CHAPTER ONE

INTRODUCTION
1. INTRODUCTION

1.1 Traffic Engineering in MPLS Networks

The capability to provide resource assurance and service differentiation in a network is often referred to as a Quality of Service (QoS) [Zhe 01]. Implementation of these QoS capabilities in the Internet has been one of the toughest challenges in its evolution, touching on almost all aspects of Internet Technologies and requiring changes to the basic architecture of the Internet. For more than a decade the Internet community has made continuous efforts to address the issue and developed a number of new technologies for enhancing the Internet with QoS capabilities. The Multi Protocol Label Switching (MPLS) [Zhe 01] and traffic engineering [Zhe 01], give service providers a set of management tools for bandwidth provisioning and performance optimization; without them, it would be difficult to support QoS on a large scale and at reasonable cost.

The basic problem addressed in traffic engineering is as follows: Given a network and traffic inside the network, how can traffic flows in the network be organized so that an optimization objective is achieved? The objective may be to maximize the utilization of resources in the network or to minimize the congestion in the network. Typically the optimal operating point is reached when traffic is evenly distributed across the network.
Traffic Engineering is mainly concerned with the performance optimization [Mal 99]. Its main objective is to reduce congestion hotspots and improve resource utilization. Traffic Engineering is an indispensable tool in the performance management of large Internet backbones. The optimization objectives are as follows: minimizing congestion, packet losses in the network, improving link utilization, minimizing the total delay experienced by packets, and increasing the number of customers with the current assets.

1.1.1 The Overlay Approach

In the following sections we present two traffic engineering approaches, Overlay and Integrated for IP over MPLS networks.

The overlay approach [Yuf 01], which has been widely used by many service providers for traffic engineering in large Internet backbones. In the overlay approach, logical connections are set up between edge nodes to form a full mesh virtual network overlaying on top of the physical topology. IP routing is then run over the virtual network. Traffic engineering objectives are achieved through carefully routing logical connections over the physical links. Although the overlay approach has been implemented in many operational networks, it has a number of well-known scaling issues.

IP routing runs over the logical connection. Any logical connection appears to be one hop away from IP perspective. The mapping of the logical connections to physical links is therefore transparent to the IP layer. These logical connections between edge nodes essentially form a full-mesh virtual
network overlaying on top of the physical topology. The overlay approach can achieve optimal traffic distribution in a network that supports multi-link load sharing. The optimal mapping between the logical connections and the physical links can be computed using a linear programming formulation.

![Fig.1.1: Full-mesh Virtual Connections](image)

A Full-mesh network on top of the physical topology is shown in the Fig 1.1. In this figure, node A, B, C, D, and E are BGP edge routers that connect to external routing domains. The solid lines are physical links. The dotted lines are logical connections between BGP routers, which in reality are mapped onto the physical links. To exchange routing information, each pair of BGP routes establishes a peer relationship. Thus the dotted lines represent the logical BGP peer connections among the BGP routers. With the overlay approach theses
dotted lines are also LSPs between edge nodes, and so the BGP peer connections and the LSPs established by the Overlay Model match perfectly.

Let us now look at how packets are forwarded from node A. When node A receives a packet, it performs lookup in the forwarding table. The nodes F, G and H are interior nodes. The Border Gateway Protocol (BGP) NEXT HOP of the route that matches the packet's destination address is the edge node from which the packet leaves the backbone network. Suppose that node C is the BGP NEXT HOP. Node A can simply put this packet on the LSP A→C. The difference between the overlay approach and the one without overlaying lies in the way the connections between the BGP nodes are set up. There are four possible paths between A and C: A→G→H→C, A→F→H→C, A→G→F→H→C and A→F→G→H→C. Without overlaying, the path from A to C is determined by an Interior Gateway Protocol (IGP) such as OSPF (Open Shortest Path First).

The overlay approach has been widely implemented in current Internet backbones, it does have some scalability issues. First, it suffers the so-called "N-square" problem. The N-Square problem is to establish full meshed logical connections between N edge nodes, each node has to set up logical connections to (N-1) other nodes. Thus, N*(N-1) logical connections have to be established for the full-mesh virtual network. As the size of the backbone network increases, the number of logical connections to be established will rise...
drastically, adding considerable management complexity and messaging 
overheads.

In the Fig 1.1, it has five edge nodes (like A,B,C,D, & E). Each node has 
to set up an LSP to four other nodes. Therefore in total there are 20 explicit 
routes (each dotted line represents two unidirectional LSPs). So, fully meshed 
virtual topology can increase the loads on IP routing protocol. Multiple LSPs 
may go over the same physical trunk. The break down of a single physical 
trunk may cause multiple LSPs to fail.

This poses a significant problem to current IP routers, as most of them 
cannot support a large number of peers. Note that multiple logical connections 
may go over the same physical link. Thus, the breakdown of a single physical 
link may cause multiple logical connections to fail, and this will exaggerate the 
routing update load.

1.1.2 Integrated Approach

Integrated Approach accomplishes traffic-engineering objectives 
without full mesh overlaying. Instead of overlaying IP routing over the logical 
virtual network, the new approach runs shortest-path IP routing natively over 
the physical topology, as it is the case in most enterprise networks. Traffic 
engineering objectives such as balanced traffic distribution (traffic is evenly 
distributed across the network) are achieved through manipulating link metrics 
for IP routing protocols such as OSPF. This approach is named as the 
integrated approach [Yuf 01] since IP routing is running over the physical
topology rather than the full-mesh virtual network. This approach can accomplish similar traffic-engineering objectives to the overlay approach but in a much more scalable way. It does not require any changes to the basic IP routing architecture and can be readily implemented in networks. With this approach the link weights are calculated to ensure balanced traffic distribution. Once the link weights are set, the OSPF routing protocol calculates the forwarding paths using the shortest-path-first computation, and packets are forwarded based on longest-prefix match. This eliminates the N-square problem altogether and reduces messaging overheads in setting up explicit routes. When a link is experiencing congestion, service providers typically increase the weight for that link in the hope that traffic will be moved away from it. These experiments, however, were done based on simple heuristics.

1.2 Our Approaches

In our research, we provide new methods to balance traffic distribution in MPLS networks. Demands have to be estimated based on traffic measurement. Our objective is to achieve Balanced Traffic Distribution so that we can minimize the maximum link utilization of the network.

Mathematically, the objective of balanced traffic distribution can be described as minimizing the maximum of link utilization [Yuf 01]. The key point of this part is that the new link weight function considers both link capacity and bandwidth. Our target is therefore to keep the max-utilization
below 100%; or, to protect against bursts, our target could be to keep max-utilization below 80% [For 00].

If traffic is splittable, we design an edge-based traffic engineering method for OSPF networks. The main idea is that we push the arbitrary traffic splitting to the network edge and still keep the network core simple. The traffic is split into a small number, and each of these traffic routed over an independent virtual overlay on top of a physical network.

1.3 Research Contributions

Our research aims at balancing traffic load in networks by designing the bandwidth-sensitive routing algorithms and the edge-based traffic engineering method.

The major contributions of this research include the following four parts:

1. Traffic Engineering (TE) [Awd 02] broadly relates to optimization of the performance of a network. The Overlay approach [Yuf 01] has been widely used by many service providers for Traffic Engineering in large Internet backbones. In this approach logical connections are set up between edge nodes to form a full mesh virtual network on top of the physical topology. Instead of overlaying IP routing over the logical virtual network, the Integrated approach [Yuf 01] runs shortest path IP routing natively over the physical topology. We investigate the quality of the routing in the Integrated approach with respect to link load, traffic distribution and link utilization. There is a method called
knapsack in data structures to find out best and profitable packing of the objects into the sack. We use that method to find out balanced routing among the routes and to improve the quality of the routing. This method strikes a good balance between the conflicting objectives of link load and optimizing the QoS routing. Let \( \alpha = \frac{\sum_{i} Wx_i}{M} \) represents the maximum link utilization.

\[ \sum Wx_i \] - represents the summation of traffic distributed over the equal cost shortest paths for a particular origin-destination pair.

\( M \) - Capacity of the link.

This optimal routing result in efficient traffic distribution and the link utilization is 75% uniformly for the entire network. In Integrated Approach link utilization is 80%.

2. Even though constraint-based routing [Cha 05] Multi-Protocol Label Switching (MPLS) is developed to address this need, since it is not widely tested or debugged, Internet Service Providers (ISPs) resort to TE methods under Open Shortest Path First (OSPF), which is the most commonly used intra-domain routing protocol. Determining OSPF link weights for optimal network performance is an NP-hard problem. As it is not possible to solve this problem, we present a subset split method to improve the efficiency and performance by minimizing the maximum link utilization in the network via a small number of link weight modifications. The results of this method are compared against results of Integrated approach. The integrated approach got
80% link utilization. In our proposed method the maximum link utilization is 75%.

3. The new Bin Packing approach is proposed here for load balancing in MPLS. The objective is to determine minimum number of bins needed to accommodate all ‘n’ objects. Likewise all the traffic flow (considered as objects) should be distributed along the number of paths (considered as bins) evenly. The bin-packing based partitioning algorithm (BPA) attempts to improve the load balance during the partitioning of the load, Unallocated traffic is first distributed using a "best-fit" approach. If this fails, the ‘most-free’ approach is adopted until all the traffic is allocated. We investigate the quality of the routing in the Integrated approach with respect to link load, traffic distribution and link utilization. Here, we calculate the maximum link utilization and minimum link utilization. The difference between these two results is considered as wastage of the link utilization. Our objective in this method is to achieve 0% wastage. This method strikes a good balance between the conflicting objectives of link load and optimizing the QoS routing and wastage of link utilization is 0%. This optimal routing result in efficient traffic distribution and the overall link utilization is uniformly 75% for the entire network. It is easy to see that some other routing arrangements may produce unbalanced traffic distribution and cause hot spots in the network.
4. Common objectives of traffic engineering include balancing traffic distribution across the network and avoiding congestion hot spots. We propose a new approach called the Bayesian approach to avoid congestion hot spots without full mesh overlaying. This approach can be illustrated with a simple network, and then present a formal analysis of the Bayesian networks [Rus 95, Kev 00] and a method for finding the congestion hot spots. Once the congestion hot spots are identified then the traffic can be distributed, so that no link in the network is either over utilized or underutilized. By applying Bayes Rule, we can find out the maximum link utilization in one route of the network is 99%. If route’s link utilization is more than 80% it is considered to be over utilized. The network load can be balanced by sharing the traffic through other routes in the network to minimize the link utilization. With this Bayesian approach the quality of the routing can be improved and congestion can be avoided.

1.4 Thesis Outline

Chapter 1 presents the overview about the QoS and the basics of Traffic engineering. It also gives basic idea about the problem.

Chapter 2 elaborates the history and evolution of traffic engineering.

Chapter 3 introduces some background information of traffic management on networks and presents theoretic fundamentals of Traffic engineering, minimizing the maximum link utilization and OSPF method.
Chapter 4 illustrates the knapsack method to improve the quality of the routing and also explains the method of achieving a good balance between the conflicting objectives of link load and optimizing the QoS routing.

Chapter 5 explains the new approach to achieve traffic engineering without full-mesh overlaying with the help of integrated approach and equal subset split method.

Chapter 6 exemplifies the bin-packing based partitioning algorithm (BPA), which attempts to improve the load balance during the partitioning of the load. Unallocated traffic is first distributed using a "best-fit" approach.

Chapter 7 demonstrates the new approach called the Bayesian approach to avoid congestion hot spots without full mesh overlaying so that load can be balanced without congestion.

Chapter 8 concludes with some observations and comments. The future enhancement and scope of the research are discussed briefly.

1.5 Conclusion

The new approaches are proposed for achieving traffic engineering in the backbones. Instead of relying on the mapping of logical connections to physical links to manage traffic flows in the network, we run IP routing natively over the physical topology, and control the distribution of traffic flows through setting appropriate link weights for shortest path routing. For any set of optimal routes shortest paths will be calculated with respect to a set of positive link weights. The results can be extended to a more generic one where any
arbitrary set of routes can be produced as shortest-paths with respect to a set of positive link weights. The performance objectives are link weights. The equal splitting rule complicates problem. Instead of routing each prefix on all equal cost paths, selectively assign next hops to (each) prefix. OSPF/ISIS can be used to support engineering objectives. The heuristics approach can be implemented to provide good performance. Any small changes to IP routing provide in better performance. Finally, the MPLS suffers none of these problems.