Trends in Technological Development:
Telecommunications as a Case Study

Presentation by

Douglas C. Sicker, Ph.D.

Director of the ITP Labs

Associate Professor of Computer Science and Telecommunications

University of Colorado at Boulder

Institute for Regulatory Law and Economics (IRLE)

Aspen Colorado

Introduction

- Purpose:

  First half - To provide an overview of the disruptive changes that have occurred in *telecommunications networks*

  Second half - To discuss some implications for "*Smart Grid*" technology

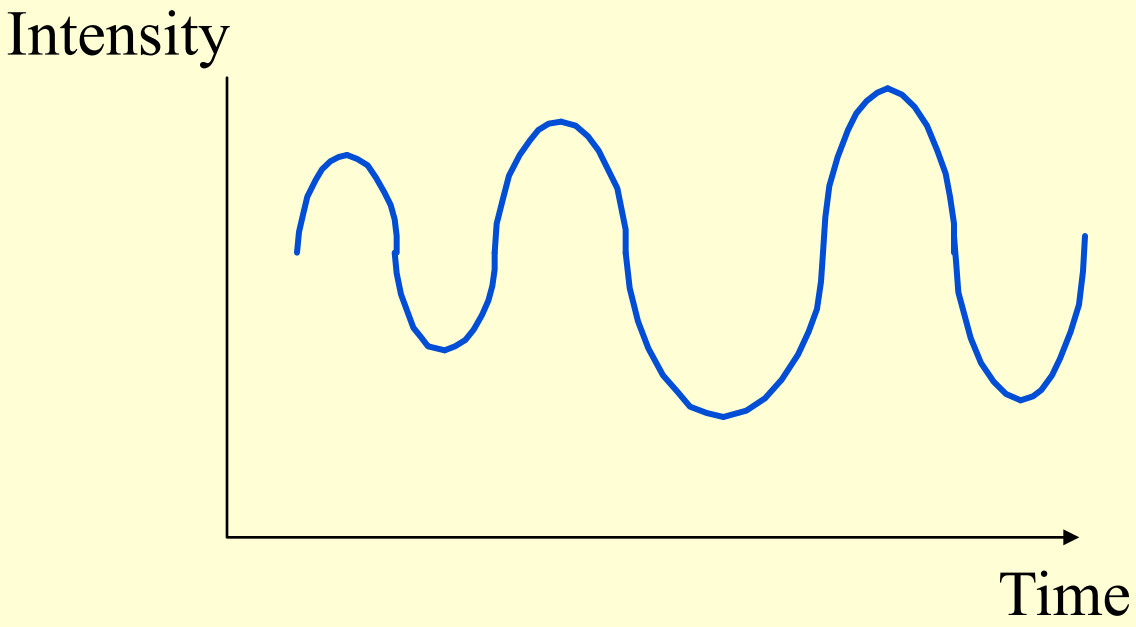
Outline

- Basic concepts
- The Internet and Broadband
  - Intelligence at the Edge
- The Wireless Revolution
- Observations on the Internet
- Implications for Smart Grids

Concepts

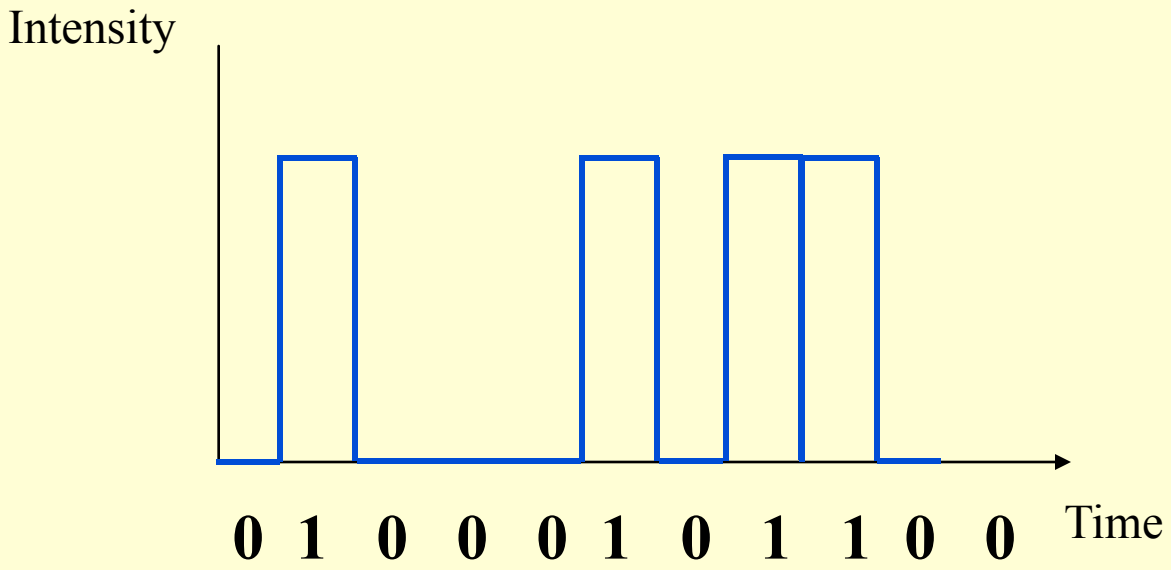
The Digital Revolution

- Analog Signal – like voice



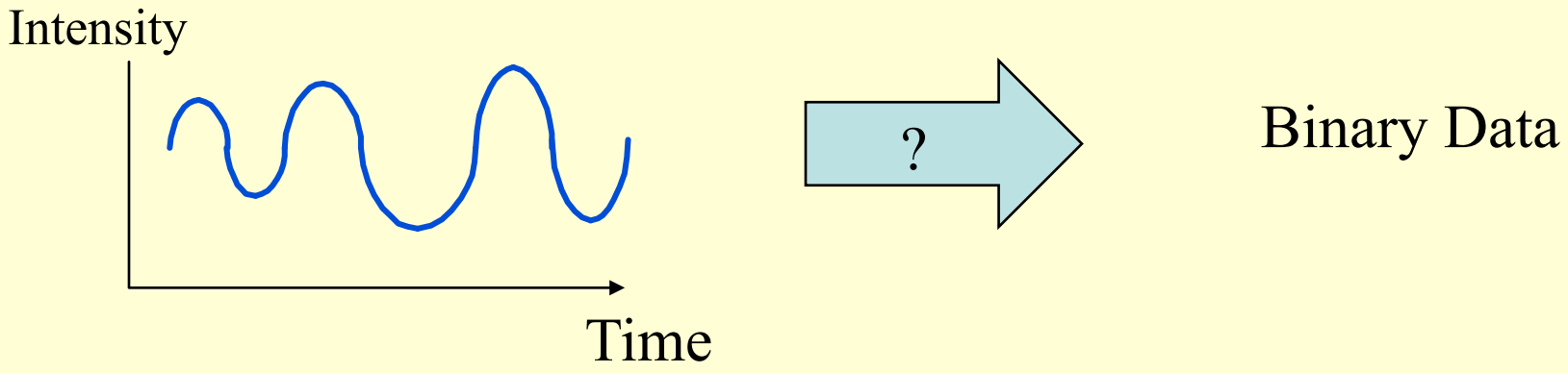
The Digital Revolution

- Digital Signal - like bits on the Internet



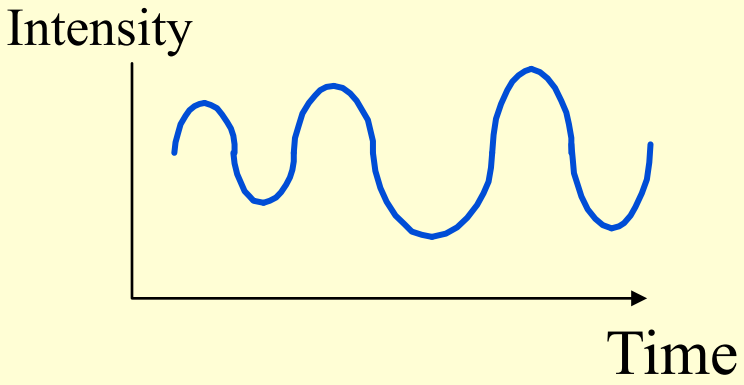
Digital Network: voice, data, image and video information carried as a sequence of ones and zeros represented by pulses of current or light or radio waves

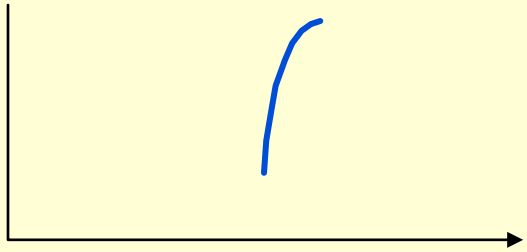
How do we make an analog signal into digital?

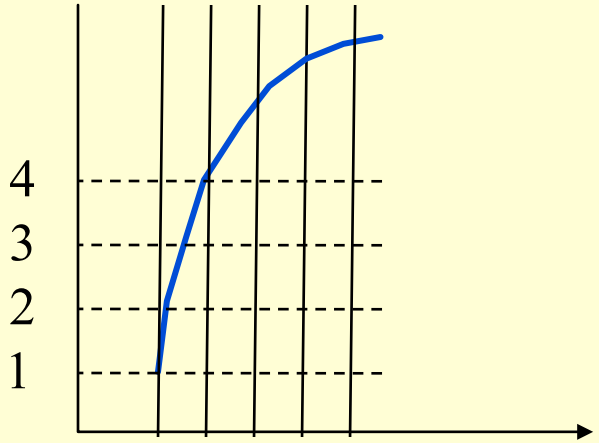


- Take the analog signal and slice it into pieces
- Then we assign values to those pieces
- We use “0” and “1” (binary) to represent this data

How do we make an analog signal into digital?

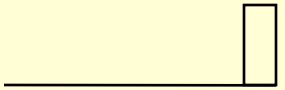






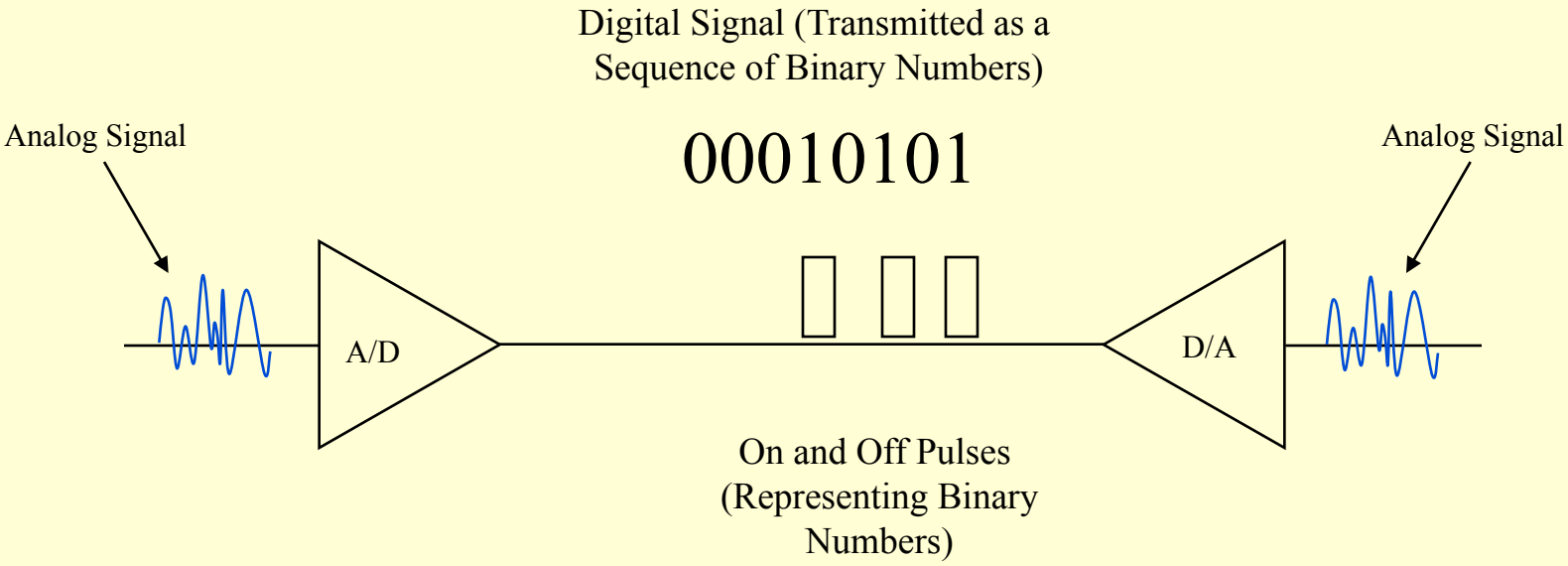
1 = 00000001
2 = 00000010

00000001



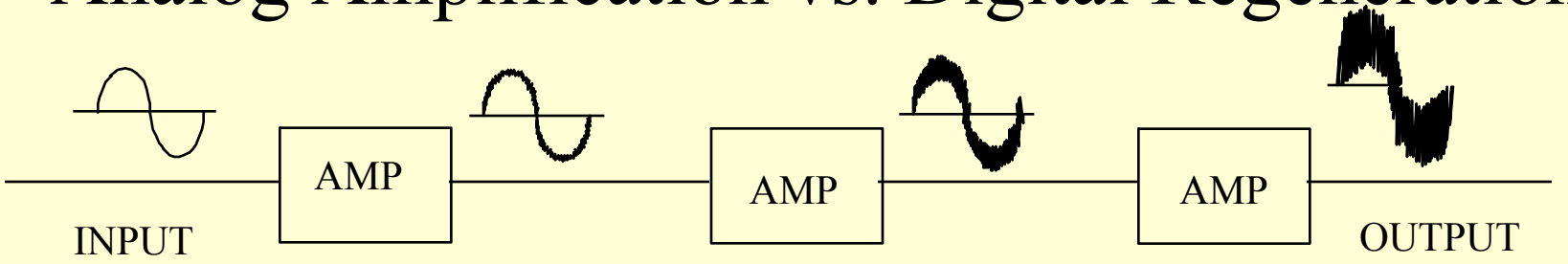
The Digital Revolution

- Analog to Digital and Digital to Analog Conversion

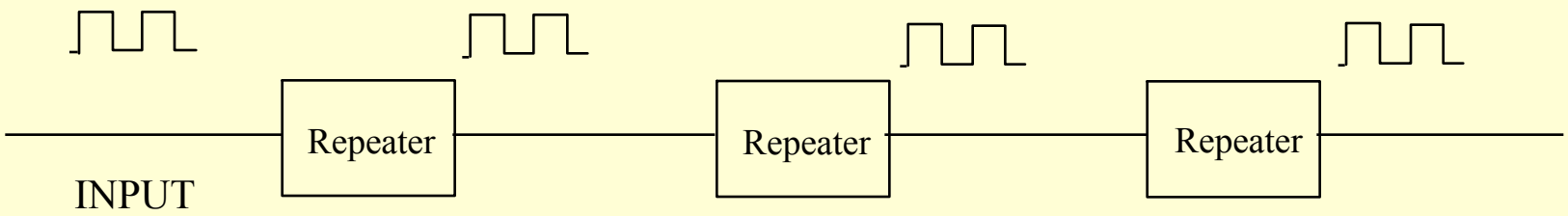


The Digital Revolution

- Why Digital?
  - Analog Amplification vs. Digital Regeneration



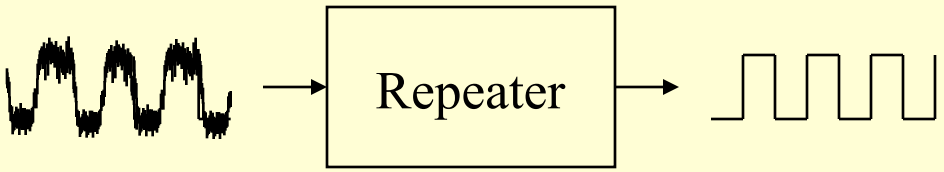
Analog Amplification: Noise Accumulates



Digital Regeneration: “Perfect” Signal is Regenerated

The Digital Revolution

- Why Digital?
  - Digital *Regeneration*



-- Other Advantages (Examples):

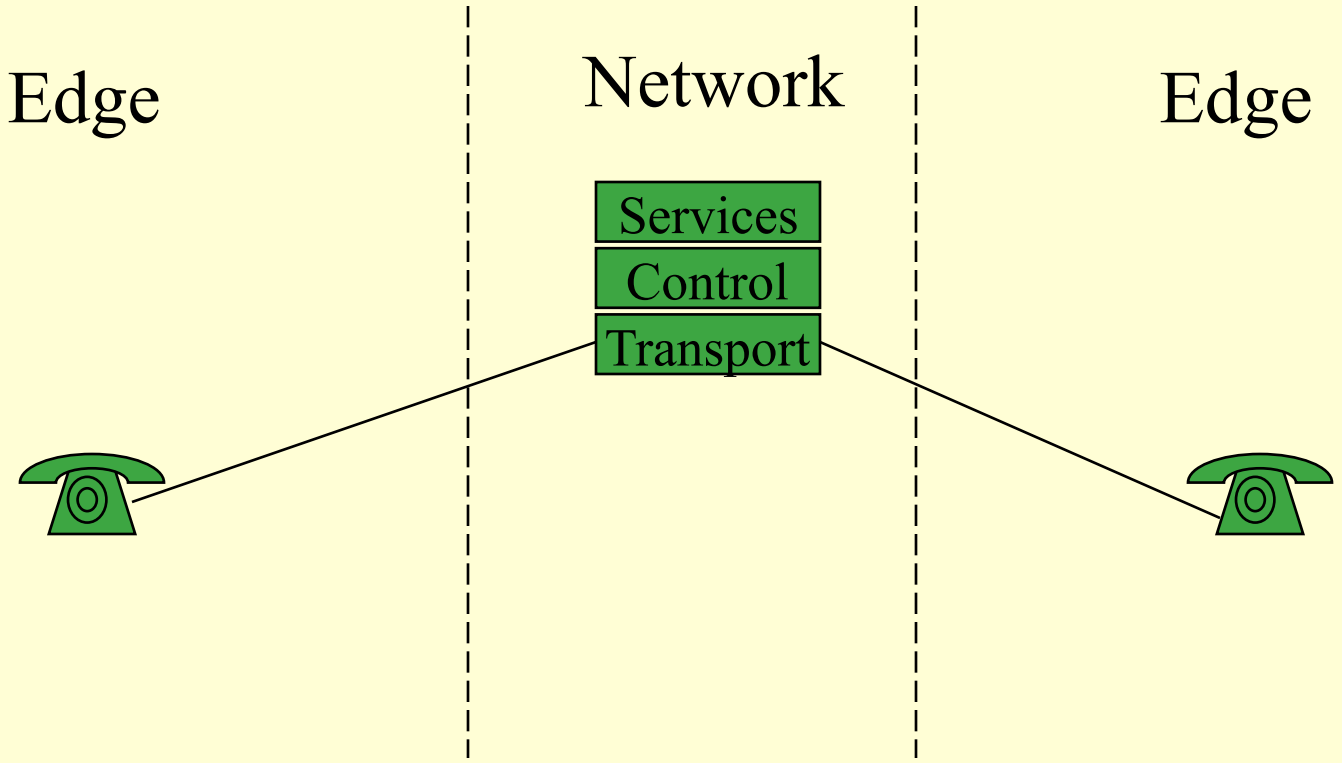
-Ease of *combining* different kinds of signals (multiplexing)

-Rapid decline in *costs* and improvements in performance of digital devices (“chips”)

Centralized vs. Distributed

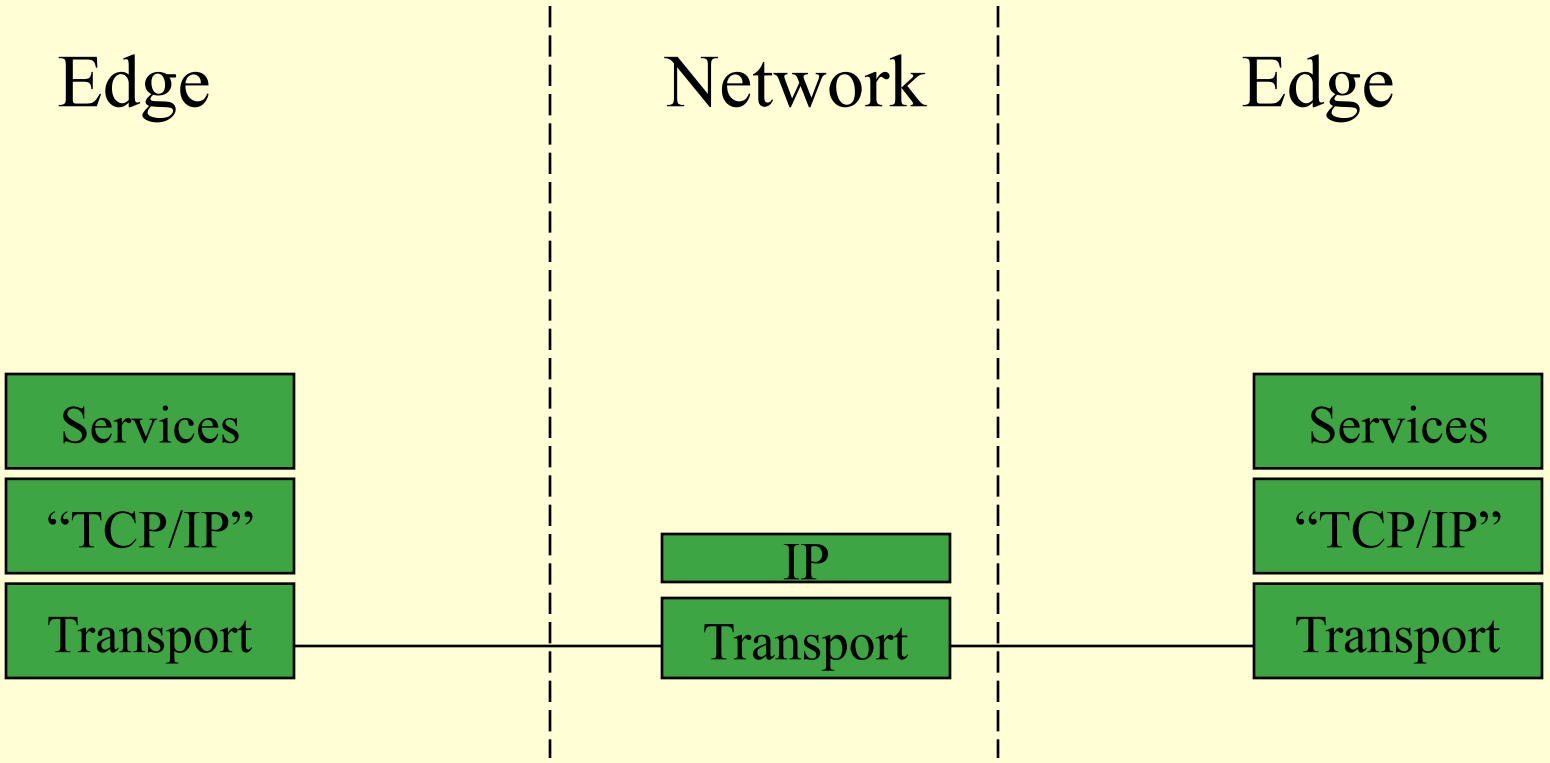
- Traditional Phone System (PSTN)
  - Circuit switching
  - "Dumb" devices
  - "Intelligence" residing in the interior of the network
  - Services created and maintained inside the network
- Internet
  - Packet forwarding
  - "Dumb" network (not really dumb and getting "smarter")
  - "Intelligent" devices
  - Services created at the edge of the network

Closed and Centralized



Traditional Phone Network Design

Open and Distributed



The Traditional Internet Model

The Race for Broadband

- What Is Bandwidth?
  - In simple terms, bandwidth is just a measure of *how much information* can be transmitted
  - The larger the bandwidth, the more information that can be transmitted in a given amount of time
  - In the digital world, bandwidth is measured in bits per second
  - Analogous measures: gallons per minute (think volume)

The Race for Broadband

- To over simplify:
  - Voice requires only narrow bandwidths (narrowband)
  - Still images require more bandwidths (wideband)*
  - Video requires broad bandwidths (broadband)

*For transmission of the image in a reasonable amount of time

The Role of the Internet

- More to it than just bandwidth
- Latency and Quality of Service (QoS)
  - In simple terms, latency refers to *delay*
  - Latency is the amount of time it takes information (e.g., a packet) to travel from source to destination

The Role of the Internet

- A Note on Latency and Quality of Service (QoS)
  - One main cause of latency is when the network cannot handle the packets fast enough (*congestion)*
  - Another being too many consumers sharing an access network (under-provisioned)
  - Another being a bandwidth hog
- In combination, latency and bandwidth define the speed and capacity of a network

The Role of the Internet

- A Note on Latency and Quality of Service (QoS)
  - *Low latency* is critical in voice communications and certain "*real-time*" data communications applications (e.g., voice and interactive games)

What is happening within the Internet and broadband?

Evolving Internet

- What technology is used to build networks?
- What is the Internet?
- What is
  - cloud computing?
  - deep packet inspection?
  - peer-to-peer?
  - network neutrality?
- What is new in wireless access networks?

Defining the Internet

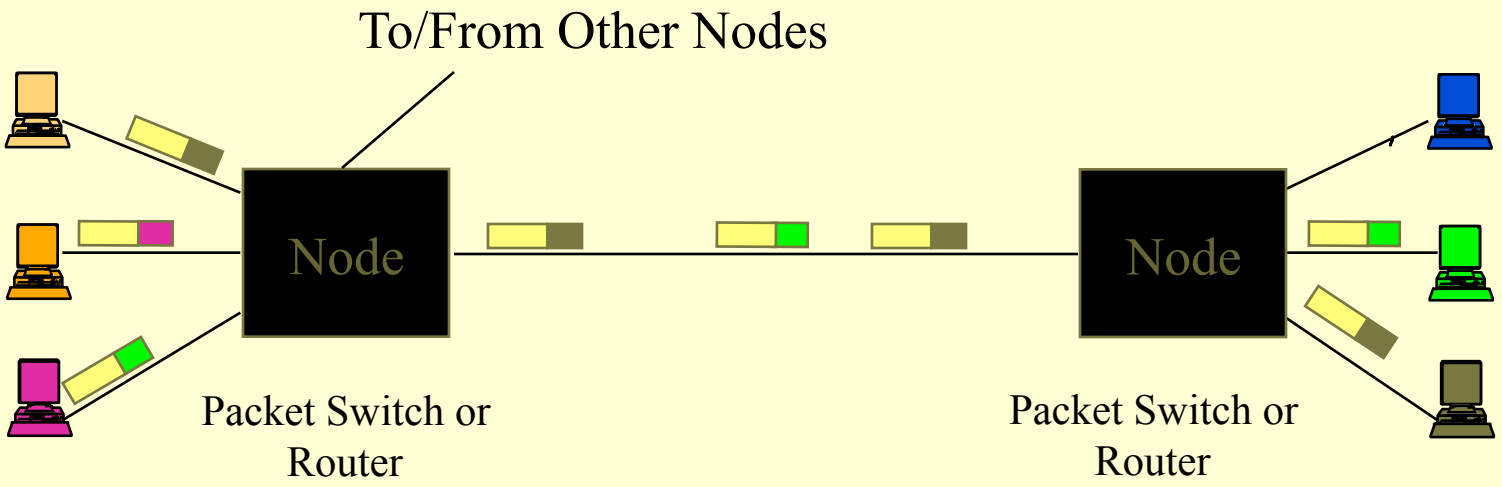
- A *network-of-networks*
- A set of protocols is the *glue* that holds it together
  - Globally interconnected through *packet networks*
- Supports a broad set of *underlying* technologies
  - Copper pair, cable, fiber, wireless
- Supports a broad set of *applications*
  - Web, Email, VoIP, Video, Gaming, File sharing, Overlays
- Provides the infrastructure on which the World Wide Web operates

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 -much more to consider
  - Based on complex technical and business designs

The Role of the Internet

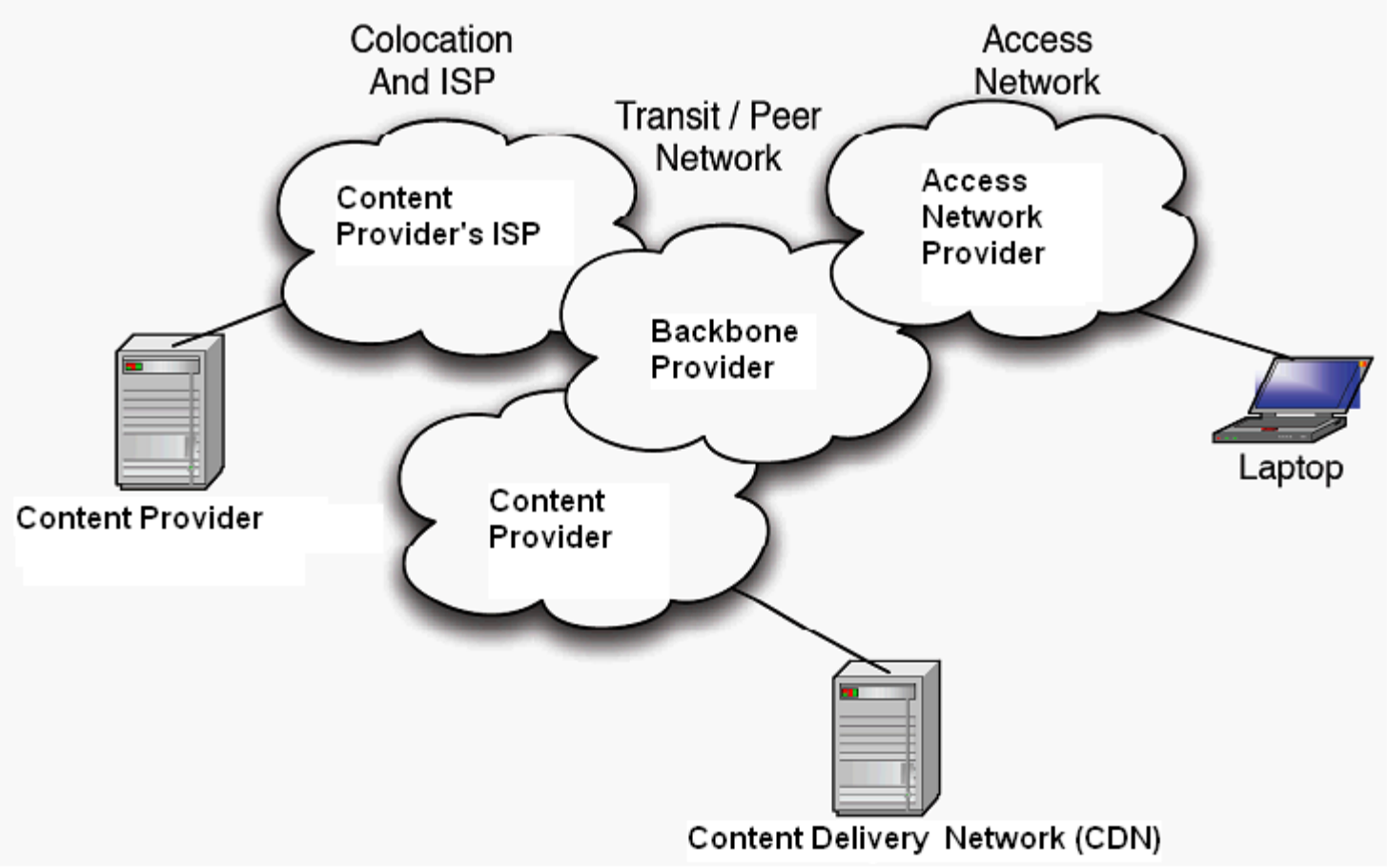
- A Packet Switched Network



Operation

- Business Relationships in the Internet
  - *Business agreements* among the networks
    - Peering and Transit (not built on 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
  - It is *more complex* than most comprehend (many messages)

Operation


Colocation
And ISP
Transit / Peer
Network
Access
Network
Content
Provider's ISP
Access
Network
Provider
Backbone
Provider
Laptop
Content Provider
Content
Provider
Content Delivery Network (CDN)

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
- Tier II service providers connect to the Tier I providers and often to each other

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 symmetric traffic has increased upload needs and has thus caused problems for asymmetric access networks
  - We should not expect traffic patterns to remain the same (we know that they are currently changing)

Common Applications

- Quality of Service
  - Latency and/or Jitter sensitive traffic – voice and video
  - Best effort traffic – web and email
- Common Applications
  - Voice – consistent rate + less than 100 kbps
  - Web (I mean web surfing) – can be < 1 to > 10 Mbps
  - Email –bursty with low average date rate demands
  - Streaming – high average rate demands
  - Real-time media / gaming– rate + latency/jitter issues
  - Peer-to-Peer (P2P) – can place high demands on the network

What is

- cloud computing?
- deep packet inspection?
- peer-to-peer?
- network neutrality?

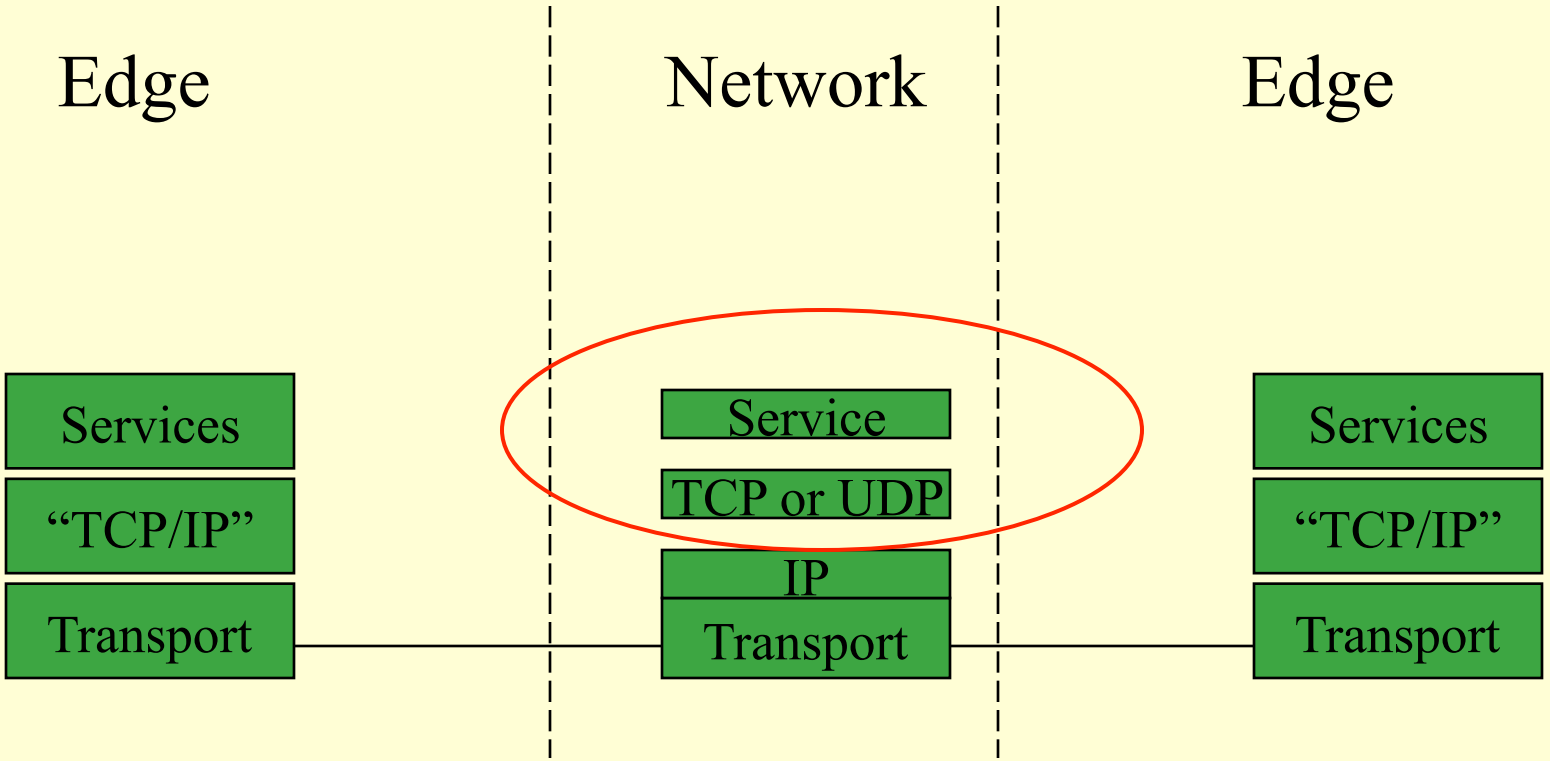
Cloud Computing

- 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

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

The Wireless Revolution

Wireless access

- What is *happening in the wireless access space*?
  - New technologies rolling out
    - LTE and WiMax
    - MIMO
    - Software Defined Radios
    - Cognitive radio
  - Programmable devices!
  - New concepts for spectrum management and usage
    - Dynamic spectrum access
    - TV white space

Observations

Observations

- There are a lot of changes underway within the Internet:
  - Many new applications emerging
    - Cloud Computing, Overlay Networks, P2P, DPI
    - Hopefully Better, Faster, Cheaper
- Internet is a complex ecosystem of interconnected networks
  - Driven by technology, policy and business
- The Internet will continue to evolve in ways that we cannot anticipate
  - Policy continues to lag technology

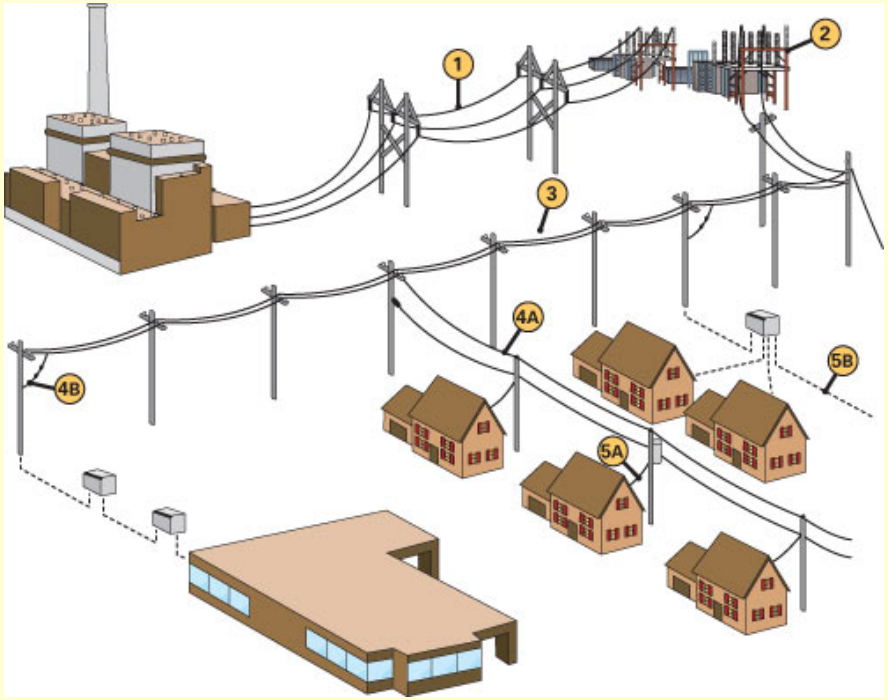
Observations

- The *signaling* network and associated *service logic* were key strategic assets of the traditional telephone industry– the "*Intelligent Network*"
- The extension of a parallel communications ("signaling") network from power generators to individual end user devices – the so called "*Smart Grid*" – has the same potential for revolutionizing the electric power industry (maybe)

Smart Grids

Background

- Elements of the Electric Grid
  - Generation
  - Transmission
  - Distribution
  - Customer Premises' Network and Devices



Source: http://my.dteenergy.com/products/electricity/images/electricFlow.jpg

Definition and Goals of Smart Grid

- No single definition of “smart grid”
- Some definitions miss elements
- Some definitions try to bias the outcome
- Really about upgrading / extending

Xcel's Definition

… an intelligent, auto-balancing, self-monitoring power grid that accepts any source of fuel (coal, sun, wind) and transforms it into a consumer's end use (heat, light, warm water) with minimal human intervention. It is a system that will allow society to optimize the use of renewable energy sources and minimize our collective environmental footprint. It is a grid that has the ability to sense when a part of its system is overloaded and reroute power to reduce that overload and prevent a potential outage situation; a grid that enables real-time communication between the consumer and utility allowing us to optimize a consumer's energy usage based on environmental and/or price preferences.

Potential Benefits

- Benefits claimed for the "Smart Grid" include:
  - Improved *reliability* (e.g., through quicker identification and location of outages and quicker load shedding)
  - Improved *efficiency* (e.g., through load leveling and other demand side management techniques such as real-time pricing) thereby reducing upward pressures on rates

Potential Benefits

- Benefits Claimed for the Smart Grid include (Cont'd)
  - Increased *innovation* (e.g., by creating an enhanced platform for the creation of new products and services – e.g., by providing support for intelligent appliances)
  - Promotion of *environmental* quality and "green" values (e.g., by facilitating consumer choice – allowing the recharging of electric vehicles during off-peak periods and thereby reducing the need to construct additional fossil fuel generating plants)

Basic Concepts

- Importance of Distinguishing Between:
  - *Centralized* vs. *Distributed* generation
  - Intelligence
  - Dynamic operation
  - *Control vs. Payload*
    - *Control (*service logic)
    - Actual delivery of the *service*
    - Note the two logically separate networks

Characteristic	Today's grid	Smart grid (vision/dream)
Consumer participation	Uninformed and non-participated	Informed, involved – DRR and DER
Generation and storage	Central generation	Distributed plug and play
Products and service	Very limited	Wholesale market and new services
Power quality	Focus on outages	Focus on options
Optimization	Silos and limited data	Expanded data and algorithms
Disturbances	Responds	Anticipates
Disasters	Vulnerable	Resilient

Observations

- The signaling network and associated service logic were key strategic assets of the traditional telephone industry– (the "Intelligent Network") prior to the rise of the Internet
- Hence the notion of a parallel signaling /control network to dramatically improve the efficiency and reliability of a physical or electronic payload delivery network has existed for decades

Further Observations

- The electric power industry has been *slow* to fully adopt the notion of distributed operations
- The extension of a parallel digital communications network from power generators to individual end user devices has the same potential for transformation of the electric power industry

Observations

- Notion of the "Smart Grid" includes:
  - Intelligence and associated control devices in local *distribution* related to supply management
  - Intelligence and associated *control devices at the edge* in the form of "smart meters" related to demand management (and perhaps supply management)
  - Intelligence within *end user* network and devices (e.g., smart appliances)
  - Intelligence in the *generation*
- *Interconnection* includes both physical interfaces and logical interconnection at the application/service, control/signaling and transport planes or layers

Closing Thoughts

- Could hold great value for consumers
- Not known how (or when) this will develop
- Uncertainty on setting the incentives correctly
- Lessons to be learned from the Internet
- Intelligence at the edge
- Distributed and open design
- Architecture matter (let's get security right)

Contact Information

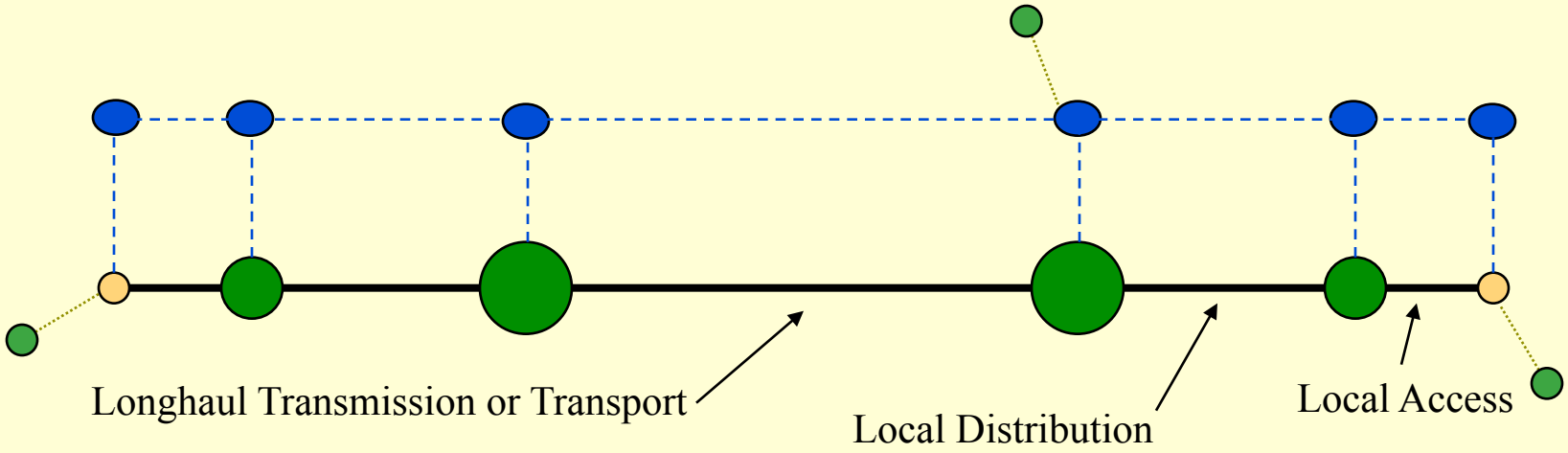
Douglas C. Sicker, Ph.D.

Associate Professor
Department of Computer Science
Interdisciplinary Telecommunications Program
University of Colorado at Boulder (430 UCB)
Boulder, Colorado 80309
303-735-4949
http://spot.colorado.edu/~sicker
Sicker@colorado.edu

- Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric power grid
- Dynamic optimization of grid operations and resources, with full cybersecurity
- Deployment and integration of distributed resources and distributed generation (DG), including renewable resources
- Development and incorporation of demand response (DR), demand-side resources, and energy-efficiency resources
- Deployment of ‘‘smart’’ technologies (i.e., real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communicating about grid operations and status, and facilitating distribution automation
- Integration of ‘‘smart’’ appliances and consumer devices (e.g., a home air conditioner that is able to be shut off remotely to reduce the demand for electric energy, such as during periods of peak demand)
- Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs), and thermal- storage air conditioning
- Provision to consumers of timely information and control options (i.e., for making decisions about equipment use based on electricity prices)
- Development of standards for communication and interoperability of smart appliances and equipment connected to the electricity grid, including the infrastructure serving the grid
- Identification and lowering of unreasonable or unnecessary barriers hampering the adoption of Smart Grid technologies, practices, and services

A Broader Perspective

- Separation of Signaling, Control and Intelligence from Actual "Payload" Delivery



Examples:
- Railroad
- Federal Express
- Telephone Network
- Intelligent Highway
- Gas Pipeline

Note Transport, Control and Service Layers

Key:
- Payload Switching or Routing (e.g., Highway Interchange or RR Switchyard)
- Signaling Network
- Signaling Network Message Switch or Router (i.e., Packet Switch)
- Intelligence or "Smarts" or Service Logic

Lessons Learned

Lessons Learned

- 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
  - Provided a much more *powerful platform* that is capable of handling not just voice but a rich combination of voice, data, image and video (multimedia) content
  - *Undermined* traditional cost/pricing, jurisdictional and regulatory models

Lessons Learned

- *Open* architectures that facilitate service creation in increasingly intelligent devices at the edge of the network create opportunities for *rapid innovation*
- Customers at the edge not only *consume* services and content but increasingly *create* them as well

Lessons Learned

- Clear *trend is toward more openness* beginning with the Internet itself and now being extended in other platforms (e.g., cellular – witness VZ wireless, Apple iPhone on AT&T network, Google phone on T-Mobile network)

Lessons Learned

- Despite trend to more openness, services and content offered by platform providers inevitably raises issues of *interoperability, interconnection and potential discrimination* ("network neutrality")
- *Proprietary* approaches, while offering potential short term advantages, can lead to long term disadvantages including vendor lock-in (cable industry)

Lessons Learned

- Importance of *enlightened regulatory approaches* that provided incentives for incumbent providers to embrace efficiencies and business opportunities offered by the disruptive technological developments (e.g., through price cap regulation and through deregulation, as appropriate)

Contact Information

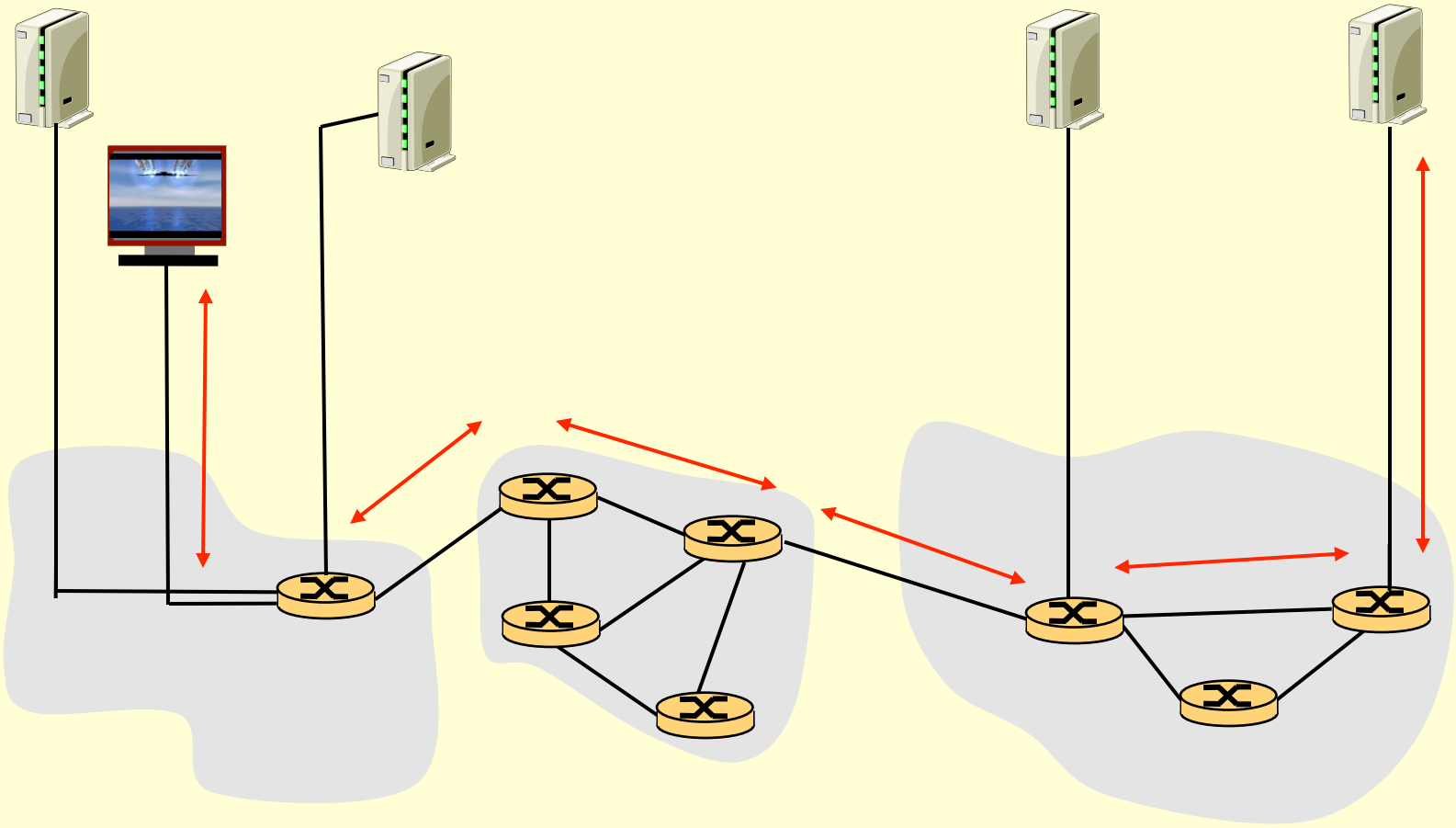
Douglas C. Sicker, Ph.D.

Associate Professor
Department of Computer Science
Interdisciplinary Telecommunications Program
University of Colorado at Boulder (430 UCB)
Boulder, Colorado 80309
303-735-4949
http://spot.colorado.edu/~sicker
Sicker@colorado.edu

Overlay Networks

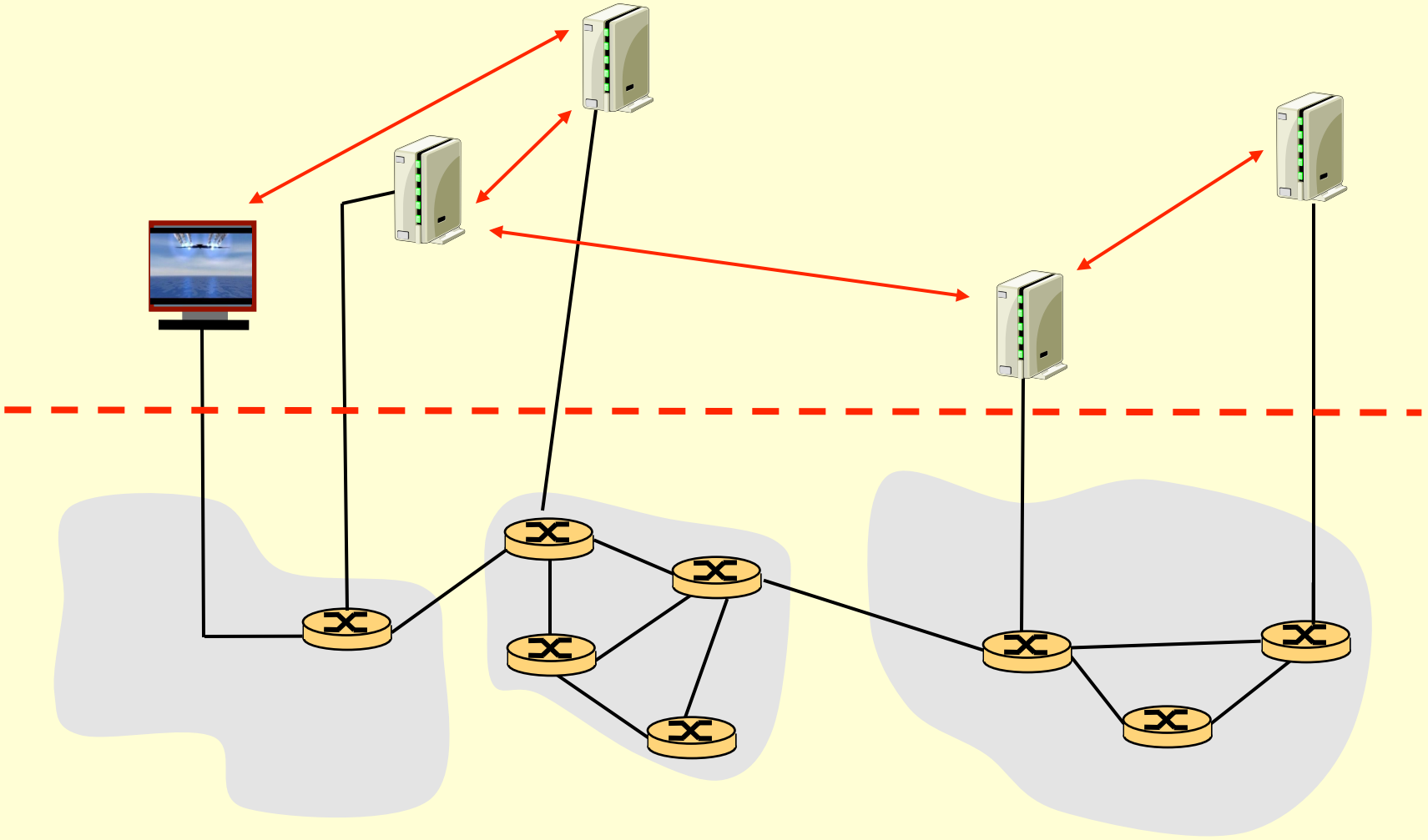
- What is an *overlay network*?
- In simple terms, a network built on top of other networks
- Many versions of this exist
  - *Could argue that Dial-up Internet access* is an overlay network
    - With common carrier non-discrimination obligation
  - *Peer-to-peer* networks are often an overlay network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

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

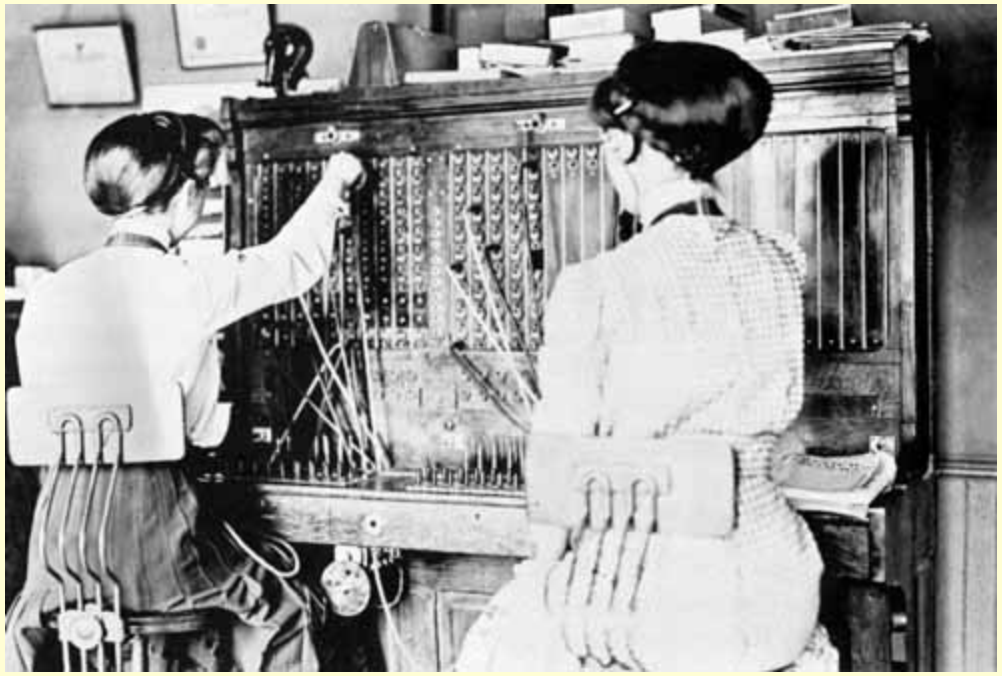
Peer-to-Peer Networks

- 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 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

The Role of the Internet

- Telephone Switching

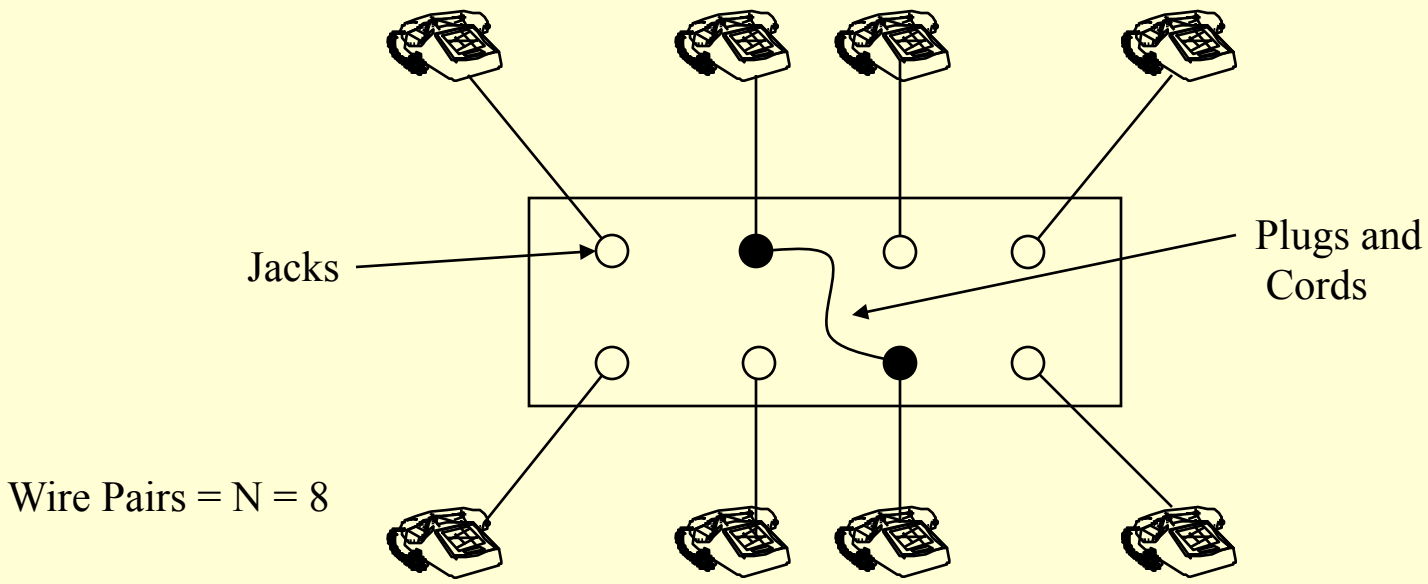


Laura Robbins and Maud Ware at telephone switchboard 1910

Source: **bchs.kearney.net/ BTales_198302.htm**

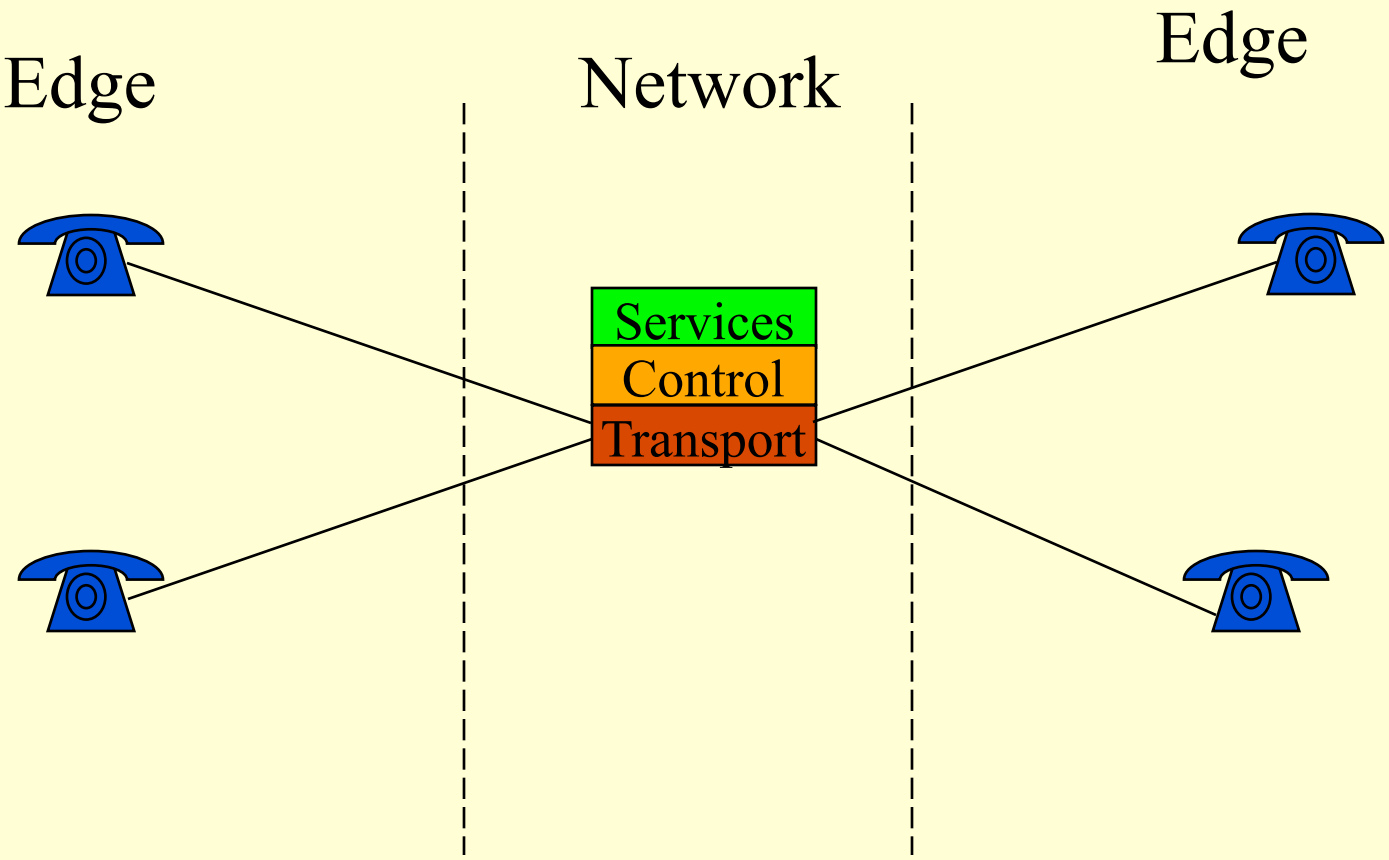
The Role of the Internet

- A Telephone Switchboard



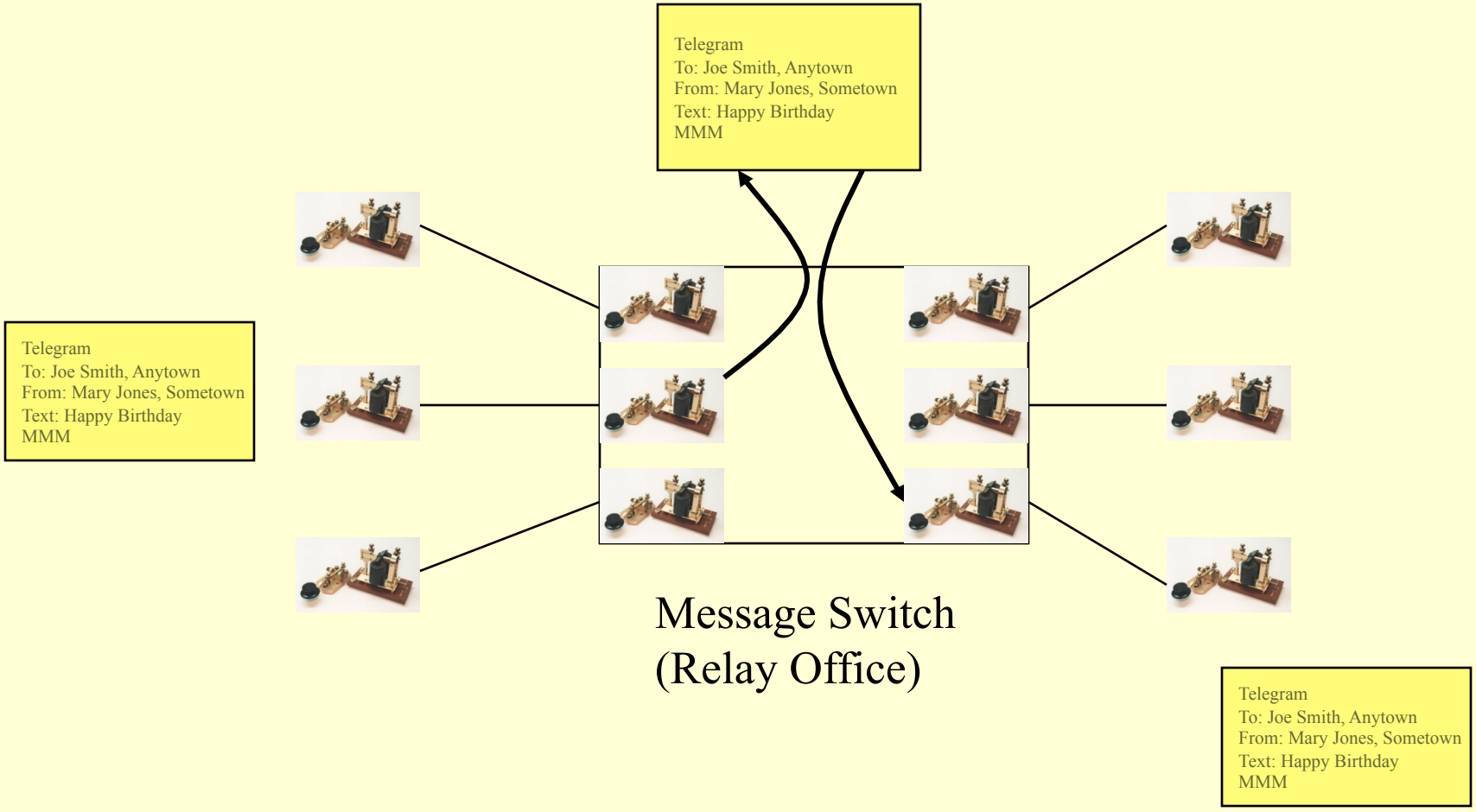
The Role of the Internet

- A Telephone Exchange



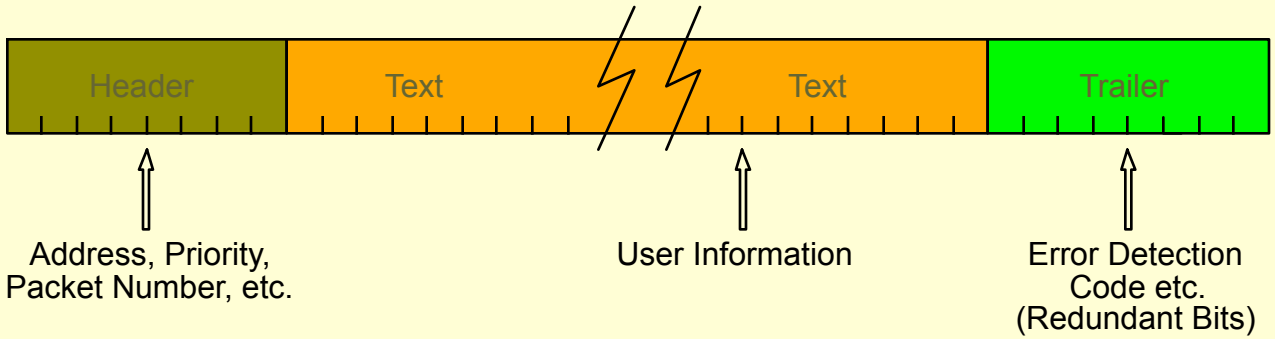
The Role of the Internet

- A Message Switch



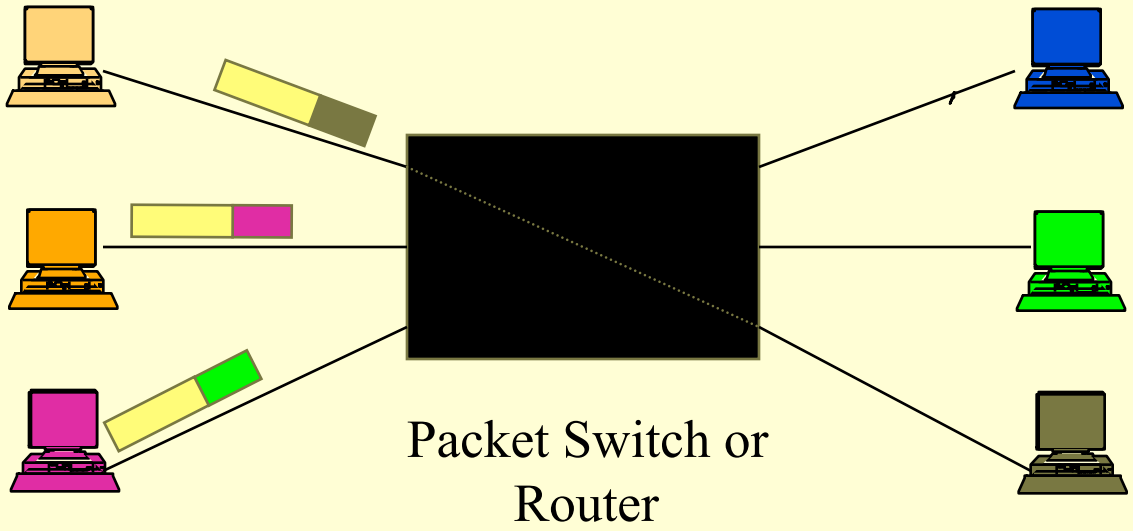
The Role of the Internet

- A Packet of Information



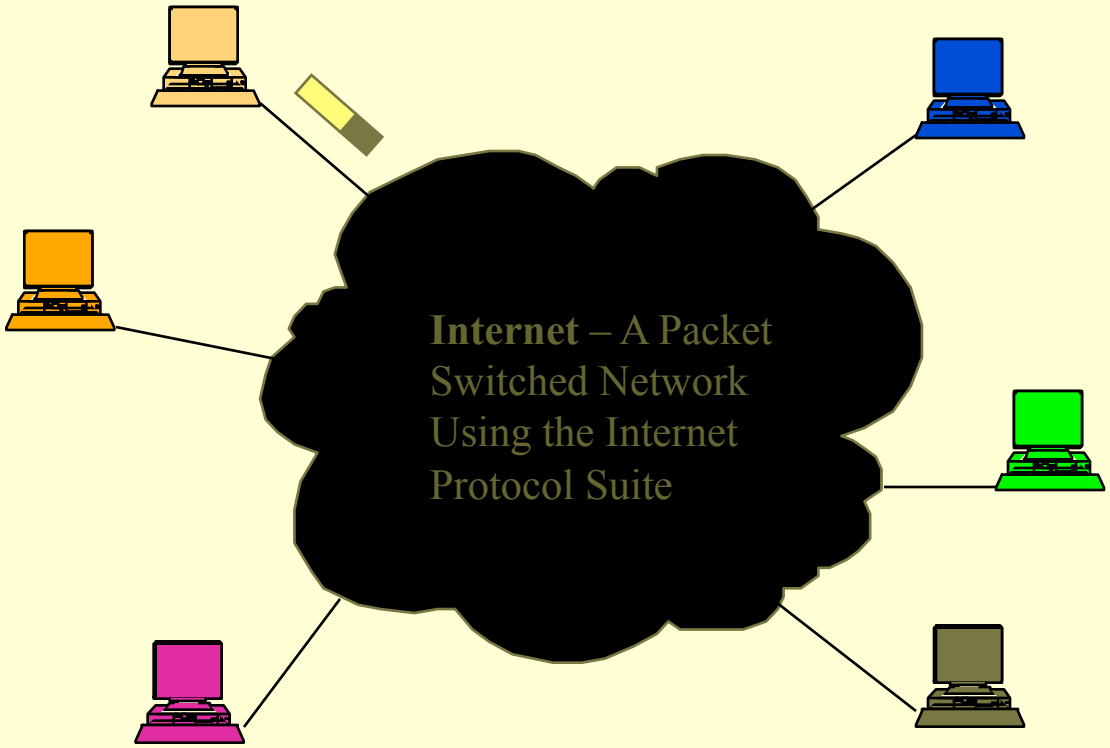
The Role of the Internet

- A Packet Switch or Router



The Role of the Internet

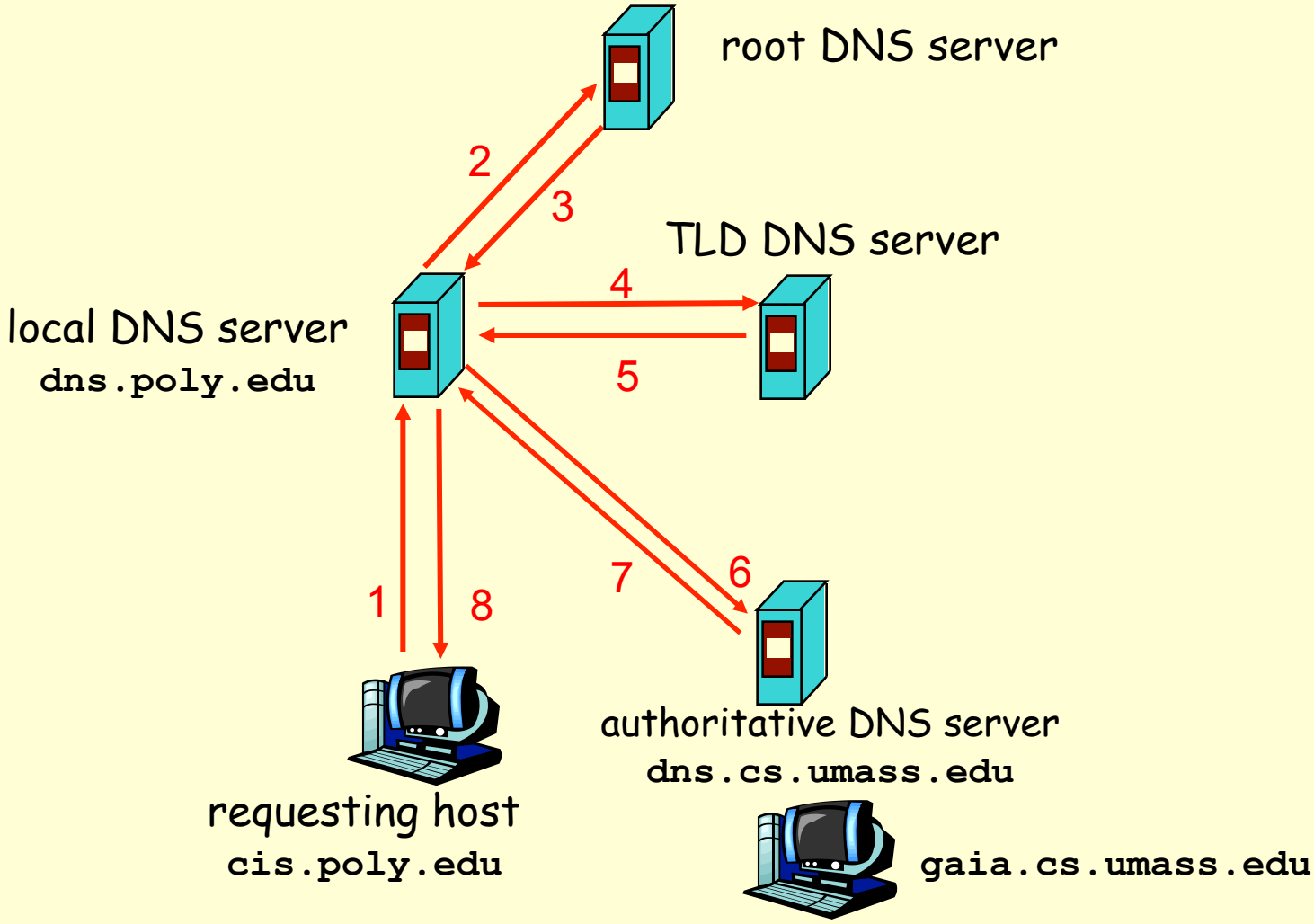
- The Internet As a “Cloud”



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

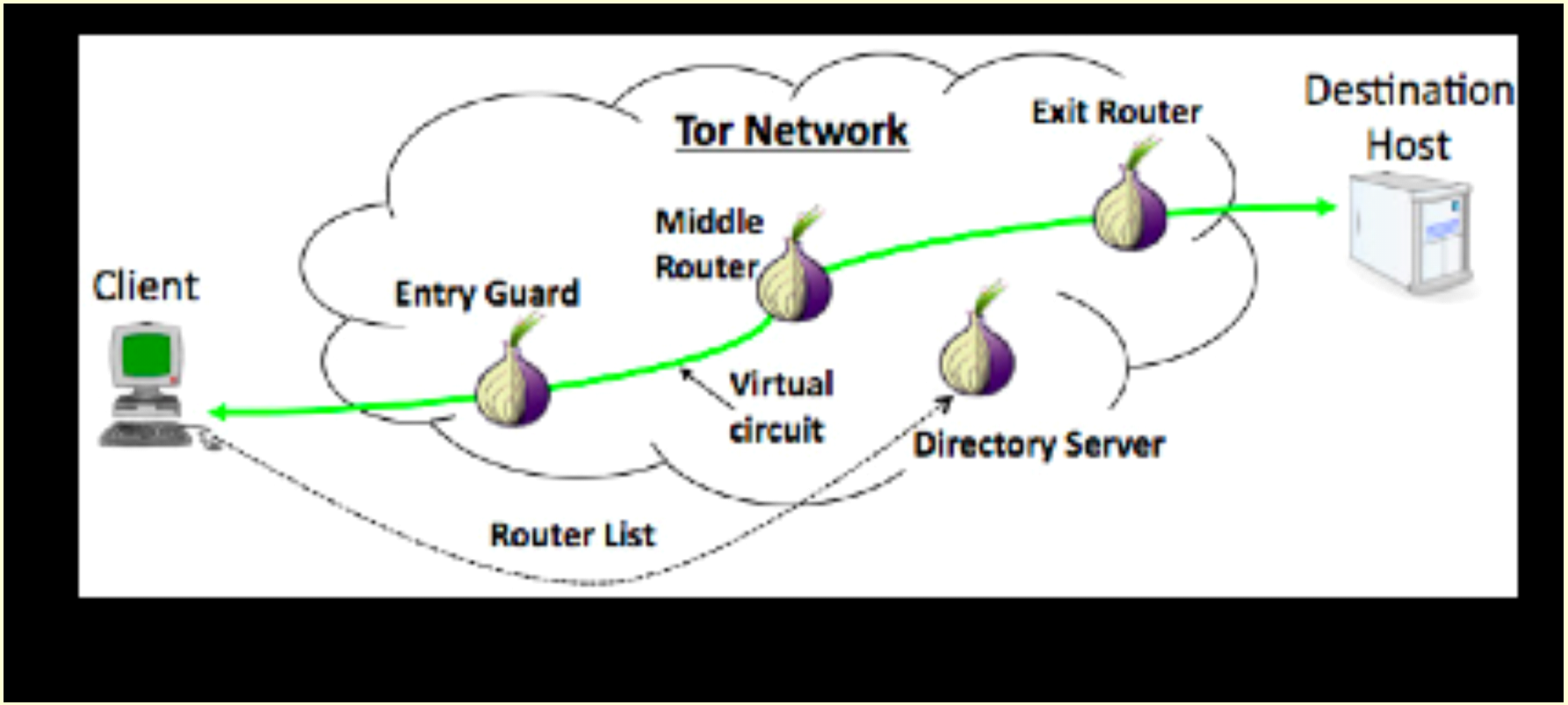


Slide adapted from Jennifer Rexford's networking course slides

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

TOR


Tor Network
Exit Router
Destination Host
Middle Router
Client
Entry Guard
Virtual circuit
Directory Server
Router List