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Clustering approach for Wireless Sensor Networks based on Cuckoo Search Strategy

Sandeep Kumar E[1], G.P. Mohanraj[2], Raghuchandra R. Goudar[3]

M.Tech Student, Department of Telecommunication Engineering, M.S. Ramaiah Institute of Technology, Bangalore, Karnataka, India[1]

B.E. Student, Department of Instrumentation Engineering, M.S. Ramaiah Institute of Technology, Bangalore, Karnataka, India[2,3]

Abstract: Wireless Sensor Networks (WSNs) are garnering lot of interest in present world applications due to its self-management capabilities with less human intervention. Energy efficiency is a critical requirement in these types of network, since majority of the sensor nodes are battery driven. In this direction, clustering protocol has proved to save more energy compared to other routing protocols. Hence, this paper proposes a novel clustering protocol, which is based on the brood parasitism of few cuckoo bird species, thereby increasing the lifetime of the network compared to basic- LEACH protocol. The simulation results prove that adding these kinds of bio-inspired computations into the pre-existing protocol design leads to enhancement in the efficiency of the network.

Keywords: brood parasitism, LEACH protocol, bio- inspired computing

I. INTRODUCTION

Wireless Sensor Networks are group of distributed computing systems with self-management capabilities. Majority of the research aims at developing novel techniques and mechanisms of improving the energy efficiency of the network. Using bio- inspired computations in solving issues of WSNs is a recent trend in research. Clustering mechanism in sensor networks has shown to reduce the communication overhead by balancing the energy consumption, employing forms of split and conquer policy. Applying meta-heuristic approaches like cuckoo search is also one of the techniques. Hence, researchers have made many noticeable contributions. Manian *et al.* [1] has proposed a clustering protocol based on cuckoo search phenomenon. The paper claims that the method improves network lifetime by balancing the energy dissipation by increasing active nodes to fifteen percent. Puteri *et al.* [2] propose a technique of finding optimal position for sensor nodes deployment with improved coverage. The paper uses a combined approach of virtual force algorithm and cuckoo search algorithm for achieving better node placement. Feng Li- Min [3] proposed a combined approach of DV-Hop and Cuckoo Search algorithms for the improvement of positioning precisions in the network. Application of cuckoo search in solving issues of WSNs is still a recent researching trend.This proposed work uses the brood parasitism of few species of cuckoo in building a novel clustering technique. The method is explained in detail in the further sections of the paper. The algorithm was implemented in MATLAB and the obtained results prove that the technique works better than the basic-LEACH protocol in improving the network lifetime conserving energy of the nodes. Steady- phase communication overhead energy is considered for the calibration and comparisons. The rest of the paper is organized as follows: section II discusses about the cuckoo's brood parasitism behavior with the associated search technique, section III deals with the radio model used to calibrate the communication energy overhead, section IV discusses about the LEACH protocol, section V deals with the proposed method, section VI deals with simulations, section VII deals with the results and discussions and VIII with the conclusions. Finally, the paper ends with few references used for this work.

II. CUCKOO SEARCH STRATEGY

This section highlights the brood parasitism behavior of cuckoo bird with the cuckoo search algorithm [5].

Fig.1 Guira Cuckoo, scientific name: *Guira guira*
[courtesy: http://www.birdforum.net/opus/Guira_Cuckoo]

The sounds produced by cuckoos are always a wonder to listen. It is an inspiration to Indian light music. One astonishing nature of these birds is the brood parasitism behavior, a peculiar behavior of the birds belonging to family Cuculidae. The brood parasitism character includes a cuckoo bird laying eggs in communal nests and even they may remove other's eggs in the nest to increase the hatching chances. Even they lay eggs in other host bird's nest, which belongs to some other species. Some species of cuckoo can even mimic the color and pattern of the host bird's egg, so that the probability of the egg being detected

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is reduced. They choose a nest with eggs just laid for increasing the chances of hatching of their eggs. The flight behavior of these birds show a Lévy flight distribution.

A. *Cuckoo Search Algorithm*

The algorithm is based on the following bird's behavioral aspects [5].

a) Each cuckoo lays one egg at a time and dumps its egg in randomly chosen nest.
b) The best nests with high quality of eggs will carry over to the next generations.
c) The number of available host nests is fixed and the egg laid by a cuckoo is discovered by the host bird with a probability of $p_a \in [0, 1]$. The host bird can either throw the egg away or abandon the nest and build completely a new nest.

B. *Pseudocode*

Begin
Objective function f(x), $x = (x_1 \ldots x_d)^T$
Generate initial population of n host nests x_i (i= 1, 2. . . n)
While (t< Max_Generation) or (stop criterion)
Get a cuckoo randomly by Lévy flights
Evaluate its quality based on the fitness function F_i
Choose a nest among n (say, j) randomly
If ($F_i > F_j$)
replace j by the new solution
End
A fraction $\mathbf{p_a}$ of worse nests are abandoned and new ones are built;
Keep the best solutions
Rank the solutions and find the current best
End
Post process results and visualization
End

The new solutions are obtained according to the equation (1) and is given by

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus \text{Lévy} \quad (1)$$

Where, α is the step size and Lévy provides randomness in obtaining new solutions. Lévy is a class of alpha- beta stable functions, which takes up different other distributions based on the value of alpha and beta.

In this work, the above behavior and strategy of cuckoo bird is taken as an inspiration for rigging this novel clustering mechanism. It is to be noted that there are no anchor nodes in this prescribed concept as majority of the clustering protocols depicts of, when it uses meta-heuristic approaches. Instead in this paper, the cuckoo optimization algorithm is adapted to perform with single step resulting in a light-weight protocol that is well suited for WSNs where resource constraints of nodes is a major issue of concern.

III. RADIO MODEL

The proposed methodology uses a classical radio model [6]. The sensor node is a transceiver. Hence, this radio model gives the energy consumed for the transmission and reception. The block diagram representation is shown in fig. 2. The radio model consists of transmitter and receiver equivalent of the nodes separated by the distance'd'. Where E_{tx}, E_{rx} are the energy consumed in the transmitter and the receiver electronics. E_{amp} is the energy consumed in the transmitter amplifier in general, and it depends on the type of propagation model chosen either free space or multipath with the acceptable bit error rate. We consider E_{fs} for free space propagation and E_{mp} for multipath propagation as the energy consumed in the amplifier circuitry. The transmitter and the receiver electronics depends on digital coding, modulation, filtering and spreading of data. Additional to this there is an aggregation energy consumption of E_{agg} per bit if the node is a cluster head.

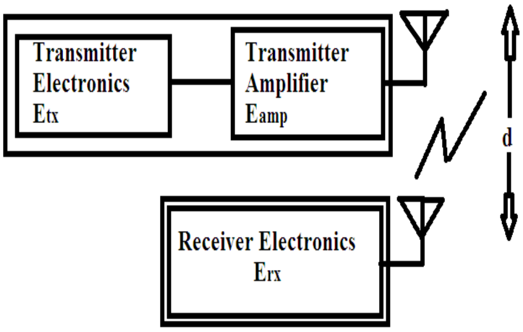

Fig.2 Radio Model

A. *Energy Consumption*

This section describes the energy consumed for communication.

B. *Packet transmission*

$$E_t = (L_P * E_{tx}) + (L_P * E_{amp} * d^n); \quad (2)$$

where, $L_P \rightarrow$ is the packet length in bits $n \rightarrow$ is the path loss component, which is 2 for free space and 4 for multipath propagation.

Suppose a node transmits a packet. Each bit in a packet consumes E_{tx} amount of transmitter electronics energy, E_{amp} amount of amplifier energy. A packet of length L_p, consumes an overall energy of E_t.

C. *Packet reception*

$$E_r = (L_P * E_{rx}); \quad (3)$$

Where, $L_P \rightarrow$ is the packet length in bits.
Suppose a node receives a packet. Each bit in a packet consumes E_{rx} amount of receiver electronics energy. A packet of length L_p, consumes an overall energy of E_r.

IV. LEACH (LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY) PROTOCOL

This section briefs out the LEACH protocol which was proposed by W.R.Heinzelman *et al.* [6]. The protocol has two phases: set-up phase and steady-state phase. The protocol executes in rounds. Rounds in LEACH have predetermined duration, through synchronized clocks, nodes know when each round starts. The setup consists of three steps. In Step 1 (advertisement step), nodes decide probabilistically whether or not to become a Cluster Head (CH) for the current round (based on its remaining energy and a globally known desired percentage of CHs). Nodes that decide to do so broadcast a message (adv) advertising this fact, at a level that can be heard by everyone in the network. To avoid collision, a carrier sense multiple access protocol is used. In Step 2 (cluster joining step), the remaining nodes pick a cluster to join based on the largest

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received signal strength of an adv message, and communicate their intention to join by sending a join req (join request) message. Once the CHs receive all the join requests, Step 3 (confirmation step) starts with the CHs broadcasting a confirmation message that includes a time slot schedule to be used by their cluster members for communication during the steady-state phase.

Given that all transmitters and receivers are calibrated, balanced and geographically distributed clusters should result. Once the the clusters are set up, the network moves on to the steady-state phase, where actual communication between sensor nodes and the Base Station (BS) takes place. Each node knows when it is its turn to transmit (Step 4), according to the time slot schedule.

The CHs collect messages from all their cluster members, aggregate these data, and send the result to the BS (Step 5). The steady-state phase consists of multiple reporting cycles, and lasts much longer compared to the setup phase.

V. DEVISED METHOD

A. Assumptions

1) All the nodes can communicate with each other and with the BS directly.
2) There is a single hop from ordinary node to CH and from CH to BS.
3) All the nodes are static and are location aware. They update their location information to the BS before entering into the set-up phase.

B. Description of the protocol

1) The BS broadcasts the percentage of CHs requirements for the entire network. Let this be P. Also it broadcasts the location information of all the nodes to the entire network.
2) After receiving this information, all the nodes will calculate a random number and compare with T(n) given by equation (4).

$$T(n) = \begin{cases} P/\left(1 - P\left(r \bmod \left(\frac{1}{P}\right)\right)\right), & n \epsilon G \\ 0 & otherwise \end{cases} \quad (4)$$

Where G are the nodes contesting for the CH position and r is the round of interest.

1) CHs broadcast a packet of interest to attract other ordinary nodes in the network. The packet consists of its distance of that CH from the BS and fit_number as the added field. Sensor nodes learn about who are the CHs and non-CH nodes in the network.

2) Ordinary nodes in the network treat CHs as the nest and attempts to choose a best CH for laying egg, which is sending JOIN_REQ for a chosen CH. JOIN_REQ is treated as the cuckoo egg. The optimal CH is chosen based on the fitness function and is given by (5).

$$F = fit\_number / [(\beta * d^2) + (\gamma * d_0^2)] \quad (5)$$

Where F is the fitness of a nest (CH), calculated on the basis on the fit_number, an integer number that is assigned to a CH based on its residual energy in that particular round. β and γ are the constants depicting the attraction of cuckoo bird towards a particular nest, d represents distance between the CH and the BS, and d_0 is the distance between the ordinary node and the CH.

d_0 is calculated as follows: randomly take one-step using equation (1). Calculate the distance between the new updated location of the ordinary node with the CH of interest, using Euclidean distance equation.

1. With the suitable values pre-set for β and γ, all the ordinary nodes select best CH choice, depending on whichever CH gains highest value for the objective function F.
2. Ordinary node sends JOIN_REQ for its chosen CH. CHs on the reception of the request generates a random probability of whether to accept or reject the request based on the threshold value, which changes from round to round and whether the rejection probability cross the threshold or not.

   Let the threshold be p_t. This phenomenon can be mapped to the rejection or acceptance of cuckoo eggs by the host bird with some probability say p_a. In this proposed work, a JOIN_REQ is considered only if $p_a > p_t$, else a node is rejected by CH.
3. The entire nodes in the plot, splits itself into formation of clusters and enter the steady-phase communication, where actually the transmission of sensed information happens between the nodes and the BS.

VI. SIMULATIONS

Algorithm was implemented in a PC with I5- 4200 U, 1.6 Hz processor with windows 7. The algorithm was coded in MATLAB 2013. The various parameters set includes percentage of CHs requirement p= 0.1 and p=0.3, γ=0.4, β=0.2 and α= 2, rest is listed in table 1.

The Lévy flight was chosen to be Cauchy distribution [7]. p_a was produced using rand () of MATLAB, fit_number was assigned between 1 to 5 depending on the residual energy of the node in the round of interest.

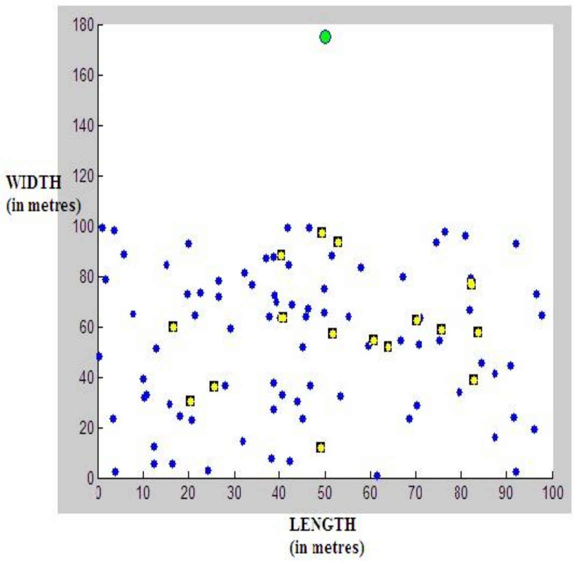

Fig.3 Network deployment

Table I. Radio characteristics and other parameters chosen for simulation

Parameter	Value
Number of nodes	100
Transmitter electronics, E_{tx}	50nJ/bit
Receiver electronics, E_{rx}	50nJ/bit
E_{mp}	0.0013pJ/bit
E_{fs}	10pJ/bit
E_{agg}	5nJ / bit
Length of plot	100 m
Width of plot	100 m
L_p (packet transmitted from CH to BS)	6400 bits
L_{ctr} (Packet transmitted from ordinary node to CH)	200 bits
Initial energy of the node	0.5 J

VII. RESULTS AND DISCUSSIONS

This section describes the results obtained with the simulation parameters set as per previous section. The simulation results of the prescribed technique is compared with the basic-LEACH and the related discussions are highlighted.

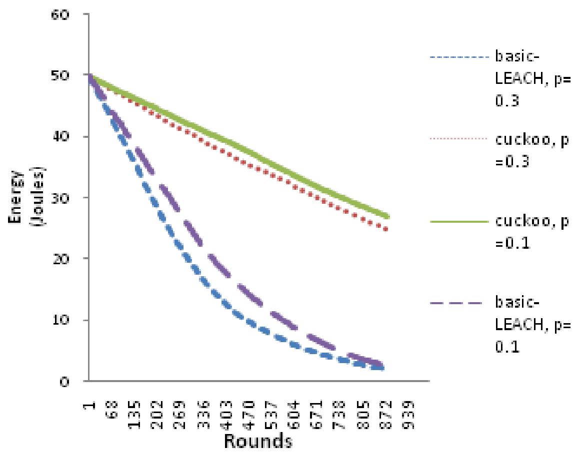

Fig. 4 Comparison of network residual energy for 1000 rounds

From fig. 4, it was observed that the proposed method consumes less network energy compared with the basic-LEACH. The graph shows a comparison results for varying values of percentage of CH requirement.

It was observed that as the percentage of CHs requirement increases the energy consumed in the network increases, but unlike basic-LEACH, there is no considerable amount energy consumption when cuckoo based clustering is adapted in the network. Simulations of fig.4 were carried for zero probability of JOIN_REQ rejection, $p_t = 0$.

Corresponding network lifetime calibration is depicted in Fig. 5. It was observed from the graph that as the percentage of CH requirement increases, network lifetime decreases due to more nodes death. It was noticed that there was no considerable amount of difference, when cuckoo based clustering is employed.

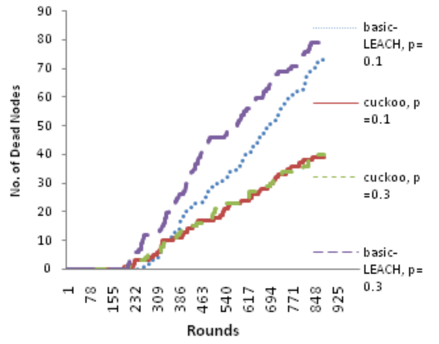

Fig. 5 Comparison of no. of dead nodes for 1000 rounds

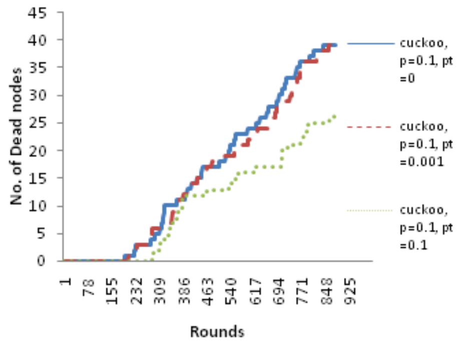

Fig. 6 Comparison of no. of dead nodes for different values of rejection probability threshold

Fig. 6 shows that as the probability of rejection of the JOIN_REQ sent by ordinary nodes increases, the sensor nodes death rate decreases. This is because the ordinary nodes due to rejection of their requests may not participate in that particular round. Hence, energy of the node is saved, leading to reduction in the node death rate. A high value of rejection probability may improve the network lifetime but considerably decreases the system throughput. Hence, a proper choice of rejection probability is always recommended. MATLAB rand () function was used to assign a random probability value for all the requesting ordinary node.In reality this probability can also be made as a function of fitness of ordinary nodes, which will be a user defined function, based on the fitness of the requesting ordinary node, a CH may decide whether to accept or reject the request based on whether the random probability calculated in the CH crosses a pre-set threshold value or not. Threshold can be changed at the BS from time to time.

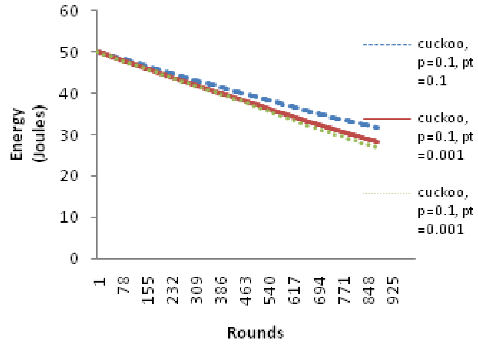

Fig. 7 Comparison of network residual energy for different values of rejection probability threshold

Fig.7 shows that as the probability of rejection increases the residual energy in the network increases. This is due to reduction of the nodes participating in the steady-phase of the network. There are various parameters that can be set while network operation. These parameters have to be properly adjusted depending on the requirement through a heuristic approach to avoid over or under operation of the network.

VIII. CONCLUSIONS

The paper discusses an application of interesting brood parasitism behavior of cuckoo bird, as an attempt towards bio- inspired computing in WSNs. The simulation results, proves that the technique gives an outstanding reduction in the network energy consumption with the prolonged network lifetime. Usage of these types of bio- inspired computing approaches brings in the improvement of the network with the minimal tradeoff with the node computation and uniform balancing of the energy consumption of the nodes in the network.

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BIOGRAPHIES

Mr. Sandeep Kumar.E completed his Bachelor of Engineering (B.E) from Jawaharlal Nehru National College of Engineering (JNNCE), Shimoga, Karnataka, India with six merit awards and distinction. Presently he is pursuing his M.Tech in Digital Communication Engineering, final year, at MSRIT. He has published 15 research papers in peer reviewed journals/ conferences of national/ international grades. His area of research interests include artificial intelligence, wireless sensor networks, image processing and pattern recognition towards bio-inspired computation. He is the active member of IEEE, IETE, ACEEE and many IEEE communities & societies.

Mr. G.P. Mohanraj is final year student of Dept. of Instrumentation Technology, pursuing Bachelor of Engineering (B. E) at M.S. Ramaiah Institute of Technology, Bangalore, Karnataka, India. His area of interest includes artificial intelligence, control systems and wireless sensor networks.

Mr. Raghuchandra R. Goudar is final year student of Dept. of Instrumentation Technology, pursuing Bachelor of Engineering (B.E) at M.S. Ramaiah Institute of Technology, Bangalore, Karnataka, India. His area of interest includes artificial intelligence and control systems.