Multi-granularity Waveband- and Wavelength-Path Network

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Abstract: Future enhancements in optical path layer enabling technologies are highlighted. The role of waveband paths in creating the next generation transport network is discussed. Some state-of-the-art key enabling technologies are demonstrated.

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1. Advances in IP backbone networking technologies

Dense WDM transmission systems with more than a tera bit per second capacity have been deployed worldwide, and wavelength path routing ring-networks that utilize ROADMs (Reconfigurable Optical Add/Drop Multiplexers) have been widely introduced in North America and Japan since 1994. These technologies offer significantly reduced transmission and node cost, and so have played a pivotal role in supporting the exponential increase in IP traffic which exceeds Moor's law (twice in 12-18 months). After 2005, the yearly traffic increase rate fell to 40-50%, but IP router throughput advances have also been diminished. The rate of improvement in CMOS performance, up to now sustained by decreases in the gate length, has been slowed due to the resultant increase in leakage current. The traffic growth rate of 40% a year is still huge and results in traffic that is 30(/160) times present traffic in 10(/15) years. Lower layer switching, under layer three IP routing, can significantly enhance power efficiency and node throughput. LSRs (Label Switch Routers) and flow routers that utilize layer 2 switching, and ODU (Optical-channel Data Unit) cross-connects and optical path cross-connects will thus be utilized more and more in metro and core networks to handle the explosion in IP traffic. Some carriers are pursuing cut through to minimize the use of costly and power consuming IP routers. In North America, Verizon is deploying L2/L1 transport systems called P-OTP [1], and in Europe, Deutsch Telecom is considering full use of ODU cross-connects [2]. In terms of power efficiencies, IP layer cut through on the layer one optical path is most efficient, but optical cross-connect technologies are still not mature enough to allow wide deployment due to the performance and cost issues that are apparent in the development of large scale optical switches. Optical path routing is hence limited to ROADM ring applications. One of the salient features of optical paths is that switch complexity does not depend on the bit rate or the protocols carried by the optical paths. An optical switch is transparent to the bit rate carried, which is completely different from electrical cross-connect switches. With electrical technologies, switching becomes more and more difficult and consumes more electrical power as the bit rate increases. Thus, the wide deployment of optical path technologies will be driven by the relentless traffic increase and raising demands to reduce the power consumption, given that the present difficulties with optical switches will eventually be mitigated.

2. Role of waveband path

At present, a wavelength path is defined and utilized as a single entity. In order to realize the future networks needed, much larger bandwidth optical paths, wavebands (bundles of optical paths) and hierarchical optical path cross-connects (HOXCs) will be adopted as the basic transport technologies. Optical switches support optical signals with a wide range of wavelengths; this means that the same switches can be used for switching multiple optical paths. Switching multiple optical paths or switching wavebands can reduce total switch size (necessary number of cross-connect switch ports) substantially [3]. This mitigates one of the major present challenges in creating large scale optical cross-connects. For example, when the waveband add/drop ratio is less than 0.5, switch scale reductions of more than 50% for a matrix-switch-based cross-connect system [4], and more than 20% for a WSS/WBSS (Wavelength/WaveBand Selective Switch) based cross-connect system [5] have been confirmed. The hierarchical path structure, on the other hand, can degrade link utilization, and this effect may be strengthened by the additional complexity created by the waveband/wavelength and the route assignment problem. This problem has been resolved recently by the development of effective hierarchical optical path network design algorithms as presented in [6, 7].

3. Application of waveband paths for ROADM ring connection

ROADM ring interconnection is, at present, performed in the electrical layer with OE/EO conversion and electrical switches. Use of the HOXC allows us to create a compact and cost-effective ring-connecting node; however, inherent differences exist in the optical path accommodation for a general mesh topology and that for a concatenated ring topology. Freedom in optical path route selection is severely limited in the ring topology and in concatenated rings. Recently we succeeded in developing a new efficient optical path accommodation method that can be applied to multiple-ROADM-ring connected networks linked via the HOXC [8]. One quantitative result presented in [8] is that the proposed method reduces the cross-connect switch scale by more than 60% while suppressing the degradation in the routing capability to only 7.6%. The significant benefit of introducing waveband routing into ring connection nodes will resolve one of the key issues preventing optical cross-connect systems from being used for ROADM ring connection.

4. Recent developments in waveband system technologies

We have developed necessary key components of the ring connecting HOXC system [9]. Their optical performances were tested and shown to be satisfactory for practical applications. The development of a ring connecting HOXC prototype around these components has been proven to be technically feasible [9]. The other recent notable hardware development is an ultra-compact Waveband Cross-Connect (WBXC) switch module [10] that will be utilized for creating cost-effective multi-degree optical cross-connect nodes. A single chip WBSS has been successfully developed using PLC technologies [11]. The device has no moving mechanical parts, requires no adjustment, and is very compact, which will lead to high reliability and low cost. Using this WBSS chip, a very compact one box WBXC module has been developed, which will be suitable in particular for application to cost-sensitive areas such as metro-edge and metro-access networks. The developed WBXC switch module size is 12.5 x 21 x 5 cm^3. The performance of the WBSS module was tested; after traversing 5 modules the power penalty was about 0.2 dB, which confirms the applicability of the WBSS to metro-edge/metro-access networking. The total throughput is 2 Tbit/s (10 Gbps x 40λs x 5 fibers). Combining two of the modules with their channel grid frequencies offset by 50 GHz, and using 50-100 GHz interleavers, upgrades the system throughput to 4 Tbit/s.

5. Conclusions

In order to create bandwidth abundant future video centric networks, enhancement of optical path layer technologies is critical. Waveband technologies will pave the way [12], and the recent advances will warrant deployment when traffic volume has reached a certain level.

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6. References

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