Future Internet Design:

Dynamic (Optical) Circuit Switching (DOCS), Ethernet Everywhere, …

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For more information, please read Chapter 1 of the book:
B. Mukherjee, *Optical WDM Networks*, Springer, 2006.

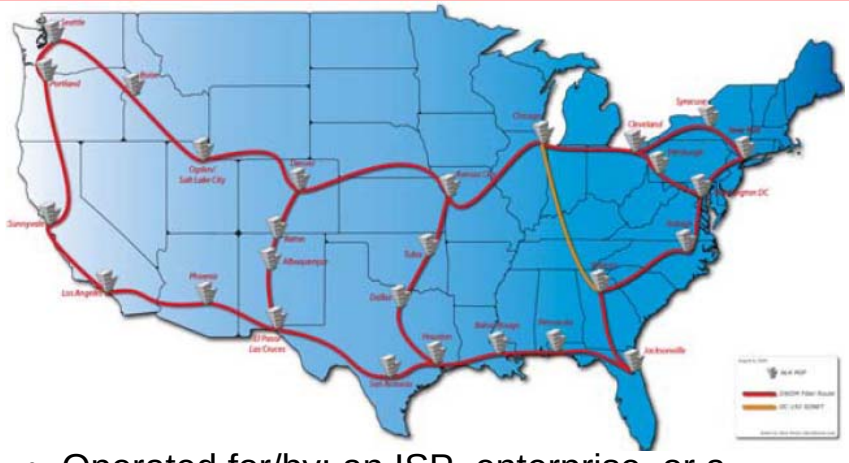
"Requirements – 1"

- Articulate research opportunities and challenges
  - in terms of Future Internet design
  - influenced by emerging optical technologies and networks
- NOT about technologies or narrowly-focused research
  - Rather… about the broad perspective of how these technologies, and their expected rapid development, might affect the larger overall network architecture, and vice versa

"Requirements – 2"

- Clean-slate approach (?)
- 15-year "runway"
- Looking back 15 years…
  - What optical networking technologies have had profound impact?
    - "Lightpath" communications (Infocom 88-89)
    - JSAC Special Issue on Optical WDM Networks (Aug. 1990)
    - "Virtual-topology" design (Infocom 94)
      - "Lambda Grid" now!
    - Survivable (optical) network architectures (Infocom 99)
    - "Optical broadband access" quite new (2001-02)

(Data) A Typical Network

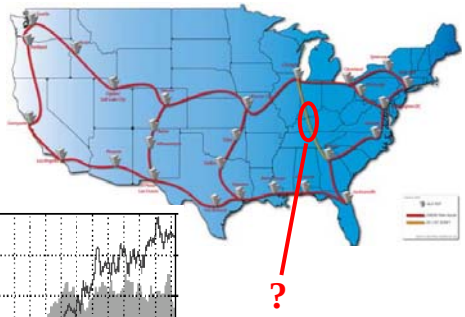


- Operated for/by: an ISP, enterprise, or a "large institutional user of bandwidth"

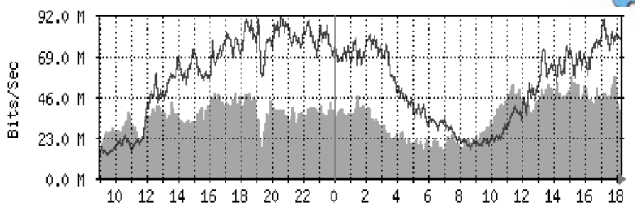
(Data) A Typical Network

- Link = ?
  - "leased line" (circuit)
  - Leased on yearly basis?
- Can we connect any two data routers with:
  - With any capacity? (1/2.5/10/40 Gbps)
  - For any duration? (min, hrs, days)
- Can we "dial for bandwidth" on an <u>as-needed</u> basis?
  - Increase, decrease, delete capacity on demand (in 10s of ms)
  - Between router interfaces?
  - Between end hosts (on e2e basis)?
- Who is the bandwidth provider?

(Data) A Typical Network



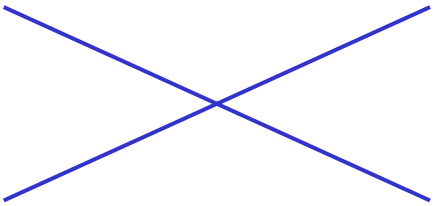
- Traffic intensity on a "link"



… measure traffic
… lease only as much bandwidth as needed
… reconfigure "grid" connectivity on demand…

Thus, We Have… An Overlay

- Layer-n network
  - e.g., n=3
  - Virtual net (reconfigurable)
  - (Lambda) Grid
  - Layer-1 VPN



- Layer-1 (fiber) network

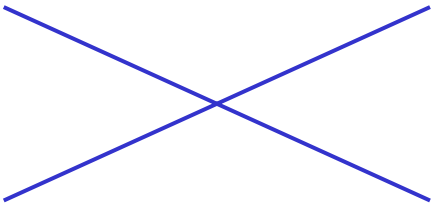
➔ "Routed-edge, switched-core" architecture?

Four Business Models

1. ***ISP owns the network*** from the "ground up" (i.e., to the duct) and only delivers IP-based services.
   - Traffic = packets; operator owns all network resources
2. ***The business owns the layer-one infrastructure*** and sells services to customers who may resell to others.
   - Traffic = "circuits"; network operator sells circuits to ISPs
   - "ISP" = enterprises and "large institutional user of bandwidth"
3. ***ISP leases fiber or transport capacity*** from a third party, and only delivers IP-based services.
   - Traffic = packets; "ISP" may not have "visibility" into network infrastructure; ISP may lease capacity from many operators
4. ***The business is a "bandwidth broker"*** which may not own any transport infrastructure, and its connections are actually carried over third-party networks.
   - "bandwidth broker" = "matchmaker"
   - "Carrier hotel", e.g., "60 Hudson, NY"

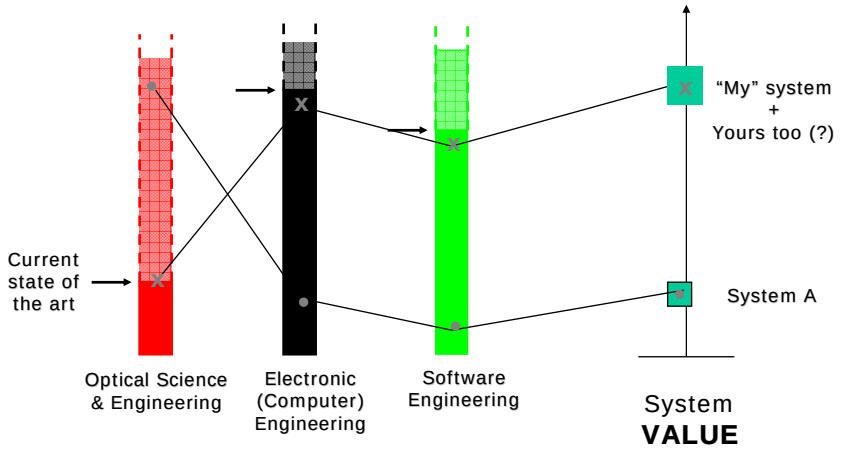
A Typical (Data) Network

- Node = ?
  - (IP) Data router
  - Optical switch--opaque (OEO)?

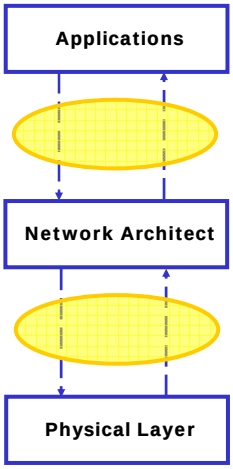


- Density please…
  - Outrageous improvement?
  - Photonic ICs?
  - Hardware acceleration

System/Network: Value Proposition



Holistic Network Design:
The Inter-Disciplinary "Layers"



("Customer" needs)

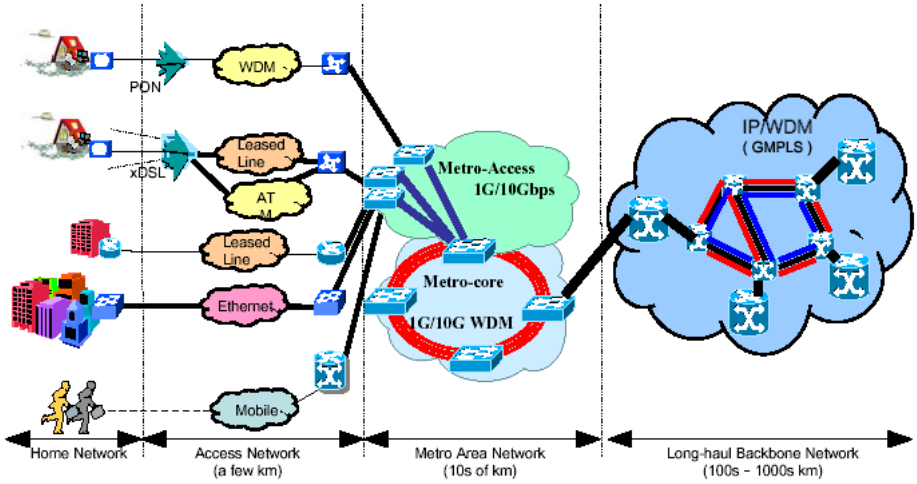
Differentiated Services:
Bandwidth: OC-192, OC-48, … , STS-1, VT1.5, …
Failure-Recovery Delay: ("X ms")
Network Economics: Pricing, SLA, …

(Michael, I, …)

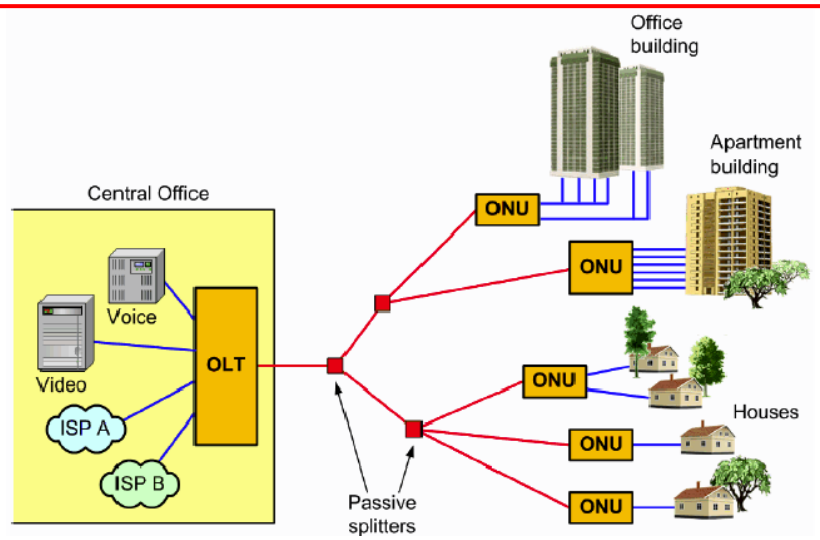
+ routing protocols to combat optical channel impairments
+ breakthroughs needed in device technologies?
- optical RAM, ultra-wideband amp, "tunable" AWG, …

(optical comm. channel) -- materials, devices, subsystems

Telecom Network Hierarchy



An Access Network (PON)



Telecom ~~Optical~~ Networks: The Road Ahead

Broadband Access

- PONs
- WDM in PONs
- Long-Reach Broadband Access
- Hybrid wireless-optical access
- Metro: The vanishing breed?

Backbone Networks

- DOCS (“dial for bandwidth”)
- Robust Network Design (multi-layer, multi-domain, multi-path, etc.)
- Ethernet Everywhere

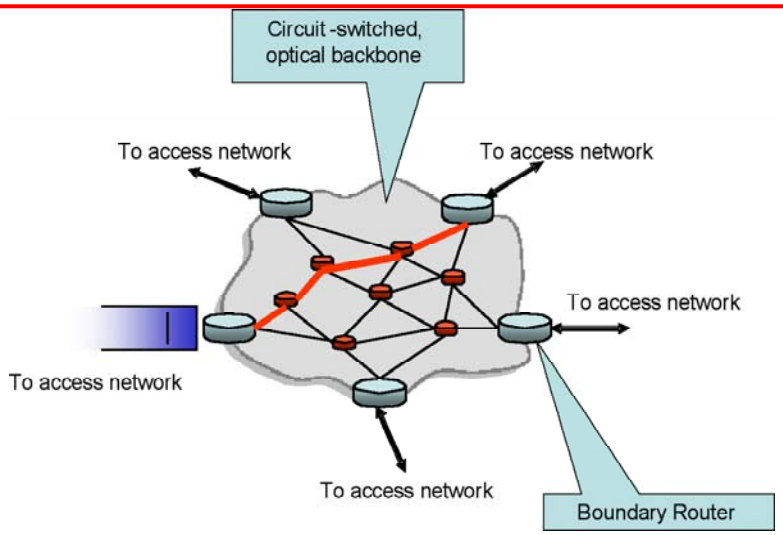
- Network Engineering (NE) (vs. TE vs. NP)
- Higher-density switches!

Traceroute: to aland.bbn.com
(UC Davis to Boston)

1 169.237.4.254 (169.237.4.254) 0.973 ms 0.747 ms 0.475 ms
2 169.237.246.238 (169.237.246.238) 0.682 ms 0.797 ms 0.741 ms
3 area2-13--area2.ucdavis.edu (128.120.2.49) 0.880 ms 0.767 ms 0.746 ms
4 area2--area0.ucdavis.edu (128.120.0.133) 0.939 ms 1.295 ms 0.856 ms
5 area0--area14.ucdavis.edu (128.120.0.222) 1.063 ms 1.484 ms 0.887 ms
6 area14--a14.ucdavis.edu (128.120.9.142) 1.009 ms 0.950 ms 0.837 ms
7 a14--ucd-hpr.ucdavis.edu (128.120.9.138) 1.177 ms 1.57[illegible]
8 * dc-oak-dc2--ucd-ge.cenic.net [illegible]
9 dc-sfo-dc1--oak-dc2-pos.cenic.n[illegible] [illegible]55 ms
10 dc-svl-dc1--sfo-dc1-pos.cenic.n[illegible] 3.923 ms 3.812 ms 3.674 ms
11 te2-3--480.tr01-plalca01.transitrail.net (137.164.131.253) 3.854 ms 4.300 ms 3.958 ms
12 bb1-g1-0.pxpaca.sbcglobal.net (198.32.176.112) 4.543 ms 4.463 ms 4.559 ms
13 151.164.93.249 (151.164.93.249) 68.968 ms 68.869 ms 69.440 ms
14 dist1-vlan30.lgtpmi.ameritech.net (65.42.245.97) 69.434 ms 69.213 ms 68.944 ms
15 rback1-g1-0.lgtpmi.sbcglobal.net (65.42.245.230) 68.845 ms 69.043 ms 69.145 ms
16 adsl-68-22-232-254.dsl.lgtpmi.ameritech.net (68.22.232.254) 823.731 ms 856.567 ms 822.425 ms
17 adsl-68-22-232-249.dsl.lgtpmi.ameritech.net (68.22.232.249) 858.838 ms 890.727 ms 859.053 ms

What is This?

DOCS Architecture: Overview



ACK: NSF FIND Program, Dan Blumenthal, Nick McKeown, and John Bowers

Why DOCS? (or DCS)

- Emerging (video-enabled) applications:
  - Video downloads
  - Massively multiplayer games
  - Video collaborations
  - Telepresence
  - IPTV
  - Applications on a wire, etc.

- If you are happy with the PMO of our networks:
  - slow downloads
  - jittery streaming
  - unreliable audio

  then DOCS is <u>not</u> for you.

DOCS: Basic Premise

- DOCS = Dynamic Optical Circuit Switching

- Approach:
  - Bursty (packet) traffic generated by users/applications
  - Aggregate traffic at the network edge
  - Establish high-bandwidth pipes between edge nodes through the network core
  - DOCS offers bandwidth-on-demand capabilities to applications (users can “dial” for bandwidth)

- Example Applications:
  - Real-time download (say within 5 sec)
  - Database/website backup (say between 1 am – 3 am, and not to exceed a 15-min duration)

DOCS Example Applications - DDRs

- DDR = Deadline-Driven Request
- Real-time file download
  - maximum transfer time a person can tolerate (perhaps 5 sec)
- Database/website/server backup: scheduled at any time, perhaps during night, but with a fixed deadline (completion time)
  - flexible application requiring high bandwidth, but not necessarily instantaneously.
- Our research: Provision DDRs in a DOCS network from two perspectives:
  - ***Time dimension***: allows flexibility w.r.t. when to when to schedule the request.
  - ***Transmission bandwidth (rate)* dimension**: allows flexibility (adjustable to network state) w.r.t. data rate to be allocated to the request.

Ethernet Everywhere

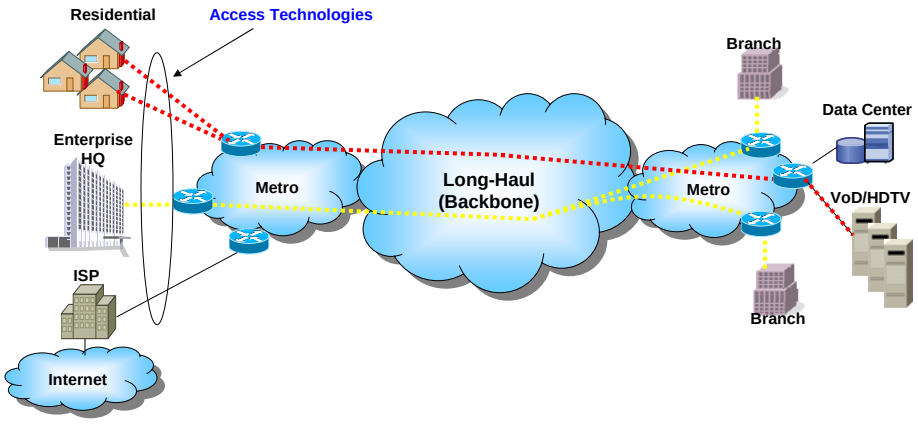
- **Ethernet is a success story in Local Area Networks (LAN)**
  - About 90% of LANs use Ethernet.
- **Extending its reach from LAN into Metro Area Networks (MAN) has already been established.**
- **Focus now is to extend Ethernet into carrier core networks.**
  - **Future mode of operation: Ethernet over WDM → native Ethernet frames directly over WDM.**
    - **Elimination of several layers of other technologies.**
      - **CapEx and OpEX savings.**
  - **Connection-oriented Ethernet.**
  - **Forwarding: VLAN-XC, Provider Backbone Transport (PBT), T-MPLS.**
- **Following requirements must be taken into account:**
  - **High resilience.**
  - **Long reach: 1500- 4000 km.**
  - **Rates of up to 100 Gbit/s Ethernet (GbE).**
  - **High degree of mesh.**

ACK: Siemens (NSN)

Transmission Rates and Mixed Line Rates

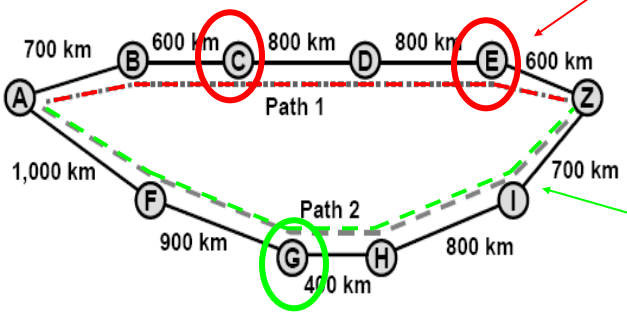
- **Ethernet Rates:**
  - 100 Gbit/s Ethernet.
    - Max possible CapEx savings.
- **Constraint: Signal transmission range for a certain rate**
  - Signal's quality depends on the physical impairments.
  - Transmission Range = Signal traveled distance after which signal quality degrades to a level that it needs regeneration.
- **Transmission Ranges:**
  - Range of 10 Gbit/s signal = 3000 km
  - Range of 100 Gbit/s signal = 500 km
- **Mixed Line Rates:**
  - 10 Gbit/s, 40 Gbit/s, 100 Gbit/s waves.
  - Need for (hierarchical) grooming.
- ***Etherpath* = Lightpath carrying Ethernet frames.**

Telecom Nets: "End-to-End" Ethernet?



Optical Bypass-Enabled Network: Distance vs. Regeneration

- Optical reach = 2,000 km
- source = A, dest = Z



Dist = 3,500 km
# Regens = 2

Dist = 3,800 km
# Regens = 1

TE vs. NE vs. NP

- **Traffic Engineering (TE)**
  - "Put the traffic where the bandwidth is"
- **Network Engineering (NE)**
  - "Put the bandwidth where the traffic is"
- **Network Planning (NP)**
  - "Put the bandwidth where the traffic is *forecasted to be*"

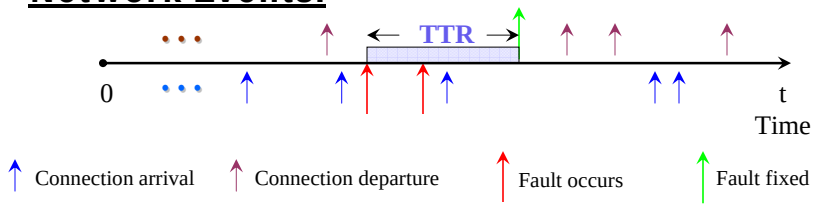
Blocking probability

- **TE** – online, dynamic, provisioning problem, ms time scale
- **NE** – intermediate problem, months time scale Exhaustion Probability
- **NP** – offline, static, dimensioning problem, 5-yr time scale

Cost ($$$)

Robust Network Design

Network Events:



Network Architecture Needs:

- *More dynamism / flexibility / agility / automation …*
- Handle multiple (near-simultaneous) faults efficiently
- Reprovision (backup) capacity when "network state" changes
  - Efficiency tradeoff: bandwidth vs. implementation
- Is a service path "ahead" or "behind" the contract (SLA)?
  - Reprovision, if necessary; role of penalty and economics in SLA
- Utilize "excess capacity"?
- …

Further Reading

Broadband Access

- PONs
- WDM in PONs – IEEE Photonics in Switching Conf. (PIS) , Aug. 07
- Long-Reach Broadband Access – stay tuned
- Hybrid wireless-optical access – JLT, Nov. 07; OFC'07; ICC'07, …
- Metro: The vanishing breed?

Backbone Networks

- DOCS ("dial for bandwidth") – PIS, Aug. 07
- Robust Network Design – Lots of literature
- Ethernet Everywhere – OFC'07 PD paper; GB'07; JLT, Jan. 08