METRO OPTICAL NETWORKS: PAST, PRESENT, and FUTURE.

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THE INTRODUCTION OF OPTICAL TRANSMISSION IN TELECOMMUNICATIONS.

- Initial application for optical transmission started in the late 1970s and were to replace wireless long haul transmission systems. These were point to point and required electrical regeneration.

- EDFA amplifiers, introduced in the 1980s, replaced electrical regenerators while Wavelength Division Multiplexing increased bandwidth capacity.

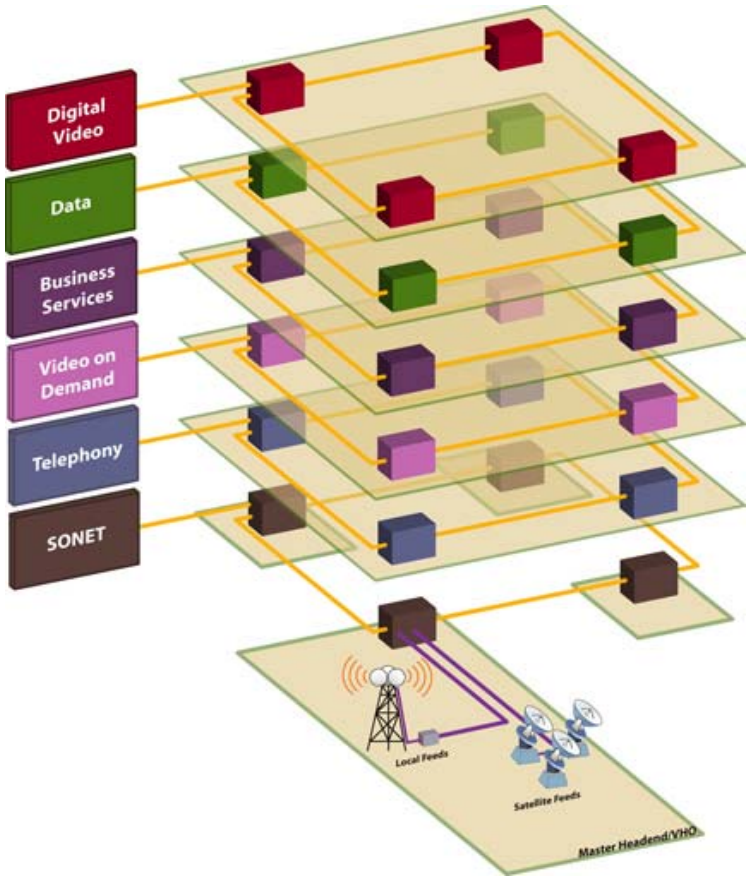
- Some systems for Metropolitan applications were developed using these technologies in the 1990s but were not successful.

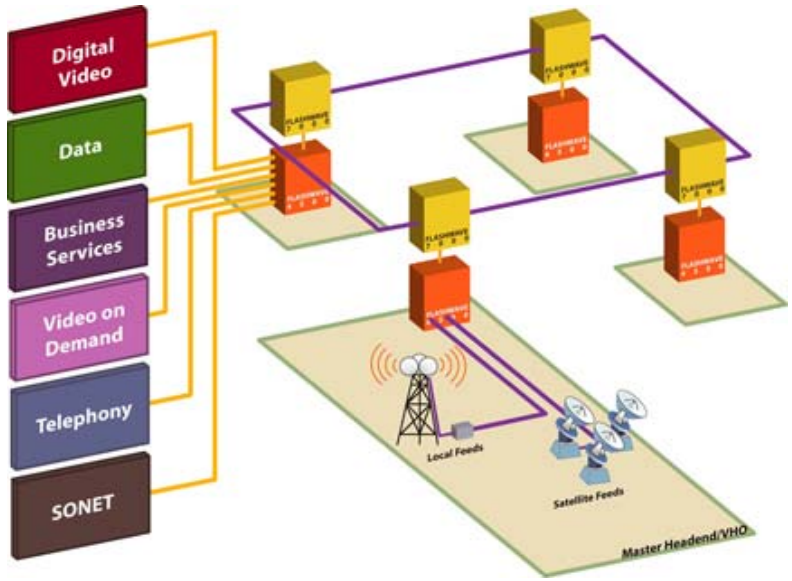
- Metropolitan systems have very different requirements from Long Haul.
  - Ring capability
  - Adding and dropping of wavelengths
  - Low cost
  - Simple to plan and use.

- New technologies in the late 1990s such as low cost amplifiers, thin film filters, and fiber Bragg gratings enabled systems to be developed for Metro applications. However, limitations such as banding of wavelengths, and power variations when wavelengths were added and dropped made these systems difficult to plan and operate. These systems required manual intervention at every site making service changes were slow and expensive. Wavelength spacing on these systems was typically 200GHz resulting in low channel counts being supported and hence high costs.

As a result of these limitations, this first generation was not heavily deployed. SONET/SDH technologies continued to dominate the Metro Networks.

SONET/SDH Networks require separate overlaid networks for each service type ad wavelength of capacity.





With Metro Optical Networks many networks can be overlaid, each using its own dedicated wavelengths. Each can use different service types and be managed independently. Packet or TDM on any wavelength.

THE SECOND GENERATION OF METRO OPTICAL TRANSPORT SYSTEMS.

- Optical technologies continued to evolve at a rapid pace; devices were improved or developed to overcome the limitations of the first generation.

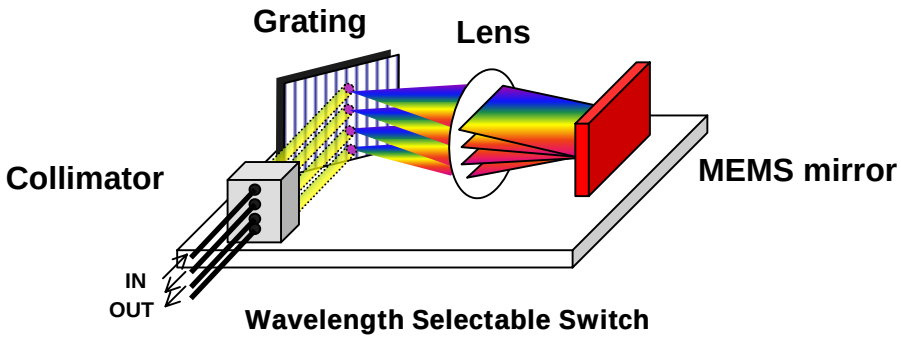
- Using these, a new generation of systems was developed in the early 2000s. The main features of this second generation were:
  - Removal of wavelength banding.
  - Closer channel spacing.
  - Switch fabrics that could reconfigure wavelengths without manual intervention.
  - Amplifier improvements that allowed changes to be made within a network without affecting other channels.

- These advances greatly improved span and traffic engineering thereby reducing operational costs and making the networks easy to plan and operate. These systems are called Re-configurable Add Drop Multiplexers (ROADMs).

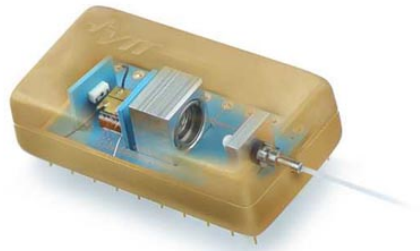
- Although improved, this generation still had limitations. In the US cable television companies adopted them as they didn't have existing SDH/SONET networks and they had simpler requirements than Telecommunications carriers. This generation also saw use in Private Enterprise rings and storage applications but market penetration although growing was still low.

This generation still was unable to break the hold of SONET/SDH transport products on the core networks of large telecomm companies.

- Wavelength Selectable Switches.
  - High wavelength operation
  - Any wavelength switching to any port
  - Multi degree operation - hubbing
- Full Band Tunable Lasers.
  - Colorless Operation.
  - Wavelength Conversion
    - Reduces blocking
  - Reduced inventory/spares.
- Flexponders
  - SONET/SDH ADM on a card.
  - Multi-Service Operation on a single card.
  - Ethernet/IP over a wavelength
- Advanced Amplifiers
  - Wide Dynamic Range.
  - Dynamic Gain Adjustment – better response to span loss change
  - Fast Transient Response on channel loss and fiber cuts.
- Improved Dispersion management.
- Advanced Forward Error Correction.
  - G.709 provides high gain and standardization.
- Standards.
  - VCAT, GFP, LCAS, G.709 FEC, GMPLS, OTN



Wavelength Selectable Switch


Tunable Laser

THE THIRD GENERATION OF METRO OPTICAL TRANSPORT SYSTEMS.

❖ Services and Bandwidth are growing rapidly. This is severely straining the Metro SONET/SDH Network's ability to scale and service this demand. Video delivery in particular is outstripping the current networks capabilities and driving demand for Metro and Regional Long Haul Optical Networks.

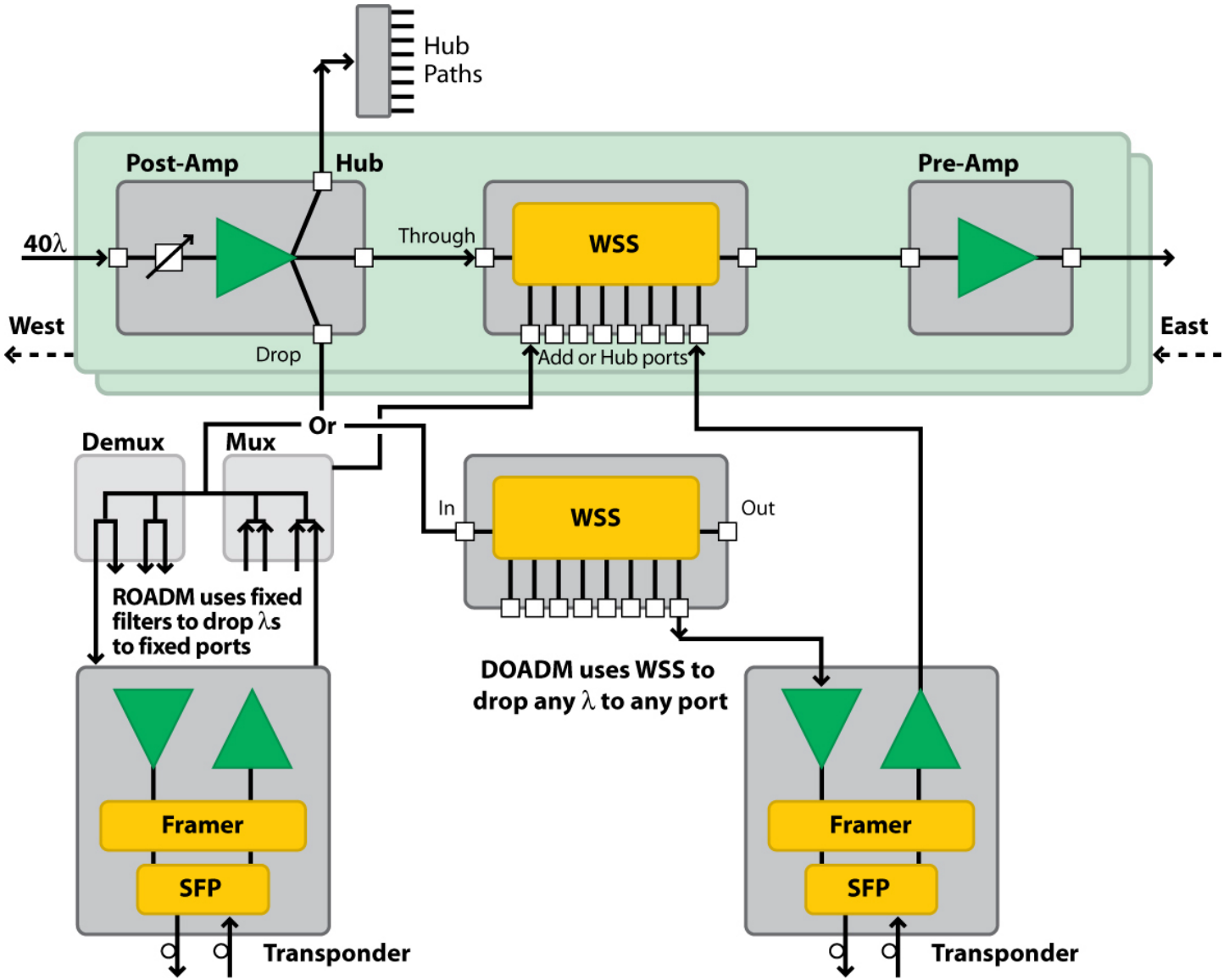
❖ The new technologies outlined have led to the development of a third generation of Metro Optical Networks. The most promising technology is a Wavelength Selectable Switch (WSS) which includes a switching function as before but also performs per channel power balancing as well as the ability to switch traffic between more than two ports. This device enables new network configurations such as hubbing and mesh, which allows network planners a great degree of flexibility.

❖ Another dramatic new feature is the use of lasers that can tune across the full range of wavelengths, allowing users to dynamically reconfigure wavelengths within a system**.** The WSS is a multi-port device which has the unique ability to allow any port to accept or drop any wavelength, when full band tunable lasers are used with the WSS any line card can operate at any wavelength. This greatly improves time to market for new services, eases inventory management, and simplifies network planning. This mode of operation is called colorless.

❖ Another major improvement is the ability to service traffic from more than just directions of fiber. Three or more degrees of freedom are enabled and this allows more complex but efficient networks to be built around a single node. This feature is called hubbing.

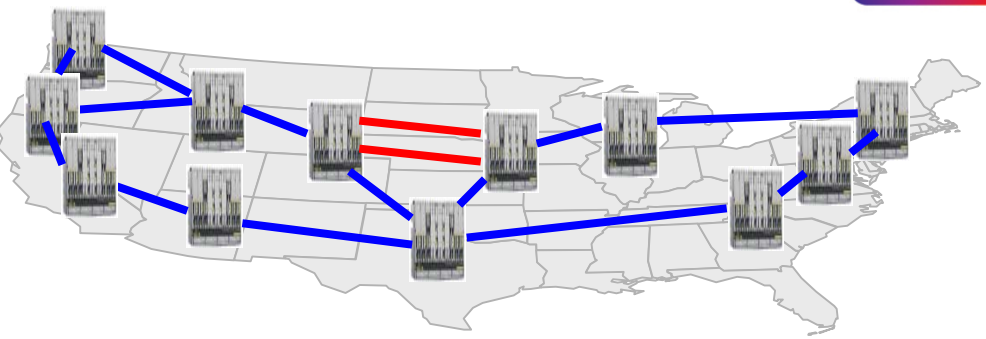
THIRD GENERATION METRO-OPTICAL NETWORKS ARE BEING NOW BEING DEPLOYED ON A LARGE SCALE AND DISPLACING SONET/SDH NETWORKS. NOTE THAT IN THE U.S. AT LEAST SONET IS NOT BEING REPLACED BUT PUSHED OUT OF THE CORE AND FURTHER TO THE EDGE.

THIRD GENERATION ARCHITECTURE EXAMPLE.



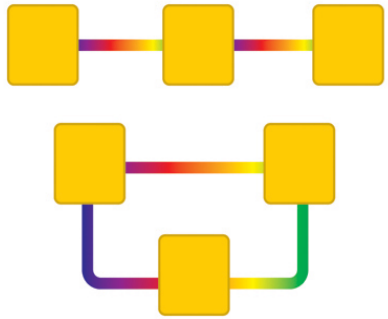
ADVANTAGES of HUBBING.

- Initially systems were point to point and had one degree of freedom.
- Adding a second degree allows Regen operation and rings to be built.
- With three degrees spurs can be dropped from rings and rings can be interconnected.
- Four or more degrees allows all the above, mesh networks, access rings to be sub-tended, and also if capacity is exceeded on one span a degree can be used to add an additional fiber for just that span to a capacity increase on just that span.

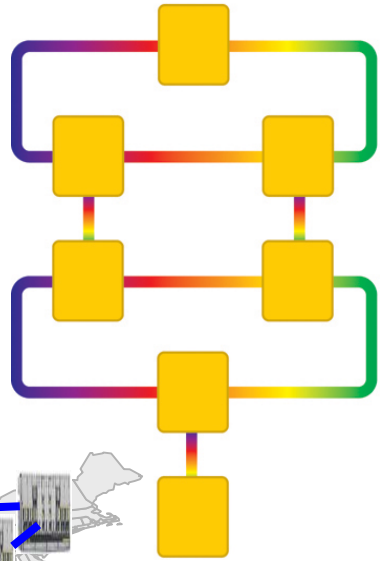


One Degree:
Point-to-Point

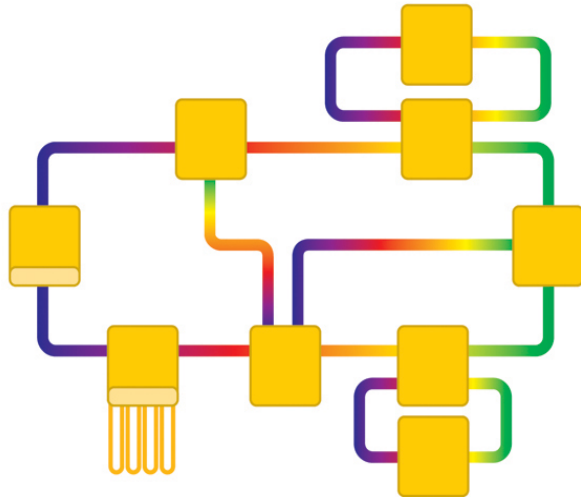
Two Degrees:
Linear Chains and Rings



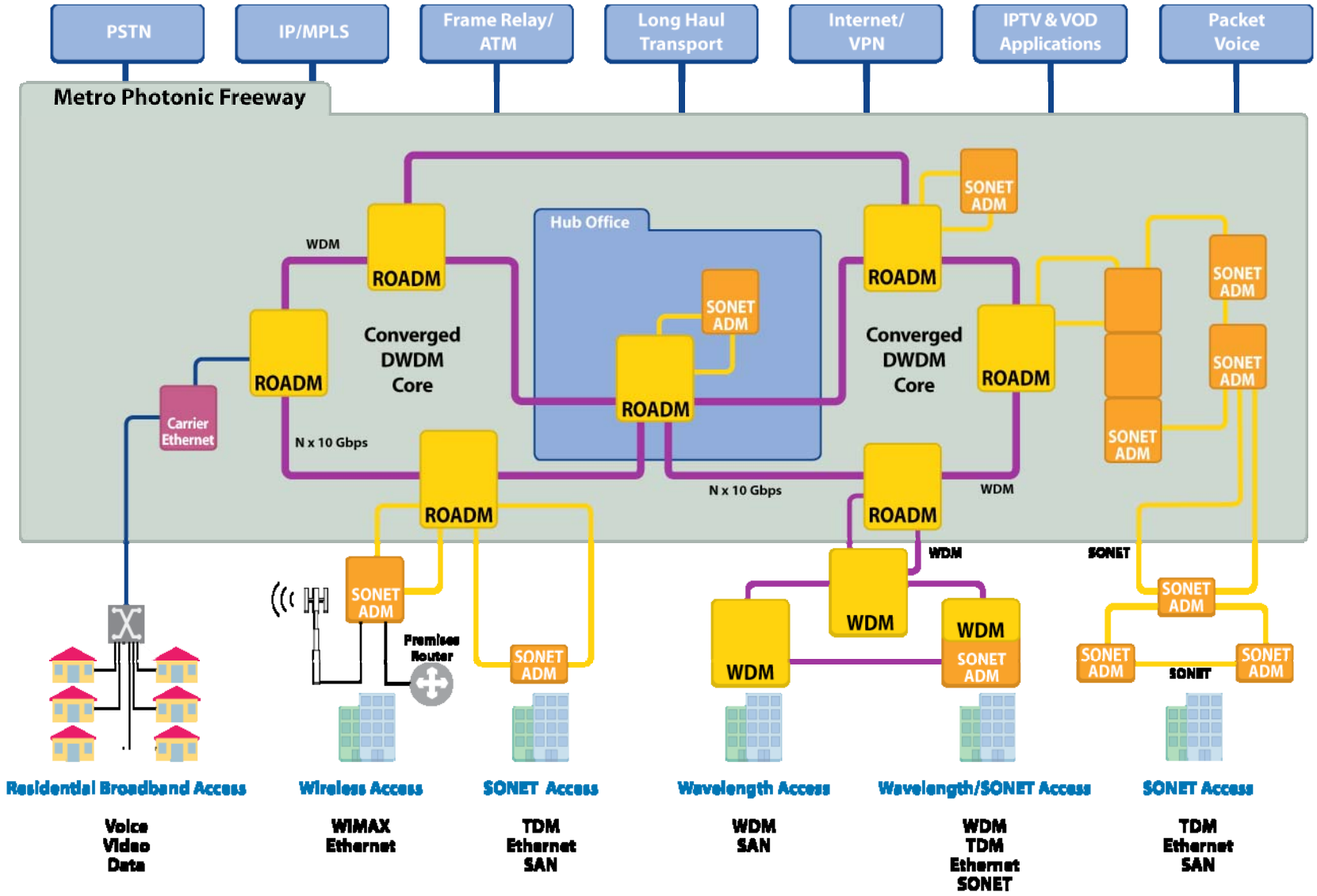
Three Degrees:
Ring Interconnect and Spurs



Four+ Degrees:
Multiple Ring Hubbing, Mesh



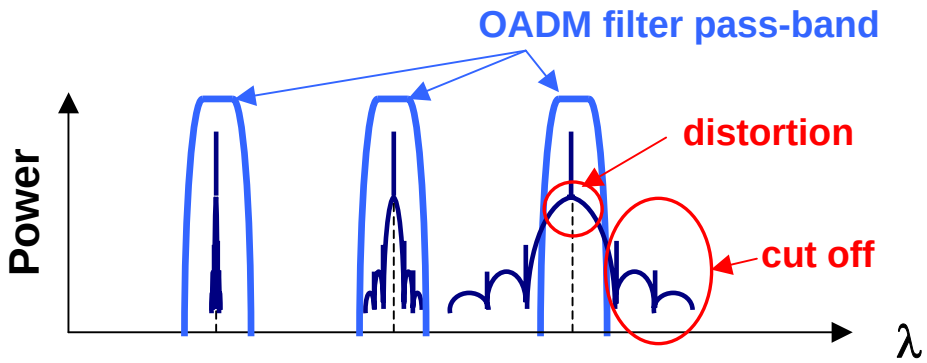
Metro Photonic Freeway

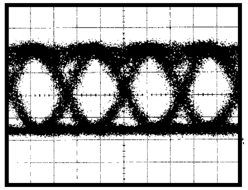
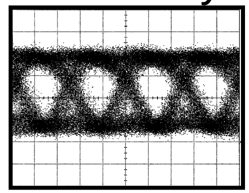
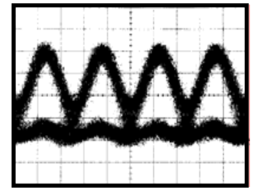
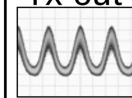
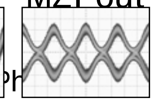
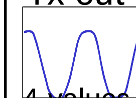
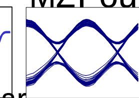
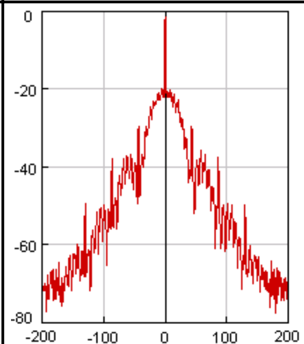
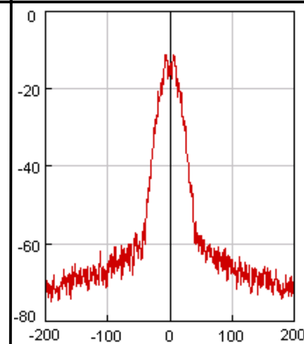
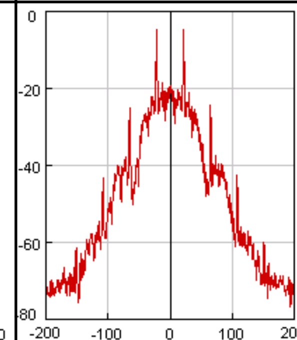
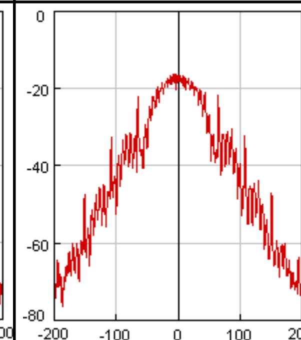
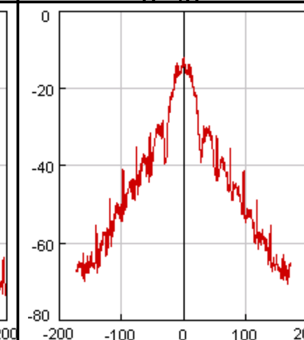


- **40GB/s.**
- Today's networks deploy 2.5Gb/s and 10Gb/s rates extensively but will migrate to 40Gb/s starting this year.
  - Higher rate client interfaces on routers
  - Capacity growth requirements
- **Challenges**
  - OSNR requirement is more stringent at 40G than 10G: 6 dB
  - Dispersion sensitivity increases: x 16
  - PMD sensitivity increases: x 4
  - Optical filtering effects due to OADM filters
  - The networks being installed today must carry 40Gb/s data without changes

- **Solution:**
  - New Modulation schemes such as RZ-DQPSK. This results in a narrow spectral width and good tolerance to fiber imperfections.

  - Tunable Dispersion Compensation and Electronic Dispersion Compensation.



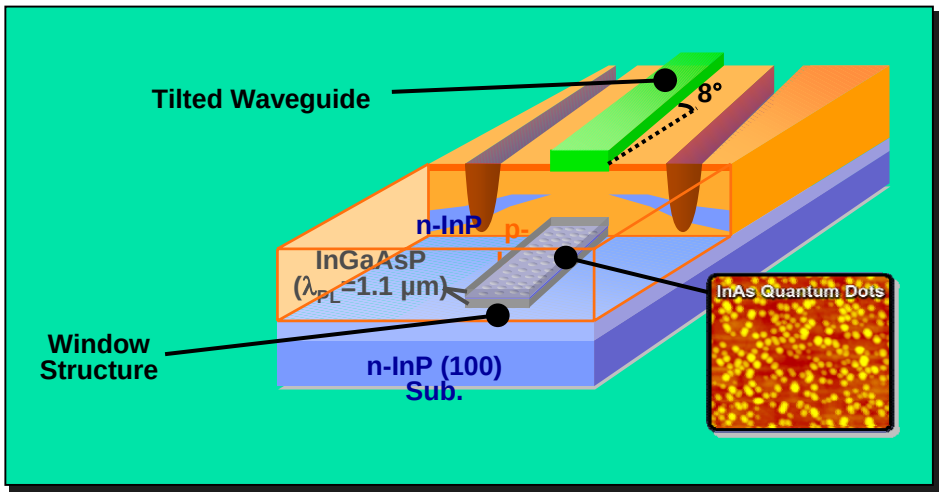
: advantage (pink) / : disadvantage (blue)	NRZ	Duobinary	CS-RZ	RZ-DPSK	RZ-DQPSK
				Tx out  MZI out  π “0”→ ΔPhase=	Tx out  MZI out  4 values are mapped to Δphase 0, π/2, π,
Optical spectra					
Optical noise tolerance	Poor	Poor	Medium	Good	Good
Chromatic dispersion tolerance	Medium	Good in linear regime	Medium	Medium	Good
PMD tolerance	Poor	Medium	Medium	Medium	Good
Optical nonlinear tolerance	Medium	Poor	Good	Good	Good
OADM cascade-ability	Good	Very good	Medium	Medium	Very good

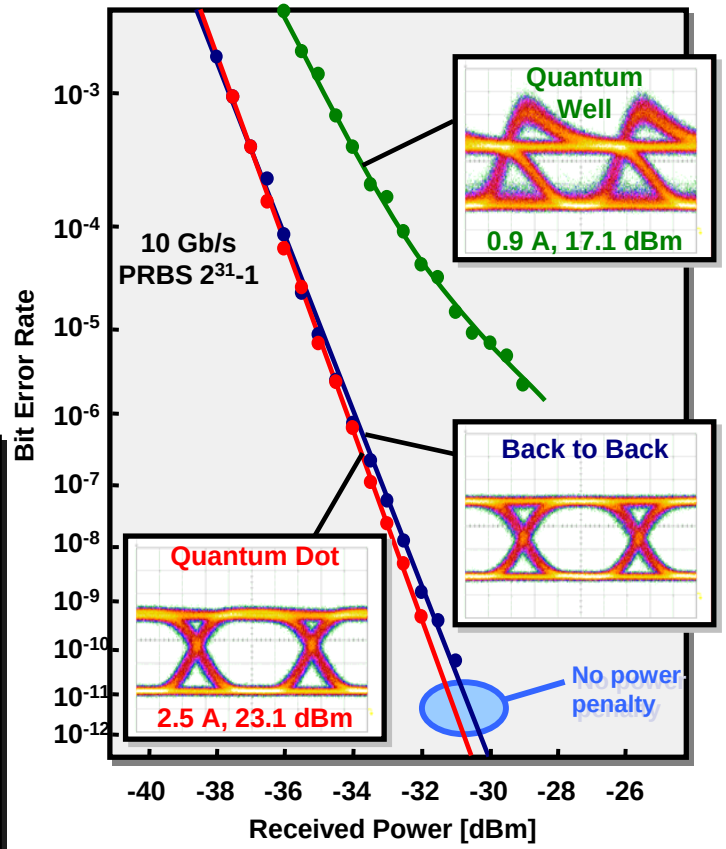
RZ-DQPSK is attractive in many aspects for high-bit rate transmission

- Service and capacity growth is at a tipping point and poised for tremendous growth. The network must keep pace and new technology will be needed to achieve this.

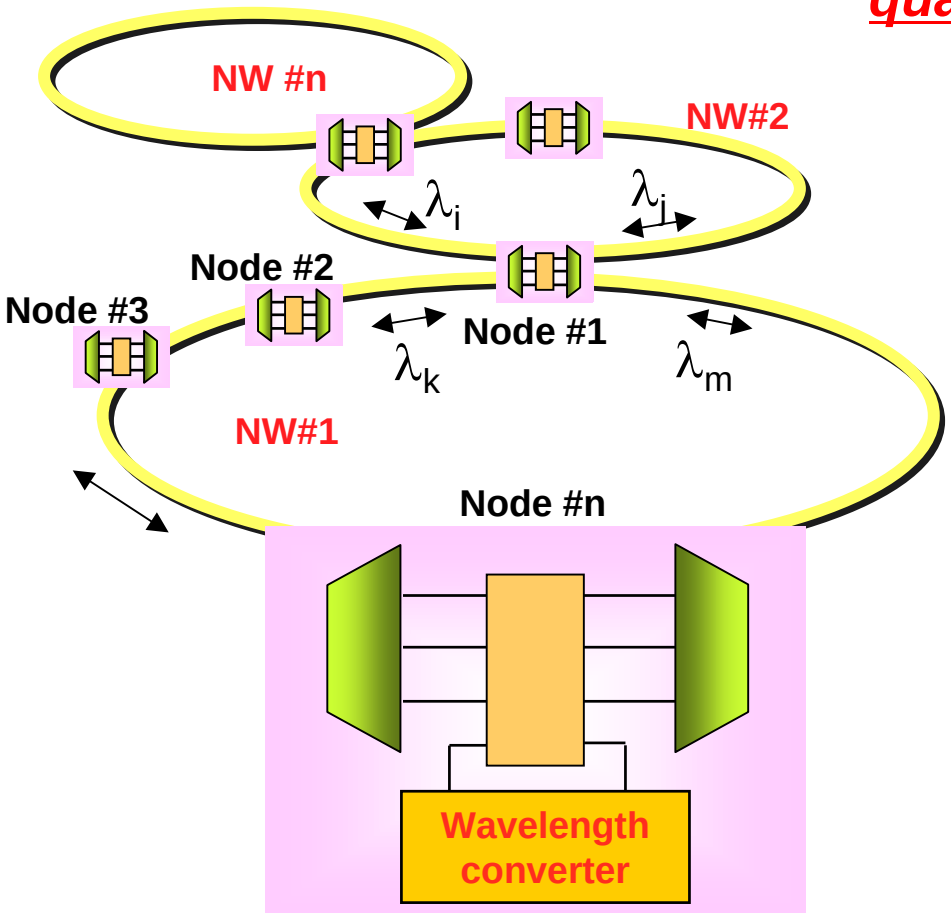
- Promising areas are Quantum dot devices which may lead to:
  - Cooler-less tunable lasers.
  - Semiconductor amplifiers.
  - Single photon emitters and switches.
  - All optical wavelength conversion.
  - > 100Gb/s operation.

SOAC

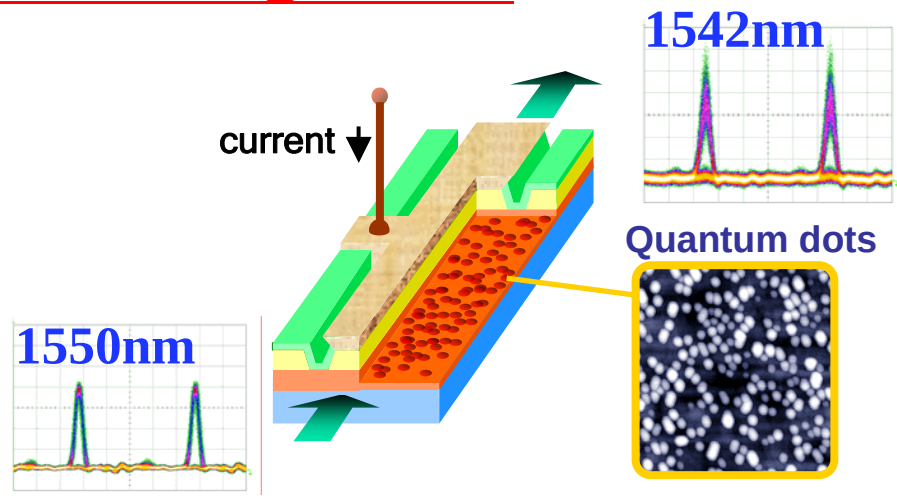




Photonic network



10-nm Wavelength conversion by quantum dots @160Gb/s



- High speed (40~160 Gb/s)
- Wide band (10~35 nm)
- Format-independent : NRZ, D(Q)PSK, etc
- Small, low cost, and low power consumption

	2005	2006 ~ 2009	2010 ~
Line rate & capacity	10 Gbps / ch ~1 Tbps / fiber	40 Gbps / ch 1-10 Tbps / fiber	40-160 Gbps / ch > 10 Tbps / fiber
Technology	Optical Hubbing R-OADM	On demand λ λ VPN	Optical signal processing Optical burst switching
Key device	WSS (~40ch, ~10ports) Full band tunable LD Dispersion-Compensation GMPLS	WSS (>100ch, 10-20ports) 3D-MEMS SW Optical 2R Multi-layer traffic-engineering	WSS (Burst switching) 3D-MEMS burst SW High speed tunable LD Wavelength converter SOA Optical 3R
Expansion of application domains	Metro WDM FTTx	Enterprise network Computer connection	Home network Next generation FTTP

Summary

- Several generations of Metro Optical Networks were developed in the past decade but they had marginal success, mainly in niche applications.
- Optical technology is advancing rapidly.
- A third generation has been introduced which are easy to plan and use and allow convergence of multiple services onto a single network. This generation is gaining widespread acceptance.
- Metro Optical Networks have reached the tipping point and are now replacing SONET/SDH in the metro area.
- Technology advances will continue and allow 40Gb/s over these networks. Future advances will consolidate the Metro Optical Network as the network's workhorse as the network transitions from traditional TDM to packets.