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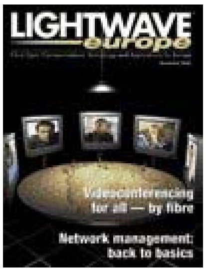

Sub-wavelength grooming using optical multi-cast

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Several different switching technologies and concepts exist in the optical transport network. Cross-connects providing O-E/E-O conversion capability at their interfaces form the most commonly available technology.

These switches may be separated into two categories:

- cross-connects operating in the digital switching domain with re-grooming capabilities (usually STM-1/STS-1); and
- cross-connects operating in the digital switching domain without grooming capabilities (usually STM-N/STS-N).

The main difference is that grooming switches can switch low-granularity signals (such as STM-1/STS-1) in the digital domain. This implies a signal-dependent switching matrix. This type of cross-connect can groom digital signals into the optical wavelengths at every node.

The result is more efficient bandwidth utilisation. Since the optical channels are groomed on a hop-by-hop basis, optimal grooming at each node is achieved. The downside to this approach is that both the interfaces and switching matrix of such cross-connects have a more complex design and are therefore more expensive and less scalable to higher bit rates and port counts.

O-E/E-O cross-connects enable the switching of the entire wavelength carrier content in the digital domain. This results in lower-cost switches that are more scalable. However, these switches are less efficient when the full wavelength capacity may not be utilised. Below, we refer to STM-1/STS-1 and STM-N/STS-N switches as

Other emerging alternatives for switching in the network core include: optical cross-connects with non-transparent O-E-O conversion-capable interfaces (see Figure 1) and an optical switching matrix; and photonic cross-connects (PXC) that provide fully transparent interfaces and an optical switching matrix.

Recently, the optical multi-cast concept has been introduced into the optical transport domain. The introduction of optical multi-cast into these nextgeneration optical transport networks may yield significant benefits for a large number of applications. Optical multi-cast enables applications such as etter network resource utilisation, more efficient optical protection mechanisms, and IP bandwidth aggregation.

Sub-wavelength grooming using optical multi-cast allows for more efficient bandwidth utilisation in wavelength-switched networks that are built using wavelength switching technologies such as PXCs and OXCs.

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Optical multi-cast: the concept
In an optical transport network, a single wavelength may traverse through several intermediate nodes to create a virtual network topology overlaid onto the physical one. The wavelength (or optical channel) may undergo wavelength conversion and/or O-E-O regeneration en route.

At the physical layer, network nodes traversed by a light-tree must include optical signal power splitters, either static or dynamic. A static optical splitter offers only a single fixed power splitting ratio. A dynamic optical splitter offers dynamic control over the splitting ratio. Today, high-granularity dynamic splitters (better than 1dB over a 20–30dB dynamic range) are available.

Wavelength switching also offers interesting possibilities with regard to reconfigurable network topology at the optical layer. The main drive for this type of functionality has been the carriers' need for fast service provisioning and optical distributed recovery schemes. This has been followed by the development of GMPLS. It offers a unified Label Switched Path service model from IP/MPLS at the packet layer to wavelength switching at the transport layer.

One of the main drawbacks to wavelength switching is the constraint set by the wavelength granularity. This leads to a restricted discrete set of bandwidth allocations in the optical domain.

Although an integrated control mechanism exists to create virtual circuits at various granularities, in the optical domain it is limited to the bandwidth of an entire wavelength (in general, 2.5 or 10Gbit/s).

By generalising the hierarchical Label Switched Path (LSP) concept from MPLS, GMPLS may offer a mechanism that will allow for the creation of several point-to-point lower-granularity packet LSPs over a single higher-bandwidth packet LSP that can also be dynamically set up over a wavelength LSP. This mechanism allows for sharing the bandwidth available on a single wavelength between multiple users.

However, in transport networks with only wavelength-switching capabilities, this doesn't solve the most important problem arising from the wavelength granularity constraint. The wavelength is a point-to-point connection only, so it is only possible to share this bandwidth between clients attached to the ingress nodes that require a connection to clients attached to a single egress node.

Optical multi-cast offers an attractive mechanism to alleviate some of these constraints. By defining optical multi-cast circuits one may set up a broadcast and select a sub-network over the transport network.

By integrating the optical multi-cast circuits into the hierarchical LSP mechanism, the extra optical wavelength bandwidth may be re-used efficiently and the overall number of wavelengths in the network reduced.

This would allow for the creation of different lower-bandwidth granularity point-to-point LSPs to several different destinations. Such a mechanism, when used in mesh architectures, would greatly improve the bandwidth and wavelength utilisation in the network.

Figure 2 describes the connectivity diagram that is required between the nodes at a given time. Using O-E/E-O switches with STM-1 grooming capabilities results in an

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optimal wavelength assignment. However, using wavelength switching (with or without conversion) will require a larger number of wavelengths than is really necessary. In this case, the proposed sub-wavelength grooming method enables the same performance as the one obtained with STM-1/STS-1 grooming capable devices.

Figure 3 describes the optical wavelength assignment for the traffic emerging from switch A (working path only) for switches employing wavelength granularity switching only.

Figure 4 describes the optical wavelength assignment for the traffic emerging from switch A (working path only) for switches employing wavelength granularity switching while using optical multi-cast for wavelength grooming. Notice that optical multi-cast enables the use of only two wavelengths in the network. This is the optimal number that is needed when using grooming switches. However, the benefits of employing wavelength granularity switches are maintained. Architectural requirements Sub-wavelength grooming causes some constraints on the design of the network architecture and the OXC. Sub-wavelength grooming depends on the realisation of optical multi-cast in the underlying optical wavelength switched network. Sub-wavelength grooming also imposes some additional requirements that are not directly related to optical multi-cast. These centre on the design of the optical cross-connect at the edges of the optical network.

The cross-connects on the ingress side of the network must have aggregation capabilities. For example, in Figure 4 switch A must provide aggregation capabilities in order to multiplex all the in-coming STM-1/STS-1 into a single out-going STM-N signal. Each branch node, in addition to the homing of optical splitters, must be capable of directing the traffic to the downstream nodes.

The cross-connects on the egress side of the network must provide de-aggregation capabilities. This means that the egress node must filter the data and pass on to its adjacent clients only the connections that are addressed to them.

Security may also become an important issue in this application. This problem arises when several clients' networks share thesame multi-cast wavelengths throughout the optical network. Since a broadcast and select network topology is used, data addressed to one node reaches several others. This consideration requires that both the aggregation and de-aggregation of the traffic be performed within a single domain where a trust relationship exists between all the nodes. This will allow label distribution in a secure environment that will nullify the possibility that data addressed to one client will reach another client. Due to the fact that optical switching networks are treated as a single domain in any case, this is not a major problem.

Protection

The proposed sub-wavelength grooming application provides a grooming method for low-bandwidth connections into an optical wavelength. The grooming mechanism may be entirely confined to the transport layer or, in future IP/MPLS over optical networks, be shared between the transport and data layer. Therefore protection must be handled both by the optical and digital domains.

The only important issue that needs to be addressed is the greater flexibility provided by a light-tree-type connection. The optical domain is constructed out of optical light-trees, hence every protection mechanism applicable to an optical multi-cast network is applicable here. These include mechanisms such as self-restoring trees, dual homing and over-laying ring-based protection schemes on mesh networks. These protection mechanisms provide additional flexibility that does not exist in legacy point-to-point connections.

Signalling requirements

An optical network can be viewed as a cloud connected to network edge devices. The optical cloud contains network nodes (OXCs and PXCs) with lambda switch capable interfaces (LSC), waveband switch capable interface (WBSC) and fibre switch capable interfaces (FSC). Each network node may have several in-coming and out-going ports connected to other network nodes as well as several in-coming and out-going ports connected to an edge device.

Control of the optical cloud may be performed through out-ofband/ in-fibre signalling or a physically diverse control network. In either case the control signalling must handle all the necessary connection control messages, status requests, light-path modification requests, and other notification messages.

In our sub-wavelength grooming application, uni-directional point-to-point connections are set up over a light tree. Only the root node has possession of all the required connectivity information. Therefore, root-initiated signalling schemes lend themselves better for this application.

The signalling scheme must allow for the set-up of a point-to-multipoint optical connection carried over the light-tree and the overlaid connection of the point-to-point LSPs from root to leaves of this tree. The signalling scheme should also allow for dynamic modification of the connectivity scheme. This requires that the signalling protocol extensions allow for set-up and tear down of LSPs and light-tree branches over the optical transport network.

Conclusion

We have examined the possible benefits offered by optical multi-cast for sub-wavelength grooming.

The analysis has shown that using optical multi-cast to perform low-granularity grooming can greatly reduce the number of wavelengths used in a wavelengthswitched network (both O-E-O and O-O-O based).

In this manner, it is possible to maintain the benefits resulting from the realisation of coarse-granularity cross-connects while maintaining the service flexibility resulting from high-granularity grooming.

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