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Accurate And Efficient Infrastructure Sensor Network for Ad Hoc Cognitive Radio Network

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Abstract—**We propose an energy-efficient network architecture that consists of ad hoc (mobile) cognitive radios (CRs) and infrastructure wireless sensor nodes. The sensor nodes within communications range of each CR are grouped into a cluster and the clusters of CRs are regularly updated according to the random mobility of the CRs. We reduce the energy consumption and the end-to-end delay of the sensor network by dividing each cluster into disjoint subsets with overlapped sensing coverage of primary user (PU) activity. Respective subset of a CR provides target detection and false alarm probabilities. Substantial energy efficiency is achieved by activating only one subset of the cluster, while putting the rest of the subsets in the cluster into sleep mode. For further increase in the efficiency and accuracy, we divide the channel access to time slots and each node in the subset can access the whole channel based on their energy. In which the node with higher energy can access the channel first and so on. So here only one node in the subset is active at a time. We compare the proposed CR network with existing approaches to demonstrate the network performance in terms of the energy consumption and the end-to-end delay.**

Index Terms—**ad hoc cognitive radios, end –to-end delay, sensor network, sensor nodes .**

I. INTRODUCTION

According to the Federal Communications Commission (FCC), utilization of the statically assigned spectrum varies from 15% to 85%, depending upon spatio-temporal variations. In order for a secondary user, which cannot be active when the primary user (PU) is active, to utilize the spectrum licensed to a PU, the activity of the PU should be closely monitored . One possible approach is to use cognitive radio (CR) transceivers for spectrum sensing and sending their observations to a fusion center to determine the presence of the PU signal. However, this approach incurs high cost and high energy consumption. A more appealing approach is to perform sensing via cost effective and dedicated sensor network. Use of the sensor network for spectrum sensing is being explored by regulatory bodies like the FCC, which has invited experts to draft proposals for the use of a sensor network with low cost/energy/delay for enhanced spectrum sensing. Energy-efficient spectrum sensing by a sensor network offers advantages such as more effective detection of a weak PU signal (by location diversity of the sensor nodes) and better protection of the PU due to high reliability in detection. Furthermore, this approach is more appropriate for mobile CRs where cooperative spectrum sensing is more difficult in the absence of a fusion center and cooperation between the CR users cannot be easily achieved. However, there are still certain challenges/disadvantages in such a network, which are yet to be resolved; examples are ownership of the sensor network, information dissemination by the sensor network, usage fees, etc. The sensor network required for spectrum sensing should be a low-cost network consisting of a large number of spatially distributed sensor nodes equipped with sensing, processing, and communications capabilities. Because the sensor nodes are characterized by their limited resources (e.g., storage capacity and processing power, and typically non-replaceable, limited capacity batteries), efficient consumption of the energy, which affects network lifetime, is a major concern. The sensor nodes carry out spectrum sensing by means of energy detection, and report the results to the CR acting as a fusion center. The decision fusion at the CR employs the OR-rule, which decides the presence of the PU signal when at least one of the sensor nodes reports its presence. The effect of location diversity is more profound with more sensor nodes involved in spectrum sensing. In this paper, we propose a CR network (CRN) with disjoint subsets for each cluster of sensor nodes as a solution to the problem – effective sensing achieved with high energy efficiency. The CRN is composed of ad hoc CRs, assigning mobility to CRs to be more general, and infrastructure sensor nodes. An ad hoc CR, which is a cluster head, is surrounded by a cluster of infrastructure sensor nodes within one-hop communication range of the CR, and each cluster is further partitioned into subsets. To achieve energy efficiency, sleepwake scheduling for the subsets based on the statistical behavior of the PU is also proposed. Main contributions of this paper are as follows,

- We proposed an energy-efficient cluster updating and subset formation (CUSF) process for the operation of ad hoc CRs assisted by an infrastructure sensor network. The CRs randomly move in time and the subsets of the clusters in the sensor network are updated accordingly. In this paper, theoretical analysis of the subset formation is also presented.
- Only one subset in a cluster is active at a time, while the others switch to sleep mode. For further reduction of energy consumption, the actual sensor nodes for spectrum sensing are selected from the given active subset according to a separately proposed algorithm. Energy savings during spectrum sensing is a critical matter with a CRN including many sensor nodes. Most of the published works consider only communication energy or processing energy when evaluating the energy consumption of the network, so energy consumed during the sensing stage is often ignored. Though energy for each sensing is considerably less than communication energy, the short interval in the periodic sensing process of the CRNs makes it significantly

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important. Thus, minimization of sensing energy helps to prolong the lifetime of the sensor network.

- Even the one active subset can be switched to sleep mode for a certain number of time slots by the proposed scheduling algorithm, based on the history of PU activity. The proposed scheduling achieves additional energy efficiency at the cost of a slightly increased error in PU detection.

For further increase the efficiency and accuracy, we divide the channel access to time slots and each node in the subset can access the whole channel based on their energy. In which the node with higher energy can access the channel first and so on. So here only one node in the subset is active at a time.

- We investigated comprehensive energy consumption of the sensor network with the proposed architecture. Overall energy consumption of the sensor network involves energy consumed in setup, sensing, sending, and sleep stages. In the literature, the energy consumed in network setup has mostly been ignored. However, due to free and frequent moves of the CRs and the subsequent CUSF process for each move, energy consumed in the setup stage is additionally considered in this paper.

II. LITERATURE SURVEY

E. Hong et.al [1] formulated Neyman_Pearson detection scheme of OFDM signals employing continuous pilot subcarriers. Since there are many unknown parameters in the Neyman_Pearson detector to be resolved, we also present a generalized log-likelihood ratio test (GLRT) spectrum sensor. The considered problem is complex and leads to a joint detection and estimation problem. The proposed GLRT spectrum sensor only needs received samples. Moreover, the proposed GLRT spectrum sensor is robust to the frequency selectivity of fading channels and symbol timing offset and carrier frequency offset. Simulations con_rm the advantages of the proposed detector.it in two-column format, including figures and tables.

J. Mitola and G. Q. Maguire Jr [2]coined Software radios arc emerging as platforms for multiband multimode personal communications systems. Radio etiquette is the set of RF bands, air interfaces, protocols, and spatial and temporal patterns that moderate the use of the radio spectrum. Cognitive radio extends the software radio with radio-domain model-based reasoning about such etiquettes. Cognitive radio enhances the flexibility of personal services through a Radio Knowledge Representation Language. This language represents knowledge of radio etiquette, devices, software modules, propagation, networks, user needs, and application scenarios in a way that supports automated reasoning about the needs of the user. This empowers software radios to conduct expressive negotiations among peers about the use of radio spectrum across fluents of space, time, and user context. With RKRL, cognitive radio agents may actively manipulate the protocol stack to adapt known etiquettes to better sates the LISCT'S needs. This transforms radio nodes from blind executors of predefined protocols to radio-domain-aware intelligent agents that search out ways to deliver the services the user wants even if that user docs not know how to obtain them. Software radio provides an ideal platform for the realization of cognitive radio.

S. Haykin [3] proposed Cognitive radio is viewed as a novel approach for improving the utilization of a precious natural resource: the radio electromagnetic spectrum. The cognitive radio, built on a software-defined radio, is defined as an intelligent wireless communication system that is aware of its environment and uses the methodology of understanding-by-building to learn from the environment and adapt to statistical variations in the input stimuli, with two primary objectives in mind:

- highly reliable communication whenever and wherever needed;
- efficient utilization of the radio spectrum.

Following the discussion of interference temperature as a new metric for the quantification and management of interference, the paper addresses three fundamental cognitive tasks.

1) Radio-scene analysis.
2) Channel-state estimation and predictive modeling.
3) Transmit-power control and dynamic spectrum management.

S. M. Mishra et.al [4] formulated Spectrum sensing. it is required for better utilization of spectrum and preventing interference with licensed users. However, detection performance in practice is often compromised with multipath fading, shadowing and receiver uncertainty issues. To mitigate the impact of these issues, cooperative spectrum sensing has been shown to be an effective method to improve the detection performance by exploiting spatial diversity. While cooperative gain such as improved detection performance and relaxed sensitivity requirement can be obtained, cooperative sensing can incur cooperation overhead. The overhead refers to any extra sensing time, delay, energy, and operations devoted to cooperative sensing and any performance degradation caused by cooperative sensing. Specifically, the cooperation method is analyzed by the fundamental components called the elements of cooperative sensing, including cooperation models, sensing techniques, hypothesis testing, data fusion, control channel and reporting, user selection, and knowledge base. To combat the channel fading suffered by the single radio, cooperative spectrum sensing is employed, to associate the detection of multiple radios. In this article, the optimization problem of detection efficiency under the constraint of detection probability is investigated.

III. EXISTING SYSTEMS

A .Infrastructure Sensor Network for Ad Hoc Cognitive Radio Network

This network architecture consists of ad hoc (mobile) cognitive radios (CRs) and infrastructure wireless sensor nodes. The sensor nodes within communications range of each CR are grouped into a cluster and the clusters of CRs are regularly updated according to the random mobility of the CRs. The energy consumption and the end-to-end delay of the sensor network is reduced by dividing each cluster into disjoint subsets with overlapped sensing coverage of primary user (PU) activity. Respective subset of a CR provides target detection and false alarm probabilities. Substantial energy efficiency is achieved by activating only one subset of the

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cluster, while putting the rest of the subsets in the cluster into sleep mode. In which additional gain in energy efficiency is obtained by selecting nodes from the active subset for actual sensing and switching the active subset to sleep mode by scheduling. The sensor nodes for actual spectrum sensing are chosen considering their respective time durations for sensing. Even the only active subset is switched to sleep mode for a certain number of time slots, utilizing the history of PU activity.

B. Cognitive radio (CR) transceivers for spectrum sensing

A cognitive transceiver is required to opportunistically use vacant spectrum resources licensed to primary users. Thus, it relies on a complete adaptive behavior composed of: reconfigurable radio frequency (RF) parts, enhanced spectrum sensing algorithms, and sophisticated machine learning techniques. Recent advances in CR transceivers hardware design and algorithms. For the RF part, three types of antennas are presented: UWB antennas, frequency-reconfigurable/tunable antennas, and UWB antennas with reconfigurable band notches. CR transceivers are required to look for and operate in white spaces, which could exist anywhere inside a wide frequency range. This comes different from conventional wireless transceivers which are bound to certain preallocated frequency bands. As a result, significant challenges have to be dealt with when designing the RF components of a CR transceiver, such as the antennas, the power amplifiers (PAs), the filters/duplexers, and the analog-to-digital and digital-toanalog converters (ADCs/DACs). 2.1. Antennas for Cognitive Radio. Two main approaches of sharing spectrum between primary users (PUs) and secondary users (SUs) exist: spectrum underlay and spectrum overlay. In the underlay approach, SUs should operate below the noise floor of PUs, and thus contingent constraints are imposed on their transmission power. Ultrawideband (UWB) technology is very suitable as the enabling technology for this approach. In spectrum overlay CR, SUs search for unused frequency bands, called white spaces, and use them for communication. UWB antennas are used for underlay CR and also for channel sensing in overlay CR. For communication in overlay CR, the antenna must be frequency reconfigurable or tunable. Single- and dual-port antennas for overlay CR can be designed. In the dual-port case, one port has UWB frequency response and is used for channel sensing, and the second port, which is frequency reconfigurable/tunable, is used for communicating. In the more challenging single-port design, the same port can have UWB response for sensing and can be reconfigured for tunable narrowband operation when required to communicate over a white space. A third possible spectrum sharing approach results from the use of the UWB technology in an overlay scheme. Here, the antennas could basically be UWB antennas but should have the ability to selectively induce frequency notches in the bands used by PUs, thus avoiding any interference to them and giving the UWB transmitters of the SUs the chance to increase their output power and hence to achieve long distance communication.

IV. PROPOSED SYSTEM AND DESCRIPTIONS

The sensor-assisted CR, namely a sensor network for dynamic and cognitive radio access (SENDORA), where information on PU activity detected by a separate sensor network is transmitted via a single sink to the CRN in multihops. The SENDORA network addressed a comprehensive perspective of a sensor-assisted CRN. Nevertheless, it is subject to failure when the sink node breaks down, and it suffers from high energy consumption as well as high end-to-end delay because of multi-hop transmissions to the CR. In a CR sensor network (CRSN), the conventional wireless sensor nodes are equipped with CR functionality. The CRSN requires highly complicated sensor nodes, so the high cost of a CRSN makes it impractical. A sensor network of clusters with a hierarchical routing protocol to increase network lifetime. With many sensor nodes, reduction of energy consumption by hierarchical routing instead of flat routing. Sensor nodes are clustered into hexagonal structure and cross-layer cluster-based energy-efficient algorithms are proposed to prolong the network lifetime and energy efficiency. A reinforcement learning-based spectrum-aware clustering algorithm that allows a member node to learn the energy and cooperative sensing costs for neighboring clusters to achieve an optimal solution. The selection of optimal cluster is formulated as Markov decision model (MDP). Heinzelman proposed an energy-efficient routing protocol with low end-to-end delay, e.g., low energy adaptive clustering hierarchy (LEACH). The LEACH protocol did not, however, consider the energy state of cluster heads and sensor nodes. To enhance energy efficiency of a sensor network, various scheduling approaches have appeared. The division of sensor network into static and mobile sink nodes, where static nodes perform sensing and mobile sink nodes gather sensing data sensed by static nodes. The mobile sink nodes are scheduled to prolong the network lifetime. Yang proposed a scheduling policy for collaborative sensing in an energy harvesting sensor network under both offline and online settings to maximize the time average utility generated by sensors. Optimal sleep-wake scheduling to extend the network lifetime is investigated further. However, these schemes result in increment of the packet delay as each sensor node waits for its next hop relay to wake up. Kim proposed packet forwarding by each sensor node to the first awake neighbor node. This method is prone to worsening the packet delay even more if the first awake node is in a direction opposite to the sink or destination node. Deng devised sensor scheduling by grouping the sensors into non-disjoint subsets. Each subset is activated successively to extend the network lifetime. However, subset formation does not take into account the residual energy of the nodes. Anastasi proposed a protocol to extend the lifetime of a sensor network by dynamically adjusting the duty-cycle of the sensor nodes. The hybrid energy-efficient distributed

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clustering protocol by Younis and Fahmy requires neighbor nodes to exchange information, which results in increased communication overhead. Vaidehi formed the subsets by random selection of the initial sensor node without considering its energy state. Furthermore, the number of subsets to be formed is assumed to be known a priori. To maximize energy efficiency of a CRN, Shi considered joint optimization of the sensing and transmission durations with the constraints on interference to the PU. They analyzed energy consumption of the CR system in terms of sensing and transmission durations, and sensing errors. Increasing the number of sensor nodes or CRs increases collision probability with the PU which adversely affects the transmission efficiency or throughput of the network. Amini proposed a trilateral optimization between sensing time, transmission time and contention time that maximizes transmission efficiency with the constraint on collision probability. An analytical model is presented for the CRs' collision with PU (because of imperfect sensing by the CRs and independent behavior of the PU) and transmission efficiency of the CR.

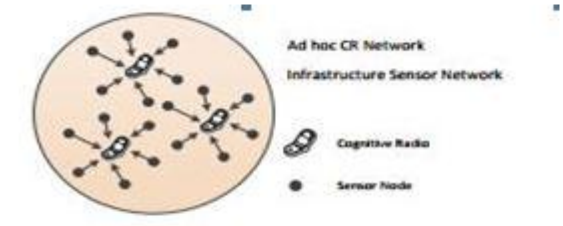

Fig. 1. Sensors-assisted CRN where CRs are surrounded by sensors nodes

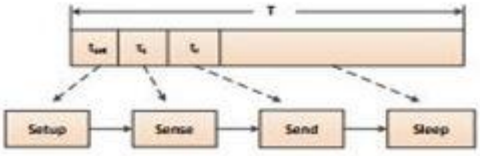

Fig 2 . Structure Of A Time Slot For The Proposed CUSF Process

V. SYSTEM DESCRIPTION

Consider the sensor-assisted CRN with ad hoc CRs in Fig. 1. Each mobile station acts as a CR that is surrounded by sensor nodes. It is assumed that the PU operates in a time slotted fashion. A sensor node in active mode goes through quadruple S-stages (setup, sense, send, and sleep) in a time slot, as shown in Fig. 2. The sensor nodes send (report) the sensing results directly to the CR that serves as a cluster head. Since an infrastructure sensor network is considered, positions of the sensor nodes are assumed to be known to the CR. It is also assumed that each sensor node knows its own position. Each CR has the ability to find its geolocation from an embedded GPS module. A CR may move in any direction within a predefined area. An error-free common control channel is assumed for the exchange of control information between nodes and the CR. All the CRs have the same communication range, denoted by rCR, and the sensor nodes have a communication range, denoted by rS. It is assumed that rS < rCR.

A. Cluster Formation

A CR broadcasts an advertisement (ADV) message which contains the identification number (ID) of the CR, its position, the nodes registered to the CR (Nodes), and a header field. The purpose of the header field is to differentiate the ADV message from other types of messages or data. Nodes within rS from the CR respond by sending a join request (J REQ), which consists of the identification number of the node (N ID) , the identification number of the destination CR (CR ID), the energy state (E rem) , e.g., amount of remaining energy of the node, and the signal-to-noise ratio (SNR) of the node. A node may receive multiple ADV messages from different CRs. In this case, the node will join the CR that is closest to it in order to consume the minimum transmission energy. Note that a node knows the position(s) of the CR(s) via the ADV messages. If a node is equi-distant from two or more CRs, it will join the CR with the smallest number of registered nodes to minimize waiting time for sending the sensing result. On receiving the J REQ from the sensor node(s), the CR adds the node(s) to the list of registered nodes, e.g., the Nodes field in the ADV message. The flow chart of the cluster formation is given in Fig. 3. An example of cluster formation of sensor nodes with their CRs is shown in Fig. 4. Ci , i = 1, ..., 4, indicates the number of sensor nodes registered to the i-th CR. The nodes are grouped into clusters 1, 2, 3, and 4, respectively. The empty circles in the figure represent unclustered nodes because of their locations outside the communication ranges of the CRs. In the figure, the clusters are formed (updated) according to the shifted CR3 and static CR1, CR2, and CR4.

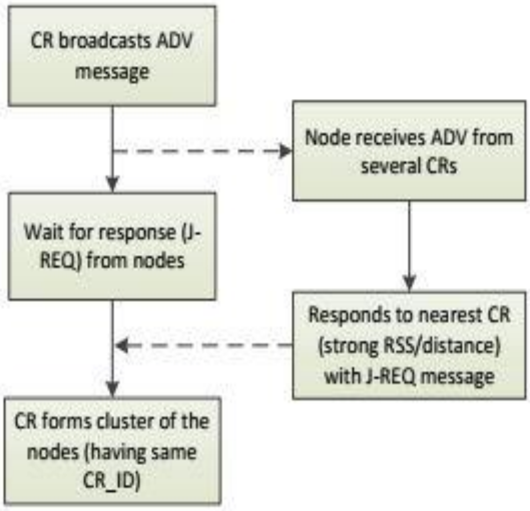

Fig 3. Flowchart For Cluster Formation.

B. *Cluster Updating*

It is assumed that a CR does not leave its position for time duration tset +τs +tr in a time slot, where tset is the network setup time, τs is the sensing time, and tr is the sending time (see Fig. 2). The cluster updating process will take place when 1) there is a change in the number of nodes registered to a CR, or 2) the position of the CR changes. When cluster updating occurs for either reason, the relocated CR initiates the update process. Unclustered nodes join the cluster of the relocated CR when they receive the ADV message from it. When a node that already joined a cluster receives the ADV message, it will leave the old (existing) cluster only if the distance to the CR of the new cluster is less than the distance to the CR of the old cluster. If the node decides to join the new cluster based on the shorter distance, the node will send a leave request (L REQ) to the CR of the old cluster and a join request (J REQ) to the CR of the new cluster.

When a CR receives an L REQ from the registered node, the node is deregistered from the CR and the CR updates its cluster and the Nodes field in the ADV message. The cluster updating procedure is shown by the flow chart in Fig. 5. An example of cluster updating is shown in Fig. 4. CR3 moves to a new position marked by the big circle and broadcasts an ADV message. Clusters for CR2 and CR4 remain unchanged because they are outside the communication range of CR3. Due to relocation of CR3, a group of nodes initially unclustered joins the cluster for CR3 (case (a) in Fig. 4) and the other group of nodes that belonged to the cluster for CR3 join the cluster for CR1 (case (b)) and another group of nodes that belong to the old cluster for CR3 become unclustered (case (c)). As a result, C1 = 27, C2 = 9, C3 = 25, C4 = 9 after cluster updating.

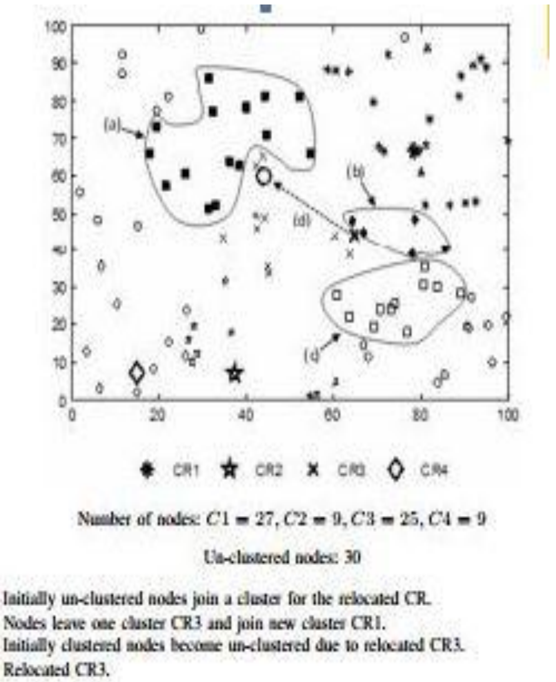

Fig 4. Cluster Formation And Cluster Updating.

C. *Subset Formation*

A cluster can be decomposed into one or more disjoint subsets, as shown in Fig. 6(b). Activating only one subset of the nodes, instead of all the subsets in a cluster, significantly reduces energy consumption because deactivated subsets are switched to sleep mode. A subset of a cluster defined for this work is a group of nodes that covers the area of a cluster with minimum overlap. To avoid early failure of sensor network operation owing to the node with the least amount of energy, subset formation begins with the node that has the most remaining energy. We need to find the number of sensor nodes in a subset that satisfies the performance criteria with minimum overlap. For example, in

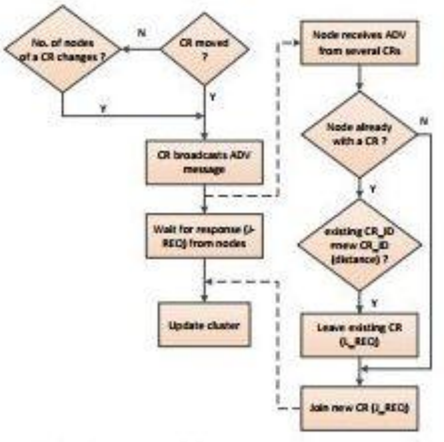

Fig 5. Flowchart for cluster updating

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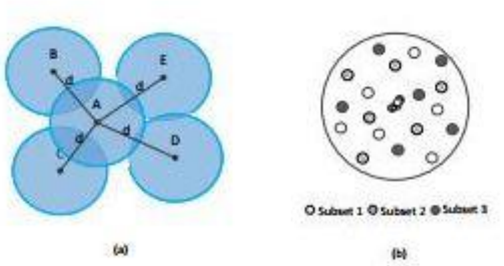

Fig 6. Subset Formation (A) Coverage Overlap (B) Disjoint Subsets

Fig. 6a, coverage of four nodes overlap with the coverage of node A, and the coverage of node D is minimally overlapped with that of node A. Therefore, node D is selected by the CR as a member of the subset. For notational simplicity, the number of subsets in a cluster is denoted as K, and the number of sensor nodes in a cluster as C. To form subsets in a cluster, an algorithm is used. While their algorithm forms subsets for a known value of K, the proposed subset formation algorithm does not require any prior information about K. Also, the number of sensor nodes, S, for each subset is analytically determined.

The following steps are performed at the CR to form subsets of a cluster. Each subset consists of sensor nodes with minimum overlap.

- Step 1: A node with the maximum energy is selected as the starting node for subset formation.
- Step 2: The selected node identifies all the sensor nodes (from the cluster) that have coverage overlap with that of the selected node and computes the distance between each overlapped node and the selected node to choose the one with the largest distance but which is less than 2 × rS.
- Step 3: The number of nodes in the subset is increased, whereas the number of cluster nodes is decreased by removing the chosen node from the cluster.
- Step 4: Steps 2 and 3 are repeated with another selected node until the number of nodes in the subset becomes S, which is derived later.
- Step 5: Steps 1-4 are repeated so that K subsets are formed, and every node in the cluster is assigned to a subset. When C is not completely divisible by S, all the remaining nodes are added to the K-th subset. The number of nodes S in a subset and the number of subsets K are analytically obtained as follows. The detection probability is defined as the probability that a sensor node correctly detects the presence of the PU signal. On the other hand, false alarm probability is defined as the probability that a sensor node incorrectly detects the presence of the PU signal when the PU signal is actually absent. The detection probability Pdj and the false alarm probability Pfj of the j-th node of a subset can be respectively given as follows:

Pdj = Qu p 2γj , √ ε (1) Pfj = Γ u, ε 2 Γ (u) where γj is the SNR at the j-th node, ε denotes the energy threshold for a local decision, u represents the number of samples, Qu is the generalized Marcum Q-function, and Γ(.), Γ(., .) are the complete, incomplete gamma functions, respectively. Note that γj is reported to the CR as a part of the J REQ message. Since the OR fusion rule is adopted at the CR, global detection probability Qd and global false alarm probability Qf are given, respectively, as

Qd = 1 − Y S j=1 (1 − Pdj) (3)

Qf = 1 − Y S j=1 (1 − Pfj). (4)

Qd and Qf must satisfy the required performance level as follows: Qd ≥ Q min d (5) Qf ≤ Q max f (6) where Qmin d is the minimum global detection probability required, and Qmax f is the maximum global false alarm probability allowed. Substitutions of (3) into (5) and (4) into (6) give

1 − Y S j=1 (1 − Pdj) ≥ Q min d ⇔ 1 − Q min d ≥ Y S j=1 (1 − Pdj) (7) 1− Y S j=1 (1 − Pfj) ≤ Q max f ⇔ 1−Q max f ≤ Y S j=1 (1 − Pfj). (8)

Let P min d be the minimum detection probability, and let P max f be the maximum false alarm probability among all the sensor nodes of the cluster. Since P min d is the minimum bound of Pdj , j = 1, ..., C and P max f is the maximum bound of Pfj ,

j = 1, ..., C, Pdj ≥ P min d and Pfj ≤ P max f , j = 1, ..., C.

Hence, (1 − P min d) S ≥ Y S j=1 (1 − Pdj) (9)

(1 − P max f) S ≤ Y S j=1 (1 − Pfj). (10)

Since equations (7) and (8) should be satisfied even when Pdj = P min d and Pfj = P max f for all the j values,

j = 1, ..., C, 1 − Q min d ≥ (1 − P min d) S (11)

1 − Q max f ≤ (1 − P max f) S (12)

Taking the logarithm of both sides of equations (11) and (12) gives log(1 − Qmin d) log(1 − P min d) ≤ S ≤ $ log(1 − Qmax f) log(1 − P max f) % (13)

where b·c is the floor function and d·e is the ceiling function. S is the maximum number of sensor nodes in a subset that satisfies the false alarm constraint [36], [37]. Hence, from equation (13), S is given as

S = $ log(1 − Qmax f) log(1 − P max f) %.

Note that S is obtained from P min d and P max f . Thus, any combination of S sensor nodes in the cluster will satisfy the minimum global detection probability Qmin d and the maximum global false alarm probability Qmax f . The number of subsets, K, in the cluster can be obtained by C divided by S as follows

K = C S (15)

Figure 7 shows examples of subsets in clusters. Since S is derived by considering P min d and P max f the actual number of nodes S¯ of different subsets of a cluster for spectrum sensing varies and is always less than or equal to S. An algorithm to determine S¯ from the consideration of the sensing time to achieve minimum energy consumption during the sensing stage is presented in subsection V-A. The required level of global detection probability Qmin d and global false alarm probability Qmax f affect the performance of CRNs, e.g., interference with the PU and utilization of the spectrum, and energy consumption of sensor networks. Increasing the minimum global detection probability guarantees more protection for the PU and leads to less interference with the PU. A higher value of Qmin d requires a larger number of sensor nodes $\bar{S}$ for actual sensing, and as a result, increases energy consumption. On the other hand, a lower value of Qmax f enhances utilization of the spectrum. Lower value of Qmax f is preferable, but results in larger size of the subset (S) and also $\bar{S}$. Therefore, a lower value of Qmax f causes higher consumption of energy. After subset formation, the CR selects the subset that has the maximum total energy, and creates a time division multiple access (TDMA) schedule for the nodes in the selected subset. This scheduling information is transmitted to the sensor nodes in the form of beacon messages by the CR. Only the nodes included in a subset are active; all other nodes in other subsets remain in sleep mode. The order of time slots in a TDMA frame is assigned according to descending order of SNR values of the sensor nodes. Thus, the first time slot is assigned to the sensor node with the highest SNR, and so on.

D. Energy Consumption During The Setup Stage

The CR nodes are assumed to be more powerful devices than sensor nodes in terms of the amount of resources. The energy consumption model by Heinzelman et al. for the sensor network is considered. Free-space pathloss is considered between the nodes and the CR, due to assumed geometrical proximity of sensor nodes to the registered CR. The total energy consumed by a sensor node can be decomposed as ET = Eset + Es + Er (16) where Eset, Es, and Er are the energy consumed in the setup stage (setting up the cluster and the subset), the sensing stage, and the sending (reporting) stage, respectively. The processing energy at the senor nodes is ignored, because it is significantly smaller than sensing and reporting energy. In this section, energy consumed for the setup stage is discussed. The energy consumed for the setup stage consists of the energy consumed in cluster formation, updating, and subset formation. Most of the existing protocols for various network architectures ignore clustering energy during network setup, making such protocols inadequate for implementation. During the cluster formation and updating process in the setup stage, energy is consumed in receiving the ADV messages that are broadcasted by the CR, and in transmitting the J REQ and/or the L REQ while responding to the relevant CRs. After receiving information about clustering from the sensor nodes, the CR performs subset formation. Energy is consumed by the sensor nodes in receiving the subset information from the CR. From these sequences, the energy consumed in the setup stage is expressed as

Eset = 2 × ERx + ET x (17)

where ERx and ET x are the energy consumed in receiving and transmitting, respectively. The transmission energy is given by

ET x = Etx−elec(l) + Etx−amp(l) = lEelec + lEamp (18)

where Eelec is the energy consumed over the unit size of the data by electronics, which depends on tasks such as digital coding, modulation, filtering, and signal spreading, and Eamp is the amplifier energy over the unit size of the data, which depends on the distance to the relevant CR and acceptable bit error rate at the CR, and l is the size of the data. The energy consumed in receiving data is given below, ignoring the Eamp in (18):

ERx = ERx−elec(l) = lEelec.

E. Energy Consumption During The Operation Stage

The operation phase consists of sensing, sending (reporting), and sleep stages. Since energy consumption during the sleep stage is negligible compared to other stages, the sleep stage is not considered here. Energy efficiency in this phase can be achieved twofold: 1) minimizing energy consumption, and 2) maximizing sleep time. The first objective is achieved by an energy-efficient network minimizing the energy in sensing and reporting. On the other hand, the second objective is realized by efficient scheduling of the subsets. A. Minimize Energy Consumption During the Sensing Stage Sensing performance of the CRN is related to energy consumption of the sensor network. A higher value for the minimum global detection probability requires a larger number of sensor nodes to satisfy the performance constraint for a subset, which increases the energy consumption for sensing. Most of the published works consider only communication or processing energy when evaluating the energy consumption of the network so energy consumed during the sensing stage is often ignored. Even though sensing energy is considerably less than communication energy, the short interval between periodic sensing processes in CR networks makes it significantly important, so minimizing sensing energy helps to prolong network lifetime. Time duration for sensing is a function of SNR . It means, for a given detection probability and a given false alarm probability, a sensor node with a comparatively clean channel causing a higher SNR takes less time for sensing an event. The time duration for sensing by the j-th node in a subset can be expressed in terms of SNR, detection probability, and false alarm probability as follows:

τsj = Q−1 (Pfj) − Q−1 (Pdj) p 2γj + 1 √ fsγj !2 (20)

where τsj and γj are the sensing time and the SNR, respectively, at the j-th node, fs is the sampling frequency, and Q(.) is the complementary cumulative distribution of a standard Gaussian. Due to different SNRs at the sensor nodes, τsj varies accordingly. However, it must be less than the predefined maximum value τs,max for timely operation of the network. The sensor node with a higher SNR performs sensing in less time and sleeps over a longer time to decrease energy consumption. The energy consumed by the j-th node in sensing is Esj = Psτsj , where Ps is the power consumed for sensing and τsj is the time duration for sensing. Energy consumed in sensing by a subset with S sensor nodes is given as

Es = X S j=1 Psτsj

With the constraints on energy consumption of the subset, minimizing the energy consumed in sensing by a subset is expressed as min Es (22a) subject to:

(i) Qd ≥ Qmin d (ii) τsj ≤ τs,max, j = 1, ..., S (22b)

Constraint (i) specifies that the cooperative detection probability should not be less than the minimum requirement Qmin d . This constraint is on detection performance. Constraint (ii) requires that the time duration for sensing of a sensor node be less than or equal to sensing duration τs,max in a time slot. Note that the constraint on the global false alarm probability is satisfied as long as S¯ is not greater than S. A heuristic approach to get the actual number of sensor nodes S¯ for sensing can be considered to solve the optimization in (22a). The heuristic approach minimizes the sensing energy by selecting the first node with the highest SNR, following the sorting of the nodes in descending order of SNR, and then calculates the time duration for sensing to get the detection probability. The sensing process continues with the second node with the second highest SNR, and so on, until constraint (i) is satisfied.

F. Maximize Sleep Time

The PU's historical behavior is considered to predict future states of the PU and to estimate the number of consecutive slots in which the subsets, including the only active subset, can be scheduled for sleep. The PU behavior is typically modeled by a two-state Markov chain, where the presence and the absence of the PU signal are modeled by busy and idle states, respectively, as shown in Fig. 8a. According to the status of the PU, sensor nodes alternate between sleep and active states, as shown in Fig. 8b. Considering temporal variation of PU activity, the PU tends to maintain its state once switched from the other state, i.e., the PU stays on a channel for at least a few slots after occupying it, or the PU will not occupy a channel for at least a few slots when switched to an idle state. From this viewpoint, positive correlation of the PU traffic is considered, i.e., pII > pIB and pBB > pBI where pab is the transition probability of the PU from state a to state b, and subscript I, B indicates idle, busy states, respectively. A moving window for recording the history of PU activity is adopted. In each slot, the latest information on the PU updates the record, and the oldest information on the PU is deleted from the other side of the window. The CR develops a history of PU activity based on the global decision in each time slot at the CR, which is based on the sensing results of the sensor nodes. However, due to errors in the sensing process of the nodes, the decision of the CR could be incorrect in some time slots. The CR overcomes the sensing errors (incorrect decisions) by receiving an acknowledgement (ACK) message from the CR receiver. The ACK message is received when the data recovered by the CR receiver are error-free. Note that the CR (transmitter) combines the individual sensing results of the sensor nodes to make a decision on data transmission to the CR receiver. During the sleep stage in Fig. 2 for sensor nodes, the CR transmits its own data to the CR receiver and receives the ACK message from it. We assume that the ACK message is very short, compared to the duration of the time slot. If the ACK message is received before timeout occurs, it means that the PU is inactive and the sensing decision is correct. If the sensing decision construes the absence of the PU and the CR transmits data but does not receive the ACK message in due time, the sensing information (decision) is considered incorrect, and the history is updated with correct information. The estimated number of consecutive time slots, ns, in which the subsets will be switched to sleep mode, is determined from the PU history according to the following algorithm.

- Step 1: Determine the maximum (Nmax) and minimum (Nmin) number of consecutive slots in which the channel is found busy from the history of the PU.
- Step 2: Find the number of i-consecutive busy slots (states) (Gi) that occurred. Repeat this step for i = Nmin to Nmax.
- Step 3: Find the number of occurrences of the busy state for i-consecutive slots in all the higher values of i. Occurrence of i+ 1 consecutive busy states automatically contains the non-overlapping occurrences of i consecutive busy states. For example, the occurrence of three consecutive 1's contains the occurrence of two consecutive 1's. So if i = 2 occurred twice and i = 3 occurred once, then the total number of i = 2 that occurred is 2 + 1 = 3. Repeat Step 3 for i = Nmin to Nmax. G s i = Gi + N Xmax j=i+1 (Gj) × j i (23)
- Step 4: Find the probability of PU appearance, which is obtained from the number of PU appearances (NP) and the total number of non-zero bits (N1) from the history of the PU. It contains both one-slot and multislot appearances of the PU. P r(NZ) = NP N1 (24)
- Step 5: Find the probability of the PU appearance for iconsecutive slots, which is calculated from the number of busy states of the PU, when it stays for i consecutive slots and the total number of non-zero bits in the history of the PU. P r(G s i) = G s i × i N1 (25)

- Step 6: Compare the values obtained in Step 5 with Step 4. Select the minimum value of i that satisfies (26) and assign it to the number of consecutive sleeping slots ns. ns = arg min i=Nmin,...,Nmax [Pr(G s i) > P r(NZ)]

The above algorithm finds the most frequent pattern of successive ‘1’s in the PU history, and takes ns pessimistically, i.e., a smaller ns is taken if two or more ns values satisfy the given criterion, not to miss the chance of spectrum utilization. From (26), the duration of ns slots is obtained close to the average period of the PU in busy states with various patterns in the history of PU activity. Two approaches to switch the subsets to sleep mode for ns slots are considered. The first approach is to switch all the subsets to sleep mode, and the second approach is to keep the selected subset with the highest remaining energy active whereas the remaining subsets are switched to sleep mode. Since switching all the subsets to sleep mode for a certain number of slots may result in reduced utilization of the spectrum holes, it is important to ensure that during sleep mode, the opportunity for transmission is not wasted. The first approach is more energy-efficient but less reliable, while the second approach is less energy-efficient but produces more reliable sensing performance. Both approaches will be evaluated by simulation. The second and third terms in (16) reduce to 0 for ns slots. If there is no movement of CRs in the ns slots, the total energy consumed is reduced to 0. Subsets are switched to sleep mode for a duration of tsleep given by tsleep = ns × T + Trem (27) where Trem = T − tset − τs − tr is the remaining time in the time slot after setup, sensing, and reporting (sending) stages.

1) Case Study 1: Let us take a case study that considers a history of PU activity within the window as follows History of the PU: H = 101101110110001111101 where ‘0’ indicates the idle state of the PU, and ‘1’ represents the busy state of the PU. The minimum and the maximum number of consecutive (successive) slots in which the PU is found busy are 2 (11) and 5 (11111), respectively. Let Gi , i = 2, ..., 5, be the number of i-consecutive busy states. Then, the most frequent pattern of PU activity indicates G2 = 2. If admitting that ‘111’ is ‘11’+‘1’ and ‘11111’ is ‘11’+‘1’+‘11’, G3 = 1 corresponds to G2 = 1 and G5 = 1 matches G2 = 2. Also, let Gs i be Gi with Gj , j = i+1, ..., Ns, taken into account. Then, Gs i ≥ Gi . For details on Gs i , refer to Step 3 above. The single ‘1’ in the streams of ‘1’s can be matched to the ‘wake’ time slot of the sensor node. From H: NP: Number of PU appearances = 6 Nmax: Max. number of consecutive busy states (1’s) = 5 Nmin: Min. number of consecutive busy states (1‘s) = 2.

G. Further Increase In Effiency And Accuracy

In previous systems the whole nodes in the subset are access the channel at the same time. Which cause more energy consumption in the network.so for further increase the efficiency and accuracy, we divide the channel access to time slots and each node in the subset can access the whole channel based on their energy. In which the node with higher energy can access the channel first and so on. So here only one node in the subset is active at a time. Suppose if there is six nodes in the subset, we have to divide channel accessing in to time slots of 1/6 th for each node such the way it has to access the whole channels in that we have to increase accuracy and also the efficiency.

VI. SIMULATION RESULTS

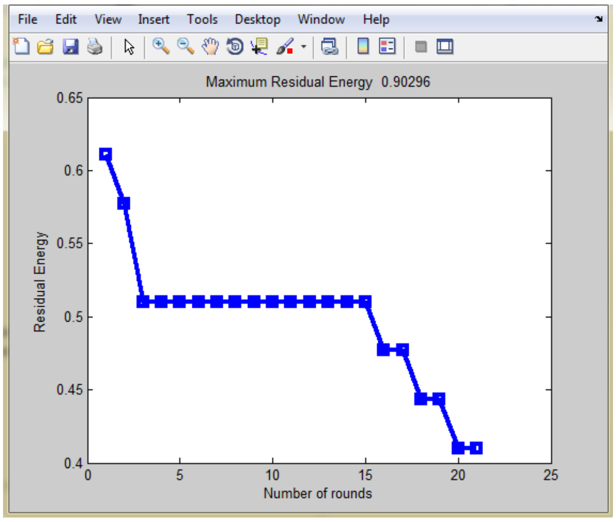

Fig 7. Maximum Residual Energy

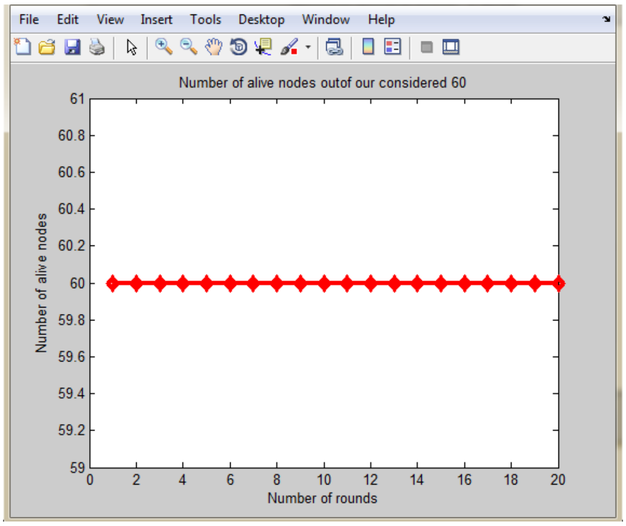

Fig 8 . Number Of Alive Nodes Out Of Our Considered 60

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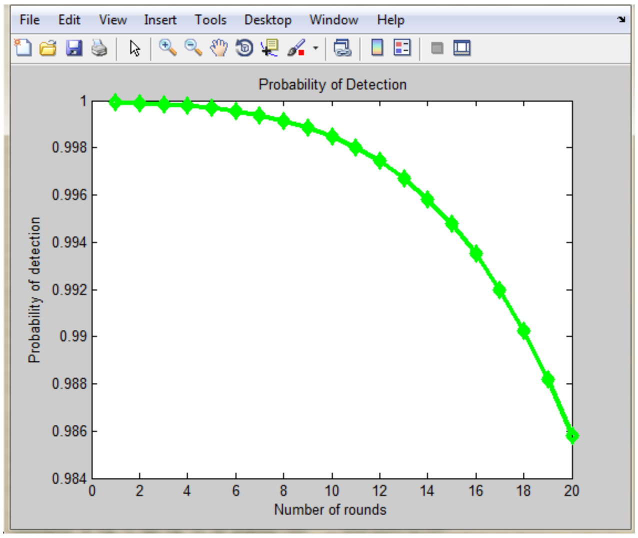

Fig 9. Probability of detection

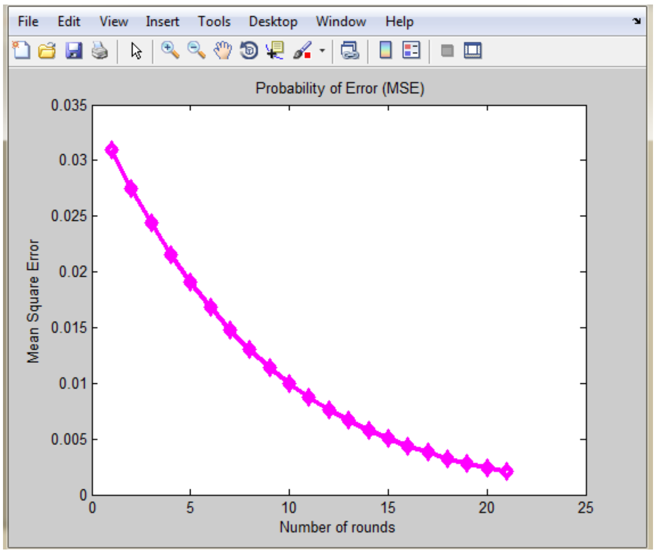

Fig 10. Probability Of Error

VII. CONCLUSION

In this paper, an ad hoc CRN with an energy-efficient process, namely the CUSF process, is proposed. Via the CUSF process, clustering and further subset formation of the sensor nodes are performed. Multiple subsets are created in a cluster and only one subset is active in sensing to reduce energy consumption. For further reduction of energy consumption, the actual sensor nodes for spectrum sensing are selected in the given active subset according to a separately proposed algorithm. In addition, all the subsets, including the one active subset, switch to sleep mode for the duration of PU activity to achieve another reduction in energy consumption. For the accuracy and higher efficiency, a time slot is provided for each node in the subset for access the channel. A novel subset scheduling algorithm to achieve this goal is developed on the basis of PU statistics. As a result, the CRN with the proposed architecture consumes significantly less energy and incurs lower end-to-end delay in comparison with the SENDORA network and the CRN with the LEACH-C protocol.

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