

# Application of Fuzzy AHP and ELECTRE to Network Selection

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**Abstract.** In a heterogeneous wireless network environment services are ubiquitously delivered over multiple wireless access technologies. Ranking of the alternatives and selection of the most efficient and suitable access network to meet the QoS requirements of a specific service, as these are defined by the user, constitutes thus an important issue. Decisions on which network to connect to are however difficult to be reached, since multiple factors of different relative importance have to be taken into consideration. This paper addresses this difficulty by adopting Multi Attribute Decision Making (MADM) methods. Fuzzy AHP, a MADM method, is initially applied to determine the weights of certain Quality of Service indicators that act as the criteria impacting the decision process. The fuzzy extension of the method, and consequently the use of fuzzy numbers, is adopted in order to incorporate the existence of fuzziness as a result of subjective evaluations. Afterwards, ELECTRE, a ranking MADM method, is applied to rank the alternatives, in this case wireless networks, based on their overall performance.

**Keywords:** Wireless Networks, Fuzzy Logic, Fuzzy Triangular Numbers, Multi Attribute Decision Making, Analytic Hierarchy Process, ELECTRE.

## 1 Introduction

The heterogeneous wireless networks integrate different access networks, such as IEEE 802.15 WPAN, IEEE 802.11 WLAN, IEEE 802.16 WMAN, GPRS/ EDGE, cdma2000, WCDMA and satellite network, etc. The proliferation of wireless access technologies, along with the evolution of the end-user terminals (smart phones, PDAs, etc. . .) are leading fast towards a ubiquitous, pervasive and rich connectivity offer, such that the end users won't just be always connected, but also always covered by multiple access networks / technologies. Selection of the most efficient and suitable access network to meet a specific application's QoS requirements has thus recently become a significant topic, the actual focus of which is maximizing the QoS experienced by the user. The end-users can potentially take wise decisions on which access network to connect to on the basis of several merit functions including the current load of the network and the cost-for-connectivity. However, since multiple factors have to be taken into account, it is no longer easy to rank the candidate networks according to

preference on a single criterion. In such cases, multiple criteria have to be combined and scaled in a meaningful way. In addition, various criteria in the decision process may oppose to each other, e.g., a desirable increase in QoS may require an undesirable increase of price. Thus, trade-offs are sometimes required.

Current approaches for network selection may involve either Fuzzy Logic-based schemes or Multi Attribute Decision Making (MADM) methods. In the first one, a group of fuzzy logic rules in the form of linguistic IF-THEN expressions have to be defined to model network selection [1] [2]. However, such rules have to be configured by the user manually prior to selection and their complexity becomes overwhelming high as the number of attributes increases. Thus, the scalability of the fuzzy logic-based schemes is extremely low, which limits their usage in wireless networks selection.

MADM on the other hand involves the selection of a series of criteria that impact the decision process and the comparison of the alternatives taking into account the relative importance of these criteria. More specifically, a weight is assigned to each criterion to reflect its importance in the final decision and then alternatives are evaluated based on their overall performance. MADM provides a solid framework for network selection, since the latter constitutes a multi-criteria problem. Several researchers have considered the use of MADM algorithms to rank candidate networks in a preference order [3]. Numerous types of MADM algorithms exist [4]. Several of them may be suitable for solving a decision problem so that the decision maker may encounter the task of selecting amongst a number of feasible methods the most appropriate one. Common QoS parameters, such as Delay, Jitter, Packet Loss, Throughput etc can be used as criteria in such schemes. Furthermore, additional criteria may involve Availability, Reputation, Access Delay, Cost etc. MADM requires also an initial indication on each parameter's relative importance with regard to other parameters. As far as network selection is concerned, such an indication may be acquired from questionnaires or measurements [5] [6]. Criteria such as user satisfaction or cost are rather subjective and it is preferable that they are expressed in linguistic terms that correspond to fuzzy numbers. Wenhui Zhang in [7] addresses the issue of imprecise criteria, whose values cannot be easily obtained.

D. Charilas et al. in [5] [6], as well as Abbas Jamalipour et al. in [8] [9], demonstrate an example of how network selection can be modeled using two MADM methods, AHP and GRA. Farooq Bari and Victor Leung demonstrate in [10] how network selection can be approached using another MADM method, called ELECTRE. This method performs pair-wise comparisons among the alternatives for each one of the criteria separately to establish outranking relationships between them.

In this paper network selection is modeled using two MADM methods: Fuzzy AHP (FAHP), which is an extended version of AHP to support fuzzy numbers, and ELECTRE. The relative importance of selection criteria is modeled as a fuzzy number since objective judgment cannot be guaranteed. Using vague comparisons, FAHP is applied to provide a fuzzy weight for each criterion involved in the selection process. Through the process of defuzzification crisp weights are finally obtained, and are used as input data for ELECTRE. The latter provides a ranking of all alternatives.

The paper is structured as follows. Section 1 is an introduction to the problem addressed. Section 2 provides an insight to fuzzy numbers, while Section 3 presents the MADM methods, FAHP and ELECTRE, to be used in the following analysis. In

section 4 a numerical example is provided, to illustrate the proposed scheme. Finally, Section 5 concludes the work.

## 2 Fuzzy Numbers

The fuzzy sets theory, introduced by Zadeh (1965) to deal with vague, imprecise and uncertain problems, has been used as a modeling tool for complex systems that can be controlled by humans but are hard to define precisely. The main characteristic of fuzziness is the grouping of individuals into classes that do not have sharply defined boundaries. An uncertain comparison can be represented by a fuzzy number. A fuzzy set is one that assigns grades of membership between 0 and 1 to objects using a particular membership function  $\mu_A(x)$ . A triangular fuzzy number is a special type of fuzzy number whose membership is defined by three real numbers, expressed as  $(l, m, u)$ , where  $l$  is the lower limit value,  $m$  is the most promising value and  $u$  is the upper limit value. Particularly, when  $l = m = u$ , fuzzy numbers become crisp numbers. The triangular fuzzy numbers are represented as shown in Figure 1.

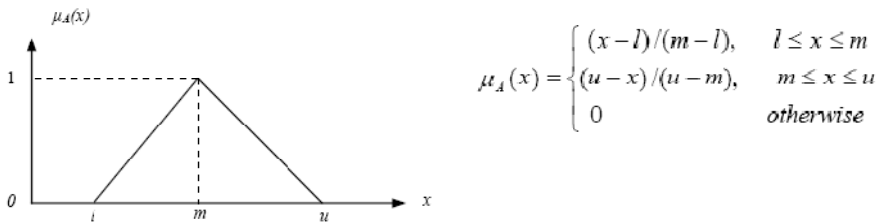


Fig. 1. Triangular Fuzzy Number

## 3 Multi-attribute Decision Making Methods

### 3.1 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is one of the extensively used multi-attribute decision-making methods. Since 1977 that Saaty [11] proposed AHP as a decision aid to help solve unstructured problems in economics, social and management sciences, the method has been applied in a variety of contexts, including telecommunications [12]. One of the main advantages of this method is the relative ease with which it handles multiple criteria. In addition to this, AHP is easy to understand and it can effectively handle both qualitative and quantitative data. Finally, the use of AHP does not involve complex mathematics.

The AHP decision problem is structured hierarchically at different levels, each level consisting of a finite number of decision elements. The top level of the hierarchy represents the overall goal, while the lowest level is composed of all possible alternatives. One or more intermediate levels embody the decision criteria and sub-criteria. The relative importance of the decision elements (weights of criteria and scores of alternatives) is assessed indirectly through a series of comparative judgments during

the second step of the decision process. The decision-maker is required to provide his/her preferences by comparing all criteria, sub-criteria and alternatives with respect to upper level decision elements. The standard preference scale used for AHP ranges from 1 that indicates “equal importance” to 9 representing “extreme importance”; however sometimes different evaluation scales can be used, such as 1 to 5. The values of the weights and scores are elicited from these comparisons and represented in a decision table.

### 3.2 Fuzzy AHP

In spite of its popularity the conventional AHP method is often criticized for its inability to adequately handle the inherent uncertainty and imprecision associated with the mapping of the decision-maker’s perception to exact numbers, i.e. for the fact that it does not reflect human thinking. A natural way to cope with uncertainty in judgments is to express the comparison ratios as fuzzy sets or fuzzy numbers, which reflect the vagueness of human thinking. In this frame, a vague evaluative judgment resulting from the comparison of any two elements at the same level of the decision hierarchy can be represented by a fuzzy number. Therefore, fuzzy AHP (FAHP), a fuzzy extension of AHP, has been developed to solve hierarchical fuzzy problems [13]. In the fuzzy-AHP procedure, the pair wise comparisons in the judgment matrix are fuzzy numbers that are modified according to the designer’s focus. Based on a set of standardized answers (linguistic variables) provided through appropriate question forms, the corresponding triangular fuzzy values are defined and the pair wise comparisons matrix  $\tilde{A}$  is constructed as

$$\tilde{A} = (\tilde{a}_{ij})_{n \times n} = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \dots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \dots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \dots & (1,1,1) \end{bmatrix}$$

where  $\tilde{a}_{ij}$  denotes a triangular fuzzy number depicting the relative strength of two elements. Note that the decision matrix is symmetric, meaning that

$$\tilde{a}_{ji} = \left[ \tilde{a}_{ij} \right]^{-1} = (l_{ij}, m_{ij}, u_{ij})^{-1} = \left( \frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}} \right)$$

Final weights of alternatives can be acquired from different methods that have been proposed in the literature. One of the most popular is the Fuzzy Extent Analysis, proposed by Chang (1996) [14]. The value of fuzzy synthetic extent with respect to the  $i_{th}$  object is defined with the help of fuzzy arithmetic operations as:

$$\tilde{S}_i = \sum_{j=1}^n \tilde{a}_{ij} \otimes \left[ \sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{kj} \right]^{-1} \tag{1}$$

The fuzzy addition operation of  $n$  extent analysis values as well as the inverse of the vector are given by equations (2) and (3) respectively.

$$\sum_{j=1}^n \tilde{a}_{ij} = \left( \sum_{j=1}^n l_{ij}, \sum_{j=1}^n m_{ij}, \sum_{j=1}^n u_{ij} \right) \tag{2}$$

$$\left[ \sum_{i=1}^n \sum_{j=1}^n \tilde{a}_{ij} \right]^{-1} = \left( \frac{1}{\sum_{i=1}^n \sum_{j=1}^n u_{ij}}, \frac{1}{\sum_{i=1}^n \sum_{j=1}^n m_{ij}}, \frac{1}{\sum_{i=1}^n \sum_{j=1}^n l_{ij}} \right) \tag{3}$$

The possibility of  $\tilde{S}_1 \geq \tilde{S}_2$  is defined as  $V(\tilde{S}_1 \geq \tilde{S}_2) = SUP_{x \geq y} [\min(\tilde{S}_1(x), \tilde{S}_2(y))]$ ,  $x$  and  $y$  being the values on the axis of the membership function of each criterion. This expression can be equivalently written as:

$$V(\tilde{S}_1 \geq \tilde{S}_2) = \begin{cases} 1, & m_1 \geq m_2 \\ 0, & l_2 \geq u_1 \\ \frac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)}, & otherwise \end{cases} \tag{4}$$

To compare  $\tilde{S}_1$  and  $\tilde{S}_2$ , both the values of  $V(\tilde{S}_1 \geq \tilde{S}_2)$  and  $V(\tilde{S}_2 \geq \tilde{S}_1)$  are needed. The possibility for a convex fuzzy number to be greater than  $k$  convex fuzzy numbers  $\tilde{S}_i$  ( $i = 1, 2, \dots, k$ ) is defined by:

$$V(\tilde{S} \geq \tilde{S}_1, \tilde{S}_2, \dots, \tilde{S}_k) = V\left[\tilde{S} \geq \tilde{S}_1 \text{ and } \tilde{S} \geq \tilde{S}_2 \text{ and } \dots \text{ and } \tilde{S} \geq \tilde{S}_k\right] = \min V(\tilde{S} \geq \tilde{S}_i), i = 1, 2, 3, \dots, k \tag{5}$$

Assuming that  $d'_i = \min V(\tilde{S}_i \geq \tilde{S}_k)$ , the weight vector is given by  $w' = (d'_1, d'_2, \dots, d'_n)^T$

Via normalization, the normalized (non-fuzzy) weight vector is

$$W = (d_1, d_2, \dots, d_n)^T \tag{6}$$

### 3.3 ELECTRE

In this section we present ELECTRE, another type of MADM algorithm, which performs pair wise comparisons among the alternatives, in order to establish outranking relationships between them. The method was first developed by Bernard Roy and its acronym stands for ELimination Et Choix Traduisant la REALité (ELimination and Choice Expressing REALity). The problem of network selection can be modeled through the use of ELECTRE as  $P = (A, C, w)$ , where

- $A = \{1, \dots, N\}$  denotes the set of alternatives, in this case candidate networks
- $C = \{1, \dots, M\}$  denotes the set of criteria impacting the decision process of network selection,
- $w = \{1, \dots, M\}$  denotes the set of weights assigned to the selected criteria depending on the information about the specific service requested or the user QoS profile, so that  $\sum_{i=1}^M w_i = 1$ .

Based on the scores achieved for each one of the selected criteria (attributes), the  $i_{th}$  candidate network can be represented by a vector as follows:

$$NW_i = [D_i \quad J_i \quad B_i \quad T_i \quad C_i]$$

For  $N$  alternative networks to be considered in the selection process, a matrix  $NW$  is formulated as follows:

$$NW = \begin{bmatrix} D_1 & J_1 & B_1 & T_1 & C_1 \\ D_2 & J_2 & B_2 & T_2 & C_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ D_N & J_N & B_N & T_N & C_N \end{bmatrix}$$

At this point attention must be drawn to the fact that the utility associated with each alternative is a monotonically decreasing function of Delay, Jitter, BER and Cost and a monotonically increasing function of Throughput. However, since ELECTRE presupposes a monotonically increasing or decreasing level of importance for all criteria considered, the modification of the method presented in [10] is adopted here as well in order to provide a complete ranking of all the alternatives. The main idea of this modification lies in the concept of a reference network, which is considered as an access network that demonstrates the desired performance with regard to all criteria in question as this is perceived by the user. The reference access network is represented as

$$NW_{ref} = [D_{ref} \quad J_{ref} \quad B_{ref} \quad T_{ref} \quad C_{ref}]$$

and is used to calculate the absolute difference between the value of each one of the attributes of matrix  $NW$  and the corresponding reference attribute value, allowing to assume that all criteria have a monotonically decreasing utility: the larger the attribute value, the farther it is from the desired or reference value. The application of ELECTRE also presupposes that the values assigned to all criteria are measured on a common scale. In order thus to remove the impact of the use of diverse measurement units, each one of the adjusted attribute values in row  $i$  of a specific column  $j$  is normalized using the equation:

$$\bar{V}_i = Value_{i,norm} = \frac{\max_{j=1\dots N}\{V_{j,adj}\} - V_{i,adj}}{\max_{j=1\dots N}\{V_{j,adj}\} - \min_{j=1\dots N}\{V_{j,adj}\}}$$

where  $V_{i,adj} = V_i - V_{i,ref}$  and  $\max_{j=1\dots N}\{V_{j,adj}\}$ ,  $\min_{j=1\dots N}\{V_{j,adj}\}$  indicate respectively the maximum and minimum measurement achieved for the specific criterion. The normalized matrix is represented as follows:

$$NW_{norm} = \begin{bmatrix} \overline{D}_1 & \overline{J}_1 & \overline{B}_1 & \overline{T}_1 & \overline{C}_1 \\ \overline{D}_2 & \overline{J}_2 & \overline{B}_2 & \overline{T}_2 & \overline{C}_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \overline{D}_N & \overline{J}_N & \overline{B}_N & \overline{T}_N & \overline{C}_N \end{bmatrix}$$

The next step involves the utilization of the relative importance of each one of the criteria impacting network selection, which has to be taken into consideration before performing pair-wise comparisons among the alternatives. The impact of the relative weights is integrated in the decision process through the calculation of a new matrix  $NW_w$  as follows:

$$NW_w = \begin{bmatrix} w_D \overline{D}_1 & w_J \overline{J}_1 & w_B \overline{B}_1 & w_T \overline{T}_1 & w_C \overline{C}_1 \\ w_D \overline{D}_2 & w_J \overline{J}_2 & w_B \overline{B}_2 & w_T \overline{T}_2 & w_C \overline{C}_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ w_D \overline{D}_N & w_J \overline{J}_N & w_B \overline{B}_N & w_T \overline{T}_N & w_C \overline{C}_N \end{bmatrix}$$

The main part of ELECTRE lies in the construction of the concordance and discordance matrices, which provide measurements of satisfaction and dissatisfaction of the decision maker when one alternative is compared to another. The values of the aforementioned matrices are calculated using concordance and discordance sets, where a concordance set constitutes a list of the attributes, for which network X is superior to network Y and a discordance set is its complementary set, comprising of the list of attributes for which network X is worse than the compared alternative Y. More specifically, the elements of the concordance and discordance matrices are calculated by equations (7) and (8) respectively.

$$c_{XY} = \sum_{j \in c_{S_{XY}}} W_j, \text{ Concordance Set} = \{j: NW_{w_{X,j}} \geq NW_{w_{Y,j}}\} \quad (7)$$

The concordance and discordance matrices are finally represented as

$$d_{XY} = \frac{\sum_{j \in d_{S_{XY}}} |(NW_{w_{X,j}}) - (NW_{w_{Y,j}})|}{\sum_j |(NW_{w_{X,j}}) - (NW_{w_{Y,j}})|}, \text{ Discordance Set} = \{j: NW_{w_{X,j}} < NW_{w_{Y,j}}\} \quad (8)$$

$$C = \begin{bmatrix} - & C_{12} & \dots & C_{1N} \\ C_{21} & - & \dots & C_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ C_{N1} & C_{N2} & \dots & - \end{bmatrix} \quad D = \begin{bmatrix} - & D_{12} & \dots & D_{1N} \\ D_{21} & - & \dots & D_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ D_{N1} & D_{N2} & \dots & - \end{bmatrix}$$

Elements of the diagonal in both matrices are not defined. The application of the method proceeds with the calculation of the net concordance and discordance indexes, where the net concordance index constitutes a measure of relative dominance of an alternative  $i$  over other alternatives when compared with a measure of dominance of other alternatives over the alternative  $i$  and a net discordance index provides a measure of relative weakness of alternative  $i$  over other alternatives when compared with a measure of weakness of other alternatives over alternative  $i$ . The net concordance and discordance indexes are calculated by equations (9) and (10). Alternatives are finally ranked based on the concordance and discordance indices as well by

taking the average of these two rankings. The network with the highest average ranking is considered to be best alternative.

$$C_i = \sum_{j \neq i}^N C_{ij} - \sum_{j \neq i}^N C_{ji} \quad (9)$$

$$D_i = \sum_{j \neq i}^N D_{ij} - \sum_{j \neq i}^N D_{ji} \quad (10)$$

## 4 Numerical Example

In this section we intend to demonstrate how the above methods can be used to model the problem of network selection. The following scenario is considered: a user wishes to access the Voice service in a cell, where four networks are available. All networks may serve the user; however, in order to optimize the QoS offered to the latter, the most efficient network has to be selected. The criteria to be taken into account in the decision process are Delay, Jitter, BER, Throughput and Cost. Of course, Delay and Jitter are of greater importance compared to other parameters, while Throughput holds minimum importance. Cost yields a variety of importance, depending on whether the user is characterized as risk seeking, risk neutral or risk adverse. Since the relative importance cannot be accurately determined, we consider the use of fuzzy logic as a valuable asset in our approach. Uncertainty in comparisons can be represented by fuzzy numbers, so that a set of possible values rather than a single value is acquired. The corresponding fuzzy numbers may derive from questionnaires or network measurements [6] [7], where the worst and best scores may form respectively the lower and upper bound of fuzzy numbers.

The first step of the network selection process is to determine the relative importance of each criterion. Since this issue escapes the scope of this work, it is assumed that individual criteria importance has already been obtained. Table 1 collects the input data. Note that the decision matrix is symmetric, meaning that  $a_{ij}=1/a_{ji}$ . This allows to fill in only the cells where criterion  $i$  is more important than criterion  $j$ . The rest of the cells are filled in by reversing the corresponding fuzzy numbers. Application of FAHP (section 3.2) provides the weights for each parameter. From (1) we obtain  $S_d=(0.1551,0.2486,0.38669)$ ,  $S_j=(0.1674,0.2557,0.42141)$ ,  $S_b=(0.0818,0.1243,0.18757)$ ,  $S_r=(0.0756,0.1227,0.17559)$ ,  $S_c=(0.1658,0.2486,0.37755)$ . The normalized weights of Table 2 deriving from (6) can be now used in the application of ELECTRE.

Table 3 presents the attribute values for all alternatives, as well as the reference values used for normalization. Tables 4 and 5 depict the normalized and weighted values respectively, as described in section 3.3.

Afterwards, the concordance and discordance matrices are formed according to (7) and (8), as shown in Table 6. The corresponding indexes are finally calculated through equations (9) and (10), providing the final ranking of the networks. Table 7 shows that both indexes point out Network 3 as the best option.



**Table 1.** Fuzzy Relative criteria importance

	Delay	Jitter	BER	Throughput	Cost
Delay	(1,1,1)	(0.667,1,1.429)	(1.5,2,2.4)	(1.6,2,2.8)	(0.8,1,1.333)
Jitter	(0.7,1,1.5)	(1,1,1)	(1.6,2,2.6)	(1.8,2,2.3)	(0.909,1,1.667)
BER	(0.417,0.5,0.667)	(0.385,0.5,0.625)	(1,1,1)	(0.75,1,1.5)	(0.385,0.5,0.556)
T/put	(0.357,0.5,0.625)	(0.333,0.455,0.556)	(0.667,1,1.333)	(1,1,1)	(0.357,0.5,0.556)
Cost	(0.75,1,1.25)	(0.6,1,1.1)	(1.8,2,2.6)	(1.8,2,2.8)	(1,1,1)

**Table 2.** Normalized weights

	Delay	Jitter	BER	Throughput	Cost
Normalized weights	0.3148	0.3249	0.036302	0.009555	0.3144

**Table 3.** Attribute values

	Delay(msec)	Jitter(msec)	BER( $\cdot 10^6$ )	Throughput(kbps)	Cost(units)
Network 1	155.5	4	0.085	18.8	25
Network 2	151.9	2.54	0.09	21.5	31
Network 3	121.3	2.79	0.06	19.6	31
Network 4	117.4	3.58	0.08	16.4	35
Reference	100	1	0.01	25	22

**Table 4.** Normalized values

	Delay	Jitter	BER	Throughput	Cost
Network 1	0	0	0.167	0.471	1
Network 2	0.095	1	0	1	0.4
Network 3	0.898	0.833	1	0.628	0.4
Network 4	1	0.305	0.333	0	0

**Table 5.** Normalized and weighted values

	Delay	Jitter	BER	Throughput	Cost
Network 1	0	0	0.001	0.004	0.314
Network 2	0.03	0.325	0	0.01	0.126
Network 3	0.283	0.271	0.036	0.006	0.126
Network 4	0.315	0.099	0.012	0	0

**Table 6.** Concordance and discordance matrices

$$C = \begin{bmatrix} - & 0.351 & 0.314 & 0.323 \\ 0.649 & - & 0.649 & 0.649 \\ 0.686 & 0.665 & - & 0.685 \\ 0.676 & 0.351 & 0.315 & - \end{bmatrix} \quad D = \begin{bmatrix} - & 0.649 & 0.756 & 0.568 \\ 0.351 & - & 0.833 & 0.451 \\ 0.243 & 0.167 & - & 0.089 \\ 0.432 & 0.549 & 0.91 & - \end{bmatrix}$$

**Table 7.** Concordance and discordance indexes

	<b>Rank C</b>	<b>Rank D</b>
<b>Network 1</b>	4	4
<b>Network 2</b>	2	2
<b>Network 3</b>	1	1
<b>Network 4</b>	3	3

## 5 Conclusions

This paper addressed the problem of network selection that characterizes service delivery over a heterogeneous mix of wireless access technologies. In this frame, application of Fuzzy AHP and ELECTRE, i.e. two MADM algorithms, for ranking network alternatives was described. Since the relative importance of each criterion over another cannot be precisely defined, fuzzy numbers were adopted in order to integrate the uncertainty of subjective judgment into the problem analysis. The proposed methodology was finally tested through a numerical example, which pointed out how the most efficient alternative, in this case network, is selected.

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