QoE-Based Dynamic Resource Allocation Algorithm of 5G Network Slicing

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Abstract. The slicing technology can meet the diversified and personalized service needs of 5G networks, schedule virtual networks dynamically and improve the operation efficiency of the network. The dynamic resource allocation algorithm among slices is the key for the application of slicing technology, which has also become a research hotspot in recent years. However, the current dynamic resource allocation algorithm of 5G network slicing has many problems such as insufficient fairness, difficulty in ensuring user satisfaction and low resource utilization rate, etc. Under the circumstances of a wide variety of 5G services, it is difficult to meet the needs of user satisfaction under differentiated service conditions only from the perspective of the network. From the perspective of Quality of Experience (QoE), a QoE evaluation system for 5G network is constructed, and a QoE-based dynamic resource allocation algorithm of 5G network slicing on the basis of this system is built in this research. The results of the simulation experiments indicate that the algorithm has significant effect in improving QoE of 5G communities, and it also has good performance in improving the resource utilization rate in the communities.

Keywords: QoE · 5G · Slice · Resource allocation · Particle swarm optimization

1 Introduction

With the development of the fifth-generation mobile communication technology (5G), compared with 4G, in addition to the increase in speed, 5G will support a wider variety of services, such as the applications including virtual reality, augmented reality, autonomous driving, remote surgery, and fully-automatic factory, etc. In order to adapt to the emerging and diverse application scenarios, the International Telecommunications Union - Radio Communications Sector (ITU-R) defined the following three application scenarios for the future of 5G [1], namely enhance Mobile Broadband (eMBB), ultra Reliable& Low Latency Communication (uRLLC), and massive Machine Type Communication (mMTC). The Next Generation Mobile Network Alliance proposes to slice

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the network with the use of virtualization, each slice being logically isolated but sharing the same physical infrastructure. The network slicing service is a variety of services with similar characteristics, so a slice can consist of one or more sub-slices.

The slicing technology can meet the diversified and personalized service requirements of 5G network [2], schedule virtual networks dynamically and improve network operation efficiency. The resource allocation algorithm among slices is the key for the application of slicing technology. Yang proposed an opportunity-based resource allocation scheme of spectrum sharing wireless virtualization [3]. However, the balance among slices is not fully considered in this scheme [4]. Kamel proposed a rapid and inspirational physical resource block allocation method [5]. However, the Quality of Service (QoS) of different services is not fully considered in this method. Yang proposed a scheduling algorithm which can adjust user priorities adaptively to optimize the packet loss rate and throughput. However, the different requirements of network slicing and different over-services are not fully considered [6]. Jia proposed an algorithm based on proportional fair resource allocation among slices [7], which focuses on the fairness problem among slices. However, different needs of different slices are not fully considered. Tang proposed a resource allocation algorithm that can maximize the network utility of slices [8], which can distinguish different slices according to the differentiation. However, the fairness among users is barely considered. Chen proposed a dynamic resource adjustment strategy based on the 5G network slicing of improved greedy algorithm [9], which has high resource utilization rate and throughput. However, the average QoE level it can reach is still not high enough.

The improvement of the throughput, resource utilization rate or quality of service (QoS) of the 5G network from the perspective of network are all considered in the above mentioned algorithms, but it is difficult to balance them with insufficient consideration or too much consideration. In fact, the essence of the network is to serve the users, and the user experience is the ultimate goal of the network as well as the survival way of the operators. More and more attention has been paid to QoE (Quality of Experience) [10], as an important indicator of user experience. QoE is taken as the core optimization goal, a QoE evaluation system for 5G network is built, and a QoE-based dynamic resource allocation algorithm of 5G network slicing in this evaluation system is built in this research to ensure the user satisfaction requirement under 5G differentiated business conditions.

2 QoE Based Evaluation System Model

The following are briefly introductions of the image registration principle, image registration method, differential evolution algorithm and other related background knowledge.

All the services and users in a 5G community are taken as the research objects in this paper. The wireless resources of the 5G community are divided into three slices, namely eMBB, uRLLC and mMTC according to the three application scenarios defined by ITU-R, as shown in Fig. 1. Due to the characteristics of the three kinds of services and the dynamic changes of users, the wireless resource scheduling among the three slices needs to be adjusted dynamically in real time according to the service characteristics and the number of users so as to meet the optimization effect of network throughput, resource utilization rate, QoS, QoE and other parameters.

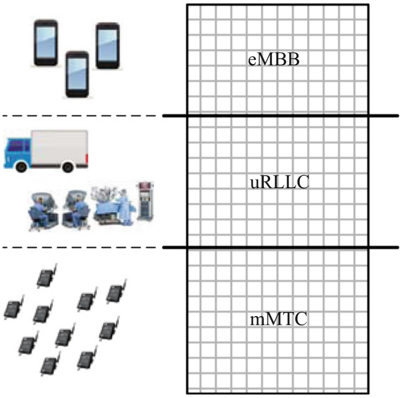

Fig. 1. 5G network slice model

With the increasing attention of operators being paid to customer satisfaction, all network indicators must serve network satisfaction, and network satisfaction is generally measured by QoE. A QoE-based evaluation system will be built in the following part, as shown in Fig. 2.

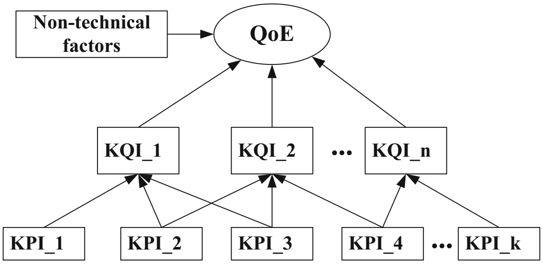

Fig. 2. QoE evaluation system

QoE is influenced by non-technical factors (fees, user subjective factors, etc.) and several KQI (Key Quality Index). Non-technical factors are not discussed in this paper and are represented by a random number. The functional relationship is as follows:

$$\text{QoE} = A^* \text{ rand } + B^*\left(W_1^* KQI_e + W_2^* KQI_u + W_3^* KQI_m\right) \tag{1}$$

where, A and B are constants, taking values of 0.3 and 0.7 respectively, and rand is a random number in the range [0, 1]. KQI_e, KQI_u and KQI_m are the KQIs of eMBB, uRLLC, and mMTC services respectively, and W, W_2 and W_3 are the KQI right values of the three kinds of services. Each KQI is determined by multiple KPIs (Key Performance Indicators). KQI and KPI have complicated mapping relationship and need to be calculated with systematical analysis.

2.1 eMBB Service Analysis

For eMBB service, the number of data of the users is very large and the requirement of transmission rate is high. The KPI related to it has a data transmission rate V and a random access success rate RA, then there is:

$$KQI_e = We_1 * P_V + We_2 * P_{RA} \tag{2}$$

where, W_{e_1} and W_{e_2} are the weights of the KPIs of the transmission rate V and the random access success rate RA respectively. P_V is the function of the transmission rate V and the allocated resource block of the eMBB slicing. P_{RA} is the function of the random access success rate RA and allocated resource block of the eMBB slicing. Under the circumstances that other conditions are not changed, the data transmission rate V has a negative exponential relationship with allocated resource block of the eMBB slicing, and the random access success rate RA and the allocated resource block of the eMBB slicing have a linear relationship within a certain range, namely:

$$P_V = -a^{-Be} + 1, \; a = 5^{\frac{1}{Xe+Be\_basic}} \tag{3}$$

$$P_{RA} = \begin{cases} 0, & Be \le Xe^{*}Be\_\text{basic} \\ \frac{Be}{Ae^{*}Be\_\text{Basic}} - \frac{Xe}{Ae}, & Xe^{*}Be\_basic < Be < (Xe + Ae)^{*}Be\_basic \\ 1, & Be \ge (Xe + Ae)^{*}Be\_\text{basic} \end{cases} \tag{4}$$

where, Be_basic is the minimum number of resource blocks required for the eMBB users. Xe is the current number of users of the eMBB service. Ae is the number of users to be accessed by the eMBB service.

2.2 uRLLC Service Analysis

For uRLLC service, the strong reliability of the service is required, and the network delay rate is low. The related KPIs have packet loss rate PL, delay rate TD, and access success rate RA, then there is:

$$KQI_u = Wu_1 * P_{PL} + Wu_2 * P_{TD} + Wu_3 * P_{RA} \tag{5}$$

where, W_{u_1}, W_{u_2} and W_{u_3} are the weights of KPIs of the transmission rate V being delayed TD and the random access success rate RA. P_{PL} is the function of packet loss rate and Bu is the allocated resource block of the uRLLC slicing. P_{TD} is the function of the transmission experiment TD and Bu, the allocated resource block of the uRLLC slicing.P_{RA} is the function of the random access success rate RA and Bu, the allocated resource block of the uRLLC slicing. Under the circumstances that other conditions are not changed, the packet loss rate PL and the transmission delay TD are in a negative exponential relationship with Bu, the allocated resource block of the uRLLC slicing. The random access success rate RA is linear with Bu, the allocated resource block of the uRLLC slicing, namely:

$$P_{PL} = -b^{-Bu} + 1, \quad b = 20^{\frac{1}{Xu^{*}Bu\_\text{basic}}} \tag{6}$$

$$P_{TD} = -c^{-Bu} + 1, \quad c = 10^{\frac{1}{Xu^{*}Bu\_b_{asic}}} \tag{7}$$

$$P_{RA} = \begin{cases} 0 & , Bu \le u^{*}Bu\_\text{basic} \\ \frac{Bu}{Au^{*}Bu\_Basic} - \frac{Xu}{Au} & , Xu^{*}Bu_{\_basic} < Bu < (Xu + Au)^{*}Bu\_\text{basic} \\ 1 & , Bu \ge (Xu + Au)^{*}Bu_2 \text{ basic} \end{cases} \tag{8}$$

where, *Bu_basic* is the minimum number of resource blocks required for the URLLC users. *Xu* is the current number of users of the eMBB service. *Au* is the number of users to be accessed by the eMBB service.

2.3 mMTC Service Analysis

For mMTC service, the high access success rate of the service is required, and the KPI related to it has the access success rate *RA*, then there is:

$$KQI_m = W_m * P_{RA} \tag{9}$$

where, W_m is the weight of the access success rate *RA*. The random access success rate *RA* and *Bm*, the allocated resource block of the mMTC slicing are proportional to a certain range, namely:

$$P_{RA} = \begin{cases} 0 & , Bm \le Xm * Bm - basic \\ \frac{Bm}{Am^{*}Bm\_basic} - \frac{Xm}{Am} & , Xm * Bm \text{ basic } < Bm < (Xm + Am)^{*}Bm\_basic \\ 1 & , Bm \ge (Xm + Am) * Bm\_\ basic \end{cases} \tag{10}$$

where, *Bm_ basic* is the minimum number of resource blocks required for the uRLLC users. *Xm* is the current number of users of the eMBB service. *Am* is the number of users to be accessed by the eMBB service.

Then, the dynamic resource allocation algorithm of 5G network slicing is constructed according to the evaluation system, and the optimization of the QoE can be achieved by scheduling by the optimization of the network slicing scheduling.

3 QoE-Based Dynamic Resource Allocation Algorithm of 5G Network Slicing

Aiming at the problems of huge computation cost and low registration efficiency of INPA in medical image registration, this paper uses DE algorithm to optimize the nearest point search process of INPA, and improves the global search ability of the algorithm by improving the mutation strategy and selection strategy of DE algorithm to avoid falling into local optimization.

In the QoE evaluation system mentioned above, under the circumstances that the number of the users in different services is stable, the number of resource blocks allocated to the eMBB, uRLLC, and mMTC services determines the overall QoE quality of the community, so the key to construct a set of QoE-based dynamic resource allocation scheme is how to allocate the number of resource blocks that are reasonably allocated for the eMBB, uRLLC, and mMTC services. If the actual number of users changes dynamically, the real-time requirements of the resource scheduling algorithm are higher.

In recent years, Particle Swarm Optimization (PSO) [11, 12] algorithm has been widely used because of its advantages of easy implementation, high precision and fast convergence. PSO algorithm is an evolutionary computational technique that was put forward by Dr. Eberhart and Dr. Kennedy in 1995 from a behavioral study of predation of birds. The algorithm was originally a simplified model inspired by the regularity of the activity of the bird clusters, and then built with the use of group intelligence. Based on the observation of the activity behavior of animal clusters, PSO algorithm uses the individual's sharing of information in the group to make the movement of the whole group generate an evolution process in the problem solving space from disorder to order, so as to obtain the optimal solution [13].

First, the PSO algorithm generates the random population P in the vector space that can satisfy the constraints. Second, it calculates the local optimal solution *gbest* of the population, and then calculates the global optimal solution *gbest*. Finally, the new population P' is obtained by the iterative algorithm until the satisfied constraint send. The PSO iterative algorithm is as follows [14]:

$$\begin{cases} v = w \cdot v + c_1 \cdot \ rand \ \cdot (pbest \ - P) + c_2 \cdot \ rand \ \cdot (\, gbest \ - P) \\ \qquad\qquad\qquad P' = P + v \end{cases} \tag{11}$$

where, v is the evolution speed of the particle group, w is the relationship weight, c_1 and c_2 are the acceleration factors, and *rand* is the random number in the range [0, 1].

Based on its advantages of easy implementation, high precision and fast convergence, it is feasible to apply PSO algorithm to QoE-based dynamic resource allocation of 5G network slicing. The algorithm description is the initial allocation based on the basic needs of the service and the secondary allocation based on QoE, as shown in Fig. 3:

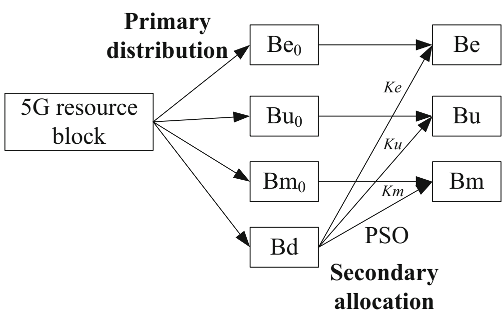

Fig. 3. The flow chart of secondary allocation of 5G network resource

In the initial allocation, basic resource blocks Be_0, Bu_0, Bm_0 are allocated to the eMBB, uRLLC and mMTC services according to the number of required basic resource blocks for different services, and the remaining resource blocks Bd are reserved for secondary allocation.

$$\begin{cases} Be_0 = Xe^{*}Be\_basic \\ Bu_0 = Xu^{*}Bu\_basic \\ Bm_0 = Xm * Bm\_basic \end{cases} \tag{12}$$

In the secondary allocation, the PSO algorithm is used to optimize the allocation of Bd. The algorithm steps are described as follows:

Step1: Generate a randomly assigned population of Bd;

Step2: Solve the QoE optimal solution *pbest* of the current population;

Step3: PSO iterative algorithm is used to solve QoE global optimal solution *pbest*;

Step4: PSO iterative algorithm;

Step5: The judgment ends.

In the above mentioned steps, $P = [B_1, B_2, \ldots, B_{20}]$, $B_i = [Be_i, Bu_i, Bm_i]'$. The PSO algorithm can be used to quickly solve the optimal allocation scheme of Bd, so as to provide a real-time solution for ensuring the QoE quality of the community.

4 Simulation Results and Analysis

To test the effectiveness of QoE-based dynamic resource allocation algorithm of 5G network slicing, comparative simulation experiment was conducted among the QoE-based dynamic resource allocation algorithm of 5G network slicing, static scheduling algorithm and carrier-to-interference ratio scheduling algorithm from the three dimensions of RB allocation, QoE quality and resource utilization rate in this research. The running effect of three scheduling algorithms in a typical 5G community was simulated, and the experimental parameters were set as follows (Tables 1, 2, 3, 4):

Table 1. User model parameters

Symbol	Parameter name	Value
Xe	Initial number of users of eMBB	80
Xu	Initial number of users of uRLLC	20
Xm	Initial number of users of mMTC	160
Ae	Number of users to be accessed of eMBB	22
Au	Number of users to be accessed of uRLLC	6
Am	Number of users to be accessed of mMTC	30

Table 2. Service parameters of the community

Symbol	Parameter name	Value
B	The total number of resource blocks that can be scheduled by the community	12000
Be_basic	Minimum number of resource blocks required for single-user eMBB services	100
Bu_basic	Minimum number of resource blocks required for single-user uRLLC services	20
Bm_basic	Minimum number of resource blocks required for single-user mMTC services	8

Table 3. QoE calculation parameters

Symbol	Parameter name	Value
A	User subjective influence factor	0.3
B	KQI influence factor	0.7
W_1	eMBB service weight	Calculated by *Xe, Xu and Xm*
W_2	uRLLC service weight	Calculated by *Xe, Xu and Xm*
W_3	mMTC service weight	Calculated by *Xe, Xu and Xm*
We_1	KPI weight of data transmission rate of eMBB service	0.8
We_2	KPI weight of random access success rate of eMBB service	0.2
Wu_1	KPI weight of packet loss rate of uRLLC service	0.4
Wu_2	KPI weight of transmission delay of uRLLC service	0.4
Wu_3	KPI weight of random access success rate of uRLLC service	0.2

Table 4. Parameters of PSO algorithm

Symbol	Parameter name	Value
W	Inertia weight	0.8
c_1	Acceleration factor	2
c_2	Acceleration factor	2

According to the parameter settings, the simulation experiment of the dynamic scheduling allocation algorithm of 5G community network slicing was conducted in MATLAB. The RB resource allocation diagram based on QoE scheduling, maximum carrier-to-interference ratio scheduling and static scheduling was obtained, as shown in Fig. 4. It can be seen that all three algorithms allocate most resources to eMBB service users who need a large amount of bandwidth. Two dynamic scheduling algorithms are more flexible than the resource scheduling of static scheduling algorithms.

The simulation experiment also calculated the QoE value of the community under the three algorithm RB allocation schemes so as to reflect the overall user satisfaction in the community under various resource allocation schemes. The variation curve of community-level QoE with the number of users in the community in the three resource scheduling algorithms is as shown in Fig. 5. It can be seen from Fig. 5 that the overall QoE quality of the community decreases with the increase of the number of users. However, the community-level QoE of the QoE based allocation scheme is significantly higher than that of the static scheduling algorithm and the maximum carrier-to-interference ratio scheduling algorithm. It shows that the QoE-based dynamic resource allocation algorithm of 5G network slicing has a significant effect in improving user satisfaction.

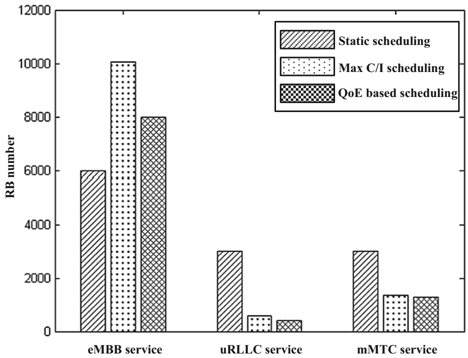

Fig. 4. RB resource service allocation map of 5G network

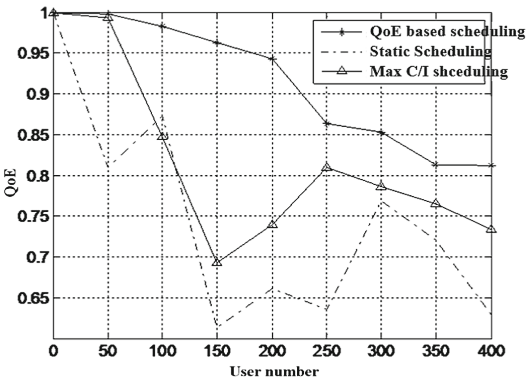

Fig. 5. The variation curve of QoE of 5G community with the number of users

Resource utilization rate is also an important indicator to evaluate the 5G resource scheduling algorithm. The variation curve of the resource utilization rate of the three algorithms with the number of users is shown in Fig. 6. It can be seen that the overall resource utilization rate of the community increases with the increase of the number of users. When the number of users is small, the resource utilization rate of the maximum carrier-to-interference ratio scheduling algorithm is low, and the resource utilization rate of the QoE based scheduling algorithm is the highest.

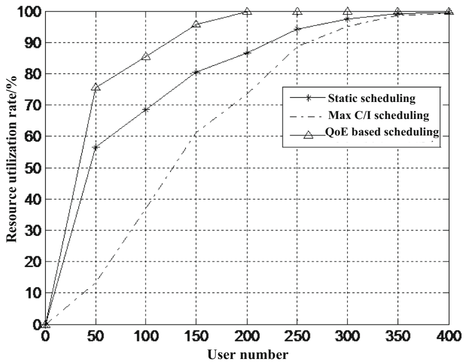

Fig. 6. The variation curve of the resource utilization of 5G community with the number of users

The above experimental results show that the QoE-based resource scheduling algorithm of 5G network can schedule dynamically according to the user model. The community-level QoE of the proposed algorithm has significant advantages over that of static scheduling algorithm and maximum carrier-to-interference ratio scheduling algorithm, and it also have the highest resource utilization rate.

5 Conclusion and Future Work

Under the circumstances of a wide variety of 5G services, it is difficult to meet the needs of user satisfaction under differentiated service conditions only from the perspective of network. A QoE evaluation system for 5G networks is constructed from the perspective of quality of experience (QoE) of users, and a QoE-based dynamic resource allocation algorithm of 5G network slicing based on this system is built in this paper. The simulation experiments show that the algorithm has a significant effect in improving the user experience quality of 5G communities, and it also has well performance in improving the resource utilization rate of the community.

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