Multihoming Aware Optimization Mechanism

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***Abstract*—Network management includes several operations that aim to maximize Fault, Configuration, Account, Performance and Security (FCAPS) goals. Performance improvement often relies on multiple criteria, leading to *NP*-Hard optimisation problems. Very often, optimization mechanisms are narrowed to a specific scenario or present deployment issues due to their associated complexity. Others, despite reducing complexity, have accuracy issues that lead to the selection of non-optimal solutions.**

MeTHODICAL is an accurate optimisation technique for path selection in multihoming scenarios that enhances network management FCAPS goals by being flexible enough to operate on distinct scenarios, supporting different applications and services and with reduced deployment complexity.

Keywords: Multihoming, FCAPS, optimization, resilience

I. INTRODUCTION

Network management includes several operations that aim to maximize FCAPS goals. The fault goal is related with mechanisms providing resilience support. The Resilience Evaluation Framework (REF) [1] is a contribution of the author assessing to what extent the fault-tolerance mechanisms supportted by a network protocol are efficient. One of the common approaches to increase resilience support is to employ multiple connections to explore different protection models (e.g., primary-backup or concurrent), as identified by the author in [2,3] and evaluated in [4,5].

Ubiquity support is another goal that is related to resilience, namely to increase levels of availability (e.g., 99.99%) and, at the same time, pursue the anywhere, anytime and anyplace connection paradigm. In this context, features such as accounting support and easy configuration are enablers of a better ubiquity support, as presented in the Ubiquity Evaluation Framework (UEF) [6,7], which allows assessing how efficient a network protocol can be regarding the ubiquity support.

Performance improvement is a goal that is pursued not only by network management, but by other areas, such as multihoming optimisation [8,9]. When such optimisation relies on multiple criteria *NP-Hard* problems arise [10,11]. Distinct optimisation techniques exist, such as Linear Programming (LP) [12] and outranking Multiple Attribute Decision Mechanism (MADM) techniques [13]. Nonetheless, they have deployment and complexity issues associated or have optimisation accuracy issues [14,15]. MeTHODICAL is an accurate optimisation technique that enhances network management goals by being flexible enough to operate on distinct scenarios, supporting different applications and services.

This paper is organized as follows: Section II introduces the motivation for MeTHODICAL, while Section III specifies the MeTHODICAL optimization proposal; Section IV specifies the evaluation methodology in distinct scenarios; Section V discusses the achieved results; Section VI concludes the paper.

II. PROBLEM STATEMENT

Network Management includes diverse operations to assure FCAPS support. The availability of multiple heterogeneous networks within different characteristics poses choices alternatives for network services or applications aiming to maximize their performance or the security levels. In these cases the selection of one or more as optimal needs to consider the multiple criteria that characterise the specificities of each network. The *NP-Hard* problem [10,11] can be solved using different optimisation techniques, which are commonly complex in terms of deployment or are tied to the scenario being optimised [16].

Outranking MADM techniques [13] are considered techniques flexible enough to accommodate quantitative and qualitative data, as the case of Analytic Hierarchy Process (AHP), having employments in distinct areas [17] due to the low complexity. Moreover, MADM are able to accommodate several criteria no matter the research problem associated [18,19]. In particular, the outranking MADM techniques formulate optimization by scoring the multiple alternatives. Indeed, the simplicity of such methods lead to a plethora of MADM techniques, ranging from techniques that apply simple functions to more complex techniques that formulate the distance to ideal alternatives, such as the Technique for Order Preference by Similarly to Ideal Solution (TOPSIS) and the Distance to Ideal Alternative (DiA) [14].

Optimization techniques dealing with *NP-Hard* problems cannot impose deployment concerns or introduce more complexity on networks that are getting each day more complex to accommodate new services. Other techniques like MADM do not require any adaptation between different scenarios but have optimization accuracy issues, where non optimal solutions may be chosen, leading to an inefficient performance improvement.

Considering the *NP-Hard* problem, optimisation techniques cannot be restricted to specific scenarios and, at the same, time they must provide accurate optimal solutions. MeTHODICAL addresses such optimisation issues in a multihoming context, where applications/services can connect to multiple heterogeneous networks, to increase resilience (fault support)

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to enable load sharing within the multiple networks to improve throughput (performance) always considering security aspects.

III. METHODICAL

MeTHODICAL is detailed in the PhD thesis [9] and on the journal paper [8]. MeTHODICAL is an efficient and flexible optimization algorithm for multihoming that considers two main type of criteria: Benefits – corresponding to all criteria that must be maximized and Costs – representing all the criteria that must be minimized. On a second step MeTHODICAL models the network and respective services/applications as a graph, which considers a source node with multiple applications or services that can use different available paths, which are attached to a particular network technology, as depicted in Fig. 1. These multiple interfaces allow the connection to the destination node. This model is inline with a modern multihoming practice and represents a significant departure from the one-to-one address-interface mapping which up to now has been prevalent in the literature. The MeTHODICAL network model also highlights the different path usage models. For instance, an application can use paths from distinct interfaces to implement the concurrent model to increase throughput (performance FCAPS), enhance the resilience levels (fault of FCAPS), as described in REF [1], or even to pursue ubiquitous connectivity, as detailed in UEF [6,7].

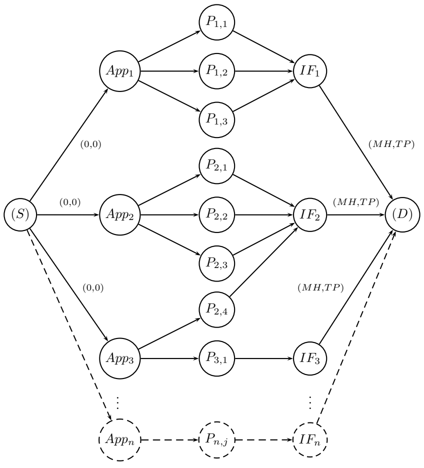

Fig. 1: MeTHODICAL Network Model, where (S) is source and (D) is the destination node. Source node models network according to Applications (App) and the available Paths ($P_{n,j}$). Paths are associated with interfaces (IF).

Algorithm 1 - MeTHODICAL path optimization

```
Require: $\alpha \in ]0,1]$ #Distance distinction factor
Require: $\sum_j^{\kappa} \mathbf{b}_j = 1$ #Benefits vector
Require: $\sum_j^{\beta} \mathbf{k}_j = 1$ #Costs vector
Require: $\sum_i^m \sum_j^{\beta} \mathbf{B}_{i,j} \geq 0$ #Benefits matrix
Require: $\sum_i^m \sum_j^{\kappa} \mathbf{K}_{i,j} \geq 0$ #Costs matrix
Require: $\mathbf{s}_{i,(t-1)} = 0$ #Initialize Score vector for $(t)ime - 1$
$\overline{\mathbf{N}_{ij}} = \frac{\mathbf{M}_{i,j}}{\sum_j^m \mathbf{M}_j}, i = 1, \cdots, n$ #Normalization
$\widehat{\mathbf{G}}_{i,j} = \mathbf{n}_j \times \overline{\mathbf{N}_{ij}}$ with $i = 1, 2, \cdots, n$ and $j = 1, 2, \cdots, m$
$I(\widehat{\mathbf{B}}_j) = max\{\widehat{\mathbf{B}}_{i,j} | i = 1, 2, \cdots, n$ and $j = 1, 2, \cdots, m\}$
$I(\widehat{\mathbf{K}}_j) = min\{\widehat{\mathbf{K}}_{i,j} | i = 1, 2, \cdots, n$ and $j = 1, 2, \cdots, m\}$
$\Delta(\widehat{\mathbf{B}}_i) = \sum_{j=1}^{\beta} \left[ \frac{[I(\widehat{\mathbf{B}}_j) - \widehat{\mathbf{B}}_{i,j}]^2}{[I(\widehat{\mathbf{B}}_j) - A(\widehat{\mathbf{B}}_j)] + \lambda} \right] A(\widehat{\mathbf{B}}_j) = m(\widehat{\mathbf{B}}_j) + v(\widehat{\mathbf{B}}_j)$
$\Delta(\widehat{\mathbf{K}}_i) = \sum_{j=1}^{\kappa} \left[ \frac{[I(\widehat{\mathbf{K}}_j) - \widehat{\mathbf{K}}_{i,j}]^2}{[I(\widehat{\mathbf{K}}_j) - A(\widehat{\mathbf{K}}_j)] + \lambda} \right] A(\widehat{\mathbf{K}}_j) = m(\widehat{\mathbf{K}}_j) - v(\widehat{\mathbf{K}}_j)$
$\mathbf{s}_i = \sqrt{\alpha \times \Delta(\widehat{\mathbf{B}}_i) + (1-\alpha) \times \Delta(\widehat{\mathbf{K}}_i)},\ i = 1, 2, \cdots, n$
$\mathbf{s}_{i,t} = \mathbf{s}_i + v\big(\mathbf{s}_i, \mathbf{s}_{i,(t-z)}\big),\ i = 1, \cdots, n$ #Set current score
$\mathbf{r}_i = order\big(\mathbf{s}_{i,t}\big)$ #Vector in crescent order
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The optimisation process in MeTHODICAL is performed after modelling the network and respective services/applications. Indeed, MeTHODICAL determines optimal paths, through a ranking score $\mathbf{s}_{i,t}$, as demonstrated in Algo. 1. The values of the different criteria for each path of the network model combine B-benefits and K-costs into $\mathbf{B}_{n,B}$ benefits and $\mathbf{K}_{n,K}$ costs matrices. To find optimal solutions, MeTHODICAL, as a MADM technique, formulates the distance of each alternative/path to an ideal path (the one that maximizes benefits and at the same time minimizes costs). Commonly, distance in MADM techniques is interpreted as the length of space between two points. In this regard, distinct forms of determining distance [20] exist. The Euclidean distance, used by TOPSIS, defines a line segment between two points. The Manhattan distance or city-block, used by DiA, defines the distance that would be travelled to get from one point to another if a grid-like path is followed. Nonetheless, both distance methods only apply to gaussian data and do not consider the path selection problem. Indeed, the traditional interpretation of distance as the length of space is not adequate for problems with multiple criteria, as they introduce high error rates [15]. The Mahalanobis distance overcomes these limitations and uses the covariance to correlate data, which can be gaussian or non-gaussian. Nonetheless, the use of covariance introduces overhead due to its computational complexity, and has only a statistical meaning when high-volume data is available (i.e., at least, three paths).

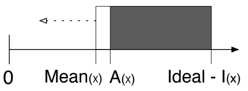

Fig. 2: Range of Relevant Benefits

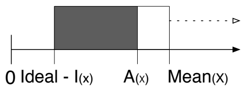

Fig. 3: Range of Relevant Costs

MeTHODICAL proposes the use of relevant ranges to determine distance (and consequently solutions closer to ideal). Such relevant ranges establish bounds based on the type of criteria, as illustrated in Fig. 2 and Fig. 3 for benefits and costs criteria, respectively. The function $A(X)$ determines the range where performance of a path criterion (e.g., path capacity) is known to be above average or close to ideal values. Therefore, the MeTHODICAL distance has associated the following advantages: First, distance correlates path criterion values using functions based on arithmetic mean, variance, minimum and maximum functions, that do not impose any restriction regarding the volume of data, as happens with covariance in the Mahalanobis distance [15]; Second, distance considers the nature of criteria or type of criteria (if aims to be maximizes or minimised).

The MeTHODICAL path optimization algorithm, depicted in Algo. 1 has the following phases:

Phase 1 - Matrix normalization with benefits type $\mathbf{B}$ and costs type $\mathbf{K}$ using the sum method [21], for a matrix $\mathbf{M}$ with n paths and m criteria. The output corresponds to $\overline{\mathbf{B}}$ and $\overline{\mathbf{K}}$ normalized matrices for benefits and costs, respectively.

Phase 2 - Weighting of normalized benefits and costs matrices by multiplying the respective weight vectors, $\widehat{\mathbf{B}}_{i,b} = \mathbf{b}_b \times \overline{\mathbf{B}_{i,b}}$ benefits and $\widehat{\mathbf{K}}_{i,c} = \mathbf{k}_c \times \overline{\mathbf{K}_{i,c}}$, with $i = 1, 2, \cdots, n$, $b = 1, 2, \cdots, B$ and $c = 1, 2, \cdots, K$. This step provides the weighted normalized $\widehat{\mathbf{B}}$ benefits and $\widehat{\mathbf{K}}$ costs matrices and allows user to specify preferences regarding the criteria affecting optimization.

Phase 3 - Determine the ideal benefits solution, by retrieving the vector with the maximized values of benefits criteria, $I(\widehat{\mathbf{B}}_j) = max\{\widehat{\mathbf{B}}_{i,j} | i = 1, 2, \cdots, n \; and \; j = 1, 2, \cdots, m\}$ for n servers and m criteria.

Phase 4 - Determine the ideal costs solution, by retrieving the vector with the minimized values of costs criteria, $I(\widehat{\mathbf{K}}_j) = min\{\widehat{\mathbf{K}}_{i,j} | i = 1, 2, \cdots, n \; and \; j = 1, 2, \cdots, m\}$ for n paths and m criteria.

Phase 5 - The distance of each path to the ideal solution is formulated according to Algo 1-5. $\Delta(\widehat{\mathbf{B}}_i)$ corresponds to the distance of benefit criteria $\widehat{\mathbf{B}}_{i,j}$ to ideal benefits solution $I(\widehat{\mathbf{B}}_j)$, for B-benefits. Benefits distance considers how far a benefit criterion $A(\widehat{\mathbf{B}}_j)$ is to the ideal solution and how far the average criterion $m(\widehat{\mathbf{B}}_j)$ values with their variance $v(\widehat{\mathbf{B}}_j)$ are to the ideal solution. The $\lambda = 0.01$ value avoids divisions by zero.

Phase 6 - Determine $\Delta(\widehat{\mathbf{K}}_i)$-distance of cost criteria $\widehat{\mathbf{K}}_{i,j}$ to ideal costs solution $I(\widehat{\mathbf{K}}_j)$ according to Algo 1-6, for K-costs. Costs distance considers how far a cost criterion is to the ideal solution and how far the average criterion values without their variance $A(\widehat{\mathbf{K}}_j)$ are to the ideal solution.

Phase 7 - Assign scores to each path ($\mathbf{s}_i$) through the combination of distances to the ideal solutions, as per Algo 1-7 for n-paths. α enables the differentiation between benefits and costs distances. For instance, with α the ranking can mainly be based on benefits or costs, and $\alpha \in]0, 1]$. $\alpha = 0.5$, is the recommended value for balancing benefits and costs in the final ranking.

Phase 8 - Set score for current time (t) for each path. Variance function $v(x)$ is employed to allow scoring stability, considering previous and current scores $\mathbf{s}_{i,(t-z)}$ and $\mathbf{s}_{i,t}$, respectively. If $v\big(\mathbf{s}_{i,(t-z)}, \mathbf{s}_{i,t}\big)$ is equal to zero, such path is stable, otherwise path is experimenting performance degradation (e.g., bursts in packet loss).

Phase 9 - Ranking is obtained by ordering the score vector for current time $\mathbf{s}_{i,t}$ in a crescent order $\mathbf{r}_i = order(\mathbf{s}_{i,t})$. The optimal server is the one with the lowest score, as it is closer to the ideal solution.

The complexity of the MeTHODICAL optimization algorithm is $O\big(n\big)$.

IV. EVALUATION

This section provides an overview of the evaluation performed by the author. Four types of evaluation have been considered: (1) MADM accuracy to validate the precision of MeTHODICAL in the identification of optimal solutions through the Design of Experiments (DOE) methodology, as presented by the author [22] and released as an open source contribution [23]. (2) To validate analytically MeTHODICAL regarding the Correct Rankings Ratio (CRR) and the Required Handover Ratio (RHR), which aim to assess how MeTHODICAL is able to reduce the number of handovers when not required, as described in the journal paper [8]. (3) Evaluate MeTHODICAL with demanding applications such as VoIP, with the goal of demonstrating the flexibility of MeTHODICAL in supporting application specific criteria, such as Mean Opinion Score (MOS) and to demonstrate the supported quality steadiness, as described in [24]. (4) To assess the performance of MeTHODICAL in a cloud testbed with the goal of employing MeTHODICAL as a real-time decision mechanism for path selection.

The results presented in the following subsections highlight the VoIP and the cloud testbed evaluations for their demand in terms of employing MeTHODICAL for real-time decision or to demonstrate its flexibility in including application specific criteria. The cloud evaluation was implemented in the TRONE project [25].

A. VoIP scenario

The evaluation of VoIP quality considered data collected in a multihomed node with IEEE 802.11n (WiFi), IEEE 802.16e (WiMAX) and IEEE 802.3 links (Gigabit). Two distinct approaches are considered, the hybrid which includes all the links and the wireless that only includes WiFi and WiMAX links. Three different VoIP codecs are used for this purpose, namely, G.711, G729 and G.723. Moreover, the flexibility introduced in MeTHODICAL to differentiate the importance of costs and benefits criteria is evaluated, considering situations where costs are more important ($\alpha = 20\%$, named as MeTHCost) and situations where benefits are more relevant ($\alpha = 80\%$, named as MeTHBen). MeTHODICAL considers balanced benefits and costs criteria ($\alpha = 50\%$) to promote comparison with related MADM techniques such as NMMD, TOPSIS and DiA. Finally, the capability of the optimization techniques to maintain a stable quality level while adapting to network changes is evaluated.

The path selection optimization techniques were compared in both scenarios with two conditions: First, the buffer size (JB) was varied with different values, JB = $\{1, 2, 4\}$, to represent situations where the buffers support 20ms, 40ms, and 80ms of voice data. Large buffer sizes tolerate delay variation but may fail to meet one way delay requirement (i.e., bellow 150ms according to ITU-T Y.1540). Finally, failures were introduced with different probabilities (FP): FP = $\{5\%, 10\%, 20\%\}$.

MeTHODICAL, NMMD, TOPSIS and DiA performance was compared using two evaluation metrics. First, VoIP performance is assessed with the MOS as the quality of experience metric. MOS uses a scale with five levels, where 5 stands for excellent, 4 for good, 3 for fair, 2 for poor and 1 for bad quality. Second, the steadiness of the quality provided by each approach was assessed through the quality stability metric, which evaluates how the techniques maintain quality levels throughout each session.

B. Cloud scenario

The cloud scenario is based on the cloud infrastructure at Portugal Telecom (PT) datacenter, which includes Cisco infrastructure for networking and computing part, VMWare solutions for virtualisation and EMC^2 for storage. In particular, MeTHODICAL was used to configure Stream Control Transport Protocol (SCTP) and enhance the multihoming support of nodes with several paths/links in real time. In this context, MeTHODICAL included the output of an anomaly-detection algorithm, which determines if a server is facing any kind of failure (e.g., high CPU utilization, no disk space). The trace score works as a cost criterion, since 0 stands for a working server, while 1 stands for a server with failures. High volume data transfer services were used including *CD* ISO images with 750MB and *DVD* ISO images with 2GB. Redundant and resilient connections to the ISO image files repositories are performed. Redundancy is achieved through the employment of two Gigabit Ethernet links, and resilience is assured by SCTP, which supports a primary-backup protection model out-of the box. For instance, when a failure occurs in an active link/path there is an automatic switch to another working link/path.

TABLE I: Configuration of failures sets

ID	**Type**	**Server 1**	
		eth0	*eth1*
W1	warning	l = 5%	none
W2		l = 15%	none
W3		$d \approx N(50, 20)$ms	none
W4		$d \approx N(100, 20)$ms	none
C1	critical	down	none
C2		down	$d \approx N(100, 20)$ms
C3		resource fail	

To assess the effectiveness of MeTHODICAL, three types of configurations were considered. The first scenario considers transfer of images using the standard TCP protocol. The second scenario features standard SCTP multihoming mechanisms. The final scenario combines MeTHODICAL, SCTP and includes Ganglia collecting CPU, disk, memory and network usage metrics, to allow anomaly detection and enhanced reconfiguration.

In addition, in each scenario two types of failures were introduced. The *Critical* failures are configured by activating CPU-intensive, disk-intensive, and memory-intensive applications. The *Warning* failures are configured by introducing high delay or packet loss. More specifically, *Warning* failures are emulated by introducing delay, d, (normally distributed, with $\mu = 50$ ms and $\sigma^2 = 20$), and $d \approx N(100, 20)$ms; and packet losses, l, (5%, 15%) at the network interfaces of the repository nodes. Configurations without failures are labelled as *none*.

Table I summarizes the sets of all failures and the interfaces where they have been applied. Resource failures were created to overcharge CPU utilization (in rates $\approx 100\%$), by introducing a high number of computer-intensive processes in the background. Specifically, 1000 processes determining the checksum of the transferred files (CD and DVDExtra) were configured to run concurrently. Checksum was determined employing the *md5sum* utility. During the resource failures, Ganglia reported CPU utilization rates around $\approx 98\%$.

Further information of the evaluation of this scenario can be found in the following publications [26]–[28].

V. RESULTS

Results achieved in the evaluation are discussed in the following paragraphs.

A. VoIP Quality

The performance of MeTHODICAL and related approaches is similar in optimal conditions, when there are no failures and with a low buffer size (JB=1). Despite not pictured, the different versions of MeTHODICAL and NMMD provide good quality, for all the buffer size configurations and for all the codecs. The behaviours of MeTHBen, MeTHCost and MeTH are coherent for the codecs types, since the G.711 codec achieves the best quality (above 4). However, when the buffer size increases, TOPSIS and DiA result in application performance degradation, as these techniques do not adapt ranking to criteria values. For instance, with JB=4, MOS in some paths has poor quality ($\approx$ 2). TOPSIS and DiA techniques, by choosing paths with lower quality (sub-optimal), are slightly more stable than MeTHODICAL and NMMD, as depicted in Table II. MeTHODICAL and NMMD do not choose underperforming paths as optimal, nonetheless these techniques are able to support stability in approximated rates ($\approx 55 - 56\%$) of TOPSIS and DiA.

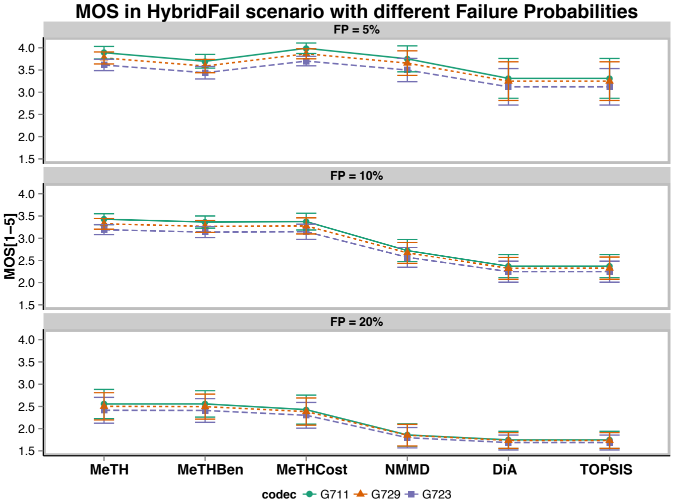

Fig. 4: MOS for Hybrid scenario with different Failure Probabilities for JB=1

Figure 4 shows the MOS obtained by the VoIP application in the hybrid scenario when failures occur with different probabilities. As expected, the G.711 codec is more robust to failures, however, when the failure probability is high ($FP = 20\%$) MOS drops bellow fair levels. The three versions

TABLE II: Steadiness of quality for the different techniques in the evaluation scenarios

Scenario	MeTHODICAL %			NMMD %			DiA %			TOPSIS %		
	G711	G729	G723	G711	G729	G723	G711	G729	G723	G711	G729	G723
Hybrid[a]	54.69	54.53	54.53	54.95	54.80	54.80	55.63	55.48	55.63	55.63	55.48	55.63
HybridFail[b]	55.80	55.59	55.53	54.59	54.23	54.31	57.50	57.06	57.16	57.50	57.06	57.16
Wireless[a]	53.96	53.81	53.80	—	—	—	54.95	54.79	54.79	54.95	54.79	54.79
WirelessFail[b]	53.69	53.52	53.53	—	—	—	54.39	54.22	54.22	54.39	54.22	54.22

[a] Results with buffer size $JB = 1$ (20ms). [b] Results with Failure Probabilities of 5%.

of MeTHODICAL are able to react to the different failures, in comparison to the related approaches. MOS is higher, with fair levels, in MeTHODICAL, MeTHBen and MeTHCost. NMMD has better performance than TOPSIS and DiA, but in $FP = 20\%$ cases, quality falls to bad levels. In terms of application quality, MeTHODICAL and NMMD outperform the DiA and TOPSIS techniques, because they correlate data, which avoids the ranking abnormality that results in the choice of underperformant paths.

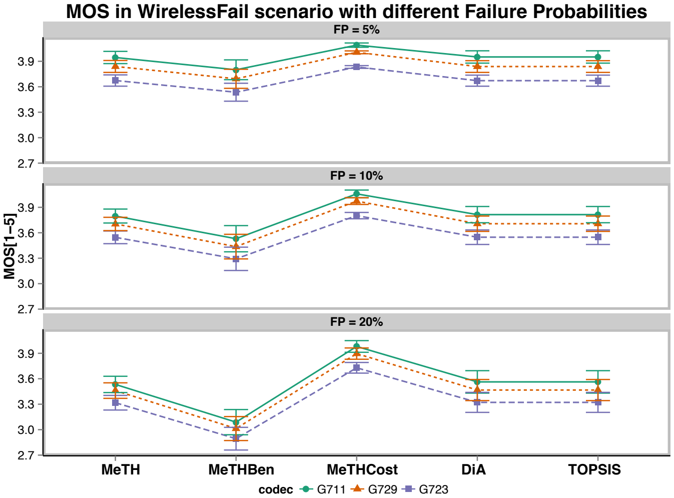

Fig. 5: MOS for WirelessFail scenario with different Failure Probabilities for JB=1

The *wireless* scenario only includes two paths to demonstrate the effectiveness of MeTHODICAL in situations with a minimum number of alternatives. The small number of paths prevents the use of NMMD, which is tied to functions that only have statistical meaning with high volume of data (i.e. at least 3 paths/alternatives). Fig. 5 shows the application quality for the wireless scenario with different failure probabilities. All the optimization techniques have similar results, since decisions are only about selecting one out of two available paths. However, the results show that the different configurations for costs and benefits in MeTHODICAL provide the desired impact. MeTHCost is able to support higher quality, almost in good levels, as opposed to fair levels of the remaining techniques. The reason for such performance relies on the fact that MeTHCost is configured to put more importance on cost criteria type (80%). Failures impact more costs criteria type, for instance RTT increases, as such any variation in this type of criteria is detected by MeTHCost. In addition, MeTHCost is slightly more stable than the remaining techniques, $\approx 54.5\%$ (value not pictured in Table II). This fact is inline with the MOS performance and is explained by the reduced number of paths to choose as optimal, only two.

B. Cloud

Server usage ratio assesses the ratio of use for each server. It is an indicator of whether the mechanisms are able to choose the most performant and reliable server. For such, all the failures were configured in the same server, namely, server 0. In this sense, the most performant cases correspond to those that choose server 1 more often. Server usage ratio for CD images in the different scenarios is summarized in Table III.

In warning and critical failure cases, SCTP and TCP choose the same server, despite the fact that in W1-W4 warning failure cases only one path is affected in the failing server. Therefore, the standard multihoming support of SCTP is able to recover and enable data transfer, which is not the case of TCP. Indeed TCP leads to disruption of service and, as a consequence, there is no quality of resilience, in all the failure cases.

The cases with MADM mechanisms have significant improvements in the performance, namely in the critical failures. In the C1-C3 cases load balancing is performed between both servers, as opposed to TCP and SCTP cases, that only select the failing server. Nonetheless, it can be observed that MeTHODICAL is able to support higher levels of resilience by choosing server 1 with higher ratios. Indeed, despite performing load balancing between servers, in some cases TOPSIS still selects the failing server. For instance, in the C1 case, server 0 is used $\approx$ 69% and server 1 $\approx$ 31%. The difference of behaviour is justifiable with the correlation functions of MeTHODICAL when determining distances for scoring. Moreover in the C3 failure case, TOPSIS wrongly selects server 0 behaving like standard and legacy users. In this case premium users do not have any gain in terms of

TABLE III: Server usage ratio for CD images

Case	Server	MeTH	TOPSIS	SCTP	TCP
Normal	0	23.31%	0%	100%	100%
	1	76.69%	100%	0%	0%
W1	0	0%	0%	100%	100%
	1	100%	100%	0%	0%
W2	0	0%	27.05%	100%	100%
	1	100%	72.95%	0%	0%
W3	0	0%	0%	100%	100%
	1	100%	100%	0%	0%
W4	0	0%	0%	100%	100%
	1	100%	100%	0%	0%
C1	0	41.32%	69.45%	100%	100%
	1	58.68%	30.55%	0%	0%
C2	0	07.77%	32.28%	100%	100%
	1	92.23%	67.72%	0%	0%
C3	0	0.02%	100%	100%	100%
	1	99.98%	0%	0%	0%

resilience. MeTHODICAL, on the opposite side, is able to enhance resilience by selecting the server higher availability rates ($\approx 99.9\%$).

In the critical and mixed failures (both interfaces of a server have failures) the performance of MeTHODICAL and TOPSIS were assessed comparatively to SCTP. As for SCTP the mixed failures have the same impact as in resources failures.

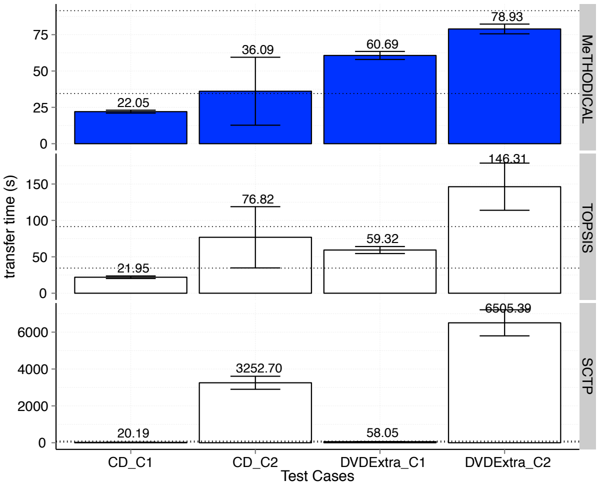

Fig. 6: Mean transfer time in critical scenario

SCTP can recover from a failing link/path to a backup path that is also characterized with a delay failure. In this case, the standard multihoming support of SCTP is a gain in terms that there is recovery from a critical failure, as pictured in Fig. 6.

All the approaches recover from *C1*- critical failure cases and *C2*- failure cases. Nonetheless, in the last type of failures, TOPSIS introduces a significative performance degradation, as shown by the high variation delay in the transfer time for DVD images. Such facts highlight the inconsistency of TOPSIS in choosing the best server, as in some cases, TOPSIS has chosen the server with the worst performance, note that the average transfer time of TOPSIS is higher in comparison to MeTHODICAL. In contrast, MeTHODICAL provides the best data transfer performance as the choice of the optimal server is consistent and efficient. For instance, MeTHODICAL does not choose the server with mixed failures in any of the tests runs.

VI. CONCLUSIONS

With the ongoing accelerated technology improvements presented, the number of devices with multiple interfaces is significantly increasing. The characteristics of these devices motivates the usage of protocols that bear an efficient network management regarding the optimised multihoming support, considering multiple criteria - the *NP-Hard* problem. The evaluation results presented above have shown the advantages of MeTHODICAL in comparison to the remaining techniques. First, the heterogeneity of scenarios regarding the number of paths demonstrates that MeTHODICAL is flexible and adapts well to the number of available paths. Second, MeTHODICAL, by correlating criteria values, is able to determine optimal paths, as those supporting higher levels of quality. Related techniques may choose as optimal paths the ones with lower levels of quality. After performing the result analysis, it was concluded that MeTHODICAL enhances quality of resilience by supporting load balancing between servers and that MeTHODICAL effectively enhances quality of resilience, by choosing the optimal server as the one with less performance overhead in all the faulty and non-faulty situations.

MeTHODICAL can enhance network management support. The improvement of the quality of resilience corresponds to a better fault support and the load sharing between multiple networks leads to a better performance.

The contributions of this thesis relies in a flexible optimisation mechanism validated in distinct scenarios within specific requirements. Such optimisation includes support for multiple criteria, and enables decisions at real-time as demonstrated in the cloud scenario. Within such innovation aspects, the next steps include the employment of MeTHODICAL in cloud controller to allow an intelligent management of resources and components and to support management operations dealing with scalability.

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