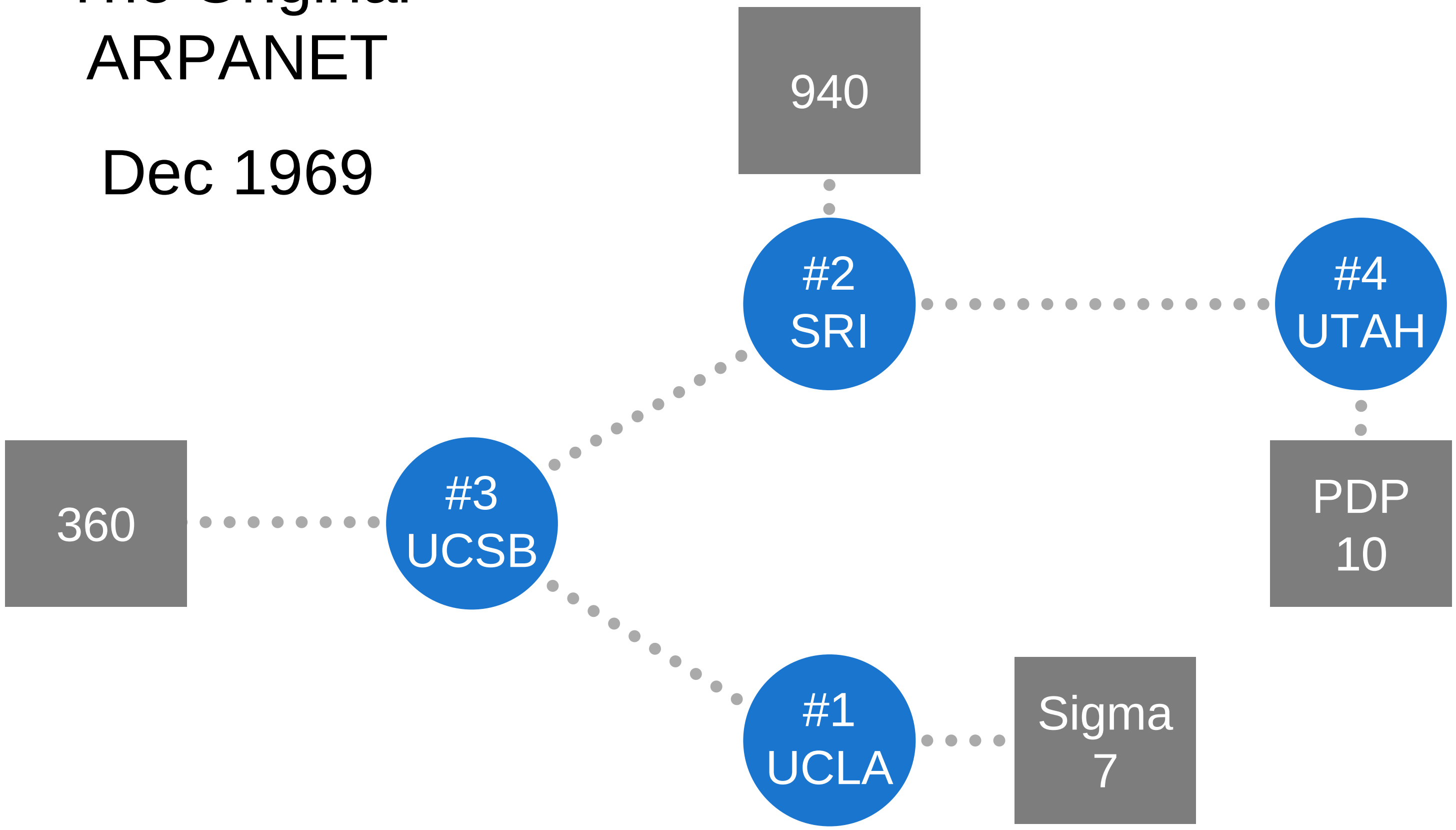
Internet Evolution
Towards IPV6 and Beyond

Vint Cerf

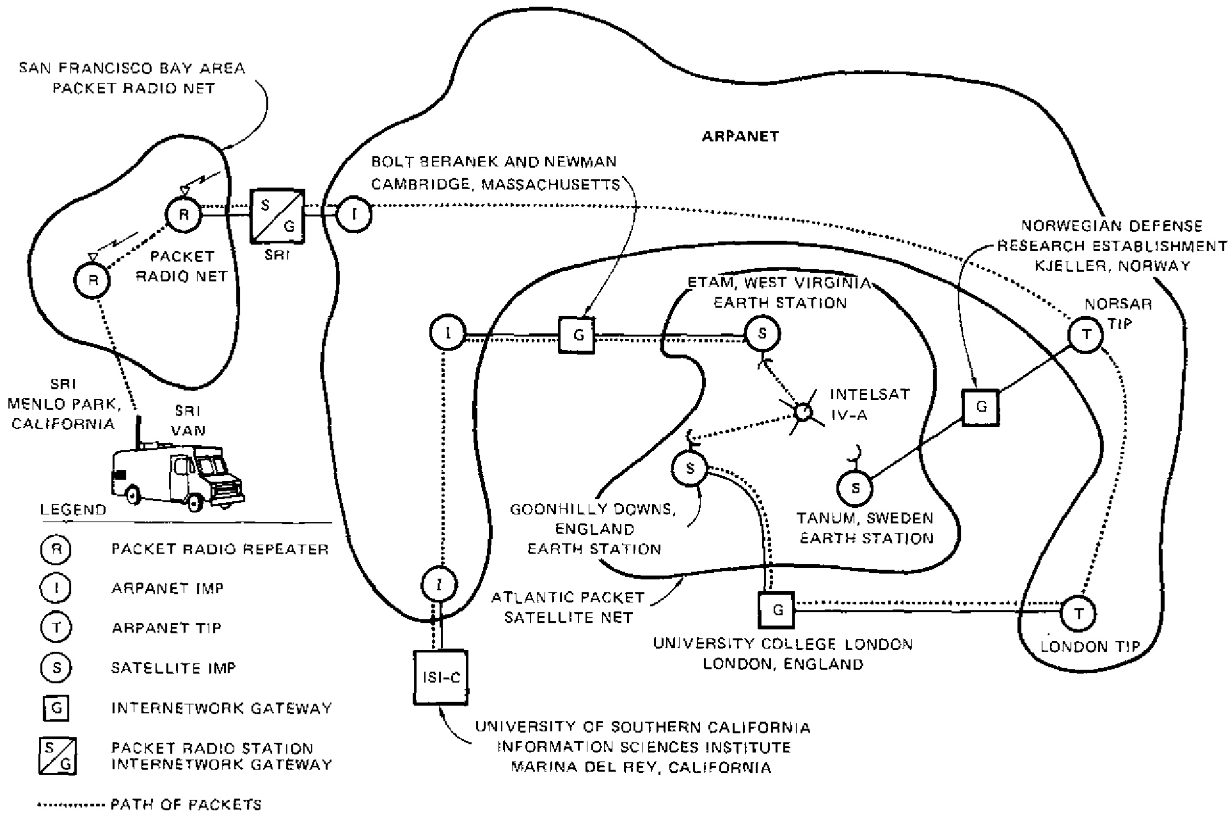
August 2009

The Original ARPANET

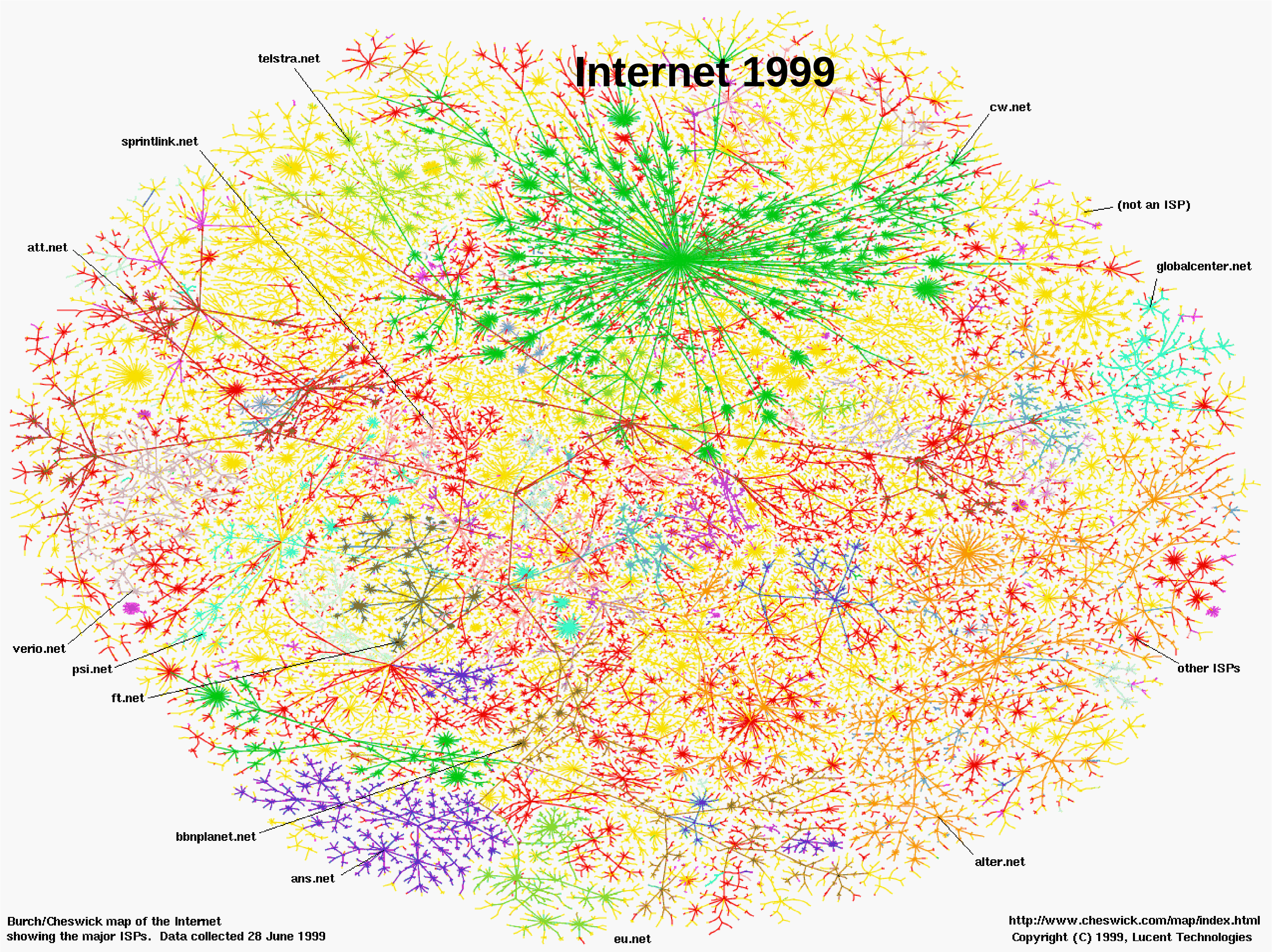
Dec 1969



First Three-Network Test of Internet



November 22, 1977


Internet 1999
telstra.net
sprintlink.net
cw.net
(not an ISP)
att.net
globalcenter.net
verio.net
psi.net
ft.net
other ISPs
bbnplanet.net
ans.net
alter.net
eu.net
Burch/Cheswick map of the Internet
showing the major ISPs. Data collected 28 June 1999
http://www.cheswick.com/map/index.html
Copyright (C) 1999, Lucent Technologies

Internet - Global Statistics 2009

625,226,456

(ftp.isc.org/www/survey/reports/current/ Jan 2009)

1,596 Million Users

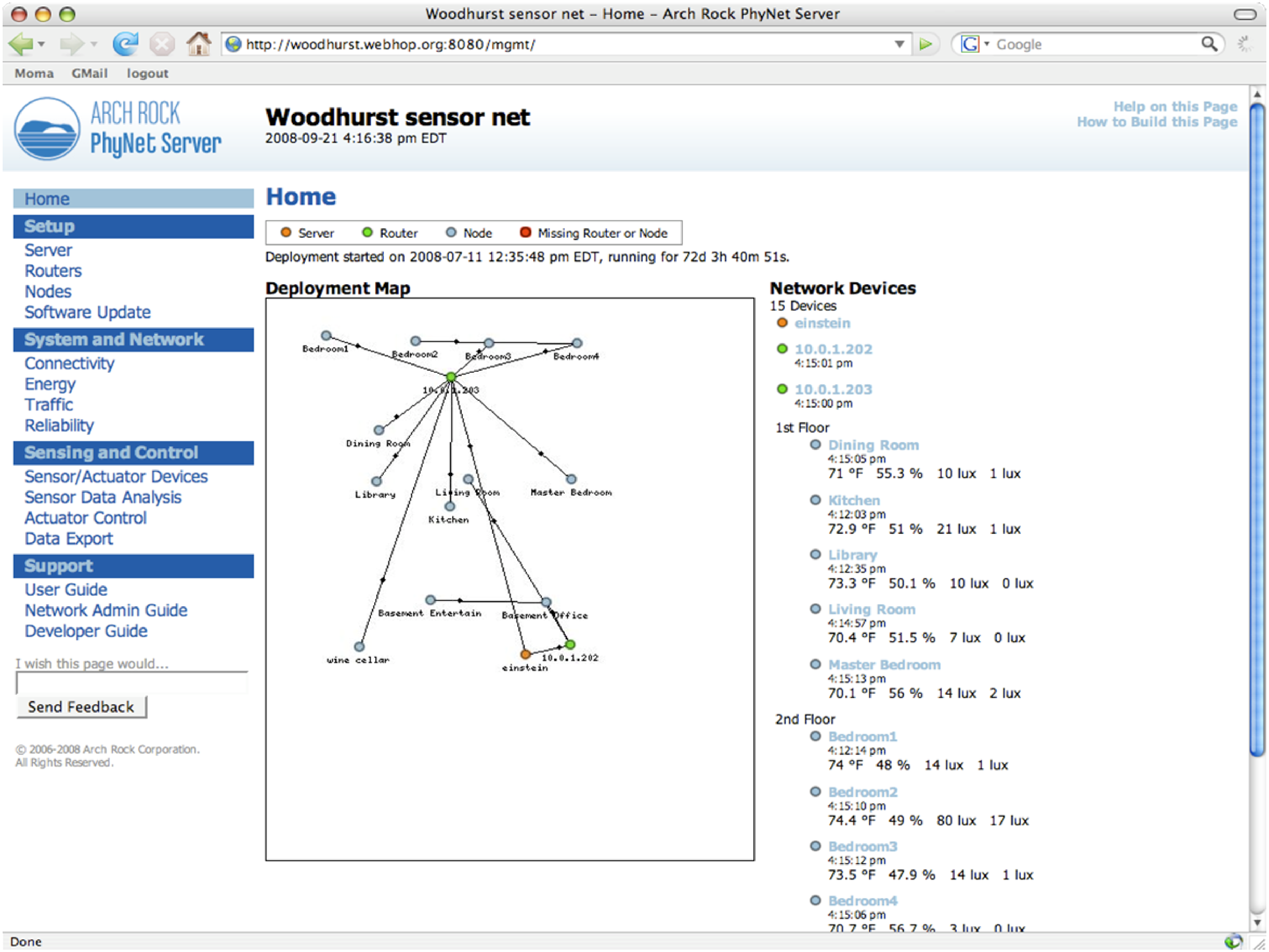
(InternetWorldStats.com, March 31, 2009)

(approx. 4 B mobiles and 1 Billion PCs)

Regional Internet Statistics 3/31/2009

Region	Internet Population	% penetration
Asia	657.1 Mil.	17.1 %
Europe	393.4 Mil.	48.9 %
North Am.	251.3 Mil.	74.4 %
LATAM/C	173.6 Mil.	29.9 %
Mid-East	45.9 Mil.	23.3 %
Oceania	20.8 Mil.	60.3 %
Africa	54.2 Mil.	5.6 %
TOTAL	1,596.3 Mil.	23.8 %

Internet-enabled Devices


Woodhurst sensor net - Home - Arch Rock PhyNet Server
http://woodhurst.webhop.org:8080/mgmt/
Google
Moma
GMail
logout
ARCH ROCK
PhyNet Server
Woodhurst sensor net
2008-09-21 4:16:38 pm EDT
Help on this Page
How to Build this Page
Home
Setup
Server
Routers
Nodes
Software Update
System and Network
Connectivity
Energy
Traffic
Reliability
Sensing and Control
Sensor/Actuator Devices
Sensor Data Analysis
Actuator Control
Data Export
Support
User Guide
Network Admin Guide
Developer Guide
I wish this page would...
Send Feedback
© 2006-2008 Arch Rock Corporation. All Rights Reserved.
Home
Server
Router
Node
Missing Router or Node
Deployment started on 2008-07-11 12:35:48 pm EDT, running for 72d 3h 40m 51s.
Deployment Map
Bedroom1
Bedroom2
Bedroom3
Bedroom4
10.0.1.203
Dining Room
Library
Living Room
Kitchen
Master Bedroom
Basement Entertain
Basement Office
wine cellar
einstein
10.0.1.202
Network Devices
15 Devices
einstein
10.0.1.202
4:15:01 pm
10.0.1.203
4:15:00 pm
1st Floor
Dining Room
4:15:05 pm
71 °F 55.3 % 10 lux 1 lux
Kitchen
4:12:03 pm
72.9 °F 51 % 21 lux 1 lux
Library
4:12:35 pm
73.3 °F 50.1 % 10 lux 0 lux
Living Room
4:14:57 pm
70.4 °F 51.5 % 7 lux 0 lux
Master Bedroom
4:15:13 pm
70.1 °F 56 % 14 lux 2 lux
2nd Floor
Bedroom1
4:12:14 pm
74 °F 48 % 14 lux 1 lux
Bedroom2
4:15:10 pm
74.4 °F 49 % 80 lux 17 lux
Bedroom3
4:15:12 pm
73.5 °F 47.9 % 14 lux 1 lux
Bedroom4
4:15:06 pm
Done

IPv4 runout diagram (Geoff Huston)

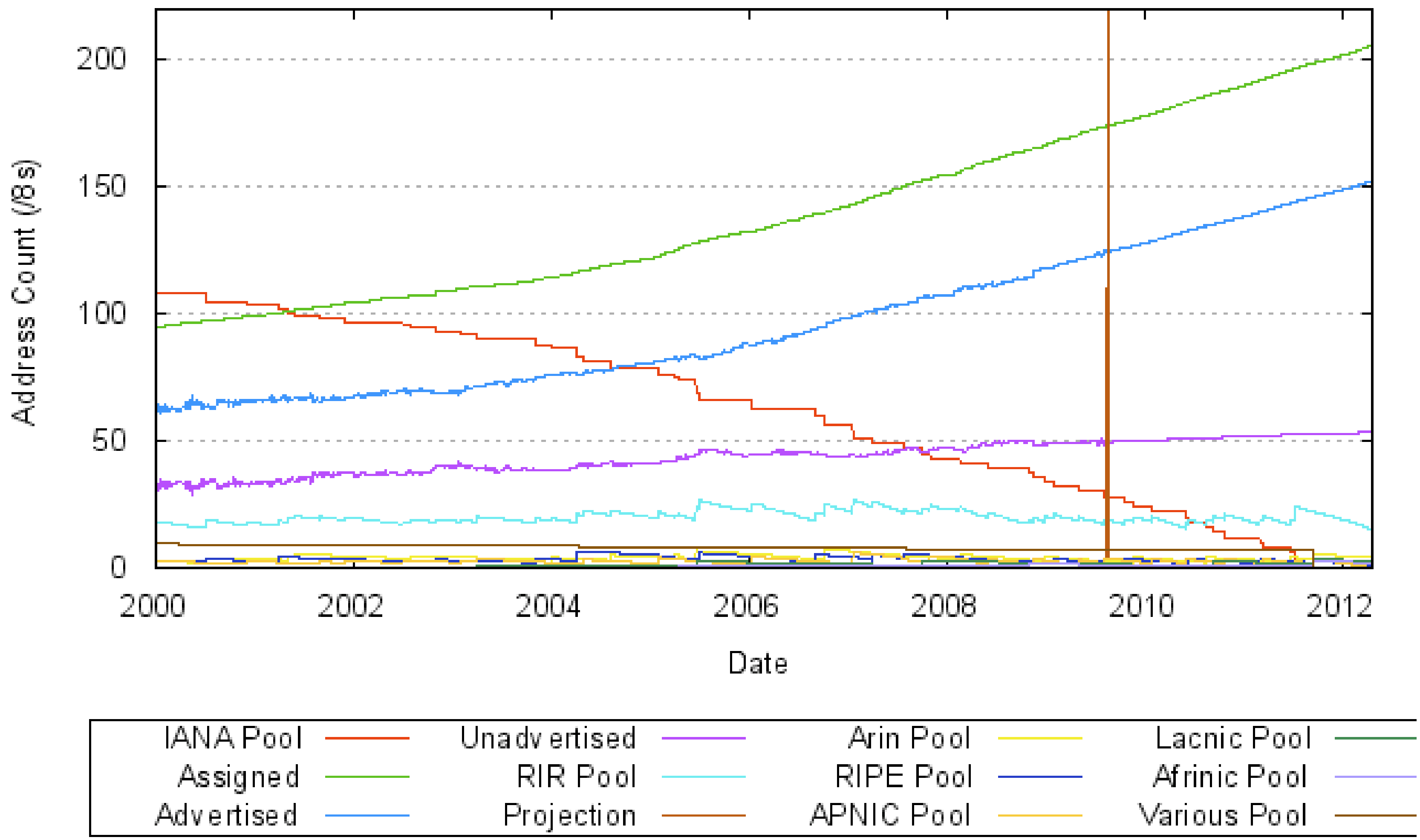
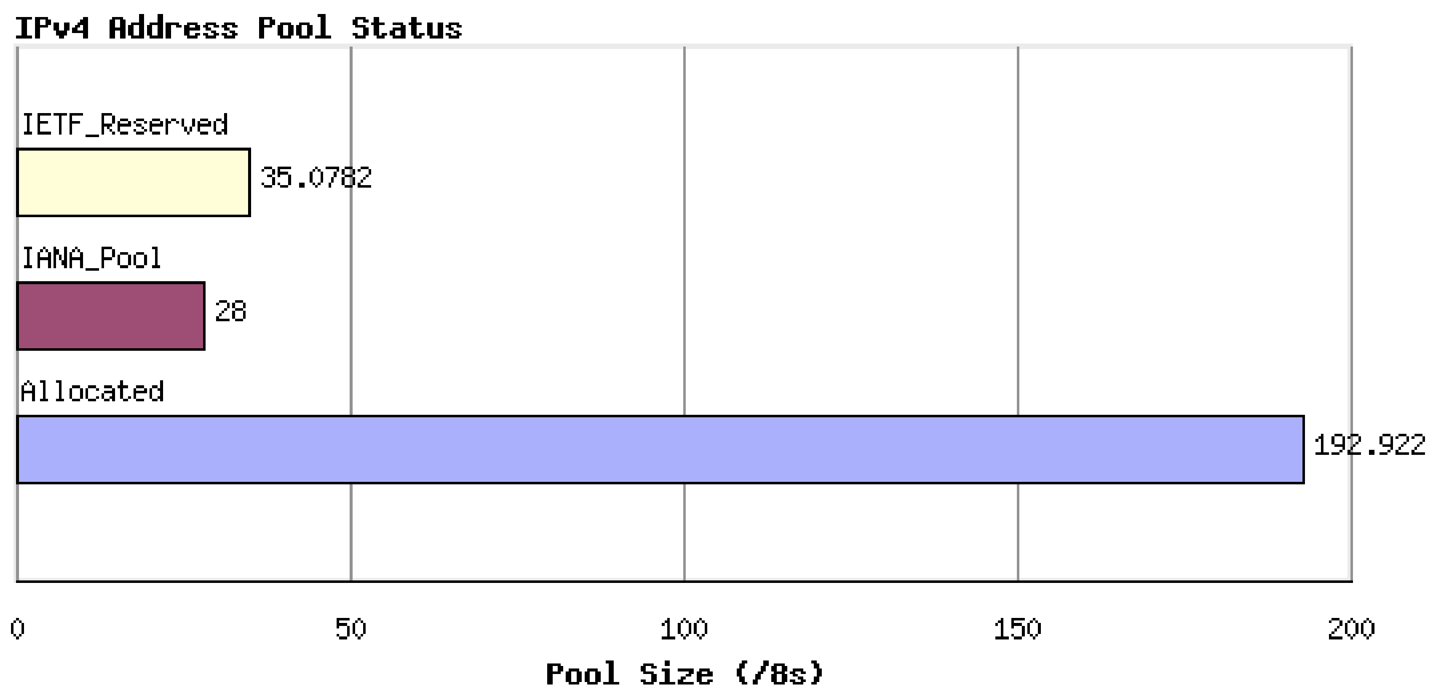


Figure 36 - Address Consumption Model

http://www.potaroo.net/tools/ipv4/index.html

IPv4 Address Pool (August 15, 2009)



IPv6

- 128 bits of address space

  340×10^{36} unique addresses

- IPSEC not optional
- Flow ID
- ipv6.google.com (animated Google logo)

IPv4 Exhaustion Observations

- Uniform allocation of IPv4 /8s to RIRs near runout
- Auction, Gray, Black Markets and Hijacking
- Multi-level NAT is fragile and awkward for P2P
- Communication partner run-out affects you (even if you have enough IPv4 address space of your own)
- Sensor networks and IP-enabled appliances (Smart Grid)

IPv6 Implementation Issues

- Concurrent operation with IPv4
- Non-interoperability of IPv4 and IPv6
- Routing table sizes, update rates, scaling
- Network Management and Provisioning
- Fragmented connectivity (peering implications)
- Allocation and Assignment units
- Business models

An interesting dialog

With only about 15 percent of unallocated IPv4 address space available doyou think IPv6 adoption is behind schedule? If so, will there become a split Internet where some hosts are allocated only IPv6 addresses while most of the Internet is still running IPv4?

An interesting dialog - 2

Yes it is behind schedule - the standards were adopted in 1996 and we should have implemented the new protocols in parallel. The software is already available for clients and servers and routers but ISPs have not implemented or interconnected using this new protocol. We really need to accelerate that implementation.

Following the IETF interim meeting in October in Montreal there's now a healthy focus on IPv6-only clients connecting to IPv4-only services and vice versa. NAT64 and Dual-stack Lite (and others) are under development in the IETF right now and both already have working implementations (so the delay to product should not be terribly large). I suspect there will be a greater diversity of hosts in the future: IPv4-only, IPv6-only, and dual-stack hosts all (ideally) talking to one another (within the limitations of translation). Eventually the cost of maintaining IPv4 infrastructure will exceed the value derived from it, since more and more customers will be forced onto IPv6 and it will be phased out. Like rotary phone dialing, however, it will probably take decades.

An interesting dialog - 3

What will it take to actually trigger adoption? Do you think Internet Service Providers will wait until the very last addresses are allocated?

An interesting dialog - 4

They seem not to recognize that the only sensible way to expand internet service is to use IPv6 rather than relying on nested NATs. Some complain that there is cost without incremental revenue but discount the fact that they can't expand their service to new customers without IP address space.ISPs will ultimately be the ones who make IPv6 happen. Customers don't know they need it and, I believe, shouldn't have to know. It_should_ be transparent to them. However, as Geoff Huston has noted, the benefit does not really accrue to those who bear the cost. Hence ISPs haven't really been motivated until recently to move on this. Other factors, like the major vendors insistence on charging extra for IPv6 capability (only changed in the last month!) and the lack of content providers on IPv6 have only helped to reinforce the business case for _not_ deploying IPv6. All this is changing right now though, and it's pretty exciting.

An interesting dialog - 5

In your opinion do you think it will be the end users or the content providers who adopt IPv6 first.

Users are unlikely to implement if there isn't anything on the other end so the content/apps providers will be the drivers - but no one can do anything useful until the ISPs respond. With transition mechanisms like Teredo and applications like BitTorrent it could be argued that, heretofore, users, acting as both user and content provider, have managed to drive some IPv6 traffic (beyond academic and research interests). Nathan Ward in New Zealand has interesting statistics on this. But a grass roots effort to change the communications protocol that the whole world uses can only be an opening gambit, and can't carry through as a middle or end game strategy. It seems to me and others that content providers need to partner with ISPs to get IPv6 services out to users (ISPs provide the pipes and content providers make the destinations/services accessible).

An interesting dialog - 7

Who do you think the transition will affect the most? Will it be: ISPs, consumers, content providers, etc.?

In some sense, the ISPs are most affected because without implementation they will not be able to increase their customer base. I think we all want one fully connected Internet and the only way to get there is to run IPv6 in parallel with IPv4.

I see also a cascading series of unpleasantness. If ISPs fail to implement IPv6 then theIPv4 Internet as a whole begins to suffer. Higher latency (because of multi-layer NAT, et alia) will make web services painfully slow and applications that already leap tall buildings to build direct connections between users (vis. Teredo, Skype, ...) will have to grow in complexity. The increased fragility would likely result in decreased Internet-derived revenue for content providers and online retailers. Like strangling the golden goose, the oxygen deprivation leads to further complications...

An interesting dialog - 8

But ISPs aren't the only ones bearing the burden. Content providers need to invest in upgraded infrastructure, rewritten software, revised monitoring, and new peering/transit relationships to get IPv6 up. Development time and engineer/operator training, added to the basic hardware and services costs, cannot be ignored either. In reality the burden is directly proportional to the size of the network needing the upgrade, the size and complexity of the software and processes that support that network, and the size of the customer-base accessing or transiting that network. Some content providers are as big, if not bigger, than many ISPs.The most a user will likely have to pay for is an upgrade to an operating system (though most are IPv6-capable right now) and an update to the software on their home firewall/router (or the purchase of a new one).

An interesting dialog - 9

Do you think the private sector will be able to complete the transition on their own or will it take a massive governmental or organizational movement?

the private sector should be able to do this. Governments can insist on IPv6 service for their use of Internet as a motivator.

Do you have any idea of the what the relative costs will be for a company like Google?

Fortunately the differential cost of acquiring IPv6 is lessening. Stories from large IPv6 deployments in China and elsewhere are surfacing that it's cheaper to run an all-IPv6 network and tunnel IPv4 over it as required than to maintain a fully dual-stacked network. I can't comment with credibility on this, but prospect is interesting.

An intersting dialog - 10

Right now Google has ipv6.google.com but does not have any of their other services offered in IPv6, what else is Google doing in implementing IPv6?

We are on track to implement access to all our services via IPv6 but this won't work well if the Internet is not fully IPv6 connected. As long as there are islands of IPv6 that we are not able to reach, our implementation of IPv6 will not service those users. The ISPs must move ahead to implement IPv6 and interconnect with each other to create a fully connected IPv6 Internet. Google has a "trusted tester" program, where we serve AAAA records to networks that meet certain criteria. We served both the RIPE58 and the IETF73 networks with almost all Google services transparently accessible over IPv6. “One personal story from IETF73 in Minneapolis: another participant, upon seeing my badge, made a point of telling me how he was sniffing the wireless network to see how much IPv6 traffic there was. He was surprised to find out that someone was accessing Gmail over IPv6! But he was doubly surprised after he figured out that _he_ was that someone!”

Domain Name System Security (DNSSEC)

- Domain Name: www.sweden.gov.se
  - Hierarchy: root zone points to .se
  - .se points to .gov
  - .gov points to www.sweden server
- Resolvers/Name Servers help users map from Domain Name to IP Address
- It is possible to compromise the Resolvers and Name Servers
- Solution: Digitally sign the domain name entries so software can verify the IP address is properly associated with the domain name
- Example application: banking and financing server validation

Near Term Changes

- DNSSEC (.se, .pr, .bg, .br, ….)
  - Phishing and Pharming, Cache poisoning
  - Root zone needs to be signed
- Internationalized Domain Names
  - Non-Latin Unicode characters
  - Potential hazards (e.g. paypal, .py (paraguay or russia?))
- New ccTLDs and gTLDs
  - ISO 3166-1 (ASCII 2 char) -> iCCTLDs?

Landscape

- Failure of Moore's Law (re: increasing clock speed)
  - Multi-core chips
  - Off-chip I/O capacity?
  - Parallel algorithms?
- Conventional Relational DB are not scaling
- Increasing need to segregate, compartment, protect data (privacy, legal protections (e.g. SEC), corporate trade secrets,…)
- Huge data collections (sensor networks, WWW, digitized everything)
- Bit-Rot problem (it's 3000, can you interpret 1997 PPT?)

Inside the Cloud

- Virtual Structures (file system, Big Table, Load Sharing)
- Data replication (for reliability or speed)
- Functionality (scheduling, MAP/REDUCE, Crawl, apps)
- Inter-machine, intra-cloud protocols (TCP/IP? Others?)
- Multiple Data Centers (replication, responsiveness)

Between the Clouds

- Inter-cloud data exchange (formats? Meta data?)
- Inter-cloud protocols (TCP/IP? Other?)
- Cloud Services? (what are they?)
- Analogy to pre-Internet (IBM/SNA, DEC/DECNET, HP/DS,…)

- Inter-Cloud communication highlights key issues
  - How to refer to other clouds?
  - How to refer to data in other clouds?
  - How to make data references persistent (unlike URLs)?
  - How to protect Clouds from various forms of attack (inside, outside)?
  - How to establish an access control regime (inside, between clouds)?
  - What semantics can we rely on with inter-cloud data exchange?
  - What notion of “object” would be useful for inter-cloud exchange?

Security and the Cloud

- Intra-cloud security
- Protection from infection, denial of service
- Access controls
  - Strong Authentication (users, hosts, processes?)
  - Hardware assisted security? Sandboxing?
  - Content access controls (discretionary, statutory)
    - Think: personnel records, health records, financial records…
    - Ephemeral access controls?
  - Data structures, efficient user/access control enforcement
- Persistent computing (reliability)
  - Cloud has to work even if parts are broken
  - Data has to be accessible even if disks fail
  - Data transfer and storage implications

Inter-Cloud Security

- How to preserve access controls after data transfers?

- How to protect inter-cloud transfers in transit?

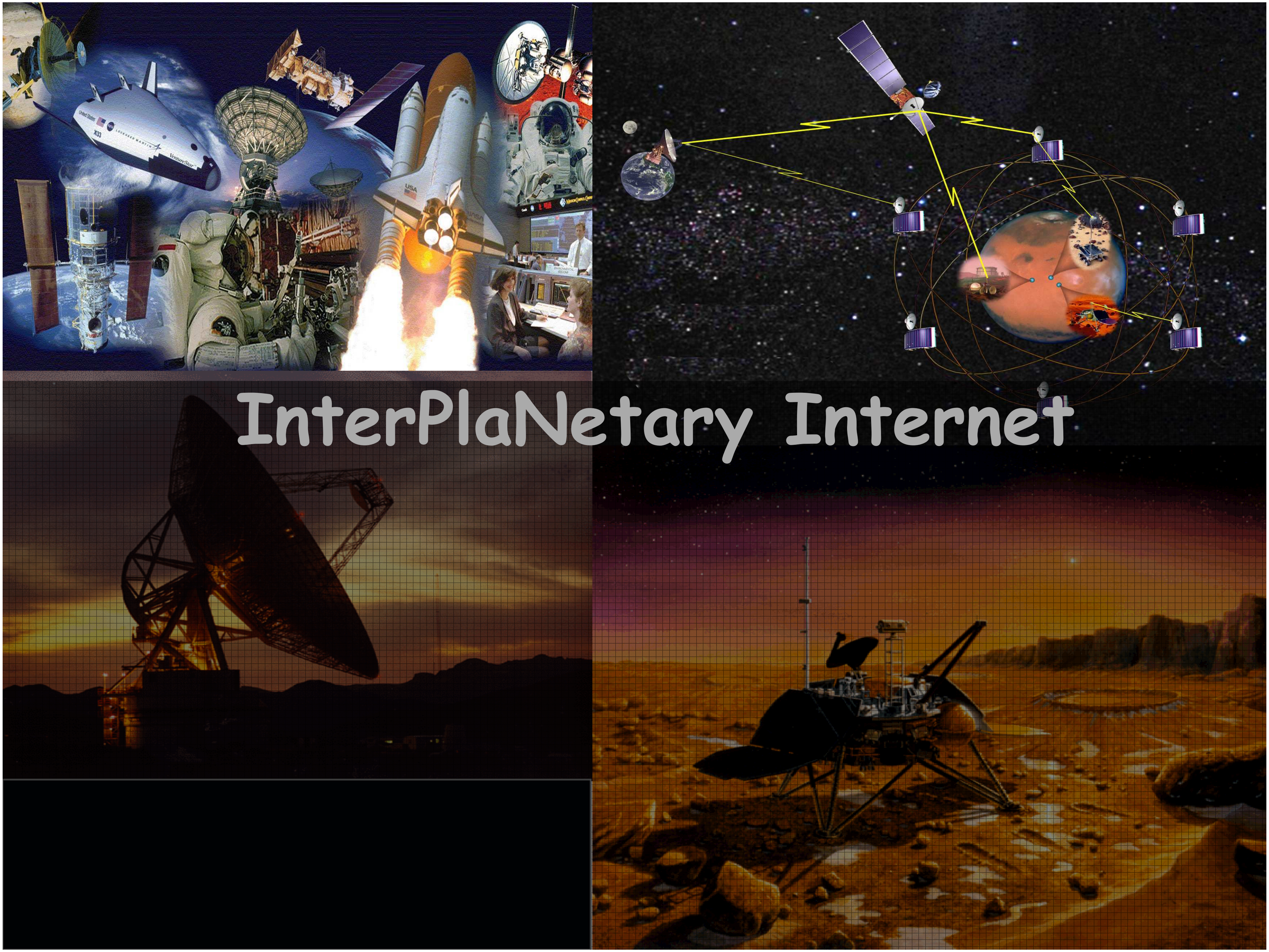
- What meta-data needs to accompany data transfers? Re-establishing context in a new Cloud.

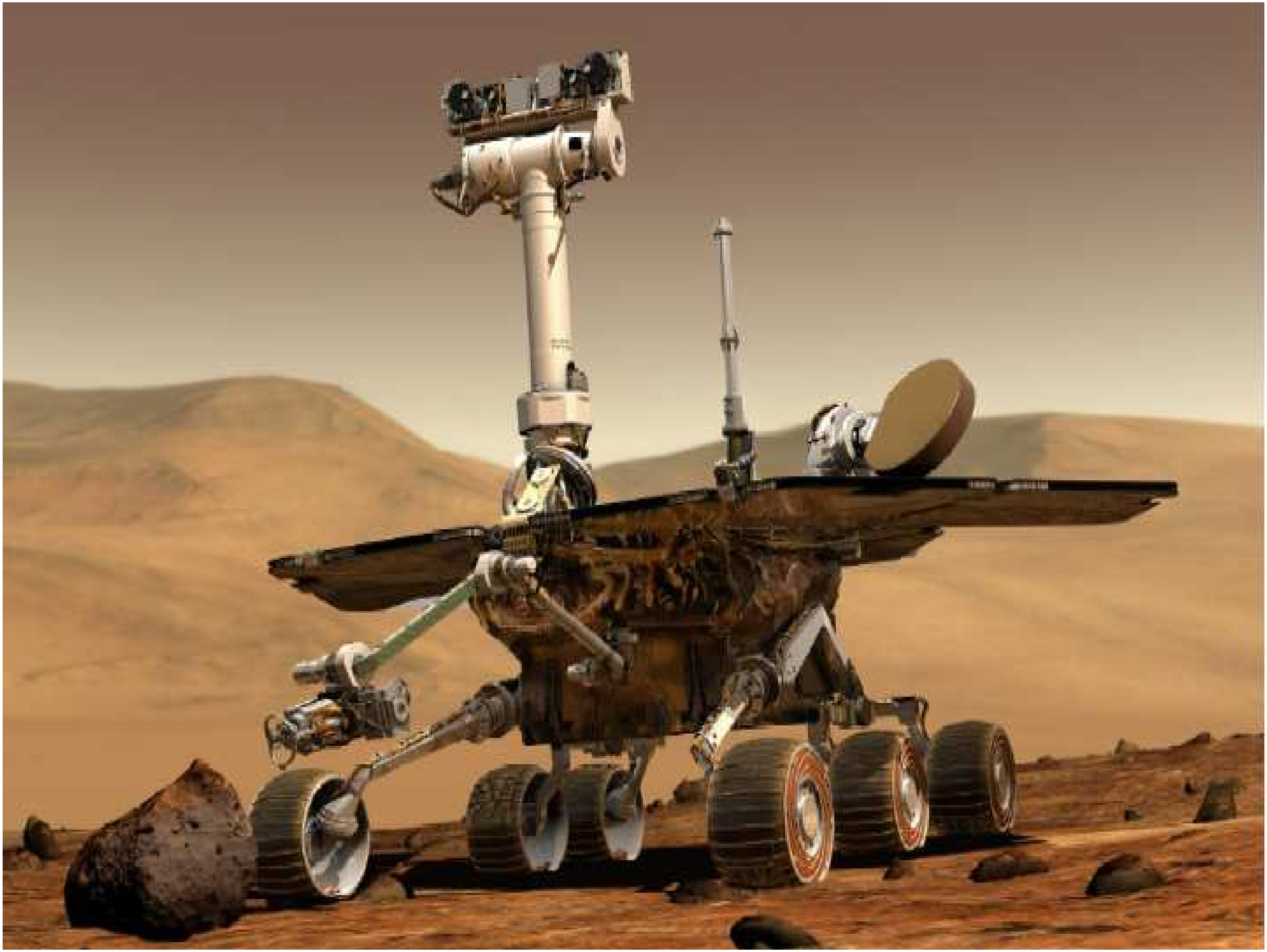
- How to protect against inter-cloud infection? (trojan horses, viruses, worms…)

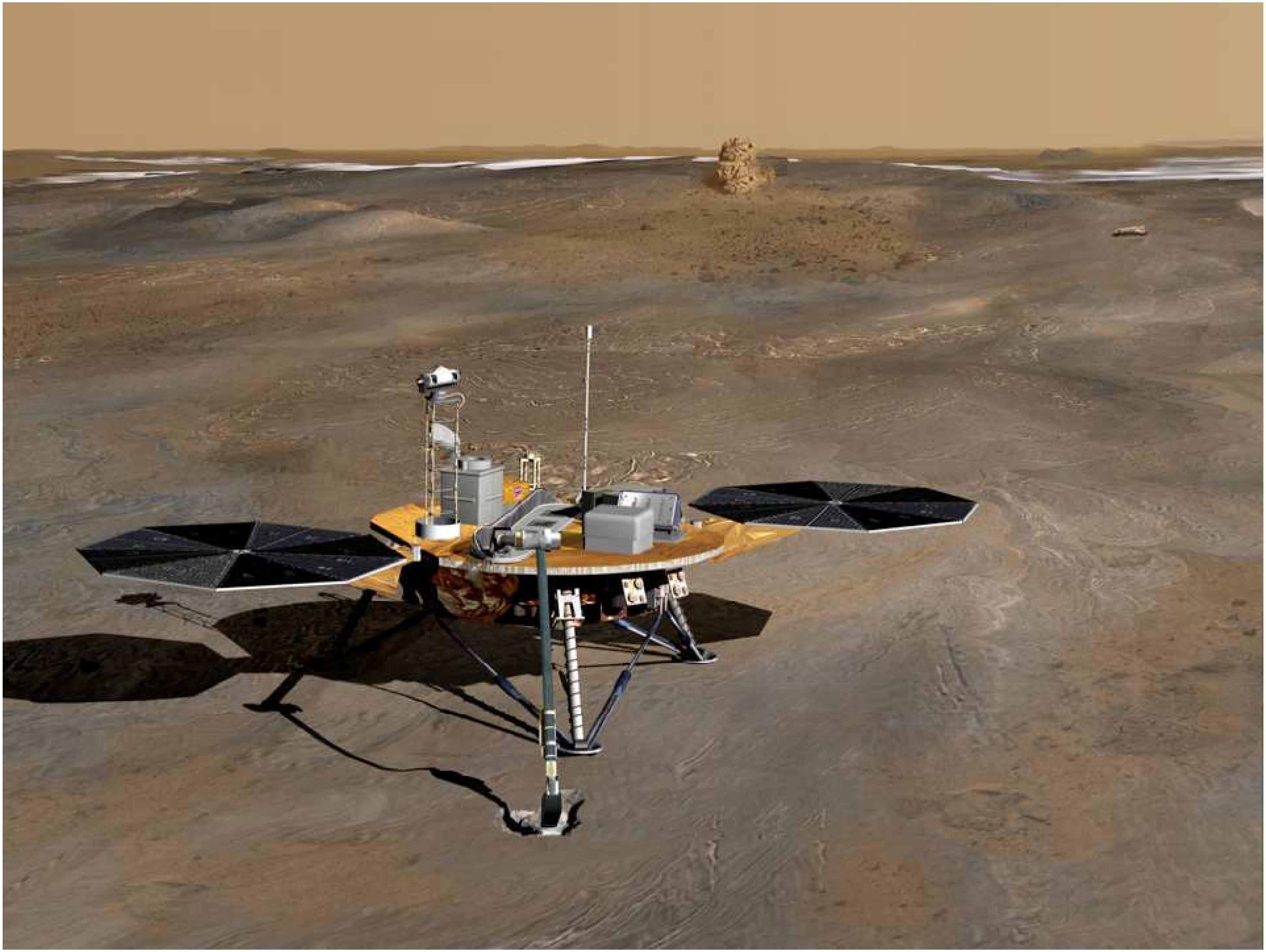
- Clouds have virtual structures made up of hundreds of thousands or even millions of computers. How to protect the integrity of the virtual structures? The physical structures?

Client/Cloud Interactions

- How does a client interact with multiple clouds?
- Is the WWW metaphor sufficient?
- Can clients create unintended and unwanted Inter-Cloud signalling paths?
- Can a client initiate multi-Cloud computations? Transfers?
- How does collaboration work in an inter-Cloud environment?

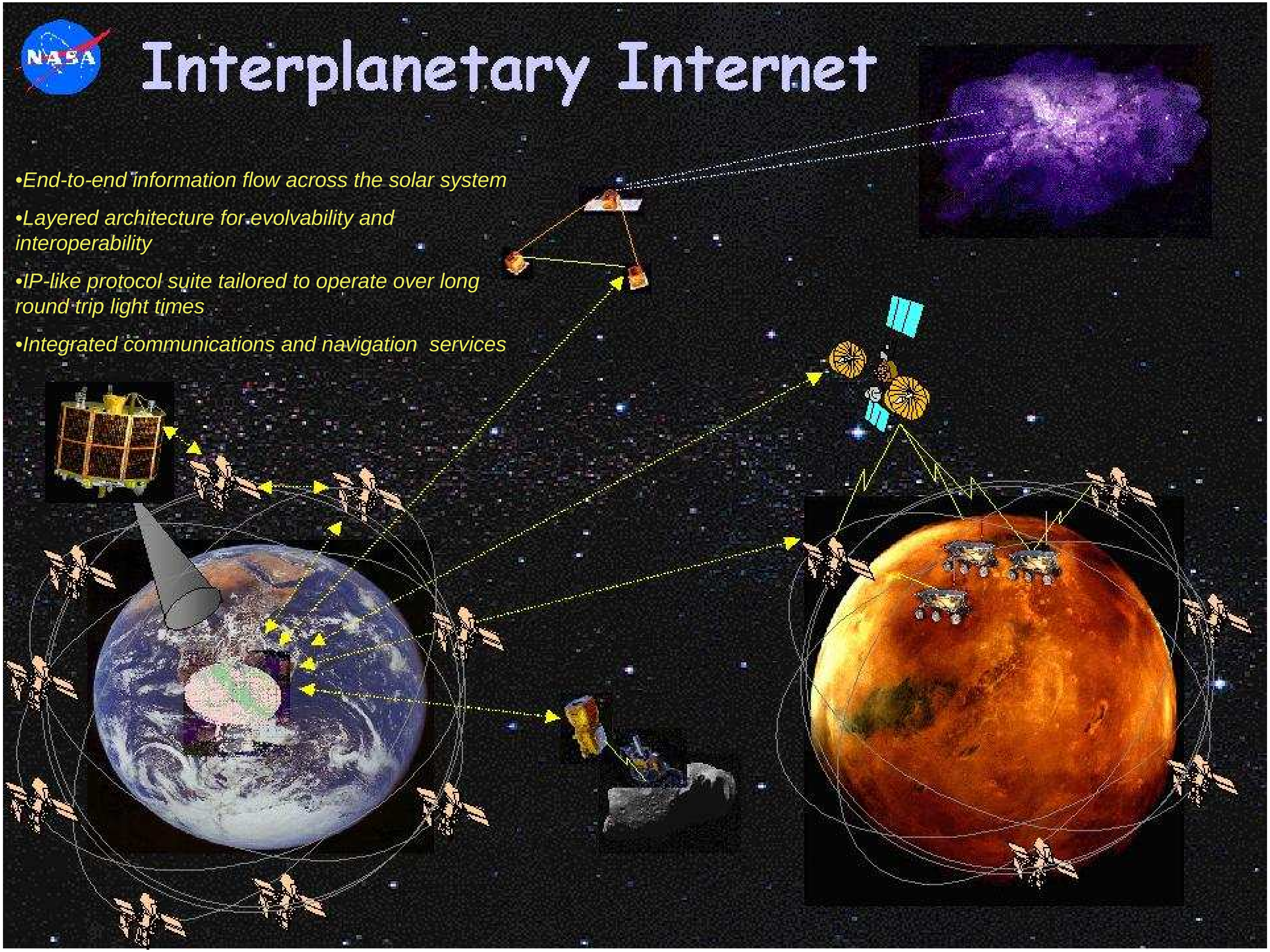

InterPlaNetary Internet





Interplanetary Internet:“InterPlaNet” (IPN)

- Planetary internets
- Interplanetary Gateways
- Interplanetary Long-Haul Architecture (RFC 4838)
  - Licklider Transport Protocol (LTP)
  - Bundle Protocol (RFC 5050)
    - Delayed Binding of Identifiers
    - Email-like behavior
- TDRSS and NASA in-space routing
- Delay and Disruption Tolerant Protocols
  - Tactical Mobile applications (DARPA)
  - Civilian Mobile applications (SameNet!)
  - Deep Impact Testing October/November 2008
  - Space Station Testing 2009
  - EPOXI Testing 2009
  - Intelsat 14 Testing 2010 (TBD)


NASA
Interplanetary Internet
•End-to-end information flow across the solar system
•Layered architecture for evolvability and interoperability
•IP-like protocol suite tailored to operate over long round trip light times
•Integrated communications and navigation services