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Traffic model for Dynamic Multicriteria Alternative Routing for Single- and Multi-service Reservation-Oriented Networks

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Abstract

This report describes the traffic model for a dynamic multicriteria alternative routing method, herein designated by DMAR, that applies to multiservice reservation-oriented networks. DMAR is based on a biobjective shortest path algorithm and it uses the following two metrics: blocking probabilities and the implied costs. The concept of implied cost is extended in this work to multiservice networks with multiple alternative paths. The traffic model also applies to single service networks, which are a particular case of the multiservice network model.

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1 Introduction

1.1 Background and Motivation

Dynamic Alternative Routing (DAR) is a simple and efficient event-dependent dynamic routing scheme that has been proposed for several technologies capable of providing reservation-oriented services like circuit switching [3], MPLS [16, 1] and optical networks [10].

Classical dynamic alternative routing methods such as DAR typically present a single optimization criterion: the maximization of the carried traffic. However, the optimization of the carried traffic typically leads to a worse maximal point-to-point blocking probability value in a single service network, and it does not guarantee fairness among the various services in a multiservice network. The Multiple Objective Dynamic Routing method (MODR) is proposed in [9] and [8] for single and multiservice networks, respectively, as an attempt to solve this problem. The purpose of MODR is to periodically calculate the set of single alternative paths that constitute a compromise solution among the objective functions, taking into consideration the state of the network. The MODR problem is solved through a heuristic based on a biobjective shortest path algorithm and using the following two metrics: blocking probabilities and the implied costs [5, 9]. The implied costs have also been proposed in [15] for a hierarchical multicriteria routing model for MPLS networks with alternative routing and with two service classes and different types of traffic flows in each class (best effort and QoS). The hierarchical model is solved by a heuristic procedure designated as Hierarchical Multiobjective Routing considering two service classes ($HMOR-S2$) and two optimization levels. The more priority network level is the same as in MODR. The less priority service level objective functions include the maximization of the best effort expected revenue and the minimization of the performance metrics for the QoS traffic (the service mean blocking probability and the maximal point-to-point blocking probability). In [14] the same authors propose a new variant of the previous heuristic that makes use of a Pareto archive strategy. This heuristic is designated as Hierarchical MultiObjective Routing with two traffic classes and a Pareto Archive Strategy ($HMOR-S2_{PAS}$) and it caches all the non-dominated solutions that are discovered during the heuristic execution time. At the end, the set of archived solutions is evaluated and the final solution is chosen using a Chebyshev distance to a reference point.

Work in [7] also proposes the use of implied costs for multicast connections and, in [17], the implied costs are used in multirate wireless networks for quantifying mobility, traffic load, call pricing, network optimization and for evaluating trade-offs between calls of different rates.

This work describes the traffic model that applies to a dynamic multicriteria alternative routing scheme inspired by DAR and MODR, herein designated by DMAR. DMAR uses an event-dependent strategy like DAR where, as in MODR, the alternative paths are periodically calculated according to the state of the network using a bicriteria routing algorithm that uses the link metrics blocking probabilities and the implied costs. However, while MODR only allows a single alternative path for each pair of end nodes, DMAR allows multiple alternative paths to share the overflow traffic for each pair of nodes.

The analytical model in which DMAR relies on is based on fixed point iterators as in [8], herein extended to multiple alternative paths, to calculate the blocking probabilities and implied costs, according to given network topology, links capacity, offered traffic matrix and routing plan (assuming Poissonian arrivals, negative exponential call durations and independence in link occupations). The blocking probability on each link is calculated using a simplified model based on the Kaufman (or Roberts) algorithm [4, 13] for small values of the link capacity, and on the uniform asymptotic approximation (UAA) for large values of the link capacity (typically for values higher than 80) [11, 12]. A similar approach is proposed in [6] for multiservice networks with multiple alternative paths.

The implied cost associated with each link was firstly proposed for single service networks (with fixed and alternative routing with a single alternative path) in [5], and extended to multiservice networks (without alternative routing) in [12, 2]. The concept of implied cost was extended for multiservice networks with a single alternative path in [8]. In this work, we have adapted the implied cost to multiservice networks with multiple alternative paths.

2 DMAR Traffic Model

Consider a multiservice network where $S = \left\{S_1, S_2, \ldots, S_{|S|}\right\}$ is the services set, $N = \{1, 2, \ldots, |N|\}$ is the nodes set and the links set is given by $L = \{\ l_1, l_2, \ldots, l_{|L|} : l_k = (u, n) \wedge u, n \in N \wedge 1 \leq k \leq |L|\ \}$. The set of M_{ij}^s link disjoint paths between each pair of end nodes i and j for service s is designated by $\mathcal{P}_{ij}^s = \left\{p_{ij}^{1s}, p_{ij}^{2s}, \ldots, p_{ij}^{M_{ij}^s s} : 1 \leq M_{ij}^s \leq |N| - 1\right\}$, where the value of M_{ij}^s may differ for different services and pairs of end nodes.

DMAR is a time and state dependent routing scheme periodically choosing the set of paths for each pair of nodes that adapts the best to the offered traffic conditions. These paths $\mathcal{P}_{ij}^{zs} = \left\{p_{ij}^{1s}, p_{ij}^{2s}, \ldots, p_{ij}^{M_{ij}^{zs}} : 1 \leq M_{ij}^{zs} \leq M_{ij}^s\right\}$ are calculated in a given time instant $t' = z(T-1)$ and they may be used until a new path update occurs in $t'' = zT$, where T is the path update interval.

In the context of dynamic alternative routing in DMAR, between path update instants, routing is done in a similar way as in DAR: in each time instant $t \in \left]z(T-1), zT\right]$, a connection between i and j for service s may only attempt two paths; the fixed first choice path p_{ij}^{1s} is attempted first and, in case of blocking, an alternative path $p_{ij}^{ms} \in \mathcal{P}_{ij}^{zs}$ is tried. If this alternative path is also denied the connection is lost, and a new alternative path to be used by future requests is randomly chosen among the set of paths for this interval, $\mathcal{P}_{ij}^{zs}$. Subsequently, one may say that $\mathcal{P}_{ij}^{ts} = \left\{p_{ij}^{1s}, p_{ij}^{ms} : p_{ij}^{ms} \in \mathcal{P}_{ij}^{zs}\right\}$.

In a network implementing the DAR method an alternative path is maintained while successful and it is randomly replaced by another admissible path when blocked. This strategy ensures that there is fairness among the set of alternative paths for each pair of nodes between update instants because alternative paths with lower blocking probabilities are used more often. Assuming that p_{ij}^{1s} is the fixed first choice path between pairs i and j for service s, the ratio of overflow traffic that is offered to each path $r_{p_{ij}^{ms}}, m = 2, \ldots, M_{ij}^{zs}$ is given by:

$$r_{p_{ij}^{2s}} : r_{p_{ij}^{3s}} : \ldots : r_{p_{ij}^{M_{ij}^{zs}}} = \frac{1}{B_{p_{ij}^{2s}}} : \frac{1}{B_{p_{ij}^{3s}}} : \ldots : \frac{1}{B_{p_{ij}^{M_{ij}^{zs}}}}, \tag{1}$$

where $\sum_{m=2}^{M_{ij}^{zs}} r_{p_{ij}^{ms}} = 1$ and $B_{p_{ij}^{ms}}$ is the blocking probability that is experienced by a connection being routed from node i to node j by path p_{ij}^{ms} [3]. It is assumed in this work that all traffic flows are homogeneous Poissonian and independent, and that there is statistical independence in the blocking of the links; therefore, $B_{p_{ij}^{ms}}$ is obtained as follows:

$$B_{p_{ij}^{ms}} = 1 - \prod_{l_k \in p_{ij}^{ms}} (1 - B_k^s), \tag{2}$$

where $B_k^s = f(C_k, \overline{d_k}, \overline{a_k})$ is calculated according to the methods in [4, 13, 11]. The calculation of B_k^s implies the knowledge of C_k, the capacity on link l_k, $\overline{d_k}$, the required bandwidth on link l_k by a connection of each service s (for which the following simplification $d_k^s = d^s, \forall l_k \in L$ applies), and the determination of $\overline{a_k}$, the average load that is offered to link l_k by each service. The average load that is offered to link l_k by service s is calculated in the following manner:

$$a_k^s = \sum_{i,j \in N : l_k \in p_{ij}^{1s}} a_{ij}^s \prod_{l_u \in p_{ij}^{1s} - \{l_k\}} (1 - B_u^s) + \sum_{i,j \in N \wedge m \geq 2 : l_k \in p_{ij}^{ms}} r_{p_{ij}^{ms}} a_{ij}^s B_{p_{ij}^{1s}} \prod_{l_n \in p_{ij}^{ms} - \{l_k\}} (1 - B_n^s), \tag{3}$$

where a_{ij}^s is the offered load between nodes i and j by service s.

The calculation of B_k^s is obtained through a fixed point iterator. Assuming an initial fixed value for B_k^s and $r_{p_{ij}^{ms}}, m = 2, \ldots, M_{ij}^{zs}$: $B_k^{s\,(0)}$, $r_{p_{ij}^{ms}}{}^{(0)} = 1/\left(M_{ij}^{zs} - 1\right)$, B_k^s is obtained as follows:

$$\begin{aligned} a_k^{s\,(x+1)} = & \sum_{i,j \in N : l_k \in p_{ij}^{1s}} a_{ij}^{s\,(x)} \prod_{l_u \in p_{ij}^{1s} - \{l_k\}} \left(1 - B_u^{s\,(x)}\right) \\ & + \sum_{i,j \in N \wedge m \geq 2 : l_k \in p_{ij}^{ms}} r_{p_{ij}^{ms}}^{(x)} a_{ij}^{s\,(x)} B_{p_{ij}^{1s}}^{(x)} \prod_{l_n \in p_{ij}^{ms} - \{l_k\}} \left(1 - B_n^{s\,(x)}\right) \end{aligned} \tag{4}$$

$$B_k^{s\,(x+1)} = f(C_k, \overline{d_k}, \overline{a_k}^{(x+1)}) \tag{5}$$

$$r_{p_{ij}^{ms}}{}^{(x+1)} = \begin{cases} 1, & if M_{ij}^{zs} = 2 \\ \dfrac{\left[B_{p_{ij}^{ms}}^{(x+1)}\right]^{-1}}{\sum_{n=2}^{M_{ij}^{zs}} \left[B_{p_{ij}^{ns}}^{(x+1)}\right]^{-1}}, & if M_{ij}^{zs} > 2 \end{cases} \tag{6}$$

$$x = 0, 1, 2, \ldots \tag{7}$$

This method of successive approximations stops after a convergence criterion is met.

It is assumed in this work that the number of on-going connections on each link, the connection holding time and the connection arrival rate on each link, have well defined averages. With these averages, it is further assumed that there is a stationary probability of choosing a particular alternative path under the state dependent routing scheme (with $\sum_{m=2}^{M_{ij}^{zs}} r_{p_{ij}^{ms}} = 1$). Consequently, for each service s, the alternative paths in the feasible set of paths between pairs of nodes i and j are chosen independently of each other, and the average end-to-end blocking probability that is experienced by a connection being routed from node i to node j in time instant $t \in \left]z(T-1), zT\right]$ for service s can be calculated as:

$$B_{ij}^{ts} = B_{p_{ij}^{1s}} \sum_{m=2}^{M_{ij}^{zs}} r_{p_{ij}^{ms}} B_{p_{ij}^{ms}}, \text{ such that } p_{ij}^{ms} \in \mathcal{P}_{ij}^{zs}. \tag{8}$$

For the case of fixed routing ($M_{ij}^{zs} = 1$), the traffic that is carried in each path p_{ij}^{1s} is obtained as follows:

$$\lambda_{p_{ij}^{1s}} = a_{ij}^{s} \prod_{l_u \in p_{ij}^{1s}} (1 - B_u^s). \tag{9}$$

In this particular situation, the implied cost [5] associated with link l_k as a result of establishing a service u connection is given by [12, 2]:

$$c_k^u = \sum_{s=1}^{S} \eta_k^{us} \left(1 - B_k^s\right)^{-1} \left[\sum_{i,j \in N : l_k \in p_{ij}^{1s}} \lambda_{p_{ij}^{1s}} \left(w^s - \sum_{l_n \in p_{ij}^{1s} - \{l_k\}} c_n^s \right) \right] \tag{10}$$

where w^s is the expected revenue for an accepted service s connection and η_k^{us} is the increase in the blocking experienced by a service s connection due to the acceptance of a service u connection on link l_k ($\eta_k^{us} = f(C_k - d^u, \overline{d_k}, \overline{a_k}) - f(C_k, \overline{d_k}, \overline{a_k})$), where the calculation is done according to the methods in [4, 13, 11], as previously mentioned. The implied cost c_k^u is obtained through a fixed point iterator.

For the case of alternative routing with a single alternative path ($M_{ij}^{zs} = 2$), the traffic that is carried in the alternative path p_{ij}^{2s} is as follows:

$$\lambda_{p_{ij}^{2s}} = a_{ij}^{s} B_{p_{ij}^{1s}} \prod_{l_u \in p_{ij}^{2s}} (1 - B_u^s). \tag{11}$$

The expression 10 is thus updated considering the generalization of the original expression (equation 7.7 in [5]) for a single service:

$$c_k^u = \sum_{s=1}^{S} \eta_k^{us} (1 - B_k^s)^{-1} \Bigg[\sum_{i,j \in N : l_k \in p_{ij}^{1s}} \lambda_{p_{ij}^{1s}} \Bigg(w^s - \sum_{l_n \in p_{ij}^{1s} - \{l_k\}} c_n^s \Bigg) + \sum_{i,j \in N : l_k \in p_{ij}^{2s}} \lambda_{p_{ij}^{2s}} \Bigg(w^s - \sum_{l_n \in p_{ij}^{2s} - \{l_k\}} c_n^s \Bigg) - \sum_{i,j \in N : l_k \in p_{ij}^{1s}} \lambda_{p_{ij}^{1s}} \Big(1 - B_{p_{ij}^{2s}} \Big) \Bigg(w^s - \sum_{l_n \in p_{ij}^{2s}} c_n^s \Bigg) \Bigg] \tag{12}$$

which is equivalent to considering the following expressions [8]:

$$c_k^u = \sum_{s=1}^{S} \eta_k^{us} (1 - B_k^s)^{-1} \Bigg[\sum_{i,j \in N : l_k \in p_{ij}^{1s}} \lambda_{p_{ij}^{1s}} \Big(s_{p_{ij}^{1s}} + c_k^s \Big) + \sum_{i,j \in N : l_k \in p_{ij}^{2s}} \lambda_{p_{ij}^{2s}} \Big(s_{p_{ij}^{2s}} + c_k^s \Big) \Bigg] \tag{13}$$

$$s_{p_{ij}^{2s}} = w^s - \sum_{l_n \in p_{ij}^{2s}} c_n^s \tag{14}$$

$$s_{p_{ij}^{1s}} = w^s - \sum_{l_n \in p_{ij}^{1s}} c_n^s - \Big(1 - B_{p_{ij}^{2s}} \Big) s_{p_{ij}^{2s}} \tag{15}$$

where $s_{p_{ij}^{2s}}$ is the surplus value of a connection on path p_{ij}^{2s}.

In a network implementing DMAR, in each time instant, only two possible paths can be used between each pair of nodes but, in a given time interval $\big]z(T-1), zT\big]$, any alternative path $p_{ij}^{ms} \in \mathcal{P}_{ij}^{zs}, m = 2, \ldots, M_{ij}^{zs}$ can be used with probability $r_{p_{ij}^{ms}}$ (subject to $\sum_{m=2}^{M_{ij}^{zs}} r_{p_{ij}^{ms}} = 1$) to route overflow traffic between end nodes i and j. In this situation, and assuming that the paths for each pair of end nodes are link disjoint, the carried traffic in each alternative path is obtained by:

$$\lambda_{p_{ij}^{ms}} = r_{p_{ij}^{ms}} a_{ij}^s B_{p_{ij}^{1s}} \prod_{l_u \in p_{ij}^{ms}} (1 - B_u^s), \ m = 2, \ldots, M_{ij}^{zs}. \tag{16}$$

To calculate c_k^u in the scope of DMAR, the expression 12 is updated as proposed:

$$c_k^u = \sum_{s=1}^{S} \eta_k^{us} (1 - B_k^s)^{-1} \Bigg[\sum_{i,j \in N : l_k \in p_{ij}^{1s}} \lambda_{p_{ij}^{1s}} \Bigg(w^s - \sum_{l_n \in p_{ij}^{1s} - \{l_k\}} c_n^s \Bigg) + \sum_{i,j \in N \wedge m \geq 2 : l_k \in p_{ij}^{ms}} \lambda_{p_{ij}^{ms}} \Bigg(w^s - \sum_{l_n \in p_{ij}^{ms} - \{l_k\}} c_n^s \Bigg) - \sum_{i,j \in N : l_k \in p_{ij}^{1s}} \lambda_{p_{ij}^{1s}} \sum_{m=2}^{M_{ij}^{zs}} r_{p_{ij}^{ms}} \Big(1 - B_{p_{ij}^{ms}} \Big) \Bigg(w^s - \sum_{l_n \in p_{ij}^{ms}} c_n^s \Bigg) \Bigg] \tag{17}$$

which is equivalent to considering the following expression:

$$c_k^u = \sum_{s=1}^{S} \eta_k^{us} (1 - B_k^s)^{-1} \Bigg[\sum_{i,j \in N : l_k \in p_{ij}^{1s}} \lambda_{p_{ij}^{1s}} \Big(s_{p_{ij}^{1s}} + c_k^s \Big) + \sum_{i,j \in N \wedge m \geq 2 : l_k \in p_{ij}^{ms}} \lambda_{p_{ij}^{ms}} \Big(s_{p_{ij}^{ms}} + c_k^s \Big) \Bigg] \tag{18}$$

$$s_{p_{ij}^{ms}} = w^s - \sum_{l_n \in p_{ij}^{ms}} c_n^s, \quad m = 2, \ldots, M_{ij}^{zs} \tag{19}$$

$$s_{p_{ij}^{1s}} = w^s - \sum_{l_n \in p_{ij}^{1s}} c_n^s - \sum_{m=2}^{M_{ij}^{zs}} r_{p_{ij}^{ms}} \left(1 - B_{p_{ij}^{ms}}\right) s_{p_{ij}^{ms}}. \tag{20}$$

The $\sum_{m=2}^{M_{ij}^{zs}} r_{p_{ij}^{ms}} \left(1 - B_{p_{ij}^{ms}}\right) s_{p_{ij}^{ms}}$ portion in the $s_{p_{ij}^{1s}}$ expression represents what is lost, in average, in path p_{ij}^{1s} due to the fact that connections that are blocked in path p_{ij}^{1s} can be routed by an alternative path $p_{ij}^{ms} \in \mathcal{P}_{ij}^{zs}, m = 2, \ldots, M_{ij}^{zs}$, if the latter is not blocked.

3 Conclusions

In this work, we propose the traffic model that applies to a dynamic multicriteria alternative routing method for reservation-oriented networks, herein designated by DMAR. The concept of implied cost is also extended to multiservice networks with multiple alternative paths. Ongoing work includes the proposal of DMAR along with its performance assessment.

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