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Multiattribute Access Selection Algorithm for Heterogeneous Wireless Networks Based on Fuzzy Network Attribute Values

XIAOXUE GUO^{1,2}, MOHD. HASBULLAH OMAR², (Member, IEEE),
KHUZAIRI MOHD ZAINI², GEN LIANG³, MAOYUAN LIN⁴, AND ZIRUN GAN³

¹School of Science, Guangdong University of Petrochemical Technology, Maoming 525000, China

²InterNetWorks Research Laboratory, School of Computing, Universiti Utara Malaysia, Sintok, Kedah 06010, Malaysia

³College of Electronic and Information Engineering, Guangdong University of Petrochemical Technology, Maoming 525000, China

⁴School of Computer Science, Guangdong University of Technology, Guangzhou 510006, China

Corresponding author: Gen Liang (l_gen@126.com)

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ABSTRACT An important feature of the wireless network scenario is that there are multi-radio access technologies in the same area, and the signal coverage of these networks overlaps each other, forming the heterogeneous wireless network area. Network selection algorithm is the key technology of heterogeneous wireless network. The common network selection algorithms are based on accurate network attribute values. However, due to the mobility of users, the interference of wireless signals and the fluctuation of network state, the network attributes obtained by the algorithms are often uncertain. To solve this problem, this paper designs a multi-attribute access selection approach based on the fuzzy network attributes. This approach calculates the network attribute values by interval hesitant fuzzy theory at first. Then, it calculates the subjective weights of network attribute values by the analytic hierarchy process and the objective weights of network attribute values by the entropy method. The integrated weights of subjective weights and objective weights are obtained by the method based on the longest geometric distance to the negative ideal solution. In the end, we calculate the scores of candidate networks by grey relational analysis based on the intuitionistic fuzzy decision matrix. The simulation shows that the algorithm proposed by this paper can select the most suitable network and reduce the number of handoffs under the environment of uncertain network attribute values.

INDEX TERMS Heterogeneous wireless networks, access selection, interval value hesitant fuzzy, integrated weight.

I. INTRODUCTION

At present, the important feature of wireless network scenario is that there are many wireless access technologies in the same area, and the signal ranges of these wireless networks overlap each other to form Heterogeneous Wireless Networks (HWNs) [1]. In the heterogeneous wireless networks, because of the differences between wireless access technologies, user terminals should consider multiple factors (e.g., network performance, service features, user preference, etc.) rather than

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signal strength when selecting networks. Therefore, access selection algorithm is a popular field in the HWNs [2], [3].

There are three main steps in access selection [4], [5]: The first step is information collection which collects the network state information (e.g., signal range, network load, network security levels, etc.), QoS (e.g., bandwidth required by service, minimal delay, etc.), terminal information (e.g., movement speed, battery capacity, etc.) and user context (e.g., user location, user preference, etc.) and send the information to the network selection decision unit and used to select the appropriate access network. The second step is decision making which is the core of network access

selection and serves a role on deciding which candidate network to choose for access and when to switch according to the algorithm. The third step is decision execution which mainly performs access operations according to the results of the second step and the corresponding network protocols.

The access selection algorithm usually adopts Multiple Attribute Decision Making (MADM) [6]–[8]. MADM normalize the collected network attribute values at first and then sort them based on their importance. Finally, the ranking result of each candidate network is obtained according to the network attribute values and weights. Some literatures use utility theory model to design access selection algorithm. The utility theory model transforms network attributes to utility values between 0 to 1 by utility functions (e.g., linear function, log function, exponential function, sigmoid function, etc.) and access to the network with the highest utility value [9], [10]. In addition, some literatures adopt mathematical models such as fuzzy logic [11]–[13], optimization calculation [14]–[16], neural network [17], [18], game theory [19]–[21] to design access selection algorithms.

In the algorithms mentioned above, access algorithms should calculate the score of candidate networks based on the accurate network attribute values. However, in the HWNs, the information collected by the access selection algorithms is often inaccurate due to various reasons such as the interference between the wireless signals of each network, the user terminal entering or quitting the network, the fluctuation of the network load [22]. Therefore, this paper aims to design a heterogeneous network access selection algorithm under the condition of uncertain network attribute values.

In this paper, we design a multi-attribute access selection algorithm for HWNs based on uncertain network attribute values, which includes calculations of network attribute values, network attribute weights, and scores of candidate network. The main contributions of this paper are shown as below:

- The paper designs an access selection calculation method for the uncertain network attribute values, considering the uncertainty of network attribute values in HWN environment. This method solves the problem of wrong network selection caused by user movement, interference of wireless signal and fluctuation of network state.
- Aiming at the problem of determining the weight of network attributes for heterogeneous wireless network access selection, the Analytic Hierarchy Process (AHP), entropy method and the longest geometric distance to the negative ideal solution method are used to calculate the integrated weight of network attributes. The weight coefficient is calculated by the mathematical programming model, and the integrated weight reflects the subjective degree and objective degree at the same time;
- The paper designs a method to calculate candidate network score, integrating grey relational analysis theory and intuitionistic fuzzy set theory.

- The proposed algorithm enables users to select the most suitable network and reduces unnecessary handoffs between different networks.

In the research of heterogeneous wireless network access selection, some algorithms (such as artificial neural networks, genetic algorithm, game theory, Markov decision process, etc.) need many iterations to gradually obtain the optimal network selection results. However, without enough iterations, these algorithms can not accurately select the appropriate network. In addition, this kind of algorithms may fall into local optimization in the calculation process, and the later convergence speed is slow, resulting in higher complexity and more calculation time. Different from other algorithms, the algorithm proposed in this paper is a top-down calculation process according to steps, and the best target network can be selected without iteration. The algorithm proposed in this paper is simple, efficient, low computational complexity and short computational time. It is suitable for the application environment of wireless network.

The rest of this paper is organized as follows. Section 2 reviews the research work related to this article. Section 3 provides a detailed calculation steps of the algorithm. In addition, Section 4 configures simulation environment parameters and discusses the experimental results. Furthermore, Section 5 summarizes the article and introduces further research.

II. RELATED WORK

Network access selection algorithm concerns the quality of service and user experience. To date, many researchers conduct deep studies on network access selection algorithms and propose a great number of access selection algorithms [23], [24].

In [25], Habbal *et al.* propose a context-aware multi-attribute access selection approach which consists of two mechanisms. The first one is the context-aware analytic hierarchy mechanism. Then, a context-aware technique for order preference by similarity to an ideal solution mechanism is employed to choose the best RAT amongst the available RATs.

In [26], Goyal *et al.* propose a HWNs access selection method based on FAHP. This approach adopts the triangular fuzzy numbers to represent the elements of voice application, video application and best effort application, and implement a nonlinear fuzzy optimization model to extract weights from comparison matrix. In addition, this approach models four different QoS attributes (i.e., bandwidth, delay, jitter and bit error rate) by utility function. Finally, the scores of each network are calculated by MADM.

In [27], Verma *et al.* propose a multi-attributes access selection algorithm. This approach determines the weights of network attributes with Analytic Hierarchy Process (AHP) according to the network performance. Then, it sorts the candidate networks by grey relational analysis (GRA). This simple and intuitive approach satisfies different types of user service level agreements.

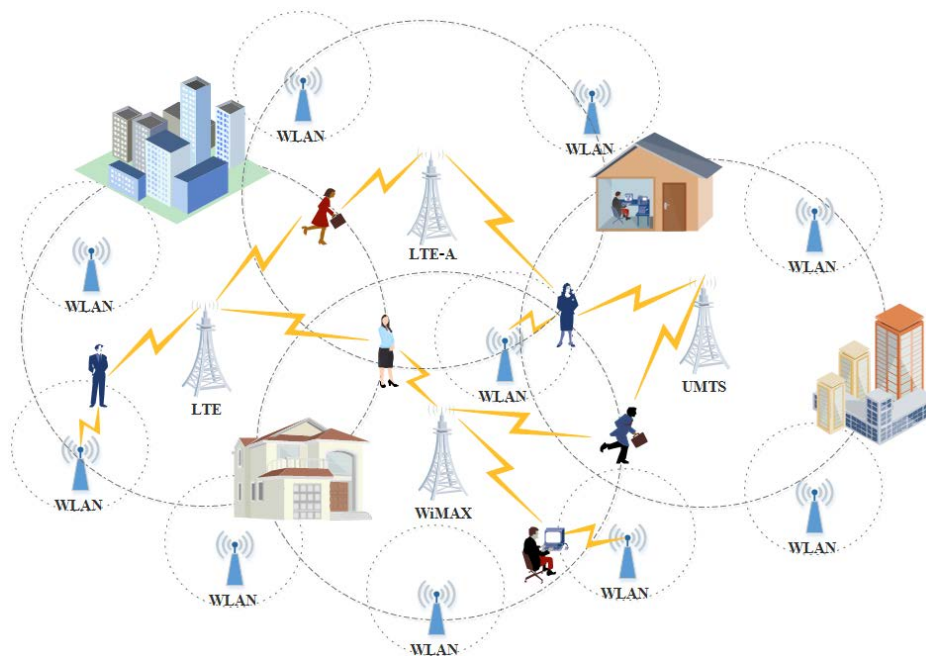


FIGURE 1. Scenario for heterogeneous wireless network access selection.

In [28], Liang *et al.* design a user-oriented access selection algorithm for HWNs, adopting utility function to calculate utility of network attribute values and fuzzy analysis hierarchy process (FAHP) to calculate the weights of network attribute values. In the end, it uses the fuzzy neural network to calculate the scores of candidate network. This algorithm can modify the parameters of membership function in the fuzzy neural network, so that the actual output scores of candidate networks are closer to the expected output scores.

In [29], Yu *et al.* propose a network access selection algorithm that integrates three factors (i.e., users, services, and networks). The approach uses FAHP and entropy method to calculate the weight, and then adopts different utility functions to normalize the network attribute values according to the requirements of applications. Finally, it integrates multiple services by group decision making and calculate the scores of candidate networks by TOPSIS method.

In [30], Guo *et al.* put forward a multi-attribute network selection algorithm that support service characteristic and user preference. The algorithm calculates utility values of network attributes for different services with utility function and computes weights and user preference with FAHP. In addition, based on the utility values and weights of network attributes, the algorithm calculates the scores of network attribute values. Finally, the scores of the candidate networks are calculated by MADM.

In [31], Zhu *et al.* model the network selection problem of edge users requesting different services as a bipartite graph, and propose a network selection algorithm based on weighted bipartite graph. The proposed algorithm combines AHP and GRA to analyze the preferences of multiple services for

different network attributes. Moreover, the proposed algorithm considers the importance of the requested services and the obtained QoE by edge users to construct system fairness index.

Compared with the above-mentioned literatures, the algorithm proposed by this paper integrates the interval hesitant fuzzy theory, the analytic hierarchy process, the entropy method, and grey relational analysis, etc., to get the integrated weights and the ranking of candidate networks.

III. SYSTEM MODEL

The scenario studied by this paper is HWNs which includes four networks (i.e., UMTS, LTE, WLAN and WiMAX). The users select the best network in the signal range of the four networks, and switches to the most appropriate network as the user moves. In this paper, the attribute values collected by the algorithms are bandwidth, delay, jitter, loss, and error. In addition, we assume that the services for user terminals are voice application, video application and data application. These services require different attribute values, so we assign suitable weights to five kinds of attribute values. Finally, we sort the scores of candidate networks according to the network attribute values and weights and choose the network with the highest score as the access network. The research scenario of this paper is presented as Figure 1.

A. CALCULATION OF NETWORK ATTRIBUTE VALUES BASED ON INTERVAL HESITANT FUZZY NUMBERS

When users are in HWN environment, they may receive a range of network attribute values rather than an accurate value. Therefore, based on the Hesitant Fuzzy Sets (HFSs), according to the literature [31], [32], this paper applies the

Interval Value Hesitant Fuzzy Sets (IVHFSs) to the study of HWNs. The specific steps are showed as below:

Step 1. Definition of network attribute values based on Interval Value Hesitant Fuzzy Element (IVHFE)

In this paper, we use the concept of IVHFE, take the network attribute values as the membership degrees, and get the optimal network by calculating the order relation of interval hesitation fuzzy set. Therefore, we first define the concept of interval hesitation fuzzy set:

Definition: Let X be a given non-empty set, and $D[0, 1]$ is a set consists of all closed subintervals on the interval $[0, 1]$. The interval hesitation fuzzy set \tilde{H} defined on set X is a mapping function from X to $D[0, 1]$. The hesitant fuzzy set on X can be expressed in mathematical form as follows:

$$\tilde{H} = \left\{ \left\langle x, \tilde{h}_{\tilde{H}}(x) \right\rangle \mid x \in X \right\} \quad (1)$$

Here, $\tilde{h}_{\tilde{H}}(x)$ is a set of different values in the interval $D[0, 1]$, which means that element x belongs to the interval hesitant fuzzy set \tilde{H} that consists of membership degrees. Element x , called as the interval hesitant fuzzy number, is a basic element to form the set \tilde{H} . It could be written as $\tilde{h} = \tilde{h}_{\tilde{H}}(x)$, i.e., $\tilde{h} = \tilde{H} \left\{ \gamma^1, \gamma^2, \dots, \gamma^{\#\tilde{h}} \right\} (\lambda = 1, 2, \dots, \#\tilde{h})$, where $\#\tilde{h}$ is the number of elements of interval hesitant fuzzy set \tilde{h} . If $\#\tilde{h} = 1$, that is, the hesitant fuzzy number h contains only a single value, we call it as interval fuzzy set. The hesitant fuzzy set is a special form of interval hesitant fuzzy set which is called as the single-valued hesitant fuzzy set. In this paper, for the convenience of discussion, we specify that the number of elements in the interval hesitant fuzzy number is 3.

In this paper, we construct a non-empty set $T = \{\text{bandwidth, delay, jitter, loss, error}\}$ which is a collection of attributes for a network under the current network environment. For example, we assume the membership degree of $T = \{\text{bandwidth, delay, jitter, loss, error}\}$ to interval hesitant fuzzy set \tilde{H} is:

$$\begin{cases} \tilde{h}_{\tilde{H}}(\text{bandwidth}) = \tilde{H} \{[0.2, 0.3], [0.2, 0.4], [0.1, 0.3]\} \\ \tilde{h}_{\tilde{H}}(\text{delay}) = \tilde{H} \{[0.1, 0.2], [0.4, 0.5], [0.5, 0.6]\} \\ \tilde{h}_{\tilde{H}}(\text{jitter}) = \tilde{H} \{[0.2, 0.3], [0.3, 0.4], [0.4, 0.5]\} \\ \tilde{h}_{\tilde{H}}(\text{loss}) = \tilde{H} \{[0.4, 0.5], [0.6, 0.7], [0.7, 0.8]\} \\ \tilde{h}_{\tilde{H}}(\text{error}) = \tilde{H} \{[0.4, 0.5], [0.7, 0.8], [0.5, 0.6]\} \end{cases} \quad (2)$$

In the formula (2), \tilde{H} is the interval hesitant fuzzy set of network attribute values, i.e.,

$$\begin{aligned} \tilde{H} = & \left\{ \left\langle \text{bandwidth}, \tilde{h}_{\tilde{H}}(\text{bandwidth}) \right\rangle, \left\langle \text{delay}, \tilde{h}_{\tilde{H}}(\text{delay}) \right\rangle \right. \\ & \left. \times \left\langle \text{jitter}, \tilde{h}_{\tilde{H}}(\text{jitter}) \right\rangle, \left\langle \text{loss}, \tilde{h}_{\tilde{H}}(\text{loss}) \right\rangle, \left\langle \text{error}, \tilde{h}_{\tilde{H}}(\text{error}) \right\rangle \right\} \end{aligned} \quad (3)$$

According to the definition of interval hesitant fuzzy set in this paper, $\tilde{h}_{\tilde{H}}(\text{bandwidth}) = \tilde{H} \{[0.2, 0.3], [0.2, 0.4], [0.1, 0.3]\}$ in formula (2) means that the membership degree of bandwidth to interval hesitant fuzzy set \tilde{H} is one of the $[0.2, 0.3]$, $[0.2, 0.4]$ and $[0.1, 0.3]$. During the decision-making process of network access selection in this paper,

users are hesitant in three specific values of the attribute bandwidth of a candidate network and think that these values are possible. Apparently, it is reasonable to utilize interval hesitant fuzzy set as a mathematical model to study access selection algorithm in HWNs scenario.

Step 2. Comparison and distance measurement of interval hesitation fuzzy numbers

During the decision-making process of access selection algorithm, the attribute values acquired by users might be unordered and the number of attribute values might be not uniform (e.g., $\tilde{h}_{\tilde{H}}(\text{bandwidth}) = \{[0.2, 0.3], [0.2, 0.4], [0.1, 0.3]\}$). Therefore, in this paper, for the comparison of the number of two interval numbers, we make the following provisions:

$$[a, b] > [c, d] \text{ if and only if } \frac{a+b}{2} > \frac{c+d}{2} \quad (4)$$

In the above formula, a and c are the lower limit of the interval, and b and d are the upper limit of the interval.

In addition, to facilitate the research, all elements of the interval hesitation fuzzy numbers are arranged in ascending order (e.g., adjust $\tilde{h}_{\tilde{H}}(\text{bandwidth}) = \{[0.2, 0.3], [0.2, 0.4], [0.1, 0.3]\}$ to $\tilde{h}_{\tilde{H}}(\text{bandwidth}) = \{[0.1, 0.3], [0.2, 0.3], [0.2, 0.4]\}$, which ensures the membership degree of interval hesitant fuzzy numbers is ordered. Moreover, we also set the number of elements of interval hesitant fuzzy numbers is 3 (i.e., $\#\tilde{h} = 3$). The interval hesitant fuzzy numbers obtained by us are uniform, which is particularly important in the subsequent calculation.

Assume that there are two interval hesitant fuzzy numbers, $\tilde{h}_1 = \tilde{H} \left\{ \gamma_1^\lambda \mid \lambda = 1, 2, \dots, \#\tilde{h}_1 \right\}$ and $\tilde{h}_2 = \tilde{H} \left\{ \gamma_2^\lambda \mid \lambda = 1, 2, \dots, \#\tilde{h}_2 \right\}$. Then, for the comparison of these two hesitant fuzzy numbers, we make the following provisions:

$$\tilde{h}_1 \geq \tilde{h}_2 \quad \text{if and only if } S(\tilde{h}_1) \geq S(\tilde{h}_2) \quad (5)$$

Here, $S(\tilde{h})$ is the score function of interval hesitant fuzzy numbers, and the definition is:

$$S(\tilde{h}) = \sum_{i=1}^l \frac{1}{2l} \left(\tilde{h}_{(i)}^L(x) + \tilde{h}_{(i)}^U(x) \right) \quad (6)$$

In formula 6, where l is the number of elements of $\tilde{h}_{\tilde{H}}(x)$, i.e., $\#\tilde{h}$. In this paper, $\#\tilde{h} = 3$. $\tilde{h}_{(i)}^L$ and $\tilde{h}_{(i)}^U$ are the lower limit and upper limit of the i -th interval number, respectively.

In addition, we calculate the distance between two interval hesitant fuzzy numbers, and the specific method is shown as follows:

$$d(\tilde{h}_1, \tilde{h}_2) = \sum_{i=1}^l \frac{1}{2l} \left(\left| \tilde{h}_{1(i)}^L - \tilde{h}_{2(i)}^L \right| + \left| \tilde{h}_{1(i)}^U - \tilde{h}_{2(i)}^U \right| \right) \quad (7)$$

In formula (7), l is the maximum number of elements in the two interval hesitant fuzzy numbers, namely: $l = \max(\#\tilde{h}_1, \#\tilde{h}_2) = \max(3, 3) = 3$.

Step 3. Construction of an interval hesitant fuzzy multi-attribute matrix

Let $X = \{x_1, x_2, \dots, x_m\}$ be the set of candidate networks. Let the set of network attribute values be $A = \{a_1, a_2, \dots, a_n\}$ and the network attribute $a_j(x_i)$ of candidate networks x_i ($i = 1, 2, \dots, m$) be interval hesitant fuzzy numbers, so the decision information matrix $\mathcal{R} = (a_j(x_i))_{m \times n}$ can be expressed as:

$$\mathcal{R} = \begin{bmatrix} a_1(x_1) & a_2(x_1) & \cdots & a_j(x_1) & \cdots & a_n(x_1) \\ a_1(x_2) & a_2(x_2) & \cdots & a_j(x_2) & \cdots & a_n(x_2) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_1(x_i) & a_2(x_i) & \cdots & a_j(x_i) & \cdots & a_n(x_i) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_1(x_m) & a_2(x_m) & \cdots & a_j(x_m) & \cdots & a_n(x_m) \end{bmatrix} \quad (8)$$

In the above formula,

$$a_j(x_i) = \tilde{h}_{ij} = \tilde{H} \left\{ \gamma_{ij}^1, \gamma_{ij}^2, \gamma_{ij}^3 \right\}, \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (9)$$

In the research scenario of HWNs in this paper, there are four candidate networks (i.e., UMTS, LTE, WLAN, and WiMAX), Each network includes 5 attribute values (i.e., bandwidth, delay, jitter, packet loss ratio, and BER), and each attribute value provides five sets of values when making decisions. Therefore, we set $m = 4, n = 5, \#h = 5$ in this paper.

Among the above five network attributes, except bandwidth, a benefit attribute, the other four attribute values are cost attributes. Benefit attribute means that the larger the index value is, the better it is, while cost attribute means that the smaller the value is, the better it is. For the convenience of comprehensive comparison of each network, we convert the cost attributes to the benefit attributes. In addition, the ranges of each attribute value are different (e.g., In UMTS network, bandwidth is generally 700kB/s to 3000kB/s, and the delay is 20 ms to 200 ms; In LTE networks, bandwidth is typically 1000kB/s to 5000kB/s and delay is 10 ms to 50 ms). To ensure the comparability between each network attributes, we normalize the network attributes. The formula of normalization is shown as below, with formula (10) for benefit attributes and formula (11) for cost attributes.

$$x'_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \quad (10)$$

$$x'_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}} \quad (11)$$

In formula (10) and formula (11), x_{ij} represents the value of network attribute j of the candidate network i , x_{\min} and x_{\max} respectively represent the minimum and maximum value of the network attribute value, x'_{ij} represents the network attribute value after normalization.

B. CALCULATION OF INTEGRATED SUBJECTIVE AND OBJECTIVE WEIGHTS OF NETWORK ATTRIBUTES

Usually, the calculation of weight of attribute values either uses subjective weight calculation method (e.g., Delphi Method, Analytic Hierarchy Process, Preference Proportion

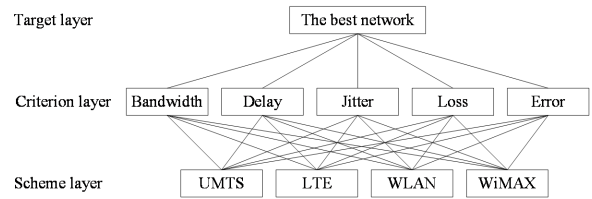


FIGURE 2. A subjective weight calculation hierarchy based on AHP.

Method) or objective weight calculation Method (e.g., Principal Component Analysis Method, Scatter Degree Method). Although subjective weight method reflects the intention of the decision maker, the decision is highly subjective. Although the objective weight method is based on a strong mathematical foundation, it does not consider the preference of the decision maker. Therefore, there are limitations in both of methods. In this paper, the subjective weights are calculated with AHP, and the objective weights are calculated with the entropy method. The final weights are obtained by the method of integrated weight based on the longest distance to the negative ideal solution.

1) CALCULATION OF SUBJECTIVE WEIGHTS OF NETWORK ATTRIBUTES

Analytic Hierarchy Process is a systemic analysis method combined with quantitative and qualitative methods, with the advantages of flexibility and simplicity [33]. During the calculation process, we compare the criterion pairwise, construct judgement matrix, determine the consistency of matrix, and obtain the weights of network attributes. The main steps are shown as below:

Step 1. Construct a hierarchy of subjective weight calculation based on AHP. Analyze the relationship between each factor of access selection in HWNs and divide the analysis object into the target layer, criteria layer, and scheme layer. The target layer is the best access network, and the criterion layer consists of network attribute values (i.e., bandwidth, delay, jitter, loss, error), and the scheme layer includes candidate networks (i.e., UMTS, LTE, WLAN, WiMAX) (Fig. 2).

Step 2. Construct a judgement matrix. According to different applications (i.e., voice application, video application and data application), compare the importance of each attribute values pairwise. Through comparing with element x_i and x_j , we get the importance level r_{ij} . The meaning of r_{ij} is shown in Table 1. Then we construct the judgement matrix of r_{ij} , $R = (r_{ij})_{m \times n}$.

Step 3. Conduct a consistency inspection of judging matrix. We use CI to represent the consistency index, and CI is defined as

$$CI = \frac{\lambda - n}{n - 1} \quad (12)$$

In the above formula, the smaller CI is, the stronger the consistency is. When $CI = 0$, the matrix has complete consistency. On the contrary, the larger the CI is, the worse the consistency is.

TABLE 1. Interpretation for importance level.

Level	Interpretation
1	Both are equally important
3	The former is slightly more important than the latter
5	The former is obviously more important than the latter
7	The former is strongly more important than the latter
9	The former is extremely more important than the latter

If x_i is compared with x_j and r_{ij} is obtained
 x_j and x_i can be compared to the results in $r_{ji} = \frac{1}{r_{ij}}$

TABLE 2. Part of value of RI.

Degree	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41

TABLE 3. Consistent matrix and weights for voice application.

Voice	Bandwidth	Delay	Jitter	Loss	Error	Weight
Bandwidth	1	1/3	1/5	1/7	1/9	0.0355
Delay	3	1	1/3	1/5	1/7	0.0699
Jitter	5	3	1	1/3	1/5	0.1378
Loss	7	5	3	1	1/3	0.2651
Error	9	7	5	3	1	0.4917

To calculate CI , we introduce the random consistency index, RI . RI is related to the degree of the comparison matrix. The larger the degree is, the easier it is to deviate from the consistency. The reference value of RI is shown (Table 2). Tables 2: part of value of RI We use the test coefficient CR to judge whether the comparison matrix passes the consistency inspection. The definition of CR is presented as below:

$$CR = \frac{CI}{RI} \tag{13}$$

In this paper, if $CR < 0.1$, the comparison matrix passes the consistency inspection. Otherwise, the comparison matrix does not pass the consistency inspection and should be reconstructed.

Step 4. Calculate weights of network attributes. In this step, we calculate the greatest eigenvalue λ and normalize eigenvector corresponded to λ to get the weights of each attribute value, ω'_j . The judgement matrix and weights of network attributes in different service is shown (Table 3-5).

2) CALCULATION OF OBJECTIVE WEIGHTS OF NETWORK ATTRIBUTES

In this paper we use entropy method to calculate the objective weights. The weights of attributes are determined according to the influence of relative change degree of attributes on the whole system. The attributes with large degrees of change are assigned larger weights. The specific steps are shown as below:

Step 1. Calculate the scores of network attribute values. Each interval hesitant fuzzy element in the interval hesitant fuzzy multi-attribute matrix, $\tilde{H} = (\tilde{h}_{ij})$, is calculated according to formula (6) to obtain the network attribute scores. Then construct a decision matrix $S = (s_{ij})$ as shown in

TABLE 4. Consistent matrix and weights for video application.

Video	Bandwidth	Delay	Jitter	Loss	Error	Weight
Bandwidth	1	1/9	1/5	1/7	1/3	0.0375
Delay	9	1	4	2	6	0.4765
Jitter	5	1/4	1	1/2	2	0.1514
Loss	7	1/2	2	1	4	0.2758
Error	3	1/6	1/2	1/4	1	0.0588

formula (14), where $1 \leq i \leq m, 1 \leq j \leq n$, according to the scores of attribute values of candidate networks.

$$S = \begin{bmatrix} S(h_{11}) & S(h_{12}) & \cdots & S(h_{1n}) & \cdots & S(h_{1n}) \\ S(h_{21}) & S(h_{22}) & \cdots & S(h_{2j}) & \cdots & S(h_{2n}) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ S(h_{i1}) & S(h_{i1}) & \cdots & S(h_{ij}) & \cdots & S(h_{in}) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ S(h_{m1}) & S(h_{m2}) & \cdots & S(h_{m1}) & \cdots & S(h_{mn}) \end{bmatrix} \tag{14}$$

Step 2. Normalize the matrix obtained in the step 1 (The cost attribute has been converted to benefit attribute in section 3.1, so we only normalize the matrix in this step) and get the normalized matrix $S' = (s'_{ij})_{m \times n}$. See the details in formula (15).

$$s'_{ij} = \frac{s_j - s_{\min}}{s_{\max} - s_{\min}} \tag{15}$$

Step 3. Put the elements of the matrix into the formula (16) and calculate the proportion of network attributes to get the proportion matrix $P = (p_{ij})_{m \times n}$.

$$p_{ij} = \frac{s'_{ij}}{\sum_{i=1}^m s'_{ij}} \tag{16}$$

Step 4. Put the matrix P into formula (17) to calculate the entropy.

$$e_j = -k \sum_{i=1}^m p_{ij} \ln(p_{ij}) \tag{17}$$

In the above formula, $k = \frac{1}{\ln(m)}$.

Step 5. Calculate the final objective weights based on the formula (18).

$$\omega''_j = \frac{1 - e_j}{\sum_{j=1}^n (1 - e_j)} \tag{18}$$

3) CALCULATION OF INTEGRATED WEIGHTS OF NETWORK ATTRIBUTES

In heterogeneous wireless network access selection algorithms, the integration of subjective weight and objective weight usually adopts a fixed proportion. In this section, we integrate the subjective weights and objective weights of network attributes based on the longest distance to the negative ideal solution. The approach to determine the final weights is shown as below:

$$\omega_j = \alpha \omega'_j + \beta \omega''_j \tag{19}$$

where α and β is the degree of trust of the subjective weights and the objective weights. To satisfy the negative distance

TABLE 5. Consistent matrix and weights for data application.

Data	Bandwidth	Delay	Jitter	Loss	Error	Weight
Bandwidth	1	7	9	3	5	0.5288
Delay	1/7	1	2	1/4	1/2	0.0715
Jitter	1/9	1/2	1	1/6	1/3	0.0432
Loss	1/3	4	6	1	2	0.2356
Error	1/5	2	3	1/2	1	0.1215

ideal scheme, we establish the following model to obtain α and β :

$$\begin{cases} \max F &= \sum_{i=1}^m \sum_{j=1}^n (s'_{ij} - s''_{ij}) \omega_j \\ &= \sum_{i=1}^m \sum_{j=1}^n (s'_{ij} - s''_{ij}) (\alpha \omega'_j + \beta \omega''_j) \\ \text{s.t.} &\alpha^2 + \beta^2 = 1 \\ &\alpha, \beta \geq 0 \end{cases} \quad (20)$$

where $s''_{ij} = \min \{s'_{ij} \mid i = 1, 2, \dots, m\}$ ($j = 1, 2, \dots, n$), is the negative solution of attribute j . By simplifying the above equation, we get:

$$\begin{cases} \alpha = \frac{\sum_{i=1}^m \sum_{j=1}^n s_{ij} \omega'_j}{\sqrt{(\sum_{i=1}^m \sum_{j=1}^n s_{ij} \omega'_j)^2 + (\sum_{i=1}^m \sum_{j=1}^n s_{ij} \omega''_j)^2}} \\ \beta = \frac{\sum_{i=1}^m \sum_{j=1}^n s_{ij} \omega''_j}{\sqrt{(\sum_{i=1}^m \sum_{j=1}^n s_{ij} \omega'_j)^2 + (\sum_{i=1}^m \sum_{j=1}^n s_{ij} \omega''_j)^2}} \end{cases} \quad (21)$$

To make integrated weights ω_j satisfy $0 \leq \omega_j \leq 1$, and $\sum_{j=1}^n \omega_j = 1$, we need to normalize α and β :

$$\begin{cases} \alpha^* = \frac{\sum_{i=1}^m \sum_{j=1}^n s_{ij} \omega'_j}{(\sum_{i=1}^m \sum_{j=1}^n s_{ij} (\omega'_j + \omega''_j))} \\ \beta^* = \frac{\sum_{i=1}^m \sum_{j=1}^n s_{ij} \omega''_j}{(\sum_{i=1}^m \sum_{j=1}^n s_{ij} (\omega'_j + \omega''_j))} \end{cases} \quad (22)$$

The final integrated weights of network attributes can be written as:

$$\omega_j = \alpha^* \omega'_j + \beta^* \omega''_j \quad (23)$$

C. CALCULATION OF SCORES OF CANDIDATE NETWORKS

In this section, based on the Intuitionistic Fuzzy Sets (IFSs), we use grey relational analysis (GRA) to get scores of candidate networks. The specific steps are shown as below:

Step 1. Construct a decision matrix $S = (s_{ij})_{m \times n}$, where s_{ij} is the score of attribute j of network i which can be obtained by formula (6).

Step 2. Normalize the decision matrix, and convert the accurate values to intuitionistic fuzzy numbers and construct an intuitionistic fuzzy decision matrix $C = (c_{ij})_{m \times n}$

$$c_{ij} = (\mu_{ij}, v_{ij}) = (s_{ij}, 1 - s_{ij}) \quad (24)$$

Step 3. Determine the positive and negative ideal solution of intuitionistic fuzzy decision matrix. In this paper, the positive ideal solution is $A^+ = (c_1^+, c_2^+, c_3^+, \dots, c_5^+)$, and the negative ideal solution is $A^- = (c_1^-, c_2^-, c_3^-, \dots, c_5^-)$,

where:

$$\begin{cases} c_j^+ = (\mu_j^+, v_j^+) = \left(\max_j \mu_{ij}, \min_j v_{ij} \right) \\ c_j^- = (\mu_j^-, v_j^-) = \left(\min_j \mu_{ij}, \max_j v_{ij} \right) \\ i = 1, 2, \dots, m; j = 1, 2, \dots, n \end{cases} \quad (25)$$

Step 4. Calculate the grey relational coefficient of candidate networks to positive ideal solution and negative ideal solution, ξ_{ij}^+ and ξ_{ij}^- :

$$\begin{cases} \xi_{ij}^+ = \frac{\min_i \min_j |c_{ij} - c_j^+| + \rho \max_i \max_j |c_{ij} - c_j^+|}{|c_{ij} - c_j^+| + \rho \max_i \max_j |c_{ij} - c_j^+|} \\ \xi_{ij}^- = \frac{\min_i \min_j |c_{ij} - c_j^-| + \rho \max_i \max_j |c_{ij} - c_j^-|}{|c_{ij} - c_j^-| + \rho \max_i \max_j |c_{ij} - c_j^-|} \end{cases} \quad (26)$$

where, $|c_{ij} - c_j^+| = |\mu_{ij} - \mu_j^+| + |v_{ij} - v_j^+| + |\pi_{ij} - \pi_j^+|$, $|c_{ij} - c_j^-| = |\mu_{ij} - \mu_j^-| + |v_{ij} - v_j^-| + |\pi_{ij} - \pi_j^-|$, and ρ ($\rho \in [0, 1]$) is the identification coefficient

Step 5. Calculate the correlation degree ξ_i^+ of the candidate network to the positive ideal solution, and the correlation degree ξ_i^- of the candidate network to the negative ideal solution, the formula is as follows:

$$\begin{cases} \xi_i^+ = \sum_{j=1}^5 \xi_{ij}^+ \omega_j, \quad i = 1, 2, \dots, m \\ \xi_i^- = \sum_{j=1}^5 \xi_{ij}^- \omega_j, \quad i = 1, 2, \dots, m \end{cases} \quad (27)$$

where ω_j is the integrated weights of attribute values in section 3.2

Step 6. Calculate the relative degree of correlation and sort candidate networks according to degree of correlation. The larger the degree of correlation is, the higher score of the network and the rank is. The formula is shown as below:

$$\xi_i = \frac{\xi_i^+}{\xi_i^+ + \xi_i^-}, \quad i = 1, 2, \dots, m \quad (28)$$

IV. SIMULATION AND RESUT ANALYSIS

A. EXPERIMENTAL ENVIRONMENT AND SIMULATION PARAMETER SETTINGS

This paper uses Matlab R2019b as the simulation platform to test and compare the algorithms mentioned herein. In the simulation, to simulate user movement or network state fluctuations, the range of network attribute values of candidate networks is shown (Table 6), with the values in brackets indicating the lowest and the highest value of the network attribute while changing dynamically. The network attribute values are normalized by formula (10) and formula (11).

Simulation includes two parts. The first part is the performance test of algorithm proposed by this paper, mainly evaluating the average performance of our algorithm under various services and the selections of candidate networks. The second part is the comparison between the algorithms proposed by this paper and the other three algorithms, mainly comparing the number of selections of candidate networks,

TABLE 6. The settings of network attribute values of candidate networks.

	Bandwidth (KB/s)	Delay (ms)	Jitter (ms)	Loss (E-6%)	Error (E-4%)
UMTS	700-3000	20-200	10-30	8-13	10-23
LTE	1000-5100	10-80	20-50	8-15	30-50
WLAN	1200-7500	80-300	30-100	10-28	30-45
WiMAX	1000-6200	20-100	5-20	10-30	10-25

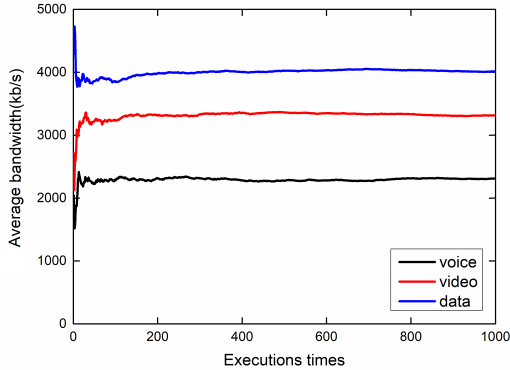


FIGURE 3. Average bandwidth value of the selected network.

the number of handoffs between networks, and the number of unnecessary handoffs under different applications.

B. PERFORMANCE TEST OF PROPOSED ALGORITHM

The average network attribute values of the network selected by voice application, video application and data application are shown in the case of 1000 dynamic changes of network attribute values (Fig. 3-7). Among the networks selected by three applications, the average bandwidth selected by the voice application is the lowest because the voice application requires low bandwidth; On the contrary, the data application requires high bandwidth, so the average bandwidth of selected network of data application is the highest (Fig. 3). Among the three services, since the weight of the delay attribute is the largest in the video service, the average delay of the selected network in the video service is the lowest (Fig. 4). The network selected for the data application has the highest average jitter, followed by the video application and voice application (Fig. 5). The average packet loss of network selected for voice application and video application are slightly lower than data application (Fig. 6). Because voice application has a high demand for bit error rate, the selected network of voice application has the lowest average bit error rate (Fig. 7). The algorithm can select the most suitable network for users according to the characteristics and the weights of different network attributes for different applications (Fig. 3-7).

The number of selections of each candidate network is shown under different applications (Fig. 8). Because the voice application does not need high bandwidth but requires a guarantee of low bit error rate and packet loss rate, so the most frequently selected network for voice application is UMTS.

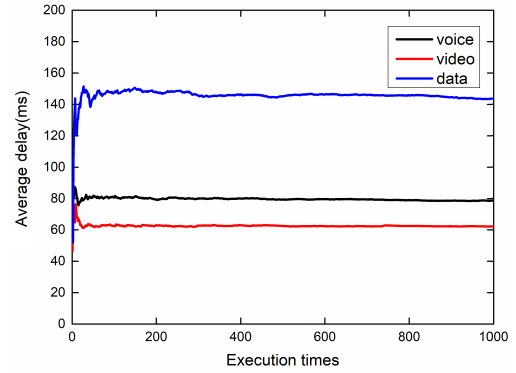


FIGURE 4. Average delay value of the selected network.

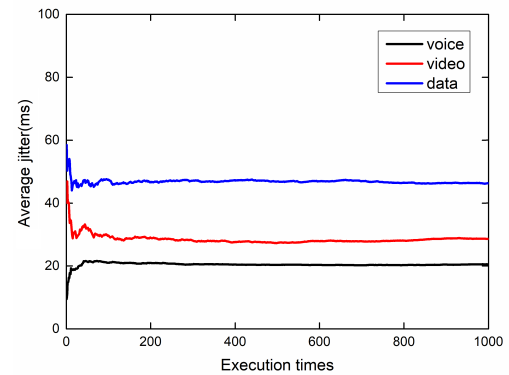


FIGURE 5. Average jitter value of the selected network.

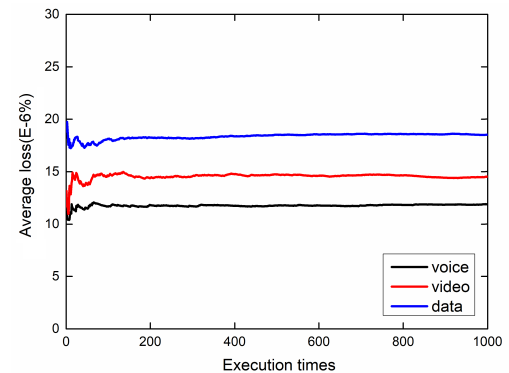


FIGURE 6. Average packet loss ratio value of the selected network.

The selections of LTE and WiMAX are fewer. Video requires a guarantee of low delay and jitter, so it select the LTE most frequently and WiMAX for a certain number of times. As for data application which requires high bandwidth, the most selected network is WLAN, while the least selected network is UMTS. The algorithm in this paper can select the most suitable network according to the characteristics of applications under the environment of dynamically changing network attributes (Fig. 8).

C. ALGORITHM COMPARISON

In this section, we compare the algorithm proposed by this paper with algorithms in Literature [25], Literature [26],

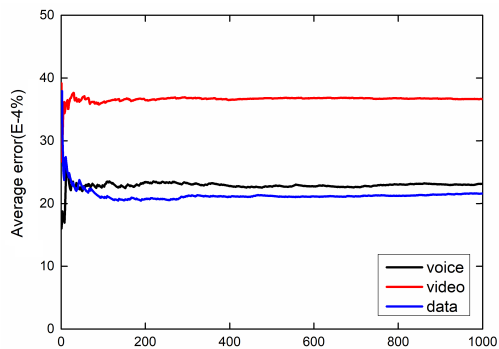


FIGURE 7. Average bit error ratio value of the selected network.

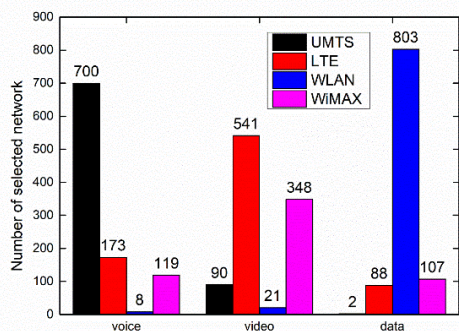


FIGURE 8. Number of selections of candidate networks under the applications of voice, video, and data.

Literature [27] which are called as Algorithm 1, Algorithm 2, and Algorithm 3 respectively as below. We mainly compare and analyze the number of selections of the network, the number of handoffs, and the number of unnecessary handoffs. In addition, for fairness, the weights of network attribute values of all algorithms are set to same in the experiments. For the voice application, the network selected by four algorithms most frequently is UMTS, with the number of selections over 700 and the second one is LTE. These four algorithms rarely choose WLAN and WiMAX (Fig. 9). For the video application, the network with the maximal selection of all algorithms is LTE. Among all networks, the algorithm proposed by this paper, algorithm 1 and algorithm 2 select LTE more than 500 times, while algorithm 3 only selects LTE 438 times. In addition, all algorithms select WiMAX more than 300 times (Fig. 10). For the data application, the network with the most selection of all algorithms is WLAN. Among all networks, the algorithm proposed by this paper, algorithm 1 and algorithm 2 select WLAN more than 800 times, while algorithm 3 selects WLAN for 755 times and WiMAX 166 times (Fig. 11).

The comparison of handoffs of each algorithm under different applications is shown (Fig. 12). Under voice application, the algorithm 1 switches most frequently, with the number of handoffs over 300 times, followed by algorithm 2, algorithm 3 and the algorithm proposed by this paper. As the algorithm in

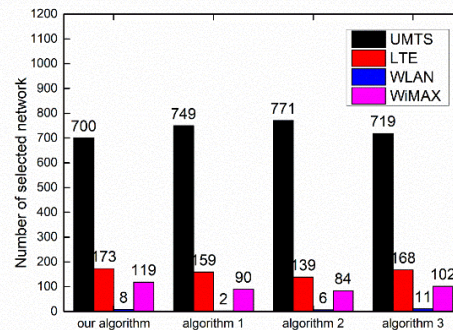


FIGURE 9. Comparison of number of selections of candidate networks under the voice application.

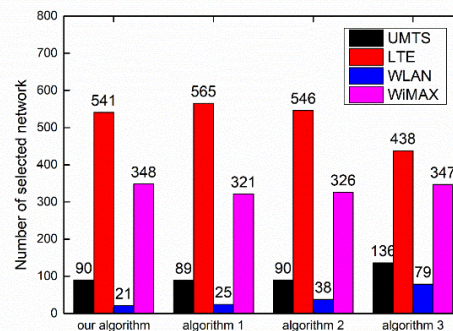


FIGURE 10. Comparison of number of selections of candidate networks under the video application.

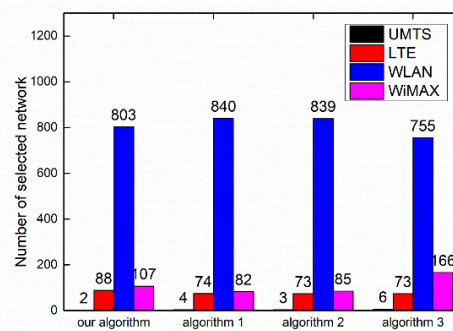


FIGURE 11. Comparison of number of selections of candidate networks under the data application.

this paper mainly selects UMTS and LTE network, the hand-off mainly occurs between UMTS and LTE, so the times of handoff are only 257. The number of handoffs of algorithm 1 is more than 300. The number of handoffs of algorithm 2 and algorithm 3 are close and less than 300. Under the video application, the number of handoffs of all algorithms is over 400. Since the algorithm proposed by paper mainly selects

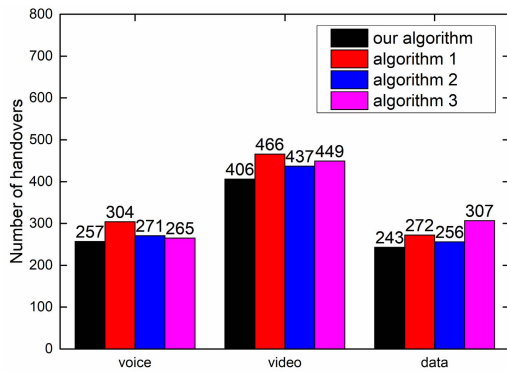


FIGURE 12. Comparison of number of handoffs between networks caused by algorithms under different applications.

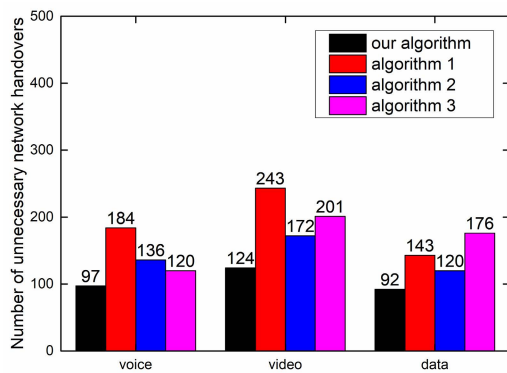


FIGURE 13. Comparison of number of unnecessary handoffs caused by algorithms under different applications.

LTE and WiMAX, and selects WLAN with fewer times, the number of handoffs of it is the least. Algorithm 1 has a higher number of handoffs in video application than other algorithms. Under the data application, the numbers of handoffs of algorithm in this paper, algorithm 1 and algorithm 2 are close, while algorithm 3 has more than 300 handoff times. Handoff of algorithm 3 mainly occurs between WLAN and WiMAX. In general, under different applications, the handoffs of the algorithm proposed by this paper is less than the other three algorithms.

According to the definition of “Unnecessary Handoff” given in Literature [23], we count the number of unnecessary handoffs caused by each algorithm under different applications. Under the voice application, the number of unnecessary handoffs of our algorithm is less than 100, and the number of unnecessary of algorithm 1 is the most, followed by the algorithm 2 and algorithm 3. In the case of video application, the number of unnecessary handoffs from low to high are our algorithm, algorithm 2, algorithm 3 and algorithm 1. For data application, the number of unnecessary handoffs of the algorithm proposed by this paper is 92, while the numbers of unnecessary handoffs of algorithm 1, algorithm 2, and algorithm 3 are 143, 120, and 176 respectively. In general, under different applications, the algorithm proposed by this paper can reduce unnecessary handoffs more effectively.

V. CONCLUSION

In a HWN environment, this paper designs a network access selection algorithm for HWNs based on the fuzzy network attribute values. This algorithm includes the calculation of network attribute values, subjective weights, objective weights, integrated weights, and scores of candidate networks. The simulation shows that this algorithm can select the most suitable network under the environment and reduce the unnecessary handoffs with inaccurate network attribute values. The algorithm is suitable for access selection in the scenario of network attribute value uncertainty. In the next research work, we will study the access selection algorithm in scenarios such as user movement, wireless signal interference, and network state fluctuations.

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MOHD. HASBULLAH OMAR (Member, IEEE) received the Bachelor of Engineering degree (Hons.) in electronics, telecommunication and computer engineering from the University of Bradford, U.K., in 1999, and the master's and Doctor of Philosophy degrees in information technology, in 2002 and 2011, respectively. He is currently an Associate Professor with the School of Computing, Universiti Utara Malaysia. His research interests include communication protocols, mobile network technology, and sensor networks.



KHUZAIRI MOHD ZAINI received the bachelor's degree in IT from Universiti Utara Malaysia, the M.Sc. degree in telecommunications from the University of London, and the Ph.D. degree in wireless computing from Universiti Sains Malaysia. He is currently a Senior Lecturer with the School of Computing, Universiti Utara Malaysia. His research interests include the computer networks performance modeling and evaluation, radio resource management, and simulation.



GEN LIANG received the Ph.D. degree in computer science and technology from the South China University of Technology, China, in 2019. He is currently a Professor and a Master Tutor with the Guangdong University of Petrochemical Technology. He has authored over 50 technical papers in major journals and conferences. His current research interests include wireless communications, radio resource management, and network simulation.



MAOYUAN LIN was born in Guangdong, in January 1998. He is currently pursuing the M.S. degree in electronic information with the Guangdong University of Technology. His current research interest includes network communication security.



ZIRUN GAN received the M.S. degree in data science from the University of Glasgow, U.K., in 2020. He is currently an Experimenter with the Guangdong University of Petrochemical Technology. His current research interests include wireless communications, data analysis, and object detection.

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XIAOXUE GUO received the B.S. and M.S. degrees in computer science and technology from South China Normal University, Guangzhou, China, in 2002 and 2006, respectively. She is currently pursuing the Ph.D. degree with the School of Computer Science and Engineering, Universiti Utara Malaysia. She is also an Associate Professor at the College of Science, Guangdong University of Petrochemical Technology. Her current research interests include wireless communications, wireless sensor networks, and network protocols.