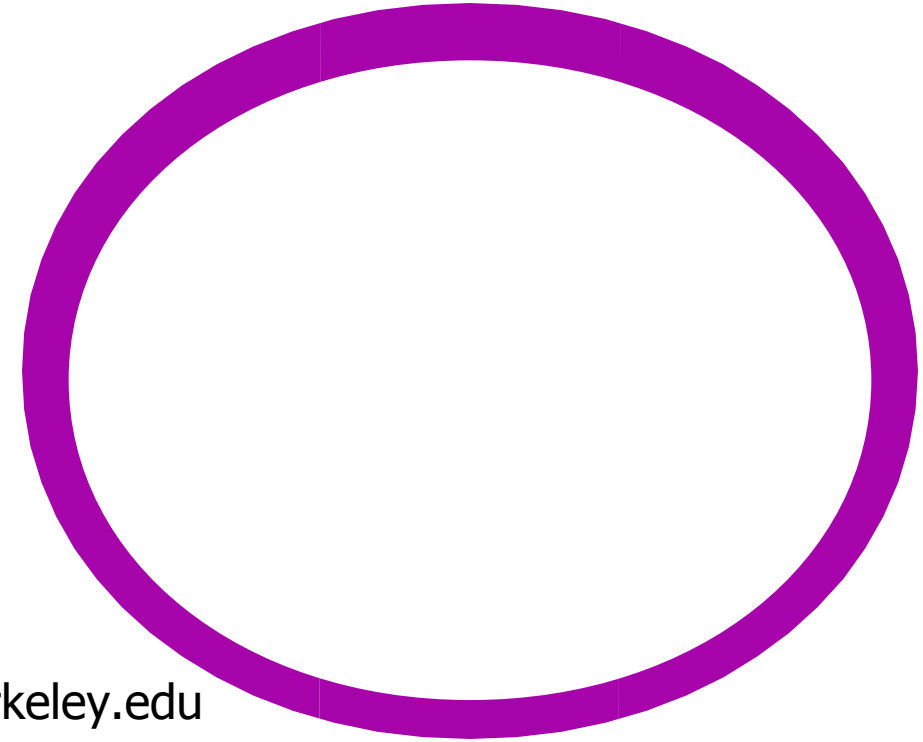
Optical Networking & DWDM



Tal Lavian

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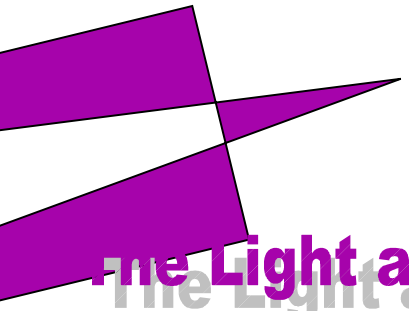
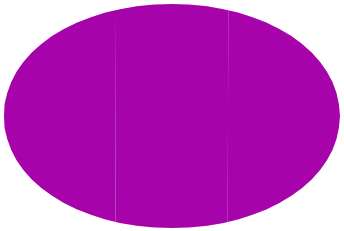


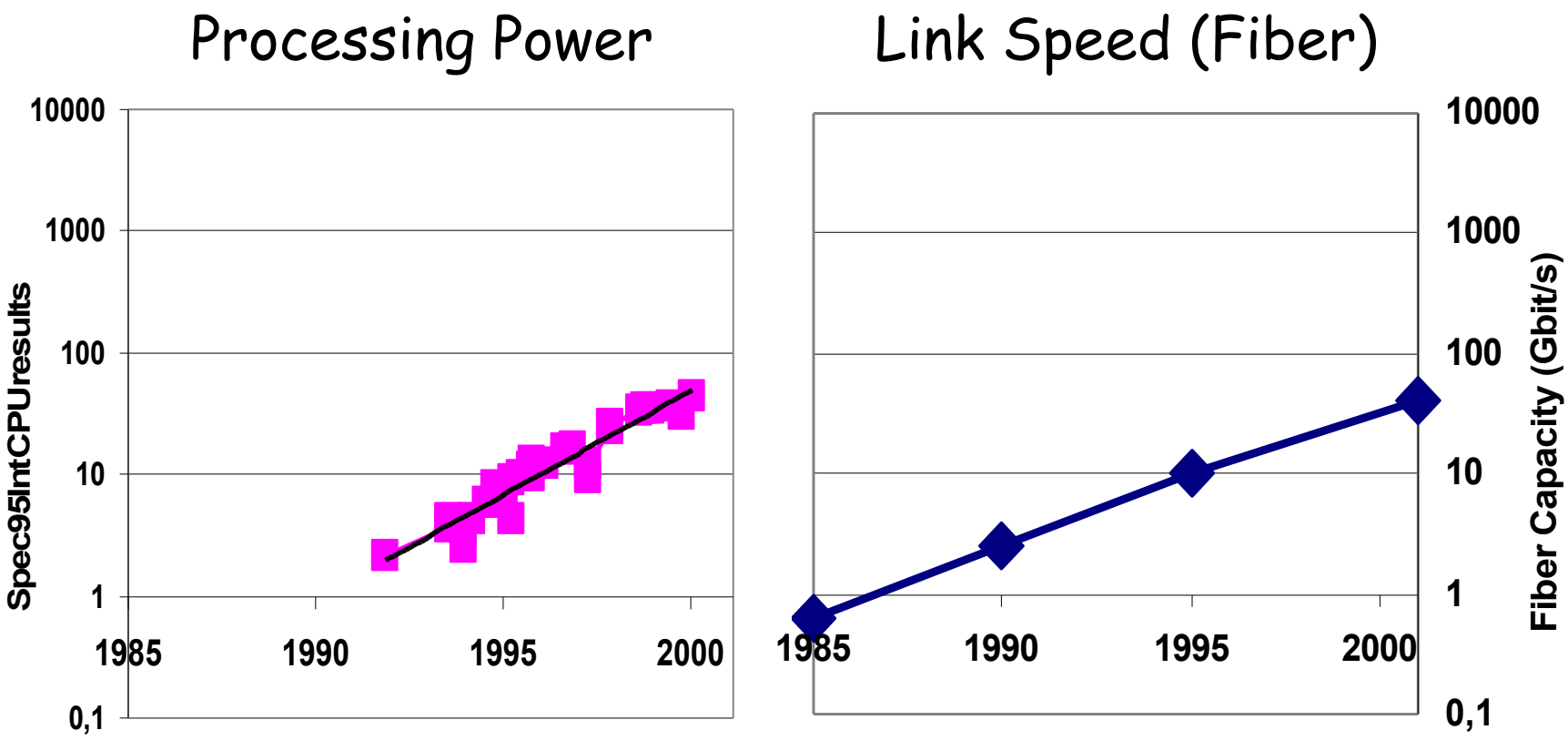


The Light at the end of the Tunnel

Agenda_

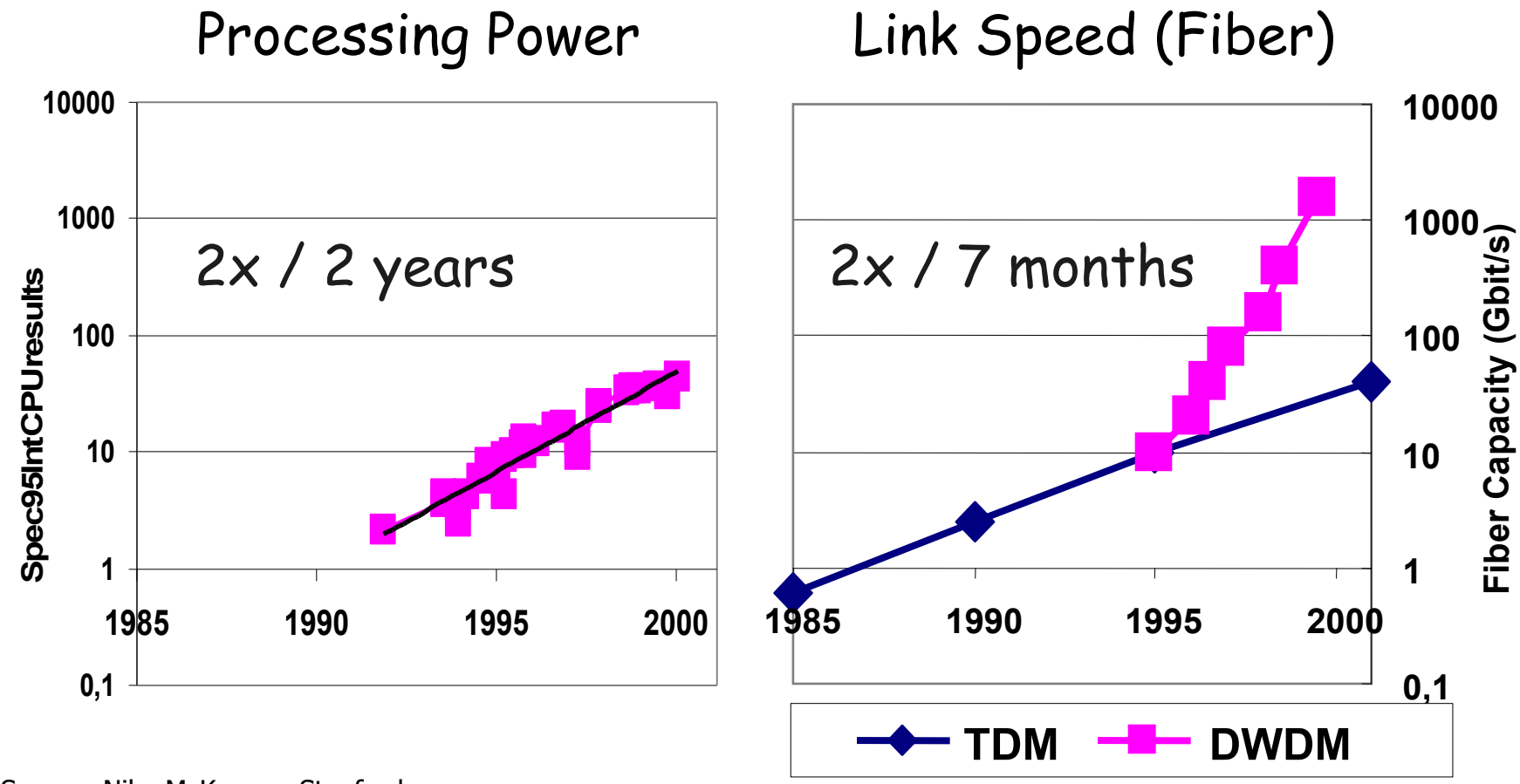
- Technology and market drivers
- Abundant bandwidth
- Underline the Internet is optical networking
- What is WDM?
- Where are the bottlenecks?
- Architecture and protection
- Summary
- Backup slides
  - Underline technologies
  - Protection Rings

Fast Links, Slow Routers



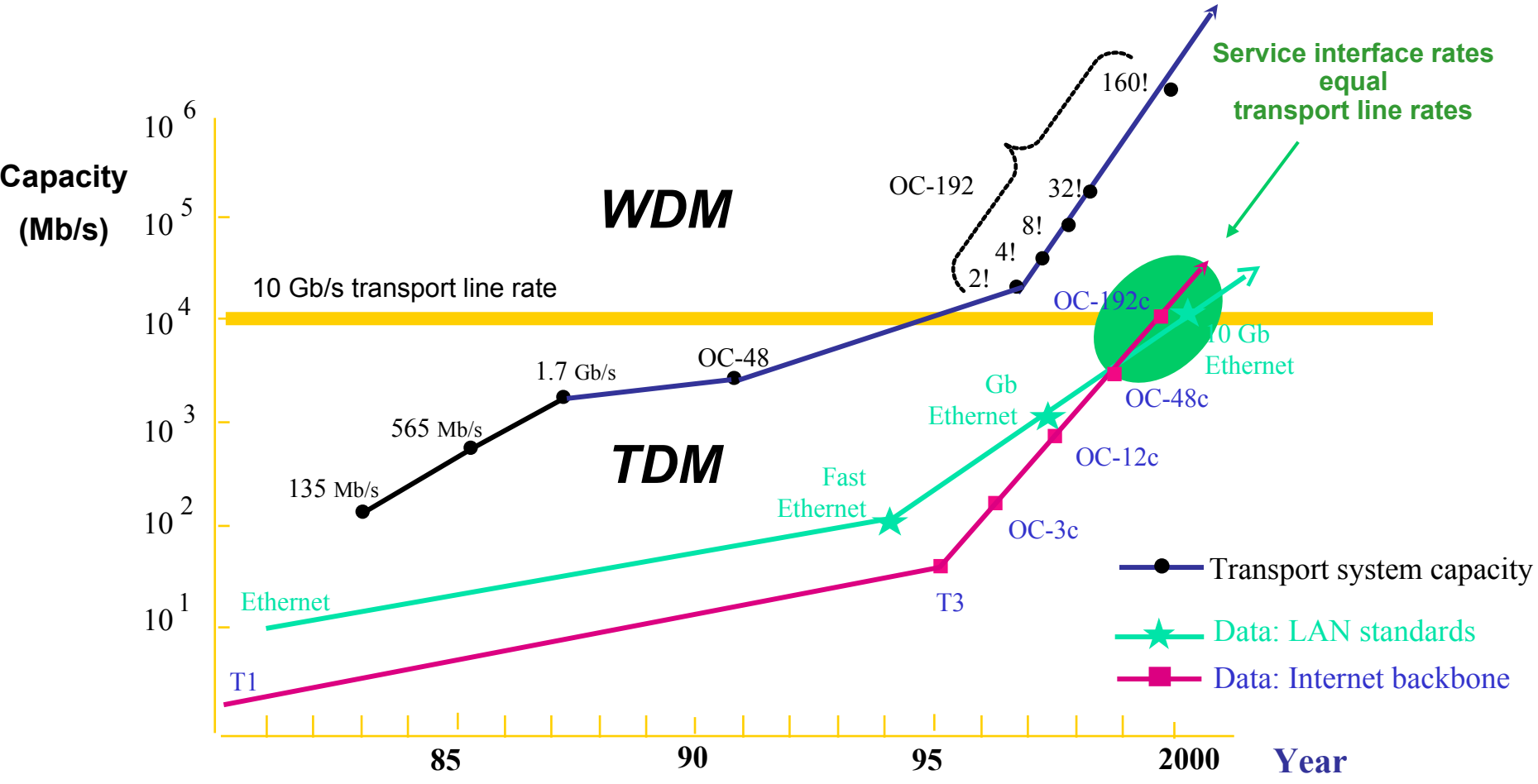
Source: Prof. Nike McKeown, Stanford

Fast Links, Slow Routers



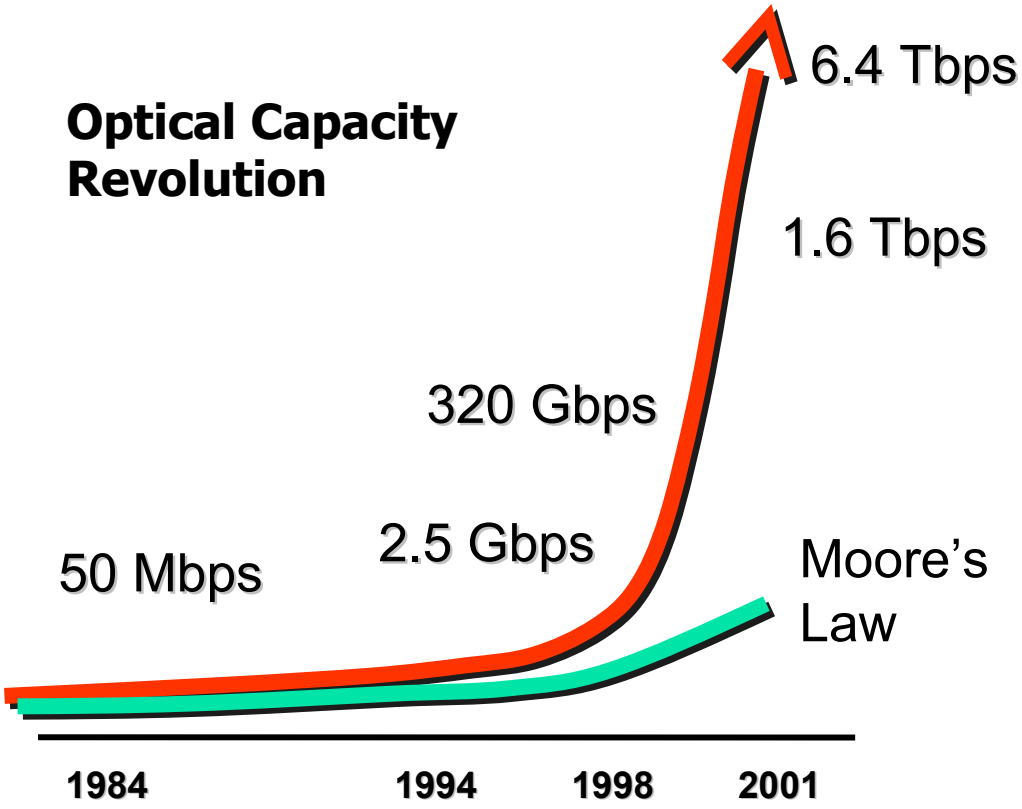
Source: Nike McKeown, Stanford

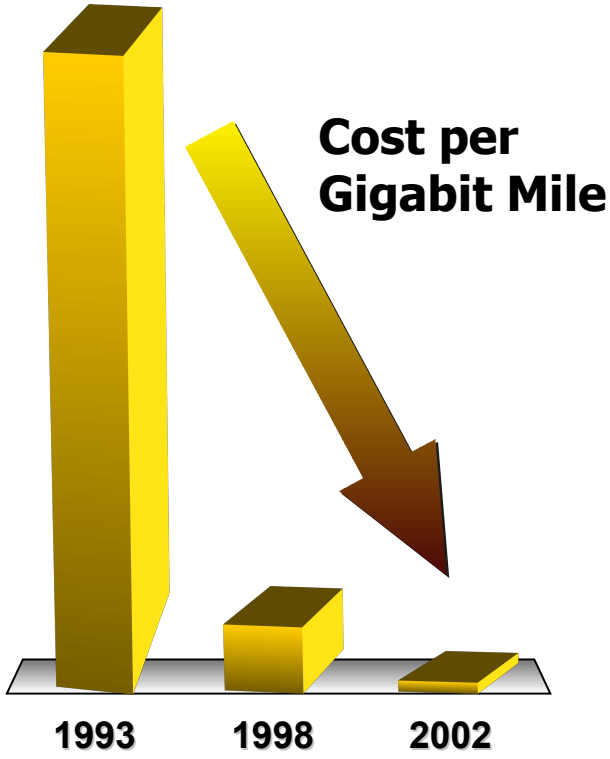
Evolving Role of Optical Layer



Source: IBM WDM research

Breakthrough...Bandwidth





Wavelengths will become the communications circuits of the future...

Source: Nortel marketing

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Abundant Bandwidth

Why does this change the playground?

- Optical core bandwidth is growing in an order of magnitude every 2 years, 4 orders of magnitude in 9 years
  - 1992 – 100Mbs (100FX, OC-3)
  - 2001 – 1.6Tbs (160 DWDM of OC-192)
  - OC-768 (40Gbs) on single ! is commercial (80Gbs in lab)
- 2-3 orders of magnitude bandwidth growth in many dimensions
  - Core – Optical bandwidth - (155mb/s ! 1Tb/s)
  - Core Metro – DWDM optical aggregation – (2.4Gb/s ! N*10Gb/s)
  - Metro – Access for businesses (T1 ! OC3, 100FX, 1-Gb/s)
  - Access – Cable, DSL, 3G – (28kb/s! 10mb/s, 1.5mb/s, 384kb/s)
  - LAN – (10mbp/s ! 10Gbp/s)

Why Does This Matter?

- How do these photonic breakthroughs affect us?
- This is a radical change to the current internet architecture
- WAN starts to be no longer the bottleneck
  - How congestion control/avoidance affected?
  - Why DiffServ if you can get all the bandwidth that you need?
  - Why do we need QoS?
  - Why do we need cache? (if we can have big pipes)
  - Where to put the data? (centralized, distributed)
  - What changes in network architecture needed?
  - What changes in system architecture needed?
  - Distributed computing, central computing, cluster computing
  - Any changes to the current routing?

Bandwidth is Becoming Commodity

- Price per bit went down by 99% in the last 5 years on the optical side
  - This is one of the problems of the current telecom market
- Optical Metro – cheap high bandwidth access
  - $1000 a month for 100FX (in major cities)
  - This is less than the cost of T1 several years ago
- Optical Long-Haul and Metro access - change of the price point
  - Reasonable price drive more users (non residential)

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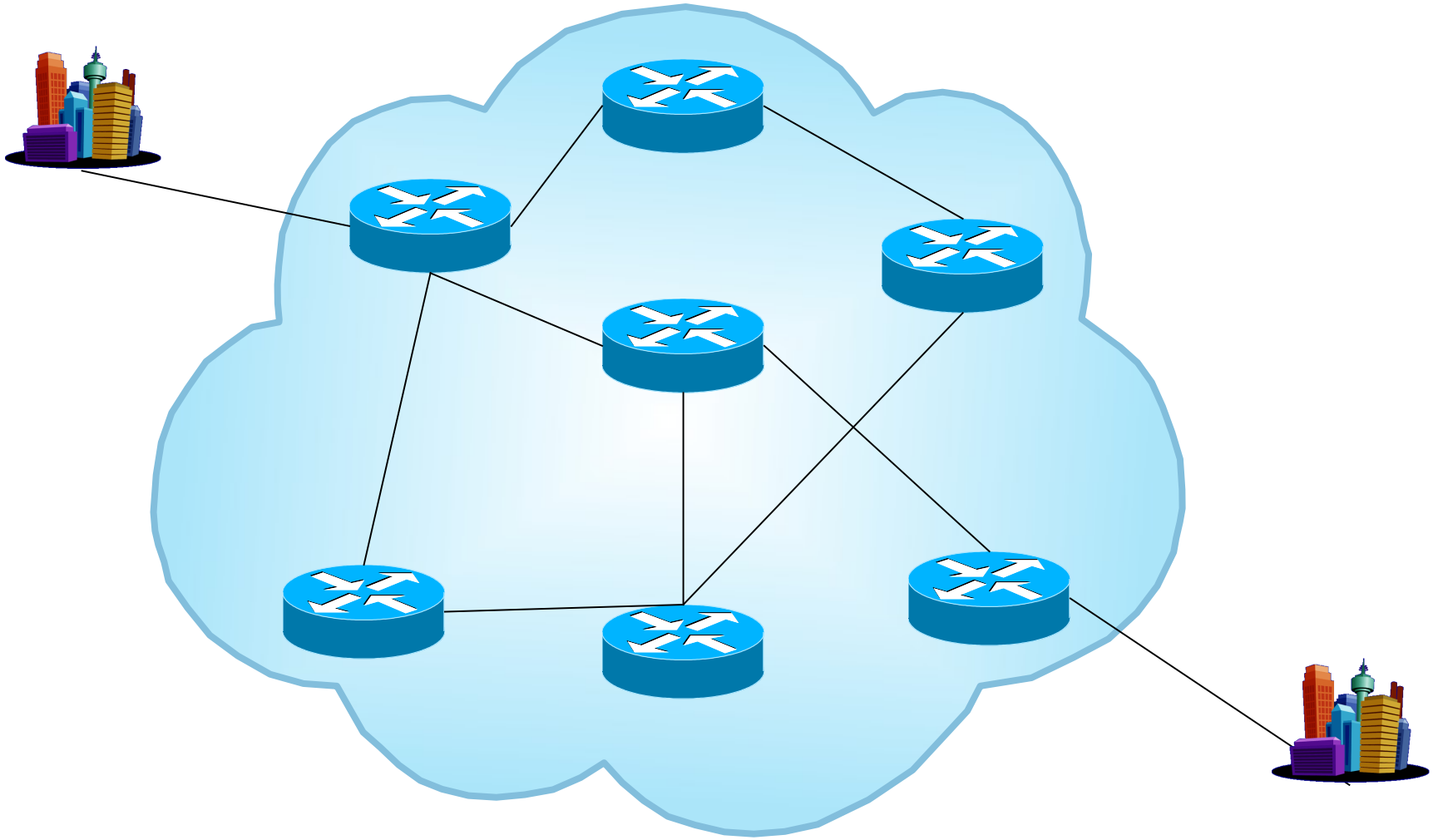
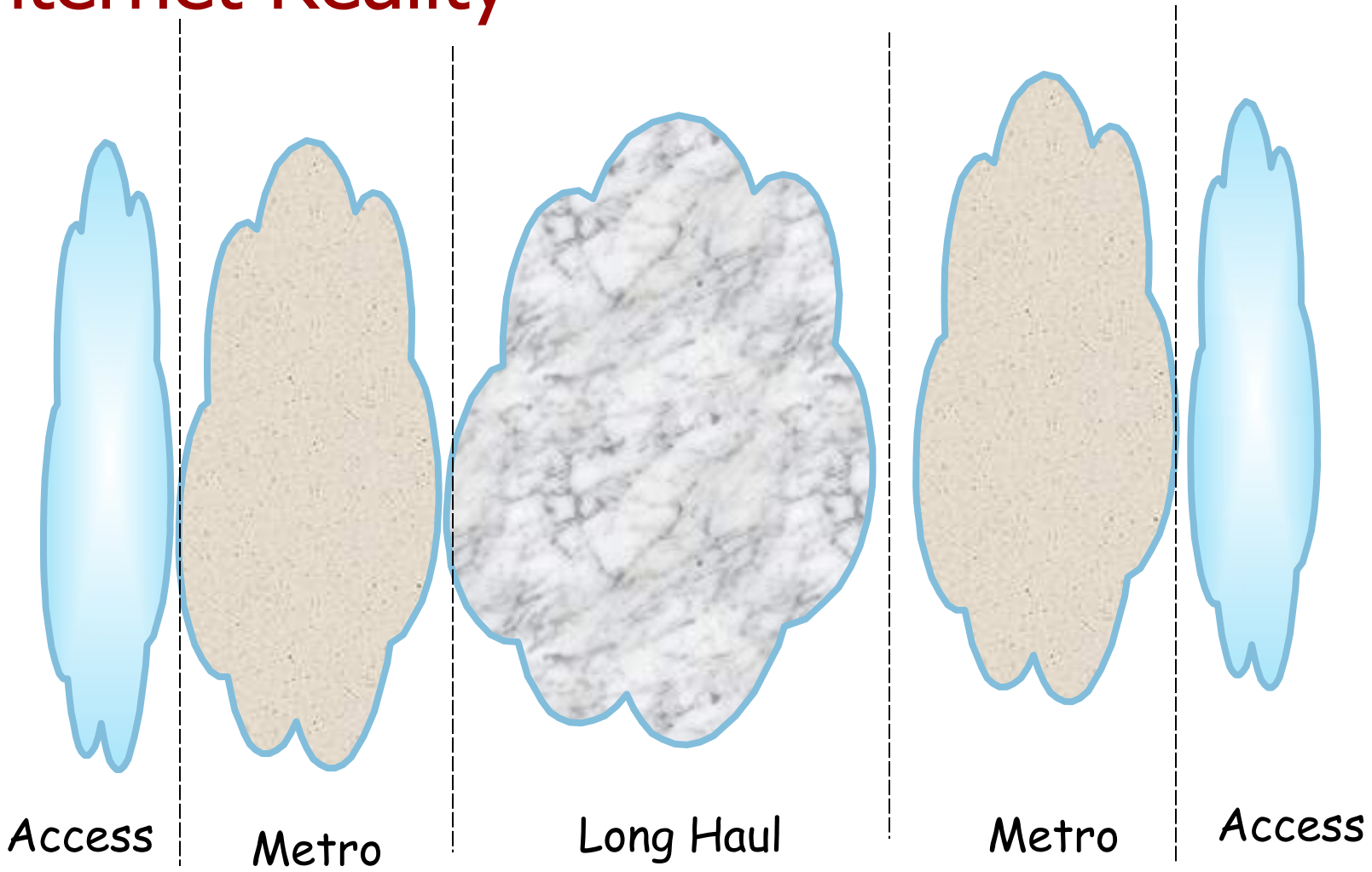
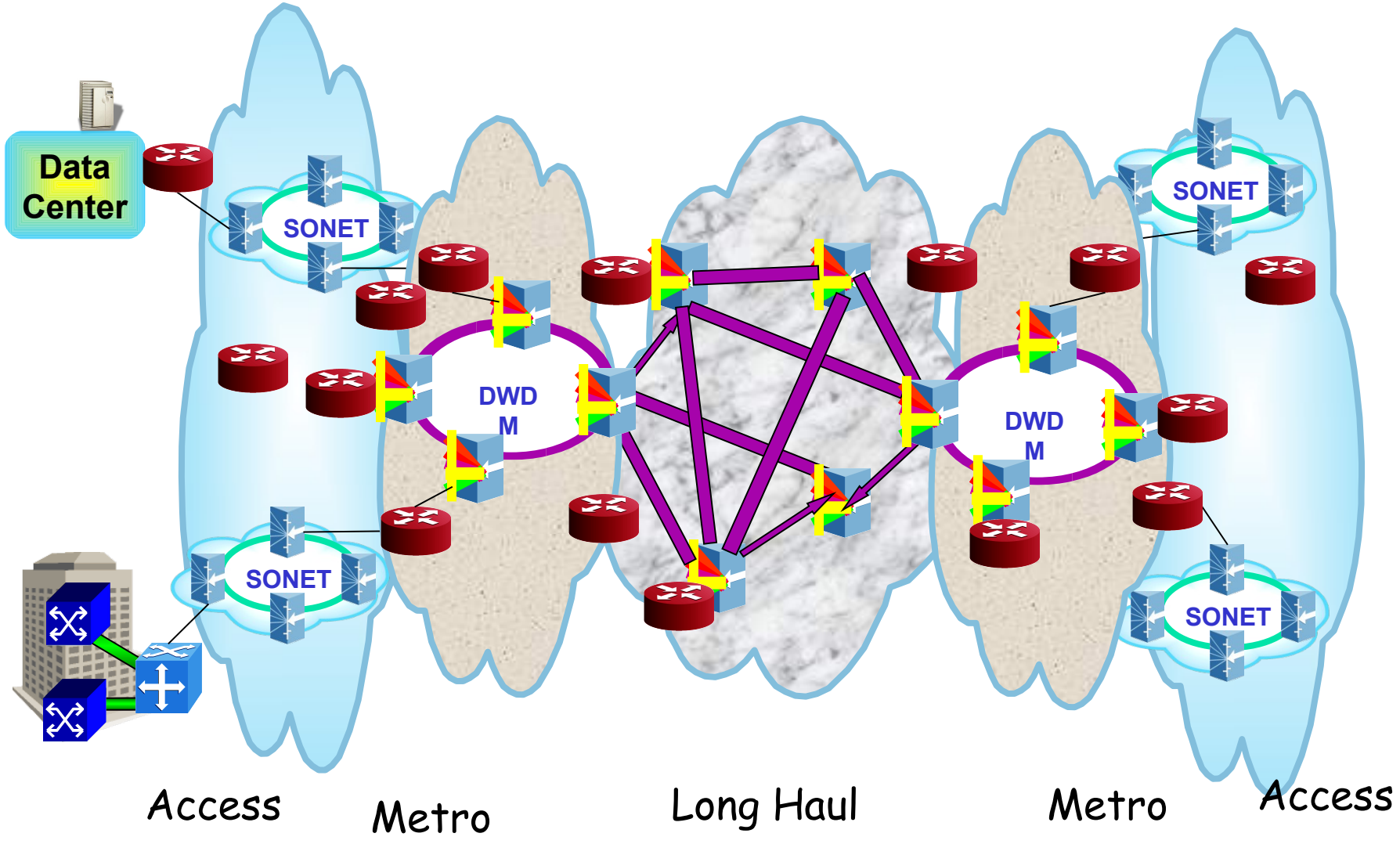
Our Concept of the Internet



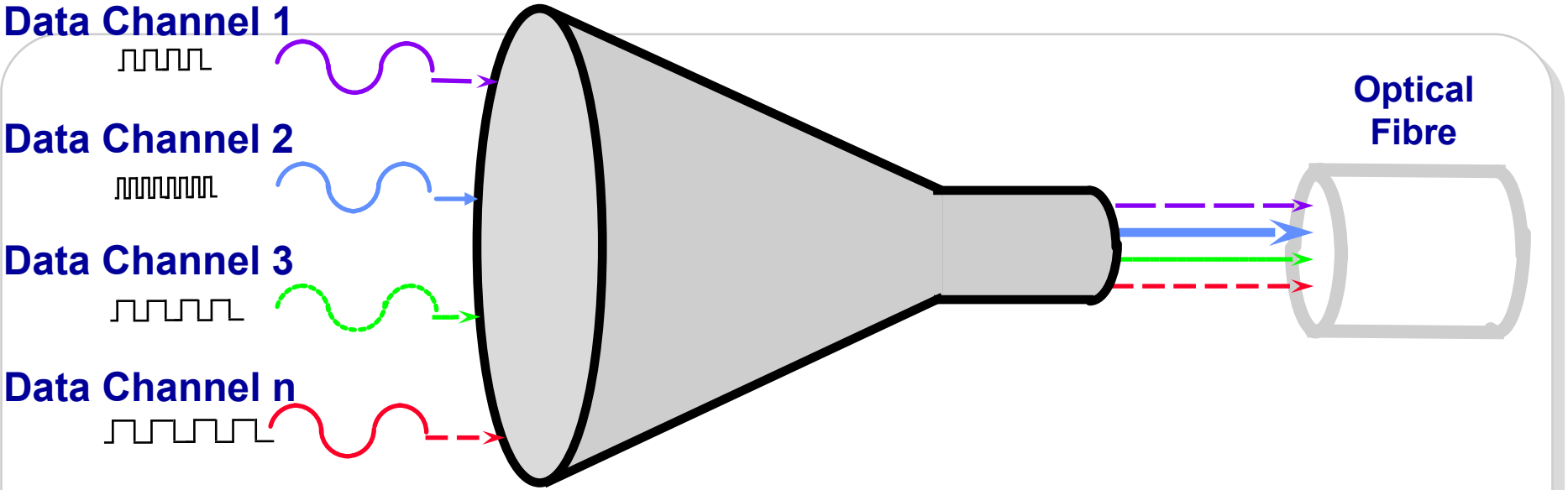
Internet Reality



Internet Reality



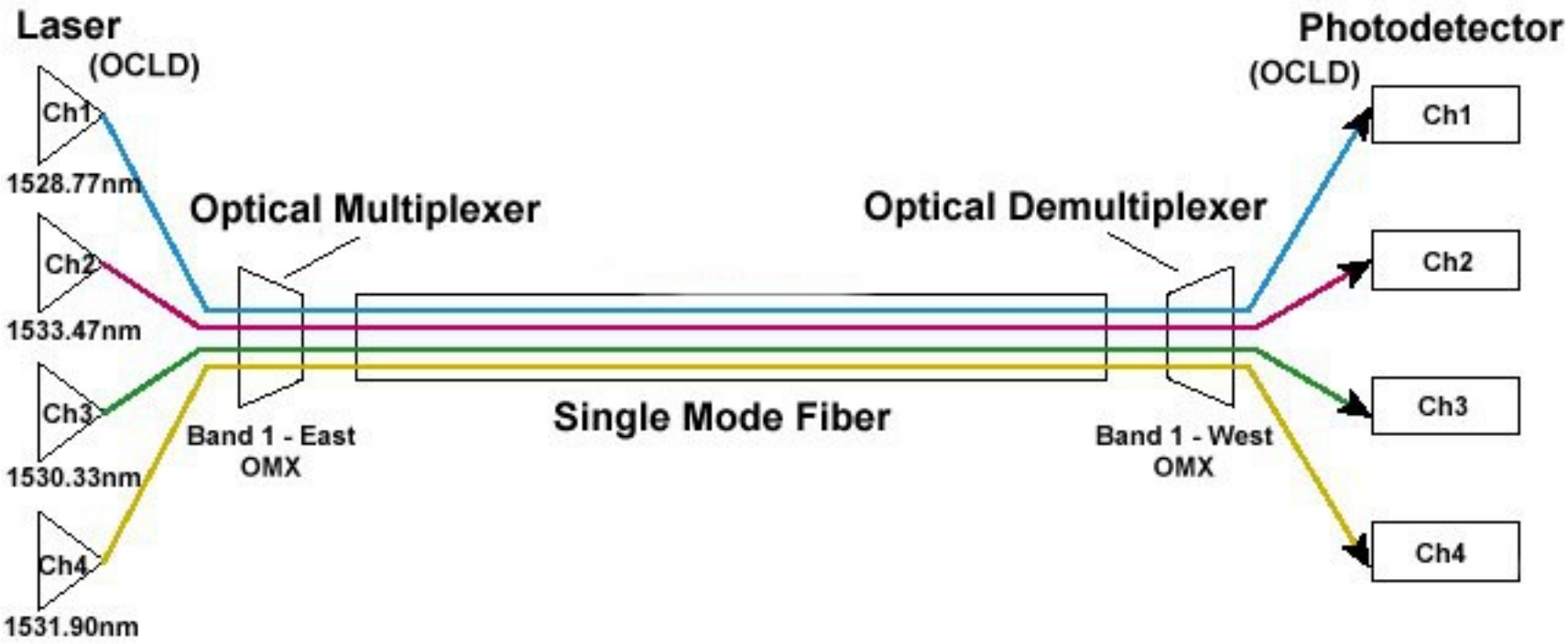
What is WDM?



Wavelength Division Multiplexing (WDM) acts as "optical funnel" using different colors of light (wavelengths) for each signal

Source: Prof. Raj Jain Ohio U

Wavelength Division Multiplexing



Source: ??

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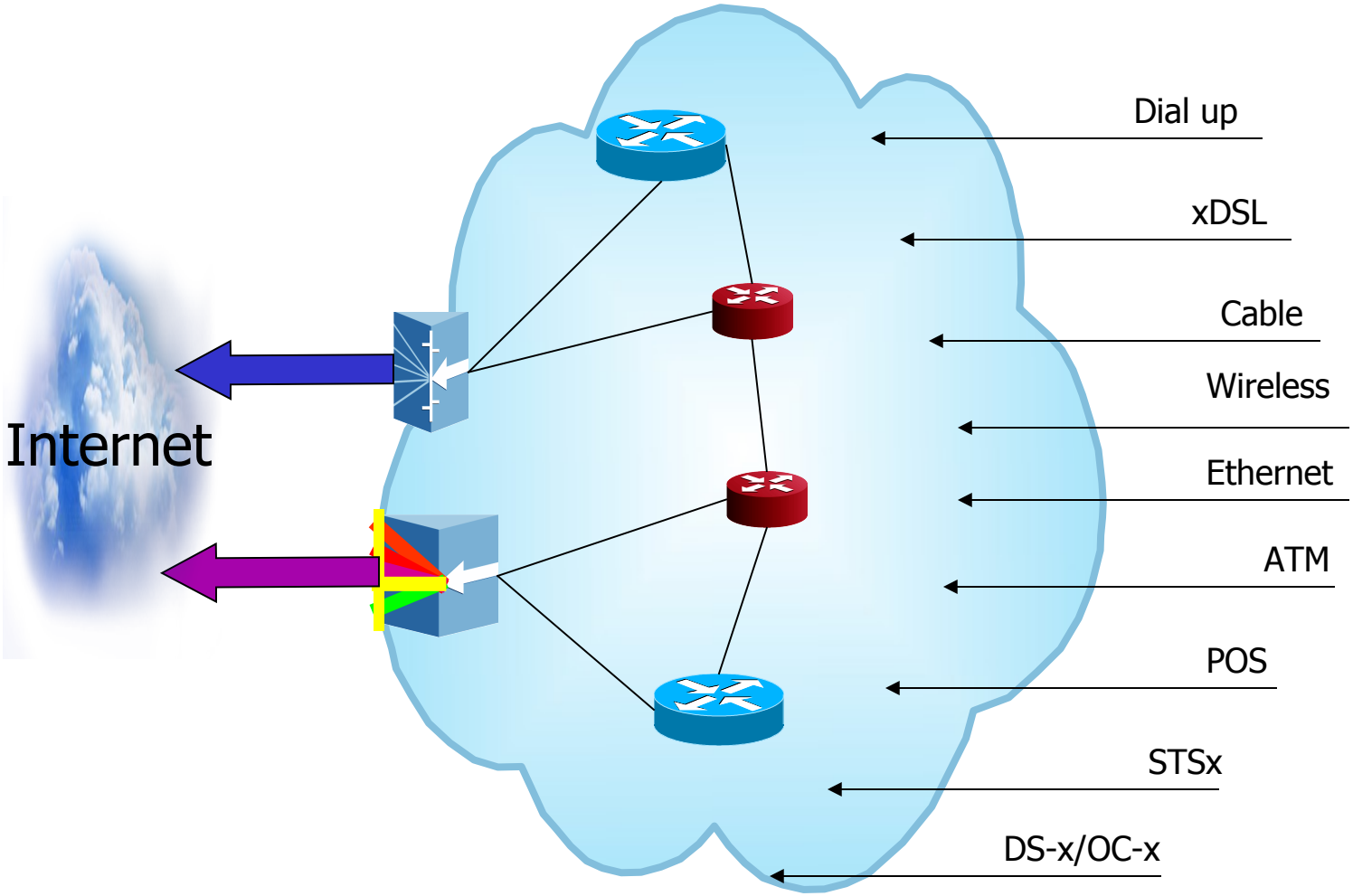
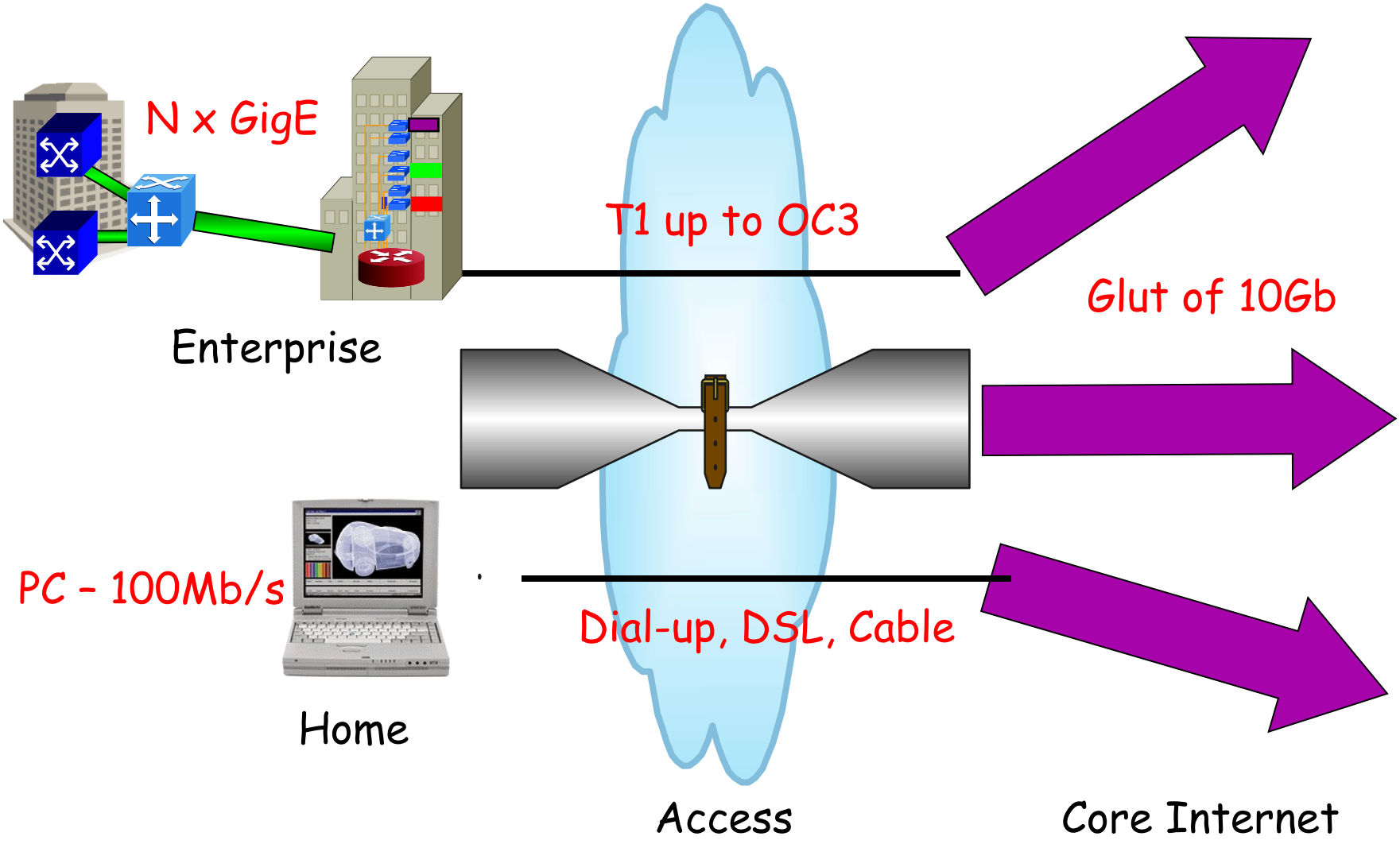
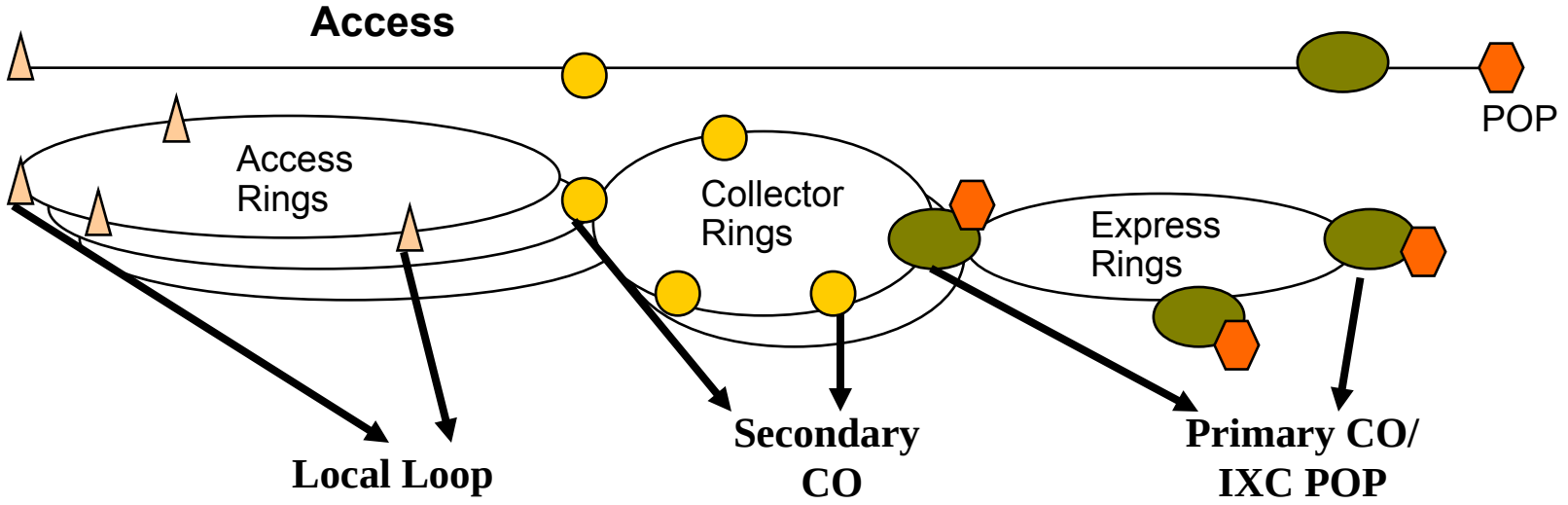
The Access


Internet
Dial up
xDSL
Cable
Wireless
Ethernet
ATM
POS
STSx
DS-x/OC-x

The Access Bottleneck



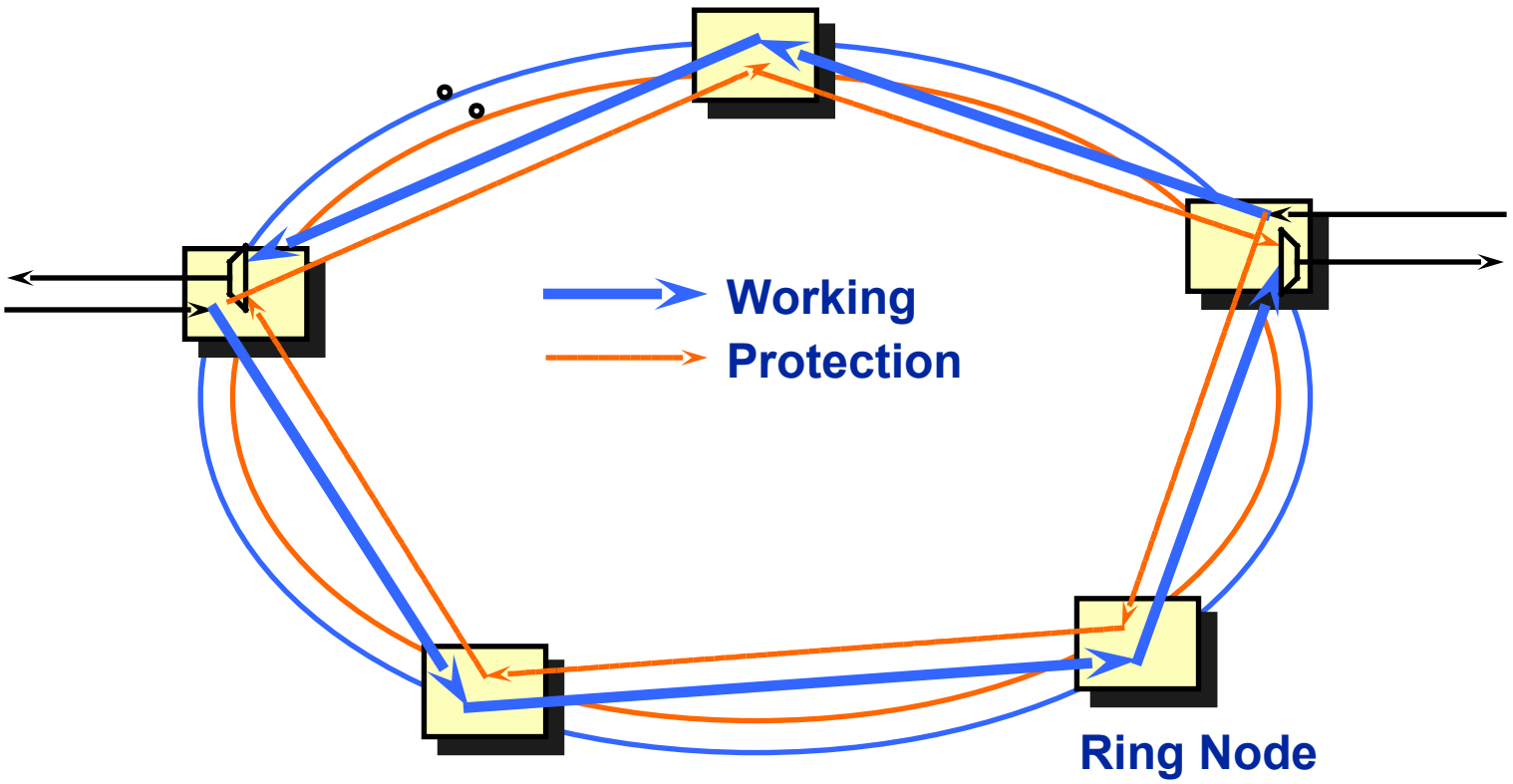
Characteristics of Metro Network Centers



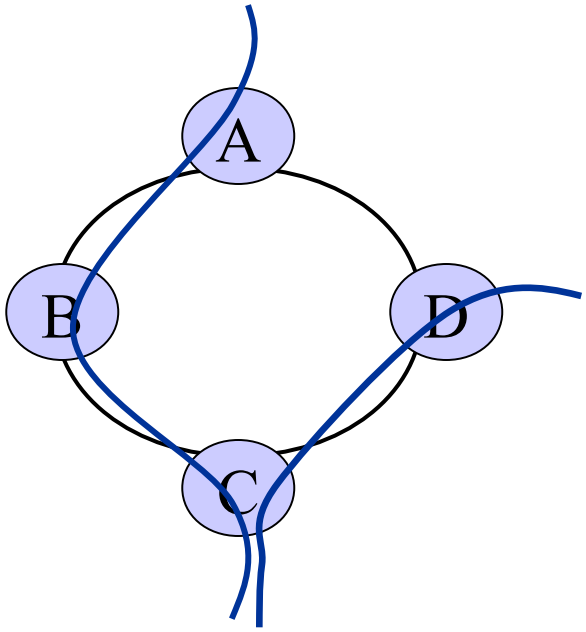
	Access	Interconnect: DS1/EC-1 BWM level: DS1/VT1.5 Mapped Nodes: 5-10%	Metro Core	Interconnect: DS3/OC-n BWM level: DS3/STS1 Mapped Nodes: 0-5%	Long Haul
Distance between nodes	0-10Km		5-10Km		5-120Km
# of fibers/conduit	12-36		12-144		12-144
# of sites passed	1-10				
# of nodes /ring	2-4		4-8		4-8
SONET Rates	OC-1/3/12		OC-12/48		OC-48/192
Topologies	Pt-pt, 2f UPSR		Pt-pt, 2f UPSR, BLSR		Pt-pt, 2f BLSR, DWDM
Traditional Interfaces	DS1, DS3		DS1, DS3		DS3, OC-n

Source: Nortel's Education

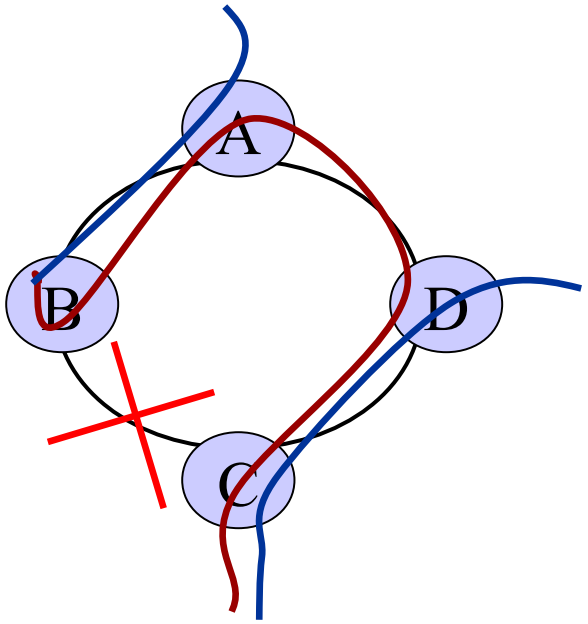
Unidirectional path switched rings



Protection example



Idle Ring



Protected Ring

If we had the bandwidth…

- What if we all had 100Mb/s at home?
  - Killer apps, other apps, services
  - Peer-to-peer video swapping
  - Is it TV, HDTV, something else?
- What if we had larger pipes at businesses?
  - 1Gbs home office, 10GE/DWDM large organizations
- How would the network architecture look, if we solve the last mile problem?

Summary_

- DWDM – phenomenal growth
- Abundant bandwidth
- Underline optical technologies
- The access is still bottleneck
- Reliability and protection

"Blindsided by Technology"

- When a base technology leaps ahead in a dramatic fashion relative to other technologies, it always reshapes what is possible
- It drives the basic fabric of how distributed systems will be built

It blindsides us all...

Source – Nortel's marketing

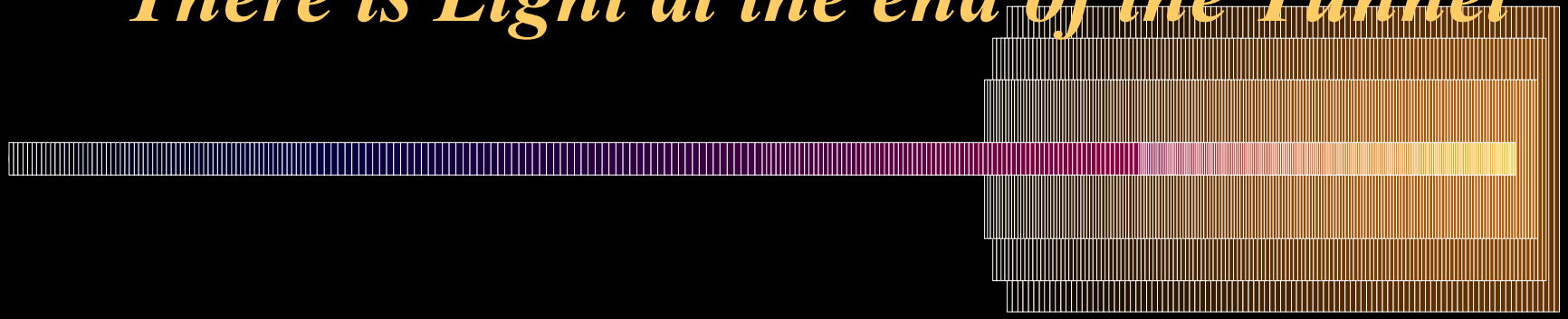
References

- Cisco optical site
- www.nortelnetworks.com
- www.lucent.com
- IBM optical research
- IETF
- OIF
- Stanford – Prof. Nick McKeown
- Ohio U – Prof. Raj Jain

The Future is Bright

- **Imagine the next 5 years.**

There is Light at the end of the Tunnel

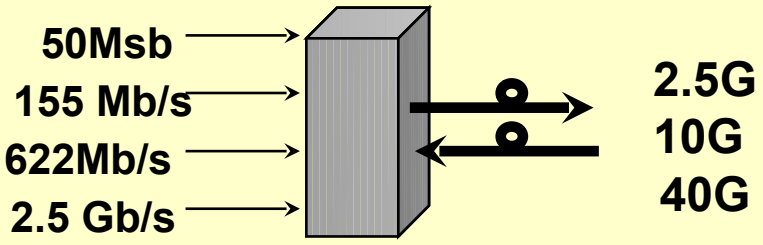


Backup Slides

DWDM underline technologies

- Wavelength – a new dimension growth
- Optical multiplexing
- Regenerators and Amplifiers
- WDM system benefits
- Filters
- Ad Drop Multiplexes

Multiplexing Options



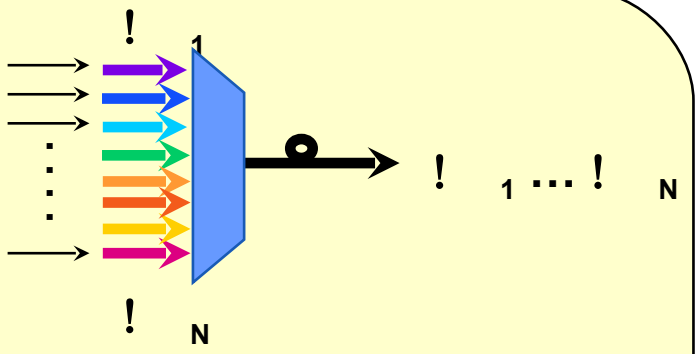
TDM

Electrical multiplexing

- 50Mb/s to 10Gb/s data services

Electrical bandwidth management

- flexible trib to aggregate time slot allocation
- flexible aggr. to aggr. time slot allocation
- flexible trib to trib connection



WDM (or DWDM)

Optical Multiplexing

- Up to 160 wavelengths today
- 2.5G, 10G, & 40G per !

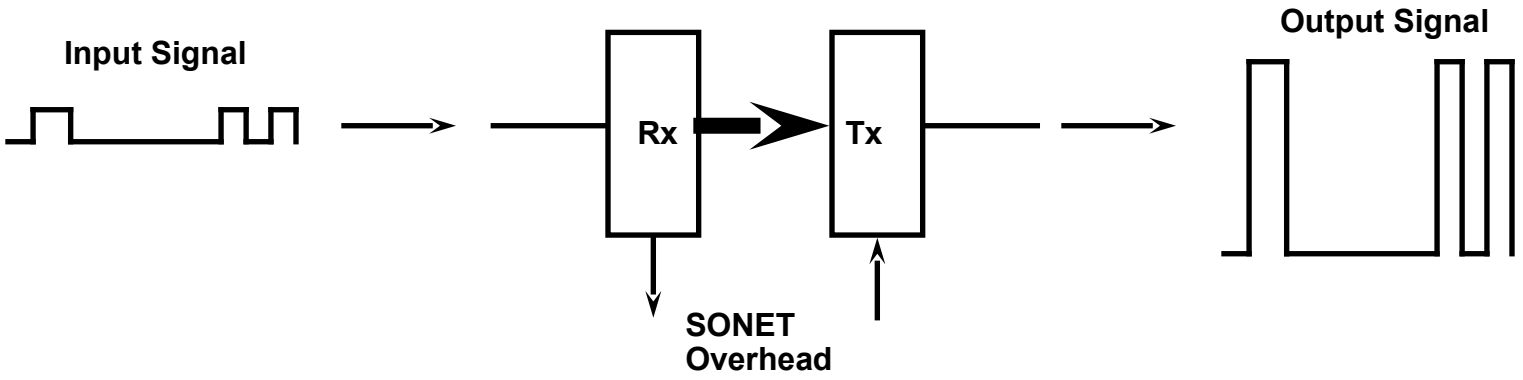
Optical bandwidth management

- Wavelength add & drop

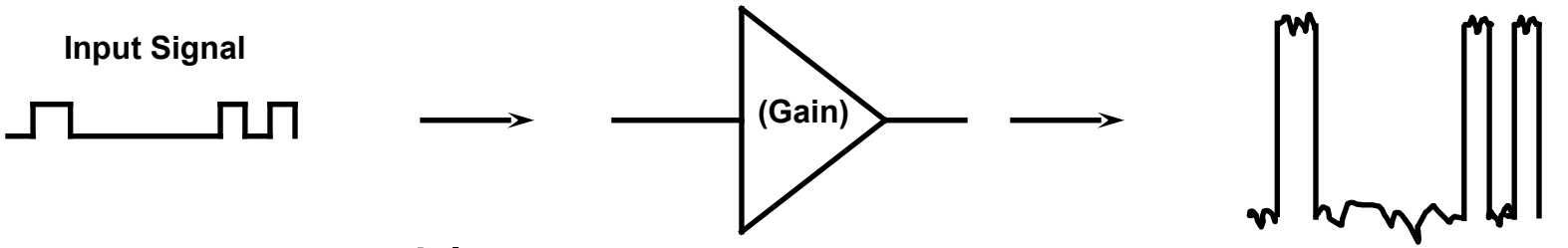
Total Capacity = TDM x WDM

Regens and Optical Amps

Regenerator



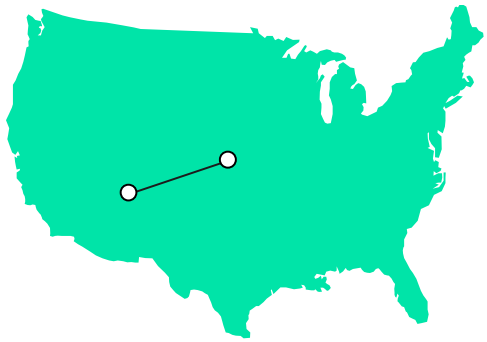
Optical Amplifier

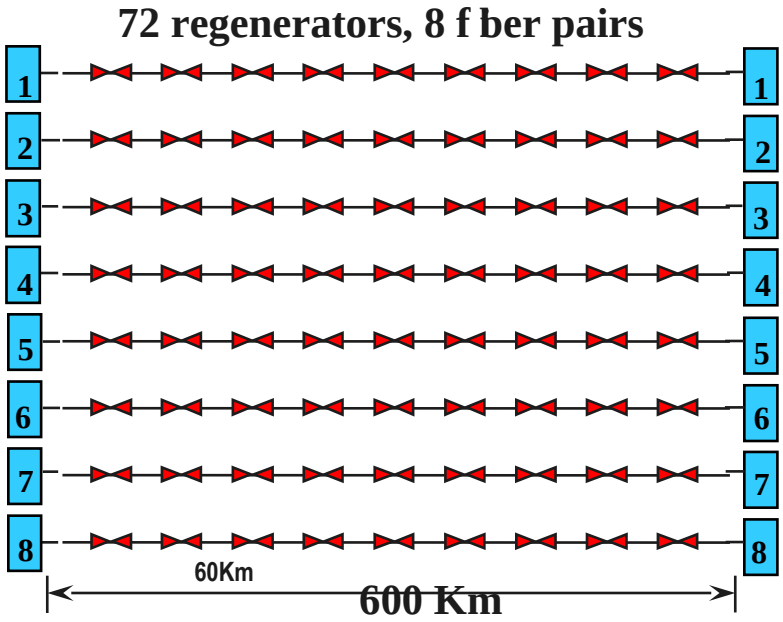


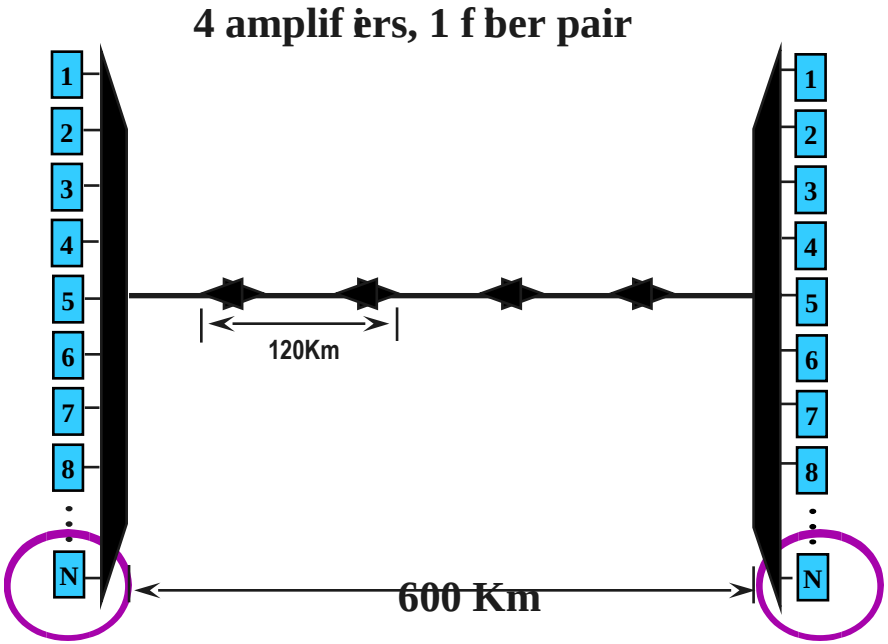
- Problems
  - Noise injected with each amplifier
  - No access to SONET overhead (transparent)

WDM System Benefits

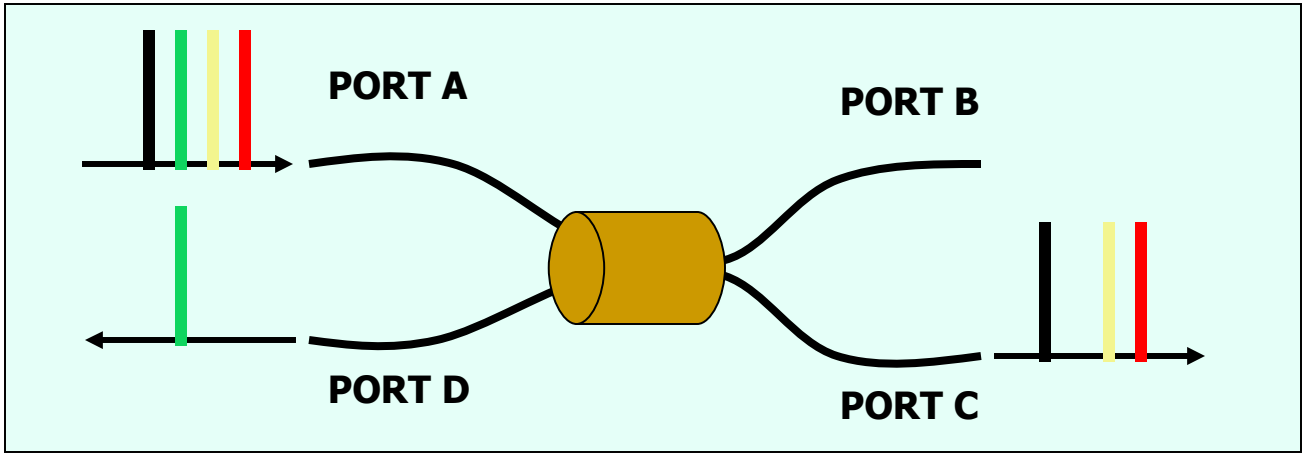
- **Lower equipment cost**
- **Lower operating cost**
- **Increased f ber capacity**
- **Shorter turn-up time**

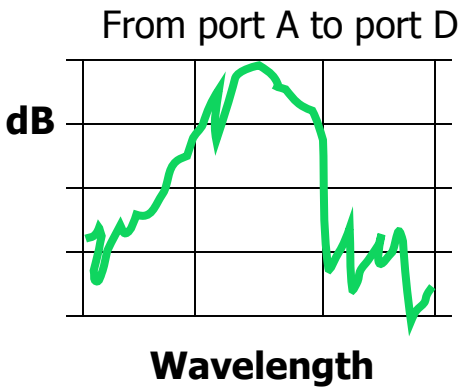


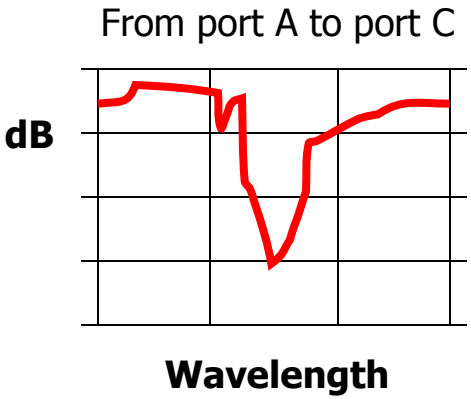




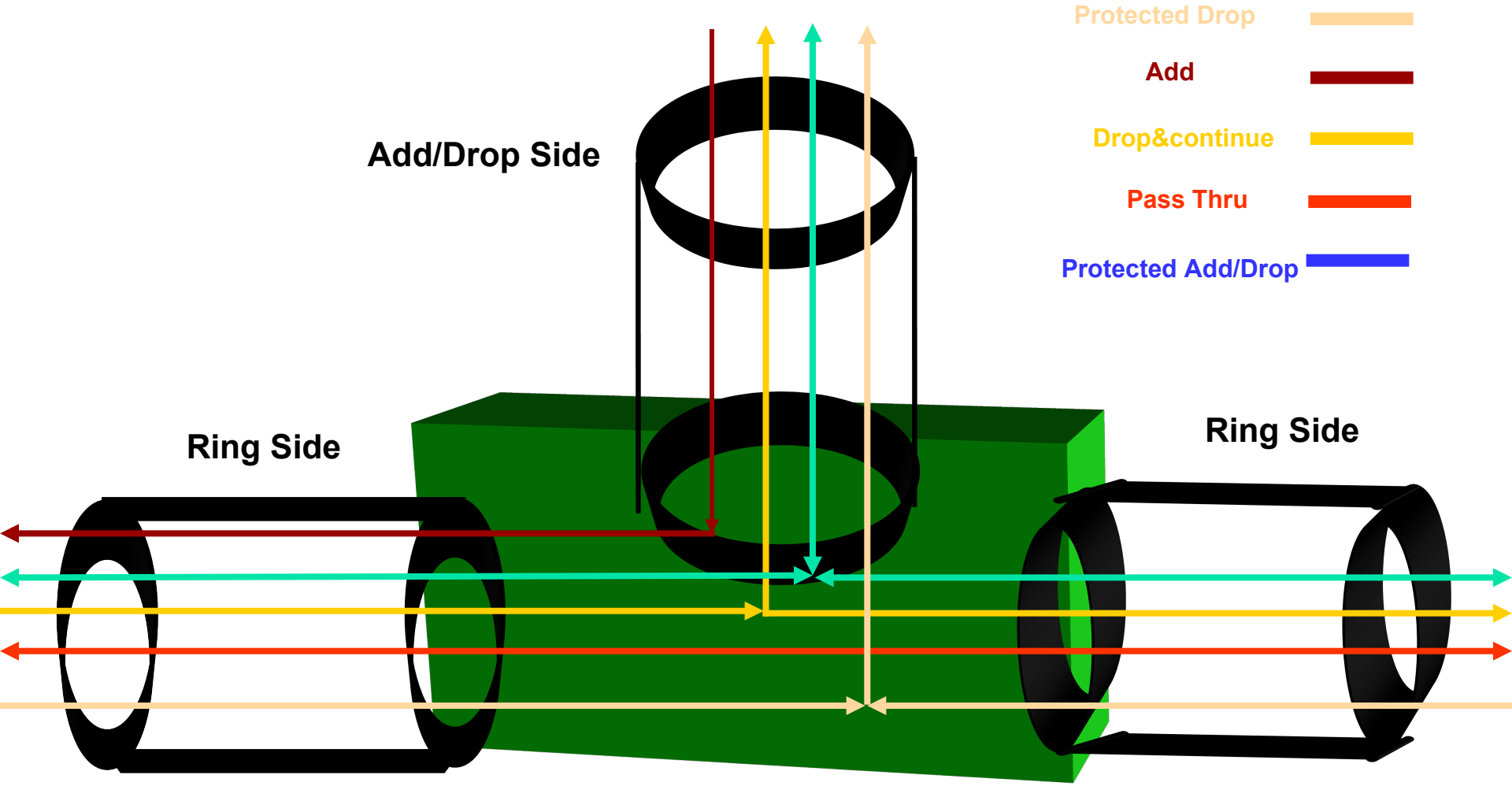
Fiber-Bragg Gratings







Add Drop Multiplexer

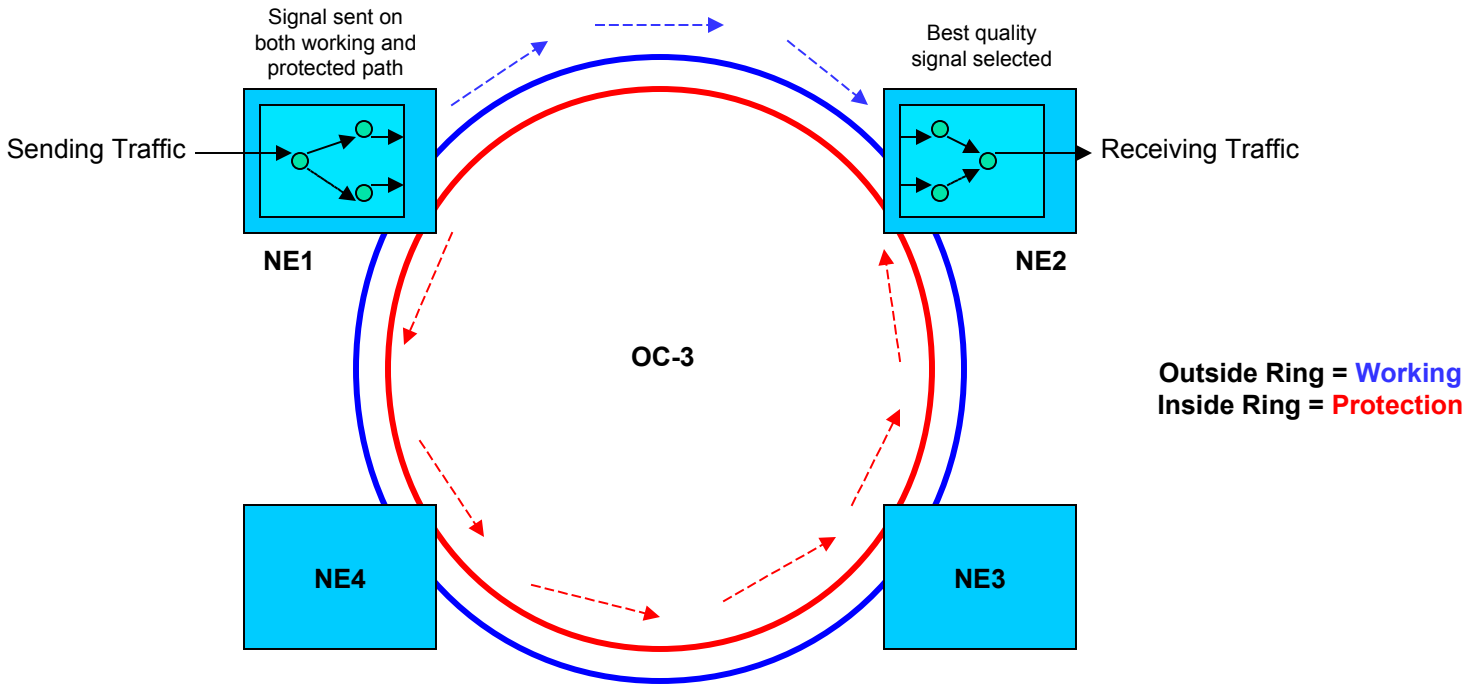


Common Protection Rings

- UPSR (Unidirectional Path Switched Ring)
- BLSR (Bidirectional Line Switched Ring)
- BLSR/4 (4-Fiber, Bidirectional Line Switched Ring)

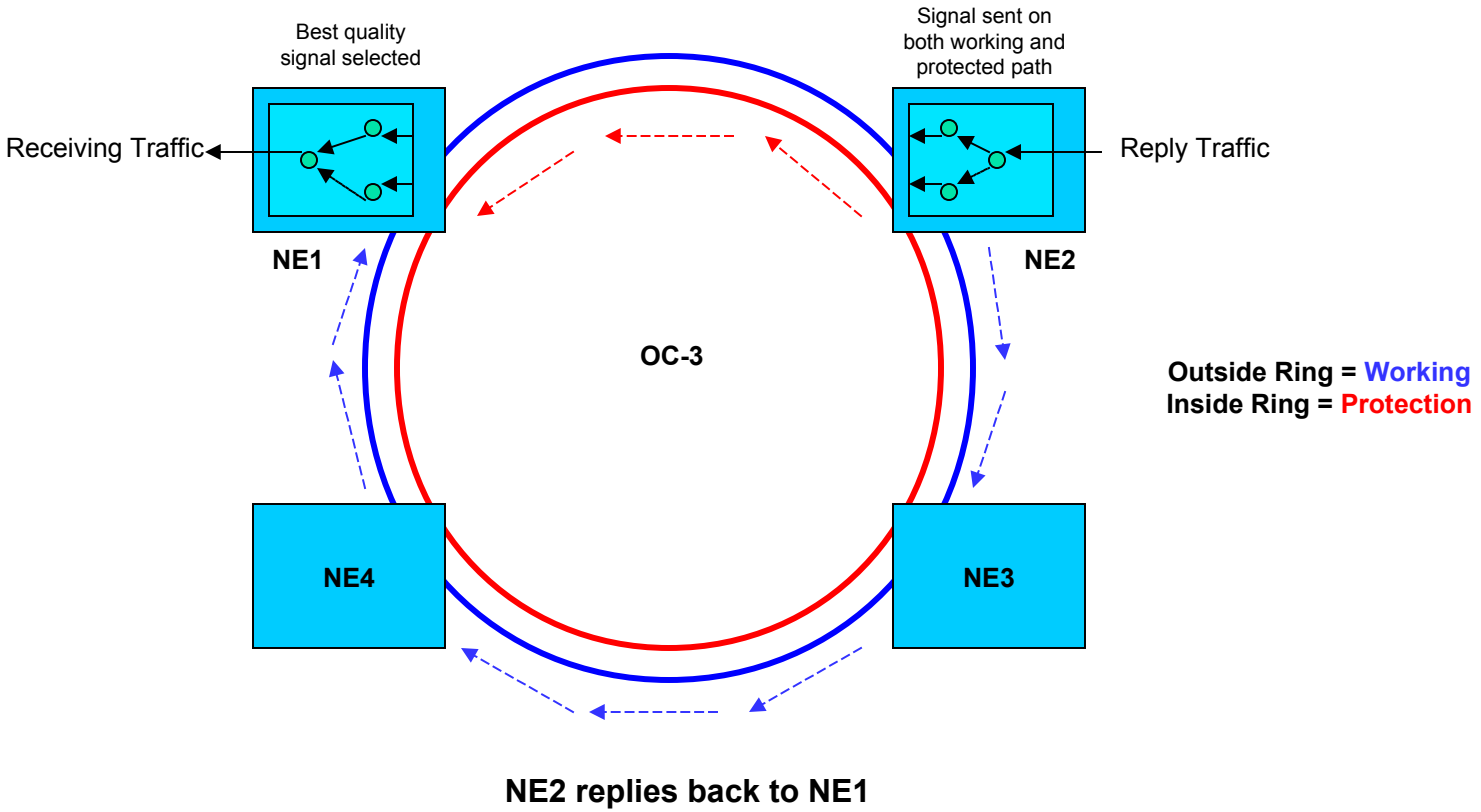
Source: "SONET – Second Edition"

UPSR – Unidirectional Path Switched Ring

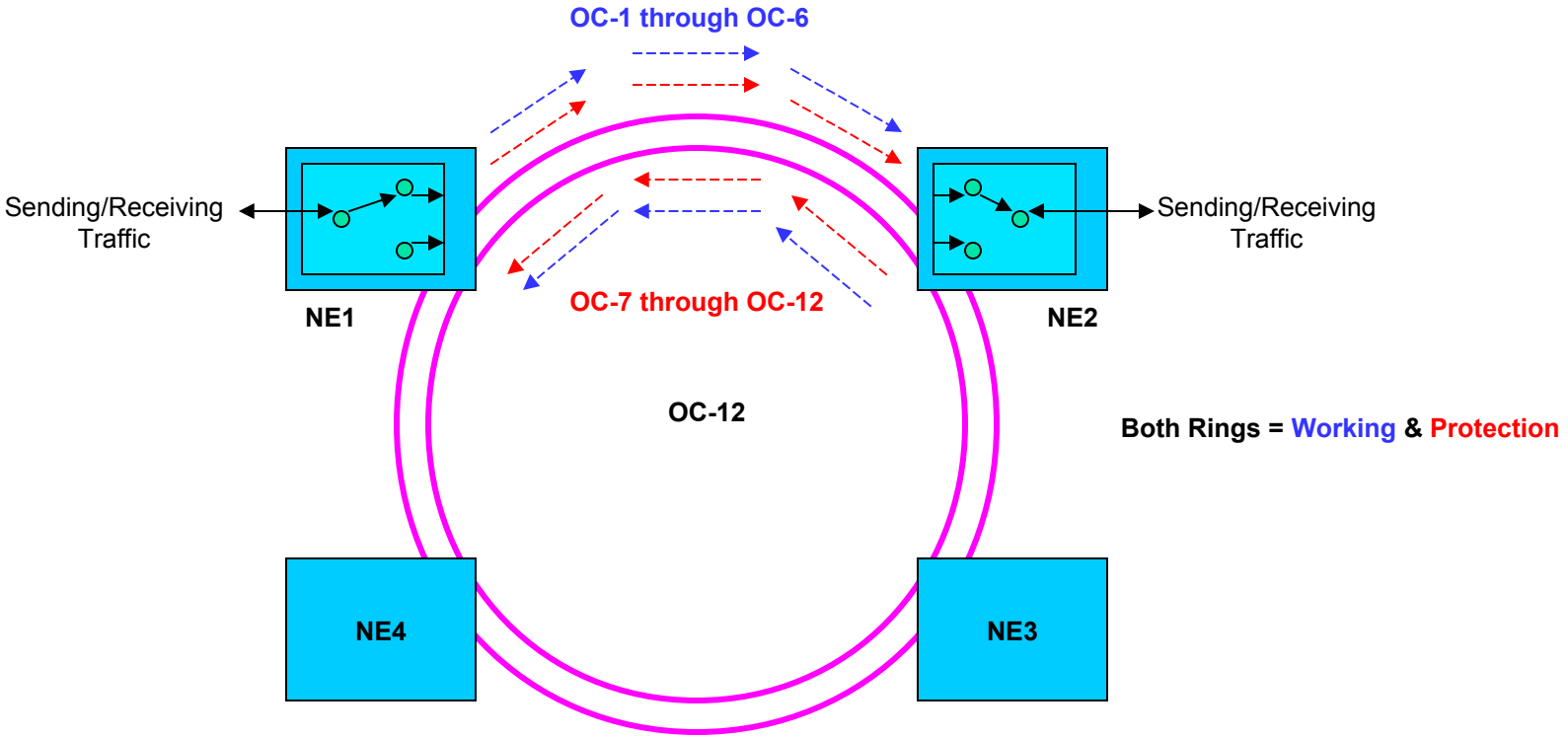


NE1 send data to NE2

UPSR – Unidirectional Path Switched Ring

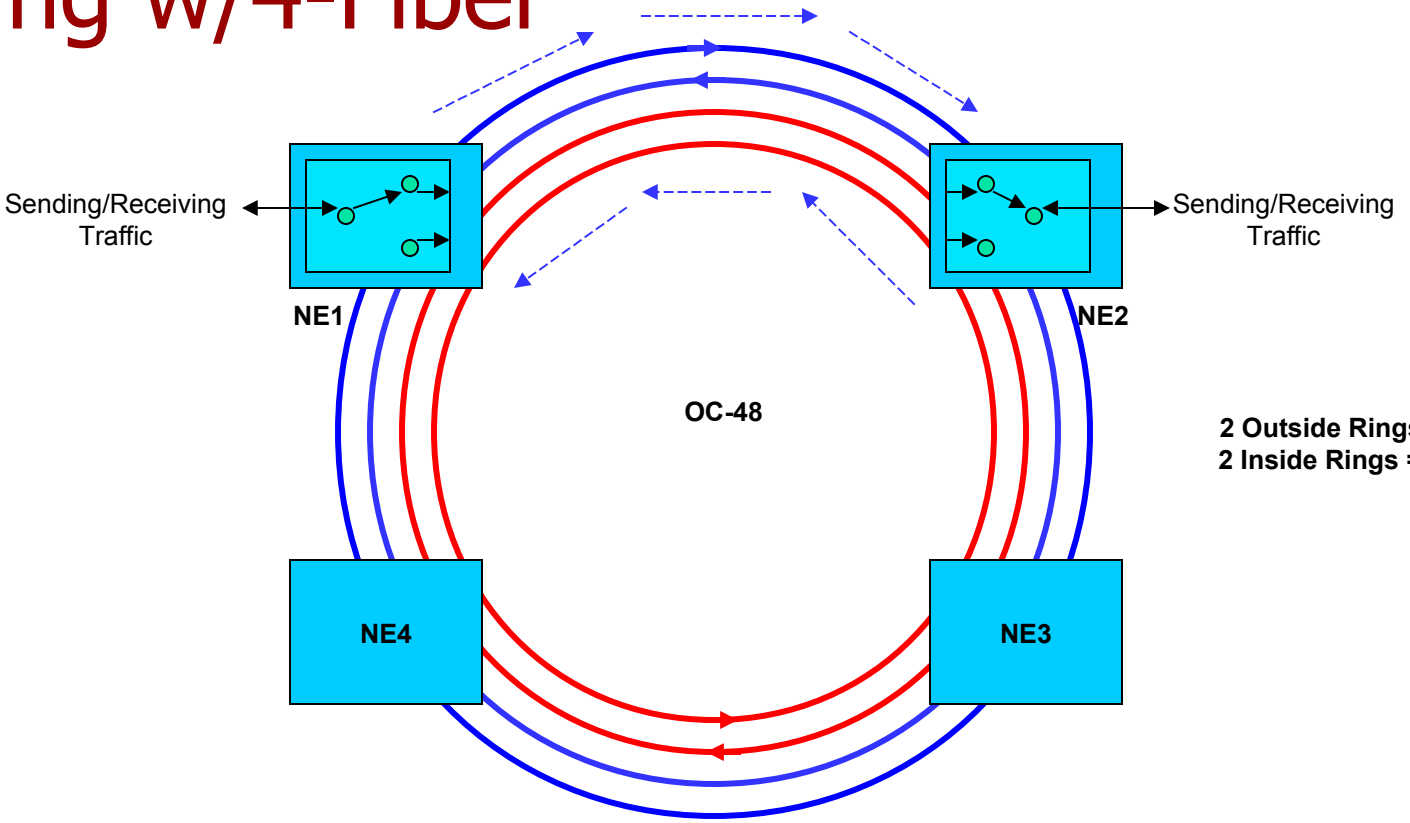


BLSR – Bidirectional Line Switched Ring



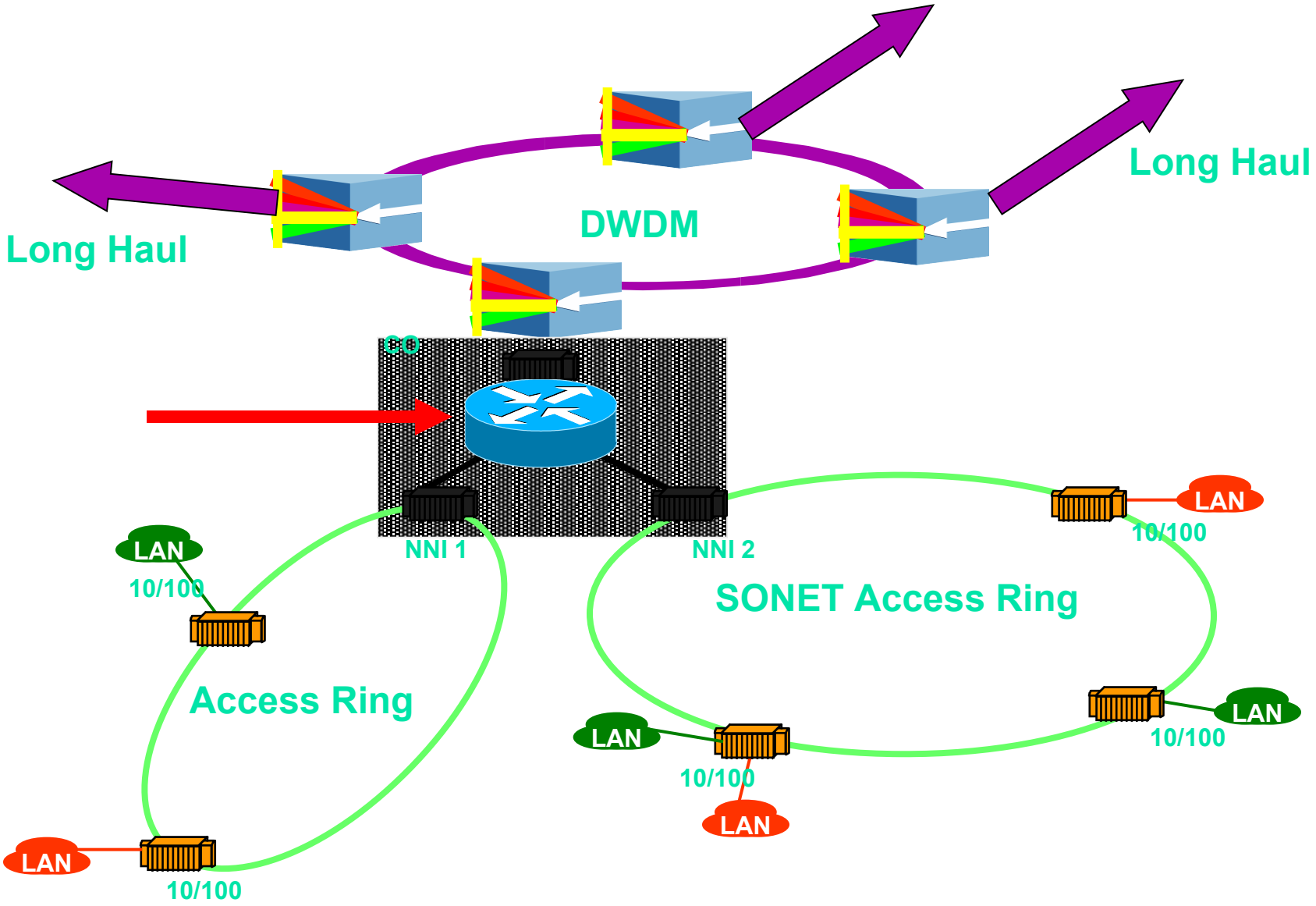
NE1 send data to NE2 & NE2 replies to NE1

BLSR/4 – Bidirectional Line Switched Ring w/4-Fiber

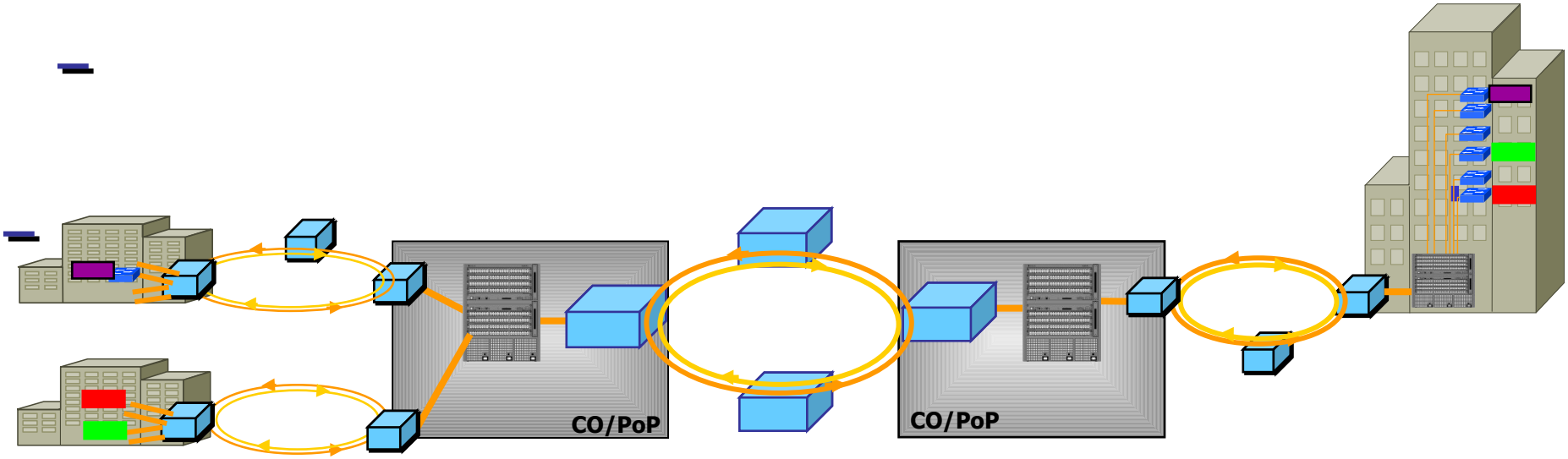


NE1 send data to NE2 & NE2 replies to NE1

Example of a new Bottleneck



Access and Metro Networks?



OC-3/OC-12 Access rings

OC-48/OC-192/Metro Backbone Rings

OC-3/OC-12 Access rings

Recent DWDM Records

- 32l x 5 Gbps to 9300 km (1998)
- 64l x 5 Gbps to 7200 km (Lucent'97)
- 100l x 10 Gbps to 400 km (Lucent'97)
- 16l x 10 Gbps to 6000 km (1998)
- 132l x 20 Gbps to 120 km (NEC'96)
- 70l x 20 Gbps to 600 km (NTT'97)
- 128l x 40 Gbps to 300 km (Alcatel'00)
- 1022 wavelengths on one fiber (Lucent'99)

Ref: Optical Fiber Conference 1996-2000 (Raj Jain)