An Energy Balanced Routing Protocol for Cognitive Wireless Sensor Networks

Hiren Kumar Deva Sarma, Bhaskar Bhuyan, Nitul Dutta

***Abstract*— Cognitive radio wireless sensor networks (CRSN) enable optimal use of spectrum which is a scarce resource. Cognitive radio technology makes the co-existence of different wireless networks with legacy networks possible sharing the same spectrum in an opportunistic manner. In this paper, we propose a routing protocol for CRSN. The protocol organizes the sensor nodes in the field in the form of some chains. Sensory data is forwarded towards the base station through different chains in energy balanced manner. The protocol exploits the power of cognitive radio technology. Our analysis shows that the proposed protocol can extend the lifetime of the network. A comparison of the proposed protocol with another similar routing protocol Energy and Cognitive Radio-aware routing protocol (ECR) [1] is presented. Future scopes of the work are outlined.**

***Index Terms*— Cognitive radio, energy balancing, routing, spectrum, wireless sensor networks.**

I. Introduction

SPECTRUM or communication frequency band is an important resource for communication which is not available in abundance. The number of communication related applications is increasing rapidly and therefore, optimal use of available spectrum by the applications is an important aspect. Cognitive radio (CR) technology can address the spectrum scarcity problem subjected to the condition that the primary users of a spectrum are not interfered. Cognitive radio technology offers a solution to increase the spectrum utilization by finding some ways to use temporarily unused spectrums in an opportunistic manner.

Ideally, wireless sensor networks (WSN) consist of hundreds or even thousands of unattended sensor nodes deployed randomly in a harsh environment. Such networks are used to monitor varieties of physical phenomena such as environment monitoring, animal movements etc. which is otherwise difficult to do. Wireless sensor networks are resource constrained. These networks suffer from different resource constraints such as limited memory, computing capability, energy and also importantly limited communication bandwidth.

The ISM (Industrial, Scientific, and Medical) bands are projected to be congested by numerous wireless networks related applications. The wireless applications are increasing at a rapid rate and these applications largely occupy ISM bands and they cause unavoidable interference among different applications. It is important to note that the lower frequency range of the licensed bands offers number of benefits, e.g., better propagation characteristics, longer transmission range, better penetration to the obstacles etc., than the unlicensed band [1].

Cognitive radio ad hoc network (CRAHN) can make use of temporarily unused spectrums and thus it increases the spectrum utilization [1]. Similarly, if cognitive radio technology is combined with wireless sensor networks, then spatially overlapping wireless networks may cooperate and coexist in the ISM bands with minimum interference and thereby these applications increase spectrum utilization in a combined manner. Thus cognitive radio technology enabled wireless sensor network or in short cognitive radio sensor network (CRSN) has already attracted research community [3][4].

In this paper, we address the issue of routing in cognitive radio sensor networks (CRSNs). The network layer of CRSNs has to major challenges, and those are i) joint node-channel assignment for enabling dynamic spectrum access and ii) design of energy efficient routing protocol for prolonged lifetime of the network. We propose a Chain based Routing protocol for CRSNs called as CRC that leverages the power of cognitive radio technology. The propose protocol extends the lifetime of the network by forwarding the data packets towards the base station in an energy balanced manner. We compare different features of the proposed protocol with another recent routing protocol proposed for CRSNs entitled Energy and Cognitive Radio-aware routing protocol (ECR) in [1]. The simulation results presented in this paper shows that CRC can extend the lifetime of the network better than ECR. The rest of the paper is organized as follows: motivation behind this work is outlined in the section II followed by its related work in section III. Section IV details the proposed protocol. Implementation issues are discussed in the section V and finally, the paper is concluded in section VI.

II. Motivation

Cognitive radio sensor network is an emerging are and it is going to offer enormous applications useful for day-to-day life. The wireless sensor networks as already mentioned are resource constrained. Such networks need novel protocols and algorithms which can utilize the available resources optimally and meet user requirements. The

Manuscript received July 30, 2013; revised Aug 20, 2013.

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existing protocols developed for cognitive radio ad hoc networks are not applicable directly to the CRSNs. The major reason is being the resource constraints the CRSNs suffer from. The need of light weight protocols in the network layer of CRSNs that can exploit the power of cognitive radio technology and can also extend the lifetime of the network optimally, are the motivations behind this work. It is important to note that frequent switching of frequency band or in other words frequent spectrum switching during communication may not be desirable as such activity is yet another source of energy consumption in limited energy CRSNs. Therefore, it is another challenge to utilize the unused spectrum in an energy efficient manner.

III. Related Work

There are studies reported related to routing in cognitive radio ad hoc networks (CRAHN) [2]. These protocols exploit the power the cognitive radio but they do not take energy efficiency into consideration. Moreover, the sensor nodes are even more resource constrained than the nodes of ad hoc networks. On the other hand, there are some studies related to energy efficient routing in wireless sensor networks [5]. For example, LEACH [6], PEGASIS [7], TEEN [8], APTEEN [9] etc. ear some of the well-known energy efficient routing protocols for WSNs. But these protocols are limited to single frequency environment only. Therefore, these protocols do not satisfy the requirements of CRSNs. Recently, an Energy-and Cognitive –Radio-aware routing protocol (ECR) is proposed in [1]. This protocol basically enhances the on-demand distance vector (AODV) routing protocol which was originally designed for mobile ad-hoc networks. In ECR, AODV is enhanced by adding cognitive radio feature to it. The protocol ECR is described through four different phases, i.e., route request, route selection, route reply, and route maintenance. The information related to residual energy availability and channel availability in the intermediate nodes in a route is gathered. This protocol also uses piggybacking mechanism adopted from dynamic source routing (DSR) protocol [10]. Through simulation studies it is shown that ECR outperforms AODV in terms of network lifetime and packet delivery ratio. However, it is a well-known fact that the route request and route reply processes generate large number of packet exchanges. This is definitely going to cause large energy expenditure. Moreover, in AODV based routing protocol, there is a need to store routing table in the intermediate nodes. The size of the routing table will grow along with the network size in terms of number of nodes. Thus resource constrained nodes are burdened with even more memory requirements. Although, ECR suggests avoiding frequent channel switching, it does not set any threshold regarding maximum number of possible channel switching in a particular route between a set of source-destination pair. The protocol also does not exploit the power of sink node to a maximum.

IV. Proposed Protocol

In this section, we describe the Chain based Routing protocol for Cognitive radio senor networks (CRC). The sensor network comprised of numbers of resource constrained sensor nodes. The sensor nodes are battery powered. Deployed sensor nodes are homogenous in terms of hardware and initial battery power which is the energy source. Over time, the sensor nodes may be left out with non-uniform level of energy. The base station is located away from the sensor field. The base station is a resourceful node and energy is not a constraint for the base station. The sensor nodes transmit data packets towards the base station in unicast mode. It is assumed that the base station has a large transmission range and it can transmit directly even to the farthest node. Generally conventional WSN cannot use unused spectrum in other band and it operates statically in particular channel in unlicensed band. But cognitive radio sensor network (CRSN) can function in multiple channels of unlicensed as well as licensed bands. CSRN can coexist with legacy networks. The users of a particular channel are classified as Primary User (PU) and Secondary User (SU). The PUs have higher priority over SUs for using the respective channels. In this work, any other network application other than CR enabled networks are considered as PUs and CR enabled networks such as CRSNs are considered as SUs. Both PUs and SUs are expected to coexist.

The proposed protocol is discussed below in terms of five phases. These are localization, synchronization, chain formation, energy balanced data forwarding, and re-formation of chains. Each of these phases is discussed in detail below.

1. Localization: The sensor nodes are to be identified with respect to their geographic locations. The base station divides the sensor field in terms of sectors as shown in the Fig. 1. There are two different parameters depending on which the sectors are formed. These are: the angle of transmission/reception of signals (θ) by the base station and the transmission radius of the base station (r). Thus each sector is represented by two parameters, i.e., the span (θ_i to θ_j) and the transmission radius range (r_a to r_b). Once the sectors are formed as shown in the figure 1 by the base station, each sensor node is assigned an appropriate sector number. The base station can assign an appropriate sector number to each sensor node, once the base station receives at least one signal from each sensor node. The angle of reception of the signal by the base station and the corresponding signal strength are used together to calculate the proper sector number for each sensor node. Each sensor node in the field is localized through this sector numbers and the relative positions of different sensor nodes are computed. At the end of this phase the base station locates each of the sensor nodes deployed in the field. This location information of a sensor node is a relative quantity. The base station does not need to take help of any GPS (Geographic Position System) based techniques in order to locate the sensor nodes. Moreover, the sensor system under consideration does not need the actual location information of each sensor node that normally is achievable through GPS based system. The relative positions of the sensor nodes are sufficient for complete localization of the nodes in the sensor network in order to make the routing decisions.

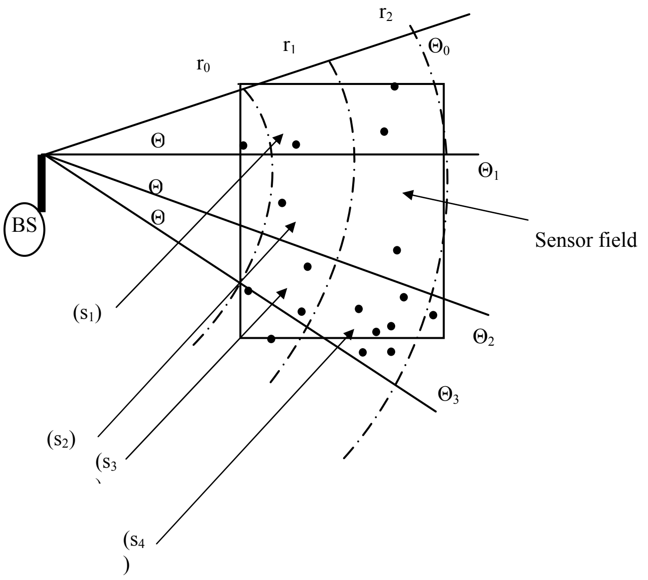

Fig. 1. Sector formation in the sensor field

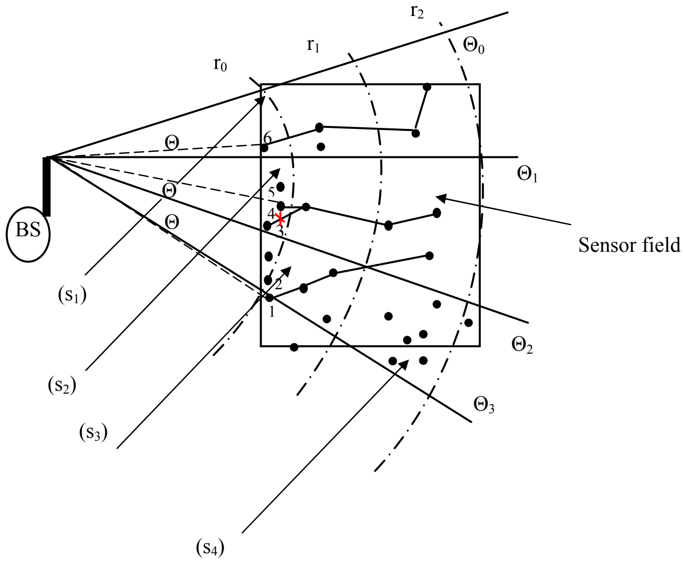

Fig. 2. Chain formation through different sectors in the sensor field

2. Synchronization: The sensor nodes are necessary to be synchronized with the base station. Since the sensor nodes are going to share different frequency bands, it is important for the base station to know the local time of different sensor nodes and they need to communicate in a synchronized manner. This feature becomes even more important for supporting real time communication. The base station and the sensor nodes can be synchronized by executing some existing standard synchronization algorithm [11][12]. Most of such algorithms involve few rounds of communication between the sensor nodes and the base station. Simple and lightweight synchronization algorithms reported in [11][12] are appropriate to apply for synchronization for resource constrained sensor nodes.

3. Chain formation: The base station organizes the sensor nodes in terms of different chains. Each chain starts from a certain node and ends at the base station. Any node interested to forward data to the base station does so, by using other intermediate nodes present in the chain connecting the sender node and the base station. The nodes constituting each chain are selected by the base station considering different parameters. The chains are formed in such a way that each node is present exactly in one chain only. Once chain formation phase is over the entire sensor field can be visualized as a set of chains. Fig. 2 shows an instance of the sensor field after chain formation. The cross in Fig. 2 indicates the cancellation of the link otherwise that link may make the node 10 present in two different chains. The parameters considered for chain formation are discussed below. Whenever a node needs to forward data to the base station, it gets a suitable chain selected by the base station as per the selection rules. Different selection rules along with different parameters are discussed below.

Each chain C can be considered as a set of vertices (V) and edges (E), thus C = (V,E). Moreover, no two chains (say C_i and C_j) can have common vertices and edges, thus $C_i \cap C_j = \phi$.

There are several parameters considered by the base station while identifying different nodes for the chains. These are enlisted below.

Residual energy level: Node with higher residual energy is preferred in order to form the chains.

Location information: The location information i.e., the sector information of each candidate node is considered for identifying the nodes for different chains. This information is helpful for identifying the next node in a chain. Normally, only one node from one sector remains present in a chain. The next node in the chain belongs to any one of the adjacent sectors.

Channel commonality: While the routes are selected, it is taken into consideration that a route should have more numbers of common channels. The routes with more numbers of common channels are preferred over the routes with less number of common channels. This is so because channel switching is a source of energy expenditure. Frequent channel switching is to be avoided in order to save energy expenditure. Here the terms route and chain are used interchangeably. Thus the nodes for a chain are selected considering the channel commonality as one of the parameters.

Number of hops: Number of hops in a route should be less in numbers. Minimum numbers of hops reduces energy consumption in a route.

Availability of licensed channel: The presence of licensed channel in a route makes it possible to have long distance transmission. It also reduces frequent channel switching. Thus a route that has licensed channel available is preferable.

4. Energy balanced data forwarding: Since some sensor nodes need to forward data of other nodes as well, the energy available in those intermediate nodes may drain out quickly if they happen to forward data of other nodes heavily and frequently. On the other hand, depending on the data transmission patterns of different nodes, some chains of nodes may be lightly loaded with data traffic. Then these chains of node will naturally live long. Such imbalance in energy consumption among the nodes is not encouraged. Moreover, if a chain of nodes involves more number of frequency bands switching than other chains then it is highly probable that the nodes in such a chain will exhaust their energy earlier than other nodes. Therefore, the data is to be forwarded towards the base station maintaining a balance of load among different chains of nodes available in the field.

It is assumed that the base station has an idea about the primary (PU) and secondary users (SU) of a channel. Depending on the availability of channels, the base station instructs the sensor nodes to forward data through different channels at different time slots. The base station is a resourceful computing node and therefore, most of the computing burdens are shifted towards the base station.

5. Re-formation of chains: If some nodes present in different chains die out then the routes break. This has significant impact on the performance of the protocol in terms of data delivery. At this stage the chains are to be formed again. The base station takes initiatives and reframes the chains among the available nodes again by calling the same procedure.

V. Implementation Issues

The proposed protocol, CRC, is lightweight. It does not incur any extensive computation. Moreover, the majority of the computational tasks are carried out by the base station. Therefore, the protocol can be implemented with simple sensor nodes which are equipped with cognitive radio enabled hardware and directional antenna. The proposed protocol does not necessitate high memory and high computing power requirements in the sensor nodes. The protocol can be implemented in simple sensor hardware and even, it does not need any Global Positioning System (GPS) support for localization. The protocol needs synchronization of the deployed sensor nodes with the base station. Therefore, the operating system in the sensor nodes should be able to handle synchronization algorithm in association with the base station.

We present some simulation results in this section. The simulation is carried out in Matlab. We consider a sensor network of varying size in terms of number of nodes. We consider different performance parameters for performance comparison of the proposed protocol (CRC) with ECR protocol [1]. We assume that there are 15 unlicensed channels and 1 licensed channel available for use. Figure 3 shows the time taken by each of the protocols for the death of the first node under same network setup. It is observed that under the influence of the proposed protocol (i.e., CRC), the life of the nodes are prolonged.

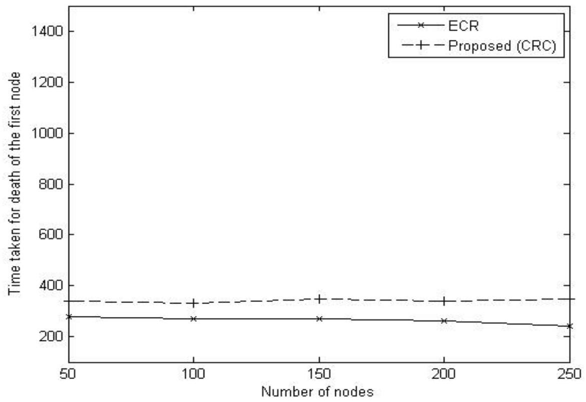

Fig 3 Time taken for the death of first node

Fig 4 shows the number of nodes alive at different time instants under the influence of the proposed and the ECR protocol. The network considered here is of 100 nodes. It is seen that the number of nodes alive under the influence of the proposed protocol is higher than that under ECR protocol. Thus the proposed protocol is more energy efficient.

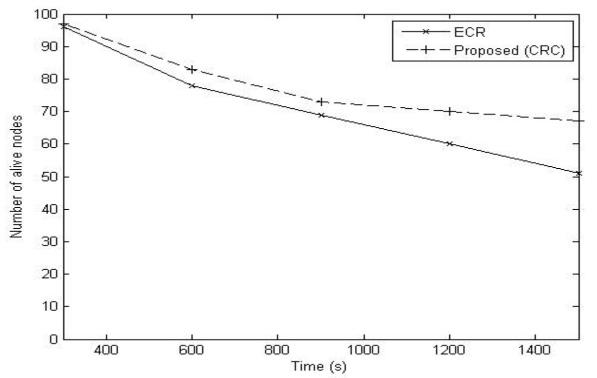

Fig 4 Number of nodes alive at different time instant

Fig 5 shows the overall energy consumption in a given network setup under the influence of both the protocols. It is observed that the energy consumption increases for both the protocols along with the increase of the network size in terms of number of nodes. But the proposed protocol consumes less energy in comparison to the ECR protocol.

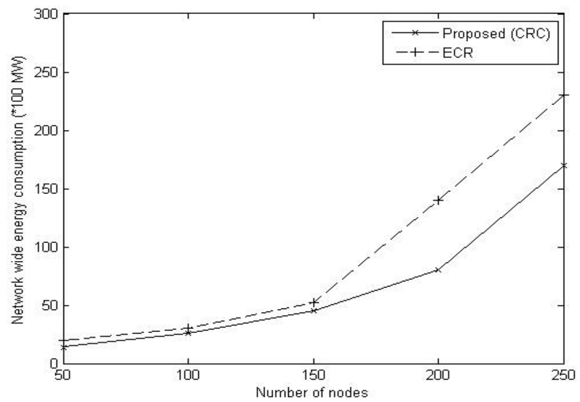

Fig 5 Network wide energy consumption with respect to different number of nodes deployed

ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Fig 6 shows the overall energy consumed by a network of 100 nodes for transmitting different numbers of data packets. It is observed that the energy consumption increases along with the increase in the number of data packets for both the protocols. But the proposed protocol outperforms the ECR protocol in terms of energy expenditure for transmitting different number of data packets.

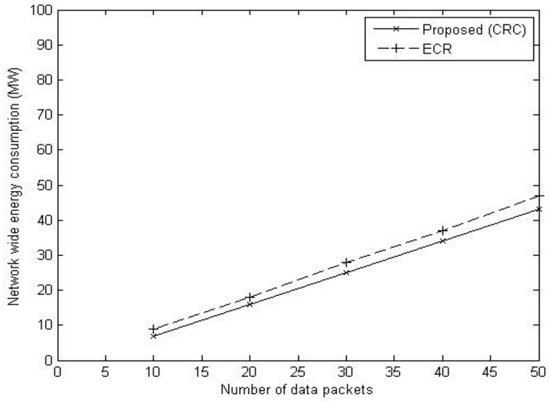

Fig 6 Network wide energy consumption w.r.t to different number of data packets transmitted

The above performance comparisons of the two protocols, namely, the proposed one i.e, CRC and the ECR protocol establishes the effectiveness of the proposed protocol.

VI. Summary and Conclusion

In this paper, we present a novel chain based routing protocol for cognitive wireless sensor networks. The characteristics of cognitive radio networks are exploited in order to forward data from ordinary sensor nodes towards the base station. While the primary users of a channel are not using it the secondary users make use of the available channel in an opportunistic manner. The base station determines the routes from sensor nodes towards the base station. Each route is nothing but a chain of nodes. The simulation results show that the proposed routing protocol is energy efficient and it performs better than ECR protocol. As a future scope of this work, the analytical modeling of the protocol can be undertaken along with rigorous analysis of the protocol.

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ISBN: 978-988-19253-1-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)