ness while fault occurring. The scheme is called as protected capacity network.

In this paper, a novel protection capacity reservation algorithm is proposed to the problem of link protection schemes in WDM (wavelength division multiplexing) mesh networks with dynamic traffic demands. The algorithm is on the basis of MST-DP (Minimum Spanning Tree -Dynamic Programming) method that networks are protected from failing though protection capacities are reserved on the pre-planned spanning tree in advance considering network load balance and resource utilization ration of network. The Spanning tree that is produced in this way is named as protection capacity tree.

In this paper, we provided a mathematical analysis to compute performance measures for producing a protection capacity tree. The algorithm mainly includes four steps as follows:

- (1) For the part of network to be protected, the WDM node matrix model and node-link matrix model are set up on the basis of the part of network topology G.
- (2) Based on the WDM node matrix model, the trunk of the protection capacity tree (i.e. the maximum capacity spanning tree of topology G) is calculated based on the combination of improving minimum spanning tree and dynamic programming algorithm.
- (3) After getting the trunk, the chords should be appended for those nodes with one degree on the trunk in order to satisfy with the protection validity. By appending chords, it is assured that each node at least have two node-degrees on the trunk. Here, the chords are appended based on the WDM node-link matrix model.
- (4) The produced chords are pruned and further simplified to optimize the resource utilization in network.

The proposed algorithm assures that every node-pair on network G keeps connection by at least two different protection routes through reserving protection capacities in the trunk and part appended chords on a pre-created capacity tree, in which the networks can be protected from failing in case of the single link or node failure happening.

The entire process of algorithm is operated based on WDM network matrix model. Compared with other protection capacity reservation algorithm, such as p-cycle and redundant tree, MST-DP algorithm isn't necessary judge loop in network, more simple algorithm complexity and easy to be realized.

MST-DP simulations test is done in the service disruption time, restorability and resource utilization compared with shared link protection (SLP) and dedicated link protection (DLP) schemes. Simulation results indicate that the MST-DP protection scheme performs very well in terms of the service disruption time, restorability and resource utilization.

6022-78, Session 9b

Proposal and demonstration of distributed lambda-IX with dynamic bandwidth management and fast fault recovery operation in layer-2 connectivity

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A distributed lambda-Internet exchange (IX) with Layer-2(L2) connectivity, which enhances L2-IX features by interacting between L2 switch (L2SW) functionalities and the generalized multi-protocol label switching (GMPLS) control plane is proposed. When an Internet service provider (ISP) peers with another ISP in the proposed IX consisting of GMPLS-controlled photonic cross connects (PXC) and L2SWs, a lambda- label switched path (LSP) between two L2SWs is established via PXC by utilizing traffic engineering (TE) links and a physical Ethernet connectivity is created for the ISP's AS border routers (ASBRs) by configured port-based virtual local area network (VLAN) with tagging streams on trunks. After exchanging external route information between the peering ISP's ASBRs with an external border gateway protocol (eBGP), those ASBRs start to exchange traffic through this lambda IX.

Firstly, we demonstrated the proposed IX with the dynamic bandwidth

modification depending on traffic flow to achieve an effective use of available network resources. The number of lambda-paths was successfully controlled between L2SWs by interacting between a traffic monitoring and GMPLS control plane and 100% throughput was successfully achieved even when the traffic volume beyond an interface speed was fed into the proposed IX. Furthermore, to verify the actual ASBR's operation, we evaluated to run a border gateway protocol (BGP) session between ASBRs and confirmed that it could stably maintain even when the bandwidth management was running.

Finally, we demonstrated the proposed IX with a fast fault recovery operation by GMPLS-controlled restoration in addition to the link aggregation technique to supply the high reliable interconnection for ISPs in the IX. Once a cable failure occurred, although one of two streams was shut down, a part of traffic was restored by the LAG technique after the period of about 30 ms. After that, the failed path was restored to an unreserved path through PXC1-PXC3-PXC2 by GMPLS-controlled restoration operation and a new logical LAG link consisting multiple Ethernet connections was automatically re-established after the period of about 2.3sec. Furthermore, we evaluated to run a BGP session between ASBRs and confirmed that it could stably maintain even when the fault recovery operation was running.

Through these demonstrations, we confirmed the proposed IX could provide the dynamic bandwidth modification according to on demand traffic fluctuation and the high-reliable traffic exchange. Furthermore, these functions were successfully operated while stably maintaining a BGP session between ISPs.

6022-79, Session 9b

Resilience in all-optical label switching networks: a node dimensioning point of view

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All-optical label switching implements the packet-by-packet routing and forwarding functions of MPLS (Multi Protocol Label Switching) directly at the optical domain. By using optical labels, the IP packets are directed through the optical network without passing them through electronics whenever a forwarding decision is necessary. Ideally this approach has the ability to route packets/bursts independently of bit rate, packet format and packet length. Still AOLS encounters new troubles in making the forwarding decisions. The lack of all-optical memory makes the AOLS nodes very complex and resource consuming. With the help of label swapping and label stripping, the local look-up tables in routers are kept scalable. We have already demonstrated that not only the capacity of the network directly influences the required amount of hardware but also the number of LSPs (Label Switched Paths) in the network plays a role in the node's hardware need. This paper will focus on difference in node dimensioning for label swapping and label stripping. Label swapping uses local labels which are interpreted and replaced in each intermediate node on the packet's path. Label stripping uses an end-to-end label which is a concatenation of a set of local sublabels. There is one sublabel per intermediate node on the packet's path. In a node the sublabel is stripped of the packet and it isn't replaced. The next node uses the next sublabel. Label stripping nodes don't have the functionality to write new labels.

The aim of this paper is to investigate the impact of resilience on the hardware dimensions of the node. To protect LSPs we can either choose to back-up the whole path (path protection) or only back-up the link that is broken (link protection). In both cases we need to foresee extra capacity on the network links and the nodes where the back-up path passes through. Protection implies that more LSPs are routed through the network. Indeed, for one original LSP in a network without protection we now need to install a working LSP (normally used) and a back-up LSP (used in case of fault). More LSPs implies the need for more hardware and thus bigger node dimensions. This paper also aims at discussing the adaptations to all-optical node architecture so that resilience is possible. E.g. to provide link protection in a label stripping network, providing more hardware isn't sufficient to adapt the network. Following the principle of label stripping we know that once a local sublabel is used it is removed. Back-up paths also need another concatenation of local labels for the

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