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Visualizing Survivability Aspects in WDM Networks

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Abstract-The impetus focus is on to provide high data transfer and utilization of high bandwidth, so the era of computer networks completed a journey from co-axial, twisted pairs cables to optical cables migrating from SONET/SDH to WDM technology based networks. This paper deals with various aspects concerned to WDM based networks in context to failure of fiber links in WDM optical networks and the survivability aspects in WDM based networks.

Keywords: **Survivability, lightpath routing, maxflow min cut theorem, maximum survivable path set, computational complexity.**

1. INTRODUCTION

The explosive growth of Web-related services over the Internet is bringing millions of new users online, thus fueling an enormous demand for bandwidth. Since we have seen that main objective in modern communication system is maximizing the utilization of bandwidth in current scenario like video conferencing or VOIP. First ATM comes in existence then SONET/SDH, which do not fulfill completely our need of maximizing bandwidth utilization, so now we are on WDM technology. In fiber optic communications, wave length-division multiplexing (WDM) is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths (i.e. colors) of laser light. This technique enables bidirectional communications over one strand of fiber, as well as multiplication of capacity. The term wavelength-division multiplexing is commonly applied to an optical carrier (which is typically described by its wavelength), whereas frequency-division multiplexing typically applies to a radio carrier (which is described by frequency). Since wavelength and frequency are tied together through a simple directly inverse relationship, the two terms actually describe the same concept. A WDM system uses a multiplexer at the transmitter to join the signals together and a de-multiplexer at the receiver to split them apart. With the right type of fiber it is possible to have a device that does both simultaneously, and can function as an optical add-drop multiplexer.WDM systems are divided into different wavelength patterns, conventional/coarse (CWDM) and dense (DWDM).Conventional WDM systems provide up to 8 channels in the third transmission window(c-Band) of silica fibers around 1550 nm. Dense wavelength division multiplexing (DWDM) uses the same transmission window but with denser channel spacing. Channel plans vary, but a typical system would use 40 channels at 100 GHz spacing or 80 channels with 50 GHz spacing. Some technologies are capable of 12.5 GHz spacing (sometimes called ultra dense WDM). Such spacing is today only achieved by free space technology. WDM, CWDM and DWDM are based on the same concept of using multiple wavelengths of light on a single fiber, but differ in spacing of the wavelengths, number of channels, and the ability to amplify the multiplexed signals in the optical space. EDFA provide efficient wideband amplification for the C-band, Raman amplification adds a mechanism for amplification in the L-band. For CWDM wideband optical amplification is not available, limiting the optical spans to several tens of kilometers.

The main characteristics of the recent ITU Coarse wavelength division multiplexing (CWDM) are that the signals are not spaced appropriately for amplification by EDFAs. This therefore limits the total CWDM optical span to somewhere near 60 km for a 2.5 Gbit/s signal, which is suitable for use in metropolitan applications. The relaxed optical stabilization requirements allow the associated costs of CWDM to approach those of non-WDM optical components. Whereas Dense wavelength multiplexing (DWDM) refers to originally to optical signals multiplexed within the 1550 nm band so as to leverage the capabilities (and cost) of erbium doped fiber amplifiers (EDFAs), which are effective for wavelengths between approximately 1525-1565 nm(C band), or 1570-1610 nm (L band). EDFAs were originally developed to replace SONET/SDH optical-electrical-optical (OEO) regenerators, which they have made practically obsolete. All-optical networks with sparse wavelength conversion[1] is the way to make WDM distinct from SONET/SDH technology. WDM systems are popular with telecommunications companies because they allow them to expand the capacity of the network without laying more fiber. By using WDM and optical amplifiers, they can accommodate several generations of technology development in their optical infrastructure without having to overhaul the backbone network. Capacity of a given link can be expanded simply by upgrades to the multiplexers and de-multiplexers at each end. This is often done by use of optical-to-electrical-to-optical (O/E/O) translation at the very edge of the transport network, thus permitting interoperation with existing equipment with optical interfaces. Most WDM systems operate on single-mode fiber optical cables, which have a core diameter of 9 micrometer. Certain forms of WDM can also be used in multi-mode fiber cables (also known as premises cables which have core diameters of 50 or 62.5 micrometer. In optical networks employing wavelength-division multiplexing (WDM), the enormous capacity of a fiber is divided into several non-overlapping wavelength channels that can transport data independently. These wavelength channels make up light paths, which are used to establish point-to-point optical connections that may span several fiber links without using routers. In wavelength selective WDM networks, a light path connection between a source and a destination must have the same wavelength in all links along its route. In wavelength interchanging WDM networks, the nodes have the capability to convert a wavelength at an incoming link to a different one at an outgoing link. Unfortunately, the high price of wavelength converters makes them less desirable. In WDM networks, provisioning light paths involves not only routing, but also wavelength assignment and this problem is referred to as the routing and wavelength assignment (RWA) problem. Due to the tremendous amount of data transported, survivability, which is the ability to reconfigure and re-establish communication upon failure, is indispensable in WDM networks. Since in reality not all the links fail at the same time, we consider the single-link failure model, where at most a single link fails at any given time. The survivable routing and wavelength assignment (SRWA) problem is to assign, given a set of light path requests, link-disjoint primary and backup light paths to each request so that the total number of accepted requests is maximized. Survivability of a network refers to the network's capability to provide continuous service in the presence of failure. A network failure may be mainly due to link or node failure. Since most modern node devices have built-in redundancy that greatly improves their reliability, failure of fiber links is more of a concern as they pass through different atmospheric conditions (like, under oceans). Again, since protection at electronic layer (ATM, IP) is more time-consuming, optical layer provides resource and time effective fault-tolerance even to upper unprotected layers. So we concentrate on survivability to a single fiber link failure (predominant form of failure) through optical layer protection. Lightpath communications [2] is a novel approach to high bandwidth optical WANs.

The survivability routing problem is decomposed into four sub-problems;

- Survivable Topology design – determines the survivable virtual topology to be imposed on the physical topology based on the traffic demands.
- Virtual Topology Routing – computes a physical path for each logical link in the virtual topology.
- Wavelength Assignment – deals with assigning a free wavelength along the computed physical path corresponding to each virtual link in the virtual topology.
- Traffic Routing – computes a virtual path to route traffic between source and destination nodes in the virtual topology.

Modern optical communication networks are constructed using a layered approach, in which Diverse routing[3] is implemented so efficiently to utilize the optical network strongly. Such a network typically consists of an electronic packet switched network (such as IP); often this packet-switched network is built on top of one or more electronic circuit switched transport networks (e.g., ATM, SONET; sometimes neither or both); and these in turn are built upon a fiber network. This multitude of layers is used in order to simplify network design and operations. However, this layering also leads to certain inefficiencies and Interoperability issues. We focus on the impact of layering on network survivability. In layered networks, a single failure at a lower layer may cause multiple failures in the upper layers. As a result, traditional schemes that protect against single failures may not be effective in cross-layer networks. We introduce the problem of maximizing the connectivity of layered networks. Connectivity metrics in layered networks have significantly different meaning than their single-layer counterparts. Results that are fundamental to survivable single-layer network design, such as the Max-Flow Min-Cut theorem, are no longer applicable to the layered setting. New metrics are proposed to measure connectivity in layered networks and analyze their properties. One of the metrics, Min Cross Layer Cut, as the objective for the survivable light path routing problem, and analyze several algorithms to produce light path routings with high survivability. This allows the resulting cross-layer architecture to be resilient to failures between layers. In WDM terminology, Physical Topology is a set of nodes interconnected with the pair of fiber links while Virtual Topology at the optical layer consists of a subset of the nodes at physical layer interconnected with light paths. The assignment of free channels of Physical topology to the links in the logical topology is performed by the Design Algorithm. And providing survivability to the physical network through virtual topology is called Design Protection. In a wavelength-routed WDM network, each fiber link can carry several light paths.

2. MOTIVATION & OBJECTIVE

Since we have seen the main objective in modern communication system is maximizing the utilization of bandwidth in current scenario like video conferencing or VOIP. First ATM comes in existence then SONET/SDH, but now we are on WDM technology in which CWDM, DWDM and UDWDM are advancements which are future of communication system which will facilitate terabits transfer over optical fiber. Main consideration is to provide Dynamic light path protection [4] in wdm networks under wavelength-continuity and risk-disjoint constraints to defend the WDM optical network from failures. The motivation behind research in WDM technology is to explore the capabilities of fiber optics system and understanding of light path routing in optical cables spanned over global network. How efficiently data are sent in form of wave lengths over optical fibers and this is quite different approach rather than the approach in SONET/SDH. Now the main issues in WDM are how can we utilize more wave lengths (i.e., colors) over optical fibers and how the finest materials can be used to make core of optical fiber and for its cladding. WDM is emerging field that will change the future of communication system, so that scope in this field is very strong to visualize and provide new approaches over existing scenario for either enhancing the wave lengths utilization, checking reliability or monitoring the survivability of WDM networks. Wave length assignments individually for individual signals very difficult and challenging, as WDM technology will be more capable we can utilize more wave lengths that can enlarge bandwidths which is advantageous to communication system. We can also evaluate the work done in WDM and earlier technologies to analyze communication system. On the complexity of and algorithms for finding the shortest path with a disjoint counterpart [5] in WDM optical network is keen interesting factor for undertaking. We can see the design protection for WDM optical networks [9] applicable in nowadays.

There are following objectives which we will deal in WDM in context of survivability:

- Study of existing WDM technology and approaches.
- Design new parameters for existing survivability approaches.
- Evaluation and comparison of new approach/parameters with existing survivability approaches.

3. LITERATURE AND RELATED WORK

Previous works on survivability are studied in [7], [8], [10], [12], [13], [14], [15].The main concern to survivability is the problem of maximizing the connectivity of layered networks (single/multiple layers) has been analyzed. Survivable IP over WDM [10] is a mathematical programming problem formulation. It has seen that survivability metrics in multi-layer networks have significantly different meaning than their single-layer counterparts. Design of a survivable WDM photonic network[8] is given to understand the survivability. Assigning survivable lightpath routing[7] in WDM network is a way to understand the physical topology as logical topology. To keep WDM network survivable from failure in, embedding of logical topologies in wdm ring networks[12] is strong survivable approach.Two survivability metrics, the Min Cross Layer Cut and the Weighted Load Factor, that measure the connectivity of a multi-layer network, and develop linear and integer formulations to compute these metrics. In addition, the metric Min Cross Layer Cut is used as the objective for the survivable light path routing problem, and develops multi-commodity flow formulations to approximate this objective. It is proved, through simulations that used algorithms produce light path routings with significantly better Min Cross Layer Cut values than existing survivable light path routing algorithm.

Insights into quantifying and optimizing survivability are different between the single layer and multilayer settings.Hence discussion of formal requirements for metrics to illustrate and qunatify survivability [17].

- **Consistency:** A network with a higher metric value should be more resilient to failures.
- **Monotonocity:** Any addition of physical or logical links to the network should not decrease the metric value.
- **Compatibility:** The metric should generalize the connectivity metric for single layer networks. In particular, when applied to the degenerated case where the physical and logical topologies are identical, the metric. should be equivalent to the connectivity of the topology

In WDM network survivability has been illustrated and modeled for single failure and multiple failures with following metrics and it is easy to verify that both metrics satisfied the above requirements:

A. Max Flow Vs Min Cut

For single-layer networks, the Max-Flow Min-Cut Theorem[18] states that the maximum amount of flow passing from the source s to the sink t always equals the minimum capacity that needs to be removed from the network so that no flow can pass from s to t. In addition, if all links have integral capacity, then there exists an integral maximum flow. This implies the maximum number of disjoint paths between s and t is the same as the minimum cut between the two nodes. Hence, the term connectivity between two nodes can be used unambiguously to refer to different measures such as maximum disjoint paths or minimum cut, and this makes it a natural choice as the standard metric for measuring network survivability. Because of its fundamental importance, we would like to investigate the Max-Flow Min-Cut relationship for multi-layer networks. We first generalize the definitions of Max Flow and Min Cut for layered networks:

Definition 1: In a multi-layer network, the Max Flow between two nodes s and t in the logical topology is the maximum number of physically disjoint $s - t$ paths in the logical topology. The Min Cut between two nodes s and t in the logical topology is the minimum number of physical links that need to be removed in order to disconnect the two nodes in the logical topology.

B. Minimum Survivable Path Set

We introduce another graph structure, called Survivable Path Set, which is useful in describing connectivity in layered networks. A survivable path set for two logical nodes s and t is the smallest set of $s - t$ logical paths such that at least one of the paths in the set survives for any single physical link failure. The Minimum Survivable Path Set, denoted as MinSPSst, is the size of the smallest survivable path set. For convenience, MinSPSst is defined to be ∞ if no survivable path set exists. In a single layer network, the value of MinSPSst reveals nothing more than the existence of disjoint paths, as its value is either two or ∞, depending on whether disjoint paths between s and t exist. However, for multi-layer networks, MinSPSst can take on other values. For example, in Figure 3, the minimum survivable path set for s and t has size three because any pair of logical links can be disconnected by a single fiber failure. In fact, it is easy to verify that:

- MinSPSst = 2 if and only if MaxFlowst ≥ 2;
- MinSPSst = ∞ if and only if MinCutst = 1.

C. Computational Complexity

For single-layer networks, because the integral Max Flow and Min Cut values are always identical to the optimal relaxed solutions, these values can be computed in polynomial time. However, computing and approximating their cross layer equivalents turns out to be much more difficult. Following theorem describes the complexity of computing the Max Flow and Min Cut for multi-layer networks.

Theorem: Computing Max Flow and Min Cut for multilayer networks is NP-hard. In addition, both values cannot be approximated within any constant factor, unless P=NP.

4. METHODOLOGY

Various approaches are available to model survivability approaches over WDM networks but ILP (integer linear programming) is embedded here because the survivability is not solvable in polynomial times i.e. survivability is NP-complete problem. The general objective of the RWA problem is to maximize the number of established connections. Each connection request must be given a route and wavelength. The wavelength must be consistent for the entire path, unless the usage of wavelength converters is assumed. Two connections requests can share the same optical link, provided a different wavelength is used.

The RWA problem can be formally defined in an integer linear program (ILP). The ILP formulation given here is taken from

Maximize:

$$C_0(p,q)=\sum_{i=1}^{N_{sd}} m_i$$

Subject to

$$m_i \geq 0,\ integer,\ i=1,2\ldots.,N_{sd}$$
$$c_{ij} \in o,1,i=1,2,\ldots.P,j=1,2,\ldots,W$$
$$C^{TB} \leq l_{W\times L\backslash}$$
$$m \leq 1_w C^T A$$
$$m_i \leq q_i \rho, i=1,2,\ldots,N_{sd}$$

$\mathbf{N_{sd}}$ is the number of source-destination pairs, while m_i is the number of connections established for each source-destination pair. L is the number of links and W is the number of wavelengths. P is the set of paths to route connections. $A : P \times N_{sd}$ is a matrix which shows which source-destination pairs are activate, $B : P \times L$ is a matrix which shows which links are activate, and $C : P \times W$ is a route and wavelength assignment matrix.

Designing of ILP and its deployment over any supportive tool like CPLEX can provide results can model the exact practical situation of optical system.

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