Lightpath restoration in SDN-based optical networks: Overview

Mpho Nkosi, Albert Lysko
Meraka Institute, CSIR
Pretoria, South Africa
e-mail: {mnkosi2, alysko}@csir.co.za

***Abstract*— Optical networks employ restoration methods to ensure efficient recovery of connections interrupted by network failures. Software Defined Networking (SDN) is emerging as the future network architectures and introduces new control planes for establishing, routing and managing optical connections in SDN-based optical networks. This paper provides a brief overview of existing SDN restoration mechanisms that can be used for lightpath restoration and also highlights restoration challenges experienced in the SDN environments.**

Keywords—Software defined networking; Restoration; lightpath; Wavelength division multiplexing; Optical networks.

I. INTRODUCTION

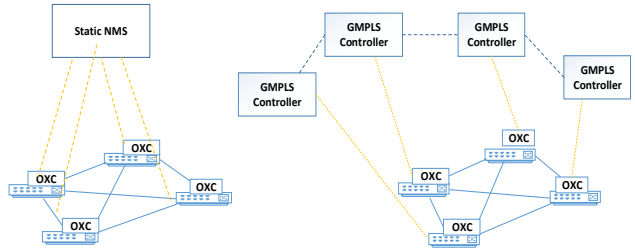
Optical connections mechanism called lightpath is employed in Wavelength Division Multiplexing (WDM) optical networks to provide services (for example, data center interconnection, network virtualisation) that usually require high bandwidth. Such services come with stringent service level agreements and thus, it is critical for a network to provide protection and restoration mechanisms to alleviate data loss [1]. When using protection mechanisms, each lightpath connection is established with backup resources in anticipation a failure. When using restoration mechanisms, an alternative lightpath connection is computed dynamically after a failure incident which caused a lightpath disruption [2]. As compared to restoration, protection guarantees short recovery times, but protection is expensive as it requires additional network resources [3].

Software defined networking framework is emerging and introduces the decoupling of the control plane from the forwarding plane. The most famous implementation of SDN is through the OpenFlow application programming interface which provides direct programming and management of the data plane (for example, routers, switches) from a centralised controller [4]. To protect and restore, OpenFlow employs mechanisms for recovering from links and switches failures. (Fast failure recovery mechanism will be defined on sections III).

Lightpath protection and restoration in the traditional optical networks is a well-researched topic covered by theoretical, simulation and experimental studies [1], [5]-[6]. It is however necessary to investigate restoration benefits that are offered by SDN architectures. This paper describes and provides an overview of the existing restoration methods for SDN-based lightpath routing. The paper also highlights some of the domains that still require more investigations as far as lightpath restoration in SDN-based optical networks is concerned. Section 2 offers an overview of a typical lightpath establishment in SDN environment. Section 3 provides overview on restoration methods in the traditional optical networks. Section 4 extends existing restoration methods as applied in OpenFlow. Section 5 concludes the paper.

II. LIGHTPATH ESTABLISHEMENT IN SOFTWARE DEFINED NETWORKS

In traditional WDM optical networks, network control and management can be centralised or distributed. In a centralised network control, as depicted in Fig.1. (a), a single centralised entity called Network Management System (NMS) is responsible for lightpath establishment and management. The centralised control network is simple and easier to manage but brings about concerns such as automatic network topology configuration when network grows, and more especially when dealing with real-time lightpath provisioning [7]. Distributed network control was introduced to overcome centralised network control limitations and to provide better scalability. As shown in Fig.1. (b), lightpath establishment and management in distributed control network can be performed by, for example, the multiple Generalised Multiprotocol Label Switching (GMPLS) controllers instead of one controller in the centralised control network. However, the distributed control networks also have some limitations such as link states advertisements [8].



(a) Centralised network control (b) Distributed Network Control

Fig. 1: Traditional Optical networks with a centralized control and a distributed control

It is hoped that SDN could offer better solutions to limitations offered by the traditional distributed optical networks. SDN introduces new network paradigm which separates the physical network from control logic from by centralising it onto a dedicated controller.

A typical OpenFlow network consists of a control plane with centralised controller connecting a data plane with one or more switches, as depicted in Fig.2. The data plane is managed directly by the controller through southbound OpenFlow protocol. OpenFlow provides the notion of flow tables and group tables instead of Forwarding Information Base (FIB) that is implemented on a traditional router/switch. The flow table contains a set of entries which specify how to handle packets. The flow entries are defined by the controller and each flow entry is configured with two timers: a hard timeout and idle timeout. The timers determine the lifespan of each flow entry and when one timer expires, its associated entry is deleted [7].

OpenFlow was initially designed to manage and control metro Ethernet based networks and as such, OpenFlow has to be extended to enable control of optical networks. Recently, research work looking at alternative options for using OpenFlow to control wavelength switched optical networks has emerged [9]-[11]. As depicted in Fig.1, two methods are used when deploying SDN-based optical networks, more particularly for lightpath establishment purposes: pure OpenFlow-based optical network (Fig.2.a) and OpenFlow/ (GMPLS) based method (fig.2.b). In pure OpenFlow-based optical network, OpenFlow controller connects directly to OpenFlow-based optical network nodes. The controller computes routing and wavelength assignments upon receiving a lightpath request and through the OpenFlow south bound interface invoke relevant Wavelength Cross Connects (WXC) to reserve and initiate all the required connections on all nodes. Two methods have been considered when using pure OpenFlow for lightpath connection: the *OpenFlow-timer* method and the *OpenFlow-ack* method [12].

The *OpenFlow-timer* method uses the normal OpenFlow operations in which the controller does not require any notification message from a switch after a flow is added into a switch. A timer is used to assume a predefined delay time before a lightpath can be established. This is so done because lightpath communication cannot be initiated without a fully configured route from the source to destination node. The *OpenFlow-ack* method extends the normal OpenFlow operations methods to include notification messages from each node after flow addition into a switch. The controller then initiate lightpath communication between a source and destination pair after all the intermediate nodes along a route have sent notifications confirming that necessary flows have been added. OpenFlow/GMPLS (as shown Fig.2.b) based optical network is an augmentation of a typical OpenFlow network. The GMPLS OpenFlow-based network works similarly as the traditional GMPLS with a centralized Path Computation Element (PCE). The data plane is managed by a GMPLS controller and the OpenFlow controller communicates all lightpath configurations and establishment to the GMPLS controller. Upon receipt of a lightpath request, the controller computes all required paths and send them to the GMPLS controller. The GMPLS controller then uses Resource Reservation Signaling Protocol with Traffic Engineering (RSVP-TE) to setup and reserve all the required paths and wavelengths. The GMPLS also initiates and tear down lightpath connections.

In both the OpenFlow-based and the GMPLS/OpenFlow optical networks, the controller maintains a database of all active lightpaths and available wavelength resources. This makes it easier to restoring traffic during network failures as the controller has global view of the network and can quickly take informed decision. This makes it easier to restoring traffic during network failures as the controller has global view of the network and can quickly take informed decision.

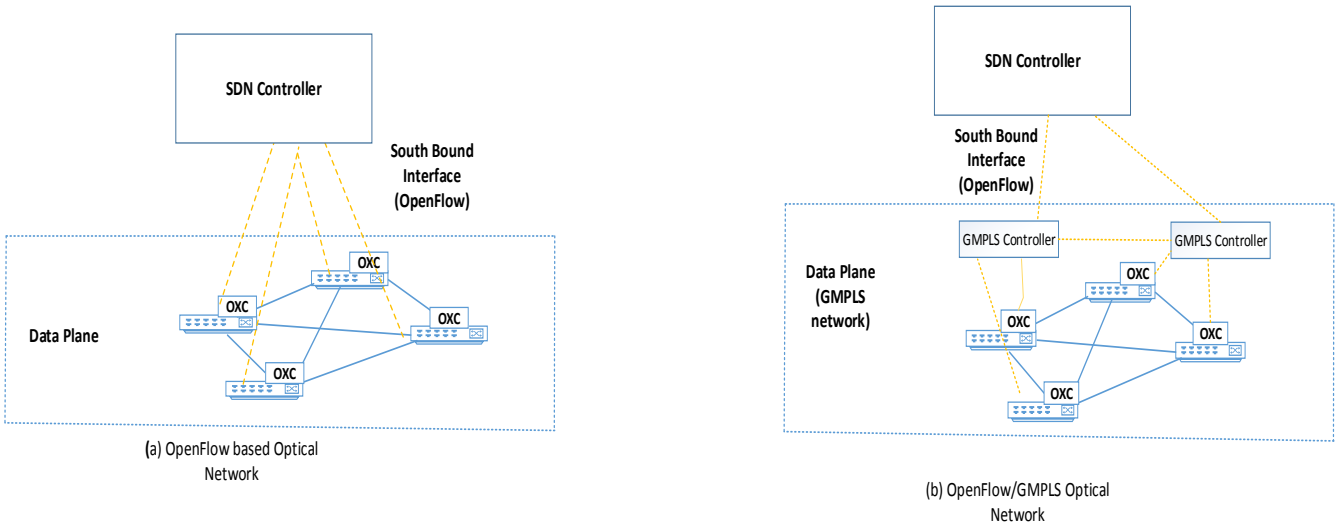


Fig. 2: SDN-based Optical network

The next section describes classical lightpath restoration methods as applied in traditional optical networks.

III. Overview on Lightpath Restoration Methods in Optical Networks

A typical WDM optical network is made up of fiber links, nodes and Optical Cross-Connects (OXC) which are interconnected by the fiber links. Usually, multiple fiber links are bundled together underground in a single conduit, so rupture to the conduit can cause multiple fibre cuts which may lead to several links failures at a time [13]. A node failure may be caused by a malfunctioning OXC, in this sense lightpath restoration is a key feature in lightpath routing that ensures minimal data loss when failure occurs. Upon a failure detection, restoration is triggered to reroute lightpaths to alternative routes (i.e. the secondary route). Lightpath restoration methods differ based on different assumptions as defined in [3]:

- *The functionality of OXC*. There are two types of OXCs: *Wavelength Interchanging Cross-Connect (WICX)* which employ wavelength converter and *Wavelength Continuity Constraint (WCC)* which restricts that a same wavelength has to be used throughout a lightpath route. Lightpath restoration method may assume WIXC or WCC.
- *Traffic demand.* Lightpath demands can either be for *dynamic traffic or static traffic*. Dynamic lightpath demands arrive randomly and are not known upfront. Static lightpath demands are known well in advance. A restoration method can assume static or dynamic traffic.
- *Network control.* Lightpath restoration can assume either a *centralised network control* or a *distributed network control.* The distributed network control is mostly used in large network and require several message protocols to be shared among nodes (for example, distributed Generic Multiprotocol labels (GMPLS) [7].
- *Performance Metric*. Lightpath restoration can assume a particular network performance metric.

As summarised in Fig.3 restoration can be provided at the optical layer or higher network layers or at multiple layers [2]. However, restoration at the optical layer is more beneficial because it ensures shorter restoration time as compared to other layers [3].

In general, restoration methods are reactive as they are triggered after a failure has occurred. Restoration methods can be classified into link-based restoration and path-based restoration. The link-based restoration method redirects traffic around a failed link or node, while on the other hand, path-based restoration computes an entirely new route after a failure has occurred. As compared to link restoration, path restoration is flexible when handling node failures.

Several efforts have recently explored the potentials of the new SDN architecture, showing that the main SDN functionalities can be used for lightpath routing and restoration [17]-[20]. The next section describes the different restoration methods applied in SDN.

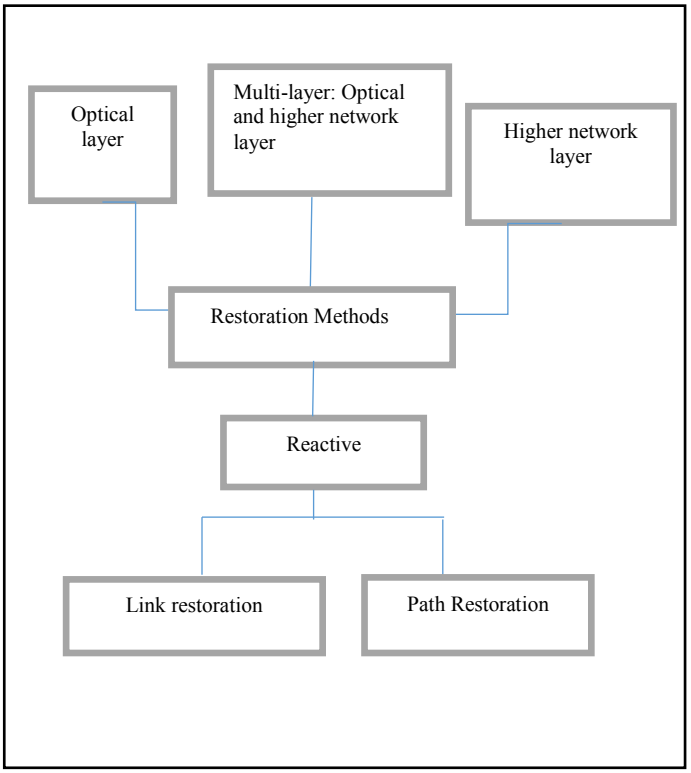


Fig.3. classification of restoration methods

As in traditional networks, OpenFlow networks can provide protection and restoration mechanisms. In this section we start by describing the standard OpenFlow protection and restoration method called *Fast failover recovery mechanism* [21]. We then look at different restorations methods as applied in SDN.

Fast failover recovery mechanism is the standard restoration method used in OpenFlow for the data plane restoration. An OpenFlow network can be deployed using a Reactive or Proactive Model [22]. In a proactive model, the controller configures the flow table entries into a switch in advance. In the reactive model, every first packet prompts the controller to configure a flow entry in the switch. As compared to reactive model, the proactive model is more efficient as the switch can continue functioning normally during connection loss with the controller. Irrespective of which model is used when deploying the network, the restoration method follow an on demand approach. That is to say, recovery from a failure (link failure or "*life of a flow entry has expired"*) depends on the time when the switch request the controller to configure a flow entry or when the switch notifies the controller about the link change status.

In case of a link failure, when the controller updates the network with new routes that avoids the failed links, the flow entries that use the failed links are not deleted from the flow table until their timers run out. Thus, this might lead to longer restoration time as the old flow entries leading to failed linked might be used [20].

A typical lightpath restoration involves the following steps: (i) tearing down the lightpath affected by a failure and

releasing its the resources, (ii) determining a new lightpath route and reserve resources and (iii) configuring the new lightpath. In SDN, the controller has a list of all configured lightpaths in the network which is stored in a database. After receiving a failure notification, a list of affected failure is determined by using the lightpath database. The affected lightpaths are teared down and their resources are released. New lightpath routes are determined and the database is updated with the new routes information.

Two SDN based lightpath restoration methods can be introduced: the independent restoration method and bundle restoration method [23]. These methods use the same notion as the fast failover mechanism but slightly refined to suit lightpath routing. In the independent restoration method, for each new lightpath route determined after a failure, the controller initiates an independent communication with each switch that forms part of the new route by sending flow modification messages. The messages are sent in parallel. In the bundle restoration method, the controller calculates all new routes for all affected lightpaths and then sends a bundle flow modification message to all involved switches to configure new flow entries and delete the flows which were used by the terminated lightpaths. The bundle restoration method recovery method is faster in time as compared to independent restoration method. This is due to the fact that in OpenFlow, all commands in a bundle message are executed as a single command. When there are multiple lightpath failures, the independent restoration method may experience node configuration delays as each flow modification command is executed independently.

The SDN-based lightpath restoration methods were both implemented in a single centralised controller network. As per the Metro Ethernet Forum and the Carrier grade requirements, the SDN restoration methods were able to restore disrupted traffic under the required 50ms [24]. As compared to GMPLS based restoration methods, the SDN-based restoration managed to considerably reduce the lightpath setup time [23].

Although the SDN-based restoration methods can restore traffic faster in the centralised controller networks, it would be interesting to see how they perform in different large distributed controller networks.

V. CONCLUSION

Lightpath restoration is a key feature that guarantees survivable lightpath routing. SDN is an emerging network framework that promises better futures of networking. This paper presented an overview of existing SDN-based lightpath restoration methods. A classical lightpath establishment in traditional is described followed by typical network control management. SDN network architecture for optical networks was also described. Lightpath restoration methods for the SDN networks were also highlighted. The SDN restoration methods promise to reduce lightpath setup time as compared to restoration methods in traditional optical networks.

VI. REFERENCES

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