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Energy aware routing in optical grid networks

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by

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ABSTRACT

In the recent years due to rapid increase in the high-bandwidth applications there is a need for developing the energy efficient routing in the WDM optical Networks. Many researchers have addressed this problems in different ways by putting the network components into sleep mode or switching off the network components in low utilization periods. In this thesis our proposed method uses the principle of *anycast* routing, where it is possible to select any one of the possible destinations from the set of available destination nodes to complete the work. A novel genetic algorithm is used for solving this problem for scheduled lightpath demands (SLD), where the start and end times of the demands are known in advance.The fitness function used in the genetic algorithm not only minimizes the power consumption of the network but also minimizes the overall(transceiver) cost of the network by minimizing the total number of lightpaths needed to implement each logical edge. The proposed method minimizes the number of lightpaths and selects a suitable route for each demand so that the power consumed by the optical grid networks can be reduced, which results in significant energy savings.

DEDICATION

To my loving parents:

Father: kodakanchi Manikyam

Mother: kodakanchi Rupa

Brother: kodakanchi manohar

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Arvind kodakanchi

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

1.1 Overview

Optical networking is a means of communication that uses signals encoded onto light to transmit information among various nodes of a telecommunications network [1]. In the early years electronic communication was used, which utilized copper wires as the communication medium. Such electronic transmission has many limitations with respect to speed, bandwidth, distance etc. Optical networks are able to overcome many of these limitations and accommodate high bandwidth applications such as videos, multimedia, online games [1].Optical networks consist of optical fibers, which can carry optical signals at different wavelengths (or channels). The optical signals are generated at the source using a transmitter and are converted back into electronic domain, using a receiver, at the destination node. As these high bandwidth applications continues to grow, there is a need to increase the speed of optical networks for which a technique called wavelength division multiplexing (WDM) can be used. WDM is a technique where optical signals with different wavelengths are combined, transmitted together, and separated again at the destination node[1].

1.1.1 Traffic models

A number of different traffic models have been considered for resource allocation in wavelength division multiplexing (WDM) optical networks [1]. The most commonly used models include static traffic (where the set of demands are fixed and known in advance), dynamic traffic (where the arrival time and duration of demands are generated randomly, based on certain distributions), and incremental traffic (demands are added to the network incrementally). However, the actual traffic load in transport networks is often predictable and periodic in nature [2]. A more appropriate model, for this type of traffic, is the scheduled traffic model (STM) proposed in [2]. In this model, the setup and teardown times of the demands are known in advance, so that the traffic routing algorithms can optimize resource allocation in both space and time. In this thesis we focus on the scheduled traffic model; a more detailed discussion of this type of traffic is given in Sec.2.3.

1.1.2 Optical Grids

Grid computing involves high performance computing with resource sharing to support data-intensive applications, and requires high speed communications [3]. A large amount of such resources, geographically distributed around the globe, remain underused. The grid paradigm offers computation and storage using these resources, such that the exact geographic location of the physical resource remains transparent to the user. This means that user requests for computation and/or storage resources may be satisfied at a number of different locations. Intelligent resource allocation strategies can use this inherent flexibility to choose a suitable destination for a specific task. This is often referred to as the *anycast* principle. Wavelength division multiplexing (WDM) optical networks become a natural choice for interconnecting the distributed computational and/or storage resources due to their high throughput, high reliability and low cost. In this context it is possible to exploit the inherent flexibility of anycasting to develop more energy efficient traffic routing strategies for WDM networks

1.2 Motivation

With the rapid increase in online data storage and high bandwidth applications over the internet, the share of the power consumption of the Information and communication Technology (ICT) is increasing and currently account for about 1-2% of the global energy consumption [4]. There is a need to develop energy-efficient design strategies at all levels for the network infrastructure. This includes design of low-power network equipment as well as energy-aware routing and resource allocation techniques at both the electronic and optical layers. WDM optical networks can play an important role in reducing the energy consumption of core network nodes, by allowing traffic to optically bypass electronic components[5]. In recent years there has been a growing recognition of the need for designing energy efficient WDM backbone networks [6]. A number of approaches have been proposed for reducing power consumption in optical networks; this includes switching off unused components such as line cards, inline amplifiers or even entire links or nodes [7], reducing electrical-optical-electrical (E-O-E) conversions [8], putting selected network components in sleep mode[7], and using intelligent traffic grooming techniques[9]. Although energy aware routing for WDM networks has received significant attention in recent years, the idea of utilizing the anycast concept for energy minimization [10, 11] has been less well studied. This is a promising new direction of research that merits more in-depth investigation to achieve meaningful energy savings. Researchers have proposed both ILP (Integer linear programming) and heuristic approaches for minimizing the power consumption in optical networks. ILPs can generate optimal solutions, but quickly become computationally intractable with increasing problem size. So, typically they are only able to handle networks of small size, with relatively few demands. Therefore it is important to develop efficient search strategies, which can give good solutions in a reasonable amount of time for the energy-efficient routing problem in WDM networks, particularly for periodic, scheduled demands.

1.3 Problem statement

In this thesis we address the energy aware traffic grooming and resource allocation problem for scheduled demands in WDM networks. Traditional energy minimization techniques for WDM networks typically use the unicast approach, where the destination node is predetermined. We plan to use the anycast principle, where selection of the destination node and the routing scheme is done in an integrated manner. In addition to reducing the overall energy consumption of the network, the proposed approach will also reduce the cost of the network, in terms of the number of transmitters/receivers needed to accommodate all the traffic.

The design problem being considered in this thesis is a complex problem, with multiple objectives. Traditional ILP formulations are not able to generate optimal solutions for this problem for networks of practical size. Therefore, we propose a genetic algorithm (GA) based approach for solving the traffic routing problem for scheduled demands in WDM networks. GA is a well known technique for solving complex optimization problems.

We present a complete GA for the design problem, which includes novel chromosome representation that concisely specifies the destination node and selected route for each demand. We also define the crossover and mutation operations on these chromosomes in such a way that the child chromosome is always guaranteed to be a valid chromosome, i.e. represent a feasible solution to the problem. Finally, we define a suitable fitness function, which can be calculated quickly for each chromosome.

In order to evaluate the performance of the proposed GA, we compare the solutions generated by the GA using the *anycast* principle with the solutions obtained using the unicast principle. For larger networks, we have compared our GA based solutions with an existing shortest-path based heuristic. We have performed simulations on different network topologies and the results indicate that the proposed approach can lead to significant improvements in terms of both energy consumption and transceiver cost.

1.4 Thesis organization

The remainder of our thesis is organized as follows. Chapter 2 gives a brief description of the fundamentals of optical networks and reviews recent research work on energy aware routing in optical networks. Chapter 3 presents our proposed GA approach for solving the energy efficient routing problem in WDM networks. Chapter 4 discusses and analyzes our simulation results and Chapter 5 concludes our work and identifies some possible directions the future work.

Chapter 2

Optical Networks

2.1 Introduction to optical networks

An optical network is a communication network (i.e. two or more computers or end devices connect with each other), in which the information is transmitted through the optical fibers in the form of optical signals [1]. In this section we review some of the basic components and fundamental concepts of optical networks

2.1.1 Optical Fiber

An optical fiber consist of a thin glass like cylindrical tube called core which is made up of silica and is surrounded by another layer of silica which is called as cladding. This cladding, which has a lower refractive index compared to the core, is surrounded by the buffer coating which protects the optical fiber from the physical damage [1], as shown in figure 2.1.1 [12].

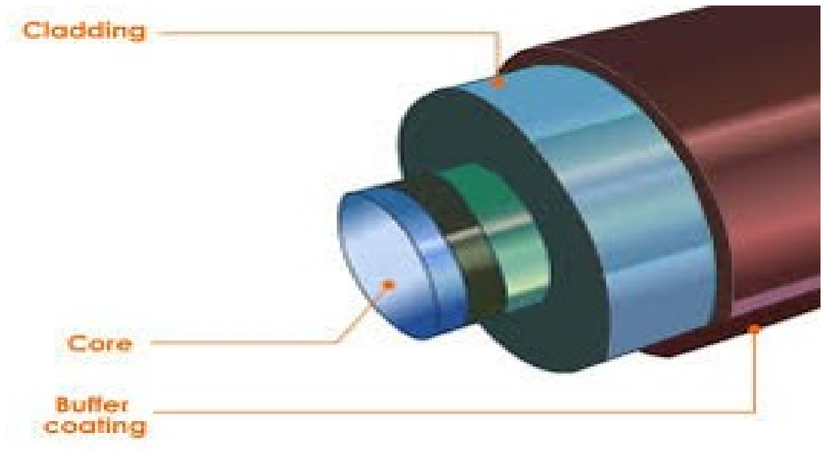

Fig. 2.1.1: Optical Fiber

When an optical signal is sent through the core at an angle greater than the critical angle, the light propagates through the core using total internal reflection [1]. Figure 2.1.2 [13] shows light propagation using total internal reflection in an optical fiber.

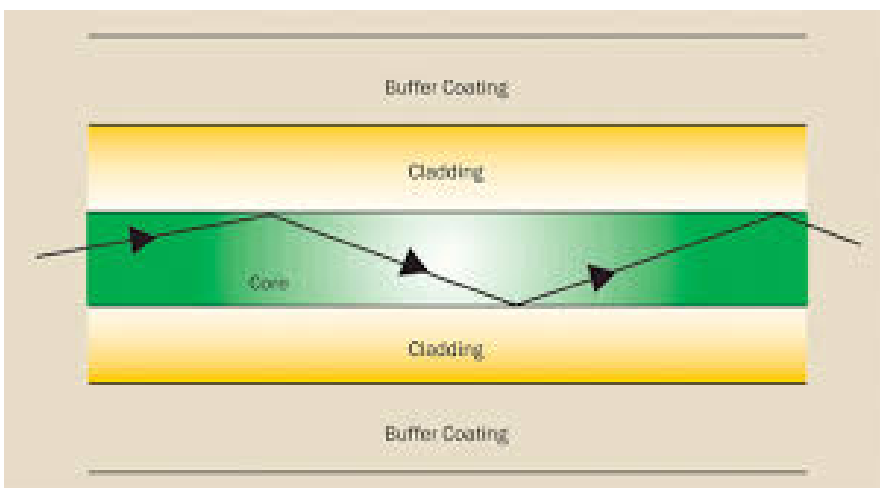

Fig. 2.1.2: Total Internal Reflection

2.1.2 Lightpath

A lightpath refers to an end-to-end optical communication channel, which may traverse multiple fibers. Between the two end nodes of the communication channel the signal remains in the optical domain, even when passing through intermediate nodes. The Figure 2.1.3 below shows an example of two lightpaths established over a physical fiber network. The first lightpath is from node 1 to node 4; the second lightpath is from node 3 to node 4.

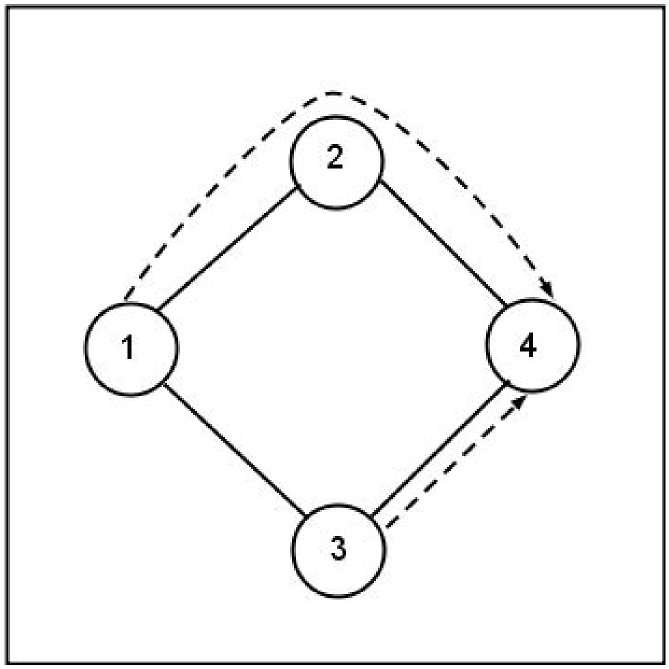

Fig. 2.1.3: Lightpath

2.1.3 Physical and Logical topologies

i) **Physical topology:** Physical network topology refers to the characterization of the physical connectivity relationships that exist among entities in a communication network [14]. In this physical topology the end nodes are connected by the fiber links. Each edge in the physical topology is bi-directional (i.e. can carry data in both the directions) and is made up of two individual unidirectional fiber links. Figure 2.1.4 shows an example of a physical topology with four nodes and four (bi-directional) links. The two unidirectional fibers for each link are shown using solid arrows. In addition, there are three lightpaths established over the network, which are shown using dashed lines. The three lightpaths in this example are as follows:

- Lightpath1: 1→3.
- Lightpath2: 3→ 2.
- Lightpath3: 4 →2.

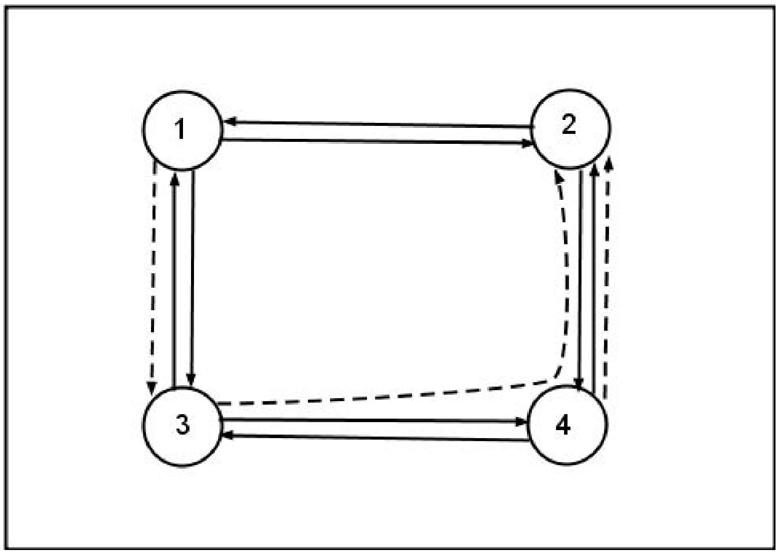

Fig. 2.1.4: physical topology

ii)**Logical topology**: The logical (or virtual) topology refers to the graph that represents the interconnection of nodes using lightpaths [15]. In the logical topology the end nodes are same as in the physical topology; but instead of fibers the lightpaths are taken as edges of the graph and these edges are called logical edges. Figure 2.1.5 below shows an example of logical topology, established over the above physical topology of Figure 2.1.4, by the three lightpaths shown above.

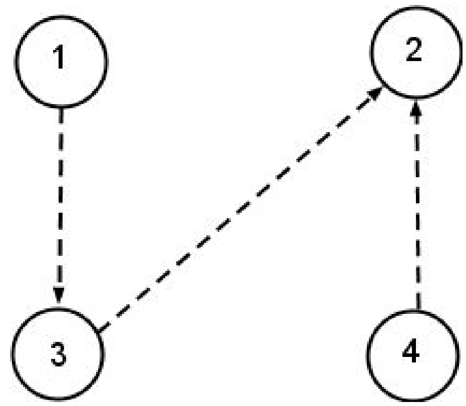

Fig. 2.1.5: Logical topology

2.1.4 Wavelength Divison Multiplexing (WDM)

Wavelength division multiplexing (WDM) is a technique where optical signals with different wavelengths are combined, transmitted together, and separated again [1]. Each fiber can accommodate a number of different wavelengths (or channels) for carrying data. Figure 2.1.6 [16] shows an example of Wavelength Division Multiplexing [23]. A number of different devices are needed to implement the various functions of a WDM network. These are discussed briefly in this section.

Transmitter (TX): In optical networks transmitters are the electronic devices, which are used to convert the electrical signal into the optical signal at a particular wavelength. The most common optical transmitters used in the optical networks are light-emitting diodes (LEDs) and laser diodes [1].

Receivers (RX): In optical networks optical receivers are the photodetectors, which are used to convert the optical signal into electrical signal, using the photo electric effect [1]

Multiplexer and Demultiplexer: In optical networks a multiplexer is a device which combines the different signals and gives a single output signal which is transmitted over the fiber. The demultiplxer serves the opposite function, which separates a single optical signal into its different constituent signals.

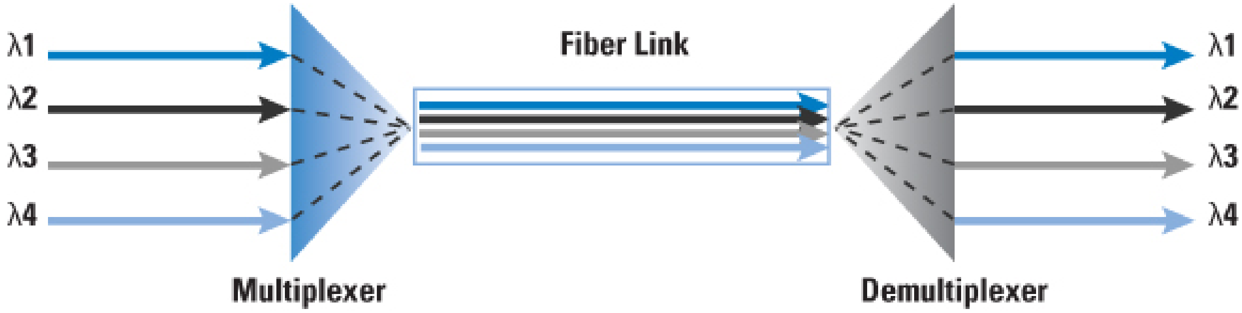

Fig. 2.1.6: wavelength Divison Multiplexing

2.1.5 Routing and Wavelength Assignment(RWA)

The Route and Wavelength Assignment (RWA) problem assigns a route over the physical topology and an available channel on each edge of that route for each lightpath established over the network [1]. One important objective of RWA is to maximize the number of lightpaths that can be accommodated in a network, by minimizing the amount of resources used. There are two main constraints in the optical network.

- Wavelength clash constraint: The same wavelength cannot be assigned to two or more lightpaths on the same link, at the same time.
- Wavelength continuity constraint: If a lightpath uses same wavelength on each link in its route, then it is said to satisfy the wavelength continuity constraint

Figure 2.1.7 shows an example of RWA for two lightpaths, over a small 4 node network. The first lightpath uses route 2→1→3; the second one uses route 2→4→1→3. Since both lightpaths traverse link 1→3, they cannot be assigned the same channel on that link. So, we have assigned two different channels $\lambda 1$ and $\lambda 2$ to the lightpaths. Also, each lightpath uses a single channel along their entire route. Therefore both constraints are satisfied by this RWA.

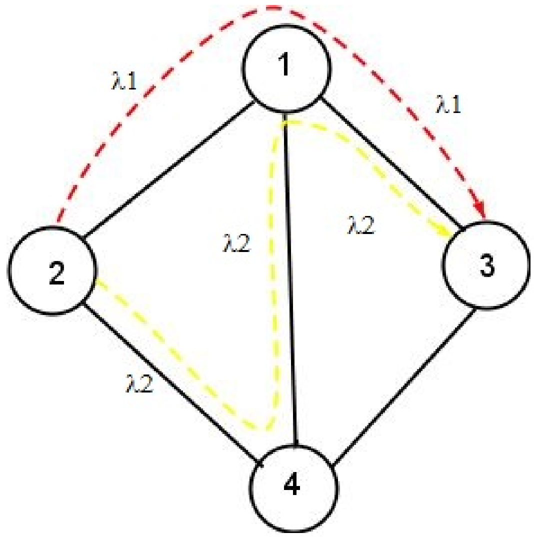

Fig. 2.1.7: wavelength Divison Multiplexing

Traffic Grooming: Traffic grooming [1] is the process where two or more low-speed traffic demands are groomed on to a single lightpath. The total bandwidth requirement of the low-speed demands on a single lightpath should not exceed the capacity of the lightpath.

2.2 Some energy consuming devices

There are many power consuming devices used in the optical networks. Some of the important components are discussed below.

Amplifiers:

Optical amplifiers are the devices used in optical networks to amplify the signal, when the signal power falls below a specified threshold [1]. Inline optical amplifiers are capable of amplifying the signal directly in the optical domain, without the need to convert it into the electrical domain.

Transceivers:

Transceivers are the devices used in the optical networks to terminate the lightpaths at each end. These transceivers are opto-electric equipment that converts the optical signals to electrical signals for further processing [17]. Figure 2.2.1 shows an example of a transceiver.

Fig. 2.2.1: Transceiver

Transponders: Transponders are the devices used in the optical fiber which are used to send and receive the signals in the optical fiber. The functionality of the transponders are similar to the transceivers i.e. converting the electrical signal into optical signal [18]. But these transponders can also convert the signal from one wavelength to another wavelength, which the transceivers cannot do.

Optical cross-connect switch:

These devices are used to switch high-speed optical signals in an optical network [1]. The connections between the outputs of the demultiplexers and the inputs of the multiplexers determine how the signals on the input fibers are routed to the output fibers. Figure 2.2.2 shows an example of static optical cross-connect switch.

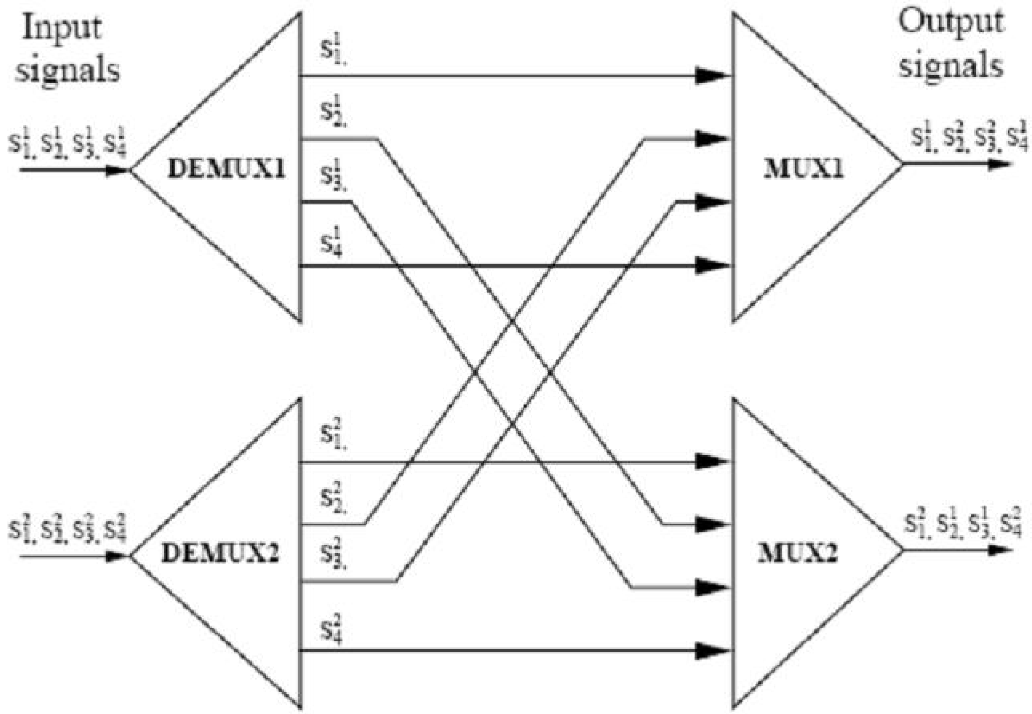

Fig. 2.2.2: static Optical-cross connect

The table 2.2.1 below shows the power consumption rates for some of the devices in an optical network[4].

Table 2.2.1: some power consuming devices

POWER CONSUMPTION OF NETWORK DEVICES

Device	Symbol	Power consumption
Electronic control system	p^{ECS}	150 W
Switching matrix input/output port pair	p^{MEMS}	107 mW
Transponder	p^{Trans}	50 W
Pre-amplifier	p^{Pre}	10 W
Post-amplifier	p^{Post}	20 W
In-line amplifier	p^{ILA}	15 W
MUX/DEMUX (passive)	–	0 W

2.3 Traffic Models

In optical networks there are three types of resource allocation schemes, based on the type of traffic model that is used to represent the traffic in the network. These different traffic models are discussed in this section.

Static Traffic: Under the static traffic model, the set traffic demands are known in advance and are expected to remain stable over a relatively long period of time. Static demands are typically taken into consideration during the network design phase.

Dynamic Traffic: For dynamic traffic, the demands are not known in advance. The start time and duration of each demand is randomly generated. The resources allocated to a demand are released when the demand is over, and can be allocated to another demand.

Scheduled Traffic: For the scheduled traffic model (STM) the demands are typically of shorter duration (similar to dynamic traffic), but their start and end times are known in advance. Resources can be shared among several demands, as long as the demands are time-disjoint. There are two types of STM that have been widely studied in the literature, as discussed below.

Fixed window scheduled traffic: For the fixed window scheduled traffic model, each scheduled traffic demand has a fixed start and end time. An individual demand can be represented by a tuple (s_p,d_p, n_p, α_p, ω_p),where s_p, is the source of the demand, d_p is the destination of the demand, n_p is the bandwidth requirement, α_p is the starting time of the demand and ω_p is the ending time of the demand.

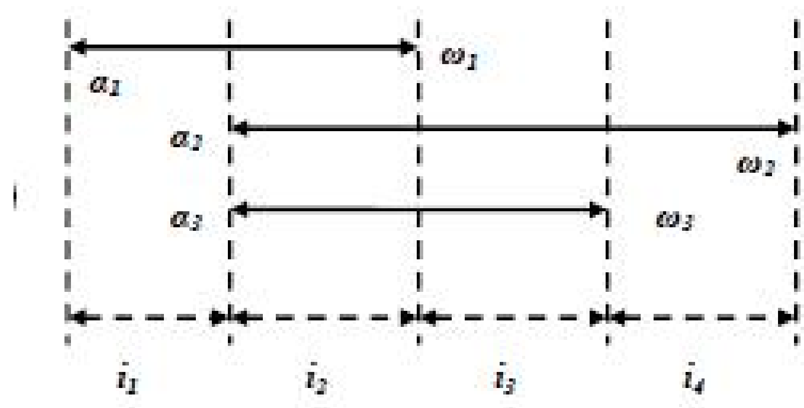

Fig. 2.3.1: scheduled Demand

Figure 2.3.1 shows an example with three scheduled demands [19], where the total time period is divided into four intervals i_1,i_2,i_3,i_4. The first demand starts at interval i_1 and ends at the end of intervali_2. Similarly the second demand starts at interval i_2 and ends at the interval i_4 and the third demand starts at i_2 and ends at the interval i_3. In this particular example, all three demands overlap in time, and therefore cannot use the same resources. In the sliding window scheduled traffic model [34] the start and end times of the demands are not in advance. Instead of the start and end times a larger window time and demand holding time is specified.

2.4 Optical Grid

Grid computing refers to where two or more computers or end devices connected with each other to share the common resources which are used for large scale and data intensive applications [1]. An important requirement of grid applications is the need for guaranteed bandwidth and delay time. WDM networks are able to provide high bandwidth and can carry large volumes of data with high degree of reliability. Therefore, optical networks are expected to play an important role in creating an efficient infrastructure for supporting such advanced grid applications; this is called optical grid or photonic grid [20].

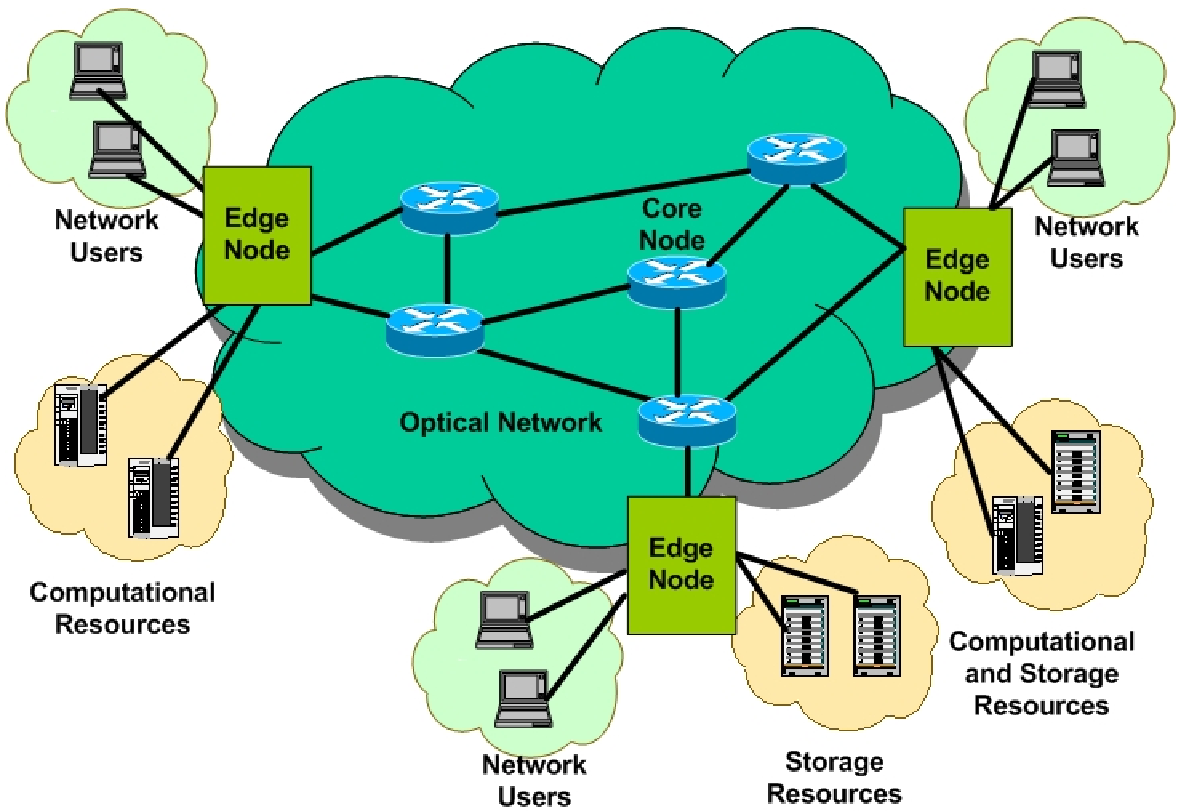

Fig. 2.4.1: Optical grid

Figure 2.4.1[21] shows an example of an optical grid network, where two or more end users are connected to two or more network resources in the network. The connection between these end users and the resources are made by using the optical fibers and switching equipment in this optical grid network.

2.5 Anycast routing

In optical grids, the main objective is to successfully execute the specific job; so the exact service location is often not important to the user. This characteristic can be exploited to further optimize the allocation of resources, by using the anycast principle [22]. In traditional unicast routing, both the source and destination are specified beforehand. In anycast routing, the destination is selected from a set of possible destinations, based on the current state of the network. A job is generated at a specified source node sp, and can be processed at any destination d_p from the set of possible destinationsD_p,where $d_p \in D_p$. several different metrics can be used to determine the preferred destination node for a particular task. A directed path from the source to the destination node, through the logical topology is known as a logical path. This includes path length, resource sharing opportunities, equipment cost and energy consumption.

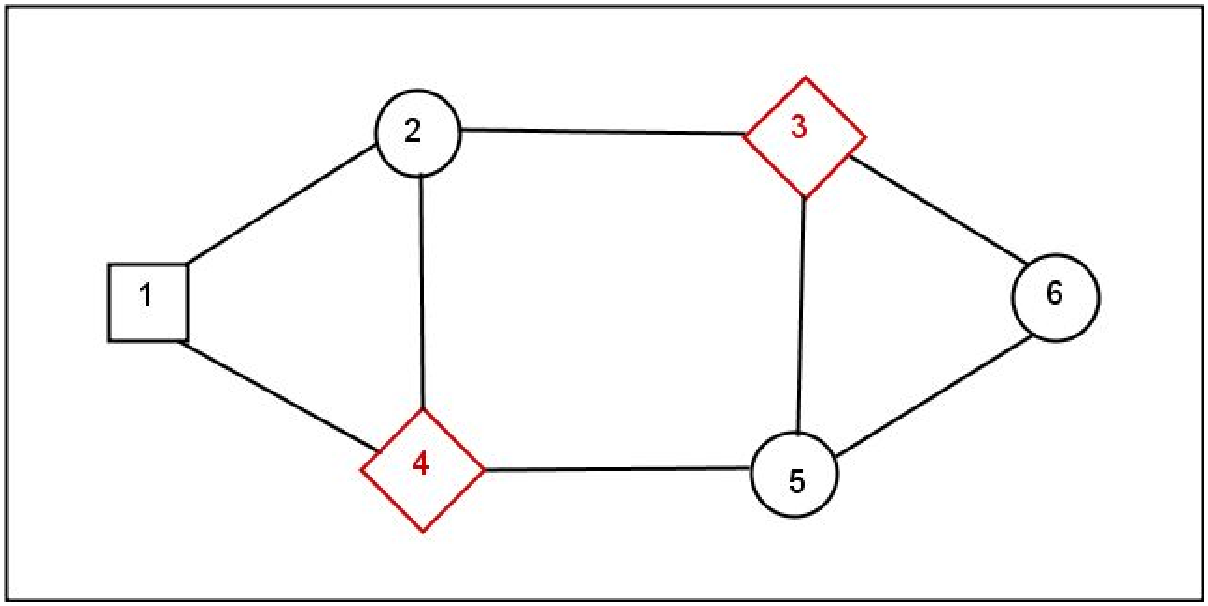

Fig. 2.5.1: Anycast Routing

Figure 2.5.1 shows an example of a single demand starting at node 1 (i.e. sp = 1), which can be processed at node 3 or node 4 (i.e. Dp = 3, 4). For each destination node, there are several possible paths that can be used to route the demand. Also at any given time there may be hundreds of such demands active in the network. In this thesis, our goal is to select a destination and route for each demand, such that the overall energy consumption and transceiver cost for the entire set of demands is minimized. This can be achieved by minimizing the number of active lightpaths in any time interval and the total number of lightpaths needed to accommodate all the traffic. We have proposed a genetic algorithm (GA) based approach [23] for solving this problem. A brief overview of the basic GA concepts and terminology is given below.

2.6 Genetic Algorithms (GA)

Genetic algorithms are the evolutionary algorithms which are used to generate useful solutions for different optimizing and search problems [24]. Before discussing the details of genetic algorithms, we present some standard terminology used in genetic algorithms.

A population is a set of candidates which can be randomly generated. Each candidate in a population is called a chromosomes. These chromosomes are made up of set of genes, which can be mutated and altered. Chromosomes exchange genetic information in a process known as recombination (or crossover) to form new chromosomes, known as children or offspring. The new chromosomes are then used in the next iteration of the evolution. In each generation the chromosome fitness value is evaluated for each chromosome. This value is based on the fitness function, which is used to estimate how close the solution is to the optimal value. In each generation, based on the fitness value, a chromosome may be selected for crossover. The better the fitness value the greater the chance of selecting the chromosome for crossover. For mutation, chromosomes are selected randomly, regardless of their fitness value. An outline of a typical genetic algorithm is given below [24].

Algorithm 1 genetic Algorithm

Input : Initial population

Output: Final population

population= Generate population()

compute fitness of individuals(population)

while (*criterion==True*) **do**

$\boldsymbol{Parent_{\alpha} = selectParent(Population_{\alpha})}$

Crossover(Parent$_{\boldsymbol{\beta}}$)

Mutate (Parent$_{\boldsymbol{\beta}}$)

$\boldsymbol{Offspring_{\gamma} = computefitnessofindividuals(Parent_{\beta})}$

Repopulate with offspring (Offspring$_{\boldsymbol{\gamma}}$, Population$_{\boldsymbol{\alpha}}$)

end while

The first step of this algorithm is to create the the initial population (i.e set of chromosomes), which are randomly generated. Next, the fitness of these chromosomes are computed based on the fitness function and the chromosomes with the lower (i.e. better) fitness values are selected as parents. Then crossover and mutation are carried out to generate new children or offspring. Finally, the offspring with the best fitness values are selected for the next generation. This process repeats until the termination criteria are satisfied.

2.7 Approaches for energy aware routing in optical networks

In [9] the authors claim that instead of using power efficient components a power aware routing should be developed so that the power consumed by the optical networks can be reduced. They propose a novel ILP that use traffic grooming, where two or more traffics can be groomed into single lightpath, depending upon the capacity and bandwidth of the lightpath. Two objectives are used, the first one is to minimize the number of lightpaths used and the second one is minimize the number of electronically switched traffic (i.e. routing the lightpaths so that it uses the less optical to electrical and electrical to optical conversions).

A small 8 node network is used for simulations and power consumption is minimized by minimizing the number of lightpaths and minimizing the number of electronically switched traffic. The authors claim that by using the traffic grooming technique we can reduce the significant energy in the optical networks

In [11] the authors claim that by using this anycast principle we can significantly reduce the amount of power consumed in the optical networks. A new ILP that uses the anycast principle for scheduled traffic model is presented. The objective of this algorithm is to minimize the number of logical edges (or lightpaths) needed to accommodate all the demands in each time interval. A number of experiments were carried out using different standard network topologies using anycast and unicast routing, for both scheduled demand and holding time unaware (HTU) traffic. The results demonstrate that by using the anycast principle energy consumption is significantly (21%-27%) reduced, compared to the unicast routing.

In [19] the authors address the power consumption problem for scheduled traffic model using the traffic grooming approach for unicast traffic. They propose a novel genetic algorithm for routing the scheduled traffic so that the power consumed by the network can be greatly reduced. Simulation experiments on various standard network topologies with different traffic loads were performed for both the fixed window model (the start and end times of the demands are known) and the sliding window model (the start and end times of the demands are not known and need to be calculated by the scheduling algorithm). The results shows that a significant reduction in power consumption can be achieved using the proposed GA, compared to standard shortest path routing.

In [25] the authors use the anycast principle to reduce energy consumption by switching selected the network components. They propose a novel ILP algorithm for solving this problem that allows the network nodes and fibers to be switched off when they are not in use. Various experiments are carried out, using different network topologies and also considering networks both with wavelength converters (WC) and without wavelength converters (NO-WC) and compared the results between them. The authors state that their approach leads to a 20 percent reduction in power consumption. Also power consumed in the NO-WC networks is less than the power consumed in WC networks.

In [26]the authors focus on minimizing the power consumed due to electrical to optical and optical to electrical conversions in the optical network. They propose a novel genetic algorithm to minimize the electrical to optical and optical to electrical conversions. The proposed algorithm also minimizes the amount of wavelengths required.

The results show that minimizing the electrical to optical and optical to electrical conversions and using the proper arrangement of wavelengths lead to significant energy savings.

Chapter 3

Energy Aware routing in optical networks

3.1 Introduction

In this chapter we are going to discuss about our proposed approach for minimization of energy consumed in the optical networks for scheduled traffic model. For this proposed approach we are using a genetic algorithm, along with the anycast principle (discussed in the Sec. 2.5) **to route a set of scheduled demands such that the energy consumption and the number of lightpaths used for satisfying the demands is minimized.**

3.2 An Illustrative example

In this thesis we are using the anycast principle for selecting the destination of the demands for each scheduled demands from the set of possible destinations. We are also using the traffic grooming technique for combining two or more traffics on to a single lightpath depending on the capacity of the lightpath, so that the number of lightpaths needed to satisfy the demands can be greatly reduced. Before discussing the proposed GA in detail, we will illustrate our approach with a simple example.

We consider the logical topology in Figure 3.2.1, which consists of 6 nodes and 6 edges. In this topology, nodes 3 and 4 (shown as hexagons) are potential destination nodes, i.e. the nodes with sufficient storage and computation resources for completing the tasks, which can originate at any of the other nodes.

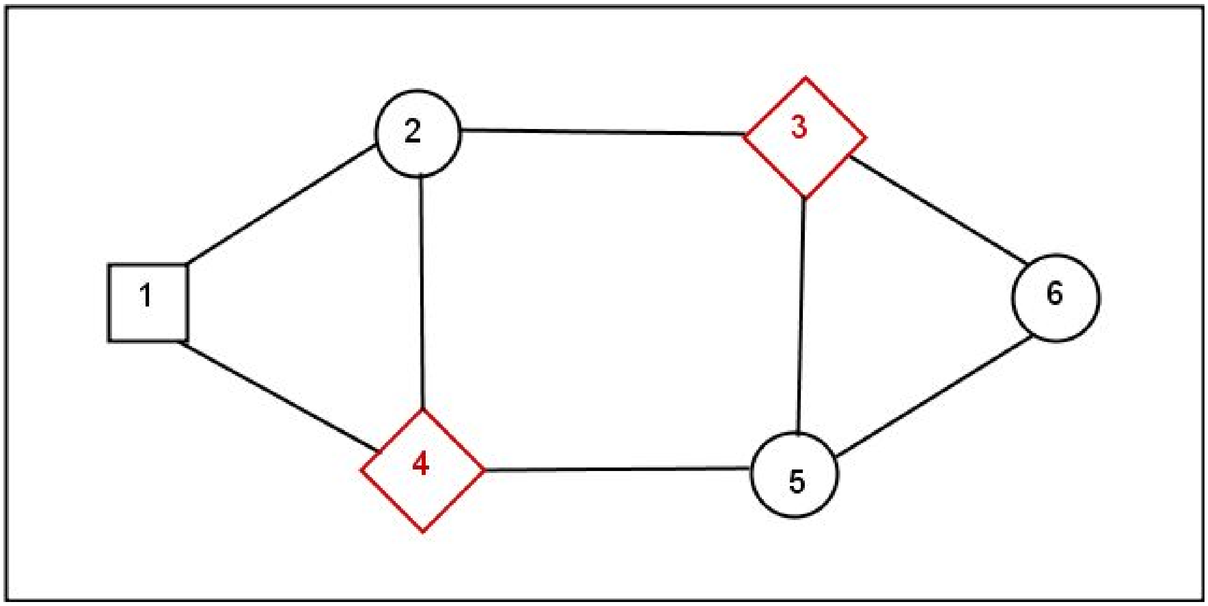

Fig. 3.2.1: 6-Node Logical topology

Let us consider six demands *q1, q2, q3, q4, q5* and *q6* to be routed in the topology. Each demand q, originates at a specific node s_q, has a given time α_p and end time ω_p , and has a specified bandwidth requirement, which is expressed as a fraction of the capacity of a single lightpath. For example, if the lightpath capacity is 10Gbps, then a bandwidth requirement of 3 Gbps would be expressed as 0.3. The total time period is divided into six intervals i_1, i_2, i_3, i_4, i_5 ,i_6. The time schedule of the demands are shown in Figure 3.2.2. For example, demand *q1* starts at the interval i_1 and ends at the interval i_6 demand *q2* starts at the interval i_1 and ends at the interval i_3 and so on. The complete information for each demand is given in Table 3.2.1

Table 3.2.1: Information of demands

Demand (q)	source node s_q	bandwidth bw_q	start time α_q	end time ω_q
q1	1	0.3	1	6
q2	1	0.9	1	3
q3	1	0.5	2	3
q4	5	0.8	1	5
q5	5	0.5	2	6
q6	5	0.5	3	5

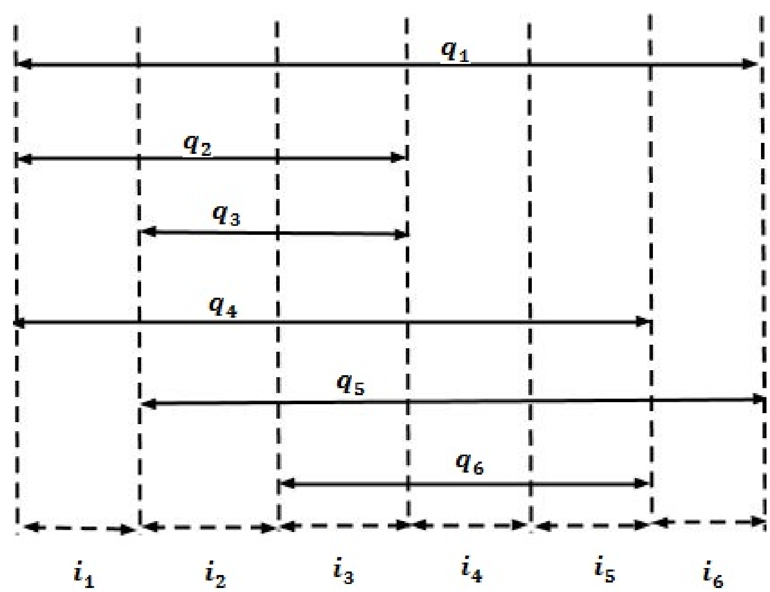

Fig. 3.2.2: Traffic scheduling

Suppose demands *q1* and *q2* have already been routed as shown in Figure 3.2.3. If demand *q3* is routed to node 4, along the path (1→4) the total traffic on edge 1→4 will be 1.2, which exceeds the capacity of a single lightpath.

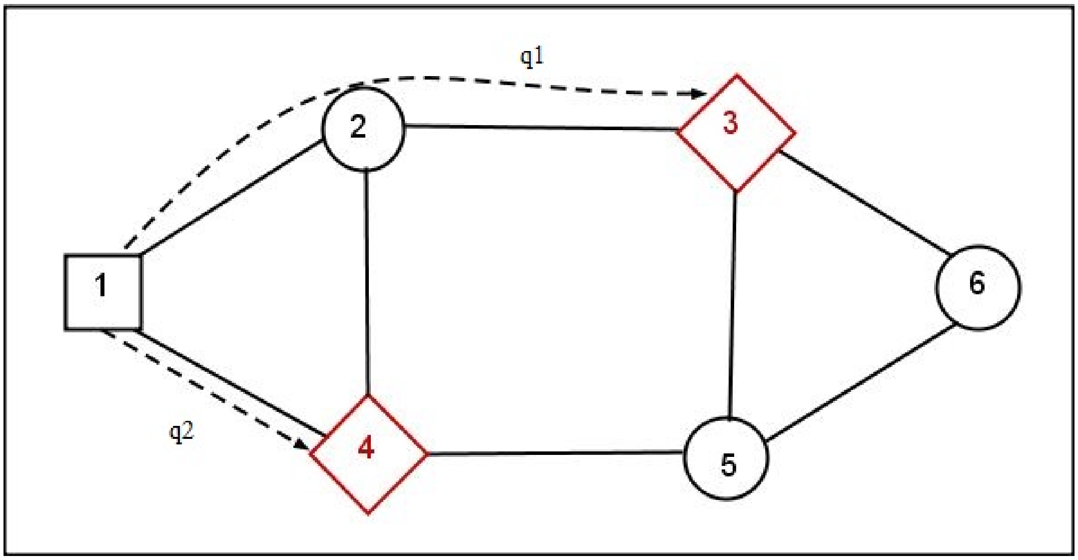

Fig. 3.2.3: Anycast Routing

This means we would need to establish an additional lightpath and incur additional energy costs due to all the devices that would be used by the new lightpath. On the other hand, if demand *q3* is routed to node 3, along the path (1→2→3), we do not need an additional lightpath. This is because demand *q3* can be combined with the demand *q1* resulting in a total bandwidth requirement of 0.3+0.5=0.8 on edges 1→2→3. Since this is less than the capacity of a single lightpath, there is no need to establish additional lightpaths and demand *q3* is accommodated using the existing lightpaths.

Again, suppose demands *q4* and *q5* are routed along the paths (5→3) and (5→4) respectively, as shown in Figure 3.2.4. Routing the demand *q6* to the destination 3 along the path (5→3) requires one more additional lightpath from (5→3) to satisfy the demand; whereas routing the demand to 4 along the path (5→4) needs no additional lightpath. The above two examples illustrate that by intelligently choosing the destination node and route, it is possible to significantly reduce the energy consumption, by minimizing the number of active lightpaths at any given time.

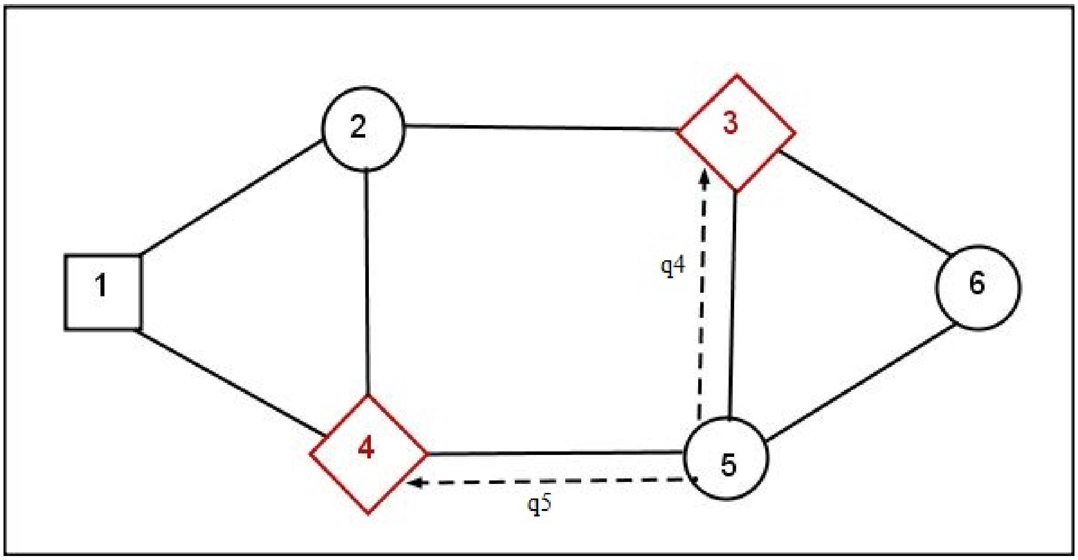

Fig. 3.2.4: Example of demand Routing

3.3 Proposed Genetic Algorithm(GA)

Genetic algorithms are a family of computational models inspired by evolution. GAs are used as adaptive algorithms for solving different practical and computational problems[27]. The main idea in GAs is to combine the good parts of the other solution [28]. In some GAs a process called elitism is used, where the best performing chromosomes from the previous generation can replace the poorly performing chromosomes of the current generation. This guarantees that the current population is at least as fit as the previous population [29]. We have used this concept in our proposed GA. A main advantage of our GA is that the crossover and mutation operations are guaranteed to generate feasible chromosomes, we dont need to modify the child chromosomes.

The main aim of our algorithm is to minimize the power consumption in the optical networks using the anycast principle, by selecting a suitable route and destination for each demand.This is achieved by our fitness function, where the first term of our fitness function minimizes the number of active lightpaths during each time interval, and the second term of the fitness fuctions minimizes the total number of lightpaths needed to implement the logical topology. In the following sections, we describe the different components of our proposed GA, including, chromosome representation, fitness function, crossover and mutation operations and termination criteria.

3.3.1 Chromosome Representation

For each demand q to be routed, we pre-compute a set of k paths over the logical topology, where $p_{q,k}$ is the k^{th} route for demand q. These paths are computed from the source node of the demand to each possible destination node, using Yens k-shortest path algorithm [30]. We represent the chromosome as an array of integers, specifying the selected path for routing each demand. The length of each chromosome is equal to the number of demands, and the integer in position k indicates the path along which demand q will be routed. So each chromosome represents a complete solution for routing all the demands over a given logical topology. Each individual component of the chromosome (which corresponds to a single demand) is known as a gene. We use the topology of figure 3.2.1 to explain our chromosome representation.
Table 3.3.1 shows four demands, with the source node of the demand show beside the demand number and lists the potential paths for each demand.

Table 3.3.1: potential paths for demands

Demand q	$p_{q,1}$	$p_{q,2}$	$p_{q,3}$	$p_{q,4}$
1:(1)	$1 \to 2 \to 3$	$1 \to 4 \to 5 \to 3$	$1 \to 4$	$1 \to 2 \to 4$
2:(2)	$2 \to 3$	$2 \to 4 \to 5 \to 3$	$2 \to 4$	$2 \to 1 \to 4$
3:(5)	$5 \to 3$	$5 \to 6 \to 3$	$5 \to 4$	$5 \to 3 \to 2 \to 4$
4:(6)	$6 \to 3$	$6 \to 5 \to 3$	$6 \to 5 \to 4$	$6 \to 3 \to 2 \to 4$

Since we are using the anycast principle for routing the demands, for each scheduled demand we have two possible destinations and compute two potential paths corresponding to each destination node. So for each demand to be routed we have four potential paths for the two possible destinations, as shown in Table 3.2. Two of the routes use node 3 as the destination and the other two routes use node 4 as the destination. So, it is clear that be specifying a route number $1 \leq r \leq 4$ for a given demand q, we are actually selecting

- a particular destination node, and
- The path to be taken from the source node to the destination node.

The chromosome represented in Fig 3.3.1 shows one possible configuration for routing the four demands in Table 3.1. For demand *q1* we use the path k=1: (1→2→3). For the demand *q2* we use the potential path k= 3: (2 → 4). For the demand *q3* we use the potential path k=4 (5→3→2→4) and for the demand *q4* we use the potential path k=2 (6→5→3).

The actual routing scheme corresponding to the chromosome depicted in Fig. 3.3.1 is shown in Fig. 3.3.2.

Fig. 3.3.1: chromosome representation

1	3	4	2

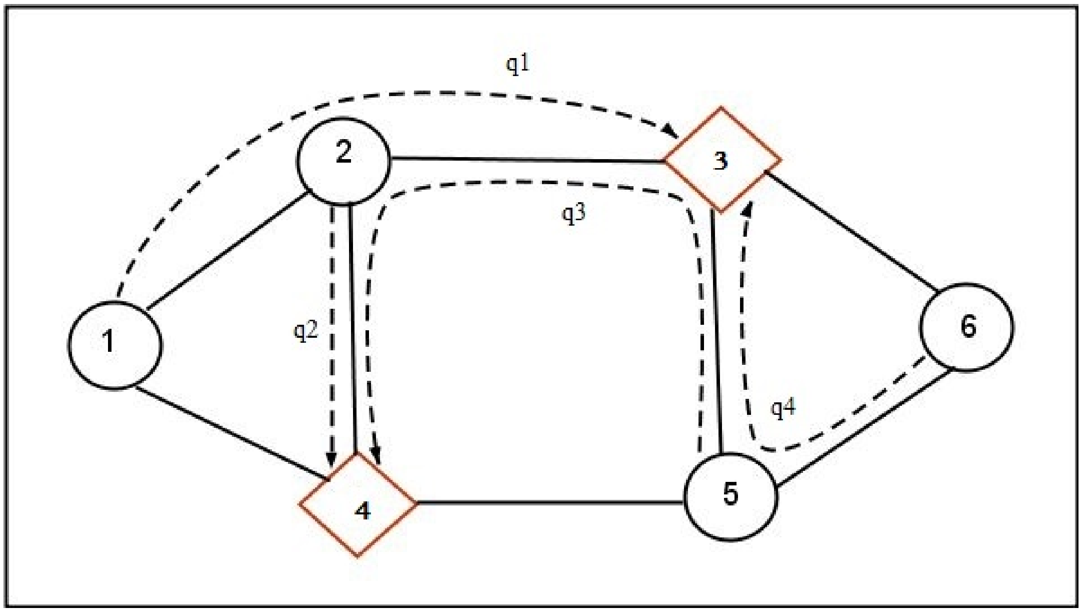

Fig. 3.3.2: Example of demand Routing

3.3.2 Initialization of population

Each chromosome in the initial population specifies a single valid path (from a set of k potential paths) for each demand. We have used Yens k-shortest paths algorithm (a well-known algorithm for finding the shortest paths [30]) to calculate the potential paths; however, our GA does not depend on the particular algorithm used to generate the potential paths for the initial population, and any suitable routing algorithm can be used. Although the initialization process ensures the validity of the paths, fitness of the chromosomes, in terms of the energy consumption or transceiver cost.

3.3.3 Fitness Function

As we know the fitness function plays an important role in the GA for selecting the chromosomes for crossover. So after generating the chromosomes we need to calculate the fitness of each chromosome. Since we are trying to minimize the power consumption in the optical networks the chromosomes with lower fitness values are considered to be better solutions and are more likely to be selected for the crossover operations. The fitness function we are using in our GA consists of two components which are shown below equation 3.1[19].

$$\sum_{i} T_i \sum_{l \epsilon L} n_{l,i} + a \sum_{l} n_l \tag{3.1}$$

Equation 3.1 essentially consists of two terms, which are added to calculate the fitness of each chromosome. In the first term $n_{l,i}$ represents the number of active lightpaths corresponding to logical edge $l \in$ L during the i^{th} time interval, and T_i is the duration of the ith interval. So $\sum_l n_{l,i}$ gives the total number of active lightpaths during interval i, over the whole topology and T_i where $\sum_l n_{l,i}$ is the corresponding energy consumption during interval i. Finally, summing over all time intervals, $\sum_i T_i \sum_l n_{l,i}$ gives the total energy consumption of the network.

The second term in equation 3.1 attempts to reduce the overall (transceiver) cost for the logical topology, by minimizing the number of lightpaths needed to implement each logical edge l. We have seen that the number of active lightpaths $n_{l,i}$ for logical edge l can vary, depending on the traffic in interval i. So, the number of transceivers used for implementing l is determined by the maximum number of active lightpaths needed for l in any given interval, i.e n_l= {max $n_{l,i}$ | i=$i_1, i_2..i_{max}$ } Finally a is a constant (weight) representing the relative cost of adding a new lightpath compared to increasing the energy consumption.

3.3.4 Selection and crossover

In genetic algorithms there are many methods for selecting a chromosome for crossover. These include tournament selection , truncation selection [31], and roulette-wheel selection[28]. In our GA, selection of the chromosomes from the population is done using the roulette-wheel method, where the chromosomes with lower (better) fitness values have more chance to be selected for the crossover, in each generation.

After selecting the chromosomes form the current population crossover is applied on the selected chromosomes to get the new child chromosomes (offsprings).The resultant child chromosomes are guaranteed to correspond to a feasible solution, with a valid path for each demand. In the below figure 3.3.3 shows the example of a simple one-point cross-over operation. Two parent chromosomes - parent A and parent B are selected from the current population and the crossover location is selected randomly. In this example, the crossover location is right after the second gene. After performing crossover, we get the resultant two child chromosomes child C and child D, each with a new routing scheme. Figure 3.3.4 shows the routing scheme corresponding to the new offspring child C.

In a similar fashion, it is possible to do k-point crossovers as well. Figure 3.3.5 shows an example of 2-point crossover, where the two crossover points are after gene 1 and gene 2 respectively. The chromosome representations for the parent and child chromosomes are as depicted in Figure 3.3.5. Finally, Figure 3.3.6 shows the final routing scheme for all the demands, for one of the offsprings (child C) created by the crossover operation.

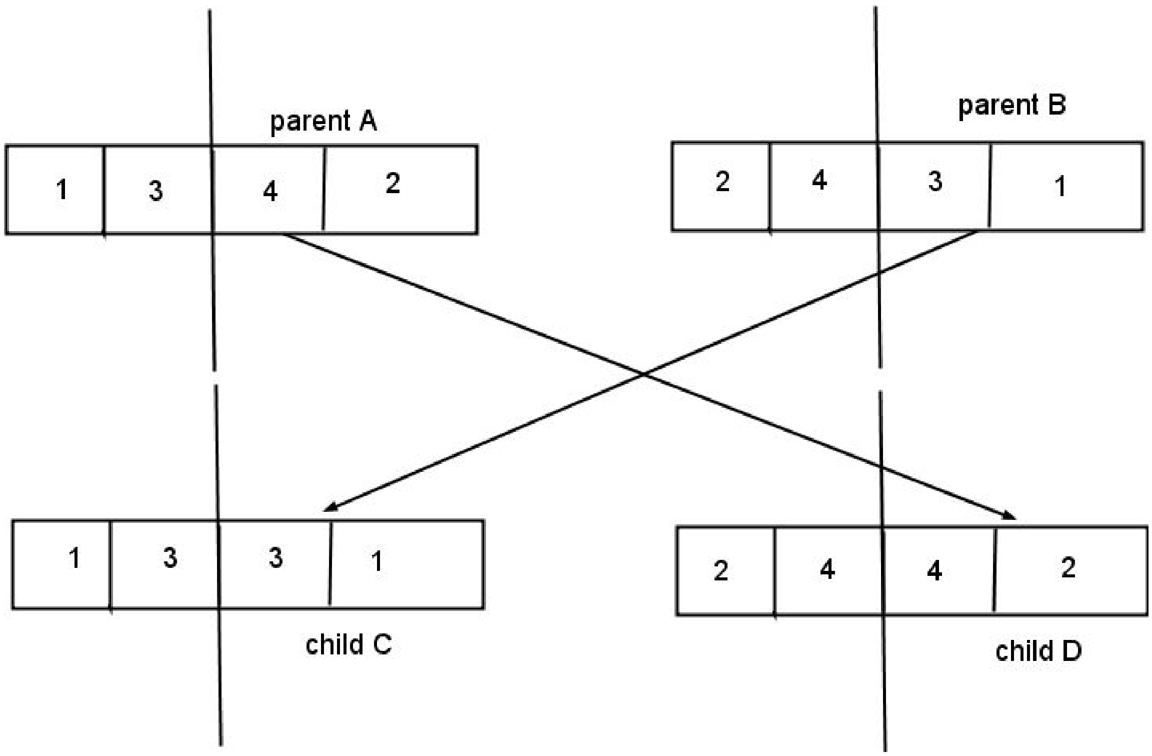

Fig. 3.3.3: Example of 1 point crossover

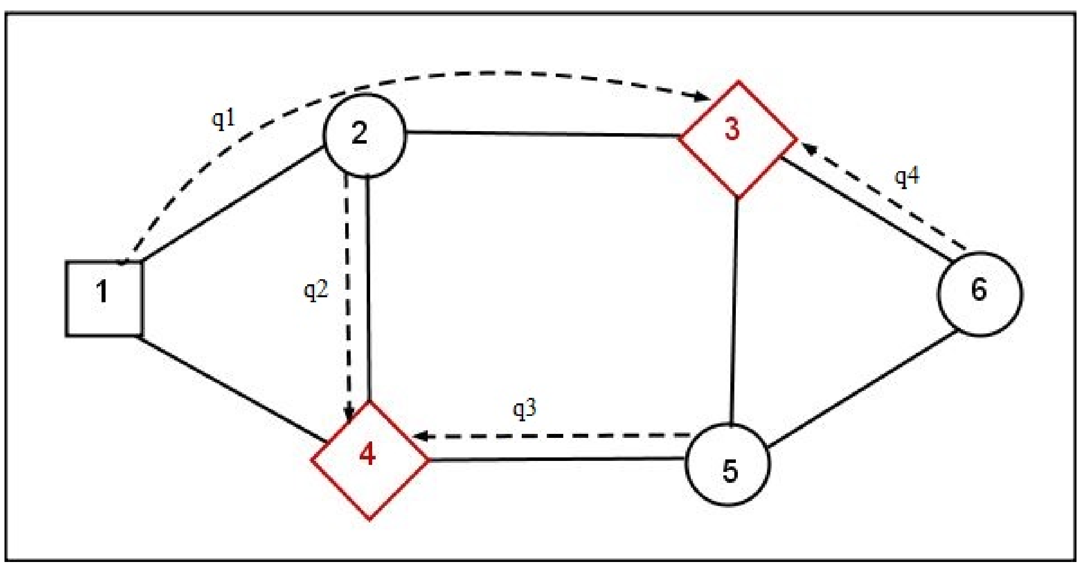

Fig. 3.3.4: Routing for child C

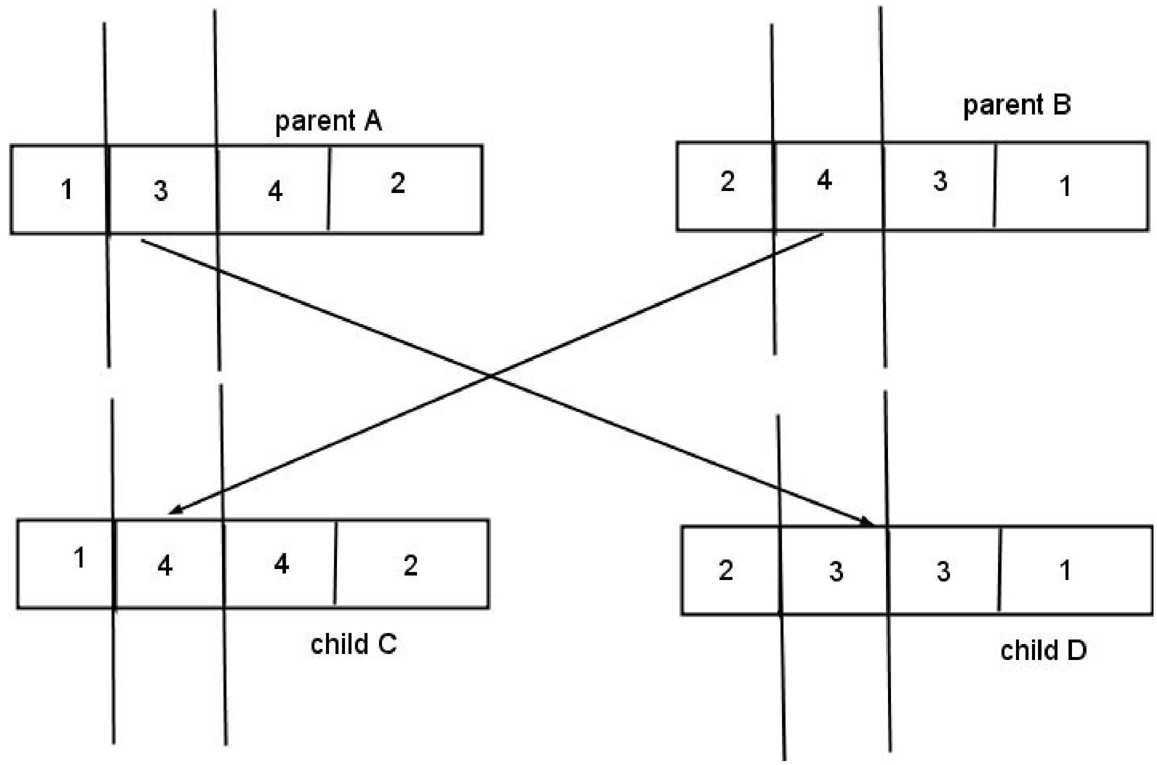

Fig. 3.3.5: Example of 2 point crossover

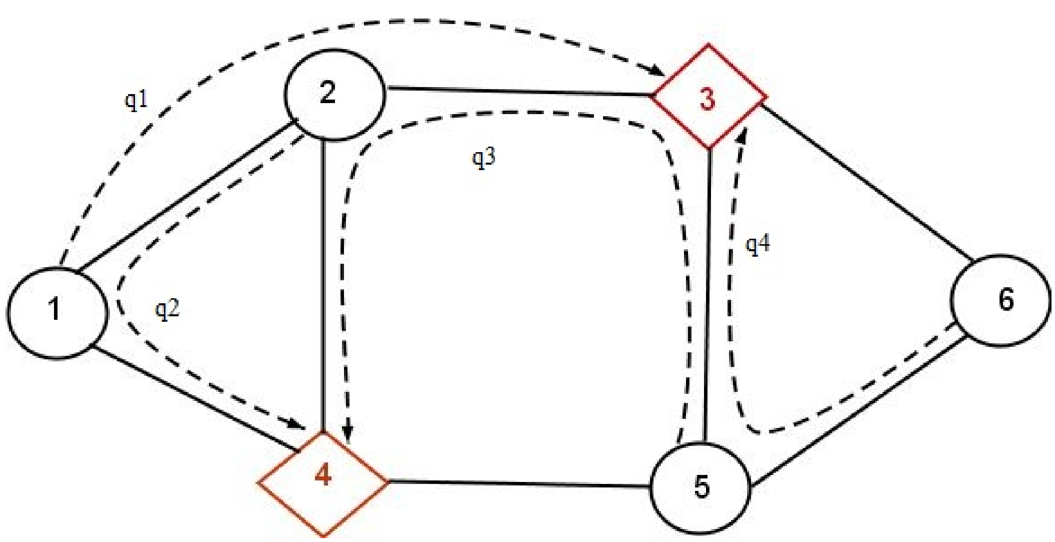

Fig. 3.3.6: Routing for child C

3.3.5 Mutation

After finishing the crossover operations mutation can be applied, with a given probability. Mutation can be useful for moving away from local optima in the search space. Mutation involves the following steps:

- A chromosome is randomly selected from the population for mutation; all chromosomes have an equal probability of being selected.
- A gene (corresponding to a specific demand) in the selected chromosome is randomly picked for mutation.
- A new route is chosen for the given demand (from the set of all potential routes for that demand). In other words, the value for that gene is changed

Figure 3.3.7 shows specific chromosome (chromosome 1) selected for mutation. In that chromosome, gene 2 is randomly designated to be changed. Finally, the selected route for this gene is changed from 3 to 2. The final chromosome (chromosome 2) after mutation is also shown in Figure 3.3.7. The routing corresponding to chromosome 2 is shown in Figure 3.3.8.

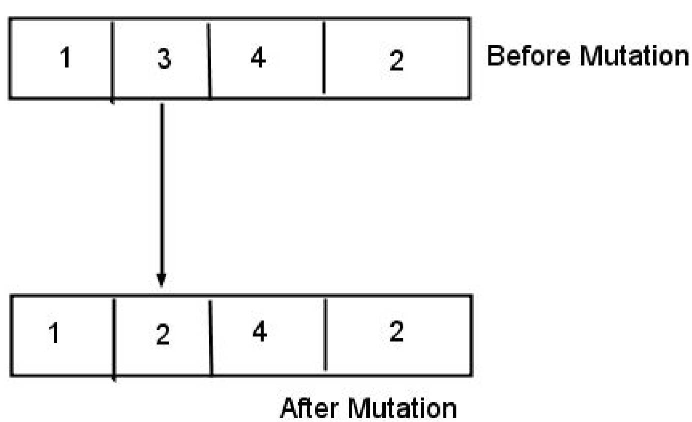

Fig. 3.3.7: Example of mutation

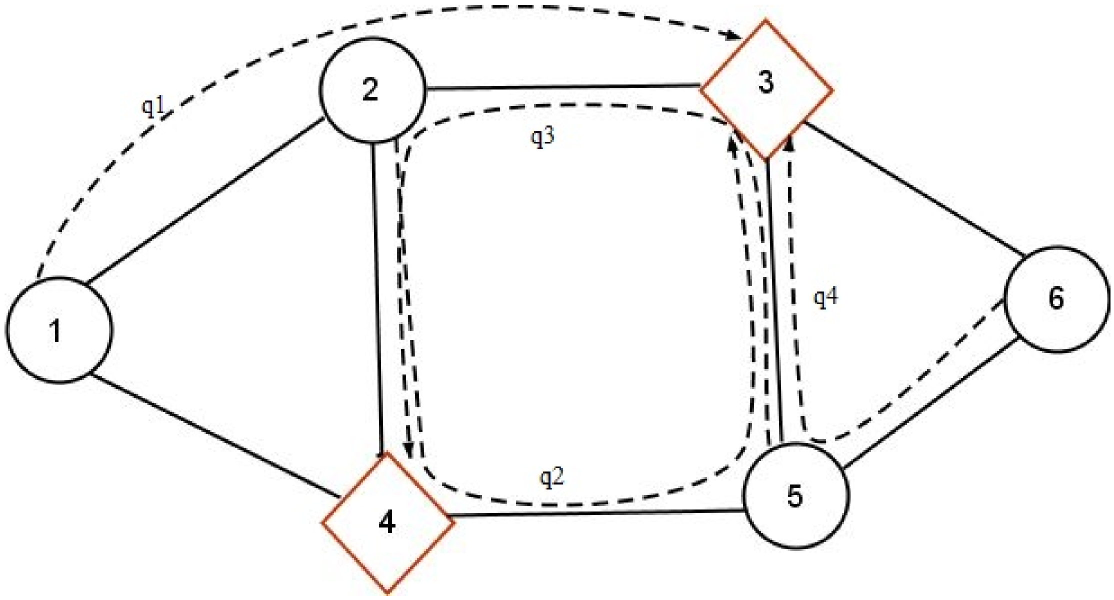

Fig. 3.3.8: Routing after mutation

3.3.6 Termination Criteria

In each iteration a new generation of chromosomes is created, until a termination condition is met. There are a number of termination criteria that are commonly used in a GA. These include reaching an pre-allocated budget, reaching a plateau in terms of the best fitness value in the population, or terminating after a fixed number of generations.In this thesis we terminate our GA using the 'fixed number of generations' criterion, i.e our algorithm stops after executing a prespecified number (1000 in our case) of iterations. This number was determined based on initial observations and trial runs. where we observed that for the problems under consideration the GA always converged within 1000 generations.

Chapter 4

Experiments and Results

In this chapter we discuss about our input network model, simulations and the results we obtained using our proposed GA approach.The results reported in this chapter are based on 4 demand set sizes for each topology, with 4 different demand sets for each demand set size i.e 16 runs for each network topology.

4.1 Simulation setup

4.1.1 Network Model

In our thesis we run our experiments on different network topologies on 6-node, 11-node, 14-node and 24-node network topologies. The figure 4.1.1 below is an example of a sample logical topology which contains 6 nodes, 8 edges and two possible destinations.

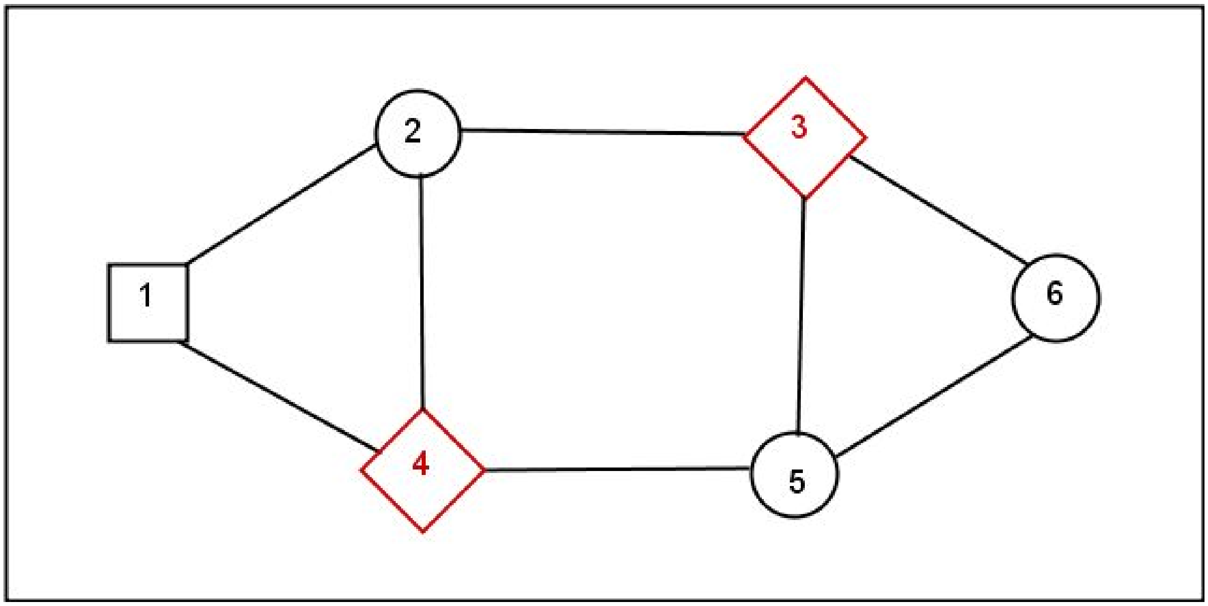

Fig. 4.1.1: 6-Node Logical topology

4.1.2 GA Inputs

The following parameters are given as inputs to our GA:

Network Topology: The network topology (N, E) is defined by the set of nodes (N) and the logical edges (E) interconnecting these nodes. Each logical edge will be implemented by one or more lightpaths. The number of lightpaths needed to implement each edge is determined by our GA.

Set of pre-computed paths: For each network topology we pre-compute k paths between each node pair. These paths are calculated using Yens k-shortest path algorithm [30], and are used to route individual demands over the logical topology. For example for s-d node pair (2, 3) of 6-node network topology in Figure 4.1, the k-shortest paths (k=5) generated using Yens algorithm are:

- 2→3
- 2→4→5→3
- 2→1→4→5→3
- 2→4→5→6→3
- 2→1→4→5→6→3

Possible destination nodes: For each topology, a set D of potential destination nodes is identified, which have sufficient storage/computing capabilities to service the set of demands.

Demand Matrix: The demand specifies the set of demands to be routed over the given topology. Each demand q is represented as(s_q, n_q, α_q, ω_q) where s_q represents the source of the demand, n_q represents the bandwidth requirement of the demand, α_q is the starting time of the demand and ω_q is the end time of the demand. The actual destination node d_q for demand q is selected by the GA from the set D of potential destination nodes that are identified for each topology, i.e. $d_q \epsilon$ D.

For our experiments we use the HP pavilion windows 64- bit operating system with a processor speed of 1.70GHz and 8 GB of RAM memory

4.2 Comparison of total fitness value

One approach for routing traffic demands is to select the nearest destination node, and then route the demand to this node using the shortest path. This is a simple and reasonable approach, which can be expected to give good results. We have used this as a benchmark. In this section we have compared our final fitness value with:

i) The shortest path fitness value, where we only consider the shortest path to each possible destination, and

ii) The unicast fitness value, where we always select the nearest node as the destination node.

4.2.1 Shortestpath Algorithm Comparison

We have run simulations using the shortest path algorithm and our GA on the same network topology and with same demands. Figure 4.2.1 shows the comparison between the shortest path fitness value and our proposed GA approach. We can see that a significant reduction (30% - 55%) in fitness value is achieved, when compared to the shortest path fitness value. This results in lower energy consumption and transceiver cost for the network.

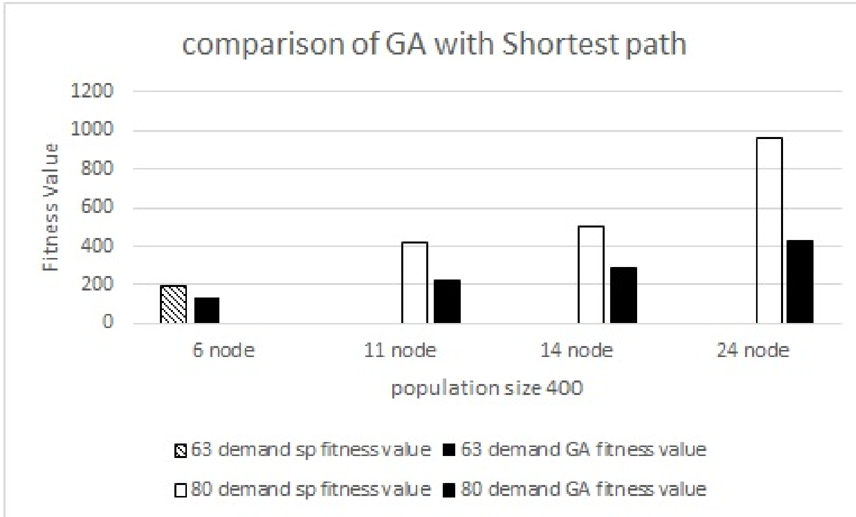

Fig. 4.2.1: 6-Node Logical topology

4.2.2 Comparison with unicast Approach

We have run the simulations for both the unicast and anycast routing approaches, with the same network topology and demand sets. Figure 4.2.2 below shows the simulation results for both the approaches for different network sizes. The results indicate that the additional flexibility in choosing the destination node (anycast routing) results in a 17% - 34% reduction in the final fitness value. when compared to the unicast routing. When compared to both shortest path and unicast approaches, the relative performance of the GA seems to improve with increasing network size.

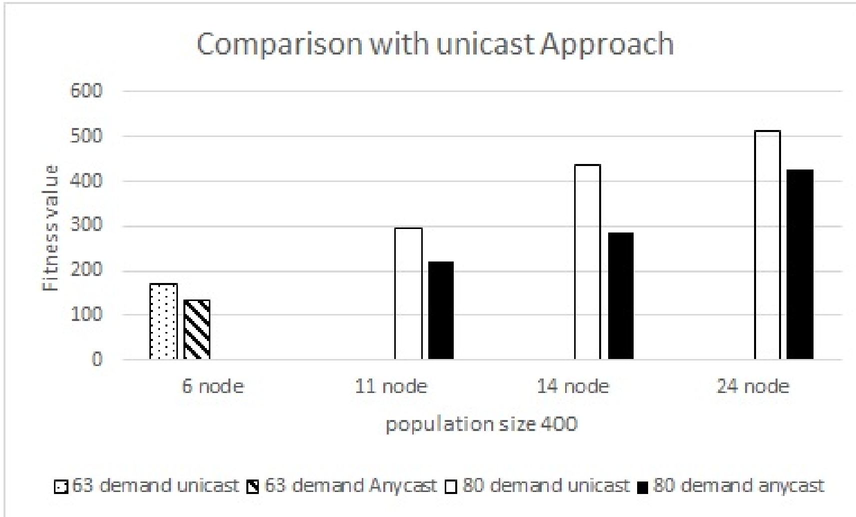

Fig. 4.2.2: 6-Node Logical topology

4.2.3 Comparison of energy consumption and number of Lightpaths

The final fitness value expressed in equation 4.1 in our GA combines two components:

$$\sum_i T_i \sum_{l \epsilon L} n_{l,i} + a \sum_l n_l \tag{4.1}$$

i) The energy consumptions, which is determined by the total number of active lightpaths over all time intervals (first term) and

ii) The total transceiver cost, which is determined by the maximum number of lightpaths needed to implement each logical edge (second term)

In this section, we consider these two components separately, and evaluate the performance of the GA for each parameter. Figures 4.2.3 and 4.2.4 below show the comparison for the energy consumption and transceiver costs (in terms of total lightpaths needed) respectively, for the different approaches we have discussed. The results clearly shows that the GA outperforms both approaches, in terms of energy consumption as well as transceiver cost.

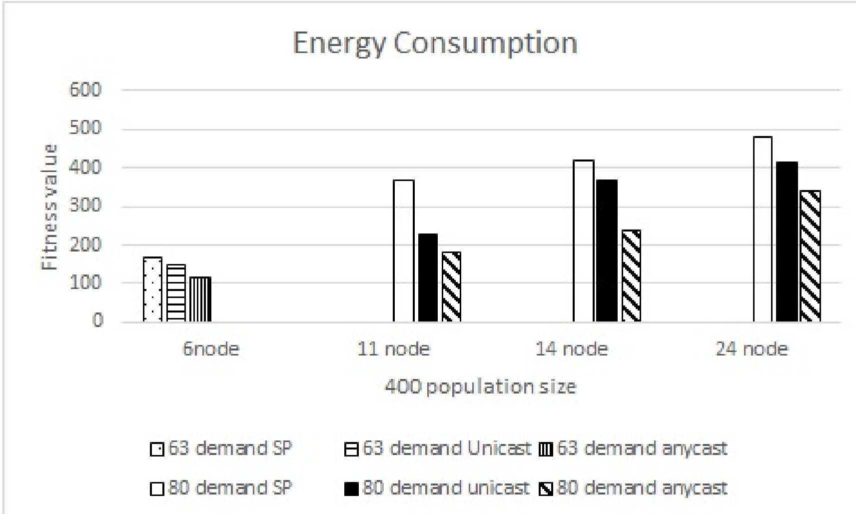

Fig. 4.2.3: Energy consumption

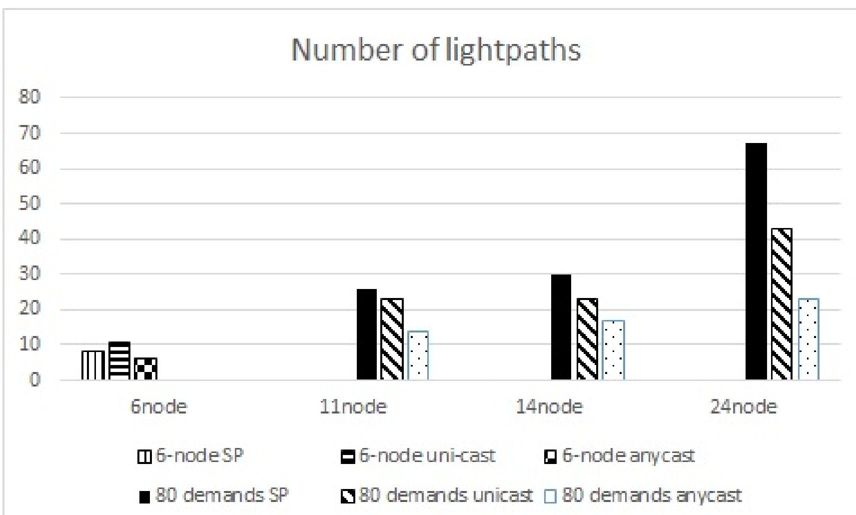

Fig. 4.2.4: Number of Lightpaths

4.3 Effect of population size and demands

Figure 4.3.1 shows the effect of demand size for different networks. As the number of demands increases, the final fitness value i.e., the combined energy consumption and transceiver cost of the network increases. This is expected because more resources are required to satisfy the larger demands sets.

For the GA, we experimented with different population sizes of 100, 400 and 800 chromosomes in each generation. Figure 4.3.2 shows the effect of population size for different demand sizes on the 14-node network topology. We can see that the population size does not seem to have a significant effect on the fitness value.

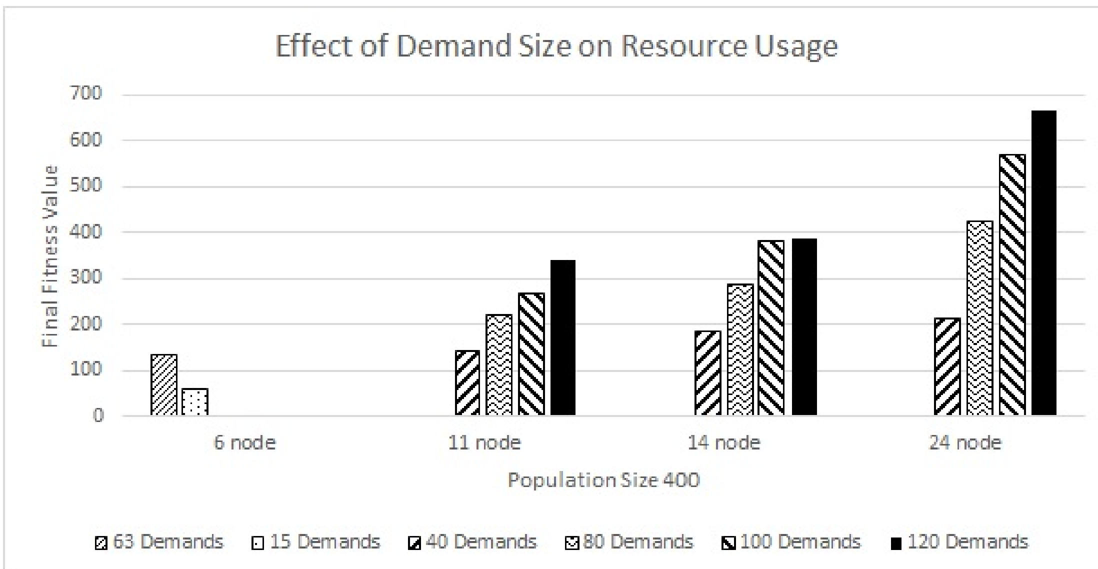

Fig. 4.3.1: Effect of demand size

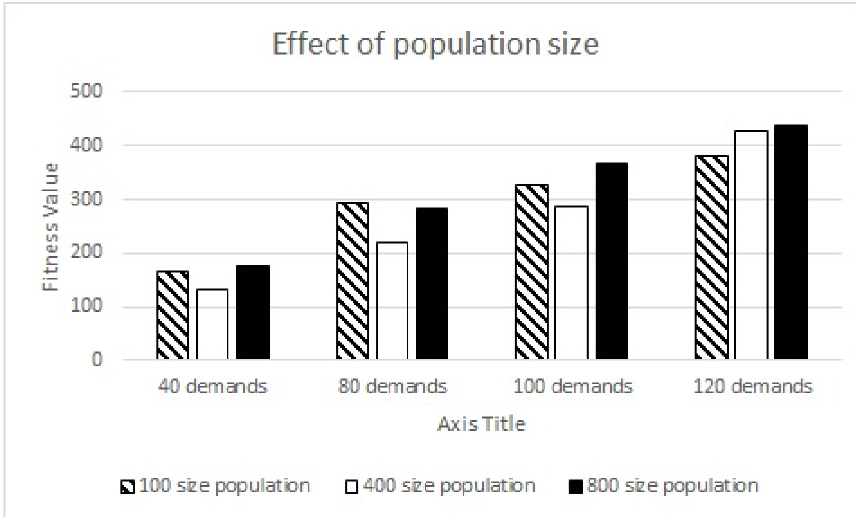

Fig. 4.3.2: Effect of population size

4.4 Computational Time

Figure 4.4.1 shows the effect of demand set size and population size on the time taken by the GA to reach a solution for the 14- topology. The results show that the solution time increases consistently with both demand set size and population size for a given network.

Figure 4.4.2 shows how the required solution time varies with the size of the network. There is a slight increase in solution time with network size, for smaller networks. However, the increase becomes more significant (for the same number of demands and population size) ,as the network size increases

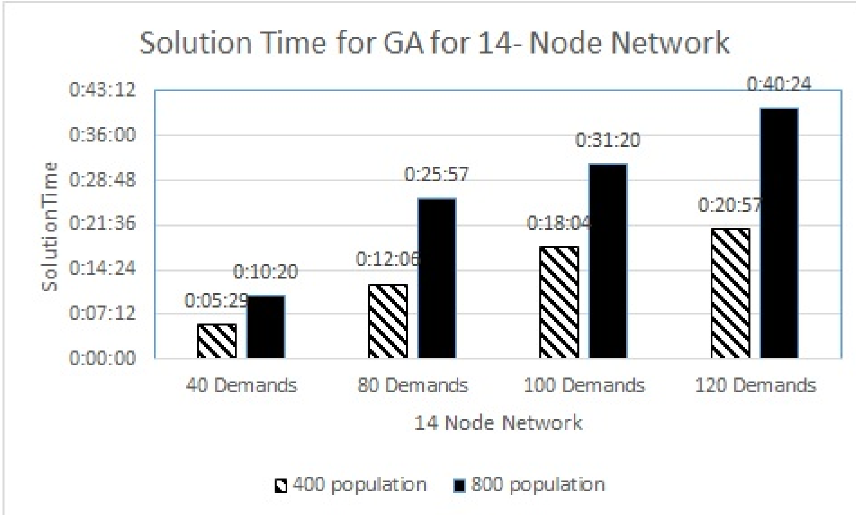

Fig. 4.4.1: Time taken by 14-Node Network

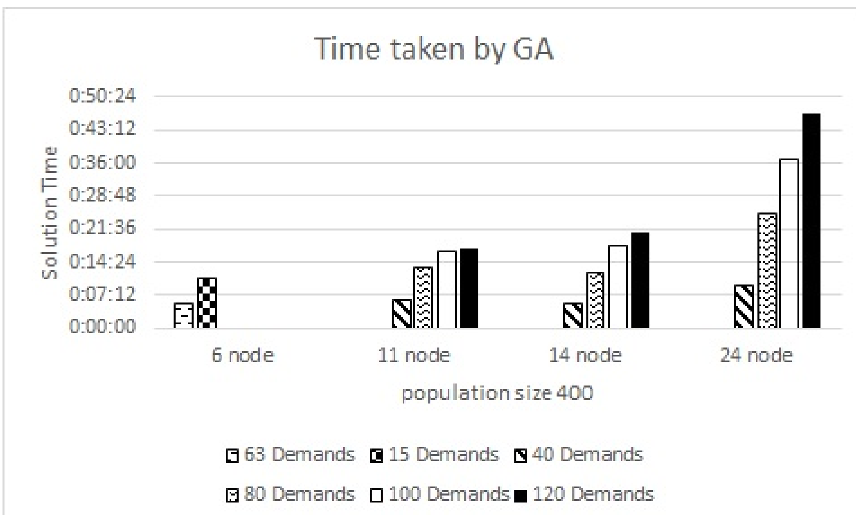

Fig. 4.4.2: Time taken by GA

Chapter 5

Conclusion and Future work

5.1 Conclusion

Due to the increase in the high-bandwidth applications over the internet the energy consumption of Information and communication technology (ICT) equipment is also increasing rapidly. Therefore there is a need to develop techniques to minimize the energy consumption. In this thesis we proposed a new energy efficient routing approach for minimizing the energy consumption in optical grid networks. To achieve this goal we proposed a novel genetic algorithm (GA) using the anycast routing principle to route the scheduled traffic demands. In this approach for minimizing the energy consumption in the optical networks we have two main objectives. The first objective is to minimize the number of active lightpaths used to satisfy the demands. The second objective is to minimize the number of lightpaths used to implement each logical edge, which reduces the cost of the optical transceivers.

The proposed approach greatly reduced the number of lightpaths needed to route a given set of traffic demands. We ran experiments using different network topologies and with different demand sets and population sizes. To evaluate the performance of our proposed approach we compared our anycast routing approach with shortest path routing and unicast routing. The simulation results clearly show that the proposed GA results in a 20% - 40% reduction in energy costs, and also reduces the cost of optical transceivers, when compared to traditional routing schemes.

5.2 Future work

In this thesis we used a scheduled traffic model for routing the traffic demands. In the scheduled traffic model we used a fixed window scheduled traffic model, where the start and end times of the demands are known in advance. An extension to our work can be to develop an approach for handling the sliding window model, where the demand holding time and a larger window time are specified. This increases the complexity of the problem, since the GA must determine the start time of the demand in addition to the destination and route.

In this thesis we have only considered fault-free networks. However, if a node or link in the network fails, it is important to re-route the traffic quickly and efficiently. Another promising direction for future work is to develop strategies to handle faults in the network.

Bibliography

[1] Wikipedia: Optical networkingWikipedia, the free encyclopedia [Online; accessed 23-April-2015].

[2] Kuri, J., Puech, N., Gagnaire, M., Dotaro, E., Douville, R.: Routing and wavelength assignment of scheduled lightpath demands. Selected Areas in Communications, IEEE Journal on **21**(8) (2003) 1231–1240

[3] Chen, Y., Bari, A., Jaekel, A.: Techniques for designing survivable optical grid networks. Journal of Communications **7**(5) (2012) 391–399

[4] Coiro, A., Listanti, M., Valenti, A., Matera, F.: Power-aware routing and wavelength assignment in multi-fiber optical networks. Journal of Optical Communications and Networking **3**(11) (2011) 816–829

[5] Chen, Y.: Resource allocation for periodic traffic demands in wdm networks. (2013)

[6] Shaabana, A.: The application of evolutionary algorithms for energy efficient grooming of scheduled sub-wavelength traffic demands in optical networks. (2013)

[7] Gupta, M., Singh, S.: Greening of the internet. In: Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications, ACM (2003) 19–26

[8] Coiro, A., Listanti, M., Valenti, A., Matera, F.: Reducing power consumption in wavelength routed networks by selective switch off of optical links. Selected Topics in Quantum Electronics, IEEE Journal of **17**(2) (2011) 428–436

[9] Yetginer, E., Rouskas, G.N.: Power efficient traffic grooming in optical wdm networks. In: Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE, IEEE (2009) 1–6

[10] Chen, Y., Jaekel, A.: Energy optimization in optical grids through anycasting. In: Communications (ICC), 2013 IEEE International Conference on, IEEE (2013) 3835–3839

[11] Chen, Y., Jaekel, A., Li, K.: Energy efficient anycast routing for scheduled lightpath demands in optical grids. In: Communications (QBSC), 2014 27th Biennial Symposium on, IEEE (2014) 10–13

[12] : The web's where you study in!" attenuation in fiber optics. n.p., n.d. web.

[13] : Fiber optics." photonics.com. n.p., n.d. web.

[14] Bejerano, Y., Breitbart, Y., Garofalakis, M., Rastogi, R.: Physical topology discovery for large multisubnet networks. In: INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies. Volume 1., IEEE (2003) 342–352

[15] Leonardi, E., Mellia, M., Marsan, M.A.: Algorithms for the logical topology design in wdm all-optical networks. Optical Networks Magazine **1**(1) (2000) 35–46

[16] Palmieri, F., et al.: Gmpls control plane services in the next-generation optical internet. The Internet Protocol Journal **11**(3) (2008) 2–18

[17] Konda, V.R., Chow, T.Y.: Algorithm for traffic grooming in optical networks to minimize the number of transceivers. In: High Performance Switching and Routing, 2001 IEEE Workshop on, IEEE (2001) 218–221

[18] Kaminow, I., Li, T., Willner, A.E.: Optical fiber telecommunications VB: systems and networks. Elsevier (2010)

[19] Jaekel, A., Pare, J., Chen, Y., Shaabana, A., Luo, F.: Traffic grooming of scheduled demands for minimizing energy consumption. Photonic Network Communications (2014) 1–13

[20] Wang, Y., Jin, Y., Guo, W., Sun, W., Hu, W., Wu, M.Y.: Joint scheduling for optical grid applications. Journal of Optical Networking **6**(3) (2007) 304–318

[21] : "telecommunication updates." : May 2011. n.p., n.d

[22] Develder, C., Dhoedt, B., Mukherjee, B., Demeester, P.: On dimensioning optical grids and the impact of scheduling. Photonic Network Communications **17**(3) (2009) 255–265

[23] Chen, M.T., Tseng, S.S.: A genetic algorithm for multicast routing under delay constraint in wdm network with different light splitting. J. Inf. Sci. Eng. **21**(1) (2005) 85–108

[24] Davis, L., et al.: Handbook of genetic algorithms. Volume 115. Van Nostrand Reinhold New York (1991)

[25] Buysse, J., Cavdar, C., De Leenheer, M., Dhoedt, B., Develder, C.: Improving energy efficiency in optical cloud networks by exploiting anycast routing. In: Asia Communications and Photonics Conference and Exhibition, Optical Society of America (2011) 83100X

[26] Atta, S., Mukhopadhyay, A.: Power-aware traffic grooming in wdm optical mesh networks for bandwidth wastage minimization: A genetic algorithm-based approach. In: Computing and Communication Systems (NCCCS), 2012 National Conference on, IEEE (2012) 1–5

[27] Booker, L.B., Goldberg, D.E., Holland, J.H.: Classifier systems and genetic algorithms. Artificial intelligence **40**(1) (1989) 235–282

[28] Goldberg, D.E., Holland, J.H.: Genetic algorithms and machine learning. Machine learning **3**(2) (1988) 95–99

[29] Ahn, C.W., Ramakrishna, R.S.: Elitism-based compact genetic algorithms. Evolutionary Computation, IEEE Transactions on **7**(4) (2003) 367–385

[30] Yen, J.Y.: Finding the k shortest loopless paths in a network. management Science **17**(11) (1971) 712–716

[31] Wikipedia: selection(genetic algorithm)Wikipedia, the free encyclopedia [Online; accessed 23-April-2015].

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