Handover Decision Using Fuzzy MADM in Heterogeneous Networks

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Abstract–**In the next generation heterogeneous wireless networks, a user with a multi-interface terminal may have network access from different service providers using various technologies. It is believed that handover decision will be based on multiple criteria as well as user preference. Various approaches have been proposed to solve the handover decision problem, but the choice of decision method appears to be arbitrary and some of the methods even give disputable results. In this paper, new handover criteria are introduced along with a new handover decision strategy. In addition, handover decision is identified as a fuzzy Multiple Attribute Decision Making (MADM) problem, and fuzzy logic is applied to deal with the imprecise information of some criteria and user preference. After a systematic analysis of various fuzzy MADM methods, a feasible approach is presented. In the end, examples are provided illustrating the proposed methods, and the sensitivity of the methods is analysed.**

Keywords: handover decision, fuzzy MADM, heterogeneous networks, utility

I. Introduction

With the exponential growth of the Internet and the wide deployment of cellular networks, wireless Internet is becoming a reality. Owing to the limited bandwidth and expensive service price of cellular networks, there is a trend to integrate the Wireless LAN (WLAN) and cellular networks, which will provide users with high speed and low cost data services within limited coverage areas, as well as any-time, any-where connection. The convergence of different technologies will be based on a common IP platform; consequently, the cooperation between different service providers will also be simplified. The IST project Moby Dick [1] is designed to achieve such a goal. In such heterogeneous networks, the heterogeneity comes in two dimensions: the technology and administrative domain. A mobile user with a multi-technology terminal can benefit from various technologies, e.g. UMTS, WLAN and Ethernet, and can also choose different service providers, which may vary in the type of service and service price. This provides a mobile user great flexibility for network access. However, the decision on which network to use becomes much more complicated, because both the number of networks and the decision criteria increase. Thus, an intelligent handover decision algorithm is very important for heterogeneous network access.

In 2G and 3G wireless networks, the selection of the service provider at the beginning of a connection is based on a priority list, and handover between service providers is normally not considered. Handover within one administrative domain is mainly used to maintain physical connection and for system load balancing. Main handover criteria are related with the link quality, such as SNR (Signal to Noise Ratio), etc. While in next generation heterogeneous wireless networks, handover between different technologies and administrative domains is possible, and handover decision will be based on more criteria, such as the price of the service, QoS support, sojourn time in a cell, battery consumption, etc. In addition, users will also play an important role in the decision making. E.g., users can indicate their preferences on certain criteria, or even dynamically change their preferences.

Facing multiple criteria during handover decision, we can no longer easily rank the candidate networks according to our preference on a single criterion. In such cases, different criteria have to be combined and scaled in a meaningful way. In addition, various criteria in the decision process may oppose to each other, e.g., when the desirable QoS increases, it may require undesirable increase in the price. Thus, trade-offs are sometimes required.

Many approaches have been proposed to solve the handover decision problem. For example, a policy-based handover mechanism for mobile multihomed hosts is presented in [2]. The handover decision is based on explicit user defined policies, and considers different criteria in the order of user defined priority. However, this approach does not consider the trade-off between criteria. Fuzzy logic has also been used for handover initiation and decision. The approach in [3] first converts the performance values of the alternatives to fuzzy numbers, and then makes decision based on heuristic decision rules. Another approach [4] uses Yager's Maxmin method to rank candidate networks. It is noticed that the use of fuzzy logic in these approaches is not to deal with imprecise information, but to combine and evaluate multiple criteria simultaneously. In fact, these problems could be well solved using classical MADM [5] methods without the involvement of fuzzy logic. In general, methods based on fuzzy logic are cumbersome to use, which require much expert knowledge and user involvement in order to make decision rules [6]. As a result, they are applicable only when the problem dimension is very small. Although some method, such as Yager's Maxmin method used in [4], is simple and easy, but it gives disputable decision result, as will be further discussed in Section IV.

The main task of this paper is to provide easy and indisputable handover decision methods suitable in heterogeneous networks. Section II outlines some new decision criteria and a new handover decision strategy. In Section III, handover decision is identified as a fuzzy MADM problem and proper methods are chosen as the result of a systematic study of the available methods. Examples and sensitivity analysis of the selected methods are presented in Section IV and Section V. The final section concludes this paper.

II. HANDOVER DECISION CRITERIA AND STRATEGY

When a user consumes the communication service provided by a network, he expects certain QoS from the network, and pays for the service according to the tariff. The user will be satisfied if optimal QoS is achieved at a minimal price. To ensure QoS, the network controls certain parameters, such as bandwidth, delay, and jitter. Those QoS parameters are useful from the technical point of view, but do not reflect the user's satisfaction. A user makes decisions based his satisfaction, which is subjective and can be modelled as a utility function [7].

ITU uses Mean Opinion Score (MOS) [8] on a scale from 1 to 5 to reflect a user's subjective quality measure of a voice call. ITU also standardized an computational model called Emodel [9]. Emodel calculates an overall rating of a call on the scale from 0 to 100 by combining different transmission impairment. The rating score can be further converted to MOS.

But for handover decision, it is impossible to measure transmission impairment such as delay and packet loss in the candidate networks before handover. Only limited information, such as SNR, estimated available bandwidth may be obtained a priori. Utility functions to estimate the subjective satisfaction of various multimedia services from a priori information are still not available in the literature. Therefore, the approach for the handover decision in this paper will not consider such a utility function, and it is left for the future work.

It is worth mentioning that some of the handover criteria information can be inherently imprecise, or the precise information is difficult to obtain. For example, the user satisfaction of the service and the preference on different criteria are imprecise. Moreover, handover may lead to latency and packet loss. Thus, when making handover decision, it is important to consider the seamlessness of the handover, which is hard to be described by an accurate number and inherently imprecise.

A handover strategy has been proposed in the previous work for heterogeneous network access [10], and it is in favour of mobile-controlled handover. The proposed handover decision strategy consists of four steps: handover initiation, pre-selection of candidate networks, candidate network capability discovery, and handover decision. The performance of the mobile terminal, such as link quality, price, bandwidth, and battery consumption, etc. are constantly monitored during communication. The handover process will be initiated when certain criteria for initiation defined by the users are met. Handover pre-selection aims to screen out unsuitable candidate networks for handover before mobile nodes start to measure the signal quality and retrieve capability information from the candidate networks. The pre-selection can use user defined policies and also consider network constraints, so that the number of possible candidate networks can be greatly reduced. Candidate network capability information may be obtained using the IETF CARD protocol [11], or via broadcast in the candidate networks. The former method can provide a wide range of capability information, but requires infrastructure support and a lengthy signalling procedure. The latter method is easy and fast, but only limited information is possible. During handover decision, the candidates are ranked with respect to the criteria and user preference, and the best candidate will be selected as the handover target.

III. HANDOVER DECISION USING FUZZY MADM

A. *Handover decision: a fuzzy MADM problem*

The above section outlines the handover strategy, this section presents the handover decision algorithm. Handover decision deals with making selection among limited number of candidate networks from various service providers and technologies with respect to different criteria. Hence, it is a typical MADM problem [5]. For instance, suppose a user is currently connected to a WCDMA cell A_1 and has to make decision among four candidate networks: A_1, A_2, A_3, and A_4, where A_3 is a WCDMA cell from a different domain, A_2 and A_4 are WLAN cells. Handover criteria considered here are price, bandwidth, SNR, sojourn time, seamlessness and battery consumption, which are denoted as: X_1, X_2, X_3, X_4, X_5 and X_6 respectively. The decision problem can be concisely expressed in the decision matrix (1), where the capabilities of each candidate are presented. Sojourn time and seamlessness, are represented using linguistic terms, and other attributes, i.e. criteria are scaled using the same unit respectively.

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccccc} X_1 & X_2 & X_3 & X_4 & X_5 & X_6 \end{array} \\ \begin{bmatrix} 10 & 30 & 80 & \text{very\_long} & \text{seamless} & 0.5 \\ 7 & 40 & 80 & \text{very\_long} & \text{very\_bad} & 0.5 \\ 1 & 80 & 20 & \text{short} & \text{very\_good} & 1 \\ 2 & 40 & 40 & \text{short} & \text{good} & 1 \end{bmatrix} \end{array} \quad (1)$$

A_1 and A_2 have much higher price and longer sojourn time than A_3 and A_4. The seamlessness for A_2 is very bad because it is in a different domain from A_1.

Suppose the user has two running applications, voice and file download. The preference on handover criteria is modelled as weights assigned by the user on the criteria; for voice are w_v and file download are w_d, which are shown in (2) and (3). The sojourn time and the seamlessness are considered as important for voice application, while the price and bandwidth are considered important for file download.

$$w_v = [medium\ medium\ low\ high\ high\ low] \quad (2)$$

$$w_d = [high\ high\ low\ low\ medium\ medium] \quad (3)$$

Classical MADM methods can not efficiently handle such decision problem above with imprecise data. Accordingly, over a dozen fuzzy MADM methods have been developed to handle the imprecise data in MADM in the last few decades [6]. However, many of these fuzzy MADM methods are cumbersome to use, because fuzzy data are operationally difficult.

B. *Fuzzy MADM method selection*

After identifying handover decision as a fuzzy MADM problem, this sub-section deals with the selection of the decision method. In the context of handover decision, the potential handover candidates and criteria can be numerous and the decision may have to be made frequently. This requires the decision method to be scalable and easy to use. In addition, it has to be flexible, so that a user can change his preference on the criteria easily.

According to the data type of the alternative's performance, fuzzy MADM methods can be categorized into three groups [6]: data are all fuzzy, all crisp, and either crisp or fuzzy. It is possible to directly use the methods in the last group for handover decision. But the methods in this group are either too cumbersome to use, or only suitable for the purpose of screening out unsuitable alternatives. The fuzzy MADM methods with data type is all fuzzy require transforming crisp data to fuzzy numbers, despite the data are crisp in nature, which not only violates the intention of fuzzy set theory, but also increases the decision complexity.

Addressing the drawbacks of existing fuzzy MADM methods, Chen and Hwang have proposed their approach to solve the MADM problem efficiently and meaningfully in a fuzzy environment [6]. The proposed approach is composed of two major phases. The first phase is to convert fuzzy data to crisp numbers, and the second phase is to apply classical MADM to determine the ranking order of the alternatives.

If the fuzzy data are linguistic terms, they can first be converted to fuzzy numbers using a conversion scale. Then the result fuzzy numbers are converted to crisp numbers. For instance, if five linguistic terms are used to represent the possible user preference: very low, low, medium, high and very high, these linguistic terms are first converted to fuzzy numbers using the conversion scale shown in Fig. 1, where both the performance score x and membership function $\mu(x)$ are in the range from 0 to 1. A fuzzy scoring method is used to convert each fuzzy number to a corresponding crisp value. For example, the five fuzzy numbers shown in Fig. 1 are converted to 0.091, 0.283, 0.5, 0.717, 0.909 respectively. Chen and Hwang have proposed eight different conversion scales with different number of linguistic terms. The same linguistic term in different conversion scales can have different crisp values. E.g., when six linguistic terms, very low, low, fairly low, fairly high, high and very high are used, the term high will be converted to the crisp number 0.75.

Chen and Hwang did not specify which classical MADM method to use. There are over a dozen classical MADM methods, some MADM methods are either very lengthy or give biased ranking [5], which will not be mentioned here. Three popular methods are considered here.

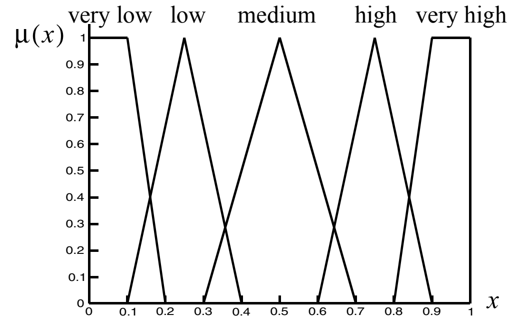

Fig. 1. Linguistic term to fuzzy number conversion scale

SAW (Simple Additive Weighting Method) is probably the best known and widely used method. The overall score of an alternative is computed as the weighted sum of all the attribute values. It is simple and easy to understand.

Analytical Hierarchical Process (AHP) develops a goal of hierarchy to solve the decision problem with a large number of attributes. It requires pairwise comparison between alternatives for each attribute in each hierarchy and the consistency check, which may be too cumbersome for a user. AHP is equivalent to SAW when the hierarchy only has three levels, thus SAW is preferable in this case.

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is based on the principle that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. It is relative simple and easy to understand.

Although DEA (Data Envelopment Analysis) is not a standard decision method, it has gained its popularity in solving decision problems since a decade before. However, this approach has great drawbacks as indicated in [13]. In addition, DEA does not allow preference among different attributes, hence, a user can not have influence on the decision making. Therefore, DEA will not be consider here.

As a summary, for handover decision, Chen and Hwang's method will be used to convert imprecise linguistic terms to crisp numbers, and SAW or TOPSIS will be applied for the final ranking. It should be noted that, different from previous approaches [3][4], the introduction of fuzzy logic in this paper is only used to deal with the inherently imprecise information. It is easy and flexible, allowing users to change the preference, or even the decision criteria for various applications in different environments.

When a user has several applications running simultaneously and requires handover, handover decision may give different results for different applications, because different weights on criteria or even different criteria may be applied. If each application follows its own handover decision result, multihoming for mobile user has to be supported. Otherwise, a balance has to made among the conflicting decision results. In principle, this is a problem of group decision making [12], and tends to be complex. Due to space limitation, it will not be covered in this paper.

IV. Numerical examples

Examples are presented in this section illustrating the usage of the selected methods and the results are compared. The decision matrix (1) is used, and the linguistic terms are converted to crisp numbers using the conversion scale from Fig. 1. The result decision matrix is shown below.

$$D = \begin{array}{c} A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{bmatrix} 10 & 30 & 80 & 0.909 & 1 & 0.5 \\ 7 & 40 & 80 & 0.909 & 0.091 & 0.5 \\ 1 & 80 & 20 & 0.283 & 0.909 & 1 \\ 2 & 40 & 40 & 0.283 & 0.717 & 1 \end{bmatrix} \tag{4}$$

User preference for voice application and file download are also converted to crisp numbers and normalized so that the sum is equal to 1. The normalized preferences, i.e. the weighting factors for voice w_v and file download w_d are:

$$w_v = \begin{bmatrix} 0.167 & 0.167 & 0.094 & 0.239 & 0.239 & 0.094 \end{bmatrix} \tag{5}$$

$$w_d = \begin{bmatrix} 0.239 & 0.239 & 0.094 & 0.094 & 0.167 & 0.167 \end{bmatrix} \tag{6}$$

In the following section, SAW, TOPSIS and MaxMin method are applied and the results are compared.

A. SAW

SAW requires a comparable scale for all elements in the decision matrix. If a criterion is benefit, i.e. the larger, the better, the comparable scale is obtained by using (7); and (8) is applicable for cost criteria. In (7) and (8) x_{ij} is the performance score of alternative A_i with respect to criterion X_j .

$$r_{ij} = x_{ij}/x_j^{max} \qquad i = 1, \ldots, 4 \;\; j = 1, \ldots, 6 \tag{7}$$

$$r_{ij} = x_j^{min}/x_{ij} \qquad i = 1, \ldots, 4 \;\; j = 1, \ldots, 6 \tag{8}$$

After scaling, the normalized decision matrix is

$$D' = \begin{array}{c} A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{bmatrix} 0.1 & 0.375 & 1 & 1 & 1 & 1 \\ 0.143 & 0.5 & 1 & 1 & 0.091 & 1 \\ 1 & 0.167 & 0.25 & 0.311 & 0.909 & 0.5 \\ 0.5 & 0.239 & 0.375 & 0.311 & 0.717 & 0.5 \end{bmatrix} \tag{9}$$

Apply the weight factors from (5) and (6), the weighted average values for A_1 , A_2 , A_3 and A_4 with respect to voice application A_v , and file download A_d are as follows:

$$A_v = \begin{bmatrix} 0.746 & 0.557 & 0.696 & 0.495 \end{bmatrix} \tag{10}$$

$$A_d = \begin{bmatrix} 0.636 & 0.524 & 0.767 & 0.507 \end{bmatrix} \tag{11}$$

B. TOPSIS

Using TOPSIS, the first step is to normalize the decision matrix using the equation below.

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{4} x_{ij}} \qquad i = 1, \ldots, 4 \;\; j = 1, \ldots, 6 \tag{12}$$

In the second step, the decision matrix for voice application is weighted using the weighting factors from (5), and result weighted normalized matrix V is

$$V = \begin{array}{c} A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{bmatrix} 0.134 & 0.049 & 0.064 & 0.161 & 0.156 & 0.030 \\ 0.094 & 0.065 & 0.064 & 0.161 & 0.014 & 0.030 \\ 0.013 & 0.130 & 0.016 & 0.050 & 0.142 & 0.060 \\ 0.027 & 0.065 & 0.024 & 0.050 & 0.112 & 0.060 \end{bmatrix} \tag{13}$$

The third step is to determine the ideal solutions A^* and the negative-ideal solutions A^- . They are shown in (14) and (15), where J is associated with the benefit criteria and J' is associated with the cost criteria.

$$\begin{aligned} A^* &= \begin{bmatrix} v_1^* & v_2^* & v_3^* & v_4^* & v_5^* & v_6^* \end{bmatrix} \\ &= \left\{ \left(\max_i v_{ij} \middle| j \in J \right), \left(\min_i v_{ij} \middle| j \in J' \right) \middle| \begin{array}{l} i = 1, \ldots, 4 \\ j = 1, \ldots, 6 \end{array} \right\} \\ &= \begin{bmatrix} 0.013 & 0.130 & 0.064 & 0.161 & 0.155 & 0.030 \end{bmatrix} \end{aligned} \tag{14}$$

$$\begin{aligned} A^* &= \begin{bmatrix} v_1^- & v_2^- & v_3^- & v_4^- & v_5^- & v_6^- \end{bmatrix} \\ &= \left\{ \left(\min_i v_{ij} \middle| j \in J \right), \left(\max_i v_{ij} \middle| j \in J' \right) \middle| \begin{array}{l} i = 1, \ldots, 4 \\ j = 1, \ldots, 6 \end{array} \right\} \\ &= \begin{bmatrix} 0.134 & 0.049 & 0.016 & 0.050 & 0.014 & 0.060 \end{bmatrix} \end{aligned} \tag{15}$$

The fourth step is to calculate the separation of each alternative from the ideal solution, and the negative ideal solution, using the formula given in (16) and (17), and the result is listed in (18) and (19) respectively.

$$S_{i*} = \sqrt{\sum_{i=1}^{6} (v_{ij} - v_j^*)^2} \qquad i = 1, \ldots, 4 \tag{16}$$

$$S_{i-} = \sqrt{\sum_{i=1}^{6} (v_{ij} - v_j^-)^2} \qquad i = 1, \ldots, 4 \tag{17}$$

$$S^* = \begin{bmatrix} 0.146 & 0.176 & 0.125 & 0.146 \end{bmatrix} \tag{18}$$

$$S^- = \begin{bmatrix} 0.189 & 0.131 & 0.194 & 0.146 \end{bmatrix} \tag{19}$$

The relative closeness to the ideal solution is calculated in the fifth step using the formula:

$$C_{i*} = S_{i-}/(S_{i-} + S_{i*}) \qquad i = 1, \ldots, 4 \tag{20}$$

The calculated relative closeness to the ideal solution for voice application C_v^* and for the file download C_d^* are:

$$C_v^* = \begin{bmatrix} 0.564 & 0.429 & 0.607 & 0.501 \end{bmatrix} \tag{21}$$

$$C_d^* = \begin{bmatrix} 0.382 & 0.369 & 0.730 & 0.571 \end{bmatrix} \tag{22}$$

C. Maxmin method

Yager's Maxmin method first computers the weight of the criteria, then the performance data of all criteria for each alter-

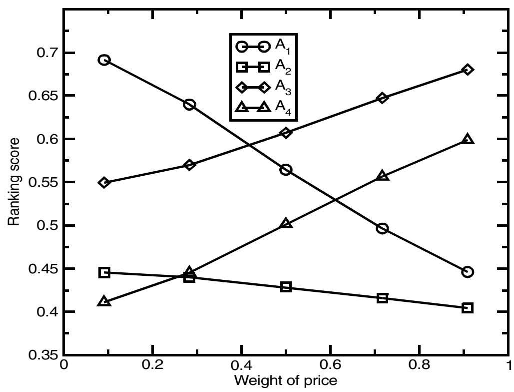

Fig. 2. Sensitivity of user preference on price using TOPSIS

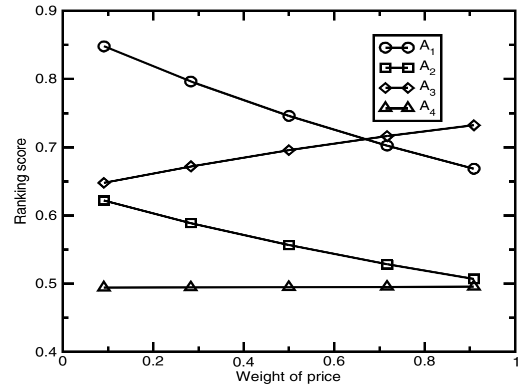

Fig. 3. Sensitivity of user preference on price using SAW

native are raised to the power of the respective attribute's weight. The selected alternative is said to maximize the minimum membership values over all the criteria i.e., it satisfies

$$\max_i \left[\min_j x_{ij}^{w_j}\right] \quad i = 1, \ldots, 4 \quad j = 1, \ldots, 6 \tag{23}$$

Using the same decision matrix (9) and the weight factors (5), the minimum membership values for each alternative are

$$\mu_i^{min} = \begin{bmatrix} 0.681 & 0.564 & 0.756 & 0.756 \end{bmatrix} \quad i = 1, \ldots, 4 \tag{24}$$

D. Comparison and conclusion

The ranking orders using different methods are summarized in Table 1. For the voice application, SAW ranks A_1 as the best, and TOPSIS ranks A_3 as the best. Both two results are reasonable, because A_1 has good scores on SNR, sojourn time, seamlessness and battery consumption, and A_3 has good scores on price and bandwidth. Obviously, Yager's Maxmin method gives a disputable result, since A_4 is ranked as the best, even though its average score is low. The reason for this is that Yager's Maxmin method only uses a small part of the information from the decision matrix. We can also notice the influence of the criterion seamlessness: even though A_2 is better than A_1 in many aspects, it has a low ranking score, because handover can not be done seamlessly.

SAW, voice	A_1, A_3, A_2, A_4
SAW, download	A_3, A_1, A_2, A_4
TOPSIS, voice	A_3, A_1, A_4, A_2;
TOPSIS, download	A_3, A_4, A_1, A_2
Yager's Maxmin, voice	A_3 or A_4

Table 1: Ranking order comparison

V. Sensitivity Analysis

From the last section, we can observe that user preference has influence on the ranking order, e.g., both SAW and TOPSIS have different ranking orders for voice and file download. This is further exemplified by the sensitivity analysis on the user preference in Fig. 2 and Fig. 3. When the user preference on price is changed, and other parameters are kept constant. We can find that the ranking result is more sensitive when TOPSIS method is used.

The performance of an attribute, i.e. the performance scores of a criterion will definitely influence the decision result. Since the handover decision is concerned with selecting the best alternative, it is worth evaluating the influence of the attributes that contribute to the first rank position.

For voice application, both the price and the bandwidth are considered as medium important. Fig. 4 and Fig. 5 show the variation of the ranking order of A_3, when the attributes with high scores i.e. price and bandwidth are changed. We can observe from Fig. 4, TOPSIS is sensitive to the attributes with high scores. E.g., when the price of A_3 drops to 1 and the bandwidth rises to 60, A_3 will be ranked as the first. By comparison with Fig. 5, SAW is less sensitive. For file download application, TOPSIS is also more sensitive to high scores than SAW. Due to space limitation, it will not be presented.

When the average score of an alternative is good, but one attribute has a low score, then the attribute with a low score will influence the ranking. For example, A_1's price is very high compared with its main competitor A_3, so it may influence the ranking of A_1. Fig. 6 shows that for TOPSIS, when A_1's price increases, its ranking order will drop, e.g. the ranking is sensitive to the price. However, for SAW, the ranking is relative stable, as shown in Fig. 7.

From the sensitivity analysis, we can conclude that TOPSIS is more sensitive to the preference on the attribute and the attribute performance, while the user preference is rather subjective, sometimes the ranking result can be subjective. On the other hand, SAW provides a conservative ranking, it is less sensitive to very good or very bad performance scores.

VI. Conclusion and Future Work

It is essentially complex to make handover decision in heterogeneous networks considering multiple criteria. The trade-off of some criteria has to be considered sometimes. There are approaches to use fuzzy logic for handover decision in order to combine and evaluate multiple criteria simultaneously. These

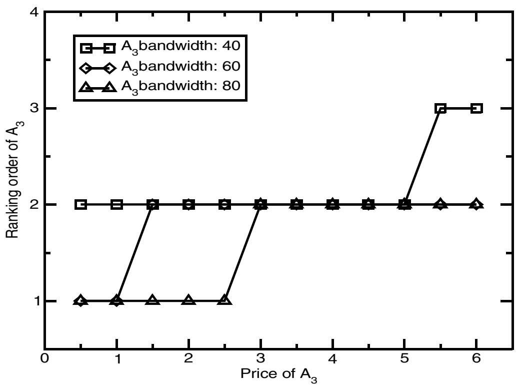

Fig. 4. Sensitivity of price and bandwidth of A_3 using TOPSIS

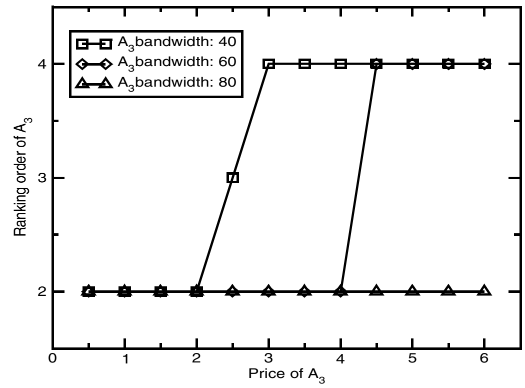

Fig. 5. Sensitivity of price and bandwidth of A_3 using SAW

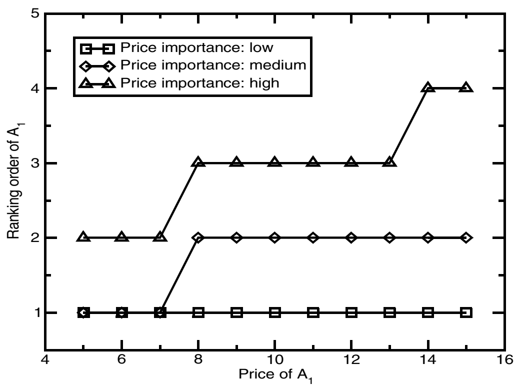

Fig. 6. Sensitivity of price of A_1 using TOPSIS

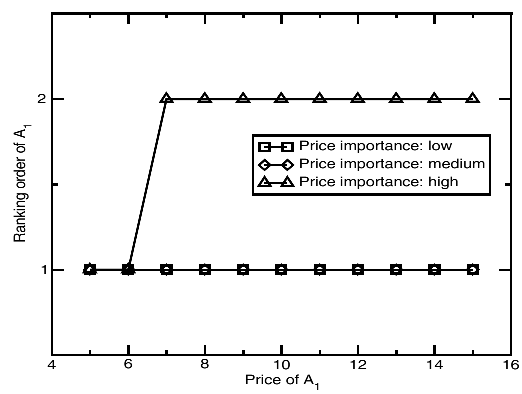

Fig. 7. Sensitivity of price of A_1 using SAW

methods are either too cumbersome to use or give disputable results. In this paper, the necessity to use fuzzy data for handover decision in heterogeneous networks is presented, and handover decision is identified as a fuzzy MADM problem, for which fuzzy logic is used to deal with imprecise handover criteria and user preference. After a systematic analysis of various decision methods, a method is proposed. For handover decision, imprecise data are first converted to crisp numbers, and then, classical MADM methods, SAW and TOPSIS are applied. Numerical examples show that TOPSIS is more sensitive to user preference and attribute values, and SAW gives a relative conservative ranking result.

In the future work, utilities for user subjective perception will be modelled. And handover decision will be based on the utility instead of using the criteria directly, which might give more realistic result. In addition, different pricing schemes will also be considered for the decision.

ACKNOWLEDGEMENT

The work presented was partly funded by the EU project IST-2000-25394 "Moby Dick".

REFERENCES

[1] Moby Dick: Mobility and Differentiated Services in a Future IP Network, http://www.ist-mobydick.org, Jan. 2003.

[2] Jukka, Ylitalo, et al., "Dynamic Network Interface Selection in Multihomed Mobile Hosts," Proceedings of the 36th Hawaii International Conference on System Sciences, Hawaii, USA, Jan. 2003.

[3] Manoreet Sigh Dang, et al., "Fuzzy Logic Based Handoff in Wireless Networks," Proceedings of IEEE VTC 2000 Spring Tokyo, Japan.

[4] P. Chan, et. al. "Mobility Management Incorporating Fuzzy Logic for a Heterogeneous IP Environment," IEEE Communication Magazine, Dec. 2001.

[5] Ching-Lai Hwang and Kwangsun Yoon, "Multiple Attribute Decision Making," Springer-Verlag, 1981.

[6] Shu-Jen Chen Ching-Lai Hwang and Frank P. Hwang, "Fuzzy Multiple Attribute Decision Making," Springer-Verlag 1992.

[7] Peter C. Fishburn, "Utility Theory for Decision Making," John Wiley & Sond, Inc., 1970.

[8] ITU-T Recommendation P.800, "Methods for subjective determination of transmission quality," Aug. 1996

[9] ITU-T Recommendation G.107, "The E-model, a computational model for use in transmission planning," Mar. 2003.

[10] Zhang W., et al, "Design and Evaluation of a Handover Decision Strategy for 4th Generation Mobile Networks," Proceedings of IEEE VTC 2003 Spring, Jeju, Korea, Apr. 2003.

[11] IETF CARD design Team, "Candidate Access Router Discovery," IETF draft-ietf-seamoby-card-protocol-00.txt, work in progress, Oct. 2002.

[12] Ching-Lai Hwang and Ming-Jeng Lin, "Group Decision Making under Multiple Criteria," Springer-Verlag, 1986.

[13] D. Bouyssou, "DEA as a tool for MCDM: some remarks," Journal of the Operational Research Society, 50, 1999.