Designing a New Networking Environment for U.S. Research & Education

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CANS 2004

Florida International University

Miami

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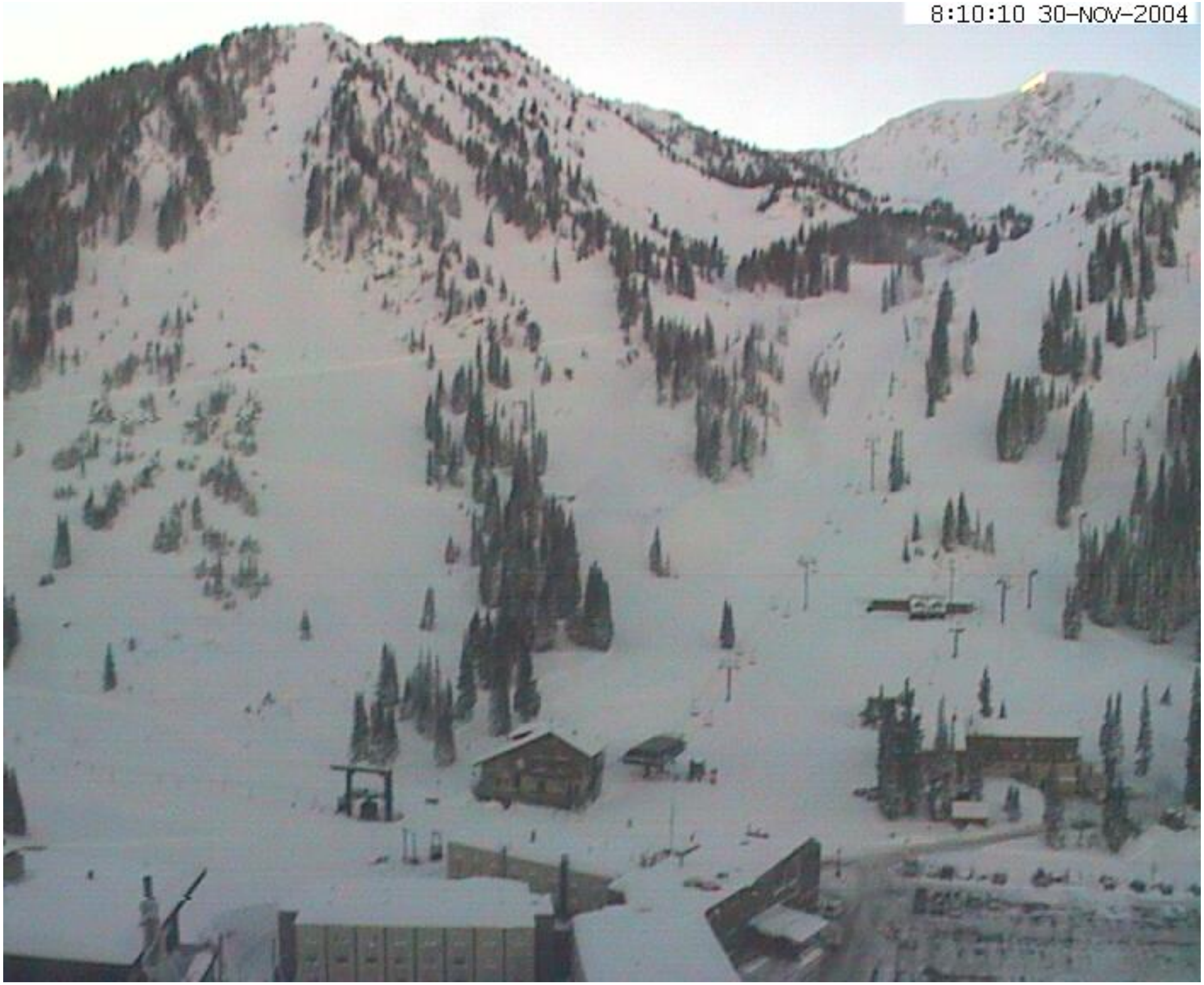
I come to Miami from a slightly different part of the country (Utah)



One view of the U.S. landscape

- The packet network won, but now can it keep up?
  - Grid computing: a distinct view of the network as a *schedulable resource*
- The telecom/IP bust has created a ‘once-in-a-lifetime’ opportunity for previous non-players in facilities-based telecommunications
  - New R&E optical networking facilities are emerging on the regional and national scales
- Active investigation of new hybrid architectures is underway

Topics for today

- High performance packet infrastructure
  - Abilene Network
- Regional Optical Networks (RONs)
  - FiberCo case study
- Future architectures
  - New York City exchange point – MAN LAN
  - Hybrid Optical & Packet Infrastructure – HOPI

Abilene Network

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Abilene Network – second generation

Abilene timeline

- Apr 1998 Network announced
  - Cisco Systems, Indiana Univ., Nortel Networks, and Qwest Communications initial partnership led by Internet2
  - 2.5-Gbps national backbone (OC-48c SONET)
- Jan 1999 Network went into production
- Second generation network upgrade
  - Oct 2001 Qwest MoU (DWDM+SONET) extension (5 years)
  - Apr 2002 Routers from Juniper Networks added
  - Dec 2003 10-Gbps upgrade complete
  - Oct 2004 Transport agreement extended by one year
- Oct 2007 Transport MoU with Qwest ends
  - The time frame for both next generation architecture finalization & decision on transport partner(s) is ~15 months from now – **early spring 2006**.

Abilene scale

September 2004

- IPv4/v6-over-DWDM (OC-192c) backbone
- 44 direct connections (OC-3c $\rightarrow$ 10 GigE)
  - 2 (soon 3) 10-GigE connections (10 Gbps)
  - 6 OC-48c connections (2.5 Gbps)
  - 2 Gigabit Ethernet connections (1 Gbps)
  - 23 connections at OC-12c (622 Mbps) or higher
- 230+ participants – research universities & labs
  - All 50 states, District of Columbia & Puerto Rico
- Expanded access
  - 113 sponsored participants
  - 34 state education networks

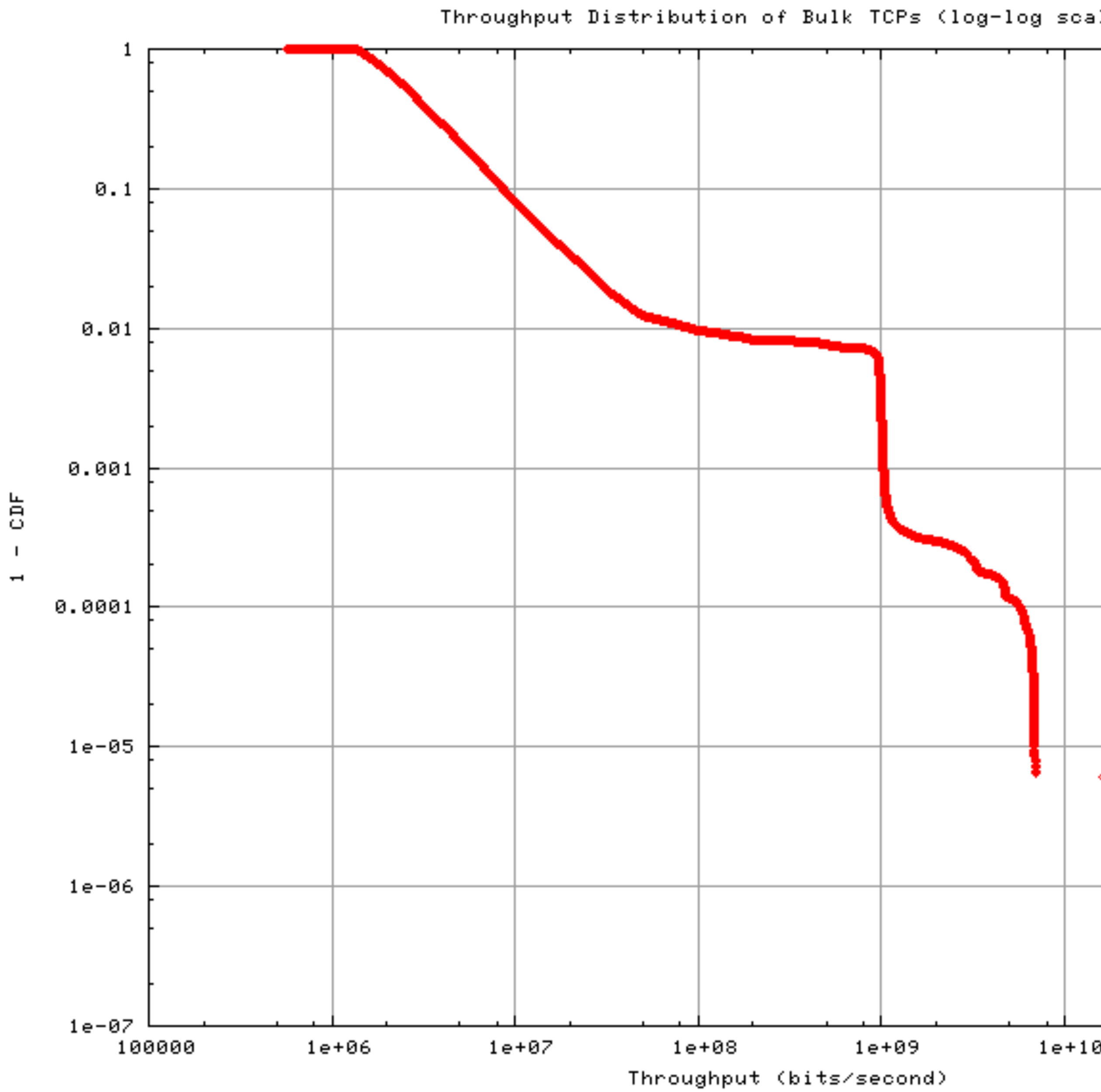
Abilene's distinguishing features

- Native advanced services – multicast & IPv6
- Ability to support large individual flows
  - Regular, routine testing: hourly 980+ Mbps TCP flows
  - Supporting multiple Internet2 Land Speed Records
  - Latest multi-stream TCP flow: 6.6 Gbps
- Home for community's advanced Internet initiatives
  - Middleware, for example
- Cost recovery model
  - Pricing scales roughly logarithmically with bandwidth
  - Aim to is to encourage utilization and experimentation
- Open measurement stance

Abilene Observatory

- A project designed to support the computer science network research and advanced engineering communities
- Two components
  - *In situ* experimentation
  - Access to comprehensive set of network performance data
- Hosted Projects
  - PlanetLab (Berkeley/Princeton/Intel Research/NSF)
  - AMP Project (SDSC/NSF)
- Access to Network Performance data
  - Objective is to maintain time-correlated data archive
  - Multiple time-corrected data views – traffic flows, passive measurements, routing data, SNMP and syslog data
- http://abilene.internet2.edu/observatory/

End-to-end performance: a persistent challenge



Bulk flow distribution (aggregate payload > 10 MBytes)

Median: 2.7 Mbps

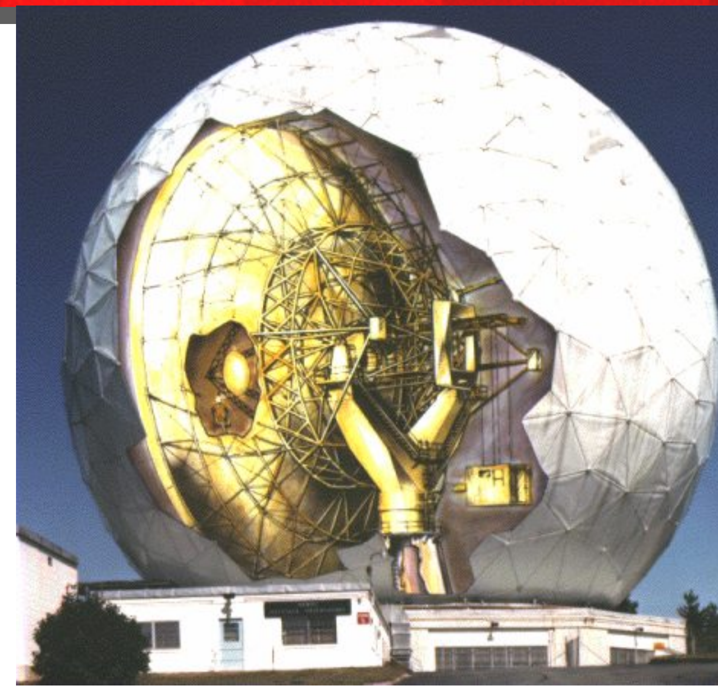
90%: 7.9 Mbps

99%: 38 Mbps

Source: Stas Shalunov (Internet2)

Very Long Baseline Interferometry (VLBI)

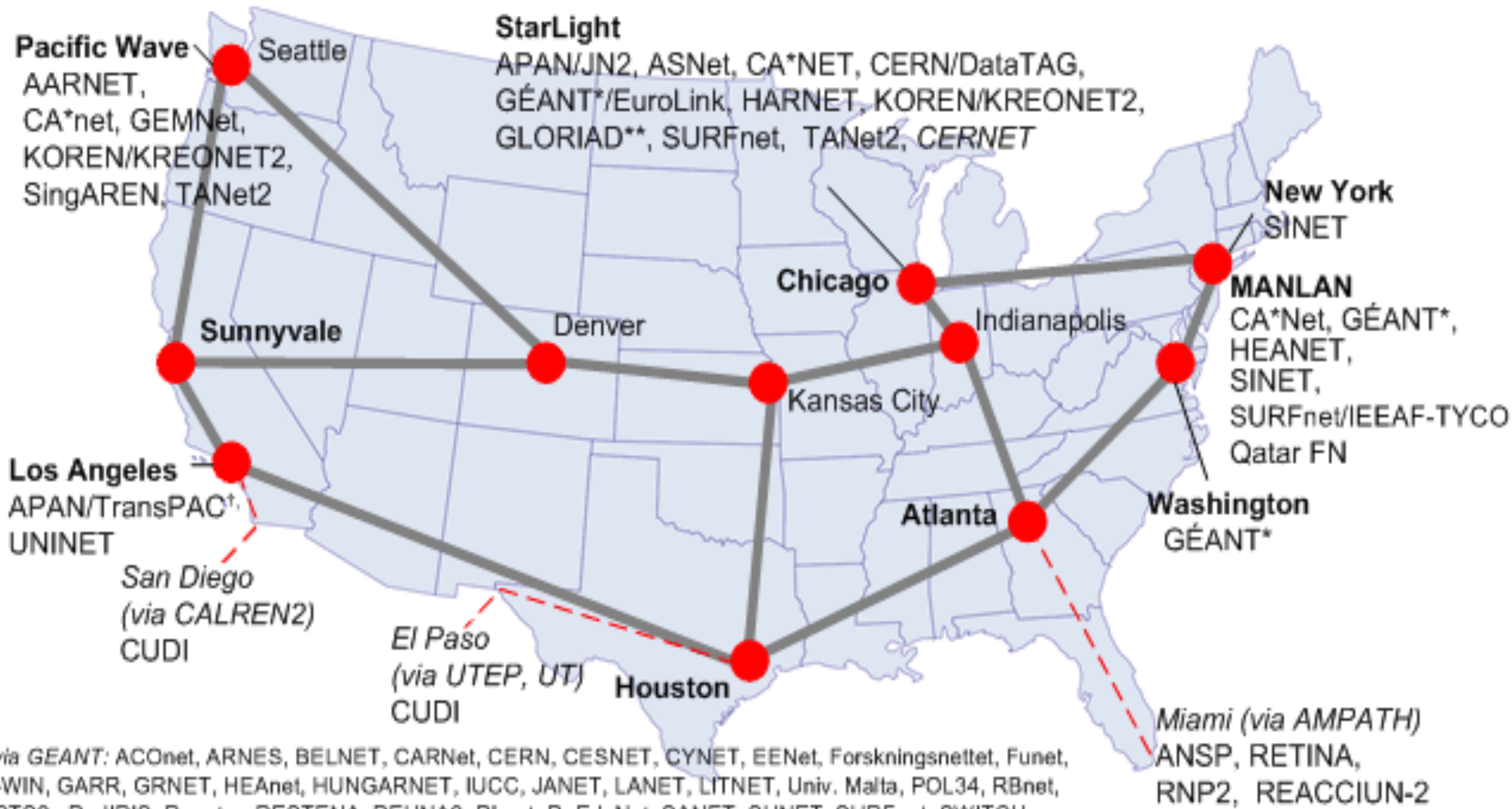
- Multiple antennae located at continental distance
- Each antennae collects data from the sky at speeds of 1-10 Gbps
- Transmit all data dynamically over Abilene (previously recorded data to tape) to correlation facility
- Correlation facility must process information from all antennas in real time (several computational challenges involved here)



MIT Haystack Observatory

Source: Alan Whitney & David Lapsley (MIT/LL); Charles Yun (Internet2)

Abilene International Peering



* *via GEANT:* ACOnet, ARNES, BELNET, CARNet, CERN, CESNET, CYNET, EENet, Forskningsnettet, Funet, G-WIN, GARR, GRNET, HEAnet, HUNGARNET, IUCC, JANET, LANET, LITNET, Univ. Malta, POL34, RBnet, RCTS2, RedIRIS, Renater, RESTENA, REUNA2, Rhnet, RoEduNet, SANET, SUNET, SURFnet, SWITCH, ULAKBYM, UNINETT

† *via APAN/TransPAC:* WIDE/JGN, IMnet, CERNet/CSTnet/NSFCNET, KOREN/KREONET2, PREGINET, SingAREN, TANET2, ThaiSARN, WIDE (v6)

** *via GLORIAD:* CSTNET, RBnet

Regional Optical Networks (RONs)

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Underlying hypothesis

- The fundamental nature of regional networking is changing
  - The *GigaPoP* model based on *provisioned, high-capacity services* steadily is being replaced – on the *metro and regional scales*
- A model of *facility-based networking built with owned assets* – Regional Optical Networks *(RONs)* – has emerged
  - Notably, this change *increases* the importance of regional networks in the traditional *three-level hierarchy* of U.S. R&E advanced networking

Distance scales for U.S. optical networking

	Distance scale (km)	*Examples*	*Equipment*
Metro	< 60	Univ. Wash (Sea), USC/ISI(LA), MAX(DC/MD/VA)	Dark fiber & end terminals
State/ Regional	< 500	I-WIRE (IL), I-LIGHT (IN), CENIC ONI	Add OO Amplifiers (or optical TDM)
Extended Regional/ National	> 500	TeraGrid 2nd Gen Abilene, NLR	Add OEO regenerators & O&M $'s

Leading & Emerging *Regional Optical Networks*

- Arkansas
- California (CALREN)
- Colorado (FRGP/BRAN)
- Connecticut (Conn. Education Network)
- Florida (Florida LambdaRail)
- Georgia (Southern Light Rail)
- Indiana (I-LIGHT)
- Illinois (I-WIRE)
- Louisiana (LONI)
- Maryland, D.C. & northern Virginia (MAX)
- Michigan (MiLR)
- Minnesota
- Minnesota
- New England region (NEREN)
- New York (NYSERNet, Cornell)
- North Carolina (NC LambdaRail)
- Ohio (Third Frontier Network)
- Oklahoma (OneNet)
- Oregon
- Pacific Northwest (Lariat – NIH BRIN, PNNL)
- Rhode Island (OSHEAN)
- SURA Crossroads (southeastern U.S.)
- Tennessee (ORNL, OneTN)
- Texas (LEARN)
- Virginia (MATP)
- Wyoming

FiberCo

- Dark fiber holding company
  - Operates on behalf of U.S. higher education and affiliates – the Internet2 membership
  - Patterned on success of Quilt commodity Internet project
  - Assignment vehicle for the regionals and NLR
  - **Fundamentally, a dark fiber *market maker* for R&E**
- Project designed to *support* optical initiatives
  - Regional (RONs)
  - National (NLR)
- Not an operational entity
  - Does not light any of its fiber
- Concept was a spin-off from NLR governance discussions
  - Internet2 took responsibility for organizational formation
  - First acquisition of dark fiber through Level 3
    - 2,600 route miles (fiber bank) – 3/2003

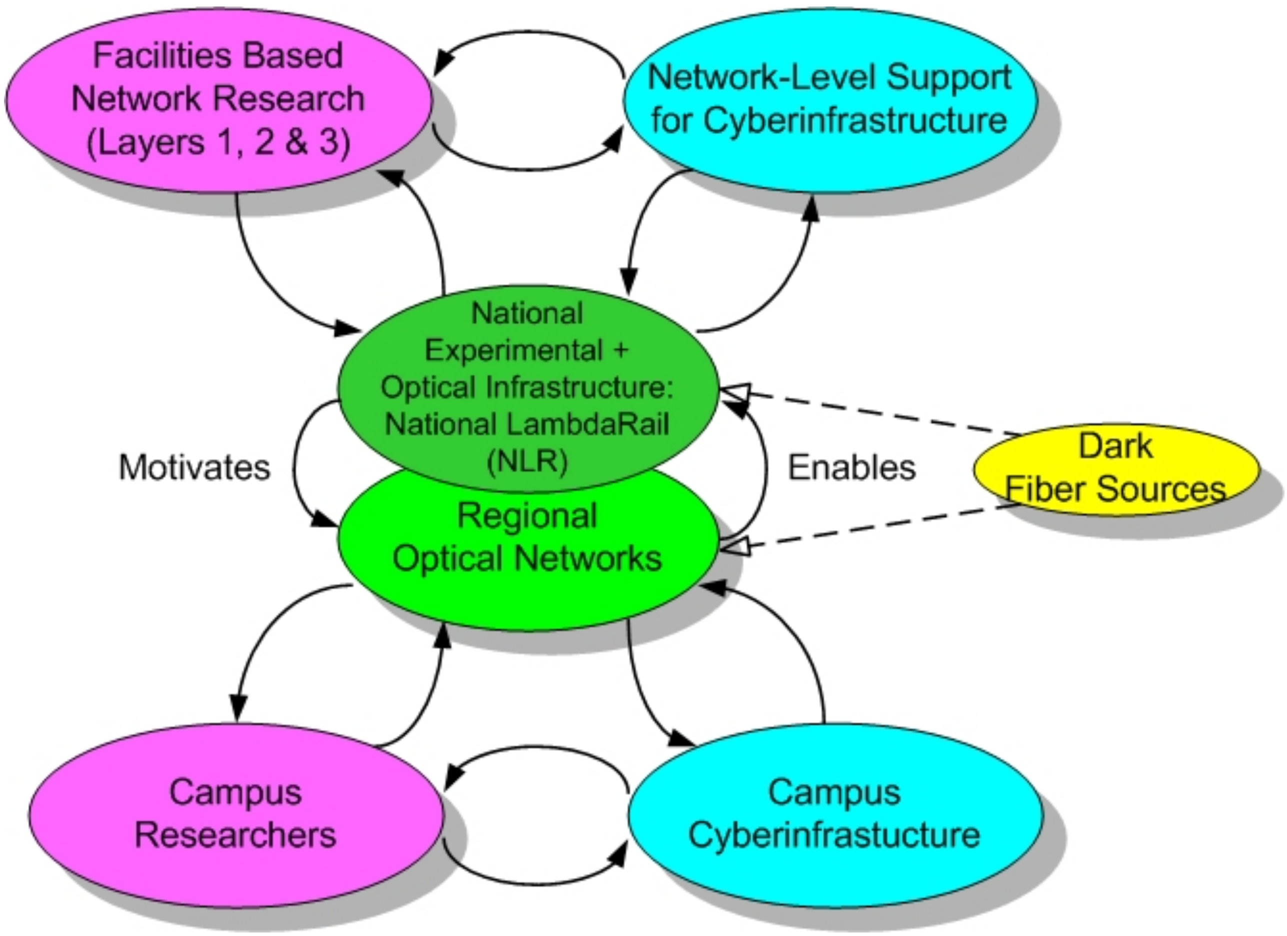
Dark fiber: gauging community-wide progress

- Aggregate dark fiber assets acquired by U.S. R&E optical initiatives (segment-miles)

CENIC (for CalREN & NLR)	6,200
FiberCo (via Level 3 for NLR & RONs)	5,660
SURA (via AT&T)	6,000
– Plus 2,000 route-miles for research	
NLR Phase 2 (WilTel & Qwest)	4,000
OARnet	1,600
ORNL (via Qwest)	900
NEREN	670
Other projects (IN,IL,MI,OR, …)	2,200+

- ***Total (conservative estimate) 27,230+***
  - Over 55% of these assets are now outside NLR
  - NLR will hold ~11,250 route-miles

National LambdaRail - Motivations



Source: Ron Johnson (U Washington) & Steve Corbató

Starting a RON … in stages

1. Convene enthusiastic/visionary regional partners
2. Identify science and other research drivers
3. Assemble a technical working group
4. Develop governance & capital approaches and preliminary business plan
5. Study availability and procure dark fiber
6. Select and procure optronics kit
7. Refine business plan (i.e., λ pricing/cost-recovery model)
8. Focus on means to extend new capabilities to the researchers on campuses
9. Learn how to operate and maintain the system
10. Install and commission plant
11. At last, provision λ's and other services!

Credit: Chris Buja (Cisco Systems) for his collaborative insights

Next steps for optical networking development

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Global Lambda Integrated Facility

World Map – December 2004

Predicted international Research & Education Network bandwidth, to be made available for scheduled application and middleware research experiments by December 2004.

www.glif.is

Visualization courtesy of
Bob Patterson, NCSA.

HOPI Project - Summary

- In the near future, we will see a richer set of capabilities available to network designers and end users
  - Core IP packet switched networks
  - A set of optically switched waves available for dynamic provisioning
- Fundamental Question: How will the core Internet architecture evolve?
- Examine a **hybrid** of shared IP packet switching and dynamically provisioned optical lambdas
- HOPI Project – Hybrid Optical and Packet Infrastructure
  - A white paper describing a testbed to model the above infrastructure is posted **http://hopi.internet2.edu**
    - Implement testbed over the next year
    - Coordinate and experiment with other similar projects
  - Design Team consisting of U.S. and international experiments

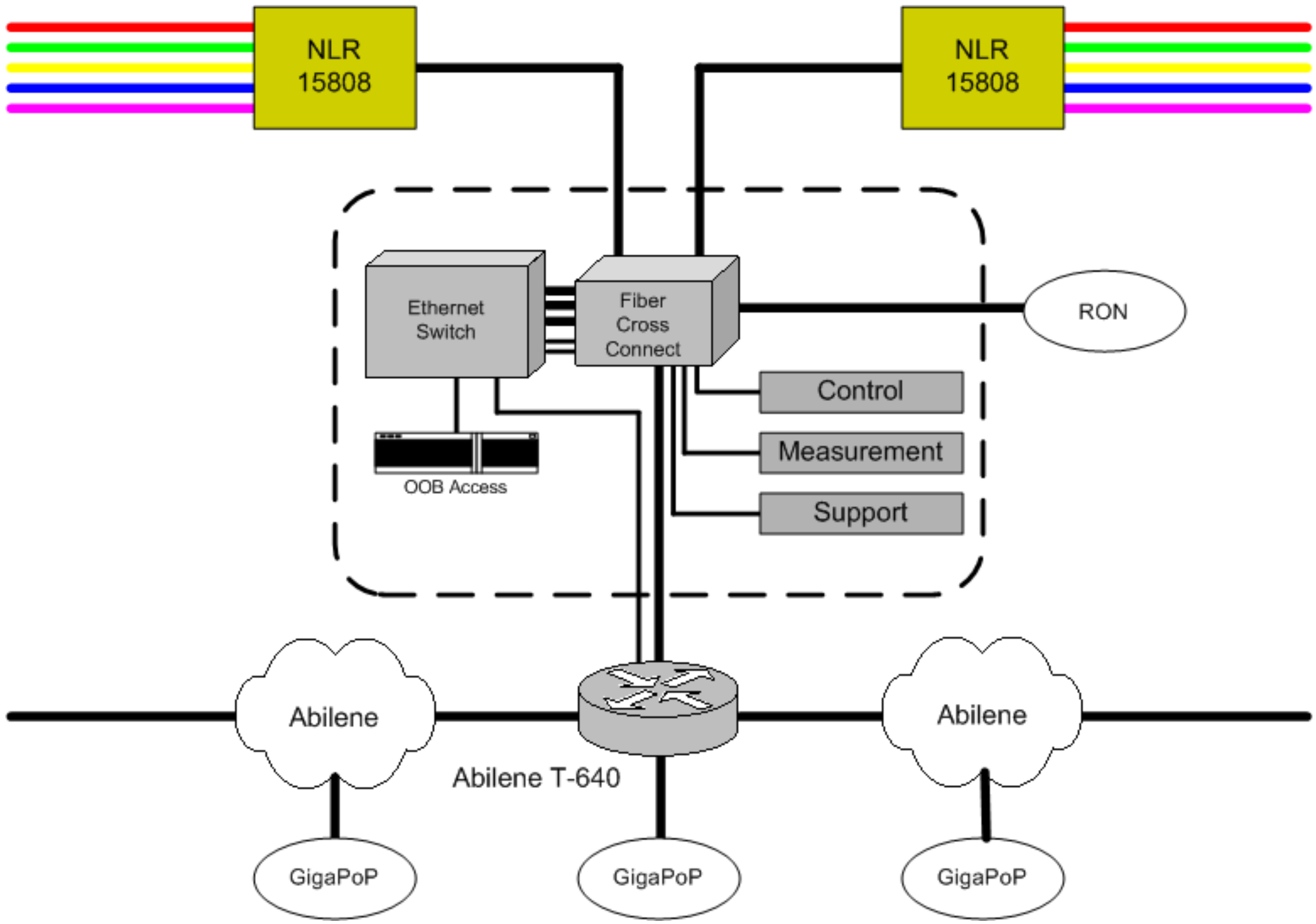
HOPI Resources

- The Abilene Network – MPLS tunnels and the 10-Gbps packet switched network
- Internet2's 10-Gbps λ on the NLR national footprint
- MAN LAN experimental facility in New York
  - IEEAF(Tyco Telecom) 10-Gbps lambda between NYC - Amsterdam
- Collaboration with the Regional Optical Networks (RONs) and other related advanced efforts (GLIF, DRAGON, SURFNet, GEANT-2)

HOPI Project

- Problems to understand
  - Goal is to look at architecture
  - Temporal degree of dynamic provisioning
  - Temporal duration of dynamic paths and requirement for scheduling
  - Topological extent of deterministic provisioning
  - Examine backbone, RON, campus hierarchy – how will a RON interface with the core network?
  - Understand connectivity to other infrastructures – for example, international or federal networks?
  - Network operations, management and measurement across administrative domains?

HOPI Node



NLR
15808
NLR
15808
Ethernet
Switch
Fiber
Cross
Connect
RON
Control
Measurement
Support
OOB Access
Abilene
Abilene
Abilene T-640
GigaPoP
GigaPoP
GigaPoP

Manhattan Landing (MAN LAN) Exchange Point - NYC

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U.S. R&E exchange points

- Star Light (Chicago)
- Pacific Wave (Seattle & LA)
- AMPATH (Miami)
- NGIX-East (DC/College Park MD)
- NGIX-West (SF Bay Area)
- MAN LAN (New York City)
- Current trend is for geographically distributed exchange points on both coasts
  - Pacific Wave (Seattle-Bay Area-LA)
  - Atlantic Wave (New York-Washington DC-Atlanta-Miami)

Manhattan Landing

- MAN LAN originally conceived as a high performance exchange point to facilitate peering between US and International Research and Education Networks
  - Facilitate peering between federal and international networks
  - Original design was layer 2, an Ethernet switch.
- MAN LAN was formed through a partnership with Indiana University, NYSERNet, Internet2, and now IEEAF
  - Indiana University provides NOC and Engineering services
  - NYSERNet provides co-location, hands and eyes, and interconnection support
- Located in 32 Avenue of the Americas in New York City
  - Collocated in the NYSERNet facility adjacent to the fiber meet me room – cross-connects simple to facilitate
  - Many other carriers maintain presences in 32 AoA
  - NYSERNet has co-location space available

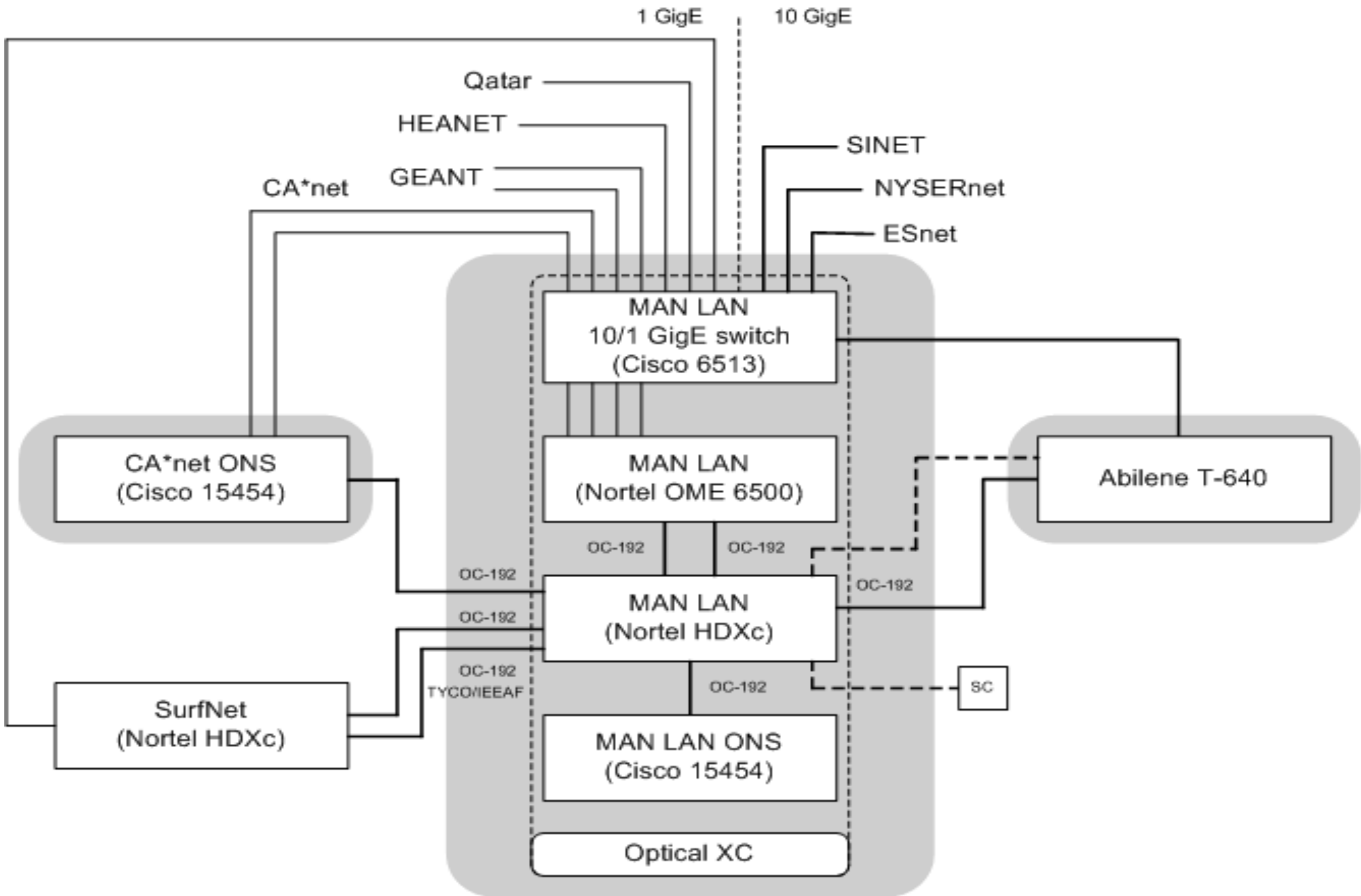
MAN LAN service models

- Production
  - Layer-2 interconnection/peering for IPv4 and IPv6
  - Layer-1 optical interconnection
- Experimental facility
  - Layer-1 optical interconnection
    - Partitioned from production service
    - Adjacent to one of first five HOPI nodes (linking Abilene IP and I2's λ over NLR)

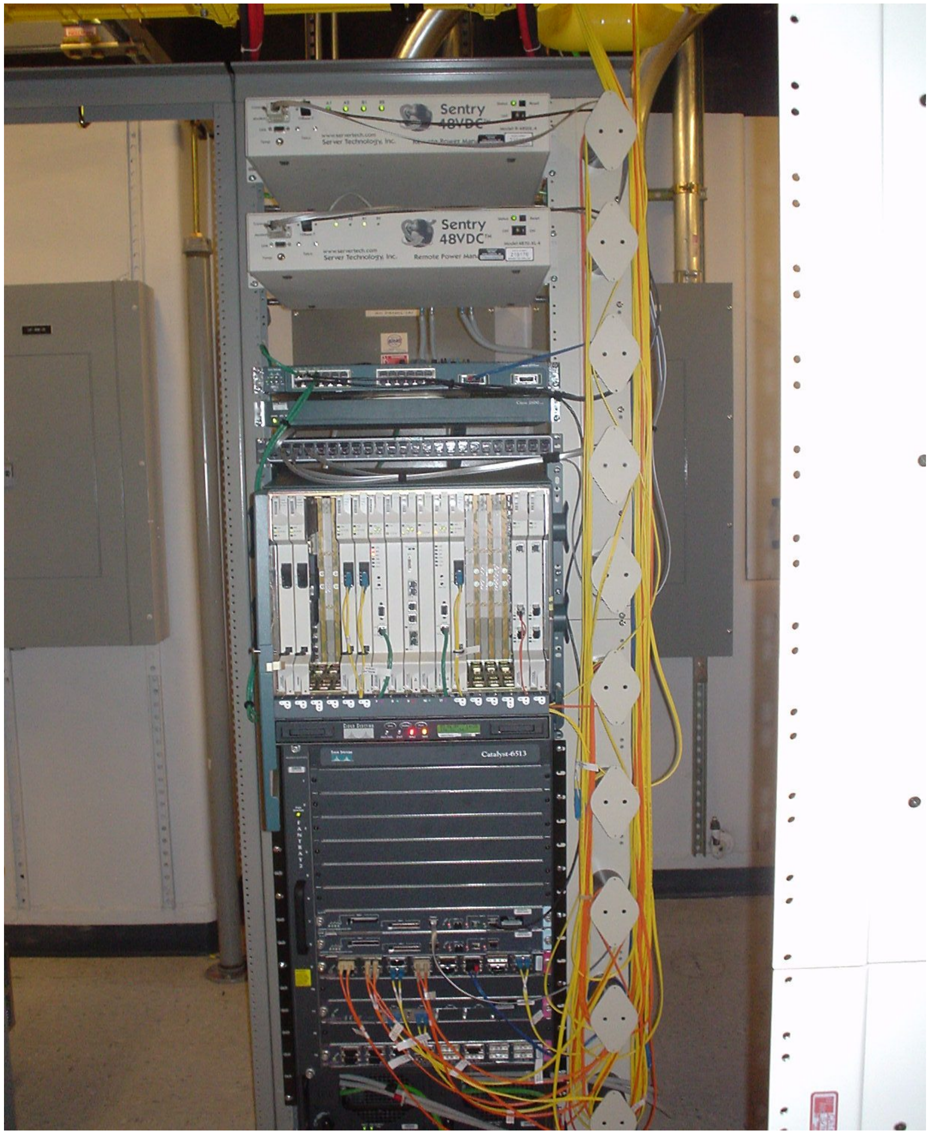
Addition of optical interconnection capabilities

- Layer-1 capabilities (production service and experimental facility) became operational in January 2004 using Cisco 15454 optical TDM
- Current interface configuration
  - 4 x 1 GigE, 2 x OC-48, 3 x OC-192
- Intent was to provide the NYC node for the Global Lambda Integration Facility (GLIF)
  - Plan developed at Reykjavik GLIF meeting – August 2003
- Also planned as part of a key node for the Internet2 HOPI project
- Currently, no additional costs are associated with MAN LAN layer-1 facilities

Upgraded configuration (November 2004)



MAN LAN rack in 32 AoA



Conclusions

- Abilene Network supports most of U.S. higher ed's collaboration needs
  - Observatory showing demonstrable impact in research facilitation
  - Network utilization growing; network capable of large flows
  - Next generation architecture needed within 1.5 years
- NLR and the RONs are providing new options for U.S. advanced networking
  - RON development is a critical activity for research competitiveness
- HOPI and related projects are exploring a unified, hybrid architecture of packets and circuits for the near future

For more information…

- http://abilene.internet2.edu
- http://abilene.internet2.edu/observatory
- http://ipv6.internet2.edu
- http://www.fiberco.org
- http://networks.internet2.edu/manlan
- http://hopi.internet2.edu
- http://www.glif.is

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