

Managing Proliferating Traffic Growth

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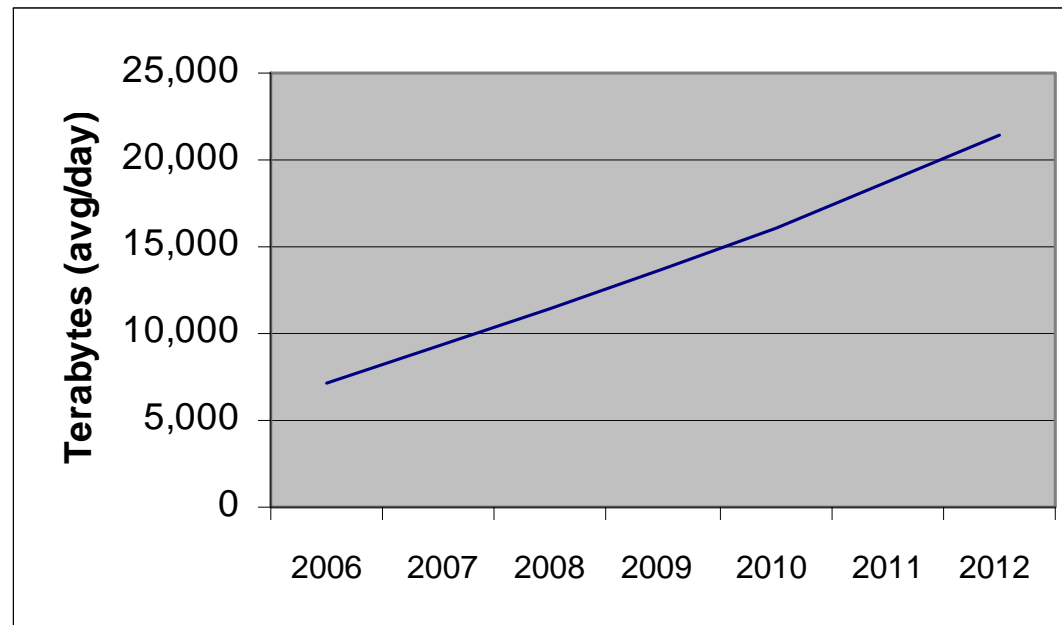
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Agenda

- Internet Traffic Growth
- Qwest IP & Optical Transport Today
 - IP/MPLS
 - Ethernet
 - Ultra Long Haul
- IP & Optical Transport Going Forward
 - IPoDWDM
 - Optical Control Plane
 - Full Optical Mesh
 - 40G vs. 100G
 - All-Optical Packet Switching

Internet Traffic Growth

- It has been reported that:
 - The average 2007 Internet-generated IP traffic is over 9,000 terabytes per day
 - The average 2012 Internet-generated IP traffic is expected to be over 21,000 terabytes per day
- Carriers need to accommodate growth while reducing costs



Internet Traffic Growth

- Several factors are leading to near-exponential bandwidth growth:
 - Organic growth – increase in customer base
 - Customer increase is compounded by content shift
 - Traffic continues to move away from simple static pages to larger multimedia embedded content and streaming video
 - Shift to larger bandwidth access demands by content providers and other high-end customers

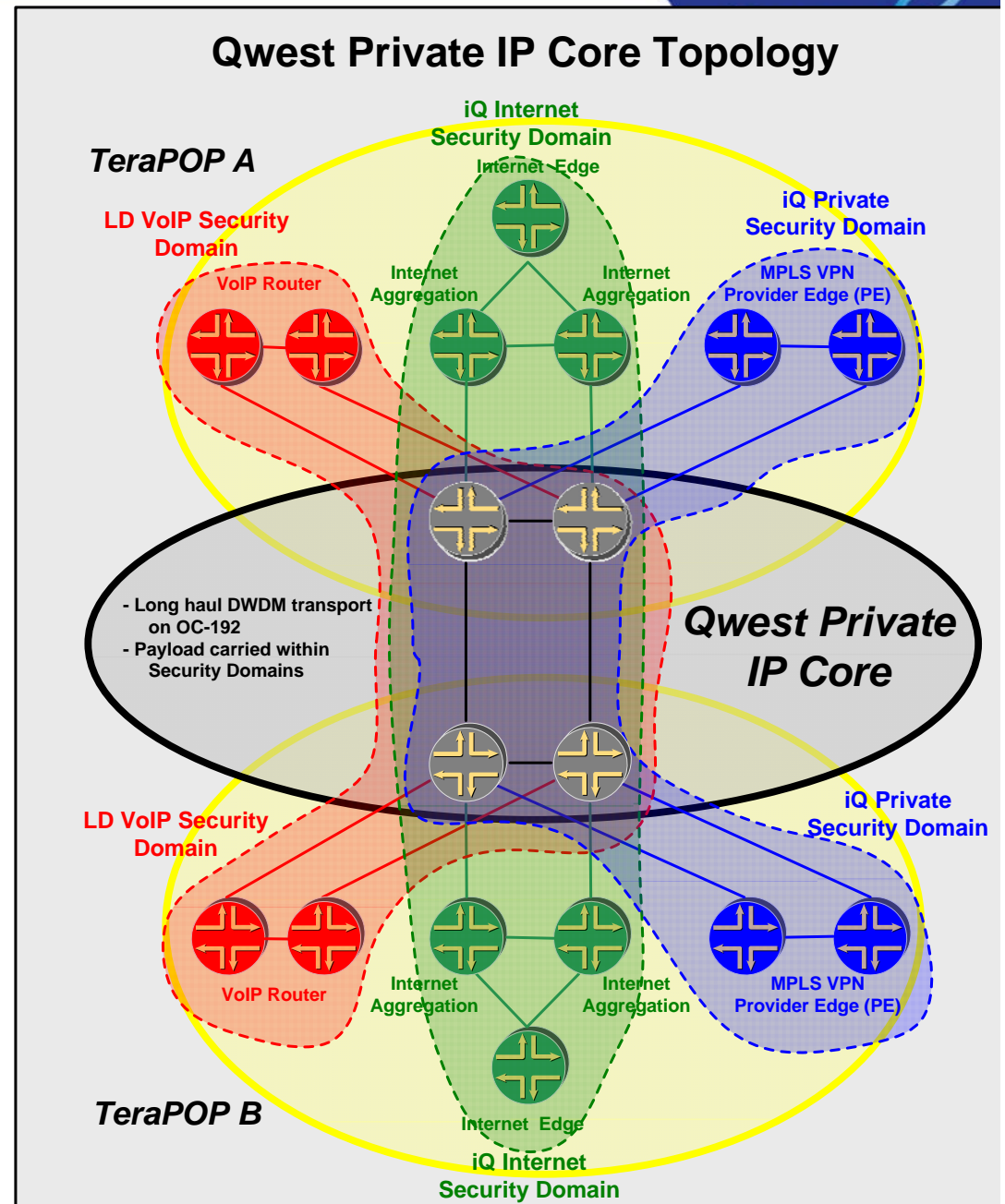
IP & Optical Transport

- Demand is primary driver of network upgrades
- Scalable, high-capacity IP core (top-10 AS; ranked by degree by CAIDA¹, February 2008)
- Four rails of nationwide, DWDM capacity (upgraded with ULH technology)

¹Cooperative Association for Internet Data Analysis <http://as-rank.caida.org/>

IP/MPLS Backbone

- Separation of private and public domains
- Separate edge routers
- Separate control planes
- Separate forwarding LSPs



IP/MPLS Backbone

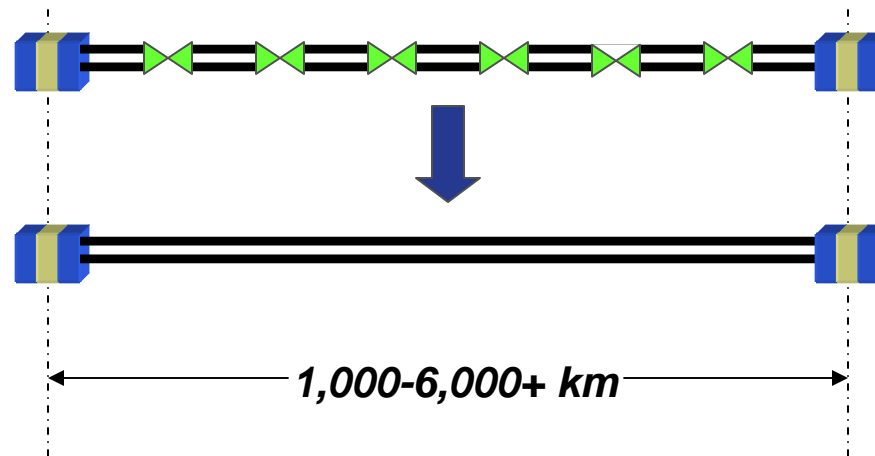
- Rapidly expanding IP private edge cities
- Ongoing transition to Ethernet-based access (GE, 10GE, and beyond)
- Growth of packet transport link capacity > 10G (Nx10GE)
- Implementation of core-based class of service (CoS)

Ethernet Evolution

- Includes a 10GE MPLS / VPLS Ethernet core
- Developing multiple access mechanisms integrating into a common core including copper-based access
- ROADM integration
 - Ethernet network elements connect directly to metro ROADM rings

Ultra Long Haul

- Advanced optics permits longer spans without regeneration
- Supports 10G and 40G DWDM structure, G.709
- Feature-rich ROADMs support current and future services



What's Next?

Optical & IP Transport

IPoDWDM

- Benefits
 - Eliminate redundant O-E-O at edge of L1 transport network
 - Potential unification with optical control plane
- Potential challenges
 - IPoDWDM could place constraints on transport network
 - Control plane and operational / NOC integration will be needed
 - Significant vendor partnering opportunity
- Compare capital
 - IPoDWDM router port cost vs. 10GE router port + transponder
 - IPoDWDM currently requires significant price drop to become attractive

Optical & IP Transport

Optical Control Plane

- Perception
 - Considerable progress is required. Benefits appear minimal until critical mass is obtained
- Benefits
 - Simplified service provisioning and shorter delivery time
 - Wavelength switching on demand
 - Rapid reroute / restoration for disaster recovery and mid-tier service offering
- Potential/remaining challenges
 - Minimal penetration of control plane-capable L1 platforms
 - Transport system must possess increased physical layer awareness and understand complex engineering rules
 - Restoration between transport systems could be problematic

Optical & IP Transport

Full Optical Mesh

- Full optical IP mesh (with optical control plane) advantages
 - Potentially eliminates intermediate data switching
 - Potentially allows for dynamic provisioning of bandwidth
 - Full optical mesh bandwidth is easier to model and manage
- Potential challenges
 - Expensive at certain scales – still requires router ports
 - N squared problem
 - Requires right bandwidth “chunk” size
 - Redundancy in a “pure” full optical mesh requires double bandwidth, along separate *physical* paths, between each pair of PoPs
 - Cooperation with other transport providers may provide for comprehensive topology

Optical Transport & IP

40G – Where Are We?

- There will be customer demand for 40G, however, from a backbone perspective:
 - 40G today is not as economical as 4x10G for both transport and IP networks (could change soon!)
 - Nx10GE mesh currently more viable than option than 40G pipes (but watching 40GE...)
 - 40G could strand capital when 100G becomes available

Optical Transport & IP

100G – Where Are We?

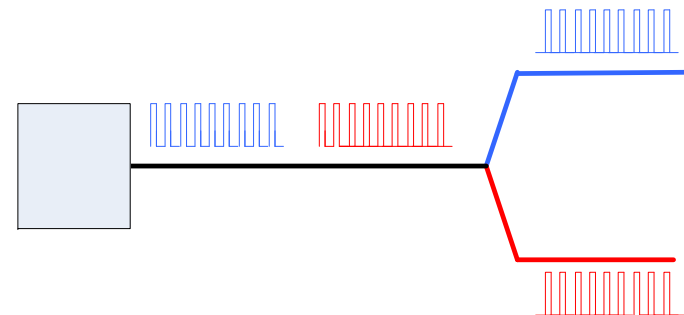
- Considerations in 100G serial transmission
 - Industry data suggests multi-level modulation schemes, with polarization multiplexing, (such as DQPSK) seems to be best format at this time
 - More complex transmit-and-receive circuit designs
 - More spectrally efficient than inverse multiplexing
 - Transmission impairments increase at the square of the data rate
 - Requires higher OSNR margin
 - Operates with lower-speed electronics (readily available 40G components)
 - 100G transmission with 40G CD, PMD, and OSNR values
 - DQPSK may enable DWDM operation on a 100 GHz grid
- Standards are in development
 - Multiple competing multiplexing structures and line rates
 - Multiple standards bodies: IEEE 802.3 HSSG, ITU Study Group 15, and Optical Internetworking Forum OIF-CEI 25G
 - Best-case estimate would see a complete standard in 2009

Evolving Solution: All-Optical Packet Switching

- Packet is switched/routed photonically, no O-E-O on the data plane
 - Could save on cost and power
 - Requires optical buffering or fixed time slots / global scheduling
 - Per packet optical compensation possibly required for long-haul networks dependent on path
 - Simple networks have been shown in research labs, but none that are realistic for a production network
 - Will require further advances in photonic integration for commercial applications

Variation: Wavelength tunable transponder that changes frequency dependent on packet destination

- Could save transponders in certain network situations, technically achievable now
- Requires global scheduler / fixed timeslots to achieve any scale



Thank You