INTELLIGENT AUTOMATION & SOFT COMPUTING, 2017
http://dx.doi.org/10.1080/10798587.2017.1306968

A Fuzzy Multi-Criteria Decision Analysis Approach for the Evaluation of the Network Service Providers in Turkey

Serkan Ballı[a] and Mustafa Tuker[b]

[a]Department of Information Systems Engineering, Faculty of Technology, Muğla Sıtkı Koçman University, Mugla, Turkey; [b]International Computer Institute, Ege University, Izmir, Turkey

ABSTRACT

Heterogeneous networks are environments where networks having different topologies and technologies can be connected. In an environment including more than one heterogeneous access network, selection of a bad network may lead to emergence of negative results such as high cost and poor service experience for the users. Ensuring the use of the most effective access network for the personal needs of individuals is a complex decision-making process. In the present study, a multi-criteria decision-making system employing fuzzy logic was developed to evaluate and select network service providers in Turkey. Fuzzy logic was used for the criteria containing uncertain and unclear information. Parameter values of the candidate networks obtained from the real world were evaluated by using Fuzzy Analytic Hierarchy Process method and then results were discussed.

KEYWORDS

Fuzzy analytic hierarchy process; Heterogeneous network; Fuzzy logic; Network service provider

1. Introduction

Heterogeneous networks consist of networks having different topologies and technologies. In general, the heterogeneous technologies provided by Network Service Provider (NSP) used to connect the Internet are classified as wired and wireless (Javaudin, Bellec, Varoutas, & Suraci, 2008). In Turkey, the current wired heterogeneous technologies provided by NSPs for home users consist of ADSL (Asymmetric Digital Subscriber Line), Fiber technology, Power-Line Communication (PLC) and high-speed Internet access offered by Cable Television operators. On the other hand, as a wireless network connection, UMTS (Universal Mobile Telecommunications System) has been put into the service of the end users.

In an environment consisting of multiple nonhomogeneous access networks, selection of the access network, which offers the most efficient service to the user in terms of all criteria considered, is an important issue. Selection of an insufficient network may lead to negative outcomes such as high costs or poor service experience for the user. Therefore, there are many studies conducted all over the world. For instance, OMEGA project is supported by many groups and the European Union (Gaudino et al., 2010). Within the context of the OMEGA project; Loeb, Liss, Ruckert, and Sauer (2009), Suraci, Oddi, Mattiacci, and Angelucci (2010), Bardin, Lalanda, and Escoffier (2010) conducted some studies with the aim of designing systems that can enable home users to use all access technologies efficiently without needing any extra hardware and wire in the environments consisting of heterogeneous networks. Hongyan, Chen, and Lingge (2003) developed a method using fuzzy logic-based multi criteria decision-making for the selection of an access network in a heterogeneous network environment. Kher, Somani, and Gupta (2005) developed a model for network selection by using fuzzy logic. In this model, it was intended to construct a sensitive and easy-to-use model through fuzzy logic by dealing with flexible criteria specific to the user and stable criteria specific to the network. Wei, Hu, and Song (2007) proposed a Fuzzy Analytic Hierarchy Process (FAHP) based model for the network selection. Bari and Leung (2007) carried out a correct sequencing of candidate wireless networks to the terminal by considering the most suitable service. For this purpose, the most suitable one among the candidate networks was determined by using multi-criteria decision-making algorithms. Cui, Yan, Cai, Gao, and Wu (2008) developed a model for the selection of the most suitable network to meet user demands based on QoS parameters by using Analytic Hierarchy Process (AHP) and stochastic multi-attribute decision-making method in a heterogeneous wireless network environment consisting of UMTS and WiMAX technologies. Hu, Zhou, Zhang, and Song (2008) proposed a new network architecture for new generation heterogeneous networks such as 2G, 3G, WLAN, WiMAX, xDSL integrated with the existing network technologies. For this purpose, they developed an intelligent model constituted by three main function modules. Alkhawlani and Ayesh (2008) proposed a general model to sort out the problem of selecting accessible network in heterogeneous wireless networks. In this model, fuzzy logic, genetic algorithms and multi-criteria decision-making methods were used. Liu, Maciocco, Kesavan, and Low (2009) worked on a cost function-based network selection algorithm in an environment consisting of WiFi, WiMAX and 3G networks. Wang and Binet (2009) proposed a network selection method by using the multi-criteria decision-making system in heterogeneous wireless networks. Piamrat, Ksentini, Bonnin, and Viho (2011) proposed a cooperative approach consisting of steps such as obtaining information from the existing networks and users, monitoring the existing sources and deciding the appropriate

CONTACT Serkan Ballı serkan@mu.edu.tr

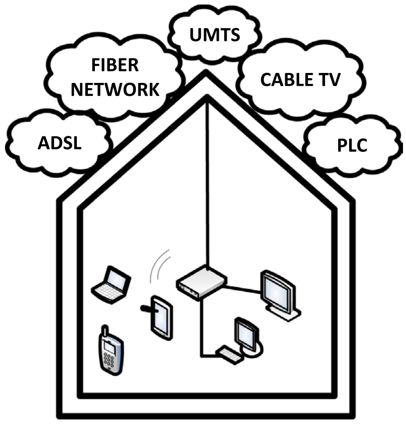

Figure 1. Heterogeneous Network Services.

network in a heterogeneous wireless network environment. TalebiFard and Leung (2011) developed a model for the selection of the most efficient network by using TOPSIS and WPM (Weighted Product Method) techniques in heterogeneous networks. Tamea (2011) proposed a model for seamless handover and selecting the best network among heterogeneous wireless networks. In the construction of this model, one of the multi-criteria decision-making methods, TOPSIS was used. Qutub and Anjali (2012) proposed a model called NANS (Network Assisted Network Selection) to select of the best network supporting the highest quality service by using dynamic network status information and the AHP method. Charilas, Markaki, Psarras, and Constantinou (2009) used FAHP and ELECTRE methods for selection of the most efficient and suitable access network to meet the QoS requirements. Zhang and Qi (2014) applied multiple attribute decision-making methods for heterogeneous network selection. Skondras, Sgora, Michalas, and Vergados (2016) used Analytic Network Process and trapezoidal interval-valued fuzzy technique as network access selection method. Charilas, Panagopoulos, and Markaki (2014) proposed a unified network selection framework using Principal Component Analysis and AHP methods.

While other works in literature evaluated the alternative networks using one goal (profile), this study evaluates the networks using four different goals (profiles). Additionally, end user performances of the networks provided by NSPs in Turkey were studied in this study. For this purpose, the user profiles were generated to determine the needs of the users. Then, heterogeneous network services were evaluated together by considering the user profiles and which service would be most efficient for a home user was investigated. Parameter values of the candidate networks used in the evaluation of heterogeneous computer networks were obtained from the real world. The significant contribution of this article was the selection of the NSPs according to four different user profiles (goals) by employing fuzzy logic and multi-criteria decision-making techniques. The selection system was developed to select the best access network that could provide the most efficient service in terms of meeting all the needs of the user. In this way, the user would be provided with maximum service in line with the needs with minimum expenditure. For ambiguous and unclear criteria, fuzzy logic was used, for evaluation and sequencing the networks, FAHP method was employed. It was seen that user requirements were effectively analyzed; sensitive evaluation and reasonable results were obtained.

2. Heterogeneous Network Services

Heterogeneous networks are environments where networks having different topologies and technologies can be connected. Heterogeneous technologies offered by service providers to be used to connect to the Internet are generally classified as wired and wireless (Javaudin et al., 2008). In Turkey, network services offered by service providers for home users can be seen in Figure 1.

ADSL technology provides high-speed data transmission between the user and service provider through copper cables used from telephone lines (Bingham, 2000; Tanenbaum, 2003). Fiber optic access network is a wired technology providing the most efficient broadband connection. As the connection is made over fiber optic cable rather than copper wires, it is more secure and faster (Tanenbaum, 2003). PLC is realized by transmitting an analogue or digital signal over a low-voltage electric distribution network. This technology is making it possible for users to have access to the Internet without needing the use of extra cable for the communication network (Newbury, 1997).

Cable Television (TV) is a broadband network technology that can be available by means of Cable TV infrastructure (Tzerefos, Sdralia, Smythe, & Cvetkovic, 1999). Cable TV provides the services in a single line such as interactive TV, the Internet, data downloading, e-mail receiving and sending, etc. (Forouzan, 2007). In relation to wireless access networks, UMTS (3G) technology was developed to provide images, data and high-speed internet connection besides voice communication (Lehr & McKnight, 2003). Heterogeneous network services do not only vary depending on their architectures, but also their parameter values offered by NSP's. The main parameters showing the efficiency of heterogeneous network services are total bandwidth, available bandwidth, delay, jitter, package loss and cost (Bari & Leung, 2007).

Total Bandwidth (TB): Maximum number of bits that can be transmitted per second on a network, channel or line is called as total bandwidth (Forouzan, 2007). *Available Bandwidth (AB)*: Available bandwidth is the bandwidth value offered by the current network during the real-time applications (Carter & Crovella, 1996). *Delay*: It is the time value of the data package travelling from the source to the destination, its unit is millisecond (Forouzan, 2007). *Jitter*: Jitter is the standard deviation of the delay between the real-time data packages. When a jitter attains a high value, this may result in loss of the data packages or resending them again (Bari & Leung, 2007). *Package Loss (PL)*: Development of large networks led to an increase in traffic load. Therefore, routers on the networks operate very intensively. While NSPs offer services to their users in this intense environment, package losses occur due to various reasons (Borella, Swider, Uludag, & Brewster, 1998). Cost: Every NSP sets a connection fee for the service it provides (Bari & Leung, 2007). Cost per byte is the cost of one-byte data traffic for the user.

3. Fuzzy Analytic Hierarchy Process

Analytic hierarchy process is a method developed by Saaty (1980) to deal with multi-criteria decision-making problems (Saaty, 1996). AHP is based on expert knowledge to carry out healthy evaluations for multi-criteria decision-making problems. As it is easy to understand by decision makers, it is widely used. However, many of the multi-criteria decision-making problems have a complicated structure.

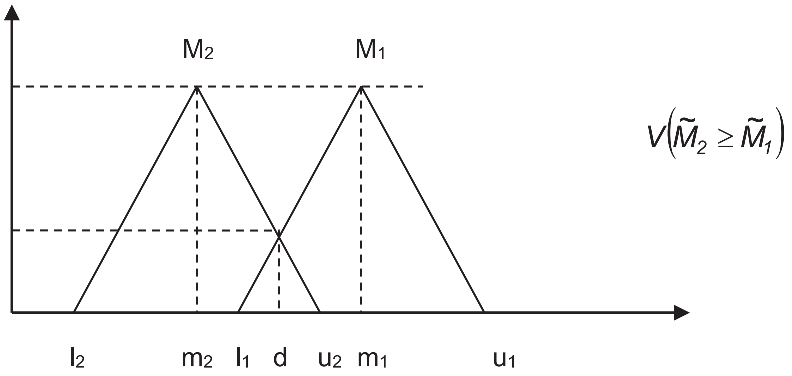

Figure 2. The Intersection between $\underline{M}_1$ and $\underline{M}_2$.

Therefore, they need to be qualitatively and quantitatively well understood and expressed. People may have successful outcomes by using uncertain information in a sensitive manner for the solution of such problems. Particularly, fuzzy sets designed to account for the mathematical ambiguity, operate like the human brain to come up with decisions made based on uncertain data (Chen, 2010). Though the traditional AHP method was designed to reflect expert knowledge, it is not successful in precisely expressing fuzzy problems that can be solved through human thinking. For these problems, fuzzy set theory was proposed by Zadeh (1965), which provides a mathematical way to represent vagueness and fuzziness in humanistic systems (Arslan & Çunkaş, 2012). To improve the abilities of AHP methods in this regard, through integration with fuzzy sets, Fuzzy AHP was designed as an alternative solution method. Van Laarhoven and Pedrycz (1983) conducted another study on FAHP. Then, FAHP became a successful method used to make decision in ambiguous and fuzzy environments.

This study employs synthetic extent values for pairwise comparisons with triangular fuzzy numbers (TFNs). Let $X = \{x_1, x_2, x_3, ..., x_n\}$ be an object set; and $G = \{g_1, g_2, g_3, ..., g_n\}$ be a goal set. An object represents an alternative or a criterion and a goal stands for the intention according to the desirability of the objects, which are to be judged. According to the Chang's method (Chang, 1992, 1996), first each object is provided for evaluation and then extent analysis is executed for each goal, g_i (Rostamzadeh & Sofian, 2011). So, m extent values of each object are found as:

$M_{gi}^1, M_{gi}^2, ...M_{gi,}^m \quad i = 1, 2, ..., n,$ where M^j_{gi} $(j = 1, 2, ..., m)$ all are TFNs. The steps of Chang's extent analysis may be provided as follows (Ballı & Korukoğlu, 2009, 2014):

Step 1**:** The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{1}$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$, perform the fuzzy addition operation of m extent analysis values for a particular matrix as follows:

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{2}$$

And to obtain $\left[\sum_{j=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$, perform the fuzzy addition operation of M^j_{gi} $(j = 1, 2, ..., m)$ values as follows:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \tag{3}$$

Then inverse of the vector is computed as Equation. 4:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \tag{4}$$

Step 2**:** As $\tilde{M}_1 = (l_1, m_1, u_1)$ and $\tilde{M}_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as:

$$V\left(\tilde{M}_2 \geq \tilde{M}_1\right) = \sup_{y \geq x} \left[\min \left(\mu_{\tilde{M}_1}(x), \mu_{\tilde{M}_2}(y) \right) \right] \tag{5}$$

In addition, it is also expressed as follows:

$$V\left(\tilde{M}_2 \geq \tilde{M}_1\right) = hgt(\tilde{M}_1 \cap \tilde{M}_2) = \mu_{M_2}(d) \tag{6}$$

$$= \begin{cases} 1, & \text{if} \quad m_2 \geq m_1 \\ 0, & \text{if} \quad l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \tag{7}$$

Figure 2 illustrates Equation. 7 where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}. To compare M_1 and M_2, both the values of $V\left(M_1 \geq M_2\right)$ and $V\left(M_2 \geq M_1\right)$ are needed.

Step 3**:** The degree of the possibility for a convex fuzzy number is greater than k. Convex fuzzy numbers M_i (i=1, 2, k) can be defined as follows:

$$V(M \geq M_1, M_2, ...M_k)$$

$$= V\left[\left(M \geq M_1\right) \quad and \quad (M \geq M_2) \quad and....and \quad (M \geq M_k) \right]$$

$$= \min \quad V(M \geq M_i), \quad i = 1, 2, 3, ..., k \tag{8}$$

Assume that $d\left(A_i\right) = \min V(S_i \geq S_k)$ for $k = 1, 2, ..., n; k \neq i$. Then the weight vector should be

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T \tag{9}$$

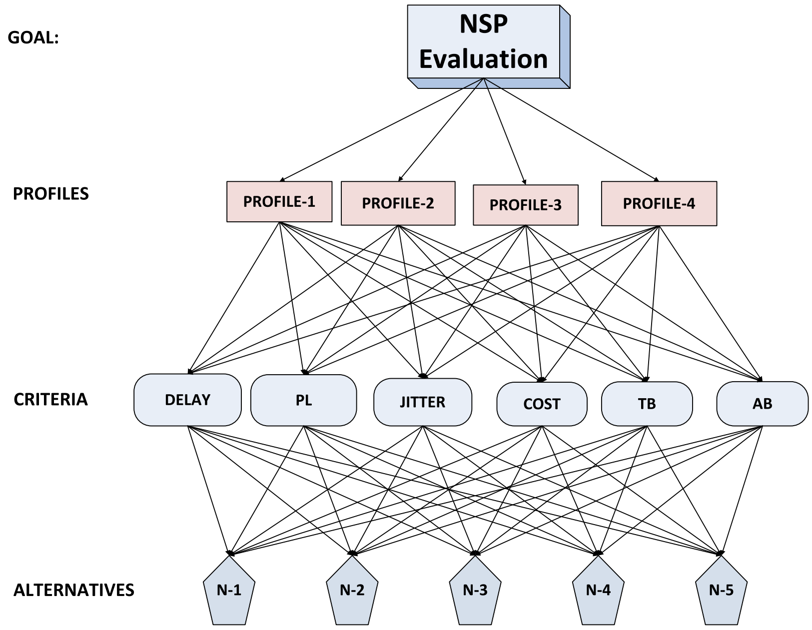

Figure 3. Hierarchic Structure of the Problem.

Table 1. Parameter Values Obtained from the Candidate Networks.

Networks	Delay (ms)	PL (%)	Jitter (ms)	Cost ()	TB (Mbps)	AB (Mbps)
N-1	119.83	0.075	7.15	0.12	7.2	2.8285
N-2	48.85	0.0102	0.25	0.09	8	0.6567
N-3	42.95	0.0135	0.213	0.12	20	0.835
N-4	52.2	1.29205	1.45	0.04	3	0.4756
N-5	49.95	0.01065	7.68	0.02	1	0.8889

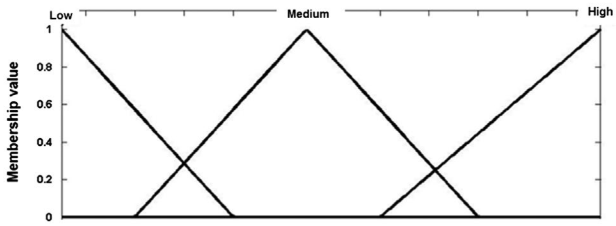

Figure 4. Membership Function for the Parameters.

Table 2. Fuzzy Values of the Parameters.

Networks	Delay	PL	Jitter	Cost	TB	AB
N-1	0.525	0.825	0.48	0.254	0.482	0.85
N-2	0.757	0.825	0.855	0.449	0.5	0.383
N-3	0.814	0.825	0.855	0.254	0.837	0.449
N-4	0.73	0.15	0.715	0.682	0.294	0.27
N-5	0.748	0.825	0.48	0.851	0.12	0.47

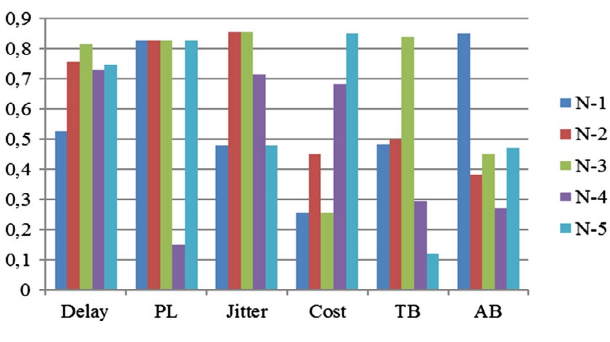

Figure 5. Performances of the Candidate Networks According to the Parameters.

Where $A_i = (i = 1, 2, \ldots n)$ are n elements.

Step 4: Subsequently, the normalized weight vectors are

$$W = (d(A_1), d(A_2), \ldots\ldots, d(A_n))^T \tag{10}$$

Where W is a non-fuzzy number.

4. Evaluation of the Network Service Providers

Every user may have a different reason for using network access. The differences among the purposes of the users may lead to emergence of differences in terms of the needs of the users. Hence, similar services were subsumed under one profile and in this way; following four different user profiles were generated. User profiles were utilized to determine, which NSP would be used for the purpose.

Profile-1: Video Conference: The purpose of this profile is to meet the needs of the user for video conferencing at the optimum level. The sensitivities of delay and jitter are very high for healthy video conferencing. The importance of AB is also very high.

Profile-2: VoIP: VoIP (Voice over Internet Protocol) is a developed application utilized by many users today for voice communications. In this profile, the sensitivities of delay and jitter are very high. TB and AB requirements are very low, cost parameter is important.

Profile-3: Streaming Media: The purpose of this user profile is to meet the needs of the user for streaming media (watching video and listening to music over the network) at the optimum level. In this profile, TB and AB requirements are very high. The delay in data packages can be tolerated to a great extent; yet, sensitivities to jitter and PL are at the medium level.

Profile-4: Interactive: The purpose of this user profile is to meet the needs of the user for the basic interactive user operations (HTTP, Telnet, SSH, FTP, E-mail) at the optimum level. It is agreed that it includes all the basic operations to be provided for all users with a minimum cost. TB requirement is medium. The importance of delay, jitter and AB parameters is low.

In this study, five different types of NSPs in Turkey were evaluated according to user profiles. Alternatives, criteria and profiles determined and hierarchic display of the problem are

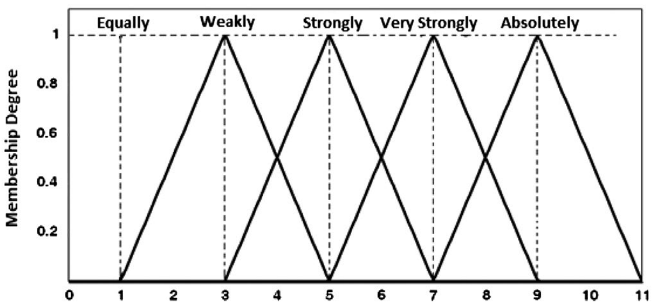

Figure 6. Triangular Fuzzy Linguistic Scale.

Table 3. Linguistic Scales and TFNs.

Linguistic Scale	TFN	Inverse TFN	Inverse Linguistic Scale
Equally Important (EI)	(1,1,1)	(1,1,1)	~EI
Weakly Important (WI)	(1,3,5)	(1/5,1/3,1)	~WI
Strongly Important (SI)	(3,5,7)	(1/7,1/5,1/3)	~SI
Very Strongly Important (VSI)	(5,7,9)	(1/9,1/7,1/5)	~VSI
Absolutely Important (AI)	(7,9,11)	(1/11,1/9,1/7)	~AI

Table 4. Fuzzy Pair-wise Comparison with Respect to the Goal of Profile-1.

Criteria	Delay	PL	Jitter	Cost	TB	AB
Delay	EI	SI	EI	WI	SI	WI
PL	~SI	EI	~SI	WI	EI	~WI
Jitter	~EI	SI	EI	WI	SI	WI
Cost	~WI	~WI	~WI	EI	~WI	~WI
TB	~SI	~EI	~SI	WI	EI	~WI
AB	~WI	WI	~WI	WI	WI	EI

presented in Figure 3. Network -1 (N-1) uses UMTS (3G) technology, Network-2 (N-2) uses ADSL technology, Network-3 (N-3) uses Fiber technology, Network-4 (N-4) uses Cable TV technology and Network-5 (N-5) uses PLC technology. Each of the candidate networks corresponds to one of the alternative solutions. The criteria are the real-time data obtained from the candidate networks. The profiles developed in line with the needs of the user allow the proper evaluation of the criteria. As a result of all the evaluations, the most suitable network was selected.

The parameters from the candidate networks were obtained in real time by using Iperf software (http://iperf.sourceforge.net/). Iperf is software free to download and is used to measure maximum TCP and UDP bandwidth performance. The parameters can vary at any moment. The state of the network may vary depending on the number of current active users and load. Thus, the tests were repeated at certain time intervals and 1000 samples were obtained for each network. The average parameter values obtained from the candidate networks are presented in Table 1.

Table 6. The Synthesis Values.

	l	m	u
*SC*1	0.107	0.296	0.780
*SC*2	0.037	0.094	0.260
*SC*3	0.107	0.296	0.780
*SC*4	0.021	0.043	0.180
*SC*5	0.037	0.094	0.260
*SC*6	0.046	0.017	0.520

Table 7. The Degrees of Possibilities.

V(*SCi* ≥ *SCj*)	*SC*1	*SC*2	*SC*3	*SC*4	*SC*5	*SC*6
*SC*1	-	1	1	1	1	1
*SC*2	0.42	-	0.42	1	1	0.72
*SC*3	1	1	-	1	1	1
*SC*4	0.22	0.73	0.22	-	0.73	0.50
*SC*5	0.42	1	0.42	1	-	0.72
*SC*6	0.77	1	0.77	1	1	-

In order to convert these values into fuzzy values, triangular membership function given in Figure 4 was used. And the fuzzy values of the parameters calculated in this way are presented in Table 2. In Figure 5, the performances of the candidate networks according to the parameters can be seen. The next operation is the calculation of criteria weights for each user profile. To do so, FAHP was used together with triangular fuzzy numbers and synthesis values for pair-wise comparisons.

In order to create a pair-wise comparison matrix, triangular fuzzy linguistic scale in Figure 6 was developed. Linguistic scale values and their corresponding fuzzy triangular numbers can be seen in Table 3.

Help of a network expert who has knowledge about used parameters and networks was applied for evaluation. For each profile and criteria, fuzzy pair-wise comparison matrices were determined by considering expert knowledge. Linguistic values found according to priority values for Profile-1 are given in Table 4 and their corresponding triangular fuzzy numbers were calculated by using the linguistic scale values given in Table 3 and presented in Table 5.

After obtaining the fuzzy pair-wise comparison matrix, weights belonging to all the criteria were calculated. According to FAHP, first synthesis values were calculated. Based on Table 5, synthesis values were found according to Equation. 1 as presented in Table 6. Then, these values were compared by using equation 7 and degrees of possibilities presented in Table 7 were obtained.

Weights for Profile-1 were calculated from Table 7 as $(0.260, 0.111, 0.260, 0.058, 0.111, 0.200)^T$. In a similar manner, all the weights of other profiles were calculated. The weights of each parameter for the user profiles are shown in Table 8.

Weighted values of the candidate networks according to FAHP method were found by multiplying fuzzy values of the candidate networks presented in Table 2 with weights calculated for each profile given in Table 8. These values are also

Table 5. Fuzzy Pair-wise Comparison Matrix for Profile-1.

	Delay	PL	Jitter	Cost	TB	AB
Delay	(1,1,1)	(3,5,7)	(1,1,1)	(1,3,5)	(3,5,7)	(1,3,5)
PL	(1/7,1/5,1/3)	(1,1,1)	(1/7,1/5,1/3)	(1,3,5)	(1,1,1)	(1/5,1/3,1)
Jitter	(1,1,1)	(3,5,7)	(1,1,1)	(1,3,5)	(3,5,7)	(1,3,5)
Cost	(1/5,1/3,1)	(1/5,1/3,1)	(1/5,1/3,1)	(1,1,1)	(1/5,1/3,1)	(1/5,1/3,1)
TB	(1/7,1/5,1/3)	(1,1,1)	(1/7,1/5,1/3)	(1,3,5)	(1,1,1)	(1/5,1/3,1)
AB	(1/7,1/5,1/3)	(1,3,5)	(1/5,1/3,1)	(1,3,5)	(1,3,5)	(1,1,1)

Table 8. Weights of Parameters for Each Profile.

	Delay	PL	Jitter	Cost	TB	AB
Profile-1	0.260	0.111	0.260	0.058	0.111	0.200
Profile-2	0.282	0.119	0.268	0.219	0.047	0.065
Profile-3	0.017	0.114	0.114	0.207	0.296	0.252
Profile-4	0.060	0.254	0.060	0.355	0.062	0.209

Table 9. Weighted Values of the Candidate Networks According to the Profiles.

	Profile-1	Profile-2	Profile-3	Profile-4
N-1	0.591	0.508	0.567	0.568
N-2	0.669	0.688	0.542	0.577
N-3	0.723	0.681	0.619	0.545
N-4	0.518	0.596	0.408	0.441
N-5	0.567	0.660	0.492	0.691

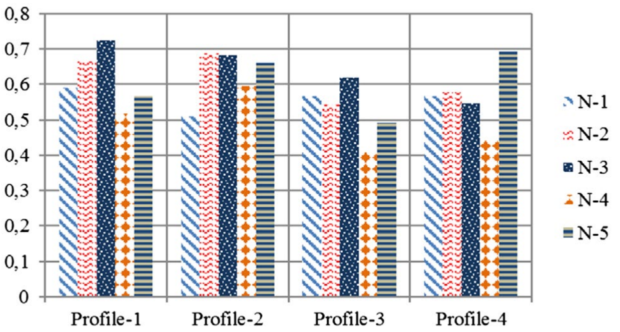

Figure 7. The Ranking of the Candidate Networks According to the Profiles.

given in Table 9. The ranking of the candidate networks according to FAHP method is presented in Figure 7.

For Profile-1, N-3 took first place among the candidate networks. The effect of keeping the user requirements for video conferencing very high is extremely influential on the result. Though N-3 took second place in terms of AB, the suitable values it produced for the delay and jitter parameters enabled it to take first place in this profile. For Profile-2, N-2 took first place among the candidate networks. In this profile, while the cost is desired to be low, delay and jitter sensitivity is desired to be high and this is believed to be highly influential on the attainment of this result. Though there were some candidate networks having costs lower than that of N-2, they came after N-2, as they did not precisely meet user requirements. For Profile-3, N-3 took first place among the candidate networks. In this profile, high requirements of TB and AB have a great influence on the result. Having low cost is also important for this profile. Though N-4 and N-5 have lower costs than N-3, they lost the competition as they have lower TB and AB values. For Profile-4, N-5 took first place among the candidate networks. As in this profile, cost parameter has very high importance and the network having the lowest cost took first place. However, N-4 having the second lowest cost took last place. This is so as the PL value of N-4 is very high. In this profile, the most important criterion after cost is PL. Though minimum cost is desired in Profile-4, as other user requirements could not be overlooked, this result was attained.

5. Conclusion

The present study addressed the question of how most effectively to select heterogeneous network services depending on the intended purpose. In general, when users are confronted with such a problem, they get into action without adequate information and make their decisions based on cost and TB values. In that case, it does not mean that it is the most efficient network enabling users to have the best results. The quality of a network is not determined solely by the cost or its having a very high TB value. Many parameters should be considered together for a sensitive evaluation and healthy result. Moreover, user requirements should be effectively analyzed and the extent to which candidate networks can meet the user requirements should be properly evaluated. In the present study, not only TB and cost criteria, but also AB, delay, jitter, PL were taken into consideration. Moreover, depending on the purpose of use and user requirements, four different profiles were created. In the environment including information ambiguous for the user, the use of fuzzy logic allowed the healthy reflection of the expert opinions on decision-making. By means of the FAHP method used, fast and healthy outcomes were obtained. FAHP ensures flexibility for the expression of expert opinions. As the weight of each criterion is different for the profiles, the most important criterion for each profile was found.

In future research, the results of the present study can be compared with the results to be obtained through different evaluation methods. By conducting various surveys on network users, new user profiles can be created or changes can be made on the existing profiles. Moreover, a network performance evaluation work emphasizing the concept of mobility through which the network users can have the most efficient uninterrupted connection service can be conducted.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Serkan Ballı is an assistant professor in the Information Systems Engineering Department at Muğla Sıtkı Koçman University, Turkey. He received an MSc degree from the Statistics and Computer Science, Mugla University, Turkey in 2005 and a Ph.D. degree in the Department of Computer Engineering, Ege University, Turkey in 2010. His research interests include fuzzy logic, expert systems, intelligent systems and decision support systems.

Mustafa Tüker is a Ph.D. candidate in the International Computer Institute, Ege University, Izmir, Turkey. He received an MSc degree from the Electronics and Computer Education, Mugla University, Turkey in 2013. His research interests include computer networks, expert systems and multi-criteria decision-making.

ORCID

Serkan Ballı http://orcid.org/0000-0002-4825-139X

References

Alkhawlani, M., & Ayesh, A. (2008). Access network selection based on fuzzy logic and genetic algorithms. *Advances in Artificial Intelligence, 8*(1), 1–12.

Arslan, M., & Çunkaş, M. (2012). Performance evaluation of sugar plants by fuzzy technique for order performance by similarity to ideal solution (TOPSIS). *Cybernetics and Systems, 43*, 529–548.

Ballı, S., & Korukoğlu, S. (2009). Operating system selection using fuzzy AHP and TOPSIS methods. *Mathematical and Computational Applications, 14*, 119–130.

Ballı, S., & Korukoğlu, S. (2014). Development of a fuzzy decision support framework for complex multi-attribute decision problems: A case study for the selection of skilful basketball players. *Expert Systems, 31*, 56–69.

Bardin, J., Lalanda, P., & Escoffier, C. (2010). *Towards an automatic integration of heterogeneous services and devices*. Paper presented at the Services Computing Conference, Hangzhou, China, 171–178.

Bari, F., & Leung, V. (2007). *Multi-attribute network selection by iterative TOPSIS for heterogeneous wireless access*. Paper presented at the Consumer Communications and Networking Conference, Las Vegas, U.S.A., 808–812.

Bingham, J.A.C. (2000). *ADSL, VDSL, and multicarrier modulation*. New York, NY: Wiley.

Borella, M.S., Swider, D., Uludag, S., & Brewster, G.B. (1998). *Internet packet loss: Measurement and implications for end-to-end QoS*. Paper presented at the Architectural and OS Support for Multimedia Applications/Flexible Communication Systems/Wireless Networks and Mobile Computing Conference, Minneapolis, Minnesota, U.S.A., 3–12.

Carter, R.L., & Crovella, M.E. (1996). Measuring bottleneck link speed in packet-switched networks. *Performance evaluation, 27*, 297–318.

Chang, D.Y. (1992). Extent analysis and synthetic decision. *Optimization Techniques and Applications, 1*, 352–355.

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

Charilas, D.E., Markaki, O.I., Psarras, J., & Constantinou, P. (2009). Application of fuzzy AHP and ELECTRE to network selection. In *Chapter in the book: Mobile lightweight wireless systems* (pp. 63–73). Berlin: Springer.

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*, 147–165.

Chen, Y. (2010). *Fuzzy AHP-based method for project risk assessment*. Paper presented at the Fuzzy Systems and Knowledge Discovery Conference, Yantai, China, 1249–1253.

Cui, H., Yan, Q., Cai, Y., Gao, Y., & Wu, L. (2008). *Heterogeneous network selection using a novel multi-attribute decision method*. Paper presented at the Communications and Networking Conference, Hangzhou, China, 153–157.

Forouzan, B.A. (2007). *Data communications & networking*. New York, NY: McGraw-Hill Education.

Gaudino, R., Cardenas, D., Bellec, M., Charbonnier, B., Evanno, N., Guignard, P., … Jager, D. (2010). Perspective in next-generation home networks: Toward optical solutions? *IEEE Communications Magazine, 48*, 39–47.

Hongyan, B., Chen, H., & Lingge, J. (2003). *Intelligent signal processing of mobility management for heterogeneous networks*. Paper presented at the Neural Networks and Signal Processing Conference, Nanjing, China, 1578–1581.

Hu, H., Zhou, W., Zhang, S., & Song, J. (2008). *A novel network selection algorithm in next generation heterogeneous network for modern service industry*. Paper presented at the Asia-Pacific Services Computing Conference, Yilan, Taiwan, 1263–1268.

Javaudin, J.P., Bellec, M., Varoutas, D., & Suraci, V. (2008). *OMEGA ICT project: Towards convergent Gigabit home networks*. Paper presented at the Personal, Indoor and Mobile Radio Communications Conference, Cannes, France, 1–5.

Kher, S., Somani, A.K., & Gupta, R. (2005). *Network selection using fuzzy logic*. Paper presented at the Broadband Networks Conference, Boston, Massachusetts, U.S.A., 876–885.

Lehr, W., & McKnight, L.W. (2003). Wireless internet access: 3G vs. WiFi? *Telecommunications Policy, 27*, 351–370.

Liu, H., Maciocco, C., Kesavan, V., & Low, A.L.Y. (2009). *Energy efficient network selection and seamless handovers in mixed networks*. Paper presented at the World of Wireless, Mobile and Multimedia Networks & Workshops Conference, Kos, Greece, 1–9.

Loeb, H.P., Liss, C., Ruckert, U., & Sauer, C. (2009). *UMAC-A Universal MAC architecture for heterogeneous home networks*. Paper presented at the Ultra Modern Telecommunications & Workshops Conference, St.Petersburg, Russia, 1–6.

Newbury, J. (1997). Deregulation of the electricity supply industry in the United Kingdom and the effects on communications services. *IEEE Transactions on Power Delivery, 12*, 590–600.

Piamrat, K., Ksentini, A., Bonnin, J.M., & Viho, C. (2011). Radio resource management in emerging heterogeneous wireless networks. *Computer Communications, 34*, 1066–1076.

Qutub, S., & Anjali, T. (2012). *Network assisted network selection*. Paper presented at the Electro/Information Technology Conference, Indianapolis, U.S.A., 1–6.

Rostamzadeh, R., & Sofian, S. (2011). Prioritizing effective 7Ms to improve production systems performance using fuzzy AHP and fuzzy TOPSIS (case study). *Expert Systems with Applications, 38*, 5166–5177.

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

Saaty, T.L. (1996). *Decision making with dependence and feedback*. Pittsburgh, PA: RWS Publications.

Skondras, E., Sgora, A., Michalas, A., & 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*, 307–329.

Suraci, V., Oddi, G., Mattiacci, N., & Angelucci, A. (2010). *Admission control and drop strategies in a UPnP-QoS controlled home network*. Paper presented at the Personal Indoor and Mobile Radio Communications Conference, Istanbul, Turkey, 2811–2816.

TalebiFard, P., & Leung, V.C.M. (2011). *A dynamic context-aware access network selection for handover in heterogeneous network environments*. Paper presented at the Computer Communications Workshops Conference, Shanghai, China, 385–390.

Tamea, G. (2011). *Seamless handover in heterogeneous wireless networks* (Ph.D. Thesis). Rome, Italy: Sapienza Universita di Roma.

Tanenbaum, A.S. (2003). *Computer networks*. New Jersey: Prentice Hall.

Tzerefos, P., Sdralia, V., Smythe, C., & Cvetkovic, S. (1999). Delivery of low bit rate isochronous streams over the DOCSIS 1.0 cable television protocol. *IEEE Transactions on Broadcasting, 45*, 206–214.

Van Laarhoven, P.J.M., & Pedrycz, W. (1983). A fuzzy extension of Saaty's priority theory. *Fuzzy sets and Systems, 11*, 199–227.

Wang, L., & Binet, D. (2009). *MADM-based network selection in heterogeneous wireless networks: A simulation study*. Paper presented at the Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology Conference, Aalborg, Denmark, 559–564.

Wei, Y., Hu, Y., & Song, J. (2007). Network selection strategy in heterogeneous multi-access environment. *The Journal of China Universities of Posts and Telecommunications, 14*, 16–20.

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

Zhang, S., & Qi, Z.H.U. (2014). Heterogeneous wireless network selection algorithm based on group decision. *The Journal of China Universities of Posts and Telecommunications, 21*, 1–9.