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Cognitive radio-based clustering for opportunistic shared spectrum access to enhance lifetime of wireless sensor network

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ABSTRACT

In recent times, Cognitive radio (CR)-based wireless sensor networks (WSNs) have been widely used for opportunistic access of the shared spectrum. In WSNs, deployment of sensor nodes (SN) may be random, or it may follow an optimized approach-based upon the application in which it is to be used. Energy efficient route selection for transferring data from a SN to the base station (BS) is the key issue to increase the lifetime of WSN. Therefore, hierarchical cluster-based data transmission from a SN to BS using multi-hop communication can be one of the effective solutions, as the transmission operation consumes more energy compared to sensing or computation. Several mechanisms have been proposed in the literature for an improvement of network lifetime. Motivated from the above, in this paper, we propose a Distance-Based Multihop Clustering and Routing (DB-MCR) protocol for heterogeneous environment to improve stability, and network lifetime of WSNs. By fixing the node densities, network region is segmented into different subregions with a specific shape. Boundaries of the segmented regions are estimated using the node densities. Segment-wise data transmissions are used for data collection at BS which provides separate bands for the nodes in different regions. A distance-based algorithm is used for election of cluster heads (CH) in which a weighted election probability (WEP) is computed to reduce the interference among the nodes. The performance of the proposed scheme is evaluated using extensive simulations with respect to network lifetime, and stability. The results obtained at initial energy $E_0 = 0.25$ J with BS located at corner show that DB-MCR improves the lifetime by 13% & 17%, and stability by 8% & 16% in comparison to MCR and SEP respectively.

1. Introduction

In recent years, we have seen rapid development in the applications of WSN operating in unlicensed spectrum bands due to overcrowded existing unlicensed spectrum [1]. Cognitive radio allows multiple users to access the shared spectrum in an opportunistic manner. Cognitive Radio-Based Sensor Node (CRSN) has the unique capability of sensing environmental

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parameters, as per its requirement. As per the requirement, CRSN used appropriate spectrum to perform the assigned task that can save the bandwidth in comparison to traditional fixed spectrum assignment approach. From the literature [1], it has been found that CRSN can be utilized in licensed or unlicensed bands. Users are divided into two categories as—primary users (PUs), and secondary users (SUs). In order to avoid interference between licensed and unlicensed users, PUs have been assigned licensed spectrum and SUs are assigned unlicensed spectrum. PU can communicate SU through spectrum sensing.

A CRSN-based network has unique capability to monitor an appropriate environmental parameter in a cooperation with other nodes [2]. Although there exist many solutions in this direction, but still CR-based WSNs are in their early stages. There is a need of lot of improvements with respect to the development of hardware, software, and algorithms for CR-based WSNs. In CR-WSNs, a large amount of power is wasted in packet re-transmission due to packet losses. CR-based WSNs can change their operating parameters for channel access to increase the lifetime by an optimized energy consumption of the SNs [3,4].

WSNs consist of thousands of SNs which are densely distributed over different geographical locations for performing their tasks such as data aggregation, and area monitoring, or processing. These SNs have capabilities of data aggregation by sensing the environment and then send the same to remote Base Station (BS) using wireless channel. SNs are self-configured but are limited in computation and communication abilities. Moreover, these nodes are battery operated which may be depleted after every operation in the network and replacement of battery may not be feasible due to deployment of nodes in different geographical regions. From the literature [3,4], it has been found that in comparison to computation, communication from SNs to BS through intermediate gateways, consumes more energy as data transmission and reception is based upon the distance between source and destination.

In recent years, various routing protocols have used clustering mechanism to reduce network traffic toward BS. These cluster-based routing protocols were based upon hierarchical routing where, few nodes have been given the responsibility to collect sensing information from its neighbors (cluster) and transfer to BS. The objective of clustering mechanism was to improve network lifetime, scalability, and energy efficiency of given WSN. In order to meet the objective of clustering, number of methods for the selection of CH were given in [3,4], where higher energy nodes are given priority to act as a gateway or CH. Clustering consists of following steps: selection of CHs, and data transmission. SNs are grouped together with each group of nodes which has a CH. Clustering has been widely investigated and a lot of research proposals are reported in the literature. Low Energy Adaptive Clustering Hierarchy (LEACH) is one of the most popular protocols in this category. The operations of LEACH [5] are divided into a finite number of rounds. Each round begins with a set-up phase when clusters are organized, followed by a steady-state phase, when data are transferred from SNs to BS through CH. After selection of CHs, each CH broadcasts an advertisement message to all the network field for giving the information that it has been selected as CH. On the basis of received signal strength (RSS), SNs can respond to nearest CH for intracluster communication. In LEACH, all SNs were assumed homogeneous, where meaning of homogeneity includes same communication, power, computation capabilities. However, to use the clustering mechanism, SN can be used as CH or CM according to the algorithm designed for selection of CH in a particular round. Therefore, to increase the lifetime of network field, node with heterogeneity capability with respect to processing power, and storage can be an option. But, the presence of heterogeneous sensors raise many technical issues related to clustering and routing. The sensor nodes having heterogeneous capabilities can be deployed in a region for performing an independent operation.

Considering above research challenges and issues, in this paper, we have selected energy heterogeneity in CRSNs for performing hierarchical cluster-based routing. The concept of advanced, and super nodes has been used which are the nodes having greater initial energy relative to ordinary nodes in the network. We propose an efficient optimized mechanism for selection of CHs which includes energy of SN and distance between SN and BS. Similar to LEACH, SEP, and MCR processing mechanism for selection of CH in DB-MCR includes setup, and steady state phases. The steady state and setup phases for the clustering segment are same as used in LEACH [5], but nodes those are near to the BS used direct communication with or without single hop. Results obtained show that DB-MCR provides enhancement in lifetime, and stability of CRSNs in WSNs.

The rest of the paper is organized as follows. Section 2 provides the detail discussion on related work and contribution of the proposed work. Section 3 describes the network model used. Section 4 illustrates the detailed execution of various steps of the proposed scheme. The performance of the proposed scheme is evaluated with respect to various metrics in comparison with SEP, and MCR in Sections 5 and 6. Finally, Section 7 concludes the paper and provides future directions.

2. Related work and contribution

2.1. Related work

Energy is a crucial issue nowadays, hence, clustering and routing are the two important mechanisms which are widely used for effective utilization of energy of every CRSN. For a detailed study on the above mentioned issues, one can refer [3,4]. Directed diffusion (DD) protocol [6] is most commonly used protocol for clustering and routing in WSNs, but SNs away from the sink die quickly in DD due to large distance data transmission, which indicates that some portion of the network is uncovered for monitoring in the CRSN environment.

2.1.1. Cognitive radio-based network

A dynamic spectrum accessing protocol named as Self Adaptive Routing (SAR) was given by Talay et al. [7] for multi-hop CRSNs. SAR includes PUs and SUs, where each SU has a single transceiver. SAR assumed that SU can communicate with PU