Staggered Clustering Protocol: SCP an Efficient Clustering Approach for Wireless Sensor Network

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***Abstract*—Wireless sensor networks are energy limited and imbalance networks, load balancing and energy efficiency is the most challenging task in these networks. The clustering algorithm is a kind of key technique used to reduce energy consumption. Many algorithms have been specifically designed for WSNs, where energy awareness is an essential design issue. The focus, however, has been given to the residual energy based clustering protocols, which might differ depending on the application and network architecture. In this paper, a staggered clustering protocol to prolong the stable region of wireless sensor networks is being proposed. Compared with classical clustering protocols, this protocol can maintain efficient load balancing of networks, and extremely prolong the network lifetime.**

***Index Terms*—Wireless sensor network, clustering , residual energy, network energy**

I. Introduction

Wireless sensor networks which consist of a large number of low-power sensor nodes that are small in size and can be employed in a wide range of applications such as in the military applications, environmental sensing and habitat monitoring [1].Wireless sensor network (WSN) refers to a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment and organizing the collected data at a central location. It is important to design such clustering protocols, which can extend network lifetime, energy consumption and throughput of the network [2]. The sensor nodes are usually irreplaceable, so it requires more attention towards energy efficient protocols. Basically, clustering is the process of grouping the sensor nodes intelligently, which will result in significant improvements in wireless sensor networks [3]. WSNs are networks of distributed autonomous devices that can sense or monitor physical or environmental conditions cooperatively. It faces many challenges mainly caused by communication failures, storage and computational constraints and limited power supply, because of their deployments at inaccessible terrains, disaster areas or polluted environments, where battery replacement or recharge is difficult or even impossible to be performed.WSNs provides reliable monitoring from far away distances. These networks are basically data gathering networks where data are highly correlated and the end user needs a high level description of the environment by the sensing nodes [4]. The sensor nodes not only senses but also processes the data to make itself meaningful by using its embedded microprocessors and also communicates those meaningful data through its transceiver [5]. It emerged due to advancement in micro electro mechanical system and digital electronics which enabled the development of low-cost, low-power,multifunctional sensor nodes that are small in size and communicate in short distances WSNs are basically data gathering networks where data are highly correlated and the end user needs a high level description of the environment by the sensing nodes [6].

Fig 1 shows the clustering architecture of a simple wireless

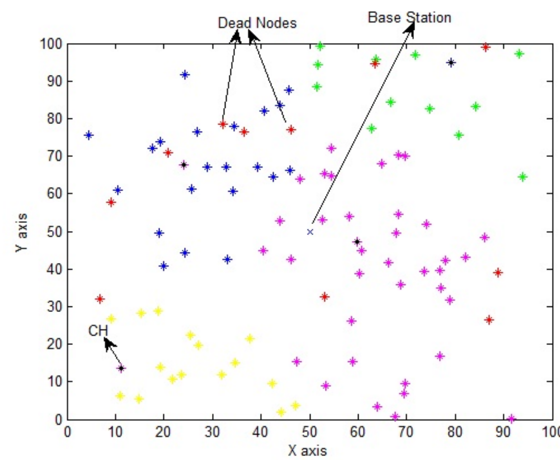

Fig. 1. Clustering in WSN

sensor network comprising of 100 nodes with a transmission range of 25mm.The cluster head is present at the middle of the sensing area.From each cluster the red colour nodes are dead nodes, and the mixture colour nodes are the CHs.

The remainder of this paper is organized as follows: A brief literature survey is given in section II.Clustering parameters for the algorithm is described in section III . Where as section IV shows a detailed description of the algorithm SCP(Staggered Clustering Protocol), simulation result and its analysis is being described in section V.Lastly, section VI concludes the paper.

II. Literature Survey

The clustered protocols has the advantage of minimizing long distance communication with the base station, through the optimized utilization of cluster head nodes and consequently, reduce the energy consumption of the network. Apart from energy consumption issues; data congestion, data loss and collision problems are also experienced in the wireless sensor networks.Data aggregation is performed at the CHs which can be simplified by decreasing the number of redundant packets via intra-cluster communication [7]. Due to the limitation of sensor node energy, emphasis is given to energy-efficient routing protocols to prolong the lifetime of sensor networks. Efficient CH election algorithms are highly desired to balance the distribution of energy load and avoid the degradation of network longevity due to the premature battery drain of any node [8]. Though the energy consumption varies greatly between the nodes in different roles, the roles must be rotated periodically. In view of energy consumption in a wireless sensor network, data transmission is the most important with respect to others. Within a clustering organization, intra-cluster communication can be single hop or multi hop, as well as inter-cluster communication [9]. Researchers have shown that multi hop communication between a data source, and a base station is usually more energy efficient than direct transmission because of the characteristics of wireless channel. Useful energy consumption can be either due to the following items: transmitting/receiving data, processing query requests and forwarding queries/data to neighbouring nodes are application specific. A network is usually designed and deployed for a specific application, and the design requirements of a network changes according to the application [10]. The number of clusters, present in the network, indeed one of the key parameters that determines the lifetime of the sensor network [11], [12]. If the number of clusters is very least then, non-cluster head nodes are likely to spend too much energy transmitting data to their cluster heads because most of the clusters will be of a large size [13]. Multi-hop communication is used for transmission of data from a sensor node to the cluster head. The elected cluster heads collect data from the member nodes in their respective clusters, aggregate the data, and send it to the base station using multi-hop communication [14]. In [15]authors tried to remove the hot spot problem, that arises in multi-hop routing. The hot spot problem arises when the cluster heads closer to the data sink dies due to the burden by heavy relay traffic. MOCA(Multi-hop Overlapping Clustering Algorithm) is a randomized, distributed multi-hop clustering algorithm for wireless sensor network.In this algorithm [16] the clusters are overlapped to facilitate many applications such as inter-cluster routing, topology discovery, node localization and recovery from cluster head failure.Duan and Fan [17] proposed a distributed energy balanced clustering algorithm for hierarchical WSN. Here the cluster heads are elected based on certain probability, which is a function of the residual energy of the node and the average energy of the network.

So to minimize the energy consumption in the network and to maximize the lifetime of the network, this paper proposes (SCP) staggered clustering protocol which solves most of the above cited problems. In addition, two clustering metrics are defined to select the best set of cluster heads, namely the power level of each node and the total communication cost in the network. This algorithm gives better lifetime and uses less energy as compared to LEACH and DEEC.

III. Clustering Parameters

In a clustering scheme, the sensor nodes in a WSN are divided into different virtual groups, and they are allocated geographically adjacent into the same cluster according to some set of rules [18].Under a cluster structure, sensor nodes may be assigned a different status or function, such as cluster head or cluster member. A cluster head normally serves as a local coordinator for its cluster, performing intra-cluster transmission arrangement, data forwarding, and so on [19].The cluster heads can consolidate the data and send it to the data centre as a single packet, thus reducing the overhead from data packet headers. Clustering has the following advantages :

- Reducing useful energy consumption by improving bandwidth utilization (i.e., reducing collisions caused by contention for the channel).
- Reducing wasteful energy consumption by reducing overhead.

Most of the algorithm aims to extend the network lifetime by balancing energy consumption among nodes and by distributing the load among different nodes from time to time. During the reformation of clusters, the cluster head is changed along with the members affiliated to it [20] . Clustering, provides resource utilization and minimizes energy consumption in WSNs by reducing the number of sensor nodes that take part in long distance transmission. In WSN, the primary concern is the energy efficiency in order to extend the utility of the network.

In a clustered network, the cost is divided into intra and inter cluster cost. The intra-cluster communication cost is from the nodes inside a cluster to the cluster head. SCP attempts to maintain the constraint of well-balanced energy consumption in the network. The nodes which have more residual energy at the beginning of each round have more chances to become a cluster head. This protocol mainly concentrates on the average energy level of each node, which can be calculated by dividing the energy level of each node at the energy level of the neighbouring nodes.

Definition (Network Density) : Suppose nodes are deployed in an area A , ρ(x, y)is defined as the network density, with the property:

$$\int_A \rho(x,y)dxdy = 1$$

Definition (Network Energy Intensity) : Network energy intensity E(x, y) is defined as the energy distribution of the network. Suppose the nodes have the same initial energy E_O, then given a region D,

$$E(x,y) = E_O N \int\limits_A \rho(x,y)dxdy$$

This algorithm uses Normal Power Calculation(NPC) to evaluate the power level of each node i.

$$NPC_i = \frac{\sum\limits_{j \in nbr_i} E_j^{current}}{|nbr| \, .E_i^{current}}$$

NPC_i is the set of neighbours of $node_i$, which are located in the detective range of $node_i$, and $|nbr|$ is the total number of nodes in the neighbour list . $E_i^{current}$ is the current residual energy of $node_i$.

NPC reflects the power distinction between the $node_i$ and its neighbours. If NPC_i is more than zero, $node_i$ is a high energy node, which means that $node_i$ have more energy than his neighbours; if $node_i$ is less than zero, $node_i$ is a low energy node, and should have less opportunity to be the cluster-head node.

In heterogeneous sensor networks, both the average power distinction and communication cost for cluster-head selection should be considered,.

$$T_{\cos t} = NPC_i \cdot \frac{\sum\limits_{j \in nbr_i} d_{i,j}^2}{|nbr|}$$

$d_{i,j}$ is the distance between $node_i$ and $node_j$, and this value should be computed by receiving sensitivity. T_{cost} provides a unified criterion for all nodes to select cluster-head nodes, which means that all nodes could use T_{cost} to select cluster-head nodes, which is the nodes with high energy and low communication cost. The radio model utilized in SCP is similar to that of LEACH. The energy consumed by the radio in transmitting L bits data over a distance d is given by the following:

$$E_{Tx}(L,d) = \begin{cases} L \times (E_{elec} + \in_{fs} \times d^2), & if\ d \le d_O, \\ L \times (E_{elec} + \in_{mp} \times d^4), & if\ d \ge d_O \end{cases}$$

where E_{elec} is the energy dissipated per bit to run the transmitter or the receiver circuit. The parameters $\in_{fs}$ and $\in_{mp}$ depend on the transmitter amplifier model used in this paper.

IV. SCP Protocol

The optimal probability of a node to become a CH is a function of spatial density, when nodes are uniformly distributed over the network. This clustering is optimal in the sense that energy consumption is well distributed among all sensor nodes, and the total energy consumption is minimal.First of all the neighbours of each node is detected, by calculating the distance amongst the nodes. When nodes have sufficient information about its neighbours, such as distance and current energy, nodes calculate T_{cost} about itself and broadcast T_{cost} to its neighbours. According to T_{cost}, each node selects the candidate node which has the minimal T_{cost}, and sends $elect_{msg}$ to the candidate node. The nodes which receive the most $elect_{msg}$ in neighbours, will announce that the cluster-head nodes are elected, and all non-cluster-head nodes chose one nearest cluster-head to join the cluster. $node_i$ working as a cluster-head is denoted by CH_i . The set of all cluster-head nodes is denoted by CH , CH $\in$ N , where N is the set of all nodes including cluster-head nodes and non-cluster-head nodes. Let us assume E_0 is the initial energy of each normal node, m fraction of advanced nodes among normal nodes are equipped with α times more energy than the normal nodes.

A. Algorithm

Algorithm 1 SCP Algorithm

d_0=($\in_{fs}$/$\in_{mp}$)*EDA
for $i \leftarrow 1$ to n **do**
  for $j \leftarrow 1$ to n **do**
    d(i,j)=sqrt((($node_i.x - node_j.x)^2$)+($node_i.y - node_j.y)^2$)
    if d(i,j)$\le$ tr && j $\neq$ i **then**
      $node_i$.nbr = $node_j$
    end if
  end for
end for
for $r \leftarrow 1$ to rmax **do**
  for $i \leftarrow 1$ to n **do**
    Calculate NPC_i and $Tcost_i$
    $node_i$.broadcast(NPC_i)
    $node_i$.broadcast($Tcost_i$)
    if $node_i.E \le 0$ **then**
      dead $=$ dead $+ 1$
    end if
    $node_i$.send(elect_msg) to all neighbours
    if $node_i$.receive(elect_msg) from $node_i$.nbr **then**
      $node_i$.ticket $=$ $node_i$.ticket $+ 1$
    end if
    if Max($Node_i$.ticket_msg) **then**
      CH $\Leftarrow$ $node_i$
    end if
    $Node_i$ is not CH, associates with nearest CH
  end for
  for $i \leftarrow 1$ to n **do**
    distance=sqrt(($node_i.x - sink.x)^2 + (node_i.y - sink.y)^2$)
    if $distance > d_0$ **then**
      $node_i$=$node_i - ((10^4)ETX*b*l+EDA*l+ \in_{mp} *b*l(distance)^4)$
    end if
    if $distance \le d_0$ **then**
      $node_i$.E=$node_i.E - ((10^4)*(ETX*b*l+EDA*l+ \in_{fs} *b*l(distance)^2))$
    end if
  end for
end for

TABLE I
SIMULATION PARAMETERS

$Parameter$	$Value$
Area	100×100
Nodes	100
Base Station	(50,50)
Initial Energy	2J
E_{elec}	50nJ/bit
$\in_{fs}$	10pJ/bit/m^2
$\in_{mp}$	0.0013pJ/bit/m^4
EDA	5nJ/bit/message
Packet Size	2000 bits
Frames/round	30

In clustering process, the distance of each node to every other node is calculated to detect the neighbours. After neighbour detection is done, each node broadcasts its current energy information to all other nodes i.e. to the neighbours. Then after getting the energy information from the neighbours, each node calculates the distance by comparing the signal strength they have received. The value of NPC(Normal Power Calculation) is calculated by dividing the summation of energy of all the neighbours with the product of total number of nodes and the energy level of the current node. In heterogeneous network it is important to calculate the transmission cost, which directly influences the lifetime of the network, so it is important to calculate the value of T_{cost}. After the calculation of NPC and T_{cost} it checks for the dead nodes. When the number of dead node reaches 50 % of the nodes it stops the algorithm.Before the start of the actual clustering process it initializes the counters packets_TO_BS and packets_TO_CH to zero.

V. Simulation and Result discussion

We simulate a wireless sensor network of 100 nodes in a 100×100 square area using MATLAB, and the sink node is located in the centre of the area. The simulation parameters are shown in table I.We assume that m is the percentage of the nodes which are equipped with a times more energy than the normal nodes. The initial energy of normal node is 2J, so the initial energy of advance node is 0.5(a + 1) J.LEACH is considered as the basic clustering algorithm which gave a new direction to the field of clustering in WSN, where as DEEC uses the two level heterogeneity to get better lifetime than the LEACH.So, we consider these two algorithms to compare the result of our algorithm.

The performance of SCP protocol is compared with LEACH and DEEC in the same heterogeneous setting, where m =0.2, a =8,b=2,l=2000 and tr is the transmission range..

Fig 2 shows the number of cluster heads created in each round.The number of CHs created in each round is not same, because the number of cluster is not fixed.According to the transmission range and the strength of energy information received, the clusters are created.If there is any node present, who doesn't come in the scope of any other CH then that becomes a CH.If we can minimize the number of cluster heads then it will be helpful for getting higher lifetime.Because, if there will be higher number of nodes will be appointed as the CH then the energy level of all the cluster heads decreases drastically; so the lifetime will be affected.

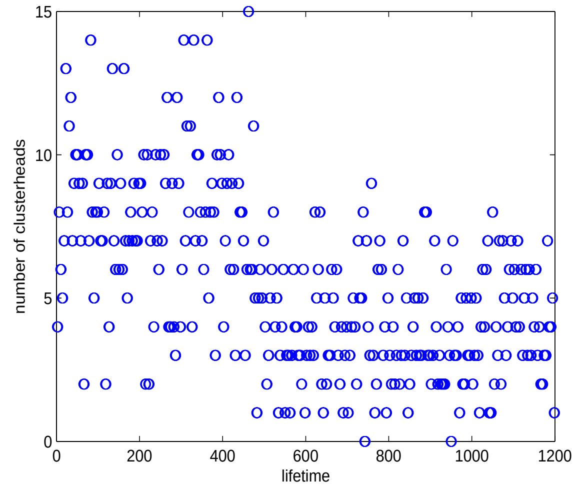

Fig. 2. Number of Cluster heads per round

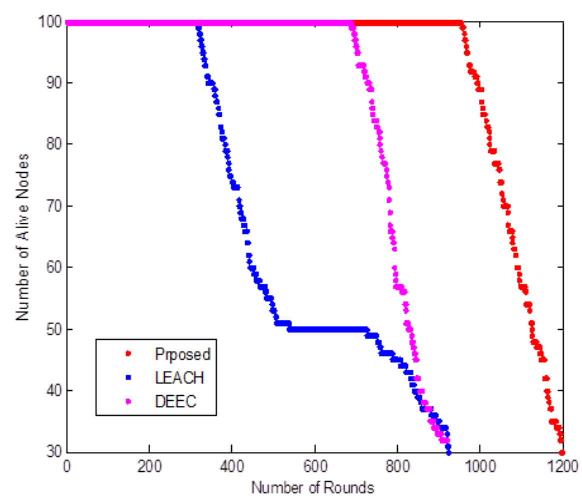

Fig. 3. Lifetime of the algorithms

Fig 3 shows that SCP extremely extend the stable region compared to LEACH by 152.16% and DEEC by 69.17%. On the other hand, SCP increases the ratio of stable region in network lifetime. SCP select high energy nodes to be the cluster-head for load balancing, and low energy nodes spend less energy than high energy nodes. So SCP avoids the death of low energy nodes to earlier and prolongs the stable region of the wireless sensor networks.

Fig 4 shows that the residual energy of SCP is higher than LEACH and DEEC. Residual energy is the ratio of actual energy, and the amount of energy left with the node. The node which is having more residual energy will have more chances to become a CH. LEACH uses random probability to select cluster-head nodes; so residual energy has no role in

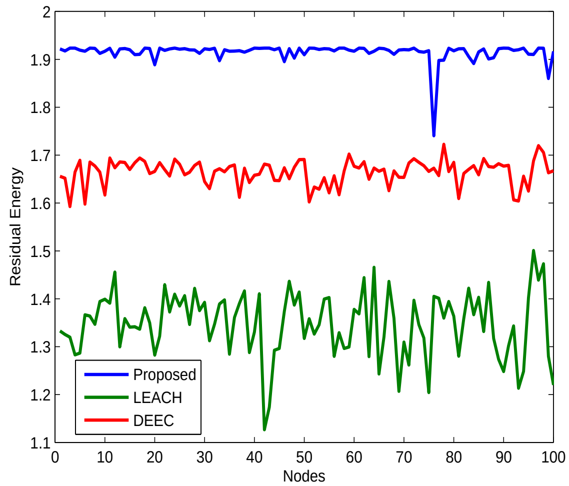

Fig. 4. Residual Energy based comparison

selection of cluster heads. But in DEEC, the advance nodes have more opportunity to be the cluster-head, so the residual energy parameter plays a small role in selection of CHs. SCP has the best performance in residual energy, because SCP do not use random mechanism for cluster-head selecting, thus SCP could accurately select the high energy node with low communication cost to be the cluster-head, and implement load balancing.

We also analyse the performance of SCP with different m and a , the experiment result show that the stable region of SCP is far more than that of LEACH and DEEC, even in the homogeneous networks.

VI. Conclusion

In this paper, SCP, a staggered clustering protocol for two-level heterogeneous wireless sensor networks is proposed. This protocol not only takes care of the efficient load balancing but also minimizes the cost of communication energy to increase the lifetime of the network. This protocol does not need any of global energy knowledge at clustering process. As long as nodes exchange local information, cluster-head nodes could be selected. SCP is scalable to a large number of nodes, because it doesn't require any prior information, It mainly depends on local information sharing like energy information and communication cost. Simulation results are discussed to describe the effect of CH selection, cluster density and frequency of re- election. In addition to energy constraints, Quality of Service metrics such as delay, data loss tolerance, and network lifetime are carefully handled to expose reliability issues for the clustering algorithm.

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