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Energy Efficient Homogeneous vs Heterogeneous LEACH

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Abstract— In Wireless sensor Networks (WSNs), it is an important task to periodically collect data from an area of interest for time-sensitive applications. The Wireless sensor network (WSN) is a type of the wireless ad-hoc networks. It consists of a large number of sensors and those are effective for gathering data in a variety of environments. Clustered sensor networks can be classified into two broad types; homogeneous and heterogeneous sensor networks. In homogeneous networks all the sensor nodes are identical in terms of battery energy and hardware complexity. On the other hand, in a heterogeneous sensor network, two or more different types of nodes with different battery energy and functionality are used. There are two desirable characteristics of a sensor network, viz. lower hardware cost, and uniform energy drainage. While heterogeneous networks achieve the former, the homogeneous networks achieve the latter. However both features cannot be incorporated in the same network. In this paper based on classification of sensor networks we are briefing LEACH as the representative single hop homogeneous network, and a sensor network with two types of nodes as a representative single hop heterogeneous network.

Keywords— Clustering, energy efficiency, homogeneous, heterogeneous, LEACH protocol, wireless sensor networks.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are being used in wide range of potential applications such as environment monitoring, military operations, target tracking and surveillance system, vehicle motion control, earthquake detection, patient monitoring systems, pollution control system etc.[1] These networks consist of SNs which are capable of monitoring and processing the data from a particular geographical location and send the same to remote location which is called as Base Station (BS). WSNs typically consist of small, inexpensive, resource con- strained devices that communicate among each other using a multi hop wireless communication. Each node of WSN is called as a SN which contains one sensor, embedded processors, limited memory, low-power radio, and is normally operated with battery. Each SN is responsible for sensing a desired event locally and for relaying a remote event sensed by other SNs so that the event is reported to the destination through BS. As SNs have limited energy so applications and protocols for WSNs should be carefully designed for optimized consumption of energy for prolonging the network lifetime. Fig. 1 shows the generalized view of WSNs, which consists of a BS, Cluster Heads (CHs) and SNs deployed in a geographical region.

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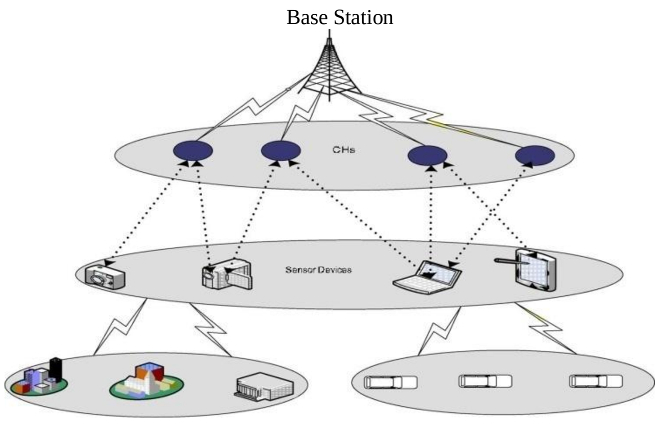
Clustered sensor networks can be classified into two broad types; homogeneous and heterogeneous sensor networks [2]. In homogeneous networks all the sensor nodes are identical in terms of battery energy and hardware complexity. With purely static clustering (cluster heads once elected, serve for the entire lifetime of the network) in a homogeneous network, it is evident that the cluster head nodes will be over-loaded with the long range transmissions to the remote base station, and the extra processing necessary for data aggregation and protocol co-ordination. As a result the cluster head nodes expire before other nodes. However it is desirable to ensure that all the nodes run out of their battery at about the same time, so that very little residual energy is wasted when the system expires. One way to ensure this is to rotate the role of a cluster head randomly and periodically over all the nodes as proposed in LEACH [5].



Community Network Vehicular Ad hoc Network
Fig. 1 Generalized view of WSN

However the downside of using a homogeneous network and role rotation is that all the nodes should be capable of acting as cluster heads, and therefore should possess the necessary hardware capabilities. On the other hand, in a heterogeneous sensor network, two or more different types of nodes with different battery energy and functionality are used. The motivation being that the more complex hardware and the extra battery energy can be embedded in few cluster head nodes, thereby reducing the hardware cost of the rest of the network. However fixing the cluster head nodes means that role rotation is no longer possible. When the sensor nodes use single hopping to reach the cluster head, the nodes that are farthest from the cluster heads always spend more energy than the nodes that are closer to the cluster heads. On the other hand when nodes use multi hopping to reach the cluster head, the nodes that are closest to the cluster head have the highest energy burden due to relaying. Consequently there always exists a non-uniform energy drainage pattern in the network. Thus there are two desirable characteristics of a sensor network, viz.

lower hardware cost, and uniform energy drainage.

While heterogeneous networks achieve the former, the homogeneous networks achieve the latter. However both features cannot be incorporated in the same network.

Clustered sensor networks could also be classified as single hop and multi-hop. A single hop network is one in which sensor nodes use single hopping to reach the cluster head. In a multi-hop network nodes use multi-hopping to reach the cluster head. In both cases, the cluster heads use single hopping to reach the base station, since we assume a remote base station.

II. SINGLE HOP NETWORKS

In a single hop network, the sensor nodes communicate directly with the cluster head using a single hop transmission [2]. The nodes are assumed to have power control features so as to adjust their transmit power.

A. Single Hop Homogeneous Network: LEACH

Following are some of the salient features of a single hop homogeneous sensor network.

• Since all the nodes are identical, the main design objective is to guarantee a certain network lifetime (in terms of number of data gathering cycles), and at the same time ensure that all the nodes expire at about the same time so that there is very little residual energy left behind when the network expires. Hence LEACH uses random and periodic rotation of the cluster heads for load balancing. Role rotation also ensures that a node which is located near the periphery of a cluster is nearer to the cluster head at some other time.

• Since each node has to be capable of acting as a cluster head, it is necessary for each node to have the hardware capable of performing long range transmissions to the remote base station, complex data computations (if required), and co-ordination of MAC and routing within a cluster.

• Since all the nodes are capable of acting as a cluster head, the failure of a few nodes does not seriously affect the working of the scheme. Thus the system is robust to node failures.

B. Single Hop Heterogeneous Networks: Two Types of Nodes

Heterogeneous sensor networks use two or more types of nodes with different functionalities. For example, the authors in [3] propose using two types of nodes; type 0 nodes which act as pure sensor nodes, and type 1 nodes which act as the cluster head nodes. Some of the salient features of such networks are:

• Since the cluster head nodes are predetermined, and the sensor nodes use single hop communication to reach the cluster head nodes, the sensor nodes near the periphery of the cluster have the highest energy expenditure among all the sensor nodes. It is this worst case energy expenditure that has to take into account in battery energy dimensioning. Thus there is a waste of energy due to the residual battery energy of the sensor nodes that are near the cluster heads.

• Since only the cluster head nodes bear the responsibility of transmitting to the distant base station, the rest of the nodes can be designed with simple hardware that enables short range communication. Thus the hardware complexity is limited to only a few nodes. On the other hand this also means that for the cluster head deployment should be carefully engineered to ensure uniform clustering.

• A cluster head node serves as the fusion point, as well as the command centre of its cluster. As a result when a cluster head node fails, all the sensor nodes in that cluster have to be re-assigned to other neighboring clusters. In the extreme case, it is possible that all the cluster head nodes might fail, thereby bringing down the entire network. Thus the system is less robust to node failure as compared to a homogeneous sensor network.

III. LITERATURE WORK

3.1 Static Clustering Protocol

In this protocol, the sensor nodes from the entire network are shown in Fig. 2 are divided into several clusters, cluster-head nodes communicate with the local base station, then the local base station feed data to the entire network of base stations, and terminal user can access useful information. The distance between the local base stations and the cluster node was very close, therefore greatly reducing the energy consumption of these nodes send their information to local base station. In view of this, static clustering protocol seems to be a more efficient communication protocol [4]-[7].

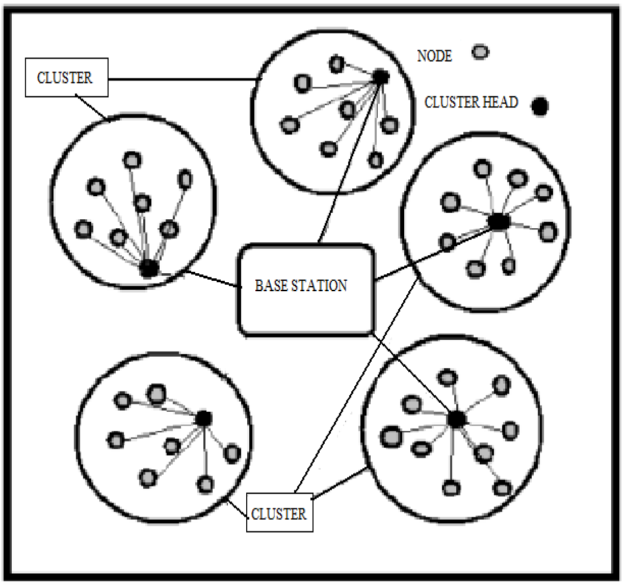


Fig.2 LEACH Protocol

However, in the entire network life cycle, these clusters and cluster-head nodes are fixed, and the local base station is assumed as a high energy nodes situation. In most cases, the local base station is an energy-constrained node. The entire network may die soon because of excessive using about local base station node.

3.2 Low-Energy Adaptive Clustering Hierarchy Protocol (LEACH)

LEACH, which was presented by Heinzelman in 2000 [9]-[10] is a low-energy adaptive clustering hierarchy for WSN. The operation of LEACH can be divided into rounds. Each round Begins with a set-up phase when the clusters are organized, followed by a steady state phase where several frames of data are transferred from the nodes to the cluster head and on to the base station.

During the set-up phase,

each sensor node tries to select itself as a cluster head according to probability model. Fig. 3 demonstrates the LEACH protocol Phases.

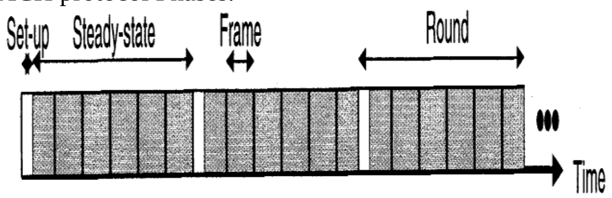


Fig. 3 LEACH Protocol Phases

The different phases involved in LEACH protocol are as follows:

3.2.1 Advertisement Phase

*Initially, when clusters are being created, each node decides whether or not to become a cluster head for the current round. This decision is based on the suggested percentage of cluster heads for the network (determined a priori) and the number of times the node has been a cluster head so far. This decision is made by the node **n** choosing a random number between 0 and 1. If the number is less than a threshold **T(n)**, the node becomes a cluster-head for the current round. The threshold is set as:*

$$\begin{cases} \frac{p}{1-p*(r \bmod \frac{1}{p})} & if\ n \in G \\ 0 & if\ n \notin G \end{cases} \quad (1)$$

*Where **p** = the desired percentage of cluster heads (i.e. 5% as suggested by LEACH), **r** = the current round, and **G** is the set of nodes that have not been cluster-heads in the last **1/p** rounds. Using this threshold, each node will be a cluster-head at some point within 1/p rounds. During round 0 (r=0) each node has a probability p of becoming a cluster-head. The nodes that are cluster-heads in round 0 cannot be cluster-heads for the next 1/p rounds. Thus the probability that the remaining nodes are cluster heads must be increased, since there are fewer nodes that are eligible to become cluster-heads. After 1/p - 1 rounds, T =1 for any nodes that have not yet been cluster-heads, and after 1/p rounds, all nodes are once again eligible to become cluster-heads. Here it is assumed that all nodes begin with the same amount of energy and being a cluster-head removes approximately the same amount of energy for each node. Each node that has elected itself a cluster-head for the current round broadcasts an advertisement message to the rest of the nodes. For this "cluster-head-advertisement" phase, the cluster-heads use a CSMA MAC protocol, and all cluster-heads transmit their advertisement using the same transmit energy. The non-cluster head nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the cluster-head nodes. After this phase is complete, each non-cluster-head node decides the cluster to which it will belong for this round. This decision is based on the received signal strength of the advertisement. Assuming symmetric propagation channels, the cluster head advertisement heard with the largest signal strength is the cluster-head to whom the minimum amount of transmitted energy is needed for communication. In the case of ties, a random cluster-head is chosen.*

3.2.2 Cluster Set Up Phase

After each node has decided to which cluster it belongs, it must inform the cluster-head node that it will be a member of the cluster. Each node transmits this information back to the cluster-head again using a CSMA MAC protocol. During this phase, all cluster-head nodes must keep their receivers on.

3.2.3 Schedule Creation Phase

The cluster-head node receives all the messages for nodes that would like to be included in the cluster. Based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule telling each node when it can transmit. This schedule is broadcast back to the nodes in the cluster.

3.2.4 Data Transmission Phase or Steady state Phase

Once the clusters are created and the TDMA schedule is fixed, data transmission can begin. Assuming nodes always have data to send, they send it during their allocated transmission time to the cluster head. This transmission uses a minimal amount of energy (chosen based on the received strength of the cluster-head advertisement). The radio of each non-cluster head node can be turned off until the node's allocated transmission time, thus minimizing energy dissipation in these nodes. The cluster head node must keep its receiver on to receive all the data from the nodes in the cluster. When all the data has been received, the cluster head node performs signal processing functions to compress the data into a single signal. For example, if the data are audio or seismic signals, the cluster-head node can beam form the individual signals to generate a composite signal. This composite signal is sent to the base station. Since the base station is far away, this is a high-energy transmission. This is the steady state operation of LEACH networks.

IV. RADIO MODEL FOR ENERGY CALCULATION

In this paper, we use the first order radio model. Here are some assumptions for the mechanism [11].

(1) All sensors are within the wireless communication range when they communicate with each other or with the BS.
(2) All sensors have homogeneous sensing, computing and communication capabilities.
(3) All sensors are randomly deployed in WSN.
(4) BS is located in the centre of the sensor networks and BS has infinity energy resource.
(5) All sensors in the network have the same initial energy resource and dissipate their energy resource at the same rate.
(6) Network lifetime is defined as the time span from the deployment to the instant when the first sensor dies (or when the entire sensors die). According to (5), all the sensors would exhaust their energy resource at the same time.

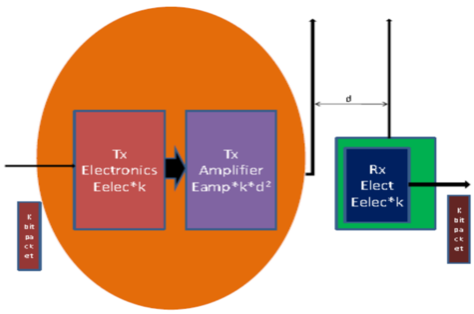


Fig.4 First Order Radio Energy Model

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(7) Both the energy dissipation of sensing data and the energy dissipation for clustering are neglected. Compared with the power consumption of CPU and Radio, the power consumption of sensor part is so small that can be neglected. Also, we suppose that all the clustering algorithms are run on the BS and no energy dissipation of clustering on sensor nodes.

(8) The time span that BS collects the information from all the sensors once is defined as a round. In a round, each sensor has only one sensed data with the same packet size.

(9) The sensors that receive the data combine one or more packets to produce a same-size resultant packet, and by this way, the number of data that need to send by radio is reduced. This is reasonable, because it is generally used to the scenario that there is much correlation among the data sensed by the different sensors.

(10) The energy dissipation of fusing one bit data is a constant value. Therefore, the equations used to calculate transmission costs and receiving costs for a 1-bit message and a distance d are respectively shown in Fig. 4.

Radio energy dissipation model adopted wireless channel models in the reference [10]. Thus, to transmit a 1-bit message a distance d, the radio expends:

$$E_{Tx}(k,d) = \begin{cases} kEelec + k\epsilon_{fs}d^2 & d < d_o \\ kEelec + k\epsilon_{fsmp}d^4 & d \geq d_o \end{cases} \quad (2)$$

The electronics energy, Eelec, depends on factors such as the digital coding, filtering and spreading of the signal, whereas the amplifier energy, ε_{fs}, d_2, ε_{mp}, d_4 depend on the distance to the receiver and the acceptable bit error rate and d_o is a distance constant. To receive this message, the radio expends:

$$E_{Rx}(d) = kEelec \quad (3)$$

V. CONCLUSION

It is evaluated Leach- heterogeneous system significantly reduces energy consumption and increase the total lifetime of the wireless sensor network compared to the homogeneous LEACH protocol. It can be seen that nodes remains alive for a longer time (rounds) in Leach-Heterogeneous system than Leach- Homogeneous system. Note that further increasing of the number of nodes in the heterogeneous system and the area does improve the network lifetime considerably. Leach-Heterogeneous System provides better performance in energy efficiency and increasing level in lifetime of the wireless sensor networks. We conclude that the heterogeneous wireless sensor networks are more suitable for real life applications as compared to the homogeneous counterpart.

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