Fuzzy MCDM Methods Application in Radio Resource Management for Modern Communication Systems

***Abstract*- Fuzzy MCDM methods are a hybrid multi criteria decision making systems where the advantages for both fuzzy logic theory and the traditional MCDM are utilized. Fuzzy MCDM systems take into account the insufficient information and the evolution of available knowledge and they are very useful to deal with the uncertain and imprecise data. The radio resource management mechanisms in modern communication systems are typical multi criteria problems and the usage of MCDM systems is mandatory to reduce the influence of the imprecise, contradictory, and dissimilar measurements of these complex communication systems.**

In this paper, two different fuzzy MCDM systems are developed to address one of the most important radio resources management mechanisms which is vertical handover (VHO). These systems use fuzzy AHP and fuzzy SAW methods. Illustrative numerical examples for the developed systems are presented. The examples show that the choice of the MCDM tool can directly affect the ranking order of the available access networks, and hence, the selection of the MCDM methods is highly critical in any VHO solution.

Keywords*- *MCDM, F-AHP, F-SAW, VHO, RRM

I. INTRODUCTION

Many multi-criteria decision making (MCDM) methods and tools have been developed and used to solve the multi-criteria problems in many fields. Several problems in the communication and electronics engineering field are multi-criteria problems in nature, where several selection and ranking criteria and several alternatives are coexisted. Most of the time, these criteria are conflict and lead to choose different alternatives. Moreover, part of these MCDM problems are multi-objective problems and several performance metrics have to be considered altogether.

Fuzzy MCDM methods are a new direction on the multi-criteria decision making systems where the advantages for both fuzzy logic theory and the traditional MCDM are utilized. Fuzzy MCDM methods take into account the insufficient information and the evolution of available knowledge are they are very useful to deal with the imprecise and uncertain data.

Radio resource management mechanisms such as the handover (HO), the vertical handover (VHO), the admission control (AC), the joint admission control (JAC), the load control (LC), the joint load control (JLC), and the radio network selection (RNS) are typical selection problems, where several decision criteria, several alternatives, several performance metrics, and several decision maker are usually coexisted.

This paper concentrate on one of these RRM mechanisms namely VHO. VHO enables users to access several networks such as WLAN, WMAN, WPAN, and WWAN in parallel. It allows the applications even the real time application to be seamlessly transferred among different networks. In fact, the methods that are developed for VHO in this paper could be used for rest of RRM mechanisms with using the appropriate mechanism criteria.

In this paper, two VHO decision making system are implemented using the most famous and efficient fuzzy MCDM methods which are F-AHP and F-SAW. These implementations are illustrated with detailed numerical examples. In addition, a simple simulation based performance analysis is carried out. The next section presents a simple background for VHO problem and fuzzy numbers, sections 3 and 4 describe our proposed F-AHP and F-SAW vertical handover algorithms. Section 5 gives a detailed illustrative examples for both developed algorithms. Section 6 presents some samples for the obtained results during the simulation of our proposed solutions. Section 7 concludes the paper and give some recommendations to develop the work on the future.

II. BACKGROUND

A. VHO Problem

In modern heterogeneous wireless networks environment, VHO mechanism supports mobile terminals to decide and select the best network between all the available networks. Any VHO solution that is based only on single criterion is not sufficient to provide a good solution and usually leads to undesirable situations such as high handover failure or high handover rate.

M. Mouâd and L. Cherkaoui [1] presented a comparison study of two hybrid solutions that combine the fuzzy logic and two MCDM methods. These methods are compared to decide which solution is relatively the best in the context of VHO problem. U. Paul and O. E. Falowo [2] proposed a network selection method that built a mathematical framework in form of IFTOPSIS to select the best network among several available network for group calls. In paper [3] a combined application of visible light communication and AHP based VHO decision-making algorithm is introduced. M. Drissi and M. Oumsis [4] presented the results for the performance comparison between three different MCDM based VHO algorithms, SAW, TOPSIS and MEW for coexisted WiFi and WiMAX networks. Also, to reduce the number of handover and the ping-pong handover effect, L. Zhang in [5] proposed a handover algorithm which utilizes the fuzzy logic to calculate the performance evaluation values of network, and then makes the handover decision.

In paper [6] a movement aware handover algorithm has been designed based on VIKOR MCDM method. To analyze the performance of the proposed solution, four simulation scenarios have been designed using four traffic classes. Paper [7] proposed a hybrid VHO solution that was based on both TOPSIS and a utility function. The simulation results showed that, the hybrid mechanism reduces the ping-pong effect, the reversal phenomenon, and the handoff failures better than TOPSIS or utility function alone. The main objective of paper [8] was to develop VHO schemes that minimize the number of unnecessary handoffs while increasing the end users satisfaction level. Both AHP & TOPSIS methods were utilized in the paper. Authors in paper [9] compared various combinations of MCDM methods for VHO to finally choose the best network that satisfies the best quality of service requirements. According to the obtained results, the fuzzy methods F-AHP and F-ANP are the best weighting methods, when they are combined with TOPSIS and GRA as the ranking methods. In order to save the power and handover times, author in paper [10] proposed an adaptive vertical handover algorithm with a prediction mechanism for heterogeneous networks.

J. and Rizkallah N. Akkari [11] proposed a software defined networking based VHO where the network with highest RSS and QoS scores is selected for handover in dense HetNets. Paper [12] presented an adaptive VHO algorithm based on F-AHP, which is used to dynamically adjust the weights of each attribute according to users' preferences and the power state of the mobile terminal. Paper [13] proposed a modified multi-criteria VHO algorithm based on artificial neural networks with quality of experience prediction scheme to improve the accuracy of the vertical handoff decision.

Our paper presents two multi-criteria VHO solutions, where five criteria are considered to express the user and operator preferences. "Quality Level" is a criterion to express the quality of service preferred by the user. The "Price" criterion describes the highest level of prices that could be accepted by user. The "Security Level" criterion illustrates the minimum level of security accepted by user. The "Received Signal Strength" criterion describes the level of signal power received from each network. The "Service Type Requirements" criterion describes the type of service requirements that is used by user.

B. Fuzzy Numbers

Figure 1 shows an example of a triangular fuzzy number (TFN), where the membership function $\mu_M(x)$*: R* [0,1] is equal to:

$$\mu_M(x) = \begin{cases} \frac{1}{m-l}x - \frac{1}{m-l}, & x \in [l, m], \\ \frac{1}{m-u}x - \frac{u}{m-u}, & x \in [m, u], \\ 0 & \text{other} \end{cases} \quad (1)$$

where $l \leq m \leq u$. l stand for the lower bound, u stands for the upper bound, and m stands for the median value of *M* with membership function being 1. Any triangular fuzzy number *M* can be represented as *(l, m, u)*. For two triangular fuzzy numbers $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, their operational laws could be summarized as follows:

1. $M_1 + M_2 = (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2)$
2. $M_1 X M_2 = (l_1 l_2,\ m_1 m_2,\ u_1 u_2)$
3. $\gamma X (l_1,\ m_1,\ u_1) = (\gamma l_1,\ \gamma m_1,\ \gamma u_1)$
4. $1/M = (l_1,\ m_1,\ u_1)^{-1} = (\frac{1}{l_1},\ \frac{1}{m_1},\ \frac{1}{u_1})$

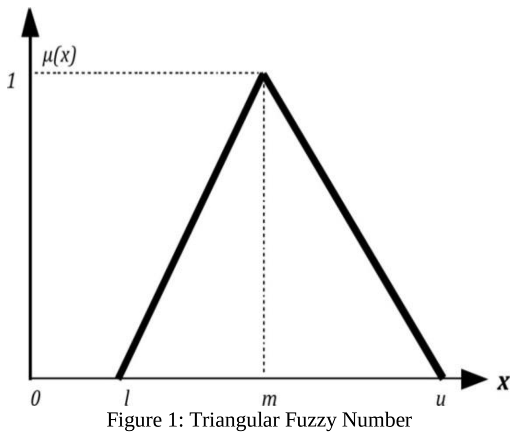

Figure 1: Triangular Fuzzy Number

III. F-AHP VERTICAL HANDOVER

Fuzzy Analytic Hierarchy Process (F-AHP) combines the fuzzy theory with basic Analytic Hierarchy Process (AHP) [14]. In F-AHP, the pair wise comparisons of both criteria and the alternatives are performed through the linguistic variables, which could be represented by triangular fuzzy numbers (TFN) or any other type of fuzzy numbers. Our proposed F-AHP VHO solution could be described in the following steps:

Step 1: the criteria and alternatives are identified and pair-wised compared via linguistic terms shown in Table 1.

Table 1: Linguistic terms and the corresponding TFNs

Saaty scale	Definition	TFN	Fuzzy Triangular Reciprocal Number
1	Equally important (Eq. Imp.)	(1, 1, 1)	(1, 1, 1)
3	Weakly important (Wk. Imp)	(2, 3, 4)	(1/4, 1/3, 1/2)
5	Fairly important (Fr. Imp.)	(4, 5, 6)	(1/6, 1/5, 1/4)
7	Strongly important (St. Imp.)	(6, 7, 8)	(1/8, 1/7, 1/6)
9	Absolutely important (Ab. Imp)	(9, 9, 9)	(1/9, 1/9, 1/9)
2 4 6 8	The intermittent values	(1, 2, 3) (3, 4, 5) (5, 6, 7) (7, 8, 9)	(1/3, 1/2, 1) (1/5, 1/4, 1/3) (1/7, 1/6, 1/5) (1/9, 1/8, 1/7)

The pair wise contribution matrix is shown in Eq. 2, where d_{ij}^k indicates the k[th] decision maker preference of i^{th} criterion over j^{th} criterion, via fuzzy triangular numbers.

$$A^k = \begin{pmatrix} d_{11}^k & d_{12}^k & \dots & d_{1n}^k \\ d_{21}^k & d_{22}^k & \dots & d_{2n}^k \\ \dots & \dots & \dots & \dots \\ d_{n1}^k & d_{n2}^k & \dots & d_{nn}^k \end{pmatrix} \quad (2)$$

Step 2: If there is K decision maker, preferences of each decision maker d_{ij}^k are averaged and d_{ij} is calculated as in the Eq. 3.

$$d_{ij} = \frac{\sum_{k=1}^{K} d_{ij}^k}{K} \quad (3)$$

Step 3: According to averaged preferences from step 2, pair wise contribution matrix is updated as shown in Eq. 4.

$$A = \begin{pmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nn} \end{pmatrix} \quad (4)$$

Step 4: The geometric mean of fuzzy comparison values of each criterion r_i is calculated as shown in Eq. 5.

$$r_i = \sqrt[n]{\left(\prod_{j=1}^{n} d_{ij}\right)} \quad i = 1.2.\dots n \quad (5)$$

Step 5: The fuzzy weights of each criterion can be found with Eq. 6.

$$w_i = \frac{r_i}{(r_1 + r_{2+} \dots . r_n)} = (lw_i . mw_i . uw_i) \quad (6)$$

Step 6: Since w_i are still fuzzy triangular numbers, they need to de-fuzzified via applying Eq.7.

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \quad (7)$$

Step 7: M_i is a non-fuzzy number. However, it still needs to be normalized by Eq. 8.

$$Ni = \frac{Mi}{\sum_{i=1}^{n} Mi} \quad (8)$$

Step 8: Multiply each alternative weight with related criteria, the scores for each alternative is calculated. The alternative (network) with the highest score is selected for VHO.

IV. FUZZY SAW VERTICAL HANDOVER

Simple Additive weighting (SAW) is one of the simplest and most often used MCDM methods and that is based on the weighted average. Let D_N, N = (1,2,3, ... t) be the set of decision makers. The C_j (j = 1,2,3, ..., n) and A_i (i = 1,2,3, ... m) are the sets of criteria and alternatives respectively. The f_{ij} is a value of j^{th} criteria for the i^{th} alternatives. The process of our VHO SAW solution consists of the following steps.

Step 1: Determine finite sets of decision makers, criteria and alternatives.

Step 2: Describe the used linguistic variables as TFNs. A suitable linguistic terms to describe the weights of criteria and the ratings of alternatives are presented on tables 2 and 3.

Table 2: Criteria linguistic terms and the corresponding TFNs

Definition	TFNs
Very Low	(1, 1, 1)
Low	(1, 2, 3)
Medium Low	(2, 3, 4)
Medium	(3, 4, 5)
Medium High	(4, 5, 6)
High	(6, 7, 8)
Very High	(9, 9, 9)

Table 3: Alternatives linguistic terms and the corresponding TFNs

Definition	TFNs
Very poor	(1, 1, 1)
Poor	(1, 2, 3)
Medium Poor	(2, 3, 4)
Fair	(3, 4, 5)
Medium High	(4, 5, 6)
Good	(6, 7, 8)
Very Good	(9, 9, 9)

Step 3: If t decision makers are existed then the fuzzy weight of criterion j is calculated with Eq. 9.

$$w_j = \frac{1}{N}\left[w_j^{(1)} + w_j^{(2)} + \cdots . + w_j^{(t)}\right] \qquad (9)$$

Also the rating of each alternative with respect to criterion j is calculated according to Eq. 10.

$$x_j = \frac{1}{N}\left[x_j^{(1)} + x_j^{(2)} + \cdots . + x_j^{(t)}\right] \qquad (10)$$

Step 4: The fuzzy decision matrix ($D^{\sim}$) for the alternatives is computed as shown in Eq. (11).

$$D^{\sim} = \begin{pmatrix} x_{11}^k & x_{12}^k & \dots & x_{1n}^k \\ x_{21}^k & & \dots & x_{2n}^k \\ \dots & \dots & \dots & \dots \\ x_{n1}^k & x_{n2}^k & \dots & x_{nn}^k \end{pmatrix} \qquad (11)$$

And for the criteria ($W^{\sim}$) as shown in Eq. (12)

$$W^{\sim} = (w1 \quad w2 \quad \dots . \quad wn) \qquad (12)$$

Step 5:. The normalized fuzzy decision matrix R is given by $R = [\boldsymbol{r}_{\boldsymbol{ij}}^{\sim}]_{m\times n}$, i = 1; 2; ... n, j = 1; 2, ... m, where

$$r_{ij}^{\sim} = \frac{x_{ij}}{(max\ x_{ij})} \qquad (13)$$

Step 6: Compute the weighted normalized matrix $V^{\sim}$ by multiplying the weights ($W_j^{\sim}$) of evaluation criteria with the normalized fuzzy decision matrix $r_{ij}^{\sim}$. $V^{\sim} = [\boldsymbol{V}_{\boldsymbol{ij}}^{\sim}]_{m\times n,}$ i = 1, 2, 3, ... n, j = 1, 2, 3, ...m, where

$$V_{ij}^{\sim} = \sum r_{ij}^{\sim} * w_j \quad i = 1,2,3,\dots,n\ , j = 1,2,\dots,m \qquad (14)$$

Step 7: Rank the alternatives and choose the one with the highest value as the preferred one.

V. Illustrative Numerical Examples

In order to make the above methods clear and to see their applicability, a real numerical examples are shown on this section. Five VHO criteria (Quality, Price, Security, RSS, and Service Type) and three alternatives (WWAN, WMAN, WLAN) are used.

A. F-AHP Vertical Handover

The Fuzzy AHP methodology is applied to the VHO problem in this subsection.

First: Determining weights of criteria

Table 4 shows the user preferences with respect to the criteria importance. According to Table 2, the pair wise TFNs comparison matrix is constructed as shown in Table 5.

For each criterion, the geometric mean of fuzzy comparison values is calculated by Eq. 5. For example, r_1 the geometric mean of "Quality" criterion is calculated as follows;

$$r_1 = \sqrt[n]{\left(\prod_{j=1}^{n} d_{ij}\right)} = \left[(1*1*6*4*4)^{1/5}; (1*1*7*5*5)^{1/5}; (1*1*8*6*6)^{1/5}\right] = [2.49; 2.81; 3.10].$$

Table 6 shows the geometric means of fuzzy comparison values of all criteria.

Table 4: Linguistic terms comparison matrix for criteria

Criteria	Quality	Price	Security	Signal Strength	Service Type
Quality		Equally important	Strongly important	Fairly important	Fairly important
Price	Equally important		Strongly important	Strongly important	Fairly important
Security					Weakly important
Signal Strength			Weakly important		
Service Type				Fairly important	

Table 5: TFNs comparison matrix for criteria

Criteria	Quality	Price	Security	Signal Strength	Service Type
Quality	(1, 1, 1)	(1, 1, 1)	(6, 7, 8)	(4, 5, 6)	(4, 5, 6)
Price	(1, 1, 1)	(1, 1, 1)	(6, 7, 8)	(6, 7, 8)	(4, 5, 6)
Security	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)	(1, 1, 1)	(1/4, 1/3, 1/2)	(2, 3, 4)
Signal Strength	(1/6, 1/5, 1/4)	(1/8, 1/7, 1/6)	(2, 3, 4)	(1, 1, 1)	(1/6, 1/5, 1/4)
Service Type	(1/6, 1/5, 1/4)	(1/6, 1/5 ,1/4)	(1/4, 1/3, 1/2)	(4, 5, 6)	(1, 1, 1)

Table 6: Geometric means of fuzzy comparison values

Criteria			
Quality	2.49	2.81	3.1
Price	2.70	3.00	3.29
Security	0.38	0.46	0.56
Signal Strength	0.37	0.44	0.49
Service Type	0.49	0.44	0.49
Total	6.43	7.3	8.16
1/Total	0.16	0.14	0.12
Increasing Order	0.12	0.14	0.16

In the next step, the fuzzy weight of "Quality" criterion w_1 is found by the help of Eq. 6 .

$$w_1 = [(2.49 * 0.12); (2.81 * 0.14); (3.10 * 0.16)] = [0.304; 0.385; 0.483]$$

Hence, the relative fuzzy weights of all criteria are given in Table 7;

Table 7: Relative fuzzy weights of each criterion

Criteria			
Quality	0.299	0.393	0.497
Price	0.324	0.421	0.526
Security	0.045	0.064	0.090
Signal Strength	0.044	0.062	0.078
Service Type	0.059	0.081	0.114

Finally, the relative non-fuzzy weight (Mi) and the normalized weights (Ni) of each criterion are calculated and tabulated in Table 8.

Table 8: Averaged and normalized relative weights of criteria

Criteria	M_i	N_i
Quality	0.396	0.385
Price	0.424	0.411
Security	0.067	0.065
Signal Strength	0.062	0.060
Service Type	0.085	0.082

Second: Determining weights of alternatives with respect to criteria

Firstly, the alternatives should be pair wise compared with respect to each criterion particularly. To save space and time, only “Quality” criterion will be handled here. User preferences for alternatives with respect to “Quality” criterion is shown on Table 9.

Table 9: User preferences with respect to “Quality” criterion

Alternatives	WLAN	WMAN	WWAN
WLAN	(1, 1, 1)		
WMAN	Fairly important	(1, 1, 1)	
WWAN	Absolutely important	Weakly important	(1, 1, 1)

Pair wise comparison matrix of alternatives with respect to “Quality” criterion is formed as Table 10.

Table 10: Comparison matrix with respect to “Quality” criterion

Alternatives	WLAN	WMAN	WWAN
WLAN	(1, 1, 1)	(1/6, 1/5, 1/4)	(1/9, 1/9, 1/9)
WMAN	(4, 5, 6)	(1, 1, 1)	(1/4, 1/3, 1/2)
WWAN	(9 ,9 ,9)	(2, 3, 4)	(1, 1, 1)

The geometric means of fuzzy comparison values (r_i) and relative fuzzy weights of alternatives for each criterion (w_i) are tabulated in Table 11.

Table 11: Geometric means and fuzzy weights of “Quality” Criterion

Alternatives	r_1		
WLAN	0.265	0.281	0.303
WMAN	1.000	1.186	1.442
WWAN	2.621	3.000	3.302
Total	3.885	4.467	5.047
1/Total	0.257	0.224	0.198
Increasing Order	0.198	0.224	0.257

w_1		
0.053	0.062	0.079
0.2	0.261	0.375
0.859	0.660	0.524

In the last step; the non-fuzzy M_i and normalized non fuzzy N_i values are obtained by using center of area method and shown in Table 12.

Table 12: Averaged and normalized relative weights of “Quality” criterion

Alternatives	M_i	N_i

WLAN	0.065	0.063
WMAN	0.279	0.272
WWAN	0.681	0.665

The normalized non-fuzzy relative weights of each alternative for each criterion are calculated and tabulated in Table 13.

Table 13: Normalized non-fuzzy relative weights of each alternative

Alternatives	Quality	Price	Security	Signal Strength	Service Type
WLAN	0.063	0.748	0.118	0.675	0.675
WMAN	0.272	0.180	0.29	0.193	0.193
WWAN	0.665	0.072	0.592	0.132	0.132

By using Table 8 and Table 13, individual scores of each alternative for each criterion are presented in Table 14.

Table 14: Aggregated results for each alternative

CRITERIA		Alternatives Scores		
Weights		WLAN	WMAN	WWAN
Quality	0.38	0.063	0.272	0.665
Price	0.41	0.748	0.18	0.072
Security	0.06	0.118	0.29	0.592
Power	0.06	0.675	0.193	0.132
Service Type	0.08	0.675	0.193	0.132
Total		0.432	0.222	0.336

Depending on this result, alternative "WLAN" has the largest total score and therefore, it is selected as the best network for VHO.

5.2 F-SAW Vertical Handover

The proposed F-SAW method is utilized to solve the VHO problem with the following steps:

Step 1: As described in F-AHP section, in this problem, five criteria, three alternatives and one decision maker are considered.

Step 2: The linguistic variables shown in Table 2 and Table 3 are used to assess the weights of five criteria and the three as shown on Table 15 and Table 16.

Table 15: The weights of five criteria according to user preferences

Criteria	Quality	Price	Security	S
Linguistic Weights	Medium Low	High	Very high	L

Table 16: The weights of alternatives according to user preferences

	Quality	Price	Security	Signal Strength	Service Type
WLAN	Fair	Very Good	Fair	Fair	Good
WMAN	Medium High	Good	Good	Medium Poor	Good
WWAN	Very Good	Poor	Good	Poor	Very Good

Step 3 & 4: The linguistic variables are converted into TFN. Table 17 shows the TFN weights of five criteria. Table 18 shows the TFN weights of the three alternatives and the alternatives decision matrix.

Table 17: TFN weights of five criteria

Criteria	Quality	Price	Security	Signal Strength	Service Type
TFN	(2, 3, 4)	(6, 7, 8)	(9, 9, 9)	(1, 2, 3)	(3, 4, 5)

Table 18: Alternatives decision matrix

	Quality	Price	Security	Signal Strength	Service Type
WLAN	(3, 4, 5)	(9, 9, 9)	(3, 4, 5)	(3, 4, 5)	(6, 7, 8)
WMAN	(4, 5, 6)	(6, 7, 8)	(6, 7, 8)	(2, 3, 4)	(4, 5, 6)
WWAN	(9, 9, 9)	(1, 2, 3)	(6, 7, 8)	(1, 2, 3)	(9, 9, 9)

Step 5: Table 19 computes fuzzy, averaged and normalized relative weights.

Table 19: Fuzzy, averaged and normalized relative weights

Criteria	Relative fuzzy weights			Averaged weight (Mi)	Normalized weight (Ni)
Quality	0.068	0.12	0.192	0.127	0.093
Price	0.204	0.28	0.384	0.289	0.213
Security	0.306	0.36	0.432	0.366	0.270
Signal Strength	1	0.08	0.144	0.408	0.301
Service Type	0.102	0.16	0.24	0.167	0.123

Step 6: Table 20 computes weighted normalized decision matrix by using Eq. 14.

Step 7: Aggregated scores of alternatives with respect to related criterion are calculated as shown on Table 21. WLAN is the alternative with the highest value is selected as the preferred RAT.

Table 20: Normalized non-fuzzy relative weights of each alternative

	Quality	Price	Security	Signal Strength	Service Type

WLAN	0.225	0.496	0.224	0.442	0.306
WMAN	0.280	0.390	0.388	0.333	0.306
WWAN	0.496	0.114	0.388	0.225	0.389

Table 21: Aggregated results for each alternative

Criterion		Alternatives Scores		
Weights		WLAN	WMAN	WWAN
Quality	0.093	0.225	0.280	0.496
Price	0.213	0.496	0.390	0.114
Security	0.270	0.224	0.388	0.388
Signal Strength	0.301	0.442	0.333	0.225
Service Type	0.123	0.306	0.306	0.389
Total		0.358	0.352	0.29

VI. EXPERIMENTS AND RESULTS STUDY

For more realistic experiments, a basic Matlab based simulation environment that define the following models are used:

1. System model define three types of networks as shown on Table 22.

Table 22: System Model

Network Type	Antenna Type	Cell Radius	Number of Cells
WWAN	Omni directional	900m	7
WMAN	Omni directional	400m	14
WLAN	Omni-directional	90m	21

2. Service model defines four types of services as shown on Table 23.

Table 23: Service Model

Service Type	Bit Rate (Mbps)	Delay Requirements (ms)
First Type	0.5	200
Second Type	1	600
Third Type	4	400
Forth Type	10	1400

3. Propagation model is defined as the summation of four components which are the Okumora- Hata distance attenuation, shadow loss, Rayleigh fading, and antenna gain.
4. Mobility model defines randomly distributed mobiles that moves in a random direction a random distance at defined time steps.

Some sample results are summarized in Table 22. As shown in Table 22, the ranking orders resulting from the two MCDM methods are not exactly the same in all examples.

Table 22. Ranking Values Examples

RANK	Example 1		Example 2		Example 3		Example 4		Example 5	
	FAHP	FSAW	FAHP	FSAW	FAHP	FSAW	FAHP	FSAW	FAHP	FSAW
1	WLAN	WLAN	WWAN	WWAN	WWAN	WWAN	WMAN	WMAN	WMAN	WLAN
2	WWAN	WWAN	WLAN	WLAN	WLAN	WMAN	WLAN	WWAN	WLAN	WMAN
3	WMAN	WMAN	WMAN	WMAN	WMAN	WLAN	WWAN	WLAN	WWAN	WWAN

Example 1 and example 2 show exactly similar orders in both methods. Examples 3 and 4 show a little bit difference in the orders, however, in both examples, the most preferable networks is still the same for both methods. Example 5 shows big differences between both methods. These differences is due to the mathematical background for two MCDM types and their way of taking the decision.

VII. CONCLUSIONS AND FUTURE WORK

Many MCDM methods are developed and utilized for selection problems such as VHO. In fact, there is not one MCDM method that could be optimal in all selection problems. The processing time, the number of criteria, the number of alternatives, and the selector experience usually are taken into account when choosing the most suitable MCDM for a specific application. In this paper, two fuzzy MCDM methods are utilized for VHO problems.

A detailed numerical illustration and basic simulation are carried out. The numerical results show that the choice of the MCDM method can affect the ranking order of the networks, and hence, the selection of the MCDM method is highly critical in any VHO MCDM-based solution.

This work could be extended in several directions, first, more MCDM could be used and compared. Also, other types of fuzzy numbers could be utilized. A detailed comparison between the two algorithms and other reference algorithms with respect
to VHO performance criteria such as handover rate should be carried out.

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