A review of Ad Hoc Cognitive Radio Network: an Energy-Efficient Infrastructure Sensor Network

Vijay Mishra
Research Scholar, Madhyanchal Professional University, Bhopal, M.P. India

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. Additional gain in energy efficiency is obtained by these promising propositions: first 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. To illustrate network performance in terms of energy usage and end-to-end delay, we compare the proposed CR network to existing techniques.**

Index Terms - **Spectrum sensing, sensor network-based spectrum sensing, ad hoc cognitive radio network, clusters and subsets, infrastructure sensor network, subset scheduling, spectrum sensing.**

INTRODUCTION

According to the Federal Communications Commission (FCC), depending on spatio-temporal variables, use of the statically allotted spectrum ranges from 15% to 85% [1,2]. The activity of the primary user (PU) should be constantly monitored in order for a secondary user, who cannot be active when the PU is active, to use the spectrum licenced to a PU [3]. One approach would be to use cognitive radio (CR) transceivers for spectrum sensing and report their findings to a fusion centre to determine the presence of the PU signal [4,5]. This strategy, however, comes at a hefty cost and consumes a lot of energy. A more tempting method is to execute sensing using a low-cost, specialised sensor network [6,7]. Regulatory agencies such as the FCC are investigating the use of sensor networks for spectrum sensing. The FCC has requested experts to write recommendations for the use of a sensor network with low cost/energy/delay for enhanced spectrum sensing. Energy-efficient spectrum sensing by a sensor network provides benefits such as more effective identification of a weak PU signal (due to sensor node location diversity) and improved PU protection due to high detection reliability [8]. Furthermore, this strategy is better suited for mobile CRs, where cooperative spectrum sensing is more challenging in the absence of a fusion centre and collaboration among CR users is problematic. However, certain challenges/disadvantages in such a network remain unresolved; for example, ownership of the sensor network, information distribution by the sensor network, usage costs, and so on.

The sensor network required for spectrum sensing should be a low-cost network comprised of a large number of spatially distributed sensor nodes having sensing, processing, and communications capabilities. Because sensor nodes have limited resources (e.g., storage space and computing power, as well as often non-replaceable, limited-capacity batteries), efficient energy usage, which affects network lifetime, is a critical challenge. The sensor nodes perform spectrum sensing via energy detection and communicate the data to the CR, which serves as a fusion center [9-10]. The OR-rule is used in decision fusion at the CR, which determines the presence of the PU signal when at least one of the sensor nodes detects its presence. With more sensor nodes participating in spectrum sensing, the effect of location variety becomes more profound.As a solution to the challenge, we offer a CR network (CRN) with disjoint subsets for each cluster of sensor nodes in this research — effective sensing with great energy efficiency. The CRN is made up of ad hoc CRs, CRs with mobility assigned to them to be broader, and infrastructure sensor nodes. An ad hoc CR, which serves as the cluster head, is surrounded by a cluster of infrastructure sensor nodes within one-hop communication range of the CR, and each cluster is further subdivided. Sleep-wake scheduling for the subgroups based on the statistical behaviour of the PU is also presented to achieve energy economy.

The following are the main contributions of this study.

- We presented an energy-efficient cluster updating and subset creation (CUSF) process for ad hoc CR operation aided by an infrastructure sensor network. The CRs shift in time at random, and the sensor network's subsets are updated correspondingly. Theoretical study of subset formation is also offered in this paper.
- Only one subset of a cluster is active at any given time, while the others go to sleep. To reduce energy consumption even further, the actual sensor nodes for spectrum sensing are chosen from the supplied active subset using a separately suggested technique. Saving energy during spectrum sensing is crucial in a CRN with multiple sensor nodes. When measuring the energy consumption of a network, most published research analyse just communication energy or processing energy, hence energy consumed during the sensing stage is frequently overlooked. Though the energy required for each sensing is far less than that required for communication, the brief interval in the CRNs' periodic sensing procedure makes it critical. As a result, reducing detecting energy helps to extend the lifetime of the sensor network.
- Based on the history of PU activity, the proposed scheduling algorithm can even switch the single active subset to sleep mode for a defined number of time slots. The proposed scheduling improves energy economy at the expense of somewhat increased PU detection inaccuracy.
- With the proposed framework, we studied the total energy usage of the sensor network. The total energy consumed by the sensor network includes energy consumed during the setup, sensing, sending, and sleep stages. The energy used in network setup has mostly gone unnoticed in the literature. However, because the CRs move freely and frequently, and the subsequent CUSF procedure for each move, the energy required during the setup step is also taken into account in this research.

RELEVANT WORK

Weiss et al. [7], as well as Liu et al. [11], suggested using a sensor network for CR. They did not, however, characterize the sensor network's architecture or topology. Mercier et al. [6] developed sensor-assisted CR, namely a sensor network for dynamic and cognitive radio access (SENDORA), in which information about PU activity observed by a separate sensor network is relayed in multi-hops to the CRN via a single sink. A full viewpoint of a sensor-assisted CRN was handled in a SENDORA network.

However, the sink node breaks down and is prone to failure and also to significant power consumption and end-to-end delaying due to multi-hop transmissions to the CR. A CR sensor (CRSN) network, where standard wireless sensor nodes have CR functions, is described by Akan et al. [12] and Joshis et al. [13]. The CRSN needs highly complex sensor nodes, and this cannot be achieved by the high cost of a CRSN. Huang et al. reported a cluster sensor network with a hierarchical routing system to enhance network life [14]. They demonstrated that, with a large number of sensor nodes, hierarchical routing, rather than flat routing, reduced energy consumption. Their work, however, is unrelated to mobile (ad hoc) CRs. To extend network lifetime and energy efficiency, sensor nodes are aggregated into hexagonal structures, and cross-layer cluster-based energy-efficient algorithms are proposed in [15]. Mustapha et al. [16] introduced a reinforcement learning-based spectrum-aware clustering algorithm that enables a member node to learn the energy and cooperative sensing costs for surrounding clusters in order to find the best solution. The best cluster is chosen using a Markov decision model (MDP). Heinzelman et al. [17] proposed an energy-efficient routing protocol with minimal end-to-end latency, such as a low energy adaptive clustering hierarchy (LEACH). The LEACH protocol, on the other hand, did not take into account the energy state of cluster heads and sensor nodes.

Various scheduling algorithms have emerged to improve the energy efficiency of a sensor network [18–20]. Zhou et al. [21] advocated dividing sensor networks into static and mobile sink nodes, with static nodes detecting and mobile sink nodes gathering sensing data felt by static nodes. The mobile sink nodes are planned to extend the network's lifetime. Yang et al. [22] developed a scheduling approach for collaborative sensing in an energy harvesting sensor network that works in both offline and online modes to maximise sensor time average utility.

Mini et al. [23] proposed a swarm optimization approach for locating sensor nodes with the appropriate sensing coverage and applied a heuristic for sensor node scheduling to maximise the theoretical network lifetime. [24–26] study optimal sleep-wake scheduling to extend network lifetime. However, these approaches cause the packet latency to increase as each sensor node waits for its next hop relay to wake up. Kim et al. [27] proposed that each sensor node forward packets to the first waking neighbour node. This approach is prone to exacerbating packet delays if the first awake node is in the opposite direction of the sink or destination node. Sensor scheduling was devised by Deng et al. [26] by grouping sensors into non-disjoint subsets. Each subset is activated in turn to extend the network's lifetime. However, the leftover energy of the nodes is not taken into account during subset construction.

Anastasi et al. [28] suggested a strategy for extending the lifetime of a sensor network by altering the duty-cycle of the sensor nodes dynamically. Younis and Fahmy's [29] hybrid energy-efficient distributed clustering technique necessitates information exchange between adjacent nodes, resulting in higher communication overhead. Vaidehi et al. [30] generated the subgroups by selecting the starting sensor node at random without regard for its energy status. Furthermore, it is expected that the number of subsets to be constructed is known a Priori.

They investigated the CR system's energy usage in terms of sensing and transmission durations, as well as sensing mistakes. Increasing the number of sensor nodes or CRs increases the likelihood of a collision with the PU, which reduces the network's transmission efficiency or throughput. Amini et al. [32] suggested a tri-lateral optimization of sensing time, transmission time, and contention time that maximises transmission efficiency while keeping collision likelihood in mind. An analytical model for CR collision with PU (due to inadequate sensing by the CRs and independent behaviour of the PU) and CR transmission efficiency is proposed.

SYSTEM DESCRIPTION

Consider the sensor-assisted CRN in Fig. 1 with ad hoc CRs. Each mobile station functions as a CR surrounded by sensor nodes. It is presumed that the PU functions on a timetable. In an active time slot, a sensor node passes through quadruple S-stages (setup, sense, send, and sleep), as shown in Fig. 1. The sensor nodes directly convey (report) the sensing findings to the CR, which serves as the cluster head. Because the CR is considering an infrastructure sensor network, the positions of the sensor nodes are believed to be known..[33] It's also expected that each sensor node is aware of its own location. Each CR may determine its location using an inbuilt GPS module.

Consider the sensor-assisted CRN with ad hoc CRs shown in Fig. 1. Each mobile station serves as a central processing unit (CR) surrounded by sensor nodes. It is presumed that the PU functions on a timetable.

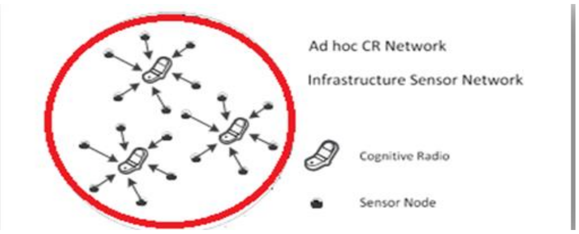

Fig.1Sensorassisted CRN, in which CRs are surrounded by sensor nodes.

A sensor node goes through quadruple S-stages (setup, sense, send, and sleep) during an active time slot, as shown in Fig. 2. The sensor nodes transmit (report) their sensing findings to the CR, which serves as the cluster head. The positions of the sensor nodes are thought to be known since the CR is considering an infrastructure sensor network. Each sensor node is also supposed to be aware of its own location. Each CR has an embedded GPS module that can be used to identify its location.

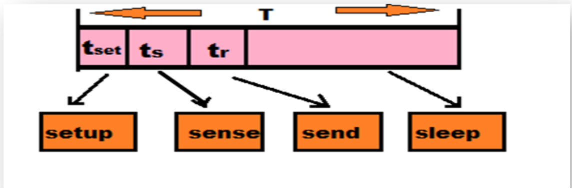

Fig.2 Time slot structure for the proposed CUSF procedure

A. Cluster Development

A CR sends out an advertisement (ADV) message that includes the CR's identification number (ID), position, the nodes registered to the CR (Nodes), and a header field. The header field's purpose is to distinguish the ADV message from other sorts of messages or data. The following is the format of the ADV message:

Header	ID	Position	Nodes

Nodes within rS of the CR reply by sending a join request (J REQ), which includes the node's identification number (N ID), the destination CR's identification number (CR ID), the node's energy state (E rem), e.g., the amount of remaining energy, and the node's signal-to-noise ratio (SNR). The J REQ format is as follows:

N_ID	CR_ID	E_rem	SNR

Multiple ADV messages from different CRs may be received by a node. In this instance, the node will join the closest CR in order to consume the least amount of transmission energy. It is worth noting that a node learns the position(s) of the CR(s) via ADV messages. If a node is equidistant from two or more CRs, it will join the CR with the fewest registered nodes to reduce the time it takes to relay the sensing result. When the CR receives the J REQ from the sensor node(s), it adds the node(s) to the list of registered nodes, as indicated by the Nodes field in the ADV message. Figure 3 depicts a flow chart of cluster formation.

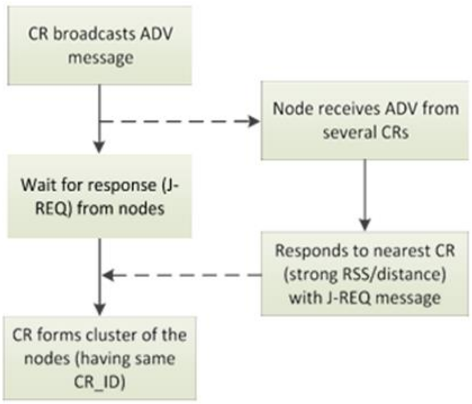

Figure 4 depicts an example of sensor node cluster construction with respective CRs. Ci, I 1,..., 4 denotes the number of sensor nodes associated with the I -th CR. The nodes are divided into four clusters: 1, 2, 3, and 4. Because they are outside the communication ranges of the CRs, the unclustered nodes in the diagram are represented by the empty circles. The clusters in the figure are produced (updated) based on the shifted CR3 and static CR1, CR2, and CR4.

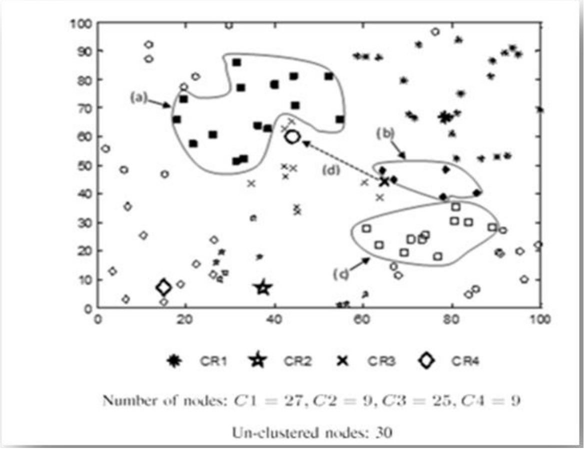

Fig.4 Cluster creation and cluster upkeep The number Ci denotes the number of sensor nodes in the i-th cluster. (a) Unclustered nodes initially join a cluster for the relocated CR. (b) Nodes quit the CR3 cluster and join the CR1 cluster. (c) Previously clustered nodes became un-clustered as a result of moved CR3. (d) CR3 has been relocated.

B. Updating Clusters

It is assumed that a CR does not leave its position in a time slot for the length tset + s + tr, where tset is the network setup time, s is the sensing time, and tr is the transmitting time (see Fig. 2). When 1) the number of nodes registered to a CR changes, or 2) the position of the CR changes, the cluster will be updated. When a cluster is updated for either of these reasons, the relocated CR starts the process. When unclustered nodes receive the ADV message from the relocated CR, they join its cluster. When a node that has previously joined a cluster receives the ADV message, it will leave the old (existing) cluster only if the distance to the new cluster's CR is smaller than the distance to the old cluster's CR. If the node chooses to join the new cluster because it is closer, it 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. The L REQ message is formatted as follows:

N_ID	CR_ID

When a CR receives a L REQ from a registered node, the node is deregistered and the CR updates its cluster and the Nodes field in the ADV message. The flow chart in Fig. 5 depicts the cluster update technique. Figure 4 depicts an example of cluster updating. CR3 relocates to a new location denoted by the large circle and sends an ADV message.

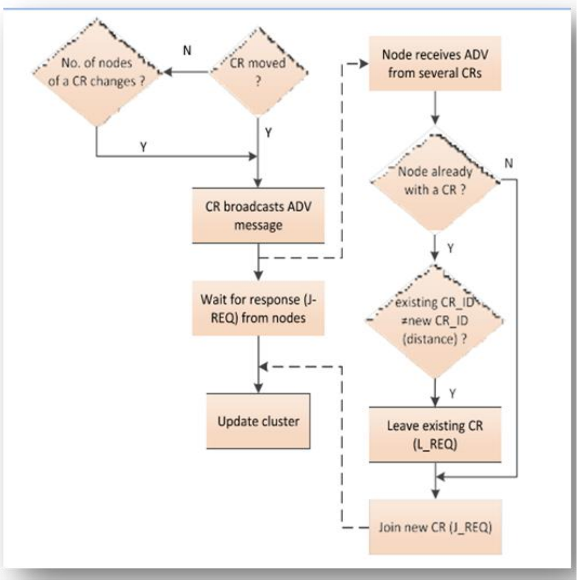

Fig.5 Flowchart for cluster updation

Because CR2 and CR4 are outside of CR3's communication range, their clusters remain unaltered. Due to CR3 relocation, a group of previously unclustered nodes join the cluster for CR3 (example (a) in Fig. 4), while another group of nodes from the cluster for CR3 join the cluster for CR1 (case (b)), and another group of nodes from the old cluster for CR3 become unclustered (case (c)). As a result, following cluster upgrading, C1 27, C2 9, C3 25, C4 9.

C. Formation of Subsets

As illustrated in Fig. 6, a cluster can be divided into one or more distinct subsets (b). Because deactivated subsets are converted to sleep mode, activating only one subset of the nodes in a cluster considerably reduces energy consumption. A subset of a cluster, as described in this work, is a group of nodes that covers the area of a cluster with the least amount of overlap. To avoid sensor network function failing prematurely due to the node with the least amount of energy, subset construction begins with the node with the maximum remaining energy.

The number of sensor nodes in a subset that meets the performance criteria with the least amount of overlap must be determined. In Fig. 6a, for example, the coverage of four nodes overlaps with that of node A, while the coverage of node D overlaps with that of node A just little. As a result, the CR chooses node D as a member of the subset. For clarity, the number of subsets in a cluster is represented as K, while the number of sensor nodes in a cluster is denoted as C. An approach similar to that of Vaidehi et al. [30] is used to construct subsets in a cluster.

Unlike their technique, which produces subsets given a known value of K, the suggested subset formation algorithm does not require any prior knowledge of K. In addition, the number of sensor nodes, S, for each subset is computed analytically. The following processes are taken at the CR to produce cluster subsets. Each subset is made up of sensor nodes with the least amount of overlap.

- Step 1: The starting node for subset construction is chosen as the node with the highest energy.
- Step 2: The selected node discovers all sensor nodes (from the cluster) whose coverage overlaps with the selected node's coverage and computes the distance between each overlapped node and the selected node to select the one with the greatest distance but less than 2 rS.
- Step 3: The number of nodes in the subset increases, while the number of cluster nodes decreases by removing the selected node from the cluster.
- Step 4: Repeat steps 2 and 3 with another picked node until the number of nodes in the subset equals S, which is later calculated.
- Step 5: Repeat steps 1-4 until K subsets are produced, and each node in the cluster is allocated to a subset. When C is not entirely divisible by S, all remaining nodes are added to the K-th subset.
- The number of nodes S in a subset and the number of subgroups K can be calculated mathematically as follows. The detection probability is defined as the likelihood of discovery. False alarm probability, on the other hand, is defined as the likelihood that a sensor node senses the presence of the PU signal when it is actually absent.

IV. ENERGY CONSUMPTION DURING THE STAGE OF SETUP

In terms of resource allocation, CR nodes are expected to be more powerful than sensor nodes. The energy consumption model proposed by Heinzelman et al. [17] for the sensor network is taken into account. Due to the expected geometrical proximity of sensor nodes to the registered CR, free-space pathloss is considered between the nodes and the CR.

ET = Eset + Es + Er decomposes the total energy spent by a sensor node [16].

Where Eset, Es, and Er are the amounts of energy used in the setup (creating the cluster and subset), sensing, and sending (reporting) stages, respectively. Because processing energy at senor nodes is substantially lower than sensing and reporting energy, it is neglected. This section discusses the energy used during the setup stage.

The energy used during the setup step is made up of the energy used during cluster construction, updating, and subset formation. During network configuration, the majority of existing protocols for various network designs neglect clustering energy.

As a result, such protocols are ineffective for deployment. During the cluster construction and updating process during the setup stage, energy is wasted in receiving the ADV messages emitted by the CR, as well as transmitting the J REQ and/or the L REQ while responding to the necessary CRs. The CR executes subset construction after receiving clustering information from the sensor nodes. The sensor nodes use energy to receive the subset information from the CR. The energy consumed during the setup step is calculated using these sequences as

Eset = 2 × ERx + ETx

Where ERx and ETx are the amounts of energy used in receiving and transmitting, respectively. ETx = Etx elec(l) + Etx amp(l) = l Eelec + l Eamp is the transmission

energy.Where Eelec is the energy consumed by electronics over the unit size of the data, which is dependent 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 is dependent on the distance to the relevant CR and the acceptable bit error rate at the CR, and l is the data size. [34,35].The energy consumed in data reception is indicated below, neglecting the Eamp in:

ERx = ERx elec (l) = Eelec l

V. ENERGY CONSUMPTION DURING THE STAGE OF OPERATION

The operation phase is divided into three stages: [36-38]sensing, transmitting (reporting), and sleep. Because energy expenditure during the sleep period is low in comparison to other stages, it is not taken into account here. In this phase, energy efficiency can be improved in two ways: 1) reducing energy use and 2) increasing sleep duration The first goal is met by an energy-efficient network that uses as little energy as possible in sensing and reporting. The second goal, on the other hand, is achieved by effective scheduling of the subgroups.

A. Reduce Energy Consumption Throughout the Sensing Stage

The CRN's sensing performance is connected to the sensor network's energy usage. A higher value for the minimal global detection probability necessitates a greater number of sensor nodes to satisfy the performance limitation for a subset, increasing sensing energy consumption. When measuring the energy consumption of a network, most published research evaluate either communication or processing energy [17], [39], hence energy consumed during the sensing stage is frequently overlooked.

B. Make the Most of Your Sleep Time

The PU's past behaviour is used to forecast future states and to estimate the number of consecutive slots in which the subsets, including the lone active subset, can be scheduled for sleep. A two-state Markov chain is commonly used to mimic PU behaviour, with busy and idle states representing the presence and absence of the PU signal, respectively.When considering the temporal variation of PU activity, the PU tends to keep its status after switching from the other state, i.e., the PU stays on a channel for at least a few slots after occupying it, or the PU does not occupy a channel for at least a few slots after switching to an idle state. From this perspective, positive correlation of PU traffic [40–42] is taken into account, i.e., pII > pIB and pBB > pBI, where pab is the PU's transition probability from state a to state b and subscript I, B represent idle and busy states, respectively.

The CR creates a history of PU activity based on the global decision in each time slot at the CR, which is based on the sensor nodes' sensing results. However, because to faults in the node sensing process, the CR's decision may be wrong in some time windows. By receiving an acknowledgement (ACK) message from the CR receiver, the CR overcomes sensing mistakes (incorrect choices).We presume that the ACK message is quite short in comparison to the time slot duration.

If the ACK message arrives before the timeout, the PU is inactive and the sensing judgement is valid. If the sensing decision interprets the absence of the PU and the CR transmits data but does not receive the ACK message in a timely manner, the sensing information (decision) is deemed wrong, and the history is corrected.

CONCLUSION

This work proposes an ad hoc CRN with an energy-efficient procedure, namely the CUSF process. The sensor nodes are clustered and further subset generated using the CUSF technique. To reduce energy usage, many subsets are constructed in a cluster and only one subset is engaged in sensing. To reduce energy consumption even further, the actual sensor nodes for spectrum sensing are chosen from the supplied active subset using a separately suggested technique. Furthermore, for the length of PU activity, all subsets, including the one active subset, transition to sleep mode, resulting in still further reduction in energy use. On the basis of PU statistics, a novel subset scheduling algorithm is designed to achieve this purpose. As a result, when compared to the SENDORA network and the CRN with the LEACH-C protocol, the CRN with the proposed architecture consumes much less energy and has a reduced end-to-end delay.

REFERENCES

[1] Report of the Spectrum Efficiency Working Group, Fed. Commun. Commission, Washington, DC, USA, Nov. 2002.

[2] Notice of Proposed Rule Making and Order: Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies (ET Docket No. 03-108), document FCC 03-322, Federal Communications Commission, Dec. 2003.

[3] E. Hong, K. Kim, and D. Har, “Spectrum sensing by parallel pairs of cross-correlators and comb filters for OFDM systems with pilot tones,” IEEE Sensors J., vol. 12, no. 7, pp. 2380–2383, Jul. 2012.

[4] J. Mitola and G. Q. Maguire, Jr., “Cognitive radio: Making software radios more personal,” IEEE Pers. Commun., vol. 6, no. 4, pp. 13–18, Aug. 1999.

[5] S. Haykin, “Cognitive radio: Brain-empowered wireless communications,” IEEE J. Sel. Areas Commun., vol. 23, no. 2, pp. 201–220, Feb. 2005.

[6] B. Mercier et al., “Sensor networks for cognitive radio: Theory and system design,” in Proc. ICT Mobile Summit, Jun. 2008, pp. 1–8.

[7] M. B. H. Weiss, S. Delaere, and W. H. Lehr, “Sensing as a service: An exploration into practical implementations of DSA,” in Proc. IEEE Symp. New Frontiers Dyn. Spectr., Apr. 2010, pp. 1–8.

[8] Notice of Inquiry: In the Matter of Promoting More Efficient Use of Spectrum Through Dynamic Spectrum Use Technologies (ET Docket No. 10-237), document FCC 10-198, Federal Communications Commission, Nov. 2010.

[9] A. Ghasemi and E. S. Sousa, “Collaborative spectrum sensing for opportunistic access in fading environments,” in Proc. 1st IEEE Int. Symp. New Frontiers Dyn. Spectr. Access Netw., Nov. 2005, pp. 131–136.

[10] S. M. Mishra, A. Sahai, and R. W. Brodersen, “Cooperative sensing among cognitive radios,” in Proc. IEEE Int. Conf. Commun. (ICC), Jun. 2006, pp. 1658–1663.

[11] X. Liu, B. G. Evans, and K. Moessner, “Energy-efficient sensor schedul- ing algorithm in cognitive radio networks employing heterogeneous sensors,” IEEE Trans. Veh. Technol., vol. 64, no. 3, pp. 1243–1249, Mar. 2015.

[12] O. B. Akan, O. Karli, and O. Ergul, “Cognitive radio sensor networks,”IEEE Netw., vol. 23, no. 4, pp. 34–40, Jul./Aug. 2009.

[13] G. P. Joshi, S. Y. Nam, and S. W. Kim, “Cognitive radio wireless sensor networks: Applications, challenges and research trends,” Sensors, vol. 13, pp. 11196–11228, Aug. 2013.

[14] Z. Huang, Y. Cheng, and W. Liu, “A novel energy-efficient routing algorithm in multi-sink wireless sensor networks,” in Proc. IEEE 10th Int. Conf. Trust, Secur. Privacy Comput. Commun. (TrustCom), Nov. 2011, pp. 1646–1651.

[15] A. S. K. Mammu, U. Hernandez-Jayo, N. Sainz, and I. de la Iglesia, “Cross-layer cluster-based energy-efficient protocol for wireless sensor networks,” Sensors, vol. 15, pp. 8314–8336, Apr. 2015.