A Qos Aware Framework for Spectrum Allocation in Cognitive Radio Networks

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Abstract
In wireless communication, because of increased use of internet the bandwidth requirement is increased. Many applications demand for a large bandwidth and higher data rate to transfer the data. On the other hand, the allocated spectrum for users remains idle many times, resulting in inefficient spectrum utilization. To overcome these issues, spectrum utilization should be increased especially when spectrum is idle. This idea is the main concept of Cognitive Radio (CR) system. This system usually focuses on sensing and allocation of vacant spectrum. System has to consider short term fluctuations in spectrum bands, and data rate and other quality-of-service (QoS) requirements of different CR users. Considering these challenges, this paper contributes to design a QoS-aware framework that achieves higher throughput and fairness in CR networks. The idle spectrum band is sensed and parameters of this band are continuously monitored by a central entity – base station (BS). Using this information, a novel parameter called opportunity index, λ in generated. The different QoS requirements of CR users are divided by grouping the users and assigning priorities indicated by priority index α. The request send by these users is represented by request index θ. With the help of these parameters, the admission control algorithm, spectrum decision algorithm and spectrum mobility algorithm work to figure out QoS requirements of CR users.

***IndexTerms* - CR Networks, Quality of Service, Spectrum sensing and Allocation**

I. INTRODUCTION

Modern wireless services have come a long way since the roll out of the conventional voice centric cellular systems. The demand for wireless access in voice communication, as well as in high data rate applications has been increasing. New generation wireless communication systems are aimed at accommodating this demand through better resource management and improved transmission technologies. Various approaches are used to improve the throughput in wireless networks. One of the methods discussed here is cognitive radio in wireless communication. Basic principle is to use the spectrum efficiently. The spectrum allocated for various bands is found to be underutilized, wasting large amount of bandwidth. This technology can be used for any band of spectrum. The standard used for cognitive radio is IEEE 802.11. The framework is divided in five modules viz. PU activity module, QoS aware characterization module, admission control module, spectrum decision module and spectrum mobility module. These modules are to be implemented in MATLAB®. The parameters generated from modules are mathematically implemented using algorithms. Creation of nodes will help to design the wireless network.

Objectives:
To detect the vacant spectrum band accurately.
To allow the CR users enter into spectrum according to their priority, using admission control algorithm.
To provide maximum QoS to CR users with the help of admission control and spectrum decision algorithms.
To monitor the PU activity and vacate the spectrum for PUS when required.
To provide better throughput for high priority CR users.
To maintain the fairness for small priority CR users

II. LITERATURE REVIEW

In CR networks, the spectrum decision function must consider the fluctuations. These fluctuations are caused by dynamic primary user (PU) activity [1].Next Generation (xG) communication networks will provide high bandwidth to mobile users via heterogeneous wireless architectures and dynamic spectrum access techniques [2]. The CR network has a centralized network entity such as a base station and associated CR users [3]. To decide on spectrum bands properly, CR networks have to consider the some issues such as dynamic PU activity, adaptive spectrum decision etc. [4].Spectrum management in open spectrum systems is different from management in voice and general wireless networks and thus, fairness is essential to provide each user with a feasible packet delivery rate [5]. Also, the optimization solutions for overall throughput and fairness using collaboration of CR users with basic QoS classifications but without a specific spectrum characterization can also be taken into consideration [6],[7]. To deal with various spectrum requirements, the CR users are classified in and prioritized into four types [8][9][10][11]. The CR users are equipped with software defined radios (SDR) transceivers in order to select the appropriate spectrum band over a wide frequency range. While working with different algorithms in framework to achieve fairness and throughput, the spectrum decision mechanism can also be implemented based on traditional weighted queuing discipline [12]. For overall fairness among CR users, we use the Jain's fairness index F [13], with some modifications and represent it as H according to our algorithms.In this paper various algorithms are designed for accurate sensing and allocation of spectrum [14]. While implementing those algorithms, blocking, dropping and failure probabilities are considered and accordingly the mathematical analysis is done before allocation [15]. With the help of modified fairness index, the overall network fairness is maintained [16]. All the controls are done at central entity BS including fairness analysis [17]. Throughput is improved due to the use of specially designed algorithms and generated throughout is compared with similar work done by other researchers recently [18], [19], [20].

III. MATERIALS AND METHODS

In the process of implementing algorithms to achieve seamless communication, one base station (BS) controls the transmission and reception. 50 CR users are considered in this network, named as 50 nodes. Each node has a software defined radio transceiver. This transceiver continuously monitors the spectrum and PU activities and this information is transferred to the BS. The CR users are assigned with different priorities. So, according to their priorities and the available spectrum band, the best suit band is allocated to the CR users, without compromising the quality of service given to other users.

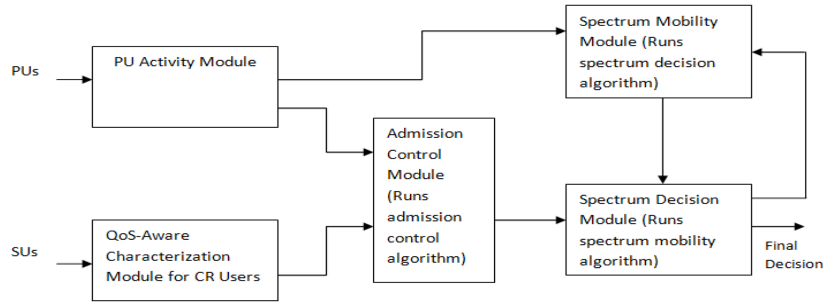

Fig. 1 Architecture for Proposed Framework

Spectrum functions such as spectrum occupied by PUs, dynamically changing spectrum availability for CR users and PU activities are handled using various queuing mechanisms. The framework is divided in five modules viz. PU activity module, QoS aware characterization module, admission control module, spectrum decision module and spectrum mobility module. These modules are to be implemented in MATLAB® For simplification, 20 licensed spectrum bands (l= 20) are considered. These are divided as 4 VHF/UHF TV bands with 6 MHz bandwidth, 4 AMPS with 30 kHz bandwidth, 4 GSM with 200 kHz bandwidth, 4 CDMA with 1.25 MHz bandwidth and 4 WCDMA with 5 MHz bandwidth. The CR users are assumed to be located within 250 meters area of coverage. The distribution as per type of CR users (type 1, 2, 3, 4) over 50 nodes is random. Type 1 users are priority 1 users, type 2 is priority2,and type 3 priority 3 and type 4 are priority 4 users. Referring fig. 1, Opportunity Index, λ is a novel QoS parameter developed to characterize the available spectrum. Characterization of spectrum includes continuously monitoring the spectrum to check the spectrum band availability, checking the specifications of available band (data rate, bandwidth etc). This is done at BS. As we are considering different types of users, the QoS requirements for these users are heterogeneous.As discussed earlier, different types of queuing are used to fulfill these requirements. Now, to express this into mathematical form the Request Index θ is derived, which is able to capture these dynamically changing heterogeneous QoS requirements of CR users. An admission control algorithm is run at BS. This algorithm is designed to balance the available spectrum and the QoS requirements of CR users. As seen in Fig.2.2, the admission control module, which runs this algorithm, has two inputs, one from PU activity module and the other from spectrum characterization module. Once the QoS requirements are stabilized and spectrum configuration process is completed, the spectrum decision algorithm in implemented. Then, the spectrum mobility module monitors the dynamic characteristics of the available spectrum using spectrum mobility algorithm and provides feedback information to the spectrum decision module for CR users to vacate the spectrum when a PU starts occurring in close vicinity to spectrum. The network shows the central entity that is base station (BS). 50 PUs are linked with BS. These are using the 20 spectrum bands according to their data requirement. 100 CR users, each associated with software defined radio (SDR) are linked to BS. Predefined priorities are assigned according to type of CR user; however, 100 users are distributed in these 4 types randomly.

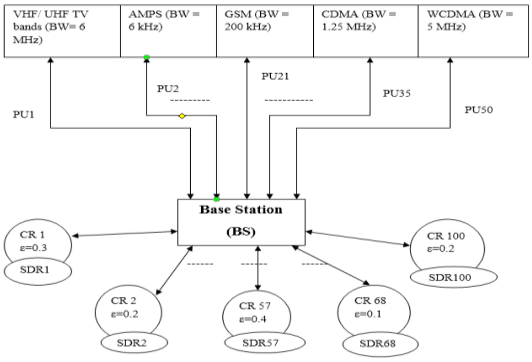

Fig. 2 Centralized Networks

$Require\ \lambda_j \wedge \theta_i \wedge \omega_i^{(j)}, \forall\ j \in [1,2,\dots,s], i \in [1,2,3,4]$

$for\ j = 1\ to\ s\ do$
 $while\ i \leq 4\ do$
  $if\ \lambda_j > \theta_i\ then$
   $\omega_i^{(j)} \Leftarrow \theta_i\ \{Perfect\ Decision\}$
   $\lambda_j \Leftarrow \lambda_j - \omega_i^{(j)}$
   $i = i + 1$
  $else\ if\ \lambda_j > \alpha_i\theta_i\ then$
   $\omega_i^{(j)} \Leftarrow \alpha_i\theta_i\ \{Smooth\ Decision\}$
   $\lambda_j \Leftarrow \lambda_j - \omega_i^{(j)}$
   $i = i + 1$
  $else$
   $\omega_i^{(j)} \Leftarrow \alpha_i\lambda_j\ \{Aggressive\ Decision\}$
   $\lambda_j \Leftarrow \lambda_j - \omega_i^{(j)}$
   $i = i + 1$
  $end\ if$
 $end\ while$
$end\ for$
$return\ Fairness\ H\ and\ Throughput\ \tau$
$plot\ Throughput$
$plot\ Fairness$

Fig. 3 Admission Control Algorithm

Priorities shown here are assumed just for illustration. These may vary in actual simulation.

IV. RESULTS AND DISCUSSION

We can see from fig. 3 that the algorithm requires opportunity index, request index and spectrum index. These parameters are compared with the assigned priorities. Every time, the total request is checked with the priority and then the request index is returned to the next module as input to that module. Fig. 4 shows that in the algorithm once the decision is taken the opportunity index decreases by the value of spectrum index and then the new opportunity index is generated for next decision making condition. Once any decision is made for any user, then the next user is taken into consideration by n = n+1 cycle. Throughput and fairness are the expected outputs or values to be returned out of this algorithm. Referring to fig. 5, when opportunity index reduces and becomes less than spectrum index, the next band is processed as the current band becomes unavailable for CR user. Now, as we are implementing all these algorithms to provide QoS to CR users without causing interference to the PU traffic, we need to check the effect of this system on the overall throughput and fairness network

For throughput, we can use the results of algorithms and mathematically, we can express as follows:

$$\omega_i^{(j)} = \theta_i \quad if\ perfect\ decision \qquad \text{(Eq. 1)}$$

$$\forall\ i\ \in [1,2,3,4];\ j\ \in [1,2,\ldots 20]\ for\ 20\ bands.$$

$$\omega_i^{(j)} = \alpha_i \theta_i if\ smooth\ decision \qquad \text{(Eq. 2)}$$

$Require\ \lambda_j \wedge\ \omega_i^{(j)}, \forall\ j\ \in [1,2,\ldots,s], i\ \in [1,2,3,4]$

$while\ j\ \leq\ s\ do$
    $if\ \lambda_j < \sum_{i=1}^{4} \omega_i^{(j)}\ then$
        $\omega_i^{(j)} \Leftarrow 0$
        $j = j + 1$
    $else$
        $j = j + 1$
    $end\ if$
$end\ while$
$return\ \omega_i^{(j)}$
$goto\ f(spec - dec)$

Fig. 4 Spectrum Decision algorithm

Fig. 5 Spectrum Mobility Algorithm

$$\forall\ i\ \in [1,2,3,4]\ ;\ j\ \in [1,2,\ldots..20]\ for\ 20\ bands$$

$$\omega_i^{(j)} = \alpha_i \lambda_j \quad if\ aggressive\ decision \text{(Eq. 3)}$$

$Require\ \lambda_j \wedge \theta_i\ \wedge\ \omega_i^{(j)}, \forall\ j\ \in [1,2,\ldots,s], i\ \in [1,2,3,4]$

$Total - op - id \Leftarrow \sum_{j=1}^{s} \lambda_j$
$\alpha_i \Leftarrow 1, \forall\ i\ \in [1,2,3,4]$
$Total - req - id\ \Leftarrow \sum_{i=1}^{4} \alpha_i \theta_i$
$while\ (Total - op - id\ \leq Total - req - id)\ \&\&\ \left(\omega_i^{(j)}\right)\ do$
    $if\ \alpha_4\ == 1\ then$
        $\alpha_4\ \Leftarrow 0.1$
        $Total - req - id \Leftarrow \sum_i^4 \alpha_i \theta_i$
    $else\ if\ \alpha_3\ == 1\ then$
        $\alpha_3 == 0.2$
        $Total - req - id \Leftarrow \sum_i^4 \alpha_i \theta_i$
    $else\ if\ \alpha_2\ == 1\ then$
        $\alpha_2 == 0.3$
        $Total - req - id \Leftarrow \sum_i^4 \alpha_i \theta_i$
    $else\ if\ \alpha_1\ == 1\ then$
        $\alpha_1 == 0.4$
        $Total - req - id \Leftarrow \sum_i^4 \alpha_i \theta_i$
    $else$
        $Total - req - id\ \Leftarrow Total - op - id$
    $end\ if$
$end\ while$
$return\ \theta_i \Leftarrow Total - req - id$
end
$display\ Total - req - id$
$plot\ Total - req - id$

$$\forall\ i\ \in [1,2,3,4];\ j\ \in [1,2,\ldots 20]\ for\ 20\ bands$$

Similarly for Fairness, we can used modified Jain's Fairness Index H as:

$$H = \frac{\sum_{j=1}^{s}(\sum_{i=1}^{4} \omega_i^{(j)})^{\wedge}2}{j.\sum_{j=1}^{s}(\sum_{i=1}^{4}(\omega_i^{(j)})^{\wedge}2)} \qquad (Eq. 4)$$

IV.1. Simulation Results for Request Index

We have generated request index, simulation an index and opportunity index from algorithms. We can see the plots in MATLAB as follows:

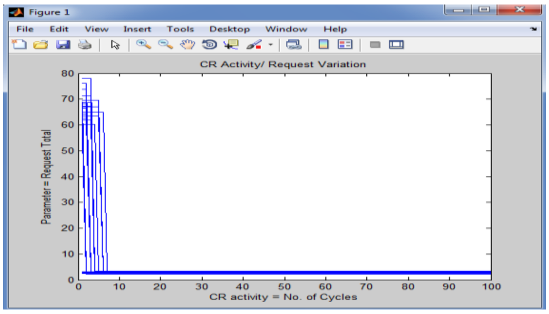

Fig. 6 Request Index Variation

It can be seen from fig. 6 that after approximately near 10 cycles, the plot becomes stable. This is because at this stage (approximately 10-15 cycles), the QoS requirements are stabilized and now they will not change for that moment.

Table 4.1: Maximum Request for Each Cycle

Cycle /users	1	2	3	4	Max Req.
C 1	0.8986	0.9565	1	0.9855	69
C2	0.9444	0.9167	0.9444	1	72
C 3	0.8472	0.9306	0.8194	0.9583	72
C 4	0.8611	0.8194	0.7778	0.8889	72
C 5	0.8611	0.8889	0.8889	0.8333	72
C6	0.8472	0.9028	0.9028	0.9028	72
C 7	0.9028	0.9028	0.9167	0.875	72
C8	0.8611	0.8472	0.875	0.8472	72
C 9	0.8611	0.9028	0.8889	0.9028	72
C 10	0.9444	0.9861	0.9167	0.9167	72

This can be considered as an intermediate output given by the algorithms in the system to achieve higher throughput and make the system fair. Table 1 shows this matrix.

IV.2 Simulation Results for Throughput

The throughput is maximized when number of type 1 (high priority) users is more than the other users. Because of high priority, these user requests are served first, increasing the total throughput. On the other hand, when the number of second or smaller priority users increases, the throughput decrease. When system has more CR users with smaller priorities, they occupy the spectrum aggressively. The QoS requirements are not strictly considered in aggressive decision. Hence, total throughout decreases. This behavior can be better understood with the help of plot. Fig. 7 shows the throughput for various types of users.

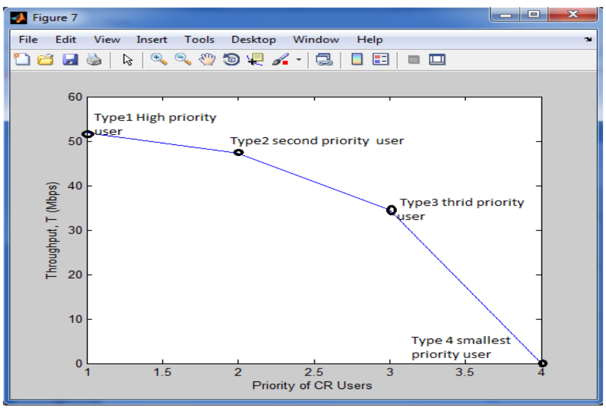

Fig. 7 Throughput for User Priorities

It can be seen from fig. 7 that throughput is maximum, near about 52.1 Mbps for high priority type 1 user. It to 48 Mbps for second priority users, about35 Mbps for third priority users and theoretically, it reaches to 0 Mbps when smallest priority type 4 users are maximum in network. This is aggressive decision in actual case. In multichannel environment, the traffic behavior will change. Naturally, in such environment, the throughput will increase for increased number of channels as shown in fig. 8. This is because opportunity index increases. Fig. 8 is a plot for throughput vs. number of channels (m).We can see that throughput is increasing as we go on increasing the number of channels. For simplification, we have considered four channels.

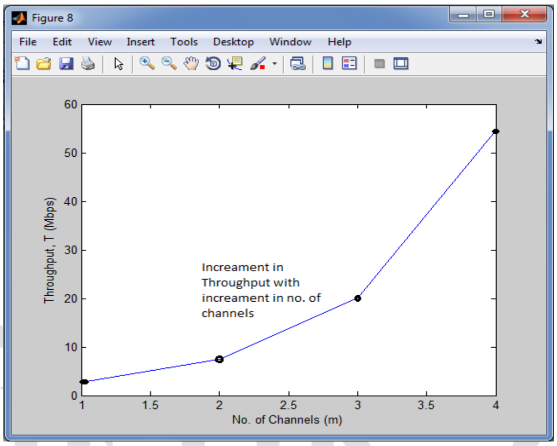

Fig. 8 Throughput in Multichannel Environment

IV.4 Comparative Analysis

In CR network technology, research is going on for throughput performance improvements. Here is a comparison table which gives results from similar work done by other researchers. Table 6.2 shows the name of text from which these results are taken, with their Author name and the environment in which the results are generated. One of the approaches is to design an algorithm for non-overlapping channel assignment [18]. In this approach, each CR user calculates its increase in throughput if the best suitable channel is allocated. On the other hand, using algorithm for overlapping channel assignment some probabilities are taken into consideration [18]. The other result used for comparative analysis uses the approach of sensor aided cognitive radio networks [19]. These networks consider scheduling windows with multiple time slots. Throughput of these timeslots is considered with controlling resource energy and without controlling resource energy in CR networks [19], [20].

Table 4.2: Comparative Analysis of Network Throughput

Text	**Throughput Performance**	**CR network**
Channel Assignment for Throughput Maximization in CR Networks	1)12 Mbps for 15 channels, reaches up to 15 Mbps for 40 channels. 2) Similarly it varies from 12 Mbps to 15 Mbps for 15 to 45 channels.	1) Varying parameters with Non overlapped channel assignment 2)5-user-sharing overlapped channel assignment
Throughput Maximization for Sensor-Aided CR Networks	1) 16 to 16.8 kbps for up to 12 timeslots. 2) 15.6 to 16.2 kbps for up to 12 timeslots	1) CRN throughput without control of resource energy. 2) CRN throughput in case of resource energy control.
Current Paper Work	1) 52 to 55 Mbps for type 1 high priority users 2) 35 to 45 Mbps for low priority type 3 or 4 users	Use of Admission Control Algorithm which configures the spectrum for decision and allocation

V.

CONCLUSIONS

After studying various algorithms in detail, it can be seen that implementation of these algorithms helped to manage these network parameters successfully. In many traditional approaches, it is observed that though network throughput is increased, the level at which it should get increased is lesser than the one achieved in this work. In dynamically changing environment, we get different results in MATLAB simulator every time we simulate the algorithms. So, for any random traffic which will be similar to our assumptions, these algorithms will definitely work to achieve the target of better performance.Thus, it can be concluded that due to specially designed algorithms, system gives throughput nearly equal to 52 to 55 Mbps for highest priority type 1 users. It goes on decreasing for lower priority users; however, still it gives about 45 Mbps and 35 Mbps for type 2 and type 3 users respectively. Network fairness is also increased for small priority users. Using this approach, small priority users get fair share in spectrum band. With reference to simulation results, it can be concluded that fairness is about 2.75 which is maximum for maximum number of type 4 users in network. Also, for multichannel environment, system gives fairness value 1, the best case condition for fairness.From all the results obtained it can be proved that algorithms designed in this project are optimized for better performance. All types of users are achieving either better throughput or fairness in network with better network performance. This is a quality measure for network which indicates that the QoS is provided as per user requirements.

The future scope for this proposed work deals with energy efficient spectrum sensing and allocation. All the activities in the network consume more energy. To design the system that will reduce the energy consumption we need to consider the total energy consumption at each activity such as spectrum sensing, allocation and the decision making process.

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