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Toward a Global Terabit Research Network

FIU AMPATH Workshop
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Indiana Pervasive Technology Laboratories

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Network-Enabled Science and Research in the 21st Century

- Science and research is becoming progressively more global with network-enabled world wide collaborative communities rapidly forming in a broad range of areas
- Many are based around a few expensive – sometimes unique – instruments or distributed complexes of sensors that produce vast amounts of data
- These global communities will carry out research based on this data

Network-Enabled Science and Research in the 21st Century

- This data will be:
  - collected via geographically distributed instruments
  - analyzed by supercomputers and large computer clusters
  - visualized with advanced 3-D display technology and
  - stored in massive or large data storage systems
- All of this will be distributed globally

I N D I A N A U N I V E R S I T Y

Examples of Network-Enabled Science

- NSF funded Grid Physics Network's (GriPhyN) need for petascale virtual data grids (i.e. capable of analyzing petabyte datasets)
  - Compact Muon Selenoid (CMS) and A Toroidal LHC Apparatus (ATLAS) experiments using the Large Hadron Collider (LHC) located at (CERN) [> 2.5 Gb/s]
  - Laser Interferometer Gravitational Wave Observatory (LIGO) [200GB-5TB data sets needing 2.5 Gb/s or greater for reasonable transfer times]
  - Atacama Large Millimeter Array (ALMA)
- Collaborative video (e.g. HDTV) [20Mb/s]
- Sloan Digital Sky Survey (SDSS) [> 1Gb/s]
- Dozens of others and growing

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A Vision for 21st Century Network-Enabled Science and Research

The vision is for this global infrastructure and data to be integrated into “Grids” – seamless global collaborative environments tailored to the specific needs of individual scientific communities

Components of Global Grids

- High performance networks are fundamental to integrating Global Grids together
- There are, very broadly speaking, three components to Global Grids:
  - Campus Networks (the last kilometer)
  - National and Regional Research and Education Networks (NRRENs)
  - Global connections between NRRENs

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Impediments to Global Grids

- Of these three components, on a world-wide scale, investment and engineering is only adequate for NRRENs
  - Campus networks rarely provide scalable bandwidth to the desktop commensurate with speeds of campus connections to NRRENs
  - Global connections between NRRENs are major bottlenecks – they are very slow compared to NRREN backbone speeds

Building Global Grids

To build a true Global Grid requires:

- Scalable campus networks providing ubiquitous high bandwidth connections to every desktop commensurate with campus connections to NRRENs
- Global connectivity between NRRENs of comparable speeds to the NRREN backbones, which is also stable, persistent and of production quality like the NRRENs themselves

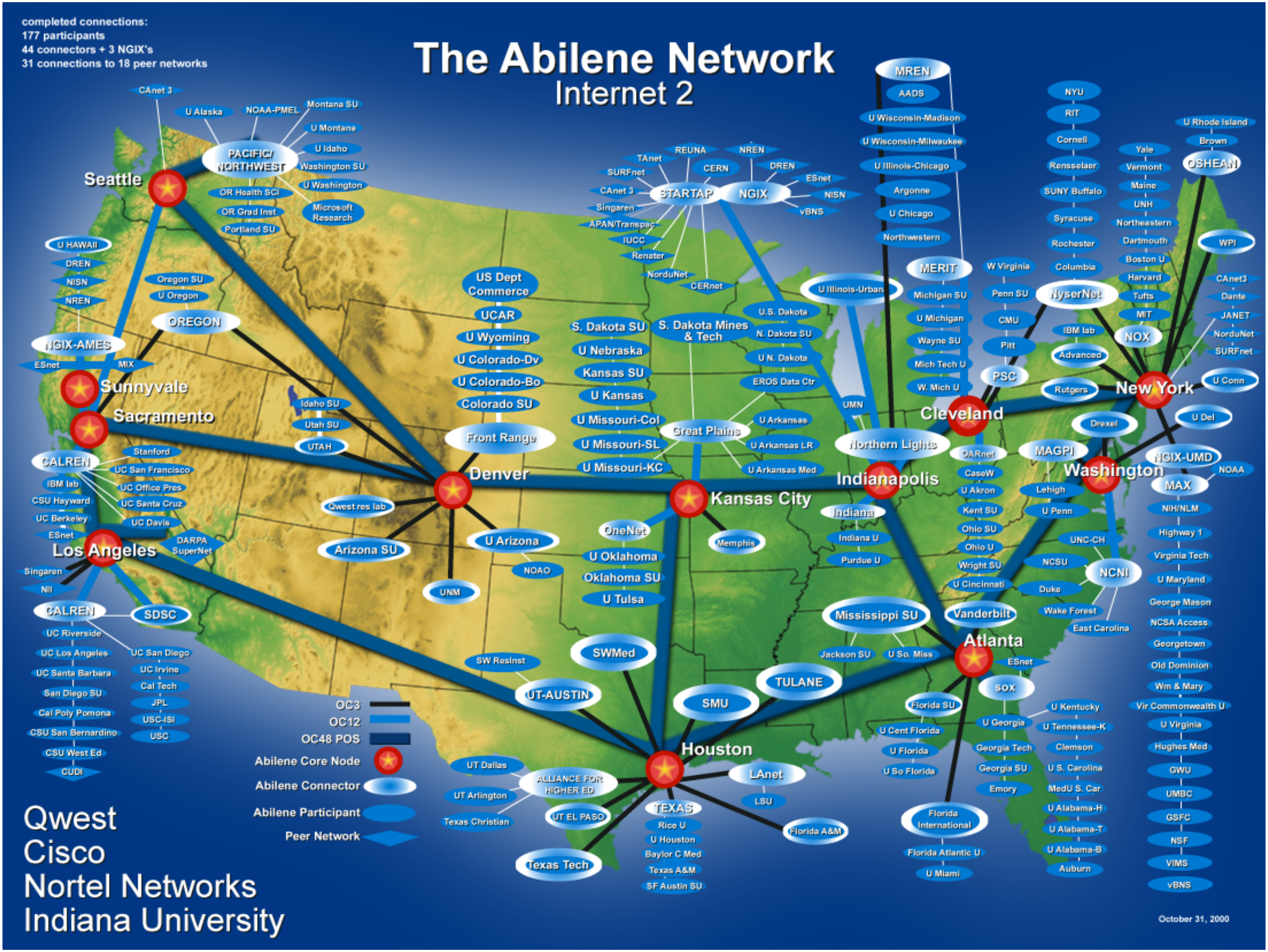
Presentation Overview

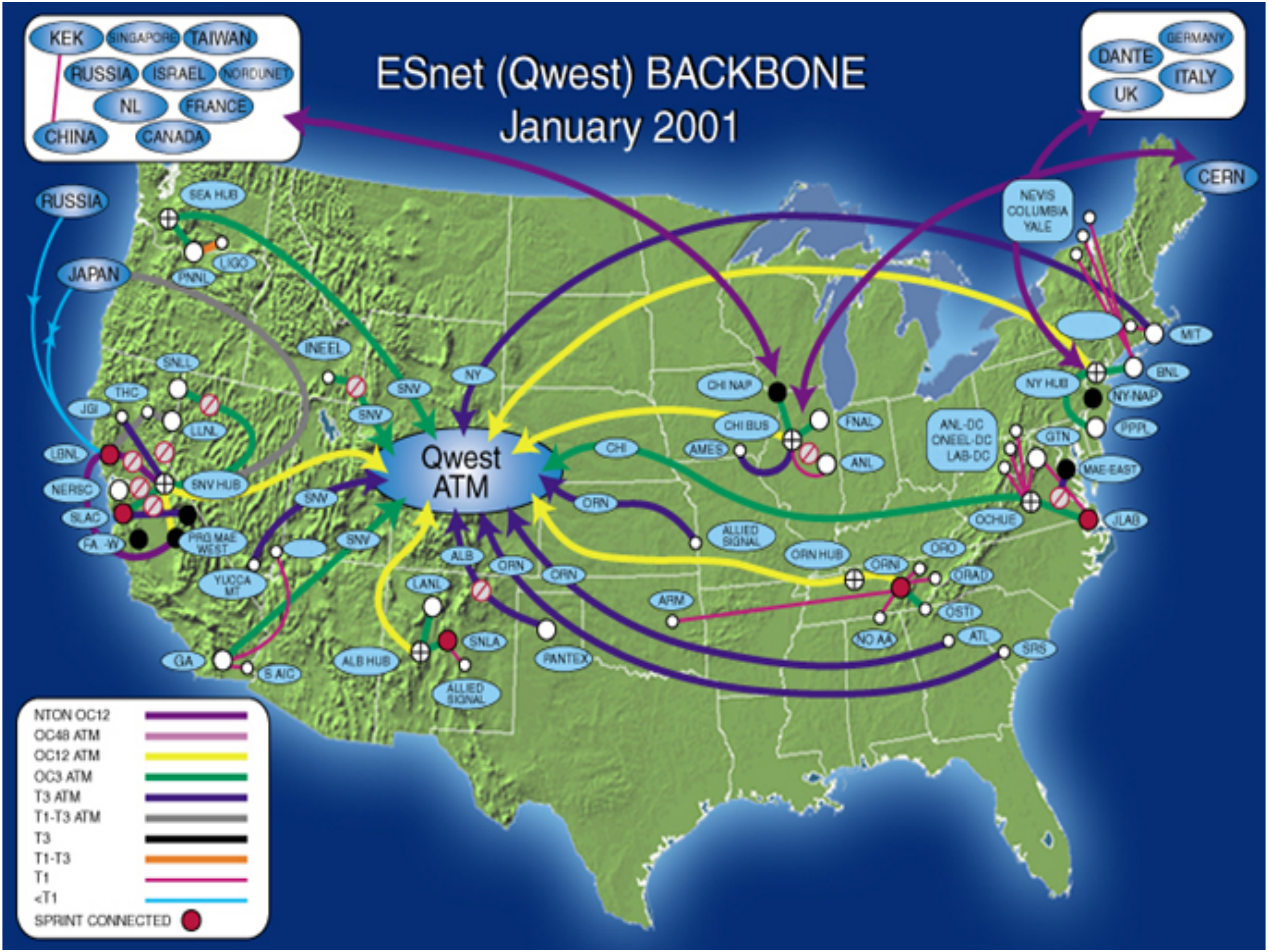
This talk

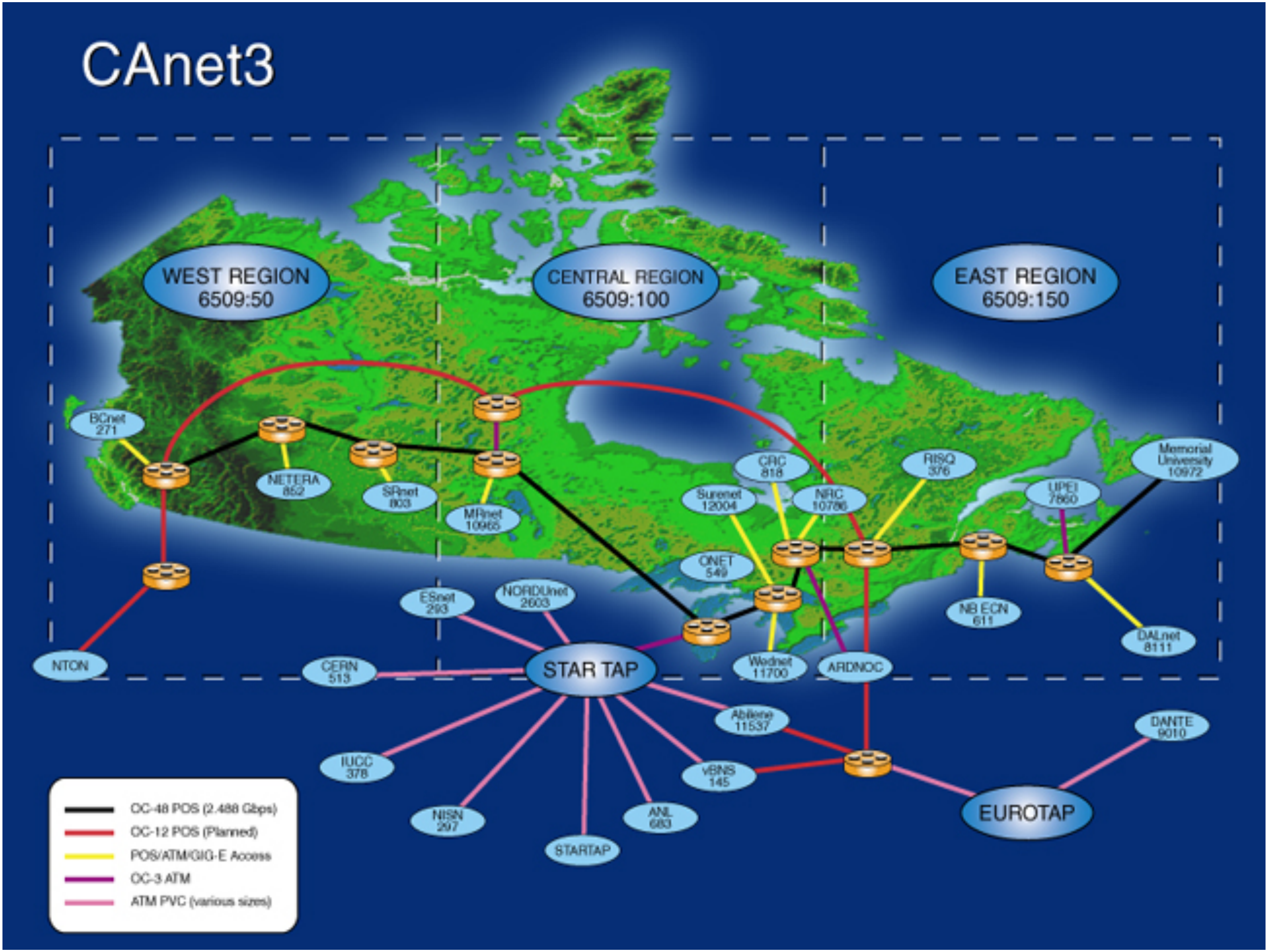
1. Describes some NRRENs and their common characteristics
2. Sketches a solution to the global connectivity problem that scales to a terabit global research network

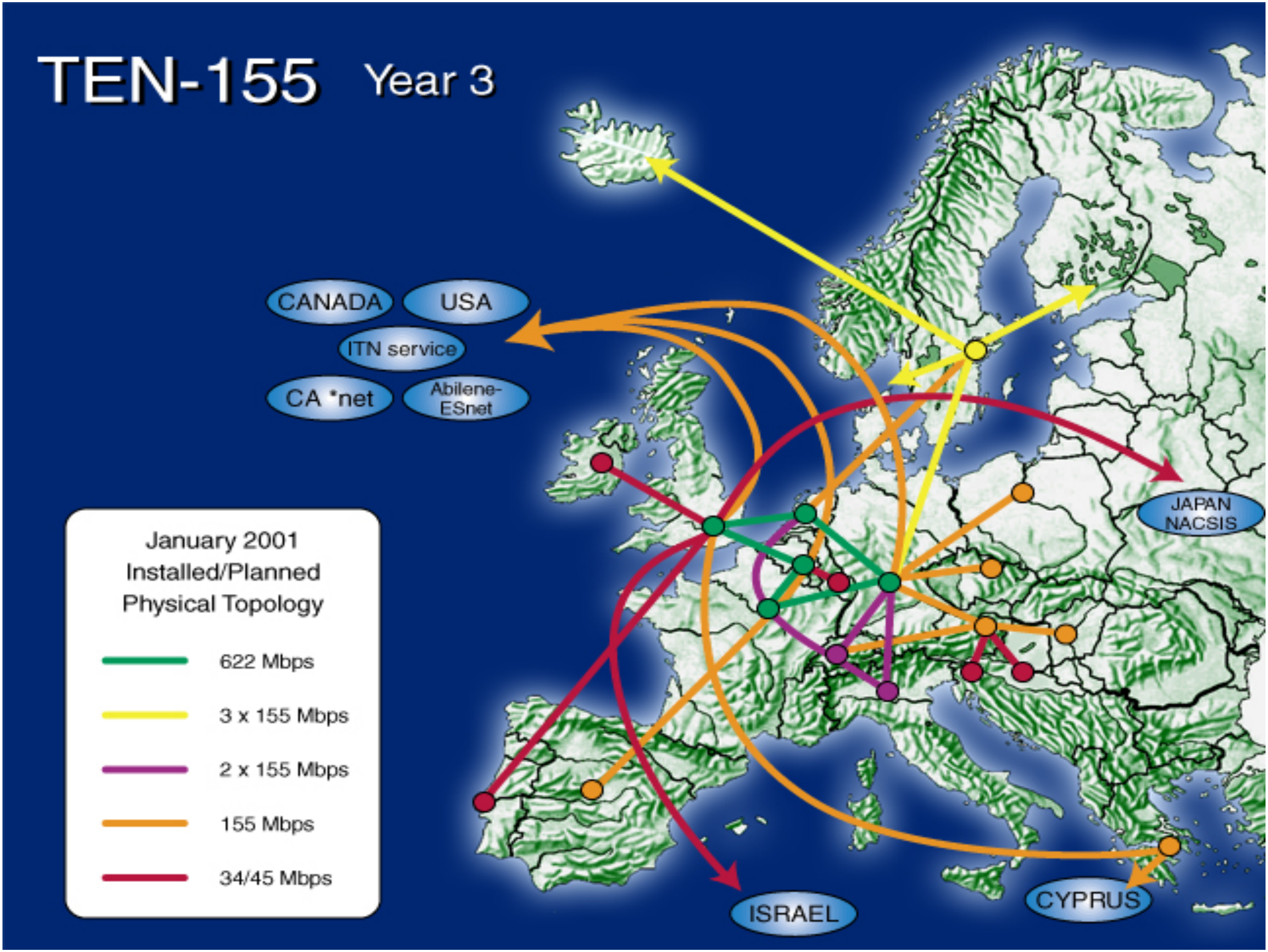
1. NRRENs

- Abilene
  - OC48 (2.4Gb/s) ->OC192 (9.6 Gb/s)
  - OC48 connected GigaPoPs (moving to min. OC12 or .6 Gb/s)
  - ITN provider
  - 1 Gb/s sustained data rates seen
- CAnet3
- US Fed nets (e.g. ESnet)
- TEN-155 -> GEANT
- APAN
- CERNET

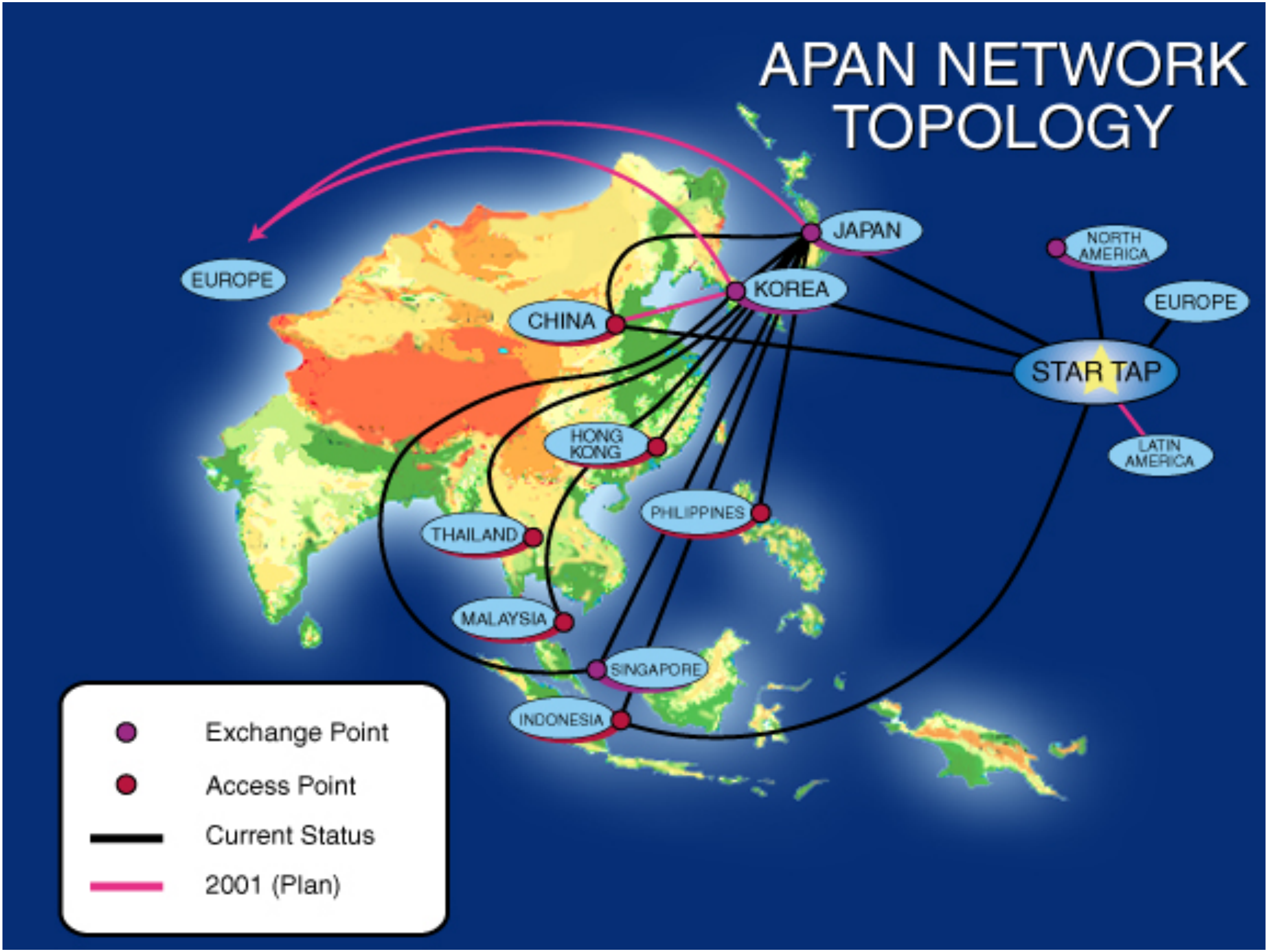

completed connections:
177 participants
44 connectors + 3 NGIX's
31 connections to 18 peer networks
The Abilene Network
Internet 2
CAnet 3
U Alaska
NOAA-PMEL
Montana SU
U Montana
U Idaho
Washington SU
U Washington
PACIFIC/ NORTHWEST
OR Health SCI
OR Grad Inst
Portland SU
Microsoft Research
Seattle
U HAWAII
DREN
NISN
NREN
Oregon SU
U Oregon
OREGON
NGIX-AMES
ESnet
MIX
Sunnyvale
Sacramento
CALREN
Stanford
UC San Francisco
UC Office Pres
UC Santa Cruz
UC Davis
IBM lab
CSU Hayward
UC Berkeley
ESnet
DARPA SuperNet
Los Angeles
Singaren
NII
CALREN
SDSC
UC Riverside
UC Los Angeles
UC Santa Barbara
San Diego SU
Cal Poly Pomona
CSU San Bernardino
CSU West Ed
CUDI
UC San Diego
UC Irvine
Cal Tech
JPL
USC-ISI
USC
Idaho SU
Utah SU
UTAH
Qwest res lab
Arizona SU
UNM
U Arizona
NOAO
Denver
US Dept Commerce
UCAR
U Wyoming
U Colorado-Dv
U Colorado-Bo
Colorado SU
Front Range
TAnet
REUNA
NREN
SURFnet
CERN
DREN
CAnet 3
ESnet
STARTAP
NGIX
NISN
Singaren
vBNS
APAN/Transpac
IUCC
Renater
NorduNet
CERnet
S. Dakota SU
U Nebraska
Kansas SU
U Kansas
U Missouri-Col
U Missouri-SL
U Missouri-KC
S. Dakota Mines & Tech
Great Plains
U.S. Dakota
N. Dakota SU
U N. Dakota
EROS Data Ctr
U Arkansas
U Arkansas LR
U Arkansas Med
Kansas City
OneNet
U Oklahoma
Oklahoma SU
U Tulsa
Memphis
SWMed
SW ResInst
UT-AUSTIN
SMU
TULANE
Houston
UT Dallas
UT Arlington
Texas Christian
ALLIANCE FOR HIGHER ED
UT EL PASO
Texas Tech
TEXAS
Rice U
U Houston
Baylor C Med
Texas A&M
SF Austin SU
LAnet
LSU
Florida A&M
MREN
AADS
U Wisconsin-Madison
U Wisconsin-Milwaukee
U Illinois-Chicago
Argonne
U Chicago
Northwestern
U Illinois-Urban
UMN
Northern Lights
Indianapolis
Indiana
Indiana U
Purdue U
MERIT
Michigan SU
U Michigan
Wayne SU
Mich Tech U
W. Mich U
W Virginia
Penn SU
CMU
Pitt
PSC
Cleveland
OARnet
CaseW
U Akron
Kent SU
Ohio SU
Ohio U
Wright SU
U Cincinnati
Mississippi SU
Jackson SU
U So. Miss
Vanderbilt
Atlanta
ESnet
SOX
Florida SU
U Cent Florida
U Florida
U So Florida
Florida International
Florida Atlantic U
U Miami
U Georgia
Georgia Tech
Georgia SU
Emory
U Kentucky
U Tennessee-K
Clemson
U S. Carolina
MedU S. Car
U Alabama-H
U Alabama-T
U Alabama-B
Auburn
NYU
RIT
Cornell
Rensselaer
SUNY Buffalo
Syracuse
Rochester
Columbia
NyserNet
IBM lab
Advanced
Rutgers
Yale
Vermont
Maine
UNH
Northeastern
Dartmouth
Boston U
Harvard
Tufts
MIT
NOX
U Rhode Island
Brown
OSHEAN
WPI
CAnet3
Dante
JANET
NorduNet
SURFnet
U Conn
New York
Drexel
MAGPI
Lehigh
U Penn
Washington
U Del
NGIX-UMD
NOAA
MAX
NIH/NLM
Highway 1
Virginia Tech
U Maryland
George Mason
NCSA Access
Georgetown
Old Dominion
Wm & Mary
Vir Commonwealth U
U Virginia
Hughes Med
GWU
UMBC
GSFC
NSF
VIMS
vBNS
UNC-CH
NCSU
Duke
NCNI
Wake Forest
East Carolina
OC3
OC12
OC48 POS
Abilene Core Node
Abilene Connector
Abilene Participant
Peer Network
Qwest
Cisco
Nortel Networks
Indiana University
October 31, 2000

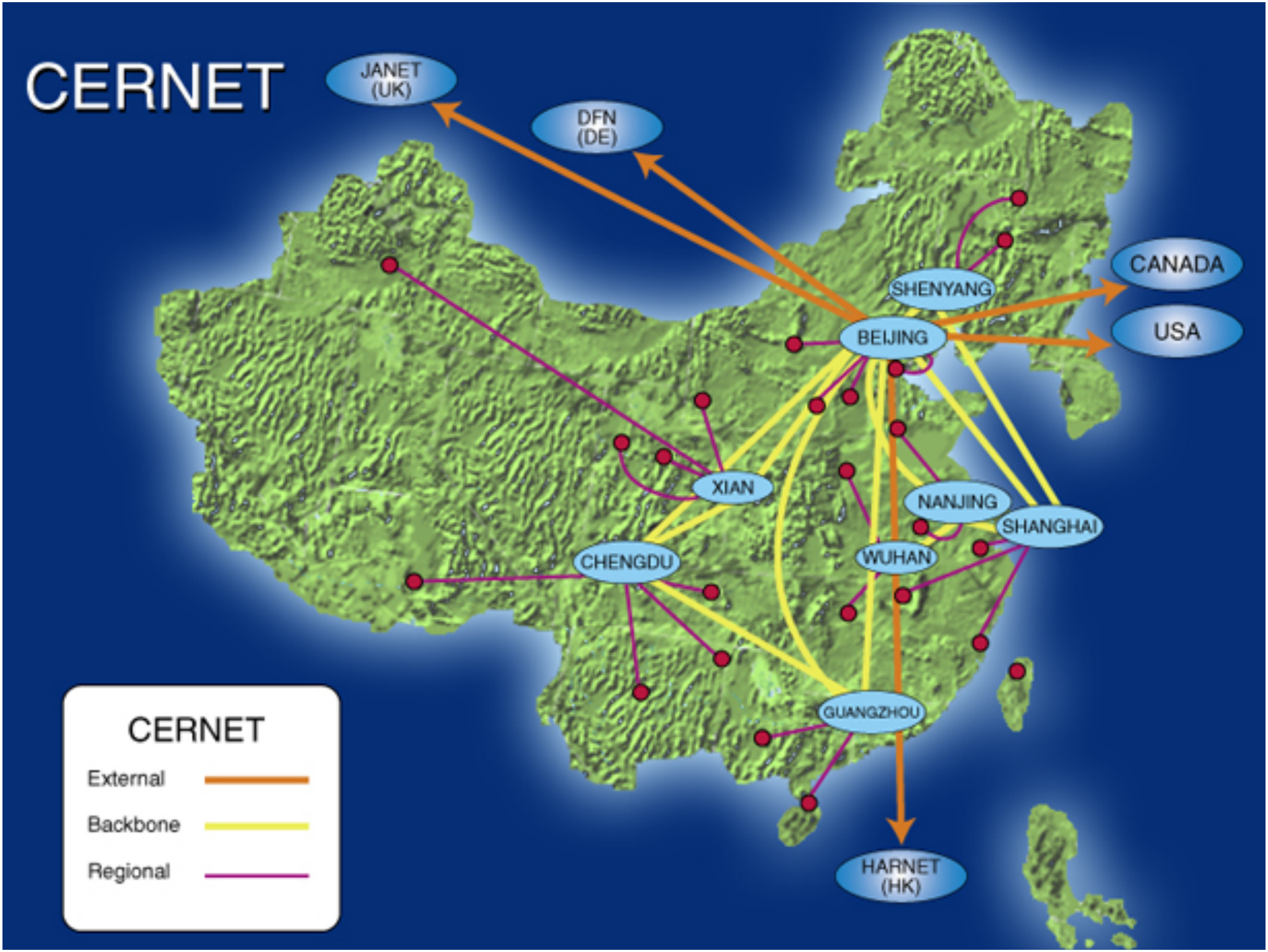

ESnet (Qwest) BACKBONE
January 2001
KEK
SINGAPORE
TAIWAN
RUSSIA
ISRAEL
NORDUNET
NL
FRANCE
CHINA
CANADA
GERMANY
DANTE
ITALY
UK
CERN
RUSSIA
JAPAN
SEA HUB
PNNL
LIGO
INEEL
SNLL
THC
JGI
LLNL
LBNL
NERSC
SLAC
FA -W
SNV HUB
PRG MAE WEST
YUCCA MT
GA
S AIC
SNV
NY
Qwest ATM
CHI NAP
CHI BUS
FNAL
AMES
ANL
CHI
ORN
ALLIED SIGNAL
ORN HUB
ORNL
ORO
ORAD
OSTI
ARM
NO AA
ATL
SRS
ALB
LANL
SNLA
ALB HUB
ALLIED SIGNAL
PANTEX
NEVIS COLUMBIA YALE
MIT
BNL
NY HUB
NY-NAP
PPPL
ANL-DC ONEEL-DC LAB-DC
GTN
MAE-EAST
OCHUE
JLAB
NTON OC12
OC48 ATM
OC12 ATM
OC3 ATM
T3 ATM
T1-T3 ATM
T3
T1-T3
T1
<T1
SPRINT CONNECTED


CAnet3
WEST REGION
6509:50
CENTRAL REGION
6509:100
EAST REGION
6509:150
BCnet
271
NETERA
852
SRnet
803
MRnet
10965
CRC
818
Surenet
12004
NRC
10786
RISQ
376
UPEI
7660
Memorial
University
10972
ONET
549
NB ECN
611
DALnet
8111
ESnet
293
NORDUnet
2603
NTON
CERN
513
STAR TAP
Wednet
11700
ARDNOC
Abilene
11537
DANTE
9010
IUCC
378
vBNS
145
NISN
297
ANL
683
STARTAP
EUROTAP
OC-48 POS (2.488 Gbps)
OC-12 POS (Planned)
POS/ATM/GIG-E Access
OC-3 ATM
ATM PVC (various sizes)



TEN-155 Year 3
CANADA
USA
ITN service
CA *net
Abilene-ESnet
JAPAN NACSIS
ISRAEL
CYPRUS
January 2001
Installed/Planned
Physical Topology
622 Mbps
3 x 155 Mbps
2 x 155 Mbps
155 Mbps
34/45 Mbps


APAN NETWORK
TOPOLOGY
EUROPE
JAPAN
NORTH
AMERICA
KOREA
EUROPE
CHINA
STAR TAP
HONG
KONG
LATIN
AMERICA
PHILIPPINES
THAILAND
MALAYSIA
SINGAPORE
INDONESIA
Exchange Point
Access Point
Current Status
2001 (Plan)


CERNET
JANET (UK)
DFN (DE)
CANADA
USA
SHENYANG
BEIJING
XIAN
NANJING
SHANGHAI
CHENGDU
WUHAN
GUANGZHOU
HARNET (HK)
CERNET
External
Backbone
Regional

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NRRENs

- OC48 backbone implemented today
  - Moving to OC192 as next evolution
- Institutions access backbone at OC12 or greater (a few connections at OC48)
- Native high-speed IPv4
- Support for IPv6 (but at much lower performance due to router constraints)

I N D I A N A U N I V E R S I T Y

NRRENs

- Advanced Services
  - Typically run as open (visible) networks, not a commercial service
  - IP multicast deployed in most backbones, but still not as production as unicast; but not reliable internationally
  - QoS – mixed results, still in it's infancy. Very little going across more than one network
- Intra-regional interconnect speeds range from OC3 to OC12, soon to be OC48 in some cases

Impediments to Building Global Grids

- International connections very slow compared with NRREN backbone speeds
- Long term funding uncertain (e.g. NSF HPIIS program)
- Global connection effort not well-coordinated
- Overly reliant on transit through US infrastructure
- Frequently connections are via ATM or IP clouds, making management of advanced services difficult
- Poor coordination of advanced service deployment
- Extreme difficulty ensuring reasonable end-to-end performance

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Connectivity to US Transit Infrastructure

APAN	100Mb/s
CERNET	10Mb/s
SingAREN	45Mb/s
TANet2	45Mb/s

NORDUnet	400Mb/s
RENATER2	45Mb/s
SURFnet	155Mb/s
MIRnet	10Mb/s
IUCC	45Mb/s
Dante	600Mb/s
CERN	155Mb/s

CA*net3	1.2Gb/s
CUDI	45Mb/s
AMPATH	45Mb/s

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STAR TAP and International Transit Service (ITN)

- STAR TAP, CAnet3 and Abilene provide some level of International transit across North America
  - Abilene offers convenient international transit at multiple landing sites, however transit not offered to other NRRENs (e.g. ESnet)
- STAR TAP requires a connection to AADS best effort ATM service (reducing the ability to deploy QoS)

I N D I A N A U N I V E R S I T Y

Indiana University

- Firsthand experience with these difficulties through its Global NOC
- http://globalnoc.iu.edu/

I N D I A N A U N I V E R S I T Y

GlobalNOC

Global Research Network Operations Center

at INDIANA UNIVERSITY

TransPAC

Euro-Link

MIRnet

AMPATH

STAR TAP

Abilene

The Global Research Network Operations Center (Global NOC) at Indiana University manages the international network connections from advanced research and education networks in the Asia/Pacific, Europe, Russia and South America to the Science Technology and Research Transit Access Point (STAR TAP) and the leading US high performance research and education networks such as Abilene (the network that supports the Internet2 project), the NSF's very high performance Backbone Network System (vBNS) and the Department of Energy's ESNET.

More Information

Email: globalnoc@iu.edu

2. Towards a Global Terabit Research Network (GTRN)

- Global network-enabled collaborative Grids require true high-speed global research and education network that:
  - provide a single global backbone interconnecting global network access points (GNAPs) that provide peering within a country or region
  - provide global backbone speeds comparable to those at NRRENS, i.e. OC192 in 2002
  - allow coordinated global advanced service deployment (e.g. QoS, IPv6, multicast)
  - is based on stable carrier infrastructure or leased or owned fiber

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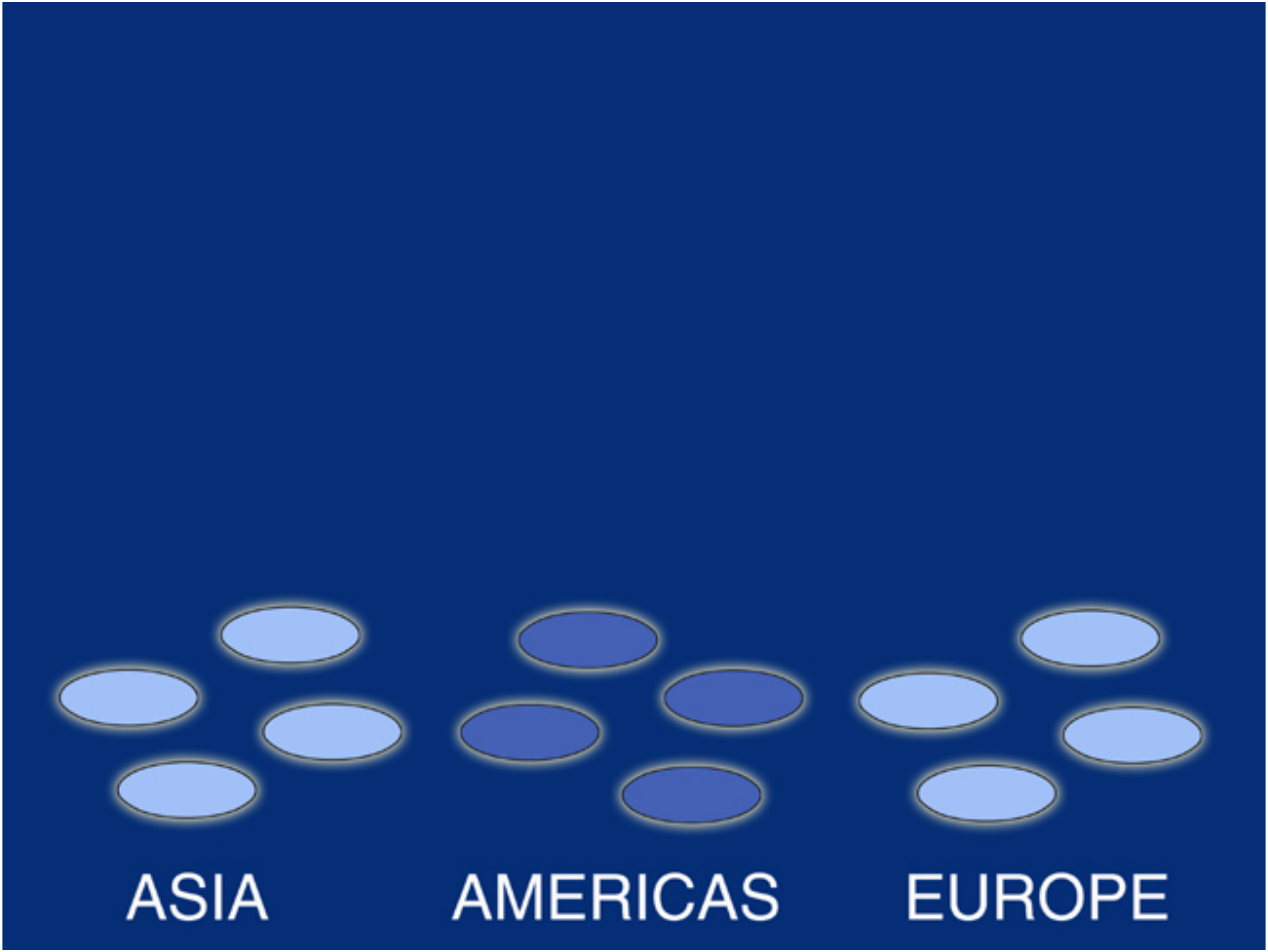
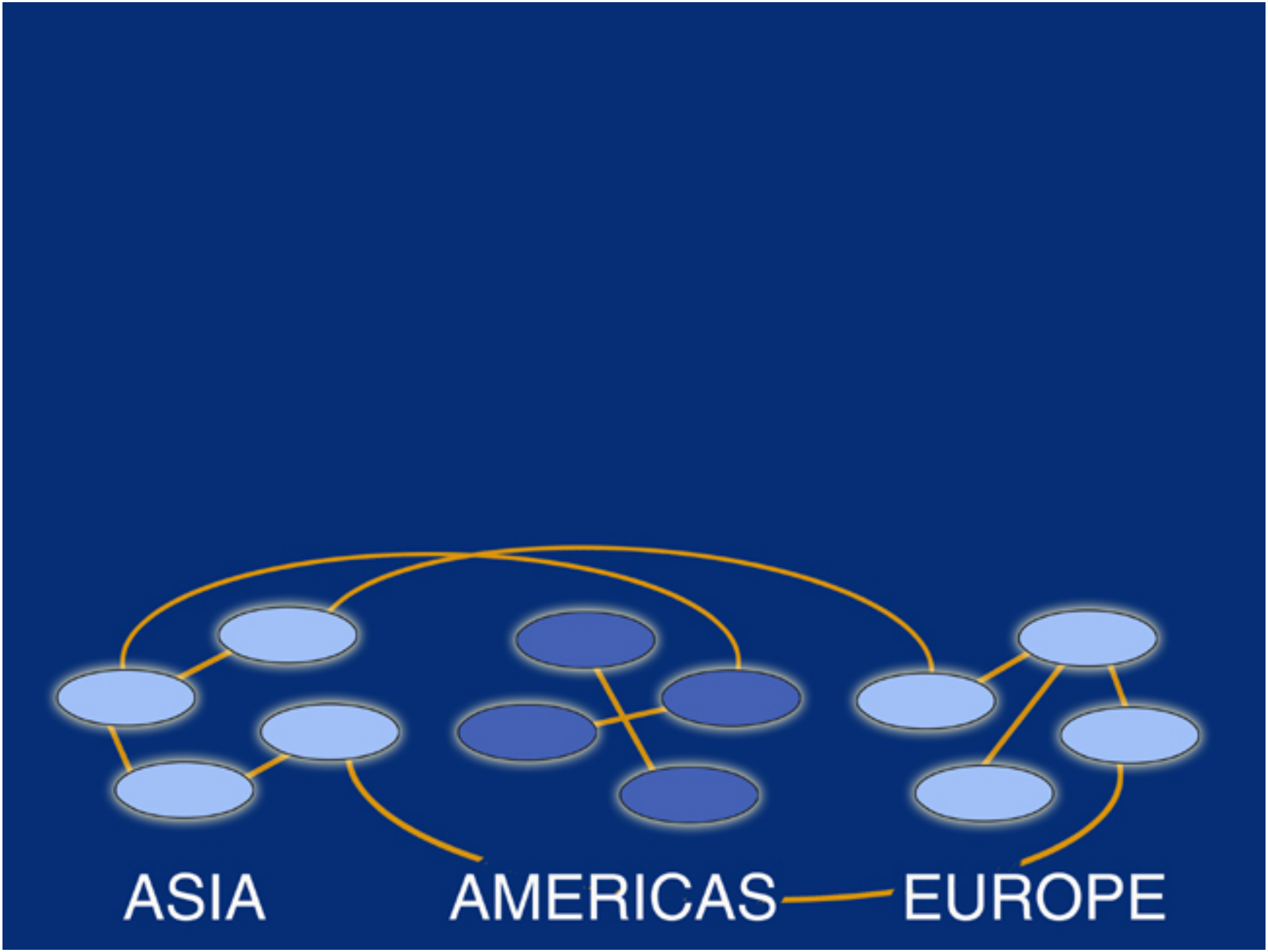
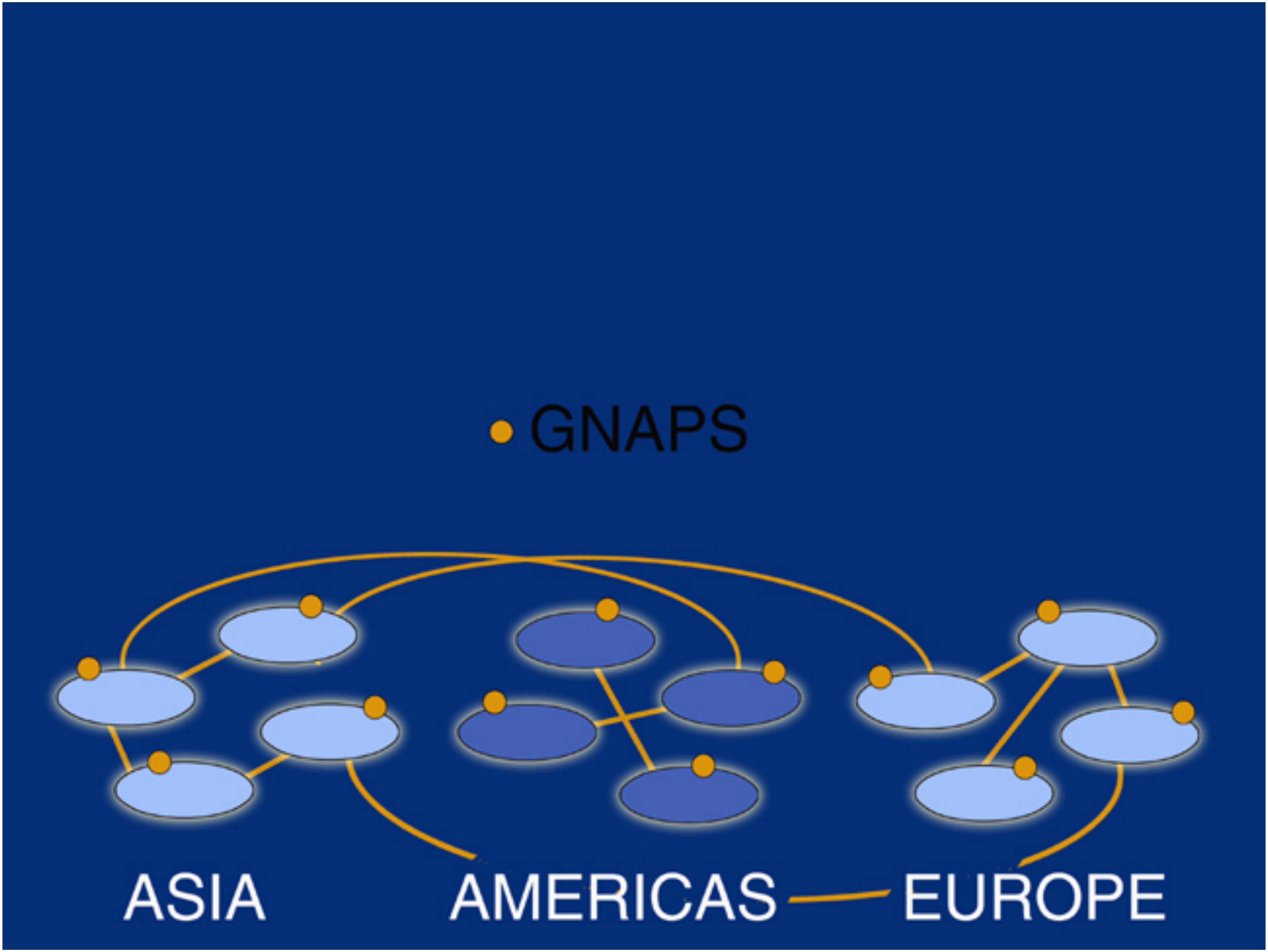
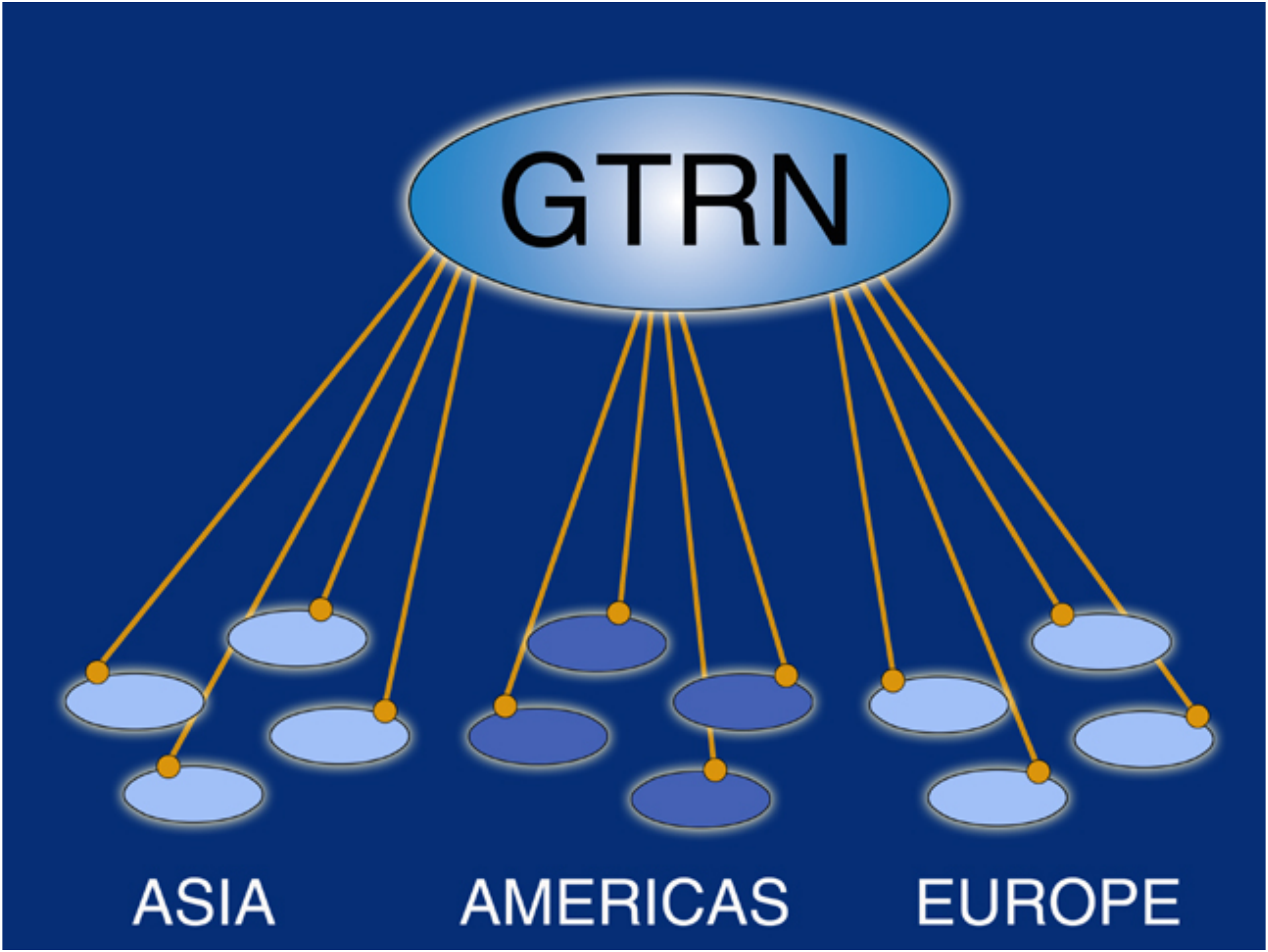
2. Towards a Global Terabit Research Network (GTRN)

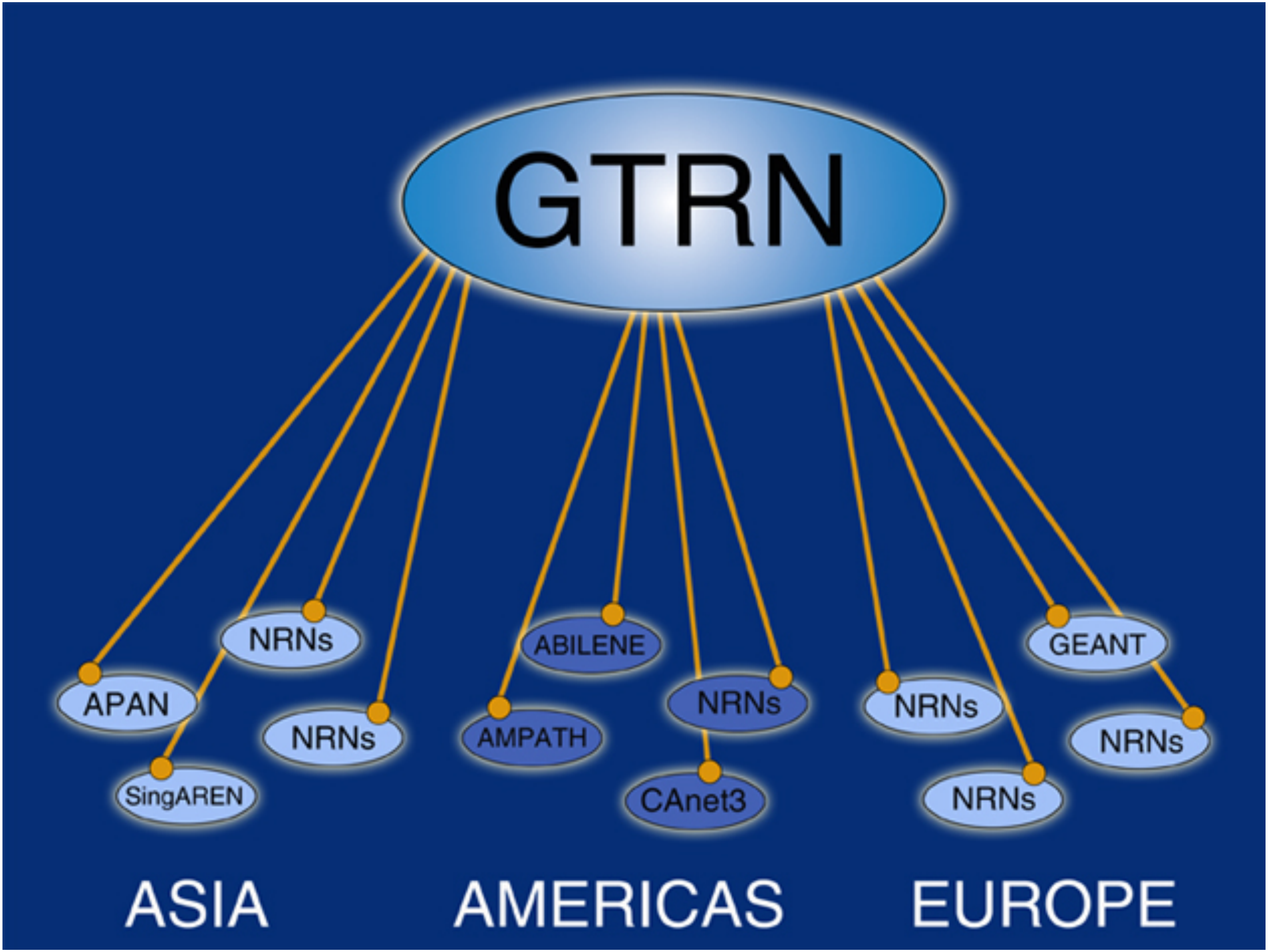
- is persistent, i.e. based on long-term (5-10 year) agreements with carriers, router vendors and optical transmission equipment vendors
- is scalable – e.g. OC768 by 2004, multiple wavelengths running striped OC768s by 2005, terabit/sec transmission by 2006
- allow GNAPs to connect at OC48 and above. To scale up as backbone speeds scale up
- provides a production service with 24x7x365 management through a global NOC


ASIA
AMERICAS
EUROPE


ASIA
AMERICAS
EUROPE


GNAPS
ASIA
AMERICAS
EUROPE


GTRN
ASIA
AMERICAS
EUROPE


GTRN
NRNs
APAN
SingAREN
NRNs
ABILENE
AMPATH
NRNs
CAnet3
NRNs
NRNs
GEANT
NRNs
ASIA
AMERICAS
EUROPE