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A Graph Theory Based Improved Spectrum Allocation Algorithm

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Abstract. *In order to solve the problem that the color spectrum allocation algorithms of graph theory has not fully consider the cognitive user actual bandwidth, a spectrum allocation based on user priority algorithm is proposed in this paper. The algorithm considers the cognitive user bandwidth requirements. By introducing the idle spectrum and user request two time factor, set user priority function, while the spectrum for secondary distribution can maximize meet user needs. Through the simulation experiment proves that the algorithm not only retains the original CSGC algorithm performance, and greatly improves the spectrum utilization.*
Keywords: Graph theory, CSGC, Priority function, Customer satisfaction

1. **Introduction.** With the rapid development of wireless communication technology and increasing wireless users, there is growingly lack of spectrum resources. As frequency spectrum resource is non-renewable, how to make better use of the existing spectrum resources has become a problem people need to solve urgently[1].The concept of cognitive radio effectively solves the problem of the shortage of spectrum resources and improves the spectrum utilization.

At present, there are many theories concerning the classical algorithm of spectrum allocation: game theory, graph theory and the bidding. The graph coloring algorithm has better flexibility and higher practicability, therefore, it has caught the attention of more researchers. In [2], the authors proposed a spectrum allocation model of a list of coloring (List-coloring, LC) algorithm. LC algorithm uses the method of open spectrum access with the goal of the maximum number of spectrum allocation under the condition of existing interference constraints. In [3], the authors presented spectrum allocation model of a color-sensitive graph coloring (color sensitive graph coloring, CSGC) algorithm. Considering the differences and interruption in spectrum efficiency, CSGC spectrum allocation algorithm obviously reduces the interference and improves the network throughput and makes the system get the maximum use of bandwidth. In [4], the authors proposed a parallel algorithm. The graph is made into a plurality of sub-graphs, which are colored simultaneously to shorten the period of spectrum allocation in order to make it adapt to the rapid changes of external wireless communication environment.

The above allocation algorithms are mainly the research on the maximization of number of spectrum allocation, but are lack of considering actual user's bandwidth requirements, which turns out that users who need small bandwidth are allocated to a larger spectrum while users who need large bandwidth are allocated to a smaller spectrum. It can't better meet the needs of users and then results in a serious waste of spectrum resources. Therefore, on the basis of the graph theory, this paper puts forward spectrum allocation algorithm based on user priority. The algorithm introduces two time factors that are respectively called idle spectrum and user demand. When the secondary spectrum distribution takes place, it can meet the farthest demands of users by setting the function of the cognitive users. From the perspectives of resource allocation and users' needs, it not only improves the fairness of spectrum allocation and efficiency of spectrum but also optimize performance of the system.

2. Overview of the traditional algorithm CSGC.

2.1. Mathematical description of the algorithm model CSGC.

Color sensitive graph coloring algorithm contains idle spectrum matrix, beneficial matrix, interference matrix, and noninterference matrix. Besides those matrixes, the paper also presents the idle time spectral matrix and user demands time matrix.

Supposed there is a cognitive radio system with N cognitive users waiting for allocation of spectrum, the cognitive user is labeled $n \in [0, N-1]$. If the reference numeral of available idle spectrum is M, the spatial frequency spectrum is labeled $m \in [0, M-1]$. The time of spectrum allocation is very short compared with that of the external environment change. Therefore, we assume that the matrices in a distribution cycle is unchangeable, the matrices are defined as follows[5]:

(1) The idle spectrum matrix L

In the cognitive radio communication system, the authorized users and cognitive users exist at the same time. When authorized users use a spectrum band, the cognitive users cannot use it and we can use the idle spectrum to represents spectrum that a user is not authorized to use in some time. $L = \{l_{n,m} | l_{n,m} \in [0, 1]\}_{N \times M}$, where N is cognitive users and M is the total number of bands. When $l_{n,m} = 1$ means the N user can use the M band, on the contrary, $l_{n,m} = 0$ means the N user cannot use the M band.

(2)The beneficial matrix B

$B = \{b_{n,m}\}_{N \times M}$, where $b_{n,m}$ is the cognitive user N obtained the benefits in the use of the available spectrum M.

(3) The interference matrix C

$C = \{C_{n,k,m}\}$, $C_{n,k,m} \in \{0, 1\}_{N \times N \times M}$ means the interference cognitive users n and k produced on the m channel at the same time. When $C_{n,k,m} = 1$ means the cognitive users n and k would produce interference when they use the M band at the same time. If $n = k$, then $C_{n,k,m} = 1 - l_{n,m}$, it is only determined by the idle spectrum matrix L.

(4) The noninterference matrix A

$A = \{a_{n,m} | a_{n,m} \in [0, 1]\}_{N \times M}$, when $a_{n,m} = 1$ represents that the M band is assigned to the N cognitive user to use. A must meet noninterference conditions: $a_{n,m} \cdot a_{k,m} = 0$, if $C_{n,k,m} = 1$; $\forall n, k < N$, $m < M$.

(5)The idle time spectral matrix

$W = \{w_m\}_{1 \times M}$ represents the idle time of the authorized spectrum m. This article assumes that in a distribution cycle, the idle time of each authorized spectrum does not change.

(6) The recognitive user's request time matrix T

$T = \{t_n\}_{N \times 1}$ represents the request time of cognitive user n. This article assumes that in a distribution cycle, the request time of every cognitive user does not change.

2.2. **CSGC Algorithm criteria.** Max-Sum-Bandwidth[6] are taken as optimized objective function of spectrum allocation. The mathematical expression is:

$$\max_{A\in\wedge_{N,M}}\left(\sum_{n=0}^{N-1}\sum_{m=0}^{M-1}a_{n,m}\cdot b_{n,m}\right)\tag{1}$$

Expression(1) is maximized benefit of the spectrum, $\wedge_{N,M}$ represents a collection of non-interference spectrum allocation matrix A which meets all the conditions.

In this paper, there are Collaborative-Max-Sum-Bandwidth and Non-Collaborative-Max-Sum-Bandwidth, whose corresponding label criteria[7]are as follows:

$$label_n=\max_{m\in l_n}b_{n,m}/(D_{n,m}+1)\tag{2}$$

The criteria of Collaborative-Max-Sum-Bandwidth(CMSB), the corresponding node and color is

$$color_n=\arg\max_{m\in l_n}\quad b_{n,m}\tag{3}$$

Where $D_{n,m}$ is the number of users who have interference conflicts with cognitive users assigned to the m spectrum who cant use the spectrum m at the same time.

With the label rule of Collaborative-Max-Sum-Bandwidth, the utilization of the spectrum can be improved. The spectrum utilization efficiency can be maximized and the global optimal system performance can be achieved in consideration of the interferences among users in the process of spectrum allocation.

The criteria of Non-Collaborative-Max-Sum-Bandwidth (NMSB), label and color expressions for the corresponding node are

$$label_n=\max_{m\in l_n}b_{n,m}\tag{4}$$

$$color_n=\arg\max_{m\in l_n}\quad b_{n,m}\tag{5}$$

The label rule of Non-Collaborative-Max-Sum-Bandwidth does not consider the interferences among users. There are Non-cooperative relationships among users, each user is selfish and only thinks about its own benefit and ignores the resulting impact on the entire system.

3. **The improved CSGC Spectrum allocation algorithm based on the user priority.** In the process of spectrum allocation, the interference relationship determines the benefits cognitive users obtain[8].In order to avoid interference and conflict, color sensitive graph coloring spectrum allocation algorithm is proposed. It greatly reduces interference[9], but does not consider the users' requirements. The paper adopts the thought of color sensitive graph coloring and takes users' needs into account, and then presents an improved CSGC spectrum allocation algorithm. The basic idea of the algorithm is to take Max-Sum-Bandwidth as the optimal objective function of the color sensitive graph coloring spectrum allocation. At the same time, in consideration of the cognitive users' spectrum requirement, customer satisfaction is put forward. Set users' priority function according to the cognitive users' satisfaction of the current spectrum allocation. Spectrum reallocation is carried out according to the priority of users' spectrum requirements.

3.1. **Users' satisfaction s_n.** Cognitive user satisfaction is closely linked with users' needs, influences the stability of the system and determines whether this system is optimal. This paper presents the concept of customer satisfaction, which is used to measure whether the cognitive users' needs are met. Set user priorities based on users' satisfaction and reallocate the spectrum to meet the demand of more users, which improves spectrum utilization. User satisfaction is the cognitive users' satisfaction degree to the current spectrum allocation [10].Customer satisfaction to the current spectrum allocation for cognitive user satisfaction. User satisfaction is defined as the proportion of idle spectrum time to user's demand time, namely

$$s_n = w_n/t_n \tag{6}$$

As it can be seen from the above equation, when $s_n \geq 1$, the user's needs are met, the higher the proportion of idle time to cognitive user's time is, the higher users' satisfaction degree is; When $0 \leq s_n < 1$, which means the user's needs are not met, the lower the proportion of idle time to cognitive user's needs(demands) time is, the lower the user's satisfaction is.

3.2. **The priority of the user p_n.**

$$p_n = 1/s_n \tag{7}$$

When the user's needs are satisfied, the user satisfaction degree is high, the corresponding spectrum allocation priority level becomes low. On the contrary, user's satisfaction is low, and spectrum allocation priority is high.

3.3. **The improved CSGC algorithm description.** In this paper, the algorithm is divided into two stages. In the first stage, Max-Sum-Bandwidth is taken as a target and spectrum is allocated for the first time. In the second stage, if some users needs cannot be satisfied, spectrum is allocated again according to user's priorities.

In improved CSGC algorithm, in the first stage of spectrum allocation, the label of each node (label) is marked on label rules. Each label corresponds to one frequency band. In each allocation select the node with the largest label value, and then assign the corresponding spectrum to the node. Update topology and delete the users who have conflicted with users who gained spectrum in the list of available spectrum. At the same time, delete lines of nodes in the same color. It will have to meet the requirements of users to temporarily exit the distribution. When updating the topology is done, the neighbor node of each node will also change. So limited situation of node interference has been changing, and the label value of the correlative node and limited interference matrix have also been updated. If free spectrum list is not empty, the spectrum allocation is done in the second phase. According to users' satisfaction of current spectrum allocation in the first phase, users will get priority. Spectrum is allocated again according to the priority from high to low. First of all, allocate the users with the highest priority. Once the users' requirements are satisfied, reduce its priority. If many cognitive users have the same priority the spectrum is allocated to the cognitive users who have the least nodes. If the graph is empty, the distribution in this cycle is over.

The algorithm process is shown in figure 1.

4. **Algorithm simulation and analysis.** This paper uses the MATLAB simulation software and simulates the improved CSGC algorithm and traditional algorithm. Take the Collaborative-Max-Sum-Bandwidth criteria and Non-Collaborative-Max-Sum-Bandwidth criteria and analyze the allocation target of the algorithm. Parameters are shown in table 1.

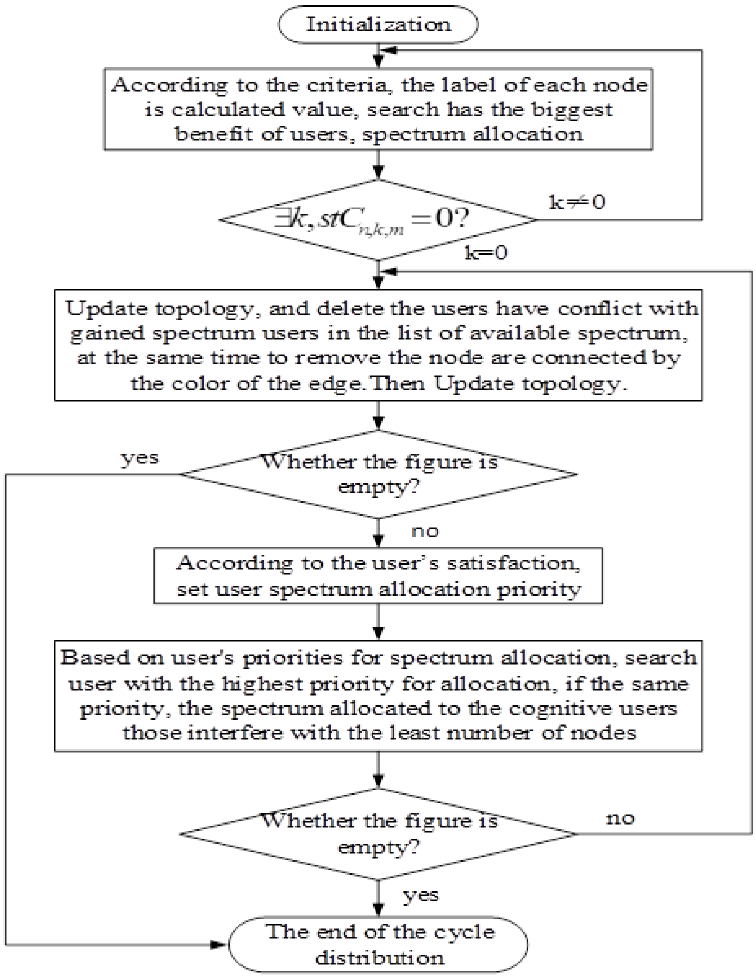

Figure 1. Flow chart of algorithm

Table 1. Simulation parameter settings

Parameter	Reference
Distribution area $/m^2$	10×10
Main users	20
Cognitive users n	4, 6
Spectrum number M	10
The maximum radiation from the primary user $/m$	2
User radiation range $/m$	[1,4]
the beneficial matrix B	According to the six of IEEE802.22 level evenly distributed, 3025, 4537.5, 6050, 9075, 12100, 13612 (The unit bit/period)
the idle spectral matrix L	Randomly generated 0, 1 binary matrix
the interference matrix C	Randomly generated 0, 1 binary symmetric matrix
user's needs(demands) time matrix T	Randomly generated line matrix

According to the implementation of algorithm and the simulation parameters. When the number of users is fixed, the number of channels ranges from 5-30 in turn. Simulate 20,000 times, compare the performance of the improved CSGC algorithm and traditional algorithm under the CMSB and NMSB criterion. The simulation results are shown in figure 2 and 3.

Figure 2 and 3 shows curves of overall system efficiency and spectrum amount in the way of cooperation and non-cooperation.

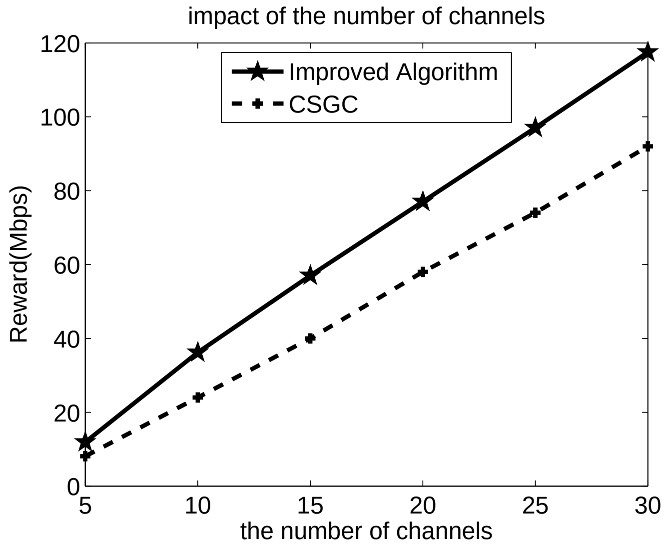

FIGURE 2. The total benefits under the rule of Collaborative-Max-Sum-Bandwidth if the number of users unchanged

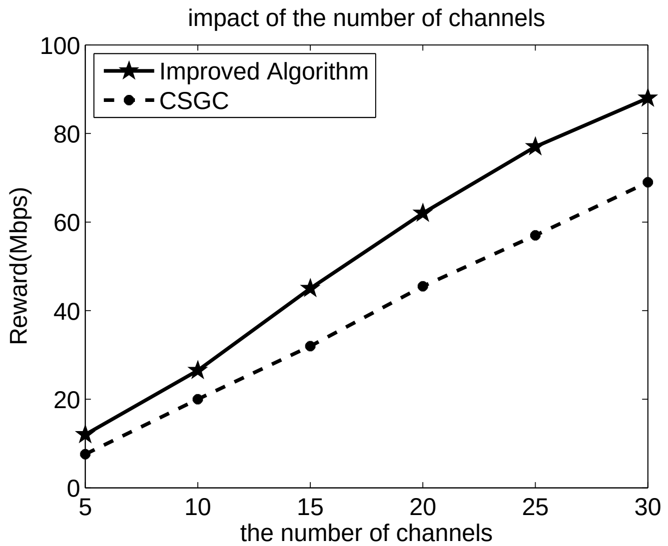

FIGURE 3. The total benefits under the rule of Non-Collaborative-Max-Sum-Bandwidth if the number of users unchanged

The figures show that if the number of users is fixed, system efficiency increases according to the growth of spectrum number. With the increase in spectrum number, the total system efficiency in the new algorithm does increase significantly. Under cooperative and non- cooperative principles, the system performance of new algorithm has increased by about 31% and 25% compared with the traditional CSGC algorithm. According to the implementation process of the algorithm and the simulation parameters settings, When the number of channels is fixed, users choose the number from 5-20 in turn, simulate 20,000 times. Compare the performance of the improved CSGC algorithm with traditional algorithm under the CMSB and NMSB criterion. The simulation results are shown in figure 4 and 5.

Figures 4 and 5 show the changing curves of cognitive users' number and system overall benefits in two kinds of collaborative approaches. In the figures, under certain number of channels, users' requirements go up and the total system benefits become low with the

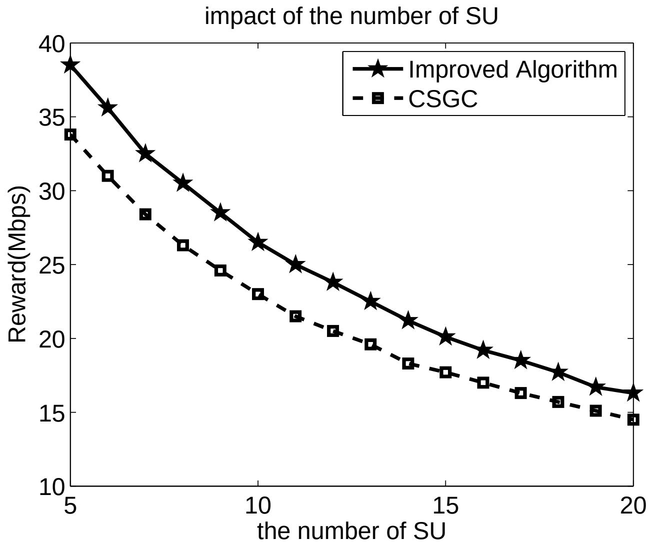

FIGURE 4. The total benefits under the rule of Collaborative-Max-Sum-Bandwidth when the number of channels is unchanged

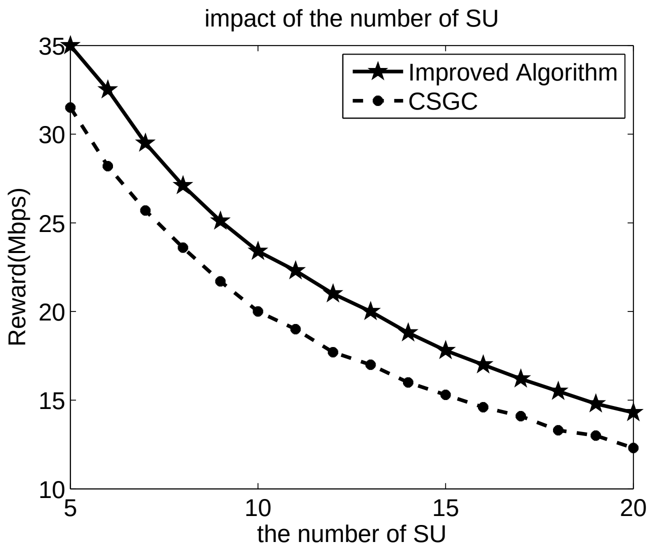

FIGURE 5. Total benefits under the rule of Non-Collaborative-Max- Sum-Bandwidth when the number of users is unchanged

increasing number of cognitive users. The total system benefits are obviously higher in the new algorithm than in traditional algorithm. In other words, in the same bandwidth, improved algorithm can support more cognitive users' access. In the cooperative and non-cooperative conditions, the new algorithm shows the high performance.

5. **Conclusions.** On the basis of in-depth study of classical graph theory model, this paper proposes an improved CSGC spectrum allocation algorithm from the perspective of cognitive users' demand. The algorithm makes rapid secondary spectrum allocation considering the user's demand. The analysis of simulation results shows that the improved algorithm can better meet the needs of the current cognitive users and improve the efficiency of spectrum allocation system compared with traditional CSSC algorithm.

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