Literature Review and Survey

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Dynamic Virtual Topology Reconfiguration in WDM Optical Networks

Survey

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Table of Contents

Abstract **1**
1 Introduction **2**
1.1 WDM optical networks *2*
1.2 Network Types *2*
1.3 Network Reconfigurability *3*
1.4 Why Reconfigure *3*
1.5 Outline of the Survey *3*
2 Issues **5**
2.1 Reconfiguration Management *5*
2.2 Reconfiguration Cost *5*
2.3 Reconfiguration time *6*
2.4 Performance *6*
2.5 Network Survivability *6*
2.6 Wavelength Assignment and Routing Problem *6*
2.7 Tuning Limitations and Latency *7*
3 Approaches to Design and Implementations **8**
3.1 Models *8*
3.1.1 Optimization-Based Model 8
3.1.2 Cost-Based Model 9
3.1.3 Traffic-Engineering-Based Model 10
3.1.4 Analytical Model 10
3.2 Methodologies/Approaches *10*
3.2.1 Minimal Disruptive/ Incremental Approach 10
3.2.2 Adaptive Approach 11
3.2.3 Single-step and Multistep Approach 11
3.2.4 Resource-Budgeting Approach 12
3.2.5 Ad hoc Approach 12
3.3 Algorithms *13*
3.3.1 Minimum-Hop/Delay Based 13
3.3.2 Minimal-Change Based 13
3.3.3 Load-Balancing Based 14
3.3.4 Optimization Based 14
3.4 Policies *14*
4 Test Bed Studies and Field Trials **16**
5 Applications **17**
5.1 Traffic Optimization *17*
5.2 Congestion Control *17*
5.3 Failure Restoration *17*
5.4 Bandwidth Trading *18*
6 Concluding Remarks **19**
Appendix – I **21**
Appendix – II **28**
Appendix – III **40**
Appendix – IV **42**
Appendix – V **44**
Appendix – VI **45**

Abstract

This survey investigates and reviews the recent past and current research efforts and activities undertaken towards the dynamic topology reconfiguration problem in Wavelength Division Multiplexed Optical Networks. The review of the literature is presented in the form of a classification schema that provide a basis for differentiating the issues, models, methodologies, algorithms and policies being employed for network reconfiguration. Literature related to Broadcast as well as Wavelength Routed Networks was covered.

1 Introduction

1.1 WDM optical networks

In the last decade, Wavelength Division Multiplexing (WDM) techniques and optical-fiber technologies have together brought a revolution in high-speed communications networks, which are now able to meet the high-bandwidth demands of current voice and data traffic. Under this technology, an optical wavelength spectrum is divided into separate independent non-overlapping channels, via wavelength-division multiplexing, and then transmitted over a single optical link between a pair of network nodes. There are numerous advantages associated with this technology such as large bandwidth, low distortion, less power requirement, and low signal attenuation etc. [61]. Field trials have revealed that a transmission rate up to several terabits per second is achievable [54].

1.2 Network Types

WDM networks can be deployed as one of the following types

- ***WDM Point-to-Point Networks***

  No details are provided as this survey will mostly discuss the reconfigurability issue in the following two types of networks.

- ***Broadcast-and-Select (Local/Metropolitan Area) WDM optical networks***

  Based on the method of communication between two nodes, these networks can be further divided into single-hop and multihop networks. For an in-depth view of the two types the reader is directed to please read [64][65] . A second classification is based on the type of network which categorizes these networks into Access and Transport Networks [50].

- ***Wavelength-routed (Wide Area) Optical Networks***

  These are the current most-favorable long-haul networks. The network consists of fiber links and active switches. A network node consists of an end user, an active switch, and a fiber link connecting the two. Communication in the network is achieved through establishment of lightpaths, which are independent channels, each having a particular wavelength, and can span over one or more optical links [25], [63], [77] .

1.3 Network Reconfigurability

Reconfigurability is one of the significant characteristics of WDM optical network, which allows a network to adapt to real-time traffic changes or ensures network survivability during equipment failures. This characteristic is achieved by the fact that WDM Optical Networks provide an architecture in which logical connections can be embedded over the underlying physical connections [50]. The optical cross-connects, optical transmitters and receivers, and wavelength converters are the components which enable the network operators to change network connectivity with the changing traffic conditions. Optical cross-connects and optical add/drop multiplexers allow a channel to be dropped or added on a router, or to pass through to its final destination [80].

The logical connectivity is established through lightpaths, each identified by an independent wavelength, which provide end-to-end connectivity for transmission over the optical medium. The concept of *Lightpath* and *LightNet* was first introduced in [25][26] and based on this concept the embedding of a virtual topology over a physical topology was made practical. Thus it resulted in minimizing the number nodes that were actively involved in network transmission. The concept of dynamically-reconfigurable lightwave networks was for the first time exploited and discussed in [5] and [46], where proposed work in the later was limited to broadcast networks. This concept was further explored in [81] and now this topic has been one of the hot topics among the communication-research community.

1.4 Why Reconfigure

As discussed in the previous section, rearrangability is one the compelling characteristic of WDM Optical networks, which allows the operators to rearrange the networks in response to changing traffic demand [7], [14], [32], [40], [46] [50],[102]. It also enables embedding of logical connectivity over the physical layer in such a fashion that in the event of an equipment failure the traffic flow can still be handled without any disruption [48], [51].

1.5 Outline of the Survey

This survey will cover dynamic reconfiguration in WDM optical networks. Discussion about reconfiguration in multicomputers networks and high-speed LANs is beyond the scope of this survey. The survey consists of 6 sections; section-1 covers the introduction to WDM optical networks, the rearrangeable networks and the need of reconfiguring WDM networks. The rest of the survey is organized as follows. Section-2 covers the primary technical issues of reconfiguration. Sections-3 gives details of approaches used for design and implementation of reconfiguration in optical networks. This section covers models, methodologies, algorithms, and policies followed for reconfiguration. Section 4 gives an overview of some important testbed studies and field trials carried out employing reconfigurable systems. Section 5 covers examples of applications of reconfiguration and reconfigurable systems, and finally section 6 presents the concluding remarks.

Appendixes I through VI contain Bibliography, Annotated Bibliography, list of researcher, list of upcoming conferences, cross-reference graph, and emails sent to the researchers.

2 Issues

Issues related to reconfiguration are important and need special attention during the design and development of a reconfiguration strategy, methodology or policy for various types of WDM networks. Following are the most common and crucial issues that were considered by most of the researches while presenting different strategies.

2.1 Reconfiguration Management

This is one of the foremost and crucial reconfiguration issues and it deals with two basic questions; first is when to reconfigure the network, and second is how the reconfiguration should follow the changing traffic patterns. Different approaches have been presented; [5], [48], [81] were the first ones to provide answers to the above two questions.

Reconfiguration management must ensure rearrangement of the network in such a way that the traffic disruption is kept to a minimum, and remains un-noticeable to the end-user. A detailed overview of this issue has been presented in [[48]] which mainly covers the transport and access multihop WDM networks. It also discusses different approaches and limitations that have been proposed by fellow researchers.

2.2 Reconfiguration Cost

Reconfiguration cost is another important issue which plays a decisive role in network reconfiguration. It becomes vital in deciding the specific need and the frequency at which the reconfiguration must be performed to overcome the network imbalance. The cost may be in the form of packet loss, packet delays, out-of-sequence arrivals, gain in throughput, and various control resources involved during the reconfiguration phase [7]. The reconfiguration cost can also be expressed in terms of the number of optical switches that are involved during the rearrangement of network [27]. In one of the reconfiguration models presented in [70] the authors have taken the average packet delay as the cost of reconfiguration, and based on this cost, different reconfiguration policies are compared. In another article [28], the cost is considered as the numbers of lightpaths that need to be reconfigured to obtain an optimal performance.

2.3 Reconfiguration time

The transition from one traffic matrix to another requires either buffering or re-routing of some of the traffic at all or most of the nodes, which causes a disruption to the flow. In today's communication networks where voice and data streams are flowing at Gigabit to terabit rates, a disruption, even of milliseconds, can cause huge packet loss or delay. This scenario is undesirable [28], therefore reconfiguration must be fast and only necessary changes be made to the network.

2.4 Performance

As discussed earlier, reconfiguration incurs some cost in terms of packet loss or delay, so frequent reconfiguration may result in huge loss or delay, which may cause performance degradation to such a level that the performance of the existing topology outperforms the reconfigured one. On the other hand a situation may arise in which a change in the traffic results in delays due to long buffering and loss due to congestion, thus reconfiguration becomes inevitable in order to improve the network performance.

It is, therefore the utmost and basic criteria that leads to the decision of whether network connectivity is optimal or there are some optimization grievances (e.g. low throughput, large packet delay etc) which require network reconfiguration. There are numerous metrics for performance measurement i.e. degree of load balancing, the amount of packet loss, network disruption, and throughput optimization etc. [7], [8], [81].

2.5 Network Survivability

The reconfiguration phase takes the network from one virtual topology to another through a number of operations involving wavelength assignments, tuning of transceivers, and branch exchanges. The changing of states makes the network susceptible to failures, as the algorithm that is handling these operations may fail. Yet there is another factor which comes from the physical layer and affects the connectivity either due to a link failure or switch failure [48], [51]. Therefore, the reconfiguration phase must have some mechanism that can handle these eventualities.

2.6 Wavelength Assignment and Routing Problem

In WDM optical networks, communication between two end-to-end ports is performed through lightpaths, where each lightpath is distinguished by a non-overlapping independent wavelength channel. The current family of optical fibers can carry a predetermined capacity that is specified in terms of bandwidth. This puts a limit on the number of wavelengths that can be transmitted via a particular link [61]. Under such circumstances the number of nodes in a network might be larger than the number of channels that can be carried over the optical link, and several nodes might be sharing single channel [7]. This mismatch between the number of nodes and number of available wavelengths gives rise to a wavelength-assignment problem. There is another issue which couples wavelength-assignment to a routing problem which is dealt with under the following constraints (a) if a lightpath spans several links it must be assigned the same wavelength and (b) on a single link each lightpath must be assigned independent wavelength [80]. A network which has wavelength converters, however, can enjoy more freedom in this respect.

2.7 Tuning Limitations and Latency

Tuning limitations are concerned with the transceivers installed at nodes for wavelength filtering. If a transceiver can only tune to a subset of the total wavelengths that a link can carry, it is called "partially tunable". Thus a network which has a deployment of partially tunable transceivers, when reconfigured, can realize only a smaller set of virtual topologies [49].

Another issue pertaining to transceivers is "tuning latency". Tuning latency is the time a transceiver takes to switch from one channel to another. Therefore, switches having larger tuning latencies badly hamper the performance of networks which require frequent reconfiguration [7].

3 Approaches to Design and Implementations

3.1 Models

In order to reconfigure virtual topology of WDM networks, researchers have used several reconfiguration models. There is no specific classification that has been defined, except [27] in which authors presented two categories that a reconfiguration phase follows, namely optimization based and cost based; however, this survey also finds two more models that have been followed for the network reconfiguration. Some readers may differ with my opinion as there are number of common factors that make the division thinner and it becomes difficult to categorized different approaches according to the presented models.

3.1.1 Optimization-Based Model

All of the approaches that follow this model perform network optimization for any given objective function. In this model, effort is not made to compare the performance of the target optimal topology and the one that might be achieved by minimal change to the current topology under given objective function. Cost is not a matter of concern as sometimes only a marginal improvement, in the objective function, is achieved by incurring huge cost [27]. A number have researchers followed the optimization-based model for network reconfiguration [14], [44], [46], [48], [76], [81], [88].

An objective function based on Minimal disruption/disturbance approach was considered in [14], [44], [48]. In [48], the authors present a minimal-disruption approach where traffic optimization is achieved through reconfiguration. The reconfiguration is performed by a sequence of branch-exchange operations. The approach taken by [14] is to minimize the number of retunings while [44] considers a shortest-path-first approach for getting the target topology.

The authors in [46] considered achievable throughput as an objective function and strived for a solution in the form of a reconfiguration that enables accommodation of optimal traffic without crossing the waveband limit of the link. The optimization objective of [81] is to optimize the network performance such that the packet loss is kept to a minimum. [76] used a combination of objective functions that include the minimal number of lightpaths established, minimizing the number of hops, and minimizing the number of physical links used to setup lightpaths.

The authors in [13] and [7] consider degree of load balancing and number of retunings as the objective functions. They proposed a framework for viewing and comparing different reconfiguration policies based on defined objective functions.

The objective function value in [88] decides how well the topology is suited for the given traffic demand. The objective functions are number of changes required to the current topology to reach to an optimal target topology, and the average weighted hop count which is defined as “average number of hops traversed by unit traffic”. They proposed a two-phase approach to the virtual-topology problem, and the target topology is obtained by a limited number of changes.

3.1.2 Cost-Based Model

The major concern of this model is to achieve a network reconfiguration with the minimal possible cost. While formulating the problem, the current, and the target, and the detail of physical topologies are considered to be known in advance. There are multiple cost factors, which may include the number switches or the number of routers involved that need to be reprogrammed for network reconfiguration. The cost may also be given in terms of the effort that is required to formulate intermediate topologies before realizing the final one [27].

According to this survey only a few of the researches have followed the cost-based model, where [102], [70], [85] are the articles which used this model. An optimal reconfiguration policy in [102] has been formulated as a multi-stage decision-making problem which considers average hop count and number of lightpaths, which need to be changed for the reconfiguration, as the objective functions. These objective functions are used for calculating the cost of reconfiguration and the benefit that reconfiguration offers. The authors used wavelengths and different number of transceivers to vary the average hop count.

The average packet delay is used as an objective function in [70], where a queuing approach has been followed for examining the benefits of network reconfiguration. In another work presented in [85] the authors considered the number of ports per node as the objective function and developed an analytical model to calculate the blocking probability for both fixed and reconfigurable systems. They conclude that overall system cost, due to configurability, reduces the required number of ports to as much as 50% per node.

In [28] the authors proposed an algorithm to reduce the reconfiguration cost, using the concept of splitting and merging the existing lightpaths. This approach considers an objective function of minimal number of changes required to get an optimal configuration through network rearrangement while keeping the congestion to a minimum.

3.1.3 Traffic-Engineering-Based Model

This model is based on the fact that fault, network provisioning, network survivability or any other traffic-engineering-based criteria can trigger the reconfiguration. [57] and [51] are the only two articles that utilize this model. In [57] a traffic-engineering-based reconfiguration model is presented for overlaying IP over WDM networks. A traffic-engineering-triggered reconfiguration system prototype was presented and implemented over a testbed of MONET WADMs. Whereas [51] is concerned with network survivability during the reconfiguration phase.

3.1.4 Analytical Model

This model is based on the concept that, due to multiple factors which affect the network performance during reconfiguration, only a single approach or algorithm cannot provide optimal results. Thus it is necessary to first investigate and examine the important facts that impact the performance and based on comparative results utilize an approach or policy that best fits under the real-time or prevailing conditions. This model has been presented and discussed in [97] which is the only article on this theme.

3.2 Methodologies/Approaches

3.2.1 Minimal Disruptive/ Incremental Approach

The rearrangement of a network from its current configuration to a target topology involves branch exchanges or exchange of connectivity links between two nodes according to traffic demand or any other objective function. Thus, during the transition phase, because of rerouting and buffering of the packets, some portion of the network become unavailable, thus causing traffic disruption. To deal with this problem [4], [44], [48], [68] followed a minimal-disruptive approach for virtual-topology reconfiguration.

The notion of minimal disruption, for the first time was introduced in [48], which is also one of the milestone papers. Under this approach the reconfiguration was realized through a sequence of branch-exchange operations in such a manner that a single pair of links was disrupted at a particular instance.

The article presented in [4] specifically applied an "incremental capacity dimensioning approach" for topology reconfiguration. Whenever network optimality was required to match a new traffic demand, the transition was performed through reconfiguration of backup paths ensuring that the transition causes minimal disruption to the flowing traffic. Authors in [44], while following minimal disruption approach, presented a solution in terms of ad hoc algorithms that utilize fewer resources at the beginning as the reconfiguration was realized in small stepwise changes made to the connections.

A reconfiguration strategy for multihop WDM packet networks was proposed and examined in [68] and the authors presented iterative reconfiguration algorithms. The reconfiguration was performed in steps and in every step only a small change was made to the virtual topology of the network. These stepwise small changes ensure minimum disruption to the network while reducing the maximum link load.

3.2.2 Adaptive Approach

The virtual topology is reconfigured through an approach in which the topology dynamically adapts to the changing traffic by monitoring the traffic streams. This approach considers reconfiguration to be an online and continuous process in which network transformation is performed when a change is observed in the traffic flow [32], [81].

The reconfiguration process proposed in [6] was carried out in such a manner that the network adapted to changing traffic in a hitless mode through sizing of ATM switches. In [32] an adaptation mechanism was proposed in which traffic was measured periodically; if periodic traffic measurement identified any fluctuation, the topology was reconfigured through addition or deletion of one lightpath at a time. In another paper [81] the authors devised policies for dynamic reconfiguration, where packet delays identify the changing traffic patterns. The authors in [102] studied issues related to reconfiguration triggered by traffic changes in optical Internet and formulated a reconfiguration policy.

3.2.3 Single-step and Multistep Approach

There are two ways to reconfigure a network taking it from the current connectivity to the optimal configuration. In the first method all of the nodes involved are rearranged in a single step; while in the multi-step process only a limited number of links/nodes are rearranged thus the whole network is reconfigured through incremental changes.

The authors in [40] classified the reconfiguration procedures into two classes; "single-step" procedures affect the whole network where every node is given a new position, whereas "multi-step" procedures incrementally reconfigure the network by changing a minimum number of nodes at a time. This was an extension of work presented in [41] where they compared single-step and multi-step procedures against tuning latency of receivers, but there they assumed no propagation delay. In [88] the authors presented a reconfiguration approach that consists of a reconfiguration phase and a fine-tuning phase. In this two-phase approach, which was developed for wavelength-routed WDM optical networks; reconfiguration was considered as an online process.

3.2.4 Resource-Budgeting Approach

Resource-based reconfiguration strategies are followed by [18], [15], [49]. The strategy proposed in [49] tries to reconfigure the network by keeping the number of wavelength routers, which are needed to realize new topology, to a minimum. This may be achieved such that the target topology is nearly similar to the current topology, while traffic optimization is also ensured. Whereas [18] follows the approach which tries to minimize the number of optical cross-connects through efficient wavelength assignment and routing of the lightpaths. [49] presented an approach which considers limitations of tunability range of transceivers used for network rearrangement.

3.2.5 Ad hoc Approach

Under this approach only a partial reconfiguration of the network is performed that provides cushions to accommodate only traffic increase, or traffic surges. This approach is followed by [2] and [74], where the former presented a topology reconfiguration scheme which reconfigures the network to cope with traffic surges by adding links temporarily to the IP layer. This scheme followed an approach in which traffic changes can be accommodated through partial modification of the existing topology, while keeping the total amount of added bandwidth to a certain level. In [74] a solution for handling traffic surges in inter-city backbone network, through reconfiguration of IP layer was proposed. The authors presented a method that tackled traffic bursts by adjusting the IP-layer link capacity which utilized a reconfigurable optical cross-connect layer for this job.

3.3 Algorithms

The following classification is based on the functions performed by algorithms that are covered under this survey. There can be several other classifications, such as heuristic based, type of search used etc.

3.3.1 Minimum-Hop/Delay Based

Under a new traffic demand the virtual topology is required to be rearranged. This is desirable to improve the performance of the network, otherwise, if not performed excessive packet delay and loss may be experienced at the end nodes. Algorithms under this category try to find out a sequence of lightpath rearrangements, which may provide minimum hop or minimum delay to the transmitted traffic stream. In [44] the authors presented a solution in terms of ad hoc algorithms which utilized a shortest-path-first approach. [76] took a two-prong approach; it presented two algorithms in which the sequence of reconfiguration is determined by sorting the lightpaths based on their length i.e. number of hops, while the third algorithm checks the effect of lightpaths on network availability. In another article [106], the authors proposed a balanced alternate-routing algorithm, which computes the shortest path in two steps. In the first step it computes a set of shortest paths between a pair of nodes and in the second step it selects the optimal one among the computed set of routes.

3.3.2 Minimal-Change Based

The approach of the algorithms under this class is based on the concept that reconfiguration can be achieved through minimal number of changes made to the current topology. This can be achieved by finding a virtual topology that is closest to the current topology, as performed by algorithm presented in [14] and [76] therefore network reconfiguration is attained with only a small number of retunings.

Two other articles, [28] and [4], followed a different concept. The establishment of lightpaths required to realize reconfiguration was limited through splitting and merging of the existing lightpaths [28].

For reconfiguration, [4] used primary lightpaths and backup lightpaths. It used the proposed MRB (Minimum Reconfiguring for Backup Lightpaths) which select appropriate wavelengths in such a way that only a minimum number of lightpaths are reconfigured.

3.3.3 Load-Balancing Based

One of the objectives of reconfiguration is to minimize the network congestion, either by diverting traffic to underutilized paths or through establishment of new lightpaths.

Algorithms presented in [66] and [68], make local changes to the network and try to come up with a connectivity in which heavily loaded links are relieved. These algorithms use iterative search and try to find out branch exchanges which come up with maximum link load reduction.

In [100] the algorithm performs wavelength selection and assignment in such a manner that the load is evenly distributed on each wavelength.

3.3.4 Optimization Based

This class of algorithms search for an optimal solution for a given objective function. Algorithms developed in [39] strive to find optimal node placement. These are meta-heuristic based greedy algorithms, and provide node placements such that nodes having maximum traffic transit among them are placed close to each other.

A lightpath routing algorithm was proposed in [18] with an aim to reconfigure the network with minimum number of optical cross connects. The reduction in OXCs can be achieved when reconfiguration does not require a lot of switch settings at nodes. Therefore, algorithms search for wavelength routing and assignment instances where it finds one such set of wavelength assignments and routing that is free of any collision of assignments of routing. A similar problem is considered in [73], where the authors present an algorithm for proper channel assignments in ShuffleNets. They argue that since the physical layout of a ShuffleNet determines the degree of reconfigurability, however, the reconfigurability can be enhanced through proper channel assignments.

3.4 Policies

There are two basic questions that are central to the problem of reconfiguration, these have already been discussed in section-1 i.e.

- *When to reconfigure a network?*
- *How to reconfigure a network?*

Answers to these questions define the policies and each answer itself constitutes a policy. The policies can be classified as threshold policies or optimal policies. There are several cost and rewards functions which determine whether a policy is optimal or threshold.

A detailed and thorough study on the design of reconfiguration policies in WDM broadcast network was carried out in [13]. Authors derived the policies on the basis of the number of retuning involved in reconfiguration transition phase. They defined that when the number of retuning involved are less than a certain level the network may be reconfigured otherwise not. They also defined some cost and reward functions, and based on these cost and reward function the frequency of reconfiguration was determined.

The authors in [102] take average hop count and number of changed lightpaths for finding the reward and cost functions for network reconfiguration, and based on rewards and cost computed, they define a set of reconfiguration policies.

Four reconfiguration policies were defined in [70] which outline how a server reconfigures a queue when it is done with the current queue. These policies were used for reconfiguration of IP access networks. [106] derived its policies based on network throughput, minimum propagation delay and cost of reconfiguration.

4 Test Bed Studies and Field Trials

This survey covers only two testbed studies and two articles on field trials. The first test-bed study was presented in [23]. This article talked about the design, integration, and demonstration of multi-wavelength reconfigurable WDM/ATM/SONET network testbed. Here performance of network components was studied and examined and management techniques for such networks were investigated. Moreover, re-arrangability characteristics and operations involved were also studied.

In another performance and testbed study of topology reconfiguration, which was presented in [59], and an extension of the early study presented in [57], the authors propose a traffic-management framework for reconfigurable IP over WDM networks. Under this framework, they propose three “one-hop traffic maximization” algorithms for topology design, and one reconfiguration migration algorithm for topology change. The results obtained from testbed simulations were analyzed and discussed. Based on these results they concluded that the proposed framework resulted in throughput gain and reduction in average hop distance compared to networks with fixed topologies. In the previous study, carried out in [57], a reconfiguration model for overlay-type IP over WDM network was proposed. Based on this model the authors developed a reconfiguration system prototype in which reconfiguration was triggered by traffic engineering based decisions. The prototype was tested for reconfiguration convergence. The test was performed over a testbed setup on MONET WADMs and IP routers.

Article [54] discusses the experimental setup, system demonstration, and results achieved, in a field trial experiment carried out on all-optical metropolitan network, which was a subnet of the German research program KOMNET in Berlin. The demonstration was performed on a WDM 60 km single mode fiber ring, consisting of reconfigurable three OADMs. All OADMs were connected to neighboring networks and were used to switch traffic to the connected networks. Transmission rate of 0.8 Tbit/sec without any error was reported. The system concept dynamically reconfigurable OADMs used in the field trial was discussed in detail by a following article [90].

5 Applications

Dynamic-reconfiguration capability facilitates control and management of network resources. Therefore reconfiguration can be used in many applications. The applications of a reconfigurable system were identified by the author in [101], where four specific applications were discussed. In this article the abilities of US West Communications Inc. digital cross-connect were outlined.

The most common application of reconfiguration can be one of the following types.

5.1 Traffic Optimization

One of the major applications of dynamic reconfiguration is to adapt the network to the changing traffic matrix. Many of the researchers have studied this aspect of traffic optimization under different approaches and assumptions [2], [4], [6], [8], [32], [74]. The network can match to the changing traffic conditions in real-time; therefore, the network can always be optimized for all loads.

5.2 Congestion Control

Network congestion results in packet delays as well packet loss which badly hampers the network performance. Reconfiguration can distribute the load approximately evenly among the lightpaths. The heavily-loaded lightpaths are augmented either by establishing new lightpaths or tearing a lightly load path and merging part of it with the heavily-loaded one [66], [66], [74], [100].

5.3 Failure Restoration

The most-promising and good feature of reconfiguration is that it can ensure failure restoration or "disaster recovery". Whenever there is a physical-link failure or equipment failure, restoration can be performed by two ways, rerouting and reconfiguration. Through network reconfiguration traffic is redistributed among the newly established virtual connectivity. Reconfiguration has the potential to restore more lightpaths than the rerouting approach [51], [79], and [101].

5.4 Bandwidth Trading

Bandwidth trading is one of the fast growing trends among the carriers and the business community. It is one of the key features of future "optical service management" [1] infrastructure. This feature allows carriers to broker wavelength-based bandwidth as a commodity. Dynamic topology reconfiguration has a very important role in the future of bandwidth trading and broker applications, because fast reconfiguration is critical for implementation of these concepts [59].

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[1] Enlightening the Optical Internet
A White Paper on Optical Service Management
Nortel Network
http://www.nortelnetworks.com/products/library/collateral/87016.25-03-00.pdf

6 Concluding Remarks[2]

Optical WDM Networks offer tremendous opportunities not only in terms of huge bandwidths but also in terms of network management and control. The changing traffic patterns, however, may devalue the optimization of the static virtual-topology design of WDM networks. Reconfiguration of virtual-topology would be required since with the changing traffic a virtual-topology optimized for a specific traffic matrix would lose its optimality [32]. Reconfiguration distributes the traffic load among lightly and heavily loaded links, thus it maximizes the link-capacity usage and improves the network performance [40]. The objective of the virtual-topology reconfiguration is to improve the network performance by satisfying the time-variant incoming traffic with the most suitable virtual-topology [102]. The ability to re-arrange the logical connectivity among network nodes, independently of the physical infrastructure, allow us to increase network utilization while providing better network performance by adapting to the bandwidth allocation to the changing traffic loads, and it also react to failures by bypassing the failed elements [50].

Reconfigurability is one of the incredible features of WDM optical networks, which provide opportunities to the network controllers to achieve high throughputs, avoid network disasters, and also control network congestion by reconfiguring the networks. One of the most promising prospects of its use is deemed in the future developing trend of customer controlled bandwidth trading [59]. VPNs can make use of this feature to achieve flexible high-bandwidth connectivity over the all-optical network infrastructure [105].

A study carried out in [31] reveals that a reconfiguration feature can significantly delay line system upgrades giving typically 10-15% saving in the network-wide wavelength requirements, resulting in greater traffic carrying capability and associated potential more revenue. Testbed studies and field trial demonstration reveal that large scale deployment of reconfigurable WDM optical network appear to be a realistic goal [23], [54], [57], [59], [90].

[2] Some of the statements are picked-up from the articles and re-written as it is or with a little change. The number in front of the statement shows the article to which it belongs

Network reconfiguration is still under research and development phase and lots of work has yet to be done. There are several aspects, which need in-depth research and study. Following are some significant and important future directions that are mentioned in the reviewed literature:

1. Distributed version of reconfiguration algorithm instead of centralized one [33].
2. Generalized mechanisms must be developed to quantify the benefits of reconfiguration of general topologies [85].
3. More experimental work is required on IP/WDM testbeds to realize deployment of operational networks [59].
4. Scheduling procedures may be defined that ensure a lesser damage due to reallocation of nodes during reconfiguration [14], [39].
5. There is need of reconfiguration procedures that realized a target-topology, which is close to the existing topology [50].
6. In-depth study of the impact of large tuning delays on reconfiguration and on the network performance is required [50], [68].

Through this survey an effort has been made to investigate and identify the research activity that has been going on the subject of dynamic reconfiguration in WDM Optical Networks. The relevant literature has been reviewed and discussed. In particular this survey discussed the issues, models, methodologies, algorithms and policies being employed for rearranging the WDM networks. Moreover, it covered the literature relating to both the broadcast, within which the access as well the transport networks, and wavelength routed WDM networks.

Appendix – I

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Appendix – II

Annotated Bibliography

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The authors presented a topology reconfiguration scheme which reconfigures the network to cope with traffic surges by adding links temporarily to IP layer. This scheme followed an approach in which traffic changes can be accommodated through partial modification of the existing topology, while keeping the total amount of added bandwidth to a certain level. A genetic algorithm was used to realize the reconfiguration. This scheme can only handle traffic surges and temporary congestion of the links.

[2] Arakawa, S.; Murata, M.; "Lightpath Management of Logical Topologies with Incremental Traffic Changes for Reliable IP over WDM Networks," *Optical Networks Magazine*, vol. 3, No. 3, pp. 68-76, May/June 2002

In this paper authors proposed an "incremental capacity dimensioning approach" for logical topology design and management in which network optimality was achieved through lightpath reconfiguration. A centralized methodology was followed for setting up the logical topology, which afterwards was adjusted incrementally as per changing traffic requirements. The proposed scheme was composed of three phases; initial phase, incremental phase, and rearrangeable phase. However, this paper mainly discussed the incremental phase, in which logical topology was adjusted through reconfiguration of backup paths, when network optimality was required to match a new traffic demand. For reconfiguration of backup paths, authors presented a heuristic algorithm "Minimum reconfiguring for Backup Paths (MRB). In this paper in new concept "Quality of Protection" (QoP) was also introduced which was nothing but reliability based classification of QoS i.e. backup protection.

[3] Bala, K.; "Towards Hitless Reconfiguration in WDM Optical Networks for ATM Transport," Proceedings *of IEEE GLOBECOM'96*, vol. 1, 18-22, pp. 316-320, Nov 1996

In this paper a methodology for reconfiguration of ATM topologies was presented. The reconfiguration was performed in such a manner that network adapted to changing traffic in a hitless mode through sizing of ATM switches. The scheme considered that the topologies were known in advance and configuration patterns were fixed. A greedy algorithm was proposed for wavelength assignment to links between two ATM ports. Bounds on the number of required wavelengths for hitless reconfiguration were also derived.

[4] Baldine, I. and Rouskas, G.N.; "Traffic Adaptive WDM Networks: A Study of Reconfiguration Issues," *Journal of Lightwave Technology*, vol. 19, No.4 , pp. 433-455, April 2001

In this paper three fundamental reconfiguration issues; frequency of reconfiguration, structure of reconfiguration phase, and quantifying the benefits of reconfiguration were discussed and solutions presented. Makovian decision process based formulation was proposed to predict traffic patterns for triggering the reconfiguration. For load balancing and network availability, five tools were proposed. For second issue, retuning strategies were proposed for tuning and regrouping the transceivers. Average packet delay and packet loss metrics were used for performance analysis and quantifying the benefits of reconfiguration. Most importantly, during analysis the effect of failures was not considered.

[5] Baldine, I. and Rouskas, G.N.; "Dynamic Reconfiguration Policies for WDM Networks" *IEEE* INFOCOM'99, vol. 1, pp. 313-320, Mar 1999

In this paper reconfiguration problem for broadcast WDM networks was discussed. Problem of reconfiguration was tackled as a two-step process. At first the degree of load balancing and the number of retuning involved in reconfiguration were identified. In second step, based on Markovian decision process a framework was established to obtain optimal reconfiguration policies for large size networks. A justification was provided for the use of optimal policies against threshold policies by analyzing the numerical results.

[6] Banerjee, D. and Mukherjee, B.; "Wavelength-Routed Optical Networks: Linear Formulation, Resource Budgeting Tradeoffs, and a Reconfiguration Study" *IEEE Transaction on Networking*, vol. 8, No. 5, pp. 598-607, Oct 2000

It is landmark paper in the field of network topology design and topology reconfiguration. It provided a solution to the optimal virtual topology design problem by minimizing the hop distance. The solution was integer linear program formulation. Two heuristics were proposed to deal with the large formulation of problem (i.e. when physical size of network grows large) and allow selection of lightpaths, routes for lightpaths and bandwidth of the path. It demonstrated optimal utilization of resources (transceivers and bandwidths) and provided analysis of resource budgeting. A reconfiguration procedure was also introduced to materialize a topology change according to new traffic matrix with minimum switch retuning.

[7] Byungjae, K.; Jong-Hoon, E.; Jinsik, P.; Chang-Joon, C.; "A lightpath routing reconfiguration algorithm for WDM optical networks," *IEEE Communications, Fifth Asia-Pacific Conference on ... and Fourth Optoelectronics and Communications Conference(APCC/OECC '99)* , vol. 1 , pp. 11-14, 1999

The authors proposed a lightpath routing reconfiguration algorithm with an objective to limit the number of optical cross-connects required for reconfiguration in general topology multihop WDM networks. The algorithm was based on branch and bound search method while the problem was tackled as integer linear program formulation. The results reveal that the number of optical cross-connects required for reconfiguration depend on similarity between existing and set of target virtual topologies. Moreover, to realize a new topology, all nodes does not require optical cross-connects.

[8] Chang, G.K.; Ellinas, G.; Gamlin, K.; Iqbal, M.; Brackett, C.; "Multi-wavelength reconfigurable WDM/ATM/SONET network testbed," *IEEE J. Lightwave Technology,* vol. 14, pp. 1320-1340, Jun 1996

This paper talked about the design, integration, and demonstration of multi wavelength reconfigurable WDM/ATM/SONET network testbed. Here performance of network components was studied and examined and management techniques for such networks were investigated. Moreover, rearrangability characteristics and operations involved were also studied.

[9] Dutta, R. and Rouskas, G.N.; "A Survey of Virtual Topology Design Algorithms for Wavelength Routed Optical Networks," *Optical Network Magazine*, vol. 1, Issue. 1, pp. 73-89, Jan 2000

This was a survey in which authors covered several issues and detailed literature on virtual topology design problem in wavelength-routed optical networks. The discussion was restricted to the context of static topology design, while related design formulations, algorithms, theoretical results, and heuristics were described and compared. The issue of reconfigurability was also discussed and relevant literature was reviewed.

[10] Ernest, P.H.H.; Mohan, G.; Bharadwaj, V.; " An Efficient Algorithm for Virtual Topology Reconfiguration in WDM Optical Ring Networks," *Proceedings of IEEE 10th* International *Conference on Computer Communications and Networks,* pp. 55-60, 2001

Authors proposed a reconfiguration algorithm for WDM transport networks with an aim to reduce the cost of reconfiguration while keeping the network congestion to a minimum. The algorithm limits the establishment of new lightpaths and realized a multi-step reconfiguration by splitting and merging existing lightpaths. In every step a small number of lightpaths were reconfigured at a predetermined time interval. This ensured the configuration of only a limited number of optical cross-connects, thereby it kept the reconfiguration cost low and the traffic disruption to a minimum.

[11] Geary, N.; Parnis, N.; Antonopoulos, A.; Drakopoulos, E.; John, "The Benefits of Reconfiguration in Optical Networks" *Networks 2002, pp. 373-378, 2002*

Authors studied the benefits of centralized manner reconfiguration process for optical networks and proposed two reconfiguration strategies. A distinct link upgrade procedure was followed to formulate the strategies in order to respond to a traffic increase in the network. Based on the proposed strategies expected capacity benefits were investigated when a centralized reconfiguration was applied to various topologies. The proposed strategies were not applicable to small size networks. The expected benefits were in the range of 10 to 15% savings in wavelength requirements for the entire network.

[12] Gencata, A.S. and Mukherjee, B.; "Virtual Topology Adaptation for WDM Mesh Networks Under Dynamic Traffic," *IEEE/ACM Transactions on Networking*, April 2003, to appear

Authors proposed an adaptation mechanism, for topology reconfiguration in WDM mesh networks, in which reconfiguration was considered a continuous and evolutionary process. In adaptation mechanism, traffic was measured periodically; if periodic traffic measurement identified any fluctuation, topology was reconfigured through addition or deletion of one lightpath at a time. The step-wise reconfiguration was achieved by either tearing-down a lightly loaded lightpath into two lightpaths with reasonable degree of loading, or a new lightpath was added to the heavily loaded lightpath. Two parameters high and low water marks were introduced to identify the factor of lightpath loading. To select a lightpath for addition or deletion, an integer linear program formulation was proposed. The method was evaluated through simulation.

[13] Gencata, A.S.; Sahasrabuddhe, L.; Mukherjee, B.; "Virtual Topology Adaption With Minimum Lightpath Change for Dynamic Traffic in WDM Mesh Networks," *Proceedings of OFC,* 2002

The authors presented a reconfiguration approach, for WDM mesh networks, in which virtual topology dynamically adapts to the changing traffic. The adaptation was realized in real-time by monitoring the changes in packet traffic volume. If a change in traffic intensity was observed then the virtual topology adapted to the change by simply adding or deleting one lightpath at a time. Results of comparatives study of the proposed method and the one that recomputed the topology from scratch were presented.

[14] Kato, M. and Oie, Y.; , "Reconfiguration algorithms based on meta-heuristics for multihop WDM lightwave networks," *IEEE International Conference on Communications (ICC 2000)*, vol. 3, pp. 1638 -1644, 2000

Three meta-heuristic based algorithms for reconfiguration in multihop WDM networks were presented. This work was an extension of an earlier work proposed in [38], and here authors added three more meta-heuristics namely simulated annealing (SA), threshold acceptance (TA), and multistart local search (MLS). The proposed algorithms search for a solutions that provide most favorable node placement for reconfiguration in multihop networks with regular topologies. The performance of the three was evaluated as a function of time required for calculation, by each, to reach a solution under a given criteria.

[15] Kato, M. and Oie, Y.; "Reconfiguration procedures for multihop WDM packet networks with non-negligible propagation delay," *Global Telecommunication Conference (GLOBECOM '01)*, vol. 4, pp.2174-2181, 2001

Authors proposed two procedures for reconfiguration in multihop WDM packet networks with non-negligible propagation delays. Authors classified the reconfiguration procedures into two classes; "single-step" procedure affects the whole network where every node is given a new position, whereas "multi-step" procedure incrementally reconfigures the network by changing minimum number of nodes at a time. This was an extension of work presented in [41] where they compared single-step and multi-step procedures against tuning latency of receivers, but there they assumed no propagation delay. So in this work they studied the effect of tuning time of receivers plus the propagation delay on total delay and packet loss in reconfiguration stage. To take care of packet loss during reconfiguration phase authors presented some mechanisms for loss avoidance.

[16] Kuleshov, V.; Banerjee, S.; "Minimal-disturbance topology reconfiguration in all-optical networks," *SPIE International Symposium on Voice, Video, and Data Communication*, Dallas Texas, 1997 vol. 3230 paper No. 15, 1997

Authors studied the reconfiguration in all-optical networks with a constraint of minimal disturbance to the established connections while transforming the network from one topology to another. They presented the solution in terms of ad hoc algorithms that followed a shortest-path-first approach. This approach was used because it utilized fewer resources at the beginning when reconfiguration was realized in small stepwise changes made to the connections. In concluding remarks they deliberated that algorithm which checked both the smallest wavelength and port congestion, performed better than the one which checked only the maximum link load during shortest path selection.

[17] Labourdette, J –F.P.; "Traffic Optimization and Reconfiguration Management of Multi wavelength Multihop Broadcast Lightwave Networks," *CN & ISDN Systems,* 1998

This paper was a review article in which a study of traffic optimization and reconfiguration management problems was carried out and the relevant literature was reviewed. The study remained focused on these two problems and was related to multihop broadcast networks; it did not cover wavelength-routed optical networks. Mathematical formulation of the two problems was presented and different heuristic algorithms were described and compared.

Several reconfiguration management strategies were also described and their merits and demerits were discussed. Future research directions related to these problems were also discussed.

[18] Labourdette, J –F.P.; Hart, F.W.; Acampora, A.S.; "Branch-Exchange Sequences for Reconfiguration of Lightwave Networks," *IEEE Transaction on Telecommunication*, 42(10), pp. 2822-2832, Oct 1994

This is one of the milestone papers in which a minimal disruptive approach was proposed for network reconfiguration. Under this approach, reconfiguration was realized through a sequence of branch-exchange operations in such a manner that a single pair of links was disrupted at a particular instance. The number of branch exchanges increase linearly with the increasing number of logical links. Thus when the size of the network grows the length of a sequence of branch exchanges follows in a linear fashion. To find a shortest sequence of branch exchanges, authors proposed three polynomial time greedy algorithms which compute a reconfiguration sequence to match the new traffic demand in minimum possible duration. The algorithms were differentiated based on the amount of work they perform, and were picked up on the basis of their performance and time complexity.

[19] Labourdette, J –F.P.; "Performance impact of partial reconfiguration on multihop lightwave networks," *IEEE/ACM Transactions on Networking (TON)*, vol. 5 Issue. 3, June 1997

In this paper the connectivity of network with partial reconfiguration and the effect of tunability restrictions on network transmitters and receivers were studied. Bounds on performance degradation were derived, where they were defined as a function of tunability restrictions. To handle the handicap of tunability restrictions, authors proposed a wavelength decomposition, assignment and grouping scheme. Through this scheme the tunability range of transmitters and receivers could be increased, thereby improving the network performance.

[20] Lee, H.; Choi, H.; Subramaniam, S.; Choi, H-A.; "Preserving Survivability during Logical Topology Reconfiguration in WDM ring networks" *International Conference on Parallel Processing 2002*, pp. 224-230, 2002

This paper addresses the issue of network survivability during reconfiguration phase. The authors proposed an approach of finding sequences of lightpath addition and deletions such that one of sequences ensures network survivability throughout reconfiguration phase. First a simple algorithm was presented and its limitations were discussed. Later they presented a heuristic algorithm which determines the number of additional wavelengths required while maintaining the cost of reconfiguration to a minimum.

[21] Liu, K.H.; Liu, C.; Pastor, J.; Roy, A.; Wei, J.Y.; "Experimental Study of Dynamic IP Topology Reconfiguration in IP/WDM Networks," *IEEE GLOBECOM Global Telecommunication Conference 2001*, vol. 1, pp. 76-80, 2001

A reconfiguration model for overlay type IP over WDM network was proposed. Based on this model authors developed a reconfiguration system prototype in which reconfiguration was triggered by traffic engineering based decisions. The prototype was tested for reconfiguration convergence. The test was performed over a testbed setup on MONET WADMs and IP routers.

[22] Liu, K.H.; Liu, C.; Pastor, J.; Roy, A.; Wei, J.Y.; "Performance and Testbed Study of Topology Reconfiguration in IP over Optical Networks" *IEEE Transactions on Communications*, vol. 50 Issue: 10, pp. 1662-1679, Oct 2002

The authors carried out a performance and testbed study of topology reconfiguration, and presented a traffic management framework for reconfigurable IP over WDM networks. Under this framework, they proposed three "one-hp traffic maximization" algorithms for topology design, and one reconfiguration migration algorithm for topology change. Results obtained from testbed simulations were analyzed and discussed. Based on these results they concluded that the proposed framework resulted in throughput gain and reduction in average hop distance compared to networks with fixed topologies

[23] Narula-Tam, A.; Modiano, E.; "Dynamic Load Balancing for WDM based packet Networks," *Proceedings of IEEE INFOCOM 2000*, pp. 1010-1019, 2000

In this paper authors proposed and examined a reconfiguration strategy for multihop WDM packet networks, and presented iterative reconfiguration algorithms. The reconfiguration was performed in steps and in every step only a small change was made to the virtual topology of the network. These stepwise small changes ensure minimum disruption to the network while on the other hand it slashed the maximum link load. The reconfiguration process lead to load balancing operations that were initiated to accommodate the rapid traffic changes. In this study authors assumed that the number of available wavelengths were unlimited.

[24] Narula-Tam, A.; Finn, S.G.; Medard, M.; "Analysis of reconfiguration in IP over WDM access networks," Optical *Fiber Communication, OFC 2001*, vol. 1, pp. MN4/1 -MN4/3, 2001

In this paper two models were presented for evaluating the benefits of reconfiguration as a function of average packet delay in IP over WDM access networks. Authors proposed four policies for network reconfiguration and derived bounds on the performance as a function of minimum-average packet delay. The performance of each was analyzed against optimally established fixed topology systems.

[25] Narula-Tam, A. and Madiano, E.; "Dynamic Load Balancing in WDM packet networks with and without wavelength constraints," *IEEE Journal on Selected Areas in Communications*, vol. 18 pp. 1972-1979, Oct 2000

In this paper a reconfiguration strategy and an iterative algorithm was presented for wavelength-routed optical networks. The strategy followed the concept of minimum disruption to the traffic flow while reducing the link load by reconfiguring the topology with step-wise local changes to the network. The impact of wavelength limitation on gain was also studied, where gain was defined was defined as maximum drop in the link load. It was shown that significant reduction in link load can be achieved even with limited number of wavelengths in the network.

[26] Phillip, P.; "Reconfigurability of Shuffle Nets in multi-star implementation" *PROC IEEE INFOCOM,* IEEE*, PISCATAWAY, NJ*,

The issue of reconfigurability in multi-star Shuffle Nets and the effect of the numbers of star-couplers on reconfiguration was investigated and studied in this work. The study was limited to symmetric multi-star Shuffle Nets and authors deliberated that maximum reconfigurability is possible through proper channel assignments. They also showed that reconfigurability is a function of number of channels available per coupler and the number of couplers used in the configuration. They proposed three channel assignment algorithms for different channel values used Shuffle Nets.

[27] Pongpaibool, P.; Doverspike, R.; Roughart, M.; Gottlieb, J.; "Handling IP traffic surges via optical layer reconfiguration," *Optical Fiber Communication Conference (OFC 2002)*, pp. 427 -428, Mar 2002

A solution for handling traffic surges in inter-city backbone network, through reconfiguration of IP layer was proposed in this work. Authors presented a method that tackled the traffic bursts by adjusting the IP-layer link capacity which utilized reconfigurable optical cross-connect layer for this job.

[28] Ramamurthy, B.; Ramakrishnan, A.; "Virtual Topology Reconfiguration of Wavelength-Routed Optical WDM Networks," *IEEE Global Telecommunication Conference GLOBECOM'00,* vol.2, pp. 1269-75, 2000

This paper proposed a solution to the topology reconfiguration problem through mathematical rigorous formulation where change in traffic pattern triggered the reconfiguration. It also discussed some previous work done in this field and proposed a modification to an algorithm presented in [14]. The modification considered balancing the amount of reconfiguration needed against a set of desired optimal network topologies. However, it did not discuss "when to trigger reconfiguration?"

[29] Reddy, G.S.K.; Manimaran, G.; Murthy, C.S.R; "Reconfiguration based failure restoration in wavelength-routed WDM optical networks," *Proc. of Dependable Systems and Networks*, *IEEE Conference,* pp. 543-552, 2000

In this paper authors discussed the mechanism of failure restoration through network reconfiguration for WDM networks. They proposed and architecture for lightpath network (LPN) manager that deals with lightpath design and lightpath realization. Under LPN manager architecture, they presented performance measures and heuristic based algorithms for lightpath realization. The paper mainly discussed lightpath realization part of the LPN manager. The efficiency of proposed algorithm was tested through simulation studies.

[30] Rouskas, G.N.; Ammar, M.H.; "Dynamic Reconfiguration in Multihop WDM Networks," *Journal of High Speed Networks*, vol. 4, No. 3, pp. 221-238, 1995

This paper answers to the two basic questions pertaining to dynamic reconfiguration and which are (a) When to trigger reconfigurations and (b) how the reconfigurations should be performed. Authors first figured out the limitations of the reconfigurations approaches presented earlier in [5]and [48], and afterwards presented a new approach that devises policies for dynamic reconfiguration of multihop WDM networks under changing traffic conditions. The performance of the network was assessed as a function of packet loss, which was experienced during reconfiguration phase. The extent of packet loss was chosen as criteria for selecting a specific policy and frequency of reconfiguration.

[31] Schein, B.; Modiano, E.; "Quantifying the Benefit of Configurability in Circuit-Switched WDM Ring Networks with Limited Ports Per Node." *IEEE Journal of Lightwave Technology*, vol. 19, no. 6, pp. 821-829, June 2001

This paper focuses on working out the benefits that can be achieved due to topology reconfiguration against fixed topology systems in WDM circuit-switched ring networks. The benefits were quantified in terms of gain in traffic capacity, where gain was defined as a ratio of loads that two systems (reconfigurable vs. fixed topology) can carry for a particular blocking probability. A stochastic system model was proposed to iteratively compute the blocking probability with limited number of ports at each node. Based on the proposed model upper and lower bounds on blocking probability were derived. The fact that this model considered port limitations signifies it from earlier models. In conclusion it was revealed that a reconfigurable system approximately needs half the number ports against fixed topology system for a specific traffic matrix.

[32] Sreenath, N.; Panesar, G.R.; and Murthy, C.S.R; "A Two-Phase Approach for Virtual Topology Reconfiguration of Wavelength-Routed WDM Optical Networks," *IEEE*, pp:371-376

Authors presented a reconfiguration approach that consists of a reconfiguration phase and a fine tuning phase. In this two-phase approach, which was developed for wavelength-routed WDM optical networks; reconfiguration was considered as an online process. The performance was studied using simulation experiments and results were analyzed. In this approach researchers did not address the implementation of the reconfiguration phase.

[33] Takagi, H.; Zhang, Y.; Jin, X.; Takagi, H.; "Virtual Topology Reconfiguration for Wide-area WDM Networks," *IEEE 2000*, pp. 835-839, 2000

Authors proposed several heuristic based reconfiguration algorithms for wide area WDM networks. The performance of all algorithms was evaluated on "NFSNET-like" network model against maximum network availability during reconfiguration, where single lightpath was considered as the basic unit of reconfiguration. From the analysis of comparative performances, authors concluded that algorithm with reasonable computational complexity; compared to simple and more complex algorithms, give very good performance i.e. good network availability.

[34] Yang, X. and Ramamurthy, B.; "An Analytical Model for Virtual Topology Reconfiguration in Optical Networks and a Case Study," *Proc. of Computer Communications and Networks*, pp. 302-308, 2002

An analytical model that compares and chooses various reconfiguration algorithms and policies was proposed for virtual topology reconfiguration in optical networks. The comparison was based on benefits and penalties that a certain algorithm/policy offers. The model facilitates adaptive selection of a particular policy or algorithm that best fits the real-time network conditions and requirements. This model is different from the rest as it analyses the impact of reconfiguration on both data and control planes.

[35] Jennifer Yates, Gisli Hjalmtysson, Albert Greenberg, "Reconfiguration in IP over WDM Access Networks" *Optical Fiber Communications*, paper Tuk4-1, Mar 2000

This paper studies the dynamic reconfiguration of lightpath performed to cushion the transients in IP traffic in WDM access networks, and investigates the potential benefits that can be exploited via reconfiguration. Authors proposed a network model and a simple lightpath reconfiguration algorithm that exploits the use of wavelengths for traffic engineering and works in such a fashion that each wavelength is approximately equally loaded. In concluding remarks they deliberated that compared to static allocation; dynamic allocation considerably improves the wavelength distribution.

[36] Zhan, L.; Chan-Hyun, and Yeo, H.G.; "Adaptive Virtual Topology Reconfiguration Policy Employing Multi-stage Traffic Prediction in Optical Internet" *IEEE High Performance Switching and Routing*, pp:127-131, 2002

The authors studied issues related to reconfiguration triggered by traffic changes in optical Internet and formulated a reconfiguration policy. Under this policy they proposed a heuristic based reconfiguration algorithm that employed a "multi-stage decision making" approach for countering the problem of continual approximation. Performance of the proposed policy was examined by analyzing and comparing the simulation results with a conventional algorithm.

[37] Zhou, B.; Zheng, J.; Mouftah, H.T.; "Dynamic reconfiguration based on balanced alternate routing algorithm (BARA) for all-optical wavelength-routed WDM Networks," *CITO Information Research Conference,* Ottawa, Oct 2000

The problem of dynamic reconfiguration of virtual topology triggered by changing traffic requirements was studied and authors proposed a balanced alternate routing algorithm for solving this problem. The problem was formulated as integer programming problem and with the goals to increase the network throughput while keeping the reconfiguration cost to a minimum. Authors ignored the wavelength assignment problem and assumed that wavelength converters were available every where. The proposed algorithm was based on genetic algorithm and the optimization was achieved through two independent stages of route computing and lightpath routing. In the first stage a set of alternate routes was computed and in the second stage route selection was performed for each lightpath.

[38] Leisching, P.; Beck, H.; Richer, A.; Stoll, D.; Fischer, G.; "Reconfigurable all-Optical Networking at Terabit Transmission Rates" Optical *Fiber Communication Conference*, vol. 1 pp. 240-242, 2000

This article discussed the experimental setup, system demonstration and results achieved in a field trial experiment carried out on all-optical metropolitan network, which was a subnet of German research program KOMNET in Berlin. The demonstration was performed on a WDM 60 km single mode fiber ring, comprising of reconfigurable three OADMs. All OADMs were connected to neighboring networks and were used to switch traffic to the connected networks. Transmission rate of 0.8 Tbits/s without any error was reported.

[39] Zheng, J.; Zhou, B.; Mouftah, H.T.; "Design and Reconfiguration of Virtual Private Networks (VPNs) over All-Optical WDM Networks," *IEEE*, pp. 599-602, 2002

The virtual topology design and reconfiguration problem related to Virtual Private Networks (VPNs) was discussed and a solution in the shape of Balanced Alternate Routing Algorithms was presented. A genetic algorithm was used for improving performance, and optimization was achieved through a two step process of i.e. through route computing and lightpath routing. The algorithm is effective for virtual topology design and reconfiguration of VPNs over all-optical WDM Networks.

[40] Alfouzan, I.; Jayasumana, A.; "Dynamic reconfiguration of wavelength-routed WDM networks," *Proc. Local Computer* Networks*, IEEE (LCN 2001)*, pp. 477-485, 2001

This paper studied the reconfiguration due to traffic changes in Wavelength Routed Optical Networks. Authors tried to find out a tradeoff between the number of retuning and the degree of load balancing among the lightpaths. For achieving an optimized solution they proposed an algorithm, Most and Least Loaded Channel Balance (MILLCB) algorithm, which reduced the load from a heavily loaded link by exchanging one node with a lightly loaded link.

Appendix – III

List of Leading Researchers

1 Ilia Baldine
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Appendix – IV

List of Recent and Forthcoming Conferences

1 SPIE APOC 2003
November 2-6, 2003
Wuhan, China
http://www.spie.org/conferences/Calls/03/apoc/

2 SPIE APOC 2002
Asia-Pacific Optical and Wireless Communication
October 13-18, 2002
Shanghai, China
http://www.spie.org/conferences/programs/02/apoc/

3 IEEE GLOBECOM 2002
November 17-21, 2002
San Francisco, CA, USA
Taipei, Taiwan
http://www.globecom2002.com/

4 IEEE GLOBECOM 2003
December 1-5, 2003
San Francisco, CA, USA
http://www.globecom2003.com/CFP1.html

5 ICC 2003
IEEE International Conference on Communications
May 11-15, 2003
Anchorage, Alaska, USA
http://www.icc2003.com/

6 IEEE INFOCOM 2003
The 22nd Annual Joint Conference of the IEEE Computer and Communication Societies
March 30- April 3, 2003
San Francisco, California, USA
http://www.ieee-infocom.org/2003/

7 SPIE ITCom 2003
September 7-11, 2003
Orange County Convention Center
Orlando, Florida USA
http://spie.org/Conferences/Calls/03/it/

8 OFC 2004: Technical Conference
February 22-27, 2004
Los Angeles Convention Center
Los Angeles California, USA

9 OFC 2003
March 23-28, 2003
Georgia World Congress Center
Atlanta, Georgia, USA
http://www.ofcconference.com/2003/splash.cfm

10 ACM SIGCOMM 2003
August 25-29, 2002
Karlsruhe, Germany
http://www.acm.org/sigcomm/sigcomm2003/

11 ACM SIGCOMM 2002
August 19-28, 2002
Pittsburgh, PA
http://www.acm.org/sigcomm/sigcomm2002/

Appendix – V

Cross Reference Graph

The cross-reference graph has been used to identify the milestone and major papers related to survey topic. The second column in the graph shows the papers that have been referred while the second-last bottom row shows the same papers, but these refer to the papers listed in the column.

The numbers in the right-most column of the graph indicate the number of times a paper has been referred, while numbers on the bottom indicates how many papers, included in the bibliography, have been referred by this paper.

A paper that has been referred by at least "9" or more papers is considered as milestone paper, while a paper that has been referred by "5" or more papers or which refers to "5" or more papers is taken as major paper. But this is not the only criterion for identifying the major papers, papers that are new on the subject and provide an in-depth and new dimension to this topic are also considered and included in the annotated bibliography.

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Click on the icon to see the cross-reference graph.

Appendix – VI

Emails Sent to Researchers

From: "Shin'ichi Arakawa" <arakawa@ics.es.osaka-u.ac.jp>

Subject: Re: Reference to paper

Date: Tue, 18 Feb 2003 09:01:26 +0900

To: gillani@uwindsor.ca

Cc: arakawa@ics.es.osaka-u.ac.jp

```
Dear Dr. Badar Gillani,
My name is Shin'ichi Arakawa, the first author of that paper.
The paper was published in,
 Optical Networks Magazine, vol. 3, number. 3,
 pp. 68--76, May/June 2002.
Thank you.
Best Regards,
  Shin'ichi Arakawa
  Graduate School of Engineering Science,
  Osaka University,
  Osaka, Japan
  E-mail: arakawa@ics.es.osaka-u.ac.jp

On Tue, 18 Feb 2003 07:55:12 +0900
"Masayuki Murata" <murata@nal.ics.es.osaka-u.ac.jp> wrote:
> -----Original Message-----
> From: Gillani B [mailto:gillani@uwindsor.ca]
> Sent: Tuesday, February 18, 2003 1:15 AM
> To: murata@cmc.osaka-u.ac.jp
> Subject: Reference to paper
>
>
> Dear Dr. Murata
>
> I have one of your papers titled "Lightpath management of logical
> topologies with incremental traffic changes for reliable IP over
WDM
> networks", but I dont have full refernce.
```

>

> Would you please send me the full reference i.e conference, symposium or

> Journal in which if that paper has been presented or published.

>

> Truly,

> Badar

>