# Access Network Selection in a Heterogeneous Environment Using the AHP and Fuzzy TOPSIS Methods

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**Abstract.** The problem of network selection across heterogeneous wireless networks has recently received much attention because of a drive for converged communication systems. However, since the selection of an access network depends on several parameters with different relative importance, such as the network and the application characteristics, the user preferences, the service cost, etc, it is a difficult task to be achieved. In this paper an effective access network selection algorithm for heterogeneous wireless networks is proposed that combines two Multi Attribute Decision Making (MADM) methods, the Analytic Hierarchy Process (AHP) method and the fuzzy Total Order Preference by Similarity to the Ideal Solution (TOPSIS) method. More specifically, the AHP method is used to determine weights of the criteria, and the fuzzy TOPSIS method is used to obtain the final access network ranking.

**Keywords:** Wireless Network; Network Selection; MADM; Heterogeneous Environment; AHP; TOPSIS; fuzzy TOPSIS.

## 1 Introduction

The increased need of users for ubiquitous service coverage and provision of different types of service leads to development of the heterogeneous networks. In such an environment, soon it will be very common for a user to hold a mobile device equipped with multiple interfaces in order to access all the wireless technologies of the heterogeneous network. However, since these wireless technologies differ widely in terms of their capabilities, cost and coverage, the selection of the optimal access network is a very challenging task.

The problem of network selection across heterogeneous wireless networks has recently received much attention because of a drive for converged communication systems. In this context, authors in [1] proposed the combined application of two mathematical

P. Chatzimisios et al. (Eds.): MobiLight 2010, LNICST 45, pp. 88–98, 2010.

techniques in an algorithm for network selection between Universal Mobile Telecommunications System (UMTS) and wireless local area networks (WLANs). Work in [2] proposed network selection based on a resource allocation strategy for efficient resource utilization in a heterogeneous network environment. In [3], the authors evaluated heterogeneous networks, using measures of specific parameters from each network.

Moreover, since the selection of an access network depends on several parameters with different relative importance, such as the network and the application characteristics, the user preferences, the service cost, etc, the access network selection problem is usually looked at from the aspect of multi-criteria analysis, and more specifically by applying different Multi Attribute Decision Making (MADM) algorithms [4,5]. More specifically, Bari and Leung [4] apply the ELECTRE method in order to solve the problem of network selection. In [5] the authors propose the TOPSIS in order to rank the candidate networks for service delivery to the terminal. Work in [6] presented an approach that combines two methods, the AHP (Analytical Hierarchy Process) and GRA (Grey Relational Analysis) in order to evaluate the total QoS. Wu *et al.* [7] applied the AHP method to determine weights of their QoS criteria for the network selection. Charilas *et al.* [8] combined Fuzzy AHP and ELECTRE in order to assign weight to the criteria and to rank the candidate networks.

In this paper, we propose an effective access network selection algorithm for heterogeneous wireless networks that combines two MADM methods, the AHP method and the fuzzy Total Order Preference by Similarity to the Ideal Solution (TOPSIS) method. More specifically, the AHP method is used to determine weights of the criteria, and the fuzzy TOPSIS method is used to obtain the final access network ranking. The novelty of this approach is that instead of applying fuzziness during the determination of the weights, the fuzziness is applied during the ranking of the candidate networks. This comes from the observation that is much easier and more precise to determine the level of influence of the criteria than to characterize the value of a criterion, e.g. the security degree of a network. For this reason linguistic values are used for the evaluation of the candidate networks, and more specifically the fuzzy TOPSIS method presented [9] is used for the final access network ranking.

The rest of the paper is organized as follows: Section 2 provides an overview of the fuzzy set theory and Section 3 presents the MADM methods, AHP and fuzzy TOPSIS that are employed in our access network selection algorithm. Section 4 illustrates a numerical example of the proposed algorithm, whereas Section 5 concludes the paper and presents future research.

## 2 Fuzzy Set Theory Basics

### 2.1 Fuzzy Numbers

The Fuzzy set theory was first introduced by Zadeh [10] in order to deal with vague, imprecise and uncertain problems, and it has been used as a modeling tool for complex systems that can be controlled by humans but are hard to define precisely [11]. The theory is based on the fuzzy sets, i.e. sets, whose elements belong to the set with some degree of membership that is most commonly expressed by real numbers in the unit interval $[0,1]$.

*Definition 1.* Assuming that X is a set, then the fuzzy set $\widetilde{A}$ on X is characterized by a membership function $\mu$ that associates with each element x in X a real number in the unit interval $[0,1]$.

*Definition 2.* A convex fuzzy variable $\widetilde{\alpha}$ is referred as fuzzy number if its membership function $\mu_{\widetilde{\alpha}}(x)$ is piecewise continuous and if has the functional value $\mu_{\widetilde{\alpha}}(x) = 1$ at precisely one of the x values with $x = x_r = x_l = 1$ where

$$x_l = \min\left[x \in IR \mid \mu_{\widetilde{\alpha}}(x) = 1\right] \text{ and } x_r = \max\left[x \in IR \mid \mu_{\widetilde{\alpha}}(x) = 1\right]$$

In this paper triangular number is used in our model. A triangular fuzzy number is defined by a triplet $(\alpha_1, \alpha_2, \alpha_3)$. The membership function $\mu_{\widetilde{\alpha}}$ of a fuzzy number $\widetilde{\alpha}$ is given by

$$\mu_{\widetilde{\alpha}}(x) = \begin{cases} 0 & x < a_1 \\ (x - \alpha_1)/(\alpha_2 - x) & a_1 \le x \le a_2 \\ (x - \alpha_3)/(\alpha_3 - \alpha_2) & a_2 \le x \le a_3 \\ 0 & x > a_3 \end{cases} \tag{1}$$

Assuming that $\widetilde{A} = (\alpha_1, \alpha_2, \alpha_3)$, $\widetilde{B} = (b_1, b_2, b_3)$ are two positive triangular fuzzy numbers, then the following operational laws can be defined:

$$\widetilde{A}(+)\widetilde{B} = (\alpha_1, \alpha_2, \alpha_3)(+)(b_1, b_2, b_3) = (\alpha_1 + b_1, \alpha_2 + b_2, \alpha_3 + b_3) \tag{2}$$

$$\widetilde{A}(-)\widetilde{B} = (\alpha_1, \alpha_2, \alpha_3)(-)(b_1, b_2, b_3) = (\alpha_1 - b_1, \alpha_2 - b_2, \alpha_3 - b_3) \tag{3}$$

$$\widetilde{A}(\cdot)\widetilde{B} = (\alpha_1, \alpha_2, \alpha_3)(\cdot)(b_1, b_2, b_3) = (\alpha_1 b_1, \alpha_2 b_2, \alpha_3 b_3) \tag{4}$$

$$\widetilde{A}(/)\widetilde{B} = (\alpha_1, \alpha_2, \alpha_3)(/)(b_1, b_2, b_3) = (\alpha_1 / b_1, \alpha_2 / b_2, \alpha_3 / b_3) \tag{5}$$

### 2.2 Linguistic Variables

Linguistic variable is a variable that is represented in linguistic terms, i.e words sentences, etc, and whose value can be modeled by a fuzzy set [12]. The concept of linguistic variables can be very useful in dealing with complex or poorly defined to be reasonably described in conventional quantitative expressions evaluation problems. In this paper the importance weights of various criteria and the ratings of qualitative criteria are expressed linguistic variables. These linguistic variables are shown in Table 1.

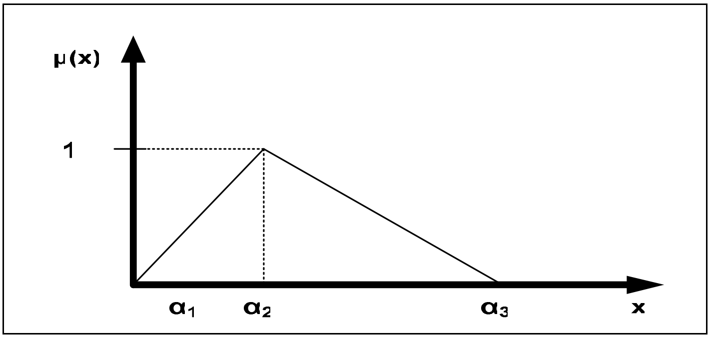

**Fig. 1.** Triangular fuzzy number

**Table 1.** Linguistic variables

| | |
|---|---|
| Very Low (VL) | (0, 0, 0.2) |
| Low (L) | (0, 0.2, 0.4) |
| Medium (M) | (0.2, 0.4, 0.6) |
| High (H) | (0.4, 0.6, 0.8) |
| Very High (VH) | (0.6, 0.8, 1) |
| Excellent (E) | (0.8, 1, 1) |

# 3 Multi-Attribute Decision Making (MADM) Methods

## 3.1 The AHP Method

The Analytic Hierarchy Process (AHP) method was introduced by Saaty [13] with goal the making of decisions about complicated problems by dividing such problems into a hierarchy of decision factors which are simple and easy to analyze. It consists of the following steps:

> Step 1- *Determination of the objective and the decision factors*: During this step the final objective of the problem is analyzed as a number of decision factors, which are also further analyzed until the problem acquires a hierarchical structure, in the lowest level of which the alternative solutions of the problem are found.
>
> Step 2- *Determination of the relative importance of the decision factors with respect to the objective:* During this step, in each level the decision factors are compared pairwise according to their levels of influence with respect to the scale shown in Table 2.

The comparison results are presented in a square matrix $A = [\alpha_{ij}]_{n\times n}$ where n are the number of factors, and $\alpha_{ii} = 1, \alpha_{ji} = 1/\alpha_{ij}, \alpha_{ij} \neq 0$.

**Table 2.** Scale of Importance

| **Intensity of importance** | **Definition** |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Extreme importance |
| 2,4,6,8 | Intermediate values |

Step 3-*Normalization and Calculation of the relative weights:* The relative weights are calculated by finding the right eigenvector (w) corresponding to the largest eigenvalue ($\lambda_{\max}$), as

$$A_w = \lambda_{\max} w \tag{6}$$

In order to avoid potential comparative inconsistency within pairs of categories, a Consistency Index (CI) is defined as

$$CI = \frac{(\lambda_{\max} - n)}{n-1} \tag{7}$$

The Consistency Ratio (CR) is calculated by dividing the CI by the Random consistency Index (RI), and is given by

$$CR = \frac{CI}{RI} \tag{8}$$

If the value of CR is smaller or equal to 10%, the inconsistency is acceptable; otherwise the subjective judgment is revised.

### 3.2 The Fuzzy TOPSIS Method

The Total Order Preference by Similarity to the Ideal Solution (TOPSIS) method was first introduced by Hwang and Yoon [14], and it is based on the idea that the best alternative should have the shortest distance from the positive ideal solution and farthest distance from the negative ideal solution. In our approach the fuzzy TOPSIS is adopted in order evaluate the candidate networks by using linguistic values.

The Fuzzy TOPSIS method consists of the following steps:

Step 1- *Construction of the fuzzy decision matrix*: The Decision Matrix is expressed as

$$\tilde{D}=\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array}\begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array} \\ \begin{bmatrix} \tilde{d}_{11} & \tilde{d}_{12} & \cdots & \tilde{d}_{1m} \\ \tilde{d}_{21} & \tilde{d}_{22} & \cdots & \tilde{d}_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{d}_{n1} & \tilde{d}_{n2} & \cdots & \tilde{d}_{nm} \end{bmatrix} \end{array} \tag{9}$$

where $A_1, A_2, \ldots, A_n$ are the possible alternatives and $C_1, C_2, \ldots, C_n$ are the criteria, which measure the performance of the alternatives. Each element $\tilde{d}_{ij}$ of the fuzzy decision matrix $\tilde{D}$ is the linguistic value of the alternative $A_i$ with respect to the criterion $C_j$. It should be noted that since the fuzzy linguistic rating $\tilde{d}_{ij}$ preserves the property that the ranges of normalized triangular fuzzy numbers belong to [0,1]; there is no need for normalization.

Step 2- *Construction of the weighted normalized fuzzy decision matrix:* The weighted normalized fuzzy decision matrix is constructed by multiplying each element $\tilde{r}_{ij}$ with its associated weight $w_j$

$$\tilde{u}_{ij} = \tilde{r}_{ij} w_j \tag{10}$$

Step 3- *Determination of the Fuzzy Positive-Ideal Solution (FPIS) and Fuzzy Negative-Ideal solution (FNIS):* The positive and negative ideal solutions, FPIS $A^+$ and FNIS $A^-$ respectively, can be defined as:

$$A^+ = \left(\tilde{u}_1^+, \tilde{u}_2^+, \ldots, \tilde{u}_n^+\right) \tag{11}$$

and

$$A^- = \left(\tilde{u}_1^-, \tilde{u}_2^-, \ldots, \tilde{u}_n^-\right) \tag{12}$$

Step 4- *Measurement of the distance of each alternative from FPIS and FNIS:* The distance of each alternative from the ideal and the negative ideal solution is given

$$S_i^+ = \sum_{i=1}^{n} d\left(\tilde{u}_{ij}, \tilde{u}_j^+\right), , j = \{1, \ldots, m\} \tag{13}$$

$$S_i^- = \sum_{i=1}^{n} d\left(\tilde{u}_{ij}, \tilde{u}_j^-\right), , j = \{1, \ldots, m\} \tag{14}$$

Step 5- *Relative Closeness Calculation:* The relative closeness is defined to determine the relative closeness of each alternative $A_i (i = 1,2,\cdots,n)$ from the ideal solution. It is expressed as

$$C_i = \frac{S_i^-}{S_i^- + S_i^+} \left(i = 1,2,\ldots,n\right) \tag{15}$$

Step 6: *Preference Order Ranking:* The best alternatives are ranked according to the $C_i$ value in descending order.

## 4 Numerical Results

In order to demonstrate how the previously described methods can be utilized for the access network selection, we consider a heterogeneous wireless network that is composed by a Universal Mobile Telecommunications System (UMTS) network, a Worldwide Interoperability for Microwave Access (WiMAX) network and two Wireless Local Area Networks (WLANs), employing the IEEE 802.11b (WLAN1) and IEEE 802.11g (WLAN2) technologies (Figure 2).

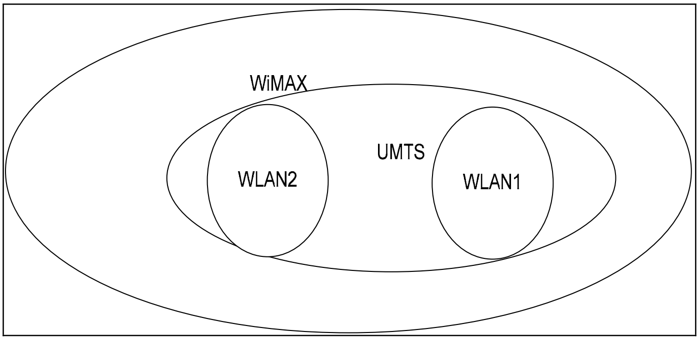

**Fig. 2.** The Network Topology

We focus our attention on the case that the decision for the network selection is influenced by the requested application indicated by the user. Thus, we consider three applications that are very often used by users, namely VoIP, media streaming and web browsing. In order to determine the importance of the network parameters in these applications, the AHP method is applied. Tables 3 and 4 present the pairwise comparison matrices for the VoIP applications that were formed using the scale of importance of Table 1, while Tables 5 and 6 present the pairwise comparison matrices for the streaming media and the web browsing applications, respectively. The results obtained from the computations based on the pairwise comparison matrices are presented in Figure 3.

**Table 3.** The pairwise comparison matrix for the basic network parameters for VoIP Applications

| VoIP | Throughput | Latency | Reliability | Cost | Security | Weight |
|---|---|---|---|---|---|---|
| Throughput | 1 | 1/5 | 1/5 | 1/3 | 5 | 0.0937 |
| Latency | 5 | 1 | 3 | 3 | 5 | 0.3455 |
| Packet Loss | 5 | 1/3 | 1 | 5 | 5 | 0.3608 |
| Cost | 3 | 1/3 | 1/5 | 1 | 5 | 0.1564 |
| Security | 1/5 | 1/5 | 1/5 | 1/5 | 1 | 0.0436 |

**Table 4.** The pairwise comparison matrix for the network latency sub-parameters for VoIP Applications

| | Delay | Jitter | Weight |
|---|---|---|---|
| Delay | 1 | 1 | 0.5 |
| Jitter | 1 | 1 | 0.5 |

**Table 5.** The pairwise comparison matrix for the basic network parameters for Streaming Media Applications

| Streaming Media | Throughput | Latency | Reliability | Cost | Security | Weight |
|---|---|---|---|---|---|---|
| Throughput | 1 | 5 | 3 | 3 | 5 | 0.4506 |
| Latency | 1/5 | 1 | 1 | 1/3 | 5 | 0.1196 |
| Packet Loss | 1/3 | 1 | 1 | 1/3 | 5 | 0.1308 |
| Cost | 1/3 | 3 | 3 | 1 | 5 | 0.2554 |
| Security | 1/5 | 1/5 | 1/5 | 1/5 | 1 | 0.0436 |

**Table 6.** The pairwise comparison matrix for the basic network parameters for Web Streaming Applications

| Web browsing | Throughput | Latency | Reliability | Cost | Security | Weight |
|---|---|---|---|---|---|---|
| Throughput | 1 | 5 | 3 | 1 | 5 | 0.3705 |
| Latency | 1/5 | 1 | 1 | 1/3 | 5 | 0.1264 |
| Packet Loss | 1/3 | 1 | 1 | 1/3 | 5 | 0.1358 |
| Cost | 1 | 3 | 3 | 1 | 5 | 0.3226 |
| Security | 1/5 | 1/5 | 1/5 | 1/5 | 1 | 0.0447 |

Since the weights of the criteria were determined, then the fuzzy TOPSIS is applied in order to rank the alternative networks. More specifically, during the first step the fuzzy decision matrix (Table 7) is established by the evaluation of alternative networks using the linguistic variables of Table 1. The linguistic variables are in the first line of each row of Table 7, while the second line represents the triangular fuzzy number which is equivalent of the respective linguistic variable.

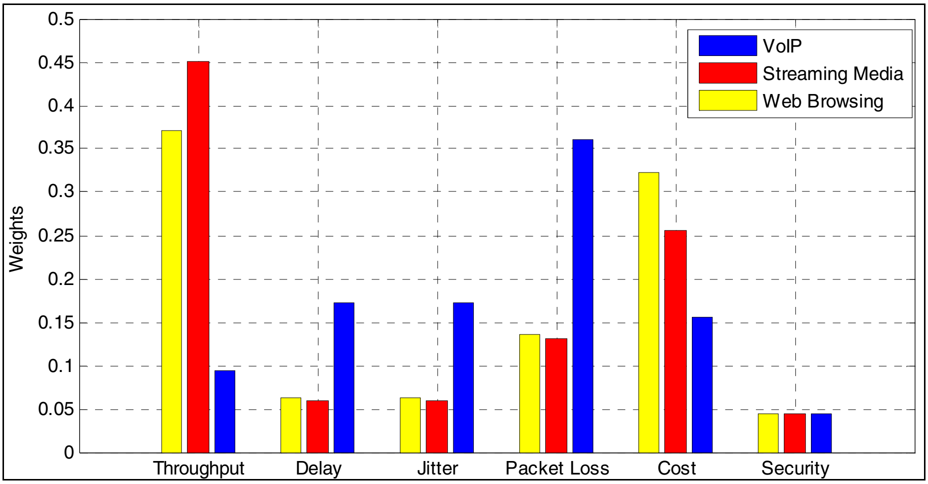

**Fig. 3.** Weights associated with attributes for different applications

After the fuzzy decision matrix was determined, the fuzzy weighted decision table is constructed by using the criteria weights calculated by AHP (Figure 3). Then, we define the fuzzy positive and negative ideal solutions FPIS $A^+$ and FNIS $A^-$ as $\tilde{u}_j^+ = (1,1,1)$ for benefit criterion, and as $\tilde{u}_j^- = (0,0,0)$ for cost criterion. Afterwards, the distance of each alternative from the ideal and the negative ideal solutions for each application is computed. Finally, the ranking of each access network for the three applications considered in this work is depicted in Figure 4.

**Table 7.** Fuzzy evaluation matrix for the alternative networks

| Networks | Throughput (Mbps) | Delay (ms) | Jitter (ms) | Packet Loss (%) | Cost (price) | Security (degree) |
|---|---|---|---|---|---|---|
| UMTS | VL<br>(0, 0.2, 0.4) | M<br>(0.2, 0.4, 0.6) | M<br>(0.2, 0.4, 0.6) | H<br>(0.4, 0.6, 0.8) | H<br>(0.4, 0.6, 0.8) | H<br>(0.4, 0.6, 0.8) |
| WiMAX | E<br>(0.8, 1, 1) | M<br>(0.2, 0.4, 0.6) | M<br>(0.2, 0.4, 0.6) | H<br>(0.4, 0.6, 0.8) | M<br>(0.2, 0.4, 0.6) | M<br>(0.2, 0.4, 0.6) |
| WLAN1 | M<br>(0.2, 0.4, 0.6) | H<br>(0.4, 0.6, 0.8) | M<br>(0.2, 0.4, 0.6) | M<br>(0.2, 0.4, 0.6) | L<br>(0, 0.2, 0.4) | L<br>(0, 0.2, 0.4) |
| WLAN2 | E<br>(0.8, 1, 1) | H<br>(0.4, 0.6, 0.8) | H<br>(0.4, 0.6, 0.8) | M<br>(0.2, 0.4, 0.6) | L<br>(0, 0.2, 0.4) | L<br>(0, 0.2, 0.4) |

**Table 8.** Distances from FPIS and FNIS for each application

| | VoIP | Streaming | Web browsing | | VoIP | Streaming | Web browsing |
|---|---|---|---|---|---|---|---|
| $S^+$ | 2,240738 | 2,347383 | 2,426126 | $S^-$ | 3,661741 | 3,562669 | 3,606211 |
| | 1,915713 | 1,975779 | 2,336375 | | 3,952175 | 3,899124 | 3,69291 |
| | 2,053605 | 2,242848 | 2,33227 | | 3,821002 | 3,639801 | 3,706624 |
| | 1,866785 | 2,012137 | 2,315001 | | 3,995848 | 3,855861 | 3,719506 |

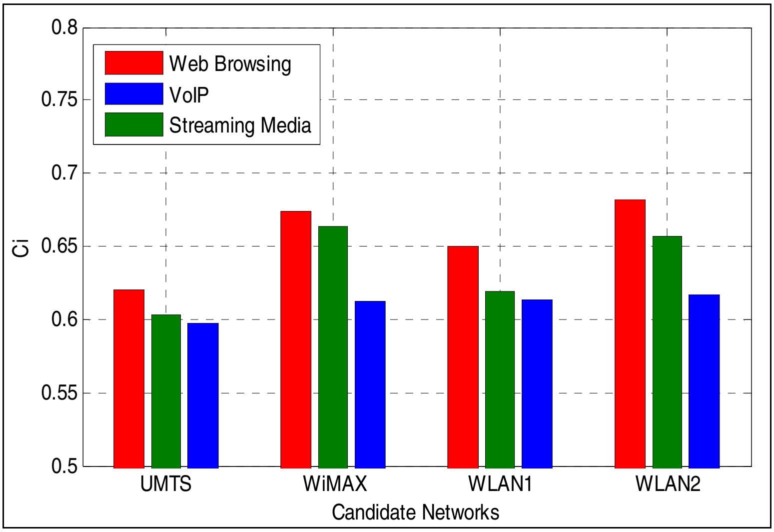

**Fig. 4.** Results obtained from the fuzzy TOPSIS algorithm for each application

## 5 Conclusions

Ubiquitous service delivery requires the selection of the optimal access network in a heterogeneous wireless environment. The MADM methods provide an effective framework for ranking the candidate networks in a heterogeneous wireless environment by means of their ratings with respect to multiple attributes. In this paper, an access network selection algorithm for heterogeneous wireless networks is proposed that combines two MADM methods, the AHP method to determine the importance of the network parameters and the TOPSIS method to rank the candidate networks. The novelty of the proposed approach is that instead of applying fuzziness during the determination of the weights, the fuzziness is applied during the ranking of the candidate networks, since it is more precise to determine the level of influence of the criteria than to characterize the value of a criterion. Numerical results showed that the combination of these two methods can be very effective for the selection of the optimal access network according to requirements of the application that the user wishes to utilize.

Future work includes evaluating the efficiency of the proposed access network selection algorithms during vertical handoffs in heterogeneous environments since the computational complexity is minimal. Moreover, we are targeting at taking into account additional criteria for the optimal network selection such as availability of network resources, Received Signal Strength (RSS) and Signal-to-Noise Ratio (SNR).

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