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Network Selection Algorithm Based on Group Decision Making for Heterogeneous Wireless Networks

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***Abstract*—Multimode terminals running multiple services at the same time are increasingly common, in response to this phenomenon, a network selection algorithm based on group decision making for heterogeneous wireless networks is presented in this paper. The algorithm considers each service from the terminal as a decision-maker, and obtains the weight vector of all network attributes for each service by the analytic hierarchy process, then uses the group decision making to synthesize these weight vectors. At the same time, the utility function is used to normalize the network attributes. At last, the network selection is made according to the synthesized weight vector and attribute utility. The simulation results show that the proposed algorithm is far superior to the TOPSIS in satisfying the QoS requirements of different class of services, and can solve the problem of network selection for a group of services from a multi-service terminal.**

Keywords-network selection; multi-service terminal; group decision making; QoS requirement

I. INTRODUCTION

With the continuous evolution of wireless technology, a large number of wireless access technologies have been applied and overlap each other to form heterogeneous networks. These technologies have their own unique advantages, so users need to adopt the appropriate algorithm to select the best network. The traditional algorithm is the one based on the received signal strength (RSS) [1], this algorithm is vulnerable to the external environment and other factors, decision results often have a degree of randomness. In [2] and [3], the heterogeneous network selection algorithm based on multiple attribute decision making(MADM) is proposed, this algorithm takes into account the influence of various factors such as user preferences, applications, networks, and terminals in the selection of the network. The analytic hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) are commonly used in MADM. Since some network parameters cannot be given specific values in practical situations, in order to enable users to make accurate decisions, some literatures introduce fuzzy logic theory to measure network parameters, and propose the algorithm based on fuzzy logic to select wireless networks [4-5]. In [6] and [7], a heterogeneous network selection algorithm based on game theory is proposed, which can balance the interests between users and users, users and networks, making network resource utilization more efficient and user satisfaction more higher.

The above algorithms are classical methods to solve the problem of heterogeneous wireless network selection, but these algorithms consider the case that the terminal runs only a class of service. In real life, terminals tend to run multiple services, such as voice communications, web browsing and file downloading, therefore the terminal should consider QoS requirements of all services simultaneously when selecting networks, making all the services in the process of selecting or switching networks not be interrupted. Although the [8-10] study the case that the terminal can run multiple services simultaneously and propose several new heterogeneous network selection algorithms based on improved MADM, but compared with the previous algorithms, these new algorithms only consider the influence of service priority, and do not make terminal services really participate in the decision-making, so these algorithms do not make the service satisfaction rate increase obviously. A network selection algorithm based on group decision making for heterogeneous wireless networks is presented in this paper, each kind of service running on the terminal is regarded as a decision-maker, and the weight vector of the network attributes for each kind of service is equal to the decision result of the decision-maker. The group decision making is used to synthesize these decision results to get the synthetic weight vector. Finally, this synthetic weight vector is used to select networks.

The rest of this paper is organized as follows. The system model of heterogeneous wireless network is established in Section II; Section III presents the network selection algorithm based on group decision making for heterogeneous wireless networks; Section IV simulates the proposed algorithm, and simulation results are compared with other algorithms; Section V summarizes this paper.

II. SYSTEM MODEL

As shown in Fig. 1, the network scenario consists of UMTS, WLAN and WiMAX. The shaded area in the figure indicates the common coverage area of the six heterogeneous wireless networks. The users are randomly distributed in this area. Assuming that each terminal is running multiple services simultaneously. How to select the network so that all services on the terminal can meet their QoS requirements is the focus of this paper.

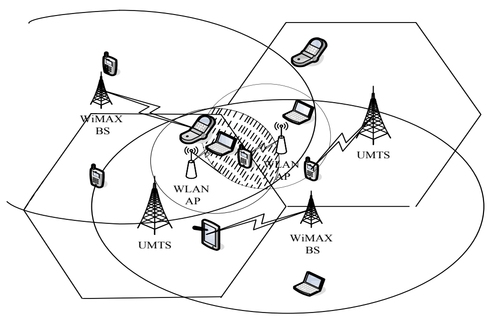

Figure 1. Heterogeneous wireless network scenarios.

The International Organization for Standardization (3GPP) classifies services into four categories: conversational class, streaming class, interactive class and background class. The conversational class is real-time, it has high requirements on transmission delay and delay jitter, and low requirements on packet loss rate and packet error rate. The streaming class is also real-time, but not as strict as the conversational class, it has high requirements on throughput and delay jitter, and low requirements on transmission delay, and allows a certain packet loss rate and wrong packet rate. The requirements on transmission delay for interactive class depend on the tolerance of the users. It has high requirements on packet loss rate, in the ideal case, zero packet loss rate is required. The background class has no requirements on the transmission delay, but like the interactive class, requiring zero packet loss rate. In this paper, three kinds of services are considered, namely, conversational class, streaming class and interactive class, and they have priority values $W_1, W_2, W_3, W_1 + W_2 + W_3 = 1$. Because the QoS requirements vary widely among different services, if all the services select the most appropriate network respectively, the terminal power consumption will be greatly increased. Therefore, this paper studies how multi-service terminals access a single network. The multi-service parallel transmission model is shown in Fig. 2.

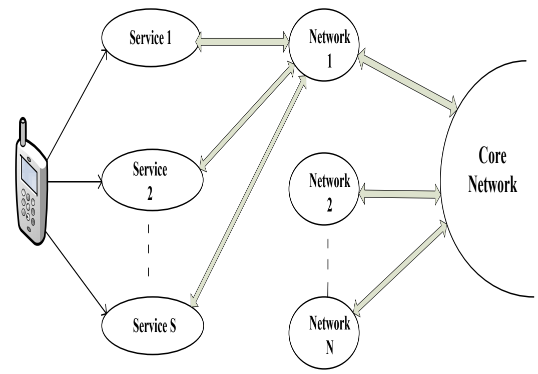

Figure 2. Multi-service parallel transmission model.

In this paper, a new network selection algorithm is proposed for the terminal running multiple services. Fig.3 illustrates the functional structure of the algorithm (the contents of the dashed box indicate the method to be used). It includes three modules: the sigmoid utility function module, which obtains the utility value of the network attribute; AHP module, obtains the network attribute weight for different services; the group decision making module obtains the synthetic attribute weights.

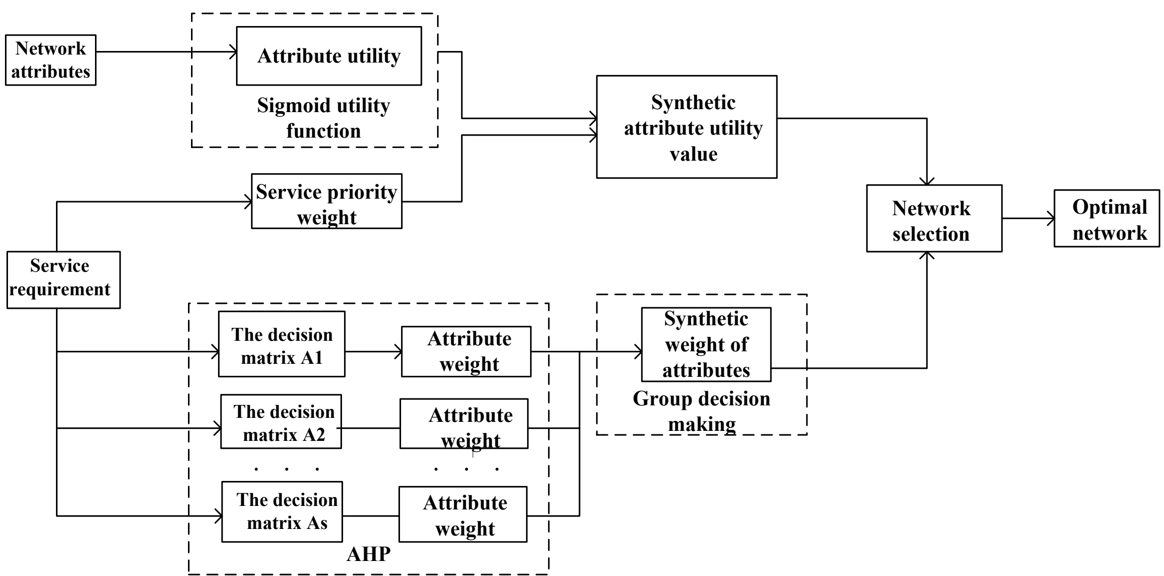

Figure 3. Functional structure diagram.

III. Network Selection Algorithm Based on Group Decision Making for Heterogeneous Wireless Networks

A. *Utility Function*

"Utility" was first used in economics, said the consumer's satisfaction with the product, in this paper, the network attribute utility is used to represent the degree to which the service is "satisfied" with these attributes. Network attributes are usually divided into upward attributes and downward attributes. Upward attributes refer to the attributes whose value is bigger, the network performance is better. Downward attributes refer to the attributes whose value is smaller, the network performance is better. In this paper, the sigmoid utility function is used to normalize the attributes, we assume that there are N networks in the heterogeneous wireless network scenario, each terminal has S services to run at the same time and there are M network attributes considered. For the upward attribute x_{ij}, the normalized attribute utility value X_{lj} for the service l is

$$X_{lj}=\begin{cases}1-e^{-\alpha_j(x_{ij}-\beta_{lj})}, x_{ij}\geq\beta_{lj}\\ 0, x_{ij}\leq\beta_{lj}\end{cases}\quad(1)$$

For the downward attribute x_{ij}, the normalized attribute utility value X_{lj} for the service l is

$$X_{lj}=\begin{cases}1-e^{\alpha_j(x_{ij}-\beta_{lj})}, x_{ij}\leq\beta_{lj}\\ 0, x_{ij}\geq\beta_{lj}\end{cases}\quad(2)$$

where $1\leq i\leq N, 1\leq l\leq S, 1\leq j\leq M$, β_{lj} denotes the threshold of the attribute j satisfying the QoS requirements of the service l. The greater the adjustment factor α_j, the steeper the curve of the function. After the network attribute is specified, the higher the utility value is, the better the performance of the corresponding network attribute is, and the value is between 0 and 1.

B. *Network Selection Algorithm Based on Group Decision Making for Heterogeneous Wireless Networks*

Group decision making evolved from the AHP. In AHP, according to the dominant relationship among the elements, the system is divided into target layer, criterion layer, and program layer. The elements under the same level are compared in pairs by experts and according to the element scale table to get the decision matrix (decision matrix element scale table is shown in Table I). However, in some cases, if only one expert makes a decision, the results are one-sided, in order to make the decision scientific and democratic, a complex system usually has many decision-makers (i.e. experts) or departments to participate in decision-making, thus when the expert consultation is conducted, multiple decision matrices will be obtained for the same criterion. Therefore, it is necessary to deal with and analyze the results of the multi-person decision making. Through the existing research and calculation, a synthetic judgment matrix is obtained from the experts. This method is the group decision making (GDM).

TABLE I. Element Scale Table

Scale	Meaning
1	Equable
3	Slightly greater
5	Fairly greater
7	Extremely greater
9	Absolutely greater
2,4,6,8	Median

The group decision making is used in network selection of multi - service terminal. Because multi-service terminals need to consider the QoS requirements of all services in the selection of the network, this paper considers each service of the terminal as a decision maker, and the weight vectors of all network attributes can be obtained by AHP, then these weight vectors are aggregated using group decision making. The following is a detailed analysis of the algorithm.

Firstly, the weight vector of all network attributes is obtained by AHP. Assuming that the decision matrices corresponding to the S services are $A_1, A_2, ..., A_S$, respectively, the resulting weight vectors are denoted as $W^1=(w_1^1, w_2^1, w_3^1, ..., w_M^1)$, $W^2=(w_1^2, w_2^2, w_3^2, ..., w_M^2)$, ..., $W^S=(w_1^S, w_2^S, w_3^S, ..., w_M^S)$. The S weight vectors are synthesized by group decision making, according to the [11], the new normalized integrated weight vector can be expressed as

$$w_t=\left(\prod_{k=1}^{S}w_t^k\right)^{1/S}\Big/\sum_{i=1}^{M}\left(\prod_{k=1}^{S}w_i^k\right)^{1/S}, 1\leq t\leq M \quad(3)$$

where w_t^k denotes the weight value of the network attribute t obtained by the decision maker k. The integrated weight vector $W=(w_1, w_2, w_3, ..., w_M)$ is obtained using (3), and the equivalent decision matrix according to W is $A=\left((w_i/w_j)_{ij}\right), 1\leq i\leq M, 1\leq j\leq M$.

After obtaining the integrated weight vector according to the group decision, it is also necessary to judge whether the vector satisfies the compatibility requirement, that is, whether the matrix A is compatible with $A_1, A_2, ..., A_S$, the compatibility indicators are

$$\begin{aligned}SI_1&=SI(A,A_1)=C(A,A_1)/M^2\\ SI_2&=SI(A,A_2)=C(A,A_2)/M^2\\ &\vdots\\ SI_S&=SI(A,A_s)=C(A,A_s)/M^2\end{aligned}\quad(4)$$

where $C(\mu,\eta)$ denotes the compatibility of the matrices μ and η, and the calculation formula is

$$C(\mu,\eta) = e^T(\mu \circ \eta^T)e \quad (5)$$

where $\mu \circ \eta^T$ is called the *Hadamard* product of matrices μ and η^T. If $SI_1, SI_2, ..., SI_S$ are less than the compatibility index $\overline{S.I.}$ (the values of $\overline{S.I.}$ are shown in Table II), then the resultant weight vector satisfies the compatibility requirement, otherwise, the decision matrices $A_1, A_2, ..., A_S$ need to be modified. When the synthesized weight vector is obtained, the weight vector can be used for network selection. In this paper, the network is selected according to the performance function, the performance function of each network can be expressed as the sum of the products of all normalized network attribute values and their weights. The performance function of the network i is as follows

$$P_i = \sum_{j=1}^{M} r_{ij} w_j, 1 \le i \le N \quad (6)$$

where $r_{ij} = \sum_{l=1}^{S} W_l X_{lj}$, X_{lj} is the j-th attribute utility value of the network i for the service l obtained by using the (1) and (2). W_l is the service priority value. The network with the highest performance value is the optimal network to be selected by the terminal.

TABLE II. COMPATIBILITY INDEX $\overline{S.I.}$

M	3	4	5	6	7	8	9	10	11	12
$\overline{S.I.}$	1.035	1.067	1.090	1.104	1.116	1.124	1.128	1.134	1.138	1.141

The above is the network selection algorithm based on GDM for heterogeneous wireless networks, the mainS steps are as follows.

Algorithm for Network Selection

Initialization: $t=0$, $A_1, A_2, ..., A_S$, W_l, β_{lj} and x_{ij}

1. Calculate the weight vectors $W^1, W^2, ..., W^s$ by AHP.
2. Obtain the synthetic weight vector according to the (3) and judge the compatibility.
3. **While** $t < 400000$
4. Normalize the network attributes to get X_{lj}.
5. Calculate the synthetic utility values of network attributes r_{ij}.
6. Select networks according to the (6).
7. Change the value of network attributes by Markov chains,then return to the step (3).
8. **End While**

IV. SIMULATION AND PERFORMANCE ANALYSIS

In order to analyze the performance of the proposed algorithm, three kinds of wireless access technologies are considered in the simulation scenarios of heterogeneous wireless networks, namely *UMTS*, *WLAN* and *WiMAX*, every wireless access technology has two networks, as shown in Fig. 1. The selected network attributes include bandwidth (B), packet delay (D), packet jitter (J), and packet loss rate (L). The QoS requirements of each service are shown in Table III [12-13], the range of the attribute values is shown in Table IV[14]. Because of the influence of external factors, the values of network attributes are always changing. Considering this situation, Markov chains are used to simulate the changes of these network attributes. Assuming that the number of Markov states of the four network attributes are 10, 20, 20 and 30 respectively, the transition probability between adjacent states is $P/2$ and the probability that the state remains unchanged is $1-P$. At the same time, this paper considers that all service priorities are the same, that is, W_1, W_2, W_3 are all 1/3.

TABLE III. QoS REQUIREMENTS OF SERVICES

Services	Conversational Class	Streaming Class	Interactive Class
B(kbps)	>32	>512	>128
D(ms)	<150	<180	<500
J(ms)	<20	<50	<100
L(%)	<0.3	<0.5	<0.05

TABLE IV. NETWORK ATTRIBUTE VALUES

Network Attributes	UMTS1	UMTS2	WLAN1	WLAN2	WiMAX1	WiMAX2
B(kbps)	100-2000	100-2000	1000-11000	1000-54000	1000-60000	1000-60000
D(ms)	25-50	25-50	100-150	100-150	60-100	60-100
J(ms)	5-10	5-10	10-20	10-20	3-10	3-10
L(%)	0.02-0.08	0.02-0.08	0.02-0.08	0.02-0.08	0.02-0.08	0.02-0.08

We assume that all terminals in the simulation scenario run three types of services simultaneously, namely, conversational class, streaming class and interactive class. The QoS requirements of the three services are different. The decision matrices corresponding to the three services established by AHP are shown in Table V.

TABLE V. DECISION MATRICES

Services	Conversational Class				Streaming Class				Interactive Class			
Attributes	*B*	*D*	*J*	*L*	*B*	*D*	*J*	*L*	*B*	*D*	*J*	*L*
B	1	1/9	1/7	3	1	5	1/5	5	1	3	7	1/7
D	9	1	3	9	1/5	1	1/9	1	1/3	1	5	1/7
J	7	1/3	1	7	5	9	1	9	1/7	1/5	1	1/9
L	1/3	1/9	1/7	1	1/5	1	1/9	1	7	7	9	1

Besides the proposed algorithm (GDM), the algorithm TOPSIS is also given as comparisSon. In order to make the results reliable, we simulate the process of multi-service terminal network selection by 400,000 times, and finally the average value of the statistics is obtained, and then the performance of the two algorithms is compared. Fig.4 shows the simulation results of the four attributes of the selected network under TOPSIS and GDM , and the result varies with the state transition probability P . For the upward attribute, the larger the value, the better the attribute performance is, the better it can meet the service requirement. For the downward attribute, the smaller the value, the better the attribute performance is. It can be seen from Fig.4 that GDM algorithm proposed in this paper has better performance than TOPSIS algorithm in terms of throughput, packet delay, packet jitter and packet loss rate, and can better meet various service requirements. This is because we use the GDM algorithm to synthesize the decision matrices obtained by different decision makers (services), and the final attribute weight is a trade-off value to ensure that the selected network can meet all the service QoS requirements.

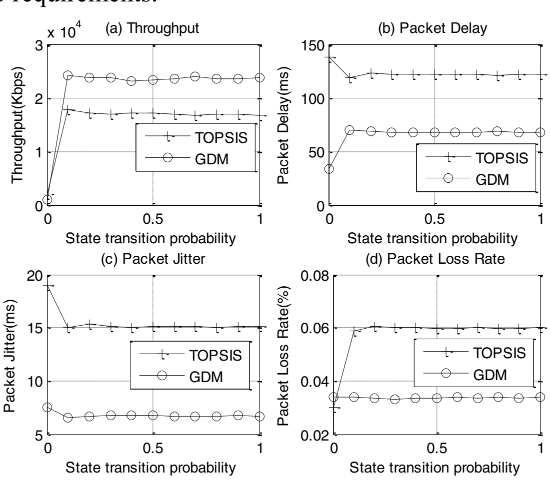

Figure 4. Four network attributes.

Fig. 5 shows the ratio represents the number of simulations that simultaneously satisfy the QoS requirements of the three kinds of services compares to the total number of simulations, the result varies with the state transition probability P . It can be seen from the figure that the network chosen based on GDM algorithm is far more capable of satisfying multi-service QoS requirements than TOPSIS -based network. This is because each kind of service can be regarded as a decision-maker when the network is selected by GDM algorithm, that is, all the services are considered in the selection of network, and the network is selected according to the characteristics of these services, so that the selection results are more reasonable, and thus able to meet a variety of service requirements.

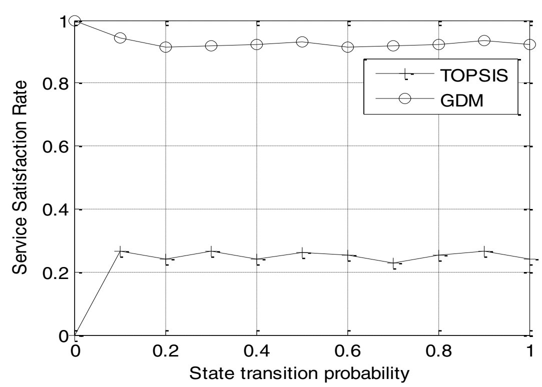

Figure 5. Service satisfaction rate.

V. CONCLUSION

This paper presents a network selection algorithm based on GDM for heterogeneous wireless networks. According to the QoS requirements of different services, we establish different attribute matrices and calculate the corresponding weight vectors. Through the group decision theory, we consider each service on the terminal as a decision-maker. The weights of the network attributes for each service are equivalent to the decision result of the decision maker, and then the results are synthesized. Finally, the network performance function is established by using this synthetic weight vector and the normalized utility values of the attributes. The network with the largest function value is the optimal one. Simulation results show that the performance of attributes obtained by the proposed algorithm is better, and the ability to meet the multi-service QoS requirements is much stronger than the TOPSIS .

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