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Modular handover algorithm for 5G HetNets with comprehensive load index

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Abstract

Most existing handover decision system (HDS) designs are monolithic, resulting in high computational cost and unbalance of overall network. A novel modular handover algorithm with a comprehensive load index for the 5th generation (5G) heterogeneous networks (HetNets) is proposed. In this paper, the handover parameters, serving as the basis for handover, are classified into network's quality of service (QoS) module, user preference (UP) module and degree of satisfaction (DS) module according to the new modular HDS design. To optimize switching process, the comprehensive network load index is deduced by using triangle module fusion operator. With respect to the existing handover algorithm, the simulation results indicate that the proposed algorithm can reduce the handover frequency and maintain user satisfaction at a higher level. Meanwhile, due to its block calculation, it can bring about 1.4 s execution time improvement.

Keywords 5G HetNets, handover, modular HDS, comprehensive load index

1 Introduction

Over the past few years, the increasing growth of mobile data traffic and intelligent terminal leads to the fact that current long term evolution (LTE) network cannot meet the demand of new multimedia services. 5G, the next generation wireless network, should outperform LTE in terms of metrics such as system capacity, spectrum utilization and connection speed. In addition to that, future wireless network architectures are envisaged to comprise of an integration of multiple wireless technologies such as 5G cellular wireless network, LTE, wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMax). They will maximize their own advantages that meet users' demands to ensure the provision of advanced services and reduced costs for both operators and users [1], and allow user equipment (UE) to have seamless mobility.

Fig. 1 illustrates architecture for 5G HetNets, with UE_1, UE_2 and UE_3 using different traffics.

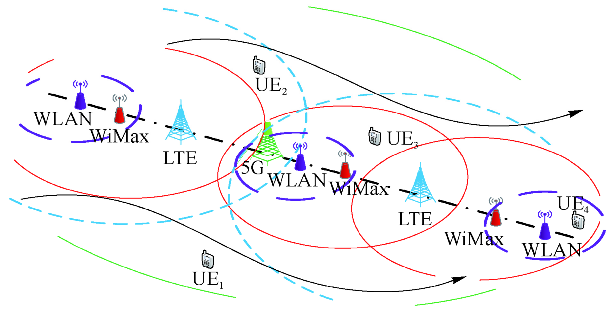

Fig. 1 Heterogeneous wireless network

In Fig. 1, when UE moves across different service areas, vertical handovers become necessary in order to maintain connectivity. To ensure the roaming and seamless vertical handover of UE in such environment, it is extremely essential to design a sufficiently smart HDS.

A number of schemes are carried out to solve vertical handover and related some techniques during several years. In Ref. [2], Singhrova et al. compared traditional handover decision strategies, and concluded that these methods are

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not sufficient to make a vertical handover decision. Queuing theory is used to trigger handover between HetNets in an advanced algorithm [3], which brings performance improvement of ping-pong effects. However, with the gradual rising of users, handover latency increases. Network selection can be initialized by user end [4] or can be based upon measurements of link quality by the network side [5], it tends to solve the handover problem by searching for the optimal solution. Based on handover optimization [6–7] or user behavior [8], UE can make the right choice to how to access optimal network in HetNets.

After all, UE aims to join the best access point, and network selection turns into a decision making problem with multiple options and attributes. Recently, multi-attribute decision making (MADM) is often used in HetNets [9–12], however, it becomes inefficient in execution time because of its traditional monolithic HDS designs. As user-centric research is increasingly crucial in 5G HetNets, load balancing is an important element to offer good quality of experience (QoE) for UE. In Ref. [13], yang et al. set up a fixed load threshold to adjust handover hysteresis margin to reduce failure rate. The effect of dynamic load balancing for each network is put forward in Ref. [14]. These schemes are limited to single network scenario, therefore, the overall load level needs to be known in HetNets.

In this paper, all the above problems are considered, and a new modular handover algorithm with comprehensive load index is presented. The purpose of new modular HDS is to reduce the computational complexity. In terms of load balancing, the algorithm introduces triangle module fusion operator to estimate the load index comprehensively in 5G HetNets.

The rest of this paper is outlined as follows. In the next section, the proposed modular handover algorithm with comprehensive load index will be discussed. Performance analyses are provided in Sect. 3. Sect. 4 gives the simulation results. Finally, Sect. 5 concludes this paper.

2 Modular handover algorithm with comprehensive load index

2.1 Modular HDS

In the present study of MADM handover algorithm, a traditional monolithic HDS is widely used, which is shown in Fig. 2. All handover parameters are calculated by a single engine in monolithic HDS, then the final score of each candidate wireless network is obtained. Since an increasing number of handover parameters give rise to generating computational complexity and long execution time, it is extremely necessary to design a new intelligent HDS, which can be satisfied with higher demand for 5G HetNets.

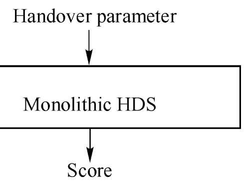


Fig. 2 Monolithic HDS design

Combining handover requirements of network side and user end, the new architecture of modular HDS is shown in Fig. 3. In Fig. 3, Q denote the output of NQ module, P denote the output of UP module. The modular HDS consists of three engines, networks' QoS (NQ) module, UP module and DS module. The handover parameters are categorized into groups according to modular HDS design, and each module is dealt by different algorithms simultaneously, which can reduce the computing time. The three modules jointly determine the final rank of candidate wireless networks.

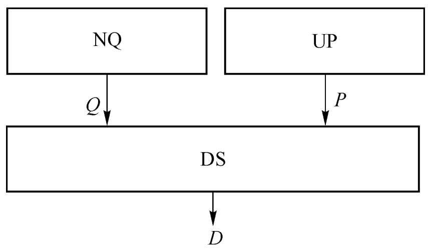


Fig. 3 Modular HDS design

2.2 NQ module

The NQ module determines the QoS provided by each candidate wireless network. Consider UE moving cross HetNets that support L types of traffics, with M available network alternatives and N network parameters. Thus, $T=\{T_1,T_2,...,T_l,...,T_L\}$ is the set of L traffics types, $A=\{A_1,A_2,...,A_i,...,A_M\}$ is the set of network alternatives and $H=\{H_1,H_2,...,H_j,...,H_N\}$ is the set of handover parameters. Each parameter's weight vector with respect to each traffic is given by: $\boldsymbol{W}^l=(W_1^l,W_2^l,...,W_j^l,...,W_N^l)$, $l=1,2,...,L$, where each W_j^l is the weight assigned to the handover parameter H_j by the traffic T_l, which satisfies $0 < W_j^l < 1$ and $\sum_{j=1}^{N} W_j^l = 1$. The NQ module problem can be formulated as a matrix form $\boldsymbol{C}$, which written by:

$$\boldsymbol{C} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1j} & \cdots & c_{1N} \\ c_{21} & c_{22} & \cdots & c_{2j} & \cdots & c_{2N} \\ \vdots & \vdots & & \vdots & & \vdots \\ c_{i1} & c_{i2} & \cdots & c_{ij} & \cdots & c_{iN} \\ \vdots & \vdots & & \vdots & & \vdots \\ c_{M1} & c_{M2} & \cdots & c_{Mj} & \cdots & c_{MN} \end{bmatrix} \tag{1}$$

where c_{ij} indicates the performance value of candidate network A_i with respect to the handover decision parameter H_j.

Because of different measurement units, it's necessary to convert primitive parameters to normalized values.

$$\boldsymbol{B} = (b_{ij});\quad i \leqslant M, j \leqslant N \tag{2}$$

where $b_{ij} = c_{ij} \Big/ \sqrt{\sum_{i=1}^{M} c_{ij}^2}$; $j = 1, 2, \ldots, N$ and it indicates the normalized value of A_i with respect to H_j.

Let Q denote the output of NQ module, then use the idea of technique for order preference by similarity to an ideal solution (TOPSIS) algorithm [15] to get Q. In TOPSIS algorithm, the optimal NQ module is one that is closest to the ideal solution and farthest from the worst case solution. The problem of obtaining the output of NQ module can be solved as follows:

Step 1 Construct the weighted normalized decision matrix $\boldsymbol{V}$ with a certain traffic T_l:

$$\boldsymbol{V} = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1j} & \cdots & v_{1N} \\ v_{21} & v_{22} & \cdots & v_{2j} & \cdots & v_{2N} \\ \vdots & \vdots & & \vdots & & \vdots \\ v_{i1} & v_{i2} & \cdots & v_{ij} & \cdots & v_{iN} \\ \vdots & \vdots & & \vdots & & \vdots \\ v_{M1} & v_{M2} & \cdots & v_{Mj} & \cdots & v_{MN} \end{bmatrix} = \begin{bmatrix} W_1^l b_{11} & W_2^l b_{12} & \cdots & W_j^l b_{1j} & \cdots & W_N^l b_{1N} \\ W_1^l b_{21} & W_2^l b_{22} & \cdots & W_j^l b_{2j} & \cdots & W_N^l b_{2N} \\ \vdots & \vdots & & \vdots & & \vdots \\ W_1^l b_{i1} & W_2^l b_{i2} & \cdots & W_j^l b_{ij} & \cdots & W_N^l b_{iN} \\ \vdots & \vdots & & \vdots & & \vdots \\ W_1^l b_{M1} & W_2^l b_{M2} & \cdots & W_j^l b_{Mj} & \cdots & W_N^l b_{MN} \end{bmatrix} \tag{3}$$

Step 2 Determine the positive ideal V_j^+ and negative ideal V_j^- alternatives. For different candidate network A_i, the positive ideal solution can be calculated as:

$$V_j^+ = \begin{cases} \max\ v_{ij} \\ \min\ v_{ij} \end{cases} \tag{4}$$

In Eq. (4), for a benefit metric (e.g., bandwidth, date rate), V_j^+ is the largest. For a cost metric (e.g., delay, jitter), V_j^+ is the lowest.

And the negative ideal solution can be calculated as:

$$V_j^- = \begin{cases} \min\ v_{ij} \\ \max\ v_{ij} \end{cases} \tag{5}$$

In Eq. (5), for a benefit metric, V_j^- is the lowest. For a cost metric, V_j^- is the largest.

Step 3 Compute the Euclid distance between each alternative from the positive ideal solution is given by:

$$G_i^+ = \sqrt{\sum_{j=1}^{N} \left(V_j^+ - v_{ij}\right)^2} \tag{6}$$

And each alternative from the negative ideal solution is given by:

$$G_i^- = \sqrt{\sum_{j=1}^{N} \left(v_{ij} - V_j^-\right)^2} \tag{7}$$

Step 4 Calculate the relative proximity to the ideal solution. The relative proximity of V_i with regard to V^+ and V^- is given by Q_i and can be calculated as follow:

$$Q_i = \frac{G_i^-}{G_i^- + G_i^+};\quad 0 < Q_i < 1 \tag{8}$$

2.3 UP module

The UP module contains the user individualization preference indicators, which resulting in different performance requirement. Because of abstraction. These indicators can only be resolved by the degree of classifiers, such as high, medium and low. In this part, the fuzzy logic is used to process UP module for several reasons, including intuition and human instinct. Fee and security are the two inputs for UP module, which are used to calculate the output of UP module P. The two handover parameters, each with three fuzzy memberships (low, medium and high) are used. From Ref. [16], the total number of fuzzy rules is 3^2=9. Each rule is assigned a decision output based on expert knowledge. A small portion of the 9 fuzzy rules are shown in Table 1, as an example.

Table 1 Fuzzy rules of UP module

Rule number	Price	Security	P
1	Low	Low	Medium
2	Low	Medium	Medium
⋮	⋮	⋮	⋮
9	High	High	Low

The aggregated fuzzified data is converted into the scalar value, using centroid method, which can be given by:

$$P = \frac{\int x\mu(x)\,\mathrm{d}x}{\int \mu(x)\,\mathrm{d}x} \tag{9}$$

where x is a variable in the scope of fuzzy sets, $\mu(x)$ represents the membership function of fuzzy sets.

2.4 DS module

The DS module is used to obtain the final network rank, which serves as the basis for user switching. The output scores, Q and P, generated by NQ and UP module respectively, are sent to the DS module. Fuzzy logic is also used as the final decision algorithm of the network selection.

Similarly, the two inputs, each with three fuzzy memberships (low, medium and high) are used. The total number of fuzzy rules required for each decision parameter is 3^2=9 [16], some of the 9 fuzzy rules are shown in Table 2.

Table 2 Fuzzy rules of DS module

Rule number	Q	P	D
1	Low	Low	Low
2	Low	Medium	Low
⋮	⋮	⋮	⋮
9	High	High	High

The final scalar score of HetNets, D, is given by:

$$D = \frac{\int y\mu(y)\,\mathrm{d}y}{\int \mu(y)\,\mathrm{d}y} \tag{10}$$

where y is a variable in the scope of fuzzy sets, $\mu(y)$ represents the membership function of fuzzy sets.

2.5 Comprehensive load index

To resolve the problem of load balancing in 5G HetNets, the comprehensive load index of network based on the above modular HDS design is proposed.

For different access systems, the network load can be represented in the rate R [17]. The load for a traffic l in network i can be obtained by $S_i^l = R(l)$. At moment t, the total load for all the traffics in network i can be followed by

$$S_i(t) = \sum_{l=1}^{L} S_i^l \tag{11}$$

As is well known, users are distributed randomly in HetNets and they can move constantly, which often leads to load unbalance of the whole network. Thus, it is necessary to estimate the overall load of the candidate networks. Let $\phi(t)$ denote the overall load factor. At moment t, the $\phi(t)$ can be calculated as

$$\phi(t) = \frac{\sum_{i=1}^{M} S_i(t)^2}{M\sum_{i=1}^{M}\left(S_i(t)\right)^2} \tag{12}$$

where $\phi(t) \in (0,1)$.

Furthermore, the available load is still an important element for a single network. Let $\psi(t)$ denote the available load, which can be expressed as

$$\psi(t) = \frac{\sum_{i=1}^{M}\left(1 - \frac{S_i(t)}{R_i^{\max}}\right)}{M} \tag{13}$$

where $\psi(t) \in (0,1)$, and $R_i^{\max}$ is the maximum rate in network i.

Considering $\phi(t)$ or $\psi(t)$ only cannot balance the whole network load, in the scheme, $\phi(t)$ and $\psi(t)$ are integrated to maximize load level. Triangle module fusion operator is a theoretical method of introducing artificial intelligence, which has higher accuracy for the integration. By using the triangle module fusion operator, the comprehensive load index $f(\phi(t),\psi(t))$ is given by the following formula:

$$f(\phi(t),\psi(t)) = \frac{\phi(t)\psi(t)}{1-\phi(t)-\psi(t)+2\phi(t)\psi(t)} \tag{14}$$

The load threshold α is set up to measure the load condition of whole network in this paper, and it compare with $f(\phi(t),\psi(t))$ before perform a handover.

From user's perspective, the optimal network is always the ideal choice for handover, however, it cannot provides good QoE for users anymore because of heavy load. In order to avoid this phenomenon of handover, we optimize the hand over process according to the comprehensive load index $f(\phi(t),\psi(t))$ based on foregoing modular handover algorithm.

The aforementioned algorithm in this paper can be concluded as follow.

Initalisation// Initiate handover
for all candidate network do
  Examine date rate, latency, jitter, packet loss
  Calculate NQ module
  Examine price, security
  Calculate UP module
then
  Calculate DS module
  Rank the network list based on D
  Choose the network i that has the largest D
  Calculate comprehensive Network Load Index $f(\phi(t),\psi(t))$
  if the network i satisfied the condition that $f(\phi(t),\psi(t)) < \alpha$ then
      Access to network i
    else if the network j that has the second largest D value satisfied then
      if its $f(\phi(t),\psi(t)) > \alpha$ then
        Access the network i
      else
        Access the network j
      end if
    else
      end handover
    end if
end if
Update the network information
end for

3 Performance analysis

3.1 User satisfaction

We have mentioned that different traffics with different weight vector $\boldsymbol{W}^l$ in Sect. 2. Users with different service grades also need a weight representing the relative importance of other users, which relates to user satisfaction. $U = \{U_1, U_2, ..., U_k, ..., U_K\}$ is defined as the set of users. For simplicity, users are divided into two categories in this paper, very important person (VIP) users and ordinary users, their weight can be denoted by δ and θ, respectively. In general, the degree of importance of VIP users are greater than ordinary users, namely $0<\theta<\delta<1$ and $\theta+\delta=1$.

According to the final value $D(i)$ for ith network, $A=\{A_1, A_2, ..., A_m, ..., A_M\}$ is defined to represent the ranking result of candidate network. For the VIP users' identity, the first m networks can meet their requirements, and for the ordinary users' identity, they access to corresponding $M-m$ network because of priority system.

Definition 1 The VIP user satisfaction can be represented as:

$$Z(i,k)=\begin{cases}\dfrac{1-\delta+D(i)}{2}; & A_i\in\{A_1, A_2, ..., A_m\}\\ \varepsilon; & A_i\in\{A_{m+1}, ..., A_M\}\end{cases} \tag{15}$$

where $U_k \in U$ and $\varepsilon \to 0$ means last $M-m$ network cannot provide the resources required by the VIP users' application, thus causes very low satisfaction extent when VIP users connect to them.

Definition 2 The ordinary user satisfaction can be represented as:

$$Z(i,k)=\begin{cases}1; & A_i\in\{A_1, A_2, ..., A_m\}\\ \dfrac{1-\theta+D(i)}{2}; & A_i\in\{A_{m+1}, ..., A_M\}\end{cases} \tag{16}$$

From proposed algorithm, in the corresponding network set $\{A_1, A_2, ..., A_m\}$, VIP users cannot access to optimal network i because of comprehensive load index. When they handover to suboptimal network i', the user's satisfaction changes as follow:

$$Z(i',k)=\rho Z(i,k) \tag{17}$$

Lemma 1 The user satisfaction is convergence, namely $0<\rho<1$.

Proof From Eq. (15), Eq. (17) can be translated into the following result:

$$\frac{1-\delta+D(i')}{2}=\rho\frac{1-\delta+D(i)}{2} \tag{18}$$

From Eq. (18), $D(i')$ can be derived in the following way:

$$D(i')=\rho[1-\delta+D(i)]+\delta-1 \tag{19}$$

Obviously, $0< D(i') < D(i) <1$.

Then, $0<\rho[1-\delta+D(i)]+\delta-1<D(i)<1$.

The proven result which obtained through calculating above equation as following:

$$0<\frac{1-\delta}{1-\delta+D(i)}<\rho<\frac{1-\delta+D(i)}{1-\delta+D(i)}=1 \tag{20}$$

Similarly, for the ordinary users in the corresponding network set $A=\{A_m, A_{m+1},..., A_M\}$, the Eq. (21) is also available

$$0<\rho<1 \tag{21}$$

The user satisfaction $Z(i,m)$ will be convergence when they switch from optimal network to suboptimal network through proposed algorithm. Still, maximum load balance of actual network environment is often achieved at the expense of user satisfaction.

3.2 Handover overhead

In the process of the communication, the handover overhead is considered as an important factor.

Lemma 2 The handover overhead O of proposed algorithm is

$$O=\sum_0^{\infty} kp_k + \frac{p_\mu}{(1-p_\mu)^2} \tag{22}$$

Proof The handover overhead consist of two parts, including network reselection signaling overhead O_1 induced by the arrival of new users and network reselection signaling overhead O_2 induced by the changing of network condition.

We assumed that each user's arrival rate obey a Poisson distribution, $(\lambda_1, \lambda_2, ..., \lambda_n)$, and total users' arrival rate conform the Poisson distribution of $(\lambda_1+\lambda_2+\cdots+\lambda_n)$. The probability of the kth users' arrival during a particular period t can be expressed by:

$$p_k=\frac{(\lambda t)^k \mathrm{e}^{-\lambda t}}{k!}; \quad \lambda=\lambda_1+\lambda_2+\cdots+\lambda_n \tag{23}$$

Thus, network reselection signaling overhead O_1 induced by the arrival of new users, which is given by:

$$O_1=\sum_0^{\infty} kp_k \tag{24}$$

Generally, the network shape is usually similar to circle, and t_2 is defined as residence time. From Ref. [2], we can obtain that t_2 takes on the exponent distribution with $1/\mu$, and the probability density function of t_2 is $f(t_2)=\mu\exp(-\mu t_2)$. When $t_2<t$, during the time interval $(0,t)$, users change their location only in the current network.

$$p_\mu=p[t_2<t]=\int_0^t \mu \mathrm{e}^{-\mu t_2}\mathrm{d}t_2=1-\mathrm{e}^{-\mu t} \tag{25}$$

where $\mu=E[v]d/(\pi s)$. d, s are used to represent the perimeter and the area of a circular network respectively, while $E[v]$ is users' average speed.

Due to k users leave the current network, network reselection signaling overhead O_2 induced by the changing of network condition is given by:

$$O_2=\sum_{k=1}^{\infty} kp_\mu^k \approx \frac{p_\mu}{(1-p_\mu)^2} \tag{26}$$

By Eqs. (24) and (26), we have the following:

$$O=O_1+O_2=\sum_0^{\infty} kp_k + \frac{p_\mu}{(1-p_\mu)^2} \tag{27}$$

From Eq. (27), the proposed algorithm's handover overhead are greatly related to user speed. When users keep moving with the increasing of $E[v]$, μ will be increased, which leads to the p_μ enlargement. Thus, for high speed users, it's better to connect to the network with larger coverage radius, which can avoid frequent handover.

4 Simulation and results

In this section, we evaluate the performance of the proposed handover algorithm using Matlab environment. The simulation scenario of 5G HetNets topology consist of 5G (A_1), WLAN (A_2), LTE (A_3) and WiMax (A_4) which is shown in Fig. 4.

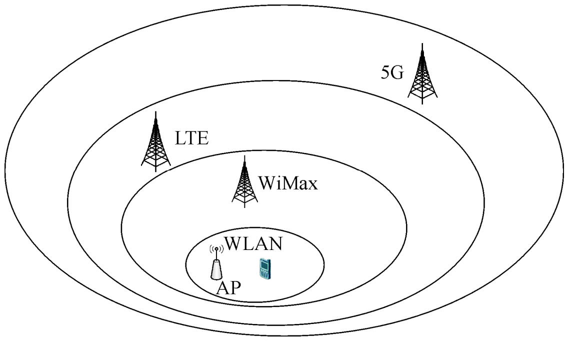


Fig. 4 Simulation scenario of HetNets

The NQ parameters of 5G are estimated according to current development status while the rest of networks' NQ parameters come from existing standards. The UP parameters of whole network are obtained through the analysis of operator's survey results. After normalization, these numerical values are presented in Table 3. In realistic wireless communications, the dynamics of NQ parameters such as date rate (H_1), delay (H_2), jitter (H_3), packet loss (H_4) are very complex. For simplicity, they are assumed change in less than 10%.

Table 3 Simulation parameters

Network	Date rate	Delay	Jitter	Loss	Price	Security
5G	0.767	0.651	0.526	0.15	Medium	High
WLAN	1.000	0.699	0.593	0.25	Low	Medium
LTE	0.434	1.000	0.751	0.40	High	Medium
WIMAX	0.466	1.000	0.742	0.40	Medium	Low

Firstly, we differentiate four types of traffic based on the 3rd generation partnership project (3GPP) agreement in 5G HetNets ie: conversation (T_1), video streaming (T_2), interaction (T_3) and background (T_4). UE with different traffics will have different requirements to the same candidate network. Thus, the DS module value in multiple traffics scenarios, namely 5G, WLAN, LTE, WIMAX, is

$$D_{T_1} = \{0.635\ 0, 0.622\ 3, 0.390\ 0, 0.155\ 0\}$$

$$D_{T_2} = \{0.637\ 7, 0.653\ 4, 0.277\ 0, 0.351\ 8\}$$

$$D_{T_3} = \{0.665\ 3, 0.738\ 6, 0.434\ 9, 0.264\ 6\}$$

$$D_{T_4} = \{0.687\ 1, 0.654\ 2, 0.390\ 0, 0.251\ 5\}$$

According to the final score, for conversation traffic demand, the order of networks are 5G, WLAN, LTE and WIMAX. Similarly, for interaction traffic demand, the optimal networks are WLAN, 5G, LTE and WIMAX, in that order. The result of network selection for four traffics as shown in Fig. 5.

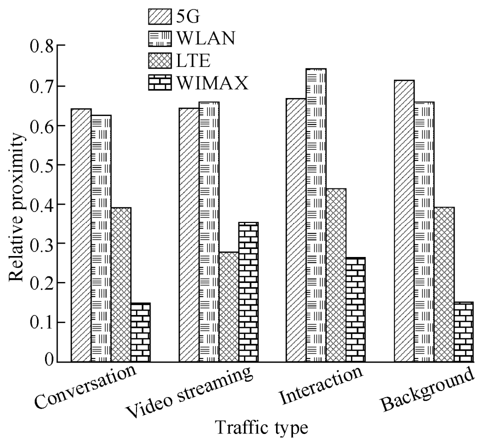
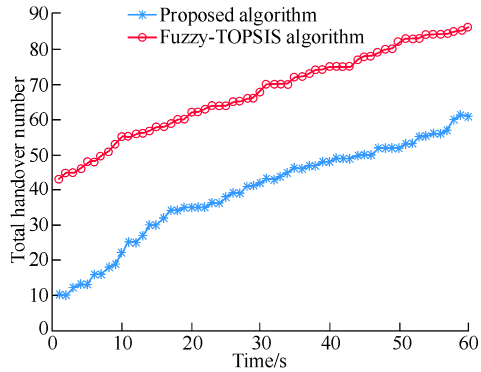


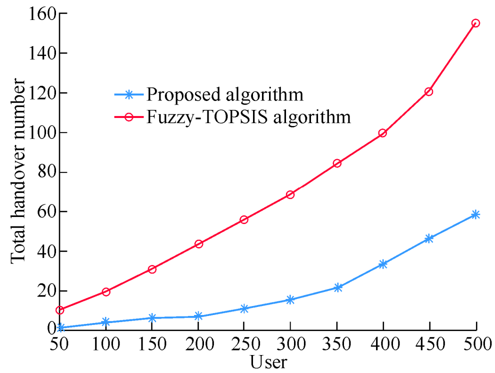
Fig. 5 Candidate network selection for four traffics

Secondly, we evaluate the performance of our proposed handover algorithm, and compare it with traditional fuzzy TOPSIS algorithm [18]. In our simulations, users are assumed to move across the 5G HetNets with 1.5 m/s and the running cycle is 1 min. The threshold for comprehensive load index is set up to $f = 0.8$.

Fig. 6 shows that the total number of handover of the proposed algorithm is much smaller than that of the fuzzy TOPSIS algorithm. The reason is that traditional algorithm compares D for different networks constantly, and always choose the optimal network to access without consider the load balance, which resulting in frequent handover in 5G HetNets environment, even frequent unnecessary handover.



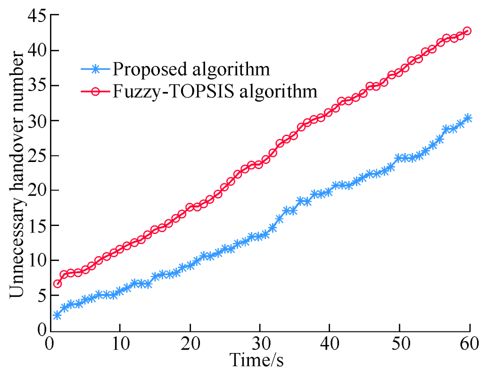
(a) During running cycle



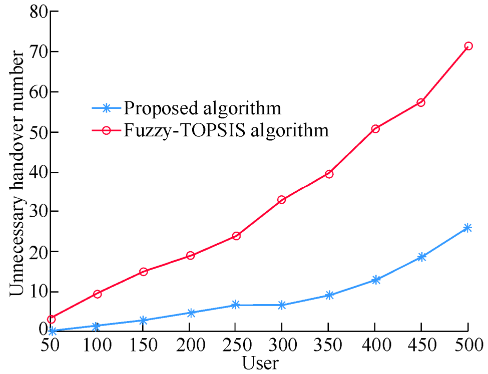
(b) Among different users

Fig. 6 The total number of handover

Next we are concerned with unnecessary switching frequency during simulations. In this paper, the unnecessary handover means that: after handover execution, users switch back to the original network in next seconds; the switching from light load network to overloaded network. A finding from Fig. 7 is that the proposed algorithm brings great improvement on unnecessary handover.



(a) During running cycle



(b) Among different users

Fig. 7 The number of unnecessary handover

Moreover, under both algorithms, the unnecessary handoff increases with user, while under proposed algorithm, it can meet the demand of real time monitoring network load, inhibited some failure or unnecessary handover because of the comprehensive load index. Hence, the proposed algorithm can reduce the unnecessary handoffs and avoid the ping-pong effect.

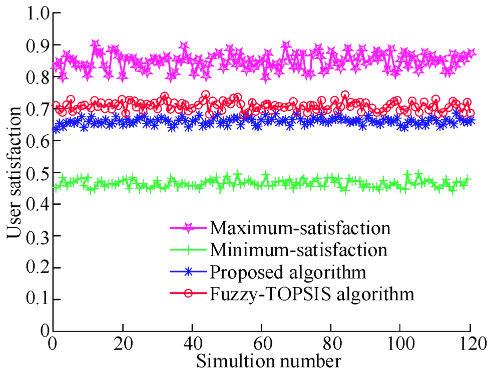


Fig. 8 Average user satisfaction

To verify the impact of this algorithm on user satisfaction, the average user satisfaction is defined as follow:

$$Z_{\mathrm{u}} = \frac{1}{K}\sum_{k=1}^{K} Z(i,k);\quad i = 1,2,\ldots,M \tag{28}$$

where K is the number of users, then we compare Z_{u} among maximum satisfaction algorithm, minimum satisfaction algorithm, the proposed algorithm and traditional fuzzy TOPSIS algorithm. The maximum satisfaction algorithm ensures that users can always access to the optimal network to maximum user satisfaction, without considering the extra issue in the process of handover, while users access to the worst one in minimum satisfaction algorithm. From Fig. 8, the maximum user satisfaction is about 0.85 and the minimum user satisfaction maintains about 0.50.

The proposed algorithm can close to maximum user satisfaction, a little lower than fuzzy TOPSIS algorithm because of comprehensive load index. It shows that the load balance of proposed algorithm is at the expense of user satisfaction.

Fig. 9 illustrates the execution time between the proposed algorithm and fuzzy TOPSIS algorithm. The proposed algorithm is based on modular HDS design while the fuzzy TOPSIS algorithm is based on traditional monolithic HDS design. This calculation was carried out on a 3.20 GHz Inter Core i5 Duo with 8 GB memory. With the same number of handover parameters, the performance of two algorithms, in terms of t, is compared in Fig. 9. The results show a reduction of almost 1.4 s in the value of t, which suggest that a significant improvement can be achieved by modular HDS design.

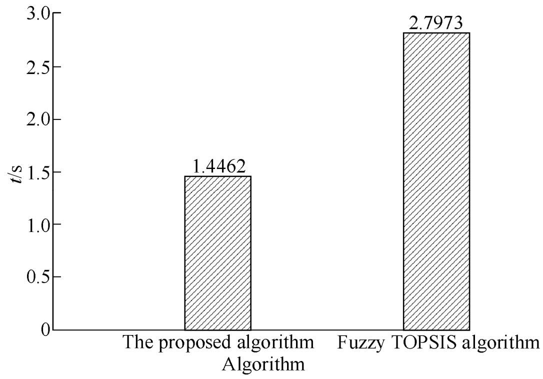


Fig. 9 Comparison of execution time for different algorithms

5 Conclusions

In this paper, a novel handover algorithm based on modular HDS design and comprehensive load index is studied. The handover parameters, serving as the basis for network selection, are classified into NQ module, UP module and DS module. Then network load level is obtained by using triangle module fusion operator. Simulation reveals that, with the proposed algorithm, the total number of handover or unnecessary handover is reduced significantly, and the execution time of the proposed algorithm is also decreases about 1.4 s. Moreover, the user satisfaction maintains a higher level.

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