RED: Residual Energy and Distance Based Clustering to Avoid Energy Hole Problem in Self-organized Wireless Sensor Networks

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Abstract. Self-Organized Wireless Sensor Network (SOWSN) is a system of sensor nodes that takes global decisions through local interactions without involvement of any central entity. Wireless sensor nodes have constrained processing capability and energy. The key characteristic used to evaluate performance of Wireless Sensor Network (WSN) is its lifetime which depends on residual energy of nodes; hence the major challenge in WSN is the efficient use of available energy. Node clustering saves energy and also shows self-organization because global decision like Cluster Head (CH) selection is taken through mutual communication between nodes. In this paper, a new clustering method based on self-organization is implemented to boost lifetime of WSN. Sensor network is divided into regions. Cluster formation relies on Residual Energy (RE) and nearest Distance (D) from CH. Node with highest residual energy becomes CH. Rest nodes join the nearest CH. Clusters are broken when residual energy of CH falls below threshold energy; causing the sensor network to get self-organized into new clusters. RED also focuses to solve the energy hole problem caused due to higher energy consumption by CHs near Sink Node or Base Station (BS).

Keywords: Wireless Sensor Network · Self-organization · Residual Energy · Threshold energy · Node distance · Energy hole

1 Introduction

Wireless sensor nodes sense data from environment and transmit it directly to BS or Sink. But it is not appropriate for large network size because nodes at very large distance from Sink will deplete their energy soon. To solve this problem, sensor nodes are clustered. Instead of each node processing the data, a single node collects data, process it and transmit to sink node. Involvement of each and every sensor in data transmission increases congestion and data collisions in network. This will drain limited energy from network. Node clustering will address these issues. Clustering ensures efficient data transmission by reducing number of sensors trying to communicate data in the WSN. It also minimizes message overhead and number of dropped packets [1].

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1.1 Energy Hole Problem in WSN

In WSNs, all data is sent to sink, hence traffic close to the sink node is higher. The CHs and sensor nodes in this area will soon run out of energy. The sink will then be inaccessible and as a result, the residual energy of nodes will be wasted [2]. This problem is called as energy hole problem in WSN.

2 Literature Survey

Literature shows that a variety of clustering algorithms have been proposed till date. Also, there are different classifications of clustering algorithms based on attributes like number of nodes in a cluster, number of clusters, centralized or distributed clustering, CH selection criteria (e.g. based on weight calculation, residual energy, distance, probability, degree, location, etc.). One major category of clustering algorithms is distance based clustering algorithms. Table 1 throws light on such type of algorithms.

3 RED Algorithm

RED is refinement of our algorithm described in [3]. Here onwards the word 'PRE' is used to indicate previous algorithm. In PRE, a node joins CH if it is within the range of a CH; irrespective of distance from another CH. RED differs from PRE in following ways:

i. Single hop connectivity between nodes and multi-hop communication between CHs along with random deployment of nodes
ii. Problem of nodes coming under overlapped coverage areas of CH is solved as nodes join nearest CH
iii. Focus on energy hole problem
iv. Change in Threshold Energy (T) for reclustering

3.1 Selection of Cluster Head

The CH selection here is not centralized i.e. BS is not involved in selecting CH. It is purely on the basis of local information and communication among the nodes. It has two advantages: Problem of network bottleneck is removed and energy required for communication between BS and nodes far away from BS is saved since energy consumption and distance are directly proportional to each other. As there is no need to communicate with BS all the time for CH selection; energy is saved. Residual Energy (RE) is the prime factor in CH selection. The first step in RED is to find number of nodes falling in each nodes' coverage area and current residual energy of each sensor node. Nodes possessing highest residual energy will become Cluster Head provided that it has at least one neighbor.

Table 1. Comparison of distance based clustering algorithms to identify parameters for CH selection and cluster formation.

Algorithm & Year	Parameters for CH selection and cluster formation	Findings and future scope
Distance based clustering Routing scheme (2007) [4]	Probability based on: i. Distance between node and BS ii. Distance of farthest node from BS (dmax) iii. Distance from closest sensor node (dmin) iv. Ratio of Residual Energy to Initial Energy	• Energy-efficient load balanced clustering • More effective than LEACH (Low Energy Adaptive Clustering Hierarchy) & EECS (Energy Efficient Clustering Scheme) in prolonging the lifespan
New threshold assignment for LEACH and xLEACH (2010) [5]	i. Modification of threshold assignment in LEACH and xLEACH by introducing the distances of nodes from BS ii. Considered Median Distance as average of maximum and minimum distance of node from BS	• Longer lifetime and more uniform energy consumption in modified LEACH & xLEACH • **Future Scope:** To use "N" (Number of nodes) in threshold assignment
Unequal clustering scheme based LEACH (2010) [6]	i. Energy Ratio (of current energy to primary energy) and Competition Distance inserted in threshold assignment of LEACH ii. Adopted round-robin in CH election	• Better energy balancing • Prolonged network lifetime • Enhancement of network stability
LEACH-SC (LEACH-Selective Cluster) (2010) [7]	i. CH election is as per LEACH protocol ii. An ordinary node N will choose a CH which is nearest to the center point between N and the sink	• Reduces & balances overall energy consumption among sensors & extends lifetime of network as compared to LEACH
DECSA (Distance-Energy Cluster Structure Algorithm) (2012) [8]	i. A node becomes first round CH (False-Cluster-Head) if r < T. Where, r: random number r between 0 and 1 and T: Predefined Threshold ii. All nodes in cluster calculate threshold to elect CH i.e. k(i)[Node]. If k(i)[Node] > k(i)[False-Cluster-Head], then it becomes true CH, else False-Cluster-Head remains CH iii. k(i) is based on remaining energy and average distance of node i from all nodes in the same cluster	• The adverse effect on energy of CH caused because of non-uniform distribution of nodes in network is reduced • Direct communication between CH with low energy and far away from BS is avoided

(continued)

Table 1. (*continued*)

Algorithm & Year	Parameters for CH selection and cluster formation	Findings and future scope
LEACH-KED (Low-Energy Adaptive Clustering Hierarchy K-means Energy Distance) (2012) [9]	After clustering by K-means algorithm, CH is elected as per smallest cost calculated using: i. Weight values, α and β (weight of distance and surplus energy respectively) ii. Candidate CH position information iii. Distance of node from cluster's geometric center, maximum distance between any pair of nodes in current cluster iv. Distance between node and BS, and farthest distance of node to BS	• Selects the optimal node as CH • Uniform clustering • Extends the network life • Minimizes total network energy consumption
Distance Based Cluster Head Selection Algorithm (2012) [10]	i. CHs are selected as per net distance of each node from BS ii. Authors used matrix to store distance between two nodes	• Compared non-CH & CH based algorithm for energy & distance • **Future Scope:** To increase number of alive nodes
DBCP (Distance Based Cluster Protocol) (2013) [11]	i. Inserted initial energy and average distance between nodes and sink to calculate threshold	• Improves network lifetime and throughput • **Future Scope:** Introduce mobile nodes in the network
GEAR-CC (Centralized Clustering Geographic Energy Aware Routing) (2013) [12]	i. Clustering method is not fixed ii. Nodes don't know which cluster they belong to; they just pass on data to next node with specific ID without caring about routing protocols	• BS optimizes transmission mechanism for all nodes based on the global information of topology and energy • Avoids hot-spot phenomenon by balancing residual energy of each node
EAC (Energy Aware Clustering) (2013) [13]	i. Introduces the energy parameter for CH selection and distance parameter for non-CH to select CH	• Balances energy load & increases network lifetime • **Future Scope:** Compare EAC with other schemes & test it in suitable WSN test bed
DBCH (Distance Based Cluster Head Algorithm) (2015) [14]	i. Based on LEACH ii. New threshold calculation using: a. Node energy b. Distance of node from BS c. Distance of CH from BS	• Better node energy balance & enhanced network lifetime as compared to LEACH • **Future Scope:** Multi-hop routing

(*continued*)

Table 1. (*continued*)

Algorithm & Year	Parameters for CH selection and cluster formation	Findings and future scope
Routing algorithm based on Non Linear weight particle swarm optimization) (2015) [15]	i. BS selects CH with higher residual energy and better location according to location of BS ii. Cluster formation with well distributed nodes based on locations and residual energy	• Independent of node density • Uniform distribution of CH across the network
Clustering technique for WSN (2015) [16]	i. Node is selected as CH if its Residual Energy > Average Network Energy (Eligible CH List is prepared). Nodes join nearest CH	• Better network performance in terms of residual energy and number of dead nodes
MERA (Multi Clustered Energy Efficient Routing Algorithm) (2015) [17]	i. Network is partitioned into L clusters as per the distance from BS. Each cluster is further divided into L clusters ii. A node is nominated as Cluster Chain Leader (CCL) that communicates to its nearest CCL & finally to sink	• Better than PEGASIS (Power Efficient GAthering in Sensor Information Systems) • Achieves its maximum energy savings due to chain & communication between neighbors • **Future Scope:** Multiple mobile sensors and sink mobility
Manhattan distance approach (2015) [18]	i. Manhattan Distance (MD)	• Problem in data transmission due to obstacles is overcome
DACA (Distance Based Angular Clustering Algorithm) (2016) [19]	i. Each node builds its neighbor table with initial cost based on node distance, bandwidth & neighbor node ID ii. Random nodes are selected as the cluster centers iii. Each node joins the cluster according to smallest distance from centre node of cluster	• Removes problem of non-coverage area and path formation • **Future Scope:** Use swarm intelligence for the routing & aggregation & compare it against existing models
Energy resourceful distance based clustering & routing (2016) [20]	CH election probability based on: i. Average Energy of network ii. Residual Energy of node iii. Average Distance between nodes and BS iv. Position of a node from BS	• Better lifetime and scalability of the network

3.2 Clustering

Node distance plays a vital role in the cluster formation of RED. If transmission range is increased, then number of neighbors of a node will also increase. The cluster formation is as follows:

i. Each CH broadcasts join request along with its ID to nodes within its coverage area. Nodes within coverage area of CH will join that CH.
ii. If a node falls in coverage area of more than one CH, it calculates its distance from each one, and joins the CH with shortest distance. This is important because the more the distance, the more the energy consumption.
iii. Each node has 0 or 1 status. 0 means node is a part of some cluster. 1 indicates a free node. Only free nodes can participate in cluster formation.

Figure 1 shows cluster formation when coverage areas of CH overlap.

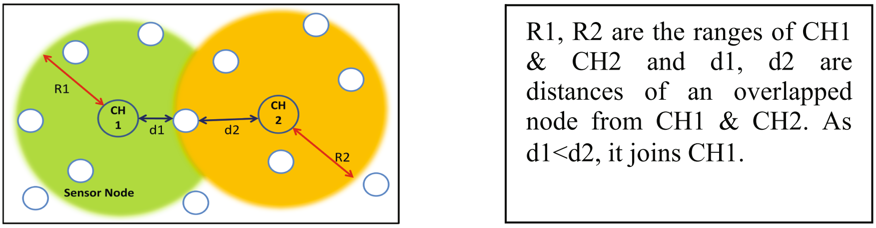

Fig. 1. Cluster formation with minimum distance.

3.3 Reclustering with Self-organization

If a node remains CH for longer time till it becomes dead, the number of alive nodes in the network will fall drastically and lifetime of WSN will be reduced significantly. Changing the CHs near Sink region helps to solve energy hole problem. Once energy of CH E(CH) goes below Threshold Energy (T), that cluster is broken and nodes are made free (Node Status changes from 0 to 1). New CH is selected again on the basis of highest RE. Remaining nodes join new CH on the basis of their distances from new CH (Node Status again changes from 1 to 0). After reformation of cluster, it may happen that some nodes have d > R. But this problem is already solved in RED because of neighbor discovery.

4 Simulation and Results of RED

RED is simulated in NS2. Table 2 shows simulation parameters. Figure 2 shows the CH selection and cluster formation. Figure 3 shows the free nodes when cluster breaks.

Table 3 shows the CH and its member nodes before and after Reclustering. Figure 4 shows Reclustering.

Table 2. Simulation parameters for RED.

Parameters	Values
Area	2000 m × 1600 m
Channel type	Wireless
Number of nodes	40, 50,…110
Initial energy	100 J
Threshold energy (T)	85 J
Transmitting range	350 m
Transmitting power	1 W
Receiving power	1 W
Simulation time	100 s

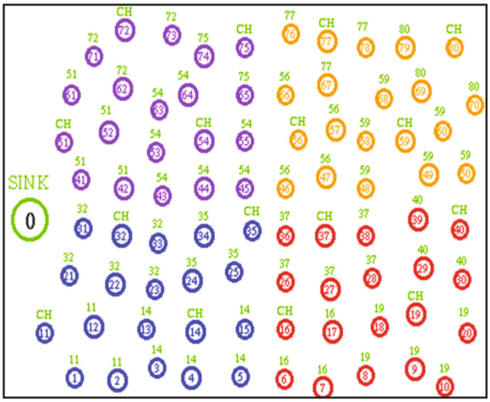

Fig. 2. CH selection & cluster formation.

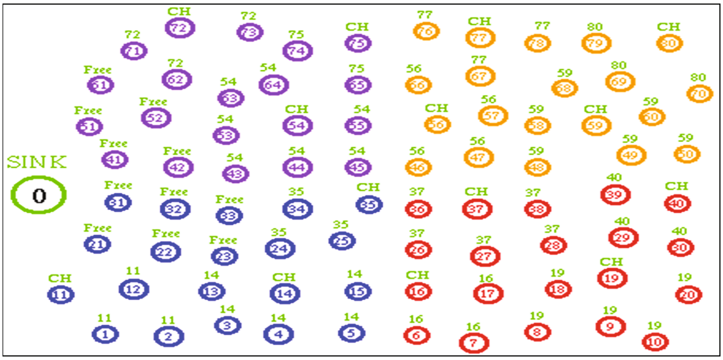

Fig. 3. Free nodes.

Table 3. Clustering and reclustering

	Before reclustering		After reclustering	
Cluster head ID	32	51	22	52
Cluster member node ID	21	41	21	41
	22	42	23	42
	23	52	31	51
	31	61	32	61
	33		33	

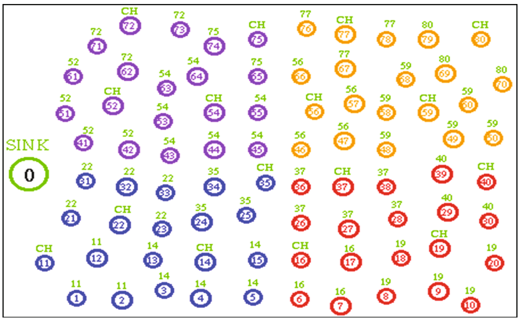

Fig. 4. Reclustering.

Table 4 shows Average Energy Consumption (AEC) and Network Lifetime (NL) of PRE & RED for varying number of nodes with transmission range 350 m.

Figures 5 and 6 show graphs corresponding to Table 4. From the graphs, it is observed that, the average energy consumption in RED is less and network lifetime is more as compared to PRE.

Table 4. Average energy consumption (AEC) and network lifetime (NL) (range: 350 m).

No. of nodes		40	50	60	70	80	90	100	110
AEC (J)	PRE	14.37	14.53	14.46	14.46	14.98	14.49	13.97	12.70
	RED	13.12	12.16	12.00	12.71	12.11	12.68	12.63	11.30
NL (Sec)	PRE	215.68	268.29	269.53	269.57	313.60	324.14	336.43	369.91
	RED	236.12	287.72	291.48	306.81	354.80	370.54	403.71	486.41

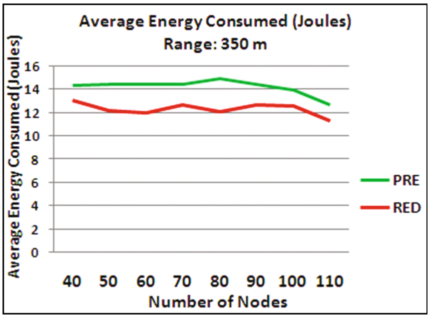

Fig. 5. Number of nodes v/s AEC

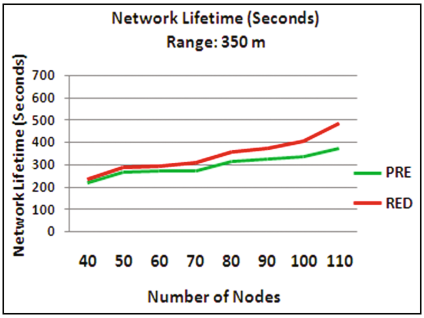

Fig. 6. Number of nodes v/s NL

5 Conclusion

The novelty of RED separates it from other state of the art approaches because most of them introduced distance factor into probability of CH selection. RED considers nearest distance for clustering. RED shows significant improvement in the results of PRE in terms of average energy consumption and network lifetime. RED further minimizes average energy consumption and extends network lifetime. In future, RED can be extended for implementation in real world applications.

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