Performance Comparison of Network Selection Algorithms in the Framework of the 802.21 Standard

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***Abstract*—The diffusion of mobile devices, equipped with many different network interfaces, offers great benefits to mobile communications, by allowing the fruition of network services through different Radio Access Networks (RANs). On the other hand, the development of the IEEE 802.21 Standard, which facilitates the interoperability between different access networks, assures further performance improvements. In this scenario, Network Selection is the action of choosing the best Radio Access Network (RAN) among a set of available heterogeneous radio links. Within this topic, the main contribution of this paper is a performance comparison, obtained through a simulator developed by using Network Simulator 2, among different network selection algorithms, within the framework of the 802.21 standard.**

***Index Terms*—Mobile Communications, IEEE 802.21 Standard, Network Selection, Performance Comparison, Simulation.**

I. INTRODUCTION

THE diffusion of mobile devices, called in this paper Mobile Nodes (MNs), equipped with many different radio network interfaces, such as WiFi, WiMax, Universal Mobile Telecommunications System (UMTS) and Long-Term Evolution (LTE), assures great improvements in mobile communications. MNs could be inside an area covered by more than one Radio Access Networks (RAN). Each RAN has its own Point of Access (PoA) called Radio Base Station (RBS) in case of cellular network-based access (UMTS, LTE) or Access Point (AP) in case of wireless local area network-based access (WiFI). Each RAN has different characteristics, defining an heterogeneous scenario. MNs can take advantage of such heterogeneity because RANs guaranteeing the best communications performance can be selected: the action is called Opportunistic Vertical Handover - Network Selection, on which this paper is focused. Network Selection is the main function of the handover procedure that is applied when an MN switches the connection from the RAN in use to another. If the RANs involved belong to the same radio technology, the handover is said horizontal (e.g., the traditional handover of cellular networks). If radio technologies are different, as in the case considered in this paper, the handover is called vertical.

An important field of practical application of the vertical handover and of the related Network Selection process is Remote Monitoring. A representation of such a service is reported in Figure 1: an MN, represented in the figure as a mobile phone, is supposed to be physically associated to an object (e.g., a train, ship) to be monitored. The arrow in Figure 1 indicates the MN movement, starting from the left, the MN detects a WiMAX RAN availability, runs a network selection process and as output of the process, decides to switch from the access technology in use to the WiMAX RAN, thus performing handover. During the movement, the MN checks the availability of alternative access networks but, also in case of availability, after running the network selection process, decides that the best RAN is the one in use. Going on, the MN detects an UMTS RAN available but, in this case, as output of the network selection algorithm, leaves the RAN in use and performs the handover. Another handover towards a new WiFi RAN is shown at the right end of Figure 1. Each MN should be connected every-time and every-where to a core network in order to access a set of dedicated services and to send data. An interesting operative framework for remote monitoring is represented by Intelligent Transportation Systems (ITSs) [1]. In this case each MN is associated to a vehicle that transports goods (e.g., a container) that need to be monitored. The MN operates as sink of the information about the monitored goods such as integrity, temperature, and position through a set of sensors and, simultaneously, allows accessing available RANs.

The purpose of this paper, which is an extended version of the paper [2], is to compare different Network Selection algorithms available in the literature. This comparison is carried out through simulations. Tested algorithms have been developed and integrated in the Network Simulator 2 (ns2) software module that integrates the functions of IEEE 802.21 standard. The paper is focused on two aspects: *i)* overview of the main Network Selection techniques in the literature, and *ii)* performance comparison among the surveyed techniques, obtained through the aforementioned simulative tool.

The paper is structured as follows: Section II summa-

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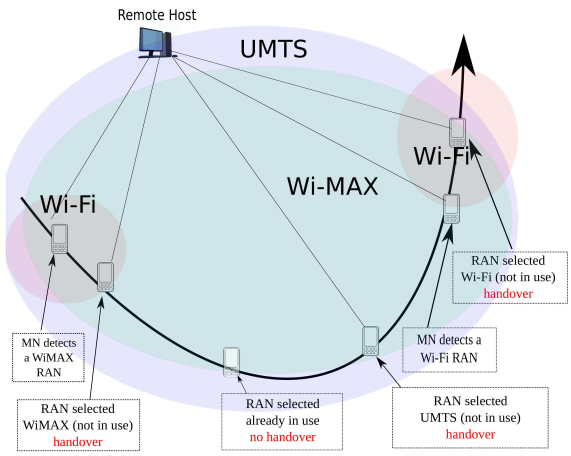

Fig. 1. Example of Remote Monitoring System.

rizes IEEE 802.21 Standard main features and functions, and highlights the crucial role of the Network Selection process. Section III surveys the most important Network Selection algorithms by distinguishing Single Performance Metric Optimization (SPMO) and Multiple Performance Metric Optimization (MPMO) techniques. Section IV describes the simulator adopted by the authors, the considered simulative scenario, the evaluated performance metrics, and the numerical results of the simulation campaign aimed at comparing the surveyed Network Selection criteria. Section V contains the conclusions.

II. IEEE 802.21 Standard

Main IEEE 802.21 Standard [3] purpose is to facilitate the whole handover process among RANs, to maintain active communications and to limit any degradation of the Quality of Service (QoS) during the handover executions. Such a type of handover, called seamless, is transparent for users because they ignores the network handover execution while they are using a mobile device. The standard defines four logical elements:

1) a MN equipped with multiple network interfaces, able to be connect to different radio technologies, which compose, from the protocol stack viewpoint, lower layers.
2) A set of functions that trigger the handover procedures of the MN protocol stack.
3) A new virtual layer, called Media Independent Handover Layer (MIH Layer), that plays the role of a common interface between each network interface, lower layers, and MN upper layers.
4) A set of logical functions, called Media Independent Handover Functions (MIHF), which enable the interaction between MIH Layer, lower and upper layers.

The standard defines three types of MIHF:

- *Media Independent Event Service* (MIES): composed of all functions that report to the upper layers information sent by the lower layers (e.g., the variations of the link conditions).
- *Media Independent Command Service* (MICS): it includes all the functions which forward control instructions from the upper layers to the lower layers (e.g., information about the available networks configurations).
- *Media Independent Information Service* (MIIS): it defines a set of functions that provide the mechanism to retrieve information and help the handover decision.

A key issue considered by the IEEE 802.21 framework is the standardization of the overall procedure needed to support the handover execution. The operations are grouped into three phases:

- *Handover Initiation*: it is the first phase of the handover and includes the signalling with the Point of Access - PoA in use, which will be changed, and some preliminary measurements on the available RANs.
- *Handover Preparation*: in this phase the MN selects the network that will be used after the handover (i.e., it runs the Handover Decisions / Network Selection procedure), and the negotiation for resource reservation aimed at guaranteeing QoS requirements is started.
- *Handover Execution*: in this final phase the traffic flows sent by the MN move to the selected RAN so leaving the network access in use.

Although all these phases, further detailed in Figure 2, are explicitly taken into account in the standard, the implementation of a specific network selection strategy is not defined. As a consequence, the choice of suitable algorithms is still an open issue.

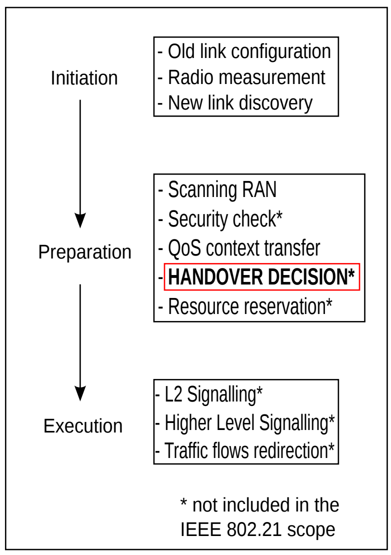

Fig. 2. Functions of the 802.21 Standard.

III. Overview of the *Network Selection* Algorithms

The literature includes two main families of Network Selection Algorithms: Single Performance Metric Optimization (SPMO), and Multi Performance Metrics Optimization (MPMO). SPMO algorithms select the RAN

by considering only one performance metric. MPMO algorithms consider multiple metrics, simultaneously, to select the RAN to be employed.
The entity taking decisions about the RAN to select is called Decision Maker (DM).

A. Single Performance Metric Optimization

From the formal viewpoint, each available network represents an alternative that is evaluated by using one performance metric, called attribute. The task DM is to determine the best alternative, among the available ones, accordingly to the maximization (minimization) of the performance metric, considered as a Utility (Cost) function. Given m available RANs, we denote the *alternatives* with the vector $\mathbf{A} = (A_1, \cdots, A_j, \cdots, A_m)$. The j-th alternative is defined as $A_j = (x_j)$, where x_j is the performance metric (or attribute). The best alternative is identified as A^{opt}_{SPMO} and is obtained by applying the following criterion:

$$A^{opt}_{SPMO} = \left\{ A_j : \arg\max_j (x_j) \right\} \quad (1)$$

Equation (1) is valid if the considered metric needs to be maximized (e.g., as in the case of received power). If a metric has to be minimized (e.g., as in the case of packet loss) the $\arg\min_j(\cdot)$ operator is applied in (1).
Among the possible metrics adopted by the algorithms of the SPMO family, a widely used choice is the RSSI, adopted in [4] and [5], where the Received Signal Strength Indicator (RSSI), usually representing the received power expressed in [dB], is the considered parameter measured during the process of horizontal handover. Obviously, the same criteria can be used for vertical handover. This selection method is very simple: the MN measures the RSSI from the PoAs of all the available RANs and chooses the one with the highest value. Even if the method is quite simple to be implemented, it does not assure satisfying performance in the case of vertical handover because different technologies may have different RSSI value ranges, making difficult a fair comparison between the values of this parameter. Actually the same RSSI absolute value can be considered a satisfactory level of received power for a RAN, while it can be insufficient for another, depending on the considered radio technology. Its applicability is limited to intra-technology selections. Another weakness of this algorithm is the “Ping Pong effect”. It consists in a repetitive and useless handover between two access networks, which happens even if the RSSI value of an alternative RAN is slightly higher than the value of the RAN in use [6]. This negatively impacts the QoS of communications and the battery lifetime of MNs. The algorithms of the SPMO family have a very low computational complexity, a low execution time and a limited power consumption. On the other hand, they may provide poor performance when the aim is optimizing multiple metrics.

B. Multi Performance Metric Optimization

Multiple metrics are simultaneously taken into account. Metrics may be structured into three categories:

i) QoS-based, such as RSSI, transmission rate, bandwidth throughput, packet loss rate, delay, and jitter.
ii) Power saving-based, such as power consumption and MN battery lifetime.
iii) Other parameters-based, such as monetary cost, user preferences, and security level assured by each RAN.

Using the same mathematical formalism employed for the SPMO case, each available network represents an alternative that is evaluated using the metrics, called, also in this case, attributes. The task of the Decision Maker - DM is to select the best alternative accordingly to a certain criterion. MPMO algorithms are often characterized by higher computational complexity with respect to SPMO ones, but they can optimize simultaneously more metrics. In practice, these algorithms assure a compromise between the needs of different metrics. While SPMO algorithms chose the optimal solution regarding a single parameter, MPMO approaches may select a suboptimal RAN considering a single parameter, but they find the optimal solution considering all the different metrics together.
Remembering that the vector of the m alternatives (i.e., the RANs) is denoted with $\mathbf{A} = (A_1, \cdots, A_j, \cdots, A_m)$, in the case of the MPMO approaches the j-th alternative is defined as $A_j = (x_{1j}, \cdots, x_{ij}, \cdots, x_{n,j})$, where x_{ij} is the value of the i-th attribute (i.e., the i-th considered metric) of the j-th alternative and n is the overall number of attributes used to evaluate each alternative. The algorithms belonging to this group are often characterized by higher computational complexity, with respect to the SPMO ones, but they can optimize simultaneously multiple metrics. Many criteria belonging to the MPMO family can be formally defined. A sub-set of them is presented in the following.

1) Simple Additive Weight - SAW: These algorithms [7] assign a value, called *cost*, to each *alternative* computed as the sum of the normalized value of each considered attribute. The normalization allows obtaining comparable attributes values (i.e., ranging in the same interval $[0-1]$). In general, weights can be applied to each attribute to differentiate its importance. The selected network is the one with the minimum *cost* as reported in (2):

$$\begin{cases} V_{SAW}(A_j) = \sum_{i=1}^{n} w_i \cdot V^{A_j}_{SAW}(x_{ij}) \\ A^{opt}_{MPMO-SAW} = \left\{ A_j : \arg\min_j \left(V(A_j) \right) \right\} \\ j = 1, \cdots, m \end{cases} \quad (2)$$

- $A^{opt}_{MPMO-SAW}$ is the alternative selected by the SAW algorithm;
- $V_{SAW}(A_j)$ is the value associated to the j-th alternative A_j (i.e., the cost);

- $V_{SAW}^{A_j}(x_{ij})$ is the normalized cost of the j-th alternative computed by considering the i-th attribute x_{ij};
- w_i is the weight associated to the i-th attribute.

The weights must be selected by respecting the condition $\sum_{i=1}^{n} w_i = 1$. The use of different weights can be useful also to separate "negative" and "positive" attributes. If an attribute represents a metric that needs to be minimized (such as packet loss rate, delay, jitter, and power consumption) is said "negative" and its weight has a positive sign; alternatively, if the attribute is representative of a metric that needs to be maximized (such as maximum capacity, RSSI, battery lifetime, and user preference) is termed "positive" and its weight is a negative value.

Similar approaches can be found in the literature in [8], [9], [10] and [11]. Among them, an inspiring example of this method is contained in [8] which minimizes a function representing a generic cost related to the employment of j-th network, depending on available bandwidth, power consumption, and monetary cost. [9] proposes a Network Selection policy by defining the cost of the j-th network as the weighted sum of RSSI and available bandwidth, preliminarily normalized.

2) Weighted Product Method - WPM: The WPM criterion [12] assigns to each alternative a cost obtained by the multiplication of the attribute values. This approach allows avoiding the normalization needed in the SAW method. The analytical formulation is reported in (3): the weight applied to each attribute to differentiate its importance is the exponent of the attribute value:

$$\begin{cases} V_{WPM}(A_j) = \prod_{i=1}^{n} V_{WPM}^{A_j}(x_{ij})^{w_i} \\ A_{MPMO-WPM}^{opt} = \left\{ A_j : \arg\min_j \left(V_{WPM}(A_j) \right) \right\} \\ j = 1, \cdots, m \end{cases} \quad (3)$$

- $A_{MPMO-WPM}^{opt}$ is the alternative selected by the WPM algorithm;
- $V_{WPM}(A_j)$ is the value associated to the j-th alternative A_j;
- $V_{WPM}^{A_j}(x_{ij})$ is the value of the i-th attribute of the j-th alternative x_{ij};
- w_i is the weight associated to the i-th attribute.

Also in this case the sign of each weight is positive if the attribute needs to be minimised and negative if it needs to be maximized.

Except for [12], WPM is not widely used even if it has a clear logic. WPM is used in [13] as a reference to present a multi-attribute error analysis in order to make more precise discrimination among competing alternatives under uncertain environment.

In general, minimizing/maximizing a product of variables is equivalent, under given conditions [14], to minimizing/maximizing the sum of logarithms. In practice, simplifying, $max \prod_{j \in J} f_j(x)$ is equivalent to $max \sum_{j \in J} ln f_j(x)$, where $f_j(x)$ are the utility functions. [14] also reminds that the maximization/minimization of the sum of the utility functions, if the utility functions are logarithmic, leads to a "proportionally fair" allocation.

For these motivations WPM has been considered as a comparison in this paper.

3) Fuzzy Logic: A well-known approach for the *Network Selection* is based on fuzzy logic [15], [16]. Fuzzy logic is derived from the Fuzzy Set Theory in which the variables may have a "truth value" that ranges between 0 and 1. In other words, fuzzy logic is a super-set of boolean logic which is employed to handle the concept of partial truth. Fuzzy logic is able to model non-linear functions in a compact-set of arbitrary accuracy, and is used to solve many industrial problems such as real time control, automatic control, data classification and decision analysis. The block diagram of a generic fuzzy

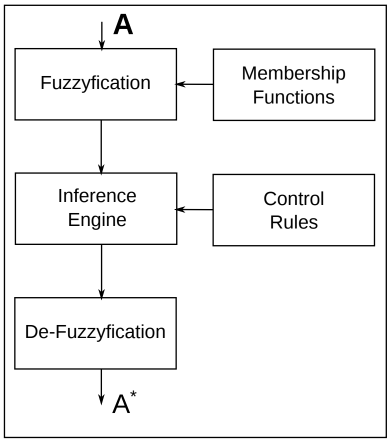

Fig. 3. Block Diagram of Fuzzy Logic Algorithm.

logic algorithm (i.e., applicable not only to the *Network Selection* but also to other problems) is reported in Figure 3. The input is the vector of available RANs (or alternatives) **A**, evaluated according to the considered performance metrics (i.e., the attributes). The first step of the algorithm is the *fuzzyfication*. It maps the value of the attributes of each RAN into the fuzzy sets according to the *membership function* of each set. Generic membership functions of three fuzzy sets are

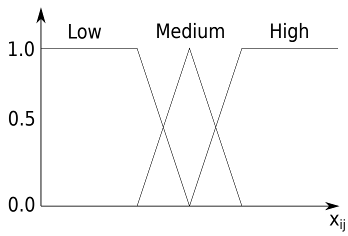

Fig. 4. Membership Function of the Fuzzy Logic Sets.

shown in Figure 4 as an example. These functions are LOW, MEDIUM and HIGH for the i-th attribute referred to the j-th alternative, x_{ij}. Each fuzzy set associated to an attribute is assigned in accordance to the value of the attribute.

The successive step consists in the employment of the *inference engine*: according to given control rules, a policy to evaluate the fuzzy set of the attributes of each RAN is defined.
The last phase is the *defuzzification*: the fuzzy output generated by the *inference engine* is used to rank the available alternatives.

4) Mixed Approach: The Mixed Approach combines the fuzzy logic with an additive cost function for the *Network Selection*. This method has been proposed in [17] where four parameters are considered as input at the DM: Received Signal Strength (*RSS*), available bandwidth, monetary cost, and user preferences. The algorithm is applied to the selection of Wireless Wide Area Networks (WWANs) and Wireless Local Area Networks (WLANs) and is composed of the following three phases:

1) normalization of input parameters for each RAN;
2) *fuzzyfication*, where the normalized values of all parameters is assigned to one of the three fuzzy set: LOW, MEDIUM, HIGH;
3) computation of Performance Evaluation Value (PEV) and selection of the RAN with the highest PEV.

Particular mixed approach is referred as Fuzzy-Simple Additive Weighted (F-SAW) in the performance evaluation. Similar *Network Selection* algorithms are described in [18], [19] and [20].

5) Technique for Order Preference by Similarity to Ideal Solution - TOPSIS: This algorithm belongs to the family of Multi Attribute Decision Making (MADM) methods.
TOPSIS is based on the concept that the chosen alternative should have the shortest distance, in euclidean terms, from the *positive-ideal* solution and the longest distance from the *negative-ideal* solution, as formally described in the following. TOPSIS method is already used in other applicative scenarios such as sensor networks [21] as well as in other fields such as economy and finance.
Coherently with the notation previously employed, we consider a selection problem with m possible RANs, or alternatives, characterized by n performance metric, or attributes. The *positive-ideal* solution is the vector $A^+ = (x_1^+, \cdots, x_i^+ \cdots, x_n^+)$, where x_i^+ is the best value of the i-th attribute computed considering the values of this attribute over all the available alternatives. Equivalently, the *negative-ideal* solution is the vector $A^- = (x_1^-, \cdots, x_i^- \cdots, x_n^-)$, where x_i^- is the worst value of the i-th attribute.
TOPSIS is aimed at ranking all possible alternatives on the basis of *positive-ideal* and of *negative-ideal* solutions and enabling the DM to choose the best one. To reach the aim a *Similarity Index* is computed by using the euclidean distance of each alternative with the *positive-* and *negative- ideal* solutions. To calculate the *Similarity Index* all the attributes are preliminarily normalized and weighted as in (4):

$$v_{ij} = w_i \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \quad j = 1, \cdots, m;\ i = 1, \cdots, n; \tag{4}$$

w_i is the weight associated to the i-th attribute. Equation 4 must hold: $\sum_{i=1}^{n} w_i = 1$.
The following step is to compute the *normalized positive-ideal* $\hat{A}^+$ and the *normalized negative-ideal* $\hat{A}^-$ solutions as in (5).

$$\begin{aligned} &\hat{A}^+ = (v_1^+, \cdots, v_i^+ \cdots, v_n^+) = \\ &= \Big((\max_j v_{ij} | i \in I_1), (\min_j v_{ij} | i \in I_2) | j = 1, \cdots, m \Big) \\ &\hat{A}^- = (v_1^-, \cdots, v_i^- \cdots, v_n^-) = \\ &\Big((\min_j v_{ij} | i \in I_1), (\max_j v_{ij} | i \in I_2) | j = 1, \cdots, m \Big) \end{aligned} \tag{5}$$

I_1 is the set of positive attributes, which needs to be maximized, and I_2 is the set of negative attributes, which needs to be minimized.
To evaluate the distance between alternatives and ideal points, the Euclidean Norm is applied as shown in (6).

$$\begin{cases} S_j^+ = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^+)} \\ S_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)} \\ j = 1, \cdots, m \end{cases} \tag{6}$$

The *Similarity Index*, for the j-th alternative A_j is shown in (7). The possible values are in the range $[0 - 1]$: $C_j = 0$ when $A_j = A^-$ and $C_j = 1$ when $A_j = A^+$. The best alternative (i.e., the selected RAN) has the highest *Similarity Index*.

$$C_j = S_j^- / (S_j^- + S_j^+) \tag{7}$$

IV. Performance Comparison

This Section is structured into three contributions: *i)* definition of all adopted performance metrics; *ii)* detailed description of the test scenario and of related parameters; *iii)* obtained numerical results and comparison.

A. Performance Metrics

Given a single MN where *Network Selection* is performed, four performance metrics (i.e., $n = 4$), equally weighted ($w_i = 0.25$, $\forall i \in [1, 4]$), have been considered:

1) Received Signal Strength Indicator ($RSSI$), measured by MN;
2) maximum Capacity (C) allowed by the selected RAN to transmit traffic from a remote host to the MN;
3) Monetary Cost (M) paid by the MN to employ a given RAN;

4) Power Consumption (P) of the MN.

$RSSI$ and C are "positive" attributes to be maximized, M and P are "negative" ones to be minimized.

C, M and P are static metrics. It means that their values are constant inside a given RAN independently of the MN position. $RSSI$ is a dynamic metric. Its value changes inside a RAN according to the MN position being $RSSI$ a function of the distance between MN and Point of Access (PoA).

B. Heterogeneous Wireless Accesses Simulator

The simulation tool adopted to test *Network Selection* algorithms is the Network Simulator 2 (*ns2*). The package provided by the National Institute of Standards and Technology (NIST) [22] has been used to simulate IEEE 802.21 standard.

Each simulated scenario contains a single MN that can access the following ten Radio Access Networks (RANs): a 2000x2000 [m] UMTS cell that covers the whole simulated area; a WiMax cell; and eight WiFi cells. Two different MN speeds are considered: 3 [m/s] (pedestrian mobility case), already shown in [2], and 10 [m/s] (vehicular mobility case). The MN mobility pattern within the considered area is random. The overall duration of the simulations is set to 500 [s]. Size and position of the cell of each RAN are randomly set for each simulation run (except for the UMTS) as well as the values of the considered attributes whose range is reported in Table I.

Data transfer has been simulated by considering a remote host generating a User Datagram Protocol (UDP) stream that is transmitted to the MN through the RAN selected by the employed *Network Selection* criterion.

TABLE I
RANGE OF THE CONSIDERED ATTRIBUTES

Parameters	Range Value
Power Consumption	[0,16-0,22] W
Monetary Cost	[1-10]
WiFi Capacity	[1-20] Mbps
WiMax Capacity	2 Mbps
UMTS Capacity	0.384 Mbps

Monetary Cost is only an indicative number that ranks the network cost from $M = 1$ (cheapest) to $M = 10$ (most expensive). During the simulation runs, the applied *Network Selection* algorithm is executed every 5 [s]. This time is called *Selection Period*. Obviously the vertical handover, and, consequently, the *Network Selection*, acts only if more then one RAN is available at the MN when the *Selection Period* expires.

C. Numerical Results

Evaluated MPMO *Network Selection* algorithms are: SAW, WPM, F-SAW and TOPSIS. Four SPMO criteria are tested. Each of them is thought to optimize one of the attributes previously defined and are identified as: $RSSI_b$, C_b, M_b and P_b.

Two more metrics are adopted to evaluate *Network Selection* algorithms:

1) the number of handovers executed by the MN (H);
2) the Packet Delay (D) measured in [s] and calculated as the difference between the packet transmission time and the time in which the packet is received by the MN.

The values reported in the following figures are obtained by sampling the metrics at each second of simulation and averaging the samples at the end of the simulation for each simulation run. Simulations have been repeated until the average values of the measured metrics reach a confidence interval of 10% of the measure with a 95% confidence level.

1) $RSSI$: The $RSSI$ is the typical metric used to estimate the quality of a generic radio link. Higher the $RSSI$, better the Quality of Service (QoS) offered to users.

$RSSI$ values are shown in Figure 5. The performance

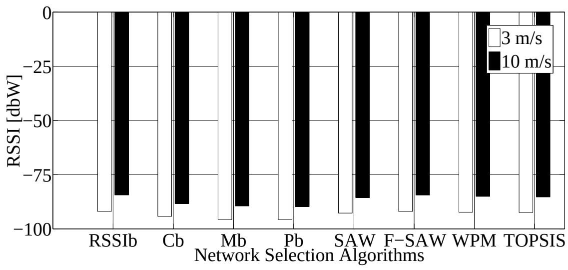

Fig. 5. Values of the $RSSI$ metric for different *Network Selection* algorithms.

of MPMO approaches is similar for both considered MN speeds. There is no advantage obtained by the employment of a specific MPMO criterion: all criteria are equivalent in terms of $RSSI$. Concerning SPMO techniques, obviously the highest $RSSI$ is obtained by the $RSSI_b$ algorithm which considers only this attribute during the selection process. It is important to note that the performance of MPMO solutions, in this case, is equivalent to the performance of the $RSSI_b$ scheme.

Concerning the two considered mobility cases, there is a slight performance increase (i.e., a higher value of the RSSI) in the vehicular mobility case with respect to the pedestrian case. Being fixed both the size of the considered area and the simulation period, this happens because, at higher speed, the MN spends more time at shorter distance from the PoAs and receives higher power levels.

2) Capacity: The Capacity (C) that a RAN assigns to the data transfer is a positive metrics that must be maximized in order to improve the QoS of the communication.

The values of the C metric are shown in Figure 6. It is possible to note a performance increase with MN speed equal to 10 [m/s] with respect to 3 [m/s] case in

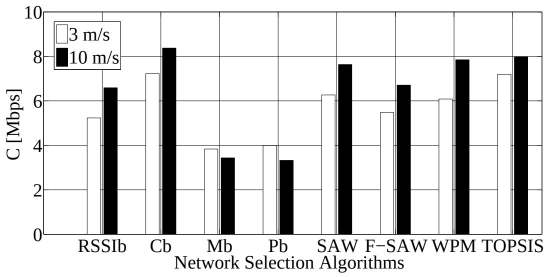

Fig. 6. Values of the C metric for different *Network Selection* algorithms.

all cases except for M_b and P_b. C_b obviously assures the best performance in both mobility cases but TOPSIS guarantees similar performance, practically overlapped to C_b for 3 [m/s] case. SAW and WPM assure satisfying performance too in particular for 10 [m/s]. F-SAW is less performing for this metric. SPMO algorithms that do not consider C as an attribute during the decision process, do not assume satisfactory performance.

3) Monetary Cost: The values of the monetary costs obtained from the simulations are reported in Figure 7. SAW, WPM and TOPSIS assure the closest performance to the M_b one. F-SAW performance is slightly worst. The cost is almost the same for the two mobility cases.

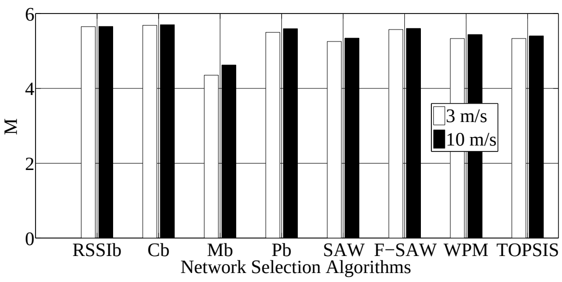

Fig. 7. Values of the M metric for different *Network Selection* algorithms.

4) Power: A user of a MN may be interested also in limiting the power consumption of the MN in order to increase battery lifetime. The values of the P metric are reported in Figure 8. Also in this case the results obtained in the two considered mobility scenarios are similar. All the algorithms assure equivalent results almost overlapped with the values obtained by P_b. The power consumed by the MN in each RAN during each simulation is constant and its value is randomly selected within the range (0,16-0,22) [W].

5) Number of Handovers: The number of executed handovers is a "negative" metric that should be minimized. An excessive number of handovers may impact negatively the QoS and the power consumption of the MN, which can be increased by the necessity to transmit the signals to carry out the handover.
The number H of executed handover during the simulated periods of 500 [s] is shown in Figure 9. The performance obtained with the two considered mobility models are,

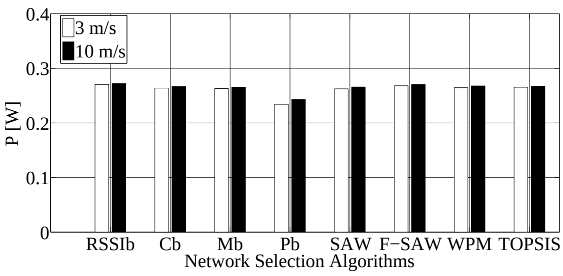

Fig. 8. Values of the P metric for different *Network Selection* algorithms.

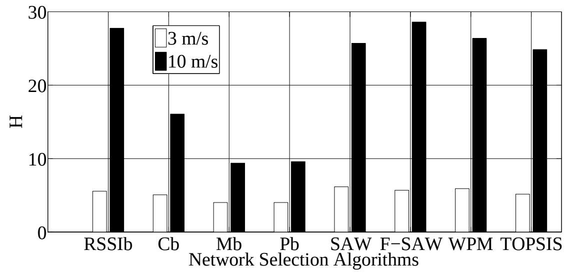

Fig. 9. Values of the H metric for different *Network Selection* algorithms.

obviously, very different. As shown in Figure 9, the number of executed handovers is much higher in the vehicular mobility case with respect to the pedestrian one: an MN moving at 10 [m/s] spends less time inside each network then a MN moving at 3 [m/s], so more handovers are necessary.
Network Selection algorithms produce the same performance trends in both mobility scenarios. C_b, P_b, and M_b are the approaches that determine the lowest number of handover executions. This happens because these algorithms consider only a single static attribute during the optimization process: when a RAN is selected, it remains in use until the MN leaves it (i.e., a Link Down event takes place [3]) or a new more effective RAN, concerning the considered metrics, is entered (i.e., a Link Up event happens [3]). On the contrary, the $RSSI_b$ algorithm takes into account an attribute, the $RSSI$, that changes dynamically within a RAN. So an handover can be executed not only after a Link Up or a Link Down event, but also when the MN is inside a network but the algorithm selects another RAN that assures a higher $RSSI$.
MPMO approaches are characterized by significant values of the H metric because they evaluate multiple attributes during the decision process and the same consideration done for $RSSI_b$ is still valid. Among MPMO algorithms, TOPSIS guarantees the lowest number of handovers.

6) Delay: Packet delay D is strictly linked to capacity C and number of handovers H. Figure 10, where D values are reported, shows that the delay is not affected by mobility scenarios. This happens because the increased number of executed handovers in the vehicular case, reported in Figure 9, is compensated by higher available capacity obtained with an MN speed of 10 [m/s], as shown in Figure 6.

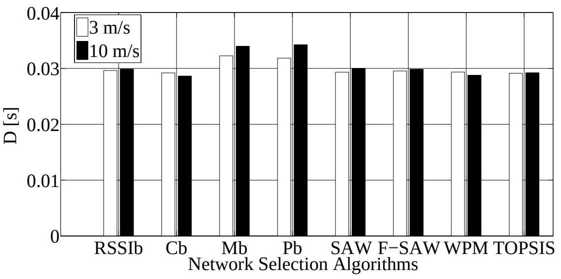

Fig. 10. Values of the D metric for different *Network Selection* algorithms.

D is approximately the same for all schemes except for M_b and P_b because they assign a small amount of capacity not compensated by the limited number of handovers.

V. CONCLUSIONS

Network Selection plays a fundamental role in mobile communications. In particular Intelligent Transportation Systems represent a possible application scenario where efficient *Network Selection* may have a positive impact.

A performance comparison of *Network Selection* algorithms employed by a Mobile Node (MN) is presented in this paper. Results are obtained through a simulator that includes IEEE 802.21 standard functions. The following Radio Access Networks (RANs) have been considered: UMTS, WiMax and WiFi. The simulated environment includes two mobility patterns for the MN: pedestrian 3 [m/s], and vehicular 10 [m/s]. Two classes of algorithms are considered: Single Performance Metric Optimization (SPMO) and Multiple Performance Metric Optimization (MPMO). MPMO techniques consider, simultaneously, different performance metrics (called attributes) during the selection process and, as a consequence, try to find a compromise among the employed metrics. Among the MPMO approaches the TOPSIS algorithm shows satisfying performance for all considered metrics.

REFERENCES

[1] E. W. C. Standards, “Intelligent transportation system.” [Online]. Available: http://www.etsi.org/website/technologies/intelligenttransportsystems.aspx
[2] I. Bisio, S. Delucchi, F. Lavagetto, and M. Marchese, “Simulative Performance Comparison of Network Selection Algorithms in the Framework of the 802.21 Standard,” in *Performance Evaluation of Computer and Telecommunication Systems (SPECTS), 2013 International Symposium on*. IEEE, July 2013.
[3] “Ieee standard for local and metropolitan area networks- part 21: Media independent handover,” *IEEE Std 802.21-2008*, pp. c1–301, 2009.
[4] G. Chen, M. Song, Y. Zhang, X. Wang, and B. Sun, “End-to-end qos guaranteed seamless handover scheme for cognitive heterogeneous networks,” in *Network Infrastructure and Digital Content, 2010 2nd IEEE International Conference on*, 2010, pp. 440–444.
[5] S. Mohanty and I. Akyildiz, “A cross-layer (layer 2 + 3) handoff management protocol for next-generation wireless systems,” *Mobile Computing, IEEE Transactions on*, vol. 5, no. 10, pp. 1347–1360, 2006.
[6] G. Chen, M. Song, Y. Zhang, X. Wang, and B. Sun, “End-to-end qos guaranteed seamless handover scheme for cognitive heterogeneous networks,” in *Network Infrastructure and Digital Content, 2010 2nd IEEE International Conference on*, sept. 2010, pp. 440 –444.
[7] W. Shen and Q.-A. Zeng, “Cost-function-based network selection strategy in integrated wireless and mobile networks,” *Vehicular Technology, IEEE Transactions on*, vol. 57, no. 6, pp. 3778 –3788, nov. 2008.
[8] H. Wang, R. Katz, and J. Giese, “Policy-enabled handoffs across heterogeneous wireless networks,” in *Mobile Computing Systems and Applications, 1999. Proceedings. WMCSA ’99. Second IEEE Workshop on*, feb 1999, pp. 51 –60.
[9] W. Shen and Q.-A. Zeng, “Cost-function-based network selection strategy in integrated wireless and mobile networks,” *Vehicular Technology, IEEE Transactions on*, vol. 57, no. 6, pp. 3778 –3788, nov. 2008.
[10] R. Chai, L. Tang, M. Xiao, and Q.-B. Chen, “Adaptive network selection algorithm based on user application profile,” in *Communications and Networking in China (CHINACOM), 2010 5th International ICST Conference on*, aug. 2010, pp. 1 –5.
[11] H. Liu, C. Maciocco, V. Kesavan, and A. Low, “Energy efficient network selection and seamless handovers in mixed networks,” in *World of Wireless, Mobile and Multimedia Networks Workshops, 2009. WoWMoM 2009. IEEE International Symposium on a*, june 2009, pp. 1 –9.
[12] Q.-T. Nguyen-Vuong, Y. Ghamri-Doudane, and N. Agoulmine, “On utility models for access network selection in wireless heterogeneous networks,” in *Network Operations and Management Symposium, 2008. NOMS 2008. IEEE*, April 2008, pp. 144–151.
[13] K. Yoon, “The propagation of errors in multiple-attribute decision analysis: A practical approach,” *The Journal of the Operational Research Society*, vol. 40, no. 7, pp. pp. 681–686, 1989.
[14] H. Yaiche, R. Mazumdar, and C. Rosenberg, “A game theoretic framework for bandwidth allocation and pricing in broadband networks,” *Networking, IEEE/ACM Transactions on*, vol. 8, no. 5, pp. 667–678, Oct 2000.
[15] Q. He, G. Chen, and L. Zhang, “A vertical handoff decision algorithm based on fuzzy control in wimax and td-scdma heterogeneous wireless networks,” in *Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on*, sept. 2010, pp. 1 –4.
[16] J. Hou and D. O’Brien, “Vertical handover-decision-making algorithm using fuzzy logic for the integrated radio-and-ow system,” *Wireless Communications, IEEE Transactions on*, vol. 5, no. 1, pp. 176–185, 2006.
[17] Q. He, “A fuzzy logic based vertical handoff decision algorithm between wwan and wlan,” in *Networking and Digital Society (ICNDS), 2010 2nd International Conference on*, vol. 2, may 2010, pp. 561 –564.
[18] Q. He, G. Chen, and L. Zhang, “A vertical handoff decision algorithm based on fuzzy control in wimax and td-scdma heterogeneous wireless networks,” in *Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on*, sept. 2010, pp. 1 –4.
[19] J. Ding, X. Xue, and G. Li, “Rss method and fuzzy logic combined vertical handoff decision algorithm,” in *Wireless Mobile and Computing (CCWMC 2009), IET International Communication Conference on*, dec. 2009, pp. 137 –139.
[20] A. Singhrova and N. Prakash, “Adaptive vertical handoff decision algorithm for wireless heterogeneous networks,” in *High Performance Computing and Communications, 2009. HPCC ’09. 11th IEEE International Conference on*, june 2009, pp. 476 –481.
[21] I. Bisio and M. Marchese, “Attributes definitions and measurement methods for madm based sink selection controls in satellite sensor networks,” in *Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008. IEEE*, 30 2008-dec. 4 2008, pp. 1 –5.
[22] U. D. of Commerce, “Nist national institue of standards and technology.” [Online]. Available: http://www.nist.gov/index.html

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