Introduction to Optical Network Design

Optical Networking: Principles and Challenges

Communication Network Design
(2020-2021)

Massimo Tornatore
massimo.tornatore@polimi.it
Dept. of Electronics, Information and Bioengineering
Politecnico di Milano

Most of the material in this lecture is by courtesy of Prof. Biswanath Mukherjee @ UCD

Email, phone, etc..

- Email: massimo.tornatore@polimi.it
- Phone: 3683
- Office hours:
  - Wednesday 11.30a.m. - 13.00pm
  - Also possible to fix an appointment
- Website
  - Course material will be uploaded on Beep

5 credits or 10 credits?

- «Communication Network Design» (CND) is a 5-credits exam:
    - 32h lectures
    - 12h exercises
    - 10h laboratory

  to be taken
  - As 5 credits, independently (only CND)
  - As 10 credits, in association with 5 credits of «Foundations of operation research» (FOR)
    - Then, you have Netw. Design (10cr) in your study plan
- <u>Be careful with the dates of FOR exams!!</u>

www.unidocs.it - Appunti e dispense per superare i tuoi esami universitari

Schedule

Data	Dove	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
Lunedì													
Martedì	26.15 (EX L.26.15)								COMMUNICATION NETWORK DESIGN esercitazione Squadra1 (dal 15/09/2020 al 22/12/2020)				
Mercoledì													
Giovedì													
Venerdì	AULA VIRTUALE							COMMUNICATION NETWORK DESIGN lezione (dal 18/09/2020 al 18/12/2020)					
Sabato													

- As I do not expect much attendance in class, I will not divide Group 1 and Group 2 on Tuesday
- First two weeks are all remote (paternity leave ☺)

Course objectives and topics

- The course is intended to provide students with the knowledge and tools necessary to design and plan communication networks
  - Two main languages for design: optimization & queueing theory
- The first part of the course focuses on optical networks
  - From devices to network (book Mukherjee)
  - Design approaches based on mathematical modeling (integer linear programming) and heuristic approaches are discussed (notes)
    - Here we will see applications of optimization!
  - Lab: Net2Plan
  - Industry seminar and projects' presentation: Nokia
- In the second part of the course:
  - Protection (book Vasseur)
  - Traffic theory for the design of circuit switching networks (notes)
    - Here we will see application of queueing theory

Detailed program

1. **Introduction to optical networks**
   - Optical networking principles and challenges: telecom network overview, business models, traffic engineering vs network engineering vs network design, Wavelength Division Multiplexing (WDM), WDM evolution.
   - Enabling Technologies: optical fiber, optical transmitters, optical receivers, optical amplifiers, switching elements.
2. **Exact and heuristic (optical core) network design methodologies**
   - Network design based on mathematical modelling: flow formulation, route formulation. Modelling of network protection: dedicated protection, shared protection. Network design by heuristic approaches: greedy, local search.
3. **Lab Session**
   - Net2Plan
4. **Protection techniques**
   - Network survivability: various protection techniques. Single- and multi-layer protection techniques: protection at IP layer, protection at physical layer. Protection techniques in SONET/SDH or OTN . Protection in the optical layer: solutions for ring networks.
5. **Queueing Theory: design of circuit-switched networks**
   - Queueing theory primer: Markov, birth death and Poisson process.
   - Introduction: Network and communication services: network types and performance targets. Traffic modeling: definition and properties. Source model: single and multiple source. Analysis of multiple-server system with assumption LCC, LCH, LCR. Evaluation of congestion and statistics of carried/lost traffic. Voice network structure and routing techniques. Dimensioning of overflow trunk: Wilkinson, Fredericks and Lindberger.

Exams & Material

- *Prerequisites*
  - A basic course on «Computer Networks»
  - A basic course on «Statistics and Probability»
- *Bibliography*
  - Mukherjee, *Optical Networks*, Springer, 2006
  - Vasseur, et al, *Network recovery*, Morgan Kaufmann, 2004.
  - Material/booklets distributed by the lecturer
  - Additional reading:
    - Medhi, Ramasamy, *Network routing,* Morgan Kaufmann, 2007.
    - Kleinrock, *Queueing Systems (Vol. 2: Computer Applications)*, Wiley, 1976
- *Exam*
  - Written test + oral examination, plus points for lab activities

- This year, all lectures will be recorded!

Optical Networks

What is an optical network?

Why are we using optical networks?

Success of optical communications

Main technical reasons

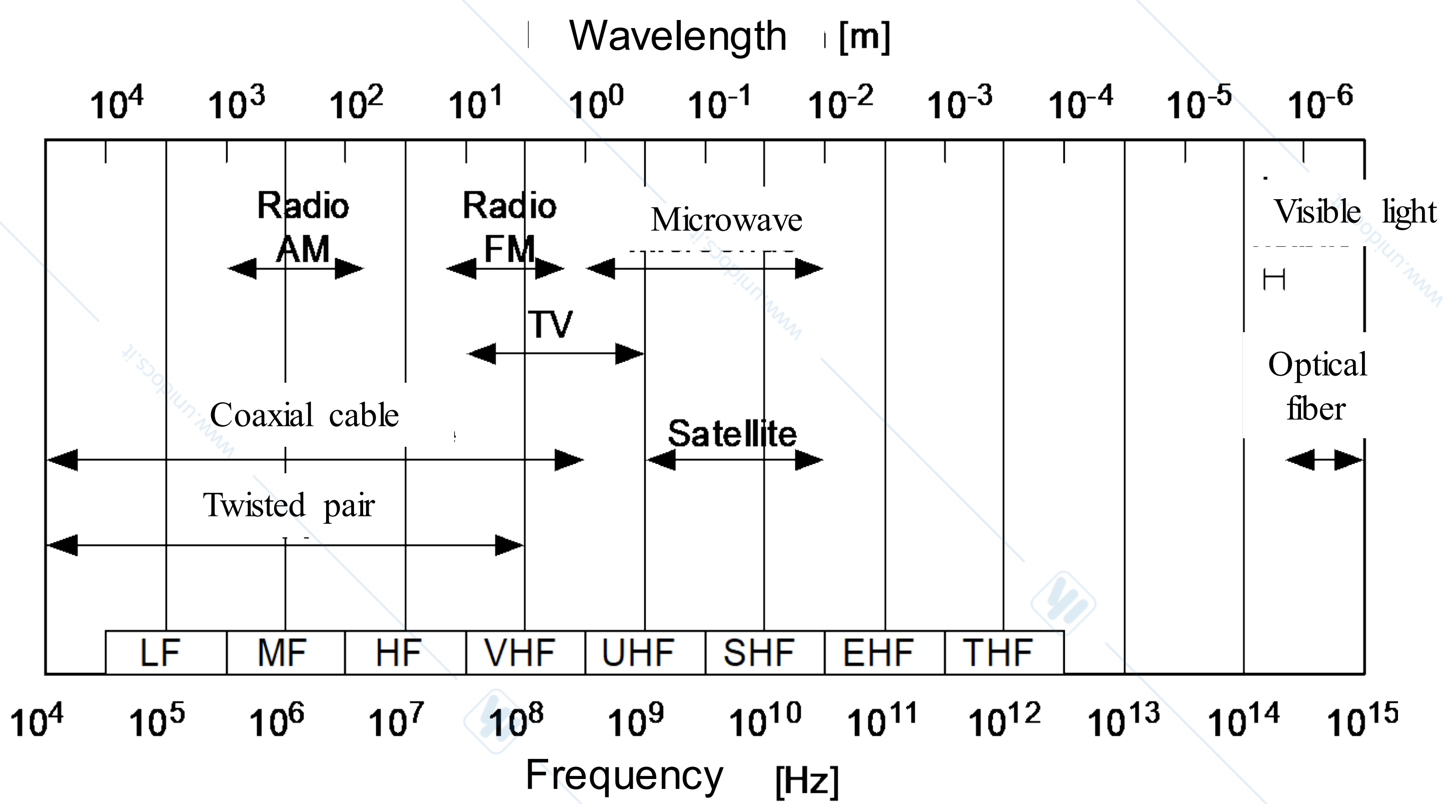
- Optical fiber advantages
  - Huge bandwidth (WDM)
  - Long range transmission (EDFA optical amplifiers)
  - Strength
  - Flexibility (transparency)
  - Low noise
  - Low cost
  - Interference immunity
  - ....
- Optical components
  - Rapid technological evolution, but still need work for:
    - increase reliability
    - decrease costs
- Ok, but from a network perspective?
  - *Convergence of services over a unique transport platform*

Fiber has immense spectrum

... see spectrum of the main transmission media

$$\lambda = \frac{v}{f}$$

$$v = c = 3 \cdot 10^8 \quad m/s$$

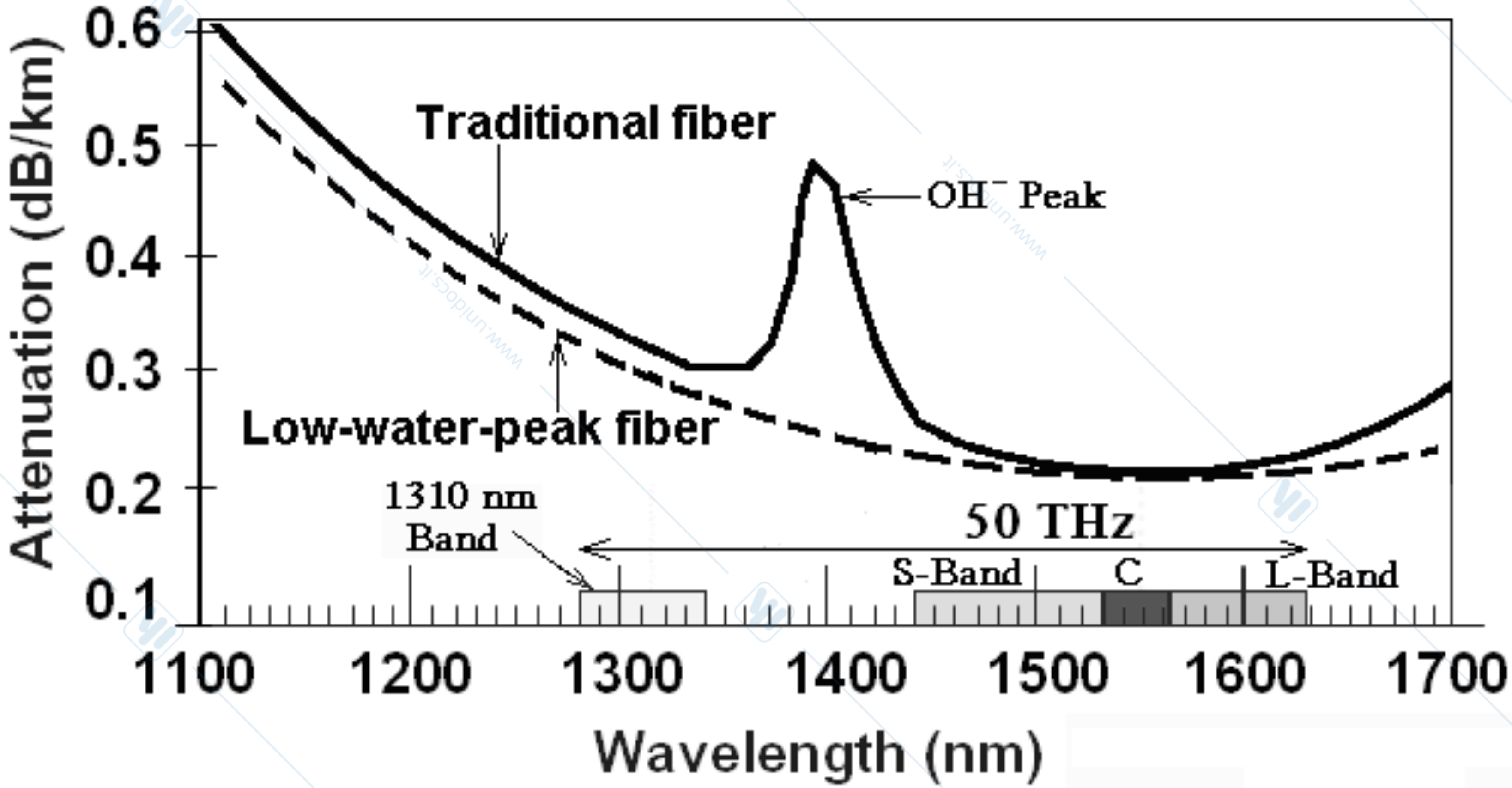


LF = Low Frequency
MF = Medium Frequency
HF = High Frequency

VHF = Very High Frequency
UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extremely High Frequency
THF = Tremendously High Frequency

Fiber has very low attenuation!

(a) All-wave fiber (true wave, Leaf, etc.) (b) Traditional fiber

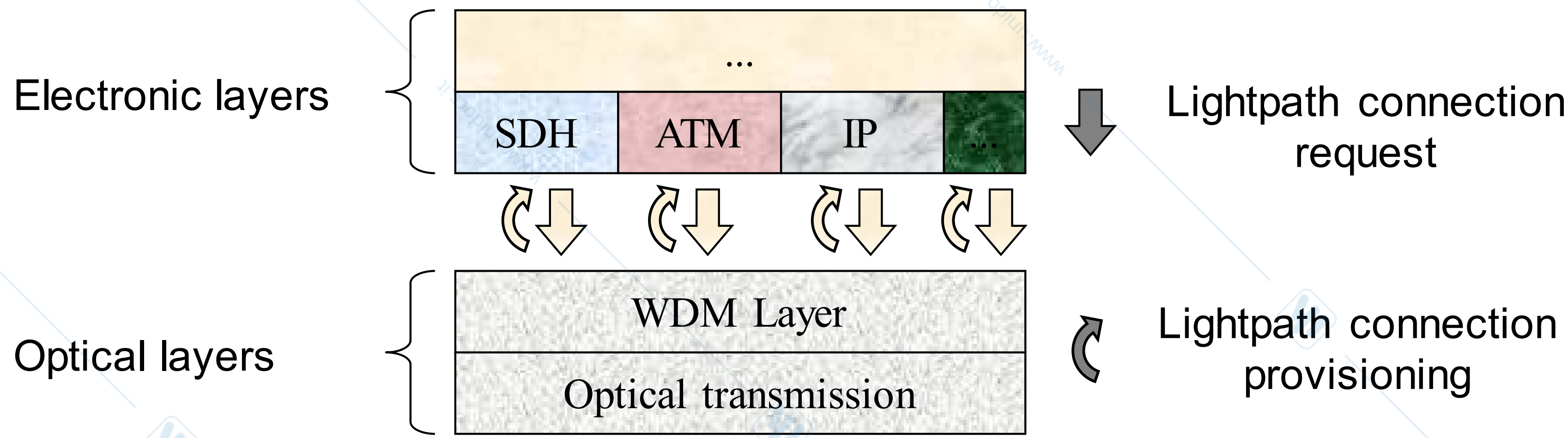


- Removal of water molecule absorption peak.
  Check: http://www.thefoa.org/tech/ref/basic/SMbands.html
- Compare attenuation in fiber vs copper after 1km!

WDM = wavelength-division multiplexing (wavelength = channel)

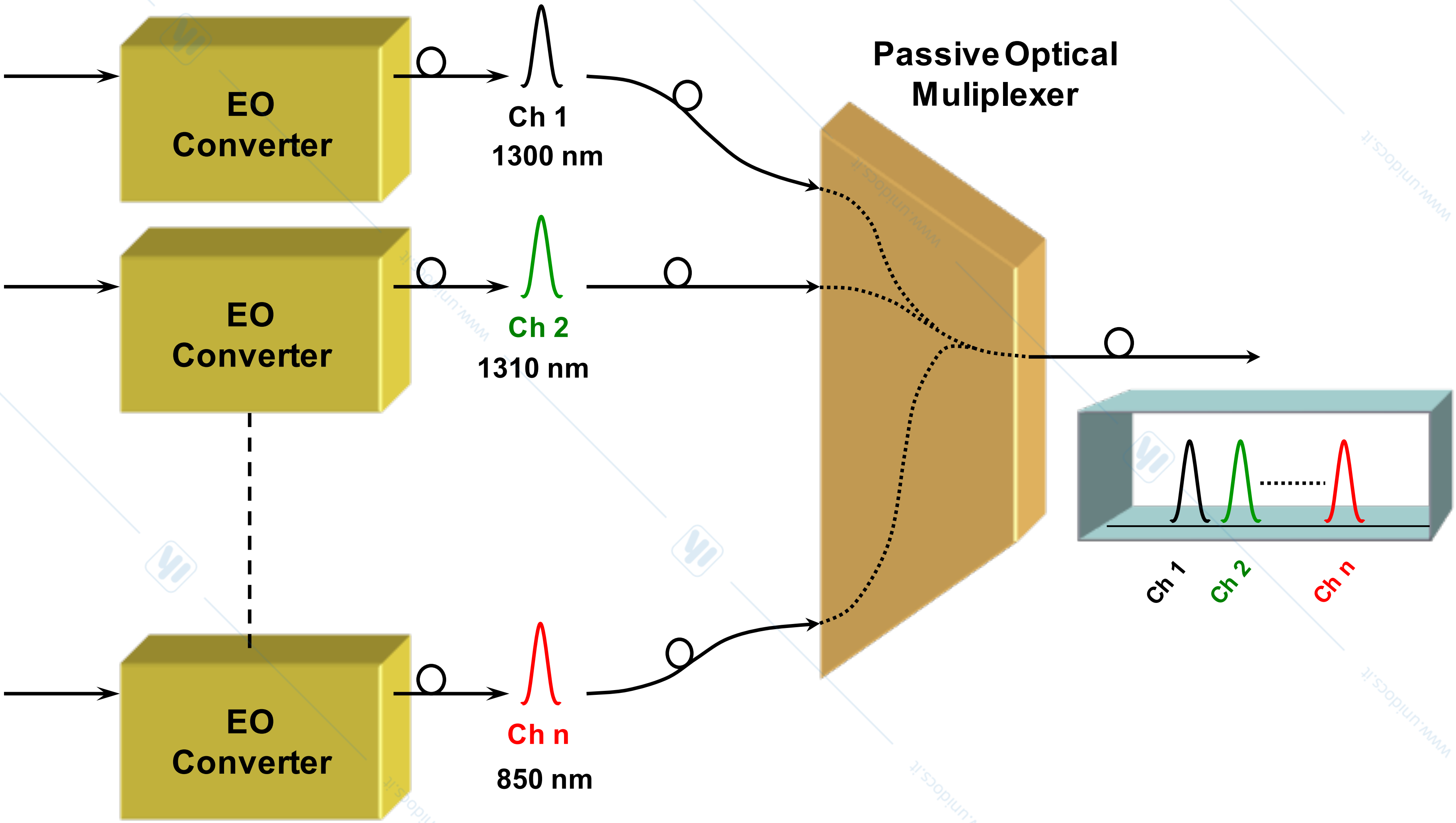
Optical networks: a "layered vision"

- Optical Networks (aka WDM layer) basic functions
  - Offers optical circuit (LIGTHPATH) for electronic layers
  - Common transport platform for a multiple protocol in L2 and L3

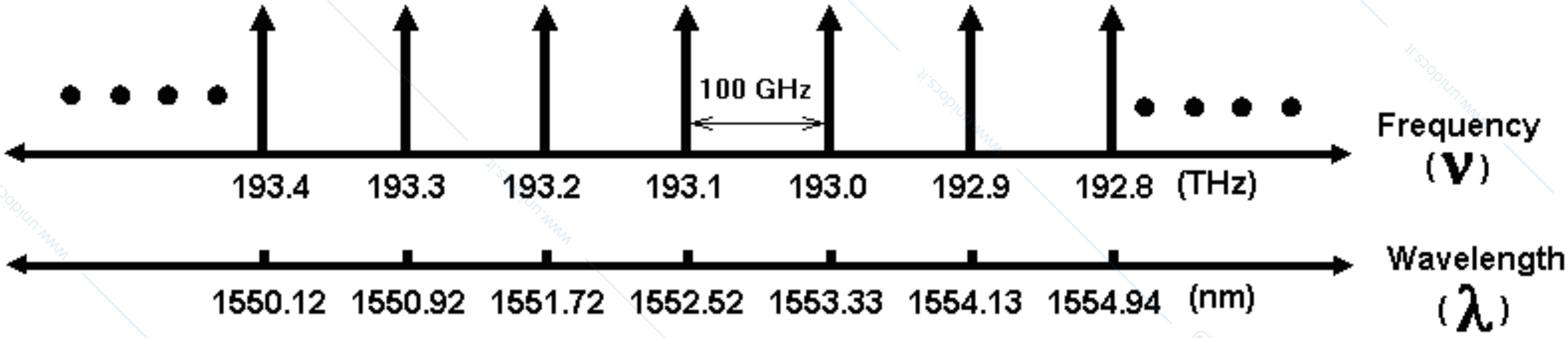


- Two fundamental operations
  - **Transmission:** Wavelength Division Multiplexing, data carried on different channels (i.e., different wavelengths) on the same fiber
  - **Switching:** WDM systems switch optical flows in the space (fiber) and wavelength domains

What's a WDM System?



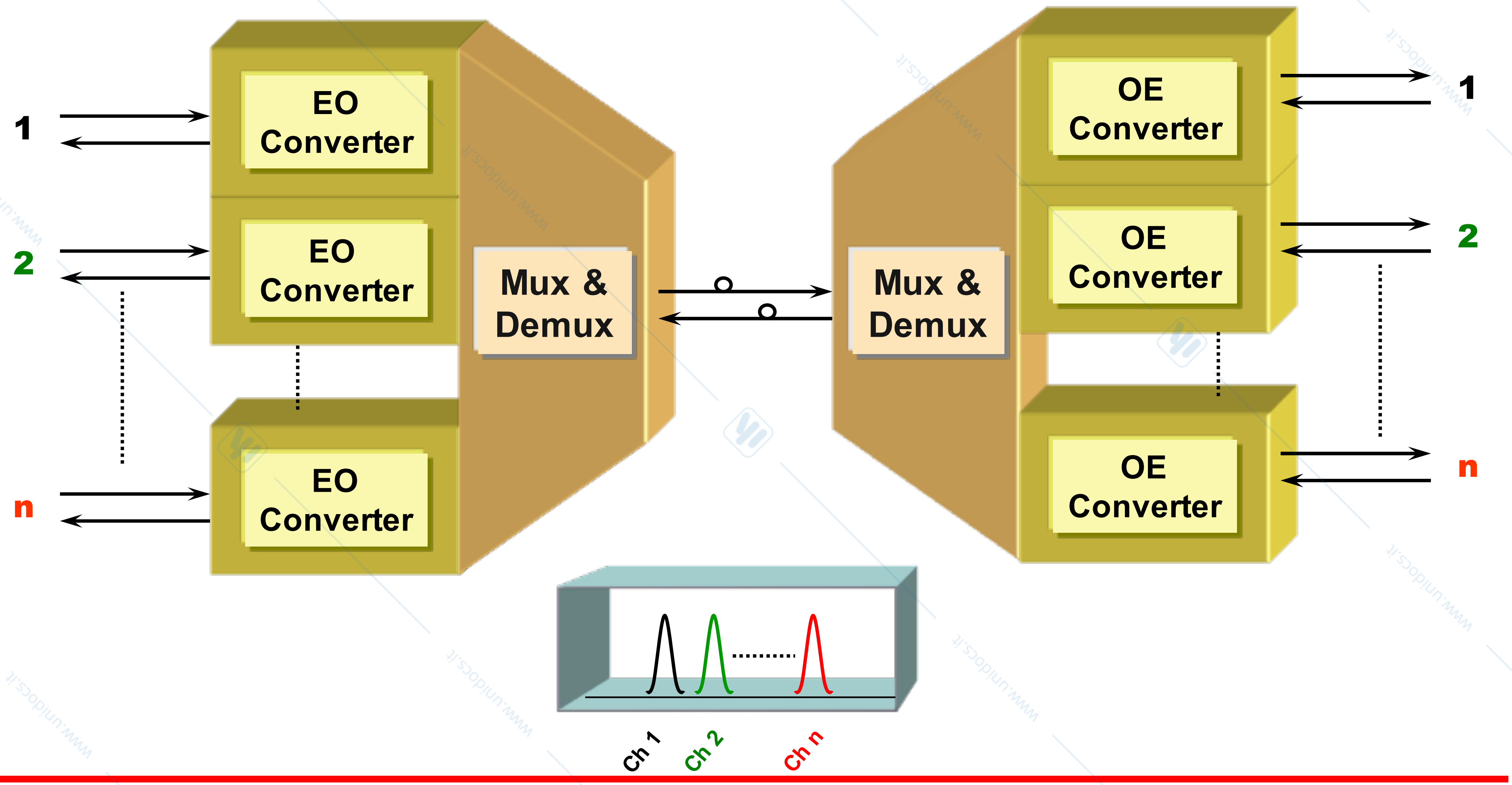
ITU-T «fixed» grid for WDM



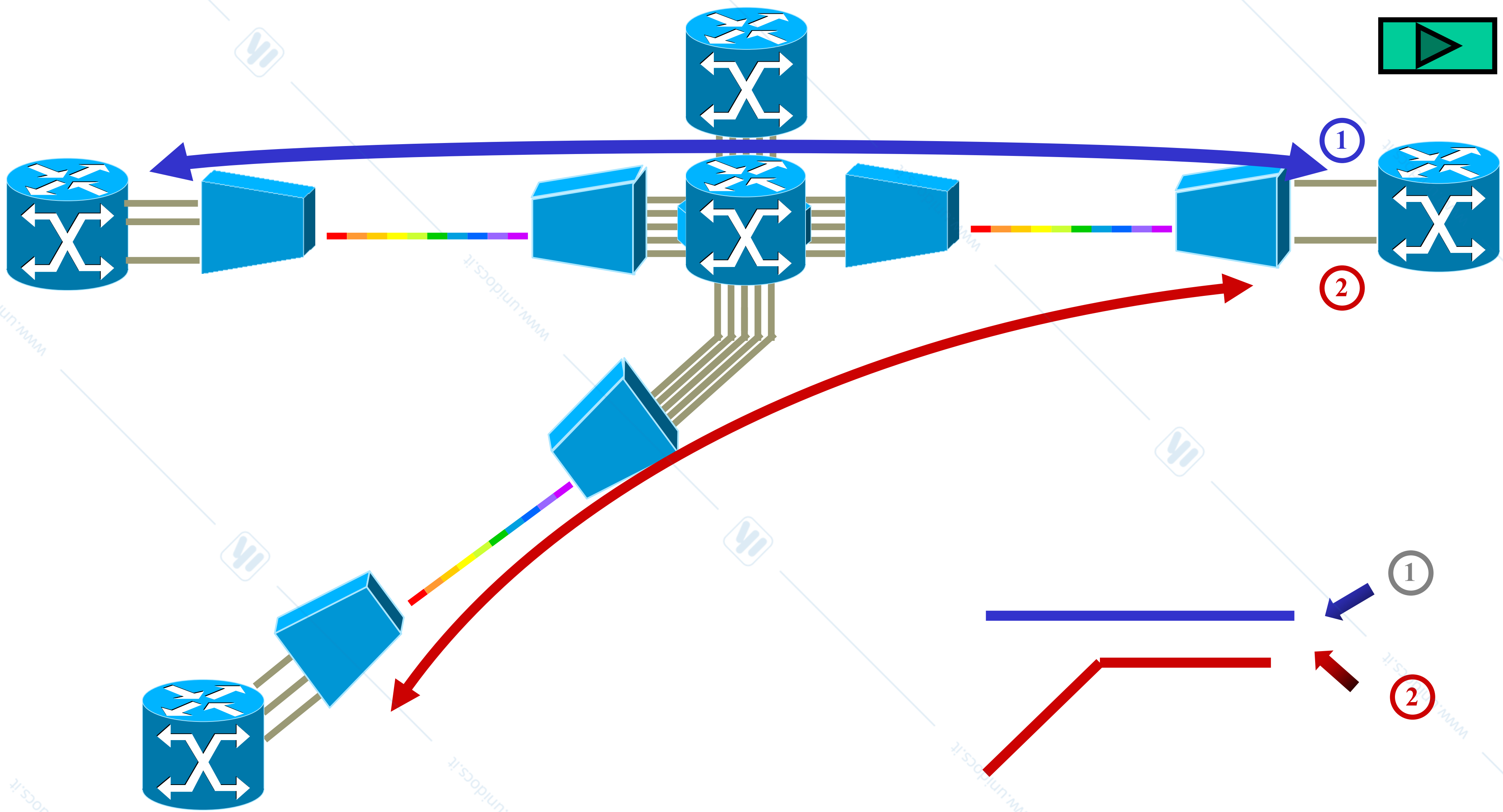
Check: ITU-T G.694.1 Spectral grids for WDM applications: DWDM frequency grid, Feb 2012.

P.S.: This is evolving to a more complex «flexible» grid, we will mention more during the course.

WDM System Function

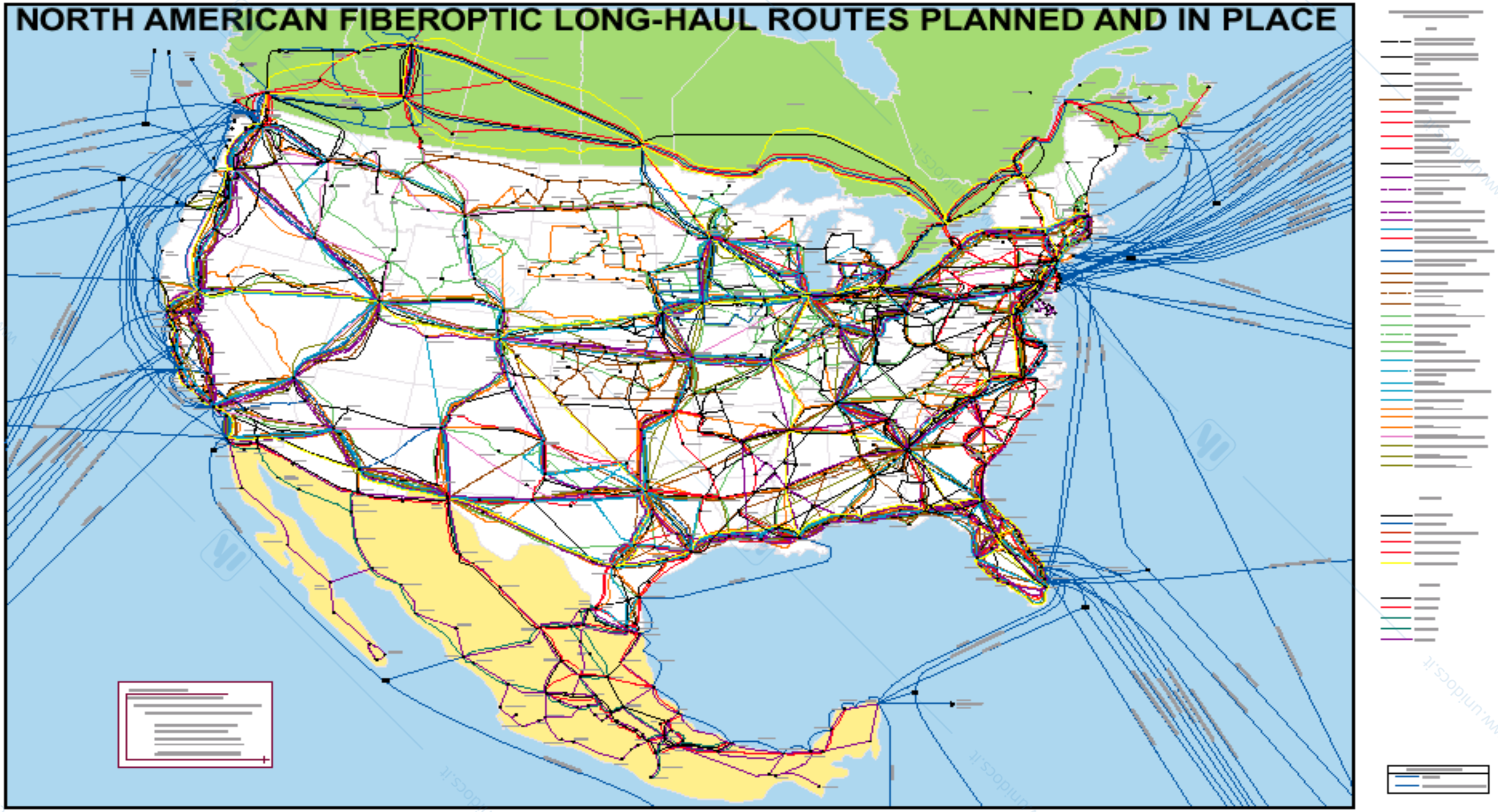


Wavelength Switching in WDM Networks



The concept of lightpath
Example: A European WDM Network

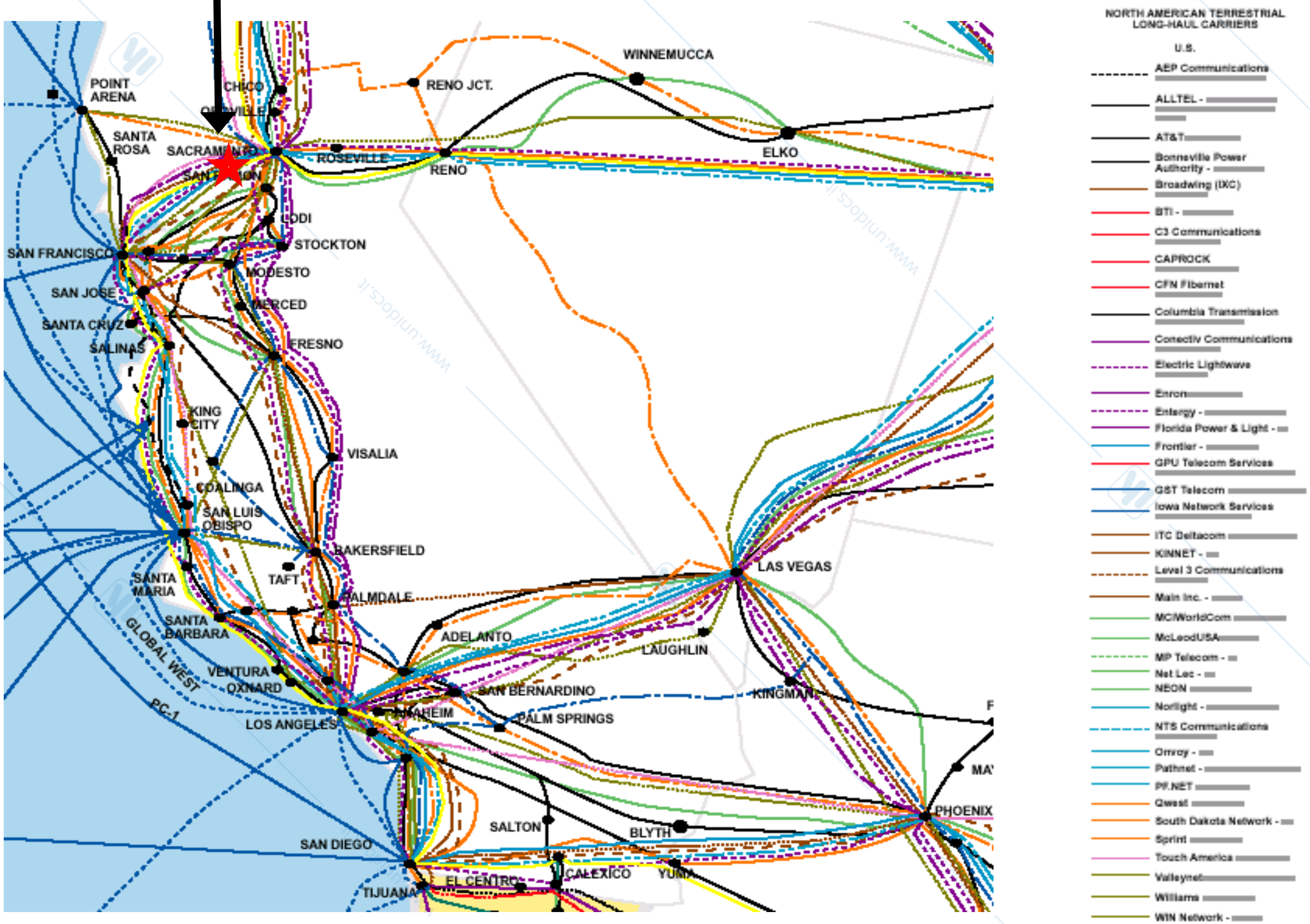
North American Fiber Routes



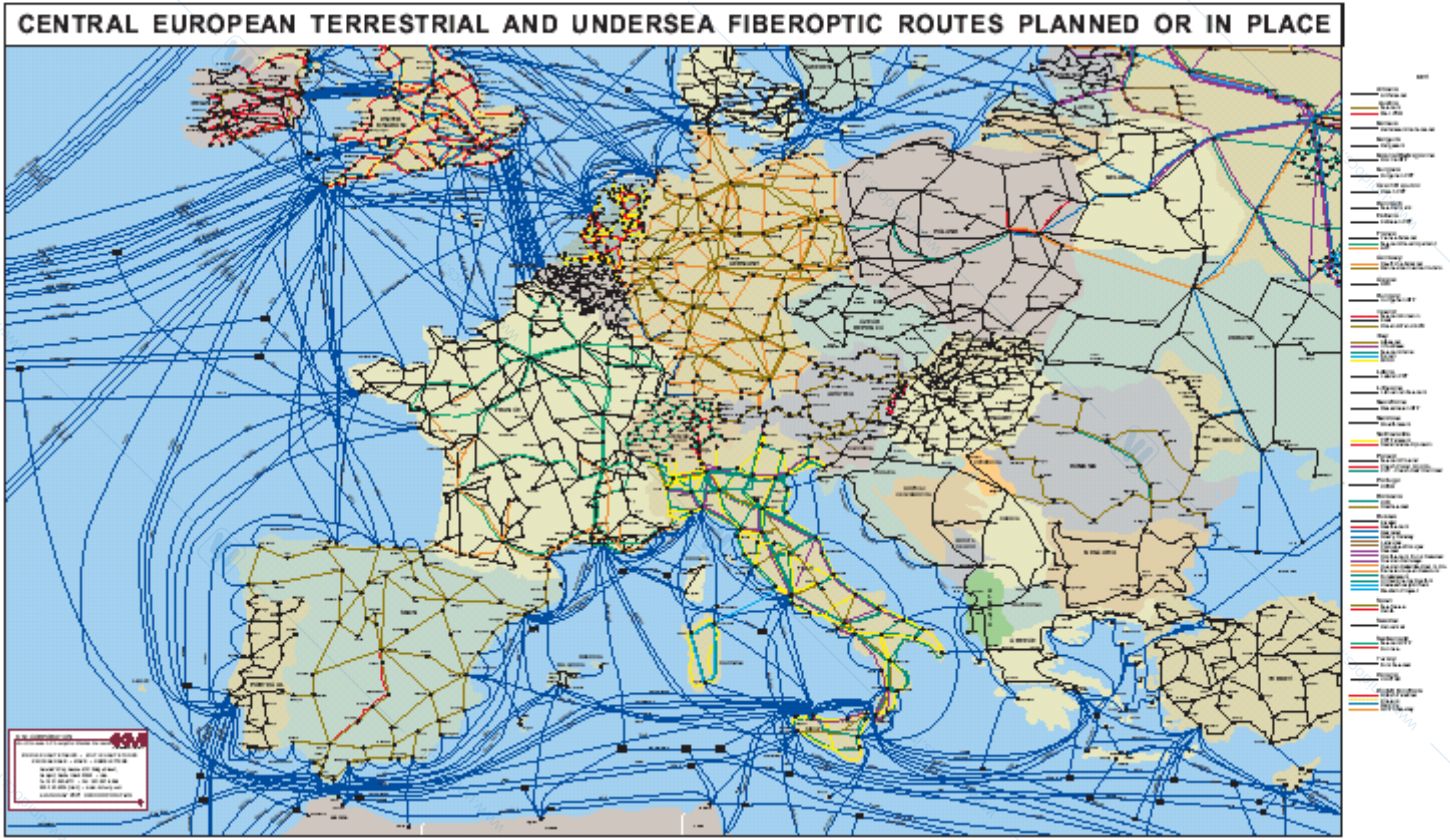
www.unidocs.it - Appunti e dispense per superare i tuoi esami universitari

California Fiber Routes

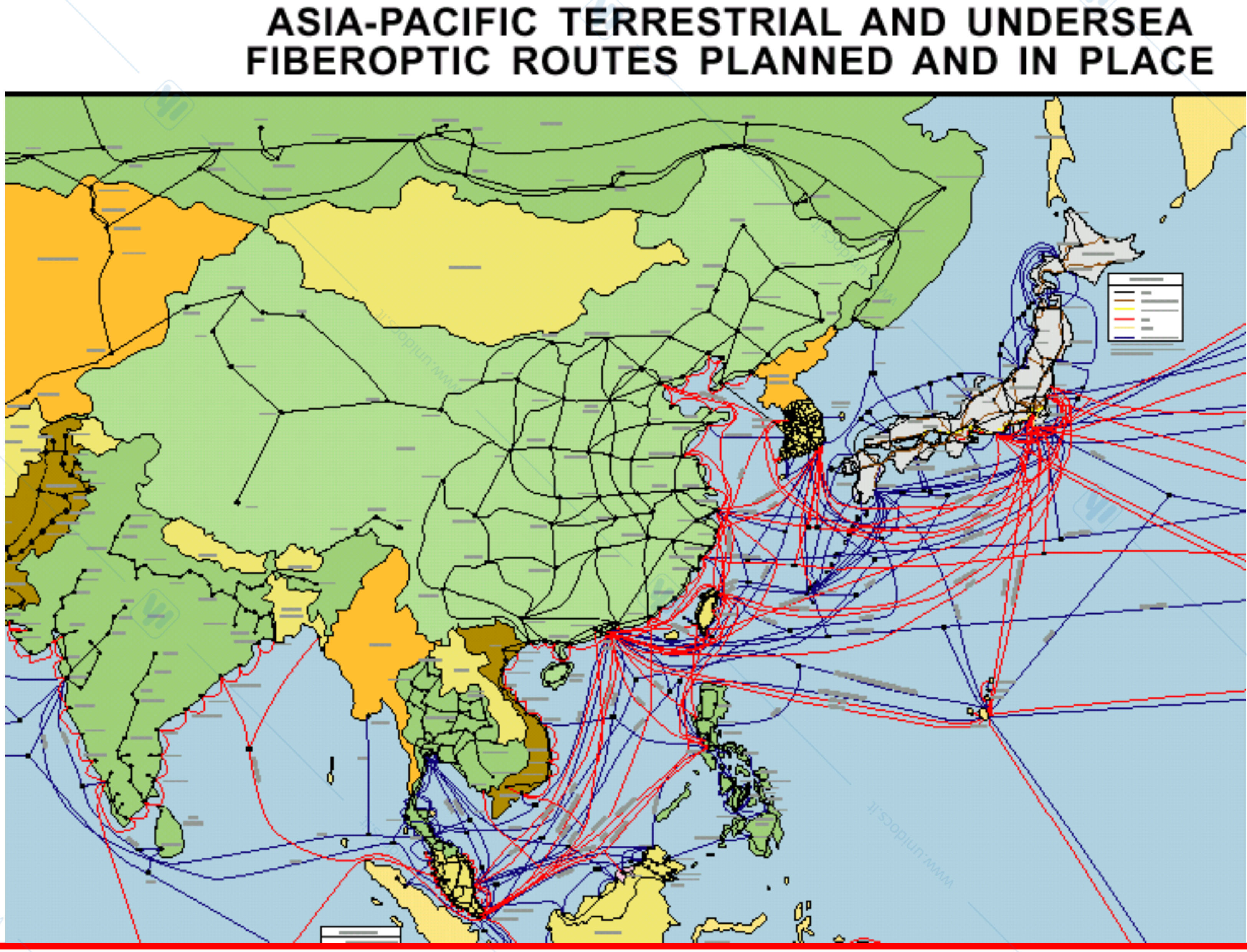
Davis (Massimo)



Central Europe Fiber Routes

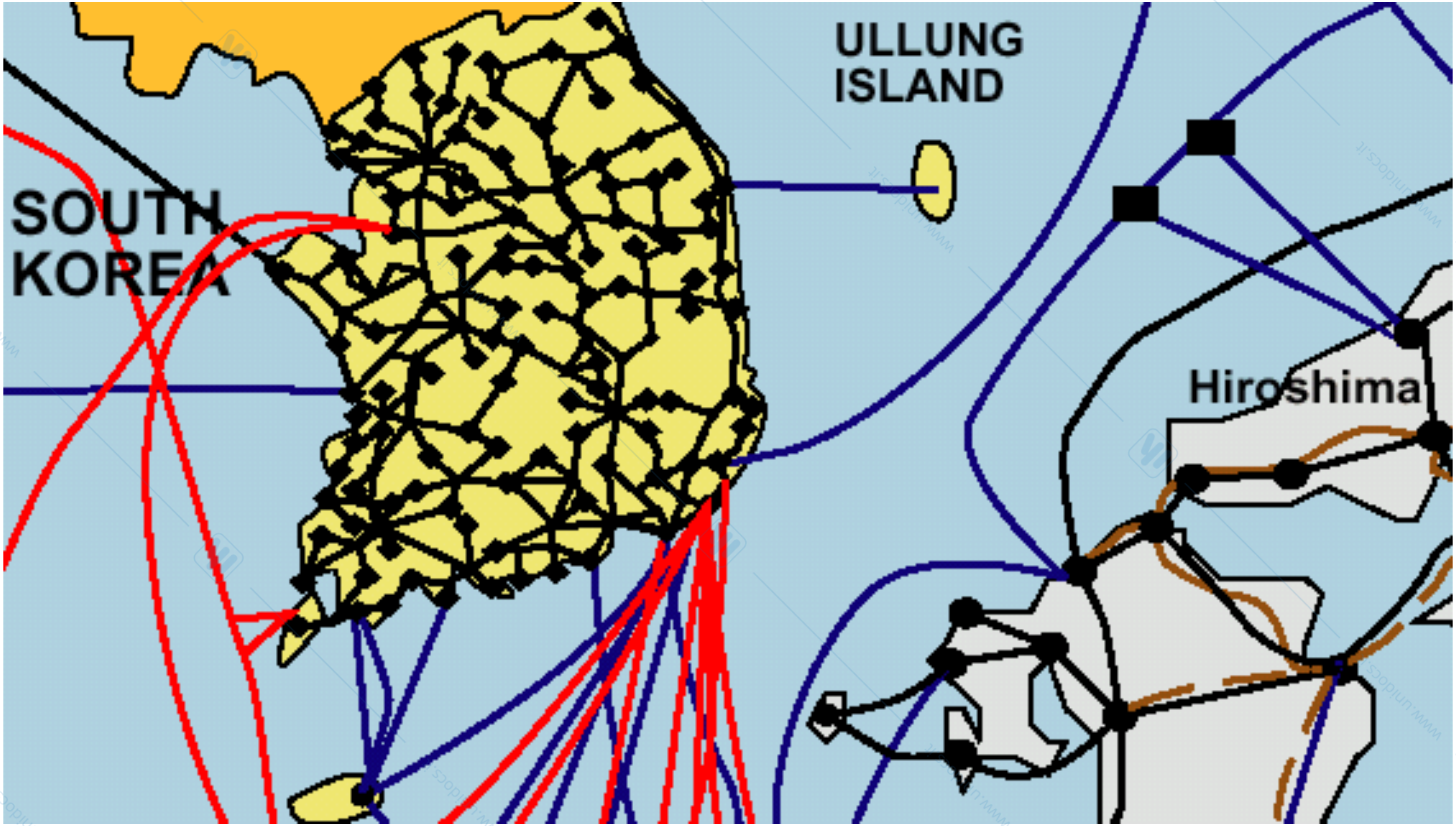


Asia-Pacific Fiber Routes

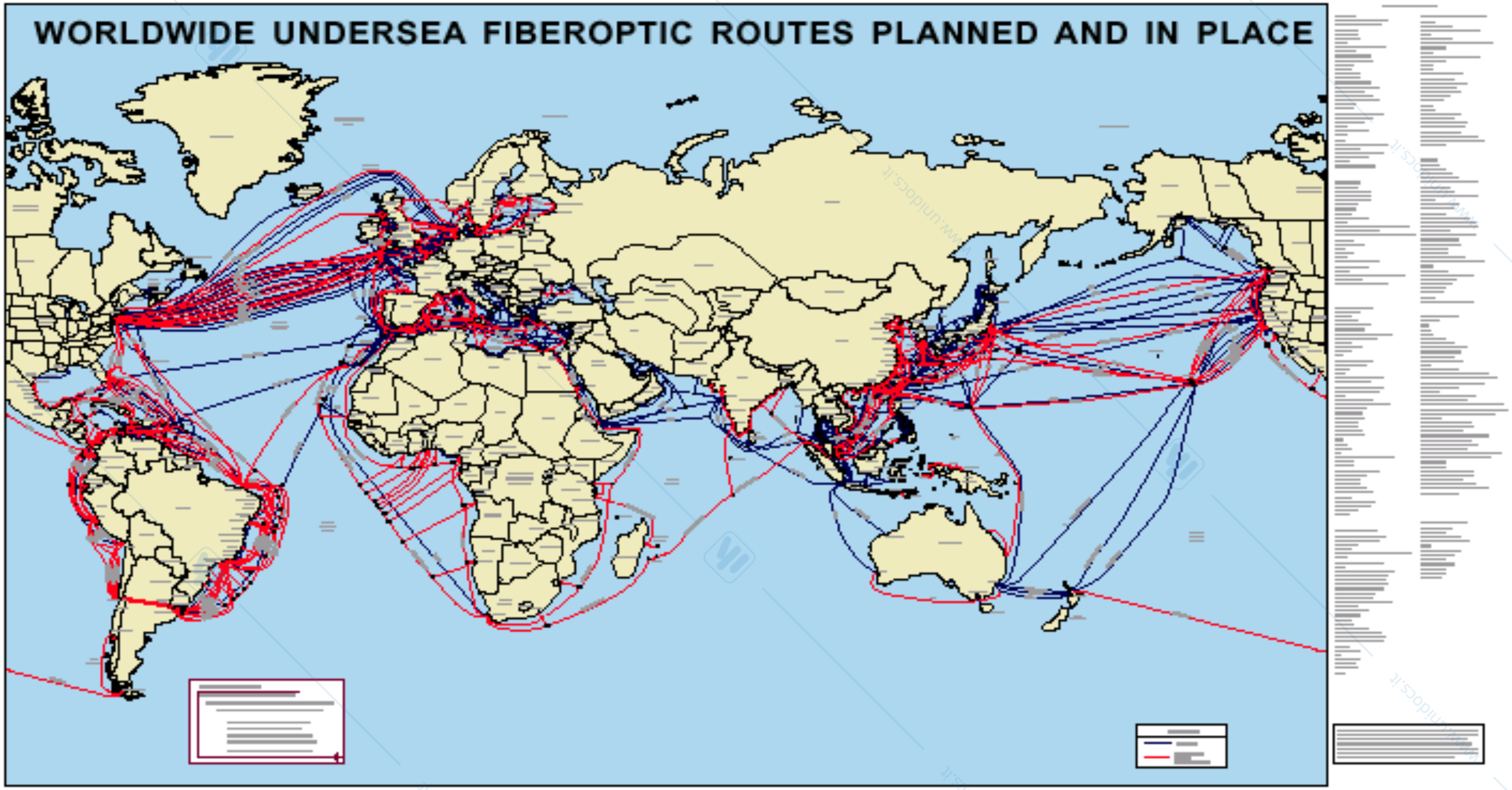


www.unidocs.it - Appunti e dispense per superare i tuoi esami universitari

South Korea Fiber Routes

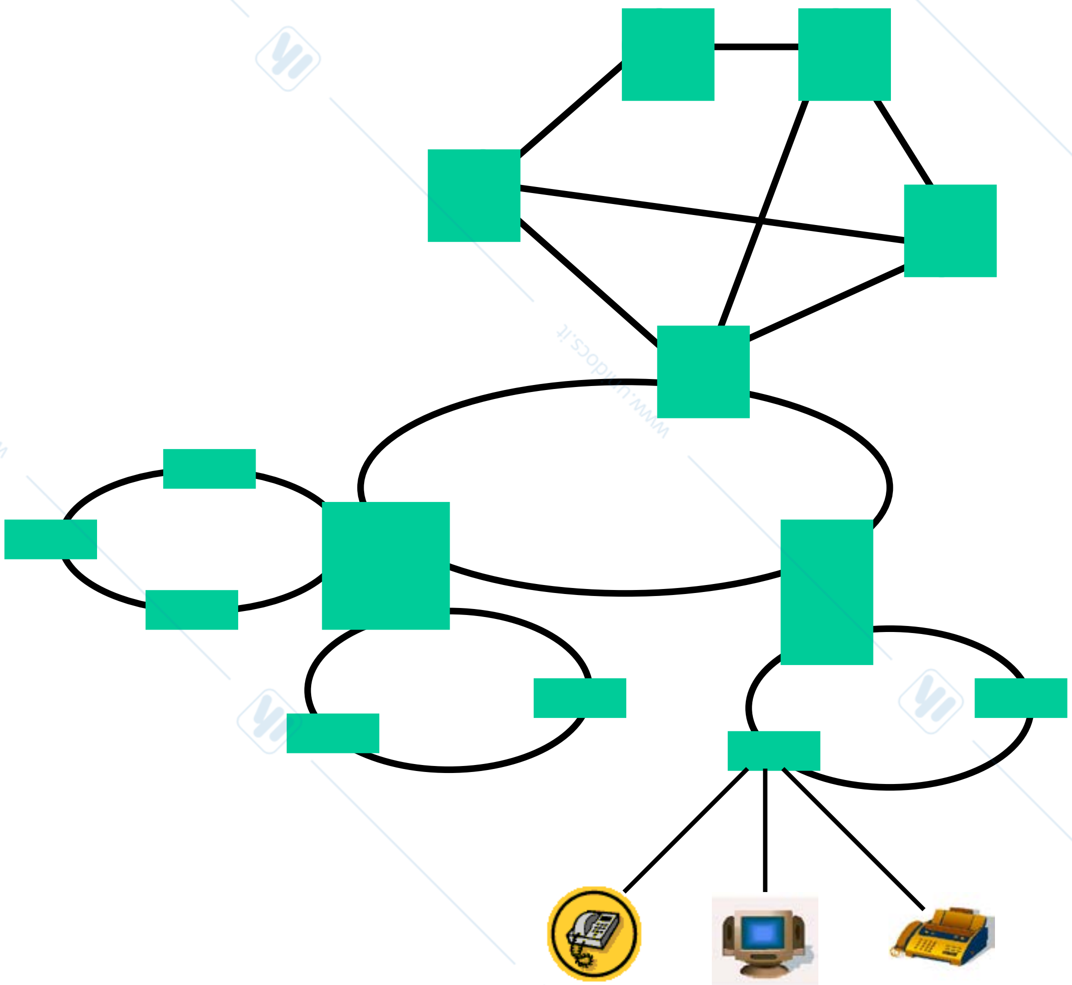


Global (Undersea) Fiber Routes



- Optics in telecom networks

Telecom Network Overview



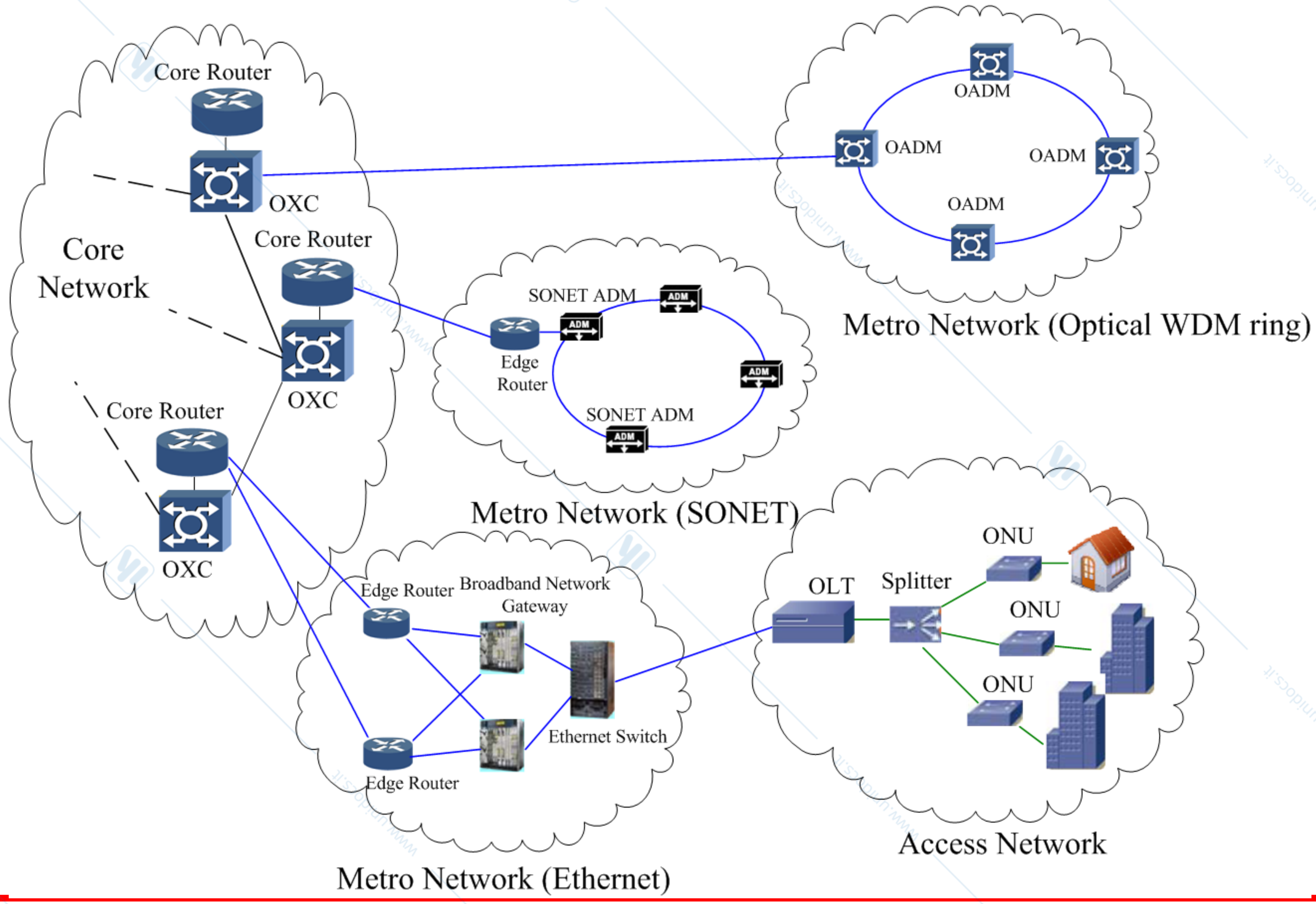
Core (or "long-haul")
- 100s-1000s km
  - Mesh
    - Mainly WDM networks (OTN)

Metro (interoffice)
- 10s of km
  - Rings
    - Sonet/SDH, GE, RPR

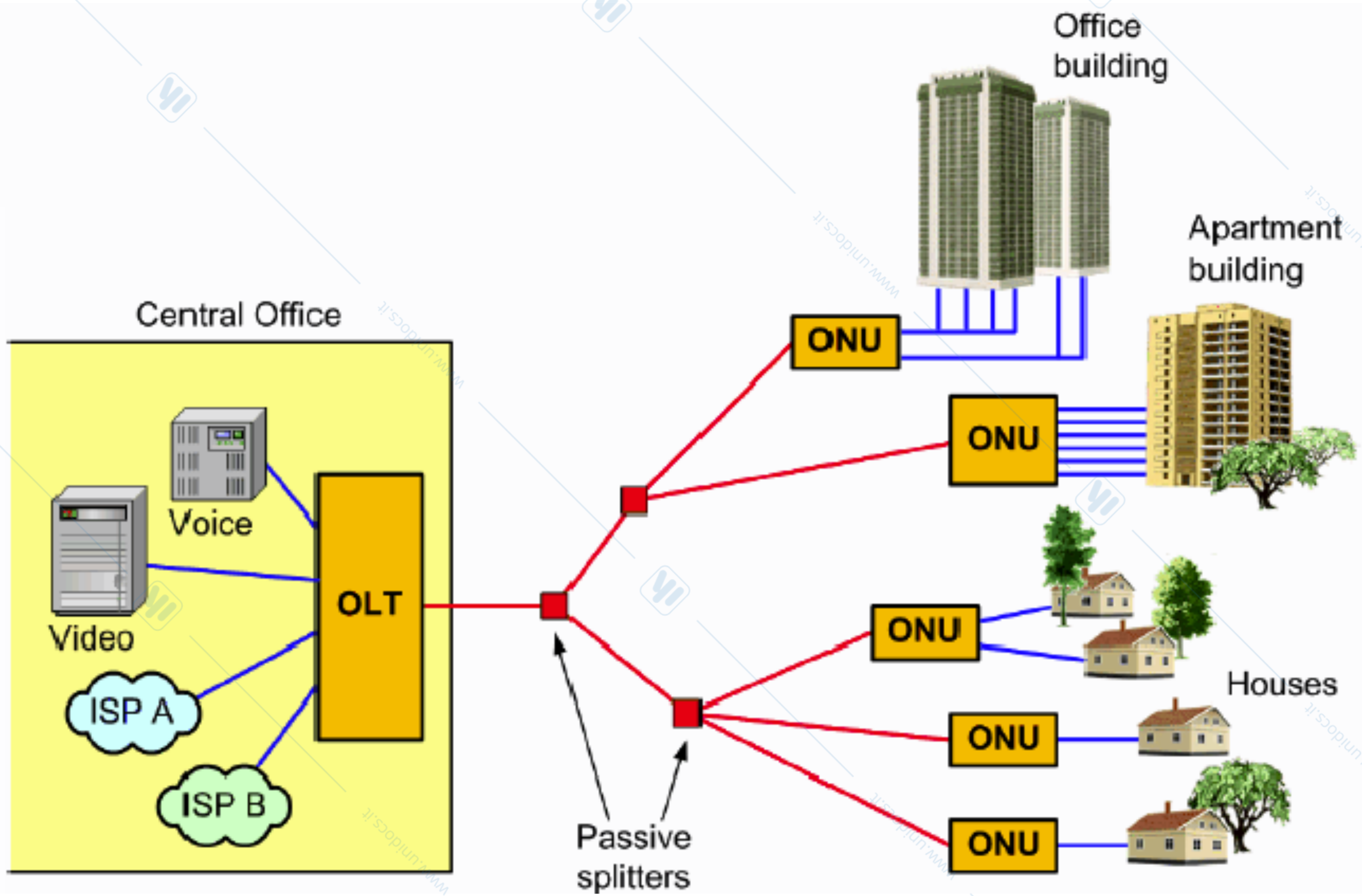
Access
- a few km
  - Hubbed rings, PONs
    - Dial-up modems, xDSL, T1/E1

Users

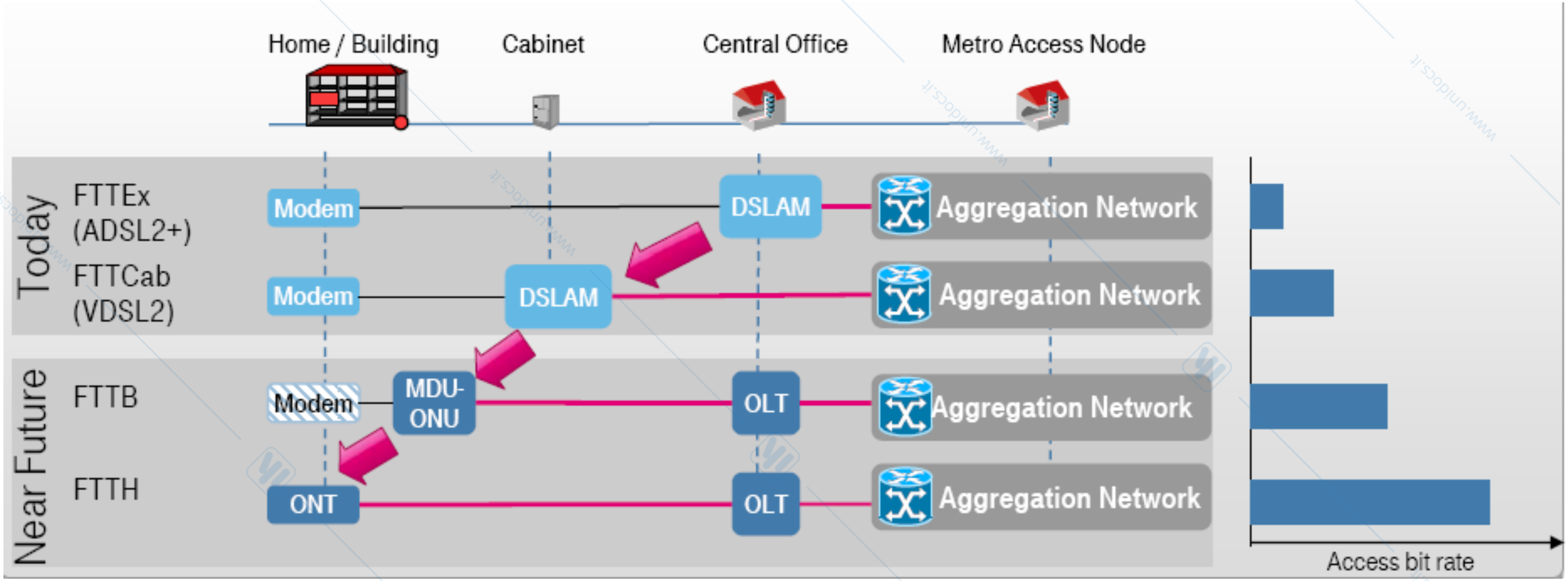
Optics in Core, Metro and Access



An Access Network (PON)



Increasing penetration of optics in access



Summarizing… What Is An Optical Network?

- It is **NOT NECESSARILY** all optical
- **Characteristics of an optical network**
  - **Transmission: optical**
  - **Switching:** could be optical, could be electronic, could be hybrid
    could be circuit, could be packet, could be burst
- **Most Used Approach Today**
  - Electronic and optical circuit switching
- **Example Utility for IP Networking**
  - Connect any two IP routers (geographically far apart) with a direct ("virtual") bandwidth pipe… of whatever capacity (1G, 10G, 100G?)
  - Increase (or decrease or delete) the capacity on demand
  - Dynamically control the "topology" connecting the IP routers
  - …

- **What is network design**

Design problems: 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, ms to mins time scale
- **NE** – intermediate problem, months time scale Exhaustion Probability
- **NP** – offline, static, dimensioning problem, 5-yr time scale

Cost (YTL, $$$)

– Different traffic types
  - Static, dynamic, scheduled, incremental...

Different design problems, different performance metrics

- Network planning
  - Optimization Metric: cost, energy, capacity
    - Note on cost: CAPEX vs OPEX!
- Traffic engineering
  - Blocking probability
    - Connection vs. Bandwidth Blocking Probability
- Network engineering
  - Upgrade time, upgrade cost, blocking , penalty, exhaustion probability, etc.…

Business model vs. Design problem

- Network operator
  - Level 3, PG&E (?)
- Service provider
  - Netflix, Google ("HyperGiants".)
- Network operator AND service provider
  - AT&T, Verizon
- Bandwidth broker
  - Many service provider, many network operators and a bandwidth broker which manages negotiation between them
    - 60 Hudson in New York, AMPATH in Miami, Palo Alto Internet Exchange (PAIX) in Palo Alto, Startap in Chicago

In the meanwhile, in Italy…

- Network operator
  - ENEL, SNAM, (Telecom)
- Service provider
  - Tiscali, Sky, Dazn
- Network operator AND service provider
  - Telecom, Fastweb
- Bandwidth broker
  - Many service provider, many network operators and a bandwidth broker which manages negotiation between them
    - E.g., https://www.mix-it.net/en/services-for-carriers/#content-1

Hyper Giants

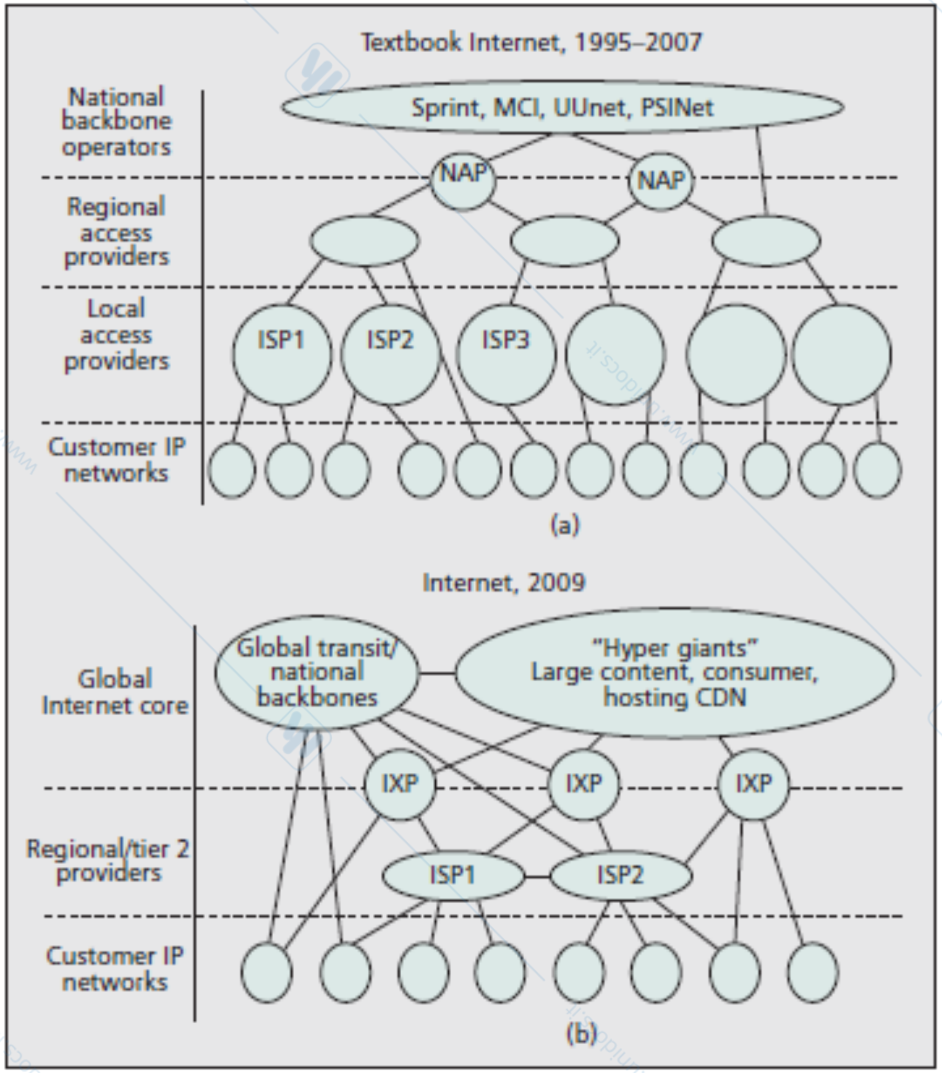


Figure 1. *Internet evolution [1]: a) 1995-2007; b) 2009.*

(a) Top ten, 2007			(b) Top ten, 2009		
Rank	Provider	%	Rank	Provider	%
1	Level(3)	5.77	1	Level(3)	9.41
2	Global Crossing	4.55	2	Global Crossing	5.7
3	ATT	3.35	3	**Google**	5.2
4	Sprint	3.2	4		
5	NTT	2.6	5		
6	Cogent	2.77	6	**Comcast**	3.12
7	Verizon	2.24	7		
8	TeliaSonera	1.82	8		
9	Savvis	1.35	9		
10	AboveNet	1.23	10		

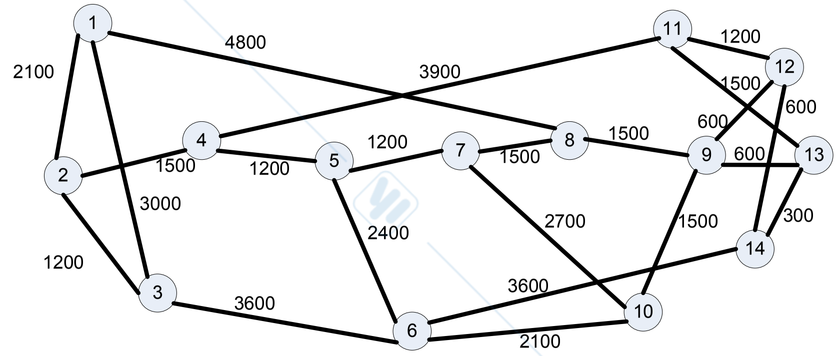
Table 1. *ATLAS top 10 public Internet bandwidth generating domains [1].*

C. Lam, et al. "Fiber optic communication technologies: What's needed for datacenter network operations", IEEE Communications Magazine 2010

From Static to Dynamic Traffic (1)

- Traditional planning: Static Traffic

Nodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	2	1	1	1	4	1	1	2	1	1	1	1	1
2	2	0	2	1	8	2	1	5	3	5	1	5	1	4
3	1	2	0	2	3	2	11	20	5	2	1	1	1	2
4	1	1	2	0	1	1	2	1	2	2	1	2	1	2
5	1	8	3	1	0	3	3	7	3	3	1	5	2	5
6	4	2	2	1	3	0	2	1	2	2	1	1	1	2
7	1	1	11	2	3	2	0	9	4	20	1	8	1	4
8	1	5	20	1	7	1	9	0	27	7	2	3	2	4
9	2	3	5	2	3	2	4	27	0	75	2	9	3	1
10	1	5	2	2	3	2	20	7	75	0	1	1	2	1
11	1	1	1	1	1	1	1	2	2	1	0	2	1	61
12	1	5	1	2	5	1	8	3	9	1	2	0	1	81
13	1	1	1	1	2	1	1	2	3	2	1	1	0	2
14	1	4	2	2	5	2	4	4	1	1	61	81	2	0



From Static to Dynamic Traffic (2)

- But traffic varies…

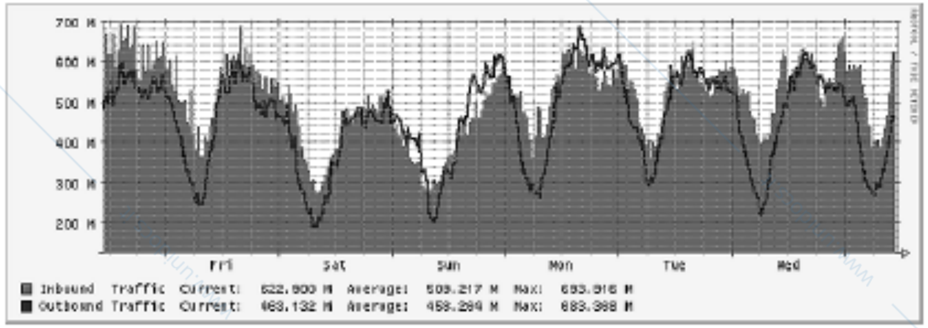
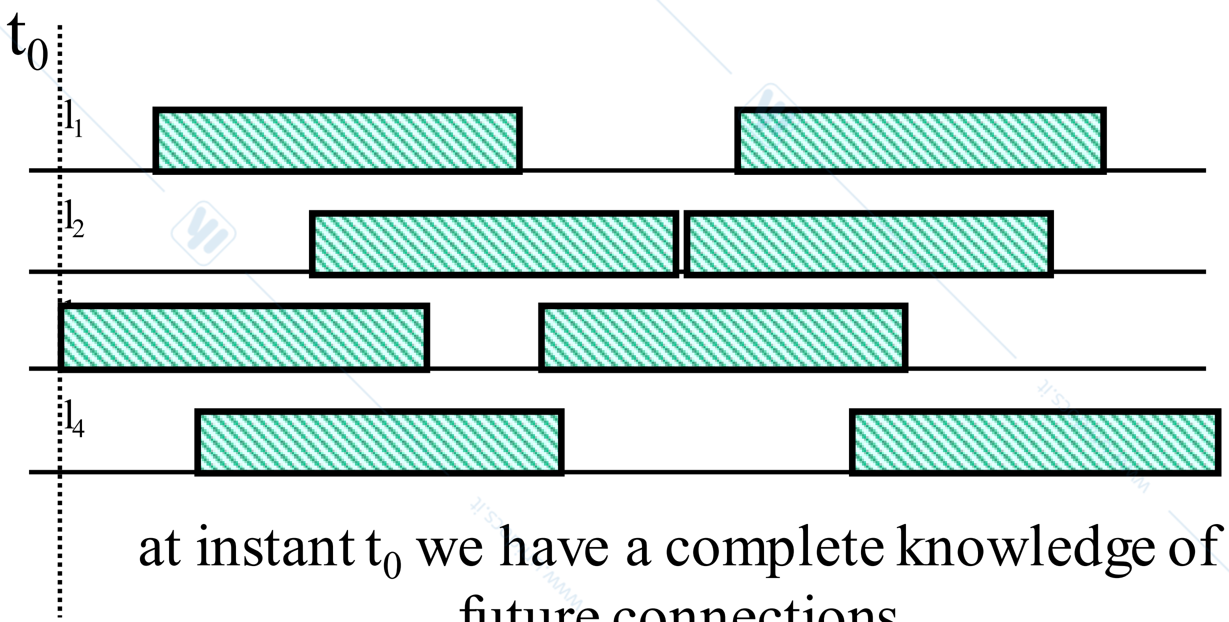


Fig. 1. Traffic on New York—Washington link of the Abilene backbone network from April 3, 2003 to April 10, 2003.

- Scheduled Traffic
  - Duration is known
  - Starting time is also given



at instant t_0 we have a complete knowledge of future connections

An example of scheduling&routing

TABLE I
EXAMPLE OF THREE SCHEDULED LIGHTPATH DEMANDS (SLDs)

No.	s	d	n	α	ω
δ_1	2	8	2	08:00	14:40
δ_2	3	7	3	11:00	13:00
δ_3	5	6	2	17:00	19:30

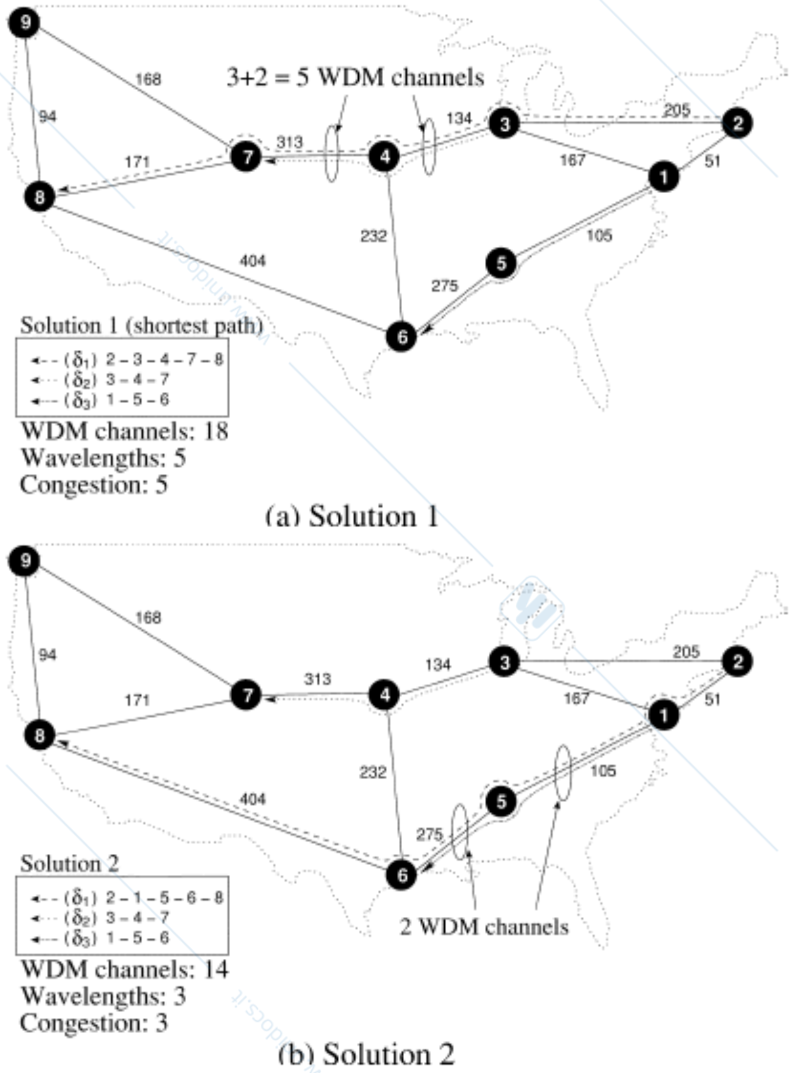
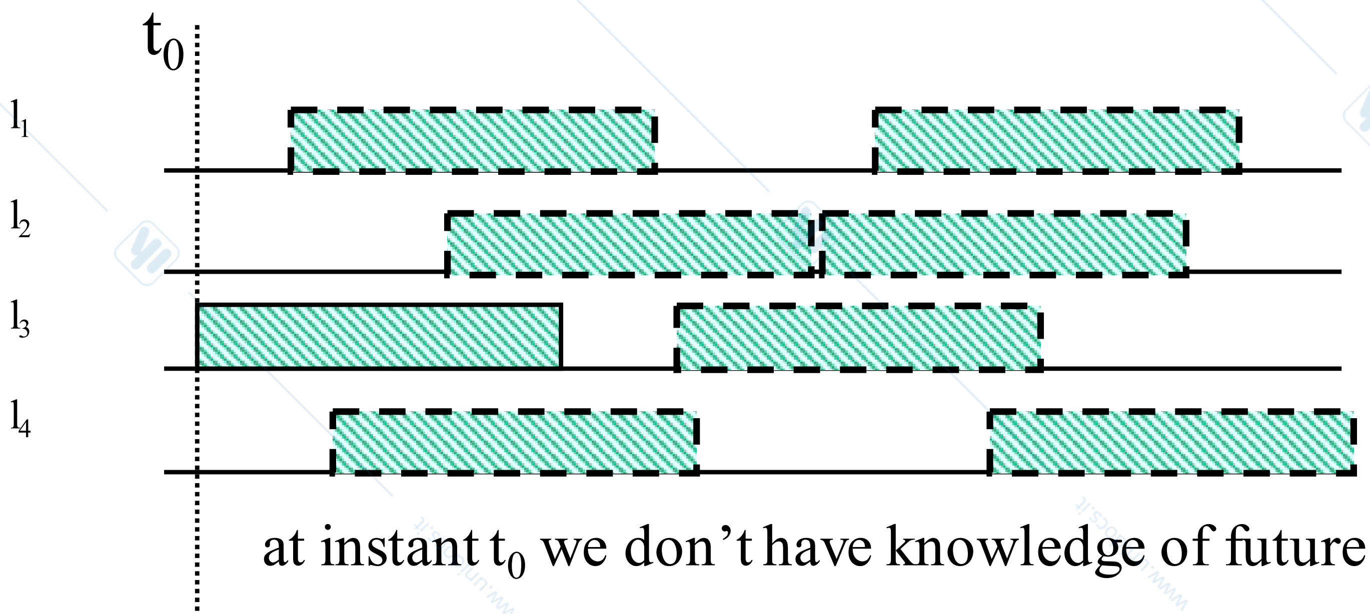


Fig. 2. Two alternative routing solutions for the SLDs of Table I.

From Static to Dynamic Traffic (3)

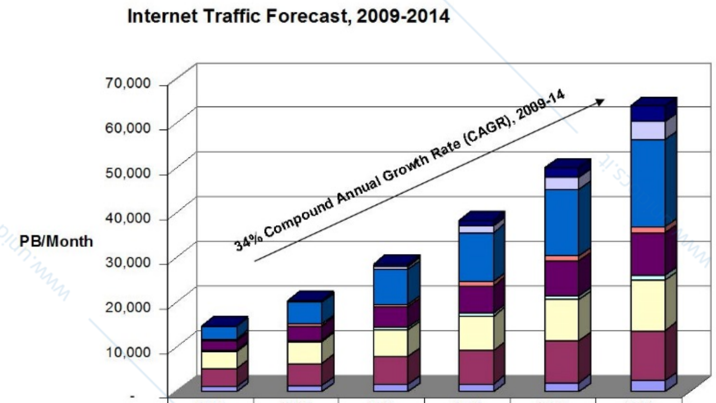
- Dynamic Traffic
  - Starting time of connections is not known in advance
  - Two options:
    - Duration Aware: connection duration is known, and can be used to improve network utilization
    - Duration Unaware



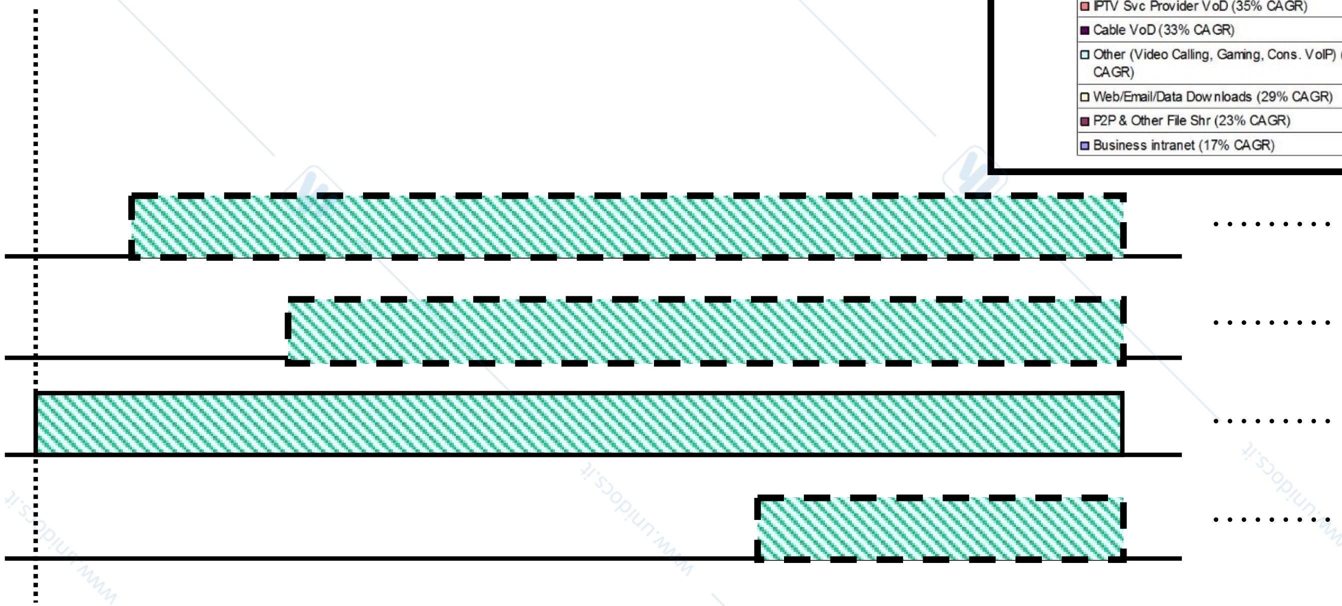
at instant t_0 we don't have knowledge of future connections,

From Scheduling to Dynamic Traffic (4)

- Incremental traffic: once connections are routed, they stay in the network



	2009	2010	2011	2012	2013	2014
Mobile Internet (108% CAGR)	91	228	538	1,158	2,132	3,528
Internet Video to TV (107% CAGR)	107	263	711	1,502	2,686	4,075
Internet Video to PC (48% CAGR)	2,776	4,725	7,718	11,026	14,838	19,468
IPTV Svc Provider VoD (35% CAGR)	329	504	714	948	1,209	1,463
Cable VoD (33% CAGR)	2,277	3,176	4,534	6,147	7,850	9,411
Other (Video Calling, Gaming, Cons. VoIP) (31% CAGR)	268	348	460	595	778	1,052
Web/Email/Data Downloads (29% CAGR)	3,701	4,795	6,095	7,617	9,281	11,240
P2P & Other File Shr (23% CAGR)	4,091	5,075	6,197	7,492	9,215	11,340
Business intranet (17% CAGR)	1,046	1,283	1,523	1,756	2,019	2,325



Analytical models and tools

Covered in the course?

- Static traffic:
  - Integer Linear Programming
  - Heuristic Optimization
- Dynamic Traffic
  - Markov chains (analytical approach)
  - Simulation
    - Switching&Routing (Prof.Maier)
- Incremental
  - Exhaustion, multi-period planning

$$\min \sum_{i=1}^{n} \hat{q}_i$$

subject to

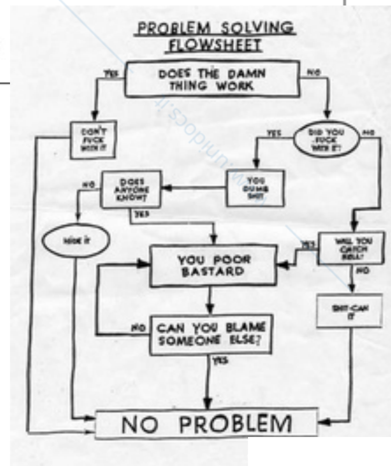
$$\hat{s}_j + \hat{q}_j \cdot w - \hat{s}_i - \hat{q}_i \cdot w \geq a'_{ij}, \qquad \forall e'_{ij} \in G'$$

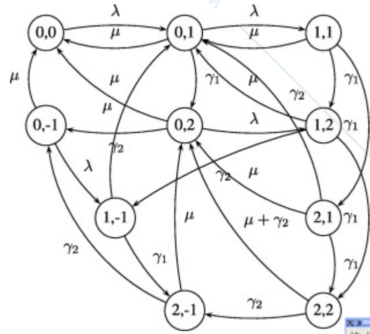
$$p_j \leq \hat{s}_i - \hat{s}_j + w \cdot \hat{x}_{ij} \leq w - p_i, \qquad \forall i, j \text{ where } i < j \text{ and } T_i, T_j \in T'$$

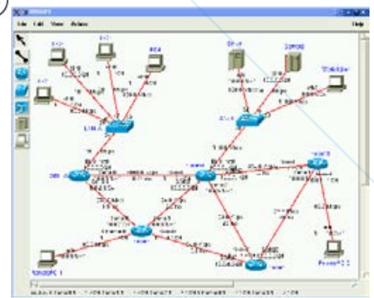
where

$$\hat{s}_i \in \langle 0, w-1 \rangle, \hat{q}_i \geq 0, \hat{x}_i \in \langle 0, 1 \rangle,$$

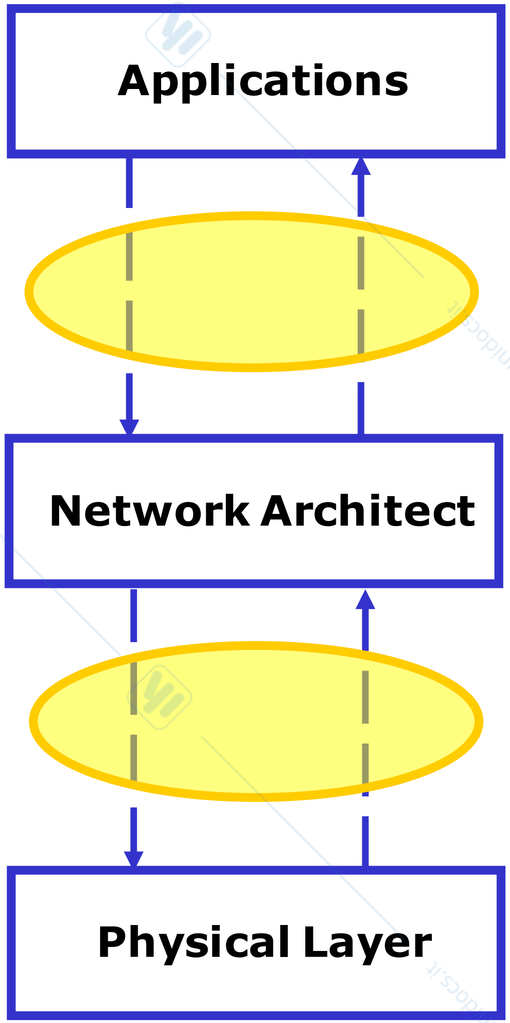
$\hat{s}_i, \hat{q}_i, \hat{x}_{ij}$ are integers.







Challenge: *cross-layer* network planning



("Customer" needs)

Differentiated Services:
Bandwidth: OC-192, OC-48, … , STS-1, VT1.5, …
Failure-Recovery Delay: The "50-ms myth!"
Network Economics: Pricing, SLA, …

(Design,TE..)

+ routing protocols that account for channel impairments

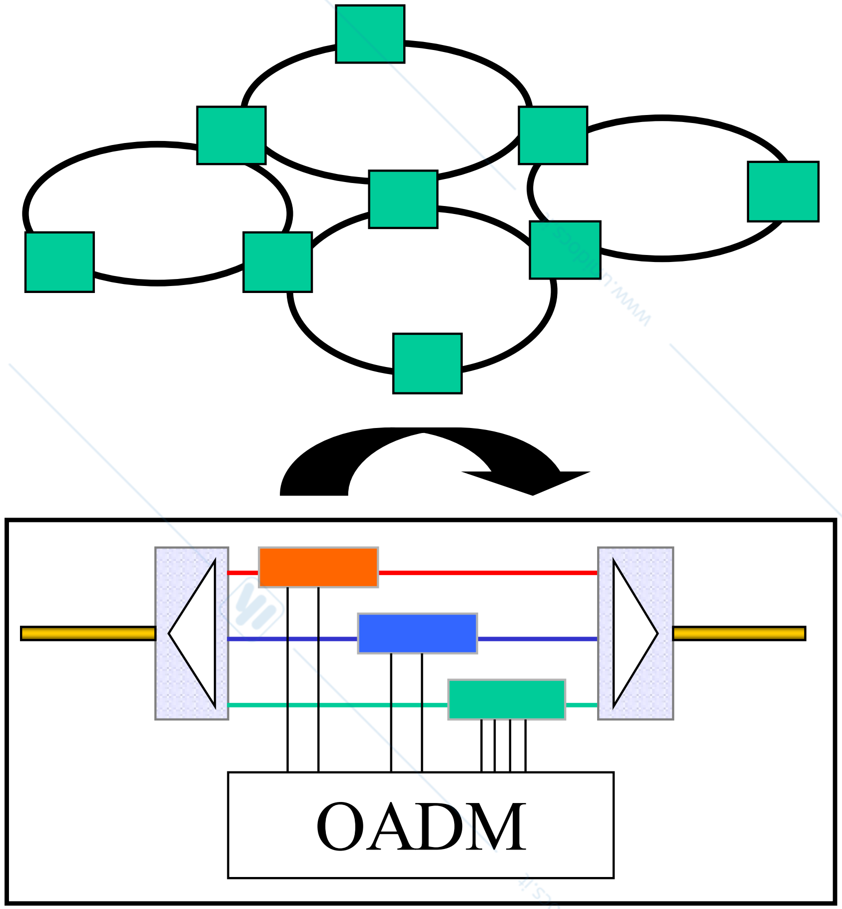
(optical/wireless channel) -- materials, devices, subsystems

Trends in future core networks

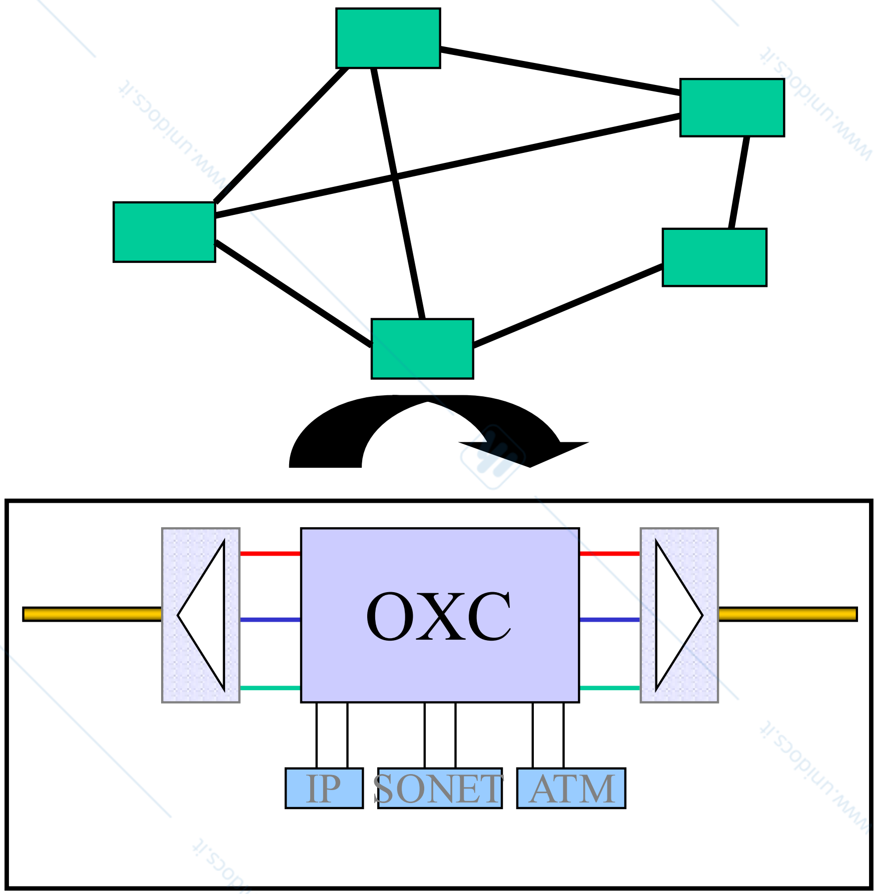
- Migration from ring to mesh
- From IPoSONEToWDM to IPoWDM
- Optical bypass
- A primer on optical equipment
  - (R-)OADM
  - OXC

Long-Haul, Backbone Network

Legacy (SONET) Net



Current trend



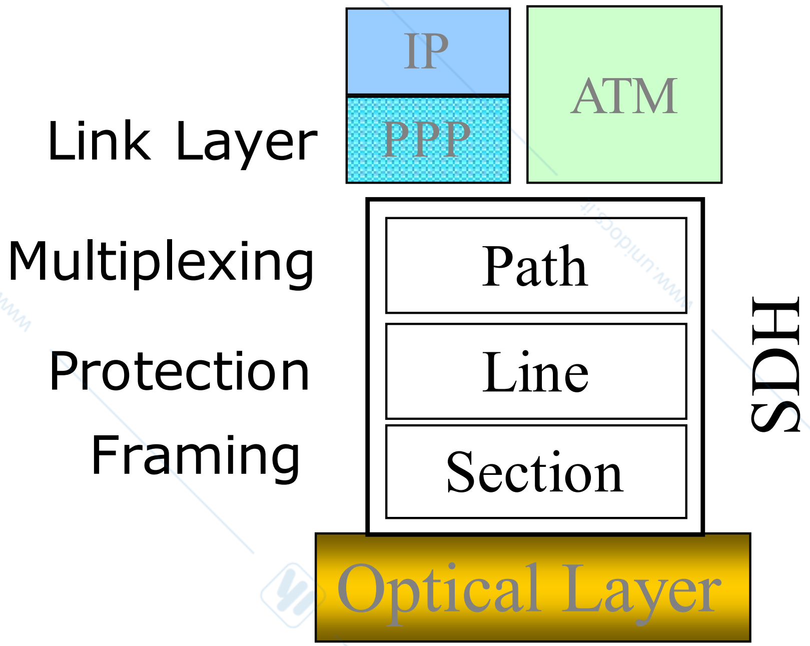
- Months to roll out new connections
- Minutes (or seconds) to set up connections

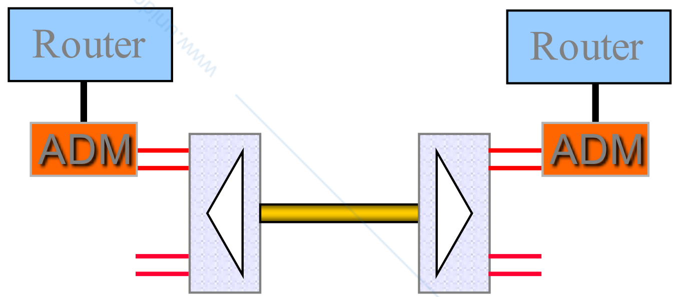
Core Network: Mesh vs. Ring

- Rings are not suitable for the core:
  - 50% capacity waste.
  - Large amount of "pass-through traffic" at inter-ring junctions… unnecessary, extra processing?
  - Need same bandwidth (and same "lambda spectrum") on all fiber segments of the ring.
  - Mesh is the natural topology for the core… that's how the fiber is laid out!

SDH/SONET-Centric View (Dying?)

IP over SDH over WDM

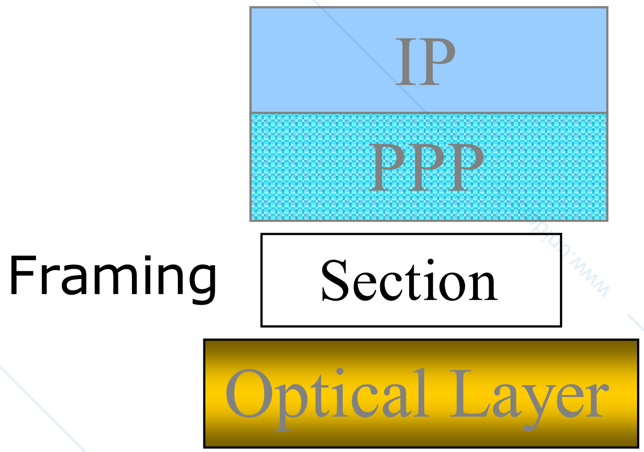


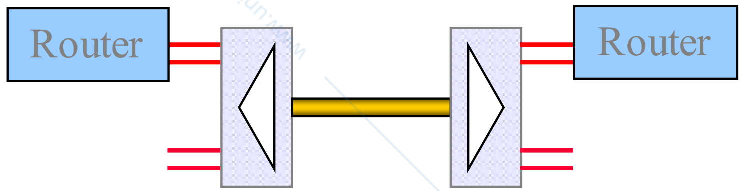


- What SDH gives:
  - Proven reliability
  - No QoS problem for voice & leased lines
  - Extensive performance monitoring

IP-Centric View

IP (over PPP) over WDM



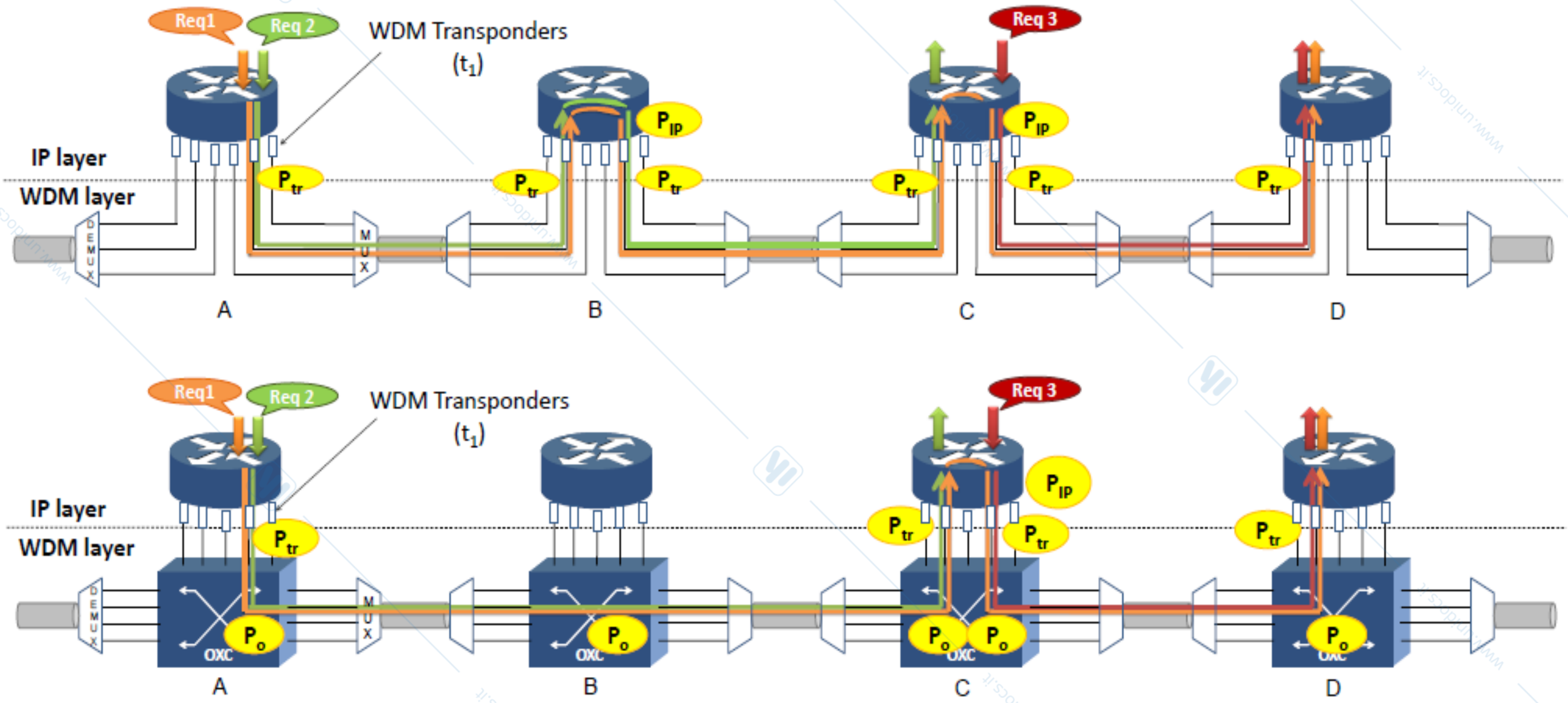


Don't need SSH (except perhaps for framing)

- Expensive
- IP can handle both voice and data
- Divide SDH functions between IP & optical layer

The concept of optical bypass

- Switching can be performed in the electronic or in the optical domain



Traceroute Example

- 2:33pm pepper (~) 27 : traceroute aland.bbn.com
- traceroute to aland.bbn.com (68.22.232.249), 30 hops max, 40 byte packets
- 1 169.237.4.254 (169.237.4.254) 6.961 ms 0.699 ms 0.448 ms
- 2 169.237.246.238 (169.237.246.238) 0.623 ms 0.661 ms 0.691 ms
- 3 area2-13-area2.ucdavis.edu (128.120.2.49) 0.926 ms 0.685 ms 0.849 ms
- 4 area2-area0.ucdavis.edu (128.120.0.133) 0.846 ms 0.642 ms 0.591 ms
- 5 area0-ucd.ucdavis.edu (128.120.0.114) 67.471 ms 67.633 ms 70.661 ms
- 6 inet-oak-isp--ucd-ge.cenic.net (137.164.24.233) 7.581 ms 8.460 ms 11.830 ms
- 7 f5.ba01.b003070-1.sfo01.atlas.cogentco.com (38.112.6.225) 73.018 ms 65.948 ms 55.990 ms
- 8 p10-0.core01.sjc03.atlas.cogentco.com (66.28.4.133) 69.680 ms 53.346 ms 74.431 ms
- 9 eq2-g4-2-1.eqsjca.sbcglobal.net (151.164.249.185) 70.071 ms 83.845 ms 82.674 ms
- 10 ex1-p9-0.eqsjca.sbcglobal.net (151.164.191.201) 71.123 ms 65.604 ms 64.093 ms
- 11 bb1-p6-0.crsfca.sbcglobal.net (151.164.41.9) 71.285 ms 68.963 ms 68.596 ms
- 12 core1-p4-0.crsfca.sbcglobal.net (151.164.240.133) 136.819 ms 182.120 ms 217.642 ms
- 13 core1-p5-0.crskut.sbcglobal.net (151.164.42.11) 95.375 ms 63.709 ms 71.437 ms
- 14 core1-p2-0.crdnco.sbcglobal.net (151.164.243.242) 102.403 ms 71.730 ms 91.980 ms
- 15 core1-p3-0.crkcmo.sbcglobal.net (151.164.188.34) 84.839 ms 67.509 ms 62.889 ms
- 16 core2-p11-0.crchil.sbcglobal.net (151.164.240.118) 80.109 ms 101.998 ms 82.066 ms
- 17 bb2-p5-0.sfldmi.ameritech.net (151.164.242.130) 76.808 ms 65.863 ms 74.787 ms
- 18 bb1-p15-0.sfldmi.ameritech.net (151.164.40.181) 74.925 ms 108.616 ms 103.503 ms
- 19 bb1-p3-0.lgtpmi.sbcglobal.net (151.164.40.101) 112.321 ms 96.089 ms 80.460 ms
- 20 dist1-vlan30.lgtpmi.ameritech.net (65.42.245.97) 92.278 ms 72.988 ms 78.367 ms
- 21 rback3-g1-0.lgtpmi.sbcglobal.net (65.42.245.230) 73.354 ms 83.651 ms 77.640 ms
- 22 adsl-68-22-232-254.dsl.lgtpmi.ameritech.net (68.22.232.254) 86.725 ms 100.490 ms 90.429 ms
- 23 adsl-68-22-232-249.dsl.lgtpmi.ameritech.net (68.22.232.249) 85.333 ms 94.014 ms 90.203 ms
- 2:41pm pepper (~) 28 :

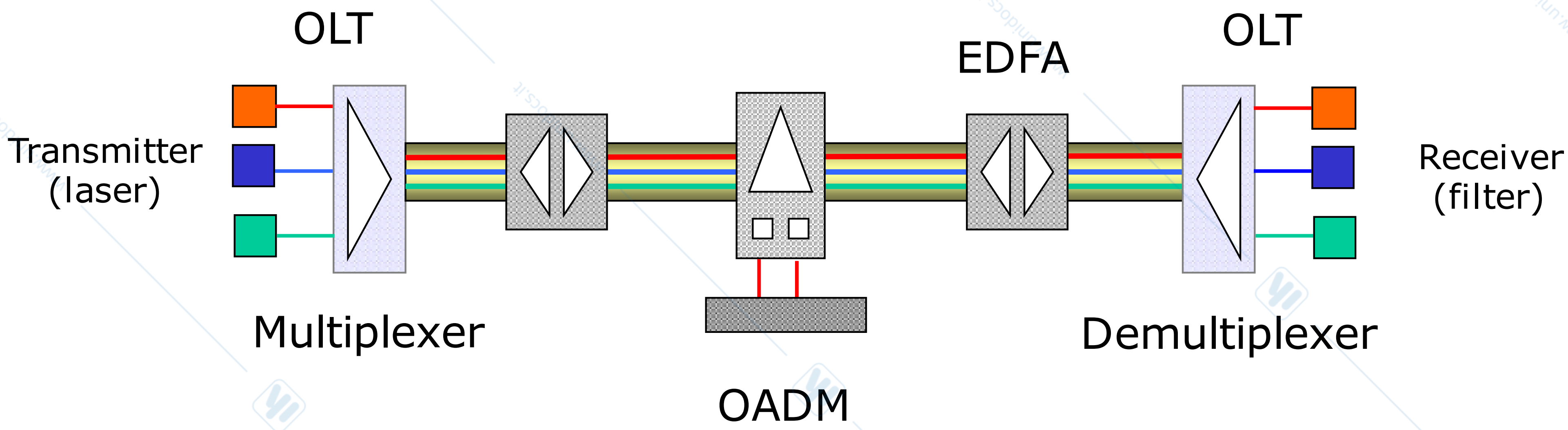
"Dial" for bandwidth

"Resolve the perpetual Internet backbone bottleneck problems by providing a scalable, cost-effective solution that empowers the service providers to offer a range of new, diverse, just-in-time services."

- IP Routers (and other edge devices) should be able to "dial for bandwidth" (OC-192, OC-48, …) on demand in real time.

Optical network components

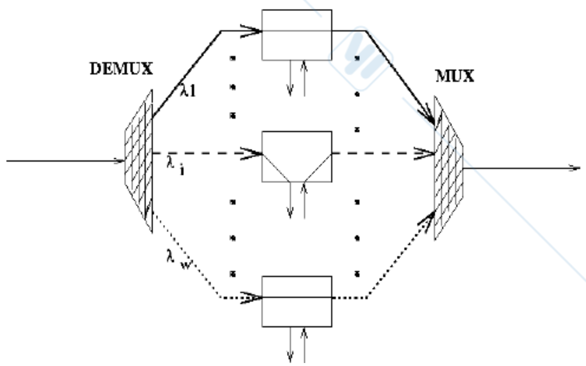
Optical Transmission Components

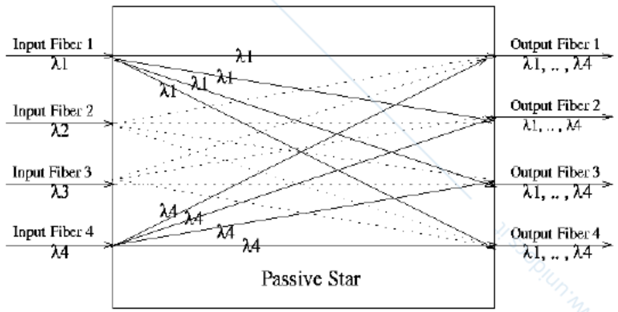


Enabling Optical Technologies

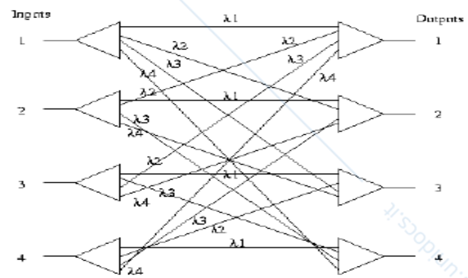
- Optical Line Terminal (OLT) (a.k.a. DWDM)
  - Transmitter/Receiver + Mux/Demux
  - Point-to-point application
- Optical Add-Drop Multiplexer (OADM)
  - Add/drop a small number of wavelengths
  - Pass most wavelengths through
- Optical Crossconnect (OXC)
  - Flexible connectivity of wavelengths between OLTs and OADMs (wavelength switching)
  - Mesh protection
- Erbium-Doped Fiber Amplifier (EDFA)

Optical switching components

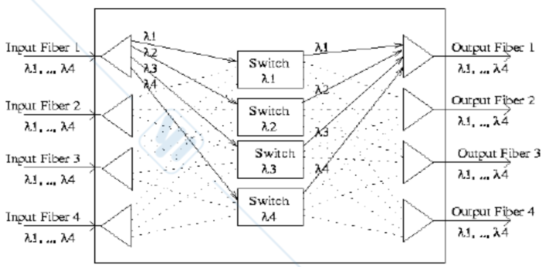




- ▹ $N \times N$ star can route N simultaneous connections, all in *broadcast* mode



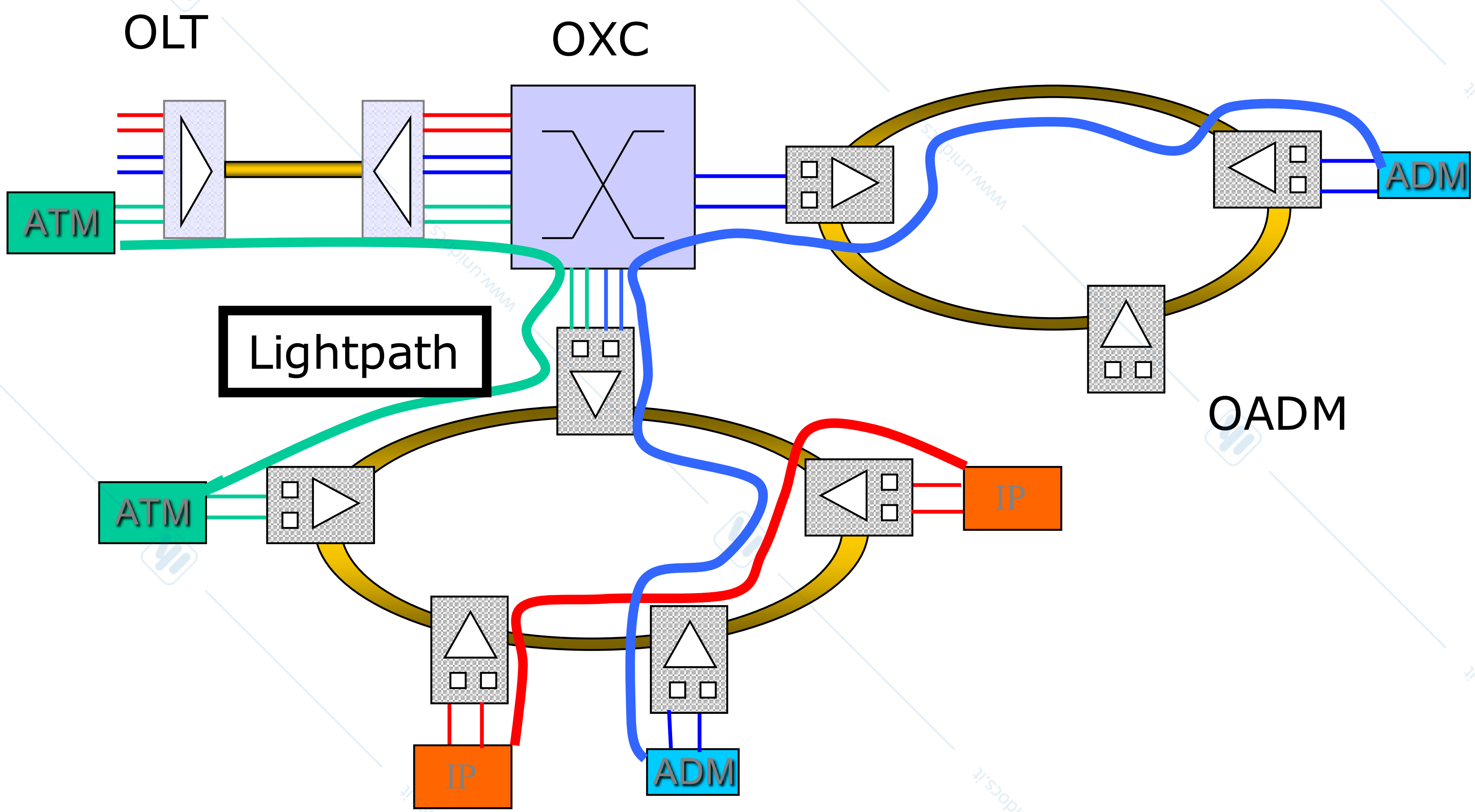
- ▹ $N \times N$ passive router can route N^2 simultaneous connections
- ▹ *Fixed routing matrix (no broadcast)*



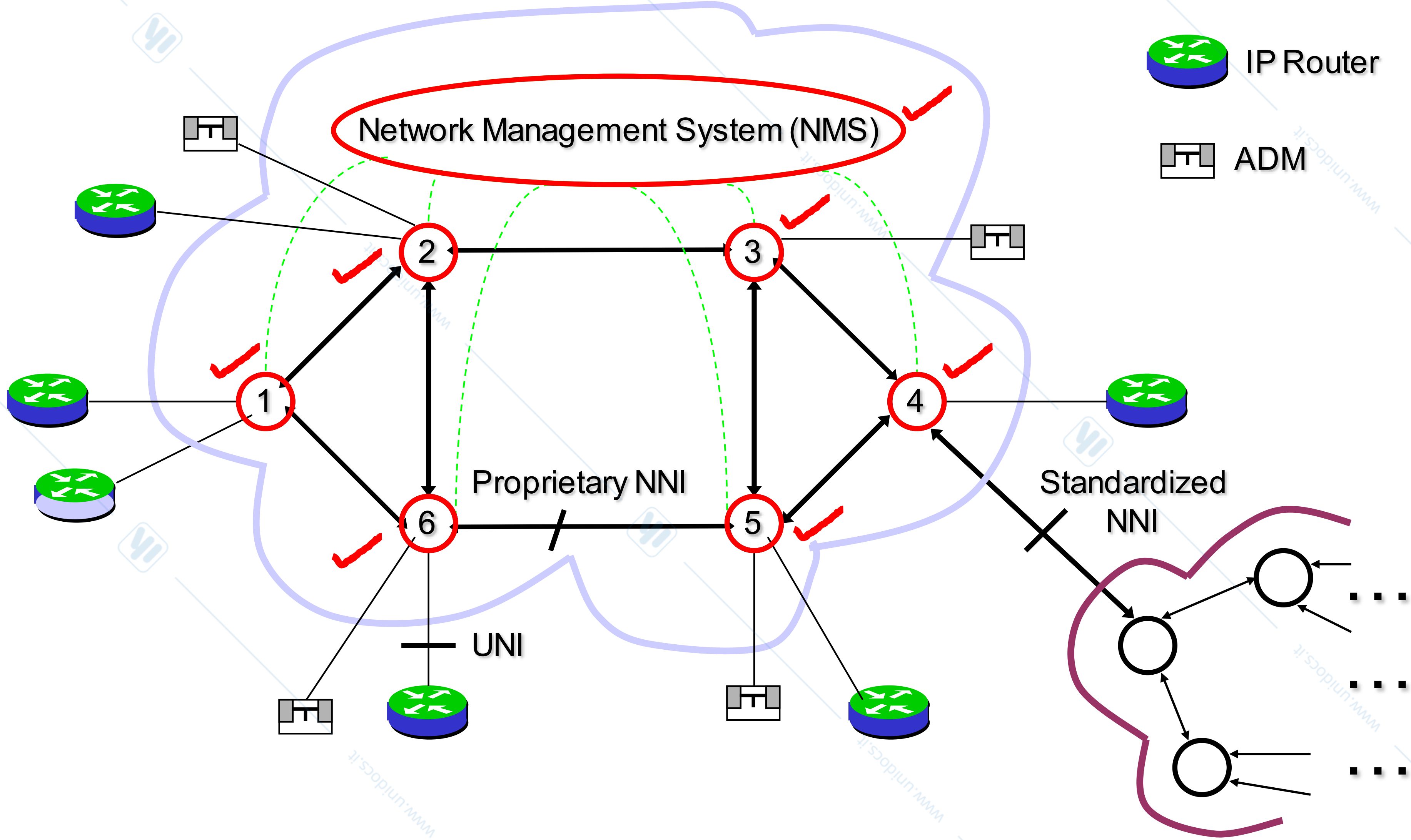
- ▹ $N \times N$ active switch can route N^2 simultaneous connections (like passive router)
- ▹ But *routing matrix is reconfigurable*
- ▹ Fault tolerance is an issue

END

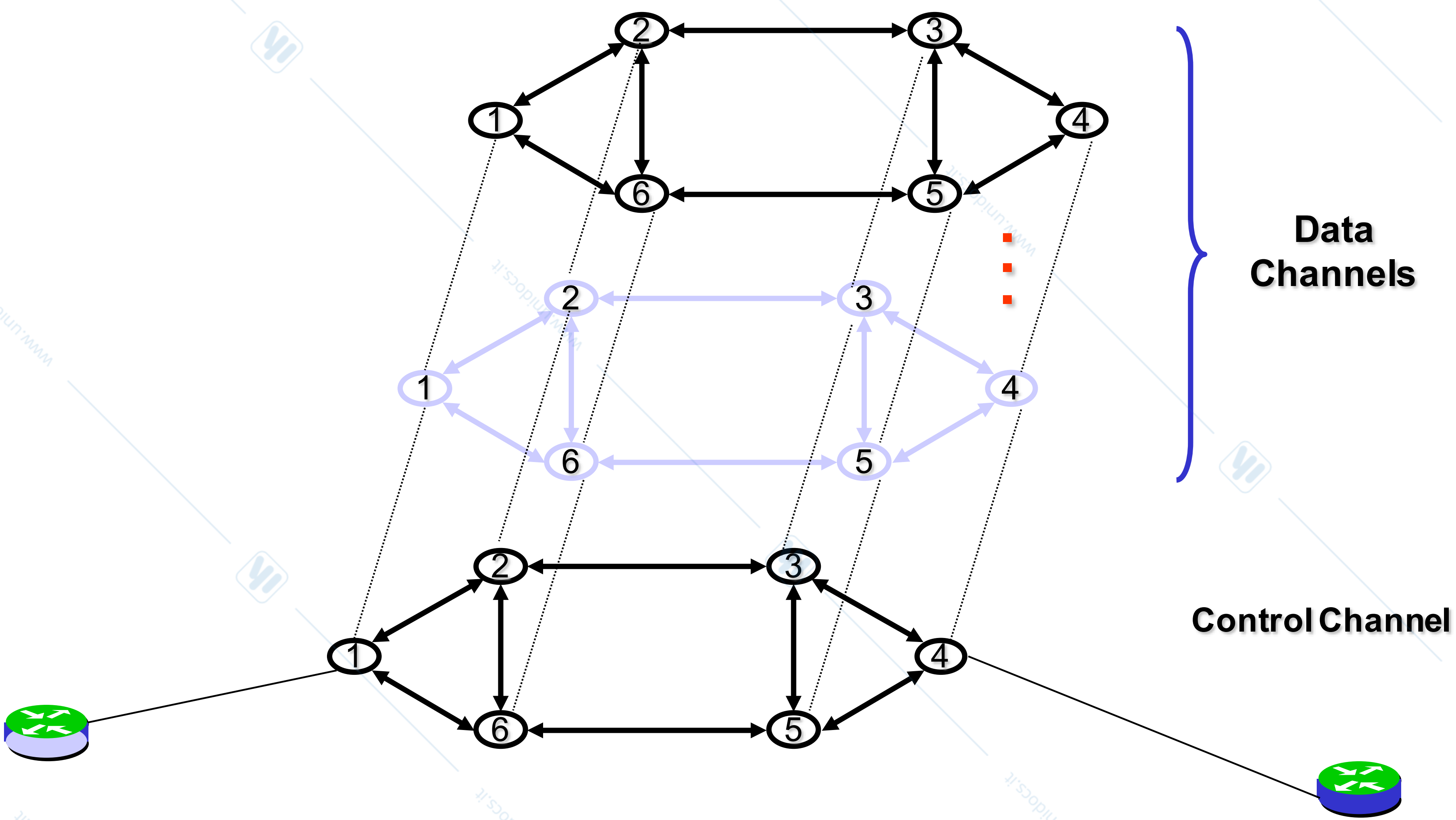
WDM Network: A Complete Picture



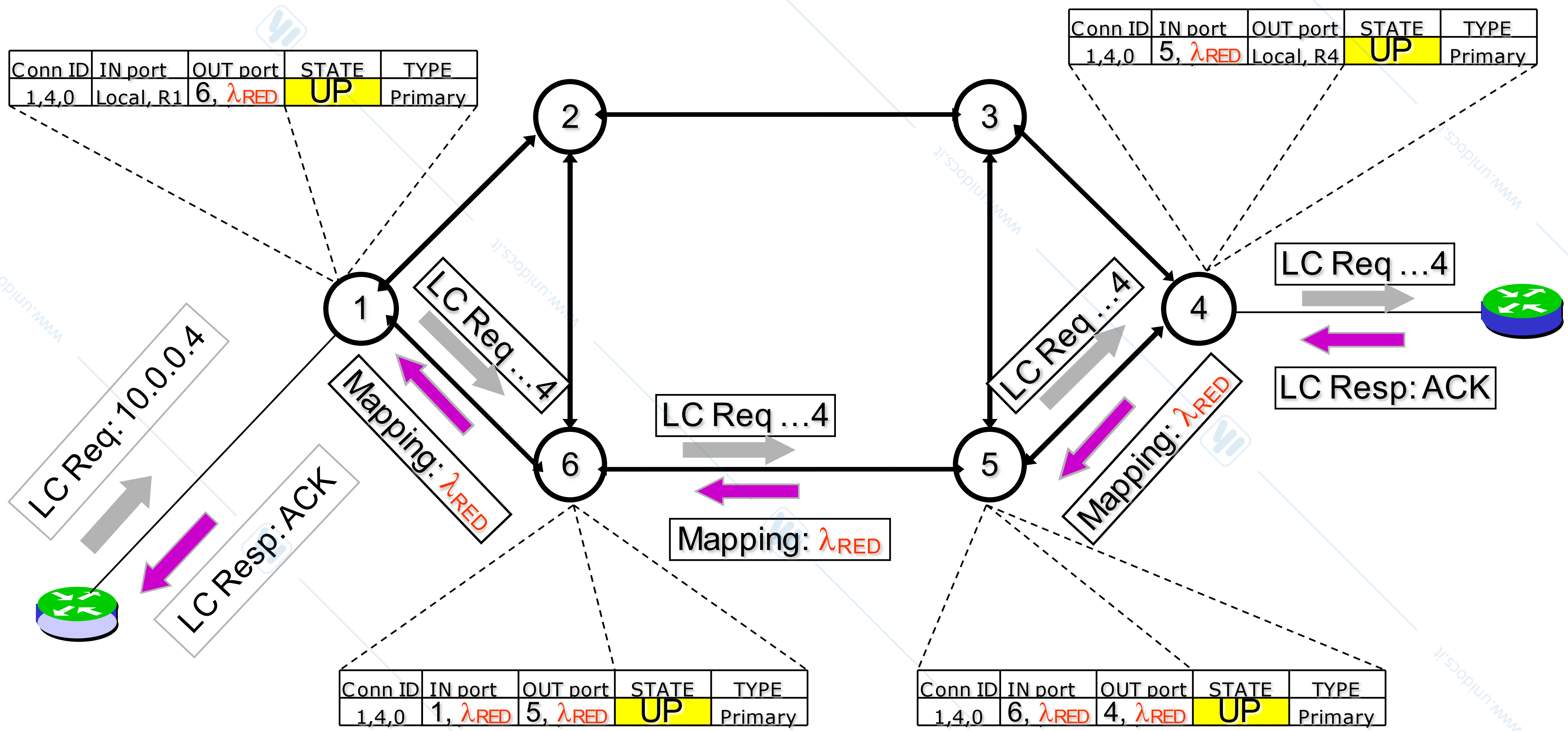
An Example Network



Wavelength "Layers"

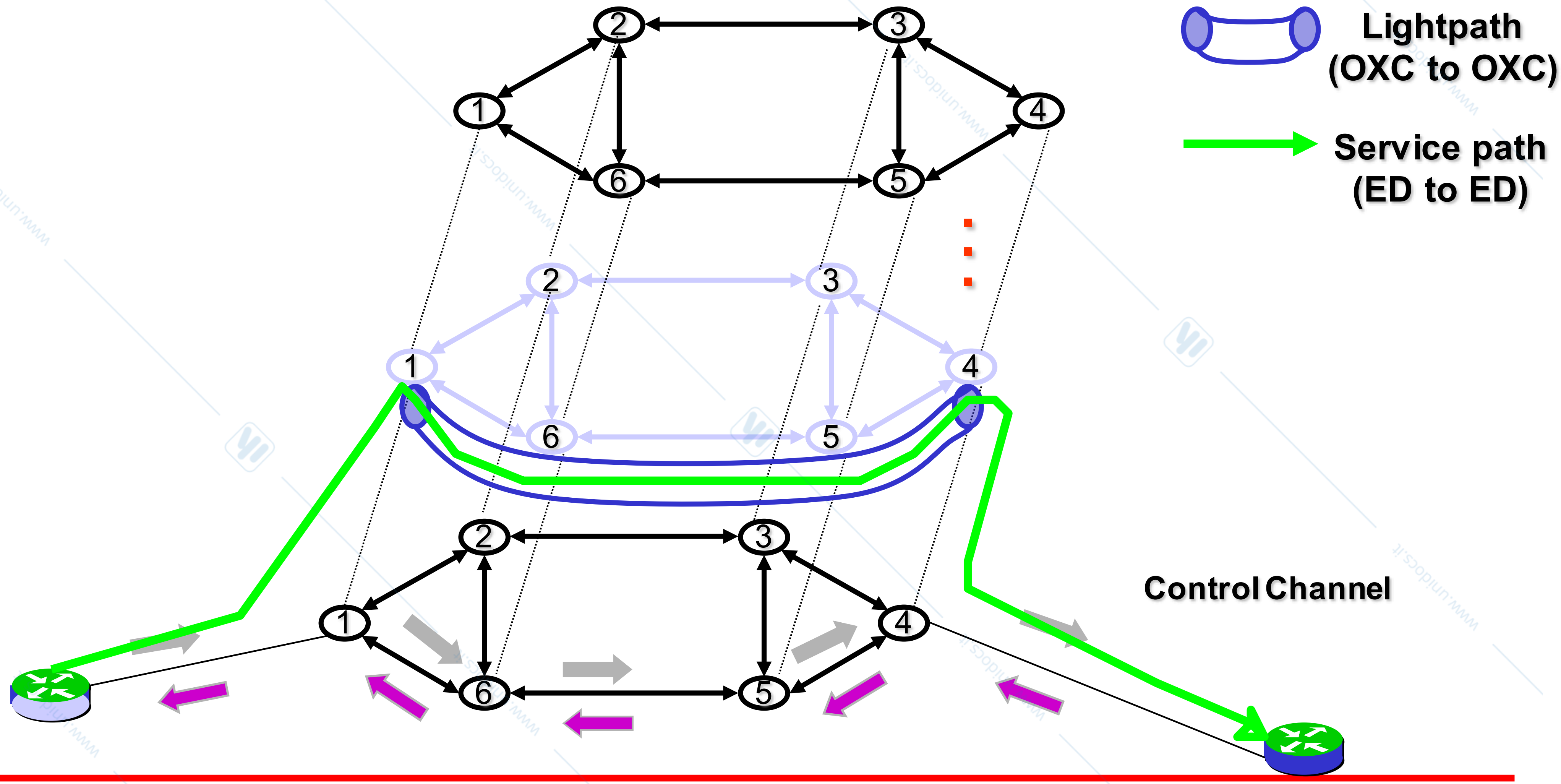


Call Setup



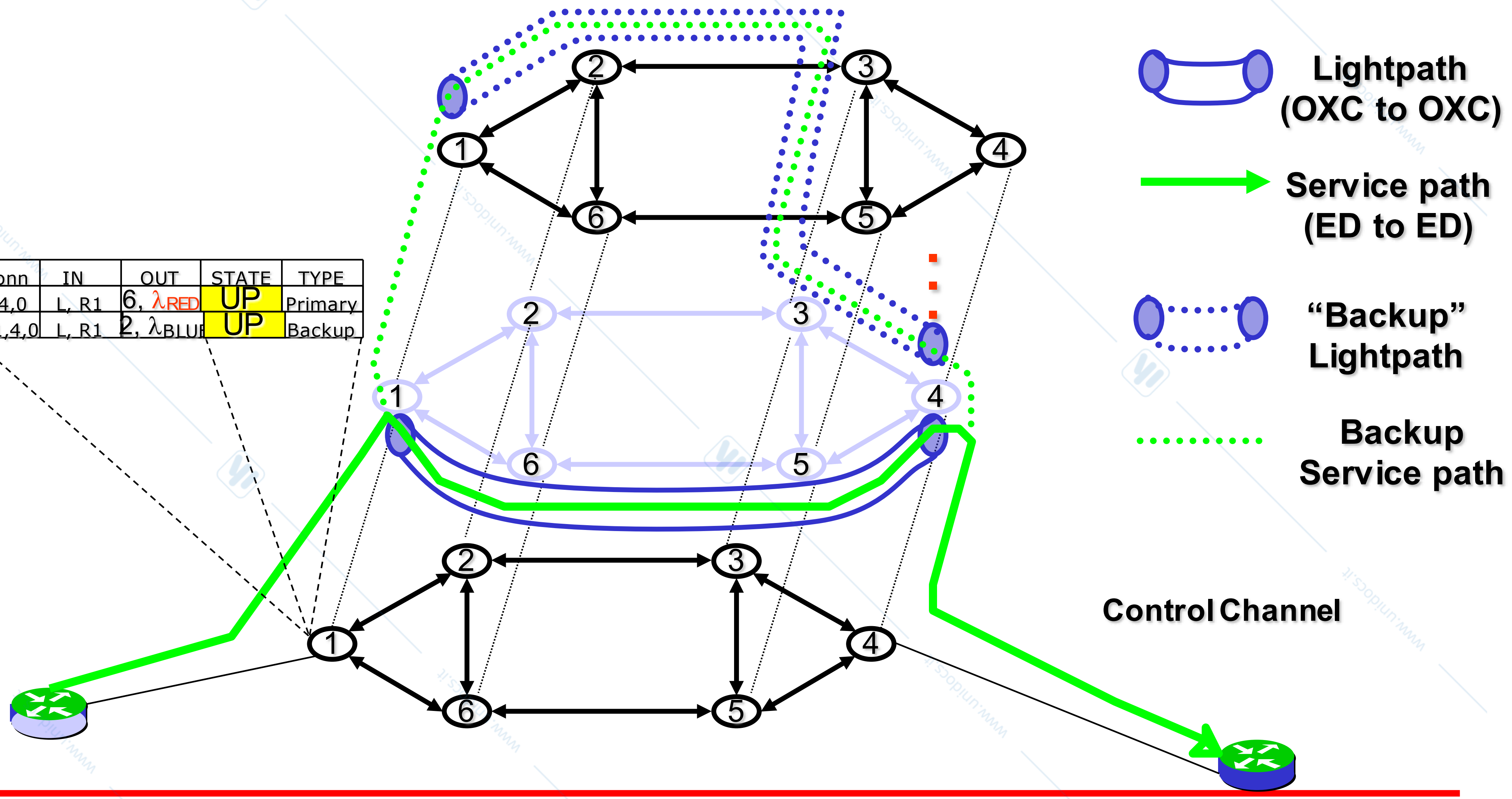
Conn ID | IN port | OUT port | STATE | TYPE
1,4,0 | Local, R1 | 6, λRED | UP | Primary
LC Req: 10.0.0.4
LC Resp: ACK
1
2
3
4
5
6
LC Req …4
Mapping: λRED
LC Req …4
Mapping: λRED
LC Req …4
Mapping: λRED
LC Req …4
LC Resp: ACK
Conn ID | IN port | OUT port | STATE | TYPE
1,4,0 | 5, λRED | Local, R4 | UP | Primary
Conn ID | IN port | OUT port | STATE | TYPE
1,4,0 | 1, λRED | 5, λRED | UP | Primary
Conn ID | IN port | OUT port | STATE | TYPE
1,4,0 | 6, λRED | 4, λRED | UP | Primary

Call Setup (contd.)

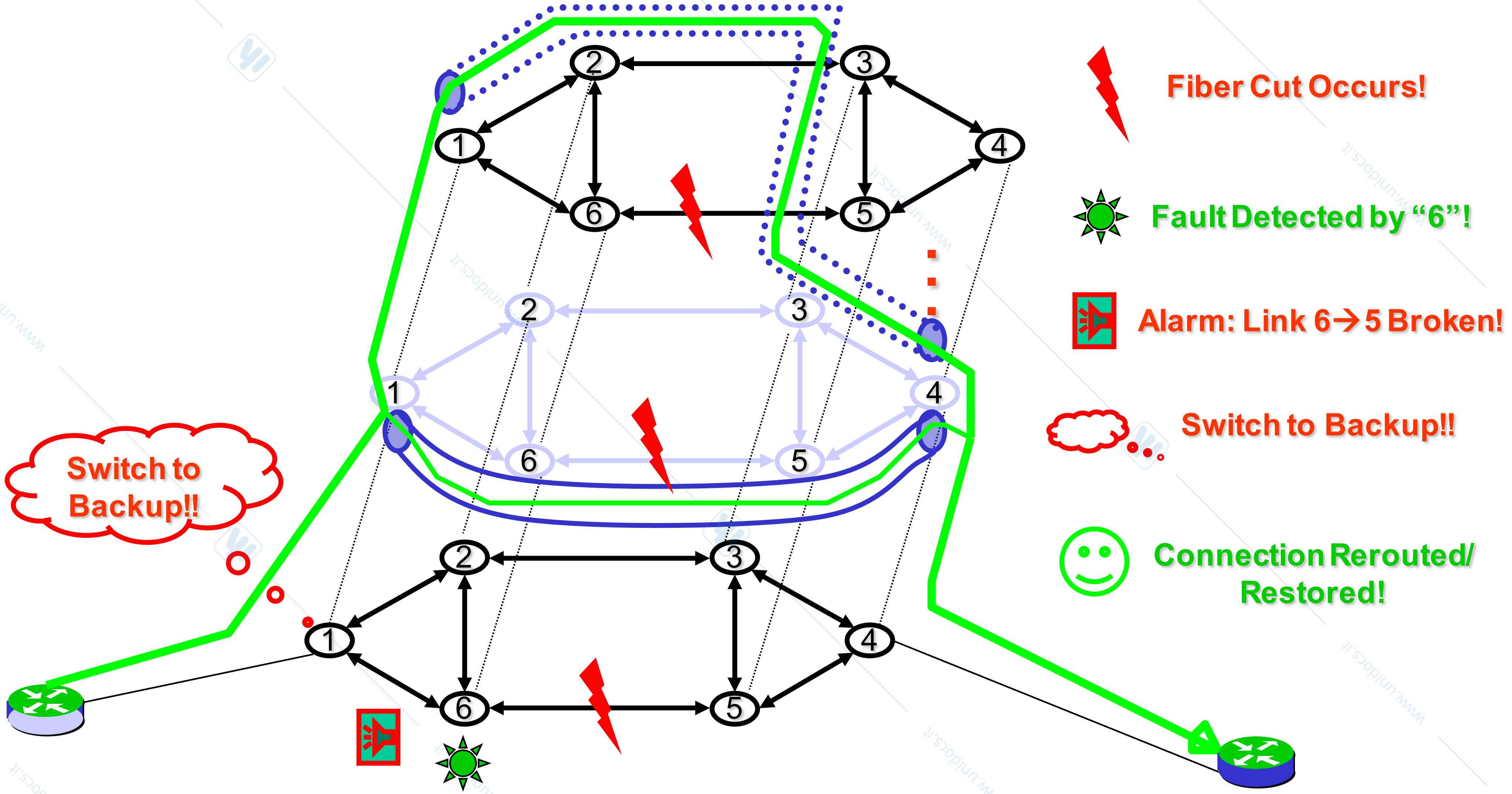


Call Setup (with Protection)

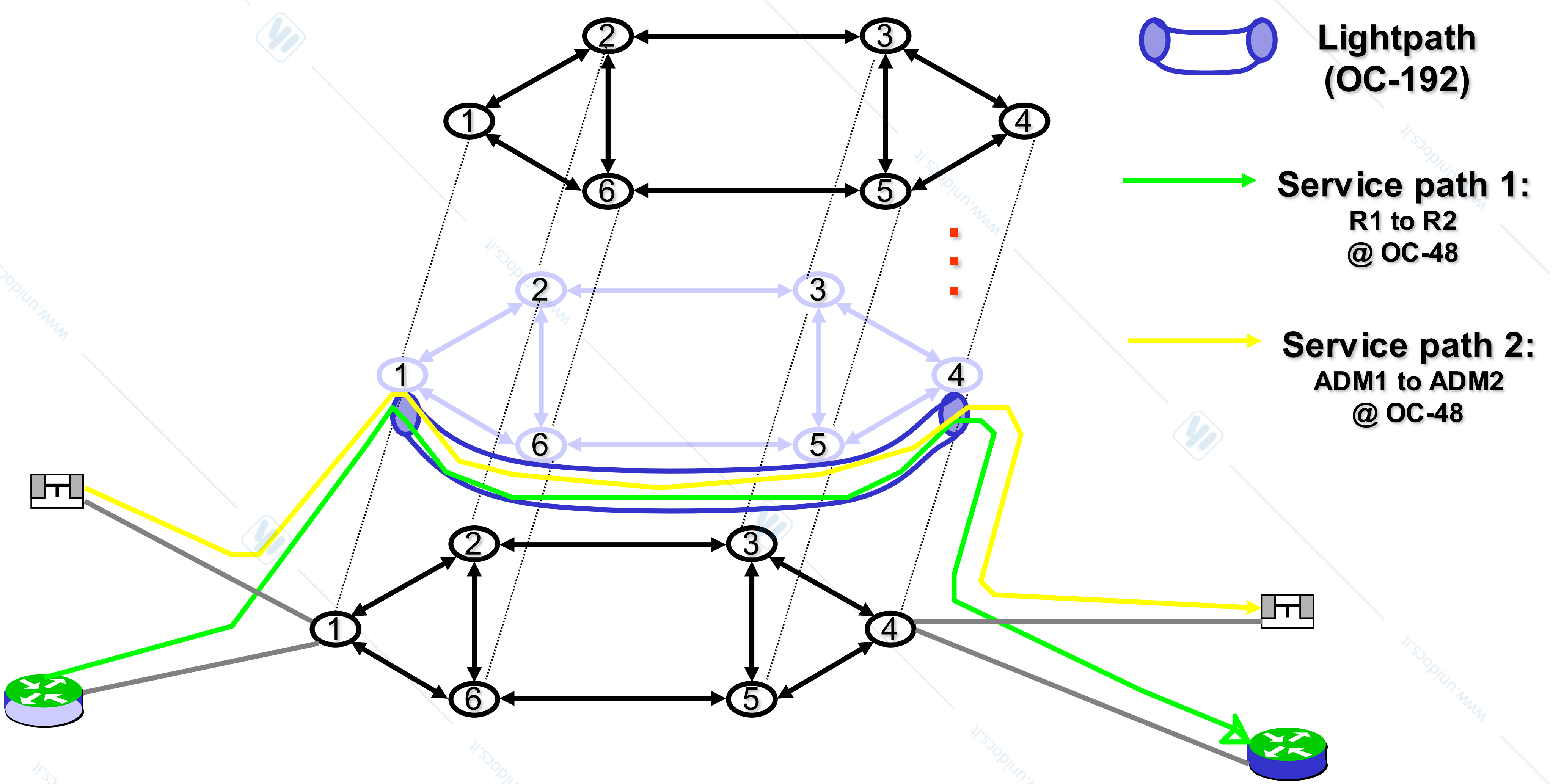
Conn	IN	OUT	STATE	TYPE
1,4,0	L, R1	6, λ_{RED}	UP	Primary
1,4,0	L, R1	2, λ_{BLUE}	UP	Backup



Fault Detection & Recovery



Traffic Grooming Example

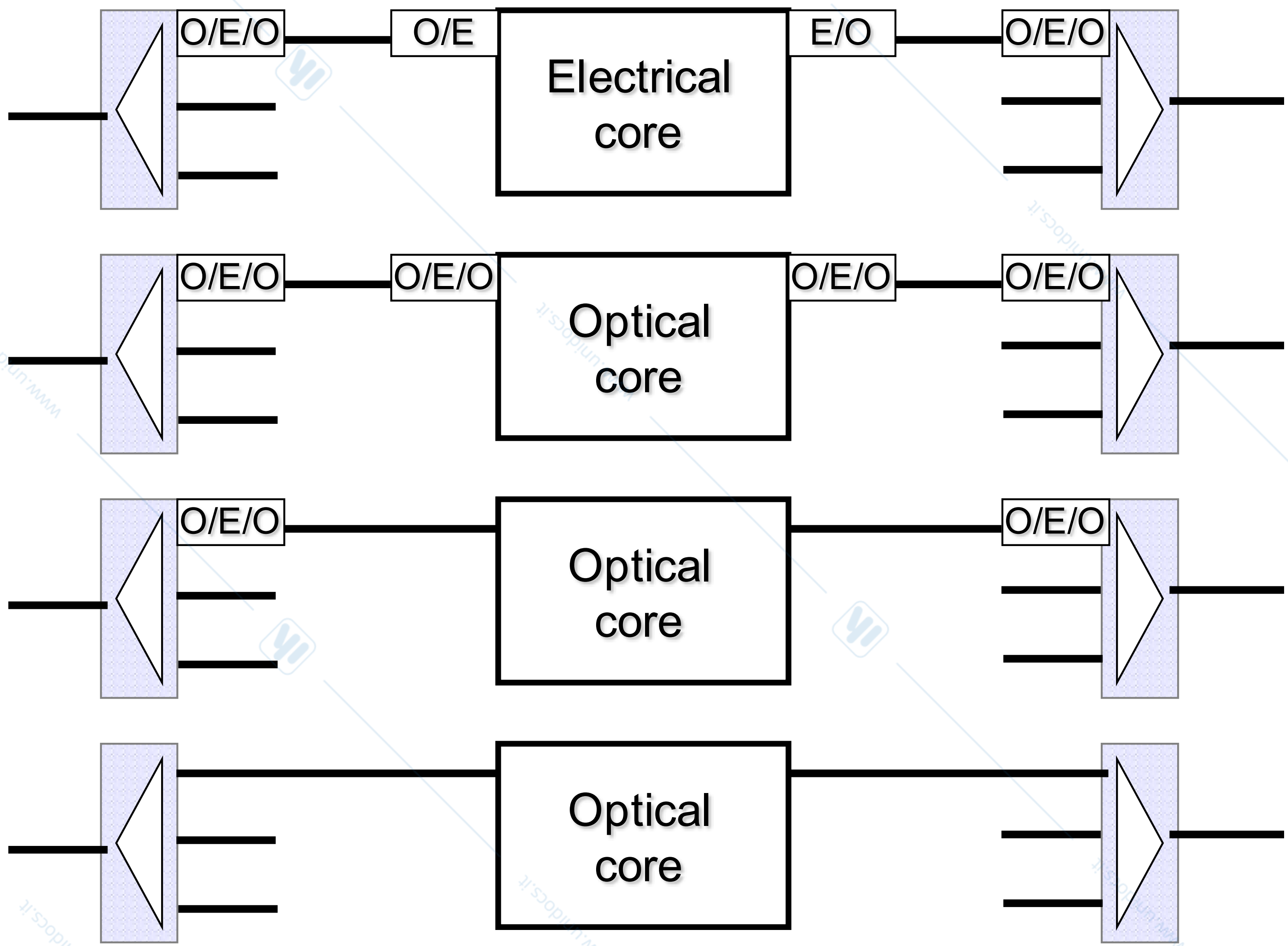


Carriers' Requirements for Optical Nets

(Carriers--AT&T, C&W, CSELT, Enron, GTS, Level 3, MCI Worldcom/UUNET, NTT, Sita Equant, Sprint, T-Nova DT, Williams)

- Rapid automatic end-to-end bandwidth (lightpath) provisioning including routing
- Provide restoration, diverse routing, and other QoS features on a per-service-path basis
- Support policy-based call acceptance, peering policies, and usage-based accounting
- Offer carrier-specified "branded" services
- Rapid deployment of new technologies/capabilities with minimum service disruption
- Protect security and reliability of the optical (control plane) layer
- Preserve network operator's ability to control network resources
- Reduce need for carrier-written software through heavy use of open protocols/software
- Ensure scalabilty of the optical layer
- OXCs and other products from different vendors or employing different technologies should interwork at the control-plane level

OXC Configurations



Opaque OXC

Optical-core OXC:
Calient, et al.
"E: not future proof"
"O: fabric not robust"

Fully-optical OXC

All-Optical Network:
Corvis, et al.

"Opaque" vs. "Transparent" OXC

	Opaque	Transparent
Optical Properties	Switching occurs in silicon. Increases power but limits scalability. Transponder allows optical links to be optimized for unique characteristics.	Dispersion, cross talk, noise, amplifier gain flatness accumulate, limiting network scalability.
Cost	$25K per OC-48 port.	Components must all be specified for the worst-case paths, increasing costs.
Network Complexity	Fits seamlessly into today's DWDM networks.	Entire networks must be engineered from the outset, limiting expansion & scalability.
System Complexity	Higher degree of complexity, with transponders and multiple switching stages (CLOS).	Can be quite simple but unproven – MEMS switch can be put on a single chip.
Performance Monitoring Fault Location	Easy	Difficult
Wavelength Translation	Easy	Difficult
Multivendor Interworking	Easy through transponders	Difficult

Backup slides

What is a Carrier?

- There are different companies' profiles in the carrier industry:
  - Inter-Exchange Carriers (IXC)
    - I.e., long-distance telephone company
  - Global Carriers (or "Greenfield" network operators)
    - Level 3, Qwest
  - National/Global Internet Service Providers
  - ILECs, CLECs, Carrier Hotels

Carriers: IXCs

Major Players	AT&T, WorldCom, Sprint
Requirement	Technology to support voice and data services over a common platform.
Current Solution	ATM -- due to its ability to support voice and data over a common platform, excellent traffic engineering capabilities, and QoS features. 60-70% traffic is pass-through only at each node, expensive SONET ADM and DCS is used to send OC-48 through the node.
Long Term	ATM less attractive due to cost and advancements in IP and MPLS-based routing. Deploy DWDM and move to IP-based routing.

Carriers: Next-Generation National Carriers ("Greenfield" Network Operators)

Major Players	Williams Communications , PF.Net, Global Crossing, Qwest, Level 3, BroadWing, WorldWide Fiber
Requirement	Provision high-bandwidth circuits throughout their networks to offer wholesale services to ISPs. Provide mesh architectures instead of inefficient SONET.
Current Solution	Terabit routers with ATM switches for traffic aggregation and management; SONET ADMs and DCS for provisioning.
Long Term	Replace SONET ADMs and DCS with OXCs to switch and provision wavelengths.

Carriers: National ISPs

Major Players	UUNet, Cable & Wireless USA, Winstar, Concentric
Requirement	Need for flexible, scalable bandwidth throughout their networks. Need transparency, high level of reliability, security and potential reconfigurability.
Current Solution	Use "routed edge, switched core" architecture based on IP routers and ATM switches; ATM used for traffic management and statistical multiplexing capabilities.
Long Term	Use MPLS for simplifying the operation and management of complex backbones; DWDM solution for the ability to lease wavelengths

Carriers: ILECs, CLECs, Carrier Hotels

Major Players	Metromedia (Above Net, PAIX), Bell Atlantic, SBC, New England Telephone, Covad, Northpoint
Requirement	Need to integrate disparate geographic and service-oriented networks into one common platform. Provide neutral colocation space.
Current Solution	Use SONET and ATM based networks.
Long Term	OXC and core optical network equipment that will allow the management of their core infrastructure and establish a platform for delivering high-bandwidth circuits (DWDM).

"Soft Optics" Features

- Network topology discovery (OSPF based)
- Lightpath provisioning
  - Intelligent routing (MPLS/CR-LDP based)
  - User-selectible routes
  - Conduit identification (for shared risk groups)
- SONET/SDH configurable interfaces
- Lightpath monitoring
- Fault detection and recovery (rerouting around failed links)
  - Differentiated fault-recovery schemes
  - Guaranteed recovery-time service
- Hitless upgrade of network segments: lightpath rolling
- Efficient grooming of sub-rate circuits
- Optical OSPF areas
- Optical VPNs
- Network Planning Tool

UNI Messages

	Type Field	UNI-C → UNI-N	UNI-N → UNI-C
Lightpath Create Request	0x01	x (1)	x
… … Response	0x02	x	x (1)
… Delete Request	0x03	x (1)	x
… … Response	0x04	x	x (1)
… Modify Request	0x05	x (1)	x
… … Response	0x06	x	x (1)
… Status Enquiry	0x07	x	
… Status	0x08		x
… Status Response	0x09	x	
UNI Hello	0x0A	x	x

Lightpath Create Request

Fields	Octets
Source Interface Addr.	4
Destination … …	4
Source User Group Identifier	8
Destination … … …	8
Lightpath ID	6
Lightpath Bandwidth	2
Transparency	2
Drop-Side Protection	2
Directionality (default: bidir)	2

Optional Fields	Octets
Source Interface Sub-Addr. TLV	5
Destination … … …	5
Protection Mode TLV	3
Lightpath Retention Mode TLV	2
Lightpath Priority TLV	2
Authentication TLV	Var

Lightpath Create (More…)

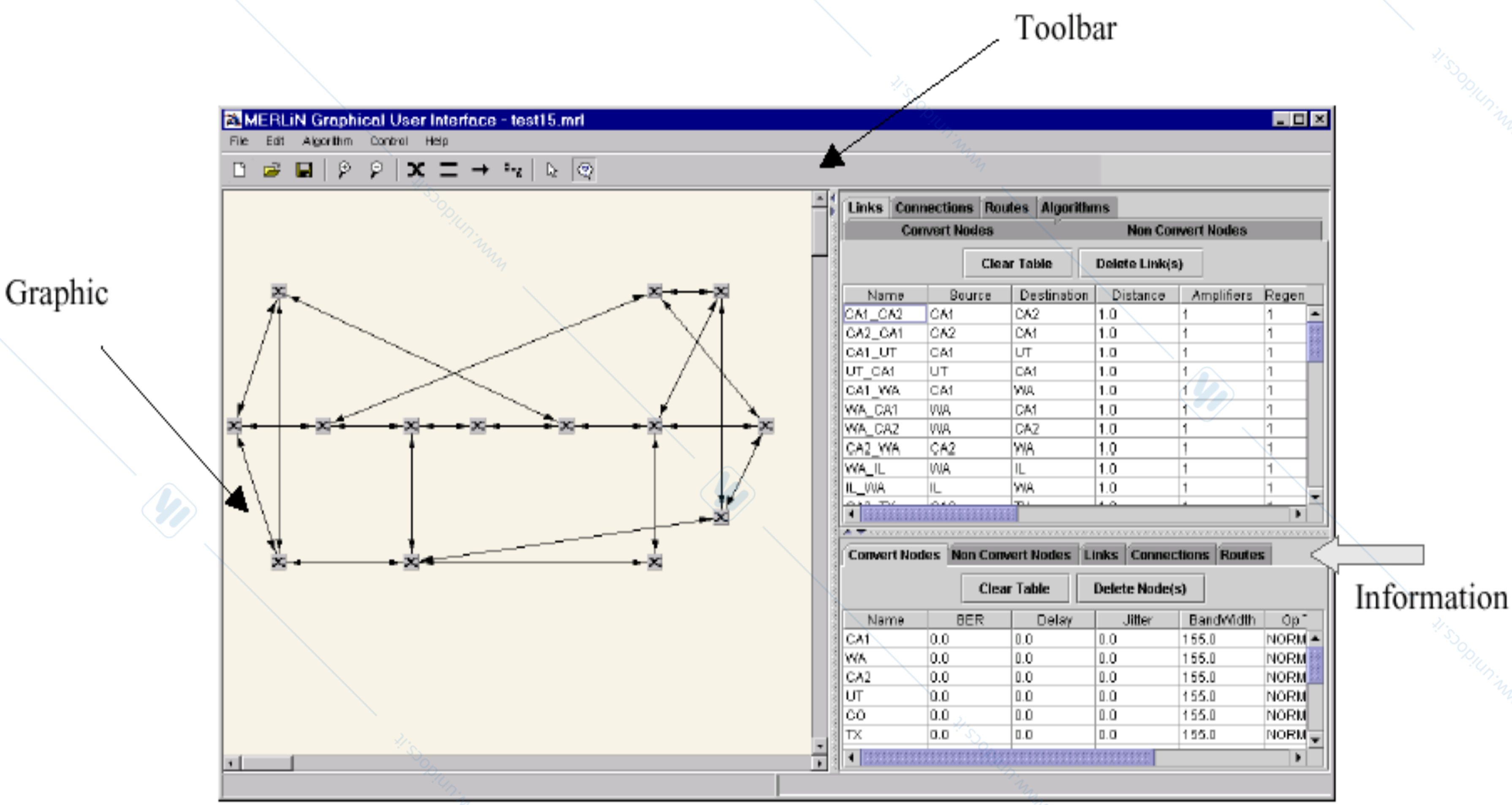
- Lightpath Bandwidth
  - 0x00: Reserved
  - 0x01: OC-48
  - 0x02: OC-192
  - 0x03: OC-768
  - 0x04: STS-1
- Lightpath Priority
  - 1 (lowest) … 8 (Highest)

- Protection Mode TLV

  Mode
  - 0x00: Unprotected & not preemptable
  - 0x01: Unprotected & preemptable
  - 0x02: 1+1, end-to-end "1+1" protection
  - 0x03: Shared-path protection

  Reversion
  - 0x01: Revert to primary path after repair
  - 0x02: Do not revert
- Retention Mode TLV
  - 0x01: Retain unrestorable primary path
  - 0x02: Delete unrestorable primary path

NMS GUI


Toolbar
Graphic
Information
MERLiN Graphical User Interface - test15.mrl
File Edit Algorithm Control Help
Links Connections Routes Algorithms
Convert Nodes Non Convert Nodes
Clear Table Delete Link(s)
Name Source Destination Distance Amplifiers Regen
CA1_CA2 CA1 CA2 1.0 1 1
CA2_CA1 CA2 CA1 1.0 1 1
CA1_UT CA1 UT 1.0 1 1
UT_CA1 UT CA1 1.0 1 1
CA1_WA CA1 WA 1.0 1 1
WA_CA1 WA CA1 1.0 1 1
WA_CA2 WA CA2 1.0 1 1
CA2_WA CA2 WA 1.0 1 1
WA_IL WA IL 1.0 1 1
IL_WA IL WA 1.0 1 1
Convert Nodes Non Convert Nodes Links Connections Routes
Clear Table Delete Node(s)
Name BER Delay Jitter BandWidth Op
CA1 0.0 0.0 0.0 155.0 NORM
WA 0.0 0.0 0.0 155.0 NORM
CA2 0.0 0.0 0.0 155.0 NORM
UT 0.0 0.0 0.0 155.0 NORM
CO 0.0 0.0 0.0 155.0 NORM
TX 0.0 0.0 0.0 155.0 NORM

Challenges in All-Optical Nets.

Impairment	P2P Link	Network-wide
Dispersion	Present	Accumulates
Nonlinearities	Present	Accumulates
Crosstalk	Somewhat	Significant
Laser Stability	Needed	Strongly needed
Filter Passband	Narrow	Wide/stable
Closed Amp Loops	--	Need to eliminate
Amp. Transients	--	Need to eliminate
Power Variations	Somewhat	Significant

B. Ramamurthy, D. Datta, H. Feng, J. P. Heritage, and B. Mukherjee, **"Impact of transmission impairments on the teletraffic performance of wavelength-routed optical networks,"** IEEE Journal of Lightwave Technology, vol. 17, no. 10, pp. 1713-1723, Oct. 1999.

___ **"Transparent vs. opaque vs. translucent wavelength-routed optical networks,"** OFC-99, San Diego, Paper TuF2, pp. 59-61, Feb. 1999.

D. Datta, J. P. Heritage, and B. Mukherjee, **"Impact of frequency drift and finite linewidth of lasers on bit-error rates in wavelength-routed optical networks,"** Proc., NCC, IIT Kharagpur, pp. 485-490, Jan. 1999.

J. Iness, B. Ramamurthy, B. Mukherjee, and **K. Bala**, **"Elimination of all-optical cycles in wavelength-routed optical networks,"** IEEE Journal of Lightwave Technology, vol. 14, pp. 1207-1217, June 1996.

Challenges in All-Optical Nets. (contd.)

- Impairments:
  - Need to combat
  - Leading-edge research conducted at UC Davis
- All *fibers*, *transmission equipment*, *lasers*, and *filters* must support "exactly the same" wavelength spectrum!
  - Cannot mix and match fiber types,
    e.g., Lucent all-wave fiber with traditional fiber
  - Lacks interoperability... tied down to a few vendors
  - Not viable... until all-optical λ converters are commercial
  - Very specialized solution!

B. Ramamurthy and B. Mukherjee, **"Wavelength conversion in optical networks: Progress and Challenges,"** IEEE Journal on Selected Areas in Communications, vol. 16, no. 7, pp. 1061-1073, Sept. 1998.

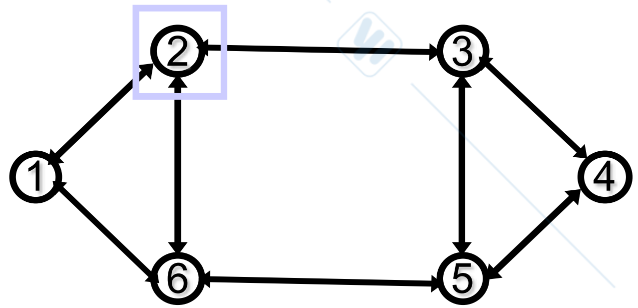
Electrical (Opaque) OXC Advantages

- Link budget "reset": impairments do not accumulate!
- Full performance monitoring
- Wavelength conversion is built in
  - higher link utilization efficiency, simpler protocol
- Multicast and broadcast
  - Built in with most electrical crossconnect chips
- Challenge: power consumption, get the heat out!

The Opaque OXC Competition

	Base System		Size (7' bay)	Status	Problems/Challenges
	Ports	Rate			
Tellium (Aurora512)	512x512	OC-48	4	shipping	Footprint too large!
Sycamore (SN16000)	256x256	OC-48	1.5	Trials	Optical backplane cabling (?) Heat (?)
Ciena/Lightera CoreDirector	256x256	OC-48	1	shipping	Getting the heat out!
Cisco/ Monterey WR	256x256	OC-48	4	Discontd.	Not working? WaRP software: elementary
Brightlinks	?	OC-48	?	Develop-ment	Hypertorus: academic?

Designing the "Junction"

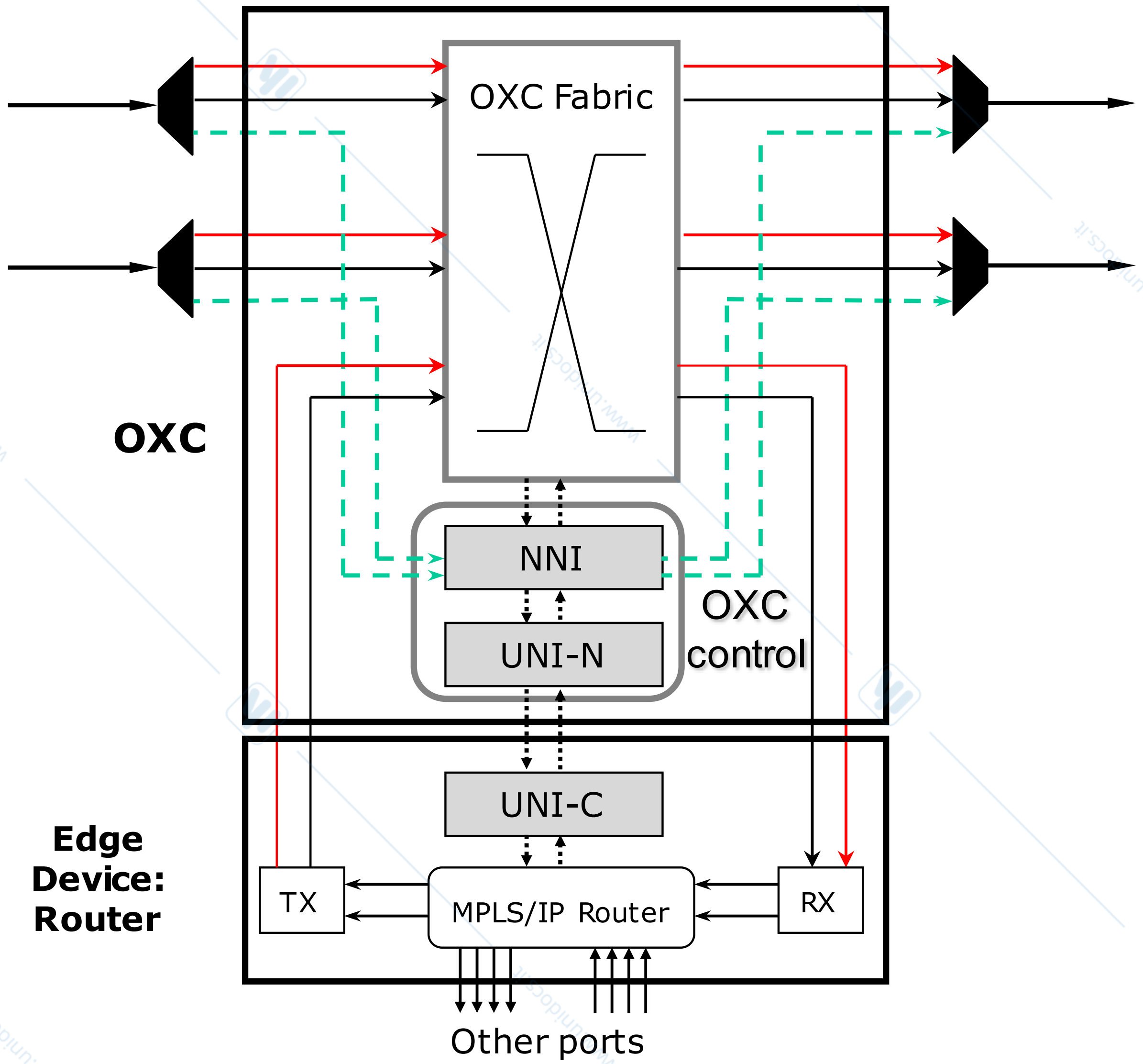


Bandwidth "Currency" →

Switching Technology ↓

	Packet or Bit	Wavelength or Lambda
Electrical	Q1 Big Fat Router (BFR) … "Cisco" approach **Bottleneck !**	Q2 "Opaque" OXC (O-E-O) Tellium, Sycamore Ciena/Lightera Cisco/Monterey **Deployable Today !**
Optical	Q4 **Optical "Label" Switching** **Research… 5-7 yrs. away !**	Q3 All-Optical λ Routing ("transparent" OXC) Nortel/Xros Lucent, Corvis, Agilent, MEMS R Us **Risky… ?? yrs. away !**

Node Architecture (IP/WDM)



Fiber Link :
Multiplexer :
Demultiplexer :
Wavelength 0 :
Wavelength 1 :
Wavelength 2 :
Transmitter array : TX
Receiver array : RX
Control component :
Control Message :

Edge Device (ED) (Router) can provide flexible software-based bandwidth provisioning capability.

What is a God Box?

- aka MSPP: Multi-Service Provisioning Platform
- Maintains circuit and cell-based services while allowing packet-based services in a bandwidth efficient manner
  - Typically combines electronic switching with wavelength switching and includes optical transponders

CISCO ONS 15454 SONET MULTISERVICE PROVISIONING PLATFORM (MSPP)

Introduction

The Cisco ONS 15454 SONET Multiservice Provisioning Platform (MSPP) provides the functions of multiple network elements in a single platform. The Cisco ONS 15454 SONET provides TDM solutions with interfaces such as DS-1, DS-3, EC-1, and data solutions with 10/100/1000 Ethernet solutions with OC-3 to OC-192 optical transport bit rates including integrated DWDM wavelengths.

Closing Quotes

- **"It is a great embarassment to the photonics fraternity to be unable, in any known branch of the art, to exhibit a cost reduction curve that comes anywhere even close to the Moore's Law curve of electronic LSI. Shame on us."**

  ... Dr. Paul Green, "Father of Optical Networking," many years at IBM, recently retired from Tellabs, in the article "Progress in Optical Networking," IEEE Communications Magazine, January 2001.

- **"Unlike electronic circuits, these [MEMS switches] are mechanical devices, and [their] reliability for telecommunication applications is still to be proven."**

  ... Dr. Armand Neukermans, Founder and CTO of Xros (now Nortel) & Dr. Rajiv Ramaswami, VP of Xros (now Nortel), in the article "MEMS Technology for Optical Networking Applications," IEEE Communications Magazine, January 2001.

The "Optical Battleground" (Jan. 2001)

- **Access**
  - Accordion: MTU
  - Adva
  - Advanced Fiber
  - Alloptic: PON
  - Anda
  - Apian
  - Aurora Nets.
  - Blaze
  - Broadband Tech
  - Finisar
  - First Fiber
  - Intelect
  - Internet Photonics
  - Lantern
  - Laurel Nets.
  - Luminous Nets
  - LuxN
  - LuxPath Nets.: MTU
  - Mainsail
  - Optical Solutions
  - Optranet: MTU
  - Pair Gain
  - Quantum Bridge
  - Sirocco (Sycamore)
  - Tenor
  - TransCom: PON
  - World Wide Packets

- **Metro**
  - Alidian
  - Astral Point
  - Atmosphere Nets
  - Atoga
  - Atrics: metro gigE
  - Centerpoint
  - Chromatis, Ignitus (Lucent)
  - Ciena
  - Coriolis
  - Cratos
  - Geyser
  - Kestrel
  - Lumentis (Ericson)
  - Mahi
  - Metera
  - Metro-Optix
  - MetroPhotonics
  - Net Insight
  - Nortel
  - ONI
  - Ocular
  - Osicom (Sorrento)
  - Qeyton
  - Roshnee
  - Tellabs
  - Terawave
  - Tropic
  - Zaffire (New Access)

- **Core/OXC**
  - Tellium
  - Sycamore
  - Ciena (Lightera)
  - Cisco (Monterey)
  - Brightlink (Corvia)

  - Calient
  - Corvis
  - Ilotron
  - Lucent
  - Nayna
  - Nortel (Xros, Qtera)
  - LuxCore
  - MEMS 'R Us
  (see components)

CapEx Slowdown-1

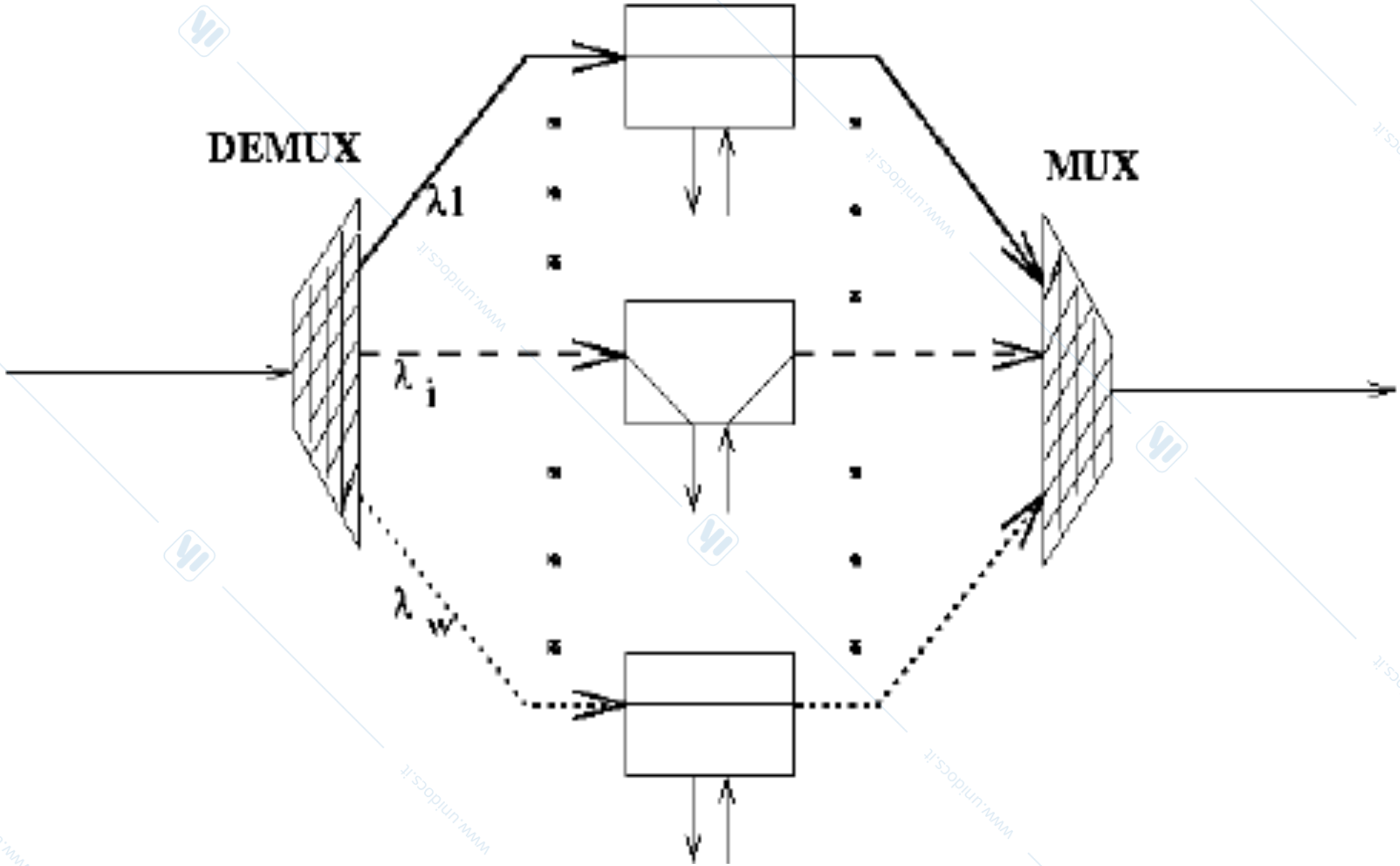
Company	2002E	2001E	2000	1999	1998
AT&T	$7,000	$8,750	$14,600	$14,300	$7,820
BellSouth	$5,400	$5,750	$7,000	$6,200	$5,200
Broadwing	$360	$670	$844	$381	$143
Genuity	$840	$1,200	$1,730	$744	$588
Global Crossing	$1,120	$4,500	$4,290	$1,960	$554
Level 3	$200	$2,700	$5,940	$3,440	$910
Qwest	$4,250	$8,500	$6,590	$3,940	$2,670
SBC	$9,600	$12,000	$13,100	$10,300	$8,880
Sprint	$3,500	$5,400	$7,200	$6,100	$4,200
Verizon	$12,000	$17,100	$17,600	$13,000	$12,800
Williams	$475	$1,500	$3,310	$1,590	$353
WorldCom	$5,500	$7,500	$10,100	$7,430	$4,820
Totals	$50,245	$75,570	$92,304	$69,385	$48,938

Sources: *Optical Oracle, Light Reading*

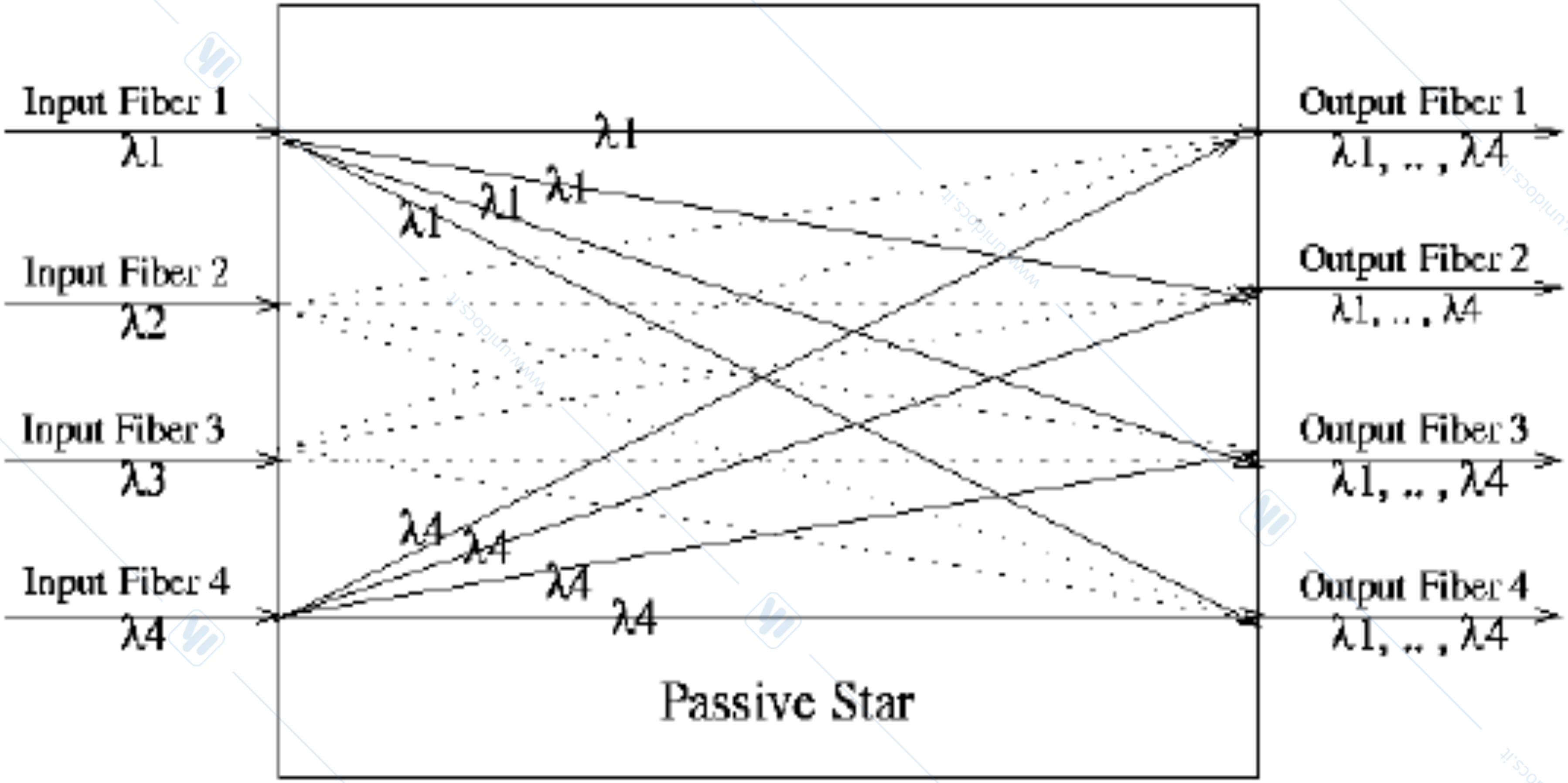
CapEx Slowdown-2

Company	2000	2001 E	% of Change Between 2000 and 2001E	2002 E	% of Change Between 2001E and 2002E
AT&T	$14,6	$8,75	-40%	$7,00	-20%
BellSouth	$7,00	$5,75	-18%	$5,40	-6%
Broadwing	$844	$670	-21%	$360	-46%
Genuity	$1,73	$1,20	-31%	$840	-30%
Global	$4,29	$4,50	5%	$1,12	-75%
Level 3	$5,94	$2,70	-55%	$200	-93%
Qwest	$6,59	$8,50	29%	$4,25	-50%
SBC	$13,1	$12,0	-8%	$9,60	-20%
Sprint	$7,20	$5,40	-25%	$3,50	-35%
Verizon	$17,6	$17,1	-3%	$12,0	-30%
Williams	$3,31	$1,50	-55%	$475	-68%
WorldCom	$10,1	$7,50	-26%	$5,50	-27%
Totals	$92,3	$75,5	-18%	$50,2	-34%

WDM Network Evolution: 2. Optical Add/Drop Multiplexer (OADM)

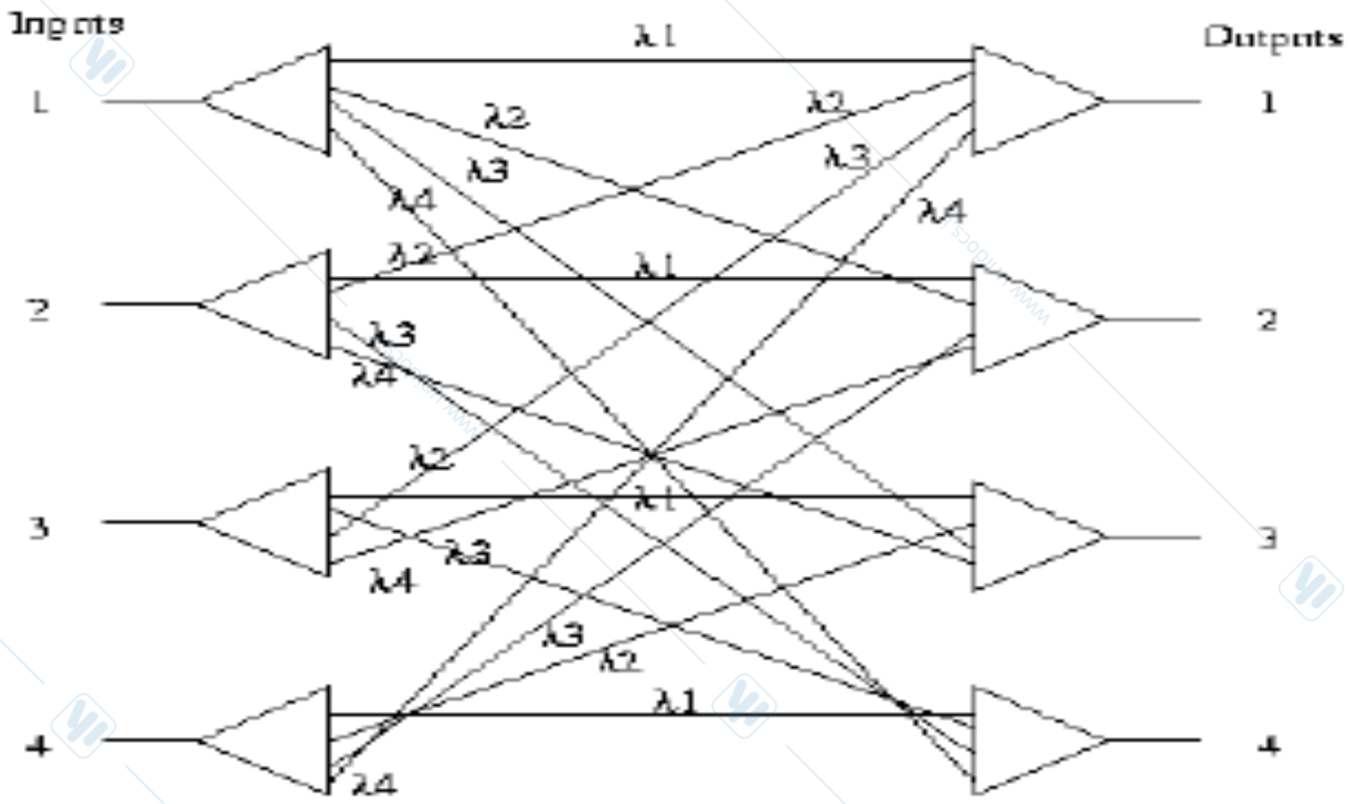


WDM Network Evolution: 3a. Crossconnect - Passive Star



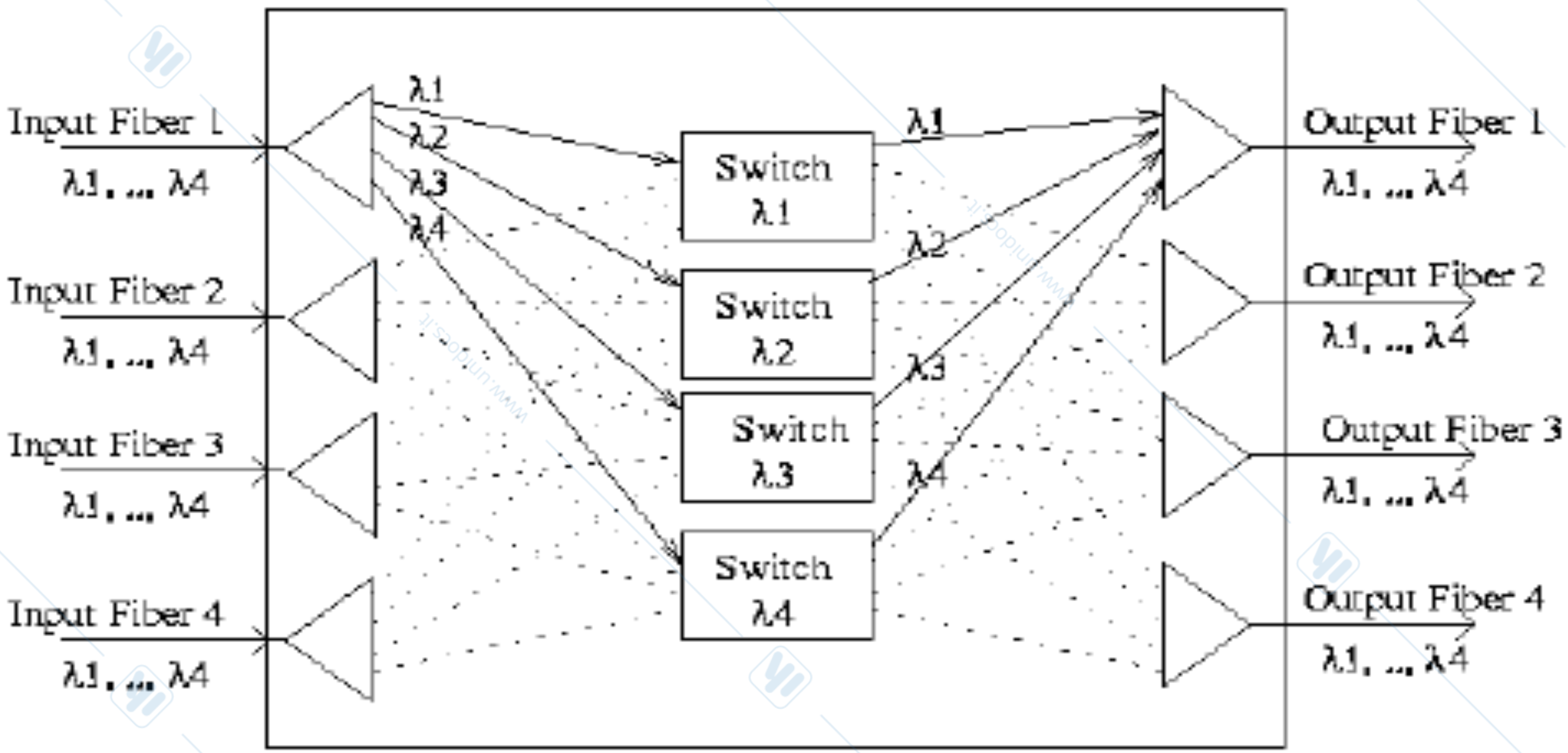
▷ $N \times N$ star can route N simultaneous connections, all in *broadcast* mode

WDM Network Evolution: 3b. Crossconnect - Passive Router



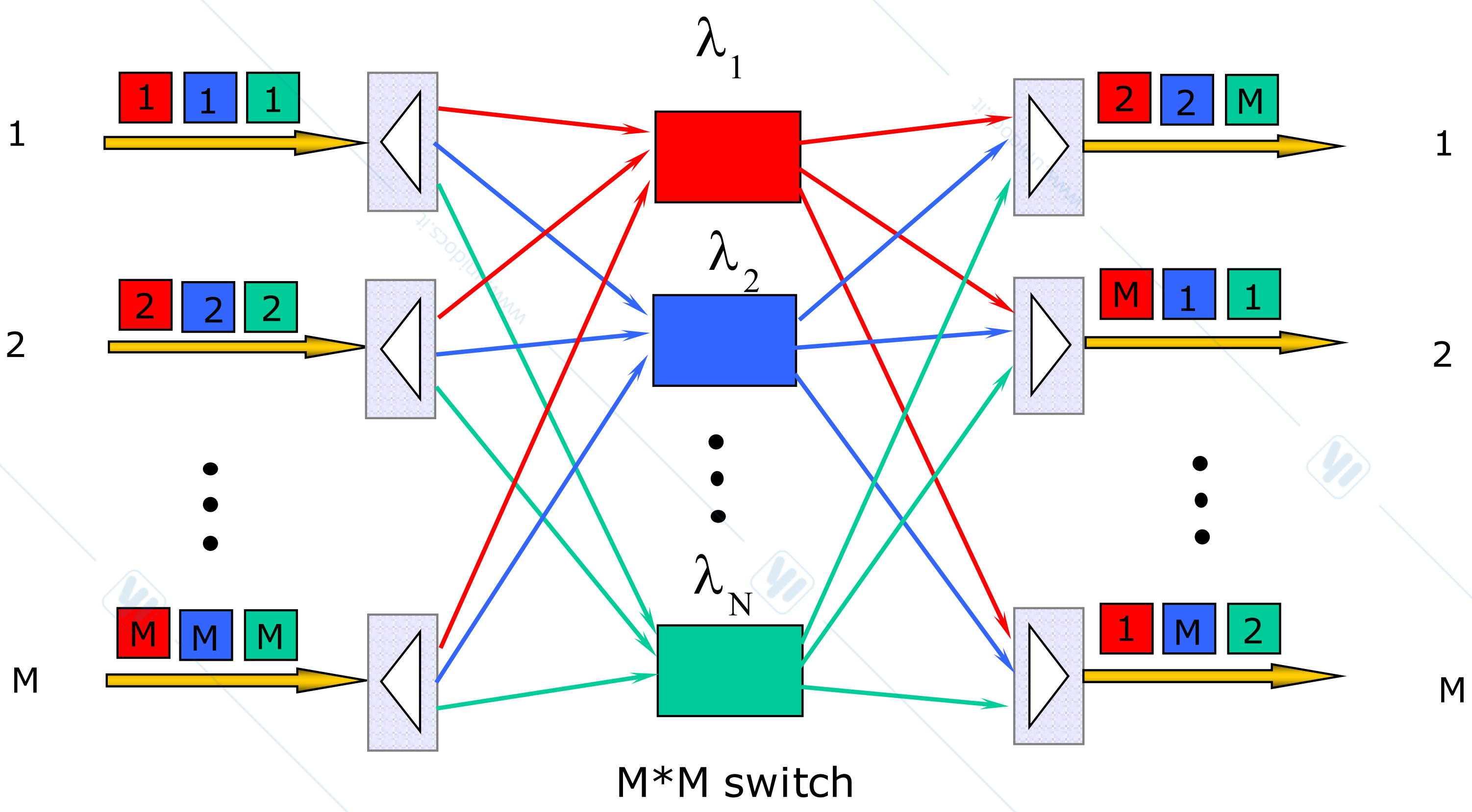
- $N \times N$ passive router can route N^2 simultaneous connections
- *Fixed routing matrix (no broadcast)*

WDM Network Evolution: 3c. Crossconnect - Active Switch



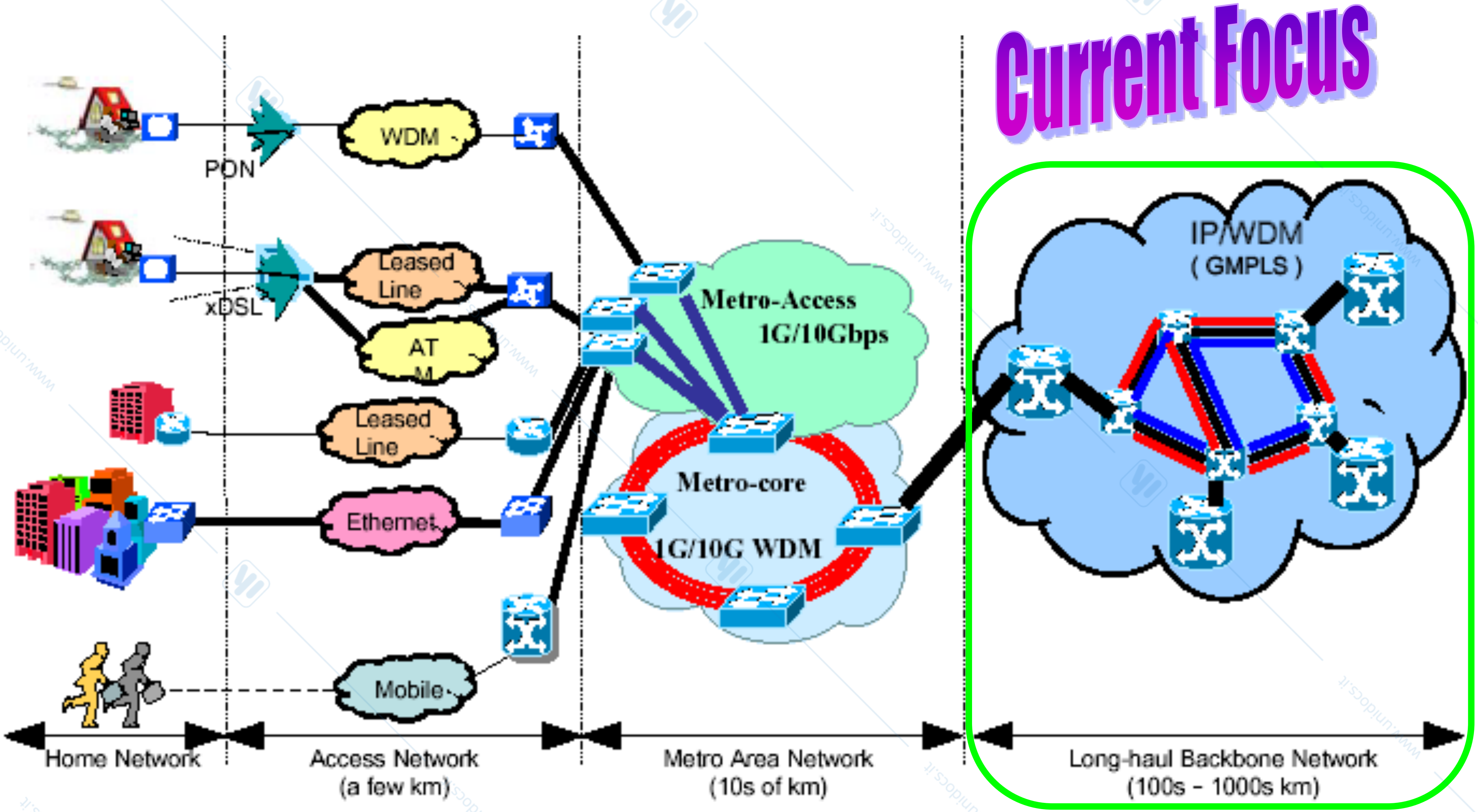
- $N \times N$ active switch can route N^2 simultaneous connections (like passive router)
- But *routing matrix is reconfigurable*
- Fault tolerance is an issue

An All-Optical OXC

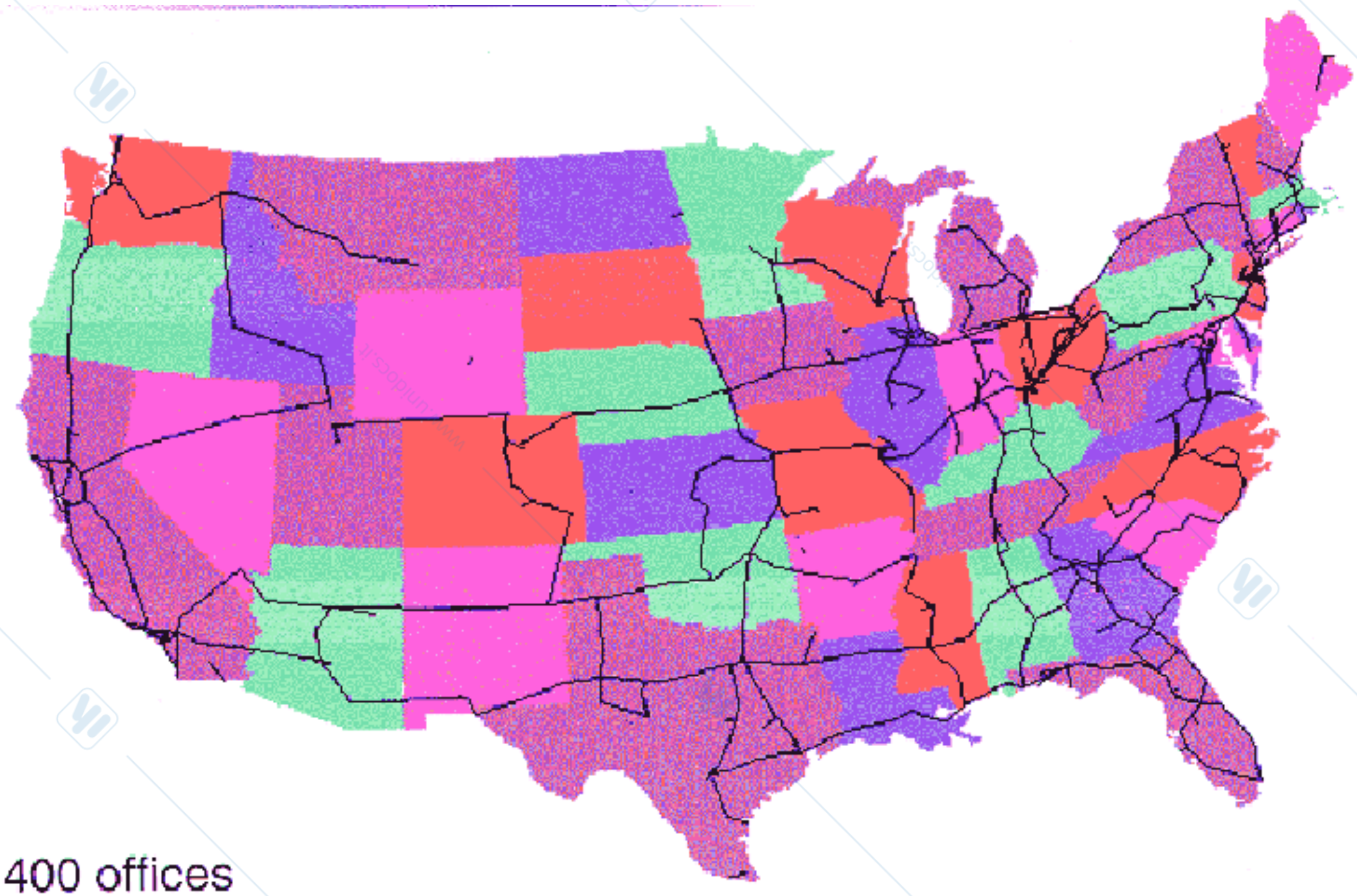


A NM*NM Crossconnect without λ Conversion

Telecom Network Hierarchy

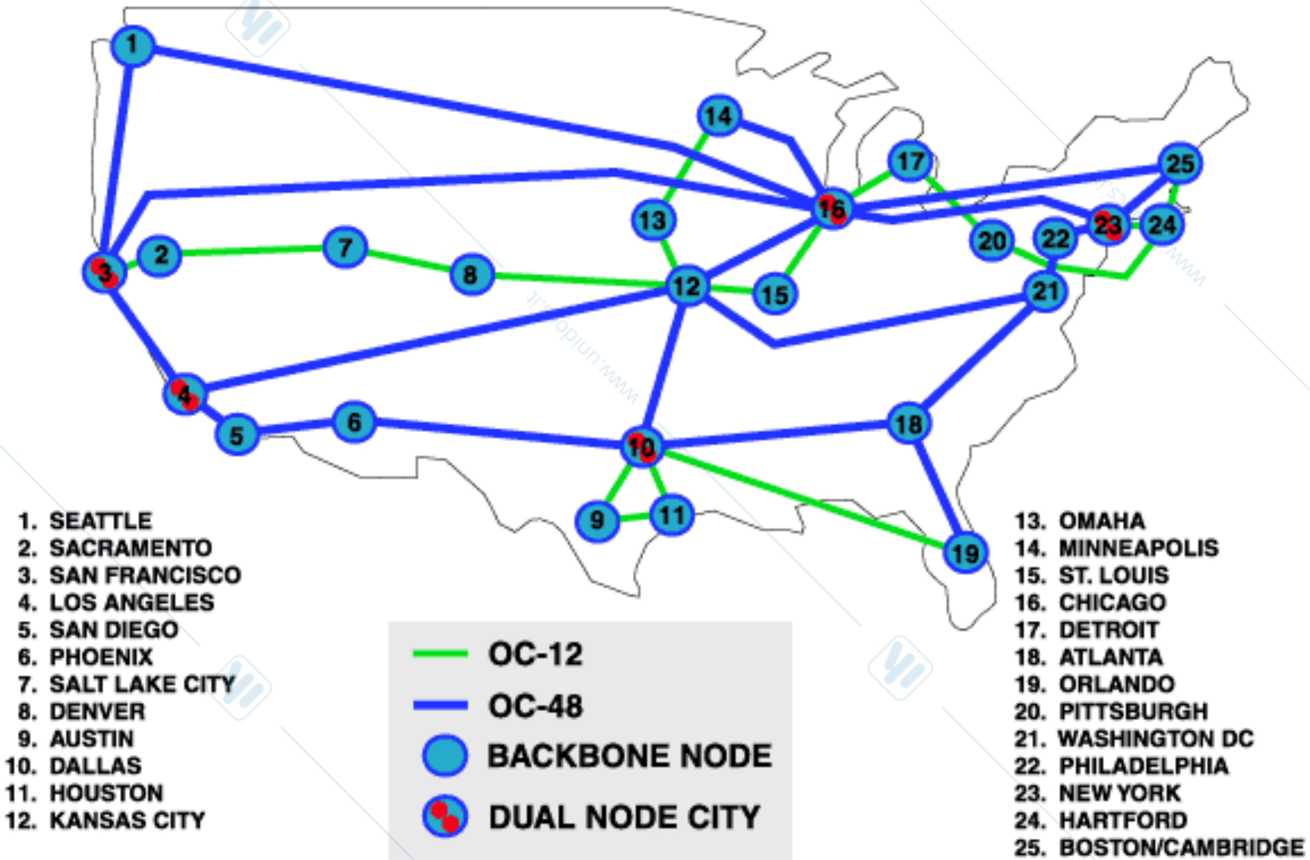


Example Carrier Network (AT&T)



~400 offices
50,000 route miles @ \$100k/mile ⇨ A \$5B investment

AT&T OC-48 IP Backbone



Note:

- Fiber laid in bundles
- Example:
  864 strands/bundle,
  10 bundles/conduit
- Intelligent software architecture for diversified routing of "working" and "backup" paths

Optical Networking: Overview and Trends

- "The industry is 1-2 yrs. into a 10-20 yr. growth curve during which time the communications, information, commerce, and entertainment industries will transform to operate primarily on new optical communication networks."
  - The network (Internet) will need to grow several 1000 times its current size over this time... over 5000 times in the US, and over 20,000 times worldwide!
- "Optical technologies are today where computing was 30 years ago when the bulky vacuum tube was the building block of computer

... Wit SoundView (venture capital company)

Optical Networking: Overview and Trends

- The optical core network will be the most important area during the next few years… technologies adopted at the core will naturally migrate closer to the edge with time.
- At the backbone, carriers are moving towards a OXC-based mesh network.
  - As the number of wavelengths increases rapidly, carriers are forced to look to OXCs for managing wavelengths, provisioning big pipes of bandwidth, protection/restoration, and traffic grooming using mesh architecture.
  - 512x512 OXCs needed today by several carriers; 1000x1000 (and higher) needed soon by AT&T, MCIWorldcom, others?
- Carriers are increasingly deploying IP directly over WDM using PoS at OC-48c and OC-192c interfaces.

Big Telecom News on Wall St: Then and Later

Then (2000)…

- March 2000—**Xros**
  - Monster 3D MEMS Xconnect
  - Acquired by Nortel for ~$3.25B
  - "*We have paid a very, very fair price for this,*" *Clarence Chandran, then Nortel #2 person*
  - No revenue/customers
  - Recently discontinued
- August 2000—**Corvis**
  - All-optical long-haul networking solution
  - Spectacular IPO (with no revenue)
  - Raised ~$1B from IPO (then valuation: ~$30B)
- Many other eye-popping IPOs and M&A
  - **Prompted several new "look-alikes"**

Later (2002)…

- Jan. 2002—**Astral Point**
  - Metro optical equipment vendor
  - Acquired by Alcatel for ~$135M
  - VC investment: ~$115M
  - Annual revenue = ~$4.5M
- **Corvis–** trading at 60 cents/share; down from $80/share!
- Carrier bankruptcies/difficulties/scandals: … (mainly "greenfield" networks)
  - **Worldcom**
  - **Williams Comm.**
  - **Global Crossing**
  - **McLeodUSA, Yipes,**
  - …
- Valuations are tumbling—public+private

Techweb > News > U. S. Telecom Contract To Sprint, Qwest > U. S. Telecom Contract To Sprint, Qw - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://www.techweb.com/wire/story/TWB20031231S0003

CMP United Business Media

TechWeb The Business Technology Network

FOCAL POINTS: Sponsored Links
IT Business Alignment, Data Management, Application Hosting, Application Performance Mgmt, Active Directory Management, Power Protection, Help Desk

SEARCH Enter term(s) Choose One .... go advanced

News | Mobile | Software | Security | E-Business & Management | Networking | Hardware | Reviews | Financial Technology | Pipeline Sites

U. S. Telecom Contract To Sprint, Qwest

December 31, 2003 (12:22 p.m. EST)
TechWeb News

The Defense Information Systems Agency has awarded four contracts totaling more than $400 million to build a global optical and data network to prime contractors Sprint and Qwest, the Reuters news agency reported.

In turn, Sprint and Qwest subcontracted some portions of the awards to Ciena Corp., Cisco Systems, Juniper Networks, and Sycamore Networks. Reuters quoted a Qwest vice president as saying the contracts were "multiyear" affairs while other analysts said the contracts could total nearly $1 billion in their initial two-year period.

Government officials at the DFSA were not immediately available for comment.

Edit View Favorites Tools Help

Back Search Favorites Media

http://www.lightreading.com/document.asp?doc_id=48165&site=lightreading

Search Web | Sign In | Mail | Games | Yahoo! | NCAA Hoops | Personals | My Yahoo! | LAUNCH

LIGHT READING

WORKING THE ECOM INDUSTRY
.lightreading.com

ECHNOLOGY CHANNELS
EWS, ANALYSIS, ND EDUCATION

hernet Channel
Channel
ultiservice Channel
etwork Processor hannel
esting Channel

itorial Calendar
hives
ssage Boards
eb Seminars
ginner's Guides
rvices News
p 10 Lists
ents
ernet Resources
ssaries

FEBRUARY 24, 2004

PREVIOUS NEWS WIRE FEED

SPONSORED BY PR Newswire United Business Media

Lucent Teams With Movaz, Wins 360

MURRAY HILL, N.J. -- Lucent Technologies (NYSE: LU - message board) today announced an agreement with Movaz Networks, an optical networking solutions supplier, to deliver next-generation optical solutions designed to help service providers address their business customers' demand for bandwidth-intensive networks.

Under the multi-year agreement, Lucent and Movaz will jointly develop new, next-generation metro dense wavelength division multiplexing (DWDM) solutions for Lucent's service provider customers using Movaz's DWDM technology. The new solutions will complement Lucent's existing Metropolis(r0 portfolio of metro optical networking products, now deployed by more than 100 customers. Lucent and Movaz will jointly develop solutions designed for the metro DWDM market, helping service providers deliver cost-effective optical bandwidth directly to their customers' premises and meeting their wavelength needs in the metro access, interoffice and regional application spaces.

The metro DWDM equipment market segment is expected to grow from an estimated $600 million in 2004 to $800 million in 2008. Currently Lucent's metro DWDM portfolio focuses on large metropolitan-wide network technology.

By working with Movaz, Lucent will extend its portfolio to the network edge, closer to the service providers' customers, enabling enterprises to take full advantage of the capabilities of service providers' advanced optical networks.

- Webinars
  Register for upcoming free Web seminars
- Case Studies
  Real-World Technology Deployments
- Light Pages
  Directory of vendors and technology
- White Papers
  Vendor Education
- Register
  Free email newsletters

www.unidocs.it - Appunti e dispense per superare i tuoi esami universitari

System: Value Proposition