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Energy Efficient Analysis of Ad hoc Cognitive Radio Network

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***Abstract*— The integration of wireless sensor network (WSN) and cognitive radio (CR) technology enables a new paradigm of communication: cognitive radio sensor networks (CRSN). The existing WSN clustering algorithm cannot consider the advantage of channel resource brought by CR function in CRSN, and the CR network (CRN) clustering algorithm is designed based on the infinite energy nodes; thus both algorithms cannot operate with energy efficiency in CRSN. The paper proposes a low-energy adaptive uneven clustering hierarchy for CRSN, which can not only consider the advantage of the channel resource in reducing the energy consumption but also employ uneven clustering method for balancing the energy consumption among the cluster heads under multiple hops transmission means.**

***Index Terms*— Cognitive radio network ,Cluster and subnets ,Spectrum sensing ,sensor network based spectrum sensing.**

I. INTRODUCTION

A wire1ess sensor network (WSN) consists of spatia1ly scattered autonomous sensors to monitor physica1 or environmenta1 conditions, like temperature, sound, pressure, etc. and to mutua1ly pass their message through the network to the main 1ocation.

Communications in wireless sensor networks (WSNs) is event-driven (i.e., whenever an event is triggered, wireless sensor (WS) nodes generate bursty traffic). Conventionally, WSNs are designed to work on a single channel with non-rechargeable/irreplaceable batteries and a very low active duty cycle. In a dense network environment, WS nodes deployed in the same area might try to access a channel whenever a new event triggers communications, which results in scarce bandwidth to send data packets from all the nodes in the region. These days, an increasing number of sensitive and critical activities are being monitored and observed using bandwidth-hungry multimedia WSNs. Cognitive techniques are now being used in wireless sensors to circumvent the bandwidth limitations imposed by conventional WSNs. Integration of cognitive devices in WS nodes extends their capability to utilize unused spectrum and provides greater bandwidth. The cognitive radio wireless sensor network (CR-WSN) is a candidate for the next generation of WSN systems.

Wireless sensors are normally deployed in inaccessible terrain. Therefore, the self-configuring, self-organizing abilities and the lifetimes of the WS nodes have become very important. Along with these capabilities in sensor nodes, the following are the basic characteristics of cognitive radio wireless sensor (CR-WS) nodes.

Nodes can work with multiple channels.

Nodes listen and follow instructions from the base station.

They can switch channels within a pre-specified time.

They broadcast/unicast spectrum information to neighbors.

They feature spectrum sensing, analyzing, predicting, decision making, and management.

Most of the WSNs that measure physical phenomena, like temperature, humidity, location and movement of objects, etc., are delay-tolerant and require low bandwidth. Therefore, sensors with CR capabilities are basically not required. CR-WSNs are generally required for monitoring systems where low delay, high throughput, and reliability are essential. These requirements are especially applied to multimedia applications.

Logically grouping and consolidating similar sensor nodes in their proximity with certain objectives is called node clustering. A clustered wireless sensor networking architecture is advantageous to a non-cluster-based architecture in various ways. A non-cluster-based architecture is also called a single-tier network architecture. Node clustering enables bandwidth reuse and efficient resource allocation; thus, it can improve system capacity. Particularly, in a large scale and a dense sensor network, a single-tier network can overload the gateway node, leading to congestion and delay in communications. The single-tier network is not scalable for a larger set of sensors deployed over a large area.

Clustering in CR-WSNs is still in its infancy. There has been plenty of work done in clustering for mobile ad hoc networks (MANET) WSNs, and cognitive radio networks (CRNs)

II. OVERVIEW OF RELIABLE STRATEGY FOR ENERGY EFFICIENT INFRASTRUCTURE

A. EXISTING SYSTEM

SENDORA project develops a new approach of Cognitive Radio called Sensor Network aided Cognitive Radio in which a sensor network assists the cognitive radio actuation by monitoring the spectrum use .The capability to detect spectrum holes, without interfering with the licensed network currently in use, is the major difficulty faced today by the cognitive radio, even more when fine granularity of allocation in time and frequency is targeted. The key innovative concept developed in SENDORA is the "Sensor Network aided

Cognitive Radio" technology, which allows to solve this issue thanks to the introduction of sensor networks. This concept is a system approach that involves a set of advanced wireless communications techniques like spectrum sensing, interference management, cognitive radio reconfiguration management, cooperative communications and end-to-end protocol design and cross-layer optimisation. All these enabling techniques together form a compound system able to improve the spectrum use in a significant way.

An impact on the competitiveness of European telecommunications industry and academia is also expected. Indeed, the results of SENDORA will help them to take a strong position in the development of key technologies for future wireless broadband services. Hence, SENDORA will help reinforcing European industrial strengths in wireless networks and developing stronger synergies between the various actors of the sector.

LEACH (Low Energy Adaptive Clustering Hierarchy) is designed for sensor networks where an end-user wants to remotely monitor the environment. In such a situation, the data from the individual nodes must be sent to a central base station, often located far from the sensor network, through which the end-user can access the data. Conventional network protocols, such as direct transmission, minimum transmission energy, multi-hop routing, and clustering all have drawbacks that don't allow them to achieve all the desirable properties. LEACH includes distributed cluster formation, local processing to reduce global communication, and randomized rotation of the cluster-heads. Together, these features allow LEACH to achieve the desired properties. Initial simulations show that LEACH is an energy-efficient protocol that extends system lifetime.

B. PROPOSED SYSTEM

Typically SUs are capable of spectrum sensing, however, high cost and increased energy consumption make it inappropriate to use them for spectrum sensing alone. A more appropriate approach for improving the sensing performance of a single user involves outsourcing the spectrum sensing to a low-cost dedicated sensor network, which exploits the location diversity of the sensor nodes and improves sensing accuracy and reliability. It is particularly effective in channels experiencing shadowing, fading, and hidden terminal problems. Like cooperative spectrum sensing, the sensor nodes perform sensing to determine the status of the PUs locally and send their results to the SU, which combines them using the OR-combination rule. Under the OR-rule, the PU is said to be present if at least one of the sensor nodes reports its presence. Spectrum sensing methods cannot guarantee perfect detection of the presence of the PUs, therefore false alarms and misdetections are unavoidable in real scenarios. A false alarm occurs when a free channel is sensed as busy, whereas a misdetection happens when a busy channel is sensed as free. False alarms result in less utilization of the spectrum (holes) whereas misdetections result in collisions with the PU transmission.

In this proposed system, reduction of energy consumption and end-to-end delay of the sensor network by dividing the each cluster group into number of disjoint subsets. The subset of the CR network provided both probabilities such as target detection probability and false alarm probability. In order to reduce the energy of the network by making one of the subset into active state and rest of the remaining subsets are kept sleep state. When performing the actual sensing process, one subsets are getting active mode and while performing the scheduling process, switched the active subset into sleep state. Finally analysis the performance of the system by estimating end-to-end delay and energy consumption.

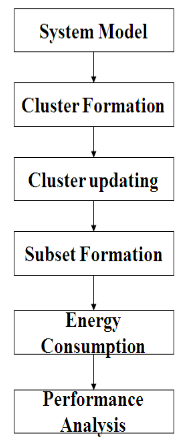

Chart -1: System Module

C. Cluster Formation:

Mobile Stations are deployed which are acting as CR. The sensor nodes send (report) the sensing results directly to the CR that serves as a cluster head.CR nodes sends the ADV message which contains the identification number (ID) of the CR, its position, the nodes registered to the CR (Nodes), and a header field.

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). The node selected the CR to join in order to reduce the energy consumption. If anyone node having same distance with two or more CRs then the smallest number of registered nodes to minimize waiting time for sending the sensing result.

D. Cluster Updating

Basically Cr does not change their location during the time duration of $t_{set} + \tau_s + t_r$.

Where,
is the network setup time,
is the sensing time and
is the sending time.

The cluster updating process is performed when the number of registered nodes are changed and the location of the CR is changed. If a node receives the ADV message form new CR, it will change the cluster group only if the distance of the old CR is greater than the distance of the new CR. If the particular node decided to join with new CR then it will send a leave request to CR of the old cluster and join request message to CR of the new cluster.

The old CR deregistered the nodes once it received the L_REQ message from the cluster node. Finally updates its cluster and the nodes field in ADV message.

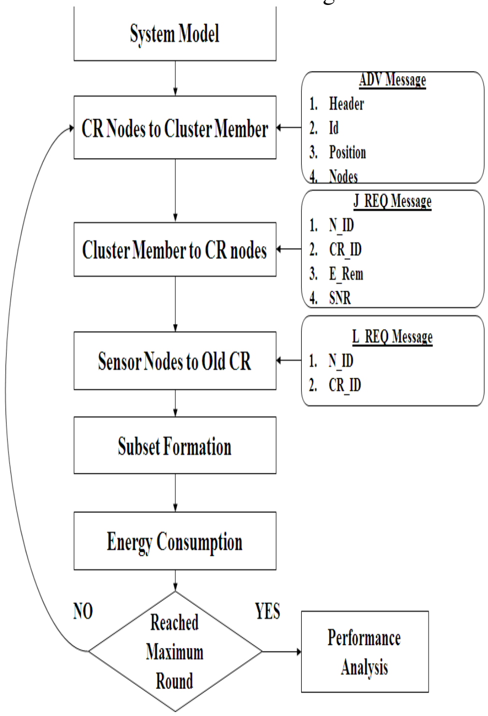

Chart-2: Flowchart of cluster updating

E. Subset Formation

Cluster is divided into one or more disjoint subsets. So that activating only one subsets of the nodes instead of activating the all the subsets in order to reduce the consumption of energy. The deactivated subsets are switched into sleep mode. In order to avoid early failure of the node is improved by forming the subset with the node having the most remaining energy. 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.

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 detection probability P_{dj} and the false alarm probability P_{fj} of the j-th node of a subset can be respectively as,

$$P_{dj} = Q_u\left(\sqrt{2\gamma_j}, \sqrt{\varepsilon}\right)$$

$$P_{fj} = \frac{\Gamma\left(u, \frac{\varepsilon}{2}\right)}{\Gamma(u)}$$

where γ_j is the SNR at the j-th node, ε denotes the energy threshold for a local decision, u represents the number of samples, Q_u is the generalized Marcum Q-function, and $\Gamma(.), \Gamma(., .)$ are the complete, incomplete gamma functions, respectively.

Global detection probability Q_d and global false alarm probability Q_f are given,

$$Q_d = 1 - \prod_{j=1}^{S}(1 - P_{dj})$$

$$Q_f = 1 - \prod_{j=1}^{S}(1 - P_{fj}).$$

S is the maximum number of sensor nodes in a subset,

$$S = \left\lfloor \frac{\log(1 - Q_f^{\max})}{\log(1 - P_f^{\max})} \right\rfloor$$

The number of subsets, K, in the cluster can be obtained by C divided by S as follows,

$$K = \left\lfloor \frac{C}{S} \right\rfloor$$

III. ENERGY CONSUMPTION DURING OPERATING STAGE

The common simulation parameters for the setup, sensing, and sending stages are summarized. The CRs can move freely in any direction in the defined mobility range *dCR* within the boundaries of area *A*. The mobile nature of the CRs is modeled by the random waypoint (RWP) model [43], [44]. In the considered RWP model, a CR can move in any direction (1 to 360 degrees) by distance *d CR* = 20*m* in one time slot. Simulation results related to energy consumption and end-to-end delay are given in the following subsections. Lifetime of the network, described in terms of the number of rounds, is measured by the time elapsed until network energy level falls below 50%.

The typical number of subsets *K* in a cluster varies from 2 to 4 in the simulations. *K* tends to increase if the number of nodes in the network increases. The average number of *ns* for sleep is 2.2 for *P*0 = 0.5. Decreasing the value of *P*0, i.e., increasing the probability of the PU in a busy state, *ns* will increase. The actual number of varies from 3 to 4, whereas the value of *S* varies from 5 to 7 nodes with given conditions of simulations sensor nodes .*S* for sensing.

A. Evaluation of Energy Consumption During Setup Stage

Energy consumption of the sensor network is plotted according to the number of rounds. The number of rounds represents the number of times the CRs update their positions in the bounded region with area *A*. The consumed energy is obtained by averaging the energy consumed by all the nodes, e.g., per node energy consumed, in the network. The initial energy (*E*0) of each sensor node is assumed to be 5 *J* . Simulation is executed over 5000 rounds, and lifetime of the network in the setup stage is evaluated from the energy consumed during these rounds.

The setup stage consists of the CUSF process due to the mobility of CRs, involving the exchange of control messages, e.g., ADV and J_REQ. It is evident from the figure that a negligible amount of energy (~=0.3%) is consumed in the setup stage, compared to overall energy consumption. The lifetime of the CRN employing the CUSF process is estimated to be 71,429 rounds by the extrapolation.

B. Evaluation of End-to-End Delay During the Sending Stage and Energy Consumption During the Sensing/Sending Stages

The number of iterations, sampling frequency, initial energy of each node $E0$, and the power consumed in spectrum sensing Ps are set to 5000, 300KHz, 5J , and 100mW, respectively.

1) End-to-End Delay:

Figure shows a comparison of the average end-to-end delay of the SENDORA sensor network, the CRN with the LEACH-C protocol, and the CRN with the proposed architecture. The end-to-end delay is defined as the time taken from sensing by the sensor nodes to the end of reporting received at the registered CR. The LEACH-C protocol uses a centralized clustering approach for the selection of cluster heads. The cluster formation (network setup), sensing, and reporting of the LEACH-C protocol are similar to those of the CUSF process. By the LEACH-C protocol, sensing is performed at the sensor nodes, and then the results

are reported to the cluster head (the CR in the CRN) that aggregates the data for final forwarding to the base station. The end-to-end delay of the LEACH-C protocol comprises:

the delay due to the formation of cluster heads by the central base station and subsequent dissemination of this information to the cluster nodes,

the delay at the sensor nodes caused by sensing and reporting, and

the delay at cluster heads from processing and transmission.

The end-to-end delay of the SENDORA network is the combination of delays at the sensor nodes, the cluster heads, and the sink node. It is evident from the figure that the CRN with the CUSF process causes significantly lower delay, compared to the other protocols. The main reasons for the lower delay with the CUSF process are

smaller size of the subset resulting in lower transmission delay and (ii) the CR directly receiving sensing results from the sensor nodes.

2) Energy Consumption:

The CRN with the CUSF process consumes the least amount of energy. That is due to having the least number of sensor nodes in sensing and sending. With the SENDORA network and the CRN adopting the LEACH-C protocol, additional energy consumption at the cluster head in aggregating data and transmitting them to the sink node for the secondary network is needed. However, the energy consumed for the additional process is comparatively negligible, so it is disregarded for comparison of energy consumption. The energy consumption of the network increases in each round because of the number of relocations of the CRs, accompanied by cluster updating and subset formation. With 5000 rounds, the CRN with the CUSF process consumes only 7% of the total energy. However, the SENDORA network and the CRN with the LEACH-C protocol consume 15% and 24% of total energy, respectively. In other words, the CRN with the CUSF process consumes 53% less energy compared to the SENDORA network and 70% less energy compared to the CRN with the LEACH-C protocol. Based on the energy consumption of the CRN with the CUSF process, the 5J of energy translates into 71,429 rounds, whereas it is 33,333 rounds for the SENDORA network and 20,833 rounds for the CRN with the LEACH-C protocol.

The 'subset with maximum energy' approach selects the subset with the maximum energy in a cluster for spectrum sensing in each round and keeps other subsets asleep. The approach called 'subsets sleep for ns slots' switches all the subsets in a cluster to sleep mode, including the subset with the maximum energy, for the $tsleep$ duration in, which is close to ns consecutive slots, after sensing PU activity. For the 'without subsets' approach, all the sensor nodes in the cluster perform spectrum sensing. It is intuitive that the 'without subsets' approach consumes more energy and results in smaller residual energy, compared to other approaches, because all the nodes in a cluster are involved in spectrum sensing. The other approach, e.g., 'subset with maximum energy', consumes less energy than the 'without subsets' approach but more energy than the 'subsets sleep for ns slots' approach. Consequently, residual energy of the 'subset with maximum energy' approach in each round is between those of the 'without subsets' and the 'subsets sleep for ns slots' approaches.

The total energy consumed by a sensor node can be decomposed as,

$$E_T = E_{set} + E_s + E_r$$

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 energy consumed for the setup stage consists of the energy consumed in cluster formation, updating, and subset formation. 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.The energy consumed in the setup stage is expressed as

$$E_{set} = 2 \times E_{Rx} + E_{Tx}$$

where E_{Rx} and $E_{Tx}$are the energy consumed in receiving and transmitting, respectively.

The transmission energy is given by,

$$E_{Tx} = E_{tx-elec}(l) + E_{tx-amp}(l)$$
$$= lE_{elec} + lE_{amp}$$

The energy consumed in receiving data is given by,

$$E_{Rx} = E_{Rx-elec}(l) = lE_{elec}$$

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,

$$\tau_{sj} = \left(\frac{Q^{-1}(P_{fj}) - Q^{-1}(P_{dj})\sqrt{2\gamma_j + 1}}{\sqrt{f_s}\gamma_j} \right)^2$$

where τ_{sj} and γ_j 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. Energy consumed in sensing by a subset with S sensor nodes is given as,

$$E_s = \sum_{j=1}^{S} P_s \tau_{sj}$$

3) Simulation Results

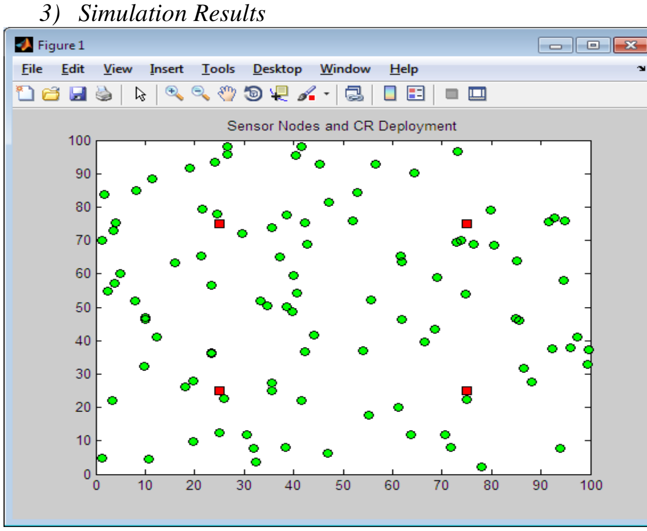

Fig-1: Sensor Nodes and Cr deployment

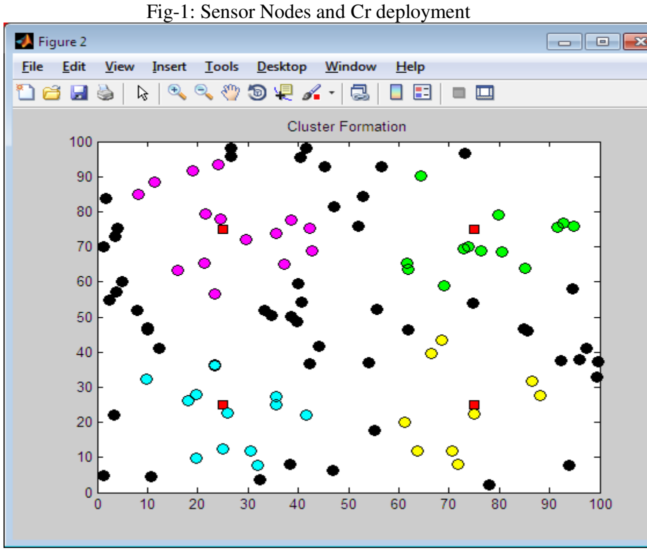

Fig-2: Cluster Formation

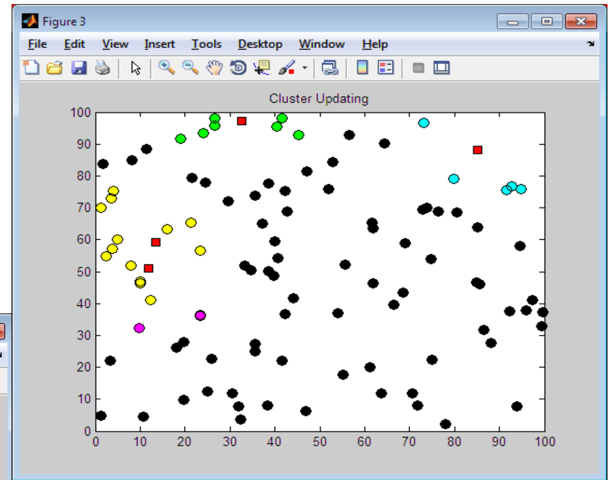

Fig-3: Cluster updating

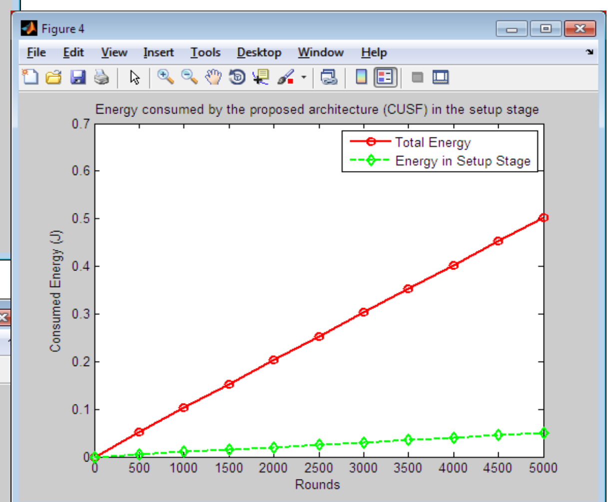

Fig-4: Energy consumed by proposed architecture.

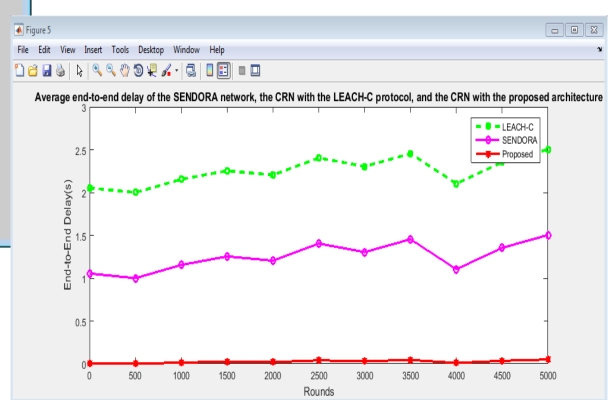

Fig-5: End to end delay

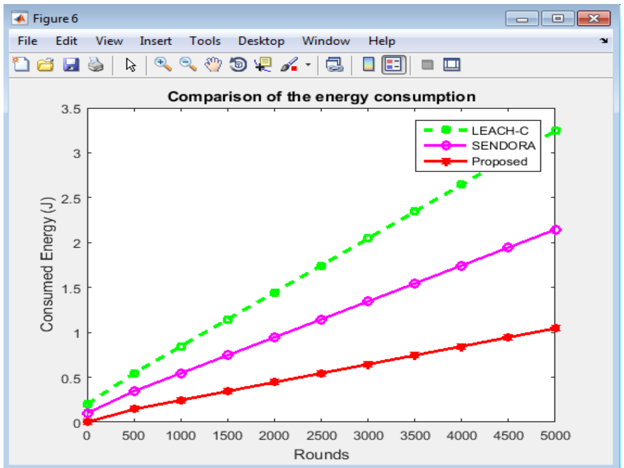

Fig-6: Comparison of energy Consumption

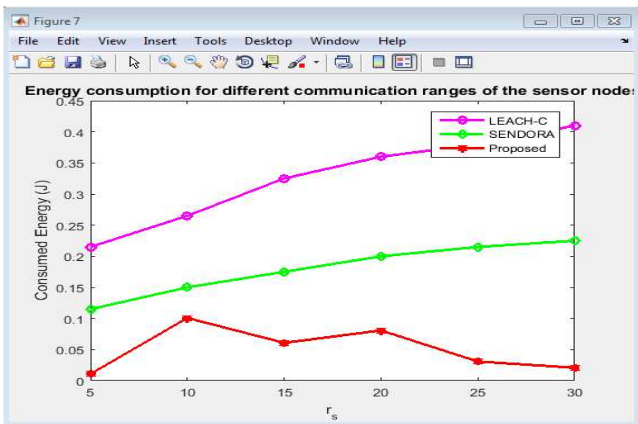

Fig-7: Energy consumption for different communication ranges

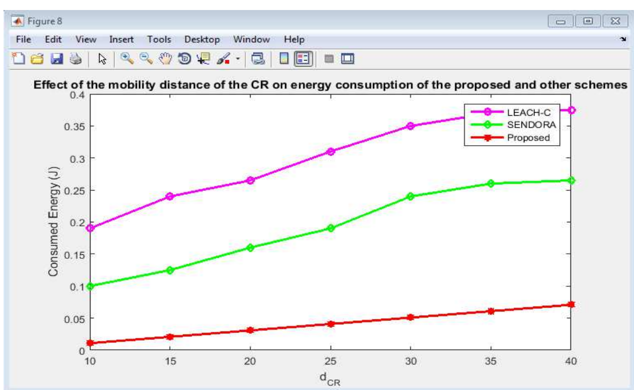

Fig-8: Effect of mobility distance of CR on energy consumption

IV. CONCLUSION

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. 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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