Extended Myopic Sensing Policy for Multiple SUs for Multichannel Opportunistic Access

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ABSTRACT
Frequency band in a spectrum consisting of multiple channels are opportunistically accessed by the secondary users (SUs) is studied. The channels allocated to the primary users (PUs) with license are also temporarily utilized by the unauthorized secondary users during the idle period of PUs. The state of each channel is modeled as a discrete-time Markov Chain process. Collisions developed among the SUs during sensing or accessing the same channel in same time slot, are efficiently handled by extending the existing myopic sensing policies. Assuming the number of channels greater than and equal to the number of SUs, the proposed method claims that collisions can be reduced, without using more than the desired number of channels rather than by increasing the weights assigned to the representatives of the dominating sets of SUs.

General Terms
Channel Assignment.

Keywords
Myopic sensing, opportunistic sensing, Markov Chain, cognitive radio.

1. INTRODUCTION
The Cognitive Radio (CR) technology in wireless networks has been proved a tremendous improvement for channel utilization among the users as suggested by Zhao *et al.* [1]. The distribution of spectrum bands among the users for wireless communications is a challenging task for the network designers. The users having authorization to access the spectrum are known as PUs. On the other hand, the users who do not have authorization to access the channel, but opportunistically access it, they are known as SUs. The unauthorized access of spectrum by SUs in the network is possible, only when it is temporarily free from the PUs. The spectrum opportunity tracking in MAC layer by SUs is an important issue for Opportunistic Spectrum Access (OSA). Due to limited sensing and access capability, a secondary user may not able to sense all the channels simultaneously. The occupancy of channels by PUs follows a Markov process model and the sensing strategy is formulated as a Partially Observable Markov Decision Process (POMDP) by considering the scenario of single SU according to Zhao *et al.* [1]. The objective in this case is to maximize the throughput of the single SU. By introducing myopic sensing strategy in the same scenario, it maximizes the immediate one step reward. It has been proved that myopic policy for channel sensing is optimal, when the state transition is positively correlated over time. Further studies on myopic sensing shows that the selection of channel is based on round-robin structure which prevents to know the accurate channel transition probabilities.

In multiple SUs scenario, whenever a user has data to send, it first senses one of the channels to know its status. Since every greedy SU tries to access the channel opportunistically, it is a challenging task to establish an optimal policy for channel selection and access without collision with other SUs. It is also necessary to improve the network throughput by considering that the channels are most likely idle. Hence to meet these challenges it requires extending the existing myopic policy for channel sensing in multiple SUs and multichannel opportunistic access scenario due to Xu et *al.* [2].

The rest of this paper is organized as follows. The existing myopic sensing policy of OSA for multiple SUs are explored in section 2 and the problem formulation and network model are presented in section 3. Section 4 describes the extended myopic policy for sensing channels by multiple SUs in multi-channel environment. Finally section 5 concludes this paper.

2. RELETED WORK
Myopic policy is one the channel sensing and accessing techniques in cognitive radio network. SUs hack channels that are allocated to the primary users during its idle period. Liu *et al.* [3] have considered a distributed spectrum sharing among competing secondary users and hence proposed a randomized sensing policy to choose a channel that is most likely idle to maximize the network throughput. In [4], Liu *et al.* proposed the cooperative myopic approach in case of multiple users for opportunistic sensing channel which shows near-optimal performance without ignoring the presence of the primary users. A randomized multi-user strategy for spectrum sharing in OSA network is proposed by Liang *et al.* [5]. They proved collisions among SUs is reduced with distributed calculations and thus achieve high spectrum utility. In [6], Zhang *et al.* have explored the optimal multiple channels cooperative spectrum sensing in non-identical sensing setting scenario in order to reduce the average sensing time without compromising the throughput. They assign different sensing time to each SU to sense channels. This is known as cooperative spectrum sensing. Lee in [7] introduced modified myopic policy to reduce collisions among multiple secondary users, and also proves that it provides higher throughput than the existing myopic policy. In [2] Xu *et al.* extends the spectrum sensing policy from single SU scenario to multiple SUs scenario. They propose two effective sensing policies for multiple SUs (1) CSA-myopic policy and (2) Adaptive grouping myopic policy. Both the policies allow collisions among SUs to occur and make immediate actions once collision is sensed. In the above policies it is proved that both collision between SUs and the network throughput depends on the number of channels. Since channels are scarce resources in wireless networks, therefore in order to reduce collisions and also to get better throughput, a graph theoretical approach is proposed in this paper.

3. PROBLEM FORMULATION AND NETWORK MODEL

Considering a primary network with N independent and stochastically identical channels that are occupied by the PUs. Each of the channels follows a slotted transmission structure and the occupancy of channel can be modeled as a discrete-time Markov chain on state space {busy, idle}. So the state of the channel n in slot t is given by $S_n \in$ {0(busy), 1(idle)}. State 0 represents that the channel is occupied by PUs while state 1 represents that the channel is idle. The probability of transition from state 0 to state 1 by the channel i is given by p_{01} and staying in the state 1 is given by p_{11}. The whole system state S_i (t) for i = 1, 2, N can be denoted as [S_1 (t), S_2 (t)…S_N(t)] $\in \{0, 1\}^N$. We consider the secondary user having packets to transmit, look for spectrum opportunities. Due to the limited capacity of hardware and energy supply, each secondary user cannot gain the knowledge about the entire spectrum. Therefore before the start of each slot t, t ≥1, its knowledge about the channel state is given by a belief vector (σ_1(t), σ_2(t)… σ_N(t)). The belief probability σ_i(t), i = 1,2,…,N, is the conditional probability that channel i is available immediately before slot t, given that all the past decisions and observations. In the scenario of multiple secondary users, the objective of myopic sensing policy is to maximize the expected immediate reward at each slot. Thus Xu *et al.* in [2] formulated a myopic sensing policy which is optimal and is given by

$$\pi^* = \arg\max \sum_{m=1}^{M} \sigma^{m}_{a_{m(t)}}(t)\, p_m^{a_{m(t)}}(t) \qquad (1)$$

where M is the number of secondary users, $p_m^{a_{m(t)}}(t)$ is the probability of winning the idle channel for SU_m in selected sensing channel $a_{m(t)}$ at slot *t*.

From the above observations it is concluded that all the SUs must cooperate with each other to avoid the collision among them. But instead of cooperating each other, the selfish SUs form an ad hoc network. In view of this, one is tempted to extend the existing policy as proposed by Xu *et al.* in [2] in order to avoid collision and also to achieve better throughput of the network. Instead of grouping channels w.r.t the number of SUs, the proposed version of sensing policy separates the secondary users using *connected dominating set* (CDS) strategy. Each of the CDSs is implemented by dynamic set operation to select a SU to play the role of a representative within the set. The representative of the CDS reserves a group of channels for sensing or accessing by all its members. In each time slot the representatives of the different sets come forward to sense the channels using round robin approach. It fixes the channels for sensing or accessing by its own members (SUs). When a collision is detected during the winning of good channel by the representative, a precaution has to be taken to avoid it. So the existing CSA-myopic sensing policy as given by Xu *et al.* [2] needs to be improved. The details are given in the subsequent section.

4. THE EXTENDED MYOPIC SENSING POLICY

In this policy, measure attention is given to avoid the collisions during the contention for accessing the channels by SUs. This can be achieved if each of the member SUs obtains a clearance from its representative (r) for sensing a channel in the beginning of each slot. We consider M isolated SUs are distributed in a two dimensional plane who do not cooperate with each other but form an ad hoc network. Each of the nodes in the network has an equal maximum transmission range of one unit. The topology of such ad hoc network can be modeled as unit-disk graph U (V, E). From the figure 1, the set of vertices V = {v_i , i = 1,2..7} are considered as SUs and the set of edges E = {(v_1,v_2),(v_2,v_3),(v_3,v_5),(v_4,v_5),(v_5,v_6),(v_2,v_7)} defines the connectivity between vertices. If two SUs lie within the transmission range of each other then there exists an edge between them as in [8] by Alzoubi *et al.*

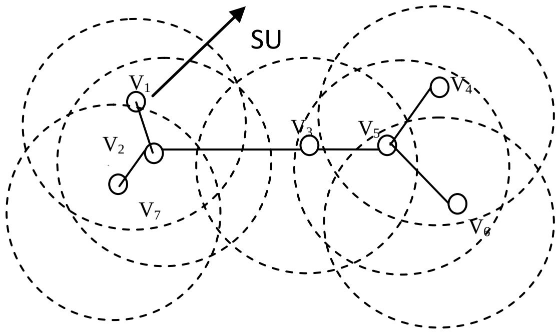

Figure 1. Wireless ad hoc network model of the secondary users using unit disk graph U (V, E).

Since ad hoc network has no physical backbone infrastructure, in order to create a virtual backbone, the concept of dominating set of the corresponding unit-disk graph is introduced as proposed by Alzoubi *et al.* [8]. Such a virtual backbone plays an active role in the connectivity management of wireless ad hoc network. In general, a *dominating set* (DS) of a graph is a subset V' of V such that each node in V \ V' is adjacent to some of the nodes in V' and a *connected dominating set* (CDS) is a dominating set which also induces a connected sub graph due to Deo [9]. A connected dominating set of a wireless ad hoc network is a CDS of the corresponding unit-disk graph. Each of the disjoint CDS generated from the network may grow, shrink or change over time. Thus such sets are known as dynamic sets as studied by Cormen *et al.* in [10]. One of the members of this CDS is designated as a representative for its own set and is assigned by an integer weight. The weight is defined as the number of secondary users present in its own set who have packets to transmit. As an illustration, for a wireless ad hoc network in figure 1, the CDSs are CDS_1 = { r_1= v_1, v_3, v_4, v_6, v_7,} and CDS_2 = { r_2 = v_2, v_5 }, where each v_i, i = 1,2,…,7; represents a secondary user. Suppose we select r_1 and r_2 be the representatives of CDS_1 and CDS_2 respectively. Since the number of members in CDS_1 and CDS_2 is 5 and 2 respectively, the representatives' r_1 and r_2 are assigned by weights 5 and 2 respectively. As per the property of CDS, any of the SUs not belongs to CDS_1 (which belongs to CDS_2) must be adjacent to at least one of the members of CDS_1. Hence, while two different representatives sense the same channel there must be a collision between them. Therefore some action must be taken to avoid such type of collisions. Similar approach is also implemented in the proposed method to not only avoid collision among them but also to save unnecessary wastage of time for sensing the channels.

Consider two representatives r_1 and r_2 of CDS_1 and CDS_2 respectively, try to sense the same channel during the same slot t. As a result, collision occurs between them. Therefore to avoid collision the winner representative is allowed to compel the looser one to sense another channel that is located at a clock position greater than *wr* (the weight of winner representative r) in a round robin structure as presented by Xu *et al.* [2]. During each time slot each of the representatives of individual CDS is allowed to sense only one channel with a hope that the channel is most likely idle. Then depending on the sensing output, the representative decides whether to access the channel or to wait for another slot.

When a member (SU) other than representative of a CDS wants to transmit packet, it has to first perform carrier sensing procedure. Each of SUs follows CSA-myopic sensing policy as given by Xu *et al.* [2] within its own group of channels that are reserved by its representative. If the channel is found idle the SU transmit packet. On receiving the acknowledgement from the receiver the user receives an immediate reward. Otherwise, the user has to wait for another turn to come up. However, since no pair of members of same CDS is adjacent to each other, therefore they always sense different channels within the reserved channels.

If collision happens during the sensing period, CSA-myopic policy resolves it by forcing the looser one to sense next channel in clockwise direction, provided channel are positively correlated.

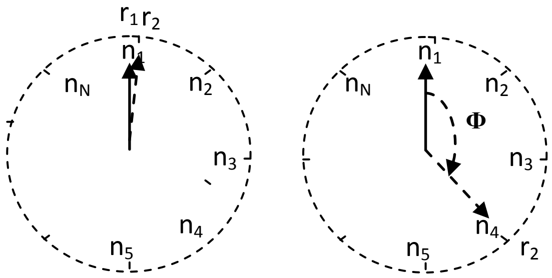

Fig 2: An instance of before and after the implementation of Extended CSA-Myopic Policy structure with multiple representatives for $p_{11} > p_{01}$ $\forall$ channels i and

$\Phi = w(r_1) + 1$

4.1 Extended CSA –Myopic Policy

The extended CSA-myopic policy follows the round robin structure for the multiple representatives (SUs). Consider there are M clock hands in channel order clock as shown in figure 2 (only for two representatives). Each clock hand is considered as a representative who executes carrier sensing before its transmission. When several representatives are competing for the same idle channel, the looser is forced by winner in the extended CSA-myopic policy to choose another channel which is located at the position whose position value is greater than the value of the weight already assigned to the winner in the clock wise direction. Let the position of r_1's clock hand in the clock dial plate as reference. Then the other clock hand positions from r_1 can be shown with the clock wise gaps $G_k(t) \in \{0,1,2\ldots wr\text{-}1\}$, $k = 2,3\ldots wr$ which follows a *wr*-state Markov Chain as given in figure 3. Where k is number of representatives. The transition matrix TM for the position states of the representatives are given in a square matrix of dimension $wr \times wr$.

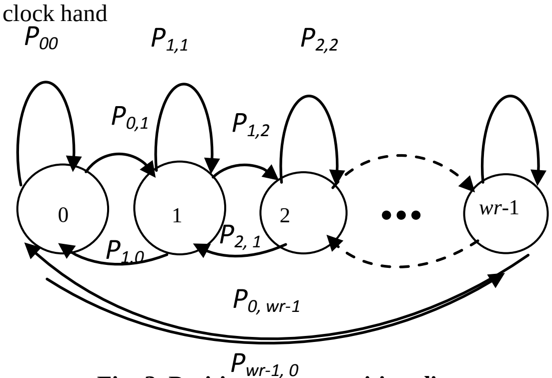

Fig: 3. Position state transition diagram.

$$
\begin{array}{c} \text{State} \\ \\ \\ TM = \\ \\ \\ \end{array}
\begin{array}{c} \\ 0 \\ 1 \\ \vdots \\ wr-2 \\ wr-1 \end{array}
\begin{array}{c}
\begin{array}{ccccc} 0 & 1 & 2 & \ldots & wr\text{-}1 \end{array} \\
\begin{bmatrix}
p_{00} & p_{01} & p_{02} & \cdots & p_{0,wr-1} \\
p_{10} & p_{11} & p_{12} & \cdots & p_{1,wr-1} \\
\cdots & \cdots & \cdots & \cdots & \cdots \\
p_{wr-2,0} & p_{wr-2,1} & p_{wr-2,2} & \cdots & p_{wr-2,wr-1} \\
p_{wr-1,0} & p_{wr-1,1} & p_{wr-1,2} & \cdots & p_{wr-1,wr-1}
\end{bmatrix}
\end{array}
$$

Each elements of transition matrix denoted by p_{ij} is called transition probability. The weight of representatives follows *wr*-state discrete Markov chain. Considering the separations among the representatives (according to their weights) belong to wr state space such that $G(t) \in \{0, 1, 2\ldots wr\text{-}1\}$. When the process changes from state i to state j it assigns a probability p_{ij}. If the separation value is 0, then two representatives sense same channel in same time slot. When the separation value $G(t) = i$, $i = 1, 2\ldots wr\text{-}1$, it concludes no collision occurs among the representatives. As they attempt to access two different channel in the same time slot. Then depending on the sensing result the secondary users decides whether to use that channel or wait for next slot.

Let $p_{00} = p_b$ is the initial probability to remain in same state 0 in slot t. Then in slot t+1, it jumps equally likely to state 1 or state *wr*-1. Since the sum of probabilities in each row of transition matrix is 1, we have

$p_{00}+p_{01}+p_{02}\ldots p_{0,wr-1} = 1$

$$\Rightarrow p_{00} + p_{01} + \ldots + p_{0,wr-1} = 1$$

$$\Rightarrow p_{01} + p_{0,wr-1} = 1 - p_{00} = 1 - p_b = p_i$$

Again as, $p_{01} = p_{0,wr-1}$

Thus, $p_{01} = p_{0,wr-1} = \frac{1}{2} p_i$.

Also $p_{10} + p_{11} + p_{12} + \ldots + p_{1,wr-1} = 1$

$$\Rightarrow p_{10} + p_{11} + p_{12} = 1$$

$$\Rightarrow p_{11} = 1 - (p_{10} + p_{12}) = 1 - 2p_{10} \ (As\ p_{10} = p_{12})$$

$$= (p_i + p_b)^2 - 2p_{10}$$

$$= p_i^2 + p_b^2 .$$

The other values of p_{ij} can be calculated by similar arguments provided j-th state is reachable from i-th state. Thus matrix TM is given by

State 0 1 2 …. *wr*-1

$$TM = \begin{array}{c} 0 \\ 1 \\ \vdots \\ wr-2 \\ wr-1 \end{array} \begin{bmatrix} p_b & \frac{1}{2}p_i & 0 & .... & \frac{1}{2}p_i \\ p_b p_i & p_b^2+p_i^2 & p_b p_i & 0 & .... \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & p_b p_i & p_b^2+p_i^2 & p_b p_i \\ p_b p_i & 0 & .... & p_b p_i & p_b^2+p_i^2 \end{bmatrix}$$

Where p_i represents the stationary idle probability of each channel and $p_b=1-p_i$ represents the stationary busy probability. Hence we have $p_i+p_b=1$. Each of the elements p_{ij} is called the transition probability that incurs for changing of i-th state to j-the state.

Since the initial probability that the system is in state j is given by π_j i.e. Pr (S_0= j) = π_j for all j, then the probability of finding the system in state j at time t = 1, 2… is also given by π_j, where π_j uniquely satisfy the following steady state equations

$$\pi_j = \sum_{i=0}^{wr-1} \pi_i p_{ij} \text{ , for j = 0, 1 … } wr\text{-1}$$

And

$$\sum_{i=0}^{wr-1} \pi_i = 1.$$

These steady state equations consist of (wr + 1) equations in which wr unknowns are to be found.

Thus from the above equations, we have

$$\pi_0 = \pi_0 p_{00} + \pi_1 p_{10} + \ldots + \pi_{wr-1} p_{wr-1,0}$$

$$\pi_1 = \pi_0 p_{01} + \pi_1 p_{11} + \ldots + \pi_{wr-1} p_{wr-1,1}$$

$$\vdots$$

$$\pi_{wr-1} = \pi_0 p_{0,wr-1\,1} + \pi_1 p_{1,wr-1} \ldots + \pi_{wr-1} p_{wr-1,wr-1}$$

Putting the values of p_{ij} from the transition matrix TM, we have

$$\pi_0 = \frac{1}{2}\pi_0 p_i + \pi_1 p_b p_i + \ldots + \pi_{wr-1} p_b p_i$$

$$\pi_1 = \frac{1}{2}\pi_0 p_i + \pi_1 \left(p_b^2 + p_i^2\right) + \pi_2\, p_b p_i$$

$$\vdots \qquad \vdots$$

$$\pi_{wr-1} = \frac{1}{2}\pi_0 p_i + \ldots \pi_{wr-2} p_b p_i + \pi_{wr-1}\left(p_b^2 + p_i^2\right)$$

$$1 = \pi_0 + \pi_1 \ldots + \pi_{wr-1}$$

Now solving the last wr-equations it can be shown,

$$\left.\begin{array}{l} \pi_0 = \Pr(G(t) = 0) = \dfrac{2p_b}{2p_b + wr - 1} \\ \pi_j = \Pr(G(t) = i) = \dfrac{1}{2p_b + wr - 1} \\ \text{for all the values of } i = 1, 2 \ldots wr\text{-1.} \end{array}\right\} \quad (2)$$

The stationary distributions π_0 and π_j of the position states given in equation (2) are defined as the probability of G(t) = 0 and G(t) = i for i= 1,2…wr-1 respectively.

When two or more representatives sense the same channel in same time slot then there is a possibility of collision among them. From the first equation of equations (2) it is concluded that, since the probability of zero separation between two representatives is a positive number, the concerned representatives sense same channel which are either busy or idle . Thus the collision probability between two representatives can be estimated using the equations (3).

$$P_{\text{collision}} = p_i \cdot \Pr(G(t) = 0) = \frac{2p_b(1-p_b)}{2p_b + wr - 1} \qquad (3)$$

From the equation 3 it concludes that the collision among any two representatives (SUs) can be reduced with the increase of weights assigned to the representatives. From the figure 4 it can be ascertained that collision probability can be reduced by increasing the number of members of CDS while keeping the number of channels (N) constant such that N > M (number of SUs in the network). It also shows that the probability of non-zero separation is positive. Which means that two users sense two different channels?

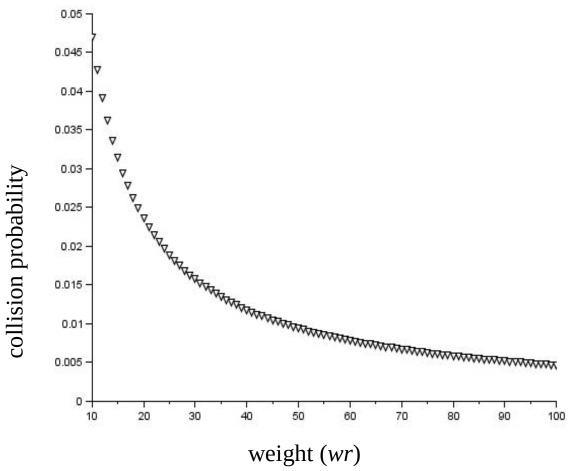

Fig 4: Performance of extended myopic policy w.r.t collision probability vs. weights of representatives (SUs).

5. CONCLUSION

The extended myopic sensing policy for multiple SUs with multiple channels scenarios exploits the channel access efficiently by reducing collisions among them. In this case the sensing policy does not increase sufficient number channels, rather tries to increase the member of SUs in a group due to the implementation of connected dominating sets and latter dynamic set operations in order to reduce collisions. The representative of the set takes the responsible for reserving the channels for sensing or accessing by its own members. It is observed that the probability of collisions among SUs is inversely proportional to the weight assigned to the representative of each connected dominating set. In future work, we will try to prove that the network throughput may increase by increasing the weights assigned to the representatives of the connected dominating sets of SUs.

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