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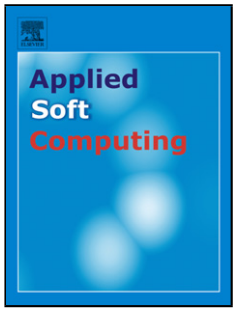

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PII: S1568-4946(17)30279-X
DOI: http://dx.doi.org/doi:10.1016/j.asoc.2017.05.026
Reference: ASOC 4230

To appear in: *Applied Soft Computing*

Received date: 18-12-2016
Revised date: 28-3-2017
Accepted date: 10-5-2017

Please cite this article as: Raman Kumar Goyal, Sakshi Kaushal, Arun Kumar Sangaiah, The utility based non-linear fuzzy AHP optimization model for network selection in heterogeneous wireless networks, Applied Soft Computing Journalhttp://dx.doi.org/10.1016/j.asoc.2017.05.026

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The Utility Based Non-Linear Fuzzy AHP Optimization Model for Network Selection in Heterogeneous Wireless Networks

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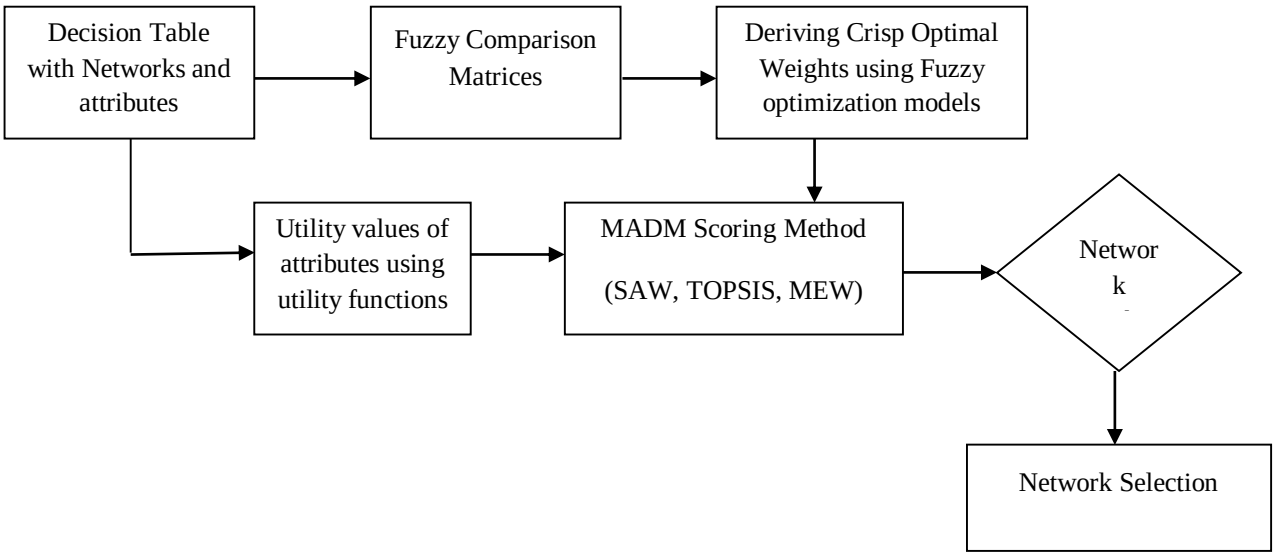
Graphical Abstract



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Highlights

- The disadvantages of using extent analysis method for network selection problems are discussed.
- Weights of network parameters are obtained by applying a nonlinear fuzzy optimization model.
- Consistency Index with this proposed model is better than the existing non-linear models.
- Parameterized utility functions are used to evaluate the utility values of network attributes.
- Results obtained for network selection with the MEW method are better than TOPSIS and SAW methods.

Abstract: Next generation wireless networks will integrate various heterogeneous technologies like WLAN, WiMax and cellular technologies etc., to support multimedia services with higher bandwidth and guaranteed quality of service (QoS). In order to keep the mobile user always connected to the best wireless network in terms of QoS parameters and user preferences, an optimal network selection technique in heterogeneous networks is required. This paper proposes a novel fuzzy-Analytic Hierarchy Process (AHP) based network selection in heterogeneous wireless networks. Triangular fuzzy numbers are used to represent the elements in the comparison matrices for voice, video and best effort applications. Deriving crisp weights from these fuzzy comparison matrices is a challenging task. When extent analysis method is applied, irrational zero weights are obtained for some attributes. Due to this, many important criteria are not considered in the decision making process. To overcome this problem, a new non-linear fuzzy optimization model for deriving crisp weights from fuzzy comparison matrices for network selection is presented. The weights obtained from this model are more consistent than the existing optimization models. Also, parameterized utility functions are used to model the different Quality of Service (QoS) attributes (bandwidth, delay, jitter, bit error rate) and user preferences (cost) for three different types of applications. Finally, scores are calculated exclusively for each network by three MADM (Multiple Attribute Decision Making) methods: Simple Additive Weighting (SAW), TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) and MEW (Multiplicative Exponential Weighting). Results show that the MEW method gives more appropriate scores with utility functions than the SAW and TOPSIS methods.

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Keywords: Network Selection, Multiple Attribute Decision Making, Fuzzy-AHP, Heterogeneous Wireless Networks, Utility functions

1. Introduction

The various heterogeneous wireless technologies like WLAN, WiMax and cellular technologies like 2G/3G etc., will be integrated in future generation wireless networks through a single IP-based core. When a mobile device roams in these heterogeneous environments, it undergoes vertical and horizontal handovers continuously. In order to provide Always Best Connected (ABC) property, an optimal Vertical Handover Decision (VHD) is required. Many VHD methods are presented in the literature that includes fuzzy logic, game theory, function based, user-centric and Markov decision process (Zekri et al. 2012). MADM methods include multiple attributes with medium complexities while the other methods have higher complexity with the increase in number of attributes. So, in this paper, the focus is only on MADM based network selection methods.

Rao (2007) has presented various MADM methods. Among these, most popular methods are SAW (Fishburn, 1967) MEW (Miller, 1969), TOPSIS (Hwang, 1981) PROMETHEE (Brans, 1985) and ELECTRE (Roy,1991). AHP method (Saaty, 1980) is widely used for providing weights to these MADM methods. Song and Jamalipour (2005) have presented AHP and Grey Rational Analysis (GRA) based technique where AHP has been used for selection criteria and GRA evaluates heterogeneous networks. The proposed methodology combines the AHP to decide the relative weights of criteria set according to network's performance, as well as the GRA to rank the network alternatives. Goyal and Kaushal (2016) have applied AHP method to find the effect of mobility of the mobile device on the handover decision process in heterogeneous wireless networks. Lahby et al. (Lahby et al, 2013) have proposed an enhanced TOPSIS method by using the Analytic Network Process (ANP) to weight the criteria and then apply the TOPSIS method. Various methods have been developed for the weight calculation of network attributes. Ahuja et al. (2014a, 2015) have proposed a novel network selection algorithm in a typical heterogeneous environment of EDGE and UMTS networks where the selection metrics are combined with PSO for relative dynamic weight optimization. Cost functions are used for network selection. Charilas et al. (2014) have presented a framework that defines the weights of attributes based on the variance of network measurements. Principal Component Analysis and AHP are applied to

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derive parameter weights through pairwise comparison matrices. Yang and Tseng (2013) have proposed handoff decision algorithm that combines Weighted Rating Mean Analysis (WRMA) to rate the relative importance of network attributes and a fuzzy methodology of TOPSIS is used to select candidate networks. Ahuja et. al (2014b) have proposed a network selection algorithm in which weight estimation of attributes is computed using entropy and TOPSIS method has been used for network ranking. To achieve the consistency ratio of greater than 0.1 in AHP, Chandavarkar and Gudetti (2015a) have proposed a Simplified and Improved AHP (SI-AHP) technique which automatically computes the reciprocal matrix of attributes. This technique is further used in Simplified and Improved Multiple Attributes Alternate Ranking method (SI-MAAR) by Chandavarkar and Gudetti (2016) for solving the rank reversal problem when a network is added or removed from the selection list. *In many situations, decision makers have to model their preferences with fuzzy values. But, all these approaches have not considered the fuzzy weights for modelling the AHP matrix.*

Fuzzy-based MADM methods are integrated for different types of selection and ranking problems (Samuel et al, 2017; Jain et al, 2016; Sangaiah et al, 2015a; Gopal et al, 2015; Sangaiah et al, 2015b). Different fuzzy based MADM methods have also been used for vertical handovers (Ismail and Roh, 2011). Chamodrakas and Martakos (2011) have presented a novel method in which diverse QoS elasticises are modeled by parameterized utility functions and the fuzzy set representation of TOPSIS method is used to rank the networks. Mehbodniya et al. (2013) have presented Fuzzy Logic Controllers (FLCs) with on Fuzzy VIKOR (FVIKOR) to select the networks in heterogeneous wireless networks. Abid et al. (2012) propose an innovative handover decision making scheme based on a single criterion utility function that rates user satisfaction and captures sensitivity for each decision criterion. Chandavarkar and Reddy (2015b) have compared the performances of different sigmodial utility functions in heterogeneous wireless networks. Drissi et al. (2017) proposes a context aware network selection based on utility functions that consider QoS requirements and user preferences. Kosmides et al. (2014) introduce three utility functions based on the type of application that users request. Drissi et al. (2016) have used Fuzzy-AHP with SAW method to keep the users Always Best Connected (ABC). Khan et al. (2017) have used fuzzy rule based system to eliminate inappropriate networks and the selection of networks is done by TOPSIS method. Zineb et al. (2017) have proposed an enhanced vertical handover based on Fuzzy Inference MADM approach for heterogeneous networks. This method is based on a MADM technique with fuzzy logic inference system to reduce handover decision time.

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Skondras et al. (2016) have applied ANP to estimate the weights, and Fuzzy TOPSIS method has been implemented for network selection. *But these methods have not applied any fuzzy prioritization methods to derive crisp weights from fuzzy comparison matrices.*

Chang (1996) has proposed an extent analysis method to Fuzzy-AHP comparison matrices for deriving crisp weights. Charilas et al. (2009) have applied the extent analysis method on Fuzzy-AHP to derive crisp weights of the network attributes, and ELECTRE method is used to rank the wireless networks. Also, Brajković et al. (2015) have proposed an extent analysis Fuzzy-AHP with TOPSIS method for optimal wireless networks. Goyal et al. (2016a) have also used extent analysis method for network selection in heterogeneous wireless networks considering various network parameters. Goyal and Kaushal (2015) have analyzed the effect of utility functions on the extent analysis method for vertical handover scenarios. *But, extent analysis method can lead to irrational zero weights in many cases (Wang et. al, 2008). Due to this, many important criterias are not considered in the decision making process. Therefore, extent analysis method can lead to zero weights for important network parameters in case of vertical handover decision problems also.*

In this paper, a novel fuzzy-Analytic Hierarchy Process (AHP) based network selection technique is presented in heterogeneous wireless networks for voice, video, and best-effort applications. Triangular fuzzy numbers are used to represent the elements in the comparison matrices. When extent analysis method is applied, irrational zero weights are obtained for some attributes in all the three network applications. To overcome this problem, a new non- linear fuzzy optimization model for deriving crisp weights from fuzzy comparison matrices is proposed. Consistency of the comparison matrix is important as it determines how consistent the judgements are made by the decision maker in the comparison matrix. Inconsistencies may typically arise when many pairwise comparisons are performed. The weights obtained from the proposed model are consistent than other fuzzy optimization methods. Also, parameterized utility functions are used to model the different Quality of Service (QoS) attributes for different applications with SAW, TOPSIS and MEW methods. With the utility functions, the actual utility values of network parameters are considered for the network selection. Therefore, handover decisions are more appropriate with the proposed utility based network selection method.

Rest of the paper is organized as follows. Section 2 presents the preliminaries required for the MADM based network selection methods. In section 3, the proposed Fuzzy-AHP based MADM technique for network selection is discussed. Section 4 presents the results and

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analysis of the proposed model with SAW, TOPSIS and MEW methods. Finally, Section 5 concludes with future directions of research.

2. Preliminaries

In this section, basics of AHP, SAW, MEW, and TOPSIS are briefly presented.

2.1 AHP

The AHP method was introduced by Saaty (1980). It is one of the most popular methods for solving complex decision making problems which decomposes the problem into a system of hierarchy of goals, attributes and alternatives (Rao, 2007). Triantaphyllou and Lin (1996) have listed the following advantages of AHP: (1) AHP can handle both quantitative and qualitative data. (2) It helps the decision maker to organize the critical aspects of a problem in a hierarchical structure. (3) Decision makers can derive criteria weights and alternatives scores from pairwise comparison matrices of AHP. (4) The consistency of the pairwise comparison matrix can be measured. (5) Very complex problems can be solved by combining AHP with various operation research techniques. With these advantages of AHP, it is widely used for MADM problems. Main steps in AHP include (Rao, 2007, Goyal and Kaushal, 2016c):

(a) Organizing the problem hierarchically

The problem is formulated in a hierarchal structure. The overall goal of the decision-making problem is placed at the topmost level. The n criteria i.e., $C_{1,}\ C_{2,}, C_3, \dots, C_n$ are placed at intermediate level and the m alternatives i.e., $A_{1,}\ A_{2,}, \dots, A_m$ are placed at the lowest level. A decision table is made between alternatives and criteria as shown in Table 1. m_{ij} represents the value of jth criterion with respect to i^{th} alternative, where $= 1,2, \dots, m\ and\ j = 1,2, \dots, n$.

(b) Construction of pairwise comparison matrices

Pairwise comparison judgment matrices are constructed by considering the preferences of the decision makers in the form of comparison ratios. These judgments matrices of criteria or alternatives can be defined from the reciprocal comparisons at the same level. Pairwise comparisons are based on standard scales (1= equal

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preference; 3= weak preference; 5= strong preference; 7= demonstrated importance; 9= absolute preference). A comparison matrix A_{n*n} with elements a_{ij} where $, j = 1,2, \ldots, n$ is shown in equation (1). Each step of comparison for a level with n elements requires $n\ (n-1)/2$ judgments.

$$A_{n*n} = \begin{bmatrix} a_{11} & a_{12} \cdots & a_{1n} \\ a_{21} & a_{22} \cdots & a_{2n} \\ \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} \cdots & a_{nn} \end{bmatrix} \tag{1}$$

(c) Calculating weights from judgment matrices

Weights of each criterion and alternatives' scores and can be derived from comparison matrices. Eigenvector method is the most common method to derive priority vector weights $(w_1, w_2, w_3, \ldots w_m\ )^T$. Then consistency of the weights should also be checked. Most common consistency method for calculating consistency is Saaty's Consistency Index method (1980).

(d) Alternatives ranking

The final step is to find the scores of each alternative by aggregating all the local scores calculated in the previous step.

2.3 SAW and MEW

Before applying the MADM methods, we have to normalize the decision table values, i.e., $(m_{ij})_{normalized}$. The normalized table is obtained by dividing the value of the beneficial attribute with the maximum value of attribute among the alternatives and by dividing the minimum value of the non-beneficial attribute among the alternatives with the value of alternative.

Simple Additive Weighing (SAW) (Fishburn, 1967) is the simplest and most widely used method MADM method for computing the overall composite score. After obtaining the weights of the attributes from the AHP method, final scores are calculated as shown in equation (2).

Final Score of ith alternative,

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$$P_i = \sum_{j=1}^{m} w_j * (m_{ij})_{normalized} \quad (2)$$

MEW (Miller, 1969) method is another method to compute the final scores which is similar to the SAW method. The main difference in this model is that instead of addition, multiplication is used as shown in equation (3).

Final Score of ith alternative,

$$P_i = \prod_{j=1}^{m} (m_{ij})_{normalized}^{w_j} \quad (3)$$

2.4 TOPSIS method

Hwang and Yoon (1981) developed TOPSIS method that is based upon the concept of Euclidean distances from the ideal best and ideal worst solutions. After obtaining the weights by AHP method the main steps of TOPSIS method can be summarized as follows:

Step 1: Obtained the normalized decision matrix with elements $(m_{ij})_{normalized}$ as shown in equation (4), where $m_{i,j}$ is the element of the matrix is gives the jth attribute of ith alternative and n is the number of alternatives.

$$(m_{ij})_{normalized} = \frac{m_{i,j}}{[\sum_{j=1}^{n} m_{i,j}^2]^{1/2}} \quad (4)$$

Step 2: Obtain the weighted normalized matrix $V_{i,j}$ as shown in equation (5). w_j is the weight given by AHP method in each application.

$$V_{i,j} = w_j (m_{ij})_{normalized} \quad (5)$$

Step 3: Obtain the ideal best (V^+) and ideal worst (V^-) solutions according to equations (6) and (7) respectively.

$$V^+ = \{\max_i (V_{i,j} | j \epsilon J); \min_i (V_{i,j} | j \epsilon J'), i = 1,2,3, \dots n\} = \{V_1^+, V_2^+, V_3^+, \dots . V_m^+\} \quad (6)$$

$$V^- = \{\min_i (V_{i,j} | j \epsilon J'); \max_i (V_{i,j} | j \epsilon J), i = 1,2,3, \dots n\} = \{V_1^-, V_2^-, V_3^-, \dots . V_m^-\} \quad (7)$$

J is associated with beneficial attributes like bandwidth and J' is associated with non beneficial attributes like cost, delay and jitter. V_j^+ indicates the ideal value of the specific

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attribute of all the alternatives. V_j^- indicates the worst value of the attribute among alternatives.

Step 4: The separation measures from ideal solution are given by the Euclidian distance as shown in the equations (8) and (9) respectively.

$$S_i^+ = \{\sum_{J=1}^{M}(V_{i,j} - V_j^+)^2\}^{1/2}, \quad i = 1,2,\ldots,n \tag{8}$$

$$S_i^- = \{\sum_{J=1}^{M}(V_{i,j} - V_j^-)^2\}^{1/2}, i = 1,2,\ldots n \tag{9}$$

Step 5: The relative closeness of alternative to the ideal solution P_i or the final score can be expressed as shown in equation (10)

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{10}$$

3. Proposed Fuzzy-AHP method for network selection

In this section, proposed Fuzzy-AHP MADM based network selection technique is presented. In section 3.1, network selection problem is organized hierarchically by determining the decision table in the form of networks and attributes. Pairwise comparison matrices are formed with triangular fuzzy numbers. Section 3.2 presents the methods for deriving crisp weights from these fuzzy comparison matrices. The utility values of attributes are obtained from parameterized utility functions as presented in section 3.3.

3.1 Forming the fuzzy comparison matrices

The process of the AHP method is for the certain judgments of the decision maker, but in the real world, there may be some problems where the decision maker is not sure about the exact preferences. So there is a need for dealing uncertainty the comparison matrices. To handle uncertainty in different situations, fuzzy sets have been implemented by Zadeh (1965). Therefore, Fuzzy-AHP has been proposed, in which the judgments in the comparison matrices are represented as fuzzy numbers or set of fuzzy numbers. Linguistic terms are easier for human beings for judgments (for example less important, highly important) than the numerical values (Cabrerizo et al, 2015; Wu et al, 2015, Morente-Molinera et al, 2016). Saaty has used the scale from 1 to 9 to convert linguistic terms into useful pairwise judgments in the comparison matrices as 1= equal preference; 3= weak preference; 5= strong preference; 7= demonstrated importance; 9= absolute preference as discussed in the previous section. So,

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if the decision maker wants to model the problem with fuzzy judgments then the conversion of linguistic terms can be modeled as: About 3 = weak preference, About 5 = strong preference and so on. These uncertain judgments can be represented as the triangular fuzzy numbers (TFNs) as shown in Table 2.

A TFN is described in equation (11) (Zimmermann, 1994)

$$\mu_{\widetilde{N}}(x) = \begin{cases} \frac{x-l}{m-l} & l \leq x \leq m \\ \frac{u-x}{u-m} & m \leq x \leq u \\ 0 & otherwise \end{cases} \tag{11}$$

$l, m\ and\ u$ respectively denote the smallest value, the most promising value and the largest possible value. The TFN $\widetilde{N}$ can be represented as (l, m, u). Fuzzy pairwise judgments can be converted to fuzzy scores as shown in Table 2 (Wang et. al, 2007), $where\ a = 2,3, \ldots, 9$ and $b, c = 1, 2, \ldots, 9\ and\ b < c$.

The network selection process considers three different applications: voice, video, and best-effort applications. TFNs are used to represent weights in the fuzzy comparison matrices. *While preparing judgment comparison matrix for each application, the priority of one attribute with respect to the other is taken as mentioned in (Yang and Tseng, 2013).* Fuzzy weights are chosen according to Table 2. For voice applications, bandwidth attribute is not as important as delay and jitter. Cost is also given a higher priority as there is a huge difference in prices offered by cellular and WLAN technologies as shown in Table 3. For video applications, bandwidth is as important parameter as delay and jitter. Cost and bit error rate are not considered important parameters for video applications and hence they both are given low priority as shown in Table 4. While in the best-effort applications, the packets are to be transferred at a lower error rate over networks. Therefore, bit error rate has the highest priority as in comparison with all the attributes as shown in Table 5. Bandwidth is relatively more important than other attributes like cost, delay and jitter. So, it has given relatively higher priority for this application. The working of the proposed network selection technique is illustrated in Fig. 1.

3.2 Deriving crisp weights from fuzzy comparison matrices

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As discussed in the above section, TFNs are used to represent the elements in comparison matrices. Deriving crisp priorities from fuzzy judgments is a challenging task. Many methods are proposed in the literature for deriving the crisp priorities from these matrices. Among these methods, the extent analysis method has been widely used. Three methods are presented for deriving the crisp weights from fuzzy pairwise comparison matrices, i.e., extent analysis method, fuzzy optimization model and the proposed model as discussed below:

(a) Extent analysis method

Extent analysis method was proposed by Chang (1996) in which X= $\{x_1, x_2, \dots, x_n\}$ and G= $\{g_1, g_2, \dots, g_m\}$ are object and goal sets, respectively. The extent analysis of m values of goals for each object can be represented in the form of $M_{g_i}^1, M_{g_i}^2, \dots, M_{g_i}^m$, where $i = 1,2, \dots, n$. All $M_{g_i}^j$ are triangular fuzzy numbers in the form of (l, m, u).

Step 1: Compute the value of the fuzzy synthetic extent, S_i, on the ith object according to the equation (12).

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes [\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j]^{-1} \tag{12}$$

where $\sum_{j=1}^{m} M_{g_i}^j = (\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j)$ and $[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j]^{-1} = (\frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} u_j}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} m_j}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} l_j})$

Step 2: Compute the degree of possibility of S_2 and S_1 as shown in equation (13). S_2 and S_1 are calculated from Step 1.

$$\text{V}(S_2 \geq S_1) = sup_{y \geq x}[\min(\mu_{S_2}(y), \mu_{S_1}(x)] \tag{13}$$

It can also be represented by equations (14) and (15).

$$\text{V}(S_2 \geq S_1) = \text{hgt}(S_1 \cap S_2) = \mu_{S_2}(d) \tag{14}$$

$$\mu_{S_2}(d) = \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) + (l_1 - m_1)} & otherwise \end{cases} \tag{15}$$

Step 3: Compute the degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers S_i. This is to be calculated as shown in equation (16).

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$$\mathrm{V}\,(S > S_1, S_2 \ldots\ldots S_k) = \min \mathrm{V}\,(S > S_i), \quad i = 1,2,\ldots k. \tag{16}$$

Step 4: Calculate the weight vector for each comparison matrix as shown in equation (17):

$$(w_1, w_2, w_3)^T = (\min \mathrm{V}(S_1 \geq S_j), \min \mathrm{V}(S_2 \geq S_j), \ldots, \min \mathrm{V}(S_k \geq S_j))^T \tag{17}$$

where $i = 1,2,\ldots k, j = 1,2.\ldots k, k \neq j$. Weights are then normalized too satisfy $\sum_{i=1}^{n} w_i = 1$.

The weights derived with extent analysis method for the applications are shown in Table 6. For voice application weight of BER is zero. For video applications, the weights of BER and cost are zero. For the best-effort applications, the weights of attributes delay, jitter, and cost are zero. Therefore, the extent analysis method has not made full use of all the information provided by fuzzy comparison matrices when it assigns irrational zero weights to some of the attributes.

To address the issue of irrational zero weights, some non-linear fuzzy optimization models have been proposed in the literature (Wang et. al, 2007, Javanbarg, 2012) as discussed in subsection (b). These optimization models also solve the problem of reciprocal symmetric matrices in Fuzzy-AHP judgments discussed in (Mikhailov, 2003).

(b) Fuzzy Optimization Model

A Comparison matrix of the Fuzzy-AHP of n criteria is represented in the form of triangular fuzzy numbers $\hat{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, where i and $j = 1,2,\ldots,n$ and n is the number of criteria or decision elements in the pairwise judgment matrix. Also

$$l_{ij} < m_{ij} < u_{ij}, \quad \text{if } i \neq j \text{ and} \tag{18}$$

$$\hat{a}_{ij} = \hat{a}_{j,i} = (1,1,1), \quad \text{if } i = j \tag{19}$$

Crisp weights $(w_1, w_2, \ldots, w_n)^T$ must satisfy the following fuzzy inequalities (Mikhailov, 2003).

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$$l_{ij} \lessapprox w_i/w_j \lessapprox u_{ij} \,, \tag{20}$$

where $w_i > 0$, $w_j > 0$, $i \neq j$.

To measure the degree of satisfaction for different crisp ratios, a membership function can be constructed as shown in the following equation:

$$\mu_{ij}\left(\frac{w_i}{w_j}\right) = \begin{cases} \dfrac{m_{ij}-\left(\frac{w_i}{w_j}\right)}{m_{ij}-l_{ij}} \,, & 0 < w_i/w_j < m_{ij} \\ \dfrac{\left(\frac{w_i}{w_j}\right)-m_{ij}}{u_{ij}-m_{ij}} \,, & w_i/w_j \geq m_{ij} \end{cases} \tag{21}$$

where $i \neq j$. This function is linearly decreasing over the interval $(0, m_{ij}]$ and linearly increasing over the interval $[m_{ij}, \infty)$. Smaller value of this function means that the exact ratio w_i/w_j is more acceptable.

To find the crisp weights $(w_1, w_2, \ldots, w_n)^T$, Wang *et al.* (2007) and Javanbarg *et al.* (2012) have presented an optimization model in which objective function is given as follows:

$$\begin{aligned} min\, J(w_1, w_2, \ldots, w_n) \\ &= min \sum_{i=1}^{n} \sum_{j=1}^{n} \left[\mu_{ij}^2\left(\frac{w_i}{w_j}\right)\right] \\ &= min \sum_{i=1}^{n} \sum_{j=1}^{n} \left\{ \delta\left(m_{ij} - \frac{w_i}{w_j}\right) * \left(\frac{m_{ij}-\frac{w_i}{w_j}}{m_{ij}-l_{ij}}\right)^2 \right. \\ &\qquad \left. + \delta\left(\frac{w_i}{w_j} - m_{ij}\right) * \left(\frac{\frac{w_i}{w_j}-m_{ij}}{u_{ij}-m_{ij}}\right)^2 \right\} \end{aligned} \tag{22}$$

subject to $\sum_{k=1}^{n} w_k = 1,\ k = 1,2\ldots,n$. where $i \neq j$, and $\delta(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$

The consistency index (γ) of the fuzzy comparison matrix after obtaining the priority vector $(w_1^*, w_2^*, w_3^* \ldots\ldots w_n^*)^T$ is calculated as shown in the equation (23) (Wang, 2007).

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$$\gamma = e^{-\alpha} \tag{23}$$

$$\text{where } \alpha = max\left\{\left\{\mu_{ij}\left(\frac{w_i^*}{w_j^*}\right)\right\} | \mathrm{i,j} = 1,2,\ldots,\mathrm{n}, \mathrm{i} \neq \mathrm{j}\right\} \tag{24}$$

where $\mu_{ij}\left(\frac{w_i^*}{w_j^*}\right)$ is the function of equation (21).

γ always satisfies $0 < \gamma \leq 1$. If it is greater than e^{-1} = 0.3679, all exact ratios are consistent.

Teaching Learning Based Optimization (TLBO) (Rao et al, 2011; Rao et al, 2012) is applied to solve the optimization problem. Solving this optimization function can lead to inconsistent crisp weights (γ<0.3679) from fuzzy comparison matrices for video and best-effort applications as shown in the Tables 9 and 10, respectively. Therefore, an optimization model is required that will increase the value of consistency index defined in equation (23) as discussed in subsection (c).

(c) Proposed Model

To solve the problem of inconsistent weights derived from the Fuzzy-AHP comparison matrices, an optimization model is proposed by Goyal and Kaushal (2016c) as shown in equation (25). We have used this optimization model to derive consistent weights from the Fuzzy-AHP comparison matrices defined in Tables 4-6 for the network selection problem.

$$\begin{aligned}
\min\ J(w_1, w_2, w_3, \ldots, w_n) &= min\{\alpha\} \\
&= \min\left\{\max\left\{\mu_{ij}\left(\frac{w_i}{w_j}\right)\right\}\right\} \\
&= \min\left\{\max\left\{\delta\left(m_{ij} - \frac{w_i}{w_j}\right) * \frac{\left(m_{ij} - \frac{w_i}{w_j}\right)}{m_{ij} - l_{ij}}\right.\right. \\
&\qquad \left.\left. + \ \delta\left(\frac{w_i}{w_j} - m_{ij}\right) * \frac{\left(\frac{w_i}{w_j} - m_{ij}\right)}{u_{ij} - m_{ij}}\right\}\right\}
\end{aligned} \tag{25}$$

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subject to $\sum_{k=1}^{n} w_k = 1,\ k = 1,2 \ldots, n$ and $\delta(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$

If the value of α is minimized, the value of γ will be maximized. Therefore, min-max optimization problem as defined in equation (25) is proposed in this paper. TLBO is again applied to solve the optimization model. With the proposed model, weights derived are more consistent than the fuzzy optimization model discussed in subsection (b) for all the applications as shown in Tables 7-9. In case of voice application for optimization model defined in equation (22) , α is calculated as following

$$\max\left(\mu_{14}\left(\frac{w_1}{w_4}\right), \mu_{21}\left(\frac{w_2}{w_1}\right), \mu_{23}\left(\frac{w_2}{w_3}\right), \mu_{24}\left(\frac{w_2}{w_4}\right), \mu_{25}\left(\frac{w_2}{w_5}\right), \mu_{31}\left(\frac{w_3}{w_1}\right), \mu_{34}\left(\frac{w_3}{w_4}\right), \mu_{51}\left(\frac{w_5}{w_1}\right), \mu_{53}\left(\frac{w_5}{w_3}\right), \mu_{54}\left(\frac{w_5}{w_4}\right)\right)$$

= max (0.3909, 0.0719, 0.5804, 0.0570, 0.6721, 0.4821, 0.1178, 0.2642, 0.4916, 0.2524) = 0.6721

Therefore CI= $e^{-0.6721} = 0.5106$. Similarly the values of CI can be calculated for other cases.

3.3 Utility Functions

Utility functions are used to obtain the actual utility value of an attribute (Chamodrakas and Martakos, 2011). Different applications with different QoS preferences will have different utility values for a same network. Thus, the individual preferences should be taken into account in the utility evaluation. The utility value of an attribute is derived based on the requirement of that attribute for a particular application. If two networks are satisfying the minimum and maximum requirements of an attribute required for that application, the utility values of both the networks for that attribute will be closer. The requirement of attributes for different applications is illustrated in Table 10 (Chamodrakas and Martakos 2011, Skondras et al. 2016, Yang and Tseng, 2013)

BER and cost requirements are considered same for all types of applications because even if a network is more expensive or having more error rate, even then a user may want to access it. Weights are given differently for each application as illustrated in the previous section. Three types of utility functions are used in this study: 1) Sigmoid function 2) Monotonically increasing function 3) Linearly decreasing function. The sigmoid function is used when the value of the minimum and maximum requirement of an attribute is given. For beneficial

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criteria like bandwidth the utility function is $f(x) = (1 + e^{-a(x-b)})^{-1}$. For non-beneficial criteria like delay and jitter, the utility function is $g(x) = 1 - f(x)$. The parameters a and b are needed to be tuned to model the elasticity for QoS parameters. For greater values of a the function becomes as a step function as illustrated in the Fig 2. When there is only the minimum requirement of the attribute, a monotonically increasing function $u(x) = (-c/x) + 1$ is used for beneficial criteria as shown in Fig. 3 and $u(x) = (-x/c)$ +1, a linear decreasing function is used for non-beneficial criteria as shown in Fig. 4 where negative values are adjusted to zero. The utility functions used and their respective parameters for attributes in three applications are shown in Table 11.

4. Evaluation of the proposed technique

4.1 Numerical Example

In order to illustrate the benefits of the proposed method we designed a simulation experiment according to application QoS requirements, the user preferences and the network characteristics. Five network attributes, bandwidth, delay, jitter, bit error rate and cost are considered for network selection. This experiment incorporates a mobile node that moves within the range of five different networks $N_1, N_{2,} N_3, N_4, and\ N_5$. Table 12 depicts the network characteristics of five networks at the time of network selection. Simulation experiments include three different applications: voice, video and best-effort applications as discussed in the previous section. The utility values obtained for network attributes for the three applications are shown in Tables 13 - 15.

4.2 Results and Discussion

In this section, results of the proposed technique are presented and discussed. Fuzzy-AHP method is used for deriving weights for network attributes. Crisp weights are derived by using the proposed non-linear optimization methods as illustrated in section 3. Crisp weights for different applications are shown in Tables 7-9. Final scores are calculated with SAW, TOPSIS and MEW methods as explained in section 2. For analysis purpose, firstly, the scores are calculated without the use of utility functions, *namely*, Fuzzy-AHP SAW, Fuzzy-AHP TOPSIS, Fuzzy-AHP MEW and then all these methods are also used to calculate the final scores with the utility values of attributes, *namely*, Utility-based Fuzzy-AHP SAW, Utility-based Fuzzy-AHP TOPSIS, and Utility based Fuzzy-AHP MEW. The proposed methods are also compared with WRMA TOPSIS (Yang and Tseng ,2013) and Chamodrakas et al.

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(2011). Network attributes' weights for these two methods are taken directly from Yang and Tseng (2013). Utility values for Chamodrakas et al. (2011) are taken from Tables 13-15. Rankings of networks with these different MADM methods for three application classes are described below:

(a) Voice

For voice applications, bandwidth attribute is not as important as delay and jitter. The networks N_1 and N_4 are ranked higher than the other networks as they offer lesser delay and jitter as compared to other networks. The rankings of networks are in the order of $N_4 > N_1 > N_2 > N_3 > N_5$ with both the Fuzzy-AHP SAW and Fuzzy-AHP TOPSIS methods as shown in Fig. 5. With Fuzzy-AHP MEW method, the network N_1 has higher priority than network N_4. But the difference between final scores of networks is greater and therefore is more susceptible to unnecessary handovers as compared with SAW and TOPSIS methods. When utility-based functions are applied, the difference between the final scores of networks has been reduced for each method. *If two or more networks are fulfilling the QoS requirements the difference between their final scores is less as their utility values for that specific QoS attribute is same.* Therefore, there is less number of handovers as compared with traditional MADM methods. The order of rankings of networks is same $N_4 > N_1 > N_2 > N_3 > N_5$ for utility-based Fuzzy-AHP SAW and utility-based Fuzzy-AHP TOPSIS methods. In utility-based fuzzy-MEW method, network N_5 is not considered as it has the utility value of zero for delay and jitter. So, the network having zero utility value of an important parameter like delay should be ignored. Also the score of network N_3 is very comparatively less as compared with other networks with this method as its jitter attribute is not within the requirements of voice application. Therefore, utility-based Fuzzy-AHP MEW method is better as compared with utility-based Fuzzy-AHP SAW and utility-based Fuzzy-AHP TOPSIS methods which give comparatively higher score to networks N_3 and N_5. Also, in comparison with WRMA TOPSIS and Chamodrakas et al. (2011) the utility based MEW method gives more appropriate ranking. In WRMA TOPSIS method, as utility values are not considered, there is a huge difference in final scores of networks. So, many unnecessary handovers may arise. In case of Chamodrakas et al. (2011), it considers N_5 in the final selection process whose utility values for delay and jitter equal to zero. Therefore, we can conclude that utility-based Fuzzy-AHP MEW is the most appropriate method for network selection for voice application.

(b) Video

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For video applications, bandwidth is as important parameter as delay and jitter whereas cost and error rate are not as important. Therefore, the rankings of networks are in the order of $N_4 > N_1 > N_2 > N_3 > N_5$ with all these Fuzzy-AP methods as shown in Fig. 6. When utility-based functions are introduced, the ranking order of networks N_1 and N_2 gets interchanged as the utility value for bandwidth attribute for N_2 is significantly greater than N_1. The order of rankings of networks is $N_4 > N_2 > N_1 > N_3 > N_5$ for utility-based Fuzzy-AHP SAW and utility-based Fuzzy-AHP TOPSIS methods. Also, the difference between the final scores of networks has been reduced. Therefore, there are less number of handovers as compared with traditional MADM methods. In utility-based fuzzy-MEW method, network N_5 is not considered as it has the utility value of zero for delay and jitter. So, the network having zero utility value of important parameters like delay and jitter should be ignored. Also the score of network N_3 is comparatively less as compared with other networks with this method as its jitter attribute is not within the requirements of video application. Therefore, utility-based MEW method is better as compared with utility-based Fuzzy-AHP SAW and utility-based Fuzzy-AHP TOPSIS methods which give comparatively higher score to networks N_3 and N_5.

In WRMA TOPSIS and Chamodrakas et al. (2011) the score of network N_3 is considerably high and it can participate quite actively in the final network selection process. But as mentioned earlier, the utility value of the jitter attribute is very less. Therefore, final scores with utility based MEW method are more appropriate than these two methods.

(c) Best Effort

In the best-effort applications, the packets are to be transferred at a lower error rate over networks. Therefore, the ranking of network N_1 is higher than the other networks. The ranking of networks is in the order of $N_1 > N_4 > N_3 > N_2 > N_5$ with both the Fuzzy-AHP SAW and Fuzzy-AHP MEW methods as shown in Fig. 7. For Fuzzy-AHP TOPSIS method network N_3 has higher priority over network N_4. N_1 has the highest priority as it offers least BER. When utility-based methods are applied, the ranking order of networks for all MADM methods becomes $N_1 > N_3 > N_4 > N_2 > N_5$. All the considered networks are satisfying the requirements for best effort application. Therefore, with the utility based MADM methods the difference between the final scores of networks has been reduced with the exception of TOPSIS method. Also, the difference between final scores of different networks is quite large in WRMA TOPSIS and Chamodrakas et al. (2011). Therefore, Utility-based Fuzzy-AHP

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SAW and utility-based Fuzzy-AHP Mew methods are appropriate for network selection for best- effort application.

If the utility of an attribute of a network is zero, the final score of that network becomes zero in MEW method. So, it does not consider that alternative network for selection. As discussed above in all the three applications, utility-based MEW method has given appropriate results than the other MADM methods.

5. Conclusion

This paper proposes a novel fuzzy-Analytic Hierarchy Process (AHP) based network selection in heterogeneous wireless networks. The Fuzzy-AHP method is used to determine the weights of the attributes. When extent analysis method is used to derive crisp weights from fuzzy comparison matrices, irrational zero weights are obtained. Therefore, a new non-linear fuzzy optimization model for deriving crisp weights from fuzzy comparison matrices is proposed. The weights obtained from this model are more consistent than other methods. Utility functions are further used to obtain the actual utility value of each network attribute. From the results, it has been found that the utility based MEW method gives more appropriate final scores for each network with utility functions than the utility based SAW and TOPSIS methods. Also, with the utility-based MADM methods unnecessary handovers can be avoided as in comparison with traditional MADM methods.

The main contributions of this research are as follows:

1) This paper presents the disadvantages of extent analysis method for network selection problems.
2) A new non-linear optimization model to derive crisp weights of the network attributes is presented. To the best of our knowledge, this paper is the first paper to derive crisp weights from fuzzy pairwise comparison matrices with non-linear fuzzy models for network selection problems.
3) Consistency Index with this proposed model is better than the existing non-linear models.
4) Parameterized utility functions are used to evaluate the utility values of network attributes and the results with the proposed utility based MADM methods are better than the traditional MADM methods. Also, it has been found that utility based MEW

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method is more appropriate than other MADM methods for network selection problems.

The proposed utility based network selection technique makes the handover decisions more appropriately to avoid unnecessary handovers. Also, the presented fuzzy optimization model can derive optimal weights for fuzzy-AHP comparison matrices that can be used in different research areas like operation research, management, engineering applications etc., where various types of applied soft computing techniques are used.

The main limitation of this work is that handover triggering and energy efficiency are not considered. In near future, efforts will be made to consider other parameters like energy efficiency and the velocity of the mobile node, etc., in the network selection process and handover triggering mechanisms will also be included to achieve seamless handovers. Also, only TFNs are considered to represent the judgments. *The scope of granular computing and trapezoidal fuzzy numbers can be explored for network selection in heterogeneous wireless networks.*

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References

Abid, M., Yahiya, T.A & Pujolle, G. (2012). A Utility-based Handover Decision Scheme for Heterogeneous Wireless Networks. IEEE Consumer Communications and Networking Conference (CCNC). pp.650-654.

Ahuja, K., Singh, B., & Khanna, R. (2014a). Particle swarm optimization based network selection in heterogeneous wireless environment. *Optik-International Journal for Light and Electron Optics, 125(1),* 214-219.

Ahuja, K., Singh, B., & Khanna, R. (2014b). Network selection based on weigh estimation of QoS parameters in heterogeneous wireless multimedia networks. *Wireless Personal Communications,* 77 (4), 3027–3040.

Ahuja, K., Singh, B., & Khanna, R. (2015).Optimal Network Selection in Heterogeneous Wireless Environment for Multimedia Services. *Wireless Personal Communications* 83 (1), 441–454.

Brajković, E., Sjekavica, T., Volarić, T. (2015). Optimal Wireless Network Selection Following Students' Online Habits Using Fuzzy AHP and TOPSIS Methods. In *IEEE Wireless Communications and Mobile Computing Conference (IWCMC),* 397-402.

Brans, J.P and Vincke, Ph. (1985). A preference ranking organization method (The PROMETHEE Method for MCDM). *Management Science.* 31 (6): 647–656.

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy Sets and Systems,* 17 (3): 233–247.

Cabrerizo, F. J., Herrera-Viedma, E. & Pedrycz, W. (2013) A Method based on PSO and Granular Computing of Linguistic Information to Solve Group Decision Making Problems defined in Heterogeneous Contexts. *European Journal of Operational Research,* 230 (3), pp. 624-633.

Chamodrakas, I., and Martakos, D. (2011). A utility-based fuzzy TOPSIS method for energy efficient network selection in heterogeneous wireless networks", *Applied Soft Computing*, 11, pp. 3734-3743, 2011.

Chandavarkar, B.R., and Guddeti, R.M.R. (2016). Simplified and improved multiple attributes alternate ranking method for vertical handover decision in heterogeneous wireless networks. *Computer Communications,* 83, pp. 81-97.

Chandavarkar, B.R., and Guddeti, R.M.R. (2015a). Simplified and Improved analytical hierarchy process aid for selecting the candidate networks in an overlay heterogeneous networks. *Wireless Personal Communications,* 83 (4), pp. 2593–2606.

Chandavarkar, B.R., and Guddeti, R.M.R. (2015b). Analysis of sigmoidal utility function based handover in heterogeneous wireless networks. International Conference on Microwave, Optical and Communication Engineering (ICMOCE), pp. 118-121.

ACCEPTED MANUSCRIPT

Chang, D.Y. (1996) Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research,* 95 (3): 649–655.

Charilas, D.E., Markaki, O.I., Psarras, J., Constantinou, P. (2009). Application of Fuzzy AHP and ELECTRE to Network Selection. In: Granelli et al (Eds.). *Mobile Lightweight Wireless Systems* pp. 63-73, Springer, Berlin Heidelberg.

Charilas, D. E., Panagopoulos, A. D., & Markaki, O. I. (2014). A unified network selection framework using principal component analysis and multi attribute decision making. *Wireless Personal Communications*, 74(1), 147–165.

Drissi M., Oumsis M., Aboutajdine D. (2016) A Fuzzy AHP Approach to Network Selection Improvement in Heterogeneous Wireless Networks. In: Abdulla P., Delporte-Gallet C. (eds) Networked Systems. NETYS 2016. Lecture Notes in Computer Science, vol 9944. Springer, Cham.

Drissi M., Oumsis M., Aboutajdine D. (2017) A Context-Aware Access Network Selection Based on Utility-Function for Handover in WLAN-LTE Environment. In: El-Azouzi R., Menasche D., Sabir E., De Pellegrini F., Benjillali M. (eds) Advances in Ubiquitous Networking 2. Lecture Notes in Electrical Engineering, vol 397. Springer, Singapore.

Fishburn, P.C. (1967). Additive utilities with incomplete product set: applications to priorities and assignments. *Operations Research Society of America*, Baltimore.

Gopal, J., Sangaiah, A.K., Basu, A., Gao, X.Z. (2015) Integration of fuzzy DEMATEL and FMCDM approach for evaluating knowledge transfer effectiveness with reference to GSD project outcome. Article in Press, *International Journal of Machine Learning and Cybernetics*, Springer Publishers, Article in Press, Doi:10.1007/s13042-015-0370-5.

Goyal, R.K., and Kaushal, S. (2015). Effect of utility based functions on fuzzy-AHP based network selection in heterogenous wireless networks. 2nd International Conference on Recent Advances in Engineering & Computational Sciences (RAECS). IEEE, pp. 1-5.

Goyal, R.K., and Kaushal, S. (2016a). Network Selection Using AHP for Fast Moving Vehicles in Heterogeneous Networks. In Chaki et al (Eds). *Advances in Intelligent Systems and Computing,* pp. 235-243, Springer, India.

Goyal, R.K., Kaushal, S., and Vaidyanathan.S. (2016b) Fuzzy AHP for Control of Data Transmission by Network Selection in Heterogeneous Wireless Networks. *International Journal of Control Theory and Applications*, 9(1), pp. 133-140.

Goyal, R.K., and Kaushal, S. (2016c). A constrained non-linear optimization model for fuzzy pairwise comparison matrices using teaching learning based optimization, *Applied Intelligence*, 45(3), pp. 652-661.

ACCEPTED MANUSCRIPT

Hwang, C.L. and Yoon, K. (1981). *Multiple attribute decision making: Methods and applications*, Springer-Verlag ,Berlin.

Ismail, A., and Roh, B., (2011). Adaptive Handovers in heterogeneous networks using fuzzy MADM, In *IEEE International Conference on Mobile IT convergence*, pp. 99-104.

Jain, V., Sangaiah, A.K., Sakhuja, S. et al. (2016). Supplier selection using fuzzy AHP and TOPSIS: a case study in the Indian automotive industry, *Neural Computing & Applications*, Springer Publishers, DOI:10.1007/s00521-016-2533-z.

Javanbarg M.B., Scawthorn, C., Kiyono, J., and Shahbodaghkhan, B. (2012). Fuzzy AHP-based multi-criteria decision making systems using particle swarm optimization. *Expert Systems with Applications* 39 (1), 960–966.

Khan, M., Ahmad, A., Khalid, S. et al. (2017). Fuzzy based multi-criteria vertical handover decision modeling in heterogeneous wireless networks. *Multimedia Tools and Applications*, doi:10.1007/s11042-016-4330-1.

Kosmides, P., Rouskas, A. & Anagnostou, M. (2014) Utility-based RAT selection optimization in heterogeneous wireless networks. *Pervasive Mobile Computing*, 12, pp. 92–111.

Lahby, M., Cherkaoui, L., and Adib, A. (2013). An Enhanced-TOPSIS Based Network Selection Technique for Next Generation Wireless Networks. In IEEE 20th International Conference on Telecommunications, 1-5.

Mehbodniya, A., Kaleem, F., Yen, K.K., Adachi, F. (2013). A fuzzy extension of VIKOR for target network selection in heterogeneous wireless environments. *Physical Communication*, 7 (1), 145–155.

Mikhailov. L., (2000). A fuzzy programming method for deriving priorities in the analytic hierarchy process. *Journal of the Operational Research Society*, 51 (3):341–349.

Mikhailov, L. (2003). Deriving priorities from fuzzy pairwise comparison judgments. Fuzzy Sets and Systems, 134 (3), 365–385.

Miller, D.W. and Starr, M.K. (1969). *Executive decisions with operations research*. Prentice Hall, Englewood Cliffs, New Jersey.

Morente-Molinera, J. A. , Mezei, J., Carlsson, C. & Herrera-Viedma, E. , (2016) Improving supervised learning classification methods using multi-granular linguistic modelling and fuzzy entropy. IEEE Transactions on Fuzzy Systems, in press. doi: 10.1109/TFUZZ.2016.2594275

Rao, R.V. (2007). *Decision making in the manufacturing environment using graph theory and fuzzy multiple attribute decision making methods.* Springer, London.

Rao, R.V., Savsani, V.J., and Vakharia, D.P. (2011). Teaching–learning-based optimization: a novel method for constrained mechanical design optimization problems. *Computer Aided Design* 43 (3), 303–315.

ACCEPTED MANUSCRIPT

Rao, R.V., Savsani V.J., and Vakharia, D.P. (2012). Teaching–learning-based optimization: an optimization method for continuous non-linear large scale problems. *Information Sciences.* 183 (1), 1–15.

Roy, B. (1991) The outranking approach and the foundations of ELECTRE methods. *Theory and Decision.* 31(1): 49–73.

Saaty, T.L. (1980). The analytic hierarchy process. McGraw-Hill, New York.

Samuel, O. W., Asogbon, G. M., Sangaiah, A. K., Fang, P., & Li, G. (2017). An integrated decision support system based on ANN and Fuzzy_AHP for heart failure risk prediction. *Expert Systems with Applications, Elsevier Publishers*, 68, 163-172.

Sangaiah, A. K., Subramaniam, P. R., &Zheng, X. (2015a). A combined fuzzy DEMATEL and fuzzy TOPSIS approach for evaluating GSD project outcome factors. *Neural Computing and Applications*, Springer Publishers, Article in Press, DOI: 10.1007/s00521-014-1771-1.

Sangaiah, A. K.,Gopal, J., Basu, A., Subramaniam, P. R(2015b). An integrated fuzzy DEMATEL, TOPSIS, and ELECTRE approach for evaluating knowledge transfer effectiveness with reference to GSD project outcome. *Neural Computing and Applications*, Springer Publishers, Article in Press, DOI: 10.1007/s00521-015-2040-7.

Skondras, E., Sgora, A., Michalas, A., and Vergados, D.D. (2016). An analytic network process and trapezoidal interval-valued fuzzy technique for order preference by similarity to ideal solution network access selection method. *International Journal of Communication Systems*, 29 (2), 307–329.

Song, Q., and Jamalipour, A. (2005). An adaptive quality-of-service network selection mechanism for heterogeneous mobile networks. *Wireless Communications and Mobile Computing*, 5 (6), 697-708, 2005.

Triantaphyllou, E. and Lin, C.T. (1996). Development and evaluation of five fuzzy multiattribute decision-making methods. *International Journal of Approximate Reasoning,* 14 (4): 281–310.

Yang, S., and Tseng, W. (2013). Design novel weighted rating of multiple attributes scheme to enhance handoff efficiency in heterogeneous wireless networks. *Computer Communications,* 36 (14), 1498–1514.

Wang, L., Chu, J., and Wu, J. (2007). Selection of optimum maintenance strategies based on a fuzzy analytic hierarchy process. *International Journal of Production Economics,* 107 (1): 151-163.

Wang, Y.M., Luo, Y., and Hua, Z. (2008). On the extent analysis method for fuzzy AHP and its applications. *European Journal of Operational Research,* 186 (2), 735–747.

Wu, J. , Chiclana, F. & Herrera-Viedma, E. (2015) Trust Based Consensus Model for Social Network in an Incomplete Linguistic Information Context. *Applied Soft Computing,* 35, pp. 827-839.

ACCEPTED MANUSCRIPT

Zekri, M., Jouaber, B., & Zeghlache, D. (2012). A review on mobility management and vertical handover solutions over heterogeneous wireless networks. *Computer Communications, 35,* 2055–2068.

Zadeh, L.A. (1965). Fuzzy sets, *Information and Control,* 8 (3): 338–353.

Zimmermann, H.J.(1994) Fuzzy set theory and its applications, Kluwer Academic Publishers, Boston.

Zineb, A.B., Ayadi, M. & Tabbane, S. (2017) An Enhanced Vertical Handover Based on Fuzzy Inference MADM Approach for Heterogeneous Networks. *Arabian Journal for Science and Engineering,* doi:10.1007/s13369-017-2418-1

Zhang , X., Deng Y., Chan F.T.S., Mahadevan ,S . (2015). A fuzzy extended analytic network process-based approach for global supplier selection. *Applied Intelligence,* 43(4):760–772.

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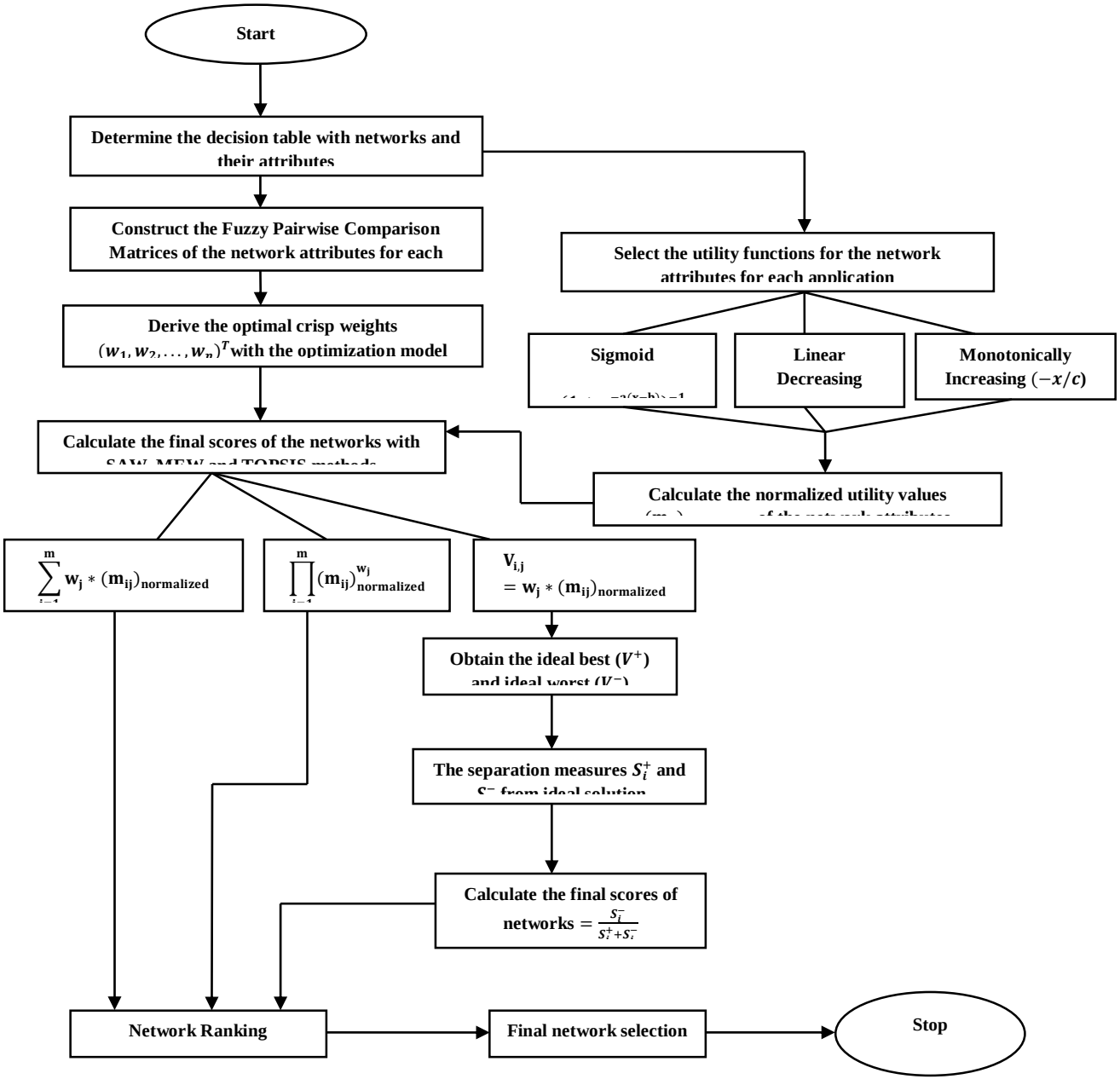
Fig 1: Working of proposed network selection technique



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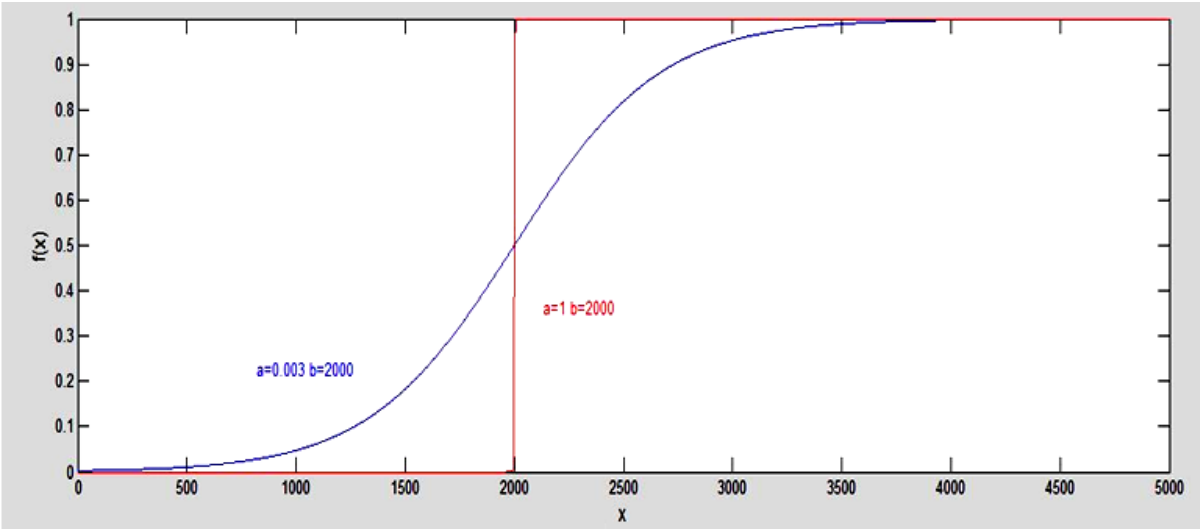

Fig 2: Sigmoid function with values of a and b

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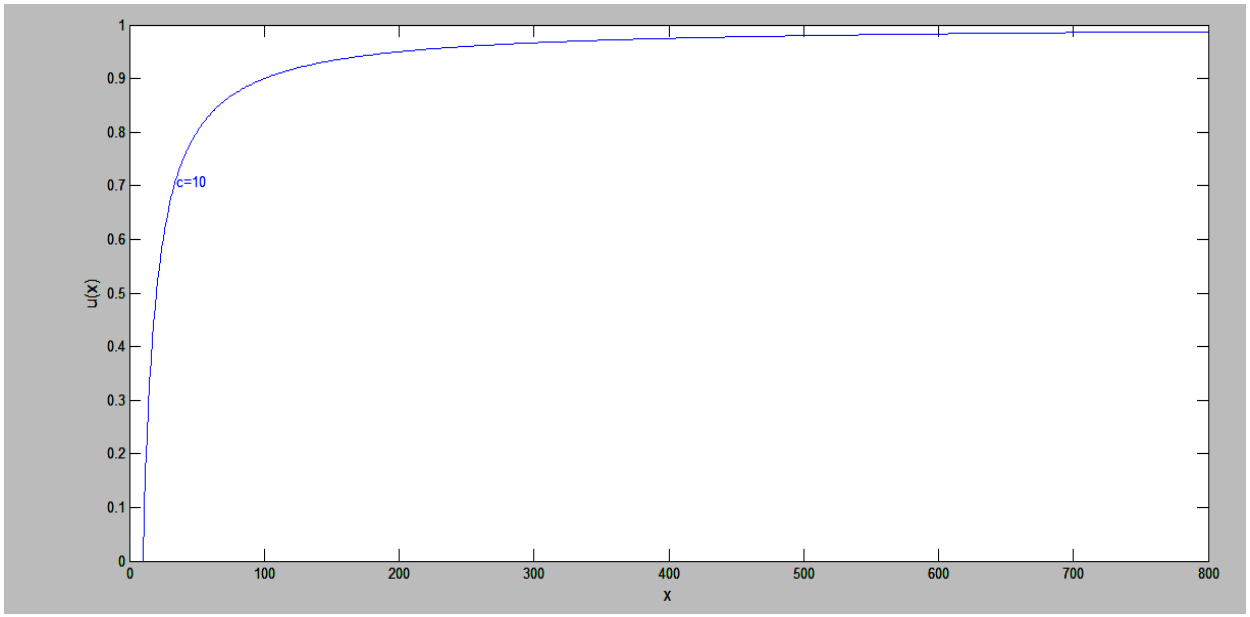

Fig 3: Monotonically increasing function with c= 10

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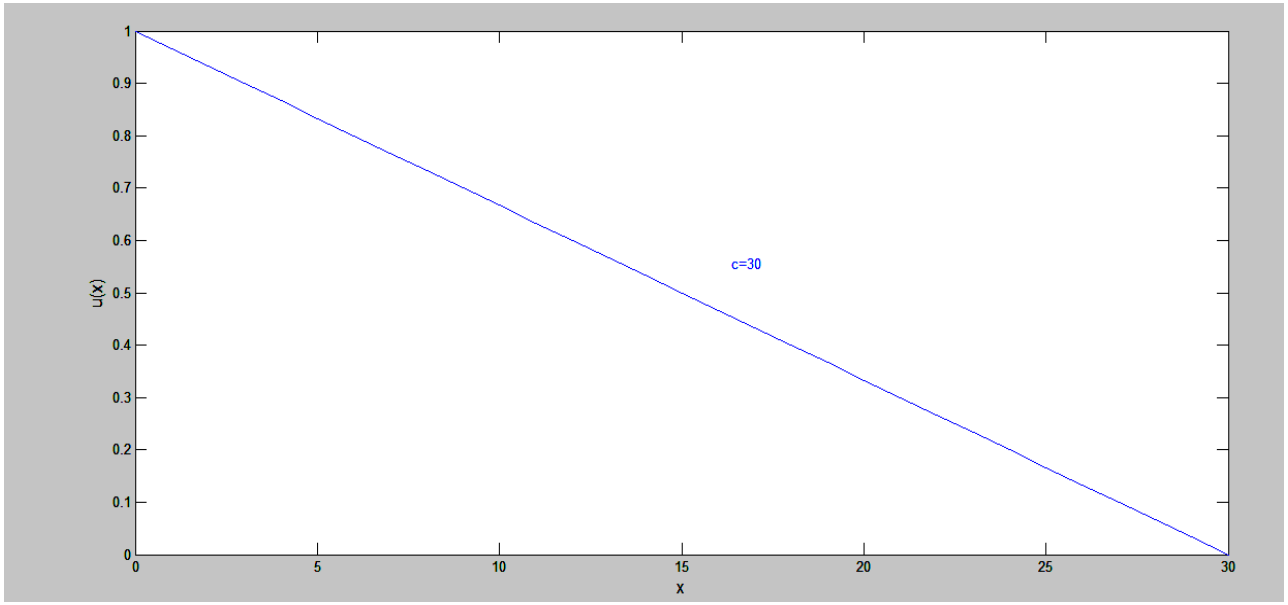

Fig 4: Linear decreasing function with c=30

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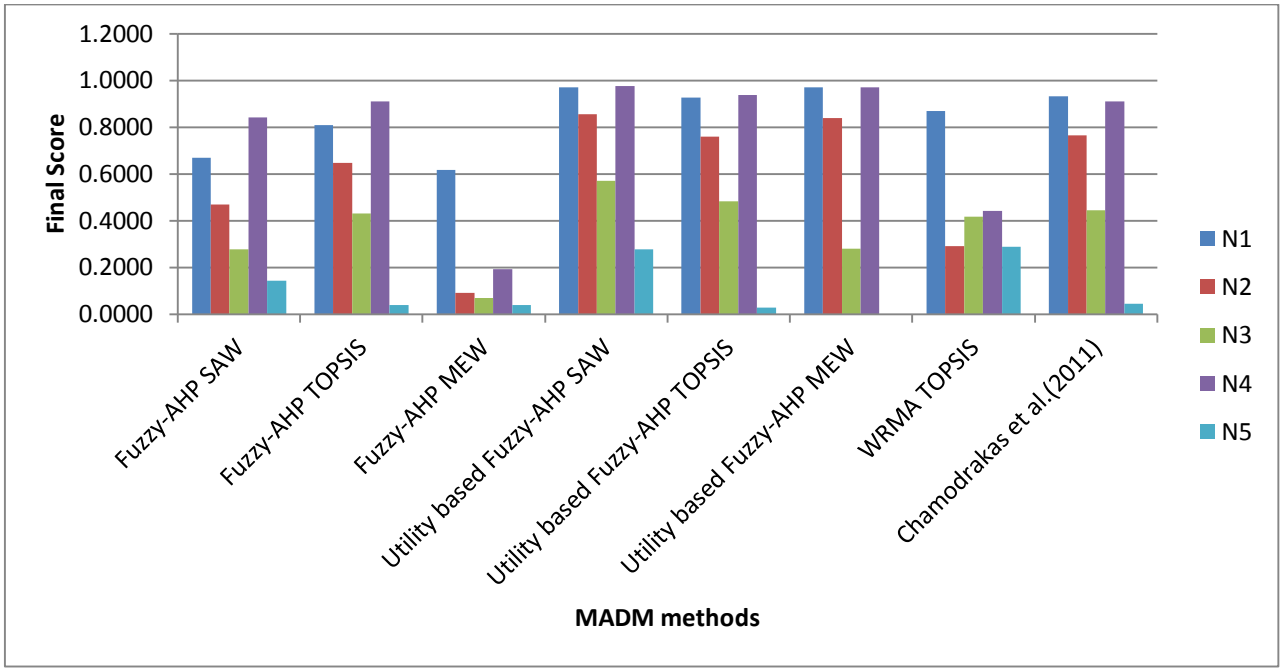

Fig. 5: Final scores of networks for different Fuzzy –AHP MADM methods for voice application

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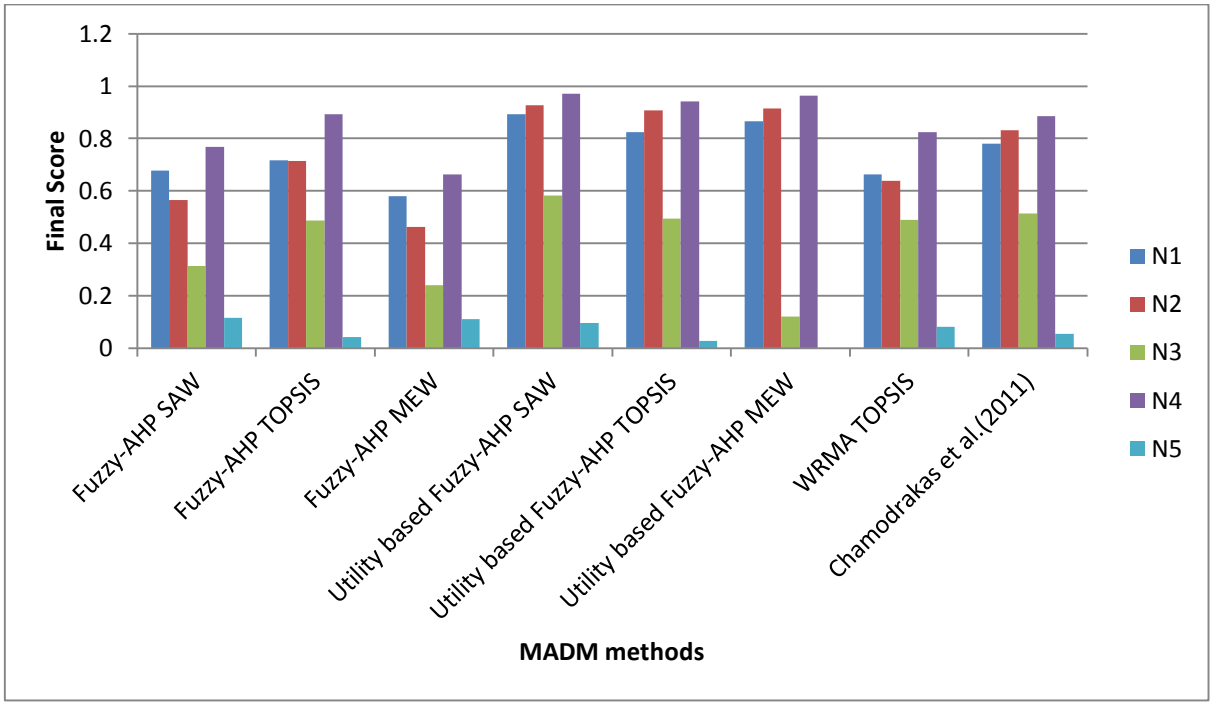

Fig. 6: Final scores of networks for different Fuzzy –AHP MADM methods for video application

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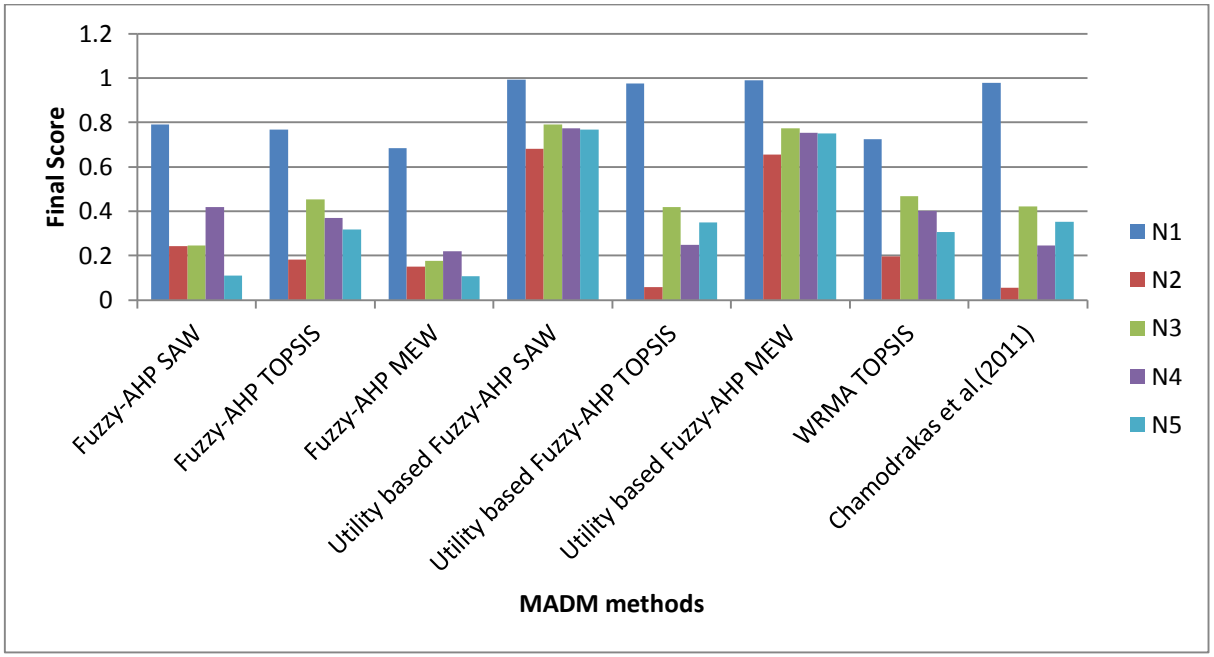

Fig. 7: Final scores of networks for different Fuzzy –AHP MADM methods for best-effort application

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Table 1 Decision table in AHP

Alternatives	**Criteria**				
	C_1	C_2	C_3	...	C_n
A_1	m_{11}	m_{12}	m_{13}		m_{1n}
A_2	m_{21}	m_{22}	m_{23}	...	m_{2n}
...	...	...	...	...	...
...	...	...	...	...	...
A_m	m_{m1}	m_{m2}	m_{m3}	...	m_{mn}

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Table 2: Fuzzy judgment scores in Fuzzy-AHP (Wang et. al, 2007)

Fuzzy judgments	Fuzzy Scores
About equal	(1/2, 1, 2)
About a times more important	(a-1, a, a+1)
Between b and c times more important	(b, (b+c)/2, c)

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Table 3: Fuzzy Comparison matrix for voice application

	Bandwidth	**Delay**	**Jitter**	**Error Rate**	**Cost**
Bandwidth	(1,1,1)	(0.25,0.33,0.5)	(0.33,0.4,1)	(1,2,3)	(0.25,.33,0.5)
Delay	(2,3,4)	(1,1,1)	(1,2,3)	(4,5,6)	(0.5,1,2)
Jitter	(2,2.5,3)	(0.33,0.5,1)	(1,1,1)	(2,3,4)	(0.33,0.5,1)
Error Rate	(0.33,0.05,1)	(0.17, 0.2, 0.25)	(0.25,0.33,0.05)	(1,1,1)	(0.17,0.2,0.25))
Cost	(2,3,4)	(0.5,1,2)	(1,2,3)	(4,5,6)	(1,1,1)

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Table 4: Fuzzy Comparison matrix for video application

	Bandwidth	**Delay**	**Jitter**	**Error Rate**	**Cost**
Bandwidth	(1,1,1)	(0.33,0.5,1)	(0.33,0.5,1)	(2,3,4)	(2,3,4)
Delay	(1,2,3)	(1,1,1)	(0.5,1,2)	(3,4,5)	(3,4,5)
Jitter	(1,2,3)	(0.5,1,2)	(1,1,1)	(3,4,5)	(3,4,5)
Error Rate	(0.25,0.33,0.5)	(0.2,0.25,0.33)	(0.2,0.25,0.33)	(1,1,1)	(0.5,1,2)
Cost	(0.25,0.33,0.5)	(0.2,0.25,0.33)	(0.2,0.25,0.33)	(0.5,1,2)	(1,1,1)

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Table 5: Fuzzy Comparison matrix for best-effort application

	Bandwidth	**Delay**	**Jitter**	**Error Rate**	**Cost**
Bandwidth	(1,1,1)	(3,4,5)	(3,4,5)	(0.2,0.25,0.33)	(3,4,5)
Delay	(0.2,0.25,0.33)	(1,1,1)	(0.5,1,2)	(0.13,0.14,0.17)	(0.5,1,2)
Jitter	(0.2,0.25,0.33)	(0.5,1,2)	(1,1,1)	(0.13,0.14,0.17)	(0.5,1,2)
Error Rate	(3,4,5)	(6,7,8)	(6,7,8)	(1,1,1)	(6,7,8)
Cost	(0.2,0.25,0.33)	(0.5,1,2)	(0.5,1,2)	(0.13,0.14,0.17)	(1,1,1)

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Table 6: Crisp weights obtained by extent analysis method

Application	Bandwidth	Delay	Jitter	BER	Cost
Voice	0.0691	0.3549	0.2211	0	0.3549
Video	0.2580	0.3710	0.3710	0	0
Best Effort	0.0065	0	0	0.9935	0

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Table 7: Crisp weights and consistency index for voice application

Method	Bandwidth	Delay	Jitter	BER	Cost	Consistency Index (γ)
Fuzzy optimization model (eq. 22)	0.0988	0.3035	0.2138	0.0614	0.3225	0.5106
Proposed model (eq.25)	0.0921	0.3195	0.2087	0.0603	0.3194	0.6234

Table 8: Crisp weights and consistency index for video application

Method	Bandwidth	Delay	Jitter	BER	Cost	Consistency Index (γ)
Fuzzy optimization model (eq. 22)	0.1555	0.3123	0.3263	0.0934	0.1125	0.1983
Proposed model (eq.25)	0.1987	0.3260	0.3256	0.0747	0.0750	0.6948

Table 9: Crisp weights and consistency index for best effort application

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Method	Bandwidth	Delay	Jitter	BER	Cost	Consistency Index (γ)
Fuzzy optimization model (eq. 22)	0.1198	1050	0.0717	0.6255	0.0780	0.1558
Proposed model (eq.25)	0.1757	0.0761	0.0804	0.5888	0.0790	0.4427

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Table 10: Requirements of network attributes for the three applications

	Bandwidth	**Delay**	**Jitter**	**BER**	**Cost**
Voice	32-64 Kbps	100-150ms	50-80ms	<30	<50
Video	512-5000Kbps	100-150ms	40-70ms	<30	<50
Best Effort	>10kbps	<20000ms	<10000ms	<30	<50

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Table 11: Utility functions for attributes for the three applications

	Voice	Video Streaming	Best Effort
Bandwidth	Sigmoid function $f(x)$ a=0.25, b=48 (Chamodrakas and Martakos, 2011)	Sigmoid function f(x) a=0.003, b=2000 (Chamodrakas and Martakos, 2011)	Monotonically increasing function $u(x)$. c=10
Delay	Sigmoid function $g(x)$ a=0.1, b=112.5 (Chamodrakas and Martakos, 2011)	Sigmoid function $g(x)$ a=0.1, b=112.5 **(**Chamodrakas and Martakos, 2011)	Linear decreasing function $u(x)$. c=20000
Jitter	Sigmoid function $g(x)$ a=0.185, b=65	Sigmoid function $g(x)$ a=0.175, b=55	Linear decreasing function $u(x)$. c=10000
Error Rate	Linear decreasing function $u(x)$. c=30	Linear decreasing function $u(x)$. c=30	Linear decreasing function $u(x)$. c=30
Cost	Linear decreasing function $u(x)$. c=50	Linear decreasing function $u(x)$. c=50	Linear decreasing function $u(x)$. c=50

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Table 12: Decision table for network selection problem

	N1	**N2**	**N3**	**N4**	**N5**
Bandwidth (kbps)	2000	5000	8000	11000	1000
Delay (ms)	50	80	90	30	200
Jitter (ms)	10	10	90	20	120
Bit Error Rate (per 10^6 bits)	1	15	9	12	10
Cost (paisa per bit)	10	20	30	6	30

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Table 13: Utility values of attributes for voice application

	N1	**N2**	**N3**	**N4**	**N5**
Bandwidth	1	1	1	1	1
Delay	0.9981	0.9627	0.9047	0.9997	0
Jitter	1	1	0.0097	0.9998	0
BER	0.9667	0.5	0.7	0.6	0.6667
Cost	0.8	0.6	0.4	0.88	0.4

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Table 14: Utility values of attribute for video application

	N1	**N2**	**N3**	**N4**	**N5**
Bandwidth	0.5	0.9999	1	1	0.0474
Delay	0.9981	0.9627	0.9047	0.9997	0
Jitter	1	1	0.0022	0.9978	0
BER	0.9667	0.5	0.7	0.6	0.6667
Cost	0.8	0.6	0.4	0.88	0.4

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Table 15: Utility values of attribute for best-effort application

	N1	N2	N3	N4	N5
Bandwidth	0.9950	0.9980	0.9988	0.9991	0.9900
Delay	0.9975	0.9960	0.9955	0.9985	0.9900
Jitter	0.9990	0.9990	0.9910	0.9980	0.9880
BER	0.9667	0.5	0.7	0.6	0.6667
Cost	0.8	0.6	0.4	0.88	0.4