Survivable Architectures and Optical Multicast Overlay for WDM Passive Optical Networks

Calvin C. K. Chan
Department of Information Engineering, The Chinese University of Hong Kong,
Shatin, N.T., HONG KONG
ckchan@ie.cuhk.edu.hk

Abstract—**WDM passive optical network is a promising approach to realize high-capacity and flexible data delivery for access network subscribers. Due to the data-centric nature of the access network traffic, high network availability and flexible data delivery are highly desirable. In this paper, various survivable architectures and optical multicast overlay schemes for WDM PONs will be reviewed. The schemes provide feasible and practical options to enhance the network functionalities of WDM-PONs.**

Keywords-wavelength division multiplexing; passive optical network; protection; multicast

I. INTRODUCTION

Wavelength-division-multiplexed passive optical network (WDM-PON) is a promising solution to provision broadband access to business and residential subscribers. However, with conventional PON architectures, which have limited protection feature, any component or fiber failure would lead to huge loss of data or even business. Therefore, the issue of network survivability has attracted more attention over the recent few years. Subscribers are now requesting high-availability services and connections. Thus, the networks should provide resilience against failures, for instance, in case of possible catastrophic events such as fire or flooding. On the other hand, with more diverse multimedia and data services available for broadband access, the access network has to be flexible enough to cope with various different modes of data or video delivery such as broadcast and multicast, in addition to point-to-point transmissions. Hence, the same data or video service can be delivered to a designated subset of subscribers, which can also be flexibly reconfigured at the optical line terminal (OLT). In this paper, we will discuss the considerations of survivable architectures for WDM-PONs, as well as schemes to realize optical overlay of broadcast or multicast data onto WDM-PONs.

II. SURVIVABLE ARCHITECTURES

Most of the conventional approaches of fault management in optical networks rely on diagnosis in higher layers, based on the status reports collected from various checkpoints on the managed optical networks. However, this would impose excessive overhead in the network signaling as well as in the network management system. In order to facilitate effective and prompt network protection and restoration, it is desirable to perform network survivability measures in the optical layer. For PON applications, equipment failure at either optical line terminal (OLT) or optical network unit (ONU) can be easily remedied by having a backup unit in the controlled environment. However, in case of any fiber cut, it would take a relatively long time to perform the repair. Therefore, survivable network architectures with protection switching are highly desirable to protect the WDM-PONs against any fiber cut.

In WDM-PONs, the fiber links are laid outside plant, thus are more vulnerable to environmental conditions. Whenever a fiber cut occurs, all wavelength channels traversing on that fiber would be interrupted and it takes much more time to repair the fiber. Conventional protection measures against fiber cut in PONs are usually achieved by 1+1 lightpath diversity with fiber link duplication and automatic protection switching (APS). As WDM-PONs offer one more dimension for the optical channels, lightpath diversity can be much more flexibly realized by adopting alternate lightpath routing of the wavelength channels on the existing network architectures, so as to by-pass the failed fiber links and to minimize the required additional fiber links for protection. Such lightpath diversity greatly depends on the network topology, which actually determines the physical paths or connections between the OLT and the ONUs.

As the network topology of WDM-PONs is quite regular, such as tree or ring, pre-planned protection schemes are usually adopted to enhance the network survivability with short traffic restoration time. Protections on the optical layer could realize short restoration time, say less than a few tens of milliseconds, to reduce the amount of data loss during service disruptions. In most cases, such traffic restoration time greatly depends on the intrinsic response of the optoelectronic detection and the optical switching devices used in protection switching, as well as the possible induced additional latency of the protection lightpath. When incorporating APS into the network, fault monitoring units have to be installed at strategic checkpoints to gather network status information. A monitoring unit can be as simple as mere optical power level monitoring to identify the possible loss of signal at a low detected optical power level. Some other novel techniques could also be employed to detect other parameters such as the presence of a particular wavelength, etc. The collected monitoring information has to be delivered to the APS units for appropriate remedies. In some cases, a signaling channel may be needed to carry the monitoring information. Besides, APS can be realized by either centralized or distributed control. In centralized control, all protection switching are performed at the OLT, after the fault alarms are collected. The ONUs still stay connected with the OLT after the APS. On the contrary, protection switching can be performed at individual ONUs instead, to realize distributed control. In this case, protection switches are incorporated in the individual ONUs, which continuously monitor the status of their attached fiber links. APS will be triggered only at the affected ONU when any fault is detected. In case of any fiber failure, the OLT does not need to perform any remedy and is transparent to such APS. However, this approach increases the complexity and cost of the ONUs.

In general, the design of survivable WDM-PON architectures should require the least amount of additional fiber link or equipment duplication to keep the complexity and cost low, while the affected traffic can be restored promptly. Representative examples of survivable architectures for WDM-PONs are listed in [1-6].

III. Optical Multicast Overlay

Multicast provides a means of point-to-multipoint communication in which one source network node sends a common message over the network only once and the copies of the message are delivered to multiple destined network nodes. Thus, it significantly enhances the network resource utilization efficiency for multiple destination traffic and improves the cost effectiveness. It has found many point-to-multipoint bandwidth-intensive applications, such as high-definition video, video-conferencing, video-on-demand, optical storage area networks, database replication, etc. Multicast can be performed either on IP routing level, namely IP multicast, or on the optical layer, namely optical multicast. For IP multicast, the network routers create optimal distribution paths according to a multicast IP destination address spanning tree structure. For optical multicast, the one-to-many lightpaths are established on the optical layer, and thus can reduce the loading of the electronic network processors or routers on the network layer and can achieve much higher processing speed. The traditional way to realize optical multicast is by means of optical power splitting, which is relatively more efficient than copying packets at the IP layer; and the problem is reduced to multicast routing and wavelength assignment. However, it suffers from power-budget constraints and increased network complexity.

Alternatively, the multicast traffic can be overlaid onto the existing point-to-point wavelength channels using various feasible and practical optical signal processing techniques. In this way, the existing access network infrastructure can be gracefully upgraded to support such new kind of multicast traffic in a more cost-effective way. The goal of supporting multicast, or selective broadcast services in a WDM-PON is to deliver the same data or video service to a designated sub-set of optical network units (ONUs), and the connections can be flexibly reconfigured at the OLT. Thus, in order to realize optical multicast overlay on a WDM-PON, two crucial features have to be carefully designed, namely how to overlay the multicast traffic to the existing network infrastructure which is carrying the two-way point-to-point traffic, as well as the overlay control technique for connection reconfiguration. Representative examples of optical multicast overlay schemes on WDM-PONs are listed in [7-14].

IV. Summary

The design issues and considerations of both survivable architectures and optical multicast overlay schemes for WDM-PONs are discussed. With such additional network functionalities, WDM-PONs would become more flexible and reliable access networks to meet the future demand of broadband access.

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