

Designing the Future Internet

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- ❑ Short history of Communications
- ❑ Evolution of Network Architecture
- ❑ Why working for the Future New Internet Now?
- ❑ Wireless, Mobility, Accessibility, Security
- ❑ Global Environment for Networking Innovations" or GENI
- ❑ Examples of New Architectures
- ❑ Generalized Internet Networking Architecture

Communication

- ❑ Exchange of Information (Communication), makes possible the Human society and the civilization
- ❑ Improvements in communication - milestones in the history of civilization
 - Language
 - Writing
 - Books
 - Electronic communication, Internet

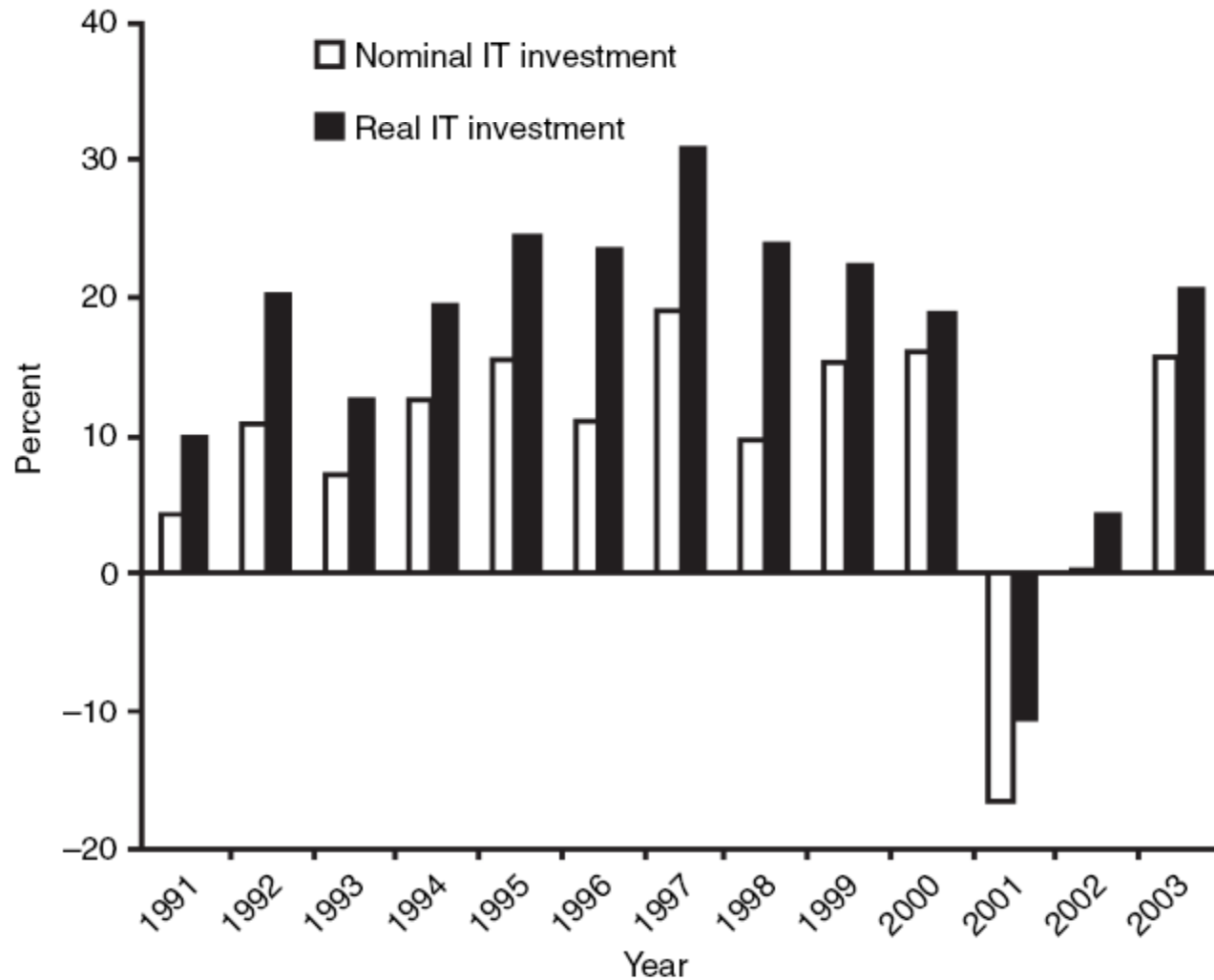
Communication with computers

- Tools created to increase and enhance our capabilities:
 - Cars, Airplanes, Microscopes, Telescopes
 - Telegraph , Telephone to communicate
 - Computers born to store and process information
 - Computers to communicate; Network - more than two computers
- Each epoch in human history is dominated by one tool:
 - Industrial Revolution: Steam engine
 - Information Age: Computers and networks
 - The Internet is the universal medium of communication

The New Economy

- ❑ Fundamental transformation in economy as businesses and individuals capitalize on new technologies, new opportunities, and national investments in computing, information, and communication technologies
- ❑ New telecommunication technologies have contributed significantly to the New Economy
 - New product capabilities for businesses and consumers
 - More efficient forms of industrial organization made possible by cheaper and more efficient communications
- ❑ While telecom sector accounts for about **one percent** of US economy, it is responsible for generating about **ten percent** of the nation's economic growth
 - How to sustain or improve on this factor of ten?

The Bubble

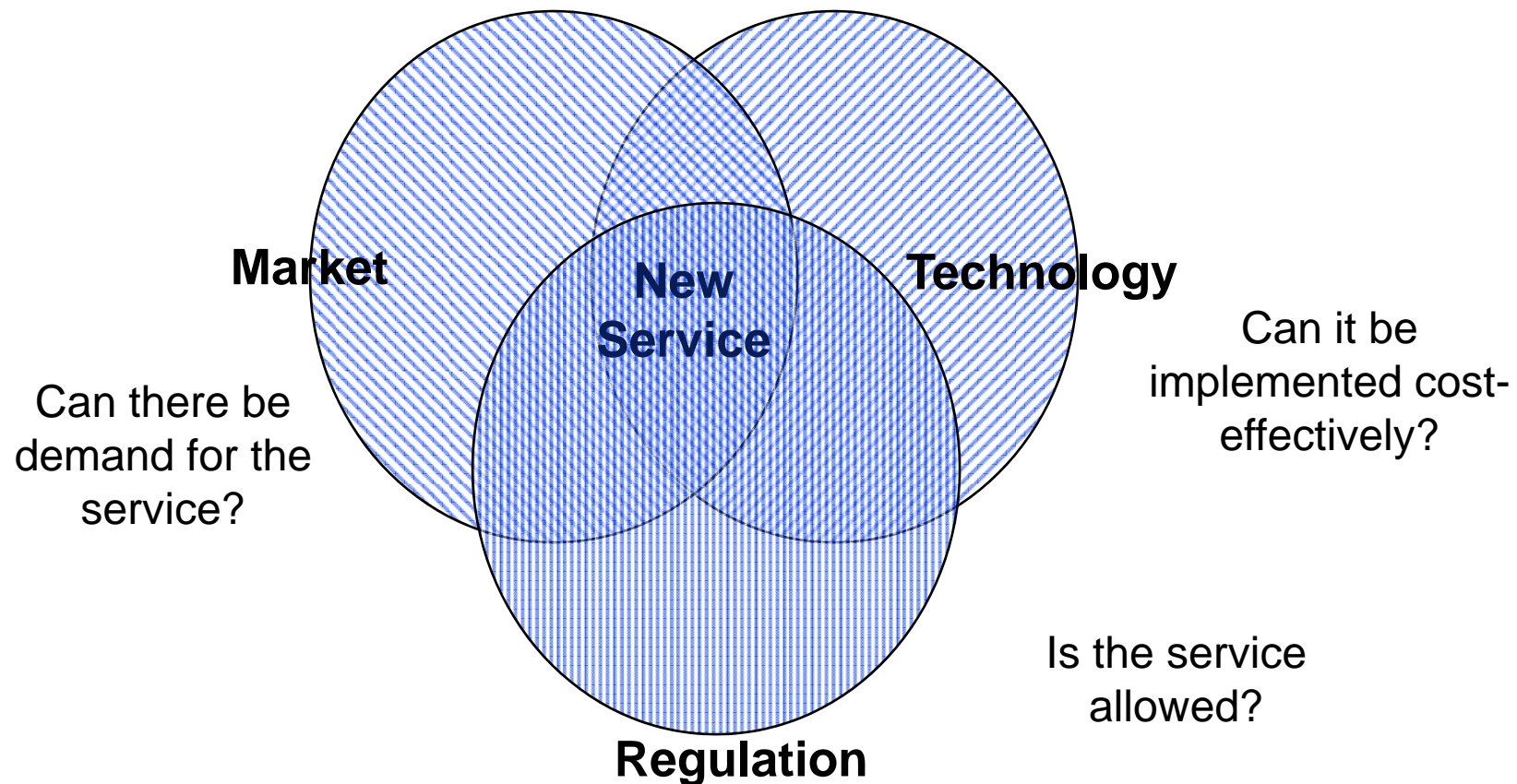


Is Technology only technical stuff ?

- ❑ Technology depends on the Socio-technical System
 - Social, Political, Economic, Institutional
- ❑ Not simply the rational product of scientists and engineers.
- ❑ Technology makes sense when seen as part of the society
- ❑ Examples:
 - Automobile engines: Internal combustion vs. steam
 - Network technologies:
 - ❑ OSI vs. TCP/IP vs. ATM, Ethernet vs. Token Ring, ISDN vs. fax
 - ❑ Future Internet?

Success Factors for New Services

- ❑ Technology not the only factor in success of a new service
- ❑ Three factors considered in new telecom services



Communication Network Architecture

- ❑ *Network architecture*: the plan that specifies how the network is built and operated
- ❑ Architecture is driven by the network services
- ❑ Overall communication process is complex
- ❑ Network architecture partitions overall communication process into separate functional areas called *layers*

Next we will trace evolution of three network architectures: telegraph, telephone, and computer networks

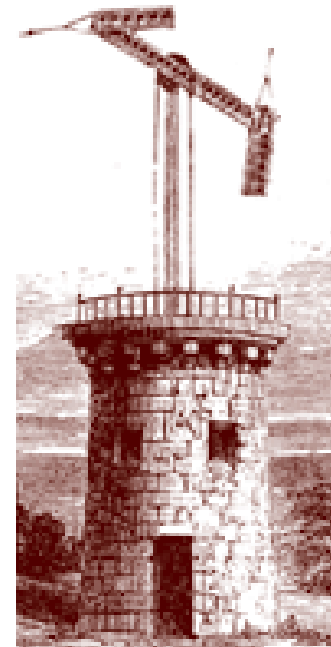
Telegraphs & Long-Distance Communications

Approaches to long-distance communications

- ❑ Courier: physical transport of the message
 - Messenger pigeons, pony express, FedEx
- ❑ Telegraph: message is transmitted across a network using signals
 - Drums, beacons, mirrors, smoke, flags, semaphores...
 - Electricity, light
- ❑ Telegraph delivers message much sooner

Optical (Visual) Telegraph

- ❑ Claude Chappe invented optical telegraph in the 1790's
- ❑ Semaphore mimicked a person with outstretched arms with flags in each hand
- ❑ Different angle combinations of arms & hands generated hundreds of possible signals
- ❑ Code for enciphering messages kept secret
- ❑ Signal could propagate 800 km in 3 minutes!



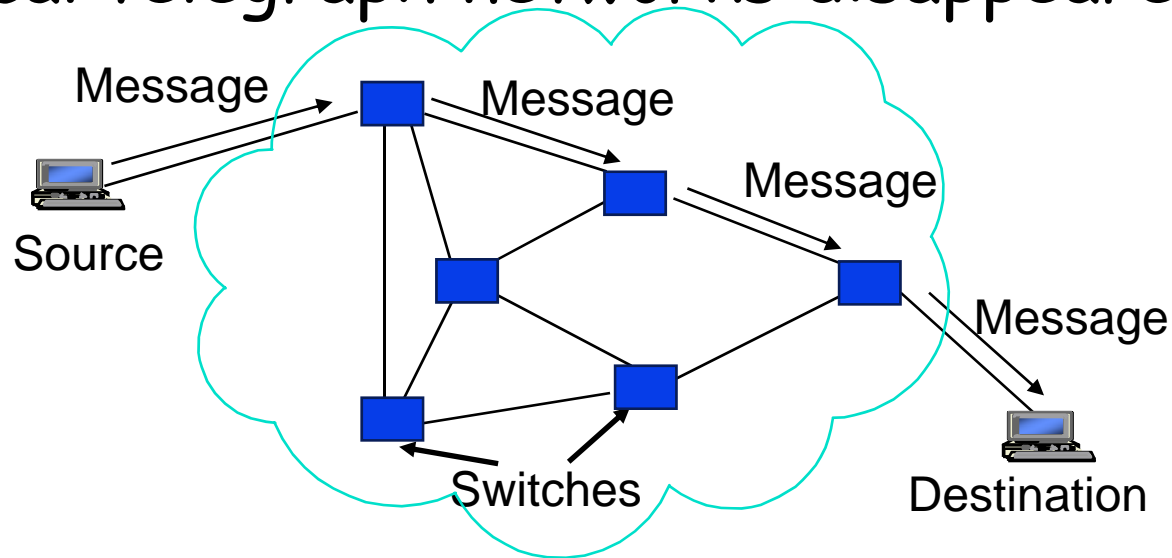
Electric Telegraph



- ❑ William Sturgeon Electro-magnet (1825)
 - Electric current in a wire wrapped around a piece of iron generates a magnetic force
- ❑ Joseph Henry (1830)
 - Current over 1 mile of wire to ring a bell
- ❑ Samuel Morse (1835)
 - Pulses of current deflect electromagnet to generate dots & dashes
 - Experimental telegraph line over 40 miles (1840)
- ❑ Signal propagates at the speed of light!!!
 - Approximately 2×10^8 meters/second in cable

Electric Telegraph Networks

- Electric telegraph networks exploded
 - Message switching & Store-and-Forward operation
 - Key elements: Addressing, Routing, Forwarding
- Optical telegraph networks disappeared



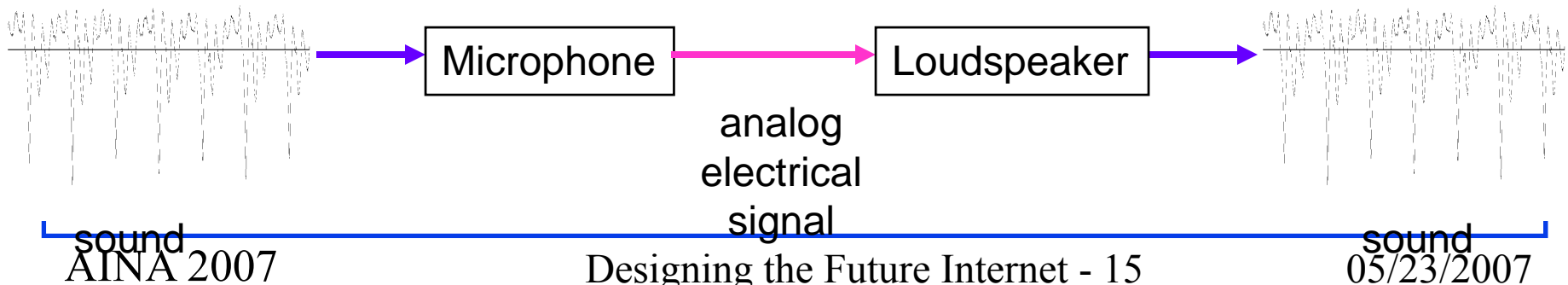
Elements of Telegraph Network Architecture

- Digital transmission
 - Text messages converted into symbols (dots/dashes, zeros/ones)
 - Transmission system designed to convey symbols
- Multiplexing
 - *Framing* needed to recover text characters
- Message Switching
 - Messages contain source & destination *addresses*
 - *Store-and-Forward*: Messages forwarded hop-by-hop across network
 - *Routing* according to destination address

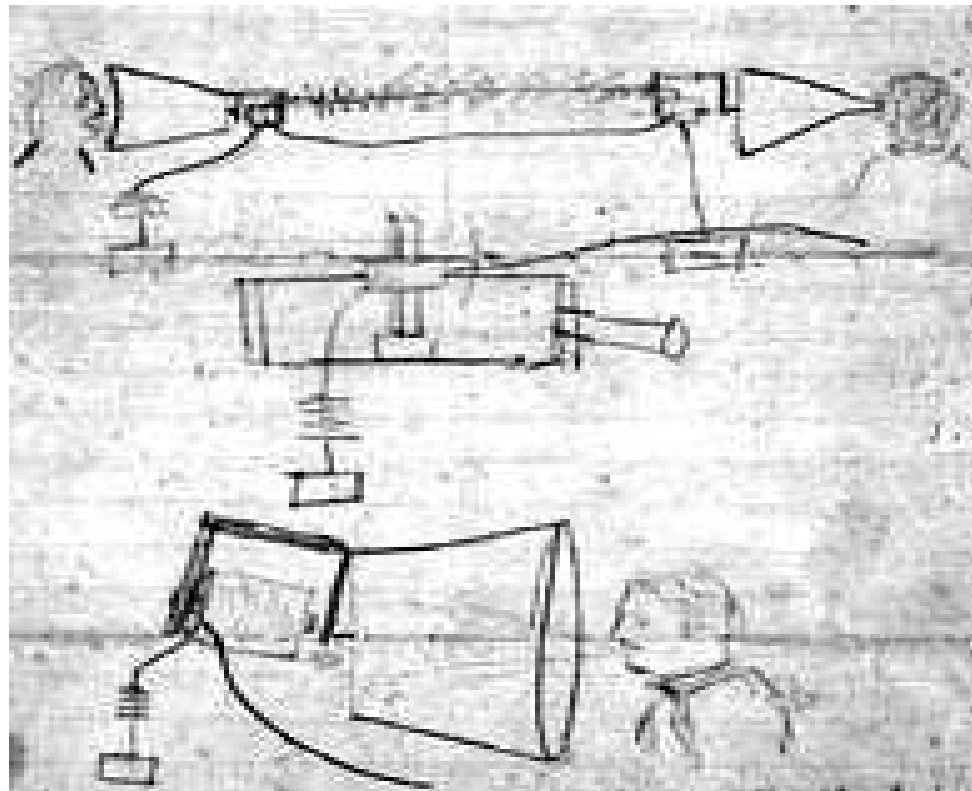
Bell's Telephone

- ❑ Alexander Graham Bell (1875) working on harmonic telegraph to multiplex telegraph signals
- ❑ Discovered voice signals can be transmitted directly
 - Microphone converts voice pressure variation (sound) into *analogous* electrical signal
 - Loudspeaker converts electrical signal back into sound
- ❑ Telephone patent granted in 1876
- ❑ Bell Telephone Company founded in 1877

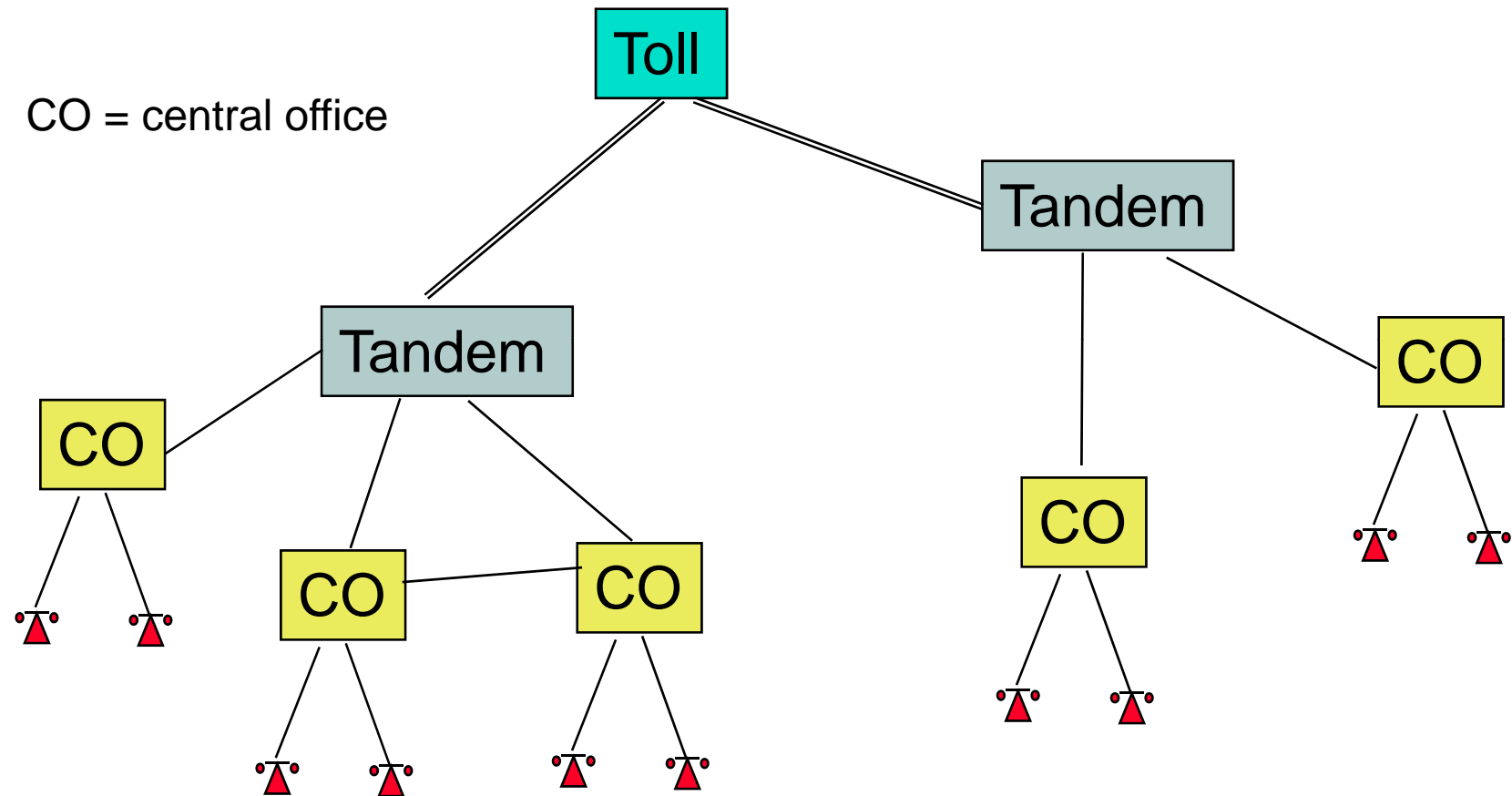
Signal for “ae” as in cat



Bell's Sketch of Telephone



Hierarchical Network Structure

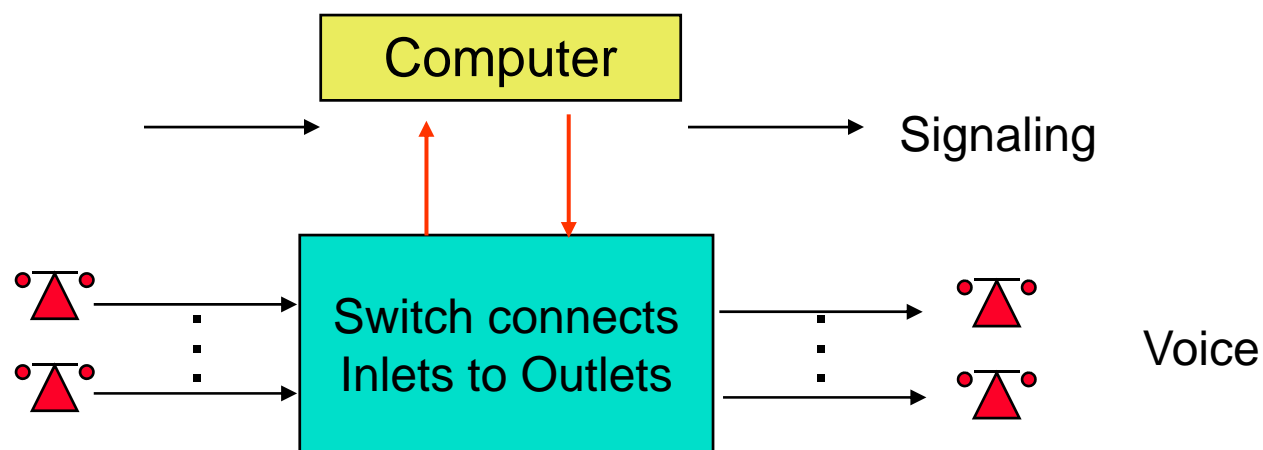


Telephone subscribers connected to local CO (central office)

Tandem & Toll switches connect CO's

Computer Connection Control

- ❑ A computer controls connection in telephone switch
- ❑ Computers exchange *signaling messages* to:
 - Coordinate set up of telephone connections
 - To implement new services such as caller ID, voice mail, . . .
 - To enable *mobility and roaming* in cellular networks
- ❑ "Intelligence" inside the network
- ❑ A separate *signaling network* is required



Elements of Telephone Network Architecture

- ❑ Digital transmission & switching
 - Digital voice; Time Division Multiplexing
- ❑ Circuit switching
 - User signals for call setup and tear-down
 - Route selected during connection setup
 - End-to-end connection across network
 - Signaling coordinates connection setup
- ❑ Hierarchical Network
 - Decimal numbering system
 - Hierarchical structure; simplified routing; scalability
- ❑ Signaling Network
 - *Intelligence inside the network*

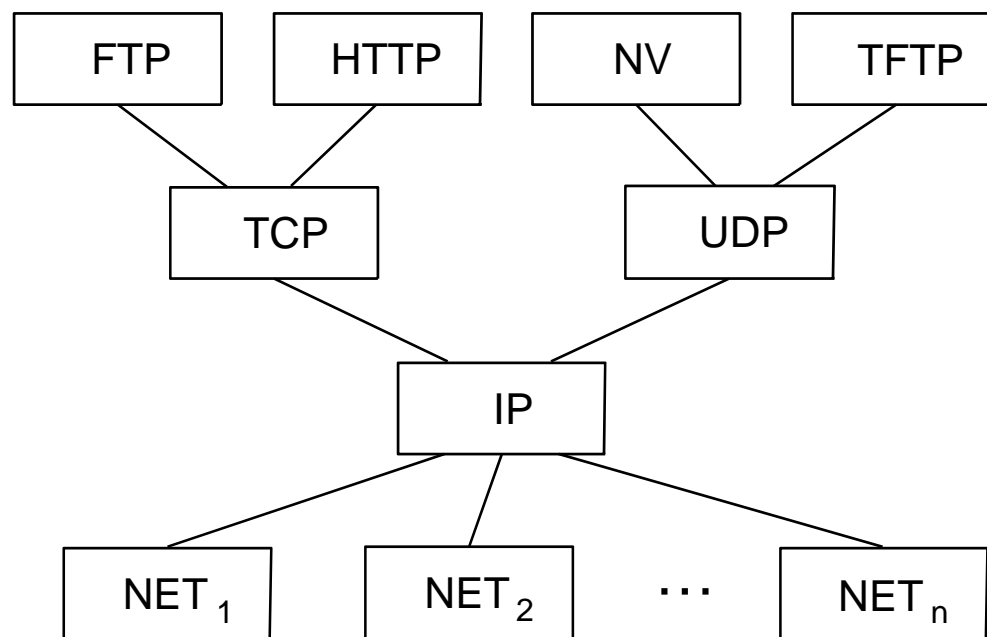
Computer Network Evolution

Overview

- ❑ *1950s*: Telegraph technology adapted to computers
- ❑ *1960s*: Dumb terminals access shared host computer
 - SABRE airline reservation system
- ❑ *1970s*: Computers connect directly to each other
 - ARPANET packet switching network
 - TCP/IP internet protocols
 - Ethernet local area network
- ❑ *1980s & 1990s*: New applications and Internet growth
 - Commercialization of Internet
 - E-mail, file transfer, web, P2P, . . .
 - Internet traffic surpasses voice traffic

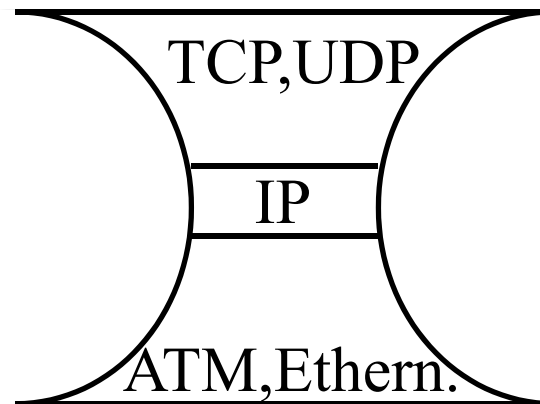
Internet Architecture

- Defined by Internet Engineering Task Force (IETF)
- Hourglass Design



Internet Protocol IP

- ❑ Hour-glass model:
 - Glue of the Internet,
 - Everything over IP, and IP over everything
 - The single common language
- ❑ Implemented at both hosts and routers
- ❑ Accommodating heterogeneity
- ❑ Minimalist approach. Best effort datagram service
- ❑ One of the main reasons of the Internet's success



Elements of Computer Network Architecture

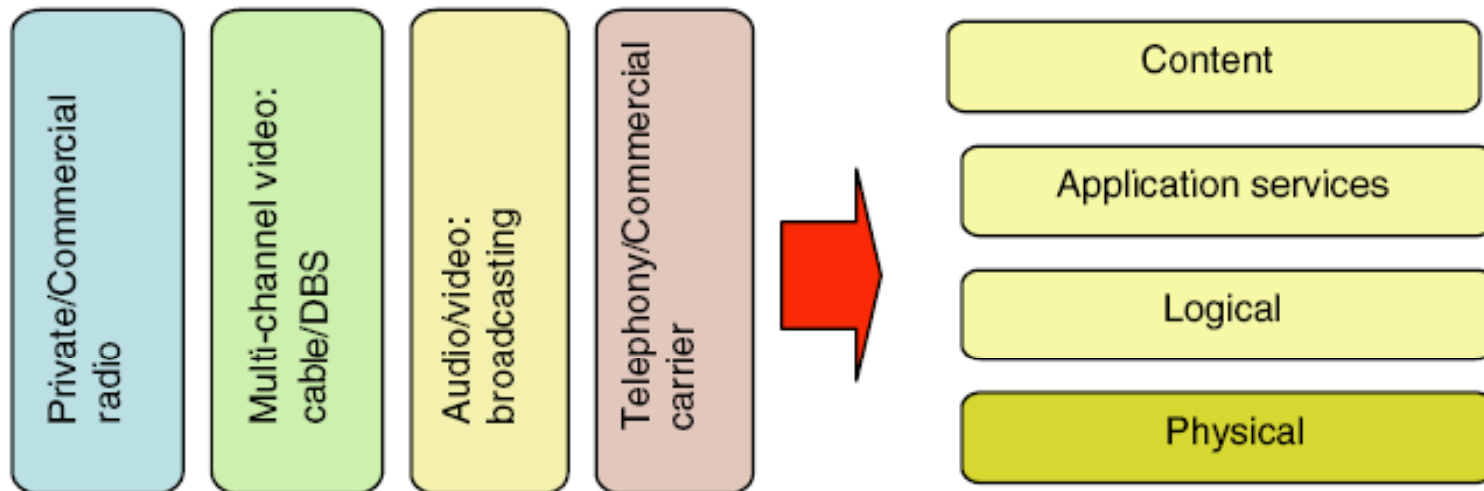
- ❑ *Congestion control* inside the network
- ❑ *Internetworking* across multiple networks using routers
- ❑ *Segmentation and reassembly* of messages into packets at the ingress to and egress from a network or internetwork
- ❑ *End-to-end transport protocols* for process-to-process communications
- ❑ *Applications* that build on the transfer of messages between computers.
- ❑ *Intelligence is at the edge of the network.*

Trends in Network Evolution

- It's all about services
 - Building networks involves huge expenditures
 - Services that generate revenues drive the network architecture
- Current trends
 - Packet switching vs. circuit switching
 - Multimedia applications
 - More versatile signaling
 - End of trust
 - Many service providers and overlay networks
 - Networking *is* a business, a huge one

The End of Stovepiping

- Transformation from vertical industrial organization in print, radio, entertainment, and broadcast to more horizontal Internet based platforms



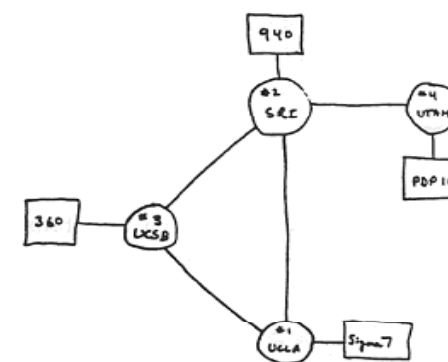
Packet vs. Circuit Switching

- Architectures appear and disappear over time
 - Telegraph (message switching)
 - Telephone (circuit switching)
 - Internet (packet switching)
- Trend towards packet switching at the edge
 - IP enables rapid introduction of new applications
 - New cellular voice networks packet-based
 - IP supports *real-time* voice and telephone network will gradually be replaced
 - However, large packet flows easier to manage by circuit-like methods

Network Architecture Evolution

- Telegraph Networks
 - Message switching & digital transmission
- Telephone Networks
 - Circuit Switching
 - Analog transmission → digital transmission
 - Mobile communications
- Internet
 - Packet switching & computer applications
- Future Internet ?

Internet Generations



THE ARPA NETWORK

DEC 1969

4 NODES

- Internet 1.0 (1969 -1989)
 - Research Project
 - RFC1 - April 1969
 - ARPA project started a few years earlier
 - IP, TCP, UDP
 - Mostly researchers
 - Industry was busy with proprietary protocols SNA, DECnet, AppleTalk, XNX

Internet 1.0

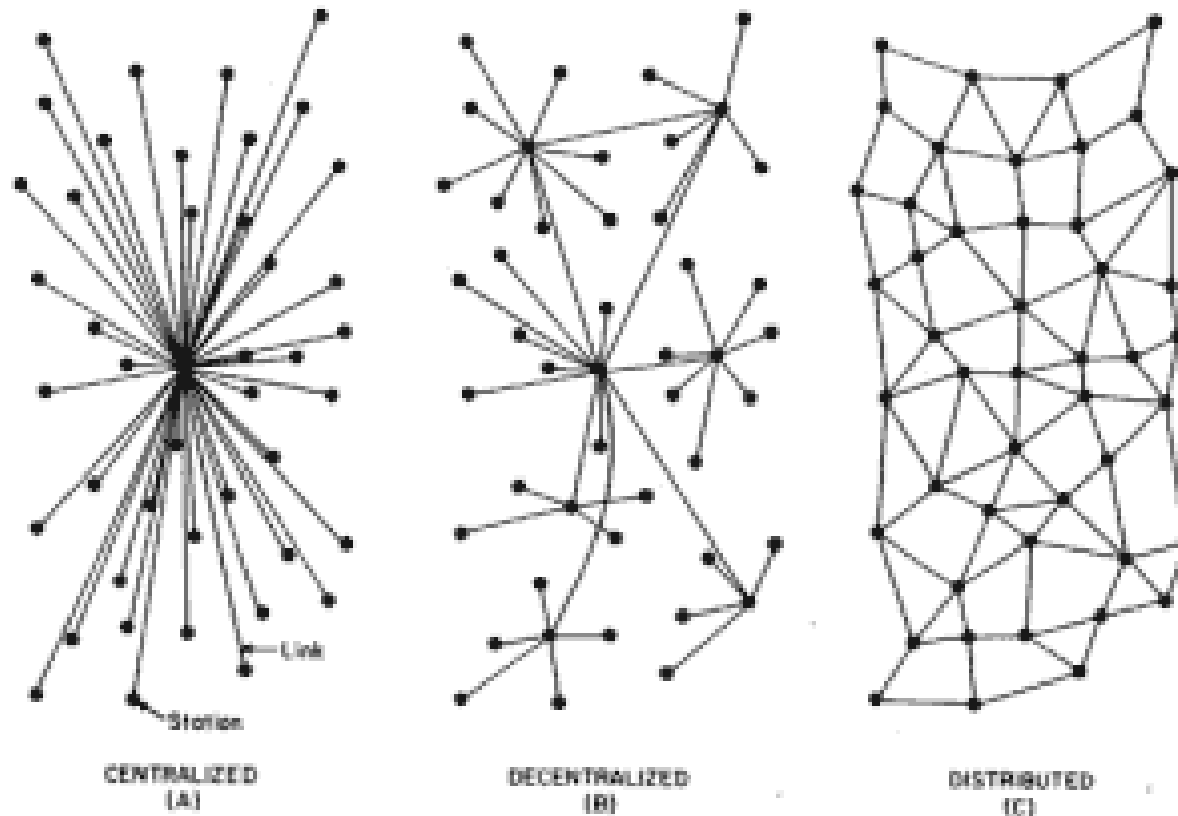
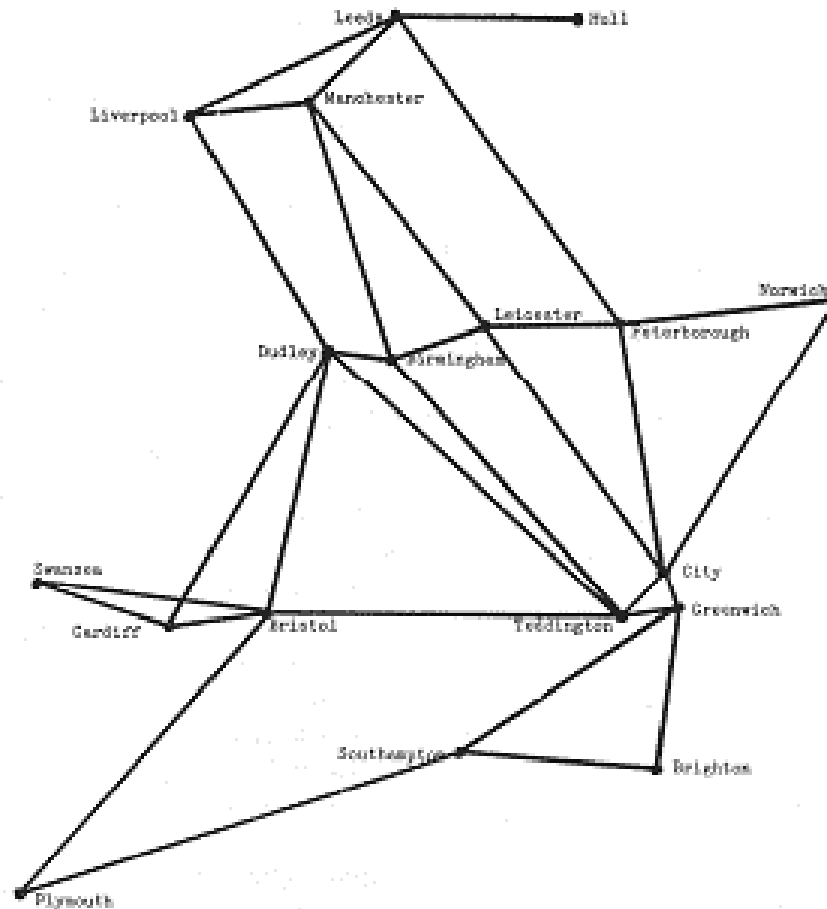


FIG. 1 – Centralized, Decentralized and Distributed Networks

- The pioneering research of Paul Baran in the 1960s, who envisioned a communications network that would survive a major enemy attack.

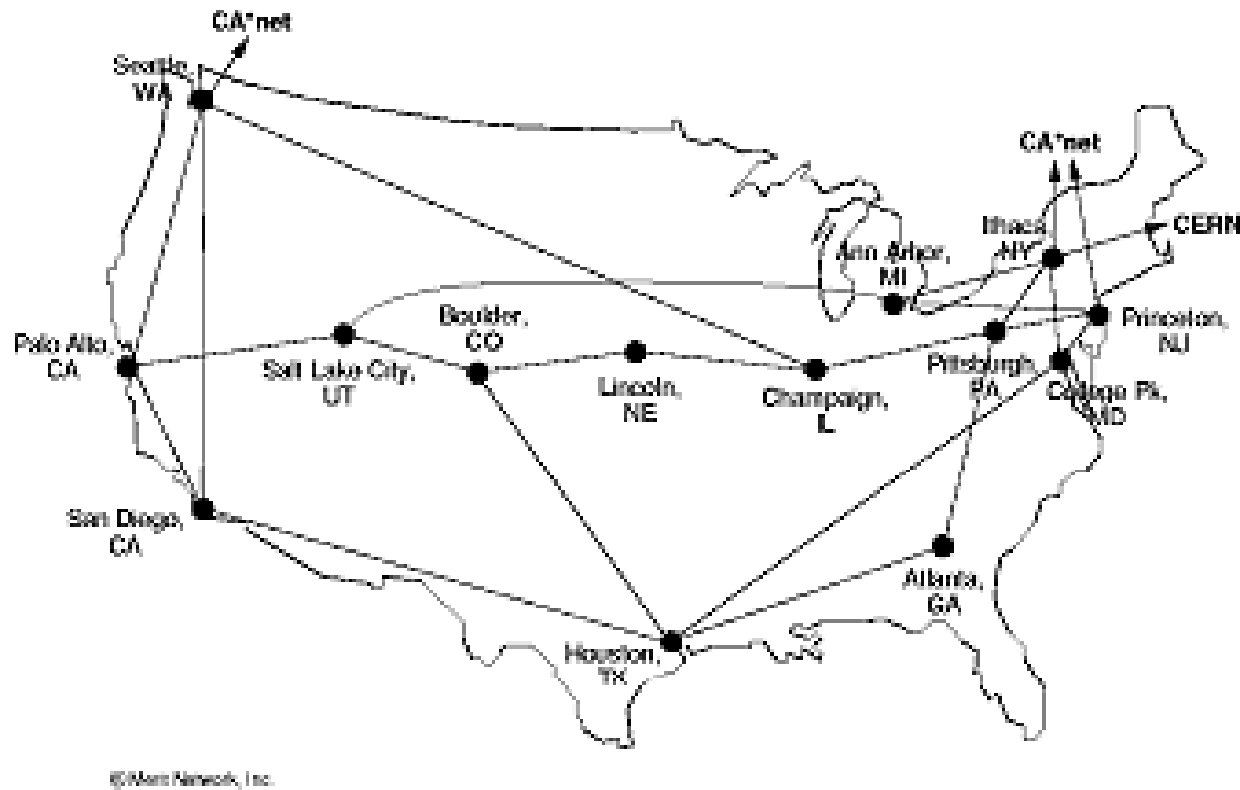
Internet 1.0



- A sketch of the packet switching network in the United Kingdom proposed by Donald Davies, a pioneer in networking in the 1960s.

Internet 1.0 - 2.0

NSFNET T1 Network 1991



Internet Generations

- Internet 2.0 (1989 - Present) - Commerce - New Requirements
 - Security RFC1108 n 1989
 - Inter-domain routing: OSPF, BGP
 - IP Multicasting
 - Address Shortage, IPv6
 - Congestion Control, Quality of Service...
 - VoIP, P2P, Skype...

Why a new Internet?

May you live in interesting times

- ❑ The existing Internet Architecture is reaching its limits.
- ❑ New technologies, mobility, security, demand for new services
- ❑ The research community is thinking to design it from the scratch, using what we know now.
- ❑ National Science Foundation is planning a \$300M+ research and infrastructure program on GENI ⇒ Most of the networking researchers will be working on GENI for the coming years
- ❑ "Global Environment for Networking Innovations" or GENI

The Future Internet:

- ❑ Worthy of our society's trust—security and availability
 - Even for managing and operating critical infrastructures
- ❑ Provides a bridge between physical and virtual worlds
 - Via instrumented and managed sensorized physical environment
- ❑ Privacy preserving in environment of pervasive sensing, computing, content, datamining . . .
- ❑ Suitable for tomorrow's technologies
- ❑ Manageable and usable
- ❑ Capable of applications support
 - Content-rich, storage, services, realtime, etc.
- ❑ Economically viable
- ❑ Fosters a social world in which we would want to live

What is Different This Time?

- Clean-slate approach
 - To overcome Internet ossification
 - Research not constrained by the features of the current Internet
 - But does not mandate rejecting what currently works
- A comprehensive coordinated effort
 - Ability to try different approaches
- Ability to experiment at scale
 - With real users and applications

CABO: Concurrent Architectures are Better Than One

- ❑ PIs: Nick Feamster, Lixin Gao and Jennifer Rexford, Institution(s): Georgia Tech, UMass Amherst and Princeton Univ.
- ❑ Separate infrastructure providers (who own and manage the physical network infrastructure) from service providers (who deploy end-to-end services to users)
- ❑ Allows a service provider to operate multiple virtual networks, each of which is tailored to a specific application
- ❑ For example, one virtual network may provide strict security guarantees but may not provide complete reachability to all destinations, while another virtual network may guarantee global reachability for applications that do not require strong security guarantees.

Designing Secure Networks from the Ground-Up

- ❑ PIs: Dan Boneh, David Mazieres, Mendel Rosenblum, Aditya Akella, Nick McKeown, Institution(s): Stanford University, University of Wisconsin-Madison
- ❑ Develop a clean-slate Internet architecture where protection from malicious network-based attacks is a fundamental design goal.
- ❑ Requiring all traffic to explicitly signal its origin as well as intent to the network at the very outset
- ❑ Develop tailor-made security architectures for private networks (e.g., enterprises) which often enforce tight controls on who can communicate with who, as well as for public servers (e.g., e-commerce sites) which are more "open" and desire to be globally visible.

Today vs. Future

	Feature	Today	Future
1	Energy Efficiency	Always-on	Green, Mostly off
2	Mobility	Mostly stationary computers	Mostly mobile <i>objects</i>
3	Computer-Human Relationship	Multi-user systems, Machine to machine	Multi-system user Personal comm. Systems
4	End Systems	Single computers	Globally distributed systems
5	Protocol Symmetry	Communication between equals, Symmetric	Unequal: PDA vs. Google Asymmetric
6	Design Goal	Research, Trusted systems	Commerce, No trust, Map to organizational structure
7	Ownership	No concept of ownership	Hierarchy of ownerships, administrations, communities
8	Sharing	Sharing, Interference, QoS Issues	Sharing and Isolation, Critical Infrastructures
9	Switching units	Packets	Packets, Circuits, Wavelengths, ...
10	Applications	Email and Web	Information retrieval, Distributed Computing and Storage, Data diffusion

Problems with Current Internet

- ❑ Assumes live end-systems
 - No communication while sleeping
- ❑ Identity and location in one (IP address)
 - Makes mobility complex
- ❑ Location Independent Addressing
 - Most services require nearest server
 - Mobility requires location
- ❑ Single-Computer to single-computer communications
 - Numerous patches needed for communication with globally distributed systems

Problems with Current Internet

- ❑ Design for research
 - Assume trusted systems
 - When used for commerce - untrusted systems
- ❑ No representation for the real end systems - humans
- ❑ Control, management, and data path are intermixed - security issues

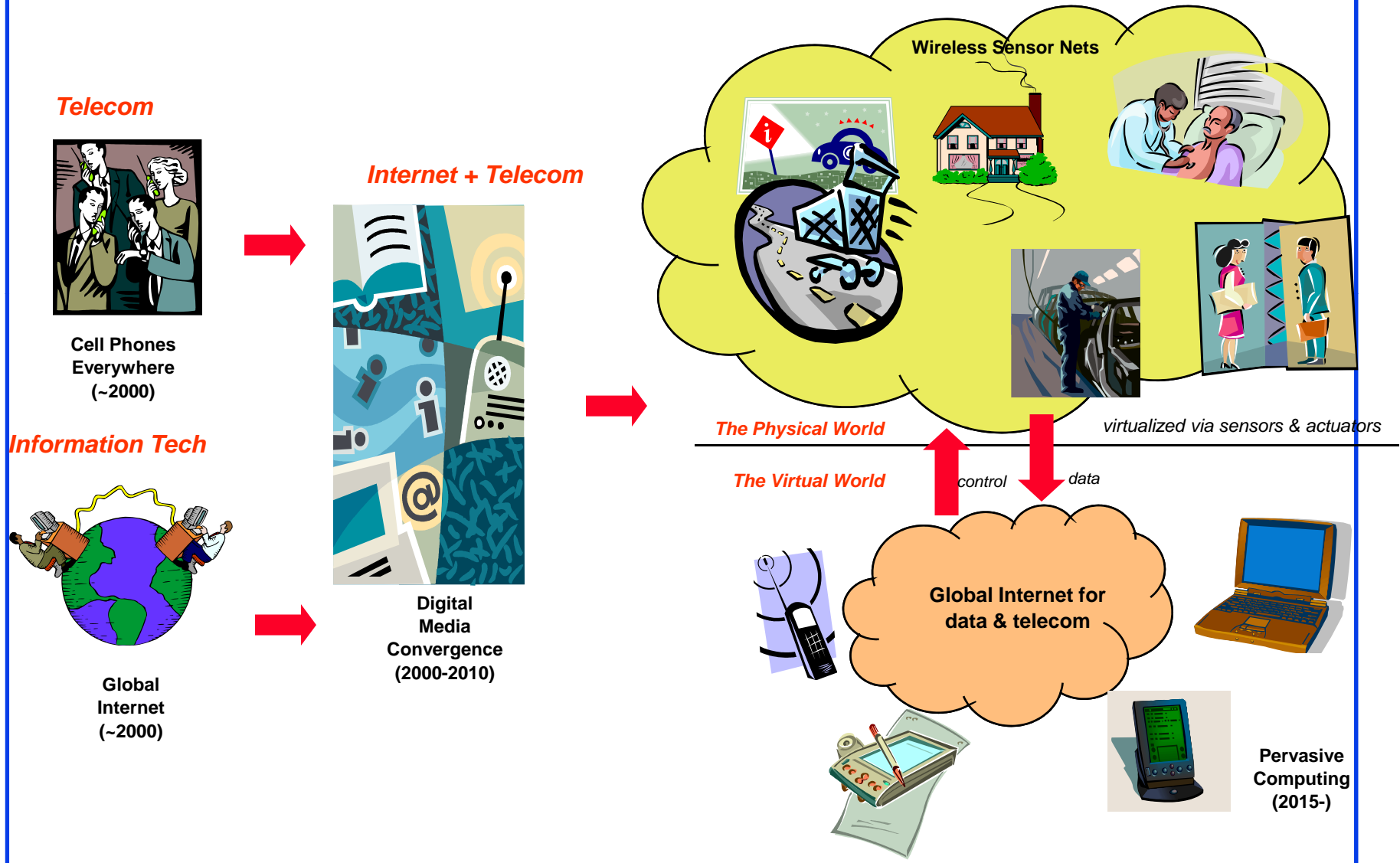
Problems with Current Internet

- ❑ Difficult to represent organizational, administrative hierarchies with just two levels: domain and inter-domain
- ❑ Symmetric protocols
 - No difference between a mote and a Google server
- ❑ Stateless
 - Can not remember a flow
 - QoS difficult
 - Security difficult

Generalized Internet Networking Architecture - GINA

1. Separates address and ID => Allow mobility
 2. Multilayered Security => Part of the design
 3. Hybrid (Packet and stream based) communication => Allow strict real time constraints
 4. ID hierarchy => Allow role based communication
 5. Address hierarchy => Allow connectivity based routing
 6. Delegation to servers => Allow energy conservation and simple devices
 7. Service based ID => Help client server traffic (Everyone trying to reach Google) = Distributed servers
 8. Control and data path separation => Allow non-packet based (e.g., wavelength routers, SONET routers) along with packet based
- Work jointly with Prof. Raj Jain of WSU

IT & Telecom Evolution



Names, IDs, Address

- ❑ Name : James Smith
- ❑ ID: 012-34-5678
- ❑ Address: 6755 Fallview Boulevard,
Niagra Falls, Ontario, Canada

- ❑ Address changes as you move, ID and Names remain the same
- ❑ Names: Company names, DNS names
- ❑ IDs: Cell phone numbers, Skype ID
- ❑ Addresses: Wired phone numbers, IP addresses

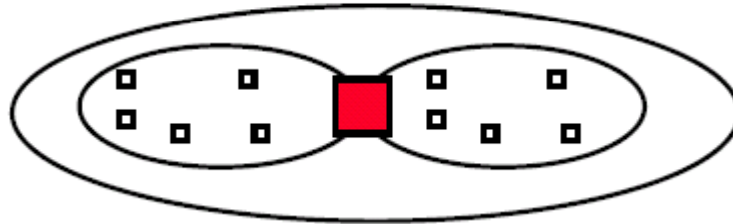
Objects

- ❑ Object = Addressable Entity
- ❑ Current: End-Systems and Intermediate Systems
- ❑ GINA:
 - Computers, Routers/Firewalls....
 - Networks
 - Humans
 - Companies, Departments, Cities, States,
 - Countries, Power grids
 - Process in a computer
 - Recursive \Rightarrow Set of Objects is also one object, e.g.,
Networks of Networks

Profiles

- Each object has a profile:
 - Names: ASCII strings for human use
 - IDs: Numeric string for computer use
 - Addresses: where the Object is located
 - Home Address, Current Address
 - Keys: Private, Public, Secret
 - Other attributes: Certificates, Computer Power, Storage Capacity, etc.
- You connect to an ID not an address

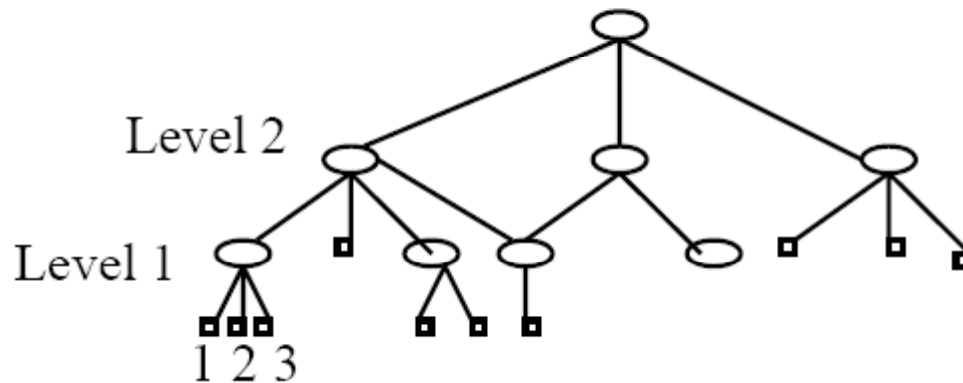
Realms=Organizations



- ❑ Object names and Ids are defined within a realm
- ❑ An object may be a member of multiple realms.
 - One or more Ids in each realm of which it is a member
- ❑ Each realm has a set of exits. Objects with local realm Ids communicate to objects outside the realm only by simply communicating with server objects at the exit.
- ❑ Realms can be treated as single object and have Names, Ids, addresses. Realms are recursive.
- ❑ Boundaries: Technological, Governmental, ISP, Organizational

Realm Hierarchy = Organizational Structure

- ❑ Universe is organized as a hierarchy of realms
- ❑ Each realm has a set of parents and a set of children
- ❑ Parent Ids can be prefixed to realm ids
- ❑ A child may have multiple parents
 - Hierarchy is not a tree
- ❑ Any path to the root of a level gives the ID for the object at that level, e.g.,
level2_id.level1_id...object_id = level2 id of object

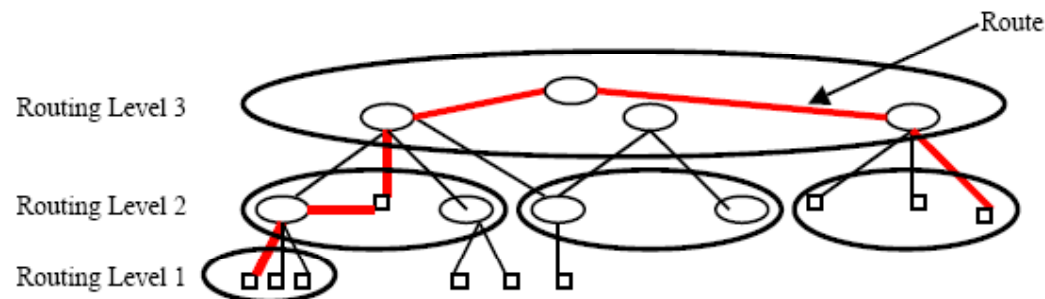


Zone Hierarchy = Network Structure

- ❑ Address of an object indicates its *physical attachment point*
- ❑ Networks are organized as a set of *zones*
- ❑ Object address in the current zone is sufficient to reach it inside that zone
- ❑ Each object registers its names, addresses, IDs, and attributes with the registry of the relevant realms
- ❑ Zones are objects and have IDs, realms, addresses too
- ❑ An object's address at higher level zones is obtained by prefixing it with of addresses of ancestor zones

Highly Scalable Hierarchical Routing

- ❑ Based on connectivity and policies
- ❑ Routing organized as paths through several levels of hierarchy
- ❑ At each level packets follow an optimal path from the entry point to that level to exit point in that zone
- ❑ Routing table exchanges at each level are used to find the optimal paths at that level

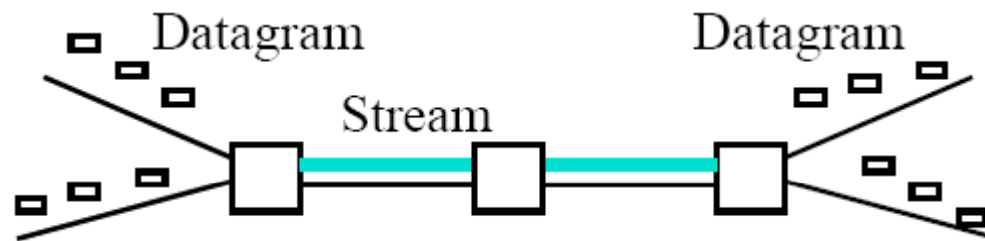


Forwarding

- ❑ You have to know the name of the destination to be able to communicate with it.
- ❑ The names can be translated to the ID of the destination by using registries at appropriate levels
- ❑ The packets contain either IDs or addresses of the destination
- ❑ IDs are translated to current address

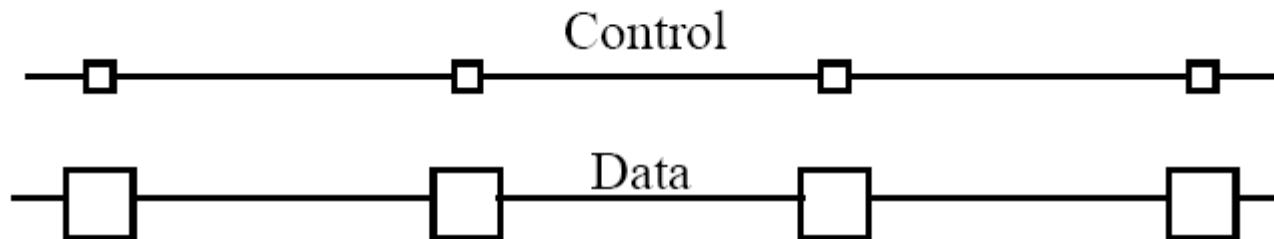
Packet and Circuit Switching

- ❑ Packets are good for sharing. Circuits are good for isolation.
- ❑ Critical applications need isolation \Rightarrow Use separate networks.
- ❑ When Internet 1.0 was designed, the circuit was the competition.
- ❑ Latest wireless networks, e.g., WiMAX offers both circuits and packets
- ❑ Offer both packet and circuit switching with intermediate granularities of multigrans and streams.



Control and Data Plane Separation

- ❑ Streams use control channel and data channel that may have separate paths
- ❑ Data plane can be packets, wavelengths, power grids, ...
- ❑ Separate planes \Rightarrow Generalized switching and Security



Server Objects

- ❑ Each realm has a set of server objects, e.g., forwarding, authentication, encryption,
- ❑ Some objects have built-in servers, e.g., an "enterprise router" may have forwarding, encryption, authentication services.
- ❑ Other objects rely on the servers in their realm
- ❑ Forwarding servers are located at the boundary of two realms
- ❑ Encryption servers encrypt the packets
- ❑ Authentication servers (AS) add their signatures to packets and verify signatures of received packets..
- ❑ Storage servers store packets while the object may be sleeping and may optionally aggregate/compress/transform/disseminate data. Could wake up objects.
- ❑ Organizational control of all policies

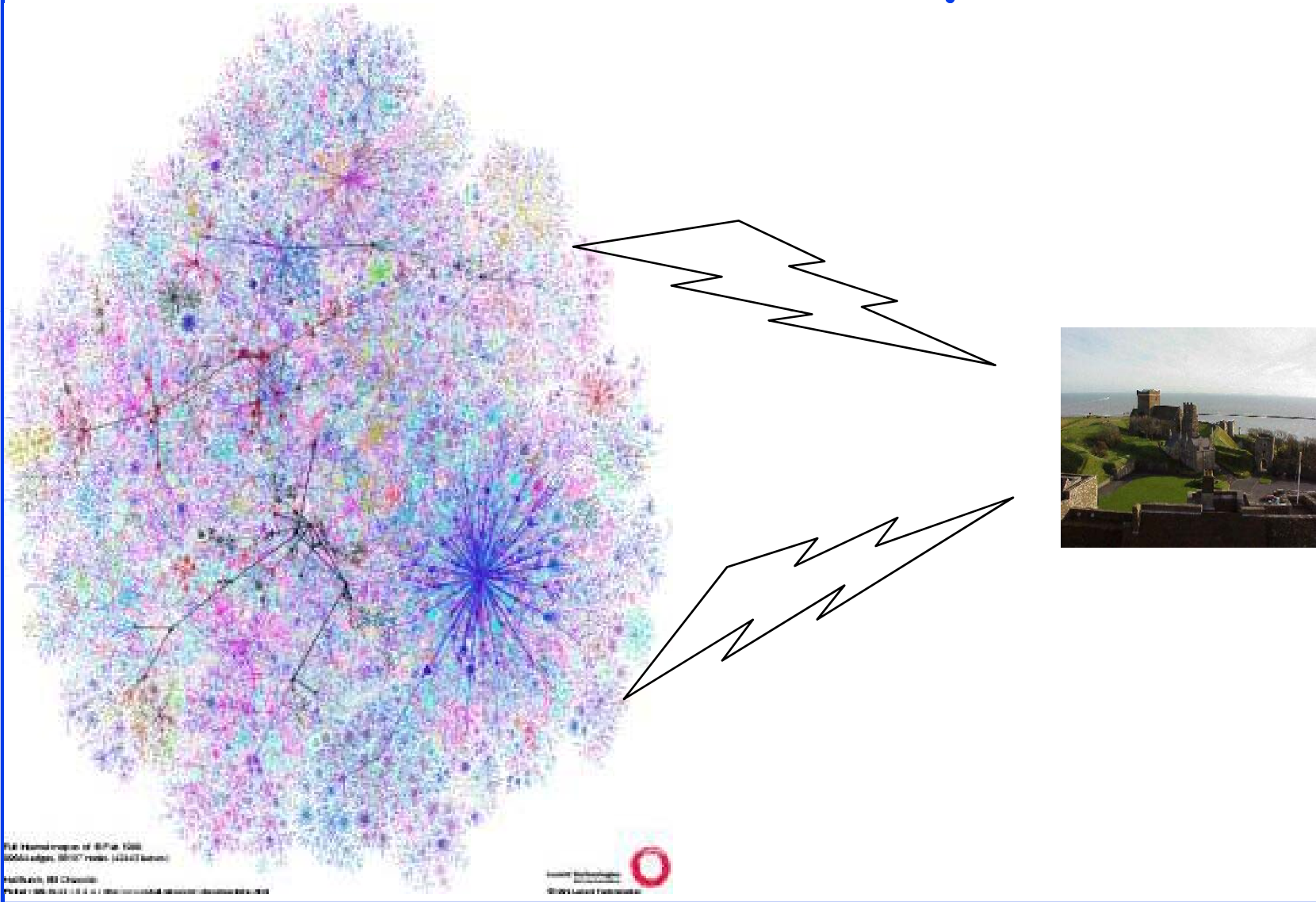
Today Security

- ❑ Our proposed architecture is based on the security lessons from existing Internet
- ❑ Security is attempted desperately by destinations in form of patches
- ❑ Most of the problems in today's Internet come from the lack of authentication

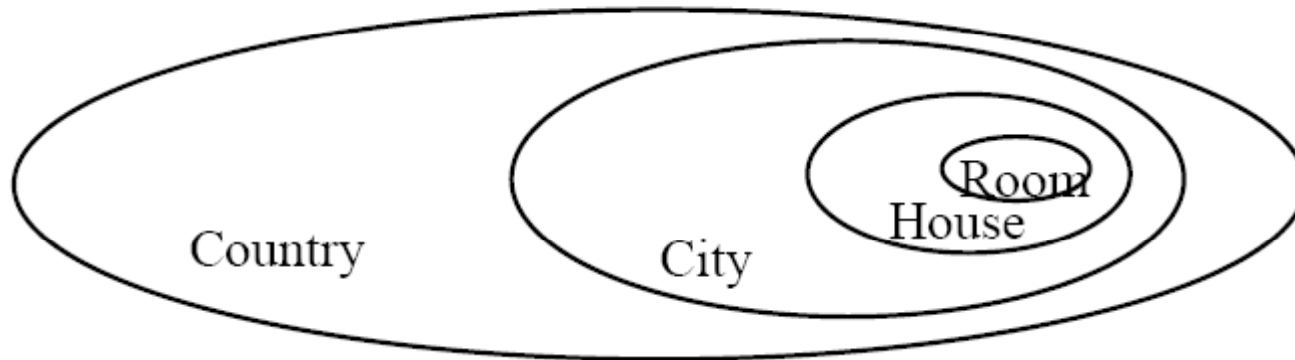
Today Security

- Authentication is applied sometime only at the destination
 - The attacker can abuse with network resources
 - Network resources (routers, etc.) become unknowingly attacker's collaborators by routing his malicious traffic
 - Destination protection becomes an extremely unscalable problem - each destination could be under attack from a very large number of attackers

Castle Solution - Extremely Unscalable



Security

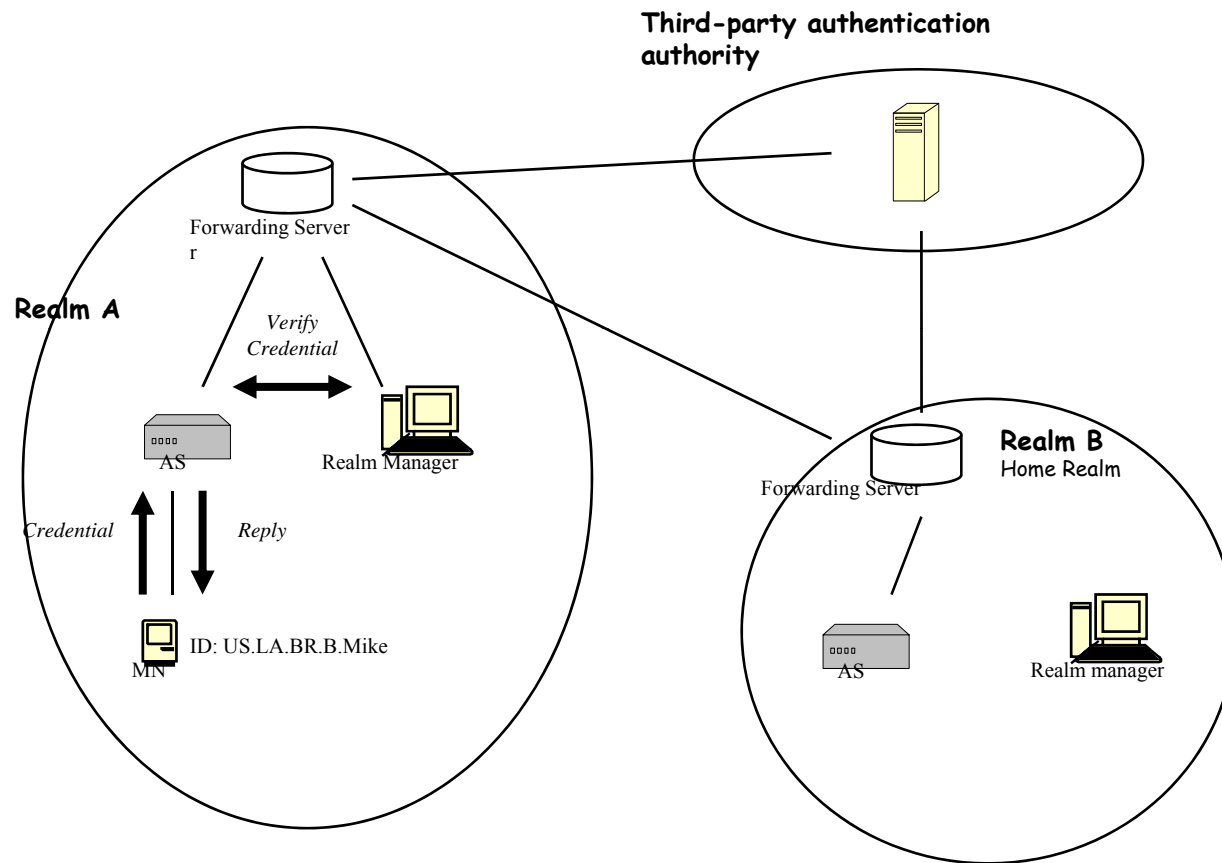


- ❑ Multi-level architecture. Gatekeepers on the entrance
- ❑ Authentication checked on entry to zone/realm. Not at every router.
- ❑ Authentication at multiple levels: country, city, home.
- ❑ Group Authentication: n-packets can be authenticated by one authentication
- ❑ VPN and firewalls are part of the architecture
- ❑ Organizational control of security

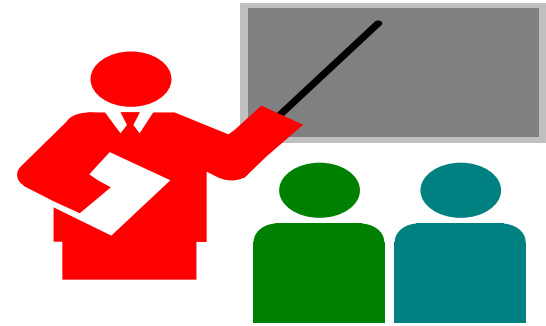
Security

- ❑ From "Permit by default" to "Stop as soon as possible"
- ❑ Access authentication will not be based on network address, but on user ID and combination of this ID and other data.
- ❑ Guarantee non-repudiation
- ❑ Each packet on the network will have an owner
- ❑ All networking services, starting from forwarding of packets, will be based on the source ID and its authentication.

Authentication



Summary



- ❑ Internet 3.0 is the next generation of Internet
- ❑ Architecture Lessons from the past
- ❑ Factors: Technology, Services, Standards
- ❑ It must be secure, green (energy efficient), allow mobility
- ❑ Must be designed for commerce
- ❑ Our proposal Generalized InterNet Architecture GINA addresses many issues

Thank You!

