Cooperative Spectrum Mobility in Heterogeneous Opportunistic Networks Using Cognitive Radio

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***Abstract*—With the advent of smarter technologies in cellular networks, often the bands used for lower versions remain unoccupied. To utilize that, in this paper, a new paradigm of cognitive radio has been proposed, where the nodes of a self-organized opportunistic ad hoc network act as the secondary users (SU) to use the white spaces of the existing cellular network. Each SU can freely move around, and in a self-organized fashion may collaborate with other neighboring SUs to gather information on the channels assigned to the cells of the primary network for cognitive use of the licensed spectrum with reduced spectrum latency. Simulation studies show that our proposed cooperative approach significantly improves the call drop/ block rate, and also results better QoS compared to the non-cooperative approach at the cost of negligible additional message overhead.**

Keywords: Cognitive radio, co-operative channel sensing, ad hoc networks, call block/ drop, spectrum latency.

I. Introduction

The emergence of powerful hand-held devices coupled with the proliferation of cloud-based applications and an ever-increasing dominance of multimedia contents in today's internet traffic have ignited an unprecedented growth of mobile data traffic in recent years. Also, the recent and fast advances in inexpensive sensor technology and wireless communications have made the design and development of large-scale ad hoc/sensor networks cost-effective and appealing in a wide range of mission-critical situations, including civilian, natural, industrial, and military, with applications ranging from health and environmental monitoring, seismic monitoring and many more. These networks are self-organized networks communicating over the ISM band. These ad hoc networks may coexist with a centralized network such as cellular, Wi-Fi, or mesh network over the same area. Traffic is mostly bursty in nature in these networks. Hence, cognitive radio (CR) may help these networks together to utilize the available spectrum efficiently through spectrum mobility. According to the conventional CR technology, an SU has to perform the following functions- (a) *spectrum sensing:* SUs scan the Primary users' (PUs) licensed spectrum to find a spectrum hole, (b)*spectrum decision:* to determine which spectrum band to use, (c)*spectrum sharing:* how to share the spectrum with other SUs, and (d) *spectrum mobility:* to release the channel on arrival of a PU. These four factors introduce time delay termed as *spectrum latency* which may cause poor QoS of the system.

So far, extensive works have been reported to reduce the *spectrum latency*. In [1] two different types of channel scanning method are proposed: proactive and reactive. Proactive method is faster for channel switching but it introduces extra overhead due to periodic scans. In [2], a prediction based channel selecting approach is proposed to minimize the scanning overhead. But to maintain freshness of data and to minimize the false alarm probability an intelligent cooperative spectrum sensing algorithm based on a non-parametric Bayesian learning model, namely the hierarchical Dirichlet process is presented in [3]. A time series-based characterization and prediction for spectrum occupancy have been proposed in [4]. Hidden Markov model (HMM) has been used to predict the usage behavior of a frequency band based on channel usage patterns in [5], [6], [7]. To share the sensing information among different SUs, from the network architectural perspective, both centralized and distributed spectrum mobility management schemes are presented in [8]. For the cellular networks, spectrum mobility has been widely investigated to tackle the exponential data traffic growth in [9], [10].

In this paper, a new paradigm of cognitive radio has been proposed. We consider a self-organized ad hoc network with nodes acting here as SUs, freely moving within the service area of a cellular network. The SUs, in general communicate among themselves using ISM band. In case of a bursty traffic, an SU may utilize a free channel of the underlying cellular network if it is available. The major challenge is the absence of any co-ordination between the two networks. This paper presents a collaborative framework of CR to make use of unused channels of the cellular network with significant reduction in the scanning latency and the scanning overhead. This approach requires a sophisticated cooperation protocol among the SUs. This cooperation has been done by exchanging control messages between the SUs using the common control channel in ISM band. On the one hand, with the advent of new smarter technologies, the bands of lower versions of cellular networks will be under-loaded, and on the other hand, in the age of Internet of Things (IoT), many small ad hoc networks will be in use around us. Under this paradigm, since the cellular network is now almost pervasive, this technology may be of great help to provide spectrum to ad hoc network users with minimum additional overhead on SUs and no

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additional infrastructure. Extensive simulation studies show that this cooperative approach helps to reduce the call drop rate, call block rate, and also the scanning overhead compared to the non-cooperative approach.

The rest of this paper is organized as follows: Section II focuses on the system model and Section III presents the algorithm for co-operative channel management. Simulation results are presented in section IV. Finally, section V concludes the paper.

II. System model and problem formulation

The CR model considered here, acts as an interface between two networks one is the PU's structured cellular network (CN), and the other is the SU's structure-less self-organized ad hoc network (AN).

The mobile SUs are deployed within the service area of the cellular network and they build up a multi-hop ad-hoc network. For exchange of control packets, the SU's use ISM band, for data packets it applies co-operative CR technique to utilize white spaces of cellular network.

Let a set of n mobile SUs $S = \{s_1, s_2, \ldots, s_n\}$ be deployed randomly over the service area of the CN, divided into a number of cells $C = \{c_1, c_2, \ldots, c_k\}$. It is assumed that each cell c_j is assigned a list of channels $\{c_j(1), c_j(2), \ldots, c_j(p)\}$ statically, satisfying the demand and the interference criteria of the cells.

It is assumed that the SU nodes are homogeneous and each SU requires a single channel for communication. When an SU s_i, currently in cell c_j, wants to send data, it scans only the channels allocated to the cell c_j discovered by it so far, until it finds a free channel. Each channel scanning step has two components: a fixed time T_{st} for the receiver to switch its sensing circuitry to the new channel and the duration T_{sense} which is required for channel detection, i.e., to sense whether the channel is busy or idle. Thus the average channel detection (acquisition) time can be written as:

$$T_{det} = S_{det}(T_{st} + T_{sense})$$

where S_{det} is the *scanning overhead*, i.e., the average number of search steps for detecting a channel. In [11], the authors have shown that in the ideal case, where probability of detection $P_d = 1$, and probability of false alarm $P_{fa} = 0$, the average value of S_{det} is,

$$S_{det} = NL\left[\frac{1-(\frac{L}{N})^L}{L} - \frac{1-(\frac{L}{N})^{L+1}}{L+1}\right]$$

where N is the total number of channels and L is the number of free channels in c_j the current cell of s_i. Our objective is to minimize the scanning overhead that in turn reduces the spectrum latency and hence improves the call drop rate or the QoS of such networks. To minimize the average scanning overhead, this paper presents a co-operative approach. Each SU in a cell c_j, initially scans the whole spectrum and detects the busy channels, and in cooperation with its neighbors, builds up a dynamic list L_j of channels allocated in a cell c_j and it is updated pro-actively as it moves across the cell boundaries. As demand appears, the SU in cell c_j, scans for a free channel from the list L_j only. This hybrid model of cooperative channel sensing and channel selection helps to reduce the scanning overhead significantly. A distributed algorithm is developed here for collaborative channel sensing to reduce call drop / block rate, the spectrum latency and overhead for channel selection.

III. Proposed Algorithm

In this paper, it is assumed that channels are statically assigned to each cell of the primary cellular network. Initially, each SU in cell c_j, with empty L_j, scans the whole spectrum to discover the *busy channels* within its cell and updates L_j. As it moves across the cells, it co-operatively exchanges the list with its neighbors and thus builds up a partial list of statically assigned channels for each cell it traversed so far, and the busy channels it discovered so far. When an SU in cell c_j wants to send data, it scans the list L_j only to find a free channel. If not found, it updates L_j collaborating with its neighbor SU's, and again scans until there is a success, or the call is blocked after a time out. Hence, in the worst case, an SU may have to scan all the channels statically assigned to a cell only, instead of the entire cellular spectrum, and thus saves the scanning overhead significantly.

A typical example with two cells is presented in Fig. 1.

On the appearance of a PU on a channel occupied by an SU, the SU releases it for the PU, and immediately switches to its next free channel. If the switching time takes longer, call drop may happen. To avoid that two or more SUs attempt the same channel, each SU broadcasts a message after obtaining a free channel and all its neighbors update their usable channel lists accordingly. The steps of the procedure to be executed by each SU are described in Algorithm 1.

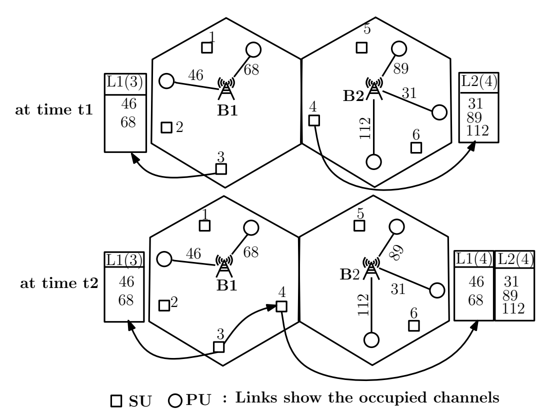

Fig. 1. Cooperative process for spectrum mobility

IV. Simulation Studies

Extensive simulation studies have been done to evaluate the performance of the proposed algorithm. For simulation, the underlying cellular network is represented by the well-known Philadelphia benchmark [12], [13].

Algorithm 1: Distributed Algorithm for spectrum mobility

Input: Set of neighbor SUs $S : \{s_1, s_2, \ldots, s_n\}$, set of base stations $B : \{b_1, b_2, \cdots, b_m\}$, success=0
Output: List of sensed channels for b_i: $L_{b_i}(s_j)$, for each b_i
for *each SU s_j in b_i* **do**
  if *new base station b_i or $L_{b_i}(s_j) = \{\emptyset\}$ broadcast req msg(s_j,b_i)* **then**
    scan the spectrum for busy channels and listen from neighbors and update list $L_{b_i}(s_j)$;
  end
  If a call is generated, then set success=0;
  scan the channels of $L_{b_i}(s_j)$ for a free channel $c(s_j)$;
  If $c(s_j)$ is found, then success=1;
  if *success ==1* **then**
    broadcast *channel_msg($c(s_j), t(s_j)$)*;
    wait for a back off time till $t(s_j)$ and occupy channel $c(s_j)$ to transmit;
    if *receives channel_msg($c(s_j), t(s_i)$) from $s_i \in S$* **then**
      If $t(s_j) > t(s_i)$, then release $c(s_j)$ and update the channel list $L_{b_i}(s_j)$;
    end
  else
    broadcast *update msg($L_{b_i}(s_j)$)* and listen from neighbors;
    scan the channels of $L_{b_i}(s_j)$;
    If a free channel is found, then set success =1;
    if $UL_{b_i}(s_j) = \{\emptyset\}$ **then**
      scan the whole spectrum to find new busy channels ;
      update the list $L_{b_i}(s_j)$ scan $L_{b_i}(s_j)$ for a free channel $c(s_j)$ until a success or time out and the call is blocked;
    end
  end
  if *receives a request / update message* **then**
    $UL_{b_i}(s_k) = L_{b_i}(s_k)/(L_{b_i}(s_j) \cap L_{b_i}(s_k))$;
    if $UL_{b_i}(s_k) \neq \{\emptyset\}$ **then**
      sends $UL_{b_i}(s_k)$ to s_k ;
    end
  end
end

A. Philadelphia Benchmarks

The Philadelphia benchmarks are defined on a 21-node cellular graph as shown in Fig. 2. Here, each node represents a hexagonal cell, and two nodes are connected, if the corresponding cells share a common boundary. The demands of the cells are represented by the demand vectors $D1$ and $D2$ as shown in Table I. In this paper, we follow the benchmark with demand $D1$ only.

Under this model, we have assumed a one-band buffering restriction such that the calls in the adjacent cells should be separated by at least 1 channel and the calls in the same cell must be separated by at least 5 channels to avoid the channel interference.

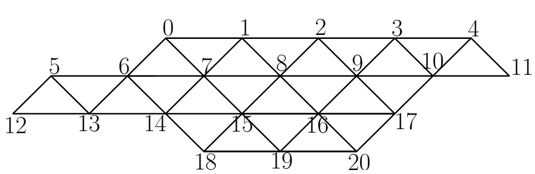

Fig. 2. Philadelphia benchmark of cellular network

B. Simulation Model

For simulation, this benchmark is used to define the underlying CN with PU's, where each node is represented by a hexagonal cell of radius 2 units. It is assumed that following a standard static channel assignment technique [13], channels are assigned to the cells satisfying the demand and the interference criteria. Calls are generated randomly with average demand specified by D_1 in discrete time steps. n SU's are distributed randomly over the area. The SUs are moving within the cellular network following a random way point mobility model with speed v, $0 \leq v \leq 1$ $unit/sec.$, and a pause time $t = 0.5$ sec between two moves. The mobile SU's form an AN and communicate directly with its neighbors within its transmission range of 2 units. According to the specified load, demands are generated for SUs randomly. The call holding time of secondary users follows an exponential distribution with mean $\mu = 2$ sec.

C. Simulation Results

We simulate our proposed algorithm in Matlab. With $50 \leq n \leq 150$, each experiment is repeated for 100 times, and the average values are shown in the graphs.

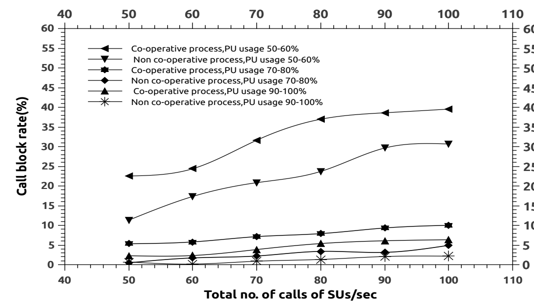

Fig. 3. Call block rate with SU demand

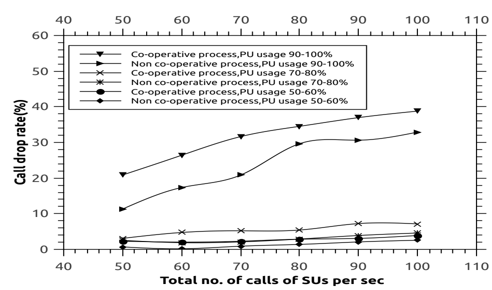

Fig. 4. Call drop rate with SU demand

Fig. 3 and Fig. 4 show the variation of call block rate and call drop rate respectively with demand of SUs. Both show that the performance is significantly better for the proposed cooperative approach compared to the non-cooperative approach.

Another interesting point is that initially the scanning overhead will be higher, since the channel lists in each SU is empty. Each s_i in cell c_j, scans the whole spectrum to sense the busy channels. Then it inserts it into L_j which grows with time in cooperation with the neighbor nodes. The transient response during this learning process is shown in Fig. 5 with $50-60\%$ occupancy of PUs channels. It shows that the network takes much shorter time to stabilize in cooperative mode.

Fig. 6 shows the variation of average spectrum scanning overhead S_{det} with channel demand of PUs. It shows that

Cell nos	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
D1	8	25	8	8	8	15	18	52	77	28	13	15	31	15	36	57	28	8	10	13	8
D2	5	5	5	8	12	25	30	25	30	40	40	45	20	30	25	15	15	30	20	20	25

TABLE I
DEMAND VECTOR OF CELLS

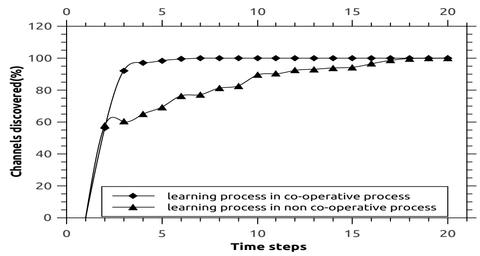

Fig. 5. Transient response during initialization

the proposed approach requires negligible amount of scanning overhead ranging from $10-25\%$ only with total 145 channels for PUs. This also proves the high efficiency of the proposed technique in terms of scanning overhead.

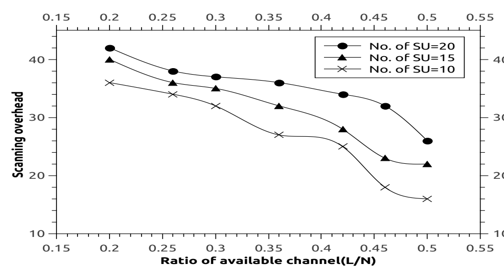

Fig. 6. Scanning overhead vs. channel availability

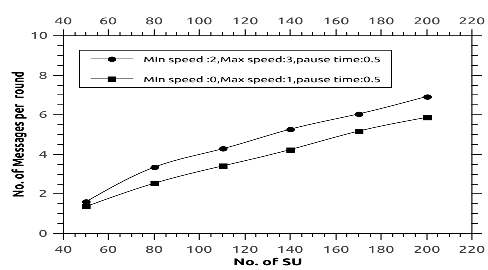

Fig. 7. Overhead for message exchange vs. no. of SU

Finally, Fig. 7 shows the message overhead in terms of number of messages exchanged per SU per discrete time step for coopeartion. For higher node mobility, message overhead is higher as is expected.

V. CONCLUSION

In this paper, a novel cooperative cognitive radio technique is proposed for better utilization of cellular spectrum by secondary users of an ad hoc network. To reduce the channel scanning time, a self-organized distributed algorithm is developed for cooperation among SUs. Simulation study shows a significant improvement in call drop rate, spectrum switching latency and scanning overhead, at the cost of negligible additional message overhead for cooperation.

With the advent of new technologies, since the bands of lower versions of cellular networks will be under-loaded, this technology may be of great help for better spectrum utilization. On the other hand, the users of the cellular networks may also act as SUs to have device to device communication using the channels of AN if they are idle. This both way sharing will certainly improve the aggregate throughput of the whole system.

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