Energy Efficient Dynamic Multi-level Hierarchical Clustering Technique for Network Discovery in Wireless Sensor Networks

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Abstract

For the past few decades wireless sensor networks have significantly drawn extensive attention of the research community. The sensor nodes are characterised by self-organising ability and energy constraint. One of the most important challenges faced in the development of WSN is the optimal energy management. In this paper, we propose a technique by which energy consumption can be reduced by introducing dynamic multilevel hierarchical clustering and where by enhancing the network lifetime. An energy consumption model is framed to make a better analysis of the system. A state transition pattern for the nodes is also allotted for the introduced nodes to make better use of the inherent energy of each node.

Keywords: Hierarchical clustering, State transition, Network lifetime

I. INTRODUCTION

Wireless sensor networks have been one of the main research topics in the last decade owing to the wide range of applications provided in the fields of public safety, medical issues, environmental monitoring, security, military and transportation. The evolution of the MEMS technology made the sensor studies even more promising. The advancements in the fields of wireless communication and digital technology along with the emergence of MEMS technology has made the development of low-cost, low-power, multi-functional, self-organising smart sensor nodes possible. The smart nodes are powered with integrated sensing, processing and communicating capabilities.

It is well acknowledged that clustering is an efficient way to save energy for sensor networks[1]. By clustering, firstly, data compression in the form of distributed source coding is applied within a cluster to reduce the number of packets to be transmitted. Secondly, the data-centric property makes an identity (e.g., an address) for a sensor node obsolete. In fact, the user is often interested in phenomena occurring in a specified area, rather than in an individual sensor node. Thirdly, randomized rotation of cluster heads helps ensure balanced energy consumption.

Heinzelman [4] introduced a hierarchical clustering algorithm for sensor networks called low energy adaptive clustering hierarchy (LEACH). LEACH is a cluster-based protocol that includes distributed cluster formation. The authors allowed for a randomized rotation of the cluster head’s role in the objective of reducing energy consumption (i.e., extending network lifetime) and to distribute the energy load evenly among the sensors in the network. LEACH uses localized coordination to enable scalability and robustness for dynamic networks and incorporates data fusion into the routing protocol in order to reduce the amount of information that must be transmitted to the base station. But selective rotation of cluster head [2] proved more advantageous.

The Hybrid Energy Efficient Distributed Clustering Protocol [HEED] [5], proposed by Ossama Younis and Sonia Fahmy, picks up the cluster head from the group of nodes on the basis of their residual energy and other parameters like the node degree [3] or proximity of the nodes to the sink node. The protocol was found to be providing an extended lifetime to the network compared to the LEACH network.

The proposed model employs Dynamic Hierarchical Clustering in which the cluster head changes after particular intervals of time on the basis of the residual energy and node degree of the nodes. The efficiency is enhanced when Hierarchical clustering is implemented by considering the traffic in the network [6].

The rest of the paper is organized as follows. Section II describes the basic technique of Dynamic Multi level Hierarchical clustering. Section III deals with the system modelling which includes an energy model for the network, a state transition pattern and a network model. Implementation of the derived algorithm is explained in Section IV. Simulation results are discussed in Section V.
II. DYNAMIC MULTILEVEL HIERARCHICAL CLUSTERING

A sensor uses its energy to carry out three main actions: acquisition of data, communication between nodes and data processing. The power consumption to perform the data acquisition is not very important. Although, it varies according to the phenomenon observed and monitoring type. The communications consume much more energy than other tasks, in emission as well as in reception.

One of the most common clustering algorithms, the dynamic clustering technique, aims at the spot formation of a cluster and dynamically choosing its cluster head on the basis of residual energy and distance between the nodes. The number of nodes constituting the cluster is also variable.

In this work, we consider wireless networks in which all the nodes in the network are homogenous and energy constrained, and each node can directly communicate with any other node in a given area. In this environment, instead of using a flat configuration, adopting the clustering approach can statistically multiplex many connections into a few paths so that the overall interferences can be reduced with well-controlled access.

Apart from being dynamic, the network designed in this paper is multi-level hierarchical in nature as shown in Fig.1. Here, a group of nodes together forms a cluster and chooses a cluster head from among the member nodes depending on the maximum residual energy, the distance between the nodes and the node degree. The cluster heads of different clusters again forms a cluster and chooses its head upon the same criteria and so on. So the whole system can be said to be multi-hierarchical in nature.

III. SYSTEM MODELLING

(a) Energy Model for the Network

It is important to consider the energy model for the network. The energy is calculated by considering the packet size and the sending distance. Let the packet size be taken as ‘k’ (in bits) and the sending distance be ‘d’.

Along with the transmission and reception energies, energy consumed at the cluster head during the processing of the aggregated data should also be taken into account. This energy is uniquely considered only for the cluster head. Thus we need to consider three energies in this case.

1. The energy during the transmission of k bits over a distance d, (E(t)).
2. The energy consumed during the reception of the same packet (E(r)). And
3. The energy consumed at the cluster head due to the processing of the data (E(p)).

The residual energy in a node after each operation or time interval is calculated by subtracting these energies which are consumed from the initial energy in the cluster head.

So the residual energy of the cluster head is given as

\[ E(c) = E(i) - (E(t) + E(r) + E(p)) \]

where Ei is the initial energy in the cluster head.

For an ordinary forwarding node, the residual energy can be calculated on the following formula as

\[ E(c) = E(i) - (E(t) + E(r)) \]

(b) State-Transition in the system

It is a peculiar characteristic of wireless sensor network that the network is active only for a particular interval of time or at the occurrence of the event. After the event, till the next event, the network need not waste its power and be in the on mode. The network, if shifted to an off mode or semi-on mode, such that it consumes less power, the lifetime of the network can be improved and the system can be made to be more energy efficient.

It is possible to set the state of the network according to the utility. We can actually take the network through 6 different modes as follows.
Mode 1: sleeping-sensing off and radio off;
Mode 2: sensing -sensing on and radio off;
Mode 3: receiving -sensing on and radio receiving;
Mode 4: transmitting –sensing on and radio transmitting;
Mode 5: listening - sensing on;
Mode 6: long sleeping- sensing off and radio off forever, not responding.

The shift of modes according to the state of the network makes it more energy efficient.

(c) The Network Model

In our network, a set of sensor nodes are considered which are randomly deployed in the square area of interest. We assume certain characteristics for our network as follows.

1. The sink node is fixed and is located away from the sensing nodes.
2. All nodes in the network are similar with limited energy. All nodes are assumed to possess same initial energy.
3. The position of each node can be located by x and y co-ordinates in 2-D geometry.
4. All nodes are assumed to have the same range of communication and the maximum range of communication is denoted as R.

IV. SYSTEM IMPLEMENTATION

An algorithm for the dynamic multilevel hierarchical clustering with state transition can be written as

1. Set a timer (Ti).
2. Check if it is the time of nodes.
3. Input the number of levels of hierarchy required (M).
4. Set a counter variable (N) to one.
5. Input the traffic density (T) of all the cluster heads.
6. Choose a set of heads such that the sum of traffic densities (T) is not more than the threshold value.
7. Find the cluster head with minimum value of T in the group.
8. Assign it as the cluster head for the next level.
9. Increment the counter to indicate the formation of one level.
10. Repeat the steps from 5 until the number of levels specified by M, is fulfilled.

This proposed energy efficient system can be implemented in two phases. The phases and the implementation of the system is explained below in detail

Phase 1

The first phase of the system aims at the setting up of a wireless sensor network scenario as shown in Fig.2 which will be dynamic in nature. In order to implement this network, we first form a network consisting of around 25 nodes and a sink node. The nodes will be capable of dynamically choosing their head.

Phase 2

In the second phase, the network is expanded to accommodate around 30 nodes as shown in Fig.3. In order to prove our assumptions and considerations energy consumed by the nodes during the selection of cluster head and the lifetime of the network is
measured and is compared with the existing wireless sensor network protocols like HEED and LEACH.

Fig. 3 Network with hierarchical clustering

The nodes in the dynamic multi-hierarchical network are also designed to be capable of opting the best adaptable mode while in this active network. This contributes considerably to the energy conservation in the network and thereby improving the lifetime.

V. SIMULATION RESULT

The proposed protocol was implemented with the help of network simulator version 2. The power consumed by each node in the network was considerably reduced due to the implementation of different states of operation and dynamic hierarchical clustering. Along with the reduced power consumption and time of death of the first node and the throughput was also found to be better. As a result, the network so formed showed an improvement in its overall lifetime and network discovery.

As depicted in Fig.4, the network lifetime using dynamic multi level hierarchical clustering protocol was compared with the existing LEACH protocol and it was found that the dynamic hierarchical clustering proves to be about 23% better in lifetime compared to LEACH. For HEED protocol, which is implemented for Ad-Hoc, does not have energy constrain issue as their energy can be replenished. A network consisting of 30 nodes was created for this comparison. The energy consumed in each network for a particular interval of time was observed and plotted. It was found that the energy consumption in the proposed network was much less compared to the other protocols.

Fig. 4 Comparison of Network lifetime

Fig. 5 Comparison of delay

When the delay of the three protocols was compared, as shown in Fig.5, the delay in the HEED protocol network was found to be the least as the nodes form an Ad-Hoc network. The delay in hierarchical clustering was found to be less compared to the delay in the LEACH protocol network.

As in the case of delay, the throughput was also found to be about 10% better in hierarchical clustering than LEACH protocol and the throughput was nearly equal to the throughput provided by the HEED protocol as depicted in Fig.6.

Fig. 6 Throughput comparison of LEACH, HEED and dynamic multi level hierarchical clustering
CONCLUSION

We have proposed a system for the sensor networks which is more energy efficient and faster in network discovery. The system was observed to provide considerably better performance when compared to the existing systems. In a sensor network deployed for fields like military, security of the packet transferred is of prime importance. The network can be modified as a secure wireless sensor network with better lifetime and energy efficiency.

REFERENCES


