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Research paper

Spectrum Aware Cluster Formation Scheme for Cognitive Radio Sensor Network

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Abstract

In Cognitive Radio Sensor Network (CRSN), a cognitive radio sensor node operated on a dynamic spectrum allocation with limited computational and energy resource. A cognitive radio sensor node must vacate an occupied channel degrading its performance due to reclustering as the common channel no longer available. Furthermore, energy is mostly consumed during data transmission mechanism. Clustering is the best architecture model to minimize energy consumption among the nodes. With the objective of a robust cluster while maximizing network lifetime, a fuzzy logic technique is proposed. A metric named relative common channel is also proposed. The fuzzy logic combines two input parameters, the relative common channel and residual energy to elect the best suitable cluster head to minimize reclustering and maximize the network lifetime. The performance of the proposed algorithm is compared with LEACH, SAFCA and CogLEACH. The results show that the CRSN has more extended network lifetime and more balanced energy consumption attributed to the robust cluster formation.

Keywords: *cognitive radio; reclustering; energy; fuzzy; network lifetime;*

1. Introduction

In Internet of Things (IoT), the wireless sensor networks (WSN) are utilized to convey information as part of machine-to-machine-based applications [1]. Existing WSN operates on the unlicensed spectrum together with the Wireless Local Area Network (WLAN), Wireless Mesh Network (WMN), Wireless Body Area Network (WBAN). The WSN performance is deprived due to the consequences of spectrum congestion, collision and interference [2] from the coexistence. The Cognitive Radio (CR) technology will enable the WSN to dynamically access the vacant licensed spectrum [2]. The spectrum adaptation in CR technology will benefit the WSN performance as it offers more potential spectrum with has better propagation characteristic [2].

The Cognitive Radio Sensor Network (CRSN) implementation is amplified with the constraint in both WSN and CR technologies [2][3]. Cluster-based topology has been identified as an energy and spectrum efficient routing topology suitable for cognitive radio network [3]. In a cluster-based topology, CH performs cognitive radio management task and communication with the Base Station (BS) for the rest of the nodes in the network. Hence, less number of nodes and channel engaged in long distant communication suitable for the opportunistic dynamic access. Clustering works is classified as the NP-complete problem [4] and therefore is address heuristically. The WSN clustering algorithmns are unsuitable for the CRSN clustering because the clusters formed will only valid if the nodes within a cluster have common channels. The static spectrum design in WSN does not address this spectrum availability.

The spectrum availabilities requirement is nonexistence in the WSN clustering. The spectrum availability requires the nodes within a cluster to share a common and idle channel for successful communication. Existing CRSN cluster-based algorithm such as CogLEACH [5] showed the performance of COGLEACH outperforms the LEACH in a CRSN environment. LEAUCH [6] proposed channel availability and load balance mechanism for multiple hops transmission. Both [5] and [6] used a weight based probabilistic approach for cluster head (CH) election in clustering in the CRSN. In [7], the Distributed Spectrum Aware Clustering proposed a K-means and group-wise constrained for clustering in the CRSN through message exchange. The CENTRE [8] proposed a temporary node to assist the sensor node in CH discovery using the partial spectrum sensing to reduce energy consumption. In ECS [9], the authors proposed a sleep mode by pairing sensor node based on closest proximity. Energy minimization is achieved though clustering and reducing number of nodes participating in the data transmission. All the above CRSN clustering algorithms focus on energy-efficiency of CRSN fail to address the spectrum mobility in the CRSN. A spectrum mobility is triggered by a returning of Primary user activity causing the channel unavailable for communication. Consequently, a CRSN will trigger a reclustering process which consumed additional energy. Therefore, a spectrum mobility must be addressed to reduce energy consumption due to unstable cluster.

The spectrum mobility can be offset by deciding a new communication channel. A cluster can switch to another communication channel within the cluster provided a multiple common channel existed between a CH and the nodes to replace the reclaimed channel. There are CRSN clustering algorithms that address spectrum mobility but not meant for time-triggered application. For example, mESAC [10] introduced re-clustering probability to minimize channel switching during event to sink cluster formation in mobile CRSN. Meanwhile, COMUS [11] proposed a high channel availability to increase common channel for re-clustering prevention in streaming multimedia content in CRSN. Meanwhile,

in [12] the authors proposed a multi parametric CRSN clustering algorithm using a cluster membership matrix for fast cluster switching for PU arrival. Both [10] and [11] are meant for event-driven applications where the data traffic is real-time and irregular. Furthermore, the clusters were not formed in the entire network.
The CRSN clustering algorithms remain a vastly unexplored domain with respect to the energy and spectrum constrained [13]. Taking in consideration of the shortcoming of the mentioned algorithms, the paper proposed a clustering algorithm with two objectives i.e. to balance the energy consumption and to setup a reliable cluster for a distributed CRSN. This paper proposed a fuzzy logic cluster scheme for a distributed CRSN for a uniform energy consumption while maintaining high common and idle channel availability for spectrum mobility intervention. Even though LEAUCH [6] balanced the CRSN energy consumption in a multi hop transmission through uneven clustering, however, the algorithm is not immune to the spectrum mobility. The proposed scheme introduces a relative channel availability parameter as opposed to channel availability presented in [5] and [6]. The fuzzy logic is deployed as it can overcome the overheads in collecting and calculating energy and location information of the CRSN node. The fuzzy technique can reduce the computation overhead [14] a contributing factor to a resource and spectrum constraint CRSN.
The work of this paper is a continuation of the CH election engaged in [15]] and therefore, the focus in this paper is mainly on the cluster formation algorithm. Unlike the physical proximity and common channel utilized in the existing CRSN clustering algorithm, the CH residual energy and relative channel availability are exploited in this paper. The remainder of this paper is organized as follows: In Section 2, the CRSN system model is discussed while in Section 3, the proposed approach is explained. In Section 4, the performance evaluation of the proposed algorithm with the LEACH, SAFCA and CogLEACH is presented. The conclusion of the paper in Section 5.

2. CRSN System Model

We assume there are N cognitive radio sensor nodes deployed in the CRSN network with their initial transmission range of r meters. Each sensor node is homogeneous and is equipped with a single interface module that switches among C channels and has a dedicated common control channel. The assumption is that the events are reported at regular interval. There also M PU within the CRSN environment which utilize C channels at any time. The C channel activity is modeled as a two state Markov ON-OFF process. The channel state changes with probabilities of PON and POFF. The PON and POFF probabilities are defined $\beta/(\beta+\alpha)$ and $\alpha/(\beta+\alpha)$ respectively where α is the transition probability of channel c from ON state to OFF state and β is the transition probability of channel c from OFF state to ON state.
For ease of analysis, we assume the channel state from spectrum sensing is accurate. Each node will perform spectrum sensing and determine its channel availability as represented in Eq. 1.
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$$a_i(t)=\left[a_1^i(t)\ a_2^i(t)\ a_3^i(t).....a_C^i(t)\right] \tag{1}$$

where represents the channel 1 is available and is occupied at time t at node i. Next, the elected CH will broadcast its ID, channel availability and residual energy. Sensor node wakes up and begins to negotiate in the cluster formation process. Each sensor node calculates the relative common channel, RCA, a new parameter. The RCA of potential CH for cluster formation at time t is formulated in Eq. 2.

$$a_{iCHi}=\frac{a_i(t)\cap a_{CH}(t)}{C} \tag{2}$$

Then, a cluster member chance (CM chance) is calculated using a fuzzy logic to select the optimal CH as defined in Section 3. Once cluster is formed, then the data transmission process can proceed. The energy consumption model proposed in [16] is adopted in the energy calculation. The energy consumption in spectrum sensing is part of the periodic sensing process of a sensor node. Therefore, there is no changes being made to the energy consumption model.

3. Proposed Fuzzy Logic Cluster Formation Technique

The proposed fuzzy logic uses two inputs and one output variable. The input variables are the relative channel availability (RCA) and the residual energy. A higher value of RCA offers more common channels existed between the sensor node and its potential CH. Therefore, if a decided communication channel is reclaimed by a PU, an intracluster communication remains to be established by switching to another channel and prevented a reclustering to occur. Meanwhile, a high energy of CH enables the node to tolerate the high CH energy requirement and avoided an early node death.
The fuzzy logic system parameters have three input membership functions as listed in Table 1. The low and high membership functions are described using the trapezoid membership function as described in Eq 3. The medium membership function is represented using the triangular membership function as shown in Eq 4. The values for both membership functions are specified in Table 2.

Table 1: Input Membership Function

Input	Membership Function		
Relative Channel Availability (RCA)	Low	Medium	High
Cluster Head Energy (CHE)	Low	Medium	High

Table 2: Membership Function Value

	Input	Membership Function			
		a	b	c	d
RCA	Low	0	0	0.05	0.25
	Med	0.1	0.5	0.7	-
	High	0.6	0.95	1	1
CHE	Low	0	0	0.035	0.17
	Med	0.01	0.2	0.4	
	High	0.3	0.45	0.5	0.5

$$\mu_{trapezoidal}(x)=\begin{cases}0, & x\le a\\ \frac{x-a}{b-a}, & a\le x\le b\\ 1, & b_1\le x\le c_1\\ \frac{d_1-x}{d_1-c_1}, & c_1\le x\le d_1\\ 0, & d_1\le x\end{cases} \tag{3}$$

$$\mu_{triangular}(x)=\begin{cases}0, & x\le a\\ \frac{x-a}{b-a}, & a\le x\le b\\ \frac{c-x}{c-b}, & b\le x\le c\\ 0, & c\le x\end{cases} \tag{4}$$

Fig. 1 and 2 show the detailed of the membership function of the three inputs, respectively.

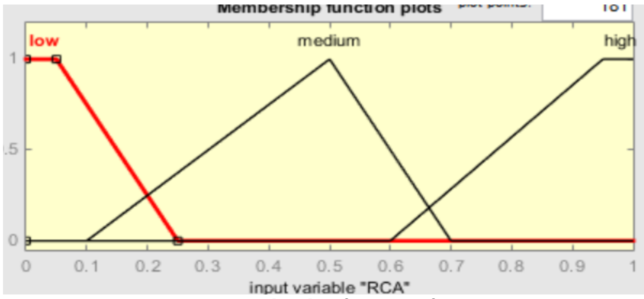

Fig. 1: Membership function of RCA

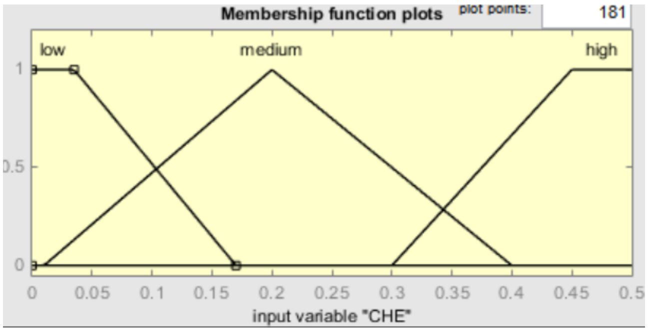

Fig.2: Membership function of CHE

Nine rules are defined heuristically by combining the two inputs and their respective membership functions as shown in Table 3.

Table 3: Fuzzy If-Then Rules

CHE	RCA	CM Chance
Low	Low	Weak
Low	Medium	Rather Weak
Low	High	Medium
Medium	Low	Medium
Medium	Medium	High Medium
Medium	High	High
High	Low	High Medium
High	Medium	High
High	High	Very High

Fig 3. shows the relationship of the CM chance and the two input functions. The CM chance increases as both the CHE and RCA increased. The center of area (COA) is selected for the defuzzification process.

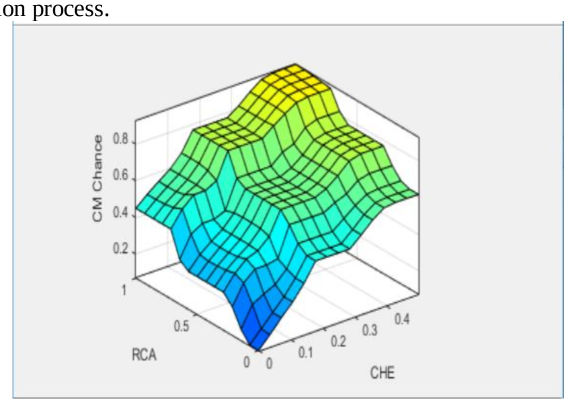

Fig. 3: CHE vs RCA fuzzy inputs relationship

4. Results and Discussion

In this section, the results of the simulation to evaluate the proposed scheme referred as FSACFA are presented. There are 100 nodes of CRSN that are identical, stationary and randomly deployed in a 100m x 100m area. Fig.4 shows the node distribution. The nodes can adjust their transmission power according to the distance of the receiving node. The BS is located at the center of the network. The distance between nodes is calculated using the received signal strength. The nodes have 0.5 J battery power. The performance of the proposed algorithm is compared with LEACH [16], SAFCA [15] and CogLEACH [4].

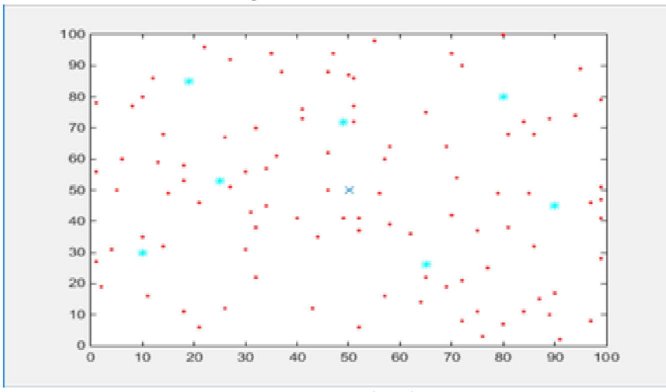

Fig. 4: CRSN Node Distribution

4.1. Evaluation of Node Lifetime

There are several definitions for the network lifetime. Lifetime can be defined as the time until the first sensor runs out of energy which applicable for sparsely deployed sensors [17]. However, the most common metrices are the First Node Died (FND), Half Nodes Died (HND) and All Nodes Died (AND) which are measured during the simulation. The simulation results are presented in Table 4.

Table 4: CRSN Node Lifetime

	FSACFA	SAFCA	CogLEACH	LEACH
FND	1213	1010	700	585
HND	1249	1288	1211	848
AND	1271	1741	1798	956

The results show that FSACFA has the highest FND among the four algorithms. Then, it is followed by SAFCA (18%), CogLEACH (53%) and the lowest is LEACH (69%). This shows the FSACFA has the lowest overall energy consumption compared to the rest of the algorithms.

In the HND, SAFCA algorithm outperforms the rest the algorithms. FSACFA algorithm is slightly lower than SAFCA (3%). Hence, the performance FSACFA is comparable to SAFCA. The performance of FSAFCA remains higher than CogLEACH (3%) and LEACH (38%) with respect to HND.

In the AND performance metric, CogLEACH outperform FSAFCA, SAFCA and LEACH. However, the low FND and HND metric of CogLEACH have reduced the number of nodes in the network as compared to number of alive nodes in FSACFA and SAFCA much earlier. This resulted in less number of nodes participated in the cluster which translates to a high AND metric in CogLEACH compared to FSACFA and SAFCA. It is obvious that the LEACH clustering algorithm has the lowest performance than the FSACFA, SAFCA and CogLEACH for all the above performance metrices.

4.2. Evaluation of CH Energy Consumption

As a CH, the node energy is consumed in intra-cluster communication, data aggregation and intercluster transmission. In this simulation, the average energy consumed by all the CHs at each round is calculated and investigated. Fig.5 shows the CH energy consumption taken randomly during the CRSN operation.

It is observed that LEACH has the highest CH energy consumption as the WSN is not spectrum aware. The CogLEACH, a spectrum aware of LEACH, has shown an improvement in CH energy consumption but the CH election rely solely on channel availability. The CH energy consumption of SAFCA is lower than CogLEACH due to its optimal CH election parameters which includes the channel availability, residual energy, node distribution and communication cost. However, FSACFA recorded the lowest CH energy consumption among LEACH, SAFCA and CogLEACH.

In addition, the CH energy consumption of FSACFA is observed to be less fluctuated implying a more balanced CH energy consumption than LEACH, SAFCA and CogLEACH. The LEACH, SAFCA and CogLEACH clustering algorithms which relied on physical proximity and common channel have higher fluctuation of CH energy consumption within the selected 50 rounds. The balanced CH energy consumption can be attributed to the fuzzy logic cluster formation that is implemented over the CH election of SAFCA.

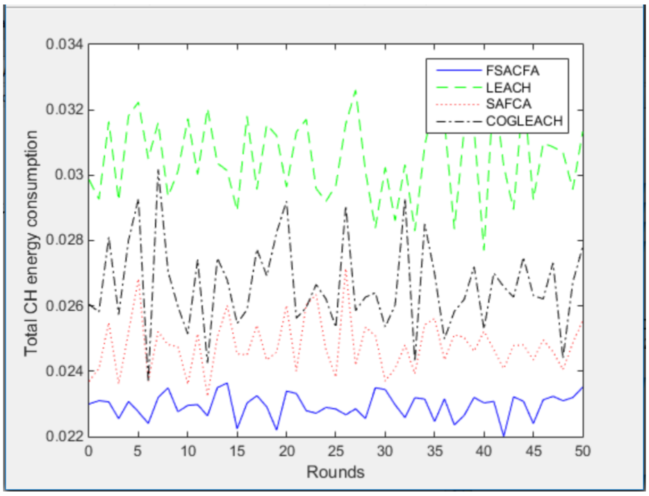

Fig. 5: Comparison of CH Energy Consumption

4.3. Evaluation of Intracluster Load Balance

In this part of the simulation, the average intra-cluster distance of a 50 random round is calculated and investigated. The intra-cluster distance in round 300 to 350 is selected in this simulation. The result in Fig. 6 shows the average intra-cluster distance of FSACFA is the lowest among the rest of the algorithms. In addition, the average intra-cluster distance of FSACFA is more consistent than LEACH, SAFCA and CogLEACH.

Fig 6 shows the FSACFA has a small but a balance cluster size with respect to energy consumption in each round. This imply that the fuzzy logic cluster formation in FSACFA enables the node to strategically select the optimal CH. Hence, the sensor node will not overcrowd a CH and will not cause a CH energy to deplete at a faster rate.

LEACH has the highest intra-cluster distance among the four algorithms. The CogLEACH and intra-cluster distance are rank between the FSACFA and SAFCA. FSACFA has the lowest intra-cluster distance than the rest of the algorithm. A sharp drop of intracluster distance, at round 305-310 and 345-350 is attributed to a high PU activity. It also shows that the FSAFCA manage to record a small intracluster distance in a high PU environment. Meanwhile, the rest of the algorithms LEACH, SAFCA and CogLEACH shows a zero intracluster distance in the same situation. This shows that cluster communication can be established as there exist alternative common channel between CH and nodes in the FSACFA, while no cluster is formed in remaining algorithm. This proved that FSACFA is capable to address the PU arrival and the cluster is more robust.

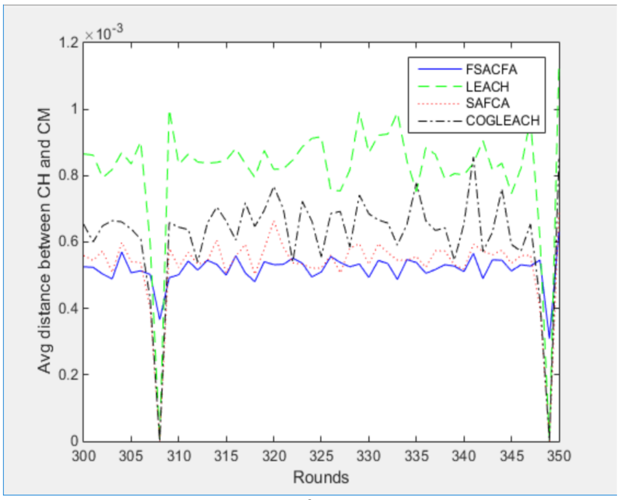

Fig 6: Comparison of CH energy consumption

4.4. Evaluation of Node Energy Consumption

To further investigate the energy consumption of CRSN, the node energy level is evaluated. A more balanced energy consumption system will have a more consistent energy level thoughout all nodes in the environment. Fig. 7 shows the level of energy in each node is recorded for all the four algorithms, i.e. FSACFA, LEACH, SAFCA and CogLEACH. The energy pattern in all the 100 nodes of LEACH has the highest fluctuations and therefore more variable. The energy level in FSACFA nodes is more stable as it has the lowest ripple as compared to LEACH, SAFCA and CogLEACH. The SAFCA and CogLEACH nodes energy is between the FSACFA and LEACH. This shows the FSACFA node energy consumption is more uniform than LEACH, SAFCA and CogLEACH.

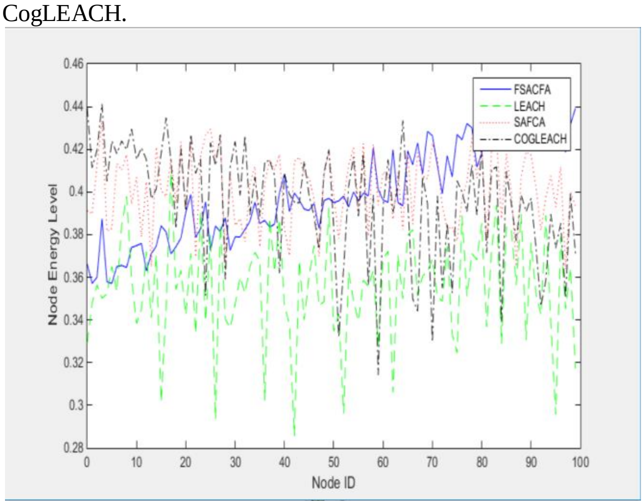

Fig 7: Node Energy Level at Round r=250

4.5. Evaluation of Throughput

The throughput of the algorithms is analyzed theoretically. It is anticipated that the throughput of FSACFA is higher than the other two spectrum aware algorithms namely the CogLEACH and SAFCA. Both CogLEACH and SAFCA exploited the channel availability in cognitive radio, but they have not address spectrum mobility due to PU arrival. As the common channel status changes, in cognitive radio, channel utilization is prioritized to the PU. Hence, no data will be transmitted until a re-clustering has completed in the next round. The PU arrival will reduce the throughput. FSACFA addresses PU arrival in a target common channel by switching to another alternative common channel. Therefore, data transmission can resume after the channel switching. This resulted of higher throughput in FSACFA. Meanwhile, the throughput of LEACH remains the lowest as CogLEACH has proved that the channel availability in CRSN improved the throughput when compared to LEACH [5].

5. Conclusion

In this paper, a fuzzy logic cluster formation technique in CRSN is presented. The performance of the algorithm is compared with LEACH, a random probability CH election, CogLEACH, a channel availability probability CH election and SAFCA, a fuzzy based CH election. These algorithms utilized the physical proximity and common channel for their cluster formation. In the proposed algorithm, two-fuzzy parameters namely, RCA and CHE are implemented to achieve a balance energy consumption and more robust cluster. It has been demonstrated that the CH energy consumption is more balanced than LEACH, SAFCA and CogLEACH. A more balance CH energy consumption has enable the CRSN to sustain the longest FND. The intracluster distance simulation has shown that the FSACFA cluster is smaller than LEACH, SAFCA and CogLEACH. This indicates that the cluster of FSACFA is smaller and more reliable to accommodate PU arrival as the sensor node and a CH shares a high relative channel availability.

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