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Enhancement of Parallel Spectrum Allocation Algorithm for UAS A/G Communication Based on Cognitive Radio Theory

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Abstract. : Cognitive radio network (CRN) is proposed to resolve the issue of the rare of available radio spectrum sources by introducing new concept of Channel assignment methods based on Dynamic spectrum allocation (DSA) algorithm, which can assign unused channel by PUs that can be allowed to recruit out with another user (the available spectrum to the SUs), So Cognitive radio technology is considered to be an efficient solution to improve the spectrum utilization efficiency of available spectrum resources and ensuring user fairness by considering choosing and using the ”free spectrum” in reasonably manner. On this paper, we will introduce a novel methodology for spectrum allocation algorithm based on the graph-coloring theory. Unlike some already existed allocation algorithms based on CSGC , our algorithm will consider the B.w matching degree between SUs B.w requirements and it's available channels B.w, the interference degree between SUs represented by tolerable values not limited to binary values as used in previous algorithms and choose the channel with efficient impact on spectrum resources allocation process . Our goal here is the enhancement and improves of the total spectrum reward by meeting SUs B.w requirements, improve SUs satisfaction rate and reduce the required running time for allocation process as much as feasible to achieve a fast channel assignment with low complexity and computational time to satisfied the special need required for a real time application especially A/G Communication.

Our simulation results show the feasibility of our proposed algorithms with graph and equation that indicates improvement in total spectrum reward, the satisfaction rate of SUs and reduction in algorithms running time overhead.

Keywords: CRN, (A/G) Communication, UAS, ATM, CSGC, Bandwidth matching, FSA, DSA, SUs, PUs.

1. INTRODUCTION

The rapid progress in the field of wireless technologies and Applications that required frequencies to operate lead to more congestion in currently available frequency spectrum resources, so the utilization of radio-frequency spectrum resources that appears more strained becomes a hot spot for future research. Meanwhile, the application of wireless broadband communications technology has been put forward as higher demand.

The survey of usage of wireless spectrum resources made by Federal Communications Commission (FCC) in 2003 [12] showed that in a condition of increasingly scarce of the wireless spectrum resource, the fixed spectrum allocation system (FSA) assigns spectrum resources statically to the licensed users which led to extremely undesirable results and low utilization percentage of most of the authorized bands that made in consecutive the average utilization of radio spectrum resources very low. Meanwhile, the unlicensed users (SUs) cannot use the idle spectrum temporarily to improve the utilization efficiency of the spectrum.

New well-known technology is considered to be an effective method to solve this scarce of radio spectrum problems called Cognitive radio (CR) [12]. Which introduced a new Dynamic mechanism to allocate the spectrum resources called Dynamic Spectrum Allocation (DSA) which aims to enhance the efficiency of spectrum utilization. As the licensed users (PUs) are absent, the unlicensed users (SUs) could sense and use tentatively this idle spectrum until PUs appears again.

a survey was done on(A/G) communications, [14] shows that the spectrum utilization in a licensed VHF Aviation band 118 MHz-137 MHz [5] Used for exchange real-time information for Air-Traffic Management (ATM) [2] is usually less than 5 %

[3] [4]. and also the endorsement of UAS technology in the civil application which required a high transmission rate for communication and control Link (C2 Link) will be a major motivation in this research area. Therefore, CRN can also be espoused for ATM and UAS communication applications [1].At present studies, there are already many types of research that analyze the spectrum allocation algorithms, including the Graph coloring model, Game theory model, and the Auction bidding model, which could benefit our approach on Air-to Ground (A/G) communications used by civil aircraft spectrum allocations. Graph coloring one of the commonly used models and has mature enough in this research area.

Based on the Graph coloring model, different types of spectrum allocation algorithms have been introduced. However, A List coloring spectrum allocation algorithm based on graph coloring theory was introduced in [7], but it didn't care about interference issues between Different SUs when using the spectrum at the same time. And also, it respectively considers the benefit and fairness as a target without thinking about tradeoff between them.

A Coloring sensitive graph code algorithm (CSGC) in [11] not only overcomes A List coloring algorithm weakness by checking the channel condition but also defines several different label rules related to different target functions according to a user application. Nevertheless, the CSGC also has drawbacks related to increasing the overall running time due to only one channel can be allocated to SUs in a single distribution cycle. The parallel algorithm proposed to overcome weakness concern the allocation time mentioned in CSGC algorithms, after that Enhancement-CSGC algorithm based on users B.w requirements introduced to improve total system utilization, SUs satisfaction rate and also reduce the required running time. However, most of the related works did not consider the B.w matching degree between the SUs requirement and the available channel B.w. Sometimes a channel is assigned to SUs, whereas the channels B.w is much larger than the SUs B.w requirement. This will result in excess B.w and decrease the spectrum utilization.

In this paper, we will take in our consideration in our proposed algorithm the Bandwidth matching degree between SUs Bandwidth requirements and it's available channels B.w and proper representation of the interference degree represented by tolerable values not limited to binary values [10] and choosing the channel with an efficient impact on the available spectrum resources allocation as our objective in the enhancement process. So we proposed an improved allocation algorithm based on the graph coloring model. In addition, in the previous researches, the interference of SUs to each other is always ignored. Nevertheless, due to the probability of miss detection, therefore our proposed algorithm introduces a new concept of tolerable interference vector that describes the interference degree that can be accepted by each SUs. Our main intention here is to satisfied SUs requirements with enhancement in total spectrum reward with a reduction in time overhead as much as feasible compared with previously used algorithms CSGC, PARALLEL [9], and PAUBR [10].

Our paper is organized as follows. Section II show a brief description of used system model and its problem formulation. In section III, introduces our proposed algorithm based on an enhanced PARALLEL algorithm. . In section IV, Simulation will be presented and discussed its results briefly with graphs. Finally, in Section V our paper conclusion and future work will be presented.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. Spectrum Allocation Models

Related to A/G communications, traditionally channel assignment used in terrestrial mobile communications based on CR can't be directly applied to A/G communication because it operates at a high speed mobility environment. According to IEEE 802.22 standard, it defines the cognitive period. In each cognitive cycle, a channel assignment was done before data transmission and then updates the list of the corresponding available channel for every SUs. As traditional channel assignment algorithms are of high complexity, so our proposed algorithm was designed to mitigate this computation complexity, through define the following certain indicator for using in channel assignment:

1) The channel assignment algorithm should have a process with low computation complexity;
2) To be launched synchronously with the cognitive period;
3) select the cognitive period carefully because the interference environment is changing rapidly

4) Satisfied SUs requirements with a reduction in time overhead.

Propose that we have I PUs and N SUs are randomly distributed in a predefined area, and the available spectrum is divided into M orthogonal Co-channel which are no overlapping. The interference among users is determined by its geographical location of mutual distances[8] between each user, each user have Omni-directional antenna for transmission. The whole network can be represented as a graph with formula Gr=(P,S,E), where $P = \{P_i| \ 1 \leq i \leq I\}$ represents the set of PUs ,$S = \{S_n| \ 1 \leq n \leq N\}$ represents the set of SUs, and $E = \{E_{i,j}| \ 1 \leq i,j \leq N\}$ represents the set of interference among SUs to PUs. Interference can be determined from mutual distance between PUs and SUs or among SUs. Assume that Pus has a relevant interference circle his center p_i with radius r_{pi} (m) for each channel where ($i \in I, m \in M$), and also SUs has a relevant interference circle his center s_n with radius r_{sn} (m) for each channel where ($n \in N, m \in M$) ,so we will have two different scenarios for interference.

Scenario 1: SUs can use the same channel at the same time with PUs in case of no intersection exists in the area of interference between SUs and PUs, with the following constraint: $r_{sn}(m) + r_{pi}(m) < d(n,i)$, $r_{si}(m) + r_{sj}(m) < d(i,j)$ Where $d(n,i)$,$d(i,j)$ represent the mutual distance between the centers of PUs and SUs or different SUs.

Scenario 2: SUs can't use the same spectrum at the same time with PUs in case of there is intersection exists in the area of interference between SUs and PUs, with the following constraint: $r_{sn}(m) + r_{pi}(m) > d(n,i)$, $r_{si}(m) + r_{sj}(m) > d(i,j)$ so in this case If SUs use the same channel with PUs, it will cause disturbance to it and lead to transmitting failure and SUs can adjust its interference radius, to avoid the conflict with PUs or introduce tolerable interference values for each SUs can sustain transmit however interference exists.

A case study of the topology appears in Fig.1.We set I=four, N=five, where I, N represent the number of PUs and SUs respectively and it can utilize channel A-C respectively in line with the previous scenarios and constraint.

The spectrum allocation problem can be represented as a graph coloring problem by representing each SU with a vertex, every channel with a unique color and an undirected edge between two vertexes will represent interference between two SUs. So when allocating channel m to user n it is like assign color m to vertex n. As represented in Fig.2.

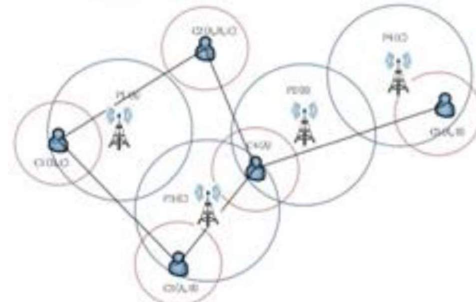

Fig.1. Case study of CRN topology

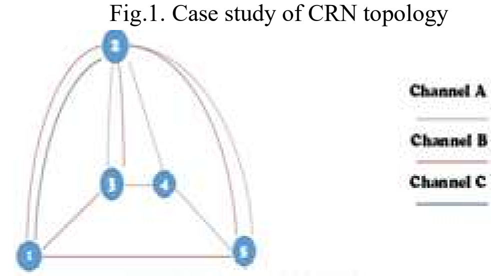

Fig.2. Graph representation for CRN

Different parameters can describe the spectrum allocation problem with assumption that position and available channels for SUs are not changed during spectrum allocation time stage (keep it short as much as possible to be applicable to real time application). The main parameter that describe spectrum allocation problem [5] appears below:

ChannelAvailabilityMatrix(V): $V=\{v_{n,m}| \quad v_{n,m} \in (0,1)\}_{N*M}$, is a N by M matrix define channel availability. Where $v_{n,m} = 1$ when the channel m is available for SUs n and $v_{n,m} = 0$ when the channel m is currently used by a PUs.

Throughput Matrix (B):$B = \{b_{n,m}\}_{N*M}$, is a N by M matrix define channel reward. $b_{n,m}$ describes the maximum throughput achieved for user n when utilize channel m

User Requirement Vector (K):$K = \{k_n\}_{Nx1}$, is a N Vector define the user requirement according to its application. Each SU needs a channel with enough B.w to transmit its data, k_n denotes the n^{th} SUs B.w requirement.

Channel Bandwidth Vector (F): $F = \{f_m\}_{Mx1}$, is a M Vector define the channel B.w values , f_m represent the value of channel m B.w .

Interference Constraint Matrix (C):$C = \{c_{n,t,m}| \ c_{n,t,m} \in (0,1)\} N*N*M$, is a N by N by M matrix define the interference condition among SUs which reflect current network topology and the channel transmission area as appears in examples in figure 1. Where $c_{n,t,m}= 1$ when SU n and SU t interfere with each other when utilize channel m simultaneously, and $c_{n,t,m} = 0$ else . We also can determine the diagonal values of C matrix as $c_{n,n,m} = 1 - v_{n,m}$ so if channel m is available to SU n ($v_{n,m} = 1$) $c_{n,n,m} = 0$ and if channel m is not available to SU $n c_{n,n,m} = 1$.

Tolerable interference vector (T): $T = \{t_n\}_{Nx1}$[11] describes the interference degree that can be accepted by each SUs with condition $c_{n,t,m} < t_n$ which means that interference degree is tolerable, i.e., user n can use the same channel m with user k simultaneously, although interference is existed.(one of our key parameter in enhancement process).

User Total Interference Matrix (D): D= $\left\{d_{n,m}\middle|\ d_{n,m} = \sum_{k=1,k\neq n}^{N} C_{n,k,m} \times v_{n,m} \times v_{k,m}\right\}_{N\times}$ is a N by M matrix which represent total interference impact for each user where $d_{n,m}$ represents the total interference impact which user n brings to other users when using channel m. It is calculated by summing up the interference degrees between user n and other users on channel m. v_n stands for the available channels in this stage of spectrum allocation

Channel Allocation Matrix (A) : where A= $\{a_{n,m}|\ a_{n,m} \in (0,1)\}_{N*M}$, is a N by M matrix define final channel allocation result. Where $a_{n,m} = 1$ If channel m is assign to user n else $a_{n,m} = 0$.

B. Optimization Problem

The main target for spectrum allocation problem can be described in terms of a utility function. So the spectrum allocation problem can formulate by using different optimization problems depending on different utility functions. Here are three common used optimization problems[6]:

- Max-Sum-Bandwidth (MSB): it's a utility function used when we need to maximize the total spectrum utilization of our networks. This optimization problem is calculated through:

$$\max_{A\in A_{N,M}} \sum_{n=1}^{N}\sum_{m=1}^{M} a_{n,m}\cdot b_{n,m} \qquad (1)$$

- Max-Min-Bandwidth (MMB): it's a utility function used when we need to maximize the assigned B.w of network to bottle necked user. This optimization problem is calculated through:

$$\max_{A\in A_{N,M}} \min_{n<N} \sum_{m=1}^{M} a_{n,m}\cdot b_{n,m} \qquad (2)$$

- Max-Proportional-Fair (MPF): it's a utility function used when we want to consider the proportionality of the total utilization and fairness in the distribution between different users. This optimization problem is calculated through:

$$\max_{A\in A_{N,M}} \sum_{n=1}^{N} \log_{10}\left(\sum_{m=1}^{M} a_{n,m}\cdot b_{n,m}\right) \qquad (3)$$

C. The Allocation Rules

There are two main types of allocation rules presented in [9], one of them considers the interference among users in the networks and it's called collaborative allocation rule and the other one, only considering each users own spectrum efficiency so it's called non-collaborative allocation rule. Her in our paper we used the utility function related to MaxSum-Bandwidth with collaborative allocation rules (CMSB) and its descriptions are shown as below:

$$Label_n = \max_{m\in v_n}\left(\frac{b_{n,m}}{d_{n,m}+1}\right) \qquad (4)$$

$$color_n = \arg\max_{m\in v_n}\left(\frac{b_{n,m}}{d_{n,m}+1}\right) \qquad (5)$$

Where, $Label_n$ is the label of each user, in essence, it is the max B.w assign for each user, say user n can obtain in this stage of allocation $color_n$ indicates that the channel m will be assigned to user n if user n get the highest priority, i.e., if the label of user n is larger than those of other users. This rule makes sure that the channel which can make the most contribution to total B.w of the networks is assigned. So, it achieved our target her to maximize the sum of B.w and improve the spectrum utilization overall.

III. SPECTRUM ALLOCATION ALGORITHMS

On this part, we will illustrate the concept of B.w matching degree in item A. then make comparison between the required running times for traditional CSGC, Parallel with our proposed Algorithms in item B. Then our algorithm objective function and a label rule is proposed in item C. then, we elaborated the spectrum allocation procedure in item D. Finally, we discussed the main KPIs for our proposed algorithm in item E.

A. Bandwidth Matching Analysis

The SU puts forward its B.w requirement according to its traffic type and applications [12], [13]. So the requirements are different among different users. In many graph color based allocation algorithms, sometimes a channel is assigned to a SU whereas the channel B.w is much larger or less than the SUs B.w requirement this will leads to an excess in B.w or useless to SUs. To mitigate this problem, the B.w matching degree concept introduced which defined by the ratio of the users B.w requirement and the channels B.w, as below:

$$\Gamma_{n,m} = \frac{k_n}{f_m} \quad (6)$$

With assumption that every SU can use only one channel per cognition cycle. So we shall assign a channel m to SU n whose B.w exceeds its B.w requirement according to the following condition:

$$\Gamma_{n,m} \leq 1 \quad (7)$$

Spectrum utilization can be maximized by assigning the channel m which fully utilized by SU n. so, it is preferred to keep the value of $\Gamma_{n,m}$ tends to 1 as much as feasible.

B. Required Running Time Analysis

List color and CSGC spectrum allocation algorithm are both based on static spectrum allocation concept for cognitive radar network topology. If there a request to add new node to current radar network, we need more time to rebuild topology. This process needs more time depending on network size and available channel. As the number of SUs and corresponding available channels increases, the required computational processing increase which will reflect on increasing the overall running time for CSGC algorithm as well, The running time can be calculated by the following Equation:

$$T_{cost} = \sum_{n=1}^{N} \sum_{m=1}^{M} a_{n,m} \quad (8)$$

Where $a_{n,m}$ represents items in allocation matrix. Then Parallel Algorithm introduced with a new concept over CSGC by dividing the allocation process into groups and work on it in parallel so during one cognition cycle we can do more assigning process according to number of groups which have a good impact on reducing the overall running time for allocation process which can be calculated by the following Equation:

Then the PAUBR algorithm introduced as its defined groups according to the matrix of the Available Channel. As the number of allocation in each group may not equal then it defines new terms: χn which refers to the max number of allocation of each group. *treport* which represents the time spend for each group for reporting their distribution status to a cognitive Base station (CBS) in order to check the satisfaction rate of SUs. μ_n which represents the max number of currently available channels for SUs, *choose* which compute the SUs $\Gamma_{n,m}$ values in different channels and keep the channel which has the maximum $\Gamma_{n,m}$ and deletes others then SUs with the highest label value will get its corresponding channel. Just because of previous added terms, the time cost of PAUBR is considering a little bit longer than that of Parallel algorithms but with added value in terms of enhancement of overall network B.w utilization factor. So the time cost for PAUBR calculated by:

finally, our proposed algorithm is introduced with adding one condition step over PAUBR in

$$T_{cost} = \max_{1 \leq m \leq M} \sum_{n=1}^{N} a_{n,m} + \max_{1 \leq m \leq M} (\chi_n) \cdot treport + \\ + \max_{1 \leq n \leq N} (\mu_n) \cdot choose \quad (10)$$

previous equation, which in case of some SUs have equal label values, then SU with lowest $d_{n,m}$ value will be assigned firstly ,So it reflects in equation 11 by adding term related to choose SUs with lowest interference impact to its neighbors which have the same label value and assign the corresponding available channel to it, that is why our algorithms have little longer time cost over PAUBR but still within acceptable range compared with CSGC and PARALLEL and the time cost for our proposed algorithms can be calculated through the following equation :

$$T_{cost} = \max_{1 \leq m \leq M} \sum_{n=1}^{N} a_{n,m} + \max_{1 \leq m \leq M} (\chi_n) \cdot treport \\ + \max_{1 \leq n \leq N} (\mu_n) \cdot choose + \min_{1 \leq n \leq N} (\mu_n) \cdot choose \quad (11)$$

C. Proposed algorithms Objective Function and Label Rule

Reward value has a direct impact on the throughput value obtained for SU when utilizing different channels with different reward values. So when we calculate SU contribution value to total spectrum reward we will consider B.w matching degree as shown in the following equation:

$$P_{n,m} = \frac{k_n}{f_m} \cdot b_{n,m} \quad (12)$$

According to CMSB in equation 1 after adding the impact of B.w matching degree our proposed Algorithms objective function can be expresses as

$$P = \max_{A \in A_{N,M}} \sum_{n=1}^{N} \sum_{m=1}^{M} a_{n,m} \cdot \frac{k_n}{f_m} \cdot b_{n,m} \qquad (13)$$

D. Spectrum allocation procedure

Our Proposed allocation algorithm procedural will introduced in steps followed with simple Flow charts for it as shown in Fig 3.

Step 1: Initialize of our main system parameters and matrices.

Step 2: rebuild the interference matrix C,D based on tolerable interference degree values for different SUs from tolerable vector T.

Step 3: compute Γn,m values for every SUs with corresponding available channel B.w and delete the channel whose Γn,m values greater than one from our topology.

Step 4: if SU has multiple available channels in one cognition cycle, keep channel which obtained the maximum Γ value and delete others from the SU available channels register.

Step 5: Our topology will be divided into groups related to the numbers of available channels.

Step 6: calculate each SUs label and corresponding channel color value in its available channel list, According to CMSB allocation rules.

Step 7: assigning the channel m to its corresponding SU n which has a maximum label value. In case there are some SUs that have equal label value at the same time, determine SU which has low $d_{n,m}$ value and assign the corresponding channel to it.

step8: Refresh the topology and therefore matrices values, Delete already assigned channel from SUs available channel lists and its interference impact on other SUs. Consequently change corresponding values of A, L, K, C, D matrices.

Step 9: the allocation process will continue until check the user requirement list K or SU available channel matrix L if it is empty, the allocation process will be finished,

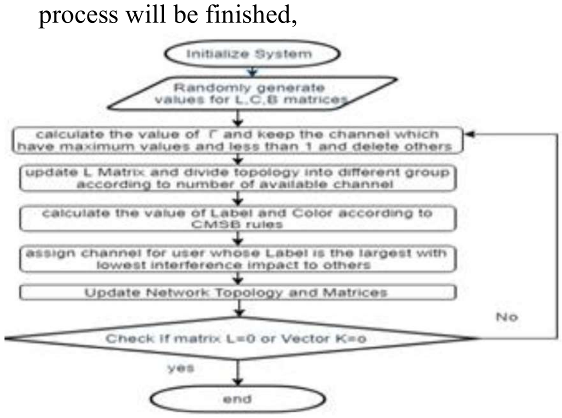

Fig. 3. Flow Charts for Our proposed allocation algorithm

E. Key Performance Indicators (KPI)

Taking in our consideration the running time for each algorithms in real-time application, we also consider the overall spectrum utilization and satisfaction rate of SUs as a key performance indicator for our proposed algorithm as below:

1) Required Running time: illustrate briefly with equation on section III item B.
2) Satisfaction rate: The satisfaction rate is ratio of the satisfied SUs to the total SUs and can be calculated with:

$$S = \frac{\tau}{\beta} \qquad (14)$$

Where τ represents the number of satisfied SUs according to Γ values. β represents the total number of SUs have the right to assign channels.

3) Total Spectrum Reward: illustrate briefly with equation on section III item C.

IV. SIMULATION RESULTS AND ANALYSIS

Our simulation will analysis with supporting graph comparison between the CSGC, PARUBR and our proposed algorithm according to previously mentioned performance metrics. With the assumption that the PUs and the SUs locations are randomly distributed in 1km x 1km square area. Each PU can randomly use one of the available m channels. The main parameter values of our algorithms represented in the following Table.

TABLE I

Parameter	Value
N.o PU I	20
N.o SU N	10
Number of Available Channel M	Varies From 10 to 30
PUs Transmission Range	4
SUs Transmission Range	2
Tolerable Interference Vector	[0.1,0.2,0.4]
Reward Matrix ,SUs required ,Channel Bandwidth	randomly generated [1 ~ 5]

SIMULATION PARAMETER

The interference constraint and environment is determined by the distribution of SUs in a predefined area and we will take the average result of 1000 simulation experiments.

First of all, the difference in the required running time for CSGC, PARALLEL, PAUBR, and our proposed Algorithms. As illustrate briefly with an equation on section III item B and we can see from this equation that CSGC required the longest allocation time among used algorithms, on contradiction Because PARALLEL algorithm didn’t care about SUs requirements and only does the allocation process , normally it will perform the allocation process in a short time.Our proposed Algorithms will consider not only the SUs B.w requirement but also its interference impact on the other SUs, so its allocation time will be a little bit longer than PARALLEL and PAUBR but still within an acceptable range for real-time Application.

Next, Fig 4 Shows the performance indicator comparison related to the overall spectrum utilization factor for the three algorithms used. Apparently, CSGC and PARALLEL have the same objective Function and they didn't consider the SUs B.w requirements into consideration which leads to some of already assigned channels to SUs can’t satisfy its requirements. In consequence, there are no benefits or contributions of some channels that already assigned neither on SUs level nor overall network utilization.so they will have the same overall network utilization and available channels, as described in [11]. However, our proposed algorithm and PAUBR make significant improvements on the overall network utilization level .PAUBR algorithm always chooses the most appropriate channels to SUs B.w requirement, so PAUBR algorithm will enhance overall network utilization because of as the number of available channels increases the percentage of SUs whose requirements satisfied increase .

Our proposed Algorithms make improvement over PAUBR by choosing the most suitable channel which has the lowest interference impact to its neighbors SUs according to $d_{n,m}$ value. Therefore, Our Proposed Algorithm get an improvement of 63 to 73 % in the overall network utilization over PARALLEL,CSGC Algorithms and 21 to 23 % Over PAUBR Algorithm that is what is shown clearly at Fig.4

At last, Fig.5 presents the comparison of the three algorithms in terms of SUs satisfaction rate, our proposed algorithms show better performance in this area compare with the PAUBR, CSGC, and PARALLEL, because it’s not only paying attention to the SUs B.w requirement but take concern about minimum degree of interference impact of SUs with others. So almost all channels which have been assigned to SUs are the best choice for it and can make them satisfied, so we can notice that from Fig. 5 The satisfaction rate grows as the number of available channels increases in our proposed Algorithm and PAUBR algorithms. In the CSGC and PARALLEL algorithms, it is not changed obviously.

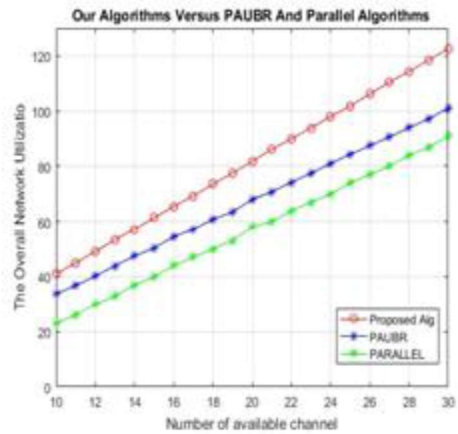

Fig. 4. Comparison between the Overall networks Utilization

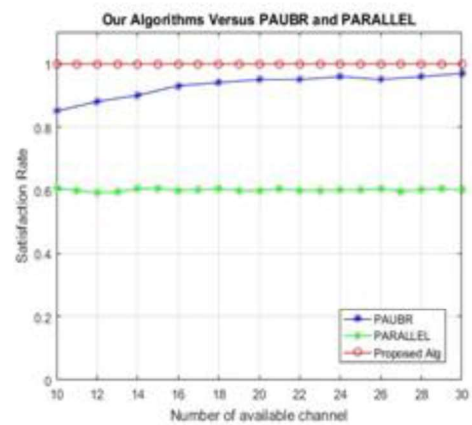

Fig. 5. Comparison of SUs Satisfaction rate

V. CONCLUSION

In this paper, we proposed an improved algorithm based on PARALLEL Algorithms with considering SUs B.w requirement, satisfaction rate and minimum interference impact to other SUs so it can reduce the channels allocation running time, improve the satisfaction rate and overall network utilization comparing with previous used algorithms (CSGC, Parallel, PAUBR), it also can satisfied the requirement for a real time application and A/G Communication that mentioned previously in Section II-A. Finally, we are working actively on adding new parameter to our algorithms that will contribute in enhancement for our algorithms to act as optimal solution for A/G Communication different application and services.

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