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Fair Resource Allocation Based on Max Weights in Cognitive Radio Networks

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Abstract- With the tremendous growth in wireless technology the increasing demand for spectrum resources is causing spectrum scarcity. Several surveys show that most of the time and at most of the places licensed bands are underutilized. Cognitive radio (CR) is a promising technology which has the ability to deal with the increasing demand of spectrum bands as it adapts itself according to the surrounding environmental conditions and transmits its data only through that band which is idle. To do this the CR needs to monitor the activity of licensed user continuously which is known as spectrum sensing. Spectrum sensing and sharing both are basic and essential functions of a CR to find the unused spectrum and share it efficiently. A limited amount of network resources have to be shared among many users in cognitive radio networks (CRNs). As per given channel conditions and total amount of available resource the system may allocate resource to users according to some performance measures. To maximize system throughput the system will allocate more resource to the users with better channel conditions, this causes starvation of resources in other users. So, fairness in resource allocation is equally important for efficient utilization of the available frequency bands. In this research paper we have proposed two max weight based methods to add fairness during resource allocation in a cognitive radio network. The simulation results obtained on MATLAB and their analysis is also presented.

Keywords- cognitive radio (CR); cognitive radio networks (CRNs); spectrum sharing; throughput maximization; fairness in resource allocation.

I.INTRODUCTION

In the past one decade wireless communication has witnessed a tremendous increase in the number of wireless devices due to which demand of radio frequency spectrum is exponentially increasing. With the advancement of wireless technology the number of frequency band users is also increasing which further leads to rise in the demand of frequency bands. Many surveys were carried out and in one such survey made by Federal Communications Commission (FCC) it was found that in New York City the maximum spectrum occupancy is about 13.1% from 30MHz to 3GHz [1]. According to these surveys it was found that spectrum scarcity problem is due to fixed spectrum allocation policies, lack of flexibility in the system and inefficient spectrum utilization like usage of public safety band (410 - 470MHz) and unlicensed band (2.4 GHz) which is only 16.6% and 1.5% respectively [2]. It has been concluded that the licensed bands are underutilized and at the same time unlicensed bands are over utilized at most of the time and at most of the places. This suggests that main problem is inefficient spectrum utilization and not the spectrum scarcity So, to overcome the underutilization of frequency spectrum CR technology was introduced by using which wireless devices can intelligently sense and exploit the unused spectrum bands of the licensed users. CR promises to maximize the spectrum utilization by locating vacant licensed bands and using it for communication purpose. Two main functionalities of a CR are Spectrum sensing and Spectrum Sharing. Spectrum sensing is the key functionality to identify the vacant spectrum bands. These techniques are used to determine whether the licensed user is using the frequency band at a particular geographic location and time or not. Each secondary user (SU) must perform spectrum sensing before using the licensed band. Spectrum sharing is the process in which the available licensed channel is shared between two or more than two SUs.

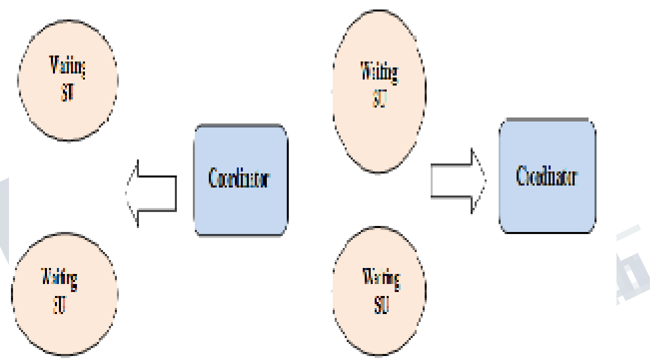
Along with spectrum sensing, spectrum sharing also equally contributes in the efficient utilization of a radio frequency spectrum. In CRNs a limited amount of network resource has to be shared among many users. The system may allocate resource to users according to channel conditions observed by users, the total amount of available resource and some performance measures. Fairness and throughput maximization are two main performance metrics that are usually used to analyse and compare the performance of various resource allocation schemes in many domains. However both of them are incompatible performance measures. To increase overall throughput of the system more resource may be allocated to the users with better channel conditions. This will cause the available resource to be used by a limited number of users leading to unfair resource allocation and starvation of resources for others users. In order to fairly distribute resource among all users of the system more resource may be allocated to the users with poor channel conditions and as a result the system throughput will be degraded.

In our research work we have focused on fairness along with throughput maximization in CRNs to avoid such throughput fairness confusion. In CRNs to maximize the throughput several methods have been proposed in literature. In [3] an optimal channel sensing is studied for a multi user CRN's with the aim of throughput maximization. In [4] an efficient channel allocation and power control scheme was proposed targeting throughput maximization of a dynamic spectrum access. Several researches have been done on throughput maximization along with fairness Prior research efforts have also focused on a wide range of fairness issues considering throughput in wireless networks. In [5] the problem of resource allocation along with fairness in accessing the wireless channels for all nodes for Wireless Mesh Networks (WMNs) is discussed. An optimization problem on maximizing network throughput via power control is proposed in [6] considering individual throughput fairness as a constraint. The trade-off between fairness and throughput during bandwidth allocation is discussed in [7].Our aim is to allocate resource to SUs in a competitive CRN with a central coordinator, maximizing throughput while maintaining fairness based upon queue length and the waiting time.

Rest of the paper is organized as follows: The system model of a centralized CRN used in our work is briefly introduced in section II. Section III presents our proposed methods to add fairness in a centralized CRN along with throughput maximization. Section IV represents the discussion of simulation results of proposed methods. Finally, paper is concluded in section V.

II.SYSTEM MODEL

We have considered a model similar to [3] which operates in a time slotted manner and is centralized CRN with a central coordinator, 'M' secondary users and 'N' licensed channels. In each time slot, channel 'i' $(1 \leq i \leq N)$ is either free or busy i.e. PUs are absent in a channel with probability 'θ_i' $\left(\in\ (0,1)\right)$ or PUs are present in a channel with probability $(1-\theta_i)$ where 'θ_i' is the primary free probability of channel 'i'. The channels $1,2,\ldots,N$ are labeled in decreasing order of their primary free probabilities. We also assume that in a time slot the primary free probabilities of all channels are distinct and remain constant. Also the signal to noise ratio (SNR) γ observed by a SU to its receiver on a given channel does not change in a given time slot. We also assume that SNR is independent and identically distributed across different channels and time slots with a common probability density function denoted by $f_\Gamma(\gamma)$.



Coordinator requests for local sensing All waiting CUs perform sensingresults of channel i from all waiting CUs and send their local sensing reports of channel/to the coordinator.

Fig.1. Model for centralized sensing

The central coordinator continuously estimates the primary free probabilities of different channels and whenever it senses a channel to be free from primary activities it requests the waiting sus (those users who are willing to access the channel) for the local sensing results. the central coordinator gathers the channel estimation results from waiting sus and makes a decision on spectrum access i.e. which su should be allowed to access the available free channel. it is assumed that no guess or recall is allowed and a dedicated control channel is fixed for reporting individual channel sensing results with no sensing errors.

III.PROPOSED FAIRNESS BASED RESOURCE ALLOCATION SCHEMES

Previous resource allocation was solely based on the channel estimation results of various sus. The su with best channel estimation results was selected to utilize the channel. By using this scheme overall throughput of the system was increasing but the available free channels were not fairly distributed among sus. Here in this section we have proposed two low complexity based resource allocation schemes which consider fairness along with throughput maximization.

A.Queue Length based Resource Allocation

We assume that the spectrum access decisions are made in a centralized fashion and are based on global knowledge of the queue lengths in the entire network. In queue length based scheme the central coordinator makes decisions based upon two factors that is the transmission rate observed by the waiting sus on the free channel and the amount of data to be sent by the waiting sus. The central coordinator always assigns free channel to that user which maximizes the product of transmission rate along with queue length.

$$\max \{R_j(t) Q_j(t)\} \qquad \text{where, } j\ (1 \le j \le M)$$

$R_j(t)$ is the rate at which user can be served at time *t* if it is chosen for service and $Q_j(t)$ is the amount of data in the queue for user ***j***.

By following this criteria if a user observes lower transmission rate on a channel due to worse channel conditions may not get chance to transmit its data in first round of allocation but as its data keeps on accumulating, it will surely get a chance to access the channel. in this way the users with lower transmission rate will not starve for free channels delay based resource allocation in our second proposed scheme the central coordinator takes spectrum access decisions based upon the waiting time of the su (time since it has raised request for a free channel to transmit its data). in this scheme, the central coordinator always gives chance to the su which maximizes the product of transmission rate along with waiting time.

$$\max \{R_j(t) W_j(t)\} \qquad \text{where, } j\ (1 \le j \le M)$$

$R_j(t)$ is the rate at which user can be served at time *t* if it is chosen for service and $W_j(t)$ is the waiting time of user ***j***.

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Simulation results

All the simulations are carried out on matlab. In simulation we fix the values of following parameters as: number of channels (n) = 9, total number of secondary users in the network (m) = 4. Snr of the channels is considered between 2 to 15db. We have simulated two resource allocation schemes. In first scheme channel allocation is done on the basis of queue length considering throughput maximization along with fairness. We have used jain's fairness index in order to measure how fairly the channels are distributed among all the users [8].

IV. SIMULATION RESULTS

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$$f(\mathrm{X}) = \frac{[\sum_{i=1}^{n} x_i]^2}{n \sum_{i=1}^{n} x_i^2}$$

Where $\mathbf{0 \le f(X) \le 1}$

$\boldsymbol{f(X)}$ is the fairness index based on resource allocation *x* where there are n individuals sharing the resource and $\boldsymbol{x_i}$, $\boldsymbol{i = (1, 2, \ldots, M)}$ is the amount of resource allocated to user *i*. A large value of $f(\mathrm{x})$ represents fairer resource allocation from the system perspective. The allocation tends to be fairer when jain's index is closer to 1.

Fig.2. Shows the comparison of proposed queue length based resource allocation scheme with the previous scheme where the allocation was being done on the basis of maximum transmission rate. Jain's fairness index is used to compare both resource allocation schemes. It is clearly visible from the figure that the proposed scheme outperforms the previous resource allocation scheme as it approaches to 1 on the fairness index. Fig.3. Compares the system throughput of queue length based resource allocation scheme with the previous resource allocation scheme. It is observed that the two curves have slight difference and the throughput achieved by proposed scheme is slightly lower than that by the previous allocation scheme. This throughput loss is due to the fact that in queue length based resource allocation scheme fairness is considered along with throughput maximization.

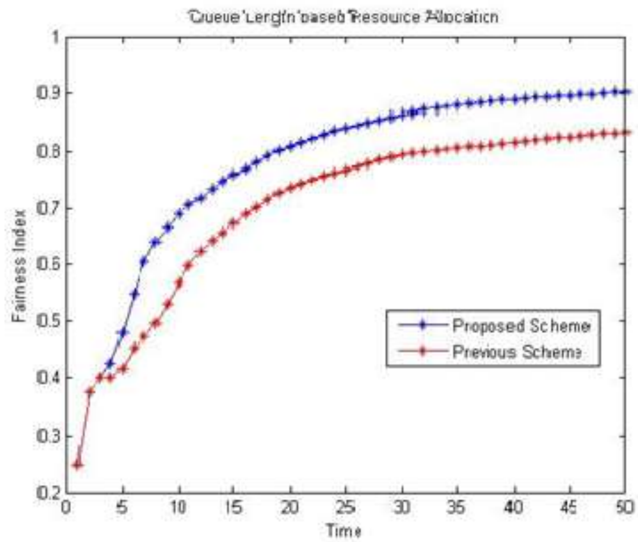

fig.2. Queue length based resource allocation

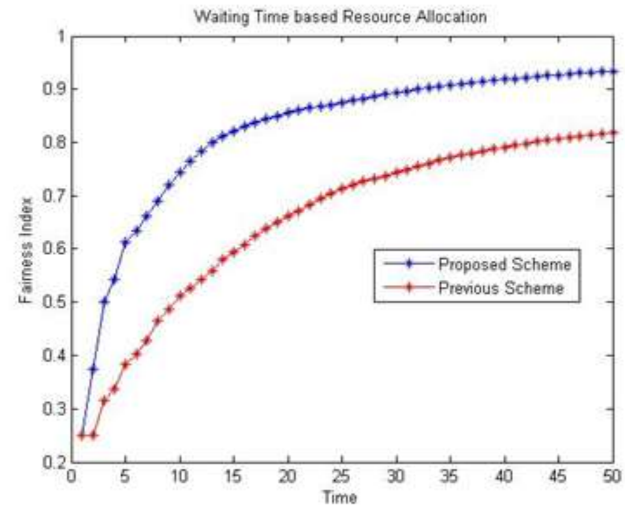

Fig.4. Delay based Resource Allocation

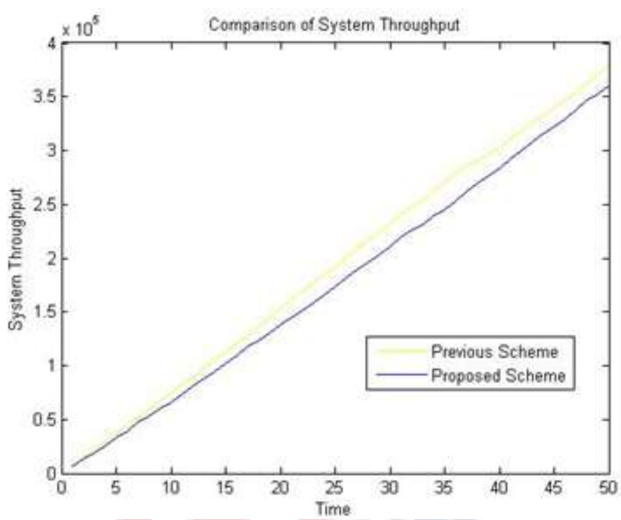

fig.3. System throughput for queue length based scheme

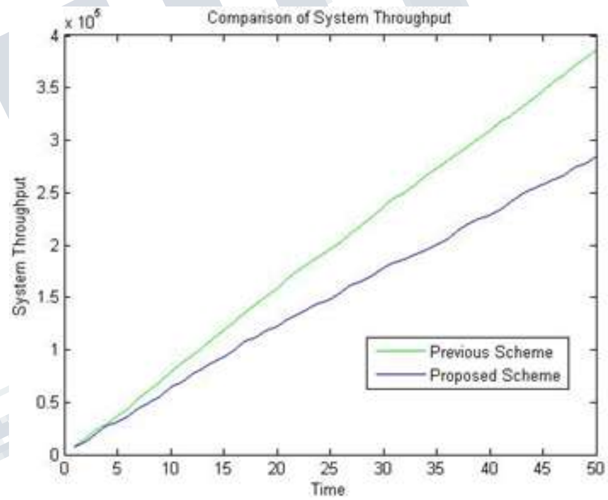

Fig.5. System throughput for time based scheme

fig.4. shows the comparison of delay based resource allocation scheme with previous scheme on jain's fairness index. it is clearly visible from the figure that proposed scheme outperforms the previous resource allocation scheme. it is clearly visible from the figure that the proposed scheme outperforms the previous resource allocation scheme as it approaches to 1 on the fairness index. fig.5. compares the overall system throughput of both the resource allocation schemes. it is observed that the two curves have quiet large difference and the throughput achieved by the proposed scheme is lower than that by the previous allocation scheme. this throughput loss is due to the fact that in waiting time based resource allocation scheme fairness is considered along with throughput maximization.

V.CONCLUSION AND FURTHER DISCUSSIONS

In our research work, we have proposed two novel fairness based resource allocation schemes in a cooperative crn to improve user satisfaction along with throughput maximization of the system. The central coordinator is the only authority to grant access to the free channel so there is no chance of collision among sus. Energy is saved by using cooperative sensing and then selecting the most appropriate su for channel access. Both proposed resource allocation schemes are efficient in terms of fairness but queue length based resource allocation scheme is observed to be better in terms of compromising with the system throughput.

Further work can be done by extending our study to find the best trade-off between overall throughput and fairness of a system so that user satisfaction is not compromised. This work can also be extended by considering the case where channel sensing is not accurate and there can be sensing errors.

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