Topological Optical Opportunities

Ruth Ann Mullen, PhD

Photon Futures, LLC

www.photonfutures.com

mullen@alumni.caltech.edu

AIM or Skype: photonrouter

Photonics Experience

- *Caltech APh, USC EE*
- *HRL*
- *University of Washington*
- *Battelle*
- *Consulting Clients*

Optical Networking Experience

- *Nextlink (now XO Communications)*
- *360networks*
- *Consulting Clients*

Outline

- Topology Drivers
- Mostly Meshes, with Rings, and Trees
  - Advantages - Examples

Topology Drivers

- Power
- Cost
- Survivability
- Traffic patterns
- Applications

Power as Topology Driver

- Co-location of server farms and data centers with nuke or hydro plants constrains topology
- Current core electrical routers are energy hogs
- All-optical routers sometimes promise higher wall-plug efficiencies
  - Packets - Labels - Bursts - Flows
- Question: Will energy efficiency of emerging technologies promise energy-independence of network topology, or not?

Cost as Topology Driver

- Photonic integration (whether for switching or routing)
- Redundancy of routes and λ's
  - Protection: pre-computed and reserved in advance
  - Restoration: dynamically provisioned as needed
- "Pay as you Grow" business models

Survivability as a Topology Driver

Varying levels of protection (as needed)

- Protection by a reserved path
  - Dedicated
  - Shared
- Restoration along alternate path
  - Discovery time
  - Provisioning time
- Unprotected connections (e.g. enterprise customer wanting carrier diversity)

Traffic Patterns Drive Topology

- Traffic drivers
  - Population - Events -Unpredictable
  - Industry - Applications
- Traffic management drivers
  - Large service providers
    - Intelligent edge routers groom bursty edge traffic onto creamy core for optical circuit switching
  - Small/emerging/enterprise networks
    - Core routers may have continuing value

Applications drive Topology

Example: Video distribution

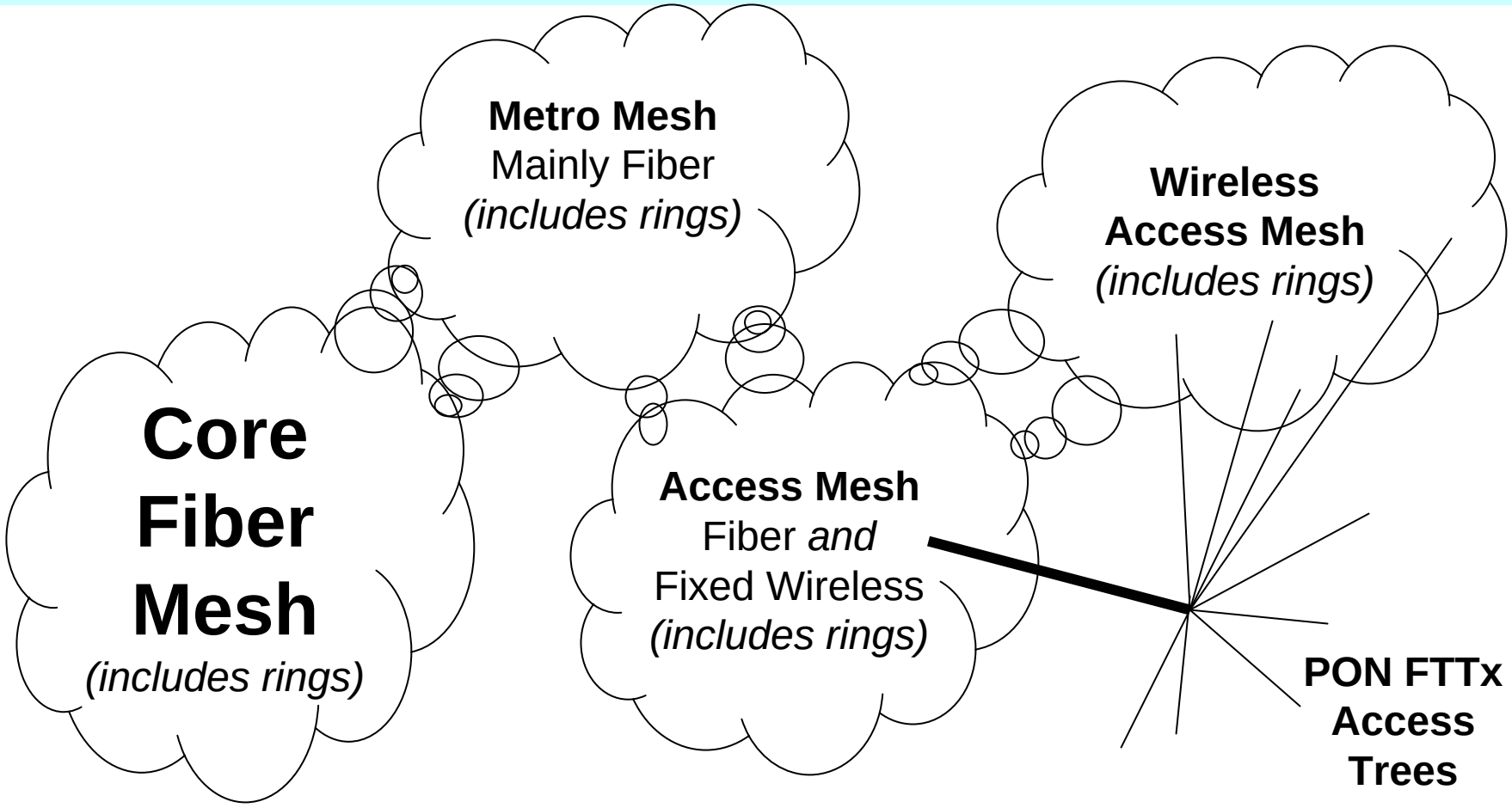
- Cable business model is supported by asymmetric tree architectures
- File-sharing applications demand more symmetric, meshy architectures

Mesh Advantages (Core, Metro, and Access)

- Survivability (esp. in presence of 2 or more points of failure, for mesh nodes into which fiber feeds come in via more than four distinct paths)
  - Protection: pre-computed and dedicated alternate paths
  - Restoration: alternate path is not pre-planned
- Varying levels of protection, as needed
  - Dedicated protection
  - Shared protection
  - Unprotected connections (e.g. enterprise customer diversity demands)
- Dynamically and remotely reconfigurable (provisionable from applications layer)
- Organic growth - “Pay as you grow”
- Multicast support
- Higher connectivity topologies facilitate space deflection in emerging Optical Packet Switched networks

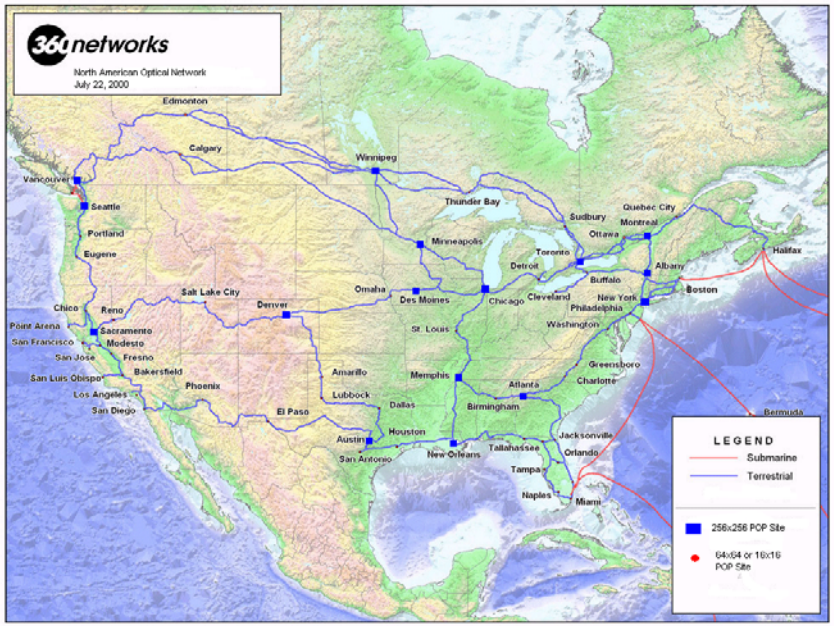
Emerging Topology: It's a Mesh

into which trees will connect



Core Optical Fiber Meshes

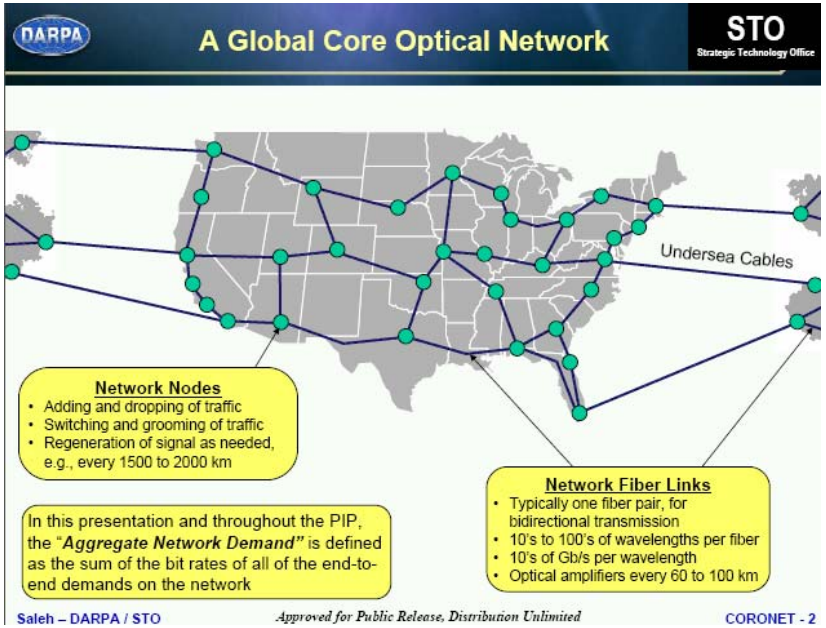
Historical Case Study
360networks – oeo mesh in 2001



3 east-west rails

Up to 6-degree nodes

Current DARPA Vision CORONET
2006 calls for ooo mesh



3 east-west rails

Mostly up to 4-degree nodes

Disruptive Changes

- Disruptive changes currently underway
  - Power (router wall plug efficiencies untenable)
  - Cost reductions via integration of diverse subsystem functions
    - optoelectronic transceivers (oeo now)
    - optical and or electro-optical processing (ooo later)
    - optical switching (oeo now, ooo later)
    - RF/optical integration (next slide)

RF-Optical Integration

- Cost drivers for cable and FTTx
- Coding efficiencies for more bits/Hz over fiber
- Wireless
  - Fixed pt-pt mm-wave wireless photonic integration
    - rf-microwave-mm-wave oscillators
    - mm-wave generators
  - Mobile wireless edge
    - Radio-over-fiber to the antenna towers
    - Optically-phased arrays
    - Connecting wireless towers in a coherent fiber

It's a Mesh

into which trees will connect

- Core Mesh (including rings)
- Metro Rings and Meshes
- Access Meshes (including rings) and Trees
  - Access meshes supportable via "pay as you grow"
    - Fiber (where fiber is available)
    - Fixed pt.-to-pt. mm-wave wireless (where fiber is unavailable or impractical)
  - Interim Topologies
    - Trees (interim PON)
      - Meshing PONS will be tricky
      - Close-in PONS may be subsumed by growth of access meshes
      - Wireless edge will mesh PON edge back to Access, Metro, and Core (via packet routing)
    - Rings (interim RPR, SONET/SDH, etc.)
  - Wireless Mesh at the Edge: mesh backhauled into core, metro, and access networks

Backup Slides

GENI Planning Challenge

Traffic Forecast Uncertainties

TE – Traffic Engineering

"Put the *traffic* where the *bandwidth* is."

NE - Network Engineering

"Put the *bandwidth* where the *traffic* is."

NP - Network Planning

"Put the *bandwidth* where the *traffic* is *forecasted to be.*"

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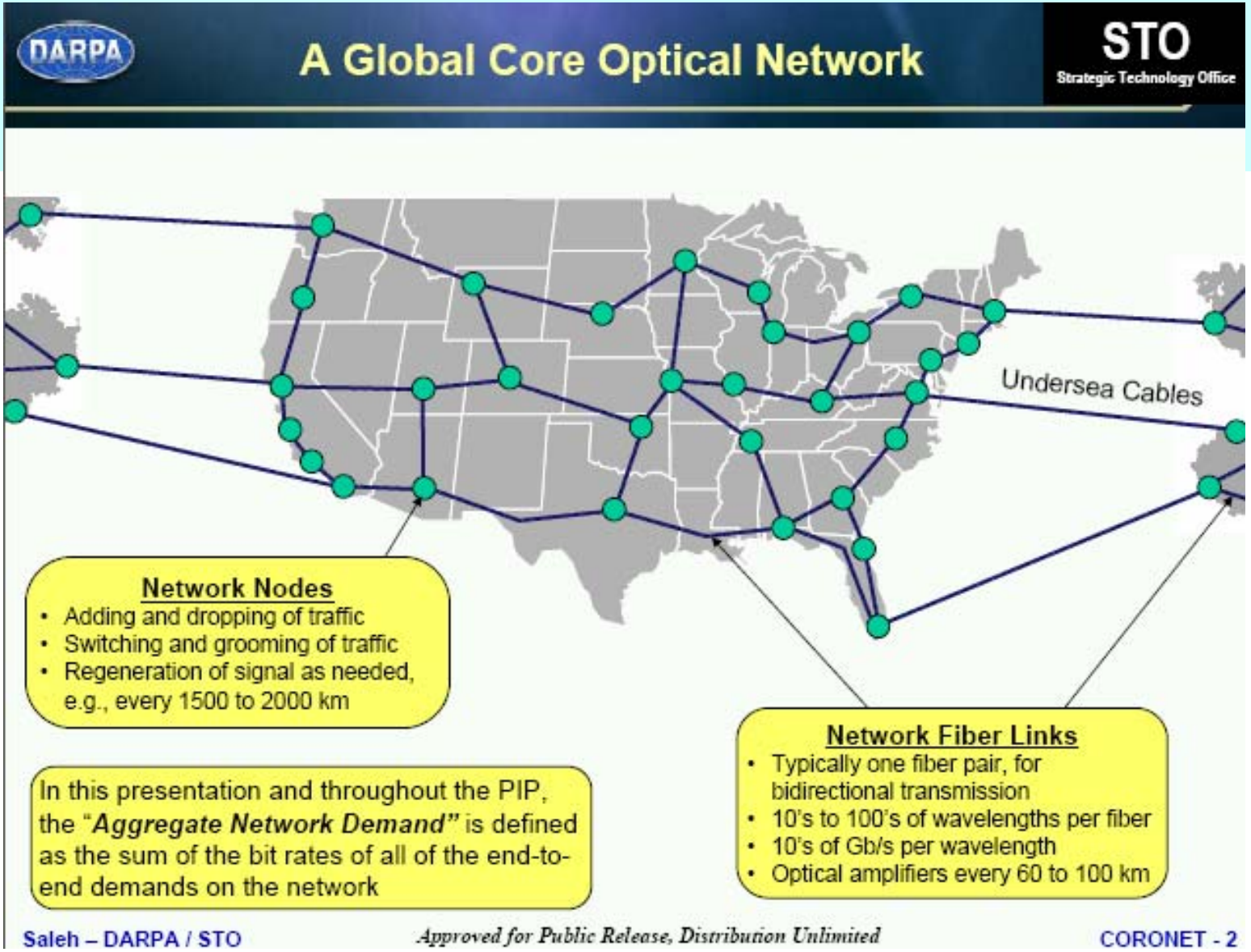
Two Scenarios

- Electrical Routing:
  - Large service providers: Statistics of large numbers from large customer base facilitates efficient aggregation at edge
- Optical Routing (of packets, flows, labels, or bursts)
  - May provide new business opportunities: smaller service providers lacking large initial customer base required to achieve efficient traffic aggregation at network edge
  - May one day be more power-efficient

"*Traffic* will go where the *bandwidth* is."

As a society, where do we want bandwidth and traffic?

- Geography: Beltway? Rust belt? Corn belt?
- Cultural: Urban? Suburban? Rural? Wilderness?
- Business: Big? Small?
- Family: Homes?
- Education: Schools?
- Trade and Security: Ports? Here, and/or abroad?


DARPA
A Global Core Optical Network
STO
Strategic Technology Office
Undersea Cables
Network Nodes
• Adding and dropping of traffic
• Switching and grooming of traffic
• Regeneration of signal as needed, e.g., every 1500 to 2000 km
In this presentation and throughout the PIP, the "Aggregate Network Demand" is defined as the sum of the bit rates of all of the end-to-end demands on the network
Network Fiber Links
• Typically one fiber pair, for bidirectional transmission
• 10's to 100's of wavelengths per fiber
• 10's of Gb/s per wavelength
• Optical amplifiers every 60 to 100 km
Saleh – DARPA / STO
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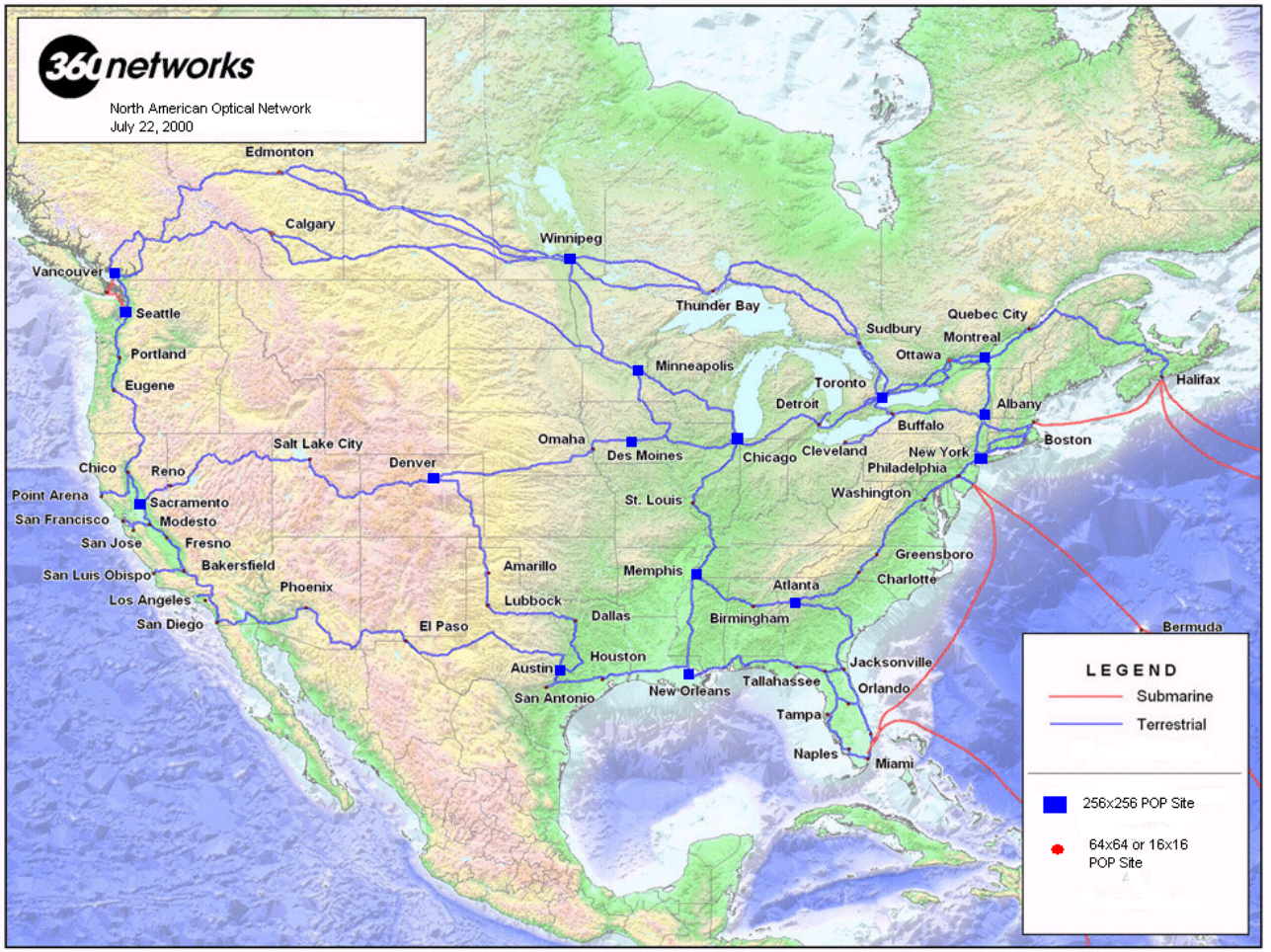
Case Study: Reconfigurable Core Fiber Optic Mesh (oeo, 2001)



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