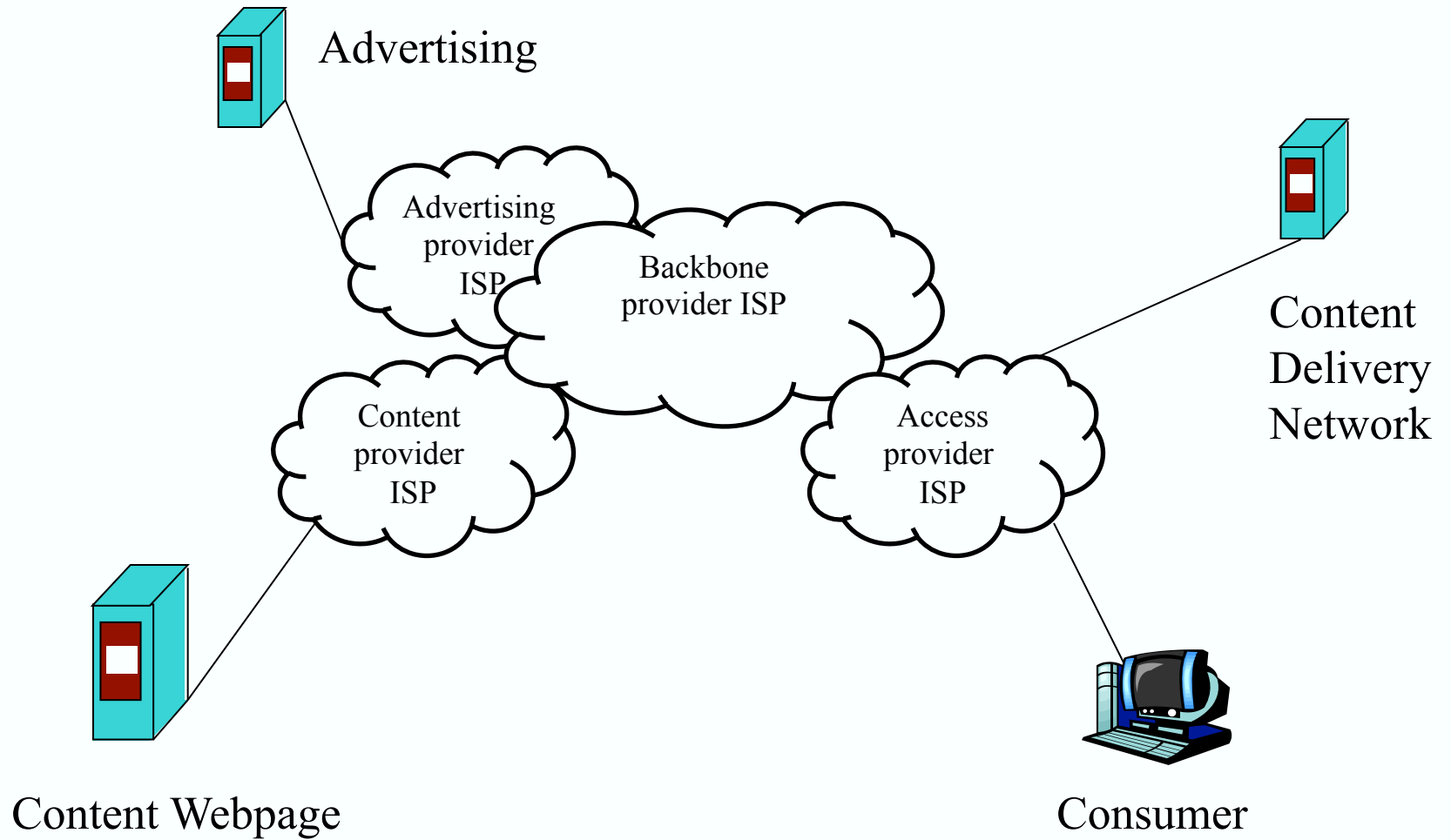
Defining the Internet

- 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 (skip)

- 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 (skip)

- **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 (skip)

- **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

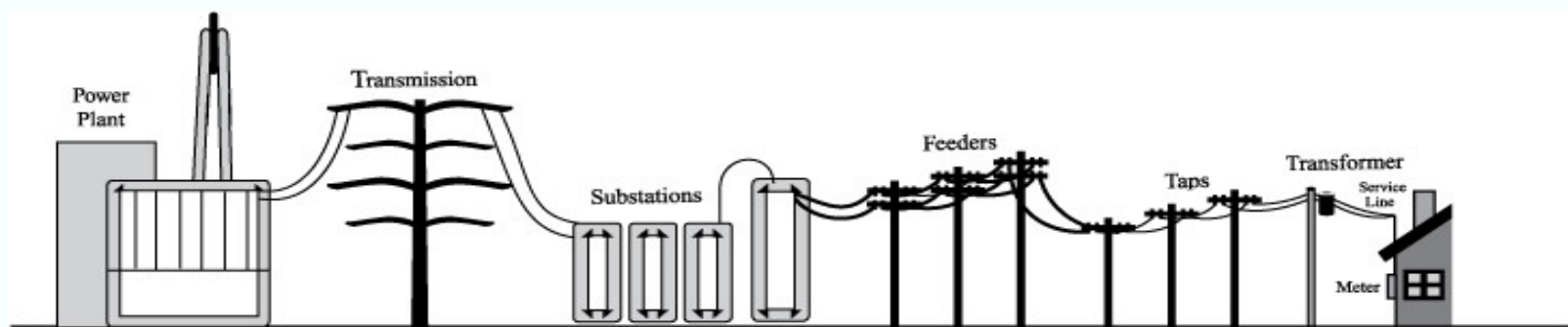
- What is *happening in the wireless access space*?
 - New standards and technologies rolling out
 - LTE and 802.11 (e.g., af and n), ZigBee
 - MIMO, Software Defined Radios and Cognitive Radio
 - Programmable devices
 - Reallocation of spectrum for commercial use
 - New concepts for spectrum management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

Power Grids

Electricity Fundamentals

Electricity Fundamentals

- 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 - steps voltage from low to high OR high to low
- Tap - phase of the electricity



Electricity Fundamentals

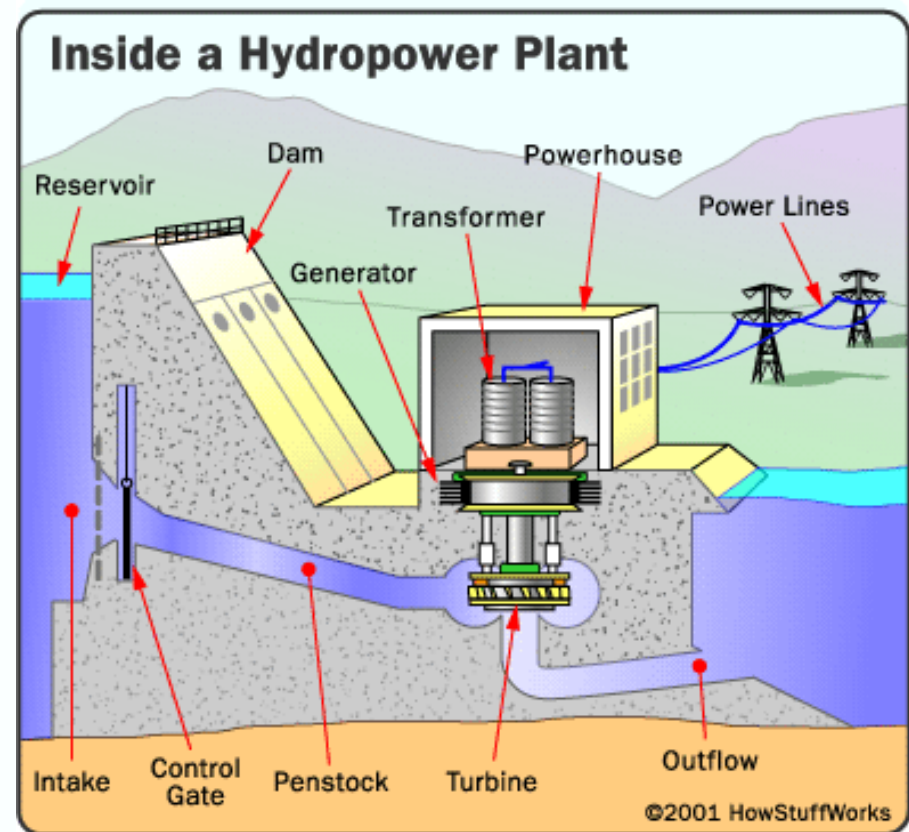
- Current - measure of the flow of charge (think water flow) - I
- Resistance - opposition to electric current (size of the pipe) - R
- Voltage - electromotive force (think water pressure) - V

$$V = IR$$

- Power - the “work” and equals voltage times current - W
- Energy - power across time - kWh

Generation

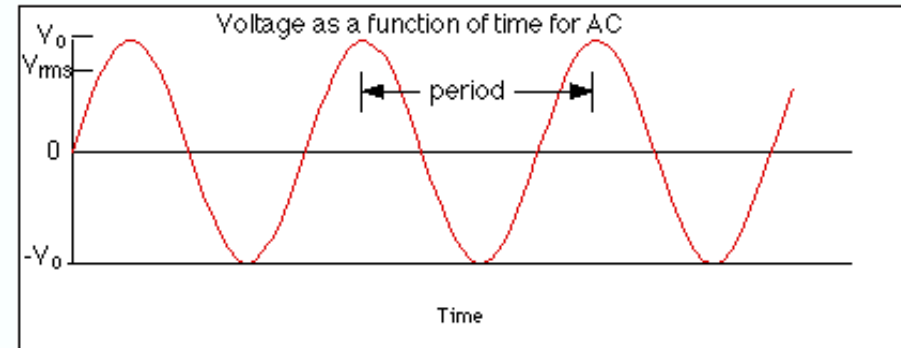
- Generation starts at a power plant or might be locally generated (residential solar)
- At the center of most power plant is a spinning electrical generator (often a turbine)
- Coal, Gas, Nuclear, Hydro, Wind



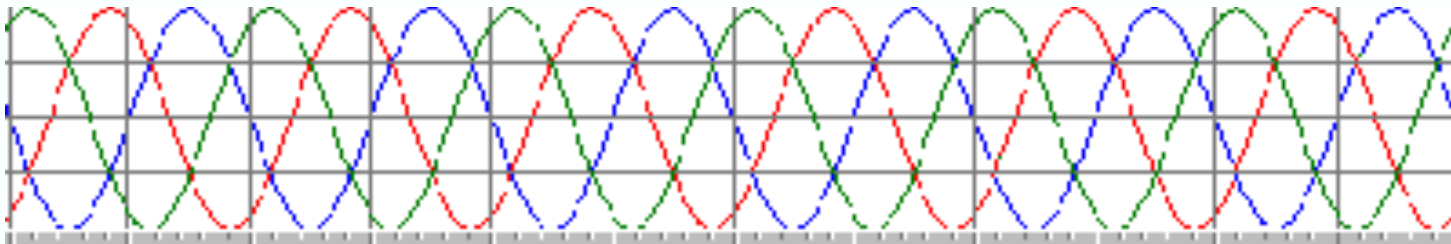
AC Power

Alternating Current (AC) power

- Single phase AC power (residential)
 - Voltage oscillates between +170 Volts and – 170 Volts ($V_{rms}=120\text{ V}$)
 - 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)



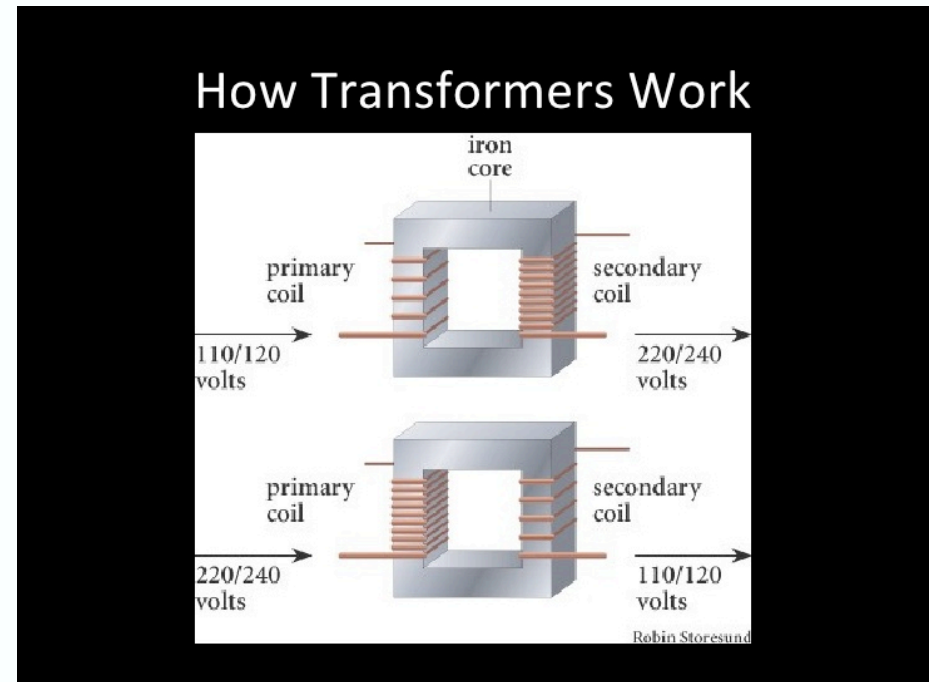
Transmission Substation

- 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
- Along the way regulator banks conditions the power

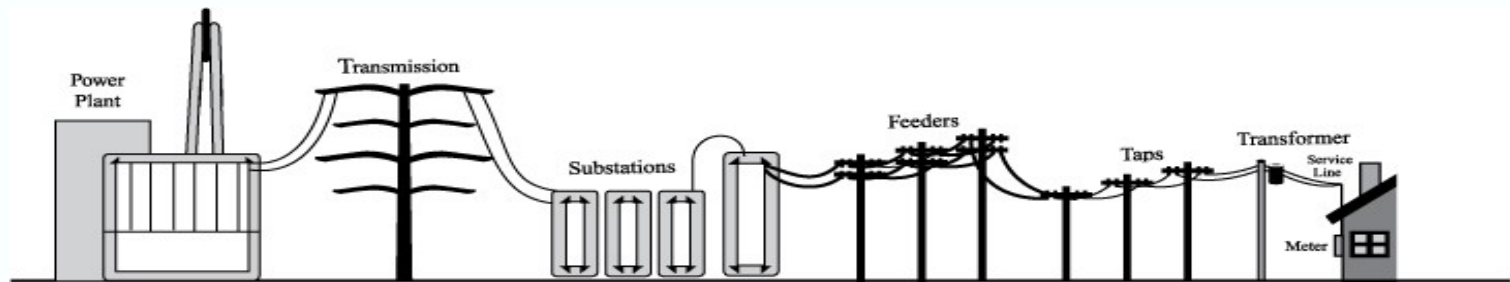
In the home...

- 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
 - Large power plants are more efficient than small (economies of scale)
 - Things didn't start out large
 - Transmission is efficient (although efficiency opportunities exist)

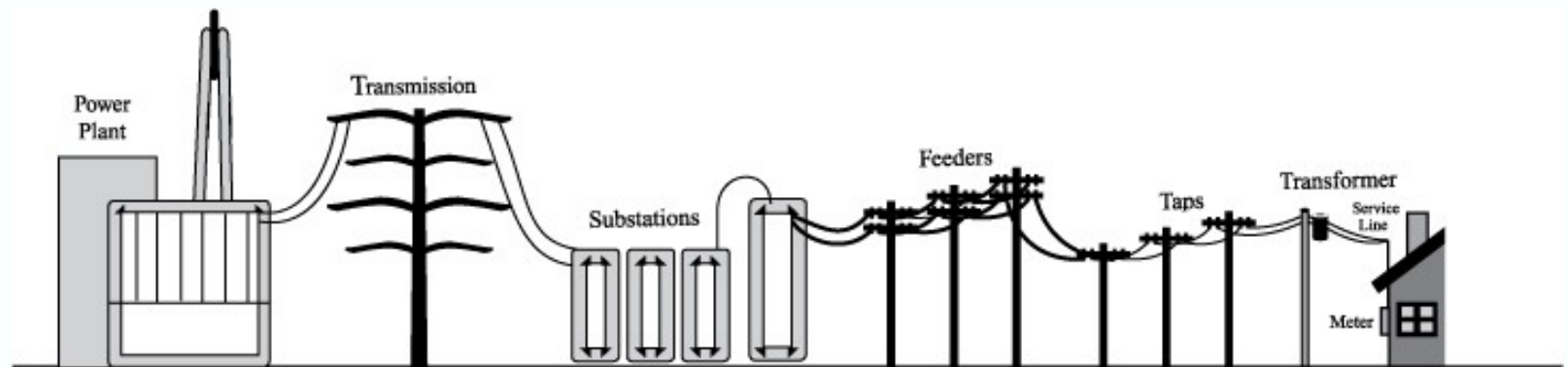


Traditional Power Grid

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.

Mine – combining 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
- Smart data and measurement
 - Demand side management
 - Phasor Measurement Units
 - wide-area measurement system (WAMS)
 - Fault detection and tolerance
- Smart pricing
- Smart appliances
- More...

Smart Grids Offer:

- Combining electrical and data infrastructures
- Energy storage devices
- Local power generation
- Flexible demand response
- Real-time distribution & customer data
- 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 how can it be justified in a business case?

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, health, privacy and security concerns
 - R&D and funding
- At the state and local level
 - Regulation and rates
 - Deployment, health, privacy and security concerns
 - Deployment and debate

Observations

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
 - OPINION -Will not deliver on 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 (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?

Contact Information

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