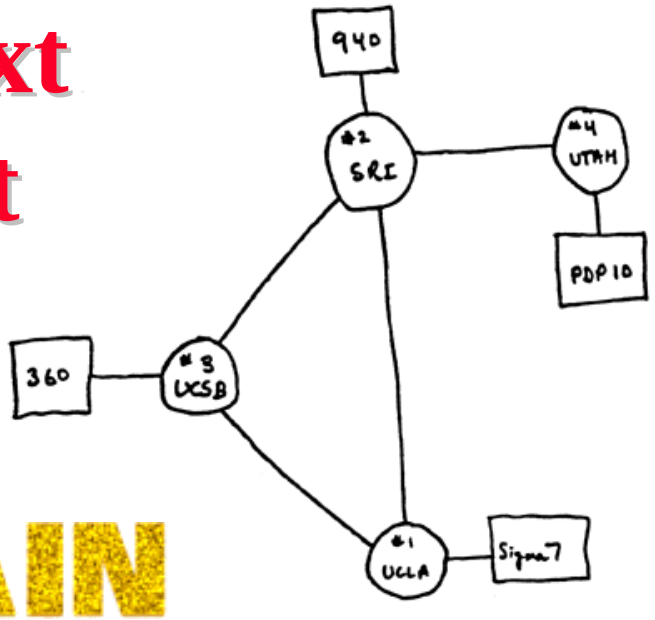
Internet 3.0: The Next Generation Internet



RAJ JAIN
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@wustl.edu

A talk at HP Labs, Palo Alto, CA
November 19, 2009

These slides and Audio/Video recordings of this talk are at:
http://www.cse.wustl.edu/~jain/talks/in3_hp.htm

Overview

1. What is Internet 3.0?
2. What are we missing in the current Internet?
3. Our Proposed Architecture for Internet 3.0

Next Generation Internet Projects

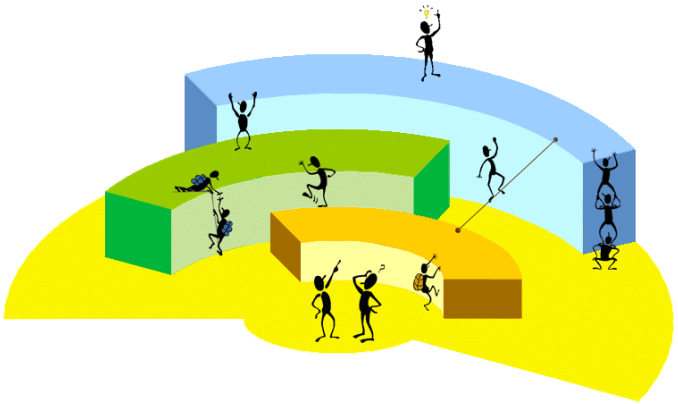
- In 2005 US National Science Foundation started a large research and infrastructure program on next generation Internet
- Q: How would you design Internet today? Clean slate design.
- "Future Internet Design" (FIND): 48+ projects
  - Stanford, MIT, Berkeley, CMU, …
  - "An Architecture for Diversified Internet" at WUSTL
- "Global Environment for Networking Innovations" (GENI): 29+ projects
- European Union: 7th Framework program
- Japan: AKARI (A small light in the dark pointing to the future)
- China, Korea, Australia, …20+ countries
- **Ref**: See our survey report, WUSTL-2009-69, Oct 2, 2009

Why to worry about Internet 3.0?

Billion dollar question!

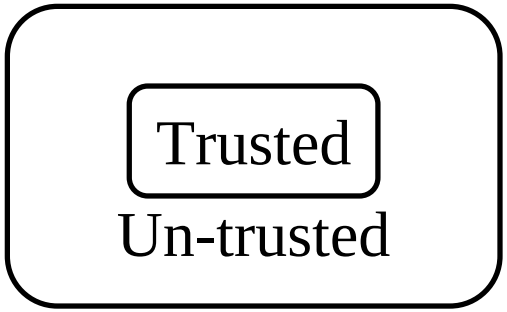
Internet 3.0: Next Generation Internet

- Internet 3.0 is the name of the Washington University project on the next generation Internet
- Named by me along the lines of "Web 2.0"
- Internet 3.0 is more intuitive then GENI/FIND
- Goal 1: Develop a *clean slate architecture* to overcome limitations of the current internet
- Goal 2: Develop an *incremental approach* to implement the architecture



Key Problems with Current Internet

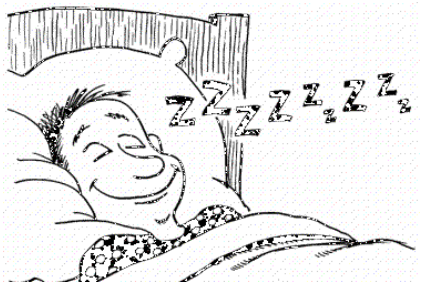
1. Designed for research
   ⇒ Trusted systems
   Used for Commerce
   ⇒ Untrusted systems
2. Difficult to represent organizational, administrative hierarchies and relationships.
   Perimeter based.
   ⇒ Difficult to enforce organizational policies



Problems (cont)

3. Identity and location in one (IP Address)
   Makes mobility complex.

4. Assumes live and awake end-systems
   Does not allow communication while sleeping.
   Many energy conscious systems today sleep.



5. No representation for real end system: the human.

Ref: Our Milcom 2006 paper

Physical vs. Logical Connectivity

- Physically and logically connected:
  All computers in my lab
  = Private Network,
  Firewalled Network

- Physically disconnected but logically connected:
  My home and office computers

- Physically connected but logically disconnected: Passengers on a plane, Neighbors, Conference attendees sharing a wireless network, A visitor

Physical connectivity ≠ Trust

Names, IDs, Locators

Name: John Smith

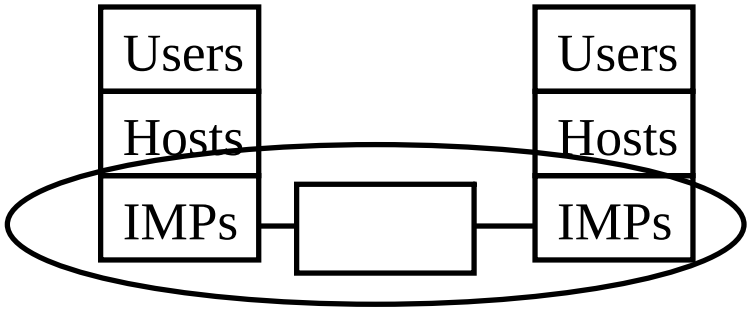
ID: 012-34-5678

Locator:
1234 Main Street
Big City, MO 12345
USA

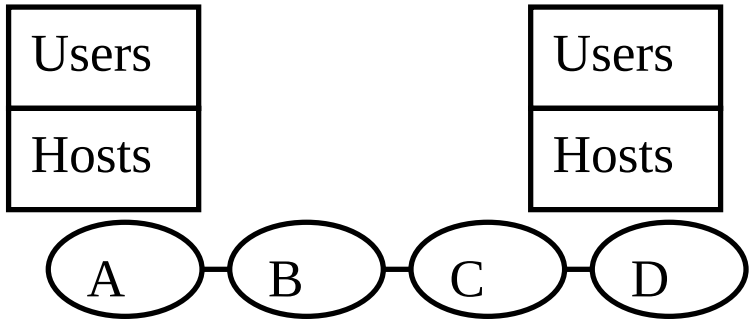
- Locator changes as you move, ID and Names remain the same.
- **Examples**:
  - Names: Company names, DNS names (microsoft.com)
  - IDs: Cell phone numbers, 800-numbers, Ethernet addresses, Skype ID, VOIP Phone number
  - Locators: Wired phone numbers, IP addresses

Internet Generations

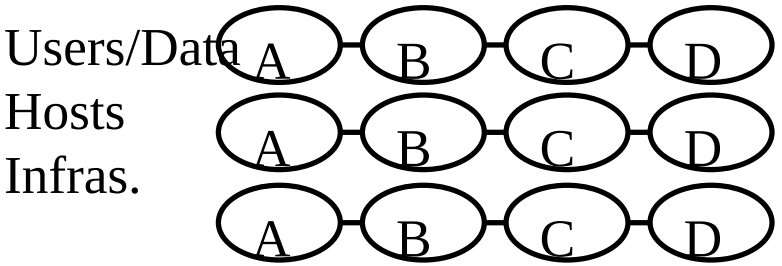
- **Internet 1.0** (1969 – 1989)
  - Single ownership ⇒ Trust
  - complete knowledge
  - Algorithmic optimality ⇒ RIP



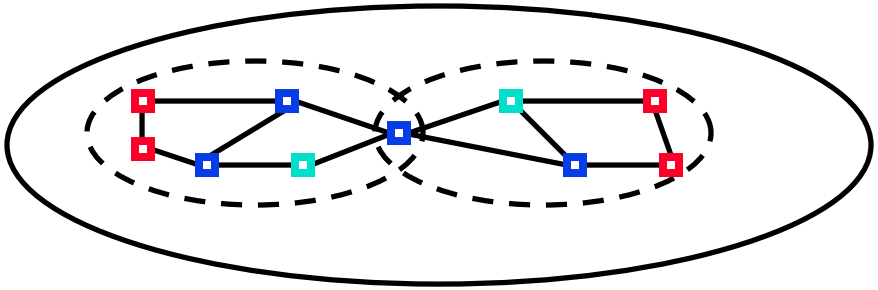
- **Internet 2.0**(1989–2009) Commerce
  - Multiple ownership of infrastructure ⇒ Distrust, **Security**
  - No knowledge of internal topology and resources
  - ***Policy based*** routing ⇒ BGP



- **Internet 3.0**(2009–2029) Commerce
  - Users, Content, Host ownership
  - Requirements, Service Negotiation
  - Mobility of users and distributed data



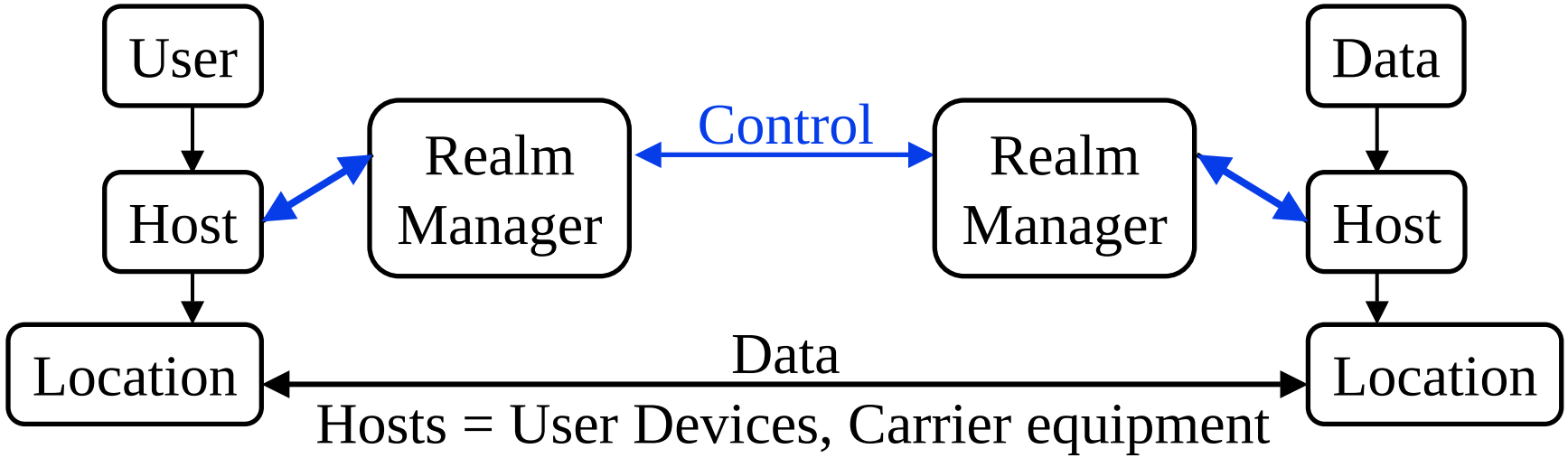
Realms



- Object names and Ids are defined within a realm
- A realm is a **logical** grouping of objects under an administrative domain
- The Administrative domain may be based on Trust Relationships
- A realm represents an organization
  - Realm managers set policies for communications
  - Realm members can share services.
  - Objects are generally members of multiple realms
- Realm Boundaries: Organizational, Governmental, ISP, P2P,…

Realm = Administrative Group

Policy Based Networking Architecture



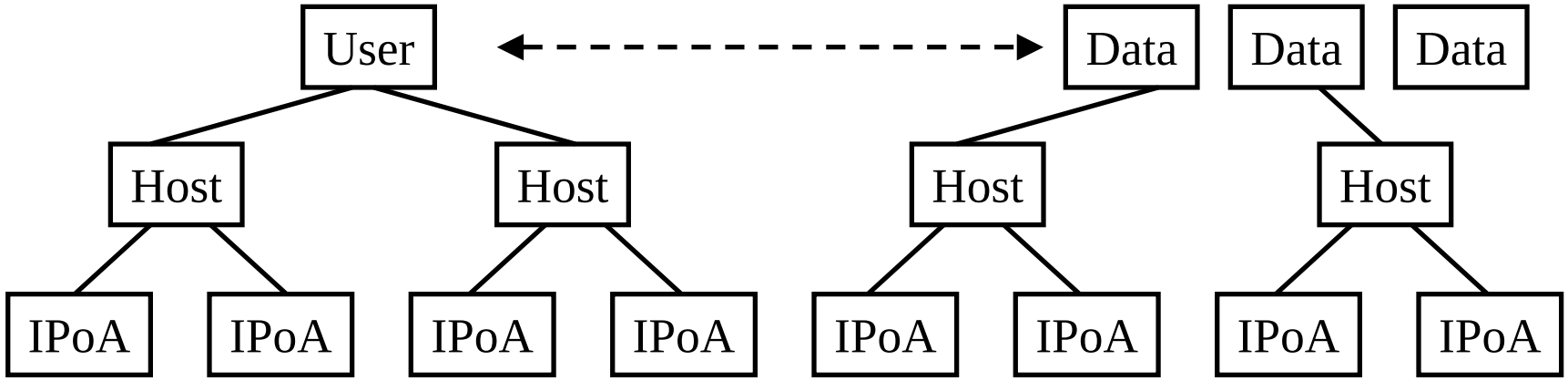
Realm managers (RM): Many organizational functions

- Allow **mobility**, multi-homing, location privacy
- **ID-Locator**: Resolve current location for a given host-ID
- Policy Monitoring. Conformance to Contracts. Troubleshooting.
- Enforce policies related to authentication, authorization, privacy
- Proxy services enabling hosts to sleep ⇒ Energy-aware networking

2. Intelligence in the network ⇒ Suitable for the masses

- Ref: Our Globecom 2008 paper [2]

User-Data Connections

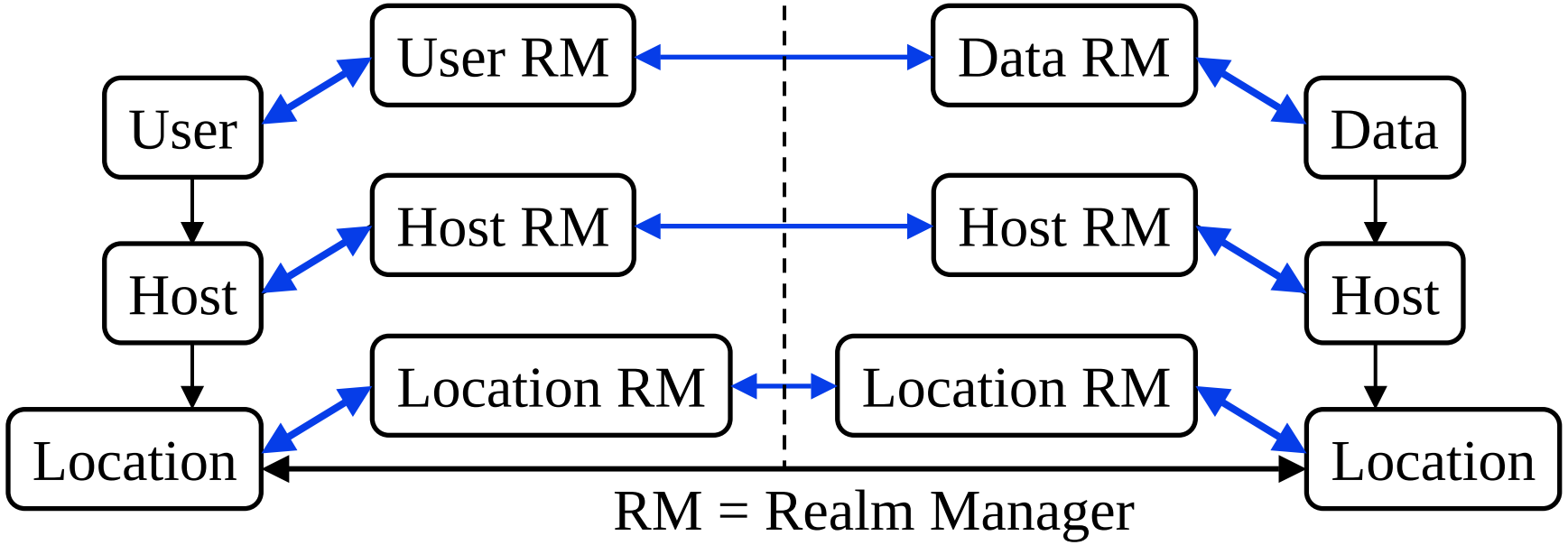


- Currently the connections are between hosts and so users are disconnected when the data or user change hosts
- The fact that data is divisible and replicable is completely ignored

User- Host- and Data Centric Models

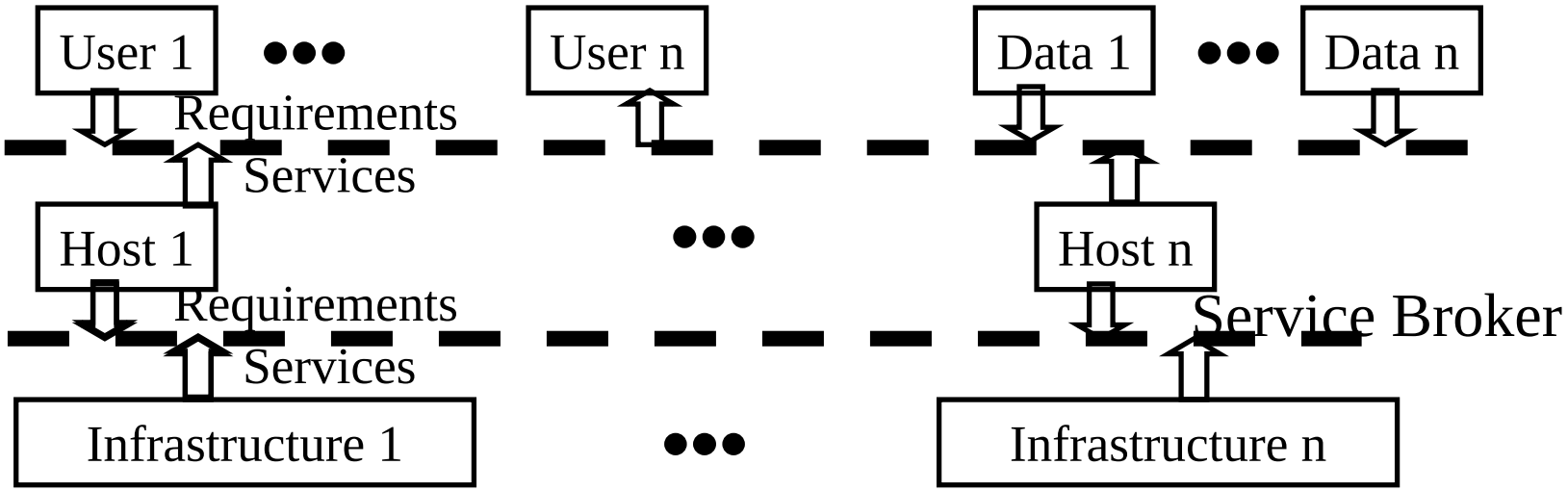
- All discussion so far assumed host-centric communication
  - Host mobility and multihoming
  - Policies, services, and trust are related to hosts
- User Centric View:
  - Bob wants to watch a movie
  - Starts it on his media server
  - Continues on his iPhone during commute to work
  - Movie exists on many servers
  - Bob may get it from different servers at different times or multiple servers at the same time
- Can we just give IDs/locators to users and treat them as hosts? No! ⇒ Policy Oriented Naming Architecture (PONA)

Policy Oriented Naming Architecture



- Both Users and data need hosts for communication
- Data is easily replicable. All copies are equally good.
- Users, Hosts, Infrastructure, Data belong to different realms (organizations).
- Each object has to follow its organizational policies.

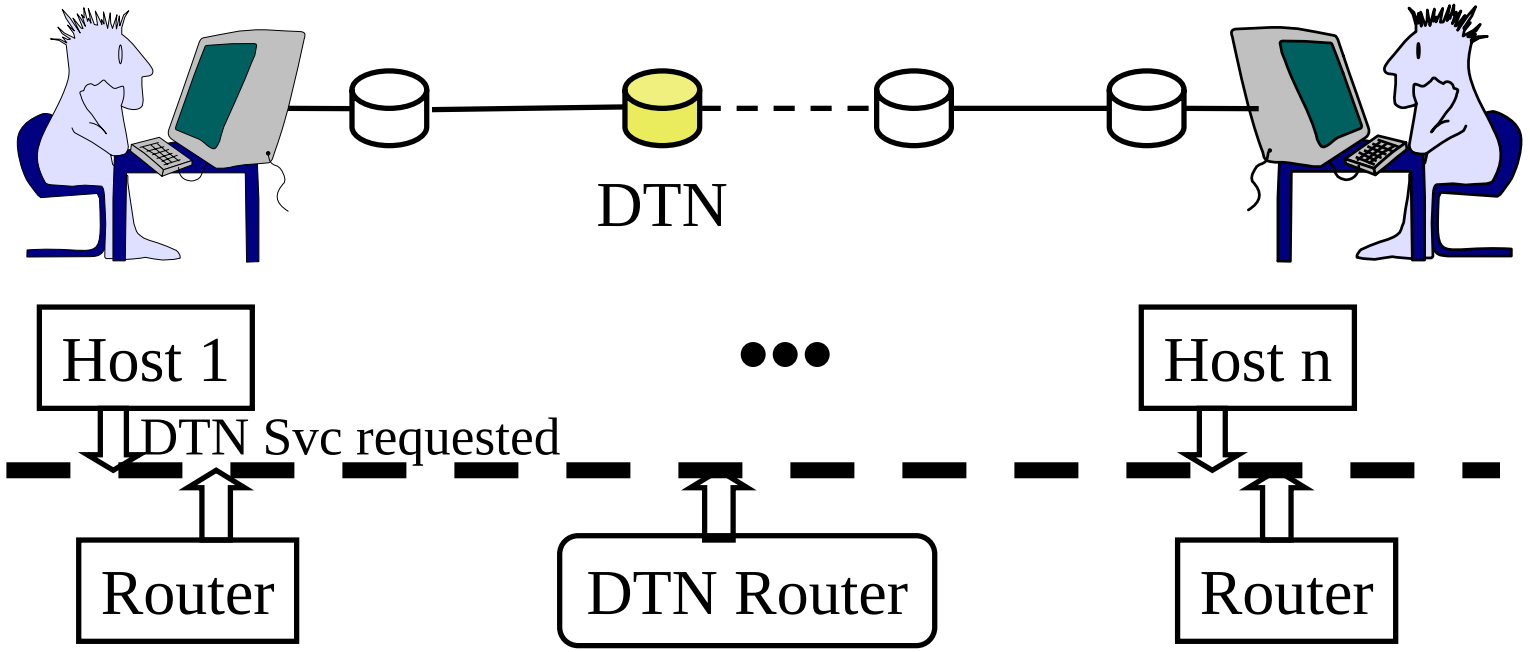
Multi-Tier Object-Oriented View



- Objects provide services. Higher tiers specify the requirements
- Tier service broker (shown by dotted line) composes a service
  – can negotiate with multiple realms in that tier
  -Can monitor and provide independent verification
- Higher tier may not/need not find details of lower tiers

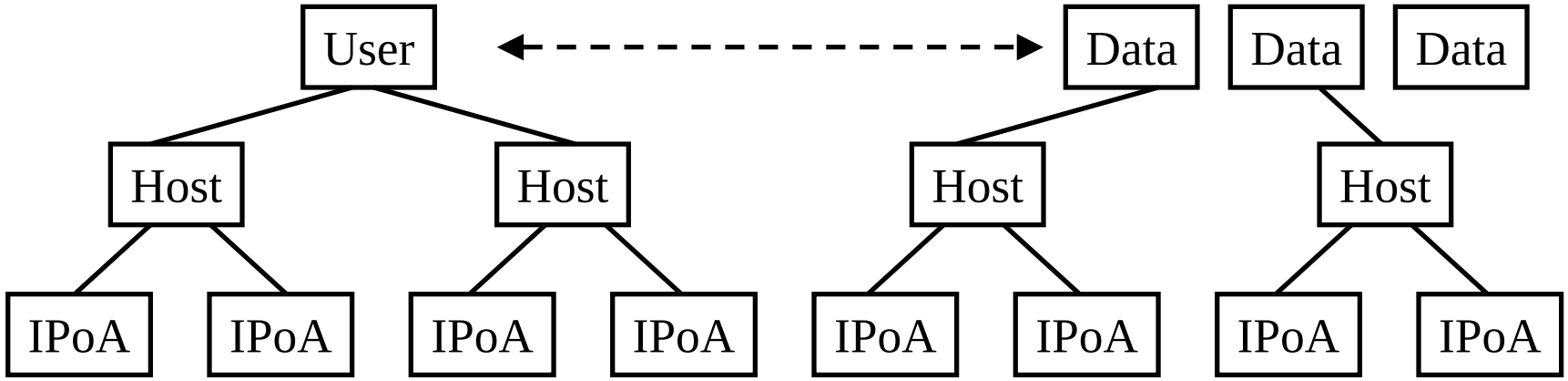
Allows creating requirement specific networking context

Disruption Tolerant Network (DTN)



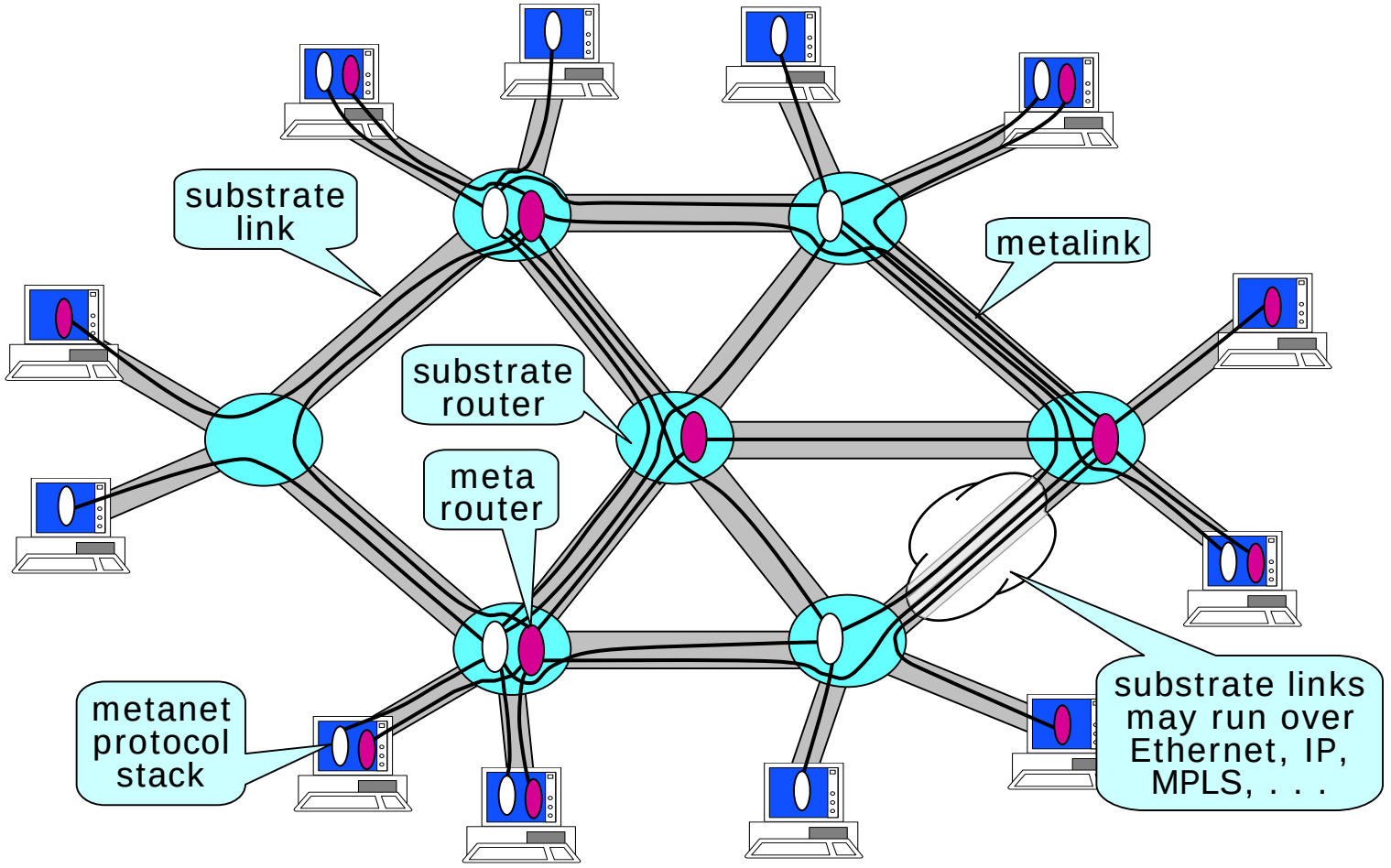
- Normally all routers on the end-to-end path should be up
- DTN-aware routers store data until it can be forwarded
- In Internet 3.0, DTN service can be advertised by DTN routers and negotiated by the service broker

Multi-Tier Issues



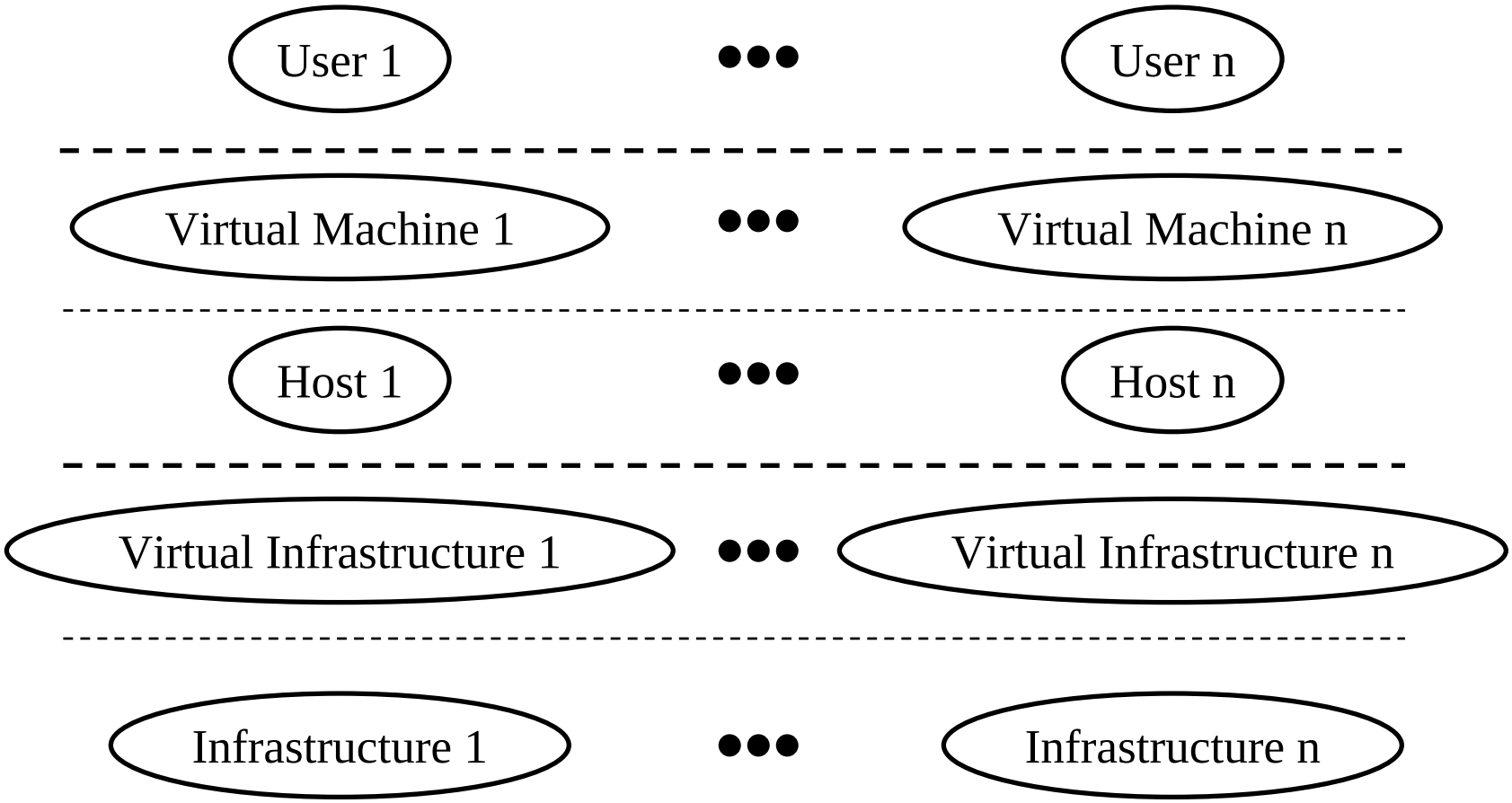
- **Multi-Tier Multi-homing**: Users are accessible via multiple hosts. Each host has multiple Infrastructure Point of Attachments (IPoAs)
- **Multi-Tier Mobility**: Users are constantly changing hosts. Hosts are changing their IPoAs.
- **Multi-Tier Virtualization**

Virtualizable Network Concept



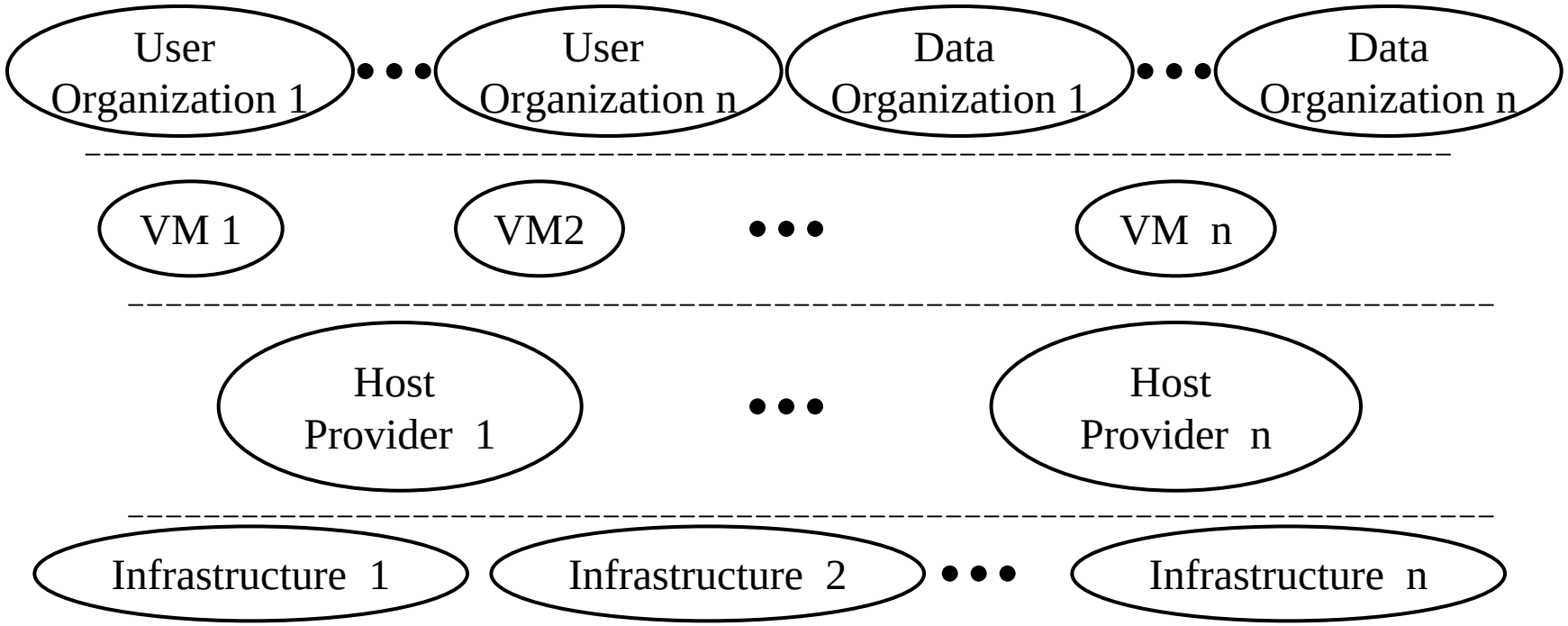
Ref: T. Anderson, L. Peterson, S. Shenker, J. Turner, "Overcoming the Internet Impasse through Virtualization," Computer, April 2005, pp. 34 – 41.

Multi-Tier Virtualization



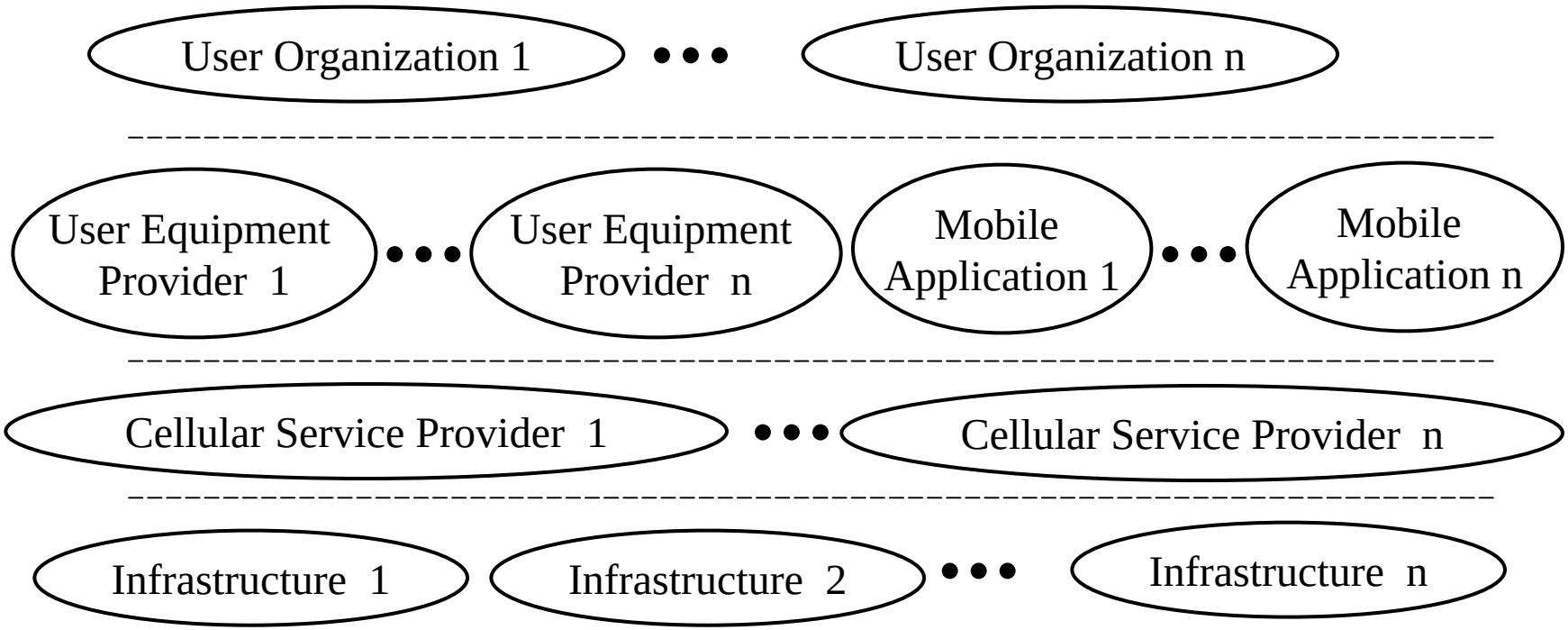
- A tier can be broken in many virtual tiers

Cloud Computing: 4-Tier



- Authenticate/authorize data using data/user policies
- Lease hosts that meet user/data policies
- Connect hosts using host policies
- Transfer data in infrastructure while meeting host requirements

Cellular Networks of the Future



- **Other Examples**:
  - P2P: File sharing groups over hosts over infrastructure
  - Distributed Services: Services over multi-homed hosts
  - National Security: Infrastructure vs. national boundaries

Internet 1.0 vs. Internet 3.0: Features

	Feature	Internet 1.0	Internet 3.0
1.	Energy Efficiency	Always-on	Green ⇒ Mostly Off
2.	Mobility	Mostly stationary computers	Mostly mobile *objects*
3.	Computer-Human Relationship	Multi-user systems ⇒ Machine to machine comm	Multi-systems user ⇒ Personal comm systems
4.	End Systems	Single computers	User/Data/Distributed systems
5.	Design Goal	Research ⇒ Trusted Systems	Commerce ⇒ No Trust Map to organizational structure
6.	Ownership	No concept of ownership	Hierarchy of ownerships

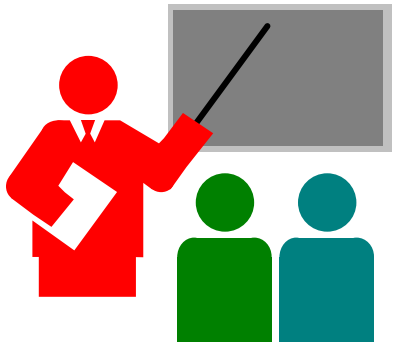
Internet 1.0 vs. Internet 3.0: Design

	Design Issue	Internet 1.0 Solution	Internet 3.0 Solution
1	Connections	Host-Host	User-Data (Hosts are intermediate systems)
2	Information	Complete knowledge of all tiers	Only service API's are disclosed
3	Resource allocation	Algorithmic Optimization	Policy based
4	Multi-homing	Host multihoming	Multi-tier multihoming (User/Data/Host)
5	Mobility	Host mobility	Multi-tier mobility (User/data/host)

Internet 3.0: Research Questions

- What API will allow objects/services to request and provide services?
- Service Broker Architecture: Economic/QoS/Security Negotiations
- Policy Models and Representation
- ID, attributes and trust models for User and Data
- What intelligence and services need to be put in the organization (realm) managers?
- Tradeoff of granularity between services provided and complexity in the network.
- Monitoring and Measurement: Self-defense, Troubleshooting, Independent verification, Conformance to contracts

Summary



1. Internet 3.0 is the next generation of Internet.
2. It must be secure, allow mobility, and be energy efficient.
3. Must be designed for commerce
   $\Rightarrow$ Must represent multi-organizational structure and policies
4. Different ownership/policies of users, hosts, infrastructure
   $\Rightarrow$ Multi-tier, object oriented, service broker architecture
5. Object-oriented architecture allows services to be composed that meet upper tier's requirements while not requiring disclosure of lower tier's mechanisms and details

Top 10 Features of Next Generation Internet

1. Security
2. Mobility
3. Disruption Tolerant
4. Green: Proxy, Sleep Modes,
5. Services: Storage, Translation, Monitoring
6. User/Data-Centric: Network support of data objects
7. Easy to use: Self-organizing, better user control
8. Organizational Representation
9. Virtualizable to create Application Specific Context
10. Policy Enforcement

References

1. Jain, R., "**Internet 3.0: Ten Problems with Current Internet Architecture and Solutions for the Next Generation**," in Proceedings of Military Communications Conference (MILCOM 2006), Washington, DC, October 23-25, 2006, http://www.cse.wustl.edu/~jain/papers/gina.htm
2. Subharthi Paul, Raj Jain, Jianli Pan, and Mic Bowman, "**A Vision of the Next Generation Internet: A Policy Oriented View**," British Computer Society Conference on Visions of Computer Science, Sep 2008, http://www.cse.wustl.edu/~jain/papers/pona.htm
3. Jianli Pan, Subharthi Paul, Raj Jain, and Mic Bowman, "**MILSA: A Mobility and Multihoming Supporting Identifier-Locator Split Architecture for Naming in the Next Generation Internet**," Globecom 2008, Nov 2008, http://www.cse.wustl.edu/~jain/papers/milsa.htm

References (Cont)

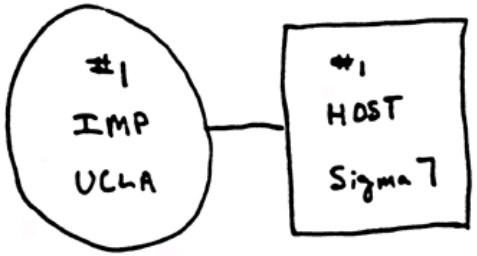
4. Jianli Pan, Raj Jain, Subharthi Paul, Mic Bowman, Xiaohu Xu, Shanzhi Chen, "**Enhanced MILSA Architecture for Naming, Addressing, Routing and Security Issues in the Next Generation Internet**," Proceedings of IEEE International Conference in Communications (ICC) 2009, Dresden, Germany, June 14-18, 2009, (sponsored by Huawei) http://www.cse.wustl.edu/~jain/papers/emilsa.htm
5. Jianli Pan, Subharthi Paul, Raj Jain, Xiaohu Xu, "**Hybrid Transition Mechanism for MILSA Architecture for the Next Generation Internet**," Proceedings of IEEE Globecom 2008 2nd International Workshop on the Networks of the Future, Hawaii, December 4, 2009, http://www.cse.wustl.edu/~jain/papers/milsat.htm

References (Cont)

6. Subharthi Paul, Jianli Pan, and Raj Jain, "**Architectures for the Future Networks and the Next Generation Internet: A Survey**," WUSTL Technical Report, WUCSE-2009-69, October 2, 2009, 59 pp., http://www.cse.wustl.edu/~jain/papers/i3survey.htm

Internet Generations

- **Internet 1.0** (1969 – 1989) – Research project
  - RFC1 is dated April 1969.
  - ARPA project started a few years earlier
  - IP, TCP, UDP
  - Mostly researchers
  - Industry was busy with proprietary protocols: SNA, DECnet, AppleTalk, XNS



- **Internet 2.0** (1989 – Present) – Commerce ⇒ new requirements
  - Security RFC1108 in 1989
  - NSFnet became commercial
  - Inter-domain routing: OSPF, BGP,
  - IP Multicasting
  - Address Shortage IPv6
  - Congestion Control, Quality of Service,…