OMP Simulation Results in IP Networks

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Abstract
These days the use of Internet almost everywhere is not surprising. However, the used traffic management solutions in the Net are restricted so they are not adequate to the contemporary services. The increasing demand on using eligible and efficient traffic management and engineering methods appears in the protocols/methods being under research/standarisation phase, such as MPLS-Traffic Engineering, OSPF-OMP, MPLS-OMP, etc. This paper discusses the application of OSPF-OMP and MPLS-OMP (OMP: Optimised MultiPath) technique for Traffic Engineering purposes in IP networks and reviews OMP simulation results.

Keywords: Traffic Engineering, Optimised MultiPath (OMP), Open Shortest Path First (OSPF), MultiProtocol Label Switching (MPLS), OPNET

1 Introduction

It is by now something of a cliché to talk about the “explosive” or “exponential” growth of the Internet, but the fact remains that it has experienced remarkable growth. The Internet is clearly getting bigger and bigger in almost any dimension that can be measured, and this expansion has created a wealth of technical challenges. The growth in both the number of users of the Internet and in their bandwidth and quality requirements has placed increasing demands on the Internet Service Providers’ networks. To meet these demands and to respond to the challenges some new techniques, algorithms, methods are required. Traffic Engineering techniques – which include dynamic load-balancing –, MPLS (MultiProtocol Label Switching) technology and Quality of Service (QoS) support in traditional IP networks could form the repository of the solutions to the future challenges.

In this paper I first briefly review the idea of Traffic Engineering, OSPF routing protocol, MPLS technology and OPNET simulation tool. Then I discuss the general issues of OMP dynamic load-
sharing algorithm and its use with OSPF and MPLS. Afterwards, as a continuation of a previous basic simulation work [8, 9, 10], I present my simulation results from two network topology approaches using OSPF, OSPF-OMP, MPLS and MPLS-OMP routing techniques, respectively. In the last two sections I summarise the results and I point out the possible future perspectives.

1.1 Traffic Engineering

Traffic Engineering (TE) is concerned with performance optimisation of operational networks [4]. In general, it encompasses the application of technology and scientific principles to the measurement, modelling, characterisation, and control of Internet traffic, and the application of such knowledge and techniques to achieve specific performance objectives.

The aspects of Traffic Engineering that are of interest concerning MPLS are measurement and control. A major goal of Internet Traffic Engineering is to facilitate efficient and reliable network operations while simultaneously optimising network resource utilisation and traffic performance. Traffic and resource oriented performance can be increased by among other things the minimisation of the congestion in the network. Adopting load-balancing policies can reduce congestion resulting from inefficient resource allocation. The objective of such strategies is to minimise maximum congestion or alternatively to minimise maximum resource utilisation, through efficient resource allocation.

1.2 OSPF

OSPF (Open Shortest Path First) is an internet routing protocol [1]. It is classified as an Interior Gateway Protocol (IGP). This means that it distributes routing information between routers belonging to a single Autonomous System (AS). The OSPF protocol is based on link-state and SPF (Shortest Path First) techniques.

In a link-state routing protocol, each router maintains a database describing the AS's topology. Each participating router has an identical database. Every individual piece of this database is a particular router's local state (e.g., the router's usable interfaces and reachable neighbours). The routers distribute their local states throughout the AS by flooding. The possible routes to reach the destination
nodes are computed from the database using the SPF algorithm that provides the shortest paths between the endpoints of the network.

1.3 MPLS

MPLS (Multi-Protocol Label Switching) [2] integrates a label-swapping framework with network layer routing. The basic idea involves assigning short fixed length labels to packets at the ingress to an MPLS cloud. The forwarding function of a conventional router involves a capacity-demanding procedure that is executed per packet in each router. MPLS simplifies the forwarding function in the routers by introducing a connection-oriented mechanism inside the traditionally connectionless IP networks so label switched paths (LSP) are set up for each route or path through the network in advance using an IGP (e.g., OSPF). Throughout the interior of the MPLS domain, the labels attached to packets are used to make forwarding decisions (usually without recourse to the original packet headers).

1.4 OPNET

OPNET (OPtimised Network Engineering Tools) [3] is a discrete event simulation tool, which provides a comprehensive development environment supporting the modelling and simulation of communication networks and which contains data collection and data analysis utilities. OPNET allows large numbers of closely spaced events in a sizeable network to be represented accurately. It uses a modelling approach where networks are built of nodes interconnected by links. Each node’s behaviour is characterised by the constituent components and these components are modelled as a state-transition diagram. I used OPNET as my simulation environment.

2 OMP Technique

I proposed to study Traffic Engineering issues in IP networks. TE is a vast research area and I focused my efforts to study OMP (Optimised MultiPath) technique, which is a dynamic load-sharing algorithm, together with OSPF and MPLS in Best Effort networks.
2.1 OSPF-OMP

OSPF may form multiple equal-cost paths between source-destination node pairs. In the absence of any explicit support to take advantage of this, a path may be chosen arbitrarily. ECMP (Equal Cost Multi-Path) technique has been utilised to divide traffic somewhat evenly among the available paths. However, an unequal division of traffic among the available paths is generally preferable. Routers generally have no knowledge of traffic loading on distant links and therefore have no basis to optimise the allocation of traffic.

OSPF-OMP [5] utilises the OSPF Opaque LSA (Link State Advertisement) option to distribute loading information inside the network, proposes a means to adjust forwarding and provides an algorithm to make the adjustments gradually enough to insure stability yet provides reasonably fast adjustment when needed.

2.2 MPLS-OMP

In an MPLS network MPLS ingress routers may establish one or more paths to a given egress to the MPLS domain. Load can be balanced across a complex topology using MPLS. It requires that the ingress router is capable of computing a hash with a sufficiently fine level of granularity based on the IP source and destination addresses and selecting a forwarding entry based on the outcome of the hash.

MPLS-OMP [6] is an extension to MPLS. It does require that the IGP be capable of flooding loading information across the network. At the MPLS ingress an algorithm is applied to select alternate paths where needed and adjust forwarding. Forwarding is adjusted gradually enough to insure stability yet fast enough to track long term changes in loading.

3 Simulation Results

The implementation and a basic examination of OMP technique in OPNET simulation environment were the objectives of a previous simulation project supported by TELIA Research AB [8, 9, 10]. As a continuation of that work my main goal concerning TE this time was to examine the
behaviour of OMP technique and make a kind of performance evaluation through running different simulations.

### 3.1 Core Network Topologies to Simulate

I examined the OMP behaviours from two network topology approaches. The first one was the network topology of a typical Internet service provider, this topology appears in a number of publications [7], and the second one was an artificial, mesh like topology that was constructed by repeating a basic network building block (see Figure 1). I used instances of this, mesh like topology ranging from 1 x 1 to 4 x 4. The link capacities of the core networks were 64 Kbps and the link costs were equal everywhere inside the networks.

![Figure 1. Core Network Topologies: ISP and Mesh](image)

In MPLS simulations the router nodes represented ATM-based gateways supporting one Ethernet and maximum 6 ATM interfaces at a selectable data rate. These nodes were connected to each other by point-to-point ATM links. In OSPF simulations the router nodes represented IP-based gateways supporting one Ethernet interface and up to 8 serial line interfaces at a selectable data rate. These
nodes were connected to each other by point-to-point serial line links. In OSPF simulations I have not used ATM technology at all.

3.2 Generated Traffic Pattern

To see the main behaviours of OMP technique on different network topologies I applied two fundamental traffic pattern approaches, a static approach and a dynamic one. I used two terminal/server pairs to offer the traffic in the event of all simulations where the terminals competed for the network resources. These terminal/server pairs were connected to randomly selected routers in case of the ISP topology while they were connected to the corner points of the core networks in case of mesh like topologies (see Figure 2) through 10 Mbps Ethernet links.

Figure 2. Traffic Generators on ISP and Mesh Topologies
In the first, static traffic pattern approach the terminals generated constant traffic (64 Kbps) during the simulation time while in the second case they generated dynamically varying traffic. The offered traffic by the terminals was TCP like traffic (I used FTP traffic with approximately 64 Kbps bandwidth requirement in the static case and I used FTP traffic to transport files with infinite size in the dynamic case) because today in IP environment the most frequent applications are TCP related ones. The simulated time interval was 4 hours long in every simulation.

### 3.3 OMP Simulation Results

As I mentioned previously, I ran OMP simulations on two different network topology approaches with two types of traffic patterns. In case of both topologies I made the same examinations. When the terminals generated constant FTP traffic I examined the average link utilisation values on every link and the position of the most loaded links in the network. Otherwise, when the terminals generated dynamic FTP traffic I examined the throughput of the network.

#### 3.3.1 Mesh Topologies

In this simulation sequence I ran 4 OSPF based simulations and 4 MPLS based simulations on every mesh topology. In the first two simulations in OSPF/MPLS based cases I tried to generate approximately 64 Kbps constant traffic by each terminal and to send it over the network with and without the use of OMP technique. The following diagram and table (see Figure 3) contain the distribution of the average link utilisation values in case of OSPF simulations. The four column pairs represent the simulated mesh topologies (where the first column indicates the “without OMP” while the second column indicates the “with OMP” results). In the diagram the red colour indicates the proportion of the most overloaded links (where the link utilisation is over 75%), the orange colour indicates the proportion of the links utilised between 50% and 75%, the yellow colour indicates the proportion of the links utilised between 25% and 50% while the green colour indicates the proportion of the links utilised under 25% of the topology in question. I will use this notation through the whole paper. The exact values can be found in the table. The rows of the table represent the different link
utilisation levels while the columns represent the simulated mesh topologies with the appropriate OSPF routing algorithm.

![Link Utilisation Distribution](image)

<table>
<thead>
<tr>
<th>Link Utilisation / Simulation Type</th>
<th>Mesh_1</th>
<th>Mesh_2</th>
<th>Mesh_3</th>
<th>Mesh_4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w/o OMP</td>
<td>w/ OMP</td>
<td>w/o OMP</td>
<td>w/ OMP</td>
</tr>
<tr>
<td>0% - 25%</td>
<td>70%</td>
<td>50%</td>
<td>81%</td>
<td>63%</td>
</tr>
<tr>
<td>25% - 50%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>19%</td>
</tr>
<tr>
<td>50% - 75%</td>
<td>0%</td>
<td>40%</td>
<td>0%</td>
<td>12%</td>
</tr>
<tr>
<td>75% - 100%</td>
<td>30%</td>
<td>10%</td>
<td>19%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Figure 3. Distribution of Link Utilisation Values on Mesh Topologies in case of OSPF Based Simulations

Figure 4 contains the distribution of the average link utilisation values in case of MPLS based simulations. The notation is the same as I used previously.
Figure 4. Distribution of Link Utilisation Values on Mesh Topologies in case of MPLS Based Simulations

In the rest of the mesh simulations I used FTP traffic to transport files with infinite size because I wanted to send as much traffic over the networks as the terminals could generate. In this scenario my goal was to examine the throughput of the networks using pure OSPF/MPLS and OSPF-OMP/MPLS-OMP routing. I mean by network throughput the average amount of the traffic which the network is capable to transmit in case of a given network topology and given source/destination nodes. The following tables (see Table 1) contain the throughput values of the mesh topologies in case of the different (OSPF/OSPF-OMP and MPLS/MPLS-OMP) routing algorithms. The first rows of the tables represent the throughput in Kbps (transmitted traffic over the network) of the adequate mesh topology and routing algorithm while the second rows represent their throughputs in percentage. (I always
compared the transmitted traffic over the network using OMP with the traffic transmitted in case of pure OSPF/MPLS routing.)

<table>
<thead>
<tr>
<th>Network Type / Simulation Type</th>
<th>Mesh_1</th>
<th>Mesh_2</th>
<th>Mesh_3</th>
<th>Mesh_4</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSPF</td>
<td>117</td>
<td>121</td>
<td>123</td>
<td>123</td>
</tr>
<tr>
<td>OSPF-OMP</td>
<td>170</td>
<td>172</td>
<td>168</td>
<td>162</td>
</tr>
<tr>
<td>Throughput in Kbit</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Throughput in percentage</td>
<td>145%</td>
<td>142%</td>
<td>136%</td>
<td>131%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Network Type / Simulation Type</th>
<th>Mesh_1</th>
<th>Mesh_2</th>
<th>Mesh_3</th>
<th>Mesh_4</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPLS</td>
<td>114</td>
<td>117</td>
<td>119</td>
<td>119</td>
</tr>
<tr>
<td>MPLS-OMP</td>
<td>165</td>
<td>291</td>
<td>233</td>
<td>282</td>
</tr>
<tr>
<td>Throughput in Kbit</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Throughput in percentage</td>
<td>144%</td>
<td>249%</td>
<td>196%</td>
<td>237%</td>
</tr>
</tbody>
</table>

Table 1. Throughput Values on Mesh Topologies in case of OSPF/MPLS Based Simulations

3.3.2 ISP Topology

In this simulation sequence I ran 4 OSPF based simulations and 4 MPLS based simulations on the ISP topology. The types of the simulations were the same as in case of mesh simulations. In the first two simulations in OSPF/MPLS based cases I tried to generate approximately 64 Kbps constant traffic by each terminal and to send it over the network with and without the use of OMP technique. Figure 5 illustrates the distribution of the average link utilisation values in the event of both OSPF/MPLS based simulations. The notation of the diagram is the same as I used previously.
In the rest of the ISP simulations I used the previously mentioned infinite traffic generators at the terminals to examine the throughput of the networks using pure OSPF/MPLS and OSPF-OMP/MPLS-OMP routing. The following table (see Table 2) contains the throughput values of the ISP topologies in case of the different routing algorithms. The first row of the table represents the throughput in Kbps (transmitted traffic over the network) in case of the different routing algorithms while the second row represents the throughput in percentage.
<table>
<thead>
<tr>
<th>Network Throughput / Simulation Type</th>
<th>ISP Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OSPF Based Simulations</td>
</tr>
<tr>
<td>w/o OMP</td>
<td>w/ OMP</td>
</tr>
<tr>
<td>Throughput in Kbit</td>
<td>116</td>
</tr>
<tr>
<td>Throughput in percentage</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2. Throughput Values on ISP Topology in case of OSPF/MPLS Based Simulations

4 Conclusions

In this paper I tried to analyse some performance aspects of OMP technique. I ran 40 simulation scenarios and I collected and presented the results. I examined the OMP behaviours from two network topology approaches (a mesh like and a general ISP) using two different generated traffic patterns (a static and a dynamic one). I focused my activity on the investigation of the behaviour related (such as throughput and utilisation) dimension of OMP performance. Thus I have examined the average link utilisation values on every link in the network; on the other hand I have examined the total throughput of the simulated network topologies.

4.1 Utilisation

Let’s consider a network topology with a traffic pattern and a routing algorithm. If the same traffic pattern is better split in the network using another routing algorithm, that is, the number of the most loaded links decreases, then we can say the network is better utilised from a kind of point of view. In my results I got that the number of the most loaded links (where the average link utilisation is between 75% and 100%) was decreased with 65% on average using OSPF-OMP and it was decreased to zero using MPLS-OMP.

Certainly, we cannot say that using OSPF-OMP the improvement of link utilisation is always 65% and using MPLS-OMP it is always 100%. It very-very depends on the network topology in question. For example, if every link cost is equal in the network (such as in my test topologies) and
only one shortest path exists between every source and destination node (such as between Terminal_1 and Server_2 in the mesh topologies), then we won’t gain any improvement using OSPF-OMP. (It is due to the Relaxed Best Path Criteria [5] used by OMP, which won’t be able to discover alternative paths.) This statement is also true in case of MPLS-OMP, that is, we cannot experience improvement in case of every topology (e.g., if only one route exists between a source and destination pair in a topology). Moreover, using MPLS-OMP the possibility of finding alternative routes and the number of these routes could be much higher due to the external routing mechanism [6] than in case of OSPF-OMP. (External routing prevents the formation of rooting loops in the network, so in MPLS-OMP the Relaxed Best Path Criteria [5] does not restrict the finding of almost all available paths.)

To summarise my observations I can only say that using OSPF-OMP we will gain better link utilisation if the network topology is suitable for load balancing and we will never experience worst result than we would use pure OSPF. Moreover, I can say that using MPLS-OMP we will gain better link utilisation if alternative paths exist in the network topology and we will never experience worst result than we would use pure MPLS or OSPF-OMP.

4.2 Network Throughput

In my simulations I examined the network throughput value generating infinite amount FTP traffic in case of pure OSPF/MPLS and OSPF-OMP/MPLS-OMP routing. As I mentioned previously, I mean by network throughput the average amount of the traffic which the network is capable to transmit in case of a given network topology and given source/destination nodes. Using OSPF-OMP I experienced 41% and using MPLS-OMP I experienced 117% improvement on average in the network throughput value in my simulation scenarios. Concerning this issue the same statement is true as in case of the Utilisation issue, that is, the improvement depends on the network topology.

Generally we can say that if the topology is suitable for using alternate paths then we can gain improvement concerning the network throughput in case of OSPF-OMP/MPLS-OMP routing and we never get worst result than we use pure OSPF/MPLS. Furthermore, using MPLS-OMP we never get worst result than we use OSPF-OMP.
5 Future Perspectives

Concerning the future perspectives of my work in load-balancing research area it would be interesting to examine also the computational related (processing cost; LSA generation cost; memory requirements) dimension of OMP performance. Furthermore, it would be required to investigate the stability of OMP and to extend the examinations over heavily changing incoming traffic pattern. Another interesting issue could be how an OMP network reacts to a failure scenario. From scientific point of view it would be appreciated to work out a formal metric which would be suitable for measuring the network utilisation and network stability in a general way.

5.1 Ideas to Improve OMP Performance

We can see that OSPF-OMP usually cannot find every alternative path between a given source and destination node (because it uses the Relaxed Best Path Criteria and its loop avoidance idea [5]). In my simulations this drawback could be observed for example in the mesh topologies where the traffic from Terminal_1 to Server_2 could travel on only one path even using OMP. If we can find another loop avoidance idea and this makes the finding of more alternative paths possible then the performance of OSPF-OMP would improve. This idea requires further considerations.

In case of MPLS-OMP, concerning the path selection method I should mention that MPLS-OMP randomly selects the next candidate path if more equal cost paths are available. This could also influence the OMP performance. If we apply a new restriction at path selection and we always select the path from more available routes, which does not contain a potential destination LER (Label Edge Router) then we could get better network throughput in case of dense topologies. This idea also requires further considerations.

6 References


[10] K. Farkas: “OMP Technique in IP Traffic Engineering”; Periodica Polytechnica journal; accepted for publication