Evaluation of a Multiobjective Alternative Routing Method in Carrier IP/MPLS Networks
(Work in Progress)

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Abstract. We present a first simplified version of the MultiObjective Dynamic Routing (MODR) method, more suitable for a realistic network environment as the computational effort is very much reduced while good results can still be reached. The simplified version presented herein is based on the results obtained from a discrete event simulation study which shows that, in case of overload, more important than the alternative routing algorithm itself is to control the excess of alternative routing traffic. Moreover, in a multiservice network in the case of lightly loaded traffic conditions, when alternative routing starts to be effective, network performance can still be improved if we can avoid alternative routing for specific traffic flows. Classical dynamic alternative routing methods for traditional ISDN networks have a trunk reservation mechanism with a similar purpose but apparently without the same performance. Our method applies to MPLS strongly meshed networks which are typical of core networks.

Keywords: QoS, MPLS Networks, alternative routing, multiobjective optimization.

1 Introduction and Motivation

The rapid transformation of the Internet into a commercial infrastructure supporting many types of services which can integrate not only best effort traffic but also IP-telephony, IP-multimedia as well as other types of services, gives rise to new routing protocols based on QoS (Quality of Service) parameters. These

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new services have network performance requirements like end-to-end delay, delay jitter, required bandwidth and packet loss probability, that must be fulfilled. This evolution seems to lead to the absorption of traditional ISDN networks by these new IP-based networks (e.g., British Telecom [1]).

Any Transport over MPLS (AToM) is a solution for transporting Layer 2 packets like ATM, Frame Relay, Ethernet, PPT or HDLC, over a single, integrated, packet-based MPLS backbone network, instead of separate networks with different network management environments. In a nutshell, AToM inserts a label in the packets at the provider-edge router, based on the Forwarding Equivalence Class (FEC), and then transports them over the backbone. A FEC is a group of IP packets which are forwarded in the same manner and for that reason they belong to the same label-switched path (LSP).

Regarding MPLS, each explicit LSP is treated as a point-to-point path that, for a given time duration, has a constant bandwidth. In MPLS, if an explicit path specified with a 'non-mandatory' preference rule attribute value is not feasible, an alternative route (or path) may be chosen [2]. Hence, if a flow request does not find available resources it needs in the first choice path, a second chance may be given to that flow as it will be possible to try a pre-computed alternative path.

On the other hand, DiffServ [3] is a coarse-grained, class-based mechanism for traffic management. DiffServ networks operate on the principle of traffic classification, where each data packet is placed into one of a limited number of traffic classes, rather than differentiating network traffic based on the requirements of an individual flow (like in IntServ networks). DiffServ has two important advantages over IntServ: all of the processing takes place before the flows enter the network, at the boundaries, and the flows are aggregated so that there is no need for routers to analyze the requirements of each individual flow, eliminating the scalability issues. However, DiffServ does not solve the problem of call admission control (CAC), which is essential for QoS guarantees. This implies that QoS, with Diffserv, is usually guaranteed by overprovision, which is not always possible.

To implement CAC there is the pre-congestion notification (PCN) architecture suggested by IETF [4] which enforces QoS by marking packets based on the utilization of links and gives early warnings before congestion occurs. To cope with the issue of exceeding bandwidth allocation, a per flow admission control is suggested for a DiffServ network, in particular a measurement-based admission control (new flow requests are blocked dynamically in response to actual (incipient) congestion on a router within the DiffServ network). In this context, instead of a lost connection, a second chance may be given to these flow requests by allowing alternative routing.

The method developed in this paper applies to DiffServ-aware-MPLS meshed networks with PCN. In our multiservice model, traffic with different bandwidth requirements is classified into the same FEC and because of that is carried in the same LSP between adjacent nodes.

In the multiservice model it is considered that, for the time duration of each flow, it requires constant bandwidth on each LSP corresponding to the effective bandwidth that is characteristic of that type of flow. Effective bandwidth can encapsulate traffic behaviour and QoS issues at the cell and packet levels [5,6]. In addition, we can forget the bursts and bandwidth variations because of the PCN-threshold-rate which allows PCN-boundary-nodes to convert measurements of PCN-markings into decisions about flow admission. At this point, blocked requests may be rerouted to an alternative path.

Our approach treats each explicit LSP as a multiservice point-to-point path with a constant bandwidth shared by all services, were each flow is admitted in the LSP if the effective bandwidth necessary for that flow is available, otherwise the flow is rejected. This behaviour together with the proper adjustment of the the PCN thresholds, allows the consideration of a quasi circuit switching capability superimposed on the current Internet routing model [2].

The necessity of dealing with multiple and multifaceted QoS requirements in the new network technological platforms makes that there are potential advantages in formulating many routing optimisation problems as multicriteria models. In the particular multiobjective formulations enable the trade-offs among different objective functions (QoS metrics or cost functions) to be treated mathematically in a fully consistent manner. In this type of formulation instead of the concept of optimal solution the concept of non-dominated solution should be used that is a solution such that it is not possible to improve one of the objective functions unless at least one of the others is worsened. A state of art review on applications of multicriteria analysis in telecommunication network design is in [7]. A recent review on multicriteria routing models with an application study, is in [8]. In references [9] (for single-service networks) and [10] (for multiservice networks) a multiobjective dynamic routing model designated as MODR was formulated and solved through a heuristic approach. This model may be considered as a particular case of the network-wide optimisation meta-model for multiobjective routing in MPLS networks proposed in [11].

The main contribution of this paper is to present a first simplification of the former MODR method, which was developed in order to obtain a more suitable version for application to a realistic IP/MPLS network environment. In particular this version aims at a significant reduction in the computational effort required by the method while maintaining good results in terms of network performance measures. The routing algorithm presented herein is based on a procedure that selectively eliminates each alternative path and is a much simplified version of the one proposed in the MODR method. Also the use of Howard costs (much easier to compute) instead of implied costs is analysed in this context.

The paper is structured as follows. In section 2, general features of the MODR method are reviewed and the new simplified version aimed at a reduction on path computational effort, is described. In section 3, simulations regarding the decrease of computational effort and some procedures will be presented. In section 4 a comparative study between two metrics (implied costs, which is the metric used by MODR method, and Howard costs, suggested in the Separable Routing scheme in [12]) is presented in order to decide which one is more effective in our routing algorithm. In section 5 conclusions are presented and discussed.

2 The Multiobjective Dynamic Routing Method

2.1 Review of the MODR Method

The MODR method applies to strongly meshed networks, in which it has been extensively documented in the literature that the first choice route should always be the direct one if it exists. This article describes a simplification/adaptation of MODR, a hierarchical Multiple Objective Dynamic Routing model for telecommunication networks, presented in [9,10]. The general purpose of MODR is to find, in a strongly meshed network, in each route updating interval, the set of alternative paths for all flows that adapt the best to the offered traffic conditions, in order to fulfill the objectives at network and service levels. In the present context we consider as strongly meshed networks, those with topological density close to a complete graph and such that for each origin-destination pair there are at least two 2-link paths. We begin by reviewing the hierarchical multiobjective alternative routing model that MODR addresses.

Notation:

- $G = (V, L)$ - undirected graph representing the network topology where V is the node set and L the arc set;
- $f_s \equiv (v_o, v_t, \gamma)$ where $v_o, v_t \in V$ and $v_o \neq v_t$ - is a traffic flow from node v_o to node v_t of service type s where γ represents a traffic descriptor which enables a complete definition of the associated stochastic process (e.g. mean service s time h_s, number n_s of links required by each connection of traffic flow f_s in every arc of each attempted path);
- F - set of all traffic flows in the network;
- $A_t(f_s) = I_t(f_s)\, h_{fs}$ where $I_t(f_s)$ represents the average arrival intensity during time period $t = nT\,(n = 1, 2, ...)$ - traffic offered (in Erlangs) for traffic flow $f_s = (v_i, v_j, \gamma) \in F$ at time t and h_{f_s} is the mean occupation time of f_s flow calls;
- $B(f_s)$ - point-to-point blocking probability for traffic flow $f_s \in F$;
- $R_t(f_s) = \left\{r^1(f_s), r^2(f_s) \,:\, r^1(f_s), r^2(f_s)\right\}$ - where $r^1(f_s)$ and $r^2(f_s)$ are loopless paths. $R_t(f_s)$ is the ordered set of paths which may be used by flow f_s at time t;
- $\bar{R}_t = \left\{R_t(f_1), \ldots, R_t\left(f_{|F|}\right)\right\}$ - routing plan for the network at time t;
- B_{ks} - blocking probability experienced by a service s call on link $l_k = (v_i, v_j) \in L$;
- C_k - capacity of link $l_k = (v_i, v_j) \in L$;
- ρ_{ks} - service s total offered traffic to link l_k (the mean of the total number of calls of type s offered to l_k during calls mean service time);
- $L_{r^i(f_s)}$ - mean blocking probability on route $r^i(f_s)$, experienced by a call of f_s;
- $\underline{d_k} = [d_{k1}, \ldots, d_{k|S|}]$ - required bandwidth on link l_k by a call of service $s \in \{1, 2, \ldots, |S|\}$, which may be interpreted as its effective bandwidth;
- $\mathcal{D}(f_s)$ - routing domain for traffic flow f_s which encompasses the set of all possible paths from origin node v_o to destination node v_t.

As stated in [9], it is assumed the following: all traffic flows are homogeneous Poissonian and independent, service times are negative exponentially distributed, there is statistical independence in the occupations of the links and routes $r^1(f_s), r^2(f_s)$ are node disjoint.

The blocking probability of a connection of type s in arc l_k is given by $B_{ks} = \mathcal{L}_s\left(\overline{d_k}, \overline{\rho_k}, C_k\right)$. As explained in [10], functions $\mathcal{L}_s$ represent the traffic calculation model that enables the marginal blocking probabilities on the links to be computed namely according to the methods in [13,14].

The MODR method relies on a heuristic for route calculation and selection based on two mechanisms: first, a biobjective shortest path algorithm (MMRA) to obtain the subset of candidate non-dominated alternative path solutions $R_t(f_s)$ for each flow, and second, a procedure to decide which alternative paths should be updated in each time interval. The problem formulation for MMRA is as follows:

$$\text{(Problem } \mathcal{P}^2\text{)} \qquad \min_{r_s \in \mathcal{D}(f_s)} m^n(r_s) = \sum_{l_k \in r_s} m^n_{ks}, n = 1, 2 \tag{1}$$

where m^i_{ks} is the value of metric i associated with link l_k and service s, $m^i(r_s)$ is the value of objective function i for path r_s. These metrics are the implied costs $m^1_{ks} = c_{ks}$, as defined in [15,10,11], and the blocking probability $m^2_{ks} = -\log(1-B_{ks})$. The log is used to transform blocking probability into an additive metric.

Let's consider the following simplifications:
$d_{ks} = d_s\left(\forall l_k \in r^i(f_s) \wedge \forall s \in S\right)$ which will also be made equal to the revenue associated with a call of all traffic flows f_s. A^o_s and A^c_s are the service s total offered and total carried traffic, respectively. A heuristic was developed to discover, in each time interval and among the set of non-dominated solutions discovered by MMRA, the set of alternative paths to update in order to guarantee a compromise solution in terms of the network level objective functions (o. fs.), (aiming at maximizing network expected revenue W_T and minimizing the maximal service mean blocking probability B_{Mm}) and service level o. fs. (in order to minimize the service mean blocking probabilities B_{ms} and the maximal point-to-point blocking probability, B_{Ms}, for each service s). The formalization of the hierarchical multiple objective dynamic alternative routing problem for multiservice networks is (Problem $\mathcal{P}^{G_S}$):

$$NL: \qquad \min_{\overline{R}_t} -W_T = -\sum_{s\in S} d_s A^c_s = -\sum_{s\in S} d_s A^o_s(1-B_{ms}) \tag{2}$$

$$\min_{\overline{R}_t} B_{Mm} = \max_{s\in S}\{B_{ms}\} \tag{3}$$

$$SL: \qquad \min_{\overline{R}_t(s)} B_{ms} = (A^o_s)^{-1} \sum_{f_s\in F_s} A_t(f_s) B(f_s),\ s = 1, \ldots, |S| \tag{4}$$

$$\min_{\overline{R}_t(s)} B_{Ms} = \max_{f_s\in F_s}\{B(f_s)\},\ s = 1, \ldots, |S| \tag{5}$$

$s.t.$ Equations of the teletraffic model to calculate$\{B(f_s)\}$ in terms of $\{A_t(f_s)\}$ and $\overline{R}_t$

Important to note that this is a hierarchical optimization problem where the first level objective functions (NL) have priority over the second level objective functions (SL).

Finally, an additional mechanism (APR - Alternative Path Removal) was introduced in the original heuristic as a service protection scheme the objective of which consisted of preventing blocking degradation in overload network situations due to excessive use of alternative routing. In this scheme, elimination of alternative routes occurs whenever the following condition stands:

$$m^1(r_s) > d_s \wedge m^2(r_s) > -z_{APR} \times \log(1 - 0.3) \tag{6}$$

where z_{APR} is just an empirical parameter used by the heuristic, which varies dynamically between 0 and 1 in the inner cycle of the procedure.

It was already proved that, assuming quasi-stationary conditions, such that the offered traffic stochastic features remain stationary during periods which are relatively long compared to the solution time, the single objective alternative routing problem is NP-complete in the strong sense. Since the problem $\mathcal{P}^{\mathcal{G}s}$ is a multiobjective one and having in mind the interdependencies between network mean blocking and maximal marginal blocking probabilities and their dependencies on the routing plan, it is expected great intractability for this problem. The foundation of the heuristic procedure is the search for a subset of the alternative path set for all flows, the elements of which should possibly be modified in a given route update period. This leads to a heuristic with two internal cycles of solution improvement that is very heavy in terms of computational cost. Details are given in [9,10]. This heuristic is now replaced by a simplified version, more suitable to be applied in real networks as described in the next sub-section.

2.2 Proposal of a Simplified Method

Our main objective, in this paper, is to propose another simpler heuristic in order to fulfil as far as possible the original objectives for the alternative routing problem. Our approach consists of seeking to update sequentially, in each time interval, only a subset of the available pairs of routes, instead of all route pairs (complete routing plan) as in the original heuristic. The number of paths to update in each time interval is directly related to the speed at which the network evolves due to changes in the offered traffic. However, as explained in [9], neither the update of all pairs nor the update of only one origin-destiny pair in each time interval is a good policy. In addition, experience has shown that at least as important as the routing algorithm itself, is the way in which direct traffic is protected in overloaded networks, as suggested in [16]. These two different but related aspects of the problem will be explained next.

Concerning the first aspect of the problem discussed above, and after a number of experiments a first simplified strategy was considered which consists of updating, in each period, the alternative routes for α pairs of nodes alone for every service. In our case study networks the recommended value was $\alpha = N/2$ where $N = |V|$ (number of network nodes). Note that this implies that all alternative routes for all services can be updated every $\frac{|F|}{|S|\alpha}$ (where $|F|$ is the total number of node to node flows) route updating periods. In other network structures different values of α might have to be considered after an experimental study with the routing method.

Let $t = n\mathcal{T}\,(n = 1, 2, \cdots)$ where $\mathcal{T}$ is the path update time interval, $\overline{R}_t^{(n)}$ the routing plan for the n$^{\text{th}}$ update interval. In addition, let's considerer $\overline{R}_t^* = \{r^2(f_s) : r^2(f_s) \text{ is updated by MMRA at } t = n\mathcal{T}\}$. Consider also that the initial origin-destiny pair value in the pseudocode below is 1-1.

1. $\overline{R}_t^{(n)} \leftarrow \overline{R}_t^{(n-1)}$
2. Calculate $\overline{B}$, $\overline{c}$, $\{B_{ms}\}$ and B_{Mm}, for $\overline{R}_t^{(n)}$ and a given $\overline{A}_t$ estimate using the fixed point iterators. Consider $\overline{R}_{t_{old}}^* = \{\}$, $\overline{R}_{t_{new}}^* = \{\}$ and counter ←0
3. while (counter < α) do
   (a) destiny ← destiny + 1
   (b) if (destiny = N+1) origin ← origin + 1 and destiny ← 1
   (c) if (origin = N+1) origin ← 1 and destiny ← 2
   (d) if (origin = destiny $\wedge$ destiny $\neq$ N) destiny ← destiny + 1
   (e) if (origin = destiny $\wedge$ destiny = N) origin ← 1 and destiny ← 2
   (f) for (s=1 until s=S) do
      i. $\overline{R}_{t_{old}}^* \leftarrow \overline{R}_{t_{old}}^* \cup \{r^2(f_s) : f_s \equiv (v_o, v_t, \gamma) \wedge\ v_o \equiv \text{origin} \wedge v_t \equiv \text{destiny}\}$
      ii. Use MMRA to determine the new $r^2(f_s)$
      iii. $\overline{R}_{t_{new}}^* \leftarrow \overline{R}_{t_{new}}^* \cup \{r^2(f_s)\}$
      iv. Selective elimination of $r^2(f_s)$ (according to criterion (8) later explained)
   (g) counter ← counter +1
4. $\overline{R}_t^{(n)} \leftarrow \overline{R}_t^{(n)} \setminus \overline{R}_{t_{old}}^* \cup \overline{R}_{t_{new}}^*$

The experimentation showed that the original MODR heuristic achieves better results in terms of global performance than the presented approach because it recalculates the routing plan for all the network flows in each update period. This was already expected, nevertheless, the gain achieved with the speed and simplicity of this new method was an incentive for the continuation of our study and lead us to second aspect of our problem.

We can define a numerical complexity value for MODR in terms of the upper bound of the number of alternative routing solutions that may be analysed in the heuristic. This complexity is of the order of $|S||\bar{F}|^2$ where $|\bar{F}|$ is the average number of traffic flows per service. For the 6 node network in the experimental study in section 2.3 this gives 2700 while the simplified heuristic only analyses $\alpha|S| = 9$ solutions, hence leading to a quite significant complexity reduction. The CPU time for the original heuristic is 21.844 seconds in a 2.8 GHz Pentium 4 while the new heuristic takes 94.3 milliseconds.

In this experimental study, extensively explained in [17], the direct traffic protection mechanism in case of overloads is based on alternative path elimination because from our experience (and [6]), it gives better global performance than trunk reservation schemes. So, with $z_{APR} = 1$ (the initial value of the parameter, which varies in the original heuristic, but which disappeared with this new approach), the path implied cost $(m^2(r_s))$ and the path blocking probability $(m^1(r_s))$ are calculated so that the alternative path is eliminated whenever condition (7) is verified:

$$m^2(r_s) > -\log(1-0.3) \wedge m^1(r_s) > d_s \tag{7}$$

2.3 Performance Evaluation

A discrete-event simulator was used for the comparative study of the MODR performance, considering the reformulation of the heuristic. Two fully meshed networks with six nodes ('A' and 'M') presented in [17] were used for this study to allow a comparison with previous work and also because simulation time for the original heuristic is very high. These networks were engineered with three services: telephone, data and video, with the required bandwidth $\overline{d} = [1, 6, 10]$ for each service and call durations of 1, 5 and 10 minutes, respectively.

Simulations were carried out with different path elimination criteria for both test networks.

Note that the constant 0.3 in equation (7) corresponds to a threshold of 30% for the blocking probability which in practice tends to protect (from excessive alternative routing) the more demanding services (since these tend to have higher blocking) leaving the less demanding services with potentially excessive alternative routes. To overcome this limitation a new factor $0.1\frac{B_{ms}}{B_{Mm}}$ was introduced in that condition so that the smaller is the mean blocking of the services relative to maximal mean of all services B_{Mm}, the lower is the blocking threshold above which the alternative route is eliminated. Our next modification consists of the substitution of the AND by the OR operator, which allows us to take more advantage of implied costs in the sense that it seems advisable to eliminate an alternative route when the corresponding implied cost is greater than the expected revenue per connection of the current traffic flow, independently of the condition on the blocking probability. This leads us to the following condition:

$$m^2(r_s) > -\log\left(1-0.1\frac{B_{Mm}}{B_{ms_d}}\right) \vee m^1(r_s) > d_s \tag{8}$$

We can state what we had already concluded from extensive simulation in both networks: that the original criterion (7) allows the highest blocking probabilities to be obtained for the less demanding services, and is slightly better for low load situations. On the contrary, condition (8) which implements fairness in the removal process of alternative paths for the different services, is the best suited for nominal and overload situations. In order to clearly evaluate the advantages of alternative routing and justify equation (8), we also present the results from a simulation with the direct routing scheme, where no alternative routes exist.

Another topic of importance is the estimation of the average traffic offered to the network by a given flow.In the simulator, the estimated offered traffic $\tilde{x}$ in the n^{th} time interval for traffic flow f_s is obtained from an estimate $\tilde{X}(n-1)$ of the offered traffic in the previous interval calculated from on-line measurements, for the same traffic flow, by using a first order moving average iteration: $\tilde{x}_{f_s}(n) = (1-b)\tilde{x}_{f_s}(n-1) + b\tilde{X}_{f_s}(n-1)$ (as suggested in [15]) with $b = 0.1$ (which is the value proposed in [18]) because while relying in traffic history still allows a slow adaptation in case of changes in the network, which is better suited for overload situations.

Another evaluated topic was the influence of the network load in path update intervals. In this respect, a comparison was made regarding a 10 seconds (a typical value in circuit-switching networks) and a 1 minute (previously used) update interval. A smaller route update interval achieves better results in underloaded situations as it allows traffic flows to be better accommodated with the frequent changes in path allocations, while a 1 minute interval has a better performance for overloaded situations because sudden changes in the offered traffic do not result in a “bad” set of paths in the following interval.

Regarding the possibility of a service dependent path update interval, different values were used depending on the service average duration at stake. None of the simulations with different service update intervals achieved good results, the 10 seconds choice (instead of the 1 minute in use in the original heuristic) being the one with the most appealing performance. This smaller update interval complements the reduced number of paths being updated in each time interval in the new heuristic, when compared with the original one.

In conclusion, the decisive factors in this approach are the load situation, the arrival rate and the alternative path selective elimination.

The comparative analysis between the original MODR and other reference dynamic routing methods is out of the scope of this work and can be consulted in [10]. A comparative study of different method variants for the test network presented in [10] is in figure 1. Note that the assumed ’nominal load’ considered in these experiments is 20% less than in [10]. The simulations results presented, obtained by the method of the independent replications, are the mid points of a 95% confidence interval. Regarding the two global network performance metrics we can conclude that the original heuristic behaves better than our simpler heuristic, if we consider the same alternative path elimination mechanism in both methods. However, if we make use of criteria (8) for the path elimination, we can obtain results that are comparable with the ones of the original heuristic, and even improved in terms of expected revenue in overload situations, achieving other non-dominated solutions in terms of global network performance. In fact, from extensive experimentation, it is possible to confirm an interesting conclusion: in a meshed network, in case of overloads, it is much more important to control the excess of alternative traffic than the alternative routing algorithm itself. Details related to service performance analysis are in [17].

Implied costs have already demonstrated to behave well in the proposed routing model. However, we decided to make a comparison with a different and much lighter metric in terms of computational effort, namely Howard costs.

In [19] a scheme is presented called Forward-Looking Routing (FLR) based on Howard costs. These costs, $\Delta(k, j)$, can be interpreted as the expected increase in the number of future blocked calls on a link l_k due to the acceptance of a call

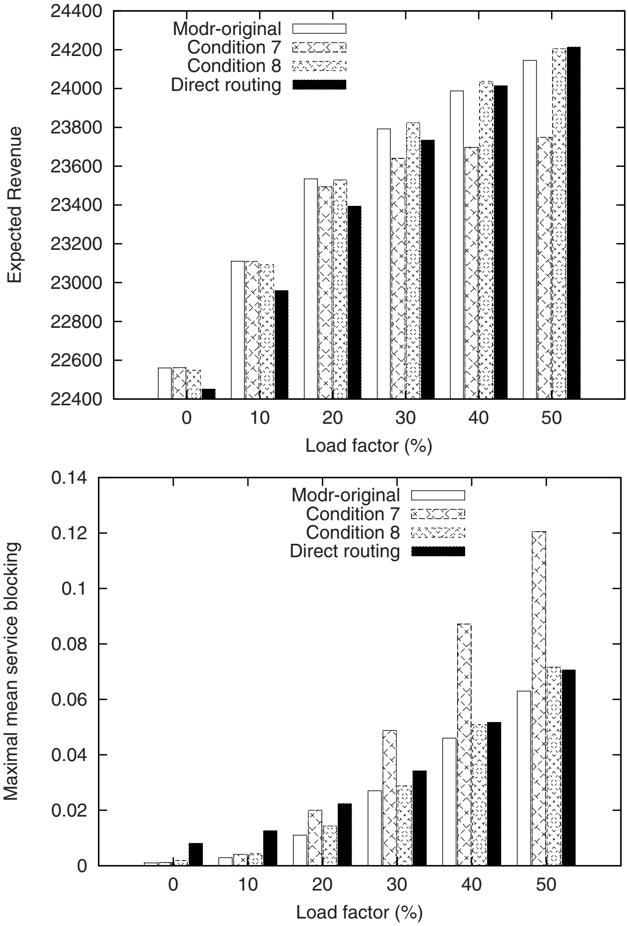

Fig. 1. Comparison with respect to the original version of MODR and direct routing – Global Performance (expected revenue and maximal mean service blocking)

when j calls are already in progress. Howard costs were adapted in a simplistic way to a multiservice environment as follows: $\Delta(k,j) = \frac{B_{ks}}{B_{k_j s}}$, $0 \leq j \leq C_k$, where $B_{k_j s} = \mathcal{L}_s\left(\overline{d_k}, \overline{\rho_k}, j\right)$ are the blocking probabilities calculated by the algorithms mentioned in the previous section.

Paths with the minimal Howard cost tend to contribute to the maximization of throughput and to an adequate load balancing, as routes with less calls in progress are the ones which tend to be chosen. As Howard costs are additive, the path cost is given by: $m^1(r_s) = \sum_{l_k \in r_s} \Delta(k_i, j_i)$. These costs replace the implied costs in the bi-objective shortest path sub-algorithm MMRA, in our revised simpler heuristic. The results for network global performance are presented in the report [17] and for this test network are very similar to those obtained with implied costs. However in other test networks Howard costs lead to worse results then implied costs using the same simplified heuristic. Therefore the introduction of Howard costs requires a careful pre-evaluation.

3 Conclusions and Further Work

Best-effort architecture does not meet the requirements of the current integrated services network Internet carrying heterogeneous data traffic. For this reason, high-speed wide area networks are likely to be connection-oriented for real-time traffic. Traffic engineering with Multiprotocol Label Switching (MPLS) is an attempt to take the best out of connection-oriented traffic engineering techniques.

The approach described in this paper attempted to implement alternative routing in IP/MPLS networks. This type of networks based on shortest-path routing have frequently localized congestion which may be smoothed by alternative routing. To achieve this, MODR formalized the routing problem as a multiobjective hierarchical routing problem in order to promote global fairness in terms of the QoS of the multiple services. Our starting point for solving this difficult problem was an 'heavy' heuristic which is here replaced by a new one, with slightly worse but similar results. Nevertheless this simplified heuristic is more suited to a realistic environment as it is a few hundred times lighter in terms of computational effort.

An interesting conclusion which confirms, in the context of MODR, the remarks in [16] is that in a meshed network, in case of overloads, it is more important to control the excess of alternative traffic than the alternative routing algorithm itself.

The work presented above is the starting point to a QoS future modelling approach to routing optimisation aiming to be applied to DiffServ-aware-MPLS meshed networks. Future work will also include MPLS Fast Reroute because MPLS was designed to meet the needs of real-time applications and, for that reason, rapid route restoration upon failure becomes crucial.

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