Catarina Francisco, Lúcia Martins, Deep Medhi

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Catarina Francisco\textsuperscript{1,2}, Lúcia Martins\textsuperscript{1,3,*}, Deep Medhi\textsuperscript{4}

\textsuperscript{1} Departamento de Engenharia Electrotécnica e de Computadores, Universidade de Coimbra

Morada: Pinhal de Marrocos, 3030-290 Coimbra, Portugal

\textsuperscript{2} Nokia Solutions and Networks Portugal S.A.

Morada: Estrada do Seminário 4, Edifício Conhecimento, 2610-171 Amadora, Portugal

\textsuperscript{3} INESC-Coimbra

Morada: Rua Sílvio Lima, Pólo II, DEEC, 3030-790 Coimbra, Portugal

\textsuperscript{4} Computer Science & Electrical Engineering Department, School of Computing and Engineering

Morada: University of Missouri–Kansas City, Kansas City, MO 64110-2499 USA

Email: catarina.francisco@nokia.com,lucia@deec.uc.pt,dmedhi@umkc.edu

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 − S2PAS) 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 $S = \{S_1, S_2, \ldots, S_{|S|}\}$ is the services set, $N = \{1, 2, \ldots, |N|\}$ is the nodes set and the links set is given by $L = \{l_1, l_2, \ldots, l_{|L|} : l_k = (u, n) \land u, n \in N \land 1 \leq k \leq |L|\}$. The set of $M_{ij}^s$ link disjoint paths between each pair of end nodes $i$ and $j$ for service $s$ is designated by $P_{ij}^s = \{p_{1s}^{ij}, p_{2s}^{ij}, \ldots, p_{M_{ij}^s}^{M_{ij}^s} : 1 \leq M_{ij}^s \leq |N| - 1\}$, 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 $P_{ij}^{z}\{s = \}\{p_{1s}^{ij}, p_{2s}^{ij}, \ldots, p_{M_{ij}^{z}\{s = \}}^{M_{ij}^{z}\{s = \}} : 1 \leq M_{ij}^{z}\{s = \} \leq |N| - 1\}$ 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 $t \in \{z(T - 1), zT\}$, 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 $p_{ij}^{m\{s = \}} \in P_{ij}^{z\{s = \}}$ 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, $P_{ij}^{z\{s = \}}$. Subsequently, one may say that $P_{ij}^{z\{s = \}} = \{p_{ij}^{1s}, p_{ij}^{m\{s = \}}, p_{ij}^{m\{s = \}} \in P_{ij}^{z\{s = \}}\}$.
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 $p_{ij}^{ms}$ 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:

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

(1)

where $\sum_{m=2}^{M_{ij}^{zs}} p_{ij}^{ms} = 1$ 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:

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

(2)

where $B_k^s = f(C_k, \overline{d_k}, \overline{\pi_k})$ 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 $d_k = d^s$; $\forall l_k \in L$ applies), and the determination of $\overline{\pi_k}$, 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:

$$
a_k^s = \sum_{i,j \in N \setminus l_k \in p_{ij}^{ms}, \overline{\pi_k} \leq 1} a_{ij}^s \prod_{l_k \in p_{ij}^{ms} \setminus \{l_k\}} (1 - B_u^s) + \sum_{i,j \in N \setminus l_k \in p_{ij}^{ms}, \overline{\pi_k} > 1} r_{p_{ij}^{ms}} a_{ij}^s B_{p_{ij}^{ms}} \prod_{l_k \in p_{ij}^{ms} \setminus \{l_k\}} (1 - B_u^s),
$$

(3)

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

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

$$
a_k^{(x+1)} = \sum_{i,j \in N \setminus l_k \in p_{ij}^{ms}, \overline{\pi_k} \leq 1} a_{ij}^{(x)} \prod_{l_k \in p_{ij}^{ms} \setminus \{l_k\}} \left(1 - B_u^{(x)}\right)
+ \sum_{i,j \in N \setminus l_k \in p_{ij}^{ms}, \overline{\pi_k} > 1} r_{p_{ij}^{ms}}^{(x)} a_{ij}^{(x)} B_{p_{ij}^{ms}}^{(x)} \prod_{l_k \in p_{ij}^{ms} \setminus \{l_k\}} \left(1 - B_u^{(x)}\right),
$$

(4)

$$
B_k^{(x+1)} = f(C_k, \overline{d_k}, \overline{\pi_k}^{(x+1)})
$$

(5)

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

(6)
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 \( \sum_{m=2}^{M_{i,j}^{s}} r_{m}^{*} = 1 \)). 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 \( t \in [z(T - 1), zT] \) for service \( s \) can be calculated as:

\[
B_{i,j}^{s} = B_{p_{i,j}^{1}}^{s} \sum_{m=2}^{M_{i,j}^{s}} r_{m}^{*} B_{p_{i,j}^{m}}^{s}, \text{ such that } p_{i,j}^{s} \in \mathcal{P}_{i,j}^{s}. \tag{8}
\]

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

\[
\lambda_{p_{i,j}^{1}} = a_{i,j}^{1} \prod_{l_{u} \in p_{i,j}^{1}} (1 - B_{u}^{*}). \tag{9}
\]

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 \([12, 2]\):

\[
c_{k}^{u} = \sum_{s=1}^{S} \eta_{k}^{u,s} (1 - B_{k}^{s})^{-1} \left[ \sum_{l_{u} \in N \setminus l_{k} \in p_{i,j}^{1} \setminus \{l_{k}\}} \lambda_{p_{i,j}^{1}}^{s} \left( w^{s} - \sum_{l_{u} \in p_{i,j}^{1} \setminus \{l_{k}\}} c_{n}^{u} \right) \right] \tag{10}
\]

where \( w^{s} \) is the expected revenue for an accepted service \( s \) connection and \( \eta_{k}^{u,s} \) is the increase in the blocking experienced by a service \( s \) connection due to the acceptance of a service \( u \) connection on link \( l_{k} \) \( (\eta_{k}^{u,s} = f(C_{k} - d^{u}, \overline{d_{k}}, \overline{w_{k}}) - f(C_{k}, \overline{d_{k}}, \overline{w_{k}})) \), 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 (\( M_{i,j}^{s} = 2 \)), the traffic that is carried in the alternative path \( p_{i,j}^{2} \) is as follows:

\[
\lambda_{p_{i,j}^{2}} = a_{i,j}^{2} B_{p_{i,j}^{1}}^{s} \prod_{l_{u} \in p_{i,j}^{2}} (1 - B_{u}^{*}). \tag{11}
\]

The expression 10 is thus updated considering the generalization of the original expression (equation 7.7 in \([5]\)) for a single service:
between each pair of nodes but, in a given time interval
where

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

\[
c_k^u = \sum_{s=1}^{S} \eta_k^{u,s} (1 - B_k^s)^{-1} \left[ \sum_{i,j \in \mathcal{N} \setminus \mathcal{L}_k} \lambda_{p_{ij}^s} \left( w^s - \sum_{l_n \in \mathcal{P}_{ij}^s \setminus \{l_k\}} c_n \right) \right]
\]

\[
+ \sum_{i,j \in \mathcal{N} \setminus \mathcal{L}_k} \lambda_{p_{ij}^s} \left( w^s - \sum_{l_n \in \mathcal{P}_{ij}^s \setminus \{l_k\}} c_n \right) - \sum_{i,j \in \mathcal{N} \setminus \mathcal{L}_k} \lambda_{p_{ij}^s} (1 - B_{p_{ij}^s}) \left( w^s - \sum_{l_n \in \mathcal{P}_{ij}^s} c_n \right) \right] \tag{12}
\]

\[
\eta \sum_{s=1}^{S} \sum_{i,j} \lambda_{p_{ij}^s} \left( s_{p_{ij}^s} + c_k \right) + \sum_{i,j \in \mathcal{N} \setminus \mathcal{L}_k} \lambda_{p_{ij}^s} \left( s_{p_{ij}^s} + c_k \right) \tag{13}
\]

\[
s_{p_{ij}^s} = w^s - \sum_{l_n \in \mathcal{P}_{ij}^s} c_n \tag{14}
\]

\[
s_{p_{ij}^s} = w^s - \sum_{l_n \in \mathcal{P}_{ij}^s} c_n - (1 - B_{p_{ij}^s}) s_{p_{ij}^s} \tag{15}
\]

where \( s_{p_{ij}^s} \) is the surplus value of a connection on path \( p_{ij}^s \).

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 \([z(T - 1), zT]\), any alternative path \( p_{ij}^m \in \mathcal{P}_{ij}^m \), \( m = 2, \ldots, M_{ij}^z \) can be used with probability \( r_{p_{ij}^m}^z \) (subject to \( \sum_{m=2}^{M_{ij}^z} r_{p_{ij}^m}^z = 1 \)) 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:

\[
\lambda_{p_{ij}^m} = r_{p_{ij}^m}^z a_{ij}^m B_{p_{ij}^m} \prod_{l_n \in \mathcal{P}_{ij}^m} (1 - B_{p_{ij}^m}), \quad m = 2, \ldots, M_{ij}^z \tag{16}
\]

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

\[
c_k^u = \sum_{s=1}^{S} \eta_k^{u,s} (1 - B_k^s)^{-1} \left[ \sum_{i,j \in \mathcal{N} \setminus \mathcal{L}_k} \lambda_{p_{ij}^s} \left( w^s - \sum_{l_n \in \mathcal{P}_{ij}^s \setminus \{l_k\}} c_n \right) \right]
\]

\[
+ \sum_{i,j \in \mathcal{N} \setminus \mathcal{L}_k} \lambda_{p_{ij}^s} \left( w^s - \sum_{l_n \in \mathcal{P}_{ij}^s \setminus \{l_k\}} c_n \right) - \sum_{i,j \in \mathcal{N} \setminus \mathcal{L}_k} \lambda_{p_{ij}^s} (1 - B_{p_{ij}^s}) \left( w^s - \sum_{l_n \in \mathcal{P}_{ij}^s} c_n \right) \right] \tag{17}
\]

\[
\eta \sum_{s=1}^{S} \sum_{i,j} \lambda_{p_{ij}^s} \left( s_{p_{ij}^s} + c_k \right) + \sum_{i,j \in \mathcal{N} \setminus \mathcal{L}_k} \lambda_{p_{ij}^s} \left( s_{p_{ij}^s} + c_k \right) \tag{18}
\]
\[ s_{p^{ms}_{ij}} = w^s - \sum_{l_n \in P^{ms}_{ij}} c^s_n, \quad m = 2, \ldots, M^{zs}_{ij} \]  

\[ s_{p^{1s}_{ij}} = w^s - \sum_{l_n \in P^{1s}_{ij}} c^s_n - \sum_{m=2}^{M^{zs}_{ij}} r_{p^{ms}_{ij}} \left(1 - B_{p^{ms}_{ij}} \right) s_{p^{ms}_{ij}}. \]  

The \( \sum_{m=2}^{M^{zs}_{ij}} r_{p^{ms}_{ij}} \left(1 - B_{p^{ms}_{ij}} \right) s_{p^{ms}_{ij}} \) portion in the \( s_{p^{1s}_{ij}} \) expression represents what is lost, in average, in path \( p^{1s}_{ij} \) due to the fact that connections that are blocked in path \( p^{1s}_{ij} \) can be routed by an alternative path \( p^{ms}_{ij} \in D^{zs}_{ij}, m = 2, \ldots, M^{zs}_{ij} \), 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.

### References


