Wide Area Networks :

Backbone Infrastructure

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Outline

- Demands for backbone b/w
- Fibre technology
  - DWDM
- Long-haul link design
- Current Backbone technology
- The near future : reducing layering
- Longer term : transparent networks

Internet Backbone growth

- ~50 million Internet hosts, ~200 million users
  - Host/user growth rate at 40-80% p.a.
  - Metcalfe's Law: "the utility of a network is proportional to the number of users squared"
- Access bandwidth increasing at 25%p.a.
  - Set to jump with DSL & Cable Modem
    - The "Internet Generation" will soon be salaried
- High percentage of long-haul traffic
  - Unlike phone service where call freq. $\propto 1/\sqrt{\text{distance}}$
  - Web caches & real media exploders may help

Huge future requirements for backbone b/w

Fibre Optics

- Multi-mode fibre : 62.5/125μm
  - Requires less precision hence cheaper : LANs
- Single-mode fibre : 8-10/125μm
  - Minimum attenuation at 1550nm
  - Better dispersion properties
    - Normally best at 1310nm, can be shifted
    - 1310nm typically used in Metropolitan area
  - NZDSF at 1550nm used for long-haul
- Fibre capacity increasing at 110%p.a. !

Transceiver Technology

- Currently at 100Gb/s for 1 channel
- Wavelength Division Multiplexing (CWDM)
  - 1310&1550nm – fused fibre couplers for de/mux
  - 4 channel 20nm spacing around 1310nm
- Dense WDM (DWDM)
  - use multiple 'colours' (λ's) simultaneously
  - e.g. 100x10Gb/s at 50GHz spacing
  - need very stable (expensive) lasers
  - wavelength tuneable lasers useful
  - gratings for demux

Optical Amplifiers

- Erbium Doped Fibre Amplifiers (EDFA)
  - few m's of Erbium doped fibre & pump laser
  - Wide bandwidth, relatively flat gain
  - 1550 'L' band, 1585 'C' band, also 'S' band
- Raman amplification
  - counter-propagating pump laser
  - Improve S/N on long-haul links

Long-haul links

- E.g. as installed by "Level (3) Inc.":
  - NZDSF fibre (1550nm)
  - 32x10Gb/s = 320Gb/s per fibre
  - 12 ducts, 96 cables/duct, 64 fibres/cable
  - 100km spans between optical amplification
    - Renting sites for equipment is expensive
    - 8 channel add/drop at each site, O/E terminated
  - 600km between signal regeneration
    - Expensive transceiver equipment
- US backbone capacity up 8000% in 5 years!
  - Level 3, Williams, Frontier, Qwest, GTE, IXC, Sprint, MCI, AT&T,…

SONET/SDH

- SONET US standard, SDH European
  - OC-3 / STM-1 155Mbp/s
  - OC-12 / STM-4 622Mbp/s
  - OC-48 / STM-16 2.4Gbp/s
  - OC-192 / STM-64 10Gbp/s
- bi-directional TDM rings with ADMs
- 50ms *protection* switch-over to other ring
  - "wastes" bandwidth, particularly for meshes
  - SONET/SDH switches under development
- Perceived as expensive
- Provisioning relatively slow

IP over ATM over SONET

- Uses SONET to provide point-to-point links between ATM switches
- Hang ATM switches off SONET ADMs
  - VC/VPs used to build a densely connected mesh
  - flexible traffic shaping/policing to provision paths
  - Can provide *restoration* capability ~100ms
- Hang IP routers off ATM switches
  - Routers see dense mesh of pt-to-pt links
  - Reduces # of high-performance routers required
    - Don’t carry "through traffic"
  - IP capable of relatively slow restoration
  - MPLS to better exploit underlying ATM in the future

Near future: IP over SONET

- "Packet over SONET" (PoS)
- Build traffic shaping into routers/tag switches
- tag-switching to make routing more efficient
  - CDIR routing tricky, especially if packet classification for QoS required
  - Virtual circuit identifier pre-pended to packets
    - "soft-state" only
- Route at the edges, tag switch in the core
- Use MPLS to fix paths for flows
  - provision alternate paths
  - provide QoS etc.

Near future: IP over "not SONET"

- CISCO "Dynamic Packet Transport"
  - Replace SONET higher layers with something more amenable to packet transfer mode
  - still uses SONET physical layer (allows tunnelling)
  - Ring based architecture
    - Rapid self-healing through ring wrapping
      - Don’t over commit critical traffic!
    - Flow-through and Local TX FIFOs in each station
    - Spatial Reuse Protocol (SRP) is bandwidth efficient
    - Uses 802.3 (Ethernet) 48 bit station addresses
    - Rudimentary QoS with two priority classes
      - Watermarks on FIFOs with back-pressure to other stations

All Optical Networks

- Really fast routers and ATM switches difficult and expensive
  - Variable buffering tricky
  - Optical-electrical-optical (OEO) conversion expensive
  - "only" on the semiconductor performance curve…
- Exploit DWDM : "transparent optical networks"
  - Use DWDM to build a *network* rather than a fat pipe
  - Use λ's like ATM Virtual Paths

Optical Components

- λ Add-Drop Multiplexers (ADMs)
  - Fibre Bragg Gratings – in common use
  - Tuneable lasers - available
  - Tuneable filters – getting there
- Optical Cross Connects (OXCs)
  - Beam steering devices
    - holographic devices – typically very lossy
    - micro-mirrors
- λ converters? – some promising technologies
- TDM ? – looks do-able
- packet routing ? – why bother…