Performance Evaluation of Network Selection Algorithms for Vertical Handover Procedures over Satellite/Terrestrial Mobile Networks

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***Abstract*—The network selection is a decisional process aimed at determining the Radio Access Network (RAN) that a Mobile Node (MN) has to use and represents the core-function of the Vertical Handover procedure. In this paper, the authors propose a new algorithm for the network selection, called Dynamic-Technique for Order of Preference by Similarity to Ideal Solution (D-TOPSIS) that is a new formulation of the TOPSIS algorithm aimed at performing the same selection but requiring a minor number of operations and consequently reducing the time necessary to perform the selection. The main contribution of this work is the evaluation of the D-TOPSIS performance in a scenario where are available simultaneously a satellite network and Wi-Fi and WiMAX networks. The proposed approach is compared with other network selection methods found in the literature in two different cases: *i)* pedestrian, with a MN speed equal to 3 [m/s] and *ii)* vehicular, with a MN speed equal to 10 [m/s]. The numerical results show that D-TOPSIS assures a good performance as well as a limited execution time in both cases.**

Index Terms*—Network Selection, Vertical Handover, Multi Attribute Decision Making, Satellite Networks.

I. INTRODUCTION

Nowadays the multitude of heterogeneous Radio Access Networks (RANs) available can assure ubiquitous communications to Mobile Nodes (MNs) independently of their positions. Among them, the Satellite Networks are very important because they assure a vast coverage area without requiring any infrastructure or any Base Station or any Access Point, and a MN has only to be equipped by an opportune interface to use this technology. As a consequence they are able to support a large mobility even in environments where other technologies, such as Wi-Fi and Wi-Max, are not available. On the other hand the satellite network can assure worst performance with respect to the classical wireless networks in terms of a minor available capacity or an higher MN power consumption to maintain active the communication. So, it is important to define a mechanism for the cooperation of all the aforementioned networks that enables the MN to dynamically select to use the most appropriate one.

In this scenario, two concepts play a fundamental role: the vertical handover and the network selection. The first process is referred to the change of the RAN used by a MN. This change is vertical if the two networks, involved in the process, belong to two different technologies. The network selection is the decisional process that is in charge to select the RAN that a MN has to use. The two issues are tightly linked because if the selected RAN is not in use the MN has to perform an handover. As a consequence, an important requirement in order to not negatively impact the whole handover process, as reported in [1], is a stringent time constraint for the selection problem. For this reason the algorithm applied to solve the network selection problem has to limit its number of operations in order to reduce the time necessary to perform the selection.

Several works in the literature are focused on the network selection problem. A wild used algorithm is the so called **RSSI Based** (see [2] and [3] among the others), that belongs to the *mono-attribute* group. This algorithm is quite simple, characterized by a limited execution time but it assures poor results because of it considers only one metric during the selection process. In fact, this algorithm measures the Received Signal Strength Identifier (RSSI) from the Access Point (AP) of all the networks available and selects the one with the highest value. But it is true that there are also other metrics, such as available Capacity, Packet Loss Rate, Packet Delay, Energy (or Power) Consumption and Monetary Cost, that may be considered in the network selection problem. As a consequence better performance can be obtained by a different group of algorithms, called *multi-attribute*, because of they are able to consider several parameters (i.e., attributes) simultaneously, selecting the network that represents a compromise among the considered attributes. Four are the most diffused algorithms of this group: *i)* the **Simple Additive Weight** (SAW), defined in [4], [5] and [6] among the others, assigns a value, often called cost, to each *alternative* computed as the weighted sum of the normalized value of each considered *attribute*. *ii)* similarly the **Weighted Product Method** (WPM) calculates a cost for each network as the weighted product of the value of each considered attribute. *iii)* The **Fuzzy Logic Based** is derived from fuzzy set theory. Concerning the network selection many papers (such as [7], [8] and [9]) present a combination of the Fuzzy Logic theory with multi-attribute algorithms. *iv)* Finally the **Technique for Order of Preference by Similarity to Ideal Solution** (TOPSIS) algorithm selects the alternative (i.e., the RAN) that simultaneously minimizes and maximizes the distance respectively between the Positive Ideal Solution and the Negative Ideal Solution. This algorithm represents the

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starting point and a standard version of the algorithm proposed by the authors.
Even if the mobile scenario is highly dynamic, some characteristics of the available RANs, evaluated during the network selection problem, remain constant until the MN is inside the related coverage areas, independently of the position of the MN. Such metrics are, for example, the monetary cost of the RAN, its level of security and the power consumption. In [10] the metrics (or parameters) are grouped in three categories: static, dynamic and semi-dynamic. A similar classification is applied in this paper and a new version of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) algorithm, called Dynamic-TOPSIS (D-TOPSIS), aimed at obtaining the same selection results and at reducing the number of operations and consequently the execution time, is presented. The rest of the paper is organized as follows: in Section II are described the TOPSIS algorithm and the D-TOPSIS proposed by the authors. The simulative scenario developed is described in Section III, and the numerical results of the execution time and of the performance comparison are discussed in the same section. Finally, the conclusions are drawn in Section IV.

II. THE PROPOSED NETWORK SELECTION ALGORITHM

The proposed algorithm is a modification of the well known TOPSIS method that, tanks to its elasticity and versatility, can be applied not only to network selection as in [11], [12] and [13] but also in other telecommunication fields such as the sensor networks [14]. The new algorithm determines the same solution of the TOPSIS but assures a great computational complexity reduction. It is worth noticing that the definition of the D-TOPSIS is reported in [15]. Nevertheless, the algorithm formulation is here presented for the sake of completeness.

A. The TOPSIS algorithm

TOPSIS considers all the *alternatives* (i.e., all the available RANs) defined by the values assumed by the considered *attributes*. The *i-th alternative* is defined by the vector $A_i = (x_{i1}, \cdots, x_{ij} \cdots, x_{in})$ for $i \in [1, m]$ where n and m are respectively the number of *attributes* and the number of *alternatives*. As reported in [16], the TOPSIS approach can be geometrically modelled with m points in a n-dimensional space where it is possible to apply the Euclidean Norm to compute the distance between each alternative and a reference point.
This algorithm is composed of the following steps:

- Calculation of the weighted normalized attribute values (1):

$$v_{ij} = w_j \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{1}$$

  for each $i = 1, \cdots, m$ *alternative*, for each $j = 1, \cdots, n$ considered *attribute*. w_j is the weigh associated to the $j - th$ *attribute*, and the condition $\sum_{j=1}^{n} w_j = 1$ must be hold.
- Identification of the Positive (A^*) and the Negative (A^-) Ideal Solution, shortly PIS and NIS respectively, as reported in (2).

$$\begin{aligned} &A^* = (v_1^*, \cdots, v_j^* \cdots, v_n^*) = \\ &= \Big((\max_i v_{ij} | j \in J_1), (\min_i v_{ij} | j \in J_2) | i = 1, \cdots, m \Big) \\ &A^- = (v_1^-, \cdots, v_j^- \cdots, v_n^-) = \\ &\Big((\min_i v_{ij} | j \in J_1), (\max_i v_{ij} | j \in J_2) | i = 1, \cdots, m \Big) \end{aligned} \tag{2}$$

  where J_1 represents the set of positive attributes, that needs to be maximized, and J_2 represents the set of negative attributes that needs to be minimized.
- Calculation of the Separation Measures (SMs), to evaluate the distance between *alternatives* and ideal point (i.e., the Separation Measures) applying the Euclidean Norm, as reported in (3).

$$\begin{aligned} S_i^* &= \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}; \quad for \quad i = 1, \cdots, m \\ S_i^- &= \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}; \quad for \quad i = 1, \cdots, m \end{aligned} \tag{3}$$

- Calculation of the Similarity Index (SI) as $C_i^* = S_i^- / (S_i^- + S_i^*)$. The values are in the range $[0-1]$, where $C_i^* = 0$ if the *alternative* coincides with the NIS (i.e., $A_i = A^-$) and $C_i^* = 1$ if the *alternative* coincides with the PIS (i.e., $A_i = A^*$). It means that the best *alternative* is the one with the higher similarity index associated.

B. New Formulation of the TOPSIS Algorithm

The new formulation of the TOPSIS algorithm is called Dynamic-TOPSIS (D-TOPSIS) to highlight the fact that the decision at the generic step t, which coincides with a given instant, takes in consideration the decision performed in the previous step $t - 1$. In more detail, the *attributes* at a generic step t used to evaluate the $i - th$ *alternative* are divided into two groups: the *static attributes* $\mathbf{s}_i(t)$, that maintain constant their values at each t step when the *alternative* is available, and the *dynamic attributes* $\mathbf{d}_i(t)$. So for the $i - th$ *alternative* it is true that $s_i(t) = s_i(t-1)$. Consequently, it is possible to modify the formulation of the TOPSIS algorithm as described in the following. Supposing the network selection performed, periodically, each T second (i.e., the selection at the step $t+1$ is taken T seconds after the selection at the step t) and defining the $i - th$ *alternative* as in (4):

$$\begin{aligned} &\mathbf{A}_i(t) = (\mathbf{s}_i(t-1), \mathbf{d}_i(t)) = (s_{i,1}(t-1), \cdots, s_{i,j}(t-1), \cdots, \\ &s_{i,n_s}(t-1), d_{i,j}(t), \cdots, d_{i,j}(t), \cdots, d_{i,n_d}(t)) \end{aligned} \tag{4}$$

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where n_s and n_d represent respectively the number of static and dynamic *attributes*.

The basic idea of the D-TOPSIS is to apply the standard version of the TOPSIS algorithm each time the set of available RANs changes (i.e., the MN enters or leaves a new RAN). Then the results obtained are saved and reused each successive selection in which the D-TOPSIS is applied, until the set of available RANs does not change again (i.e., MN enters or leaves another RAN). In other words the following steps, necessary to perform the selection, are different depending on the number of available alternatives at the instant t ($m(t)$). In practice, if $m(t) = m(t-1)$ is employed the dynamic version of the algorithm, while, if this condition is not verified, the standard version of the algorithm is employed. To clarify the D-TOPSIS approach, the aforementioned distance is represented in Figure 1. It is worth noticing that in this case only two *attributes* are considered ($n = 2$) for the sake of simplicity but this choice is not a limitation. Both the *attributes* are positive (i.e., they must be maximized). One of them is static (s_1) and the other is dynamic (d_1). In Figure 1 is represented only the distance from the NIS, nevertheless similar conclusions can be drawn for the PIS. In Figure 1 the

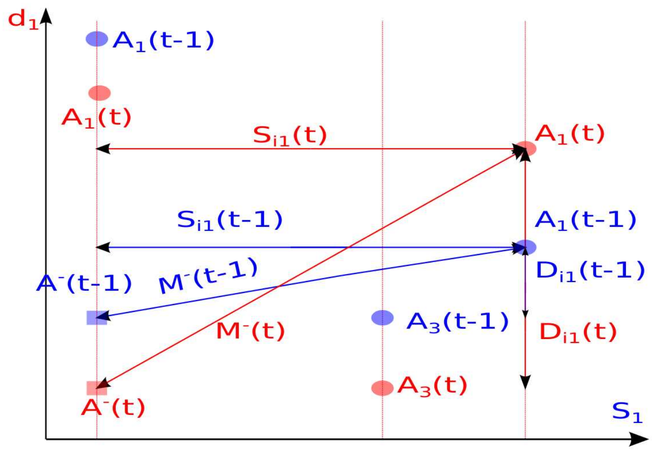

Fig. 1: Distance of the $i-th$ alternative from the Negative Ideal Solution (NIS)

NIS at the step t, $A^-(t)$ and $t-1$, $A^-(t-1)$, are identified by two squares, red and blue, respectively. The distance between the NIS and the $i-th$ *alternative* at the $t-th$ instant is determined by the two components $S_{i1}(t)$ and $D_{i1}(t)$, called in this work *Partial Distances*, that must be calculated for each *alternative* during each execution of the TOPSIS algorithm. It is possible to view in Figure 1 that $S_{i1}(t) = S_{i1}(t-1)$ and, consequently, it is not necessary to calculate the value of this parameter. It obviously reduces the number of the operation needed to carry out the RAN selection. Obviously this reduction becomes larger if the considered number of static parameters or the number of *alternatives* increase.

Starting from these considerations, and supposing that the number of available *alternatives* has not changed since the last network selection decision, the algorithm proposed is composed of the following phases:

- Calculation of the weighted normalized values of dynamic *attributes* only.
- Identification of the components of the Positive $A^*(t)$ and the Negative $A^-(t)$ Ideal Solution referred to the dynamic attributes. The other components of both vectors, referred to the static *attributes*, computed during the last standard TOPSIS execution, are constant, so it is not necessary to compute them again.
- Calculation of the *Partial Distances* for all the dynamic attributes between each *alternative* and the Ideal Solutions. This distance is defined as the square of the difference between the values assumed by the weighted normalized attribute and its ideal value. Also in this step the static attributes are not considered because their *Partial Distances* are equal to the distances computed during the last standard TOPSIS execution.
- Calculation of the Separation Measures (SMs) of each alternative, combining the *Partial Distances* of the dynamic attributes, calculated in the previous step and the *Partial Distances* of the static attributes, calculated in the last standard TOPSIS execution. The SM for a generic alternative is defined as the square root applied to the sum of the *Partial Distances* of all its attributes.
- Calculation of the Similarity Index as defined in the standard TOPSIS formulation. Clearly, also for the D-TOPSIS the highest Similarity Index identifies the best alternative.

Starting from the described phases, the reduction in the number of necessary operations is obvious. In practice, applying the D-TOPSIS for each *alternative*, it is not necessary to calculate both values of the *Partial Distances* for the static *attributes*. These values are stored during the last execution of the standard TOPSIS and simply loaded during the execution of the D-TOPSIS. Only the *Partial Distances* referred to the dynamic attributes must be calculated in order to compute the Separation Measures and the Similarity Index.

III. Performance Investigation

A. The Reference Scenario

The scenario taken as a reference in this paper is composed by a remote host that communicates with a MN. Two different MN speeds are considered: 3 [m/s] (pedestrian mobility case) and 10 [m/s] (vehicular mobility case). The communication is constituted by a UDP traffic flow that is transmitted by a remote host to a MN. Three different types of RANs are considered: Satellite Network, with a single footprint that covers the whole area, Wi-MAX, with again a single coverage area and eight Wi-Fi areas. The network selection is performed periodically each $T = 5$ [s]. Each simulation duration is set equal to 500 [s].

The metrics considered during the network selection are four: the Received Signal Strength Indicator, (*RSSI*), measured by the MN, the Capacity that the network reserves to the MN (*C*), the Monetary Cost (*MC*) paid by the user to use the network and the Power Consumption (*P*) of the MN. Obviously the first two *attributes* are positive while the others are negative. It is worth noticing that, according with [10], *C*, *MC* and *P* are static *attributes* while *RSSI* is a dynamic *attribute*, computed as a function of the distance between the MN and the AP of the RAN in use for all the RAN except for the satellite network in which it is kept constant in all the cell. So $n_s = 3$ and $n_d = 1$.

Nine network selection algorithms are considered: five multi-attribute approaches, among them TOPSIS and D-TOPSIS are included. The other four are representative of each group presented in Section I. The other four are single-attribute, each of them is focused only on optimizing one of the considered attributes: *i)* Received Signal Strength Indicator based ($RSSI_b$), *ii)* Capacity based (C_b), *iii)* Monetary Cost based (MC_b) and *iv)* Power Consumption based (P_b).

The simulated scenario adopted has been developed through the Network Simulator 2 (*ns-2*). The dimension and the position of the coverage areas of each access network are randomly set in each simulation. Likewise the values of the considered attributes vary in each executed simulation, over the range reported in Table I. The Monetary Cost is modelled

TABLE I: RANGE VALUE OF THE ATTRIBUTE CONSIDERED

Parameters	Range Value
Power Consumption	[0,16 - 0,22] w
Monetary Cost	[1-10]
Wi-Fi Capacity	[1 - 20] Mbps
Wi-Max Capacity	2 Mbps
Satellite Network Capacity	0.384 Mbps

as an indicative number that ranks the network from the cheapest (*MC* $= 1$), to the most expensive (*MC* $= 10$) while the satellite capacity is obtained considering a bandwidth equal to $200[KHz]$, $C/N = 5.7[dB]$.

The numerical results obtained through a simulative campaign are grouped into two sets. The first one is aimed at highlighting the improvement assured by the D-TOPSIS, with respect to the standard TOPSIS and also with respect to the other algorithms, in terms of execution time. The second set reports a comparison between the performance obtained by the two TOPSIS versions that converge on the same solution and by the aforementioned algorithms.

B. Execution Time Comparison

Figure 2 shows the execution time for all the considered network selection algorithms for a different number of RANs, from two, the minimum number of *alternatives* to perform the network selection, to ten, the total number of RANs in the simulated scenario. D-TOPSIS is the second fastest algorithm among the considered ones; only the single-attribute method is faster. On the other hand these algorithms give poor results and a sub-optimal selection as highlighted in the next subsection. The execution time of the standard TOPSIS has intermediate performance while the fuzzy algorithm is the slowest algorithm because it implements several operation during the so called *fuzzyfication* and the *defuzzyfication* phases. So it is clear the advantage assured by the D-TOPSIS in terms of execution time, not only with respect to the standard TOPSIS but also with respect to all the other multi-attribute network selection algorithms.

Finally, it is possible to note that the difference between the execution times increases if the number of *alternatives* increases.

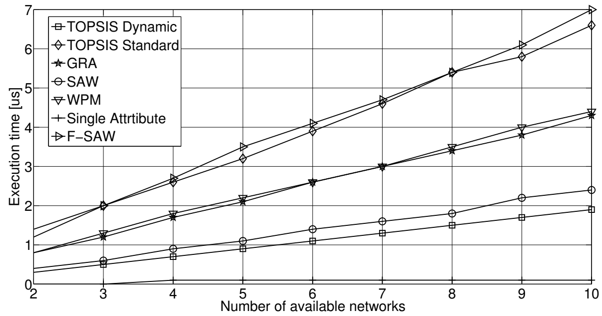

Fig. 2: Distance of the $i-th$ *alternative* from the Negative Ideal Solution

C. Performance Comparison

In this subsection, the performance obtained with the aforementioned algorithms are compared. As it is possible to see in Figure 3, the value of the metric H is much higher when the MN moves at a speed of 10 m/s with respect to when it moves at 3 m/s. This occurs because the MN is inside of each RAN for less time if its speed increases, and the scenario changes its characteristics more quickly.

Observing the power received by the MN, plotted in Figure 4, expressed by the metrics RSSI, it is possible to observe that also in this case the best results are obtained by pedestrian mobility. In fact, the permanence time of the node inside the Wi-Fi or WiMAX cells is higher for the pedestrian pace with respect to the case of vehicular mobility. If the node speed increases, it is necessary to use satellite networks more frequently which provide worse performance but at the same time more ample coverage.

Similar considerations can be made for the values assumed for some other metrics, especially the allocated capacity C (Figure 5) and the power consumption of the MN P (Figure 6). As a matter of fact also in this case a wider use of satellite networks corresponds to a worsening in the values assumed by the two metrics we have considered in this paper.

Different behaviour, characterized the delay of the traffic flows transmitted in downlink (D) and the monetary cost (MC) paid by the mobile node to use the network, plotted respectively in Figure 7 and in Figure 8. It is possible to observe similar performance for the two mobility types considered. In fact, the use of satellite networks guarantees minor allocated capacity at the terminal, but this reduction does not particularly affect the perceived delay of traffic flow, because the allocated capacity is sufficient to guarantee satisfying average performance. As far as monetary cost is concerned, we have decided to impose the cost in the same range for both the satellite network and the other networks we have considered in this paper.

It is worth noticing that the comparison between the two mobility types is not fair because the MN in the vehicular mobility follows a longer path with respect to the pedestrian mobility. As a consequence when the speed is 10 m/s the MN stays outside the Wi-Fi and WiMAX coverage area for a longer time, and, consequently, it has to use the satellite network. Nevertheless, the performance comparison among the network selection algorithm is fear in both the considered mobility scenarios.

Considering the numerical results obtained through the conducted simulation campaign, one can observe that with a MN speed equal to 3 m/s the multi-attribute algorithms assure best performance with respect to the single-attribute ones even if these algorithms determine a minor number of handover executions (H) and a minor execution time. Moreover, it is possible to view that among the multi-attribute algorithms the best performance are obtained with both the TOPSIS algorithms that perform the same selection, choosing the RAN that assure the best compromise between the adopted attributes.

Similar results can be obtained considering the MN speed equal to 10 ms. A slight difference is that in this case also the SAW algorithm, and not only the TOPSIS algorithm, assure the best compromise among the considered performance metrics.

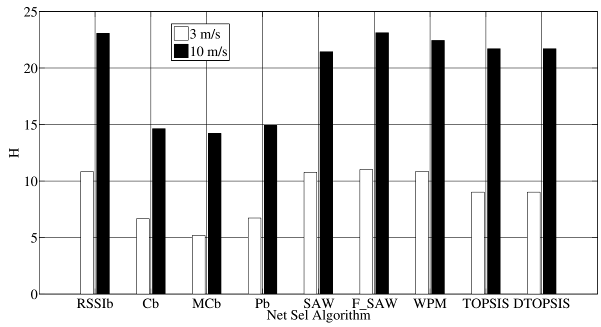

Fig. 3: Values of the H metric for different network selection algorithms for the two MN speed considered.

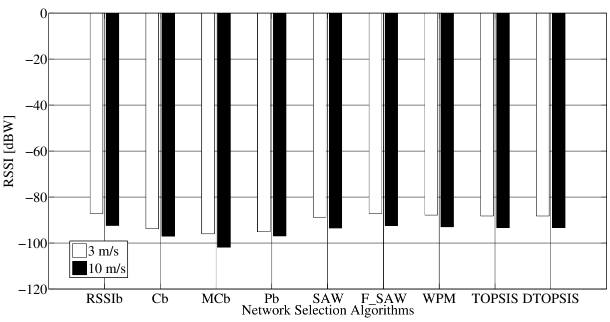

Fig. 4: Values of the $RSSI$ metric for different network selection algorithms for the two MN speed considered.

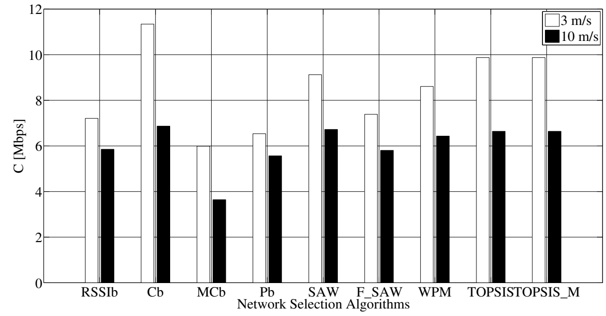

Fig. 5: Values of the C metric for different network selection algorithms for the two MN speed considered.

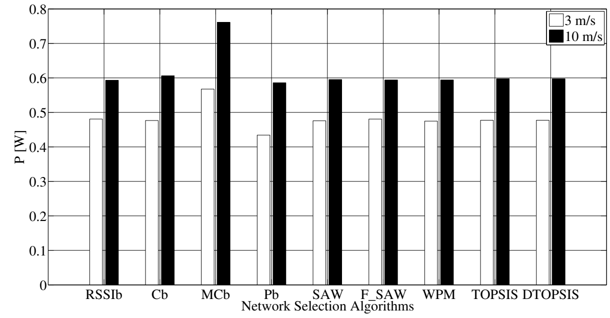

Fig. 6: Values of the P metric for different network selection algorithms for the two MN speed considered.

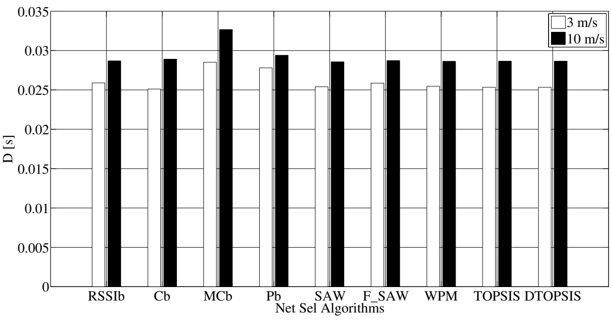

Fig. 7: Values of the D metric for different network selection algorithms for the two MN speed considered.

IV. CONCLUSIONS

A stringent time limit requirement in the network selection process is necessary to optimize the handover execution. Consequently, the network selection algorithms should be designed by limiting the number of operations needed to perform the selection. Starting from this necessity, a new version of the TOPSIS algorithm applied to the network selection problem, called D-TOPSIS, is proposed in this paper. It is aimed at determining the same selections but with a large reduction of the number of required operations.

The performance obtained by using D-TOPSIS are compared with the performance obtained by using the most important network selection policies found in the literature. Two mobility

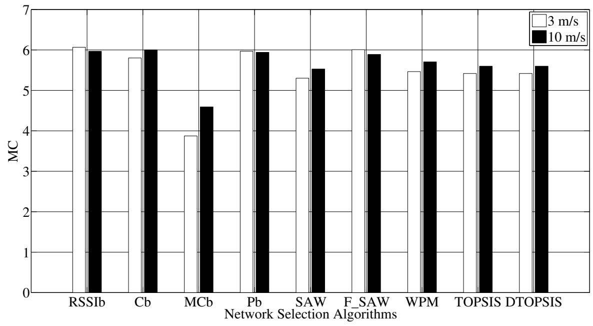

Fig. 8: Values of the MC metric for different network selection algorithms for the two MN speed considered.

scenarios have been considered: the pedestrian and the vehicular case. The numerical results demonstrate that the TOPSIS based approaches improve the performance of the network selection process and, in particular, D-TOPSIS reduces the execution time needed to carry out the network selection.

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