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DEVELOPMENT OF VACATE ON DEMAND ALGORITHM IN COGNITIVE RADIO NETWORKS

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ABSTRACT—Cognitive radio networks (CRNs) have been recognized as an advanced and promising paradigm to address the spectrum under-utilization problem. Cognitive Radio (CR) users improve spectrum efficiency by opportunistic spectrum access when the licensed spectrum is not occupied by the primary users (PUs). CR users also need to sense the spectrum and vacate the channel upon the detection of the PU's presence to protect PUs from harmful interference. To achieve these fundamental CR functions, CR users usually coordinate with each other by using a common medium for control message exchange ensuring a priority of PUs over CR users. This paper presents the Vacate on Demand (VD) algorithm which enables dynamic spectrum access and ensures to vacate the assigned channel in case of PU activity and move the CR user to some other vacant channel to make spectrum available to PUs as well as to CR users. The basic idea is to use a ranking table of the available channels based on the PU activity detected on each channel. The VD algorithm is characterized by two features: (a) vacate the assigned channel in case of PU activity, (b) move the CR user to some other vacant channel in minimum possible time. We evaluate the performance of our algorithm through analysis and MATLAB simulations.

Keywords—cognitive radio; spectrum sensing; ranking table

1. INTRODUCTION

As the most precious natural resources, available electromagnetic radio spectrums are becoming more and more crowded. The restricted spectrum and low utilization ratio require a new communication paradigm to exploit existing spectrum resources. With the fast growth in wireless technology in the last few decades, there is an increased use of devices and services in the unlicensed band. So unlicensed frequency bands in the 2.4GHz and 5.8GHz range are being many a times used by wireless sensor networks, Wi-Fi hotspots, wireless mesh networks and mobile ad-hoc networks for a variety applications. Spectrum scarcity in the unlicensed band is further affected by the interfering radiation caused by commercial microwave ovens and electrical machinery. While the frequencies reserved for licensed use such as television broadcast, are not always occupied, leading to inefficient utilization of the resource. The newly up-coming CR paradigm has promised to address these issues. CR technology aims to enhance the spectrum utilization in the licensed frequencies, and also alleviate the congestion in the 2.4GHz ISM band by allowing the CR users to opportunistically transmit in the vacant portions of the licensed spectrum [10]. These radios are enabled with the ability to decide transmission parameters such as modulation type, power, transmission rate and channel through local coordination based on their perception of the state of the network and the physical environment. The Federal Communications Commission (FCC) has encouraged work in spectrum sharing issues by initiating steps to free up bandwidth in the 54 − 72MHz, 76 − 88MHz, 174 − 216MHz, and 470 − 806MHz bands. The FCC assigns these completely vacated spectrum bands to licensed holders also termed as primary users, for large geographical regions on a long-term basis.

Cognitive radio is the key technology for next generation communication, i.e. for dynamic spectrum access (DSA) networks. It utilizes the spectrum more efficiently in an opportunistic fashion without interfering with the primary users. It differs from conventional radio, as it can equip users with cognitive capability and reconfigurability. Cognitive capability implies that secondary users can identify the best available spectrum – by sensing and gathering information from the surrounding environment, such as information about transmission frequency, bandwidth, power, modulation, etc. While reconfigurability refers to the ability to rapidly adapt the operational parameters according to the sensed information in order to achieve the optimal performance. This enables secondary users to sense the available spectrum, then select the best available channel, synchronize spectrum access with other users, and release the channel if a primary user reclaims the spectrum usage right.[9] When constructing cognitive radio networks, quality of service (QoS) of primary users must be highly ensured. Otherwise, the arbitrary deployment of secondary network will inevitably bring lots of interference to primary users, violating the essence of cognitive radio. When secondary users coexist with primary users, primary users have priority to use the spectrum. They have to perform real-time wideband monitoring of the licensed spectrum to be used. When secondary users are allowed to transmit data simultaneously with a primary user, certain parameters like the radius of keep-out region around primary receiver, acceptable interference levels, and transmission power control should not be violated. If secondary users are only allowed to transmit when the primary users are not using the spectrum, they need to be aware of the primary users‟ reappearance through various detection techniques and a good spectrum handoff mechanism is required to provide secondary users with smooth frequency transition with low latency.

The above spectrum management-related challenges necessitate novel design techniques spanning several layers of the protocol stack on a single device. In addition, the interaction between several nodes and its impact needs to be considered. Thus much of the research work today is focused on requirements for cognitive radio ad hoc networks protocol applicable to all the layers- physical, link, network and transport. Effective Routing algorithms are needed to accommodate the spectrum dynamics and ensure satisfying network performance such as high network capacity and throughput, short latency and low packet loss. Due to the heterogeneity of spectrum availability among nodes, routing problem cannot be well solved without considering the spectrum allocation. In this survey paper, elaborates on the inter-dependence between selection of route and spectrum management is done and spectrum sensing and routing protocols are studied.

II. SYSTEM MODEL

We consider the co-existence of PUs and CR users in the same geographical area. PUs are licensed to use a fixed spectrum, which can be divided into a set U= {1, 2. . . N} of N no overlapping orthogonal channels. For simplicity, we assume that all channels have the same capacity. CR users can access licensed bands if they do not interfere with ongoing PU transmissions. To prevent interference to PUs from CR users, CR users should vacate the channel as soon as PU returns on its assigned channel. Therefore a ranking table as in [7] is proposed where channels are ranked on the basis of PU activity detected on each channel. A node performs spectrum sensing periodically after a time out and the period of the sensing cycle is assumed to be equal to the sum of the sensing duration and the time out period. The sensing results are used to build a ranking table of the available channels based on the PU activity detected on each channel. Therefore, channels

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are ordered based on the PU activity. The channels are ranked from top to bottom. Towards bottom, PU occupied channels are placed whereas towards top free channels are placed.

The process of making ranking table is summarised in Fig. 1. In Fig. 1(a), we have shown that periodic sensing capable of sensing spectrum opportunities using energy detectors, cyclostationary feature extraction, pilot signals, or cooperative sensing [1] is performed to get the information about the vacant channels and occupied channels. Fig. 1(b) shows the ranking table after getting results from periodic sensing. The metric to evaluate the reallocation mechanism i.e. to reallocate a channel to CR user is expected time (Texp) which is defined as the expected time of getting a free channel when a PU returns on its assigned channel. As we have ranked channels in a ranking table, the algorithm proposed here will decide the common hopping sequence for the CR users. We have divided the ranking table into two portions and set a threshold level at channel number N/2. Below it we have assumed that the probability of PUs activity is maximum and above it CR user's activity is maximum (according to ranking table). The CH sequence that CR users will follow has to take this threshold level into consideration. Then we have set another level at channel number 3N/4 and assumed that the probability of CR user's activity above it is maximum and below it is minimum. These two levels and assumptions are the foundation of the VD algorithm. In the next section we will discuss the algorithm.

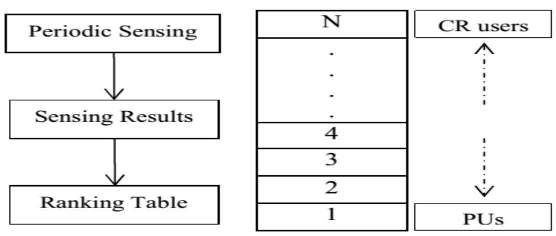

Fig. 1 (a) Process of ranking table formation (b) Ranking table

III. VACATE ON DEMAND ALGORITHM

CH sequence for the CR users to get a new vacant channel will use the ranking table. The threshold level i.e. the channel number N/2 is the place where the CR users move eventually and starts hopping till the task of getting a vacant channel is accomplished. The basic idea is whenever a PU returns on its assigned channel, the CR users will move to channel number N/2 and starts hopping one by one upwards and sense whether the channel is occupied or not. If already occupied, they continue hopping till they find a vacant channel up to channel number 3N/4. If a vacant channel is not found in this portion, they will start hopping downward from channel number N/2 in search of a vacant channel. Let the time taken to sense a channel about its occupancy is τ units, then to sense m channels the time taken is mτ units. According to how much time it will take by CR users to get a free channel, three cases could be possible. i) Best case: There is a probability that the CR users, at first instance finds the channel number N/2, the threshold level channel vacant, then immediately the channel would be assigned to the CR users and time taken is the least possible time, say τ0. ii) Average case: There is a probability that the CR users will find a vacant channel in the interval from channel number N/2 to channel number 3N/4, hopping one by one and each hop takes time τ units, then after hopping on m channels, CR users finds a vacant channel after mτ units of time. iii) worst case: There is a probability that the CR users will not find any vacant channel in the interval from channel number N/2 to 3N/4, then the CR users will have to hop one by one downwards from channel number N/2 and if it finds any vacant channel, then it will take it. After the next sensing interval, it will have to vacate the channel and again search for a vacant channel in the interval from N/2 to 3N/4 because there is always a higher probability that a PU request for its channel in that interval. We are assuming that CR users will find a vacant

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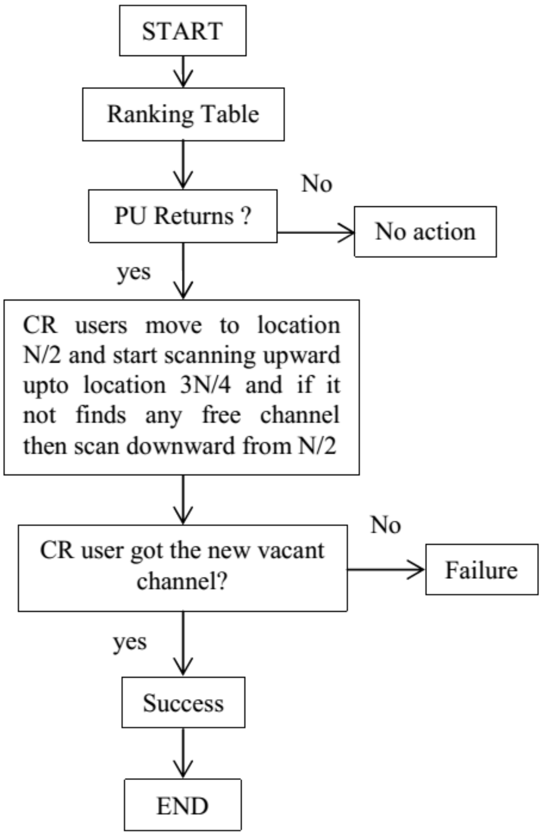
channel in the interval from channel number N/2 to 3N/4. The process is summarised in Fig. 2



(a)

```
VD Algorithm
Input N, τ, i;
Output channel c, T_exp
i=N/2;
X: If C(i)==0 & i<3N/4 //LOOP-1 (SENSING UPWARD)
c= C;
else i++ goto lable X
if i>3N/4
j=N/2-1;
Y: If C(j)==0 & j>0 //LOOP-2 (SENSING DOWNWARD)
c= C;
else j-- goto lable Y
END
```

(b)

The VD algorithm is formally described in Fig. 2(b) where N is the no. of channels, τ is the time to sense a channel and Texp is the expected time to get a vacant channel. In the VD Algorithm, failure i.e. CR users will not find any free channel occurs only when channels are occupied by PUs and it is obviously the case because PUs should always be on priority over CR users. Therefore we can again characterize the behaviour of the VD algorithm based on PU activity for three cases.

1) Low primary user traffic load

As in the first step of the VD algorithm, a ranking table based on the PU activity is formed. It indicates the PU traffic and the amount of occupied channels out of total N channels by PUs. Based on the ranking table, if the number of occupied channels is less than 50%, i.e. the channels starting from channel number N/2 are all free, then it will be considered as a low PU traffic load and is also the best case. In this case, the CR users hopping in search for a vacant channel, immediately, without any delay would be assigned channel number N/2 and the time taken would be negligible, say τ0. An e.g. is shown in Fig. 3(a) wherein let CR users were initially using channel number N-1 and suddenly PU returns on this channel, then CR users will eventually move to channel number N/2 vacating the channel for PU. In Fig. 3(a, b and c), channels occupied by PUs are shown shaded.

2) Medium primary user traffic load

If the number of PU occupied channels is more than 50% (N/2) but below 75% (3N/4), then it would be considered as a case of medium traffic load, where in CR users hopping in search of vacant channels would come to location N/2 first and then start hopping upwards one by one. Time taken to hop on one channel is taken as τ unit. After hopping on m channels, if it finds a vacant channel, it would move to that vacant channel after T exp (expected time) units of time. An e.g. is shown in Fig. 3(b) where the dotted line indicates the hopping and as in previous example if initially CR users were on channel N-1 and if PU returns, it would start hopping from channel number N/2 upwards and move to a vacant channel.

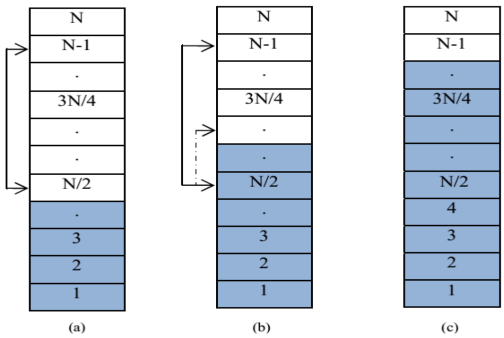


Fig. 3. (a) Low PU traffic load, (b) Medium traffic load, (c) High traffic load

3) High primary user traffic load

If all the channels from channel number N/2 to 3N/4 in the ranking table are occupied by PUs, then there is obviously a very high PU traffic on the network. In this case, when CR users end up hopping up to channel number 3N/4(finds no vacant channel), then the CR users will start hopping downwards from channel number N/2 as there is a probability that some channels got vacant due to communication completion between PUs. While hopping downwards if CR users finds a vacant channel, it would take it and in case if there is not any vacant channel, then CR users will have to stop hopping and this is a case of failure. While if CR users finds a vacant channel and they occupies it. In the next cycle the CR users here will again start hopping from channel number N/2 to 3N/4 in search of a vacant channel because below N/2, probability of PUs return is very high. Fig. 3(c) shows the case when PU traffic is very high.

IV. SIMULATION

A simulation tool in Mat lab was built in order to evaluate the performance of our VD algorithm, focusing in particular the expected time taken to get a free channel by CR users on return of PU on its assigned channel giving immediate priority to PUs over CR users. We assumed that in ranking table, the channels above channel number 3N/4 are reserved for rendezvous for CR users, although rendezvous between CR users is not an issue of this work. The number of available channels N is set in the beginning and does not change during the simulation time. The traffic for both the PU and CR user can be obtained after having the ranking table formed after a sensing cycle. The channels in the ranking table are placed according to sensing results and the amount of time of being occupied. The channels which are occupied for most of the time are placed at the bottom and we will consider the probability of channels of being occupied in simulation. As we have already described there might be three possible cases depending on the PU traffic load, here we have assumed the time taken to get a vacant channel in case of low PU traffic load is negligible, say $\tau 0$. Similarly, the time taken to get a free channel can be obtained by considering the probability that a free channel is available or not. As stated for medium PU traffic load, there is a probability that CR users hopping in search of a vacant channel immediately gets a channel above channel number N/2 or a channel just below channel number 3N/4. So, the time taken for getting a free channel depends on number of hops. Depending on the probability of channels of being occupied after a sensing cycle, we can calculate the expected time to find a vacant channel for the three cases described above by using the formula in (1). We have formulated the expected time to get a free channel in (1), taking in evidence the probability of each channel about its occupancy. Here we have taken the probability of success (getting a free channel) as p and probability of not getting a free channel as q. If channel number N/2 is free, then the expected time taken is $p(N/2)\tau$ where $p(N/2)$ is the probability that channel number N/2 is free and τ is the time taken to hop on one channel. Similarly, if channel number N/2 is not free, then it will hop one by one in search of a vacant channel and search till channel number 3N/4.

$$Expected\ Time = p\left(\frac{N}{2}\right).\tau + q\left(\frac{N}{2}\right).p\left(\frac{N}{2}+1\right).2\tau$$
$$+q\left(\frac{N}{2}+1\right).p\left(\frac{N}{2}+2\right).3\tau \ldots\ldots$$
$$+q\left(\frac{3.N}{4}-1\right).p\left(\frac{3.N}{4}\right).\frac{N}{4}.\tau$$
$$+q\left(\frac{3.N}{4}\right).p\left(\frac{N}{2}-1\right).\left(\frac{N}{4}+1\right).\tau \ldots\ldots$$
$$+q(2).p(1).\frac{3.N}{4}.\tau \qquad (1)$$

We can have expected time taken (Texp) to get a free or vacant channel by using (1). Moreover, for simplicity it is assumed that in case a CR user doesn't find a vacant channel, the CR user packet is dropped instead of being retransmitted i.e. the failure. Finally, it is assumed to ignore collisions among CR user packets because the goal of this paper is to show the CR user behaviour towards the PU activity, putting in evidence how efficiently CR users are able to exploit the spectrum holes. It is to be noted that our algorithm makes provision for CR users to move to some other vacant channel to make room for PUs as opposed to other schemes [3, 5, 6, 8, 9] where the main concern is rendezvous. In [5], sequence based rendezvous is proposed but no provision is there for PU return.

These schemes have calculated the expected time to rendezvous (TTR) w.r.t number of channels as a measure of performance evaluation. Whereas, we are focusing in particular the expected time taken by CR users to get a free channel w.r.t number of hops making any rendezvous scheme robust to PU activity. The main parameters set in the simulations are defined as follows: the duration of one hop τ = 1 unit, Number of channels N, expected time taken to get a free channel T exp,. We can show the behaviour of the VD algorithm by taking an example. In the example to be followed, we have taken the total number of channels, N as 28 and we have assigned probability to each channel based on how much time it has been occupied.

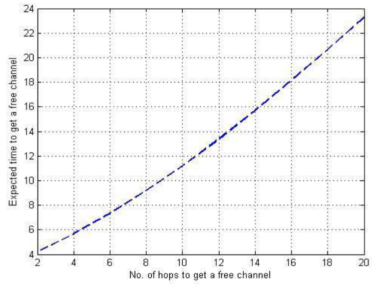


Figure 4. Expected time to get a free channel vs. the number of hops

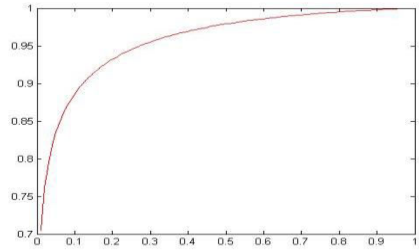


Figure 5: no of channels vs free channel expected time

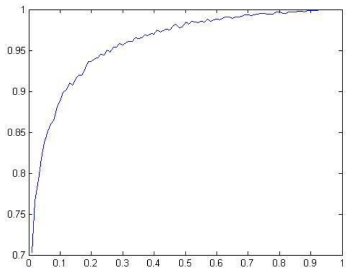


Figure6: exponential time response

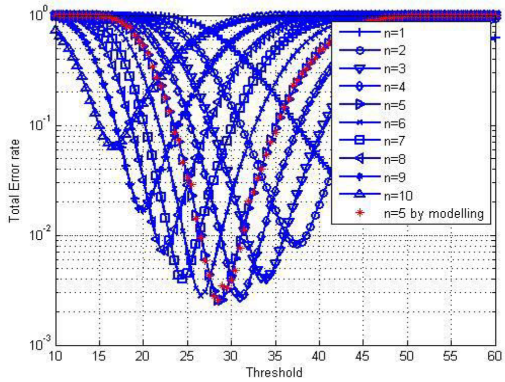


Figure 7 expected error rate vs threshold rate response

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V. CONCLUSION AND FUTURE WORK

In this paper we proposed the VD, a new channel-hopping algorithm for CR users on return of PUs aiming at providing priority to PUs over CR users. It also makes a provision for CR users to find a vacant channel in the least possible time. Our hopping sequence is fixed which makes immediate room for CR users in case of PU return. A ranking table based on sensing results is used where the channels with less PU activity are placed towards top of a ranking table and channels with more frequent PU activity are placed towards bottom of the ranking table. So, Channels are ordered based on PU activity detected. We have set a threshold at channel number N/2 from where the hopping starts in case of PU return on its assigned channel. In low PU traffic case, immediately channel number N/2 would be assigned to CR users, whereas in medium or high PU traffic, CR users will have to hop one by one on the channels according to a set criterion in the algorithm. We have evaluated the expected time to get a free channel w.r.t. number of hops and it has been concluded that if the PU traffic is below 50% of the total channels available, then it would be the best case as in this case there wouldn't be any delay in allocating a channel to CR users on return of PUs. And if the traffic is more than 50% then definitely the expected time would depend on the number of hops it takes to get a free channel. Further study can be carried on including a provision for rendezvous of CR users as well which simultaneously can provide flexibility to PUs.

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