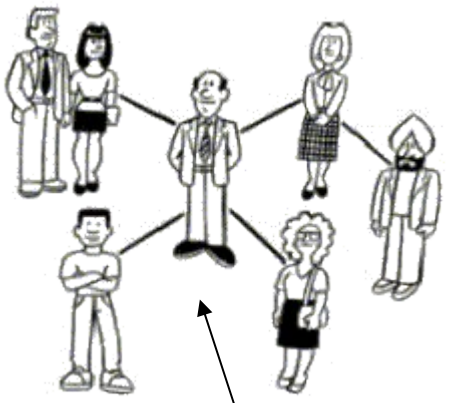
CSCD 443/533
Advanced Networks
Winter 2017



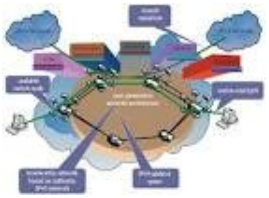
Lecture 9
Network Design and Performance

Read: Chapter 1.3.2 and Chapter 5.1

Topics

- Design of Networks
  - Principles
- What is the true design of the Internet?
  - Is the Internet Successful?
  - Are there problems with the existing Design?
- What proposed designs are for Next Generation Internet?
  - Who is designing this next Internet?

Designing a Network



- If you were designing a general purpose network
  - What are the requirements for your network?
    - Think about tasks a network needs to perform
    - Take a few minutes and list some requirements
    - Write them down ...

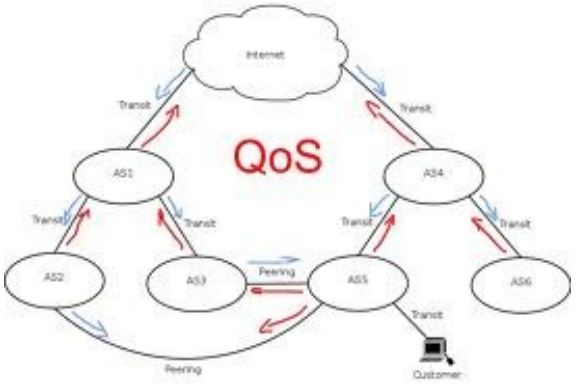
General Requirements for Networks

- Users - Accommodate some number of users
  - Plan for shared use of network
  - Privacy and Security
- Applications - Diverse network applications
  - Text based - file transfers, Web pages
  - Multi-media, video, images and voice
  - Can't always anticipate next **Killer Application**
- Performance and Efficiency
  - Location of Services affects performance
- Reliability and Redundancy
  - Accommodate network failure
  - Build in redundancy if you can

Multiple Users

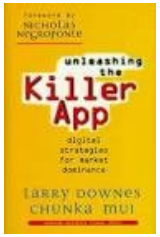
- Fairness - Must fairly share common network links
- What works best in an environment where number of users is unknown and network use varies?
- Statistical Multiplexing
  - Works better than static allocation of resources like time or frequency division multiplexing
  - Fairness achieved by limiting size of packets
    - Packets from multiple users each have a turn

Multiple Users



- Questions to Ask ...
- Do you want to allow prioritized traffic?
  - Is some traffic “better” than others?
- What about real-time applications or other critically labeled traffic?
- Is Internet designed to allow for this?

Diverse Applications



- Applications vary over time
- Recall first Killer Applications of original Internet .... Email, Spreadsheets, FTP, Telnet
- What are killer applications in today's Internet?

Diverse Applications Common Services

- One way to view network applications
  - Define characteristics common to certain types of applications
  - Call them Communication Patterns
    - A lot like programming “Design Patterns”

Diverse Applications, Common Services

- Helps in planning network resources
- File transfer pattern
  - User requests file, Server provides it
  - Small amount of data in request
  - Larger amount of data in reply

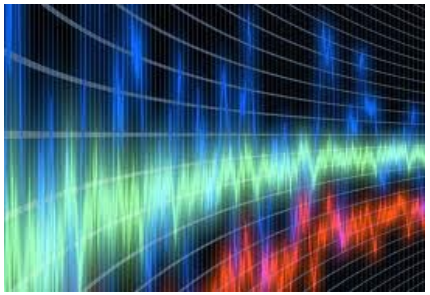
  Channel Characteristics
    - Data must be delivered in-order
    - Every packet must get there
    - Tolerate delays

- **What other applications are like this?**

Diverse Applications, Common Services

- Other Patterns
  - Video-on-demand, Videoconferencing
    - Video is streamed when requested
    - Go both ways in video conference
    - More a stream of bytes instead of distinct set of packets
    - Channel Characteristics
      - Must be in-order, no out-of-order frames
      - Can tolerate some loss,
      - Should support multicast

Diverse Applications Common Services

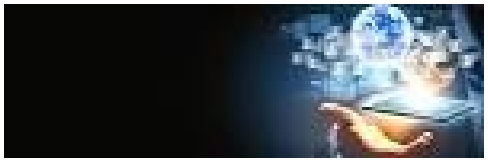


- More Patterns
  - Audio on-demand
    - Variation of video on-demand
    - Has some real-time aspects, must be given priority over other traffic, known as Quality of Service (QOS)
    - Has real limitations on delay it can tolerate
    - Audio signal must be played in order, can tolerate some frame loss
  - Other Patterns? ... think of applications you use

Diverse Applications, Common Services

- Other Patterns
  - P2P
    - Equal exchange between peers
    - Like file transfer
  - On-Line Games
    - Many clients connect to server
    - More data from server to clients, than from clients to server ? All games the same?
  - SSH/Telnet/VPN Tunnels
    - Everything typed is echoed on client's machine
    - Pretty equal traffic between client and remote host

Performance and Efficiency Location of Services



- A fundamental design decision, affects performance
  - **Where do I put my network services?**
  - Services needed to coordinate traffic between hosts
    - Errors, packet loss, retransmission and congestion control
    - Should we make routers and switches more intelligent to handle these things or let applications take care of them in the hosts?
  - How is this handled in current Internet ?

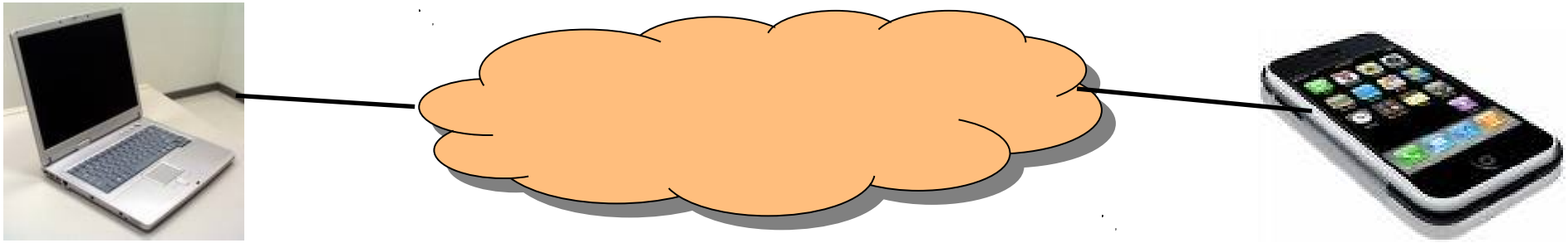
Location of Services
Telephone Network: Dumb Edge, Smart Core

- Dumb phones
  - You dial a number
  - Speak and listen … that's it
- Smart switches
  - Set up and tear down a circuit
  - Forward audio along the path
- On purpose, limited services
  - Audio
  - **Later** a little smarter, caller-id, call forwarding etc.
  - **Much Later** handled data too

Location of Services
Internet: Smart Edge, Dumb Core

End-to-End Principle

Whenever possible, communications complexity should operate at end-points of communication system



Programmability

With programmable end hosts, new network services can be added at any time, by anyone

Is that happening today?

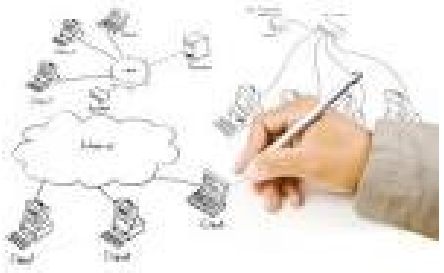
Reliability and Redundancy

- Internet is most robust communications network ever designed
- Seems to be able to adapt itself to damage or outages to individual sections

Reliability and Redundancy

- Internet has no single point of control
  - There is an administration by coalition of participants
  - Loss of individual computers and networks does not affect its overall reliability
  - Protocols designed to operate autonomously, they fix themselves
    - **Example:** RIP, OSPF and BGP find new routes if routes become unavailable
  - One feature helps with both Reliability and Redundancy

Internet Success

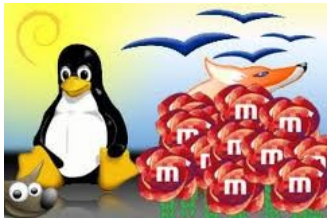


- Three Main Decisions
    1. Network Applications are just software
    2. Layered Architecture
        - Separation of Services by layer
        - One common protocol IP in the middle
    3. Decentralized Control

Internet Success

1. Network Applications Just Software

- Network applications just software running on commodity machines



  - Don't need hardware upgrades to provide new functionality
- As computers became faster
- More and more applications using multimedia
  - Examples: Web browser and server, video over the Web – YouTube, Google everything, chat programs and VOIP applications

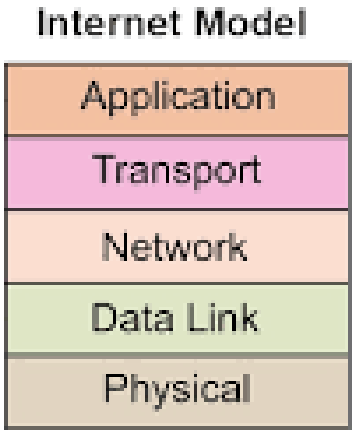
Internet Success

2. Layers

Separation of Services

Modular Subdivision of the Problem

- Each layer relies on services from layer below
- Each layer exports services to layer above
- Hides implementation details
- Layers can change without disturbing other layers

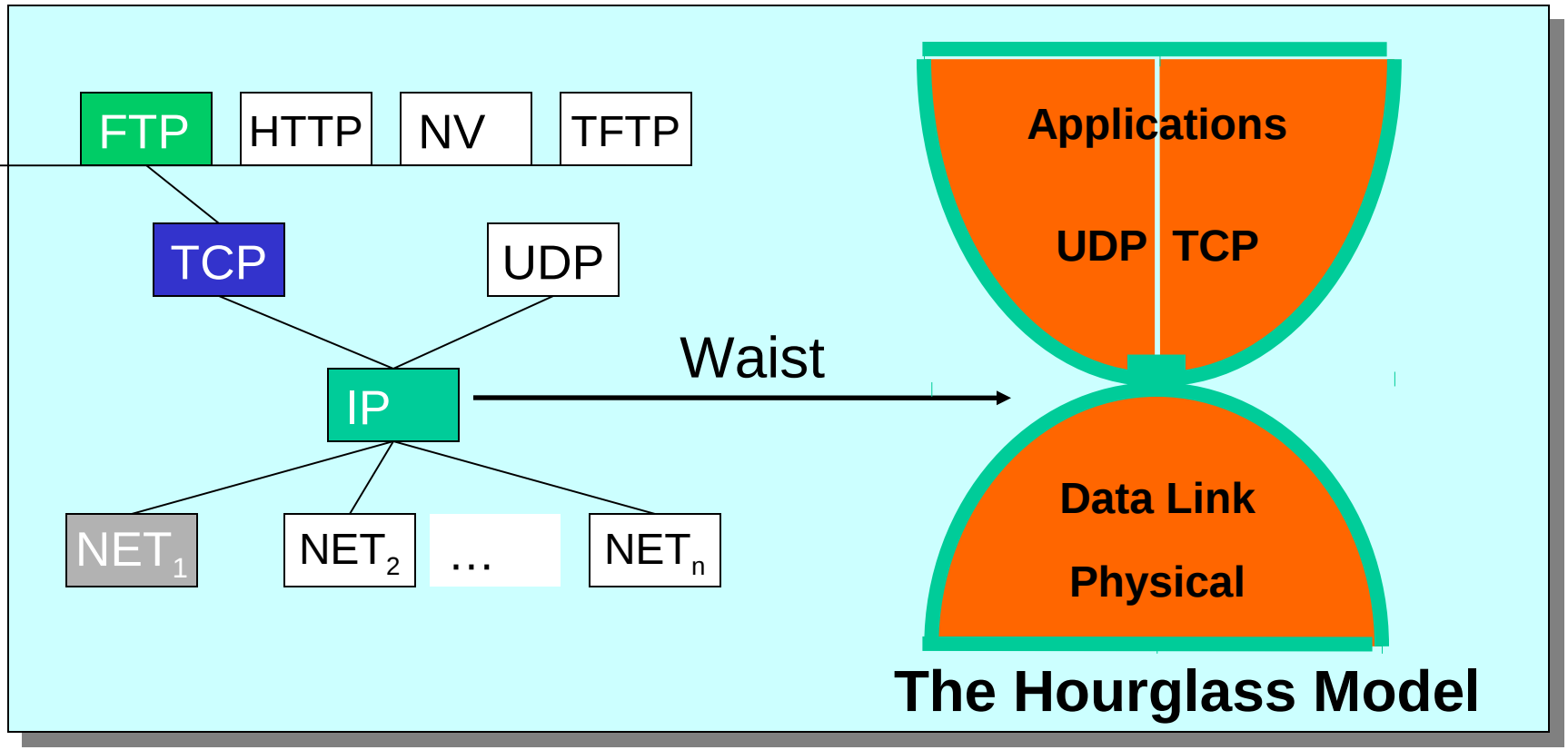


Internet Success
Layers

2. Layers "Hourglass Shape"

- IP is focal point of architecture
- Allows common method of exchanging packets
- But, also allows anything to run over IP and IP runs over a multitude of mediums

The Narrow Waist of IP



The waist facilitates interoperability

Physical layer also has multiple protocols

Above and Below the Waist

- IP over Anything
  - Protocol runs on anything - physical layer
  - Accommodate innovation in link technology
- Anything over IP
  - Many transport protocols can be built
  - Though, in practice, mostly TCP and UDP
    - TCP: ordered, reliable stream of bytes
    - UDP: simple (unreliable) message delivery
    - Realtime protocols too
  - And any applications on top of that

Internet Successful

3. Decentralized Control

- Network organization critical to success of and adaptability of network
- Could have one entity deciding everything and imposing updates on everything
- Simpler and more efficient, but not feasible in the long run
- Turns out decentralization is better for large scale, networks

Benefits of Decentralization: Scalability

- a. Scalability
  - Addressing
    - Internet routers only need to know how to reach ***blocks*** of addresses (e.g., 12.0.0.0/8)
  - Routing
    - Link failure in one network is typically not visible in another
  - Naming
    - Look-up of www.cnn.com doesn't go to same server as look-up of www.princeton.edu

Benefits of Decentralization: Autonomy

- b. Autonomy
  - Allow different parties to manage different parts of the system, and apply their own policies
  - Addressing
    - ARIN delegates address space to AT&T, who delegates smaller blocks to its customers
  - Routing
    - AT&T controls flow of traffic through its backbone, others do the same
  - Naming
    - CNN controls addresses for www.cnn.com

Problems Related to Design Decisions

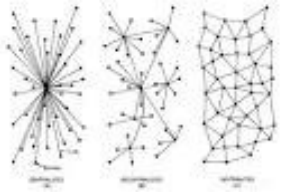
- Turns out that not all design decisions resulted in perfect network
- There are continuing problems related to some of the original design decisions
  - Think about current Internet problems
- What are some problems?

Problems Tied to Design Decisions

- Programmable Hosts – Security Issues
  - Easy to spoof IP addresses, e-mail addresses, …
  - Incentives for users to violate congestion control
  - Malicious users can launch Denial-of-Service attacks
- Best-effort packet-delivery service
  - Inefficient in high-loss environments (wireless)
  - Poor performance for interactive applications

Problems Tied to Design Decisions

- Layering and the IP narrow waist
  - Low efficiency due to many layers of headers
  - Poor visibility into underlying layers
  - Complex network management due to multiple interconnected protocols and systems



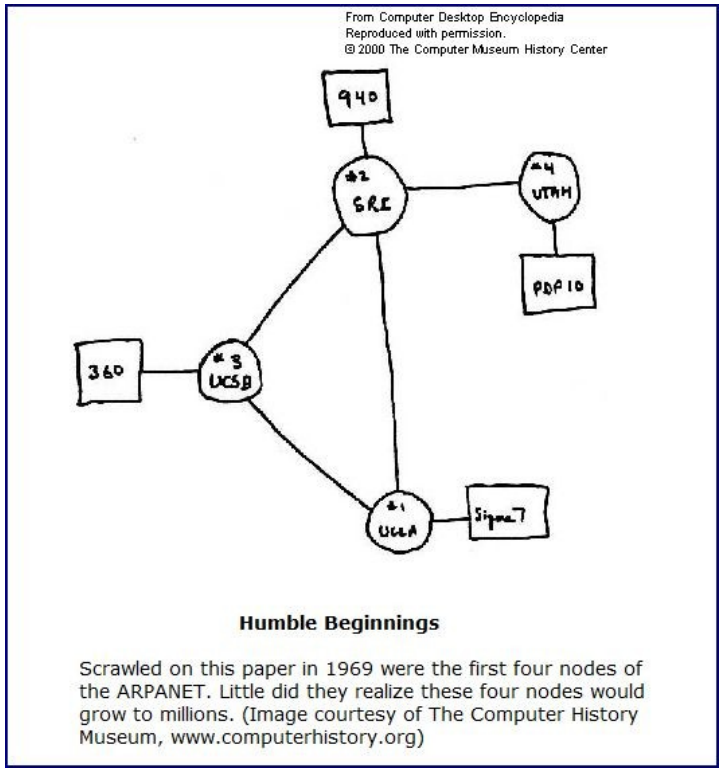
- Decentralized control
  - Hierarchical addressing makes mobility difficult, and requires careful configuration
  - Autonomy makes measurement, and troubleshooting plus accountability hard
  - Autonomy makes protocol changes difficult

Recurring Problems

- Security Issues
  - Protocols that rely on good behavior
  - Incomplete or non-existent registries, keys, …
- Network management
  - Many coupled, decentralized control loops
  - Limited visibility into layers and networks
- Application performance requirements
  - Real-time, interactive applications

Current Internet Recap

- Original Design
  - End-to-end Model
    - Hosts talk to hosts directly
  - Smart endpoints, dumb core
  - Protocols in Layers – Stack
  - Users not in the model
  - Add functionality as software
  - No security, No Quality of Service



Future Design Internet

Current Internet

- Who manages the current Internet?

Who Manages the Internet?

- Several Groups, Actually ….
- The Internet Society A nonprofit organization that develops Internet standards, policies and education
  http://www.isoc.org/
  - Internet Society (ISOC) organizational home

    Internet Engineering Task Force (IETF)
- The Internet Engineering Task Force (IETF)

  http://www.ietf.org/
  - International organization, has open membership policy with several working groups
  - Each working group concentrates on a specific topic, such as Internet security
  - Working groups try to maintain Internet's architecture and stability

Who Manages the Internet?

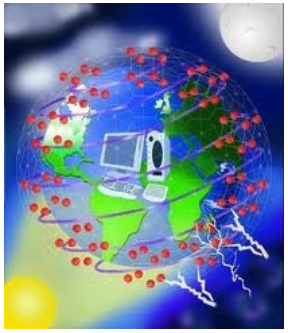
- The Internet Architecture Board (IAB) An IETF committee, IAB's mission oversee design of Internet protocols and standards

  http://www.iab.org/

- The Internet Corporation for Assigned Names and Numbers (ICANN) A private nonprofit corporation, ICANN manages the Internet's Domain Name System (DNS) http://www.icann.org/en/about/
  - **ICANN** is responsible for making sure that every domain name links to the correct IP address

    http://www.icann.org/
  - **IANA** is part of ICANN
    - Internet assigned numbers - http://www.iana.org/

Future Internet



The Internet

- Current
  - Difficult to manage huge numbers of dynamically attached devices, wireless mobility, personal area networks
  - Lacks built-in features for performance monitoring and security
- Future
  - Idea that we can't incrementally improve but need a **Clean-Slate** approach
  - Many proposals from all around the world …

Good Overview Paper

http://www.cse.wustl.edu/~jain/papers/internet.htm

Future Internet
Key Research Topics

- Security needs to be key feature and integral part of architecture
- Host-to-host packet based delivery to platform built on data, content, users instead of machines
- Must have experimental test beds for new architecture
- Mobility or ubiquitous access to network
- Cloud computing-centric architecture

One Proposed Model

- Policy Oriented Network Architecture (PONA)
  - Hosts not best end points, Users and Data as endpoints of communication
  - Promotes
    - Data Centric, User Centric and Host Centric
    - Architecture is flexible
    - New Protocol Stack

      Upper Infrastructure

      Virtualization layer - Either Users/Data mapped to actual hosts

      Lower Infrastructure

    If Data-Centric, Data is mapped to publisher host

    If User-Centric, Users are mobile so take communication with them

http://www.cse.wustl.edu/~jain/papers/pona.htm

Worldwide Future Internet

National Science Foundation
WHERE DISCOVERIES BEGIN

US Projects

Future Internet Design (FIND)

- FIND invites research community to consider requirements for a global network of 15 years from now, and asks

- "How we could build such a network if we are not constrained by the current Internet – if we could design it from scratch"

http://www.nets-find.net

Worldwide Future Internet

National Science Foundation
WHERE DISCOVERIES BEGIN

Future Internet Architecture (FIA) - Based on FIND which funded 50 projects

- Next phase to pull together the projects,
  - Named Data Networking – UCLA – content centric model vs. packet based
  - Mobility First – Rutgers University – No fixed endpoints – mobile is now the rule
  - Nebula – Cloud computing – Univ. of Pennsylvania – speaks for itself
  - XIA – eXpressive Internet Architecture – Carnegie Mellon -

Architecture based on security

Worldwide Future Internet

US Projects

Global Environment for Network Innovations (GENI)

GENI sponsored by NSF, is a virtual laboratory and testbed for exploring future Internets at scale

"GENI creates major opportunities to understand, innovate and transform global networks and their interactions with society"

http://www.geni.net/

Worldwide Future Internet

New Future Internet initiatives have been started all over the world

- AsiaFI:
  - Asia Future Internet Forum (AsiaFI) was founded in 2007 to coordinate research and development on Future Internet among countries in Asia as well as with other continents.
  - http://www.asiafi.net/

China:

- China Next Generation Internet (CNGI)
- Started 2004, second phase 2009~
- IPv6-based
- http://www.edu.cn/cernet_1377/index.shtml

Worldwide Efforts New Internet

Korea

- **Future Internet Forum**
  - The "Future Internet Forum" aims to provide an opportunity to review the forefront information and knowledge on the timely subject of new Internet architecture and related issues. A direction for the future R&D in Internet is expected to be shaped as a result of the presentations and discussion among the experts.
- http://www.fif.kr/

Japan

- **New Generation Network Promotion Forum (NWGN)**
  - Aim to achieve a new-generation network that extends beyond the conventional IP network through new design concepts and technology.
- http://forum.nwgn.jp/english/index.html

European Union Perspective

- European Union has Own View
  - "*The Internet of the future should provide better services, more intelligence, greater involvement and participation. It needs to reflect the European social and ethical values: free, open and more interoperable.*"
    - The European Commission aims to shape this future internet as a powerful, open, data-driven, user-centric, interoperable platform
- This group is calling for
  - Open comment period – Nov – Jan 2017
  - Online documents and discussion
  - Research program
  - Workshops
- Seems to be very inclusive … and very current

https://ec.europa.eu/digital-single-market/en/next-generation-internet-initiative

Problems and Issues
Moving Forward

Lack of infrastructure-level (and service-level) support for e.g.

- Monitoring
- Security
- Resilience

- Inertia towards change
  - IPv4, BGP...

Future Trends

Various stakeholders have differing/conflicting requirements

- End Users
- Telecommunications Service Provider
- Regulatory & Other Government Agencies
- Protocol Developer / Standardization Bodies / Hardware & Software Manufacturers
- Application Developers
- Military

Future Trends Conclusion

Requirements analysis outcome

- Different stakeholders want different things ...and conflicting things
- Heterogeneity will rule
- Conclusion:

  No “one-size-fits-all” solution

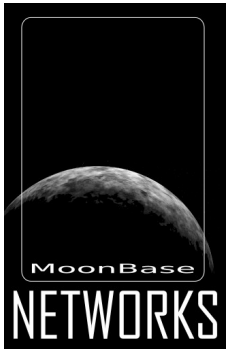
Future Trends Conclusion

- Way Forward
  - No patches to current Internet
    Clean-slate idea
  - Future architecture must support evolution
    - Potential user needs
  - Out of all the proposals there will be winners and losers

Summary

- Designing a successful network is challenging
- Many requirements
- Design decisions can allow a network to adapt successfully to change over time
- Some of the attributes of large-scale networks are similar to any complex system

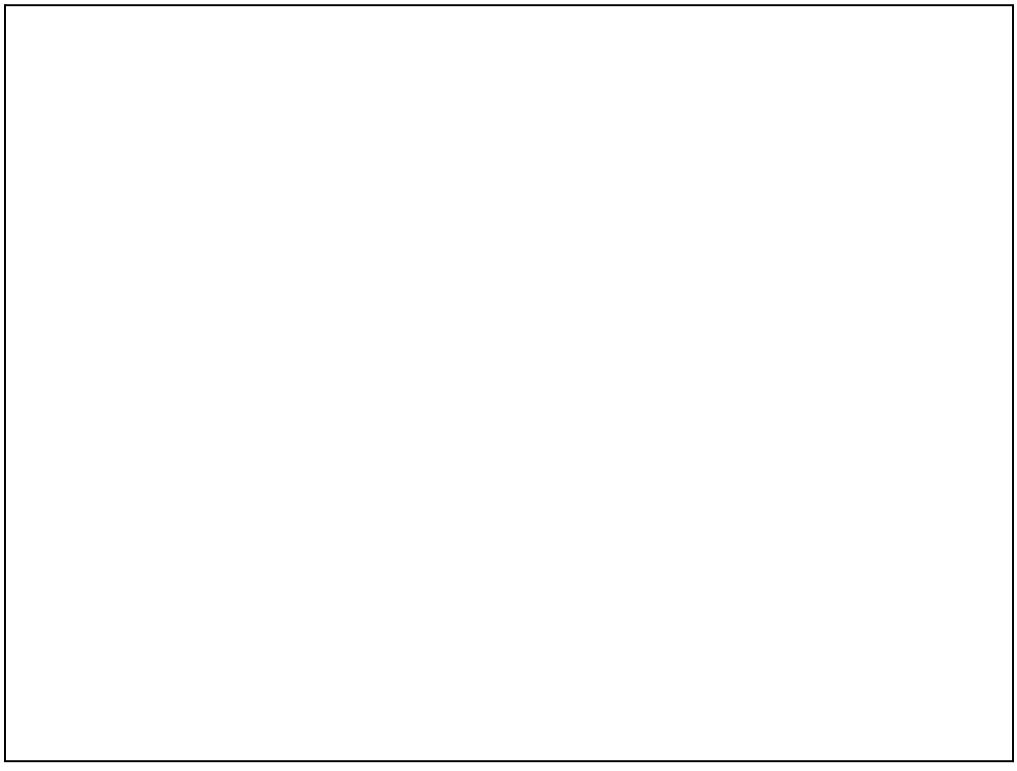
Are there networks on the moon?

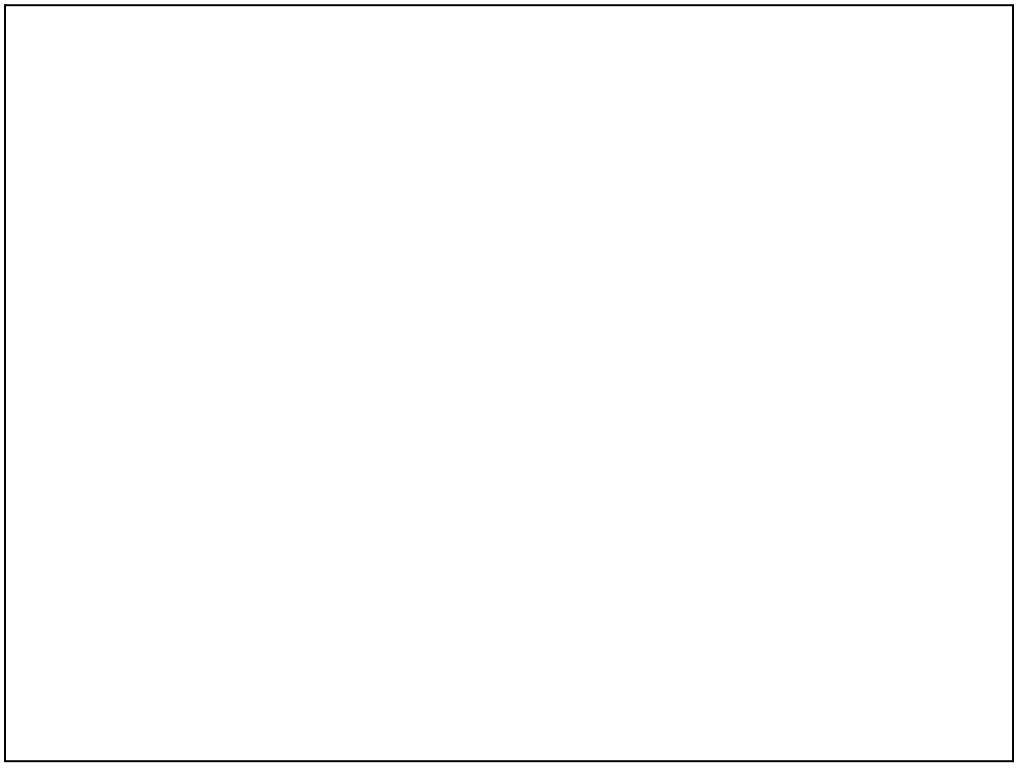


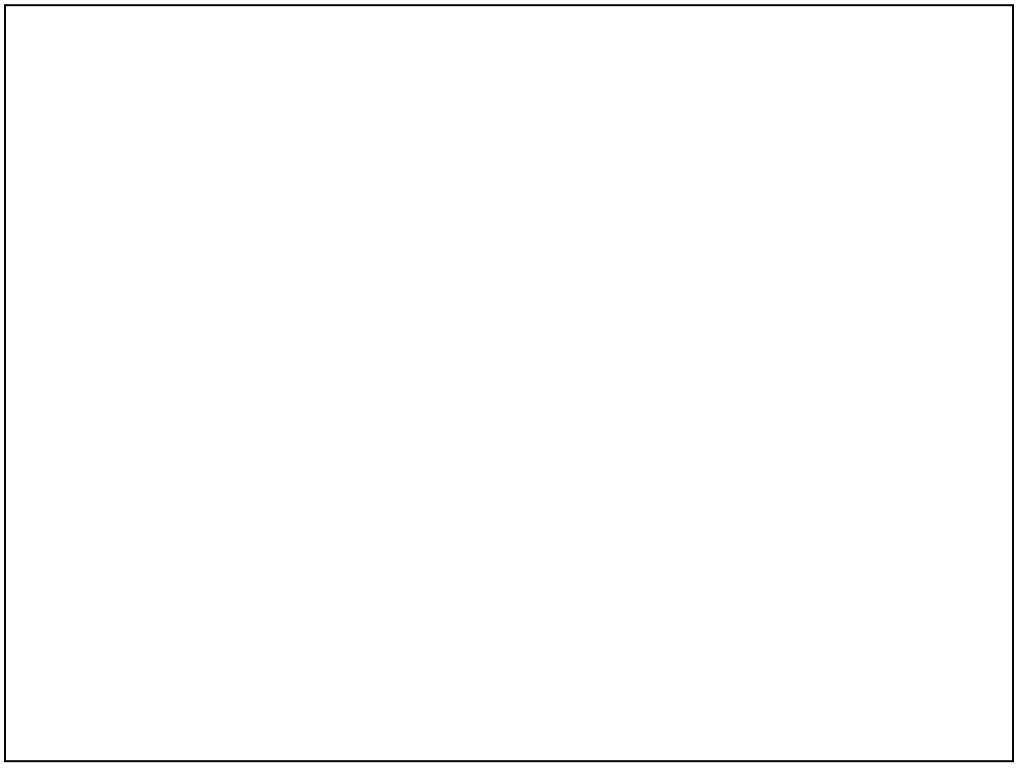
Reading and Assignment:

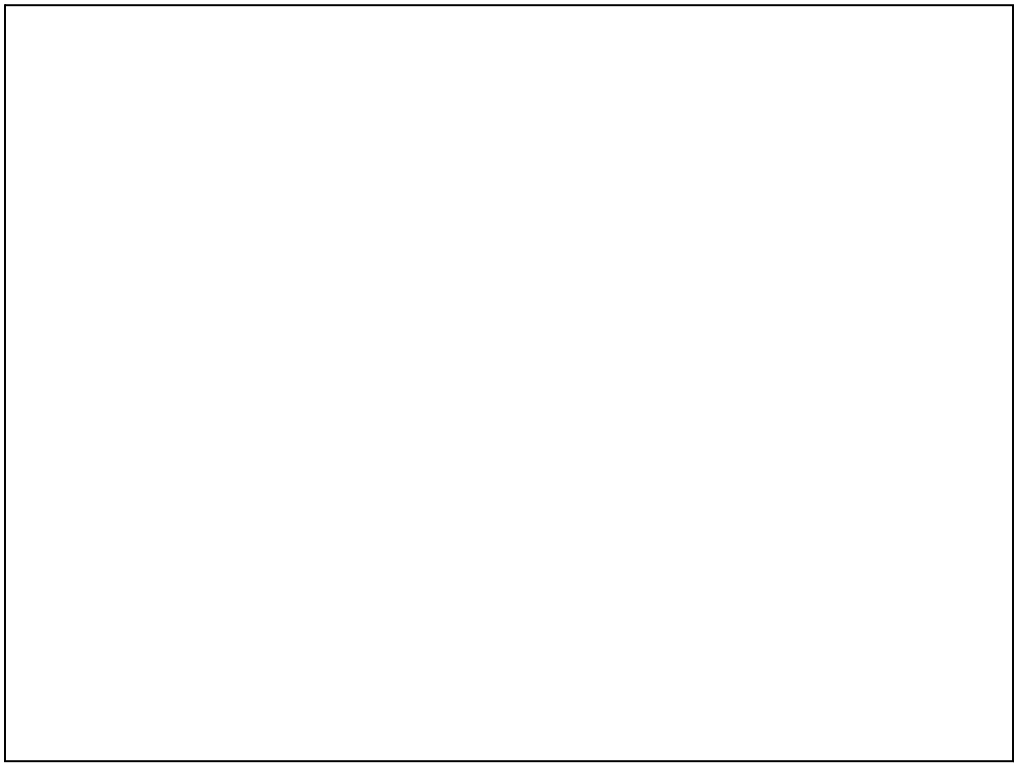
Read the papers and we talk about them on **Wednesday**

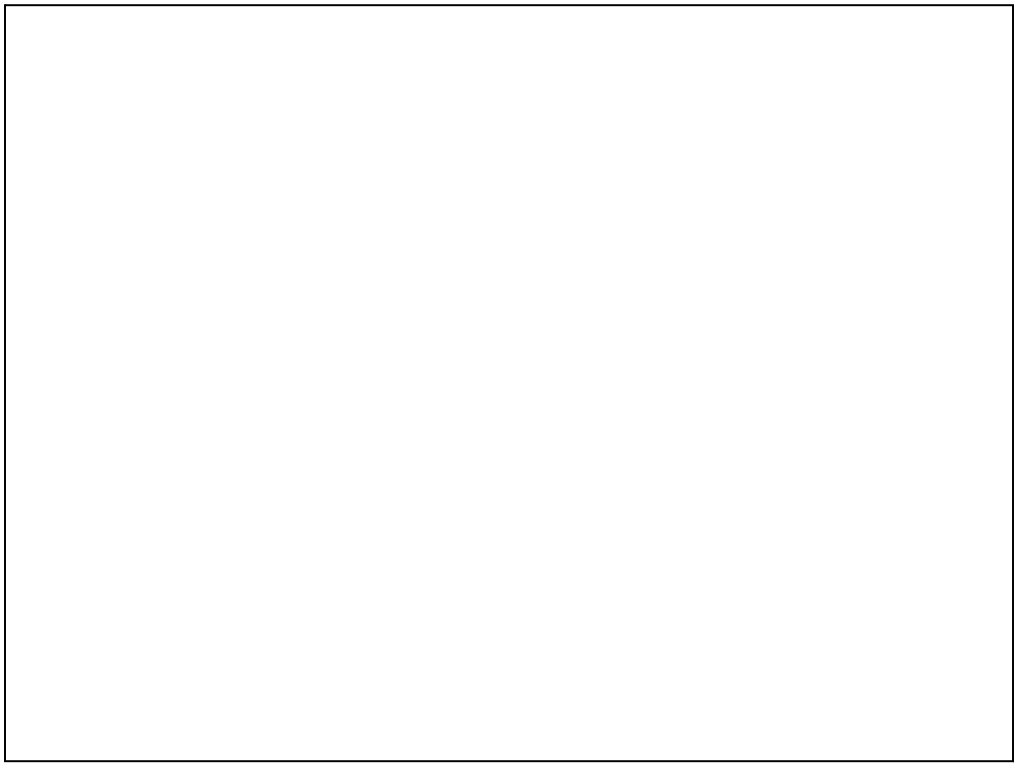
See Assignments page.

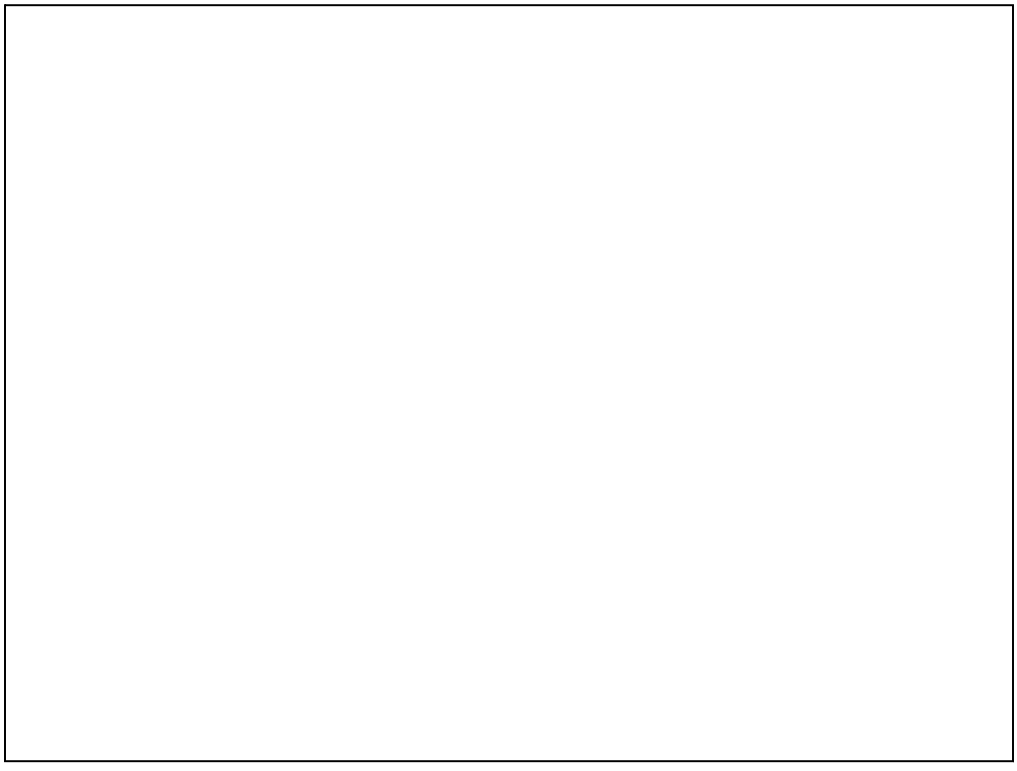


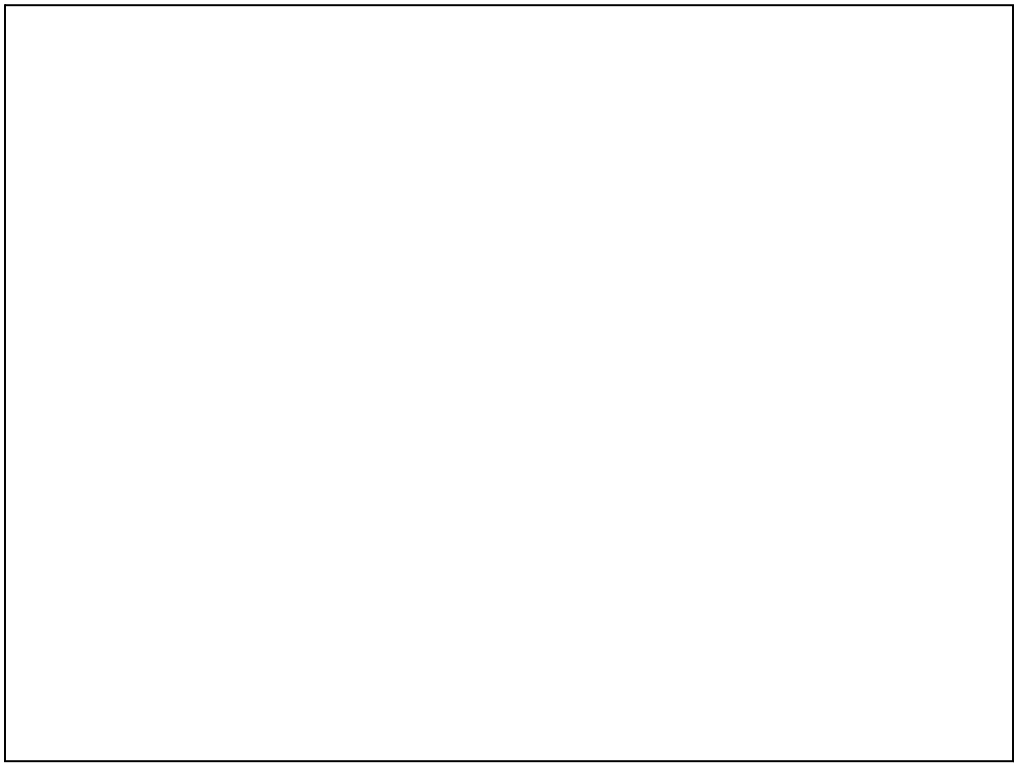


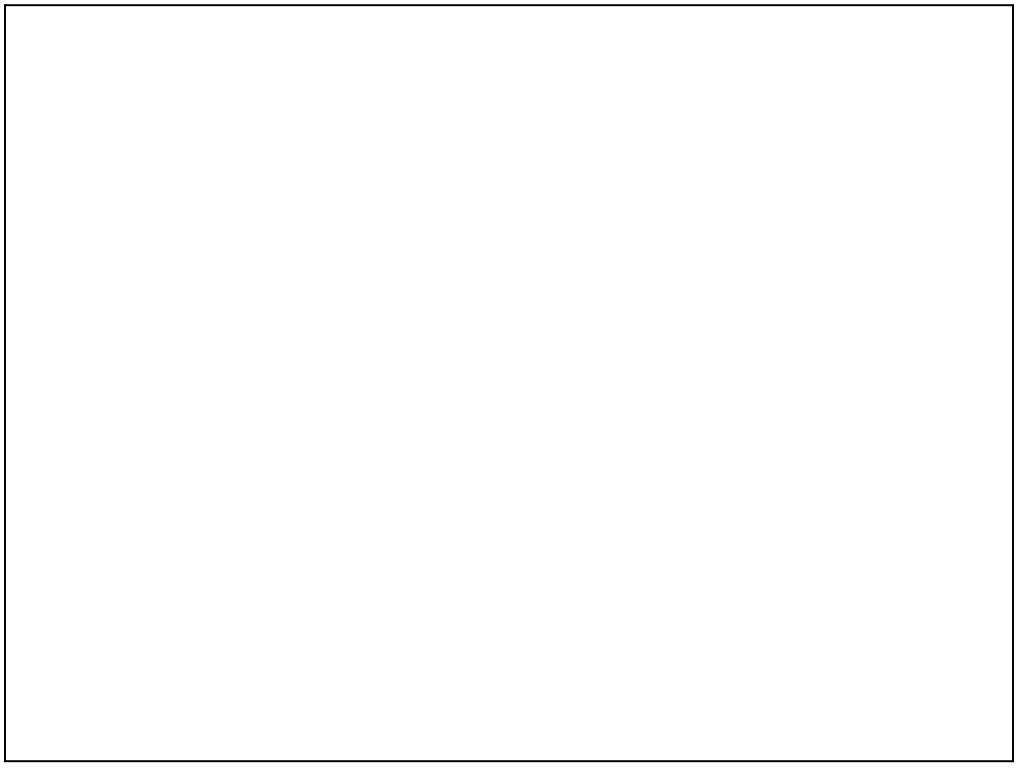


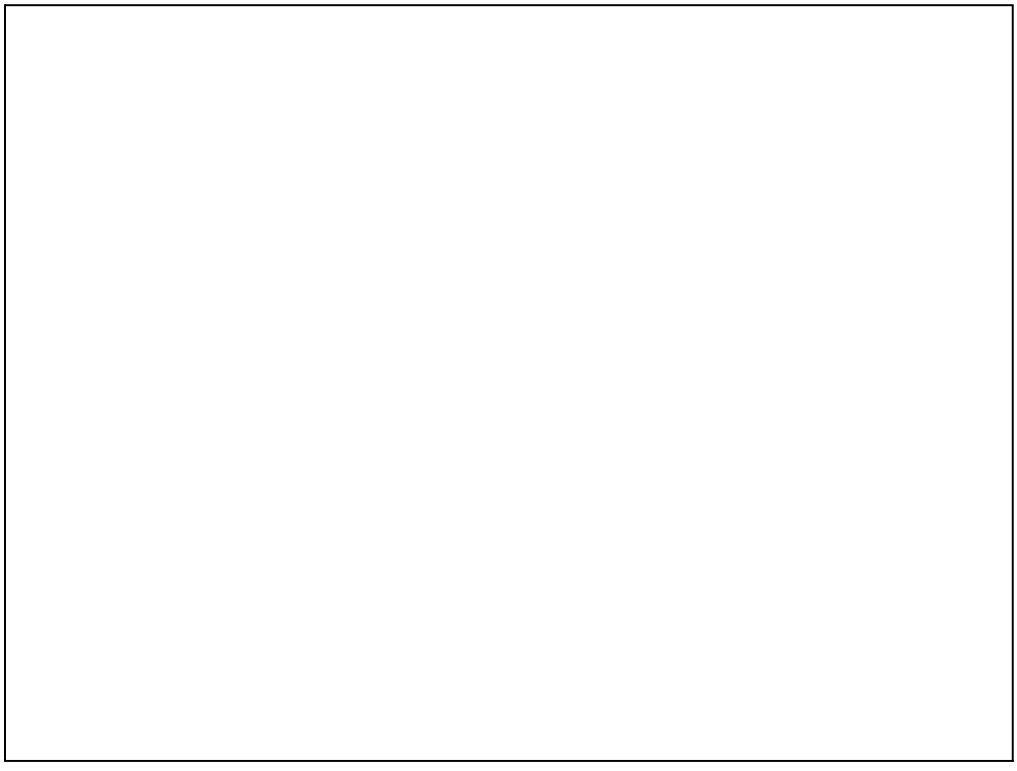


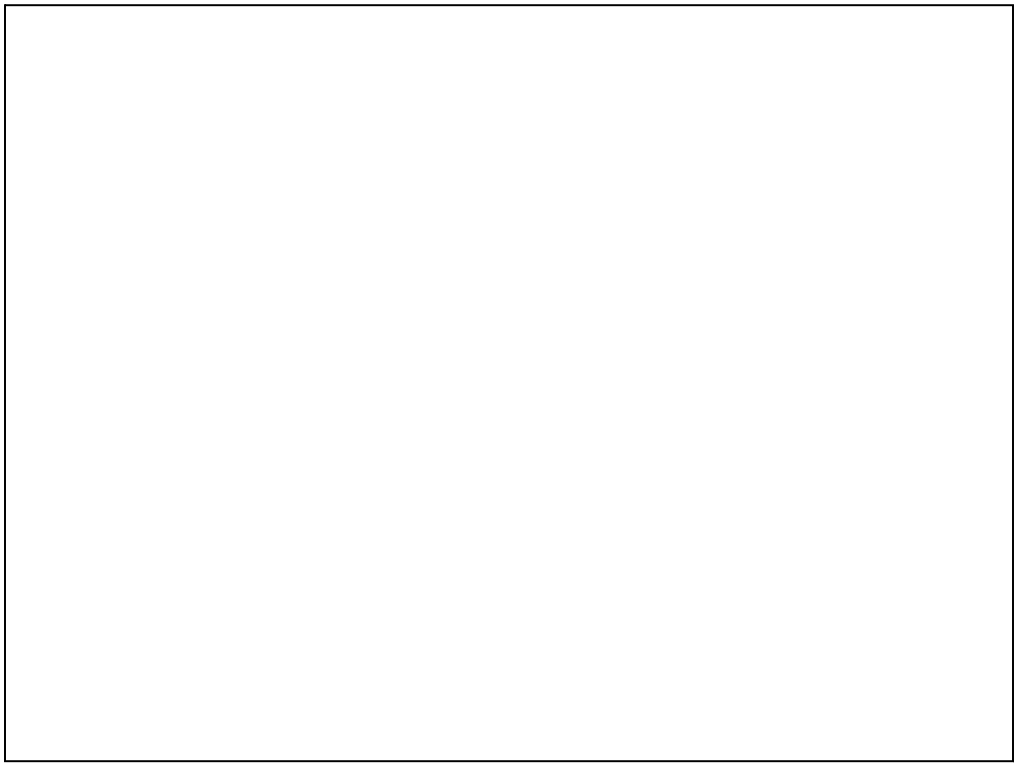


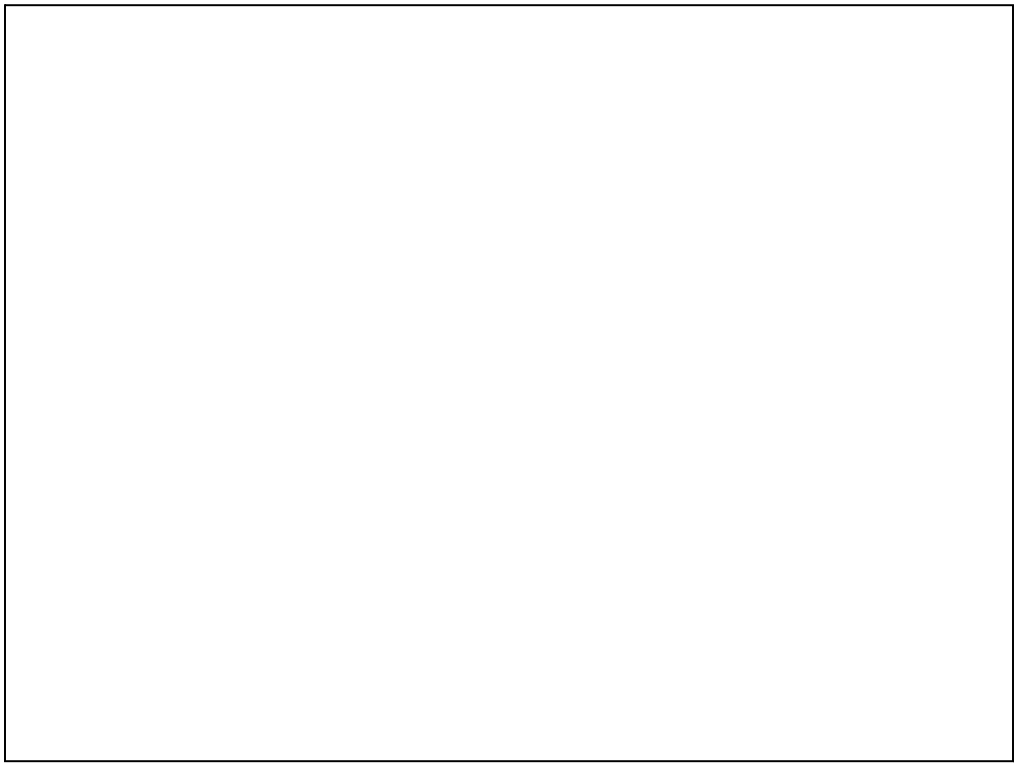


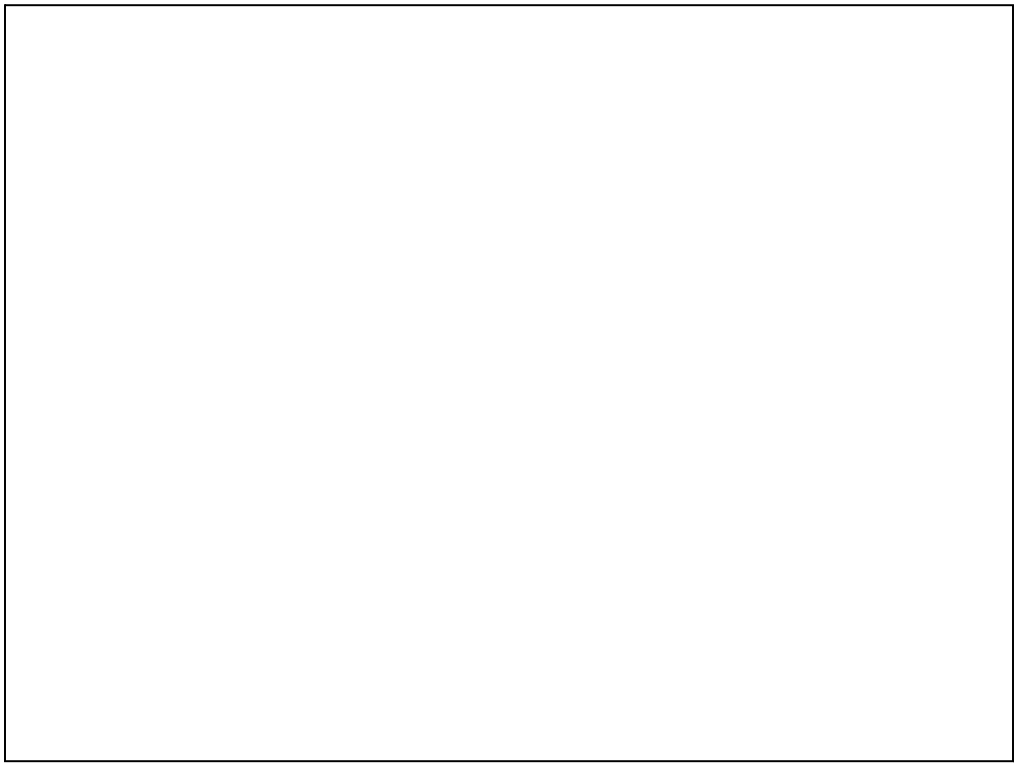


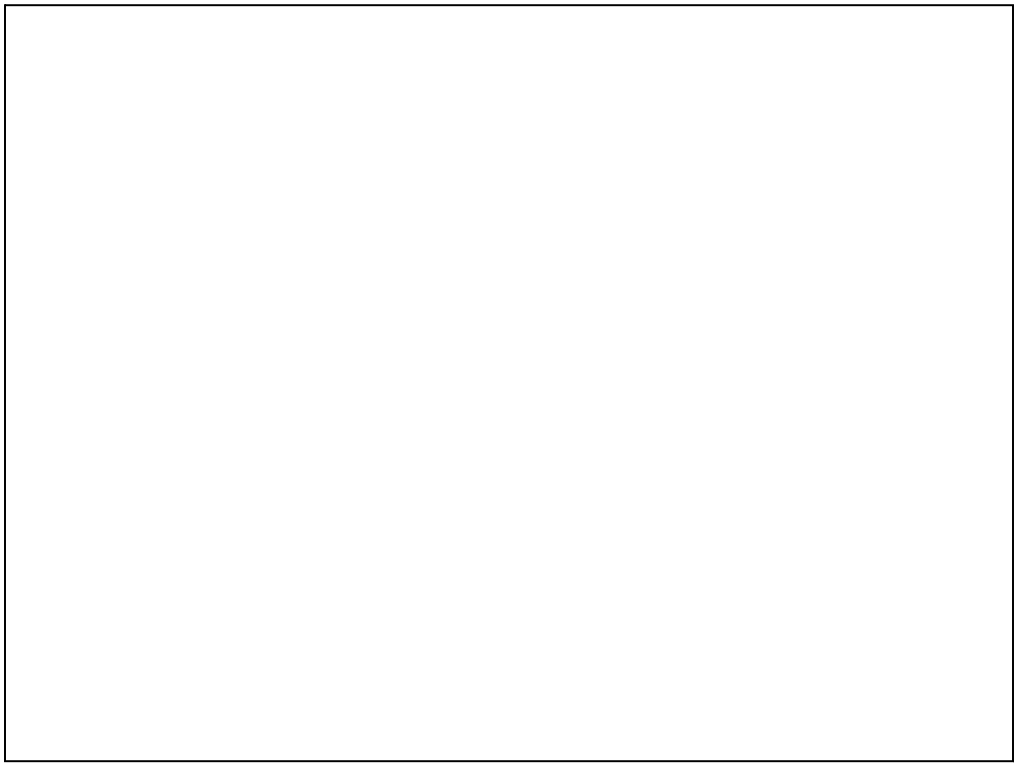


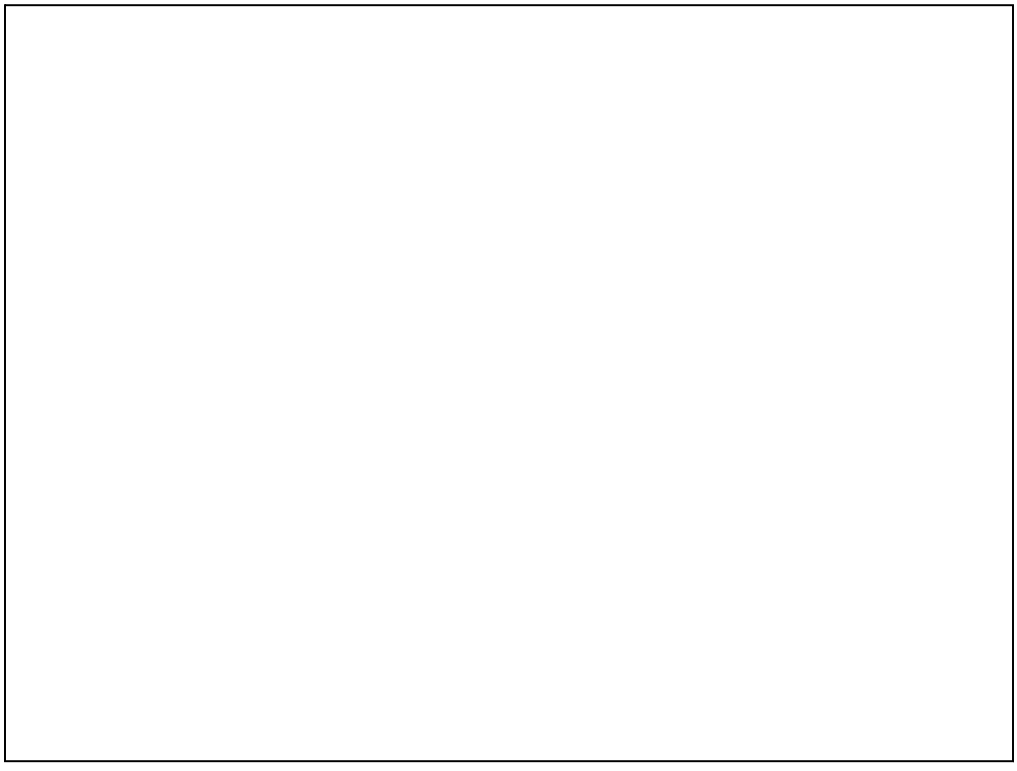


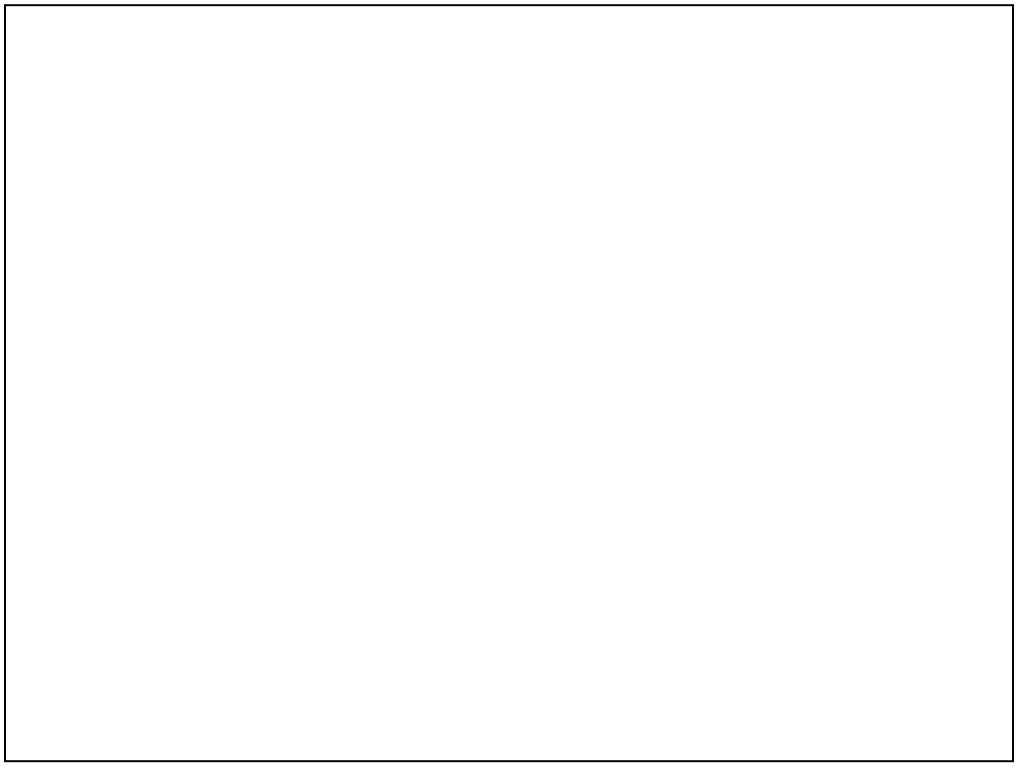












Reliability and Redundancy

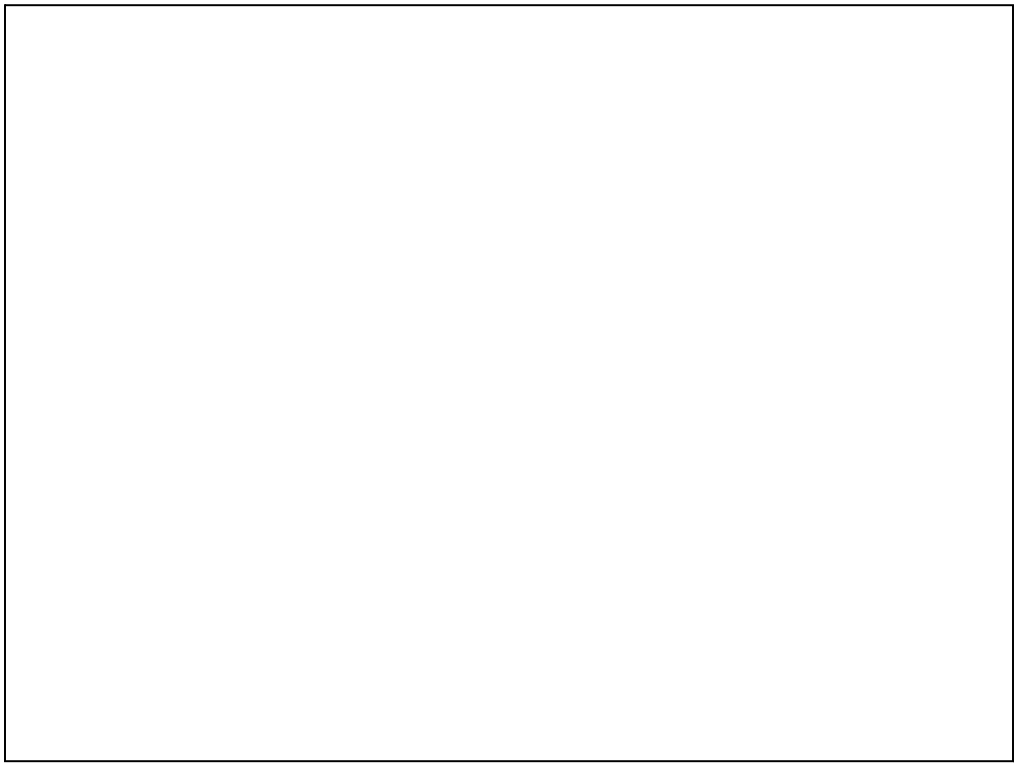
- Internet is most robust communications network ever designed
- Seems to be able to adapt itself to damage or outages to individual sections

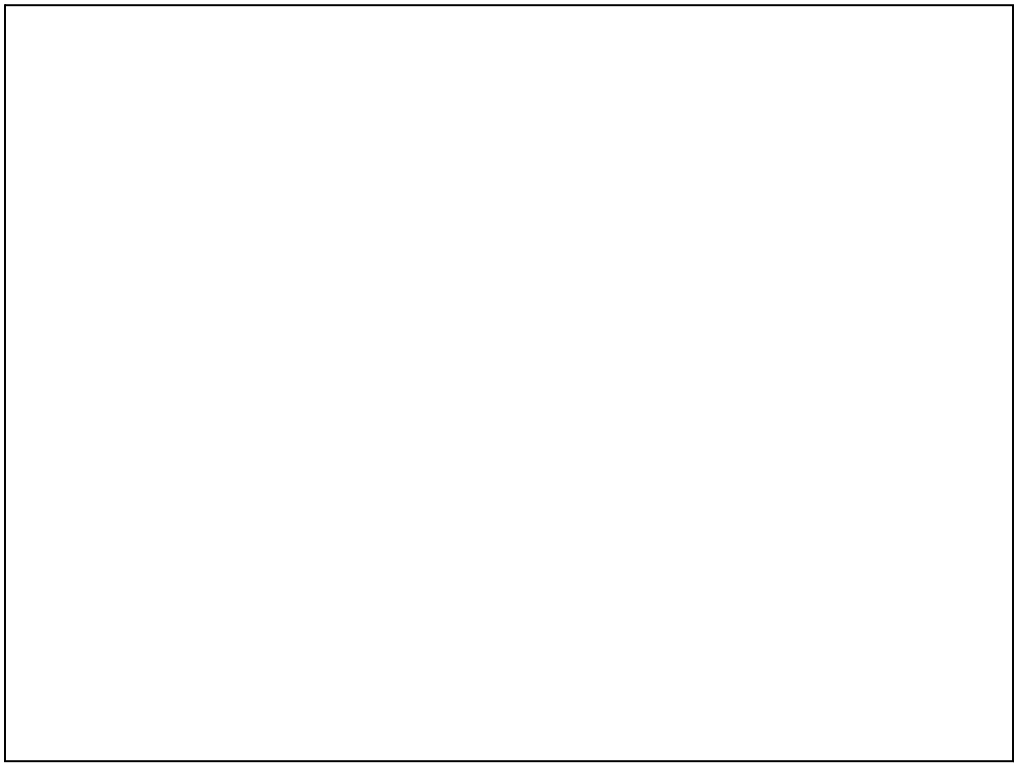
Reliability and Redundancy

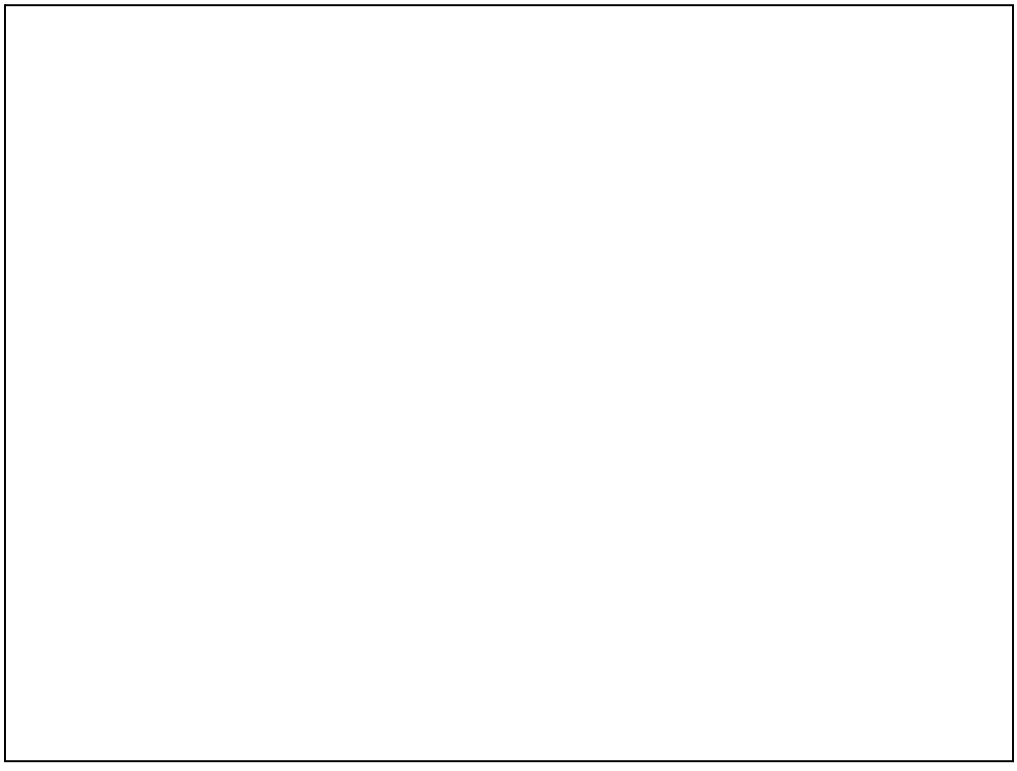
- Internet has no single point of control
  - There is an administration by coalition of participants
  - Loss of individual computers and networks does not affect its overall reliability
  - Protocols designed to operate autonomously, they fix themselves
    - **Example:** RIP, OSPF and BGP find new routes if routes become unavailable
  - One feature helps with both Reliability and Redundancy

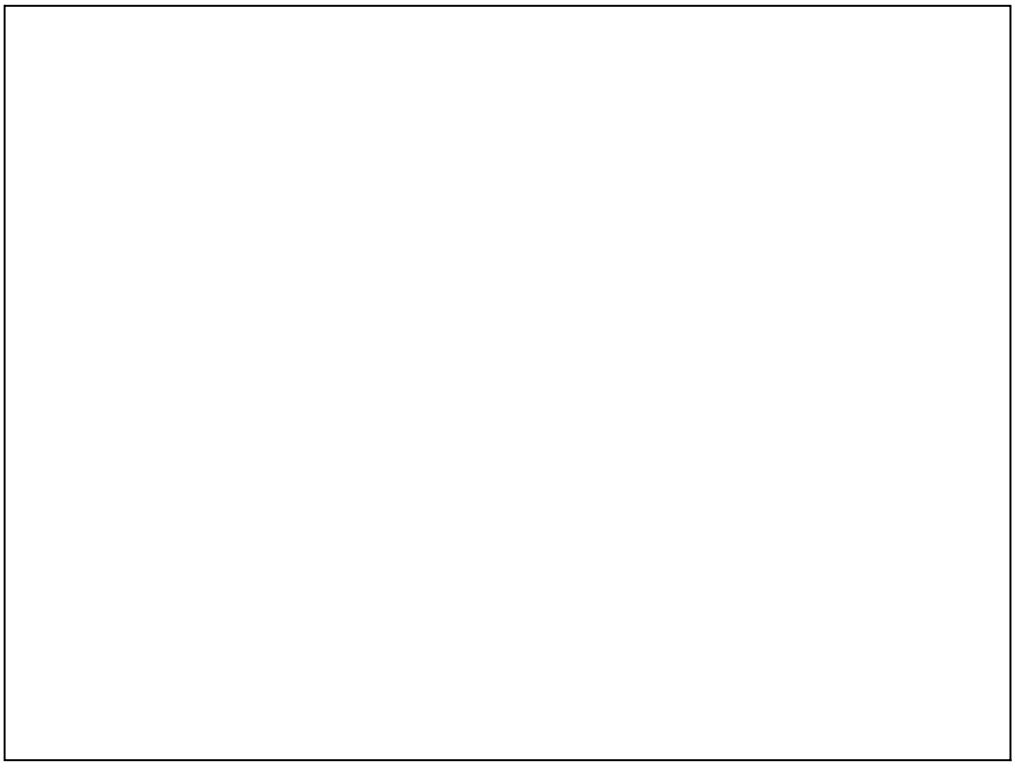
Internet Success

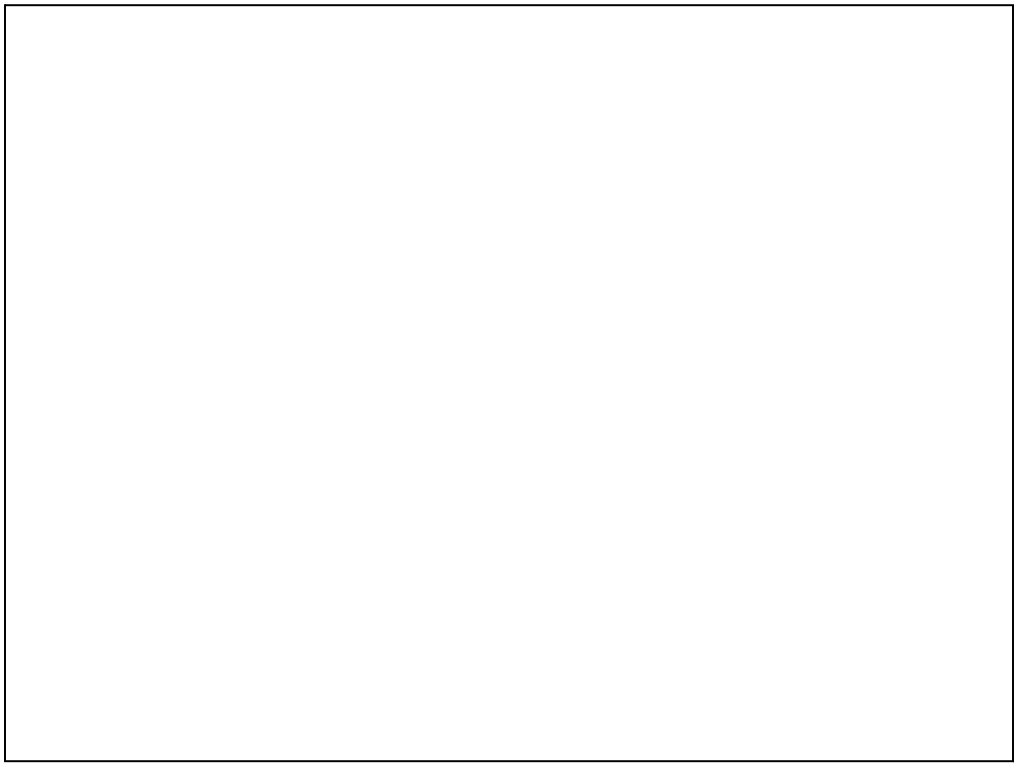
- Three Main Decisions
  1. Network Applications are just software
  2. Layered Architecture
     - Separation of Services by layer
     - One common protocol IP in the middle
  3. Decentralized Control

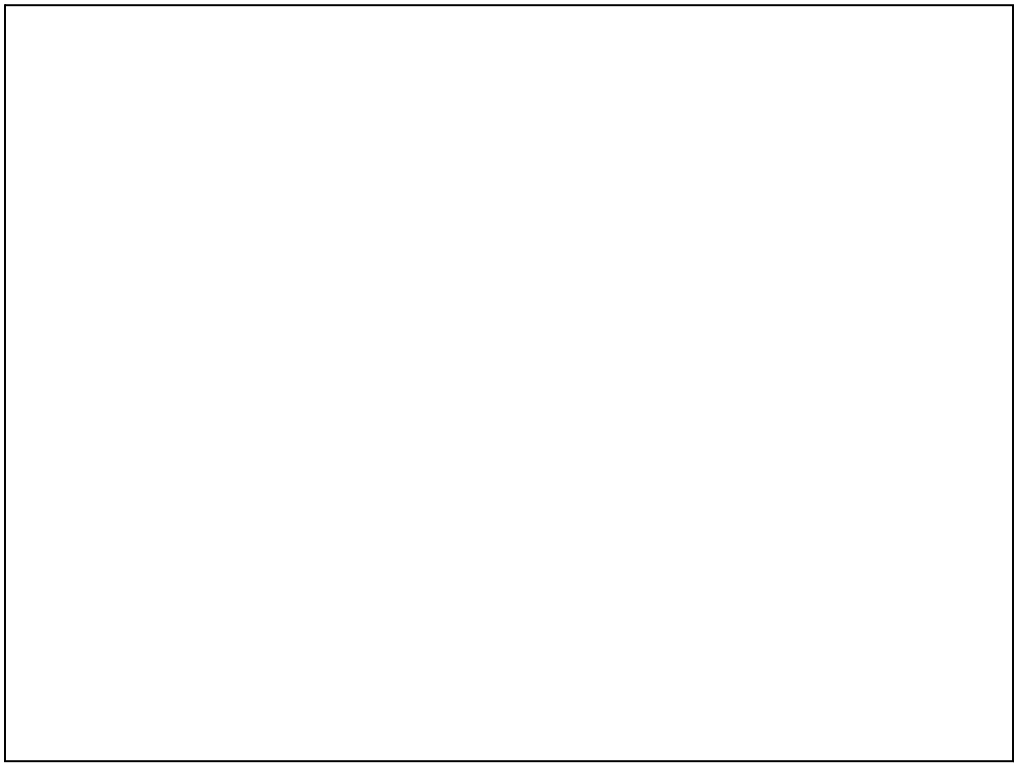


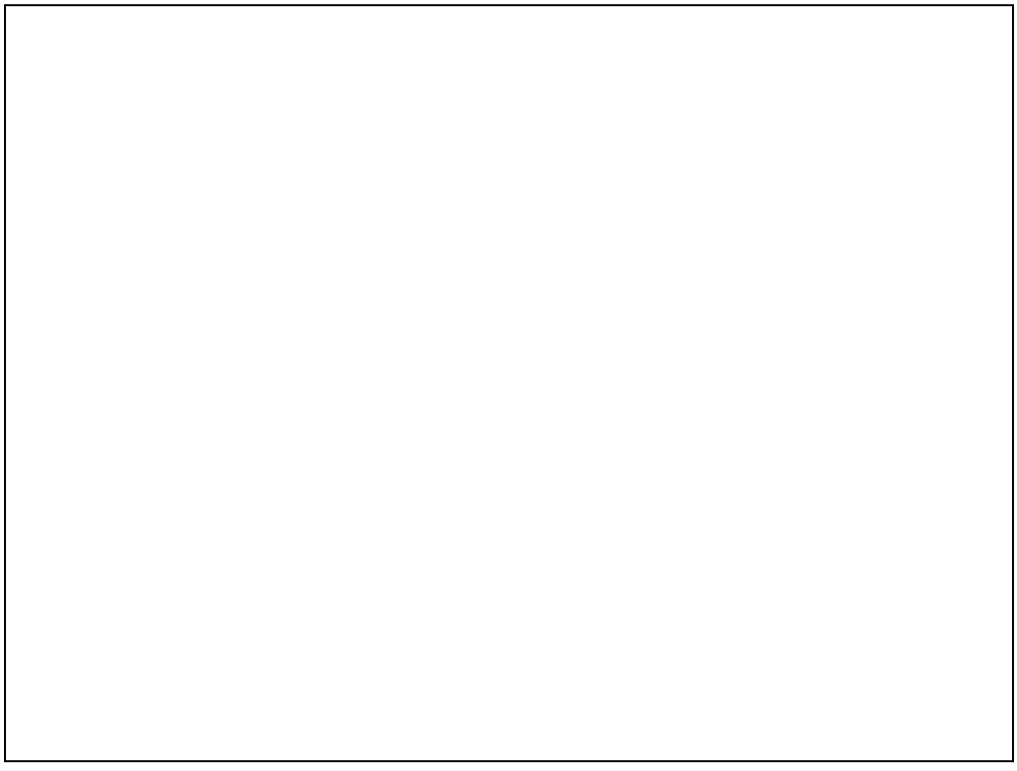


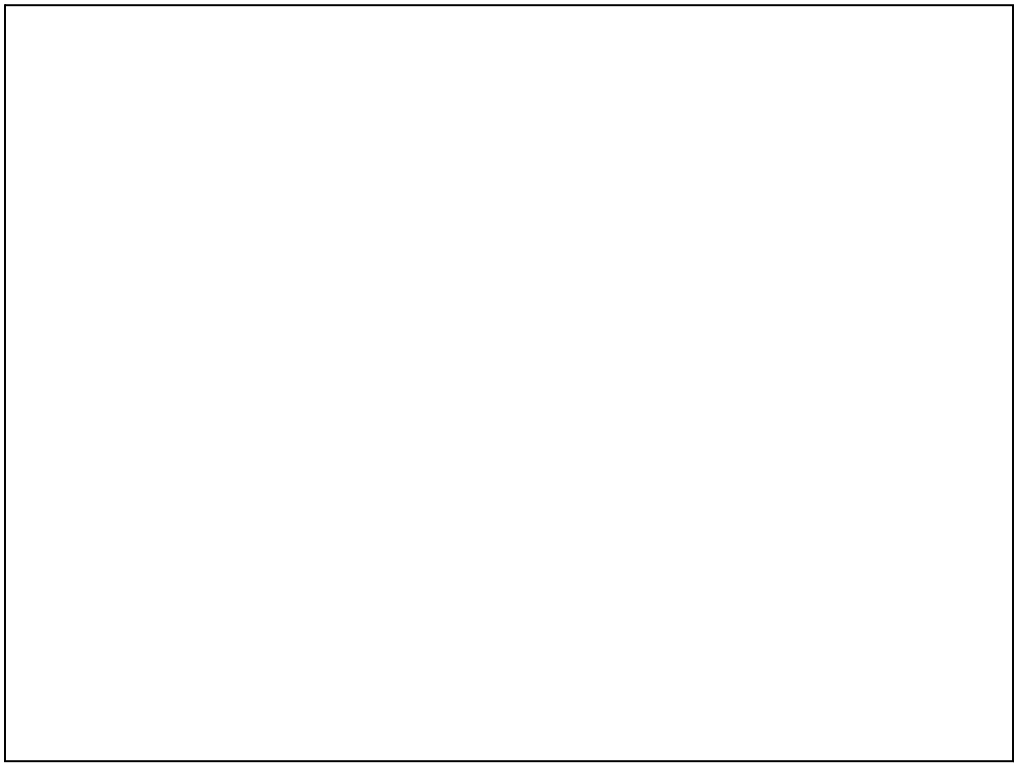


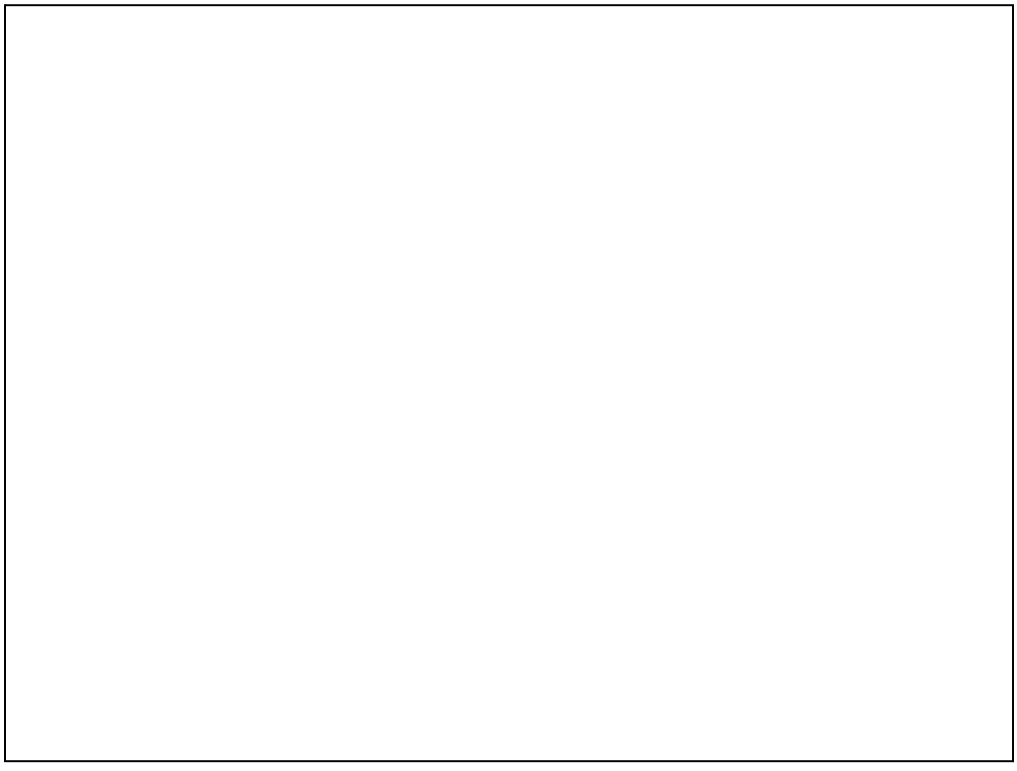


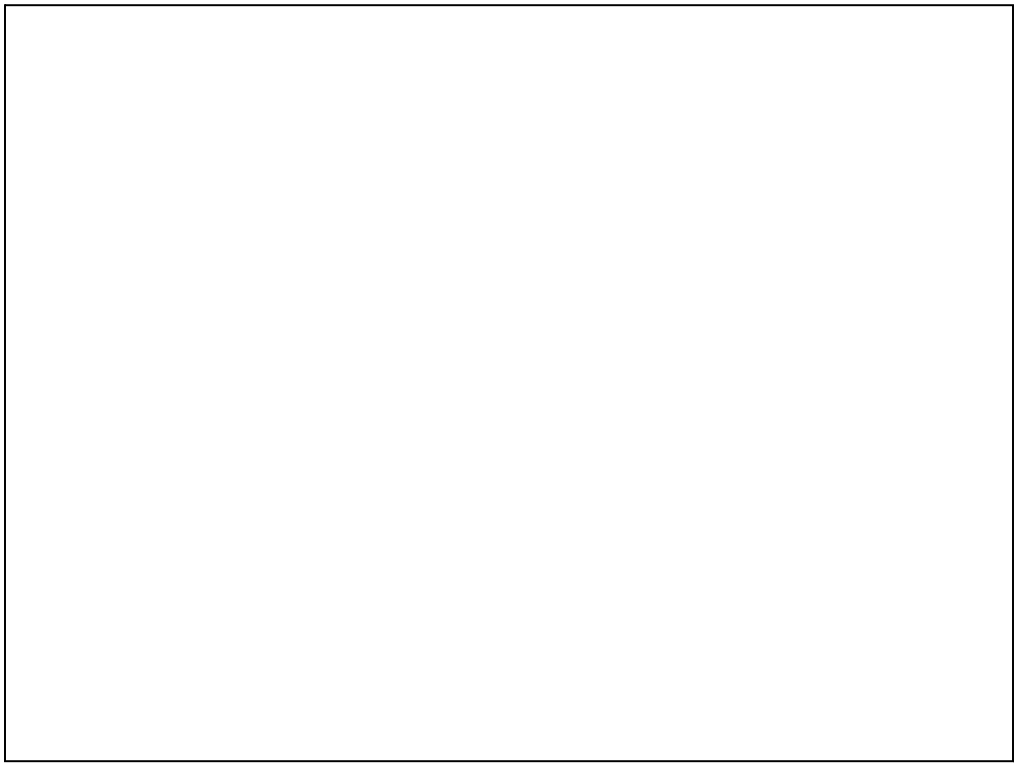


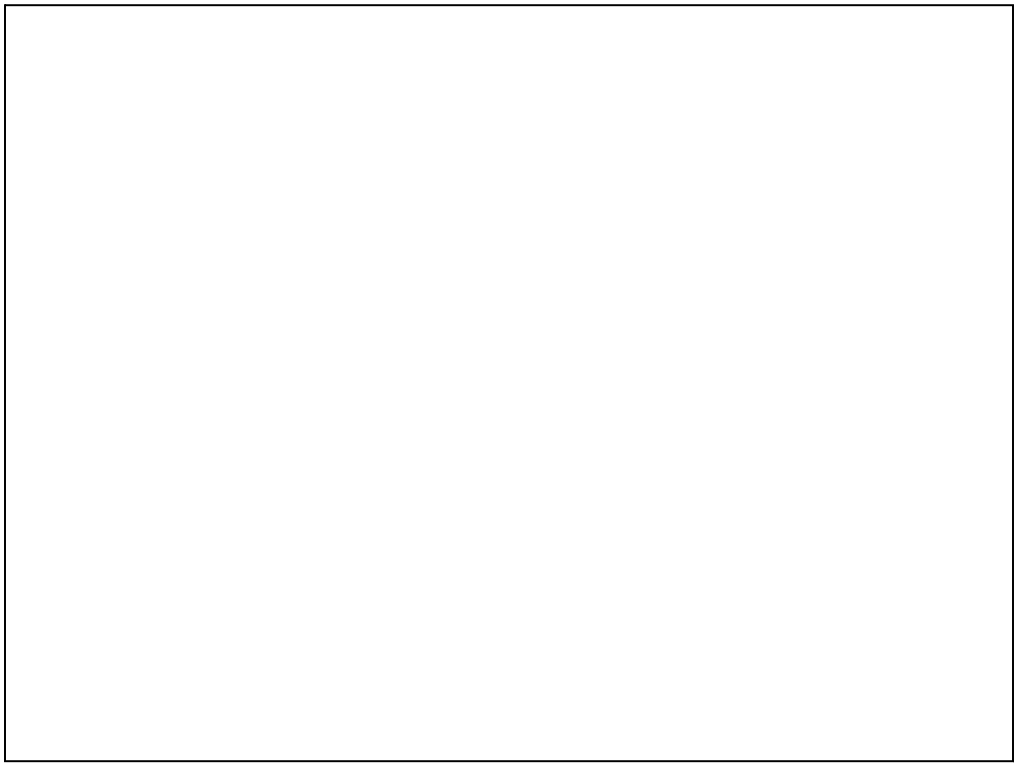


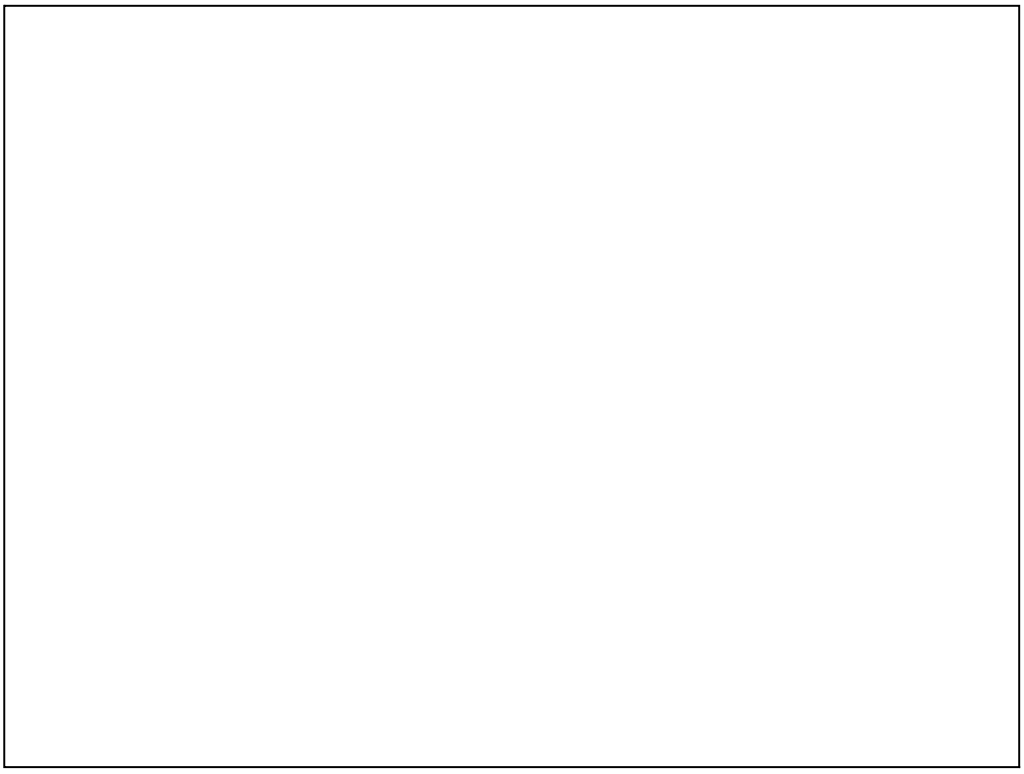






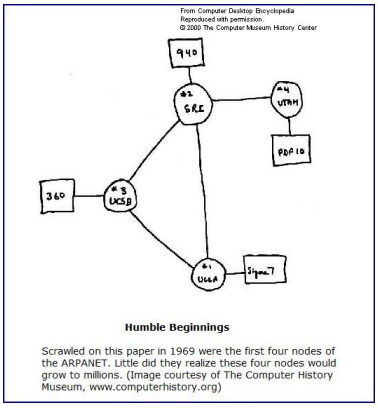






Current Internet Recap

- Original Design
  - End-to-end Model
    - Hosts talk to hosts directly
  - Smart endpoints, dumb core
  - Protocols in Layers – Stack
  - Users not in the model
  - Add functionality as software
  - No security, No Quality of Service



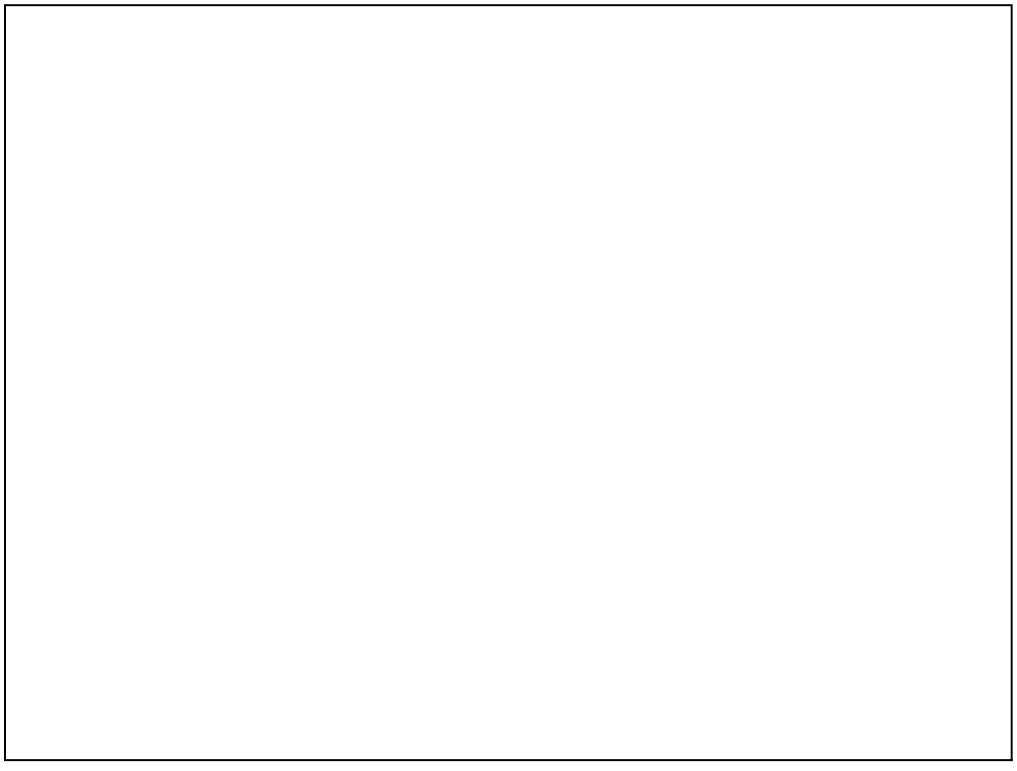
Humble Beginnings

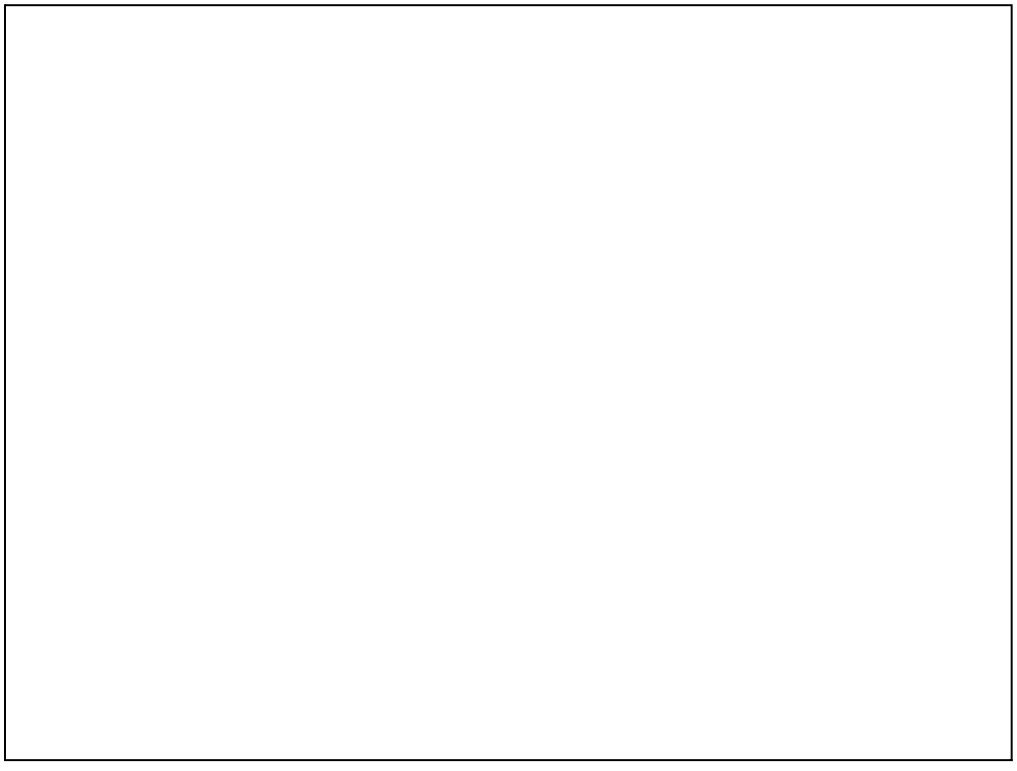
Scrawled on this paper in 1969 were the first four nodes of the ARPANET. Little did they realize these four nodes would grow to millions. (Image courtesy of The Computer History Museum, www.computerhistory.org)

Future Design Internet

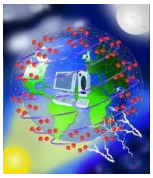
Current Internet

- Who manages the current Internet?





Future Internet



The Internet

- Current
  - Difficult to manage huge numbers of dynamically attached devices, wireless mobility, personal area networks
  - Lacks built-in features for performance monitoring and security
- Future
  - Idea that we can't incrementally improve but need a **Clean-Slate** approach
  - Many proposals from all around the world …

Good Overview Paper

http://www.cse.wustl.edu/~jain/papers/internet.htm

Future Internet
Key Research Topics

- Security needs to be key feature and integral part of architecture
- Host-to-host packet based delivery to platform built on data, content, users instead of machines
- Must have experimental test beds for new architecture
- Mobility or ubiquitous access to network
- Cloud computing-centric architecture

One Proposed Model

- Policy Oriented Network Architecture (PONA)
  - Hosts not best end points, Users and Data as endpoints of communication
  - Promotes
    - Data Centric, User Centric and Host Centric
    - Architecture is flexible
    - New Protocol Stack

      Upper Infrastructure

      Virtualization layer - Either Users/Data mapped to actual hosts

      Lower Infrastructure

      If Data-Centric, Data is mapped to publisher host

      If User-Centric, Users are mobile so take communication with them

http://www.cse.wustl.edu/~jain/papers/pona.htm

Worldwide Future Internet

National Science Foundation
WHERE DISCOVERIES BEGIN

US Projects

Future Internet Design (FIND)

- FIND invites research community to consider requirements for a global network of 15 years from now, and asks

- "How we could build such a network if we are not constrained by the current Internet – if we could design it from scratch"

http://www.nets-find.net

Worldwide Future Internet

Future Internet Architecture (FIA) - Based on FIND which funded 50 projects

- Next phase to pull together the projects,
  - Named Data Networking – UCLA – content centric model vs. packet based
  - Mobility First – Rutgers University – No fixed endpoints – mobile is now the rule
  - Nebula – Cloud computing – Univ. of Pennsylvania – speaks for itself
  - XIA – eXpressive Internet Architecture – Carnegie Mellon -

Architecture based on security

Worldwide Future Internet

US Projects

Global Environment for Network Innovations (GENI)

GENI sponsored by NSF, is a virtual laboratory and testbed for exploring future Internets at scale

"GENI creates major opportunities to understand, innovate and transform global networks and their interactions with society"

http://www.geni.net/

Worldwide Future Internet

New Future Internet initiatives have been started all over the world

Asia Future Internet Forum AsiaFI

- AsiaFI:
  - Asia Future Internet Forum (AsiaFI) was founded in 2007 to coordinate research and development on Future Internet among countries in Asia as well as with other continents.
  - http://www.asiafi.net/

China:

- China Next Generation Internet (CNGI)
- Started 2004, second phase 2009~
- IPv6-based
- http://www.edu.cn/cernet_1377/index.shtml

Worldwide Efforts New Internet

Korea

- **Future Internet Forum**
  - The "Future Internet Forum" aims to provide an opportunity to review the forefront information and knowledge on the timely subject of new Internet architecture and related issues. A direction for the future R&D in Internet is expected to be shaped as a result of the presentations and discussion among the experts.
- http://www.fif.kr/

Japan

- **New Generation Network Promotion Forum (NWGN)**
  - Aim to achieve a new-generation network that extends beyond the conventional IP network through new design concepts and technology.
- http://forum.nwgn.jp/english/index.html

European Union Perspective

- European Union has Own View
  - "*The Internet of the future should provide better services, more intelligence, greater involvement and participation. It needs to reflect the European social and ethical values: free, open and more interoperable.*"
    - The European Commission aims to shape this future internet as a powerful, open, data-driven, user-centric, interoperable platform
- This group is calling for
  - Open comment period – Nov – Jan 2017
  - Online documents and discussion
  - Research program
  - Workshops
- Seems to be very inclusive … and very current

https://ec.europa.eu/digital-single-market/en/next-generation-internet-initiative

Problems and Issues
Moving Forward

Lack of infrastructure-level (and service-level) support for e.g.

- Monitoring
- Security
- Resilience

- Inertia towards change
  - IPv4, BGP...

Future Trends

Various stakeholders have differing/conflicting requirements

- End Users
- Telecommunications Service Provider
- Regulatory & Other Government Agencies
- Protocol Developer / Standardization Bodies / Hardware & Software Manufacturers
- Application Developers
- Military

Future Trends Conclusion

Requirements analysis outcome

- Different stakeholders want different things ...and conflicting things
- Heterogeneity will rule
- Conclusion:

  No “one-size-fits-all” solution

Future Trends Conclusion

- Way Forward
  - No patches to current Internet
    Clean-slate idea
  - Future architecture must support evolution
    - Potential user needs
  - Out of all the proposals there will be winners and losers