An Ant Colony Optimization Implementation for Dynamic Routing and Wavelength Assignment in Optical Networks

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Introduction

Recent advances in optical technology have made Dense Wavelength Division Multiplexing (DWDM) commercially viable. Traditional Wavelength Division Multiplexing (WDM) has been around for over 20 years, allowing for several wavelengths per fiber. DWDM multiplexing can use at least 40 wavelengths per fiber. Some systems have been developed that use 160 wavelengths per fiber. [6]

There are two main results from these advancements. First the capacity of a single fiber has increased tremendously. Consider an optical fiber using a data rate of 10 Gbps. Using a two channel WDM approach will allow the link to achieve a 20 Gbps data rate. However, using a 160 channel DWDM approach will allow a combined data rate of 1,600 Gbps or 1.6 Tbps. This represents an improvement by a factor of 80, further improving the utility of optical networking. Copper wiring and wireless cannot come close to these data rates.

The second result is an increased need for Routing and Wavelength Assignment (RWA) algorithms to choose near-optimal solutions. In general, optimal solutions are not possible as RWA is a known NP Complete problem via a reduction to the multi-commodity flow problem. [4] It seems intuitive that a bad approximation for a traditional WDM system will be much closer to the optimal solution than a bad approximation for a DWDM system. As such, there has been an increased amount of time and effort spent on finding better RWA algorithms.

The remainder of this paper is organized as follows. The next section discusses the Previous Research on RWA Algorithms. Then we discuss the significance of the problem and formally define our problem.

Our preliminary work is then presented, followed by the future work section. The final section is a listing of our references.

Previous Research

There are two main branches of research in RWA algorithms: static RWA and dynamic RWA. Both approaches first consider the routing aspect and then choose a wavelength based upon the route selected. Let us take a brief review of both approaches.

Static Routing

In the static routing approach, all connection requests are known in advance. In other words, both the routes and wavelength assignment can be calculated off-line. The input to the problem is a network topology and a set of connection requests. These approaches typically use one of two optimization approaches: minimize the number of wavelengths necessary to meet the traffic demands or maximize the number of connections that can be established (minimize the blocking probability). [13]

The typical method of solving a static scenario optimally is through an Integer Linear Program (ILP). This approach can be used for smaller networks. A formulation for RWA is given in [13]. An improved formulation that uses fewer variables and thus runs more quickly is given in [12]. However, this approach is not feasible for medium and large networks due to the complexity of solving ILPs.

For larger network simulations, approximation algorithms are used. Some typical heuristics are a partial branch-and-bound algorithm [3] and a relaxation of the integer constraints [1]. Another approach is to randomize the routing and focus on the wavelength assignment [2]. These solutions tend to be good enough, but are usually far from optimal.

Another approach for static RWA is to use a graph theoretic approach. Both the multi-commodity flow problem and graph coloring problem can be translated into RWA problems [4]. In [6] such an approach was used to show approximation bounds for various types of graphs (directed trees, single source multi-commodity and strongly connected graphs). Most of the current research in static routing is studying graph theoretic approaches; the ILP approach is well-studied.

Dynamic Routing

In the dynamic routing approach, the connection requests are not known in advance. In other words, routes and wavelength assignment are calculated on the fly. There are three main categories of dynamic routing: fixed routing, fixed-alternate routing, and adaptive routing.

Fixed Routing. The most basic approach is to use the same fixed route for all source-definition pairs. These routes are typically generated using either Dijkstra's algorithm or the Bellman-Ford algorithm. The advantage of this approach is simplicity. The main disadvantages are that this can lead to higher blocking probabilities as some resources are used and low fault tolerance if a link is unavailable.

Fixed Alternate Routing. This approach is an extension of Fixed Routing. A list of routes is stored for all source-destination pairs. One well known algorithm for calculating the *k* disjoint paths is given in [11]. To meet a connection request, the source node attempts to establish the connection based upon the list of routes, in sequence. This approach has been shown to be a significant improvement over Fixed Routing. [9]

Adaptive Routing. In this approach, the routes are chosen dynamically, based upon the current network state. A list of routes is still stored for all pairs and the goal is to choose the route that is the least congested. The level of congestion is based upon the level number of wavelengths currently in use. A disadvantage is the computational complexity and increased network overhead; however this approach has been shown to perform much better than fixed-alternate routing. [5]

Once the route is selected, various heuristics can be used to select the appropriate wavelength. The simplest approach is to choose randomly, but this leads to poorer performance. The most common approach is to use the first-fitting wavelength. In this scheme, the wavelengths are ordered and the first available wavelength is selected. This approach leads to better performance. Both random and first-fit do not add any additional communication overhead to the network. [13]

Two competing methods are to use the least-used or most-used wavelengths. Both require additional network traffic to calculate the level of usage. Least-used performs very poorly (even worse than random) while most-used performs very well. [10]

The most-used approach performs the best for single-fiber networks, but some approaches have been developed for multi-fiber networks: min product, least-loaded, max-sum, and relative capacity loss. A couple of approaches have also been developed to address fairness concerns: wavelength reservation and protecting threshold. [13]

Problem Definition

Our approach is to use Ant Colony Optimization (ACO) to solve the Adaptive Routing RWA technique. The RWA problem is formally defined as follows: for a given graph $G = (V, E)$ where $V = \{v_1,\ldots,v_{|V|}\}$ is the set of all optical switches and $E = \{e_1,\ldots,e_{|E|}\}$ is the set of all fiber links between optic routers. Assume all fiber links can support up to N concurrent interference-free transmissions using N different wavelengths $\Lambda = \{\lambda_1,\ldots,\lambda_N\}$. At time t, there is a set of connection requirements $Q = \{q_1,\ldots,q_{|Q|}\}$ where $q_i = \{s_i,d_i\},(s_i \in V, d_i \in V, s_i \neq d_i)$ represents a connection requirement from node s_i to d_i. Note that there may be multiple connection requirements for one source-destination pair. A feasible solution of this problem is a joint RWA scheme $R = \{r_1,\ldots,r_{|Q|}\}$ where $r_i = (p_i, \lambda_i)$ includes a wavelength assignment $\lambda_i \in \Lambda$ and a path $p_i = (s_i,\ldots,d_i)$. In a solution, each r_i assigns wavelength λ_i to all links in path p_i. For a wavelength of a link, if it is assigned for n paths, it is defined to have m blockings, where $m = n - 1$ if $n > 1$ and $m = 0$ otherwise. The number of blockings in a link is the number of blockings on all assigned wavelengths of the link. The object function $f(R)$ of the RWA problem is the number of blockings on all links. Our object is to find a joint RWA scheme R such that $f(R)$ is minimized.

A specific network will be tested. This is a standard approach as there is no standard network and traffic model to use (such as TSPLIB). The NSFNet (a 13-node network based on the original NSF network in the United States) and the CERNET (a 22-node network from China) are two popular choices for algorithm testing. Connections will be added and subtracted in a dynamic fashion. The number of successful and blocked connections will be tracked.

Our program will assume that each of the links is independent, i.e. there is no interference between channels on a fiber. This assumption is clearly not representative of real world networks, however most routing algorithms make this assumption. It is likely possible to consider the physical interference effects using ACO; however this is outside the scope of this paper due to the non-linearity of these effects.

Significance of Problem

This is clearly a very significant problem to study. Network utilization is only going to increase in the future and optical networks will be necessary to meet this extra demand. Neither electrical wired or wireless networks have enough capacity to be practical for this demand.

Current algorithms are not satisfactory. They tend to be either overly simplistic (leading to poor performance) or overly complex (meaning they aren't practical for usage). There are some implementations using ACO [7,8], but these also seem to be very simplistic.

The goal is to develop an algorithm that is computationally feasible and also leads to superior network performance. ACO seems very well suited for this type of problem and we expect that our implementation will improve upon the adaptive routing plus first-fit approach.

Preliminary Work

Our preliminary work is limited to a literature survey relating to both RWA algorithms and ACO implementations. Most of the work on this project remains to be completed.

Future Work

There are several important requirements for our future work. The obvious requirement is the development of a simulation program. As a first step in our program design we will develop a baseline to compare against. In other words, we plan to implement an adaptive routing with the first-fit wavelength assignment heuristic. This algorithm should represent the current state-of-the-art approach.

The next step will be the implementation of the ACO algorithms. We will probably use the Max-Min Ant System (MMAS) and/or Ant Colony System (ACS). We will test the various parameters of each approach to find the optimal design for our networks.

The final step will be to compare the results of the baseline against the ACO implementations. The results will be presented in a final paper and presentation with suggestions for work in the future. The final goal is to prepare a paper and submit it to an artificial intelligence or optical networking conference.

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