Chapter 1

Introduction and Scope of the Thesis

1.1 Preamble

In the past few years, there has been a growing interest in WDM optical networks. Fiber optic technology used in these networks has emerged as the most promising candidate for bandwidth intensive applications because of the enormous bandwidth of optical fibers and the capacity of multiplexing channels onto a single fiber through wavelength division multiplexing (WDM) technique [1,2].

Wavelength Division Multiplexing (WDM) refers to the use of distinct wavelengths over an optical fiber to implement separate channels. A lightpath between a source node and a destination node in a WDM optical network is defined by a route between them and a free wavelength on that route. The lightpath must use same wavelength on every link of the route and this is called the wavelength-continuity constraint. To establish a lightpath between a source-destination pair through routing and assigning wavelength to the route is known as lightpath allocation problem or Routing and Wavelength Assignment (RWA) problem. This function is of fundamental importance in the design of WDM optical networks because the number of wavelengths that each fiber can carry simultaneously is limited. Hence, the problem of lightpath allocation is chosen as the topic of research for the present work.
1.2 WDM Optical Network

A point-to-point interconnection of optical wavelength routers using optical fiber links is known as the physical topology of a WDM optical network. The nodes in the network are competent of routing different wavelengths at an input port to different output ports. The transmitters can send signals to only the destined receiver instead of broadcasting them to all receivers. Hence, these nodes are sometimes called wavelength routers.

A wavelength Add-Drop Multiplexer (ADM) passes traffic on certain wavelengths through without interruption, while traffic on other wavelengths is terminated optically, i.e. the wavelength is dropped. Some wavelengths can also be added, i.e. traffic can be injected at this node using those wavelengths [3].

An Optical Cross-Connect (OXC) takes in a signal at each of the wavelengths at an input port, and routes it to a particular output port, independent of the other wavelengths. An OXC with N input and N output ports capable of handling W wavelengths can be thought as W independent N x N switches [3].

A wavelength converter is an optical device that converts optical signal from one wavelength to another wavelength. When light path is to be established but wavelength conflict is encountered in a link, the corresponding node can use a wavelength converter to resolve this conflict in order to establish the light path. In general, wavelength converter can increase the probability of establishing lightpath successfully. Therefore, they can improve the performance of all optical networks. Though the use of converters is advantageous, it increases cost of a network. Hence, converters should be placed in a network in such a way that reduces the blocking probability as well as the cost of the network.
1.3 WDM-TDM Optical Network

In WDM technology the whole bandwidth of an optical fiber is divided among a number of non-overlapping wavelengths, each of which is capable of carrying high-speed optical data. In recent years, the bandwidth of a wavelength has been increased to about 50 Tbps. Thus, the bandwidth capacity on a wavelength is too large for certain traffic requirements. One way to provide fractional wavelength capacity is to split a wavelength in multiple time slots and multiplex traffic on that wavelength. Therefore, each wavelength running at the line rate of OC-N can carry several low-speed OC-M (M < N) traffic channels in TDM fashion. For example, an OC-48 line can carry 16 OC-3 channels. The resulting networks are called WDM-TDM networks or WDM traffic grooming networks. The ratio of N to the smallest value of M is called grooming ratio [4].

1.4 A Brief Review

[3,5-8] focuses on the routing and wavelength assignment (RWA) problem in wavelength routed WDM optical networks. In [5], the RWA problem is examined and various routing approaches and wavelength assignment approaches proposed in the literature are reviewed. A new wavelength-assignment scheme, called Distributed Relative Capacity Loss (DRCL) is proposed, which works well in distributed controlled networks, and the performance of DRCL is demonstrated through simulation. In [7], three related problems in wavelength routed optical networks with no wavelength conversion are studied. These are logical topology problem, routing and wavelength assignment problem and provisioning problem.
The proposed RWA algorithm constructs a solution from the result obtained by solving the mixed integer linear program, which is used for the formulation of the problem with a view to design optimal logical topology. In [8], Zhang and Acampora presented a heuristic algorithm for effectively assigning a limited number of wavelengths. The heuristic is tested on a realistic traffic model, and the call blocking performance of new requests for virtual connections is studied through extensive simulations and compared against the blocking performance of an ideal infinite capacity centralized switch. They found that the blocking performance of the network is almost the same as that of the ideal centralized switch. In [9], Sengupta, Bandyopadhyay, Balla and Jaekel studied both centralized and distributed schemes for dynamic routing in WDM optical networks. In [10], Li and Somani presented two dynamic routing algorithms based on path and neighborhood link congestion in WDM optical networks. In wavelength routed WDM networks, a control mechanism is required to set up and take down all-optical connections. Upon the arrival of a connection request, this mechanism must be able to select a route, assign a wavelength to the connection and configure the appropriate optical switches in the network. The mechanism must be able to provide updates to reflect which wavelengths are currently being used on each link. In [11], authors have reviewed control mechanisms proposed in the literature. All-optical networks are networks for which all data paths remain optical from input to output. In [12], Pankaj and Gallager presented a lower bound on the number of wavelengths required for permutation routing as a function of the size and degree of an all-optical network. In a permutation routing problem each node is the origin of one session and the destination of one session at any given time. Designing a virtual topology on a physical network consists of deciding the lightpaths to be set up in terms of their source and destination nodes and
wavelength assignment. Banerjee, Yoo and Chen [13] provided two heuristic algorithms for constructing a logical or virtual topology that reduces maximum logical connection congestion. They have also presented an improved lower bound for maximum congestion on any link in the logical topology. Dutta and Rouskas [3] provided a complete formulation of the problem, algorithms and results reported in the literature in the field. They have also discussed another important characteristic of optical networks, namely the reconfigurability issue. Ramaswami and Sivarajan, in [14], considered the problem of routing connections in a reconfigurable optical network using wavelength division multiplexing. They have derived an upper bound on the carried traffic of connections for any routing and wavelength assignment algorithm in such a network. They have also derived a similar bound for optical networks using dynamic wavelength converters. Finally, they have quantified the amount of wavelength reuse achievable in large networks and their results show that wavelength converters offer a 10 – 40% increase in the amount of reuse achievable when the number of wavelengths available is small.

Due to limited number of wavelengths on a fiber it may not always be possible to allocate a lightpath between a source and a destination. In that case, an optical device called wavelength converter may be used to convert a wavelength to a desired wavelength required for a different link. In [15], Chlamtac, Farago and Zhang introduced the concept of semilightpath. A lightpath is a fully optical transmission path, while a semilightpath is a transmission path constructed by chaining together several lightpaths, using wavelength conversion at their junctions. They have presented a fast algorithm to optimally route lightpaths and semilightpaths taking into account both the cost of using the wavelengths on links and the cost of wavelength conversion. A survey of the enabling technologies, design methods and analytical models used in wavelength convertible networks is
provided in [16]. [17-21] proposes methods to model and calculate the blocking probabilities in WDM optical networks with converter as well as without converter.

Traffic grooming means packing low speed traffic streams into higher speed streams. In a WDM ring network, each wavelength can carry several lower rate traffic streams in TDM fashion. A wavelength needs to be added or dropped, only at the two end nodes of a connection. Hence, ADMs at intermediate nodes will electronically bypass this timeslot. Instead of having an ADM on every wavelength at every node, it may be possible to have some nodes on some wavelength where no ADM is needed on any time slot; thus, the total number of ADMs in the networks can be reduced. This problem of ADM minimization has been reported in [22-28]. In [29], extension of the traffic grooming problem in a single ring network is studied for non-uniform traffic. The problem is posed as an integer linear program and then solved using a simulated-annealing based heuristic algorithm. Traffic grooming in interconnected multi-WDM rings is also studied here.

1.5 Scope of the Thesis

The following works are reported in this thesis.

i) Heuristics for wavelength assignment to static lightpaths in WDM optical networks.

ii) Distributed schemes for wavelength assignment to dynamic lightpaths in WDM optical networks.
iii) An evolutionary scheme for optimal allocation of wavelength converters in WDM optical networks.

iv) A heuristic to minimize add-drop multiplexers used in WDM-TDM optical ring networks.


Summary of the aforementioned works are provided below on the basis of the consecutive chapter headings.

1.5.1 Heuristic Algorithms for Assigning Wavelengths to Static Lightpaths in WDM Optical Networks

Heuristics for assigning wavelengths to static lightpaths in WDM optical networks are presented here. Given a network and lightpath requests, the problem is to assign wavelengths to the lightpaths so as to minimize the number of wavelengths used. The problem is posed as a graph-coloring problem, which is then solved using heuristics. Given the physical topology and lightpath requests, we first construct an auxiliary graph, whose nodes represent lightpaths, and next color this auxiliary graph. Beginning with a temporary label for each lightpath, when the algorithm terminates, each lightpath is assigned a permanent wavelength color. The time complexity of the algorithms are calculated to be $O(N^3)$ and $O(N^2)$.
respectively, where \( N \) is the number of lightpaths to be colored. It has also been shown that the algorithms are optimal in the number of wavelengths used for coloring the lightpaths.

### 1.5.2 Distributed Schemes for Assigning Wavelengths to Dynamic Lightpaths in WDM Optical Networks

The problem of establishing lightpaths between a given source-destination pair through routing and assigning wavelength to the route is known as *routing and wavelength assignment (RWA)* problem. Here, we have proposed a set of distributed schemes for assigning wavelengths to dynamic lightpaths in WDM optical networks. We have made a comparative study of different distributed schemes in terms of blocking probability and average call setup time.

### 1.5.3 An Evolutionary Approach for Optimal Allocation of Wavelength Converters in WDM Optical Networks

Here, we propose an evolutionary approach for optimal allocation of wavelength converters in WDM optical networks. Since wavelength converters are expensive, it is desirable that each node in a WDM network should use minimum number of wavelength converters to achieve near-ideal performance. For this purpose the searching capability of evolutionary algorithms have been exploited. Consequently a performance index has been used to enhance the accuracy and convergence of the algorithm proposed. The corresponding merits are justified by analyzing the
critical situations that may arise in practical problems. The distinguished feature of
the proposed algorithm is that it efficiently determines the optimal solution for
allocation of wavelength converters among the nodes in the WDM optical network
depending on various intuitively effective information such as sum of total
utilization, individual-node utilization, spatial problem and connectivity of a node
with other nodes simultaneously. Simulation results demonstrate that the proposed
algorithm can efficiently solve the problem of Optimal Wavelength Converters
Allocation (OWCA) in practical WDM optical networks.

1.5.4 A Heuristic Algorithm for Minimization of Add-Drop
Multiplexers in WDM-TDM Optical Ring Networks

In recent years, minimization of the SONET-ADMs in WDM optical networks has
gained lot of attention in both the research and commercial arenas. This motivates
the research presented here. First of all, a heuristic algorithm is formulated for
static traffic grooming in WDM uni-directional ring networks with an eye to
minimize the number of required ADMs. To justify the effectiveness of the
algorithm, the algorithm is compared with the results proposed in the literature
with the same network configuration and traffic matrix. The distinguished feature
of the proposed heuristic algorithm is that it efficiently pairs up the given static
traffic to reach an appreciable solution.
1.5.5 An Evolutionary Approach for Minimization of Add-Drop Multiplexers in WDM-TDM Optical Networks

The enhanced searching capability of an evolutionary optimization algorithm has been exploited here to solve the ADM minimization problem in WDM-TDM optical networks. It has been established that shuffling the calls in a certain sequence for a given traffic matrix can lead to the optimum number of required ADMs. First of all, some good populations based on intuitive reasoning have been introduced in the initial population to enhance the convergence of the evolutionary algorithm. Subsequently, it is used to optimize the number of ADMs required. To justify the effectiveness of the proposed algorithm, it is compared with an algorithm presented in the literature for the same network configuration and traffic matrix. The distinguished feature of the proposed algorithm is that it efficiently shuffles the given static traffic to obtain the optimum solution.

1.6 Organization of the Thesis

The rest of the thesis is organized as follows. In Chapter 2, two heuristics for wavelength assignment to static lightpaths in WDM optical networks are described. Chapter 3 presents distributed schemes for wavelength assignment to dynamic lightpaths in WDM optical networks. An evolutionary scheme for allocation of wavelength converters in WDM optical networks that tries to minimize the number of wavelength converters used is presented in Chapter 4. Chapter 5 introduces a simple heuristic to minimize add-drop multiplexers used in WDM-TDM optical ring networks. Chapter 6 provides a genetic algorithm for
minimization of add-drop multiplexers in WDM-TDM optical networks where the network structure may be other than the ring also. Finally, in Chapter 7, conclusions are drawn along with a discussion on the scope of further research in this direction.

References


