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Minimizing Energy of Cluster Based Cooperative Spectrum Sensing in Cognitive Radio Network Using Genetic Algorithm

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ABSTRACT: Due to the massive and growing number of wireless devices, the scarcity of available frequency spectrum is a challenging issue. Spectrum sensing is one of the fundamental blocks in the operation of Cognitive radio. Energy efficient spectrum sensing and data communication to extend the life time of the cognitive sensor network is an important issue of interest to reduce the energy consumption in cooperative spectrum sensing for increasing lifetime of CRN. This paper presents an energy aware clustering algorithm (EAC) that enhances spectrum sensing performance. Then we derived network wide energy consumption model in terms of sensing energy consumption, set-up phase energy consumption and reporting energy consumption to FC by using Radio Energy Model. Further it includes the optimization of total energy consumption Using Multi–Objective Genetic Algorithm to increase the lifetime of CR-WSN.

KEYWORDS: Cognitive Radio Network (CRN), Cooperative Spectrum Sensing, Energy Aware clustering (EAC) Algorithm, Fusion Centre (FC), Multi Objective Genetic Algorithm (MOGA).

I. INTRODUCTION

The radio frequency spectrum is one of the most valuable natural resource. Due to the tremendous demand of radio channel this has led to the scarcity of frequency spectrum. Cognitive Radio (CR) has been a key technology that provides efficient utilization of spectrum and overcome the issue of spectrum scarcity. CR technology works by sensing the unused spectrum called white spaces or spectrum holes and allocating it to the Secondary User (unlicensed user) without causing interference to the Primary User (licensed user). If the PU arrival is sensed on the network and no more spectrum bands are available then one of the SU needs to free the band and that is assigned to the primary user [1], [2].Federal Communications Commission (FCC) results in early 1990s rescued the technologists by deducing that a part of licensed spectrum is free most of the time providing good spectral opportunities for the unlicensed access. To address this, it was finally decided that the spectrum scarcity can be economically used as a new road to wireless communications by dynamically switching between frequencies, called Dynamic Spectrum Access (DSA). One of the promising solutions to increase the availability of frequency spectrum to these wireless devices is to add the Cognitive Radio (CR) capability to such devices. The conventional Wireless Sensor Network (WSN) operates in overcrowded ISM (Industrial, Scientific and medical) band. If the WSN is embedded with cognitive capabilities it gives new dimension and opportunities to researchers and industry which will help to design new algorithms, hardware and software. WSN with cognitive technology can reduce collision, interference, latency by effective channel utilization. Hence reducing the power consumption and increasing the network lifetime.

Spectrum sensing is one of the most important functions in CR to identify the available spectrum holes and to protect the PU from interference. Cooperative spectrum sensing occurs when a group or network of cognitive radios share there spectrum sensing information. This provides a better picture of the spectrum usage over the area where the cognitive radios are located. The main idea of cooperative sensing is to enhance the sensing performance by exploiting the spatial diversity in the observations of spatially located CR users. By cooperation, CR users can share their sensing

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information for making a combined decision more accurate than the individual decisions. While cognitive radio cooperative spectrum sensing is obviously more complicated than a single non-cooperative system, it has many advantages that outweigh the added complexity. Naturally cooperative spectrum sensing is not applicable in all applications, but where it is applicable, considerable improvements in system performance can be gained. Some of the main advantages of cooperative spectrum sensing is that it can overcome the issues like *SNR wall problem, hidden node problem, and reduces false alarm probability* [3], [4].So cooperative spectrum sensing improves spectrum sensing performance in which multiple sensing nodes share their sensing results and decide on the availability of spectrum holes. Although, the technique yields better sensing performance, it also incurs heavy communication overhead,high energy consumption, extra sensing time and complexity [5], [6]. Out of these issues Energy consumption is one of the major issue which directly affects the lifetime of network. So in the direction to achieve the longer lifetime of the network our system should be more energy efficient. This paper proposed a cluster based cooperative spectrum sensing and analysis of energy consumption using radio energy model to reduce the energy consumption and increase lifetime of the network [8], [10].

II. RELATED WORK

Energy detection algorithm is employed to detect primary users signal. The received signal waveform is filtered and converted into discrete signal samples by a band-pass filter and analog-to-digital converter respectively. Energy-detection based approach is the most common technique of spectrum sensing because of its low computational and simplicity. It does not require any prior information of the PU's signal. In Energy detection, signal is detected based on the sensed energy which is compared with a threshold if it is less than threshold, the channel is considered to be available. Average energy of the signal samples N_0 obtained from the integrator $y(t)$ is compared with a *threshold* λ to detect the presence of primary user [11], [12], [13], [14]. Thus, the received signal at the SU $y(t)$can be expressed as –

$$y(t) = \begin{cases} n(t) & ; \quad H_0 \\ h(t) * s(t) + n(t) & ; \quad H_1 \end{cases} \tag{1}$$

Where,H_0 denotes the primary user is absent (Null Hypothesis), H_1 denotes presence of primary user, $n(t)$denotes zero-mean Additive White Gaussian noise (AWGN) at the SU. $s(t)$denotes the received signal waveform at SU and $h(t)$ is the Complex channel gain between PU transmitter and SU receiver. Performance of spectrum sensing technique can be measure based on probability of detection(P_d), probability of false alarm (P_f) probability of miss-detection(P_m) for the ithcognitive radio SU. Suppose the channels between secondary users and the common receiver are perfect and decision fusion is utilized at the FC, sensing performance is usually measured by the false alarm probability Q_f, the detection probability Q_d and the missing probability Q_m of the cooperative spectrum sensing are then given by –

$$Q_d = P\left\{{}^{H_1}/_{H_1}\right\} = 1 - \sum_{i=1}^{N} 1 - P_{d,i} \tag{2}$$

$$Q_f = P\left\{{}^{H_1}/_{H_0}\right\} = 1 - \sum_{i=1}^{N} 1 - P_{f,i} \tag{3}$$

$$Q_m = 1 - \sum_{i=1}^{N} P_{d,i} \tag{4}$$

A maximum a posteriori (MAP) detection scheme is used for the energy detection so that optimal detection of PU activities can be achieved. The PU activities can be model using two state Markov chain as shown in fig 1. ON state denotes the presence of PU signal, OFF state denotes absence of PU signal [7].

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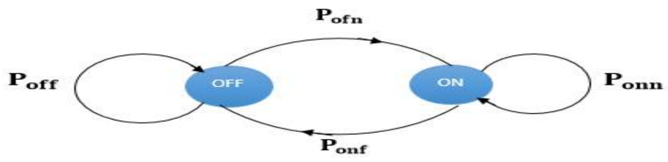

Fig.1 Primary user state model

The transition probabilities from ON to ON and from ON to OFF are denoted as $P_{onn}$and P_{onf} respectively. Similarly, transition probabilities from OFF to OFF and from OFF to ON are denoted as P_{off} and P_{ofn} respectively. Therefore, based on the PU activity, a posteriori probabilities can be estimated as –

$$P_{onn} = \frac{P_{ofn}}{P_{ofn}+P_{off}} \quad (5)$$

$$P_{off} = \frac{P_{off}}{P_{ofn}+P_{off}} \quad (6)$$

Where, P_{onn} and P_{off} denote probabilities of the period of ON and OFF states respectively. Performance of spectrum sensing technique can be measure based on probability of detection P_d and probability of false alarmP_f. Probability of detection is the probability that indicates presence of PU in the spectrum band given as –

$$P_d(\lambda) = P_r[\Upsilon > \lambda / H_1] \quad (7)$$

$$P_d(\lambda) = Q\left(\frac{\lambda - 2B_w T(\sigma_n^2 + \sigma_z^2)}{\sqrt{4B_w T(\sigma_n^2 + \sigma_z^2)^2}}\right).P_{on} \quad (8)$$

Where $Q(.)$ is generalized *Marcum Q-function.* Probability of false alarm indicates presence of PU's signal when there is no primary users in the spectrum bands, this phenomenon limits utilization of spectrum bands.

$$P_f(\lambda) = P_r[\Upsilon > \lambda \backslash H_0].P_{off} \quad (9)$$

$$P_f(\lambda) = Q\left(\frac{\lambda - 2B_w T\sigma_n^2}{\sqrt{4B_w T\sigma_n^4}}\right).P_{off} \quad (10)$$

III. PROPOSED SYSTEM MODEL

Heinzelman*et.al* proposed a Radio energy consumption model for sensors based on the observation that the energy consumption would likely be dominated by the data communications subsystem. We have assumed the same radio model which has been used in earlier works [15]. For the radio hardware, the transmitter dissipates energy to run the transmitter radio electronics and power amplifier while, receiver dissipates energy to run the receive radio electronics. For the scenario described in this dissertation, both the free space (d^2 power loss) and multi path fading (d^4 power loss) channel models is used depending on the distance between the transmitter and receiver. If the distance is less than threshold, the Free Space model is used, otherwise the Multipath model is used. In the radio model of transmitter amplifier, we use α = 2 for free space model and α = 4 for multipath loss model.Thus if a Node transmits L No. of bits, the energy consumed by node transmitter will be –

$$E_{TX}(L,d) = E_{elec}.L + E_{amp}(L,d) = \begin{cases} L.E_{elec} + L.E_{fs}.d^2 & (if\ d < d_0) \\ L.E_{elec} + L.E_{mp}.d^4 & (if\ d > d_0) \end{cases}$$

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Where d_0 is the distance threshold and it is given by–

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}}$$

The Energy spend by Receiver Radio to receive L bit message is given as –

$$E_{RX}(L, d) = E_{elec} . L$$

We are assumed that network consists of a Fusion Centre (FC) or sink node that serve as a gate way and N number of cognitive radio nodes that act as sensor nodes and local detectors. The nodes are uniformly distributed in a square area of (L×L) sides and are organized into M number of clusters in which each cluster occupies an area assumed to be $L^2/_M$square meters. Each cluster has a fusion centre (FC) that decides on the existence of primary user based on the local decisions received from the local detectors. It is assumed that primary user's signals are unknown and hence each cognitive radio node is equipped with energy detection algorithm to sense the spectrum band for spectrum holes. Also control information is exchanged through a common control channel and all nodes initially have equal amount of energy. The network is partitioned into *M* number of clusters and each cluster have some cluster members (CM) that perform spectrum sensing and a cluster head (CH) that coordinates the spectrum sensing as shown in Fig.4 –

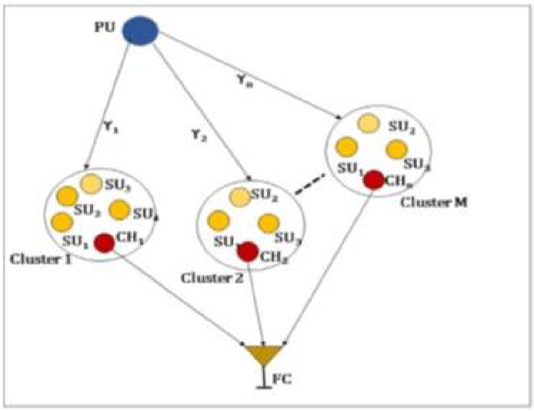

Fig.2 cluster based co-operative spectrum sensing.

The major tasks of the CHs are to perform *data aggregation, data forwarding, and decision fusion* on the local decisions received from CMs to determine the existence of PU and coordinate local sensing i.e. selecting CMs that would periodically sense the spectrum band. However, these tasks drain significant amount of energy from the battery of the node. Therefore, energy load of all nodes need to be balance in such a way that nodes deplete their energy virtually at the same time. In order to achieve this, the role of CH and sensing node would be rotated among the nodes based on their thresholds. The energy-aware clustering algorithm consists of three phases: *Initialization phase*, *Set up phase andCoordination phase*. The initialization phase involves CH emergence, the set up phase deals with formation of the cluster. On the other hand, the coordination phase deals with determining optimal number of cooperative sensing nodes for each cluster and selecting eligible sensing nodes based on threshold. In the initialization phase, nodes compute their thresholds $\boldsymbol{cht_i}$ and compete for the role of cluster head. Residual energy and neighbourhood nodes within the node's radio range serve as the basis for competing for the role of CH. Nodes with high threshold would most likely emerge as the CHs while their neighbouring nodes become the cluster members.
If $\boldsymbol{cht_i}$ is a threshold value that determines the emergence of node N_i as a cluster head within the period $\boldsymbol{\tau}$ for $\boldsymbol{i_{th}}$ round. The probability $P_{ch,i}(\tau)$of a node emerged as cluster is given as –

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$$P_{ch,i}(\tau) = \begin{cases} 1 & if\ 0 < cht_i \le 1 \\ 0 & if\ cht_i = 0 \end{cases} \quad (11)$$

$$cht_i(\tau) = \frac{E_i^{curr}}{E_i^{int}} \times \frac{n_g}{N} \quad (12)$$

Where $E_i^{int}$and E_i^{curr} are the initial and current energies of the node respectively, denotes average number of neighborhood nodes and N is the number of nodes in the network [9].
In the set up phase, once a node emerged as cluster head, it broadcasts an advertisement packet A_{packet}inviting other neighbouring nodes to join the cluster. Node that decided to join the cluster based on the received signal strength RSS of the advertisement packet, notifies the CH by sending back acknowledgment packet $J_{packet.}$ Initially all the nodes have equal probability to become the cluster head. Depending upon the random number selected the nodes themselves decide whether to become the cluster head or not. The nodes eligible to become cluster heads then broadcast its decision with larger signal strength so as to reach all the member nodes. E_{mp} is the amplification power needed to transmit the signal. The energy dissipated in setup phase can be calculated as follows [15].If *M* numbers of nodes are the CH's then to transmit the *B bit* message over a distance *d* energy required *f*oreach node is –

$$E_{TX} = M(BE_{ele} + BE_{mp}D^4) \quad (13)$$

To receive this message from CH the $(N - M)$number of *CM* will consume the energy –

$$E_{RX} = (N - M)BE_{elec} \quad (14)$$

When the nodes hear the cluster head message from the CHs they check for the signal with highest signal strength. The signal from the CH which is closest will have highest signal strength. So the node will join the corresponding Head. For joining as member the nodes will send a request to the CH. To transmit the join request the energy dissipated is as follows –

$$E_{TX} = (N - M)\left(BE_{ele} + BE_{fs}D^2\right) \quad (15)$$

To receive the join request the CH will need the energy as follows –

$$E_{RX} = (N - M)BE_{elec} \quad (16)$$

When all the member nodes join their closest cluster head the cluster formation is completed. CHs then decide the TDMA schedule and send it to all the member nodes.

$$E_{TX} = (M)BE_{ele} + BE_{fs}D^2 \quad (17)$$

The schedule sent by CHs will be received by all the member nodes consuming the energy as follows –

$$E_{RX} = (N - M)BE_{elec} \quad (18)$$

Now the total energy consumed in Cluster Setup E_{setup} using equations 13, 14, 15, 16, 17 & 18 is

$$E_{setup} = B\left\{2(N - M)E_{elec} + NBE_{fs}D^2 + MBE_{mp}D^4\right\} \quad (19)$$

In the coordination phase, BS determines the optimal number of cooperative sensing nodes for each of the clusters and communicates it to the CHs. At every round$R_{d,i}$, each CH selects some CMs within its cluster to serve as sensing nodes based on their thresholds. If $Cmt_i(\tau)$ is a threshold that determined successful selection of a node as sensing node, then the probability $P_{sn,i}(\tau)$ of selecting CM_i as sensing node is given as –

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$$P_{sn,i}(\tau) = \begin{cases} 1 & if \;\; 0 < Cmt_i(\tau) \le 1 \\ 0 & if \;\; Cmt_i(\tau) > 1 \end{cases} \quad (20)$$

$$Cmt_i(\tau) = E_{th} \times \frac{d_{th}.n_s}{N_{cl}} \quad (21)$$

Where, N_{cl}denotes number of CMs, n_s is the optimal number of sensing nodes in the cluster, E_{th} denotes energy threshold, d_{th} is the Euclidian distance threshold that can be used to prioritize CMs that are well separated from one another so as to elude correlation shadowing within the cluster in cooperative sensing. Flow chart for the algorithm of Energy aware Clustering scheme is given in fig. (3) –

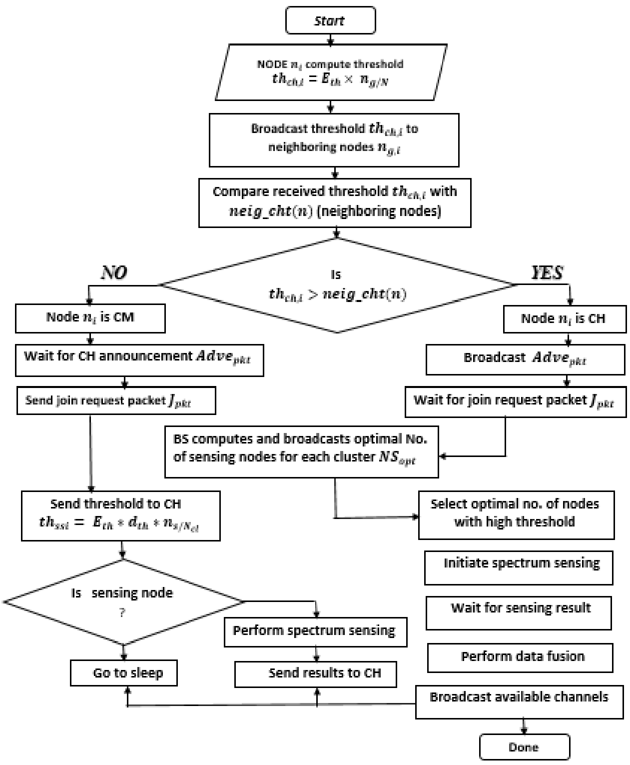

Fig. 3 Energy aware clustering algorithm

IV. ENERGY ANALYSIS USING MOGA

Energy consumption for spectrum sensing E_{ss} is basically the sum of energy consumed for listening to a channel and receiving N_0 observation samples over a sensing duration of T, and the energy required to process the received signal samples (signal shaping and modulation, etc) and make local decision. This energy cost increases along with increase in number of cooperative sensing nodes N and it is mainly influence by sensing duration. Therefore, energy dissipated by i-th node for sensing spectrum band is given as –

$$E_{ss}(n_i) = TE_{sr} + E_{sp} \quad (22)$$

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Where E_{sr} is the electronic circuit energy consumption of i-th nodes for receiving N_0 signal samples and E_{sp} denotes energy cost for processing N_0signal samples. If the sample of sensed spectrum has the spectrum bandwidth of B_w then total sensing energy for a single frame is –

$$E_{ss}(n_i) = \left(\frac{N_0 E_{sr}}{2B_w} + E_{sp}\right) \tag{23}$$

Analytical model of network energy consumption is presented as the sum of energy consumed in the formation of Cluster, Spectrum Sensing $E_{ss}$and energy required to transmit data packets E_{td} as well as to receive data E_{rd}packets. Spectrum sensing and reporting sensing results to Fusion center and data communication between cluster heads and cluster members consumes large amount of energy. Therefore, minimizing energy consumption due to spectrum sensing and data communication saves significant amount of energy and extends lifetime of the network. The total energy consumption of the cluster based cognitive radio sensor network is expressed as below –

$$\mathrm{E_{total}} = \mathrm{E_{sensing}} + \mathrm{E_{setup}} + \mathrm{E_{reporting}}$$

The total reporting energy consumed will be the sum of the energy consumed in the communication between CM to CH, and the energy consumed in the communication between CH to FC i.e. –

$$E_{reporting} = E_{rep(CM-CH)} + E_{rep(CH-FC)} \tag{24}$$

If total number of sensing nodes are *N* and total number of cluster Heads are *M* in *L*×*L* region of CRSN and if we are assuming CRSN is homogeneously distributed with *(N/M)* No. of nodes per cluster then the reporting energy between CM and CH is given by –

$$E_{CM-CH} = BE_{elec} + BE_{fs}D^2_{CM-CH} \tag{25}$$

Where,$D_{CM-CH}$is distance between *CM* and*CH*.The expected D_{CM-CH} can be calculated from –

$$D = \left(0.159\, BE_{fs}\frac{L^2}{M}\right)^{0.5} \tag{26}$$

Since each cluster has one *CH* and $\left(\frac{N}{M}-1\right)$*CM's*, so energy consumption of one cluster in reporting using equations (25) and (26) is given as –

$$E_{CM-CH} = \left(\frac{N}{M}-1\right)\left(BE_{elec} + 0.159\, BE_{fs}\frac{L^2}{M}\right) \tag{27}$$

Energy consumed by each cluster head to report the sensing data to FC will be the sum of Electronic energy consumed to receive sensing information from $(N/M-1)$ CM's, Energy dissipation to aggregate the sensed data and energy consumed to transmit sensing information to CH. So the total energy consumed in reporting by CH is given by –

$$\mathrm{E_{CH-FC}} = \mathrm{E_{receive}} + \mathrm{E_{agg}} + \mathrm{E_{Tx-BS}} \tag{28}$$

Where, $E_{receive}$ is the energy to receive sensed data by$(N/M-1)CM$.

$$E_{receive} = \left(\frac{N}{M}-1\right)BE_{elec} \tag{29}$$

And E_{agg} is the data aggregation energy of N/M cluster nodes at CH. Since distance between CH and Base Station is presumably long, transmission energy dissipation model follows frissD^4 multipath power loss as following –

$$E_{Tx-FC} = BE_{elec} + BE_{mp}D^4_{CH-FC} \tag{30}$$

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Now equation (28) can be rewritten using equations (29) and (30) as following –

$$E_{CH-FC} = \left(\frac{N}{M} - 1\right) BE_{elec} + \frac{N}{M} BE_{agg} + BE_{elec} + BE_{mp} D^4_{CH-FC} \quad (31)$$

Where D^4_{CH-FC} is the transmission distance between CH and FC. So total Energy consumption for one cluster in reporting sensed information to FC is given by –

$$(E_{cluster})_{Rep.} = E_{Rep}(CM - CH) + E_{Rep}(CH - FC) \quad (32)$$

$$(E_{cluster})_{Rep.} = \left(\frac{N}{M} - 1\right)\left(BE_{elec} + 0.159\, BE_{fs} \frac{L^2}{M}\right) + \left(\frac{N}{M} - 1\right) BE_{elec} + \frac{N}{M} BE_{agg} + BE_{elec} + BE_{mp} D^4_{CH-FC} \quad (33)$$

Since there are M number of clusters, then total energy consumed in Reporting sensing information to FC by whole CRN is given as –

$$(E_{Total})_{Rep.} = M\left[\left(\frac{N}{M} - 1\right)\left(BE_{elec} + 0.159BE_{fs} \frac{L^2}{M}\right) + \left(\frac{N}{M} - 1\right) BE_{elec} + \frac{N}{M} BE_{agg} + BE_{elec} + BE_{mp} D^4_{CH-FC}\right] \quad (34)$$

By solving above expression, expression of Total Reporting Energy in simplified form can be expresses as below –

$$(E_{Total})_{Rep.} = (2N - M)BE_{elec} + NBE_{agg} + 0.159L^2\left(\frac{N}{M} - 1\right) BE_{fs} + MBE_{mp} D^4_{CH-FC} \quad (35)$$

Therefore total energy Consumption Cluster based CSS for one frame can be formulated as below –

$$E_{Total} = E_{setup} + E_{sensing} + E_{Reporting} \quad (36)$$

Our target is to minimize E_{Total} to save battery life, minimize power consumed, increase life time and improve performance of CRN. It has been found that using evolutionary algorithms such as Multi Objective Genetic Algorithm is a highly effective way of finding multiple effective solutions in a single simulation run and it is used for the optimization problem. The main ideas of GA are based on Darwin's theory of evolution. These ideas are then embraced to computational algorithm to discover answers for a given objective function in an optimization problem. Chromosome is the solution for this optimization problem in which a group of chromosomes is called a Population. The algorithm begins with an initial population of irregular chromosomes that are then calculated based on the fitness function (objective function) to choose great ones which are called Parents. The chromosomes that donate the best fitness value are called Elite children and are elected to participate in the next generation. Then the lasting chromosomes will be subjected to some processes called, crossover and mutation to generate the next generation. The above steps are refined till the optimum value of the fitness function is obtained. The flowchart shown below to summarizes the steps of GA. [16], [17], [18].

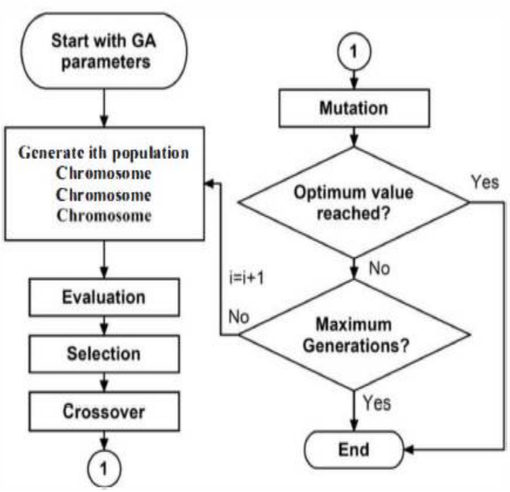

Fig. 4 Genetic Algorithm

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V. Simulation Results

To minimize Total Energy consumption in CRN we have to choose the Objective Function which we have to minimize. So in Multi Objective Genetic Algorithm the optimization problem can be written as –

$$Minimize\{E(M, N, D_{CH-FC})\}$$

$$\text{Subjected to } \sum_{i=1}^{M} \sum_{j=1}^{N} E_{Total}$$

Following table contains the same energy radio model parameters which I used in my simulation work -

Parameters	Values
Max. No. of SU	100
Max No. of Clusters	10
No. of Users per Cluster	10
E_{elec}	50 nj/bit
E_{fs}	10 pj/bit/m^2
E_{mp}	0.0013 pj/bit/m^4
E_{agg}	50 nj/bit
CRSN Area	200×200
SNR	14.6 dB

TABLE – 1 Simulation parameter

In fig. 5 the Reporting energy consumed in the network in two different schemes is explained. It can be seen that the performance of cluster based cooperative spectrum sensing mode is better than the traditional cooperative spectrum sensing. The result shows in the case of 100 SUs. There is a great reduction in the consumed energy in the clustering mode compared to the traditional cooperative spectrum sensing where the total number of users are divided into groups. Each group has 10 users. Hence cluster based cooperative spectrum sensing can tool up an energy efficient scheme and improve sensing performance.

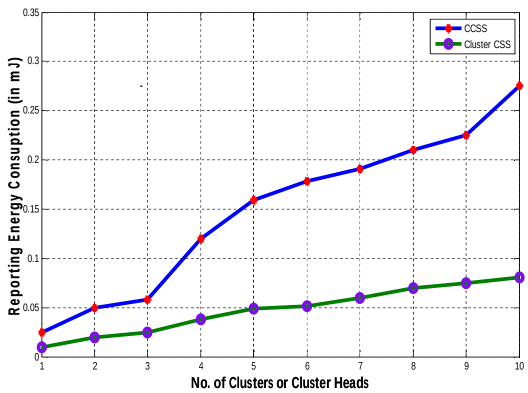

Fig.6Fig 5 Energy consumed in two modes

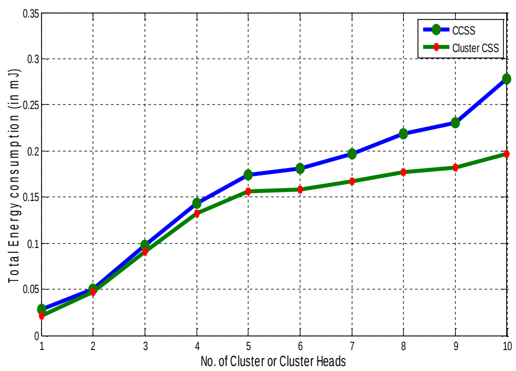

Fig.6 Energy consumed vs. No. of CH

Fig. 6 shows that total energy consumption at MOGA clustering scheme which is less than that used by traditional cooperative spectrum sensing mode. It can be observe that with increasing the No. of cluster Head that are transmitting

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results to FC, the energy performance of MOGA clustering approach is better than traditional clustering scheme. In other words, MOGA clustering approach can provide an energy efficient transmission scheme.
The optimized values of Total Energy consumption and Reporting Energy are obtained at threshold value of 90 meters (distance) based on MOGA in equation (36).

VI. CONCLUSION

This paper proposed a cluster based cooperative spectrum sensing scheme and optimization of energy consumption using MOGA. Traditional cooperative spectrum sensing is also explained. Simulation results show that proposed approach performance is better than traditional cooperative sensing scheme and can be used to minimize network wide energy consumption as data communication and spectrum sensing energy costs. Moreover it increases lifetime of the network.

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