Employing Multi-Attribute Decision Making Methods for Vertical Handoff Decision

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***Abstract*—Handoff in heterogeneous wireless networks will provide wider choice and higher quality of service (QoS) to the users. Heterogeneous networks consisting of Worldwide Interoperability for Microwave Access (WiMAX) and Wireless Fidelity (WiFi) networks are being deployed worldwide. This paper describes the modality of multi-attribute decision making methods in vertical handoff for wireless networks. Multiple attribute for decision making including user preference will increase the complexity of handoff process. Various approaches have been proposed to solve the complexity problem of handoff decision. Inthis paper, Analytic Hierarchy Process (AHP) method, is used for weight estimation and then preference ranking organization method for enrichment evaluations (PROMETHEE) is proposed for handoff decision from WiMAX to WiFI.**

Keywords—Analytical Hierarchy Process (AHP);Multi-Attribute Decision Making (MADM);Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE).

I. INTRODUCTION

Handoff in heterogeneous wireless networks will provide wider choice and higher quality of service (QoS) to the users. It consists of Worldwide Interoperability for Microwave Access (WiMAX) and Wireless Fidelity (WiFi) networks are being deployed worldwide. Nevertheless, the growth of WLAN andWiMAX networks have created new issues and challenges in the handoff decision algorithms as these technologies have their own unique characteristics, in terms of QoS, bandwidth allocation throughput, mobility management, and service availability.

The vertical handoff process involves three main phases [9], [10], namely system discovery, vertical handoff decision, and vertical handoff execution. During the system discovery phase, the mobile terminal determines which networks can be used. These networks may also advertise the supported data rates and Quality of Service (QoS) parameters. Since the users are mobile, this phase may be invoked periodically. In the vertical handoff decision phase, the mobile terminal determines whether the connections should continue using the existing selected network or be switched to another network. The decision may depend on various parameters including the type of the application (e.g., conversational, streaming), minimum bandwidth and delay required by the application, access cost, transmit power, and the user's preferences. During the vertical handoff execution phase, the connections in the mobile terminal are re-routed from the existing network to the new network in a seamless manner. This phase also includes the authentication, authorization, and transfer of a user's context information.

Handoff based on Fuzzy logic algorithm has beenused for handoff initiation and decision in [1], whereinalternatives are first converted into fuzzy number and thenhandoff decision is derived based on decision rules. The use of methods based on fuzzy logic are more cumbersome due to much involvement of user [2]. The handoff problem isidentified as a fuzzy MADM problem and fuzzy logic isapplied to deal with the imprecise information of someattributes and user preference [3]. Various vertical handoff decision algorithms have been proposed recently. In [3], the vertical handoff decision is formulated as a fuzzy multiple attribute decision making problem. Two ranking methods are proposed: Simple Additive Weighting (SAW) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). In [4], the network selection for vertical handoff is modeled by the Analytic Hierarchy Process (AHP) and the Grey Relational Analysis (GRA). In [5], a performance comparison among SAW, TOPSIS, GRA, and the Multiplicative Exponent Weighting (MEW) for vertical handoff decision is presented.

A multi-layer framework for vertical handoff is proposed in [6]. In [7], a utility-based strategy for network selection is proposed. In [8], the vertical handoff decision is evaluated via a handoff cost function and a handoff threshold function which can be adapted to changes in the network environment dynamically. Fully centralized schemes, such as in [11], try to maximize a network wide utility as a solution to the association optimization problem.

The remainder of the paper is organized as follows. We will first describe the weight estimation using AHP in part A of section II and PROMETHEE method in part B of section II. The evaluation of algorithms is presented in Section III. Results and detailed discussions are presented in Section IV.In Section V, conclusions and an outlook to future research are provided.

II. MULTI-ATTRIBUTE DECISION MAKING METHODS

A Multiple criterion decision making (MCDM) refers to decision making in the presence of multiple, usually conflicting criteria. The MCDM problems can be broadly classified into two categories: multiple attribute decision making (MADM) and multiple objective decision making (MODM), depending on whether the problem is alternative selection problem or a objective problem. The multiple attribute decision making is employed when problem which involves selection from among finite number of alternatives. Alternatives, Attributes, weight or relative importance of each attribute and measure of performance of alternatives with respect to the attributes are the main parts in each decision table of MADM methods [12, 13].

A. Weight Estimation using AHP

Analytical hierarchy process (AHP) is one of the most popular analytical techniques for solving complex decision making problems [14, 15]. A number of functional characteristics make AHP a useful methodology. These include the ability to handle decision situations involving subjective judgments, multiple decision makers, and the ability to provide measures of consistency of preferences [16].

Step 1: Determine the objective and the evaluation attributes. Determine the decision matrix

Step 2: Determine the relative importance of different attributes with respect to the goal or objective. Construct a pair-wise comparison matrix using a scale of relative importance. The judgments are entered using the fundamental scale of the analytic hierarchy process [14, 15].

TABLE I: Saaty's 1–9 scale of pair wise comparison

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2 4 6 8	Intermediate values

Assuming M attributes, the pair-wise comparison of attribute i with attribute j yields a square matrix B_{M*M} where b_{ij} denotes the comparative importance of attribute i with respect to attribute j. In the matrix, b_{ij}= 1 when i = j and b_{ji}= $1/b_{ij}$.

$$B_{M*M} = \begin{bmatrix} 1 & b12 & b13 & - & b1M \\ b21 & 1 & b23 & - & b2M \\ - & - & - & - & - \\ bM1 & bM2 & bM3 & - & 1 \end{bmatrix}$$

Step 3: Find the relative normalized weight (w_j) of each attribute by (a) calculating the geometric mean of the i-th row, and (b) normalizing the geometric means of rows in the comparison matrix. This can be represented as:

$$GM_j = [\prod_{j=1}^{M} b_{ij}]^{1/M} \quad (1)$$

$$w_j = \frac{GM_j}{\sum_j^M GM_j} \quad (2)$$

The geometric mean method of AHP is commonly used to determine the relative normalized weights of the attributes, because of its simplicity, easy determination of the maximum Eigen value, and reduction in inconsistency of judgments.

a) Calculate matrices A3 and A4 such that A3 = A1 * A2 and A4 = A3 / A2, where A2 = $[w_1, w_2, \ldots, w_j]^T$. where A1 is relative importance matrix.

b) Determine the maximum Eigen value λmax that is the average of matrix A4.

c) Calculate the consistency index CI = (λmax - M) / (M - 1). The smaller the value of CI, the smaller is the deviation from the consistency.

d) Obtain the random index (RI) for the number of attributes used in decision making. Refer to Table II for details.

TABLE II: Random Index (RI) values

Attributes	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
RI	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

e) Calculate the consistency ratio CR = CI/RI. Usually, a CR of 0.1 or less is considered as acceptable, and it reflects an informed judgment attributable to the knowledge of the analyst regarding the problem under study.

B. Decision Making using PROMETHEE

Brans et al. [17] introduced Preference Ranking Organization Method for Enrichment Evaluations. PROMETHEE belongs to the category of outranking methods. In this section, the focus is put on the PROMETHEE method and AHP method is incorporated for deciding the attributes' weights. The improved PROMETHEE method [13] involves a pair wise comparison of alternatives on each single attribute in order to determine partial binary relations denoting the strength of preference of an alternative 'a1' over alternative 'a2'. In the evaluation table, the alternatives are evaluated on different attributes. The improved PROMETHEE methodology for decision making is described as follows:

Step 1: the decision matrix: The decision matrix is expressed as

TABLE III: Decision Table in MADM methods

Alternatives	*Attributes (weights)*					
	B_1 (w_1)	B_2 (w_2)	B_3 (w_3)	-	-	B_m(w_m)
A_1	C_{11}	C_{12}	C_{13}	-	-	C_{14}
A_2	C_{21}	C_{22}	C_{23}	-	-	C_{24}
A_3	C_{31}	C_{32}	C_{33}	-	-	C_{34}
-	-	-	-	-	-	-
-	-	-	-	-	-	-
A_n	C_{n1}	C_{n2}	C_{n3}	-	-	C_{nm}

The decision table, given in Table III, shows alternatives, A_i (for i = 1, 2, . . . , n), attributes, B_j (for j = 1, 2, . . . , m), weights of attributes, w_j(for j = 1, 2, . . . , m) and the measures of performance of alternatives, C_{ij} (for i = 1, 2, . . . , n; j = 1, 2, . . . , m). Given multi attribute decision making method and the decision table information, the task of the decision maker is to find the best alternative and/or to rank the entire set of alternatives. To consider all possible attributes in decision problem, the elements in the decision table must be normalized to the same units.

Step 2: In the PROMETHEE method suggested by Brans et al. [17], there is no systematic way to assign weights of relative importance of attributes. Hence, in the improved PROMETHEE method AHP method is suggested [13] for deciding the weights of relative importance of the attributes. The procedure for the same is as explained in the step 2 of the AHP method.

Step 3: Comparing the contribution of the alternatives in terms of each attribute. The preference function (P_j) translates the difference between the evaluations obtained by two alternatives (a1 and a2) in terms of a particular attribute, into a preference degree ranging from 0 to 1. Let P_j, a1a2 be the preference function associated to the attribute b_j.

$$P_j, a_1a_2 = G_j[b_j(a1) - b_j(a2)] \quad (3)$$

Where G_j is a non-decreasing function of the observed deviation (d) between two alternatives 'a1' and 'a2' over the attribute 'b_j'.

If the decision maker specifies a preference function Pi and weight w_i for each attribute 'b_j' (j = 1, 2, …, M) of the problem, then the multiple attribute preference index Πa1a2 is defined as the weighted average of the preference functions P_j:

$$\prod_{a1a2} = \sum_{j=1}^{M} w_j P_{j,a1a2} \quad (4)$$

Πa1a2 represents the intensity of preference of the decision maker of alternative'a1' over alternative 'a2', when considering simultaneously all the attributes. Its value ranges from 0 to 1.

For improved PROMETHEE outranking relations, the leaving flow, entering flow, and the net flow for an alternative 'a' belonging to a set of alternatives A are defined by the following Eqs.:

$$\varphi^{+}(a) = \sum_{x\varepsilon A} \Pi_{xa} \quad (5)$$
$$\varphi^{-}(a) = \sum_{x\varepsilon A} \Pi_{xa} \quad (6)$$

$$\varphi\,(a) = \varphi^{+}(a) - \varphi^{-}(a) \quad (7)$$

$\varphi^{+}(a)$is called the leaving flow, $\varphi^{-}(a)$is called the entering flow, and $\varphi\,(a)$ iscalled the net flow. $\varphi^{+}(a)$is the measure of the outranking character of 'a' (i.e. dominance of alternative 'a' over all other alternatives) and $\varphi^{-}(a)$gives theoutranked character of 'a' (i.e. degree to which alternative 'a' is dominated by allother alternatives). The net flow, $\varphi\,(a)$, represents a value function, whereby ahigher value reflects a higher attractiveness of alternative 'a'. The net flow values are used to indicate the outranking relationship between the alternatives.

III. Evaluation of Algorithms in Wireless Environment

A. Handoffs from WiMAX to WiFi

Through query response procedure with information server, the mobile node can discover suitable WiFi network. Several factors such as Quality of Service (QoS), Power requirement, cost associated with it etc plays key role to decide handoff to WiFi. After successful discovery, mobile node initiates the handoff procedure.The mobile node may choose to configure the WiMAX after successful handoff, as it permits the mobile node to switch back to WiMAZ quickly in case of coverage drop or degrades. Sample dataset were taken from [18] for alternative selection problem such as multiplayer interactive gaming (refer TABLE IV), streaming media (refer TABLE V) and media content download (refer TABLE VI) is as follows:

TABLE IV: Alternative networks for multiplayer interactive gaming

Networks	*Bandwidth guideline (kbps)*	*Delay guideline (ms)*	*Jitter guideline (ms)*
WiFi1	20	10	150
WiFi2	50	25	10
WiFi3	10	516	50
WiFi4	25	5	40

TABLE V: Alternative networks for streaming media

Networks	*Bandwidth guideline (kbps)*	*Delay guideline (ms)*	*Jitter guideline (ms)*
WiFi1	220	150	200
WiFi2	500	16	50
WiFi3	10000	15	5
WiFi4	2000	1100	50
WiFi5	1000	16	150
WiFi6	500	100	50
WiFi7	500	250	350

TABLE VI: Alternative networks for media content download

Networks	*Bandwidth guideline (kbps)*	*Delay guideline (ms)*	*Jitter guideline (ms)*
WiFi1	500	200	50
WiFi2	2000	100	10
WiFi3	1000	120	30
WiFi4	2000	10	5
WiFi5	2000	200	30
WiFi6	1000	120	50
WiFi7	2000	35	100

IV. Results

A. Weight estimation using AHP

Designed to reflect the way people actually think, AHP continues to be the most highly regarded and widely used decision making method. AHP can efficiently deal with objective as well as subjective attributes. In this research work AHP is used to estimate the weights of attributes. Detailed step by step procedure and validation is provided in section II, part A.

a) Multiplayer interactive gaming

Step 1: Decision table for multiplayer interactive gaming is same as TABLE IV.

Step 2: pair-wise comparison matrix

TABLE VII: pair-wise comparison matrix of multiplayer interactive gaming

	Bandwidth	*Delay*	*Jitter*
Bandwidth	1	1	3
Delay	1	1	3
Jitter	1/3	1/3	1

Step 3: Weight estimation through geometric mean
$W_{bandwidth}$= 0.4286; W_{delay}= 0.4286; $W_{bandwidth}$= 0.1429.

CR = 0.0000000077369 which is far less than 0.1, so the weights are acceptable.

b) Streaming media

Step 1: Decision table for streaming media is same as TABLE V.

Step 2: pair-wise comparison matrix

TABLE VIII: pair-wise comparison matrix of streaming media

	Bandwidth	*Delay*	*Jitter*
Bandwidth	1	5	3
Delay	1/5	1	1/3
Jitter	1/3	3	1

Step 3: Weight estimation through geometric mean

$W_{bandwidth}$= 0.6370; W_{delay}= 0.1047; $W_{bandwidth}$= 0.2583.

CR = 0.0370 which is less than 0.1, so the weights are acceptable.

c) Media content download

Step 1: Decision table for media content is same as TABLE VI.
Step 2: pair-wise comparison matrix

TABLE IX: pair-wise comparison matrix of media content download

	Bandwidth	*Delay*	*Jitter*
Bandwidth	1	5	5
Delay	1/5	1	2
Jitter	1/5	1/2	1

Step 3: Weight estimation through geometric mean

$W_{bandwidth}$= 0.7088; W_{delay}= 0.1786; $W_{bandwidth}$= 0.1125.

CR = 0.0516 which is far less than 0.1, so the weights are acceptable.

B. Alternative selection using PROMETHEE

Here the alternatives are evaluated using PROMETHEE based on considered attributes.

TABLE X: Alternative networks for multiplayer interactive gaming

Networks	$\varphi(a)$ *(Net flow)*	*Rank*
WiFi1	-0.4286	3
WiFi2	1.2857	2
WiFi3	-2.7143	4
WiFi4	1.8571	1

TABLE XI: Alternative networks for streaming media

Networks	$\varphi(a)$ *(Net flow)*	*Rank*
WiFi1	-5.0645	7
WiFi2	-0.4432	4
WiFi3	6.0000	1
WiFi4	2.4361	2
WiFi5	1.0716	3
WiFi6	-0.7574	5
WiFi7	-3.2426	6

TABLE XII: Alternative networks for media content download

Networks	$\varphi(a)$ *(Net flow)*	*Rank*
WiFi1	-5.4838	7
WiFi2	2.9339	2
WiFi3	-2.1927	5
WiFi4	3.8734	1
WiFi5	1.3460	4
WiFi6	-2.6428	6
WiFi7	2.1659	3

V. CONCLUSIONS

In this paper, to determine the weights of the attributes, AHP is used. Improved PROMETHEE method is used for decision making of handoff. For multiplayer interactive gaming where the CR is 0.0000000077369, WiFi4 is selected as first choice; whereas for streaming media WiFi3 is first choice and for media content download WiFi4 is first choice by PROMETHEE method.

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