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Clustering in Wireless Sensor Networks: Performance Comparison of LEACH & LEACH-C Protocols Using NS2

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Abstract

Every type of network, be it wired or wireless, will be influenced by several key factors for its efficient functioning. Routing issue, applicable to all types of networks, is one among the several such key factors. Wireless Sensor Networks (WSN) has not been exception to this. Moreover, such issues are very critical due to severe resource constraints like efficient energy utilization, lifetime of network, and drastic environmental conditions in WSNs. Neither hop-by-hop or neither direct reach ability is possible in case of WSNs. In this regard, many routing protocols have been proposed to optimize the efficiency of WSNs amidst of above mentioned severe resource constraints. Out of these, clustering algorithms have gained more importance, in increasing the life time of the WSN, because of their approach in cluster head selection and data aggregation. LEACH (distributed) is the first clustering routing protocol which is proven to be better compared to other such algorithms. This paper elaborately compares two important clustering protocols, namely LEACH and LEACH-C (centralized), using NS2 tool for several chosen scenarios, and analysis of simulation results against chosen performance metrics with latency and network lifetime being major among them. The paper will be concluded by mentioning the observations made from analyses of results about these protocols.

Keywords: Wireless Sensor Network; Routing, LEACH; LEACH-C; Clustering

1. Introduction

Due to stringent constraints and very nature of radio communication it is impossible to think of, in a typical WSN, every sensor node to be able to reach Gateway node directly. Inevitably, hop-by-hop basis data transfer will be chosen to meet constraints. But, hop-by-hop mode of communication increases

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overhead on routing table management in all sensor nodes and quickly brings down lifetime of those nodes which are very near to Gateway since they will be extensively used as relay nodes. This makes network to be virtually non-existent. Many routing protocols have been proposed to solve such routing issues. Out of these, clustering algorithms have been of much interest as they well balance several key factors of WSN operation simultaneously. Choosing one arbitrary node to act as servicing node for several sensor nodes than each trying to reach Gateway node can extend network lifetime and bring down energy utilization considerably. This process of choosing one node to act as servicing node for several neighbor nodes is known as 'clustering'. The concept of hierarchical clustering comes when levels of hierarchy are increased. The level of hierarchy can be increased to some extent to attain the maximum lifetime of the network based on the requirement of application of WSN. For example, if the application consists of thousands of nodes, then it may be desirable to prefer two level hierarchies or three level hierarchies.

In the rest of this paper, section 2 gives related work, sections 3 briefly discusses about working of LEACH and LEACH-C clustering protocols, section 4 presents details about simulation using NS2 tool and results; in section 5 analysis of simulation results will be presented. Paper is concluded in section 6 by mentioning the effectiveness of LEACH over LEACH-C.

2. Related Work

Clustering algorithms can be classified as Distributed Clustering & Centralized Clustering. Distributed clustering techniques are further classified into four sub types based on the cluster formation criteria and parameters used for CH election as Identity based, Neighborhood information based, Probabilistic, and Iterative respectively. Linked Cluster Algorithm (LCA) proposed by [2] belongs to Identity based clustering taking unique node identifiers as key factor to choose cluster heads. Further improvement is provided in terms of LCA2 [2], to eliminate chances of multiple cluster head selection.

There are couple of protocols proposed using Neighborhood information based approach. Highest-Connectivity Cluster Algorithm (HCCA) [2], is based on choosing a node as cluster head which has highest number of neighbors at 1-hop distance with strict clock synchronization requirements. Max-Min D-Cluster Algorithm [8], selects cluster head in such way that none of its neighbors are d-hop away from it providing better load balancing without clock synchronization requirements. Weighted Clustering Algorithm (WCA) [9], works based on the principle of non-periodic invocation of itself only when topology reconfiguration has become inevitable due to an arbitrary sensor node loosing connectivity with its cluster head while trying to balance combination of several required parameters in the form of common factor called 'combined weight'. Grid-clustering ROUting Protocol (GROUP) [10], includes multiple sinks with one of them considered as ' primary sink' being responsible for dynamically selecting cluster heads forming grid-like structure.

Probabilistic Approaches for clustering in WSN relies upon prior assigned probability values for sensor nodes. Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol proposed in [1] provides a balancing of energy usage by random rotation of cluster heads meanwhile assuring uniform load balancing in one-hop sensor networks. Two-Level LEACH (TL-LEACH) is discussed in [5], which is an extension to LEACH, proposing primary and secondary level cluster head selection to minimize energy utilization. Energy Efficient Clustering Scheme (EECS) proposes non-iterative, dynamic, and localized competition based process for selection of cluster heads based on residual energy of sensor nodes providing lower message overhead and uniform distribution of cluster heads [6]. Hybrid Energy Efficient Distributed Clustering (HEED) proposes a methodology which takes into account residual energy of sensor nodes and intra-cluster communication costs while making selection of cluster heads in multi hop sensor networks [7].

Iterative clustering protocols that need to be mentioned here are: DCA [2], SPAN [4], and ACE [3]. Distributed Clustering Algorithm (DCA) protocol uses delayed willingness announcement technique for any sensor before becoming cluster head thereby giving chance for other higher-weighted (preference conditions) neighbor sensor nodes to have chance of becoming cluster heads. SPAN is a randomized cluster head selection process with localized decision making which is based on number of sensor nodes being benefitted and its own energy levels for a sensor node that is likely to become cluster head. Algorithm for Cluster Establishment is an emergent protocol with two distinct phases of cluster head selection: a randomized new cluster 'spawning phase' and 'migration phase' for existing clusters to achieve highly uniform non-overlapping cluster formation. But, in general, iterative approaches for clustering suffer from their convergence speed dependency upon network diameter.

LEACH-C [18], BCDCP [11], DMSTRP [12], and LEACH-F [13] are protocols of interest in centralized clustering approach. LEACH-C proposes transmission of location awareness and energy levels by each sensor node to base station and sensor nodes with energy level above predetermined threshold are chosen to become cluster heads by base station itself. Base Station Controlled Dynamic Clustering Protocol (BCDCP) also relies on base station for election of cluster heads from a group of sensor nodes by applying residual energy and predetermined energy threshold as a criteria but with a distinction of so elected sensor nodes being capable for operating in 'sensing mode' and 'cluster mode'. Dynamic Minimum Spanning Tree Routing Protocol tries to improve BCDCP behavior by retaining much of its other characteristics. It applies Spanning Tree concept to make optimal decisions about inter-clusters & intra-clusters. In this regard, DMSTRP turns out to be elegant solution for large networks whereas LEACH-C and BCDCP being better for relatively small networks. LEACH-F is same as LEACH-C as far as cluster head selection is concerned. But, in LEACH-F clusters are fixed once they are formed. Role of cluster head gets rotated for different sensor nodes within each cluster.

Also, there exists a work [14] comparing LEACH and LEACH-C protocols but very briefly. In this regard, motivation of this paper has been to provide elaborated comparisons of LEACH & LEACH-C for parameters like latency and network lifetime etc.

3. Working of LEACH & LEACH-C Protocols

In general both of these work in rounds. There are two distinct operational phases in each round, namely Cluster Set up phase and Steady-State phases. Cluster Set up phase includes cluster head advertisements and Scheduling of nodes within each cluster by respective cluster heads. Steady-State phase involves transmission of data from nodes to their respective cluster heads at scheduled time intervals. Common aspects applicable to both of these protocols and important ones to be understood are:

1. Randomized rotation of the cluster "base stations" or "cluster heads" and the corresponding clusters.
2. Local compression to reduce global communication

For detailed design and working discussion of these protocols one can refer to [1] & [18] respectively.

3. 1. Comparison of LEACH and LEACH-C

LEACH	LEACH-C
It is a distributed clustering algorithm.	It is a centralized clustering algorithm
Any node can choose itself as a cluster head independent of other nodes.	Cluster heads are elected by base station
Cluster heads are elected based on Probabilistic threshold that is randomly chosen by the node.	BS runs centralized cluster formation algorithm to elect CHs based on energy level of a node and its distance from BS
It is neither guaranteed that desired number of cluster heads will be formed nor even distribution of cluster heads in the network.	It is guaranteed that desired number of cluster heads will be created and evenly distributed among the nodes in the network.
Set up phase consists of choosing cluster heads randomly, such that every node becomes cluster head at least once.	Every node may not get a chance to become CH, and same node may become CH for the next rounds as BS takes control of network.
Life time of network will be less compared to that of LEACH-C	Life time of network will be more compared to that of LEACH
Start up energy dissipation will be less compared to that of LEACH-C	Start up energy dissipation will be more compared to that of LEACH
Data signals received at BS will be less compared to that of LEACH-C	Data signals received at BS will be more compared to that of LEACH
Total energy dissipation will be more compared to that of LEACH-C	Total energy dissipation will be less compared to that of LEACH

4. Simulation & Results

Both LEACH & LEACH-C protocols are simulated using NS-2.34. The parameters taken in to consideration for evaluating LEACH & LEACH-C are as follows:

- Time v/s No of data signals received at BS
- Time v/s Start up energy dissipation
- Time v/s Total energy dissipation
- Time v/s Number of nodes alive
- Number of nodes v/s Network Lifetime
- Number of clusters v/s Network Lifetime
- Base station location v/s Total energy dissipation
- Base station location v/s Network Lifetime

- Round number v/s Average Latency

To simplify the simulation of these protocols few assumptions are made. Those are as follows:

- Initial energy of nodes is same.
- Nodes are static
- Nodes are assumed to have sufficient transmission range to reach other nodes
- Homogeneous distribution of nodes.
- Nodes always have to send the data.

Details of the simulation environment are mentioned in Table 1, given below:

Table. 1. Simulation Environment Specifications

Simulation area	100*100
Simulation time	3600 s
Initial energy of node	2 J
Transmitter Amplifier Energy Dissipation: Efriss_amp Etwo_ray_amp	 10 pJ/bit/m2 0.0013 nJ/bit/m4
Radio bit rate-Rb	1mbps
Channel Type	Channel/wireless Channel
Radio Propagation Model	Two ray ground
Antenna Model	Antenna/omniantenna
Energy Model	Battery
Communication Channel	Bi direction

Results obtained for parameters of interest are shown in following figures (with 100 nodes & number of clusters = 5):

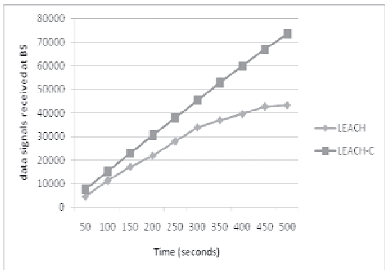

Fig.1. Time v/s No of data signals received At base station

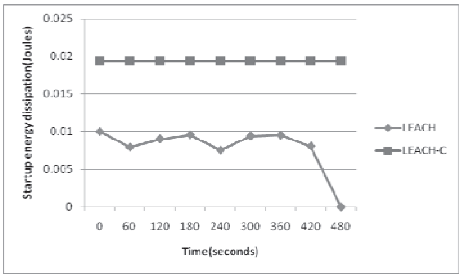

Fig. 2. Time v/s startup energy dissipation

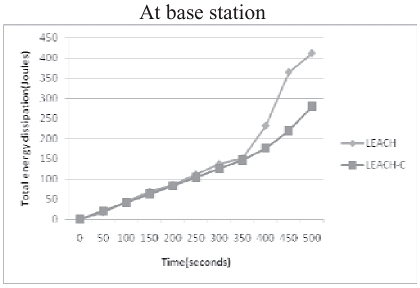

Fig. 3. Time v/s total energy dissipation

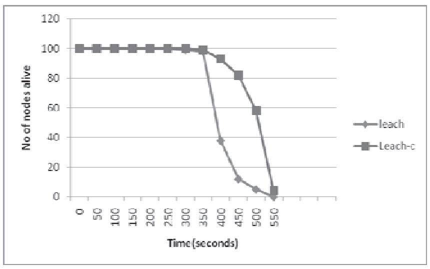

Fig. 4. Time v/s No. of nodes alive

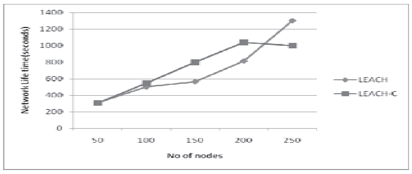

Fig. 5. No. of nodes v/s network lifetime

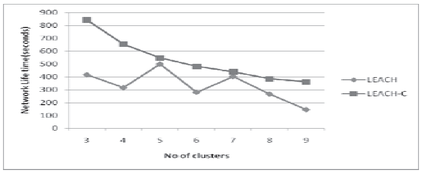

Fig. 6. No of clusters v/s network lifetime

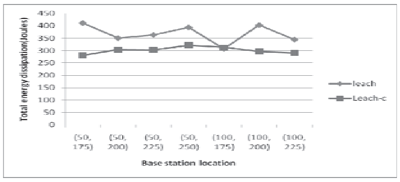

Fig. 7. Base station location v/s total energy dissipation

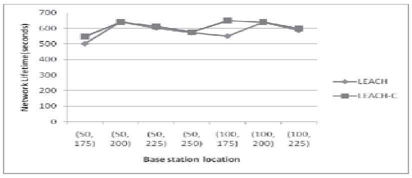

Fig. 8. Base station location v/s network lifetime

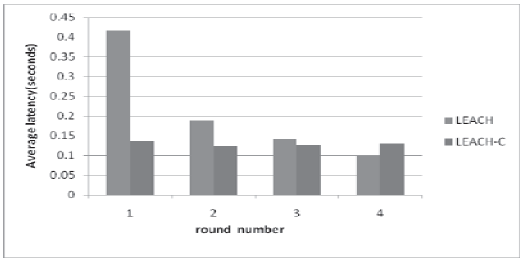

Fig. 9. Round number vs Average latency where each round lasts for 20 seconds

5. Analyses of Results

It is observed from the graph in Fig. 1 that as the time increases, no of data signals received at BS through LEACH-C linearly increase compared to that of LEACH and able to deliver more no of data signals compared to that of LEACH because, in LEACH-C, BS knows the network topology and hence it can form good clusters compared to that of LEACH.

From Fig. 2 it can be observed that start up energy dissipation is constant and more compared to that of LEACH, because of overhead in cluster set up formation in LEACH-C.

Graph in Fig. 3 conveys that total energy dissipation linearly increases in LEACH-C compared to that of LEACH, because BS creates desired number of cluster heads and evenly distribute them so that appropriate cluster sizes can be formed and hence change in total energy dissipation will be less compared to that of LEACH. As LEACH follows probabilistic method of selection, uneven distribution of cluster heads may be possible sometimes which leads to sudden increase in energy dissipation.

We can also see from Fig. 4 that no of nodes alive decreases slowly in LEACH-C compared to that in LEACH reasoning the same that uneven distribution and undesired no of cluster heads might be formed in LEACH. .

It can also be seen from Fig. 5 that, as there is possibility of more energy dissipation in LEACH, network lifetime in LEACH will also be less obviously, whereas network life time constantly increases in LEACH-C because BS controls network by running centralized control formation algorithm.

Further, from Fig. 6, it is observable that for a 100 node network, optimal number of cluster heads should be 5 in LEACH and 3 to 5 in LEACH-C, and the reason that why the network life time decreases is because, as the number of cluster heads increases, data from each CH is expected and hence communication overhead increases, reducing local processing and data aggregation within each cluster.
Fig. 7 shows that location of BS also influence energy dissipation. As Bs moves far from network, distance between node and BS increases, and hence energy dissipated will be more to send data to BS.
Finally, Fig. 8 briefs that as BS moves to different locations from the network, uneven increase and decrease in life time can be observed which implies that, BS location also influences network life time.

Finally, Fig. 9 shows how latency period changes in each round in LEACH and LEACH-C. Here latency is defined as the difference between current and previous time at which data is received at BS. It can be observed from the graph that latency is more in LEACH compared to that of LEACH-C at every round as undesirable no of cluster heads are formed with uneven distribution in the network. But in 4^{th} round, latency with LEACH is less compared to that in LEACH-C as correct number of cluster heads with even distribution are formed in the network.
Between LEACH & LEACH-C following conclusions can be made by following above mentioned observations. It can be concluded that LEACH and LEACH-C both performs well when number of cluster heads, and number of nodes in the network are chosen appropriately depending upon nature & application of WSN.

LEACH is distributed, random and probabilistic algorithm bringing no overhead for BS in making clustering decisions. It performs well giving more network life time than LEACH-C only when uniformly distributed clustered network is formed and it does not assure about desired number of cluster heads and consideration of overall network parameters like residual energy of every sensor node in the network etc., while making decisions about clustering.
LEACH-C, on the other hand, can be chosen when centralized and deterministic approach for clustering is required. Also, LEACH-C covers entire network, in terms of residual energy of each sensor node in network, before deciding clusters. This may bring in more uniform distribution of clusters than in case of LEACH. But, disadvantage of LEACH-C is that it increases overhead on BS since it is involved in each & every aspect of clustering process.

6. Conclusion

Wireless Sensor Networks, which may be spread over vast geographical area, are finding applications in many areas. In this context, there is need of approaches which can manage these WSNs in better way. In this regard, this paper, presented need for clustering to overcome several limitations of WSNs. Detailed discussion about existing work is provided. Brief working of chosen clustering protocols, namely LEACH & LEACH-C, is presented. We also presented the simulation results and analyses of these protocols. As a conclusion of observation from results, it can be mentioned that LEACH can be preferred if localized coordination of nodes in clustering without involving BS is of high priority than other factors like assurance over desired number of clusters etc.; and LEACH-C can be chosen when centralized and deterministic approach covering entire network is expected still bringing in increased network lifetime and desired number of clusters.

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