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Energy efficient cluster formation in wireless sensor networks

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Abstract
Energy is saved through load distribution. Instead of all nodes sending data to the base station, some representative nodes, called cluster heads, collect data from members and send aggregated data to the base station. There are many such approaches in the literature, all differ in the method and frequency of cluster head selection. This dissertation proposes a new method of cluster head selection.
The nodes of the network are categorized as interior and exterior nodes based on the density of other nodes in the surrounding. The ratio of interior type of neighbors to exterior type of neighbors of a node is used to decide the level of a node. This level in combination with distance of a node from the base station is used to decide whether it will act as a cluster head or not. As the energy of nodes depletes, some neighbors may die thus changing the level of the node. At this point, new cluster heads are selected. Due to this the energy of network is consumed in a balanced manner.
Simulation experiments are designed to compare the proposed method with other popular clustering algorithms. Overall impression of results is that the proposed method gives a longer network life due to properly distributed energy consumption throughout the network.

Keywords: Clusetring, WSNs, LEACH, region of interest, cluster head

Introduction
Wireless Sensor networks, though efficient, come with a number of issues, particularly related to the energy consumption in the network. Clustering is one refined technique to address most of these issues. However, overall balanced energy consumption throughout the network is desired. Concepts of density applied to the problem results in extended performance of the network.

Wireless Sensor Networks
Sensing and monitoring tasks require tools that can efficiently perform the task and return desirable results. Using Wireless Sensor Networks (WSNs) for the same has been proved to be a soon since years [1]. WSNs can be defined as a network of nodes that are distributed specifically or autonomously in a given area, also called the Region of Interest (RoI). Each of the nodes performs three tasks: sensing, processing and communicating with the base station. Sensing implies monitoring the given area or a part thereof depending upon the range of a node. Processing implies local computations on the sensed data according to the application requirements. The communication phase then involves communication between the nodes and the base station to send the sensed processed data from the nodes to the base station. The sensing process ends with the transfer of the sensed data to the base station. As successful and simple as these networks seem, they too have certain performance issues to cope with, in terms of memory, bandwidth, processing and most important of all energy.

Energy issues in WSNs
Out of all challenges and issues of WSNs, eradicating the energy issues seems to be the most researched topic in the field of WSNs [2]. The nodes rely on a limited battery life for energy. Batteries are irreplaceable and cannot be recharged and that adds to complication especially in situations when all or some nodes fail in the middle of sensing. Another energy issue is related to the way the nodes are deployed; if randomly, then the nodes may continuously focusing on one part of the region of interest having no location information of other nodes and thereby leading to energy wastage and increased energy consumption.

Due to the limited bandwidth of each node, extended energy is consumed when distance from a node to the base station is large. A reliable solution to the problem is multi-hop communication, but the intermediate nodes behaving as hops in this case have increased energy consumption due to high probability of them getting exhausted earlier than usual. Any of the two discussed issues: random deployment and multi-hop communication, in addition, bring about an uneven energy distribution in the network. The network has to be re-routed or re-organized can be considered as plausible solutions but do not necessarily guarantee success. Another challenge to solve is the environment or the type of network. In a dynamic environment, the nodes regularly change their positions which add to the usual energy consumed, reason being the additional requirement of updating location information regularly.

Energy saving through clustering

The one plausible solution to the various issues discussed is to aggregate data and transfer the data to the base station via nodes serving as local base stations. These local base stations get the sensed data from each of the nearby nodes, process/aggregate it and transfer the aggregated data to the base station. The local base stations serve as Cluster Heads (CH) when talked in terms of clustering. Inherently, marking of such nodes is similar to finding cluster centers/representatives with exactly one cluster formation in one sub region. Advantages of clustering in WSNs are numerous, some of which are discussed below.

- **Load balancing:** The overall load is distributed within the cluster heads (processing and communication) and member nodes (sensing).
- **Preventing redundant message exchange:** Limit is placed on the messages exchanged between individual nodes. Each node directly communicates to its respective CH. This in turn reduces the message and the communication complexity of the network.
- **Collision reduction:** The limited resources in the network within a large set of nodes communicating with each other may lead to collisions. Reduced communication results in reduced collisions and in return, reduced latency.
- **Reduced failure chances:** With cluster heads, even in cases when the individual nodes die between the sensing task, the network doesn't fail since the cluster heads continue the process. Also, the cluster heads are selected repeatedly so as to not overload the initially selected CHs. CHs, as is clear, has more responsibilities to fulfill in the sensing task and therefore require more energy.

Major clustering approaches for WSNs

The clustering protocols in WSNs differ in the criteria of selecting cluster heads. Unlike the usual data clustering algorithms that are space-based and choose the cluster representatives/centers based on distance or similarity measures, cluster head selection criteria in WSNs can be on the basis of variability of cluster count (fixed, variable), mobility of nodes (static/dynamic environment), uniformity in the size of cluster (even, uneven), inter and intra cluster routing (single/multi-hop), density of nodes and more. Also, the cluster-head reselection criteria may vary; reselection can happen round wise or when the drop in the total energy of the network reaches to a certain percentage. The credit of bringing the concept of clustering in WSNs goes back to Heinzelman *et al* [3] who proposed the very first clustering protocol by the name LEACH. A variety of clustering algorithms have been proposed since then. Ref [4, 5, 6, 7, 8, 9] discuss some popular clustering protocols.

Problem Statement

Clustering in WSNs leads to energy-efficient performance of the underlying network. If the energy consumed in the network throughout the sensing process is balanced, it further adds to the performance. Combining the same with some concepts of density may give even better results. The problem statement can therefore be stated as

"To design a clustering protocol with balanced energy consumption using concepts from density based approach to clustering"

Related Work

Clustering in Wireless Sensor Networks has found wide acceptance both by researchers and practitioners. The base of all clustering algorithms is the LEACH protocol. The researchers designing and developing clustering protocols since then have a somewhat same methodology as of LEACH: selecting CHs, announcement of CHs, assignment of nodes to these CHs, sensing, processing, transfer of data to BS, reselection of CHs and repeating the process till a specific criterion is met. The protocol is explained in detail in the next section with its areas of improvement and the recent developments in clustering in WSNs.

LEACH Protocol

The most primitive of clustering algorithms for WSNs that provide energy efficiency and good quality results is the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol by Heinzelman *et al* [3]. The aim of the protocol is to help organize the nodes in a clustering hierarchy with each cluster having a cluster head or precisely, a local base station. The nodes after sensing and processing phases have to pass the sensed data to these local base stations which then pass the same to the main base station. Each local base station is responsible for aggregating the data from all its member nodes. There are limited CHs in a network and therefore these, instead of all nodes, participating in the transfer significantly reduce the energy and increase the lifetime of the network. In order to prevent draining of energies of these cluster heads, they are reselected at every round of the protocol. The protocol performs its operations in rounds, with each round partitioned further into two phases – set-up and steady. The set-up phase involves organization of clusters while the steady phase involves transfer of data to the BS. While organizing clusters, the decision of whether a node is to be elected as a CH is done. It is further dependent on the number of clusters a network suggests having, the number of times a node has been assigned a CH already and a pre-defined threshold. Each node has to select a random number between 0 and 1. This number is then compared with the threshold value; if number less than the specified threshold, the node is elected as a CH. The computation of threshold is done using the equation

$$T(n) = \begin{cases} \dfrac{P}{1 - P * (r \bmod \frac{1}{P})} \text{ if } n \in G \\ 0 \text{ otherwise} \end{cases} \quad (1)$$

Where,
P represents the percentage of CHs desired for the network, r refers to the current round and G represents the set of nodes that are not been assigned CHs in the last $1/P$ rounds. The nodes on being selected as CHs send an advertisement message to the remaining nodes. The nodes then decide which cluster they will be a part of for the current round based on the received signal strength of the CHs. The CHs with more signal strength is chosen by the nodes. The nodes then send a membership message to the CHs they will join. The process is repeated every round on reselection of CHs. The next phase is the steady phase, responsible for node sensing and data transfer to the BS. The sent data to the CHs from the remaining nodes of the cluster is compressed and aggregated followed by sensing it to the BS. A round is completed within a pre-specified time after which the set-up phase again starts.
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Proposed Protocol
The proposed protocol also decides the frequency of cluster head selection process.

Interior and exterior nodes
A node is categorized as an interior or an exterior node. This categorization is done based on the number of neighbors of each node. By neighbors, we mean the nodes that lie within the transmission range of the sensor nodes. As per Ester *et al* [10], the minimum number of neighbors that make a node as an interior node is 4. The same criterion is used in the dissertation. The nodes that are not interior are the exterior nodes. The concept of interior and exterior neighbors is illustrated in Figure. Node A is an interior node because of more than 4 points within the range of the node. Likewise, node B fails to fulfill the criterion of interior nodes with only one neighbor and is therefore an exterior node.

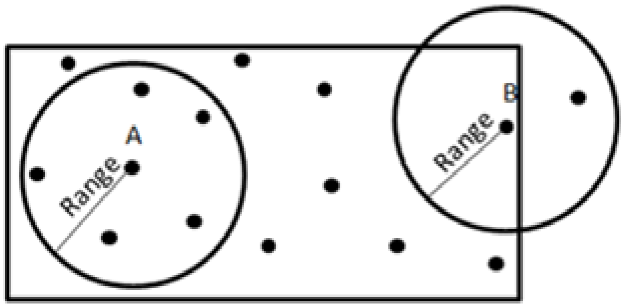

Fig: Illustration of interior and exterior nodes

Cluster Head Selection Criteria
The CHs are selected based on the following criteria.

- **Levels of density:** The levels for any node are decided based on the percentage of interior nodes of any node. If all the neighbors to a node are interior or say the percentage is 100%, the node lies in level 1. The nodes in level 1, therefore, lie in the dense region because of all neighbors being interior. Levels 2, 3 and 4 correspond to 75%, 50% and 25% of interior neighbors to a node. The levels indicate the density of nodes.
- **Distance of a node from BS:** Distance of a node from the base station should be less than 2* transmission range of a node. This means that the messages from the CHs to the BS should reach within 2 hops to have a reduced communication complexity. The importance is therefore given to those nodes that are nearer to the base station through this criterion.

Results and Discussions
The efficacy of the proposed clustering scheme is tested by comparing it with similar popular clustering algorithms. Implementation of the proposal and the protocols to be tested is done on a popular computing environment. Testing is done by varying the number of nodes and the deployment area and on the basis of certain criteria. Results of the experiments through exact results and visualized outputs give a better understanding of the performance.

Hardware and software used
The experiments on the proposed clustering protocol have been conducted on MATLAB computing platform on an Intel (R) Core (TM) i3-2130 CPU with 64-bit Windows 8.1 Operating System. Version 2007B of MATLAB is used.
MATLAB stands for MATrix LABoratory. It is a great environment for numeric data calculations and works in multiple paradigms; also a fourth generation programming language. Developed by Math Works in late 90's, the platform is popular enough to have gained more than a million users already [11]. The platform is used by academicians as well as in the corporate sector in the fields of science, commerce and economics. Such popularity is due to the several privileges the platform grants to its users, some of which are discussed below.

- Simple C/C++ like language
- Online help facility available 24/7
- Built in algorithms and functions
- Interfacing with languages like C/C++, Fortran, Pascal and Java
- Easy creation of user interfaces
- Easy plotting of functions and data
- Great ability to solve complex matrix and numeric calculations

Windows 8.1 is an improved version of Windows version 8 of Microsoft after critical acclaims from the users. The improved version possess an improved Start Screen, additional applications and snap views, tighter cloud integration namely 'One Drive', a unified search system powered by Bing, Internet Explorer 11 and more. The ease of use along with advanced features makes it a very trusted computing environment and commonly used by all.

Simulation Setup
The performance of the proposed clustering protocol is tested against the popular LEACH [3], DEGRA [7] and EED [8] protocols on the basis of the following criteria.

- **Total Residual Energy:** This factor corresponds to the amount of energy left in the network at any given instant.

- **Time consumption per round:** It denotes the time (in seconds) consumed by the network per round of the protocol.
- **Network lifetime:** Network lifetime here refers to the number of rounds a protocol takes to execute the sensing task till the node drop count reaches 75%.

The fall or rise in the performance of the protocol is judged by varying the number of nodes and the simulation area on the basis of the above discussed criteria. The first set of results depicts the effect of varying nodes on the protocol and the second set evaluates its performance by varying simulation area.

Effect of number of nodes

The impact of the number of nodes in the working of the protocol is depicted in this section. The number of nodes is varied from 250 to 350 at an interval of 25 keeping the simulation area fixed at 100 X 100 m^2 and the results are noted. The impact is first observed in terms of the left energy of the network at fixed interval of rounds. Tables 5.2 to 5.6 list the exact results for the proposed as well as LEACH [3], DEGRA [7] and EED [8]. The corresponding results are graphically displayed in Fig. 5.1 to 5.5. The graphs depict the fall of energy of the network with passing rounds more clearly. The empty sections in the tables indicate the fact that no energy is left.

Table: Energy of network at fixed interval of rounds for different protocols, nodes=250

Rounds	LEACH	DEGRA	EED	Proposed
1	125	125	125	125
50	82.07926	106.6484	101.8251	109.3347
100	46.88813	89.3455	83.67425	98.09152
150	31.26667	71.68976	75.21389	88.75103
200	21.57556	54.37117	68.812	80.3937
250	15.31887	36.97471	62.66448	72.44484
300	10.33728	19.91572	55.94589	63.00325
350		5.664861	49.4409	53.41634
400			44.63287	45.87272
450			40.1271	38.82479
500			34.5909	32.26088
550			28.38391	26.70717
600			22.66392	21.79144
650			17.82243	17.54508
700			13.80284	14.15978
750			10.56213	11.53994
800			7.812865	9.432249

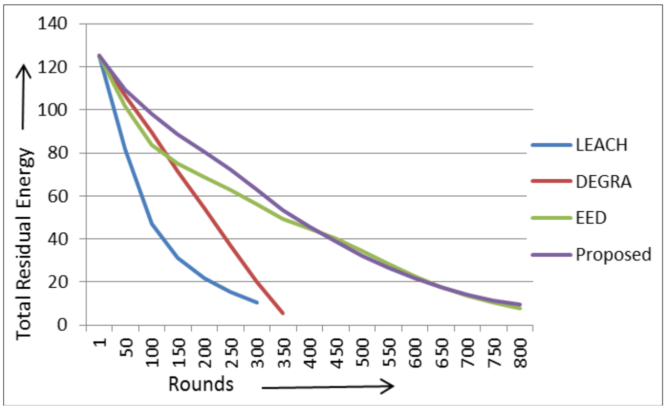

Fig: Fall of network energy with rounds, nodes=250

Conclusion

The efficacy of the proposal is evaluated with comparison of the proposal with popular clustering algorithms like LEACH, DEGRA and EED. The performance evaluation is done in terms of total residual energy, network lifetime and time consumption per round of the protocols. The experiments analyze the performance by varying the number of nodes and the simulation area of the network. A maximized lifetime with faster execution and slowest decrease in the energy of the network makes the proposed improvement visible and the proposed protocol better than the protocols compared.

The proposal is headed taking in mind homogeneous settings in the network and a static environment. Also, the sensor nodes are distributed autonomously and not specifically in the region of interest. Extension of the proposal in heterogeneous settings, dynamic environment and with nodes placed at specific targets is a future area to work upon.

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