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Implementation of Channel Hopping Algorithm in Cognitive Radio Network & MANET

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Abstract: Dynamic spectrum access by the unlicensed secondary users (nodes) in the Cognitive Radio Network without harmful (potential) interference to the licensed users is an intelligent and efficient use of the Licensed Spectrum Bands. The nodes in a cognitive radio network(CRN) performs periodic local spectrum sensing & dynamically detects the vacant or unused spectrum around them in the form of free channels or spectrum holes which are used for communication among cognitive radio(CR) nodes. If any vacant channel is detected by the secondary user or CR node, it is strictly the responsibility of the CR node to vacate the channel upon the return of Primary User (PU) so that the Licensed user doesn't get any potential interference from the CR user. This paper presents an algorithm called 'Vacate on Demand algorithm' which performs two main functions.1) Vacating the channel by CR user in case of PU return or after the completion of every sensing interval.2) Moving the CR user to some other vacant channel. After the completion of periodic spectrum sensing activity by CR nodes, based on the sensing results, a ranking table is formed which contains the total channels arranged from bottom to top in the order of Primary User activity. The algorithm uses this ranking table for quickly vacating the occupied channel by CR user in case of PU return & dynamically searches for vacant channel in the ranking table. This paper also compares the expected time to get a free channel in CRN with that of a MANET (Mobile Ad hoc Network).The performance of the above algorithm is analyzed using MATLAB simulation.

Key words: Cognitive radio, Ranking table, VD algorithm, MANET.

I. INTRODUCTION

The aim for future mobile systems is to support high user capacities and enhanced peak data rates targeting 100 Mbps for high and 1 Gbps for low mobility. Crucial performance metrics include bandwidth, spectral efficiency, latency, mobility and coverage. Another key requirement of next generation mobile networks is the seamless handover between different networks while maintaining compatibility with legacy architecture and existing security mechanisms. [1] Hence, academia and industry are heavily involved in developing novel tools and methods to tackle the above issues. The major concern in wireless networks is spectrum availability. Bandwidth is scarce and comes at a premium. Thus, here is a need for an efficient allocation and sharing of the available spectrum resources. As a result, one of the burning research topics in which many researchers are currently engaged in is Dynamic Spectrum Access (DSA). DSA exploits the existing wireless spectrum opportunistically which in turn is feasible via cognitive radio (CR) techniques. [2] One of the key challenges in CR research is the detection of weak signals over a wide spectrum range. In addition, there is a trade-off between the complexity of the system, the speed at which it can sense and implement spectrum changes and the probability of error. [2] Although numerous different methods have been devised to deal with this challenge, this paper focuses on a recent innovative technique for the reliable detection of signals and selection of networks. This technique is based on the use of cyclostationary signatures, which exploit the inherent cyclostationarity embedded in the cyclic prefix of an OFDM signal. This is primarily due to the fact that future systems are likely to employ multicarrierchannels by adopting Orthogonal Frequency Division Multiplexing(OFDM). [1] Cyclostationary signatures for CR applications is a topic that has attracted the attention ofmany researchers across the globe. The use of these signatures though can be applied in a different researchdomain of equivalent importance, namely system capacity in cellular networks. The most practical way of improving user capacity is by decreasing the cell size. However, doing so leads to increased co-channel interference (CCI). Novel algorithms for boosting data rates have been proposed by several researchers but these usually come at the cost of impractical computational complexity.

Cognitive radio networks (CRNs) have been recognized asan advanced and promising paradigm to address the spectrum under-utilization problem. It does so by opportunistically identifying the vacant portions of the spectrum known as *spectrum holes* and transmitting in them, while ensuring that the licensed users of the spectrum are not affected [1,2]. In the context of CRNs, the owner of a licensed channel is referred to as a *primary user* (PU) and other users of the channel are referred to as *cognitive radio* (CR) users or *secondary users*(SUs). Each CR user is equipped with one or more cognitive radios, which are capable of opportunistically identifying vacant portions of the spectrum and hopping between them without causing interference to the PUs of the spectrum. Cognitive Radio users also need to vacate the channel upon the detection of the PU's presence to protect PUs from harmful interference.

In this study, we focus on the design of an algorithm which can allocate a channel to PU immediately when it

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returns on its assigned channel without letting it wait and move the CR user to some other vacant channel. The classical rendezvous solutions are not suitable for cognitive radio networks as theyare not able to adapt to the dynamic behaviour of the primary network and, consequently, they can't avoid interference to the PUs. Previously proposed solutions assume that after the rendezvous of a node pair over a given channel, they perform the entire data packet exchange over that channel.There is no mechanism to vacate the spectrum band due to the appearanceof a PU. In our approach, the hopping sequence for the CR users is fixed and uses the latest sensing results by favouringthe data exchange over the channels with the lowest PU activity. Contributions of this work are summarized as follows.

i) **New algorithm giving immediate priority to PUsover CR users**: a vacate on demand (VD) common hoppingalgorithm is proposed to achieve immediate allocation without letting the PU wait to get back its assigned channel from CR user.

ii) **Move the CR user to some other vacant channel inminimum possible time**: a ranking table as in [7] of the available channels based on the PU activity detected on each channel is used where the channels are ordered based on the PU activity, starting from the channels where the lowest PU activity is detected.

The rest of this paper is organized as follows. In Section II we present our proposed method. VD algorithm and its theoretical analysis is presented in Section III. Simulation is conducted in Section IV. We conclude our work in section V.

II. PROPOSED METHOD

We consider the co-existence of PUs and CR users in the samegeographical area. PUs are licensed to use a fixed spectrum, which can be divided into a set $U = \{1, 2, . . . , N\}$ of Nnonoverlappingorthogonal 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 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 summarized in Fig. 1. In Fig. 1(a), we have shown that periodic sensing capable of sensing spectrum opportunities using either 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 definedas 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 usersactivity 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 users 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.

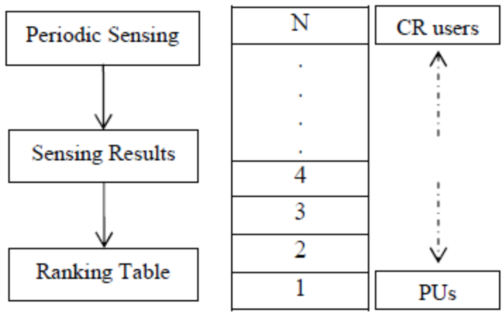

Fig. 1 (a) Process of ranking table formation (b) Ranking table

III. VACATE ON DEMAND ALGORITHM

Channelhopping sequence for the CR users to get a new vacant channelwill 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 tochannel 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 $m\tau$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 $\tau 0$. ii) *Average case*: There is a probabilitythat 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 $m\tau$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

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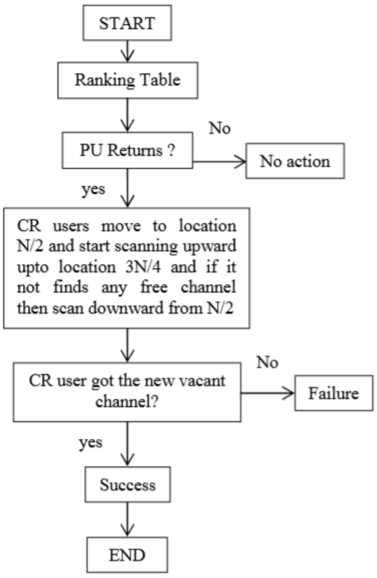
from channel number N/2 and if itfinds any vacant channel, then it will take it. After the next sensing interval, it will have to vacate the channel and again search for a vacant channel in the interval from N/2 to 3N/4 because there is always a higher probability that a PU request for its channel in that interval. We are assuming that CR users will find a vacant channel in the interval from channel number N/2 to 3N/4. The process is summarized 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)

Fig. 2 (a) and (b), The Vacate on Demand Algorithm.

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 Texpis 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 behavior 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 mchannels, if it finds a vacant channel, it would move to that vacant channel after Texp (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.

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 upto 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, ifCR userfind 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,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.

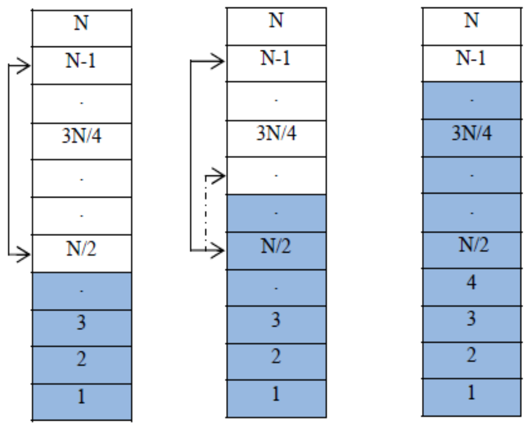


Fig. 3. (a) Low PU traffic load, (b) Medium traffic load, (c) High traffic load

4. Mobile Adhoc Network:

A Mobile Ad-hoc Network (MANET) is a self-configuring network of mobile routers (and associated hosts) connected by wireless links - the union of which form a random topology. The routers are free to move randomly and organize themselves at random; thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a standalone fashion, or may be connected to the larger Internet. Minimal configuration and quick deployment make ad hoc networks suitable for emergency situations like natural or human- induced disasters, military conflicts, emergency medical situations etc.

5. MANET Connectivity Analysis:

In thispaper, we considered the MANETsuch that a node*i* cancommunicate directly with another node *j* only if the distance along the line between nodes *i* and *j* is less than or equal to *k*.

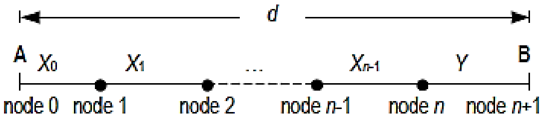


Fig.1. One-dimensional MANET model.

We begin by defining node 0 to be node A, node 1 to be the node closest to the right side of node 0, node 2 to be the node closest to the right side of node 1, and so on (see Fig. 1). Let $X_i$be the random variable of the distance between node i and node i+1, i=0,1,2,…,n–1, and Y be the random variable of the distance between node n and node B. Similar to the technique used in [4], nodes A and B are connected only if $X_i \le 1$, i=0,1,2,…,n–1 and $Y \le 1$. Define $q_n(k)$ to be the probability density function of X_i, i=0,1,2,…,n–1, that is, the distance between nodes i and i+1 is k. A distance k is formed between neighboring nodes i and i+1 if node i is placed at a particular location, say, z away from mnode A, and all other nodes are placed outside the segment between z and $z+k$. Due to the uniform placement of all intermediate nodes, ignoring the border effect, we get

$$q_n(k) = n\left(\frac{1}{d}\right)\left(1-\frac{k}{d}\right)^{n-1}, \quad 0 \le k \le d. \tag{1}$$

IV. SIMULATION RESULTS

A simulation tool in Matlab was built in order to evaluate theperformance 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, thechannels above channel number 3N/4 are reserved forrendezvous 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 duringthe simulation time. The traffic for both the PU and CR user can be obtained after having the ranking table formed after asensing 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 casesdepending 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 τ0. 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 PUtraffic 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)τ 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 andsearch till channel number 3N/4.

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 behavior towards the PU activity, putting in evidence how efficiently CR users are able to exploit the spectrum holes.

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

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 thesimulations are defined as follows:

the duration of one hop τ = 1 unit, Number of channels N, expected time taken to get a free channel Texp,. 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. Let, for illustration, we have taken the values of probability of channels from bottom to top as follows:

(0.98, 0.97, 0.96, 0.94, 0.92, 0.90, 0.89, 0.86, 0.84, 0.83, 0.82,0.78, 0.72, 0.71, 0.70, 0.69, 0.67, 0.62, 0.60, 0.51, 0.49, 0.45, 0.42, 0.40, 0.37, 0.35, 0.20, 0.18)

The relationship between expected time to get a free channel and number of hops to geta free channel for the example we have taken is shown in Fig.4.As we have earlier defined, when PU traffic is low, the time taken to get a free channel is negligible as shown in Fig. (4) because, the CR users doesn't need to hop in search of a vacant channel and as number of hops increases, the expected time to get a free channel increases.

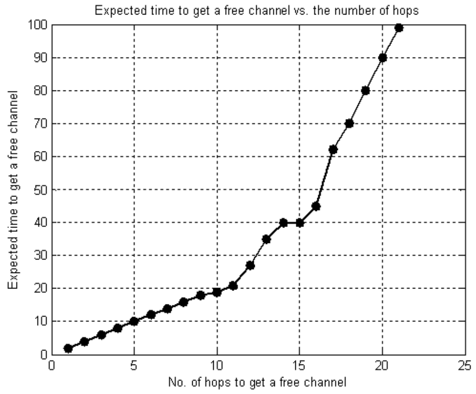


Fig.4 Expected time to get a free channel vs. the number of hops.

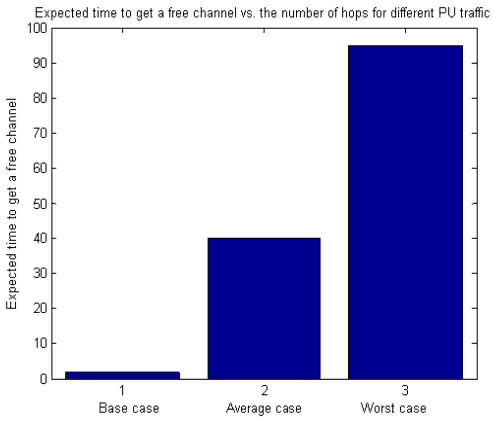


Fig.5 Expected time to get a free channel vs. the number of hops fordifferent PU traffic.

For the example that we have taken, the relationship between expected time and number ofhops shows that the expected time is maximum when CR users doesn't find any vacant channel (hopping on all channels upto channel number 3N/4) and is calculated to be 97.88 units and the minimum expected time to get a free channel is 1.42 units. It is to be noted that we have calculated expected time to get a free channel for CR users i.e. the relocation time of CR users to some other vacant channel as opposed to time to rendezvous (TTR)in other schemes. There could be three possible cases as defined earlier i.e. best case when traffic is below 50%, average case when traffic is upto 75% and worst case when traffic is more than 75%. For the example we have taken, Fig. (5) shows the expected time to get a free channel for the three PU traffic load conditions & Fig.(6)shows the comparison of CRN & MANET.

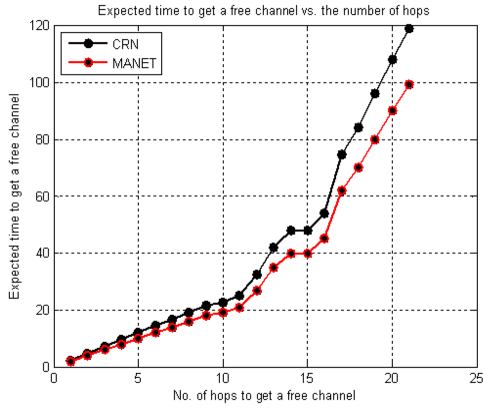


Fig.6 Comparison of CRN and MANET.

V. CONCLUSION

This paper proposed the VD Algorithm, a new channel-hoppingalgorithm 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. This paper sets 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.

This paper evaluatesthe 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.For increasing the spectrum efficiency, this paper implements the vacate on demand algorithm in Mobile Adhoc Networks.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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