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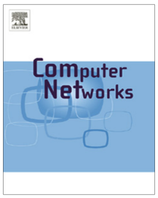

MeTHODICAL: Towards the next generation of multihomed applications

Bruno Sousa [b,*], Kostas Pentikousis [a], Marilia Curado [b]

[a] *European Center for Information and Communication Technologies, EUREF Campus Haus 13, Targauer Straße 12-15, 10829 Berlin, Germany*
[b] *Center for Informatics and System University of Coimbra (CISUC), Polo II Pinhal de Marrocos, 3030-290 Coimbra, Portugal*

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ABSTRACT

We introduce MeTHODICAL, a multihoming-aware decision-making mechanism which enables applications to capitalize on multihoming availability. MeTHODICAL employs an algorithm that establishes the foundation for assigning weights to multiple criteria, and a path optimization algorithm that performs path selection restricted by multiple multihoming and traffic performance criteria, a well-known NP-hard problem. The feasibility of the MeTHODICAL weighting criteria algorithm is demonstrated in this paper for different classes of service as specified in ITU-Y.1541. The algorithm is shown to have a time complexity of $O(mc^{n\nu})$. The path optimization algorithm, with a time complexity of $O(n \cdot m)$, is evaluated for the 1:1 and 1 + 1 protection models and is compared with previous proposals in this area. Results from our testbed evaluation demonstrate that the MeTHODICAL path optimization algorithm does not suffer from ranking abnormalities, nor does it require high-volume data to be efficient. The results show that heuristics can enhance the performance of MeTHODICAL and eliminate handover side-effects.

1. Introduction

Multihoming and multiaccess in IP networks have been lately fostered by the exponential growth in availability of devices with multiple built-in communication technologies. Paradigms where hosts have access to various networks have been in the research agenda for over a decade. Multihoming has long been adopted to increase resilience, dependability, and performance in high-end servers. At the other end of the network node spectrum, mobile phone manufacturers have been integrating different cellular radio access technologies into multi-band cell phones to realize global reachability and ease migration. Efficient multihoming and multiaccess support in heterogeneous networks are still difficult to achieve due to the current use of path selection mechanisms that are based on presets and static policies [1].

Optimized path selection mechanisms need to consider multiple criteria, such as availability, capacity, monetary cost, packet loss, delay, and IP delay variation, so that overall performance is improved. Indeed, profit is assured if benefits are maximized and costs are minimized. Within this context, path selection becomes a NP-hard problem [2,3]. Efficient multihoming and multiaccess support can be provided by optimization techniques that enable solutions with low computation complexity that foster deployment. For instance, Linear and Integer Programming [4] techniques provide optimal solutions, but increase complexity in terms of deployment. On the other hand, MADM techniques [5] are a natural choice, as they allow subjective and qualitative criteria to be incorporated in weighting and path selection algorithms.

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[*] Corresponding author. Tel.: +351 239 790000; fax: +351 239 701266.
E-mail addresses: bmsousa@dei.uc.pt (B. Sousa), k.pentikousis@eict.de (K. Pentikousis), marilia@dei.uc.pt (M. Curado).

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When coping with multiple criteria in path selection, the importance of each criterion is a fundamental aspect. As, from a user perspective, the best path can be the one that provides higher capacity, and has low monetary costs and small packet loss ratios. Criteria preference is often associated with subjectivity [6]. For instance, to achieve the same goal (e.g., improve resilience), users can associate more importance to the *availability* criterion than to the *recovery* criterion of resilience. Fuzzy logic mitigates subjectivity, but by itself, it is not enough to support consistent judgments (i.e., no guarantee on the preference of one criterion over others) as discussed in [7]. Optimization techniques, such as DiA [8] and NMMD [9] do not consider objective weights determination in their formulation. A criteria-weighting algorithm is introduced in MeTHODICAL to establish consistent weights for path optimization problems. We consider different type of applications, included in the ITU Y-1541 [10] specification to demonstrate the capabilities of the criteria weighting algorithm. For each application weights are determined in a consistent way.

The criteria that is employed by optimization techniques, is often restricted to traffic performance or to a small multihoming subset (i.e., energy, coverage) that does not characterize efficiently multihoming [11,12]. That is, next generation multihomed applications need to consider a complete criteria set regarding traffic performance and multihoming [1]. In this context, MeTHODICAL has been designed to meet the following goals: First, to determine optimal paths by considering multihoming and Traffic Performance (TP) criteria, as well as the tradeoff between benefits and costs. Second, to support different heuristics that can provide finer control on optimal path selection. For instance, we can choose simultaneous paths if a *1 + 1* protection model is required, or simply choose a backup path for primary path failures (1:1 protection model) [11]. Finally, to enable easy deployment, without being constrained to any particular technology or application.

To the best of our knowledge, MeTHODICAL is the first mechanism to be multihoming-aware with a complete specification for optimization, including criteria weighting and path optimization under different protection models. In the path selection problem, multihoming goals are considered, namely, resilience and ubiquity. Moreover, criteria impacting application performance, such as packet loss and one way delay, are also considered. The first contribution of MeTHODICAL is a weighting algorithm that determines weights objectively and in a consistent manner. Furthermore, the weighting algorithm is defined in a flexible form that can be employed by optimization techniques considering any number of weights. The second major contribution of MeTHODICAL is the enhanced path selection algorithm. MeTHODICAL formulates optimal paths by considering the type of criteria, benefits or costs, by establishing relevant ranges, on which values of criteria maximize profit, and by introducing a stabilization factor that does not have ranking abnormalities. In addition, optimal paths are determined by considering the path usage model. The primary-backup model (or 1:1) chooses a path to act as backup of a path marked as primary. The backup path is only chosen when the primary fails. The concurrent model (or 1 + 1) allows using paths simultaneously to increase throughput [11]. The choice of the protection model is performed, before applications start. Commonly, techniques addressing the path selection problem only consider the primary-backup model, while this proposal supports both models.

Evaluation results including MeTHODICAL and related approaches demonstrate that the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is inconsistent, and that NMMD is not efficient when there is a low-number of path alternatives. Moreover, the results show that TOPSIS, DiA and NMMD are not able to select optimal paths accurately. MeTHODICAL and respective heuristics are able to select paths in all cases, including those with low or moderate number of path alternatives.

The remainder of this paper is organized as follows: Section 2 overviews related work and Section 3 defines MeTHODICAL. Section 4 details the evaluation to assess MeTHODICAL accuracy. The achieved results are discussed in Section 5, and the paper is concluded in Section 6.

2. Related work

We overview related work in two main areas: First, path optimization techniques, specifically MADM techniques for optimal path selection. Then, we consider approaches on criteria weighting algorithms.

2.1. Optimization techniques for optimal path selection

Optimal path determination is not trivial when multiple criteria are considered, such as availability, monetary cost, packet loss, delay, IP delay variation, just to name a few. Indeed, path selection is a NP-hard problem [2,3], which can be solved by employing optimization techniques like Linear and Integer Programming [4], MADM [5], Multi-Armed Bandits approaches [13], polynomial time approximation schemes [3] or multi objective programming techniques [14].

Linear and Integer Programming provide optimal solutions as they are tailored for complex problems but are difficult to use in practice. Multi-Armed Bandits approaches have deployment issues, as both problem formulation and corresponding policies have some limitations when exploring different combinations. The polynomial time approximation schemes are mainly tailored for delay-constrained least cost problems, where the minimum cost is subject to a given delay constraint. Multi-objective programming techniques share the same issues as linear programming approaches, as they express the objectives in functions where criteria are correlated. Moreover, these approaches require considerable modifications for each optimization problem, even if the difference between problems is only the addition of a new criterion.

We restrict the universe of path optimization approaches with multiple criteria, which is an NP-Hard problem, to MADM techniques, due to their capacity in incorporating multiple criteria, which can be combined with weighting algorithms [15]. For instance, techniques like TOPSIS [16], DiA [8] and NMMD [9] employ simple mathematical operations to establish the preferences of alternatives, by providing ranking of alternatives. TOPSIS,