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Heterogeneous wireless network selection algorithm based on group decision

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Abstract

In the environment of heterogeneous wireless networks, it is vital to select a currently optimal network for applications and subscribers. The use of multiple attribute decision making (MADM) for heterogeneous network selection can provide subscribers with satisfactory service quality. Converting heterogeneous network selection into a MADM problem, the authors present an improved algorithm for MADM based on group decision theory. The algorithm combines weight vectors of multiple attribute decision making to obtain a combinational weight vector. Then the results' compatibility will be assessed. If they do not meet the requirements of compatibility, the judgment matrix will be modified until a comprehensive vector that satisfies compatibility requirements is produced. The vector is combined with simple weighting method (SAW) for network selection. Simulation shows that the algorithm can provide users with satisfactory quality of service (QoS).

Keywords heterogeneous network, MADM, group decision, compatibility

1 Introduction

In terms of next generation wireless network, the heterogeneous network is one of the most promising ones. It will organically integrate a variety of wireless access technology, including the existing systems and the coming ones, to meet the requirements for various applications in the future. As the key technology in resource management of wireless heterogeneous network, network selection algorithm aims to provide users with satisfactory service quality. Not only the network properties but also the user's preference is considered during the process, so this technology is becoming a hot research topic in the field of communication.

MADM method is one of the most efficient methods in heterogeneous network selection algorithm. The classic MADM algorithm includes SAW method, multiplication index weighting algorithms (MEW), technique for order preference by similarity to an ideal solution (TOPSIS), grey relational analysis (GRA) [1], Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [2], and elimination and choice translating reality (ELECTRE) [3], etc. These MADMs are always related to multiple attribute weight vectors, and the vector is supposed to consider the objective attributes of the network, user's preferences and traffic class. Commonly used objective weighting methods include entropy method (EW) [4], standard deviation method [4], etc. Classic subjective methods include the analytic hierarchy process (AHP) [5] method and G-1 method [6]. Many documents combine the subjective weight with the objective one for network selection. In Ref. [7], subjective weight determined by AHP method and objective weight of EW are weighted linearly, and the combinational weight will be combined with SAW method for network selection. But this method does not show how the weighted coefficients are calculated. A balanced algorithm was presented in Ref. [8], in which the subjective weight of AHP and the objective method of EW are combined based on group decision to produce a

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combinational weight vector. But this method only involves two decision makers, whose quantity is a little in a group decision process, leaving group decision incapable of taking full advantage of the characteristics of collecting multiple decision makers' wisdom. In Ref. [9], the authors put forward an algorithm which connects AHP method with GRA method for network selection. But this algorithm is too complex and lacks enough theoretical support.

Aiming at these shortcomings, the authors put forward an improved method based on combing weighting methods for group decisions. Firstly, we use AHP and G-1 method to obtain two subjective weight vectors respectively. Secondly, the EW method and standard deviation are used to get two objective weight vectors differently. Four kinds of methods represent four decision makers, including two subjective decision makers and two objective ones. The quantity of decision makers is reasonable and each of them is representative. Based on the theory of group decision, four weight vectors are combined to generate a new weight vector, whose compatibility will be verified later according to the theory of compatibility. If it does not meet the requirements of compatibility, the judgment matrix will be modified, ensuring the matrix respond to the objective attribute of the network. This method can not only make full use of the advantage of the characteristics of collecting multiple decision makers' wisdom in a group decision process, but also give full consideration to the user needs and network conditions, the simulation results illustrate that the algorithm can provide satisfactory QoS for different applications.

The rest of the article is arranged as following, the second part gives the system model. The third part introduces the weighting method involved and the theories of group decision and compatibility. The fourth part presents simulation results and the last section summarizes the text.

2 System model

Heterogeneous network model of this article shown in Fig. 1 contains three types of heterogeneous network and six base stations, including two wireless local area networks (WLAN) base stations, two worldwide interoperability for microwave access (WiMAX) stations and two universal mobile telecommunication system (UMTS) stations.

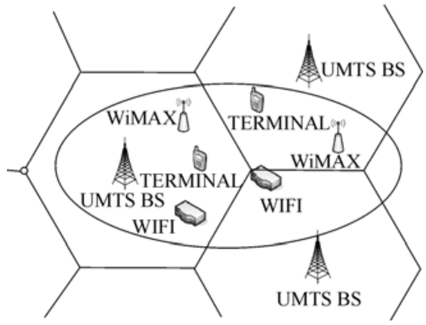

Fig. 1 Heterogeneous network model

Algorithm block diagram is shown in Fig. 2. According to it, the authors give objective parameters and use EW method and standard deviation method to calculate the objective weight vectors, and give subjective parameters to obtain subjective attribute weight vectors by AHP and G-1. AHP can make the relative importance values between indexes accurate. When facing with a certain number of indexes, the order relation will be inaccurate, while G-1 can determine the only index order relation. Consequently, they complement each other. Subjective weighting method is related to experience, while the objective ones cannot consider user preference.

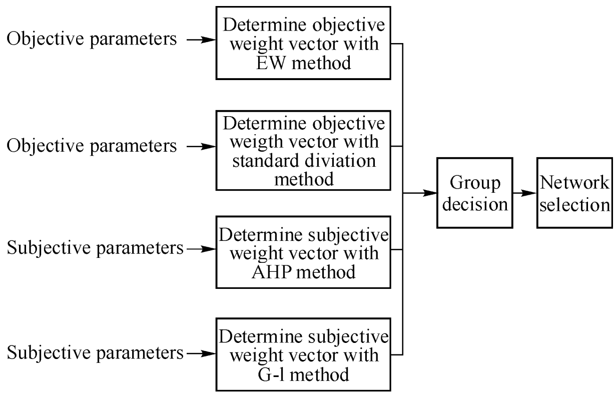

Fig. 2 Diagram of the algorithm

Therefore, the combination of the two kinds of methods can both consider the objective situation of networks and user preference. Four methods mean four decision makers. Using the theory of group decision, the four weight vectors can be combined to generate a new weight vector, thus a comprehensive weight vector $\boldsymbol{W}$ is obtained. Finally, SAW is adopted as well for network selection.

3 Determination of weight vector

MADM typically involves the determination of weight vector. The traditional method which determines the weight vector can be classified as subjective and objective types. Subjective ways include AHP, G-1, Delphi method [10] and so on. Objective ways include entropy weight method, standard deviation, criteria importance through inter criteria correlation (CRITIC) method, etc. Each way has its own characteristics. Therefore, in order to consider factors such as user preference, traffic class, objective attributes of network and to make full use of the characteristics of group decision, a variety of subjective and objective methods for determining weight vectors to get a multiple attribute weight vector is synthesized. The authors select AHP and G-1 as subjective ways, and adopt EW and standard deviation method as objective methods. After acquiring the combinational weight vector by the four weighting methods based on group decision theory, the vector's compatibility to ensure its rationality will be verifies. The vector which meets the requirements of compatibility will be combined with SAW for network selections.

3.1 Determination of objective weight

In this article, the objective ways include EW method and standard deviation method. Using the heterogeneous network model of this paper, the attribute parameters for network selection contain the available bandwidth (which is marked as *B*), peak data rate (*R*), packet delay (*D*), packet jitter (*J*), packet loss (*L*) and cost per bit (*C*). Objective weight can be calculated by using network attribute parameters, and the parameters are show in Table 1.

Table 1 Network parameters in Refs. [11–12]

Network	B/MHz	$R/(\mathrm{Mbit \cdot s^{-1}})$	D/ms	J/ms	$L/10^{-6}$	C/bit^{-1}
UMTS1	0.1~2.0	2	25~50	5~10	20~80	0.6
UMTS1	0.1~2.0	2	25~50	5~10	20~80	0.8
WLAN1	1~11	11	100~150	10~20	20~80	0.1
WLAN2	1~54	54	100~150	10~20	20~80	0.05
WiMAX1	1~60	60	60~100	3~10	20~80	0.5
WiMAX2	1~60	60	60~100	3~10	20~80	0.4

It assumes that the attribute matrix of the network is $\boldsymbol{R}' = (x_{ij})_{6\times 6}$, there are six types of networks and six heterogeneous networks. x_{ij} is as the value of the *j*th attribute of the *i*th network, and $1 \leqslant i \leqslant 6, 1 \leqslant j \leqslant 6$, the value of x_{ij} falls within each scope in table 1. In general, there are two kinds of attribute called efficiency attribute (the larger the better) and cost attribute (the smaller the better) [13]. Among the attributes involved in this algorithm, available bandwidth and peak data rate belong to efficiency type, and the rest are cost attributes. As a matter of these and according to Ref. [13], for *B* and *R*, their formula for standardization is

$$r_{ij} = \frac{x_{ij}}{x_{\max}^j + x_{\min}^j}; \quad 1 \leqslant j \leqslant 2 \tag{1}$$

For *D*, *J* and *C*, the formula for standardization is

$$r_{ij} = \frac{x_{\max}^i + x_{\min}^i - x_{ij}}{x_{\max}^j + x_{\min}^j}; \quad 3 \leqslant j \leqslant 6 \tag{2}$$

The standardized attribute matrix of the network of EW and standard deviation is $\boldsymbol{R}' = (r_{ij})_{6\times 6}$.

3.1.1 Entropy method

Following the steps in Ref. [4], the process is as follows

Standardization

$$\overline{r}_{ij} = \frac{r_{ij}}{\sum_{i=1}^{6} r_{ij}}; \quad 1 \leqslant j \leqslant 6 \tag{3}$$

Attribute information entropy

$$H_i = -K \sum_{j=1}^{6} \overline{r}_{ij} \ln \overline{r}_{ij}; \quad 1 \leqslant i \leqslant 6 \tag{4}$$

where K=1/ln 6

Calculating weight vector

$$w_j^{\mathrm{EW}} = \frac{1 - H_i}{6 - \sum_{j=1}^{6} H_i}; \quad 1 \leqslant i \leqslant 6 \tag{5}$$

Through the EW method, the weight vector can be obtained: $\boldsymbol{W}^{\mathrm{EW}} = (w_1^{\mathrm{EW}}, w_2^{\mathrm{EW}}, w_3^{\mathrm{EW}}, w_4^{\mathrm{EW}}, w_5^{\mathrm{EW}}, w_6^{\mathrm{EW}})^{\mathrm{T}}$.

3.1.2 Standard deviation method

The principle of standard deviation method is similar to that of EW method. Generally, the standard deviation of a certain index is directly proportional to the variation of the parameter values, that is to say, if the standard deviation is greater, so is the degree of variation. Meanwhile, the amount of information is offered bigger, the role it plays in the evaluation work is more important and the weight is bigger. But the weight becomes smaller. The attribute standard deviation formula of the six networks is

$$\left.\begin{aligned} \sigma_j &= \sqrt{\frac{\sum_{i=1}^{6} (r_{ij} - \overline{r}_j)^2}{6}}; \quad 1 \leqslant j \leqslant 6 \\ \overline{r}_j &= \frac{\sum_{i=1}^{6} r_{ij}}{6}; \quad 1 \leqslant j \leqslant 6 \end{aligned}\right\} \tag{6}$$

The formula using the standard deviation to calculate the weight vector of six networks is

$$w_j^{\sigma} = \frac{\sigma_j}{\sum\limits_{j=1}^{6} \sigma_j}; \quad j = 1, 2, \ldots, 6 \tag{7}$$

The weight vector calculated by the standard deviation method is $\boldsymbol{W}^{\sigma} = (w_1^{\sigma}, w_2^{\sigma}, w_3^{\sigma}, w_4^{\sigma}, w_5^{\sigma}, w_6^{\sigma})^{\mathrm{T}}$.

3.2 The determination of subjective weight

Subjective ways consist of AHP and G-1 method in this article. According to different type of traffic, the judgment matrix of subjective method varies. The judgment matrix in AHP is $\boldsymbol{A}^{\mathrm{AHP}}$, and the matrix of G-1 is $\boldsymbol{G}^{\text{G-1}}$. The matrix of AHP and G-1 in each traffic class is given in Table 2 and Table 4 respectively. Therefore, under a certain traffic class, $\boldsymbol{A}^{\mathrm{AHP}}$ and $\boldsymbol{G}^{\text{G-1}}$ are response to the judgment matrix in Table 2 and Table 4.

3.2.1 AHP method

In a given traffic class, the judgment matrix of AHP method is $\boldsymbol{A}^{\mathrm{AHP}}$, and the judgment decision matrix of each application type is shown in Table 2 differently.

Under each traffic, combined with the matrix in Table 2 and followed the steps in Ref. [5], the weight vector of the AHP method can be calculated as $\boldsymbol{W}^{\mathrm{AHP}} = (w_1^{\mathrm{AHP}}, w_2^{\mathrm{AHP}}, w_3^{\mathrm{AHP}}, w_4^{\mathrm{AHP}}, w_5^{\mathrm{AHP}}, w_6^{\mathrm{AHP}})^{\mathrm{T}}$.

Table 2 Judgment matrix corresponding to different traffic classes (AHP) in Ref. [8]

Attributes	Conversational						Streaming					
	B	*R*	*D*	*J*	*L*	*C*	*B*	*R*	*D*	*J*	*L*	*C*
B	1	1	1/9	1/5	1/3	1/3	1	2	4	5	4	1/5
R	1	1	1/9	1/5	1/3	1/3	1/2	1	3	4	3	1/4
D	9	9	1	3	4	4	1/4	1/3	1	3	1/3	1/8
J	5	5	1/3	1	2	2	1/5	1/4	1/3	1	1/5	1/9
L	3	3	1/4	1/2	1	2	1/4	1/3	3	5	1	1/7
C	3	3	1/4	1/2	1/2	1	5	4	8	9	7	1
Attributes	**Interactive**						**Background**					
	B	*R*	*D*	*J*	*L*	*C*	*B*	*R*	*D*	*J*	*L*	*C*
B	1	1	2	3	1/7	1/7	1	2	1	1	1/3	1/5
R	1	1	2	3	1/7	1/8	1/2	1	1	1	1/4	1/7
D	1/2	1/2	1	2	1/8	1/9	1	1	1	1	1/5	1/6
J	1/3	1/3	1/2	1	1/9	1/9	1	1	1	1	1/4	1/7
L	7	7	8	9	1	1/5	3	4	5	4	1	1/3
C	7	8	9	9	5	1	5	7	6	7	3	1

3.2.2 G-1 method

The G-1determining the subjective weight is divided into three steps. First, evaluating indexes according to certain evaluation standard of importance. Second, giving the ratio of importance between adjacent indexes which are sorted, and finally, calculating the weight of each index. Specific steps are as follows:

1) Determine the order

In this step, all the attributes under certain evaluating standard of importance are supposed to be sorted. Sorting information of each application of the six heterogeneous networks is given as following: the conversational business: *R*>*J*>*B*>*C*>*P*>*L*; the steaming business: *L*>*B*>*P*>*R*>*J*>*C*; the interactive business: *L*>*C*>*R*>*J*>*B*>*P*; the background business: *C*>*L*>*J*>*R*>*B*>*R*.

2) The relative importance judgment between adjacent attributes

Under certain evaluating standard of importance, the relative importance ratio between adjacent attributes is

$$\frac{w_{k-1}}{w_k} = r_k; \quad 2 \leqslant k \leqslant 6 \tag{8}$$

k is a variable which distinguishes parameters. w_k refers to weight of *k*th parameter. The assignment of r_k can be referred to Table 3, which was defined in Ref. [6].

Table 3 Assignment of r_k in Ref. [6]

r	Instruction
1.0	Index x_{k-1} and x_k have the same importance
1.2	Index x_{k-1} is slightly more important than x_k
1.4	Index x_{k-1} is obviously more important than x_k
1.6	Index x_{k-1} is far more important than x_k
1.8	Index x_{k-1} is extremely more important than x_k

The values of *r* is given by considering the values in Table 2 and Table 3 to ensure the consistence of subjective judgment in each traffic class. The process of obtaining *r* is as follows: comparing the relative importance values of each parameter in judgment matrix of AHP under a certain application, it can obtain a precise index order relation. According to the order relation, the adjacent parameter is compared and the relative importance values between them are obtained. Finally, the relative importance values into *r*, for instance should be converted, if the value is 4, the corresponding *r* will be 1.4. As a result, Table 4 is obtained.

3) The determination of weight

Firstly, the most important attribute's weight w_6 is calculated, and then the subsequent weight in turn.

The following formula is used to determine the weight w_6.

$$w_6 = \frac{1}{1+\sum_{k=2}^{6}\prod_{i=k}^{6} r_i} \tag{9}$$

By Eq. (8), the subsequent weights is acquired.

$$w_{k-1} = r_k w_k; \quad k = 6,5,\dots,2 \tag{10}$$

Combining with the above formula and referring to the values of r in Table 4, the subjective weight vector, using G-1, can be obtained in certain traffic class, which is $\boldsymbol{W}^{\text{G-1}} = (w_1^{\text{G-1}}, w_2^{\text{G-1}}, w_3^{\text{G-1}}, w_4^{\text{G-1}}, w_5^{\text{G-1}}, w_6^{\text{G-1}})^{\text{T}}$.

Table 4 The judgment matrix corresponding to different types (G-1)

Traffic class	r_2	r_3	r_4	r_5	r_6	Sorting
Conversational	1.2	1.6	1.0	1.2	1.2	*R>J>B>C>P>L*
Streaming	1.8	1.0	1.0	1.0	1.0	*L>B>P>R>J>C*
Interactive	1.0	1.8	1.0	1.4	1.0	*L>C>R>J>B>P*
Background	1.2	1.4	1.0	1.0	1.2	*C>L>J>R>B>R*

3.3 Group decision and compatibility

3.3.1 Group decision

The advantage of group decision should be realized by collecting group members' wisdom [14], so its members must be guaranteed to certain numbers, each of them is supposed to be representative. Four decision methods selected here consist of two objective ways and two subjective ways namely entropy value method and standard deviation method. Meanwhile, the quantity of them is reasonable. The weight vector of network attribute based on group decision is required; it can not only make use of the advantage of the characteristics of collecting multiple decision makers' wisdom in a group decision process, but also give considerations to the user's needs and network conditions. The authors will explain how to use the theory of group decision-making and compatibility to combine the four weight vectors.

Assuming that $\boldsymbol{A}=(a_{ij})$, $\boldsymbol{B}=(b_{ij})$ and $\boldsymbol{C}=(c_{ij})$ are n order positive reciprocal matrices, the sorted vector of $\boldsymbol{A}$ is $\boldsymbol{W}=(w_1, w_2, \dots, w_n)^{\text{T}}$ and the matrix $\boldsymbol{A}^{\text{C}}=(w_i/w_j)$ is called the characteristic matrix of $\boldsymbol{A}$. Define the product of $\boldsymbol{A}$ and $\boldsymbol{B}$ $C(\boldsymbol{A},\boldsymbol{B}) = \boldsymbol{e}^{\text{T}}(\boldsymbol{A}\boldsymbol{B}^{\text{T}})\boldsymbol{e}$ as the compatibility of $\boldsymbol{A}$ and $\boldsymbol{B}$, including $\boldsymbol{e}^{\text{T}}$=(1,1,…,1). For convenience, its lg is taken as compatibility, which is $C_{\text{L}}(\boldsymbol{A},\boldsymbol{B}) = \sum_i\sum_j \lg^2(a_{ij}b_{ji})$. In general, $C_{\text{L}}(\boldsymbol{A},\boldsymbol{B}) \geqslant 0$, if $C_{\text{L}}(\boldsymbol{A},\boldsymbol{B})=0$, $\boldsymbol{A}$ and $\boldsymbol{B}$ are fully compatible.

Four weighting methods are based on the same network parameters, determining four different sorted vectors $\boldsymbol{W}^{\text{EW}}$, $\boldsymbol{W}^{\sigma}$, $\boldsymbol{W}^{\text{AHP}}$ and $\boldsymbol{W}^{\text{G-1}}$. For convenience of calculation, it is noted that $\boldsymbol{W}^{\text{EW}} = \boldsymbol{W}^1 = (w_1^1, w_2^1, w_3^1, w_4^1, w_5^1, w_6^1)^{\text{T}}$, $\boldsymbol{W}^{\sigma} = \boldsymbol{W}^2 = (w_1^2, w_2^2, w_3^2, w_4^2, w_5^2, w_6^2)^{\text{T}}$, $\boldsymbol{W}^{\text{AHP}} = \boldsymbol{W}^3 = (w_1^3, w_2^3, w_3^3, w_4^3, w_5^3, w_6^3)^{\text{T}}$, $\boldsymbol{W}^{\text{G-1}} = \boldsymbol{W}^4 = (w_1^4, w_2^4, w_3^4, w_4^4, w_5^4, w_6^4)^{\text{T}}$. The characteristic matrices corresponding to four sorted vectors are noted as $\boldsymbol{A}^{\text{EW}}$, $\boldsymbol{A}^{\sigma}$, $\boldsymbol{A}^{\text{AHP}}$, $\boldsymbol{A}^{\text{G-1}}$, the combinational vector is the one which, in the logarithmic sense, makes characteristic matrix ($\boldsymbol{A}^{\text{EW}}$, $\boldsymbol{A}^{\sigma}$, $\boldsymbol{A}^{\text{AHP}}$ and $\boldsymbol{A}^{\text{G-1}}$) compatible to the comprehensive characteristic matrix, under that condition, the value of $P = \sum_{i,j=1}^{6}\sum_{k=1}^{4}\lg^2\left[\left(w_i/w_j\right)\left(w_j^{(k)}/w_i^{(k)}\right)\right]$ will reach minimum. If $\boldsymbol{W}=(w_1, w_2, w_3, w_4, w_5, w_6)^{\text{T}}$ makes P the minimum, it should get

$$\frac{\partial P}{\partial t} = 0; \quad 1 \leqslant t \leqslant 6 \tag{11}$$

$\sum_{i=1}^{6} w_i = 1$, the solution of Eq. (11) is

$$w_t = \frac{w_t^{\text{EW}} w_t^{\sigma} w_t^{\text{AHP}} w_t^{\text{G-1}}}{\sum_{t=1}^{6}(w_t^{\text{EW}} w_t^{\sigma} w_t^{\text{AHP}} w_t^{\text{G-1}})^{1/4}} = \frac{w_t^1 w_t^2 w_t^3 w_t^4}{\sum_{t=1}^{6}(w_t^1 w_t^2 w_t^3 w_t^4)^{1/4}} \tag{12}$$

According to the above formula, it can be obtained the geometric comprehensive vector of the four weight vectors $W=(w_1, w_2, w_3, w_4, w_5, w_6)^{\text{T}}$

And the comprehensive characteristic matrix $\boldsymbol{A}^{\text{C}} = [(w_i/w_j)]$; $1 \leqslant i, j \leqslant 6$.

The authors define the index S_{I} ($\boldsymbol{A}$, $\boldsymbol{B}$) =C($\boldsymbol{A}$, $\boldsymbol{B}$)/n^2 as the compatibility indicator [15] of matrix of $\boldsymbol{A}$ and $\boldsymbol{B}$. Generally, $\boldsymbol{A}$ and $\boldsymbol{B}$ are compatible. When $S_{\text{I}}(\boldsymbol{A},\boldsymbol{B}) \leqslant 0.1[(n-1)/n]R_{R.I.}+1$, the compatibility between A and B is satisfactory. For convenience of judgment, $\overline{S_{\text{I}}} = 0.1[(n-1)/n]R_{R.I.}+1$ is taken as boundary value of compatibility index, and when $S_{\text{I}}(\boldsymbol{A},\boldsymbol{B}) \leqslant \overline{S_{\text{I}}}$ the compatibility of $\boldsymbol{A}$ and $\boldsymbol{B}$ is satisfactory will be considered. The thresholds of S_{I} are shown in Table 5.

Table 5 Thresholds of S_{I}

n	$\overline{S_{\text{I}}}$	n	$\overline{S_{\text{I}}}$
1	1	7	1.116
2	1	8	1.124
3	1.035	9	1.128
4	1.067	10	1.134
5	1.090	11	1.138
6	1.104	12	1.141

In order to guarantee the rationality of the combined vector, compatibility test on the synthetic weight vector is carried to make sure comprehensive characteristic matrix $\boldsymbol{A}^{\mathrm{C}}$ and characteristic matrix ($\boldsymbol{A}^{\mathrm{EW}}$, $\boldsymbol{A}^{\sigma}$, $\boldsymbol{A}^{\mathrm{AHP}}$ and $\boldsymbol{A}^{\mathrm{G\text{-}1}}$) satisfactorily compatible. The indicator indices are as follows respectively.

$$S_{\mathrm{I1}} = S_{\mathrm{I}}(\boldsymbol{A}^{\mathrm{C}}, \boldsymbol{A}^{\mathrm{EW}}) = \frac{C(\boldsymbol{A}^{\mathrm{C}}, \boldsymbol{A}^{\mathrm{EW}})}{M^2} = \sum_{i=1}^{M}\sum_{j=1}^{M}\frac{w_i}{w_j}\frac{w_j^{\mathrm{EW}}}{w_i^{\mathrm{EW}}} = \frac{\sum_{i=1}^{M}\frac{w_i}{w_i^{\mathrm{EW}}}\sum_{j=1}^{M}\frac{w_j^{\mathrm{EW}}}{w_j}}{M^2} \tag{13}$$

$$S_{\mathrm{I2}} = S_{\mathrm{I}}(\boldsymbol{A}^{\mathrm{C}}, \boldsymbol{A}^{\sigma}) = \frac{C(\boldsymbol{A}^{\mathrm{C}}, \boldsymbol{A}^{\sigma})}{M^2} = \sum_{i=1}^{M}\sum_{j=1}^{M}\frac{w_i}{w_j}\frac{w_j^{\sigma}}{w_i^{\sigma}} = \frac{\sum_{i=1}^{M}\frac{w_i}{w_i^{\sigma}}\sum_{j=1}^{M}\frac{w_j^{\sigma}}{w_j}}{M^2} \tag{14}$$

$$S_{\mathrm{I3}} = S_{\mathrm{I}}(\boldsymbol{A}^{\mathrm{C}}, \boldsymbol{A}^{\mathrm{G\text{-}1}}) = \frac{C(\boldsymbol{A}^{\mathrm{C}}, \boldsymbol{A}^{\mathrm{G\text{-}1}})}{M^2} = \sum_{i=1}^{M}\sum_{j=1}^{M}\frac{w_i}{w_j}\frac{w_j^{\mathrm{G\text{-}1}}}{w_i^{\mathrm{G\text{-}1}}} = \frac{\sum_{i=1}^{M}\frac{w_i}{w_i^{\mathrm{G\text{-}1}}}\sum_{j=1}^{M}\frac{w_j^{\mathrm{G\text{-}1}}}{w_j}}{M^2} \tag{15}$$

$$S_{\mathrm{I4}} = S_{\mathrm{I}}(\boldsymbol{A}^{\mathrm{C}}, \boldsymbol{A}^{\mathrm{AHP}}) = \frac{C(\boldsymbol{A}^{\mathrm{C}}, \boldsymbol{A}^{\mathrm{AHP}})}{M^2} \tag{16}$$

where $M=n=6$.

When the four compatibility indices are all less than the threshold of $\overline{S_{\mathrm{I}}}$, the synthetic weight vector will meet the requirement of compatibilities. The vector based on group decision will combine with SAW for network selections. The performance function of each network can be represented as

$$F = \sum_{j=1}^{6} w_j r_{ij};\quad 1 \leqslant i \leqslant 6 \tag{17}$$

The best network is

$$F^* = \arg\max_{i\in 6}\sum_{j\in 6} w_j r_{ij} \tag{18}$$

The algorithm process diagram is shown in Fig. 3. The specific steps are

Step 1 Network attributes are changed obeying the principle of the markov chain. Assuming that every network attribute has several markov states, the probability of the each state's transformation to two adjacent is $P/2$, the probability of the first and the last states' shift is P and the probability of no changes is P. After changes obeying markov principle, a specific network attribute matrix is produced.

Step 2 First, the network attribute matrix will be standardized. Actually, there are two types of network attributes: efficiency and cost one. The former is a the-larger-the-better attribute and the latter is the-smaller-the-better. Among the attributes involved in this algorithm, available bandwidth and peak data rate belong to efficiency type, and the rest are cost attributes. For B and R, their formula for standardization is Eq. (1), for D, J and C, the formula for standardization is Eq. (2). After standardization, all attribute parameters will fall between 0 and 1.

Step 3 The standardized network attribute matrix is combined with EW and standard deviation, two objective weight vectors are determined as

$$\boldsymbol{W}^{\mathrm{EW}} = \boldsymbol{W}^1 = (w_1^1, w_2^1, w_3^1, w_4^1, w_5^1, w_6^1)^{\mathrm{T}}$$

$$\boldsymbol{W}^{\sigma} = \boldsymbol{W}^2 = (w_1^2, w_2^2, w_3^2, w_4^2, w_5^2, w_6^2)^{\mathrm{T}}$$

Under a certain application type, the judgment matrix is given (Table 2) and AHP is used to calculate a subjective weight vector $\boldsymbol{W}^{\mathrm{AHP}} = \boldsymbol{W}^3 = (w_1^3, w_2^3, w_3^3, w_4^3, w_5^3, w_6^3)^{\mathrm{T}}$. Similarly, the judgment matrix is given and a second weight vector can be obtained using G-1. The vector is $\boldsymbol{W}^{\mathrm{G\text{-}1}} = \boldsymbol{W}^4 = (w_1^4, w_2^4, w_3^4, w_4^4, w_5^4, w_6^4)^{\mathrm{T}}$.

Step 4 The theory of group decision is applied to combine the four calculated weight vectors and the geometric combinational vector $\boldsymbol{W}$ is obtained, using Eq. (12), its characteristic matrix $\boldsymbol{A}^{\mathrm{C}}$ is got. Then the four compatibility indicators of $\boldsymbol{A}^{\mathrm{C}}$ with the four characteristic matrix ($\boldsymbol{A}^{\mathrm{EW}}$, $\boldsymbol{A}^{\sigma}$, $\boldsymbol{A}^{\mathrm{AHP}}$ and $\boldsymbol{A}^{\mathrm{G\text{-}1}}$) are acquired when using Eqs. (13), (14), (15) and (16).

Step 5 It is supposed to judge whether all the indicators are less than their compatibility index thresholds of $\overline{S_{\mathrm{I}}}$ in the same order in this step. If they do not meet the compatibility requirements, the subjective judgment matrix should be modified, and so the authors will calculate them again. Otherwise, the work will enter step 6.

Step 6 The above five steps produce a geometric combinational weight vector meeting the compatibility requirements. The vector will be combined in this step with SAW to get the numbers of best network in current networks environment.

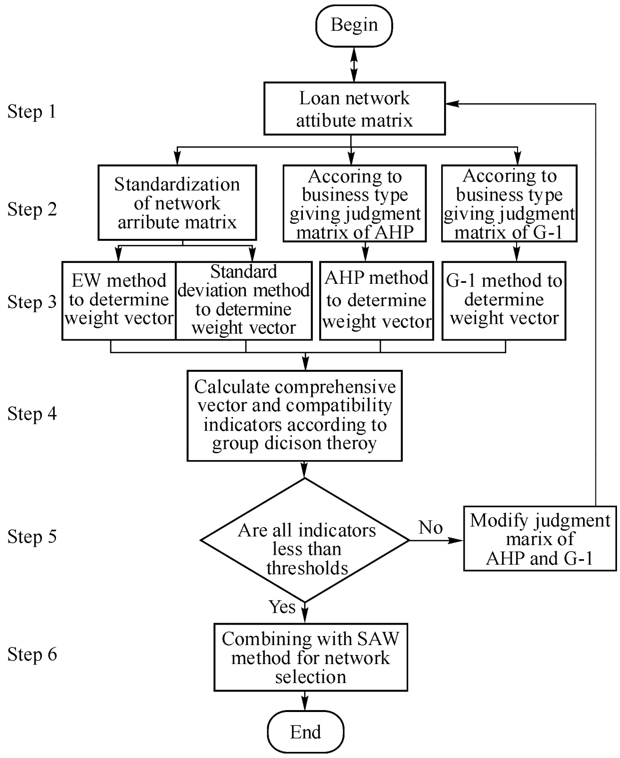

Fig. 3 Flow chart of algorithm

4 Simulation analysis

The heterogeneous networks involved in simulation are WALN, UMTS and WiMAX, and each type contains two networks. group algorithm is compared with EW-AHP [7] and group decision making (GDM) [8] algorithms in the simulation. The EW-AHP algorithm combines EW and AHP linearly regarded as two decision maker adoptions, that is similar to our algorithm. GDM algorithm also adopts group decision theory. Therefore, the authors compare the algorithm with the two ones.

Network attributes changes are obeyed principle of the markov chain. Assuming that each network attribute is of several markov states, the transforming of the probability of each state to the two adjacent is $P/2$, the probability of first and last states' shift is P and the probability of no change is P. The terminals are more likely network performing selection and switch if P is bigger.

The authors select four types of traffic to measure algorithm performance, but decision depending on application is subjective. Method of AHP and G-1 are adopted and their judgment matrices are given as Table 2 and Table 4.

Figs. 4, 5 and 6 demonstrate the performance of the conversational business. Voice communication of conversational application requires low latency and low bandwidth. Video communication of the business needs low latency and enough bandwidth. It can be seen from the judgment matrix in Table 2 and Table 4 that the delay situation in conversational business is paid more attentions. Although the three algorithms have nearly the same performances, it can still found that the group algorithm can provide the lowest delay and jitter and relatively high bandwidth, so the algorithm can satisfy the QoS of users.

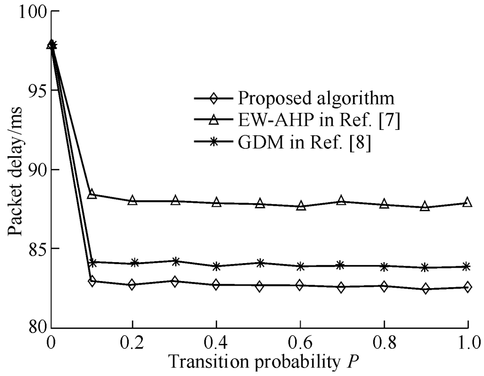

Fig. 4 Delay of conversational traffic

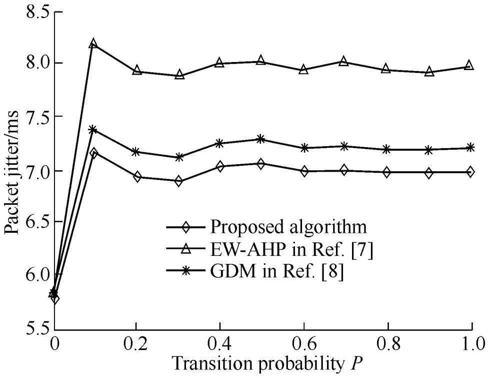

Fig. 5 Jitter of conversational traffic

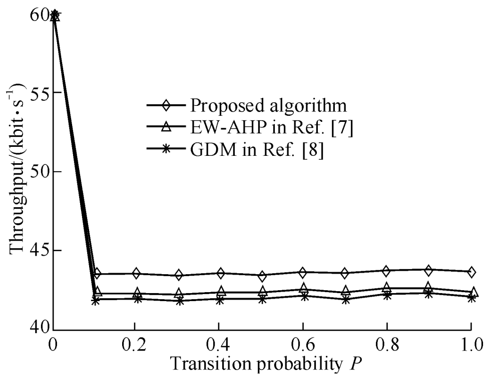

Fig. 6 Throughput of conversational traffic

Figs. 7, 8 and 9 illustrate the performance of streaming business. Streaming traffic permits high error rate and some delay and demands high bandwidth, which can be seen in the judgment matrix in Table 2 and Table 4, where throughput is emphasized in the streaming business. From the figures, it can be seen that when comparing with other two algorithms, the algorithm is capable to offer the lowest packet jitter, satisfying packet loss and optimal bandwidth.

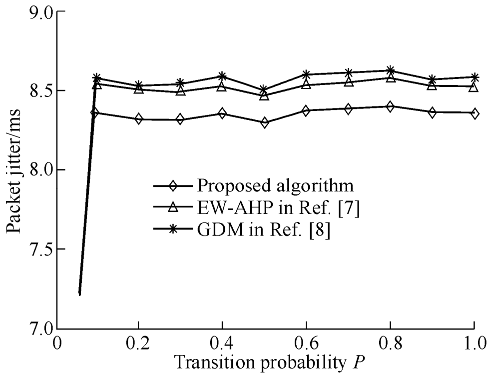

Fig. 7 Jitter of streaming traffic

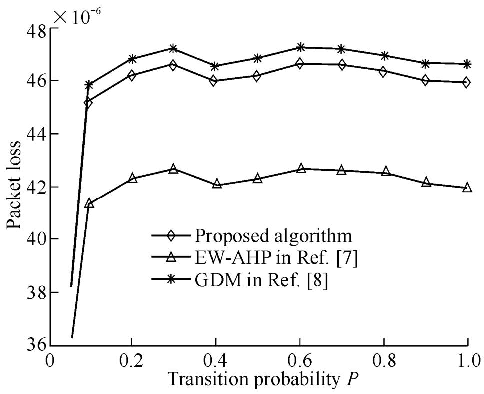

Fig. 8 Packet loss of streaming traffic

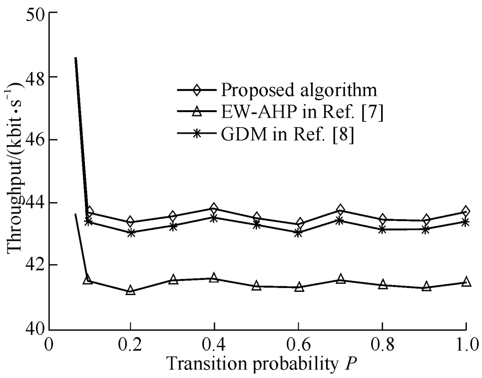

Fig. 9 Throughput of streaming traffic

Figs. 10, 11 and 12 show the performance of interactive business. Interactive business has error rate limitation and requires relatively low time delay and relatively high data downlink rate, which can be seen from the judgment matrix in Table 2 and Table 4, where packet loss stands out. When compared with other two algorithms, the algorithm can provide a best state of packet loss and relatively high throughput with least cost. When P is no more than 0.1, packet loss is lower even more and so is the cost.

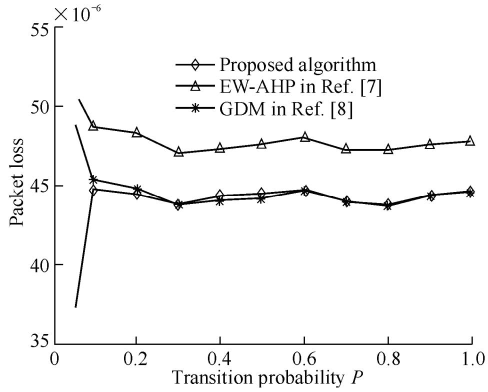

Fig. 10 Packet loss of interactive traffic

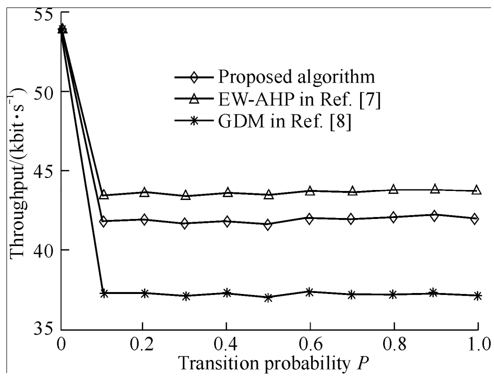

Fig. 11 Throughput of interactive traffic

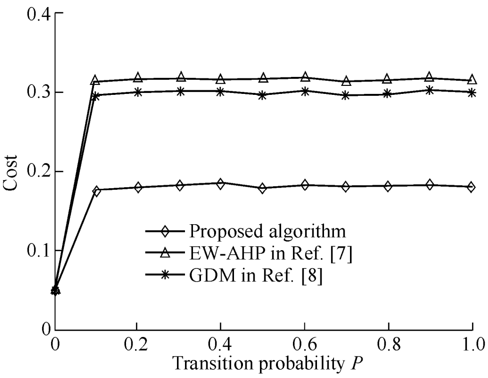

Fig. 12 Cost of interactive traffic

Figs. 13 and 14 demonstrate the performance of background business, which demands low latency and error rat. It can be seen in the judgment matrix in Table 2 and Table 4, where packet loss is emphasized. From the grapes we can see that when compared to other two algorithms, our algorithm can offer the best state of packet loss. Besides, it is obvious that the algorithm mentioned above is superior to the other two in terms of cost and is also important to the traffic class.

According to simulations, combing with the characteristics of a variety of applications, the authors can conclude that the algorithm can provide satisfying QoS requirements for users in certain traffic class.

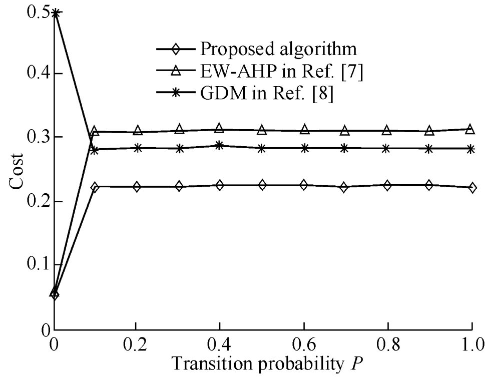

Fig. 13 Cost of background traffic

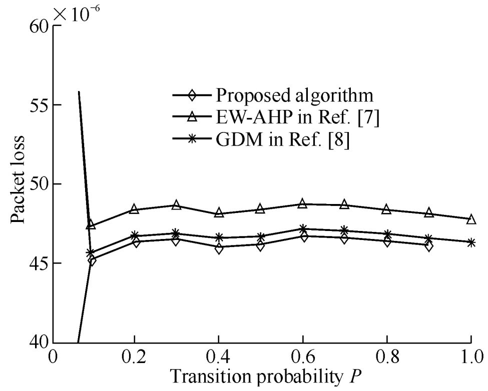

Fig. 14 Packet loss of background traffic

5 Conclusions

In this article, an improved network selection algorithm is presented by using group decision theory to combine several weight vectors of multiple attribute decision making. The heterogeneous network model and the entropy weight methods, as well as the standard deviation method are presented. The method of AHP and G-1 for weight vectors is given, and so the theory of group decision is introduced. The characteristics of collecting decision makers' wisdom can be fully taken advantage in heterogeneous environment. Apart from these, the traffic class, network status and users' preference are also considered when using theory of group decision-making to synthesize four weight vectors, which are calculated through four weighting methods, producing a combinational weight vector. The rationality of the vector is verified as well by judging the compatibility indicators. Simulations show that, in certain traffic class, the algorithm is capable to offer users a good QoS.

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