ETSHRA: Energy Efficient Threshold Sensitive Hierarchical Routing Algorithm for Cognitive Wireless Sensor Networks

Shahansha Quadri and Garimella Rama Murthy

***Abstract*—Today's wireless networks are regulated by government organizations where a fixed spectrum is assigned to license holders for a specific geographic region. The spectrum usage is dominated in some areas and a major amount of it is underutilized. The spectrum utilization ranges from 15% to 85% depending on the area and time of usage. The limited spectrum availability and its inefficient use have lead to the development of new approaches where licensed and unlicensed networks can exist in the same area and utilize the existing spectrum in the most efficient manner. One such approach is to use a spectrum sensor network to sense the spectrum availability in the primary network (licensed network) and provide the details to the cognitive wireless sensor network (secondary network or unlicensed network). In this paper we propose a novel algorithm for cognitive wireless sensor network to use the available spectrum in the primary network in an opportunistic manner. The main aim of our algorithm is to optimize the data aggregation and transmission process by using hard and soft thresholds while routing the data in the cognitive wireless sensor networks. Our approach when applied to a sensor field reduces the amount of data being transmitted throughout the network and helps in increasing the lifetime of the network. This helps the cognitive wireless sensor network in making quick and right decision while selecting the channel in which it can operate in the primary network. We show that our approach outperforms other existing solutions such as leveling, gossiping and PASCAL up to 35% and is more energy efficient than these solutions.**

***Index Terms*—Clustering, cognitive wireless sensor networks, gossiping, leveling, spectrum holes, spectrum sharing.**

I. INTRODUCTION

Routing in cognitive wireless sensor networks [1] is very challenging due to several characteristics and factors that differentiate them from other communication networks. Sensor nodes, which are the basic building blocks of wireless sensor networks, are inexpensive, tiny with finite energy resource in the form of a battery. These nodes are equipped with data processing and communication capabilities and can measure the environmental conditions by sensing the data and transforming it to an electrical signal. The sensor then sends the collected data in the form of an electrical signal through the radio transmitter to the base station (sink) either directly or through intermediate gateways.

Recent advances in wireless sensor networks [2] have lead to many new algorithms where energy utilization and reliability were the key areas of concern. These routing protocols may differ based on the application and the network design. With the reduction in the size and cost of sensor nodes and the increasing need to monitor the process in remote areas, cognitive wireless sensor networks are gaining importance. For this reason, cognitive wireless sensor networks should be set up in such a way that the nodes utilize least amount of energy and maximize efficient utilization of the resources to increase the lifetime of the network and achieve reliability. Recent advances in wireless communications show that spectrum sensors can be deployed in a cognitive radio environment to support the existence of both licensed and unlicensed users in the same area by providing information on current spectrum occupancy. Spectrum sensor nodes can detect the temporally unused spectrum (also known as spectrum hole or white space) in the licensed band of the primary network and provide this information to the unlicensed users in the cognitive wireless sensor network. Based on this information, the unlicensed cognitive wireless sensor network can temporally use the licensed band if the spectrum hole is detected. If a licensed user further uses the licensed band that is temporally used by the unlicensed user, then the unlicensed user moves to another spectrum band or stays in the same band by altering its transmission and reception power levels to avoid interference with the licensed user.

In this paper we reconsider the approach of leveling [3] and clustering [4] along with binary tree formation and hard and soft threshold assignment where the sensors are first divided into logical concentric zones called levels based on power levels and then into clusters. Clustering and binary tree formation not only ensures successful aggregation of data within the cluster head but also guarantees successful transmission of data towards the sink. Hard and soft thresholds help the cognitive wireless sensor network [1] to find the channel bandwidth in the spectrum holes in the primary network in a specific range in which it can transmit data. Simulation results show that this technique is more energy efficient than using only leveling.

The rest of this paper is organized as follows. In section 2, related work is discussed. In section 3, a model of cognitive wireless sensor network is discussed. In section 4, issues addressed and assumptions made are covered. Our proposed protocol is discussed in section 5. In section 6, we discuss simulation results. Finally, section 7 concludes the paper and section 8 discusses the future work.

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II. Related Work

Recent works have proven that clustering is a very efficient mechanism that saves lot of energy and utilizes the available resources in an efficient manner. LEACH: Low Energy Adaptive Clustering hierarchy [4] is one such application specific clustering algorithm that uses dynamic clustering and periodic cluster head rotation. Initially, cluster heads are chosen randomly and non-cluster heads align themselves to one of the cluster heads. LEACH doesn't guarantee uniform distribution of cluster heads and also assumes that cluster heads consume uniform energy. Contrary to LEACH, HEED [5] guarantees uniform distribution of cluster heads throughout the network but does not assume uniform energy consumption by the cluster heads. The main drawback of both LEACH and HEED is that they both terminate after a constant number of iterations irrespective of the size of the network.

The idea proposed by LEACH was an inspiration for many other hierarchical routing protocols. PASCAL [6] uses the concept of partitioning levels into sectors of increasing angular measure. Power efficient Gathering in Sensor Information Systems (PEGASIS) [7], Hierarchical Pegasis [7], Threshold Sensitive Energy efficient Sensor Network Protocol (TEEN) [7] and Adaptive Threshold Sensitive Energy efficient Sensor Network Protocol (APTEEN) [7] are some of the other hierarchical routing protocols proposed so far. All the algorithms proposed so far uses only one technique or the other, but the authors in this paper propose to use a hybrid algorithm that uses leveling, clustering, binary tree formation and hard and soft threshold assignment to overcome the shortcomings of leveling and PASCAL algorithms in terms of reliability, energy efficiency and data aggregation.

III. A Model of Cognitive Wireless Sensor Network

A cognitive radio is a wireless node that can change its transmission and reception parameters to use or share the spectrum in an opportunistic manner without affecting the licensed users. Since current approach is to divide the spectrum into small segments that are mostly underutilized, regulation authorities are coming up with the idea of opening some bands for cognitive use.

This cognitive radio technology enables the cognitive wireless sensor network to detect the available spectrum and the presence of licensed users in the primary network, select the best available channel for the secondary users and use it if it is available and vacate the channel when a primary user is detected. This can be achieved by deploying a spectrum sensor network in the primary network that can sense the spectrum availability and provide the information to the cognitive wireless sensor networks as shown in the figure 1. Based on the spectrum availability the secondary network uses the primary network opportunistically.

IV. Issues Addressed and Assumptions

The issues addressed in our proposed protocol are as follows:

1) Reduce the amount of data being transferred to the base station by removing duplicate data that arrives from multiple sensor nodes.

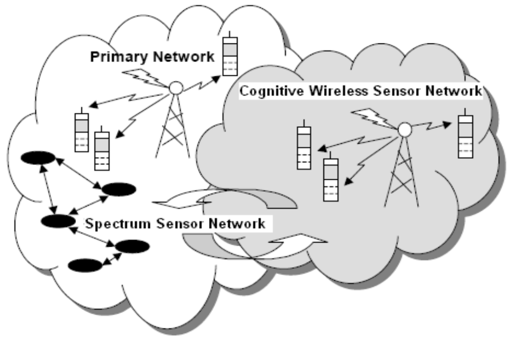

Fig. 1. Shows the primary network and the cognitive wireless sensor network. The spectrum sensor network present in the primary network senses the spectrum hole and provides the information to the cognitive wireless sensor network. Based on the spectrum availability information, the cognitive wireless sensor network uses the primary network opportunistically.

2) Uses gossiping to avoid unnecessary flooding of data throughout the network.
3) To create an energy efficient path to transfer data towards the base station.

The assumptions made are as follows:

1) The network is static with densely populated sensor nodes.
2) The nodes are uniformly scattered in the sensor field.
3) All the nodes have equal amount of energy and capabilities inside the network.
4) A cluster will fall in a single level.
5) Base station can transmit signals of various power levels.

V. Our Proposed Protocol

The main aim of our algorithm is to optimize the data aggregation and transmission process in the cognitive wireless sensor network by using hard and soft thresholds while routing the data. This can be achieved by dividing the network into levels and clusters and forming a binary tree structure to reduce the amount of data being transferred to the base station. Our proposed protocol accomplishes this process through the following steps.

1) Leveling and cluster formation.
2) Binary tree formation, hard and soft threshold assignment.
3) Event detection, data aggregation and cluster head rotation.

We discuss these steps in detail below.

A. Leveling and Cluster Formation

We assume that the base station can transmit signals of various power levels. Initially, the base station sends a minimum power signal as shown in figure 2. All the nodes that receive the signal set their level as 1.Then the base station increases its signal power and sends a second signal. All the nodes that receive this signal and don't have a level assigned to them set their level as 2. This process of increasing the signal power by the base station and assignment of the levels to the nodes goes on until all the nodes have got a level assigned to them or till the maximum power level at which the base station can transmit a signal is reached. Now the number of levels in the network is equal to the number of signals transmitted by the base station.

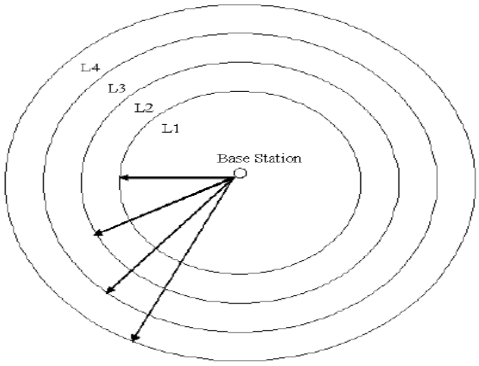

Fig. 2. Base station transmitting various powers signals and levels being formed (shown as L1, L2, L3 and L4) based on the power signal.

After leveling, clustering [8] phase begins. Initially, the cluster heads are chosen and these cluster heads broadcast a message about its new status and all the nodes align themselves to a cluster head based on the proximity and the level to which they belong. These nodes become members of the cluster of the same level. Now every node in the network belongs to a cluster with a cluster head for each cluster. From [4] we assume that the optimal number of cluster heads in the network is 5%. After the entire network is built, the network contains concentric zones called levels and each level contains certain number of clusters. Each cluster contains cluster head and member nodes as shown in figure 3.

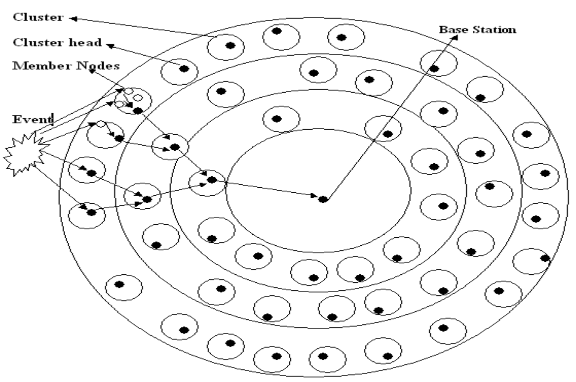

Fig. 3. Shows the message flow from the event point to the base station. The dark circle in the cluster represents the cluster head and hollow circles represent member nodes.

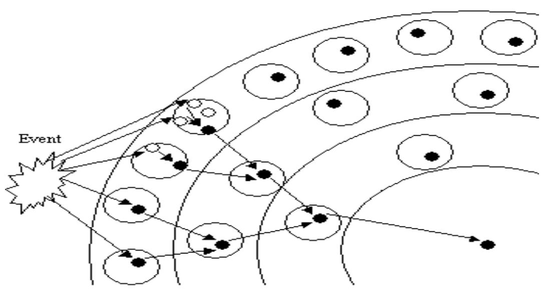

Fig. 4. Binary tree formation to reduce the number of messages transmitted in the direction of base station.

B. *Binary Tree Formation, Hard and Soft Threshold Assignment*

Once leveling and cluster formation are complete, we propose to form a chain from the cluster heads in the form of a binary tree so that each cluster head transmits to and receives from a neighboring cluster head instead of far away cluster heads. With this approach, each cluster head in a lower level will have two cluster heads in the very next higher level as its child nodes as shown in figure 4.

This process goes on till all the cluster heads have a parent and child relationships assigned to them or till the highest level in the network is reached. The key idea to form this binary tree hierarchy is to transmit the data in the direction of the base station and to reduce the number of transmissions and receptions by using data aggregation at the parent node if there is data coming from both the child nodes.

Once binary tree formation is complete, the cluster heads broadcast two threshold signals to the member nodes. These are called hard and soft thresholds. Hard threshold is the minimum value for the attribute that can trigger the sensor to switch on its transmitter and transmit signal to the cluster head when the event is in a specific range of interest and avoids unnecessary transmissions of irrelevant data. Once the node senses the value equal to or greater than the hard threshold, it transmits the data only when the value of the event changes by an amount equal to or greater than the soft threshold value. The soft threshold value is used to reduce the number of transmissions if there is very little or no change in the value of the sensed event. Both hard and soft values can be adjusted to control the number of packet transmissions in the range of our interest. Thus hard and soft values reduce the number of unnecessary transmissions by a much significant level.

C. *Event Detection, Data Aggregation and Cluster Head Rotation*

From [4] we assume that computation would be much less energy consuming than communication and there by perform data aggregation/fusion to achieve energy efficiency. Consider that an event has occurred and a couple of sensor nodes have detected the event and has to send data to the base station. The sensor nodes send the data to their cluster heads. The cluster head checks if duplicate data of the same event has arrived from multiple nodes. If there are any similar packets, then the cluster head combines the data that has arrived from multiple nodes thereby sending a single set of data in the direction of the base station. After data aggregation, the cluster head gossips the message to the nearest cluster head that belong to a level lower than the originating cluster head. Now this cluster head will transfer the data to the next nearest cluster head in the lower level and this process continues until the base station receives the message.

Let us consider that an event has occurred in level 4 as shown in figure 3 and some sensors have detected the event and send the message to the cluster head. The cluster head sends the message to the nearest cluster head in the lower level after data aggregation. Thus unnecessary flooding of messages has been avoided to the maximum extent there by achieving energy efficiency and optimization.

Cluster Head Rotation: From [4], we assume that all sensor nodes including the cluster heads are homogenous, having same capacity in terms of power [9], computation and communication. This may quickly drain the energy of the cluster head since most of the computation and communication is performed using the cluster head. To overcome this problem we propose to rotate the cluster head after certain amount of cluster head energy is exhausted to balance the energy dissipation of the nodes. This is decided by the nodes choosing a random number between 0 and 1[4]. A cluster head is rotated randomly over time and a new node is selected to become a cluster head for the current round if the random number is less than the following threshold:

$$T(n) = \begin{cases} \dfrac{p}{1-p\left(r \bmod \frac{1}{p}\right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

where p = percentage of cluster heads (e.g. 0.05 or 5%), r is the current round and G is the set of nodes that were not cluster heads in the last 1/p rounds. With this cluster head rotation mechanism, the ex cluster head can still be active and detect events. Thus, there is huge increase in the lifetime of the network as well as reduction in the number of messages lost.

VI. Simulation Results

We made a comparative study of the traditional leveling algorithms with our proposed algorithm and the simulation results show that our approach outperforms the existing algorithms by increasing the lifetime of the network and is more energy efficient and reliable to be used in a cognitive radio environment. The results were obtained by conducting several runs of experiment.

Fig. 5 shows that with a network model of 900 nodes that has been used in the simulation, there is a major increase in the performance of the network and our proposed approach (ETSHRA) outperforms the traditional leveling protocol. Thus we show that clustering along with binary tree structure and threshold values will be more useful in forwarding the data packets to the base station than using only leveling.

In Fig. 6, we show that with a 900 node network, ETSHRA approach has a larger network life and is more energy efficient than gossiping algorithm. With 900 nodes network the gossiping protocol network dies down around 650 events where as our protocol can withstand up to 1000 events.

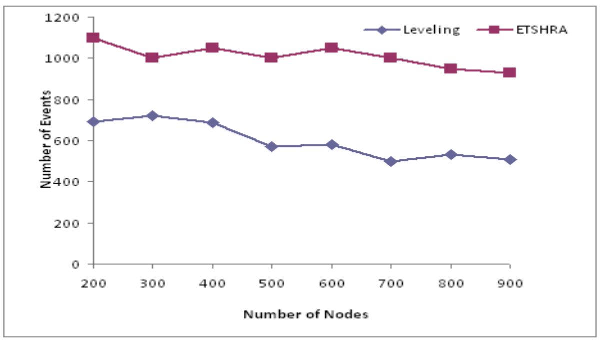

Fig. 5. ETSHRA vs. leveling

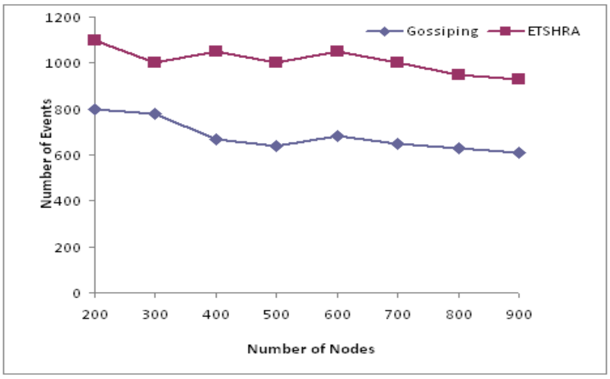

Fig. 6. ETSHRA vs. gossiping

Fig. 7. below shows that there is drastic increase in the performance of the network life and our proposed approach outperforms the PASCAL [6] algorithm.

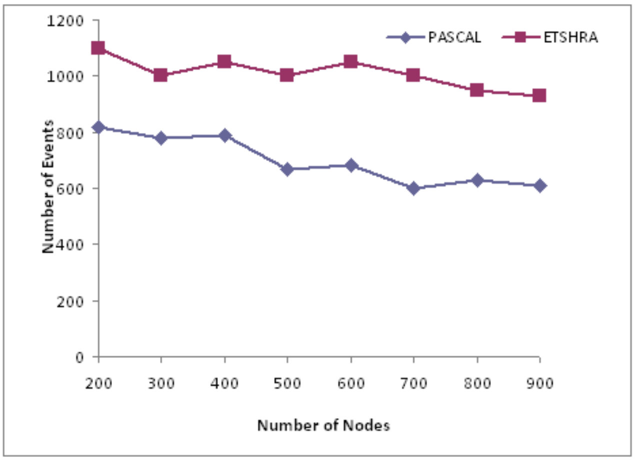

Fig. 7. ETSHRA vs. PASCAL

VII. Conclusion

In this paper we have proposed a novel algorithm for a cognitive wireless sensor network that can use the primary network opportunistically based on the spectrum availability. The algorithm introduces the concepts of binary tree formation, hard and soft threshold assignments and cluster head rotation on top of leveling and clustering. Through simulations and comparisons with existing protocols we have shown that the issues listed in section 4 are successfully resolved thereby increasing the lifetime of the network and making it energy efficient and reliable. Thus the proposed ETSHRA algorithm achieves a superior performance in contrast to other leveling protocols and can be implemented for spectrum sharing in the cognitive wireless sensor networks.

VIII. Future Work

In this paper we mainly concentrated on clustering within the same level. In future we would like to improve the network performance when a cluster falls in two levels, which can improve the energy efficiency of our protocol to a much greater extent and thus increase the lifetime of the network.

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