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# Vacate on Demand Algorithm in Cognitive Radio Networks

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***Abstract***

***Cognitive radio networks (CRNs) have been recogni zed as an advanced and promising paradigm to address the spectrum under-utilization problem. Cognitive Radio (CR)users improve spectrum efficien cy by opportunistic spectrum access when the licen sed spectrum is not occupied by the primary users (PUs). CR users also need to sense the spectrum and vacatethe channel upon the detection of the PU's presence to protectPUs from harmful interference. To achieve these fundamentalCR functions, CR users usually coordinate with each other byusing a common medium for control message exchange ensuringa priority of PUs over CR users. This paper presents the Vacateon Demand (VD) algorithm which enables dynamic spectrumaccess and ensures to vacate the assigned channel in case of PUactivity and move the CR user to some other vacant channel tomake spectrum available to PUs as well as to CR users. The basicidea is to use a ranking table of the available channels based onthe PU activity detected on each channel. The VD algorithm ischaracterized by two features: (a) vacate the assigned channel incase of PU activity, (b) move the CR user to some other vacantchannel in minimum possible time. We evaluate the performanceof our algorithm through analysis and MATLAB simulations.***

***Keywords—cognitive radio; spectrum sensing; ranking table***

## 1. INTRODUCTION

In this paper we introduce cognitive radio approach thatis expected to perform more significant role in the view of efficient utilization of the spectrum resources in thefuture wireless communication networks. The spectrumutilization efficiency is defined as the ratio of information transferred to the amount of spectrum utilization.Our approach is reactive approach, in that it enables, vianegotiation, learning, reasoning, predict ion, active sense, identification, changes in the base station's parameter tomeet the new services requirements in modern wirelessnetworks and future challenges in cellular systems. Amajor challenge with cognitive radio approach is to bedone in near real-time and to keep up with an everchanging RF environment without overly computationally complex. Various res ource allocation strategies are proposed to optimize the resource allocation in cellularsystem by reducing the call blocking probability in cellular systems. The call blocking probabilityis often measured in terms of two blocking probabilities,the arriving call blocking prob ability, and the handover blocking probability. Analys es and studies in show that the call blocking probabi lity in handover iscaused by two main parameters, interference and delay.Interference leads to missed and blocked calls due toerrors in the digital signalling. Between transmitter (BaseStation, BS) and receiver (Mobile Station, MS), the channel is modelled by several key parameters. These parameters vary significantly with the environment (urban,rural, mountains).There are different type of interference that when not minimized, decreases the ratio of carrier to interference power at the periphery of the cells, causing diminished system capacity, more handover, and more dropped calls. To reduce the handover blocking probability in cellular systems has been proposed various schemes as, prioritized handover schemes and handover with queuing. In some application fields like real time communication and industrial automation is needed to ensure a seamless and lossless handoff. Which means the handover latency should be zero. For efficient hand over management, Handover is a basic mobile network Capability for dynamic support of terminal migration. Handover Management is the process of initiating and ensuring a seamless and lossless handover of a mobile terminal from the region covered by one base station to another base station. In this paper we consider the handover call blocking probability in cellular systems.

## II. SYSTEM MODEL

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 Nno overlapping orthogonal channels. For simplicity, weassume that all channels have the same capacity. CR users canaccess licensed bands if they do not interfere with ongoing PUtransmissions. To prevent interference to PUs from CR users,CR users should vacate the channel as soon as PU returns onits assigned channel. Therefore a ranking table as in [7] isproposed where channels are ranked on the basis of PUactivity detected on each channel. A node performs spectrumsensing periodically after a time out and the period of thesensing cycle is assumed to be equal to the sum of the sensingduration and the time out period. The sensing results are usedto build a ranking table of the available channels based on thePU activity detected on each channel. Therefore, channels areordered based on the PU activity. The channels are rankedfrom top to bottom. Towards bottom, PU occupied channelsare placed whereas towards top free channels are placed.

The process of making ranking table is summarised in Fig. 1. InFig. 1(a), we have shown that periodic sensing capable ofsensing spectrum opportunities using energy detectors, cyclostationary feature extrac tion, pilot signals, or cooperativesensing [1] is performed to get the information about thevacant channels and occupied channels. Fig. 1(b) shows the ranking table after getting results from periodic sensing. The metric to evaluate the reallocation mech anism i.e. to reallocatea channel to CR user is expected time (Texp) which is definedas the expected time of getting a free channel when a PUreturns on its assigned channel. As we have ranked channels ina ranking table, the algorithm proposed here will decide the common hopping sequence for the CR users. We have dividedthe ranking table into two portions and set a threshold level atchannel number N/2. Below it we have assumed that theprobability of PUs activity is maximum and above it CR user'sactivity is maximum (according to ranking table). The CHsequence that CR users will follow has to take this thresholdlevel 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.

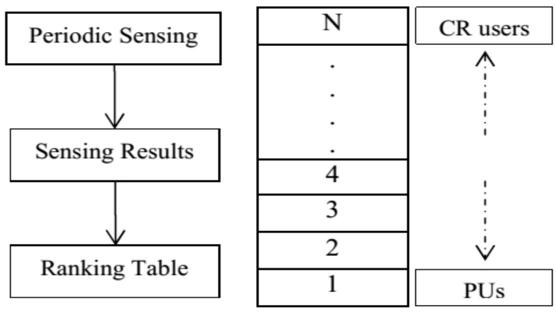


Fig. 1 (a) Process of ranking table formation (b) Ranking table

## III. VACATE ON DEMAND ALGORITHM

CH sequence for the CR users to get a new vacant channelwill use the ranking table. The threshold level i.e. the channelnumber N/2 is the place where the CR users move eventuallyand starts hopping till the task of getting a vacant channelis accomplished. The basic idea is whenever a PU returns onits assigned channel, the CR users will move to channelnumber N/2 and starts hopping one by one upwards and sensewhether 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 thisportion, they will start hopping downward from channelnumber N/2 in search of a vacant

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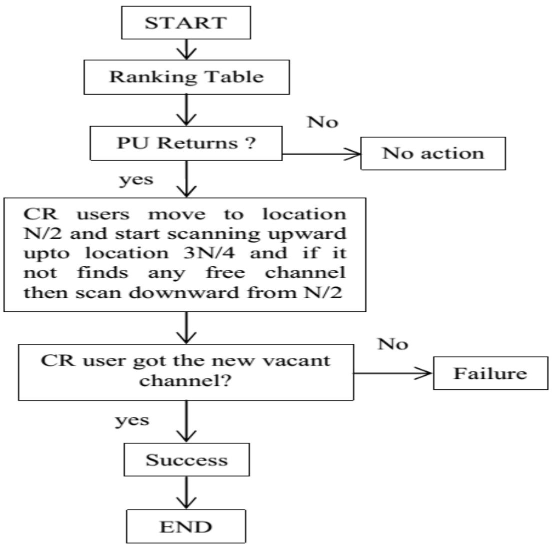
channel. Let the time takento sense a channel about its occupancy is τ units, then to sensem channels the time taken is mτ units. According to how muchtime it will take by CR users to get a free channel, three casescould be possible. i) Best case: There is a probability that theCR users, at first instance finds the channel number N/2, thethreshold level channel vacant, then immediately the channelwould be assigned to the CR users and time taken is the leastpossible time, say τ0. ii) Average case: There is a probability that the CR users will find a vacant channel in the intervalfrom channel number N/2 to channel number 3N/4, hoppingone by one and each hop takes time τ units, then after hoppingon m channels, CR users finds a vacant channel after mτ unitsof time. iii) worst case: There is a probability that the CRusers will not find any vacant channel in the interval fromchannel number N/2 to 3N/4, then the CR users will have tohop one by one downwards from channel number N/2 and if itfinds any vacant channel, then it will take it. After the nextsensing interval, it will have to vacate the channel and againsearch for a vacant channel in the interval from N/2 to 3N/4because there is always a higher probability that a PU requestfor its channel in that interval. We are assuming that CR userswill find a vacant channel in the interval from channel numberN/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 Nis the no. of channels, τ is the time to sense a channel and Texpis the expected time to get a vacant channel. In the VDAlgorithm, failure i.e. CR users will not find any free channeloccurs only when channels are occupied by PUs and it isobviously the case because PUs should always be on priorityover CR users. Therefore we can again characterize thebehaviour of the VD algorithm based on PU activity for threecases.

### 1) Low primary user traffic load

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

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### 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 acase of medium traffic load, where in CR users hopping insearch of vacant channels would come to location N/2 firstand then start hopping upwards one by one. Time taken to hopon one channel is taken as τ unit. After hopping on mchannels, if it finds a vacant channel, it would move to thatvacant channel after Texp (expected time) units of time. An e.g.is shown in Fig. 3(b) where the dotted line indicates thehopping and as in previous example if initially CR users wereon channel N-1 and if PU returns, it would start hopping fromchannel number N/2 upwards and move to a vacant channel.

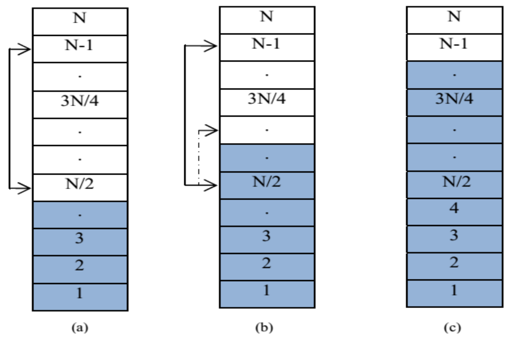


Fig. 3. (a) Low PU traffic load, (b) Medium traffic load, (c) High traffic load

### 3) High primary user traffic load

If all the channels from channel number N/2 to 3N/4 in theranking table are occupied by PUs, then there is obviously avery high PU traffic on the network. In this case, when CRusers end up hopping up to channel number 3N/4( finds novacant channel), then the CR users will start hoppingdownwards from channel number N/2 as there is a probabilitythat some channels got vacant due to communicationcompletion between PUs. While hopping downwards if CRusers finds a vacant channel, it would take it and in case ifthere is not any vacant channel, then CR users will have tostop hopping and this is a case of failure. While if CR usersfinds a vacant channel and they occupies it. In the next cyclethe CR users here will again start hopping from channelnumber N/2 to 3N/4 in search of a vacant channel becausebelow 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 theperformance of our VD algorithm, focusing in particular theexpected time taken to get a free channel by CR users onreturn of PU on its assigned channel giving immediate priorityto 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 CRusers is not an issue of this work. The number of availablechannels N is set in the beginning and does not change duringthe simulation time. The traffic for both the PU and CR usercan be obtained after having the ranking table formed after asensing cycle. The channels in the ranking table are placedaccording to sensing results and the amount of time of beingoccupied. The channels which are occupied for most of thetime are placed at the bottom and we will consider theprobability of channels of being occupied in simulation. As wehave already described there might be three possible casesdepending on the PU traffic load, here we have assumed thetime taken to get a vacant channel in case of low PU trafficload is negligible, say τ0. Similarly, the time taken to get a freechannel can be obtained by considering the probability that afree channel is available or not. As stated for medium PUtraffic load, there is a probability that CR users hopping insearch of a vacant channel immediately gets a channel abovechannel number N/2 or a channel just below channel number3N/4. So, the time taken for getting a free channel depends onnumber of hops. Depending on the probability of channels ofbeing occupied after a sensing cycle, we can calculate theexpected time to find a vacant channel for the three casesdescribed above by using the formula in (1). We haveformulated the expected time to get a free channel in (1),taking in evidence the probability of each channel about itsoccupancy. Here we have taken the probability of success (getting a free channel) as p and probability of

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not getting afree channel as q. If channel number N/2 is free, then theexpected time taken is p(N/2)τ where p(N/2) is the probabilitythat channel number N/2 is free and τ is the time taken to hopon 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.

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

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

These schemes have calculated the expected time torendezvous (TTR) w.r.t number of channels as a measure ofperformance evaluation. Whereas, we are focusing inparticular the expected time taken by CR users to get a freechannel w.r.t number of hops making any rendezvous schemerobust 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 afree channel Texp,. We can show the behaviour of the VDalgorithm by taking an example. In the example to befollowed, we have taken the total number of channels, N as 28and we have assigned probability to each channel based onhow much time it has been occupied.

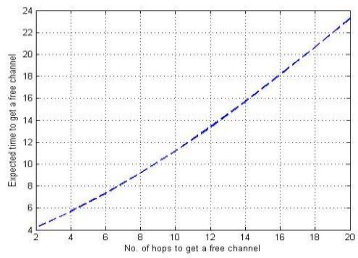


Figure 4. Expected time to get a free channel vs. the number of hops

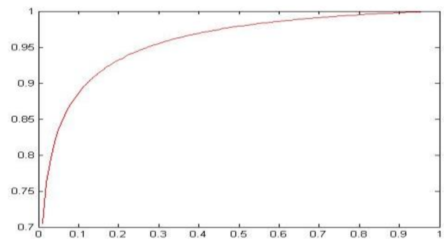

Figure 5: no of channels vs free channel expected time

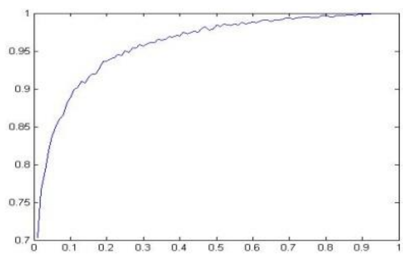

Figure6: exponential time response

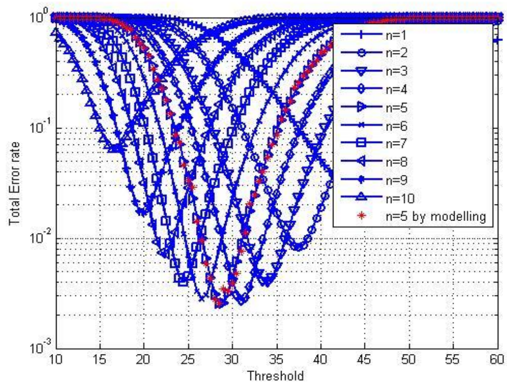


Figure 7 expected error rate vs threshold rate response

## V. CONCLUSION AND FUTURE WORK

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

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