Performance Analysis of Cognitive Radio Based Internet-Of-Things Network for Energy Efficiency and Spectrum Utilization

Palak Thakur, Payal Patial, Prabhat Thakur

Abstract: Energy and Spectrum are the two basic requirements in the realm of Internet-of-Things (IoT). The network of IoT is becoming larger day by day and the design of spectrum and energy efficient solution is a quite challenging task because of the rapid increase of connecting devices in IoT network. To make the system more energy and spectral efficient, energy harvesting and cognitive radio (CR) are the proficient solutions, respectively. This paper introduces a spectral and energy efficient design for CR based sensor networks. We present a network architecture, in which nodes or other sensing devices can use the spectrum opportunistically and energy harvesting can be done from different ambient sources. We then propose an 1) energy alancing scheme for heterogeneous network in which nodes will have different energy levels and 2) Cluster head (CH) selection scheme which will only be performed on the few nodes of network having the highest current energy to accomplish the ultimate goal of energy balancing in network, this analysis is performed with in the cluster. Furthermore, for the spectral efficiency, we propose a channel management scheme based on cognitive radio to allot the best available channel having highest reliability in respect of the bit error rate (BER) using. Comprehensive results exhibit the effectiveness in the performance of the proposed spectral and energy efficient schemes and show better performance over other schemes.

Index Choice: Channel management, clustering, cognitive Radio, energy management, Internet-of-Things,

I. INTRODUCTION

The Internet-of-things (IoT) is a potential technology leading towards the new era of communication which facilitate connectivity among physical objects [1]. Devices in this network are increasing day by day thus the IoT networks are facing the challenges like need of spectrum and energy requirement. The primary cause for these sort of difficulties isa huge number of devices in the network. Cognitive Radio and Energy Management Techniques are the two efficient methods to overcome the problem of spectrum shortage and energy balancing respectively.

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- **Cognitive Radio** is a efficient solution to overcome the problem of spectrum sharing [2]-[4] by allowing the unlicensed users to coexist with licensed users [1], [5]. Cognitive Radio use available spectrum which makes it spectrum efficient technology [6].

- **Energy Management** plays a crucial role in increasing the lifetime of the network by using different protocols or by using the mechanism of energy harvesting. Some of of these commonly used protocols are LEACH (Low Energy Clustering Hierarchy), Stable Election Protocol (SEP) and Zonal-stable Election Protocol (ZEP)[7].Energy Harvesting is a another technology which can increase the energy efficiency by providing the energy from ambient resources [8].

A. Contribution

In this paper, we examine the different technologies of spectral and energy efficient CRSN for IoT. We have proposed the energy efficient scheme to ameliorate the lifetime of the network by deploying the gateway nodes and making the network heterogeneous in terms of energy. The work flow of this paper is as follows:

1. Energy Management Scheme:
   - Full operational mode (FOM)
   - Dynamic operational mode(DOM)
2. CH selection Scheme
3. Cache Nodes
4. Channel Management Scheme

The paper is designed as follows, the related work is presented in Section II providing the description of work done in the area of IoT. Further, Section III provides the Proposed Work and the system model is presented in Section IV. The simulation results are in Section V and finally Section VI concludes the paper.

II. RELATEDWORK

- Saleem Aslam, et.al (2018) proposed a novel energy and spectrum efficient mechanism for improving spectral and energy efficiency in cognitive radio sensor networks (CRSN) [9]. The spectrum was accessed opportunistically and energy was harvested from ambient RF sources by this proposed architecture. The best quality channel in terms

of stability and reliability was assigned to the sensor nodes by proposing a channel management mechanism to achieve reliable intra-cluster reporting. Highly effective results were achieved which showed that this approach provided highly spectrum efficient mechanism and was also better that previously existing approaches Basma of Vertex Covers. The energy and communication costs which add up when the network is monitored are minimized through the proposed approach. As per the simulation results it was seen that appropriate energy-efficient solution was achieved for monitoring IoT networks by applying proposed technique.

- Santiago S, et.al (2017) proposed a novel implementation and design to improve the energy efficient routing of IoT networks [11]. The performance of network was optimized by integrating the routing metrics. For selecting the preferential path and increasing the lifetime of networks, the energy aware metrics were merged by the proposed technique using fuzzy inference system. MATLAB simulator was used to perform simulations and the results achieved showed the performance level of around 63% when implementing proposed technique.

- S.Nisha, et.al (2017) proposed a protocol for IoT which was named as ESMR (Energy Efficient Self-organizing Multicast Routing) [12]. The nodes were considered to be the ones which already existed in the network. Multiple measurements along with Markov process were used for measuring the weight of network node in case of non-network nodes.

Mostafa, et.al (2018) proposed an III-phase mathematical model for handling the optimized scheduling within IoT networks [10]. The Vertex Cover Problem was solved iteratively in the initial phase to generate the different subsets of nodes which cover the complete graph. The other two phases managed the optimized scheduling

- K. Suresh, et.al (2016) studied that for minimizing the energy Minimum Energy Consumption Algorithm(MECA), several techniques were proposed over time [13]. However, because of the direct distribution of nodes in the network, these techniques were considered to be inefficient. To control and regulate the energy factors in IoT efficiently, an Energy Efficient IoT approach was proposed named EEIoT. The energy harvesting of IoT was reduced by this self-adaptive technique. Towards the end, a comparative analysis of existing and proposed techniques on the basis of various energy consumption factors was performed which showed that the proposed approach outperformed other techniques.

- Muneer Bani Yasin, et.al (2016) proposed a dynamic tuning approach such that the update message interval within CoAP could be adjusted [14]. The battery level of the transmitting node was considered to be the base of proposed algorithm. Here, with the reduction in the battery level the update interval was maximized. Through the simulation results it was seen that around 25% of extension in the lifetime of network was achieved when implementing the proposed approach in the IoT network.

TABLE I
Summary of Literature survey

Ref.	Objective	Paper/Year	Remarks
[15]	Energy Management in IoT based smart homes	Efficient energy management for Internet-of-things in smart cities/2017	Energy management is divided into two parts: energy harvesting and energy efficient solution
[16]	Transfer of power and information simultaneously by using MIMO technology	MIMO broadcasting for simultaneous wireless information and power transfer/2013	Architecture Power splitting & Time switching are analyzed
[17]	Amalgamated energy and spectrum management	Integrated energy and spectrum harvesting for 5G wireless communications/2015	Energy management is done by using MAC protocols
[18]	Selection of Cluster Head using modified LEACH	Adaptation of leach routing protocol to cognitive radio sensor networks/2012	Lifetime of the network is increased by locating the CH in suitable location
[19]	CH selection is based on the Weights considering the average and residual energy of the nodes	Energy efficient clustering scheme for prolonging the lifetime of wireless sensor network with isolated nodes/2015	Lifetime of the network is prolonged by selecting the energy rich node as CH
[20]	RF energy harvesting based wireless sensor network	Energy harvesting and spectrum sharing protocol for wireless sensor networks/2015	Achieve optimal throughput and network lifetime

[21]	Efficient solution of energy and spectrum scarcity in IoT	Energy and Spectral efficient cognitive radio sensor network for Internet-of-Things/2018	Energy efficiency has been increased and by using CR the opportunistic spectrum sharing is done.
Proposed	Energy management in heterogeneous network by deploying the cache nodes	Performance analysis of Cognitive radio based Internet-of-things Network for energy efficiency and spectrum utilization	Network lifetime and the residual energy is increased

III. NETWORK MODEL

In this research work, the novel energy efficient approach is proposed for the better energy efficiency in IoT. The protocol which is more energy efficient is based on the approach of clustering and node heterogeneity which is explained in this section.

A. Energy Efficient Model

For an IoT framework which incorporates C number of clusters, N numbers of nodes inside each cluster, data channels are of M number and one control channel inside each and every cluster, a cluster based improved Cognitive Radio Sensor Network (ICRSN) is considered [22]. The sensor nodes are expected to be equipped with various wireless interfaces to such that information transmission and harvesting can be performed. The intra-cluster communication tasks are managed reliably using a different local control channel. A approach of clustering through which sensing nodes are divided into several groups utilizing k-means clustering [23]algorithm is applied for dealing with the energy and spectral variations occurring in the time and space. The transmission power is minimized through clustering which thus helps in developing the overall lifetime of networks. The transmission time includes the total time consumed in between the deployment and non-active state of ICRSN [14]. When certain number of nodes die the in network is known to be non-functional[24][25]. Following mathematical representation can be used to describe the clustering by the k-means algorithm[23].

$$\gamma = \sum_{l=1}^{C} \sum_{i=1}^{N} \partial_{il} \ (1)$$

Here, the distance existing betweenthe center of corresponding cluster $l$and node i is denoted by ∂_{il}. The global view of ICRSNs is represented by the parameterΥ. The clusters are assumed to be non-overlapping. Thus, for every cluster, similar sets of channels are provided. Channel k can be allotted only to one node in a cluster. The feasibility that the sensor nodes of similar cluster will collide is eliminated here. Selecting the CH is the next prime task after cluster formation. There is a random selection of CH in the first step. Since the energy level of all the nodes is same, this assumption is considered as valid.

The next step applies the CH selection method [26]. Spectrum sensing, reporting and monitoring of tasks parallel with energy harvesting are the few tasks performed by each of the sensor node. Similarly, spectrum sensing, data reception and channel allocation are some of the tasks performed by CH. Further, environment monitoring and data transmission are also performed by CH. The figure 1 below shows the architecture of cluster-based sensor network for IoT. The spectrum band of PUs which use parameter adaptation and spectrum sensing approach of CR are accessed by the nodes.

The spectral utilization and efficiency are optimized by this process. The data that is gathered by the nodes is forwarded by CH to the gateway node which forwards it to the cloud linked to that network [27]. To store and process the received information a protocol stack is provided in the cloud. The required information can be restored from the cloud by the network manager. The sink node is assumed to lie within the transmission range of CH. In an intra-cluster environment, energy and spectrum management are focused on such that simplicity and illustration can be handled. Similar scheme is applied to all the clusters because of the distributed nature of operations. Thus, over the entire network energy and spectral efficiency are achieved. In the HEACHS protocol, the nodes are heterogeneous in nature means the configuration of the nodes are different. The gateway nodes are used in between the base station and CH. The CH will transfer the data to gateway nodes and then the gateway nodes will pass information to base station. This routing will reduce the consumption of energy in the network as compared to EMS protocol. The proposed architecture of the network for IoT is presented in Fig.1.
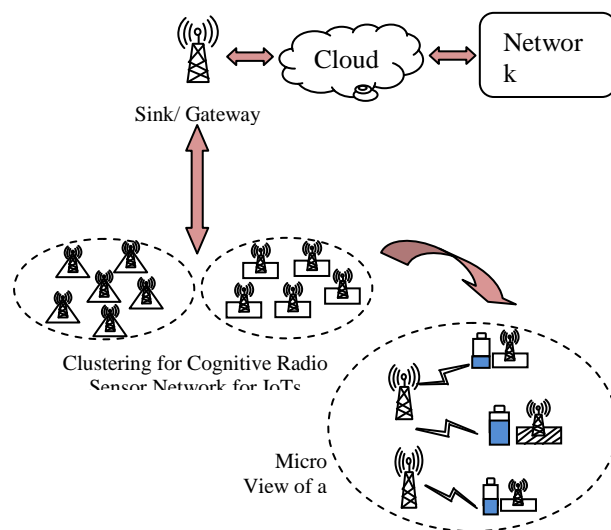

Fig.1: Energy efficient architecture for IoT

The sensor nodes and CH perform several tasks. The CH receives the Energy

information packet EIPs that includes node ID, current levels from each node initially [28]. Thus, average energy and current levels of all the nodes will be included in CH. For transmitting EIP, E_i^{er} extentt of energy is consumed by the ith sensor node which is also called the energy reporting process. The spectrum sensing task is performed by every node after forwarding EIP. A local control channel is used by the node to report its observation. E_i^{ss} and E_i^{sr} are the respective energy consumption values of ith sensor node for the spectrum sensing and reporting. Further, the environmental monitoring task which consumes E_i^m energy is executed by the sensing node. The monitoring results are transmitted from the CH to the ith node once the request of reporting is received from CH. Further, E_i^{rcv} and E_i^{dt} are the respective energy expenditures when reporting request is received from CH and for the transmission of the monitored data to CH. The following equation (2) calculates the total amount of energy consumed by i[th] node (E_i^{cons}) during a frame as:

$$E_i^{cons} = E_i^{er} + E_i^{ss} + E_i^{sr} + E_i^m + E_i^{rcv} + E_i^{dt} + E_i^{idle} \quad (2)$$

Here, the node i consumes E_i^{idle} energy when it is in idle state. The sensor nodes are expected to be heterogeneous in nature in the c_l cluster [29]. Following equation (3) calculates the energy consumed by i_0[th] CH (E_{i0}^{cons}) in one frame from the CH's perspective as:

$$E_{i0}^{cons} = E_{i0}^{rer} + E_{i0}^{ss} + E_{i0}^{rsr} + E_{i0}^{pr} + E_{i0}^m + E_{i0}^{drq} + E_{i0}^{drcv} + E_{i0}^{idle/snkr} \quad (3)$$

Here, the energies used by CH i_0 for receiving the EIP's, gathering the spectrum sensing results from remaining sensor nodes and executing spectrum sensing tasks are represented as $E_{i0}^{rer}, E_{i0}^{rsr}, E_{i0}^{ss}$ respectively. Further, while processing the spectrum sensing reports, atmospheric monitoring, data reception and data request tasks, the amount of energy consumed by CH denoted by i_0 is provided as $E_{i0}^{pr}, E_{i0}^m, E_{i0}^{drcv}, E_{i0}^{drq}$ respectively. The data is forwarded by the CH to the sink node as per the request. The data is forwarded to the sink and E_{i0}^{snkr} energy is consumed in case if the request arrives. Otherwise, E_{i0}^{idle} is consumed in the idle state.

B. Frame Structure

The frames are equipped of a functional and control slots. It is interpreted that nodes are designed with a separate unit for harvesting the energy sources in environment, so that nodes can collect the energy. The CH is chosen for the particular numbers of frame which is stated as CH tenure T_{CH}. For instance, if the node i is CH for $T_{CH} = 20$ in frame index r=21, at that point it can go about as CH from frame index r=21 to 40. At the start of 40th frame index , all nodes will send their average and present/ current energy levels to CH. CH will select the new cluster head on the basis of defined criteria in section IV.

C. Energy Harvesting Model

The energy can be harvested from ambient RF sources by the

sensor nodes [29]. Certain factors like the transmitting power of source, surrounding propagation properties and harvesting circuit can define the energy harvested by nodes. The following equation (4) calculates the energy harvested $E_{Hi,u}$ from u[th] RF source by the ith node as:

$$E_{Hi,u} = \Gamma P_u \frac{G_u G_i \lambda_u^\alpha}{4\pi d_{i,u}^\alpha} h_t \quad (4)$$

Here, the antenna gains achieved from i[th] node and u[th] energy harvesting source are represented as G_i and G_u respectively. The power the of signal that is transmitted by u[th] source of energy is denoted by P_u. The distance existing in between the ith node and u[th] energy harvesting source is denoted by $d_{i,u}$. The path-loss exponent is denoted here by α and the harvesting efficiency by Γ. The wavelength of RF signal is denoted by λ and the harvesting duration by h_t.

TABLE II
SYMBOLS IN THIS PAPER

Symbols	Description
N	Number of Sensor Node
C	Clusters in the network
r	Frame Index
i	Sensor node index
i_0	CH index
E_i^{cons}	Energy consumed by node i during a single frame
E_{i0}^{cons}	Amount of consumed by i_0th CH during a single frame
$E_{Hi,u}$	Total harvested energy by sensor node i from u[th] source
Γ	Harvesting Efficiency
E_{th}	Energy Threshold
$E_{i,c}$	Current/Present energy level of node i
$E_{i,a}$	Average energy of node i

IV. FRAMEWORK OF ENERGY AND SPECTRUM FOR IoT

A. Energy Management Scheme (EMS)

The EMS includes of an mode switching of the energy method and a CH selection method which is the most important aspect of energy management in IoT [29]-[31]. Heterogeneous sensor network comprises of sensor nodes with different capabilities, for example, different energy levels, computational

power, sensing range, etc. In this paper, we introduced the heterogeneous network[32]-[35] in which nodes will have different energy levels and different types of nodes.

1) **Mode switching of the Energy:**

Energy mode technique enables nodes to choose their mode as per their present energy level. Let $E_{i,c}$ indicates the current/present energy level of nodes. Fig.2 portrays the two modes for the ith node. In FCM (full capability mode), the nodes performs harvesting of energy, environmental monitoring, and other supporting task related to CRSN. The condition for FCM, the total consumed energy in a given frame should always be equal to or greater than the total harvested energy. In RCM (reduced capability mode), the nodes perform just the task of harvesting. The ith node will check its level of energy and move from FCM to RCM when energy falls down the threshold level E_{th} as shownin figure 2.Taking RCM and FCM in consideration[21][32], two extra modes are presented known as (1) dynamic operating mode (DOM) and(2) fixed operating mode (FOM)[33]. In DOM, nodes can switch among RCM and FCM, though in FOM nodes can just work in FCM[21].
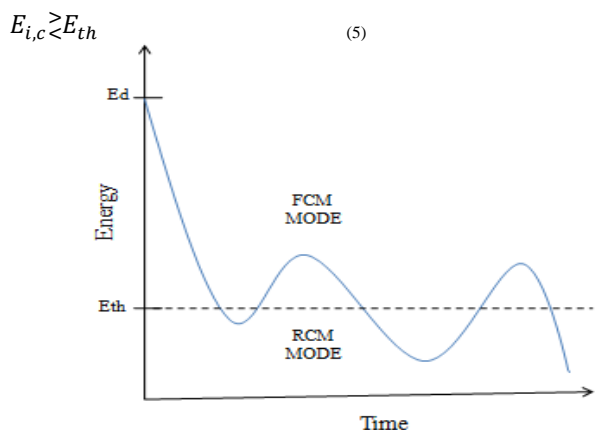
$$E_{i,c} \gtrless E_{th} \qquad (5)$$

Fig.2: Different energy aware modes

2) Selection of Cluster head

The selection of CH accomplishes balancing of energy by choosing the energy-rich sensor node as CH on rotational premise for the initial frame tenure whereas for the second round another selection criteria is presented which includes past and present energy levels of nodes. Nodes may have a high level of energy at a specific time of moment by remaining longer in RCM. However, the nodes can rapidly exhaust their energy because of their high departure rate and low energy arrival rate. Consequently, by taking the past energy values into consideration, the node with a low departure rate is selected as a CH[21][36]. The mechanism for CH is described below:

1) Every sensor node in the network send their EIP to the prior chosen CH that contains: ID of the node, average and present or current energy level during the selection frame.

2) When CH receives EIP from all nodes, the prior chosen CH maximizes Eic/Eia so as to choose the next CH. The selection of CH is detailed as below:

$$max \frac{E_{i,c}}{E_{i,a}} \qquad (6)$$

Fig.3 shows the flow diagram of the reference work and the proposed work, in modified work extra gateway node, is there for long-distance communication and the cache nodes are also deployed to save the most frequent data to avoid the over-consumption of the energy. When the base station will make a request for the required data, if that data is available at cache nodes the data can be forwarded from there only otherwise the request will be forwarded to CH.

B. Channel Management Scheme (CMS)

For selecting the best channel in terms of reliability and stability, CH employs a CMS. The sensor nodes are requested to transmit the monitored data once the reporting process is initiated by CH [20]. In response, the desired data is forwarded on the designated channel to CH by the nodes. The CH generates the sharing pattern using CMS. CR technology is included within the sensor nodes due to which the environmental monitored data is forwarded to CH in the reporting process through the available channels. Higher transmission power is used by PUs such that they can stay either static or mobile. A slotted structure is assumed to be followed by the primary networks [21]. A random process is followed when forwarding PUs where in each slot duration the channel state varies randomly. Every channel is characterized on the basis of PU index by CH on the basis of sensing reports gathered from various sensor nodes. Over various channels the V recent PU activities are stored by CH. A model with two states that includes OFF and ON state is used to model the PU behavior. Let S regions each with weight $\Phi_{k,r}^s$ be generated by dividing the history samples V. In manner that new history samples have more or higher weights in comparison to previous samples the weights are assigned. It is because of the fact that the information related to the behavior of PU is provided by the recent samples. Following equation (7) calculates the average PU index over R frames for channel k as:

$$\gamma_k = \frac{1}{R}\sum_{r=1}^{R}\sum_{s=1}^{S}\Phi_{k,r}^s\theta_{k,r}^s \qquad (7)$$

Here, the numbers of consecutive busy states (H1) of channel k within specific history areas are indicated by$\theta_{k,r}^s$. The channel is considered to be highly stable when the value of γ_k is small. The PU history is incorporated by the average PU index. A channel can be detected as being idle and available in one scenario however, QoS degradation to the nodes can be caused when PU arrives on that channel. The view regarding energy of nodes and stability of channel is provided by the rationale behind the history based node and channel selection[37].Following equation (8) calculates the reliability $Q_{r,k}$ of k[th]channel in frame r as:

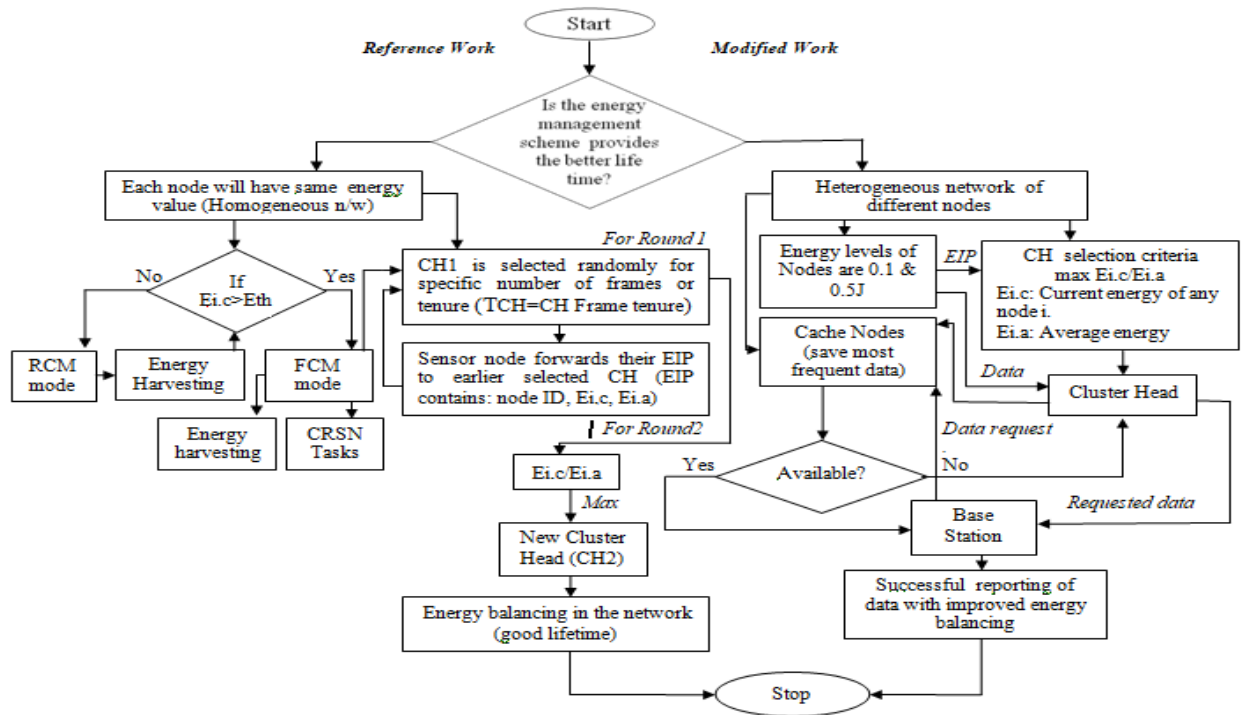$$Q_{r,k} = \frac{1}{\beta_{i,k}} \qquad (8)$$

Fig.3: Flow-diagram of the proposed approach

Here, the ith node on k-th channel has the bit error rate (BER) denoted by $\beta_{i,k}$. The binary phase shift keying is assumed to be utilized by i[th] sensor node. $\beta_{i,k} = \frac{1}{2}e^{-\xi_{b,k}}$. The energy per bit to noise power spectral density is denoted by $\xi_{b,k}$.

Maximization of the channels reliability while ensuring the PU index for all the chosen channels is the major aim of channel allocation process [21]. Based on the requirement of data transferred by nodes CMS is invoked. The formula for maximization of reliability is given as:

$$\max \sum_{k=1}^{M} m_k Q_{r,k}$$
$$Subject\,to: \gamma_k \leq W, \forall k \in \{1,2,\dots,M\} \qquad (9)$$
$$m_k = \{0,1\}$$

Here, to check if the channel k is occupied by the sensor nodes or not, binary variable m_k. The maximum PU index limit up to which the channel remains stable is denoted by W. To achieve higher stability, the channels with PU index (γ_k) less than W are chosen as the channels are used by sensor nodes in an opportunistic manner. It means that the channels with low arrival of PU can be used for data transmission[38].

TABLE III
PARAMETERS

Parameters	Values
Nodes in each cluster	34
Nodes Energy	0.1J, 0.5 J

Energy used in transmission (E_{tx})	50 (nJ/bit)
Dissipated energy for intra-cluster communication ($\mathcal{E}_{fs}$)	10 (pJ/bit/m2)
Dissipated energy for CH to sink communication($\mathcal{E}_{amp}$)	0.0013(pJ/bit/m2)
Size of EIP	0.5kb
Modulation Scheme	DBPSK

IV. SIMULATION RESULT

The energy efficient model is proposed in this research work. The HEACHS energy efficient protocol use the heterogeneous sensor nodes for the information sensing. The sensing information will be passed through the cache nodes to base station. In the HEACHS energy efficient protocol, cluster head send information to cache nodes which pass information to the base station. In this section, we check the functionality of new framework. The area of 700×700m is taken in which 500 sensors nodes are distributed uniformly. The whole area is divided into small cluster, each cluster will have equal number of nodes i.e N=20. The performance of proposed Heterogeneous energy aware CH selection (HEACHS) with Energy management scheme (EMS) , Current/Present & Average energy based selection of CH (CAECHS)[19][21][[39][40], Energy aware CH selection (EACHS) is compared in Section V. In proposed HEACHS the network is heterogeneous and there are some gateway nodes as mentioned in Section IV. In EMS, CH is selected on the basis

of current and average energy with energy harvesting whereas CEACHS consider present and average energy for the selection of CH and EACHS consider only remaining energy for the selection of CH.

Fig.4 and Fig.5 shows the senor node index versus average residual energy for HEACHS for 250 and 3000 frames respectively and compared with EMS, CEACHS, EACHS. It is clear that the proposed HEACHS have better lifetime as compared to other schemes. Fig.6 illustrates the frame index versus number of alive nodes for HEACHS and compared with EMS and it is clearly visible that proposed schemes have more number of alive nodes when compared with existing scheme. Fig.7 depicts the number of packet sent versus rounds. HEACHS sent more number of packets successfully when compared to the EMS.
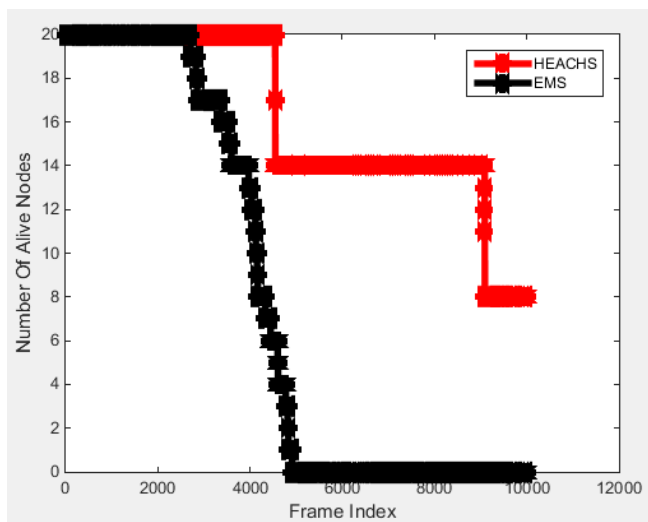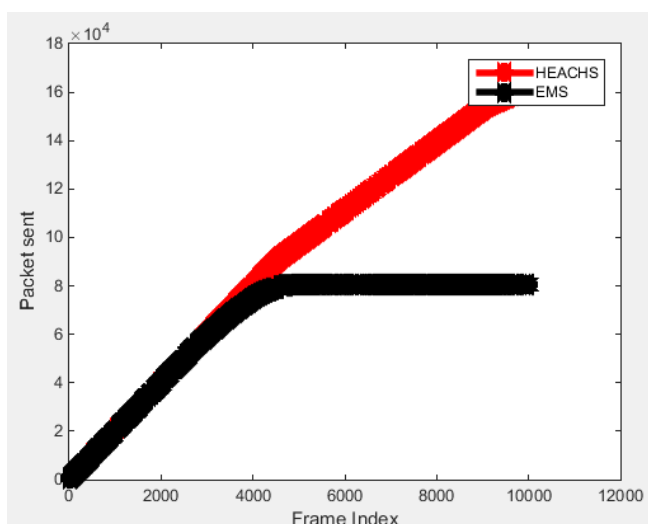

Fig.6: Alive Nodes in the Network

Fig.4: Average Residual Energy for 250 Frames

Fig.7: Number of packets sent successfully

VI. CONCLUSION

Cognitive radio and Internet of Things have risen as promising innovations to upgrade our lives by proficiently and smartly utilizing the current resources. This paper addressed two principle difficulties to the CRSN for IoT: (1) energy efficiency and (2) spectrum/channel management. Mode switching of energy ,CH selection algorithm, Cache nodes deployment are introduced for better energy efficiency in the network. Mode switching allows nodes to operate in two modes (FOM and DOM) accordingly. CH is selected on the basis of present and average of the nodes in order to balance the energy in the network. whereas, gateway nodes are there to store the most frequent data to reduce the consumption of energy in the network. Gateway nodes are deployed near to the base station which will also promote the multi hop communication. Simulation results show the expansion in the lifetime of the network in terms of functional nodes and residual energy. The proposed HEACHS shows higher alive nodes as compared to the EMS, EACHS &CAECH schemes respectively. In, future this work can be extended to incorporate the different levels of clustering in the network.
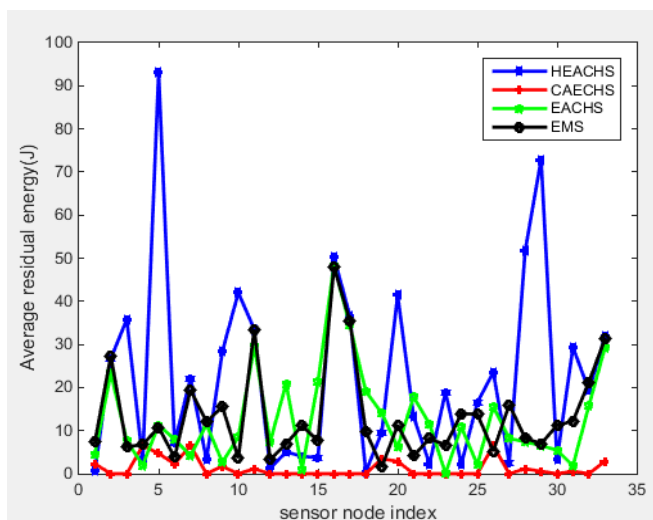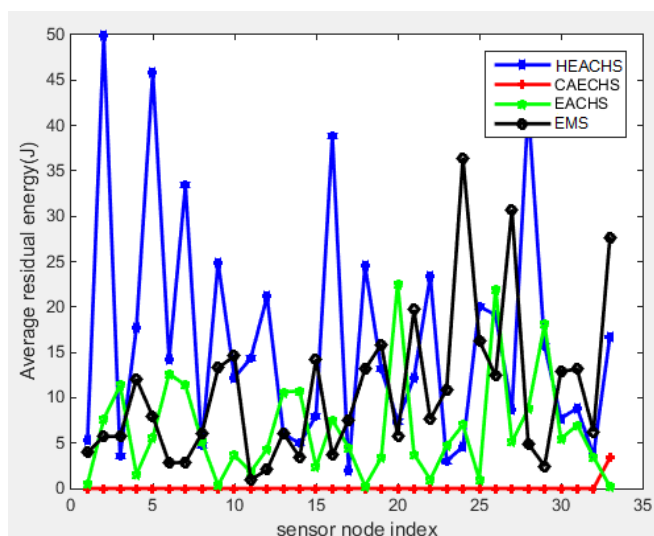

Fig.5: Average Residual Energy for 3000 Frames

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