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Multi-Attribute Synergetic Decision-Making Algorithm for 5G Integrated Heterogeneous Wireless Network

Xiaoxin Wu, Chenwei Feng*, Yaxi Yang, and Silei Li

Abstract—The next-generation communication network will be primarily based on the 5G networks, with multiple wireless Radio Access Technologies (RATs) coexisting. The factors influencing user experience are complex and diverse, making it difficult for any single wireless technology to meet all user needs. Most existing network selection algorithms focus on either the user side or the network side, leading to the problem of network load imbalance. Therefore, this paper proposes a Multi-Attribute Synergetic Decision (MASD) algorithm for 5G integrated heterogeneous wireless network. First, implement the pre-filtering of the candidate network set. Taking into account the diversity of user services, this algorithm focuses on Quality of Service (QoS), user preferences, and network load. Analytic Hierarchy Process (AHP) and Standard Deviation (SD) are used to calculate the weights of each attribute. Based on the synergetic theory, the entropy value of the candidate network system is obtained. Simulation results demonstrate that this algorithm effectively coordinates various factors to select the most suitable network for access. It reduces unnecessary handovers, avoids the ping-pong effect, and achieves load balancing to a certain extent.

1. INTRODUCTION

The 5G integrated network is an important research direction for future development, with vast application prospects. How to enable users to select the optimal network that matches their preferences and network characteristics is a key research focus of the 5G converged network [1].

In heterogeneous wireless networks, network selection is considered a complex problem that often requires simultaneous consideration of numerous potential factors. At times, these factors may even be contradictory to each other [2]. Indeed, the key lies in achieving a balance among multiple factors to ensure that terminals connect to the appropriate network. Moreover, due to the rapid changes in network environments, the decision-making speed should not be excessively slow, which calls for a moderate complexity level of the algorithm model.

Compared with other algorithms, the selection algorithm based on Multi-Attribute Decision-Making (MADM) considers a variety of factors. The model complexity is moderate; the decision-making speed is fast; and it has high flexibility and accuracy. Currently, commonly used MADM algorithms include Simple Additive Weighting (SAW), Multiplicative Exponential Weighting (MEW), AHP, Fuzzy Analytic Hierarchy Process (FAHP), Entropy Weighting (Entropy), SD, Grey Relational Analysis (GRA), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), etc. [3].

Most existing research works facilitate network selection to some extent, but there are also limitations and challenges. For example, only the subjective weight of the attribute is considered, and the objective aspect is ignored; the difference of user preference and multiple application types are not considered; only from the user's point of view, the network load balancing problem is ignored. In

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view of the above problems, this paper proposes a heterogeneous network selection algorithm based on AHP, SD algorithm, and synergetic theory, named Multi-attribute Synergetic Decision (MASD) algorithm. The algorithm first uses Received Signal Strength (RSS) and terminal moving speed to realize the preliminary screening of the candidate network set; secondly, the AHP and SD algorithms are used to comprehensively consider the subjective and objective factors of network attributes; finally, QoS, user preference, and load balancing are considered jointly, so an appropriate network is selected for the terminal to access. The simulation results prove the effectiveness of the algorithm in this paper.

The rest of the paper is organized as follows. Section 2 reviews the related work of network selection. Section 3 introduces the heterogeneous network system model and the network pre-screening mechanism. Section 4 gives the user's preference for each index. Section 5 constructs the utility function of each decision index. Section 6 describes the MASD network selection algorithm. Section 7 evaluates and analyzes the performance of the MASD algorithm through simulation experiments. Finally, Section 8 summarizes this paper.

2. RELATED WORK

In recent years, due to the complexity and challenges of heterogeneous network selection decisions, several mechanisms have been proposed to comprehensively consider multiple factors. Compared to other non-MADM methods, MADM methods have gained extensive study due to their simplicity and moderate model complexity.

Paper [1] proposes a cognitive heterogeneous network vertical handover decision scheme that combines subjective and objective weighting with GRA. This approach reduces the total number of handovers and abnormal ranking rate. Paper [4] presents a network selection model that integrates multiple attributes. It utilizes fuzzy logic theory to process the decision matrix of network attributes and obtain the weight preferences of network attributes based on the business requirements. Finally, the algorithm evaluates the candidate networks using the total utility value, effectively reducing the ping-pong effect in dynamic environments. Paper [5] proposes an MADM method based on fuzzy network attributes. The algorithm utilizes AHP and Entropy to calculate preferences for network attributes. The comprehensive weight is obtained by using TOPSIS. Finally, on the basis of fuzzy sets, the algorithm employs GRA to obtain scores for candidate networks, which can select the most suitable network and reduce unnecessary handovers caused by inaccurate network attribute values. The algorithm [6] incorporates Quality of Experience (QoE) into the decision mechanism and proposes a QoE estimation method based on a stochastic neural network to determine the correlation between QoE and QoS in heterogeneous networks. In [3], the authors propose a group vertical handover decision algorithm (GVHO) based on non-cooperative game theory. The algorithm utilizes multiple decision attributes and dynamic user preferences as game strategies to select the optimal network for group vertical handover at the Nash equilibrium. In [7], an MADM selection algorithm is proposed for cognitive wireless networks. The algorithm utilizes AHP to calculate attribute weights and employ TOPSIS to rank the networks. However, it does not consider the objective weights of the attributes. Yu and Zhang [8] propose a heterogeneous network selection algorithm that combines three typical MADM methods: FAHP, Entropy, and TOPSIS. The user preferences and network properties are considered, combined with the threshold to select the appropriate network access. The authors in [9] propose the integration of fuzzy logic into Software Defined Networking (SDN) to assist in Femto Access Point and Device-to-Device (D2D) discovery. Fuzzy logic is combined with AHP and TOPSIS, and the ultimate goal is to select the network with the highest QoE score. Song et al. [10] proposed a network selection algorithm based on FAHP, SD, and GRA. The algorithm utilizes FAHP and SD to respectively calculate the subjective and objective weight for network attributes. Additionally, the GRA method is employed to rank the candidate networks. Paper [11] proposes an algorithm that integrates fuzzy logic and MADM methods. This algorithm ensures that the handover process is triggered at the right time and connects to the optimal neighboring base station. Paper [12] proposes a novel handover decision algorithm. It utilizes multiple factors as decision criteria and employs the MADM method to prioritize each factor based on the mobile station's location. Paper [13] proposes a Vertical Handover (VHO) algorithm based on a multi-objective optimization model and takes into account the dynamic characteristics of the network and QoS requirements of the users. Paper [14] presents a two-stage handover optimization algorithm consisting of the handover initialization stage and network decision stage. It utilizes FAHP to assign weights to key parameters and employs the Elimination and Choice Expressing Reality (ELECTRE) method to rank different networks. In [15], the scores of all available networks are calculated based on subjective weight and Entropy weight using SAW, MEW, and TOPSIS. The calculated scores are used to determine the target network.

3. SYSTEM MODEL AND PRE-SCREENING MECHANISM WITH NETWORK

3.1. System Model

This paper considers a heterogeneous network system model composed of 5G macro base stations, 5G micro base stations, LTE-A, and Wi-Fi 6 networks. The system model is illustrated in Figure 1. The network parameters considered in the simulation include network bandwidth, delay, jitter, and packet loss rate. The simulated 5G service types include Virtual Reality (VR)/Augmented Reality (AR) services, healthcare services, intelligent transportation services, and industrial automation services. The scenario includes multiple users, and it is assumed that terminals can perform a variety of services.

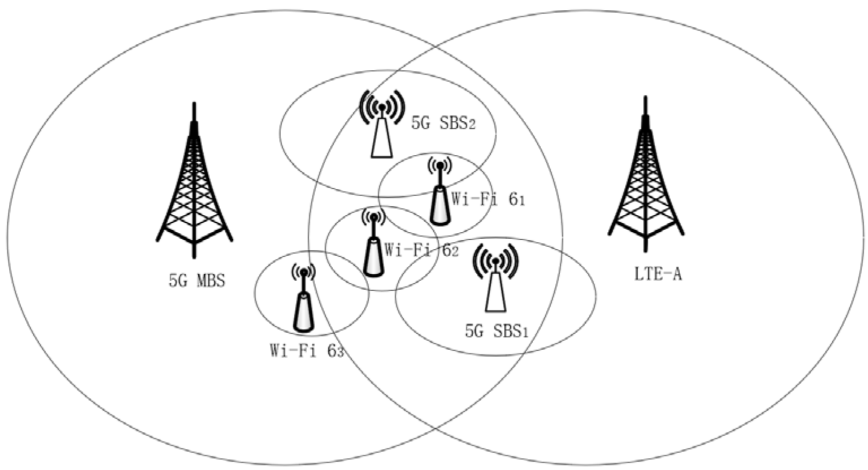

Figure 1. Simulation system model.

3.2. Network Pre-Screening

Under multi-network coverage, the user's motion status causes the set of optional networks to change frequently during movement. In order to meet the normal execution of the business and reduce the impact of the number of switching on the network, the difference between the user's business is ignored, and the unreasonable network is eliminated first. Considering that the RSS of some networks is relatively weak, accessing these networks will affect the normal service transmission. At the same time, there are many networks with relatively small coverage in the mobile path of mobile users, and high-speed mobile users are easy to enter and leave the same network in a short time, resulting in unnecessary switching. Therefore, this paper considers RSS and user movement speed to perform a quick pre-screening of network collections.

3.2.1. Consider the Received Signal Strength

$$u_{n,m} = \begin{cases} 1, & RSS_{n,m} \geq RSS_{TH,n} \\ 0, & RSS_{n,m} < RSS_{TH,n} \end{cases}, \quad \forall n \in N,\ \forall m \in M \tag{1}$$

In formula (1), $RSS_{n,m}$ represents the signal strength of network n received by user m, and $RSS_{TH,n}$ represents the threshold for different network signal strengths.

3.2.2. Consider the User Movement Speed

Considering that the coverage area of Wi-Fi 6 and 5G micro base station is relatively small, there is a potential for a ping-pong effect when the user's speed is high. Therefore, we set the speed threshold. If the user's speed exceeds the threshold, the utility function will be 0; otherwise, it will be 1.

$$u'_{n,m} = \begin{cases} 1, & V_{TH,n} \geq V_m \ and \ n \ is \ Wi-Fi \ 6 \ or \ 5\text{G} \ micro \ base \ station \\ 0, & V_{TH,n} < V_m \ and \ n \ is \ Wi-Fi \ 6 \ or \ 5\text{G} \ micro \ base \ station, \\ 1, & n \ is \ LTE-A \ or \ 5\text{G} \ macro \ base \ station \end{cases} \quad \forall n \in N, \ \forall m \in M \tag{2}$$

In formula (2), V_m represents the mobile speed of user m, and $V_{TH,n}$ represents the threshold of network n (Wi-Fi 6/5G micro base station) for accepting the mobile speed of the terminal.

3.2.3. Consider of RSS and User Movement Speed

$$u_{pre} = u_{n,m} * u'_{n,m}, \quad \forall n \in N, \ \forall m \in M \tag{3}$$

In formula (3), if the pre-screening utility value u_{pre} of user m for all candidate networks is 0, the network with the maximum RSS is selected for access.

Based on the heterogeneous network simulation scenario shown in Figure 1, the mobile paths of high-speed mobile users passing through 5G MBS, 5G SBS_2, and LTE-A networks and passing through 5G MBS, Wi-Fi 6_3, and LTE-A networks are simulated, respectively. The changes in the optional network set after the pre-screening stage are as follows: from the original 5G MBS, 5G SBS_2, and LTE-A networks to 5G MBS and LTE-A networks; from the original 5G MBS, Wi-Fi 6_3, and LTE-A networks to 5G MBS and LTE-A networks. Obviously, the network pre-screening based on RSS and user movement speed can effectively reduce the size of candidate networks and reduce unnecessary switching. Therefore, pre-screening is scalable in 5G dense heterogeneous network systems and can effectively reduce the system overhead caused by executing a complete algorithm for all networks in a complex network environment.

4. DETERMINING THE WEIGHT OF SERVICE CHARACTERISTICS

4.1. Analytic Hierarchy Process

AHP is an analytical method for solving multi-objective decision-making problems. For a complex system consisting of many interrelated and restrictive factors, the relationship between the factors can be determined quantitatively by AHP. Therefore, the MASD algorithm uses AHP to consider multiple attributes of networks and determine the subjective weights of attributes under different services.

1) Establish a Hierarchical Structure Model

The primary task of AHP is to establish a hierarchical structure and stratify the problem into the target layer, criterion layer, and scheme layer [16]. The target layer is the optimization goal of the problem; the criterion layer includes network properties, and the scheme layer is all feasible scheme choices [17]. In this paper, the criterion layer is divided into two layers, and the hierarchical structure model is shown in Figure 2. The first layer consists of three components: user preferences, service quality, and available resources, represented as $A = \{P, Q, L\}$. The other layer addresses QoS for different business requirements, including bandwidth, delay, packet loss rate, and jitter, represented as $B = \{W, D, R, V\}$. These levels are both connected and mutually restricted.

2) Construct a Decision Matrix

Because different services have different requirements for various indicators of the network, it is necessary to use a decision matrix to represent the importance of a business to different attributes of the network [18]. In view of the difference in the impact of each network attribute on the business in the criterion layer, the 1–9 scale method can be used to establish a decision matrix among network attributes. Therefore, remember the first-level decision matrix $A = (a_{mn})_{3\times3}$ and the second-level attribute importance decision matrix $B_k = (b_{mn})_{4\times4}$. Their properties are shown in formula (4) and

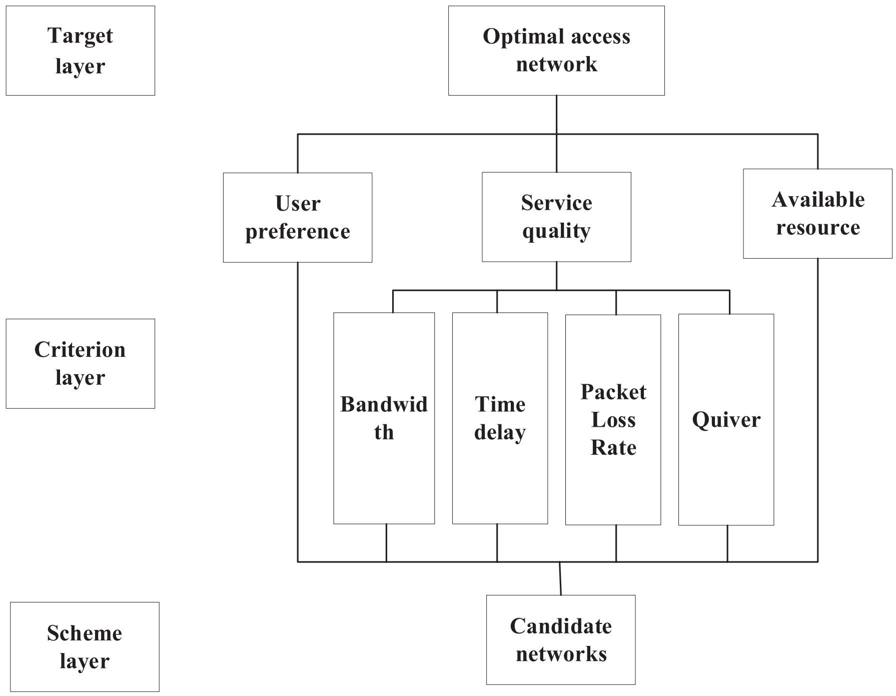

Figure 2. Hierarchical structure model.

formula (5), respectively.

$$A = \begin{array}{c} \\ P \\ Q \\ L \end{array} \begin{array}{c} \begin{array}{ccc} P & Q & L \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \end{array}$$

$$\begin{cases} a_{mn} > 0 \\ a_{mn} = \dfrac{1}{a_{nm}} \\ a_{mm} = 1 \end{cases} \tag{4}$$

where a_{mn} represents the ratio of the importance of attribute m to attribute n in the first layer.

$$B_k = \begin{array}{c} \\ W \\ D \\ R \\ V \end{array} \begin{array}{c} \begin{array}{cccc} W & D & R & V \end{array} \\ \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \end{bmatrix} \end{array}$$

$$\begin{cases} b_{mn} > 0 \\ b_{mn} = \dfrac{1}{b_{nm}} \\ b_{mm} = 1 \end{cases} \tag{5}$$

where b_{mn} represents the ratio of the importance of attribute m to attribute n in the second layer, and k corresponds to different business types.

3) Determine the Weight

The maximum eigenvalues $\lambda_{\max 1}$ and $\lambda_{\max 2}$, along with the eigenvectors w_1 and w_2 of the decision matrices A and B established for a specific business type, can be determined using the eigenvalue method. As shown in formula (6) and formula (7)

$$Aw_1 = \lambda_{\max 1} w_1 \tag{6}$$

$$Bw_2 = \lambda_{\max 2} w_2 \tag{7}$$

By normalizing the above feature vectors w_1 and w_2, the weight value of each network attribute can be obtained. Note that the attribute weight of the first layer is w', and the attribute weight of the second layer is w^s. As shown in formula (8) and formula (9)

$$w' = [w'_P, w'_Q, w'_L] \tag{8}$$

$$w^s = [w^s_W, w^s_D, w^s_R, w^s_V] \tag{9}$$

4) Consistency Check

Since the establishment of the above decision matrix is highly subjective, it is necessary to use a consistency test to judge its rationality. The formulas for calculating the Consistency Index (CI) and the average Random Index (RI) are shown in formula (10) and formula (11).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{10}$$

In formula (10), $\lambda_{\max}$ represents the maximum eigenvalue of the decision matrix, and n represents the order of the decision matrix.

$$RI = \frac{\lambda'_{\max} - n}{n - 1} \tag{11}$$

In formula (11), $\lambda'_{\max}$ represents the average of the maximum eigenvalues of the matrix roots.

Using the ratio of CI to RI to calculate the Consistency Ratio (CR), as shown in formula (12)

$$CR = \frac{CI}{RI} \tag{12}$$

4.2. Standard Deviation

The SD method is mainly used to characterize the variation of data from the corresponding mean [2]. Since there is no human factor interference in the calculation process, SD is used in network selection to calculate the objective weights of attributes. In network selection, the larger the standard deviation of the attribute is, the greater the information is contained in the attribute, and a larger weight should be assigned; vice versa. The main steps are as follows:

First, when a user is making a network decision, it is necessary to construct a parameter matrix C based on the attribute values of candidate networks.

$$C = (c_{ij})_{m \times n} \tag{13}$$

In formula (13), m represents the total number of networks, n the number of attributes, and c_{ij} the value associated with attribute j in network i in the heterogeneous network.

Second, the matrix parameter c_{ij} needs to be normalized to obtain the normalized parameter c'_{ij}:

$$c'_{ij} = \frac{c_{ij}}{\sqrt{\sum_{i=1}^{m} c_{ij}^2}}, \quad i = 1, \ldots, m, \ j = 1, \ldots, n \tag{14}$$

In formula (14), c'_{ij} represents the value corresponding to the attribute j in the candidate network i in the normalization matrix C'.

Third, the standard deviation σ_j of the network attribute j is calculated using formula (15).

$$\sigma_j = \sqrt{\sum_{i=1}^{m} \left(c'_{ij} - \frac{1}{m} \sum_{i=1}^{m} c'_{ij} \right)^2}, \quad i = 1, 2, \ldots, m, \ j = 1, 2, \ldots, n \tag{15}$$

Finally, σ_j is used to calculate the objective weight w^o_j of the network attribute j in formula (16).

$$w^o_j = \frac{\sigma_j}{\sum_{j=1}^{n} \sigma_j}, \quad j = 1, 2, \cdots, n \tag{16}$$

4.3. Allocation Coefficients for Subjective and Objective Weights

Based on the analysis conducted earlier, to ensure that the network selection results meet both the user's business requirements and the objective network performance, this paper adopts a minimization mathematical model to maintain the optimality and consistency of subjective and objective network utilities. In this context, the greater the total utility of subjective and objective QoS is, the more optimal it is, and the smaller the deviation is, the more consistent it is [19]. The mathematical model is as follows.

$$\min F = -\sum_{i=1}^{m}\sum_{j=1}^{n}(\eta w_j^s u_{ij} + \lambda w_j^o u_{ij}) + \sum_{i=1}^{m}\left(\left(\sum_{j=1}^{n}\eta w_j^s u_{ij} - \sum_{j=1}^{n}\lambda w_j^o u_{ij}\right)^2\right) \tag{17}$$

$$st\begin{cases}\sum_{j=1}^{n} w_j^s = 1, \quad \sum_{j=1}^{n} w_j^o = 1\\ \eta+\lambda=1, \quad 0\le\eta\le1, \quad 0\le\lambda\le1\end{cases} \tag{18}$$

In formula (17)–(18), η and λ respectively represent the allocation coefficients for subjective and objective weights. w_j^s represents the subjective weight for attribute j, w_j^o the objective weight for attribute j, and u_{ij} the utility value of attribute j obtained in the scheme of network i.

The Lagrangian function $L(\eta,\lambda,\mu)$ is given by formula (19), where μ is the Lagrange coefficient.

$$L(\eta,\lambda,\mu) = F + \mu(\eta+\lambda-1) \tag{19}$$

Let's take the partial derivatives of the Lagrangian function L with respect to η, λ, and μ and set them equal to zero. Then solving the formula (20) can get η and λ.

$$\begin{cases}\dfrac{\partial F}{\partial \eta} + \mu = 0\\ \dfrac{\partial F}{\partial \lambda} + \mu = 0\\ \eta+\lambda-1=0\end{cases} \tag{20}$$

5. ESTABLISHMENT OF UTILITY FUNCTION

5.1. Attribute Utility Function

In heterogeneous network selection, the utility function is used to qualitatively and quantitatively analyze the satisfaction of users with network attributes. First, the utility function should be quadratically differentiable in the interval. Secondly, the utility function is a non-decreasing function. Finally, the utility function must be monotonic. The Sigmoid function satisfies the above characteristics, so it is suitable for the construction of utility functions in heterogeneous wireless networks.

The utility function is used to calculate the utility values of various services with respect to network attributes, while also standardizing the attribute values. For benefit-type attributes, the higher the attribute value is, the greater the utility value is, using the utility function $u(x)$ as shown in formula (21); for cost-type attributes, it is the opposite, so the utility function is $1-u(x)$.

$$u(x) = \frac{1}{1+e^{p(q-x)}}, \quad \beta < x < \alpha \tag{21}$$

In formula (21), q and p determine the center position and steepness of the Sigmoid function curve, while α and β are the upper and lower threshold values of the attribute.

By using the Sigmoid function, the center position can be determined by the parameter q. By adjusting the parameter p, the sensitivity of user business requirements can be reflected more accurately, enabling a better understanding of the variations in network attribute standards.

5.2. User Preferences

In order to calculate the ranking of different user services with respect to each candidate network [7], it needs to decompose the user service preference for the network. The calculation steps are as follows.

First, calculate the preference levels of the AR/VR, healthcare, intelligent transportation, and industrial automation business types for the bandwidth, delay, packet loss rate, and jitter attributes. Construct the relationship matrix between different business types and network attributes using AHP, as shown the decision matrix B_k in Subsection 4.1. Then, calculate the corresponding weights matrix $U_B = (u_{bj})$, where b represents the business type, and j represents the network attributes.

Second, construct the relationship matrix between network attributes and candidate networks. Since different network attributes have different importance to different networks, use the decision matrix to construct bandwidth, delay, packet loss rate, and jitter for 5G macro base station (M), 5G micro base station (S), LTE-A (L), and Wi-Fi 6 (W). Based on the varying network attributes, pairwise comparisons are made to determine the importance of M, S, L, and W. The results of comparisons are used to construct the decision matrix D_j, and the corresponding weights matrix $U_D = (u_{jn})$ are calculated using AHP, where j represents the network attribute, and n represents the network type. Note that $D_j = (d_{mn})_{4\times 4}$, which has the properties shown in formula (22).

$$D_j = \begin{array}{c} \\ M \\ S \\ L \\ W \end{array} \begin{array}{c} \begin{array}{cccc} M & S & L & W \end{array} \\ \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} \\ d_{21} & d_{22} & d_{23} & d_{24} \\ d_{31} & d_{32} & d_{33} & d_{34} \\ d_{41} & d_{42} & d_{43} & d_{44} \end{bmatrix} \end{array}$$

$$\begin{cases} d_{mn} > 0 \\ d_{mn} = \dfrac{1}{d_{nm}} \\ d_{mm} = 1 \end{cases} \tag{22}$$

where j corresponds to different network attributes, $j = 1, 2, \ldots, n$. d_{mn} represents the ratio of the importance of candidate network m to candidate network n.

Finally, the user preference value $U_{Preference}$ of different services on various networks is defined as shown in formula (23) [20].

$$U_{Preference} = U_B * U_D \tag{23}$$

5.3. Utility Function of Network Load

Considering that both service quality and user preferences are viewed from the user's perspective, users tend to prioritize networks with better performance. As a result, some networks may become heavily loaded while others remain relatively idle, wasting network resources. Therefore, in network selection, network load balancing should also be considered on the basis of ensuring user service experience.

Network load can directly reflect the degree of network congestion. By considering the network load while satisfying user preferences, it is possible to achieve balanced network resource allocation. The network load rate l is defined as in formula (24).

$$l = \frac{Q_n}{Q_t} \tag{24}$$

In formula (24), Q_n represents the resources occupied by the already connected services in the network, and Q_t represents the total resources of the network.

The utility function U_{Load} of the load is shown in formula (25) [21].

$$U_{Load}(l) = \begin{cases} 1 - e^{\alpha(l-\beta)}, & l \le \beta \\ 0, & l \ge \beta \end{cases} \tag{25}$$

$$0 \le l \le 1 \tag{26}$$

In formulas (25)–(26), l represents the size of the load attribute value of the current network. α is the adjustment factor, and β represents the load property threshold.

6. MULTI-ATTRIBUTE SYNERGETIC DECISION-MAKING ALGORITHM

6.1. Synergetic Theory

Synergetics is an emerging discipline, created by Professor Harken, which focuses on the evolution of a system from a disordered state to an ordered state. A composite system is composed of multiple subsystems, and each subsystem has a cooperative and synergistic effect through nonlinear interaction, so the whole system has a certain self-organizing structure. The order parameter is an important concept of synergetics, which dominates the movement of each subsystem.

In this paper, Synergetic theory is applied to the selection of heterogeneous wireless networks. We regard heterogeneous network selection as a systematic problem, and each candidate network is considered as a complex system. It takes into account both network and user perspectives, with the complex system consisting of three subsystems: service quality, user preferences, and available load. The selection of the candidate network is determined by the coordination degree of the three subsystems, the higher the coordination degree, the better the network performance.

6.2. Network Sorting and Selection

Obtain the weight and utility value of the order parameter components of the three subsystems, and use SAW to calculate the order degree u_p of the candidate network subsystem.

$$u_p = \sum_{j=1}^{n} w_{pj} u_{pj}, \quad p = 1, 2, \ldots, k \tag{27}$$

$$\sum_{j=1}^{n} w_{pj} = 1, \quad p = 1, 2, \ldots, k \tag{28}$$

In formulas (27)–(28), w_{pj} and u_{pj} are the weights and utility function values of the order parameter component j in the candidate network subsystem p, respectively.

Using a single subjective weight value for the final network selection can result in biased decision outcomes. Therefore, to ensure the rationality of the final decision, it is necessary to comprehensively consider the influence of both subjective and objective factors. Based on the allocation coefficients η and λ obtained from 4.3, the comprehensive subjective and objective weights w_{pj} for each attribute can be calculated.

$$w_{pj} = \eta w_{pj}^{s} + \lambda w_{pj}^{o}, \quad j = 1,2, \ldots, n, \quad p = 1,2, \ldots, k \tag{29}$$

In formula (29), w_{pj}^{s} is the subjective weight of attribute j in subsystem p, and w_{pj}^{o} is the objective weight of attribute j in subsystem p.

The better the overall order of the system is, the higher the degree of cooperation is among the candidate network subsystems [22]. The order degree of the system can be expressed by the size of entropy in information theory, so the concept of entropy is used to reflect the degree of coordination among subsystems. The smaller the system entropy value is, the better the overall order of the system is, and the corresponding network i is the optimal network. The system entropy value U_i of the candidate network i is specifically expressed as follows.

$$U_i = -\sum_{p=1}^{k} w_p \frac{1 - u_{ip}}{k} \log\left(\frac{1 - u_{ip}}{k}\right), \quad i = 1, 2, ..., m, \quad p = 1, 2, ..., k \tag{30}$$

In formula (30), w_p represents the importance of subsystem p in the total system, which is the weight of the first layer determined by AHP in 4.1. u_{ip} is the order degree of subsystem p in candidate network i.

6.3. Algorithm Flow

The flowchart of the network selection algorithm in this paper is shown in Figure 3. The process is roughly as follows: First, pre-screen the network according to the user's received signal strength and

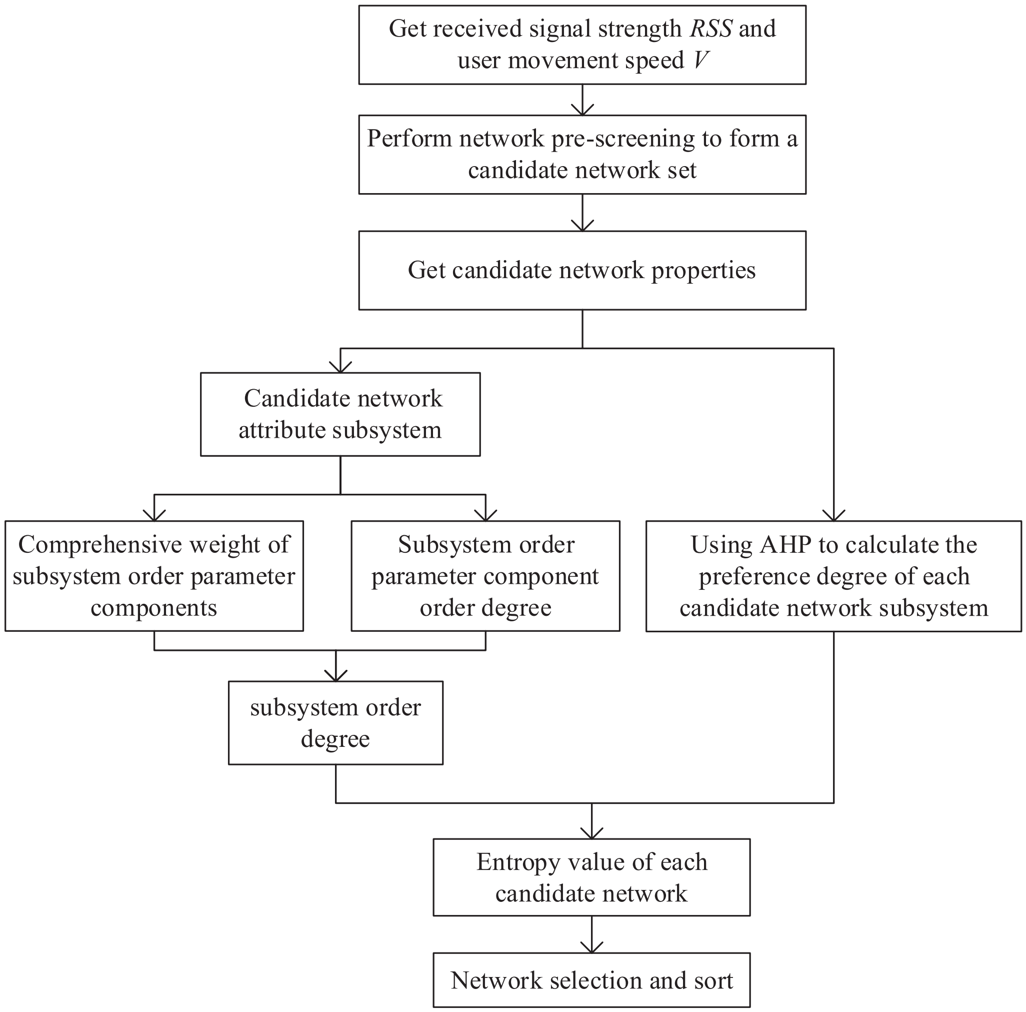

Figure 3. Algorithm flow chart.

moving speed. Secondly, the network attribute judgment matrix is constructed under different business scenarios, and the subjective and objective weights are respectively obtained by using AHP and SD. Then calculate the order degree of the order parameter component of the subsystem, and combine the comprehensive weight to obtain the order degree of the subsystem. Finally, collaborate with the three subsystems of QoS, user preference, and available resources to obtain the system entropy values of candidate networks. At the same time, perform network ranking and selection.

7. SIMULATION AND ANALYSIS

7.1. Simulation Parameters Setting

In the experiment, the HetNets system consists of 5G macro base stations, 5G micro base stations, LTE-A and Wi-Fi 6 networks. For the ease of observation and analysis, consider that four types of networks can accommodate the same number of users. Assuming that user services follow the Poisson distribution, the arrival rate λ is set to 0.05. The service time follows an exponential distribution with a mean of 120 s. The basic properties of networks are shown in Table 1.

The relative importance value of the judgment matrix in this paper is only the subjective evaluation, which is mainly used to explain the idea of the algorithm, and the specific value can be adjusted flexibly according to the actual situation. In this paper, the first-layer decision matrix A in heterogeneous

Table 1. Network simulation parameters.

parameters	5G macro base station (MBS)	5G micro base station (SBS)	Wi-Fi 6	LTE-A
Number of networks	1	2	3	1
Coverage (m)	1000	250	150	1000
Bandwidth (Mbps)	900	700	600	500
Delay (ms)	1	0.5	5	15
Packet loss rate	1	0.5	3	8
Jitter (ms)	2	1	3	10
Number of networks	200	200	200	200

network selection is shown in Table 2. For the second layer decision matrix, the QoS indicator decision matrix B_k of different business types constructed in this paper is shown in Table 3. Among them, VR/AR services have high quality requirements for image quality, so it needs large bandwidth. Healthcare services require high demands on delay, jitter, and packet loss rate. Intelligent transportation services require ultra-low delay and high reliability connection. Industrial automation services have the highest demand for network delay and reliability. The relationship matrix D_j between different network properties and candidate networks in this paper is shown in Table 4.

Table 2. The decision matrix of the first layer.

Network	Q	P	L
Q	1	2	2
P	1/2	1	1
L	1/2	1	1

Table 3. Decision matrices for different service types.

VR/AR services	Healthcare services	Intelligent transportation services	Industrial automation services
$\begin{matrix} 1 & 3 & 5 & 7 \\ \frac{1}{3} & 1 & 3 & 5 \\ \frac{1}{5} & \frac{1}{3} & 1 & 3 \\ \frac{1}{7} & \frac{1}{5} & \frac{1}{3} & 1 \end{matrix}$	$\begin{matrix} 1 & \frac{1}{7} & \frac{1}{5} & \frac{1}{2} \\ 7 & 1 & 2 & 3 \\ 5 & \frac{1}{2} & 1 & 2 \\ 2 & \frac{1}{3} & \frac{1}{2} & 1 \end{matrix}$	$\begin{matrix} 1 & \frac{1}{5} & \frac{1}{3} & 2 \\ 5 & 1 & 2 & 8 \\ 3 & \frac{1}{2} & 1 & 6 \\ \frac{1}{2} & \frac{1}{8} & \frac{1}{6} & 1 \end{matrix}$	$\begin{matrix} 1 & \frac{1}{6} & \frac{1}{5} & \frac{1}{2} \\ 6 & 1 & 2 & 4 \\ 5 & \frac{1}{2} & 1 & 2 \\ 2 & \frac{1}{4} & \frac{1}{2} & 1 \end{matrix}$

Table 4. Decision matrices for different attributes.

Bandwidth	Delay	Packet loss rate	Jitter
$\begin{matrix} 1 & \frac{1}{3} & \frac{1}{8} & \frac{1}{5} \\ 3 & 1 & \frac{1}{5} & \frac{1}{3} \\ 8 & 5 & 1 & 3 \\ 5 & 3 & \frac{1}{3} & 1 \end{matrix}$	$\begin{matrix} 1 & \frac{1}{4} & \frac{1}{6} & \frac{1}{7} \\ 4 & 1 & \frac{1}{2} & \frac{1}{3} \\ 6 & 2 & 1 & \frac{1}{2} \\ 7 & 3 & 2 & 1 \end{matrix}$	$\begin{matrix} 1 & \frac{1}{4} & \frac{1}{6} & \frac{1}{7} \\ 4 & 1 & \frac{1}{2} & \frac{1}{3} \\ 6 & 2 & 1 & \frac{1}{2} \\ 7 & 3 & 2 & 1 \end{matrix}$	$\begin{matrix} 1 & \frac{1}{2} & \frac{1}{3} & \frac{1}{5} \\ 2 & 1 & \frac{1}{2} & \frac{1}{3} \\ 3 & 2 & 1 & \frac{1}{2} \\ 5 & 3 & 2 & 1 \end{matrix}$

7.2. Simulation Result Analysis

In order to verify the performance of the algorithm proposed in this paper, the comparative analysis of relevant evaluation indicators is carried out using the MATLAB simulation platform. The MASD algorithm is compared with network selection algorithm based on QoS Requirement (QR), network selection algorithm based on QoS and User Preferences (QAUP), and network selection algorithm based on Multi-Attribute TOPSIS (MAT), and the pros and cons of the algorithm are measured from the three performance indicators of switching times, network sorting selection, and load balancing.

7.2.1. Analysis of the Number of Handoffs

The used simulation scenario is illustrated in Figure 1, where multiple overlapping heterogeneous networks are formed by the four types of wireless networks. Users are randomly distributed in the area at the initial moment, assuming that the user's maximum moving speed is 30 m/s, and the moving speed and direction are randomly changed at regular intervals. The degree of ping-pong effect of the algorithm is measured by counting the number of handoffs caused by the difference in the optimal network for each mobile user during each business continuation process.

The number of handoffs of the four algorithms in Figure 4 increases with an increase in the number of users. The number of handoffs of the MASD algorithm is lower than that of MAT, QR, and QAUP algorithms when the number of users is different. The reason is that the MASD algorithm effectively considers the impact of mobile speed and RSS on the network selection of mobile users. It includes a pre-screening process for networks, which reduces the set of candidate networks that users can choose from. This helps to minimize the number of handoffs due to limited network coverage when users have high mobility, thereby reducing the occurrence of ping-pong effects.

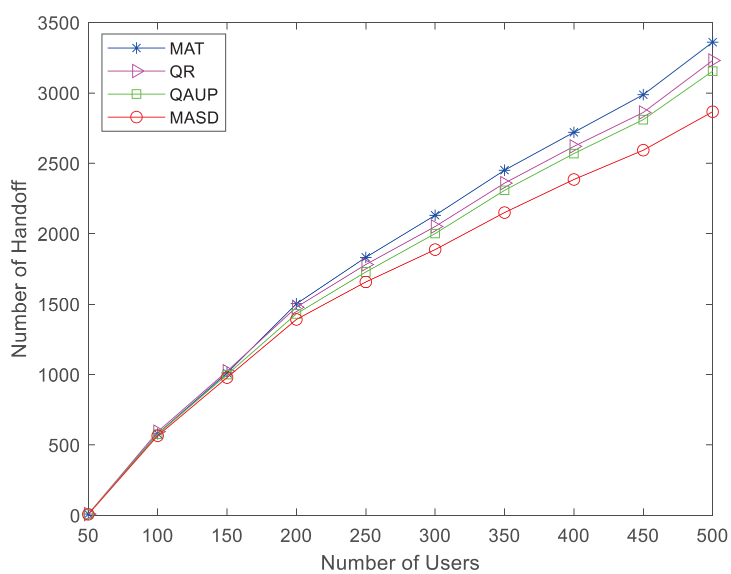

Figure 4. Number of handoff.

7.2.2. Network Sorting and Selection

1) The QR algorithm and MASD algorithm are simulated under different services. The simulation results are shown in Figure 5.

Figure 5 shows that for AR/VR services, the selection and ranking of each network in the QR algorithm is 5G micro base station > 5G macro base station > Wi-Fi 6 > LTE-A. In the MASD algorithm, the order of network selection is 5G macro base station > 5G micro base station > Wi-Fi 6 > LTE-A. The reason is that there is a minimal difference in the total utility values of QoS between 5G

Figure 5. Network selection and ranking of different algorithms under four business types.

macro base stations and 5G micro base stations, and both options satisfy the user's requirements. The MASD algorithm takes into account the ranking of the importance of network attributes under different business requests, as well as the preferences of different business types for candidate networks. The AR/VR business prefers high bandwidth, so it is more reasonable to select the 5G macro base station as the best access network.

For healthcare services, intelligent transportation services, and industrial automation services, there is a high demand for network latency and reliability. The preference order of the two algorithms for different networks is as follows: 5G micro base stations > 5G macro base stations > Wi-Fi 6 > LTE-A. The MASD algorithm considers the user's preference for the network. The ranking result is the same as the QR algorithm. In terms of latency and reliability, 5G micro base stations exhibit the best performance. Therefore, for the three business types of healthcare business, intelligent transportation business and industrial automation business, the results of the network selection and sorting of the two algorithms are the same, which is in line with the actual situation.

2) By simulating a single user moving in different heterogeneous network environments and obtaining the network selection results of the simulated user, the accuracy and effectiveness of the MASD algorithm are validated. Assuming that the speed of the mobile user satisfies $V < V_{TH,n}$, and the user only runs a single service at a certain moment, the user selects network access according to different service requests at different moments.

The simulation scene is shown in Figure 6. The heterogeneous network consists of one 5G macro base station, one LTE-A network, three Wi-Fi 6 networks, and two 5G micro base stations. Assuming that the user moves from left to right at a constant speed, from point A in the figure to point k, the user initiates AR/VR business at point A (T1 moment); when moving to point E (T5 moment), the AR/VR services ends, the user initiates healthcare services; after the user arrives at point H at T8 moment, intelligent transportation services are initiated; finally, the user moves to point J at T10, the business type requested by the user is industrial automation. Through simulation, the network selection result at each moment is shown in Figure 7.

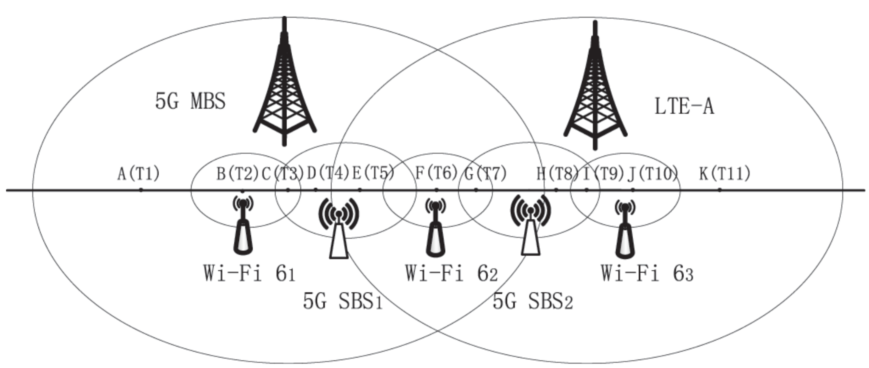

Figure 6. Single-user simulation scenario.

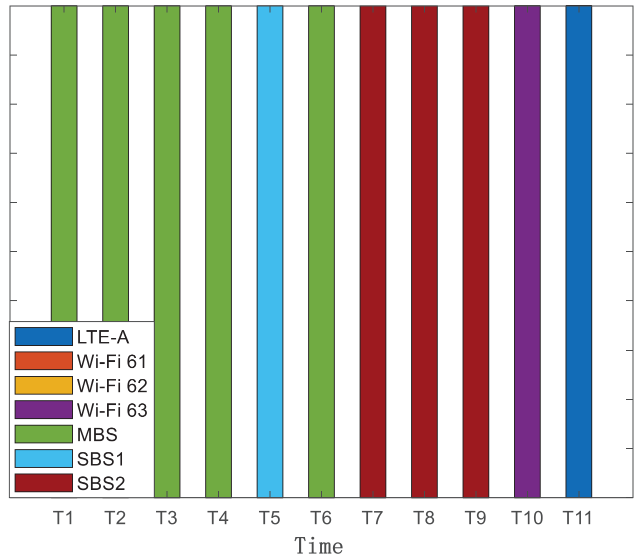

Figure 7. User network selection at different times.

The entire process will be analyzed below, and the correctness and effectiveness of the user's choice to access the network at each moment in this algorithm will be examined.

At T1-T4 moment, the service type requested by the user is AR/VR service. Point A is only covered by MBS, so the optional network for the terminal is only MBS, and the user accesses MBS. From T2 to T4, the mobile user is in the common coverage area of MBS and Wi-Fi 6_1, MBS, SBS_1 and Wi-Fi 6_1, MBS and SBS_1, respectively. AR/VR services have higher bandwidth requirements, and the simulation network parameter table shows that the 5G macro base station has the largest bandwidth, which is more suitable for completing AR/VR services, so the terminal chooses to access the 5G macro base station, which is in line with the actual situation.

At T5-T7 moment, the mobile user is in the common coverage area of MBS, LTE-A and SBS_1, MBS, LTE-A and Wi-Fi 6_2, MBS, LTE-A, Wi-Fi 6_2 and SBS_2, respectively. The type of service initiated by the user is healthcare service, which requires low latency, jitter, and packet loss rate. According to Figure 5, the selection ranking of the four networks is as follows: 5G micro base stations, 5G macro base stations, Wi-Fi 6, and LTE-A. Therefore, at point E, the terminal will choose to connect to SBS_1. At point F, the terminal will choose to connect to MBS. At point G, the terminal will choose to connect to SBS_2.

At T8, the user is in the coverage area of LTE-A and SBS_2, and the total utility value of the 5G micro base station is larger than the LTE-A network, so the terminal accesses SBS_2. At T9, the user is in the coverage area of LTE-A, Wi-Fi 6_3, and SBS_2, and the ranking of SBS_2 is higher than the other two networks, so the terminal accesses SBS_2. The service initiated by the terminal at moment T8 and T9 is intelligent traffic service, which is preferred for the property of delay. The 5G micro base station is more popular because of its smaller delay attribute, so the choice is in line with the actual situation.

At T10, the user is in the overlapping coverage area of LTE-A and Wi-Fi 6_3, and the service type initiated is industrial automation service. From the ranking of the two, it can be seen that the terminal accesses Wi-Fi 6_3. At T11, the user is only within the coverage of the single network of LTE-A, and the service is directly provided by LTE-A network.

7.2.3. Load Balancing

To verify the performance of the algorithm, the simulation is considered to take place in the overlapping part of 5G macro base station, 5G micro base station, Wi-Fi 6 and LTE-A network. It is assumed that the user is stationary in the area, and the user is at a random location. The service arrival rate of users obeys a Poisson distribution with $\lambda = 1/20$, and the service time obeys an exponential distribution with a mean of 120 s.

1) Assuming that users can request different types of services, evaluate the change in blocking rate with an increasing number of users under the QR, QAUP, MAT, and MASD algorithms, considering the variability in service selection results for each user.

Figure 8 shows the changes in the access blocking rates of the four algorithms as the number of users increases. By observing the changes in the curves in Figure 8, it can be concluded that as the number of users increases, the blocking rate increases for all four algorithms. When the number of users reaches about 40, the QAUP and QR algorithms begin to block; when the number of users reaches about 80, the MAT algorithm begins to block; the MASD algorithm starts to block when the number of users is 120. The blocking rate of the MASD algorithm is lower than the other three algorithms in the case of different user numbers. The reason is that the access mechanisms of QR and QAUP cause a large number of users to preferentially access their preferred network without taking into account changes in network load. So the network blocking rate will increase, and blocking will occur when the number of users is small. Although the MAT algorithm reduces the blocking rate to some extent, the

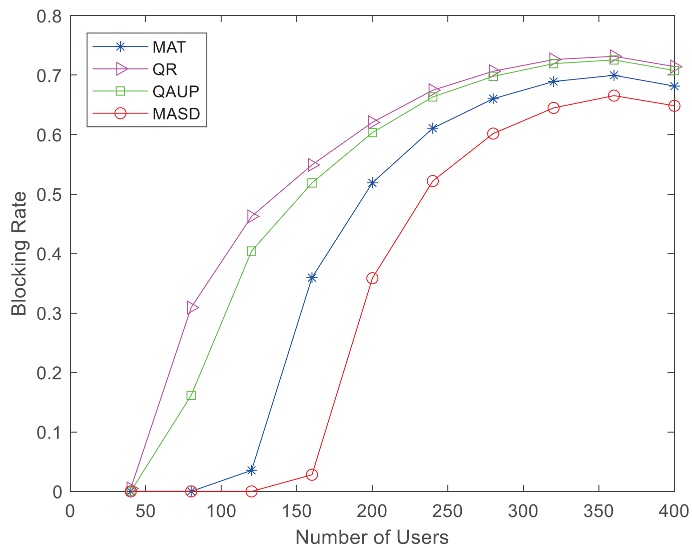

Figure 8. The change of blocking rate with the number of users.

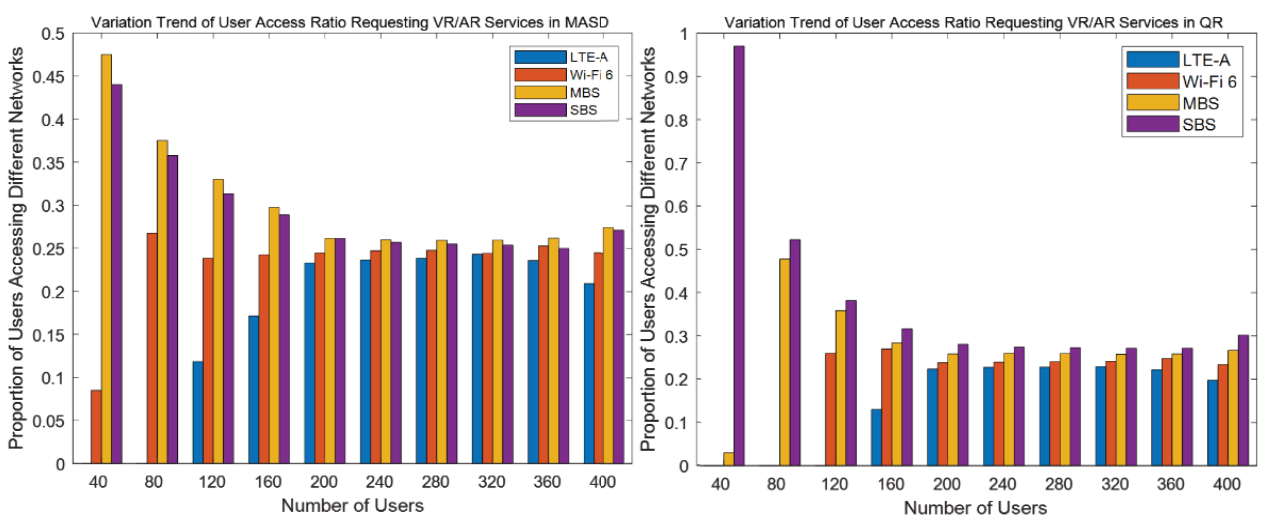

Figure 9. Network access status under AR/VR services.

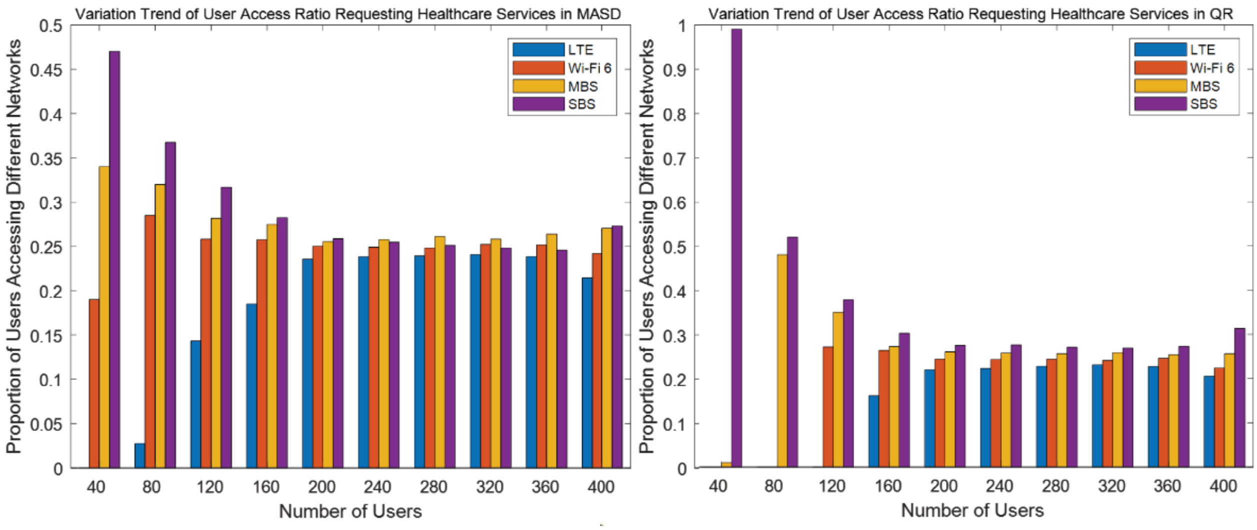

Figure 10. Network access status under healthcare services.

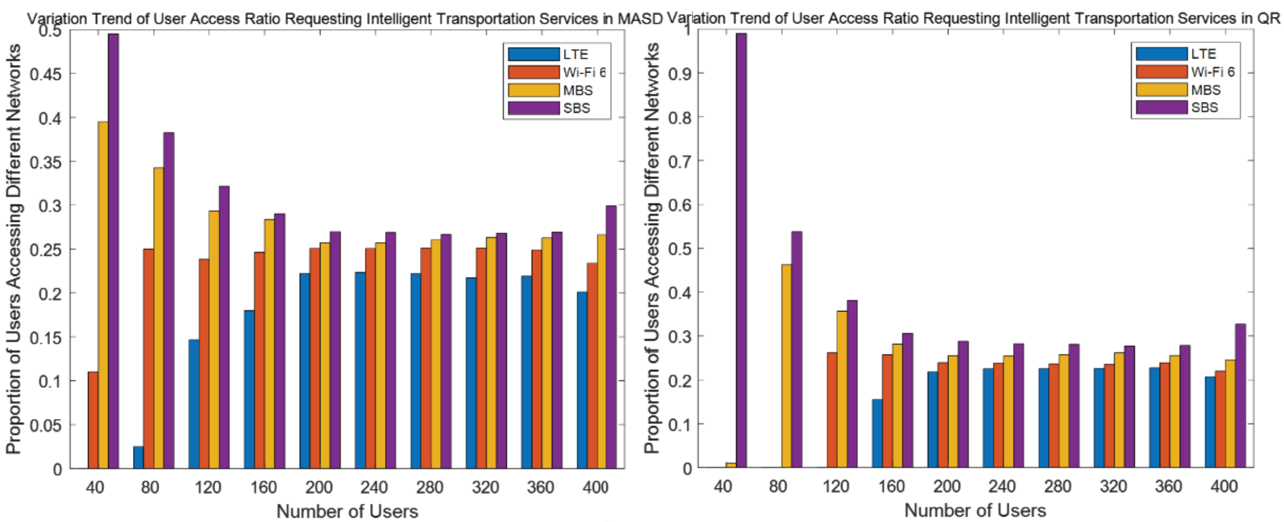

Figure 11. Network access status under intelligent transportation services.

effect is not as good as the MASD algorithm. The reason is that MASD takes into account the quality of network service, user preferences, and available load, effectively reducing traffic congestion.

2) Observe the changes of QR and MASD algorithms in user access networks under different business types, and evaluate their performance. In order to observe the dynamics of user selection, it is assumed that all users request the same type of service, and the four networks accommodate the same number of users.

From Figures 9–12, it can be observed that in the four different types of business scenarios, the gap in network access proportions between the two algorithms decreases as the number of users increases. The reason is that as the number of users increases, the available resources of the network decrease, and finally the access proportion of each network tends to be about 25%. Because the MASD algorithm considers the available load, and the QR algorithm gives priority to the network with better total utility of QoS, the network load of the MASD algorithm is more balanced under different numbers of users.

Furthermore, for the AR/VR business, as shown in Figure 9, when network resources are abundant, the network access situation of the MASD algorithm satisfies 5G macro base station > 5G micro-macro

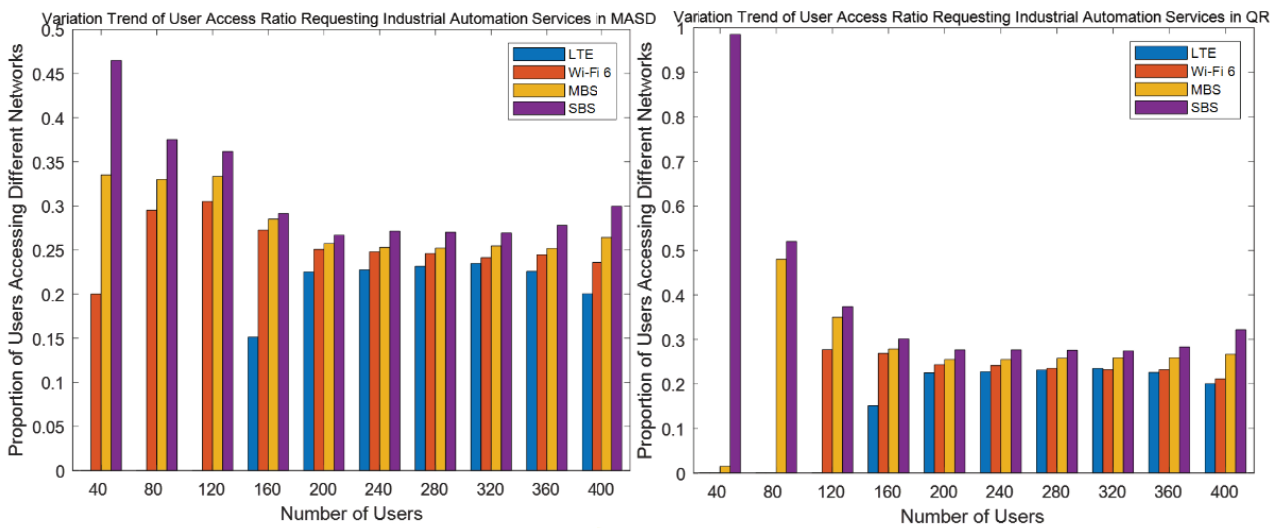

Figure 12. Network access status under industrial automation services.

base station > Wi-Fi 6 > LTE-A under different numbers of users. For the other three business types, as shown in Figures 10–12, when the network is rich in available resources, the MASD algorithm network access ratio is 5G micro base station > 5G macro base station > Wi-Fi 6 > LTE-A, and the network access ratio under the four business types is in line with the user's preference. The MASD algorithm considers the user's preference and QoS requirement so that the 5G macro base station and 5G micro base station are better choices. At the same time, the actual network load is also considered to avoid network congestion caused by excessive selection of service requests for the same network and improve the utilization rate of network resources. This shows that the MASD algorithm synergizes QoS, user preference for the network, and available load.

8. CONCLUSION

This paper proposes a heterogeneous wireless network selection algorithm that combines service characteristics, user preferences, and network load. Meanwhile, the algorithm considers multiple decision attributes to comprehensively evaluate candidate networks. In this algorithm, the utility value of network attributes for different services is considered; the comprehensive weight of network attributes is obtained by combining AHP and SD; and the order of entropy values of candidate network systems is obtained by using synergistic theory. The simulation results indicate that the algorithm proposed in this paper is capable of connecting users to the most suitable network based on their business types. Additionally, the algorithm effectively reduces the number of handoffs through pre-screening in high-speed scenarios. In low-speed scenarios, the algorithm can achieve a certain level of load balancing by considering the collaborative QoS, user preferences, and available load based on the requested business types.

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