Cyberinfrastructure and Networks: The Advanced Networks and Services Underpinning the Large-Scale Science of DOE’s Office of Science

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ESnet Provides Global High-Speed Internet Connectivity for DOE Facilities and Collaborators (ca. Summer, 2005)

ESnet IP core: Packet over SONET Optical Ring and Hubs

42 end user sites
- Office Of Science Sponsored (22)
- NNSA Sponsored (12)
- Joint Sponsored (3)
- Other Sponsored (NSF LIGO, NOAA)
- Laboratory Sponsored (6)

commercial and R&E peering points
- IP
- SNV
- ESnet core hubs

Abilene high-speed peering points with Internet2/Abilene

International (high speed)
- 10 Gb/s SDN core
- 10G/s IP core
- 2.5 Gb/s IP core
- MAN rings (≥ 10 G/s)
- OC12 ATM (622 Mb/s)
- OC12 / GigEthernet
- OC3 (155 Mb/s)
- 45 Mb/s and less
DOE Office of Science Drivers for Networking

- The role of ESnet is to provide networking for the Office of Science Labs and their collaborators.

- The large-scale science that is the mission of the Office of Science is dependent on networks for:
  - Sharing of massive amounts of data
  - Supporting thousands of collaborators world-wide
  - Distributed data processing
  - Distributed simulation, visualization, and computational steering
  - Distributed data management

- These issues were explored in two Office of Science workshops that formulated networking requirements to meet the needs of the science programs (see refs.).
CERN / LHC High Energy Physics Data Provides One of Science’s Most Challenging Data Management Problems (CMS is one of several experiments at LHC)

2000 physicists in 31 countries are involved in this 20-year experiment in which DOE is a major player.

Grid infrastructure spread over the US and Europe coordinates the data analysis.
LHC Networking

• This picture represents the MONARCH model – a hierarchical, bulk data transfer model

• Still accurate for Tier 0 (CERN) to Tier 1 (experiment data centers) data movement

• Probably not accurate for the Tier 2 (analysis) sites
Example: Complicated Workflow – Many Sites

- discover objects
- identify potential type Ia
- final type Ia identification

NEAT and Palomar

data analysis and collaboration

50–100 field images per night

almost 1000 galaxies per field

brightening objects

initial candidates

rapidly changing bright objects

type 1a candidates

library of simulations

historical data for object discovery

Type Ia supernova used for cosmology studies

simulation and collaboration

very element mix to further discriminate

refined candidates

type Ia supernova

Berkeley Lab

WIYN

Isaac Newton

Cerro Tololo

scheduled follow-up spectroscopy at Keck

scheduled follow-up imaging at Hubble, Cerro Tololo, WIYN, Isaac Newton

Supernova Cosmology Project, Perlmutter, et al. (http://www.supernova.lbl.gov)
Distributed Workflow

- Distributed / Grid based workflow systems involve many interacting computing and storage elements that *rely on “smooth” inter-element communication for effective operation*

- The new LHC Grid based data analysis model will involve networks connecting dozens of sites and thousands of systems for each analysis “center”
Example: Multidisciplinary Simulation

A “complete” approach to climate modeling involves many interacting models and data that are provided by different groups at different locations (Tim Killeen, NCAR).

Distributed Multidisciplinary Simulation

• Distributed multidisciplinary simulation involves integrating computing elements at several remote locations
  
  o Requires co-scheduling of computing, data storage, and network elements
  
  o Also Quality of Service (e.g. bandwidth guarantees)
  
  o There is not a lot of experience with this scenario yet, but it is coming (e.g. the new Office of Science supercomputing facility at Oak Ridge National Lab has a distributed computing elements model)
### Projected Science Requirements for Networking

<table>
<thead>
<tr>
<th>Science Areas considered in the Workshop [1] (not including Nuclear Physics and Supercomputing)</th>
<th>Today <em>End2End Throughput</em></th>
<th>5 years <em>End2End Documented Throughput Requirements</em></th>
<th>5-10 Years <em>End2End Estimated Throughput Requirements</em></th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Energy Physics</td>
<td>0.5 Gb/s</td>
<td>100 Gb/s</td>
<td>1000 Gb/s</td>
<td>high bulk throughput with deadlines (<em>Grid based analysis systems require QoS</em>)</td>
</tr>
<tr>
<td>Climate (Data &amp; Computation)</td>
<td>0.5 Gb/s</td>
<td>160-200 Gb/s</td>
<td>N x 1000 Gb/s</td>
<td>high bulk throughput</td>
</tr>
<tr>
<td>SNS NanoScience</td>
<td>Not yet started</td>
<td>1 Gb/s</td>
<td>1000 Gb/s</td>
<td>remote control and time critical throughput (QoS)</td>
</tr>
<tr>
<td>Fusion Energy</td>
<td>0.066 Gb/s (500 MB/s burst)</td>
<td>0.198 Gb/s (500MB/20 sec. burst)</td>
<td>N x 1000 Gb/s</td>
<td>time critical throughput (QoS)</td>
</tr>
<tr>
<td>Astrophysics</td>
<td>0.013 Gb/s (1 TBy/week)</td>
<td><em>N</em>N multicast*</td>
<td>1000 Gb/s</td>
<td>computational steering and collaborations</td>
</tr>
<tr>
<td>Genomics Data &amp; Computation</td>
<td>0.091 Gb/s (1 TBy/day)</td>
<td><em>100s of users</em></td>
<td>1000 Gb/s</td>
<td>high throughput and steering</td>
</tr>
</tbody>
</table>
Observed Drivers for the Evolution of ESnet

ESnet is Currently Transporting About 530 Terabytes/mo. and this volume is increasing exponentially.

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and this volume is increasing exponentially.
Who Generates ESnet Traffic?

ESnet Inter-Sector Traffic Summary, Jan 03 / Feb 04/ Nov 04

Note
- more than 90% of the ESnet traffic is OSC traffic
- less than 20% of the traffic is inter-Lab

DOE sites

DOE is a net supplier of data because DOE facilities are used by universities and commercial entities, as well as by DOE researchers


double arrow 72/68/62%

ESnet

~25/19/13%

Commercial

21/14/10%

R&E (mostly universities)

14/12/9%

Peering Points

International
(almost entirely R&E sites)

17/10/14%

10/13/16%

53/49/50%

DOE collaborator traffic, inc. data

9/26/25%

4/6/13%

Traffic coming into ESnet = Green
Traffic leaving ESnet = Blue
Traffic between ESnet sites
% = of total ingress or egress traffic
A Small Number of Science Users Account for a Significant Fraction of all ESnet Traffic

ESnet Top 100 Host-to-Host Flows, Feb., 2005

Class 1: DOE Lab-International R&E

Class 2: Lab-U.S. (domestic) R&E

Class 3: Lab-Lab (domestic)

Class 4: Lab-Comm. (domestic)

Notes:
1) This data does not include intra-Lab (LAN) traffic (ESnet ends at the Lab border routers, so science traffic on the Lab LANs is invisible to ESnet)
2) Some Labs have private links that are not part of ESnet - that traffic is not represented here.
Source and Destination of the Top 30 Flows, Feb. 2005

Terabytes/Month

SLAC (US) → RAL (UK)
SLAC (US) → WestGrid (CA)
SLAC (US) → LIGO (US) → Caltech (US)
Fermilab (US) → IN2P3 (FR)
LIGO (US) → Karlsruhe (DE)
SLAC (US) → INFN CNAF (IT)
SLAC (US) → RAL (UK)
Fermilab (US) → MIT (US)
Fermilab (US) → Johns Hopkins
SLAC (US) → U. Texas, Austin (US)
IN2P3 (FR) → Fermilab (US)
IN2P3 (FR) → Fermilab (US)
LLNL (US) → UC Davis (US)
LLNL (US) → UC Davis (US)
Qwest (US) → Fermilab (US)
Qwest (US) → ESnet (US)
Fermilab (US) → U. Toronto (CA)
Fermilab (US) → U. Toronto (CA)
BNL (US) → Fermilab (US)
BNL (US) → Fermilab (US)
BNL (US) → Fermilab (US)
BNL (US) → Fermilab (US)
CERN (CH) → Fermilab (US)
Lab-Lab (domestic)
Lab-Comm. (domestic)
Observed Drivers for ESnet Evolution

• The observed combination of
  o exponential growth in ESnet traffic, and
  o large science data flows becoming a significant fraction of all ESnet traffic

show that the projections of the science community are reasonable and are being realized

• The current predominance of international traffic is due to high-energy physics
  o However, all of the LHC US tier-2 data analysis centers are at US universities
  o As the tier-2 centers come on-line, the DOE Lab to US university traffic will increase substantially

• High energy physics is several years ahead of the other science disciplines in data generation
  o Several other disciplines and facilities (e.g. climate modeling and the supercomputer centers) will contribute comparable amounts of additional traffic in the next few years
1) Network *bandwidth must increase substantially, not just in the backbone but all the way to the sites and the attached computing and storage systems*

2) A *highly reliable network is critical for science* – when large-scale experiments depend on the network for success, the network must not fail

3) There must be *network services* that can guarantee various forms of *quality-of-service* (e.g., bandwidth guarantees) and provide *traffic isolation*

4) A *production, extremely reliable, IP network* with Internet services must support Lab operations and the process of small and medium scale science
ESnet’s Place in U. S. and International Science

- ESnet and Abilene together provide most of the nation’s transit networking for basic science
  - Abilene provides national transit networking for most of the US universities by interconnecting the regional networks (mostly via the GigaPoPs)
  - ESnet provides national transit networking for the DOE Labs

- ESnet differs from Internet2/Abilene in that
  - Abilene interconnects regional R&E networks – it does not connect sites or provide commercial peering
  - ESnet serves the role of a tier 1 ISP for the DOE Labs
    - Provides site connectivity
    - Provides full commercial peering so that the Labs have full Internet access
ESnet and GEANT

- GEANT plays a role in Europe similar to Abilene and ESnet in the US – it interconnects the European National Research and Education Networks, to which the European R&E sites connect

- GEANT currently carries essentially all ESnet traffic to Europe (LHC use of LHCnet to CERN is still ramping up)
Ensuring High Bandwidth, Cross Domain Flows

• ESnet and Abilene have recently established high-speed interconnects and cross-network routing

• Goal is that DOE Lab ↔ Univ. connectivity should be as good as Lab ↔ Lab and Univ. ↔ Univ.
  - Constant monitoring is the key
  - US LHC Tier 2 sites need to be incorporated

• The **Abilene-ESnet-GEANT joint monitoring infrastructure** is expected to become operational over the next several months (by mid-fall, 2005)
Monitoring DOE Lab ↔ University Connectivity

- Current monitor infrastructure (red&green) and target infrastructure
- Uniform distribution around ESnet and around Abilene
- All US LHC tier-2 sites will be added as monitors

Initial site monitors:
- DOE Labs w/ monitors
- Universities w/ monitors
- Network hubs
- High-speed cross connects: ESnet ↔ Internet2/Abilene (scheduled for FY05)
One Way Packet Delays Provide a Fair Bit of Information

The result of a congested tail circuit to FNAL

Normal: Fixed delay from one site to another that is primarily a function of geographic separation

The result of problems with the monitoring system at CERN, not the network
A three part strategy for the evolution of ESnet

1) *Metropolitan Area Network* (MAN) rings to provide
   - dual site connectivity for reliability
   - much higher site-to-core bandwidth
   - support for both production IP and circuit-based traffic

2) A *Science Data Network* (SDN) core for
   - provisioned, guaranteed bandwidth circuits to support large, high-speed science data flows
   - very high total bandwidth
   - multiply connecting MAN rings for protection against hub failure
   - alternate path for production IP traffic

3) A *High-reliability IP core* (e.g. the current ESnet core) to address
   - general science requirements
   - Lab operational requirements
   - Backup for the SDN core
   - vehicle for science services
Strategy For The Evolution of ESnet: Two Core Networks and Metro. Area Rings

- IP core hubs
- SDN/NLR hubs
- Primary DOE Labs
- New hubs

Production IP core (10-20 Gbps)
Science Data Network core (30-50 Gbps)
Metropolitan Area Networks (20+ Gbps)
Lab supplied (10+ Gbps)
International connections (10-40 Gbps)
ESnet MAN Architecture (e.g. Chicago)

- ESnet production IP core
- Core router
- ESnet managed λ / circuit services
tunneled through the IP backbone
- ESnet management and monitoring
- 2-4 x 10 Gbps channels
- R&E peerings
- International peerings
- Site gateway router
- Site LAN
- Site LAN
- Monitor
- Monitor
- ESnet SDN core
- Starlight
- switches managing multiple lambdas
- ESnet production IP service
- FNAL
- ANL
- core router
- Site equip.
- Site gatewa...
First Two Steps in the Evolution of ESnet

1) The SF Bay Area MAN will provide to the five OSC Bay Area sites
   - Very high speed site access – 20 Gb/s
   - Fully redundant site access

2) The first two segments of the second national 10 Gb/s core – the Science Data Network – are San Diego to Sunnyvale to Seattle
ESnet SF Bay Area MAN Ring (Sept., 2005)

- 2 λs (2 X 10 Gb/s channels) in a ring configuration, and delivered as 10 GigEther circuits
  - 10-50X current site bandwidth
- Dual site connection (independent “east” and “west” connections) to each site
- Will be used as a 10 Gb/s production IP ring and 2 X 10 Gb/s paths (for circuit services) to each site
- Qwest contract signed for two lambdas 2/2005 with options on two more
- Project completion date is 9/2005
SF Bay Area MAN – Typical Site Configuration

max. of 2x10G connections on any line card to avoid switch limitations

West
\(\lambda_1\) and \(\lambda_2\)

SF BA MAN

East
\(\lambda_1\) and \(\lambda_2\)

ESnet

Site LAN

nx1GE or 10GE IP

0-10 Gb/s drop-off IP traffic

0-10 Gb/s pass-through VLAN traffic

0-10 Gb/s pass-through IP traffic

0-20 Gb/s VLAN traffic

Site

1 or 2 x 10 GE (provisioned circuits via VLANS)

= 24 x 1 GE line cards

= 4 x 10 GE line cards (using 2 ports max. per card)
Evolution of ESnet – Step One:
SF Bay Area MAN and West Coast SDN

- GEANT (Europe)
- CERN
- Asia-Pacific
- Australia
- San Diego
- LA
- Sunnyvale
- Seattle
- El Paso
- Albuquerque
- SUNY
- Metropolitan Area Rings
- Science Data Network Core (SDN) (NLR circuits)
- IP Core (Qwest)
- Production IP core
- In service by Sept., 2005
- Planned
- Science Data Network core
- Metropolitan Area Networks
- Lab supplied
- International connections

IP core hubs
SDN/NLR hubs
Primary DOE Labs
New hubs
ESnet Goal – 2009/2010

- 10 Gbps enterprise IP traffic
- 40-60 Gbps circuit based transport

ESnet Science Data Network (2nd Core – 30-50 Gbps, National Lambda Rail)

ESnet IP Core (≥10 Gbps)
Near-Term Needs for LHC Networking

- The data movement requirements of the several experiments at the CERN/LHC are considerable.
- Original MONARC model (CY2000 - Models of Networked Analysis at Regional Centres for LHC Experiments – Harvey Newman’s slide, above) predicted:
  - Initial need for 10 Gb/s dedicated bandwidth for LHC startup (2007) to each of the US Tier 1 Data Centers.
    - By 2010 the number is expected to 20-40 Gb/s per Center.
  - Initial need for 1 Gb/s from the Tier 1 Centers to each of the associated Tier 2 centers.
Near-Term Needs for LHC Networking

• However, with the LHC commitment to Grid based data analysis systems, the *expected bandwidth and network service requirements* for the Tier 2 centers *are much greater than the MONARCH bulk data movement model*
  o MONARCH still probably holds for the Tier0 (CERN) – Tier 1 transfers
  o For widely distributed Grid workflow systems QoS is considered essential
    - Without a smooth flow of data between workflow nodes the overall system would likely be very inefficient due to stalling the computing and storage elements

• Both high bandwidth and QoS network services must be addressed for LHC data analysis
T0/T1/T2 Interconnectivity

T2s and T1s are inter-connected by the general purpose research networks.

Any Tier-2 may access data at any Tier-1.

Dedicated 10 Gbit links

LHC Network Operations Working Group, LHC Computing Grid Project
Near-Term Needs for North American LHC Networking

• **Primary data paths** from LHC Tier 0 to Tier 1 Centers will be dedicated 10Gb/s circuits

• **Backup paths** must be provided
  - About day’s worth of data can be buffered at CERN
  - However, unless both the network and the analysis systems are over-provisioned it may not be possible to catch up even when the network is restored

• **Three level backup strategy**
  - Primary: Dedicated 10G circuits provided by CERN and DOE
  - Secondary: Preemptable 10G circuits (e.g. ESnet’s SDN, NSF’s IRNC links, GLIF, CA*net4)
  - Tertiary: Assignable QoS bandwidth on the production networks (ESnet, Abilene, GEANT, CA*net4)
Proposed LHC high-level architecture

Tier2s

Tier1s

Tier0

L3 Backbones

Main connection

Backup connection
LHC Networking and ESnet, Abilene, and GEANT

• USLHCnet (CERN+DOE funded) supports US participation in the LHC experiments
  o Dedicated high bandwidth circuits from CERN to the U.S. transfer LHC data to the US Tier 1 data centers (FNAL and BNL)

• ESnet is responsible for getting the data from the trans-Atlantic connection points for the European circuits (Chicago and NYC) to the Tier 1 sites
  o ESnet is also responsible for providing backup paths from the trans-Atlantic connection points to the Tier 1 sites

• Abilene is responsible for getting data from ESnet to the Tier 2 sites

• The new ESnet architecture (Science Data Network) is intended to accommodate the anticipated 20-40 Gb/s from LHC to US (both US tier 1 centers are on ESnet)
Abilene* and LHC Tier 2, Near-Term Networking

**Atlas Tier 2 Centers**
- University of Texas at Arlington
- University of Oklahoma Norman
- University of New Mexico Albuquerque
- Langston University
- University of Chicago
- Indiana University Bloomington
- Boston University
- Harvard University
- University of Michigan

**CMS Tier 2 Centers**
- MIT
- University of Florida at Gainesville
- University of Nebraska at Lincoln
- University of Wisconsin at Madison
- Caltech
- Purdue University
- University of California San Diego

**Tier 1 Centers**
- ESnet IP core hubs
- New hubs
- ESnet SDN/NLR hubs

**10G connections to USLHC or ESnet**

**Cross connects with Internet2/Abilene**

**NLR PoPs**
- Vancouver
- Toronto

**CMS Tier 2 Centers**
- MIT
- University of Florida at Gainesville
- University of Nebraska at Lincoln
- University of Wisconsin at Madison
- Caltech
- Purdue University
- University of California San Diego
QoS - New Network Service

• New network services are critical for ESnet to meet the needs of large-scale science like the LHC

• Most important new network service is *dynamically provisioned virtual circuits* that provide
  
  o Traffic isolation
    - will enable the use of high-performance, non-standard transport mechanisms that cannot co-exist with commodity TCP based transport
      (see, e.g., Tom Dunigan’s compendium [http://www.csm.orl.gov/~dunigan/netperf/netlinks.html](http://www.csm.orl.gov/~dunigan/netperf/netlinks.html)

  o Guaranteed bandwidth
    - the only way that we have currently to address deadline scheduling – e.g. where fixed amounts of data have to reach sites on a fixed schedule in order that the processing does not fall behind far enough so that it could never catch up – very important for experiment data analysis
OSCARS: Guaranteed Bandwidth Service

• Must accommodate networks that are shared resources
  o Multiple QoS paths
  o Guaranteed minimum level of service for best effort traffic
  o Allocation management
    - There will be hundreds of contenders with different science priorities
OSCARS: Guaranteed Bandwidth Service

• Virtual circuits must be set up end-to-end across ESnet, Abilene, and GEANT, as well as the campuses
  o There are many issues that are poorly understood
  o To ensure compatibility the work is a collaboration with the other major science R&E networks
    - code is being jointly developed with Internet2's Bandwidth Reservation for User Work (BRUW) project – part of the Abilene HOPI (Hybrid Optical-Packet Infrastructure) project
    - Close cooperation with the GEANT virtual circuit project ("lightpaths – Joint Research Activity 3 project")
• To address all of the issues is complex
  - There are many potential restriction points
  - There are many users that would like priority service, which must be rationed
Between ESnet, Abilene, GEANT, and the connected regional R&E networks, there will be dozens of lambdas in production networks that are shared between thousands of users who want to use virtual circuits.
Federated Trust Services

• Remote, multi-institutional, identity authentication is critical for distributed, collaborative science in order to permit sharing computing and data resources, and other Grid services

• Managing cross site trust agreements among many organizations is crucial for authentication in collaborative environments
  - ESnet assists in negotiating and managing the cross-site, cross-organization, and international trust relationships to provide policies that are tailored to collaborative science

• The form of the ESnet trust services are driven entirely by the requirements of the science community and direct input from the science community
ESnet Public Key Infrastructure

- ESnet provides Public Key Infrastructure and X.509 identity certificates that are the basis of secure, cross-site authentication of people and Grid systems.

- These services ([www.doegrids.org](http://www.doegrids.org)) provide:
  - Several Certification Authorities (CA) with different uses and policies that issue certificates after validating request against policy.
  - This service was the basis of the first routine sharing of HEP computing resources between US and Europe.
ESnet Public Key Infrastructure

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- The characteristics and policy of the several PKI certificate issuing authorities are driven by the science community and policy oversight (the Policy Management Authority – PMA) is provided by the science community + ESnet staff.

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  - Several Certification Authorities (CA) with different uses and policies that issue certificates after validating certificate requests against policy.

  - This service was the basis of the first routine sharing of HEP computing resources between US and Europe.
ESnet Public Key Infrastructure

- Root CA is kept off-line in a vault
- Subordinate CAs are kept in locked, alarmed racks in an access controlled machine room and have dedicated firewalls
- CAs with different policies as required by the science community
  - DOEGrids CA has a policy tailored to accommodate international science collaboration
  - NERSC CA policy integrates CA and certificate issuance with NIM (NERSC user accounts management services)
  - FusionGrid CA supports the FusionGrid roaming authentication and authorization services, providing complete key lifecycle management
DOEGrids CA (one of several CAs) Usage Statistics

Production service began in June 2003

<table>
<thead>
<tr>
<th>Certificate Type</th>
<th>Year 1999</th>
<th>Total No. of Certificates</th>
<th>Total No. of Requests</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Certificates</td>
<td>1999</td>
<td>5479</td>
<td></td>
</tr>
<tr>
<td>Host &amp; Service Certificates</td>
<td>3461</td>
<td>7006</td>
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<tr>
<td>ESnet SSL Server CA Certificates</td>
<td></td>
<td>38</td>
<td></td>
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<tr>
<td>DOEGrids CA 2 CA Certificates (NERSC)</td>
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<td>15</td>
<td></td>
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<tr>
<td>FusionGRID CA certificates</td>
<td></td>
<td>76</td>
<td></td>
</tr>
</tbody>
</table>

* Report as of Jun 15, 2005
DOEGrids CA Usage - Virtual Organization Breakdown

DOEGrids CA Statistics (5479)

- ANL: 3.5%
- DOEgrid: 0.3%
- ESG: 0.8%
- ESnet: 0.4%
- FusionGRID: 4.8%
- iVDGL: 18.8%
- FNAL: 8.9%
- NERSC: 3.2%
- LBNL: 1.2%
- ORNL: 0.6%
- PNNL: 0.6%
- PPDG: 15.2%
- *Others: 41.2%
- NCC-EPA: 0.1%
- LCG: 0.6%

*DOE-NSF collab.

“Other” is mostly auto renewal certs (via the Replacement Certificate interface) that does not provide VO information
Conference on the Future of e-Science Research: 2005

North American Policy Management Authority

• The Americas Grid, Policy Management Authority

• An important step toward regularizing the management of trust in the international science community

• Driven by European requirements for a single Grid Certificate Authority policy representing scientific/research communities in the Americas

• Investigate Cross-signing and CA Hierarchies support for the science community

• Investigate alternative authentication services

• Peer with the other Grid Regional Policy Management Authorities (PMA).
  o European Grid PMA [www.eugridpma.org]
  o Asian Pacific Grid PMA [www.apgridpma.org]

• Started in Fall 2004 [www.TAGPMA.org]

• Founding members
  o DOEGrids (ESnet)
  o Fermi National Accelerator Laboratory
  o SLAC
  o TeraGrid (NSF)
  o CANARIE (Canadian national R&E network)
References – DOE Network Related Planning Workshops

 ➢ 1) High Performance Network Planning Workshop, August 2002
    http://www.doecollaboratory.org/meetings/hpnpw

 ➢ 2) DOE Science Networking Roadmap Meeting, June 2003
    http://www.es.net/hypertext/welcome/pr/Roadmap/index.html

3) DOE Workshop on Ultra High-Speed Transport Protocols and Network Provisioning for Large-Scale Science Applications, April 2003

4) Science Case for Large Scale Simulation, June 2003
    http://www.pnl.gov/scales/

5) Workshop on the Road Map for the Revitalization of High End Computing, June 2003
    http://www.cra.org/Activities/workshops/nitrd
    http://www.sc.doe.gov/ascr/20040510_hecrtf.pdf (public report)

6) ASCR Strategic Planning Workshop, July 2003
    http://www.fp-mcs.anl.gov/ascr-july03spw

7) Planning Workshops-Office of Science Data-Management Strategy, March & May 2004
   o http://www-conf.slac.stanford.edu/dmw2004