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Improved Energy Aware Cluster based Data Routing Scheme for WSN

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Abstract

Wireless sensor network (WSN) consists of several tiny devices that are dispersed randomly for gathering network field. Clustering mechanism divides the WSN into different sub-regions called clusters. Individual cluster is consisting of cluster head (CH) and member nodes. The main research challenges behind clustering mechanism are to optimize network overheads with efficient data delivery. Sensor nodes are operated by batteries and practically it is not feasible to replace them during sensing the environment so energy should be effectively utilized among sensors for improving overall network performance. This research paper presents an improved energy aware cluster based data routing (i-ECBR) scheme, by dividing the network regions into uniform sized square partitions and localized CH election mechanism. In addition, consistent end-to-end data routing is performed for improving data dissemination. Simulation results illustrate that our proposed scheme outperforms than existing work in terms of different performance metrics.

***Keywords**: clustering, network lifetime, energy consumption, route discovery, clusters management*

1. Introduction

WSN consists of several sensor nodes with one or many sink nodes that are scattered in a physical environment to sense the events and gathering data. Sensor nodes sense the environment gathering information, integrate the data and send the achieved information to sink node or base station (BS). The sink in turn queries the sensor nodes for information [1]. The sensor nodes are small devices with small batteries and recharging of these batteries is impractical in deployed scenarios. Therefore to reduce energy usage and prolong lifetime is main design criteria for sensor networks. Structure and unstructured are two main categories of WSNs. Unstructured WSN consist of dense collection of wireless sensor nodes. After deployed, the nodes left unattended to do data gathering and reporting. Manage connectivity and detecting nodes or link failures is difficult in unstructured WSN because there is large number of nodes. On other side sensor nodes are deployed in pre defined manner in structured WSN. Structured network reduces network maintenance and expenses [2]. Adhoc routing protocols are not feasible in WSN due to limited energy and computing capabilities. Sensor nodes are limited in memory, bandwidth, transmission power and energy. Such types of constraints have posed many research issues to prolong network lifetime.

WSN consist number of nodes with limited memory, processing, power and energy resources. Due to such limited resources monitoring the interested physical environment by numerous sensing devices for a long period of time makes it a challenging task. Saving energy to enhance the network's lifetime is a critical problem in WSN and therefore "how to enhanced and improve the WSN lifetime" is a crucial question. The primary objective of WSN is data collection and transmission. Free space and multipath fading are two types of models in for WSN. There is a nonlinear relationship between each node in terms of the energy consumption of wireless communication. The energy consumption of free space model is much smaller than

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that of multipath fading model. When sensor node is far away from BS, it may be run out of energy shortly that would lead to quality reduction of network [3].

Dynamic hierarchical routing protocol LEACH[4] consists of several rounds and each single has setup and steady phases. All sensor nodes consist of homogeneous structure. CH is selected in setup phase and then dynamically different clusters are formed. Each cluster has its local CH and sensor nodes. Selected CH sends an advertised message to all nodes and nodes response on that received message. After receiving all the data from nodes CH aggregate and compress them and transfer to sink node. LEACH selects the CH periodically. Random number is generated by each node and the node will be selected as CH if this random number is smaller than predefine threshold value. The predefine value set to zero if this same node has elected again as a CH for same round. In steady phase TDMA is used so that every member node send data to CH when receive its own time slot. The threshold formula for LEACH is shown in Equation (1).

$$T_n = \begin{cases} \frac{P}{1-P*\left(r \bmod \frac{1}{P}\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

P shows the desired percentage of CHs, r denotes the current round, and G is the set of nodes that have not been elected as CHs in the last 1/p round.

LEACH-B proposed that the protocol needs to ensure that the partition of cluster is balance and uniform to save the energy consumption among nodes and to prolong the lifetime of the network. To accomplish this objective, the number of CHs needs to be dominated and the network needs an optimal CHs. Authors in [5] have proved that WSN will be energy efficient if the network has between 3 and 5 clusters from the total 100 sensor nodes. It means the optimal percentage of CHs range from 3% to 5%. LEACH-B improved the original LEACH algorithm by taking the node's residual energy into consideration and keeping the constant and near optimal number of CHs at each round.

Authors proposed Energy Efficient Extended LEACH (EEE LEACH) [6] protocol to enhance the network lifetime and energy efficiency by introducing an approach to minimize the communication distance among nodes based on multi level clustering. Energy efficiency of the network may be increased by keeping radio communication distance minimum. Network lifetime and energy efficiency can be enhancing by increase the number of clusters because it decreases ration communication distance. It divides the network into two layers for cluster formulation. CHs selection and member nodes send their data in first layer. The procedure of CH selection is same as in LEACH. In second layer CHs find the nearest master CH in order to forward its data .When master CH received data from CHs then it aggregate and compress them to forward towards BS. EEE LEACH improved the network lifetime by introducing the role of master CHs in second layer but it causes routing overheads that gives congestions and delay problems in the network.

Authors proposed [7] cluster based k-means protocol to form the k-clusters of objects based on the euclidean distance. Initially the CHs are selected on the basis of random number as in LEACH to form the initial clusters. Then after the formation of initial clusters, centroid is determined to find the center location of each cluster and the node is selected as a new CH which is closer to centroid. The role of CH is rotated when energy is drain out from certain energy threshold. It prolongs network lifetime and energy efficiency of WSN than proposed schemes [4, 8].

A New Routing Protocol for Efficient and Secure WSN [9] improves network lifetime and energy efficiency . It is round based scheme and network area is divided into a number of squares, each has same number nodes. Squares remain same and do not change in every round. A square is a cluster and all clusters do not change in all rounds. A cluster consists of four cells. CHs are elected in each cell at the start of new round. Data is send towards sink node in multi hop manner. To provide secure communication among nodes, setup server distributes different management keys in each round. It balances the energy consumption among sensor nodes and gives secure communication mechanism for WSN.

In energy efficient clustering scheme (EECS) [10] candidates nodes compete for the ability to elevate to CH for a current round. Each round has fixed time interval and re-clustering occurs at the start of next round. In this approach candidate nodes broadcast their residual energy to neighboring nodes. If a given node does not find a node with more residual energy, it becomes a CH. EECS use different way for cluster formation than LEACH. LEACH performs cluster formulation based on the minimum distance of sensor nodes to their corresponding CH. EECS extends LEACH protocol by dynamic sizing of clusters based on cluster distance from the BS.

Tree based clustering (TBC) [11] is another energy efficient approach that aims to prolong network lifetime. At the start of each round, nodes are elected as CHs on the basis of stochastic process. Each cluster maintains a tree structure using distance factor where elected CH is the root of it. Nodes send their data packets to parent node inside the tree and CH forwards the aggregated data towards BS directly. Although, it significantly improved network lifetime by decreases the long distance communication during intra-cluster communication but at the start of each round random CHs selection causes unbalanced clusters formation.Table 1 presents the summary of energy efficient cluster based routing approaches that have discussed in this section.

LEACH-DT [12] takes into account the distances of sensor nodes towards BS in order to appoint the set of CHs and balances the energy depletion in network field. Basically, LEACH-DT is a customized version of LEACH protocol in which probability of CH election is modified by incorporating distance factor. During data forwarding, source CH broadcast ADV message and based on least distance, the next-hop relay node is elected. In this way, shortest multi-hop route is accomplished towards BS. Although, LEACH-DT improved network lifetime as compare to original LEACH, however, the number of clusters are not uniformly distributed and CH election mechanism is non-optimized.

Table1. Methodology and Problems of Different Clustering Based Energy Efficient Schemes

Energy Efficient Protocols in WSN	Methodology Clusters Formation	Issues
LEACH	Probabilistic based	Predefined CHs and residual energy is not considered for CH selection
LEACH-B	Random number and residual energy	Single hop and energy distribution is imbalancce.
EEE LEACH	Randomly	Sub-optimal clusters formation
K-means CH selection	Euclidean	clustering overheads and uneven load distribution among clusters
Routing Protocol for Efficient and Secure WSN	Grid based	Communication overheads
EECS	Node residual energy	Unbalance energy consumption in network field
TBC	Randomly	Sub-optimal clusters generations and excessive energy consumption during inter-cluster communications
LEACH-DT	Distance based	Additional energy consumption and network overheads

Energy efficiency with robust routing is a vital task among research community for WSN applications. Due to limited constraints on the part of nodes, reliable and efficient data forwarding should be considered while proposing energy efficient scheme. In addition, the CHs being a focal point within cluster boundary, its appropriate selection increases network lifetime and improves network connectivity. Thus, design of energy effiicient cluster based routing scheme is an key research problem for enhancing overall network performance [13, 14]. The rest of the research paper is organized as follows. Our *i-ECBR algorithm* is presented in section 2. Research method is shown in section 3. Simulation results and discussions are covered in section 4. Section 5 concludes the paper and suggests for future work.

2. Proposed Method

In this section we present detailed description of *i-ECBR* scheme, including how to partition the sensing field into uniform sized square partitions and initiates CH selection within each partition. Furthermore, the routing mechanism for data dissemination is also discussed. *i-ECBR* is divided into two main phases. Firstly, *i-ECBR* performs nodes clustering and secondly optimal paths are constructed for robust routing. Before going to describe *i-ECBR* scheme, we highlight the various nework assumptions that are listed as follows:

1. All nodes are deployed randomly and remain static.
2. All nodes have homogenous structure and sense data periodically.
3. BS has location information of all sensor nodes.
4. All nodes will use the same radio channel for communication with each other.
5. All the nodes communicate via a shared bidirectional wireless channel.
6. No new nodes can be added after network deployment.

The steps undertaken in *i-ECBR* scheme are discussed as follows:

Step 1: Suppose that *n* number of sensor nodes is randomly deployed in network field. At the beginning, each sensor node sends its location information towards BS using appropriate adjacent node. Based on optimal numeral of clusters (p) and nodes distribution (n), BS initiates the procedure of virtual network portioning by dividing entire sensor field into identical sized square partitions via eq. 2, where strong positive and negative linear correlation exists between input n and output z. Next, by using nodes position, a centroid for each partition is determined.

$$z = n * p \tag{2}$$

Step 2: The nodes that are relatively closer towards respective centroid are grouped into single cluster boundary with a unique ID.

Step 3: After the formation of different clusters, a localized CH election is announced among member nodes thereby only limited number of nodes is partiticipated and reducing communication overheads. During election mechanism, node's local information is summed up in weighted method based on eq.3, where $\alpha + \beta + \gamma = 1$. Finally, nodes those are relatively nearer to centroid with high energy condition and neighbor's density are elected as CHs. Afterwards; each elected CH informs its status to all member nodes by broadcasting ADV message.

$$n_i = \alpha * energy + \beta * \left(\frac{1}{distance}\right) + \gamma * neighbors \tag{3}$$

Step 4: To receive and aggregate the sensory data from nodes, all selected CHs announced their local TDMA schedules. Accordingly, each node sends its data towards associated CH when it receives time slot.

Step 5: Subsequently, to achieve data transmission, intermediate nodes are elected to construct routing paths. Each source node determines a composite routing function based on residual energy, distance and link quality factors. The routing function gives energy efficient, relatively closer with least estimated transmission time neighbor node as next-hop. This procedure continued until an optimized multi-hop routing path is constructed towards destination.

Step 6: In addition, to balance the energy consumption among data forwarder nodes, their role is shifted during data dissemination when energy level is reached to certain threshold. In such case, current data forwarder node set its next-hop flag to false and sends route error message towards source node. Accordingly, source node discovers alternative data forwarder node based on composite routing function as mentioned in step 5, which results in improving data delivery performance and reducing network latency.

Step 7: As in data routing, the CHs consumed excessive energy consumption and highly involved in routes adjustment process. Unlike most of existing schemes, those perform re-election mechanism on periodic basis and lead to additional network overheads with high communication cost. *i-ECBR* rotates the role of elected CHs based on certain event i.e. when the residual energy of current CH is drops to certain threshold, an appropriate node is selected as next CH by using step 3. Afterwards, newly elected CHs floods their status information among member nodes and update the transmission schedule for data dissemination.

i-ECBR scheme improved energy conservation and routing performance as compared to existing solutions due to some aspects. Firstly, distinct regions are constructed based on nodes distribution rather than predefined network partitions. In addition, optimized candidates are selected for the role of CHs with minimum overheads and energy consumption. Secondly, based on adaptive routing mechanism, intermediate nodes are appointed as next-hop for data forwarding thereby improved network throughput. Moreover, to balance the traffic load among routing paths, the role of data forwarder nodes are shifted based on certain event. At the end, in order to improve network connectivity and lifetime, the position of CHs is rotated in dynamic manner that leads to energy balancing among nodes and prolonging overall network performance.

3. Research Method

In this section we present our simulation model that has been used in different experiments by using well known tool network simulator (NS2) [15]. We randomly deployed varying sensor nodes in sensor field of 100 X 100 dimension. All sensor nodes are location aware via GPS or any positioning algorithm. Energy model assumed as being used in [4] and a considered free space radio propagation model. The system parameters that have been used in experiments are shown in Table 2. We compared *i-ECBR* scheme with relavent clustering approaches i.e. LEACH-DT and K-means with respect to different performance evalution metrics.

Table 2. System Parameters

Parameter	Value
Network area	100*100m
Nodes	50-300
Initial energy	2J
Energy threshold	50%
Optimal no. of clusters	5%
Data packet size	100 bytes
Base station energy	100
Transport layer protocol	UDP
Simulation time	1000sec

4. Results and Discussion

In this section we used three different performance metrics: clustering overheads, average end-to-end delay and network throughput to evaluate the performance of *i-ECBR* scheme with relavent clustering schemes. The simulation results of performed experiments are discussed in sub-sequent sections.

4.1. Clustering Overheads

Figure 1 shows the clustering overheads against varying number of nodes. Obviously, the clustering energy increases when number of nodes are increase in network field. This is due to with increase in nodes density, the number of send/receive is also increase that leads to increasing clustering energy dissipation. The simulation results illustrate the *i-ECBR* scheme significantly reduces the clustering overheads as compare to existing schemes. Unlike existing schemes, *i-ECBR* divided the whole sensor area into uniform sized non-overlapping network partitions based on nodes distribution, which results in grouping relatively closer nodes into a particular cluster. Furthermore, the number of clusters increases/decreases when increase/decrease in network size. In addition, the election process is initiates within bounded region that leads to reduce communication expenditure and energy consumption. Rather than perform re-clustering of whole network field on periodic basis, the role of CHs are dynamically rotated among member nodes.

4.2. Average End-to-End Delay

Figure 2 illustrates average end-to-end delay among different cluster based energy efficient schemes against different number of nodes. It is seen that end-to-end delay of all the schemes increased by incrementing the number of nodes. This is due to, higher the network size incurs additional network overheads and congestion during data forwarding. However, proposed *i-ECBR* achieved lower average end-to-end delay as compared to existing relavent schemes. Existing schemes exhibit a higher end-to-end delay in data forwarding process because of constructing non-optimized routing path which leads to more route beakages and frequent re-transmissions.

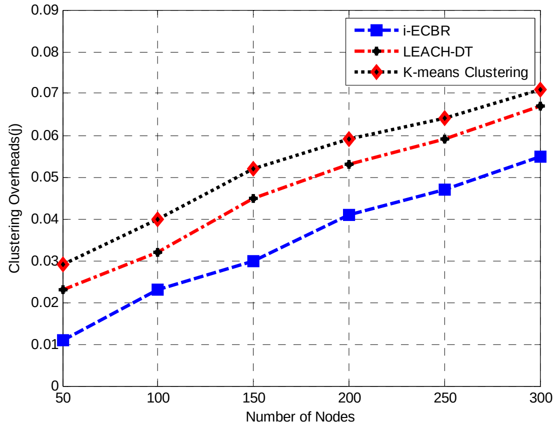

Figure 1. Clustering overheads v/s number of nodes

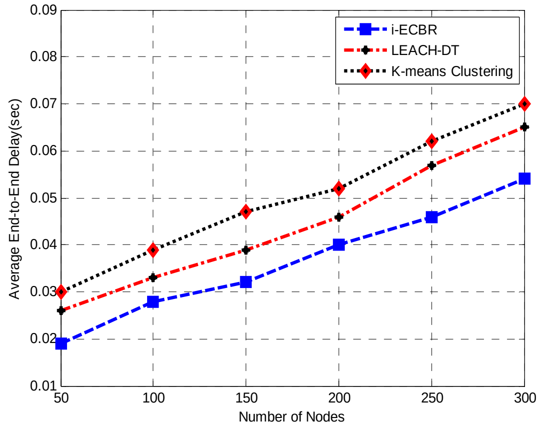

Figure 2. Average end-to-end delay v/s number of nodes

4.3. Network Throughput

Network throughput means how many data packets have been successfully received at receive end. In single hop, nodes directly send their aggregated data to sink node and due to distance factor they excessively consumed energy level, which results in more packets lose. Figure 3 illustrates the network throughput as a function of network size. It is observed that *i-ECBR* scheme remarkly improved throughput as compare to existing approaches. Basically, existing cluster based energy efficient routing schemes determine construct shortest routing path for data transmission based on minimum number of hops. Due to this, those schemes highly decrease the achievable data delivery performance because of low flexibility against exhausted nodes, which results in lower routing performance.

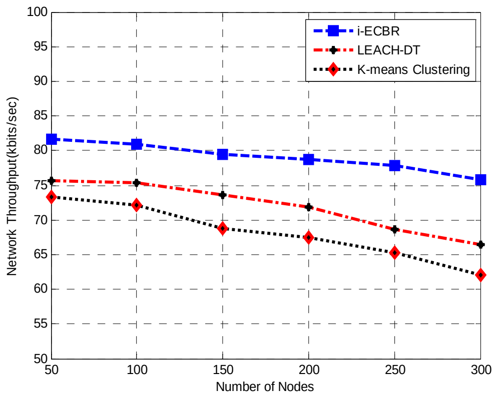

Figure 3. Network throughput v/s number of nodes

5. Conclusion

To improve the energy conservation while reliable data delivery are the main research aim in WSN. The *i-ECBR* divides the entire sensor filed into balance sized non-overlapping clusters based on nodes distribution. In addition, the election overheads are minimized as they are executed inside the cluster boundary. Moreover, optimized routing paths are constructed towards destination in terms of multi-facet method thereby improving routing performance. In order to balance the load distribution and improve network lifetime, the positions of focal points are rotated on demand basis with least computational overheads. At the end, simulation results are discussed and proven that *i-ECBR* scheme outperforms in terms of clustering overheads, network throughput and end-to-end delay as compared to existing work. In future work, we will further improve the performance of *i-ECBR* scheme by incorporating hetrogenouse network characteristics.

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