A Survey of Cluster-based Hierarchical Routing Protocols

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Abstract:

Wireless Sensor Networks consists of small miniaturized Sensor nodes which collect data from their environment and route to a central Base Station. Due to their resource constraint nature, various routing protocols have been design to reduce the consumption of energy of the nodes. In this paper we have presented a brief survey of Cluster-based Hierarchical routing protocols. These protocols organize the nodes into small groups known as Clusters. One node per Cluster is elected as Cluster-Head (CH) in each round to transmit the data to the Base Station. CHs are either selected by the desire node itself or by the Base Station. We have presented a comparison among these clustering protocols in Section based on various features which highlights their transmission mode and selection algorithms for CHs.

Keywords: Wireless Sensor Network, LEACH, Cluster Head, Base Station

1. Introduction

Advancement in Micro-Electro-Mechanical System (MEMS) has enabled the development of miniaturized sensor nodes [1]. These tiny nodes collaborate with each other via RF communication in ISM (Industrial, Scientific and Medical) band to form Wireless Sensor Network (WSN). Wireless Sensor Networkis a breakthrough in the world of wireless communication. It is hard to imagine an application without WSN. They have the capabilities to reach hostile and remote locations where the presence of human being is hazardous and out of reach of traditional wired and wireless communication [1]. These networks are attracting a lot of research and billions of dollars [2] are currently being invested in these networks to bring a comfort in human life. These networks are unique as compared to traditional wired and wireless networks because they possess seal-healing and self-organizing characteristics which differentiate them from other networks. Regardless of their unique characteristics, they are constraints on resources. These small sensor nodes are very small in size and hence energy is a limited resource. Apart from energy, these nodes are low on battery power, memory, processing capabilities, security features and available bandwidth [1]. These nodes are capable to deliver the captured phenomena of interest to the base station via multi-hop or single hop link. However, multi-hop links are preferred mode of communication in order to reduce the consumption of energy. Like any network, routing in WSN is characterized by various types of routing protocols. Routing in WSN is a challenging task and hence the design of routing protocols as well. Routing protocols in WSN are of three types: Data-Centric, Location-Based and Clustering-Hierarchical. Data-centric protocols route the data to their hop (upper level) nodes and the data ultimately reaches the base station. The problem with these protocols is that a large amount of redundant data is being transmitted to the base station. The base station is only interested in a brief description of the data about the phenomena of interest (an event). In location based routing data

is always being transmitted to the specific location of the nodes and this type of communication becomes highly cumbersome and complicated in case of mobility of the nodes. The most optimal results are being achieved with Cluster-based Hierarchical protocols in which the nodes organize themselves into groups known as Clusters. One node among each cluster is elected as the leader known as Cluster head. The cluster head collect data from each node in a particular cluster and transmit to the base station after aggregation. The cluster head is rotated in each round in order to balance the load among all the nodes in a particular cluster [3]. The scope of this paper is restricted to a brief survey of these protocols in order to enhance the life time of the nodes and ultimately the life time of the network.

The paper is organized into four major sections. In Section II, a brief literature overview is presented. In Section III, comparison of various Cluster-based Hierarchical protocols is being made. Section IV concludes the paper with future directions.

2. Clustered-Based Routing Protocols Overview

LEACH [4]: Low-Energy Adaptive Clustering Hierarchical or LEACH rotates Cluster Heads (CHs) in each round randomly. The purpose of this rotation is to balance consumption of energy among all the nodes in the cluster.

LEACH protocol operates in rounds. Each round consists of a Setup Phase and Steady-State Phase. Cluster formation and Cluster Heads selection take place during Setup phase. The flow of data to the base station via Cluster Heads is initiated in Steady-State phase. In Setup phase, a node wishing to become a CH choses a random number between 0 and 1. If this number is less than the threshold value of equation 1, it is elected as CH. Once a node is elected as CH, it advertises its decision to the nodes in its close vicinity. Based on the signal strength of CHs advertisement message, a normal sensor node choses it's CH. The threshold value is

$$T(n) = \begin{cases} \frac{p}{1 - p\,(r \bmod 1/p)}, & n \in G \\ 0 & n \notin G \end{cases} \qquad \text{Equ. 1}$$

Here p is optimal percentage of CH nodes, r is the current round and n is the number of nodes which have not been elected as CHs in the previous 1/p rounds and must belong to the set G, where G are all the nodes which are not elected in the previous 1/p rounds.

LEACH-C [5]: Centralized LEACH protocol uses the same Steady State phase of the LEACH protocol but with slight modification in the Setup phase.In this protocol, the CHs are being selected by the base station using simulated annealing algorithm [6]. In each round, the nodes transmit their location information and residual energy to the base station. Based on residual energy of the nodes, the base station elects an optimal number of nodes in each round. Optimal number of nodes to be elected as CHs is predetermined at the time of deployment; normally 5% of nodes are elected as CHs in each round.

CELL-LEACH [7]: Introduces the concept of cell in LEACH protocol. In this protocol, WSN is divided into clusters. Each cluster has seven cells and one CH. Each Cell has a Cell-Head which act as a mini-CH. The position of CH and Cell-Head changes in each round but the Clusters and cells are fixed throughout the network lifetime. Base station transmit an event of interest (to be sensed) to the all the CHs which in turn forward to the respective Cell-Heads. Cell-Heads broadcast the phenomena of interest to their respective cell members. Cell-Head allocate TDMA slots for each of its cell member. When any of the nodes in the cell capture the event, it broadcast it to its Cell-Head which perform data aggregation and fusion. It is interesting to note that unlike LEACH protocol, Cell-Leach perform data aggregation at the Cell level (by Cell-Head) and at the Cluster Level (by CH). Hence more efficient data signal is delivered at the BS.

I-LEACH [8]: Improved-LEACH protocol serves two functions: detection of Twin nodes and assignment of Sub-Cluster Head (SCH) nodes. WSN is deployed randomly and hence it is highly probable that two or more nodes will be located very close to each other. These nodes are known as Twin nodes. It is obvious that these nodes will sense the same event and hence it become necessary to keep one of the two twin nodes in sleep mode until the first one run out of

energy. Leach protocol does not guarantee uniform distribution of CH nodes and hence some of the nodes have to transmit over longer distance to reach CH nodes. Also, some CH manages more than threshold number of nodes and hence drain out its energy quickly as compared to other CHs. Improved-LEACH aims to address the above mentioned issues.

E-LEACH [9]: Energy-LEACH protocol modifies LEACH by frequently selecting node with more energy as CHs. This protocol is based on the assumption that nodes starts with equal amount of energy at the beginning. During first round as all the nodes have equal energy, any of the n nodes (n is less than N) can be elected as CHs with probability p, where n=N*p. After the first round, all the nodes in the network have roughly different energy level. In the second round, again n nodes which have higher residual energy than the rest of the nodes will be elected as CHs. This approach balances the energy load among all the nodes of the network.

MH-LEACH [10]: Multi-Hop LEACH protocol is almost identical to LEACH. It differs from leach in the transmission pattern to the base station (BS). In leach protocol, the CHs transmit data directly to the base station irrespective of the distance between the CHs and the base station. If the base station is located far away from the CH, this protocol will consume large amount of energy. For this purpose, communication among the CHs nodes is multi-hop. This protocol benefits large sensor networks. First the cluster members send data to its respective CH. Then the cluster head transmits to another CH instead of the Base station. Ultimately data is send to the CH which is optimally located and has the least distance to base station.

BCDCP [11]: In Base Station Controlled Dynamic Clustering Protocol (BCDCP), all the nodes of the network send their energy level to the Base Station. The base station calculates the average of all the energy levels. All the nodes whose energy levels are above the average level (the one calculated by the base station) are eligible to be elected as CHs. Let S be the set of nodes whose energy levels are greater than the average level. The job of the BS is to select an optimal number of CHs (N_{Ch}) from the set S (Obviously if 100 nodes send their energy level to the BS, and the BS calculates the average and if there are 40 nodes whose energy level is greater than average, it does not mean that all the 40 should be elected as CH because 40 is not optimal number in a network of 100 nodes). For this purpose the base station has to perform the following two tasks.

- Select two nodes (which have very high energy and located at a far distance) from the set S.
- Arrange all other nodes around these two nodes so that clusters are formed and this will enable help in data transmission (Steady-State phase, because instead of nodes sending to BS, They will send to these CHs).

Once two nodes, s1 and s2 are selected, the BS has to form clusters. For this purpose the BS uses a special Iterative Cluster Splitting Algorithm. This algorithm split the network into two clusters. Next, it arranges the nodes around s1 and s2 and continues this process of splitting until optimal numbers of clusters are formed. The single iteration of this cluster splitting algorithm consists of the following steps.

- From the set S, select two nodes s1 and s2 which are at far distance (maximum distance) from each other.
- Group other nodes around s1 or s2. The association of a node with either s1 or s2 depends on the signal strength of s1 or s2 on that node.
- Try to have approximately equal number of nodes around s1 and s2 so that two equal clusters are formed.
- Split S into two subset S1 and S2 and this result in further clustering and hence more CHs.

Once CHs are selected and Clusters are formed, then CH to CH data is transmitted. The base station selects the minimum energy route which will result in the flow of data to the BS. The nodes will transfer their data to their respective CHs. Once all CHs have performed data aggregation, they will send the data to BS through one of the CH. Now the question which arises is which one among the CHs will be elected to

transfer the data to BS (CH will collect data from all the CH and transmit to BS). The answer is that the selection of this CH is random. Anyone of the CH can be elected to perform this job. The reason for this is that if CH near the BS is chosen all the time to perform this task then it will drain out its energy and will die and hence will degrade the network lifetime.

Next step is scheduling. BCDCP protocol allows the nodes to schedule themselves with the TDMA slots assign to them. Each node is assigned a two bit SCID (Schedule creation ID). This ID is used to allow the node to schedule its transmission with respective TDMA slots. The purpose of SCID is to avoid collision (both intra and inter cluster collision). For example, the BS assigns SCID to the BS which is 00. Once this SCID is allotted to the BS, nodes with SCID 01, 10 and 11 will transmit their data to BS

BIDRP [12]: Base Station Initiated Dynamic Routing Protocol (BIDRP)uses the heterogeneous WSN concept because CH nodes have high energy. In BIDRP, some nodes are high energy nodes which are elected as CHs. The Energy of Model of this protocol is given in equation 2.

$$E = \Phi I \qquad \text{(Equ.2)}$$

Where Φ is the amount of energy consumed to sense a single bit, I is the number of bits in an information (message) which is sensed in one round.

According to BIDRP, all the nodes in WSN are classified as: BS, CHs, SNs. BS is high energy node and has high amount of energy (it is not energy constraint). It is located in a fixed place away from network most of the time.

SNs are energy constraint sensor nodes which are in a fixed location. They only sense data and transmit to CH without aggregation or relaying.

CH nodes are the high energy nodes in the network and have fixed location. They perform data aggregation and have the following characteristics unlike SNs.

- CH nodes are high energy nodes as compare to SNs and have their own Node ID
- CH can calculate their location
- CH nodes perform data aggregation in order to reduce redundancy in the data.

3. Comparison of Clustering Hierarchical Protocols

Protocols	CH Selection	CH Selection Algorithm	Intra-Cluster Communication	Communication Pattern (CH to BS)
LEACH	Random	Probabilistic (Based on Random Number outcome)	TDMA Scheduling	Single Hop
LEACH-C	Centralized	Simulated-Annealing	TDMA Scheduling	Single Hop
CELL-LEACH	Centralized (First Round) Energy-Based (Onward)	Average-Energy Threshold	Cell-Based TDMA Scheduling	Multi hop
I-LEACH	Random	Probabilistic (Based on Random Number outcome)	TDMA Scheduling	Single Hop (In case of both CHs and Sub-CHs)
E-LEACH	Random	Probabilistic (High-Energy Node Selection Approach)	TDMA Scheduling	Single Hop
MH-LEACH	Random	Probabilistic (Based on Random Number outcome)	TDMA Scheduling	Multi Hop
BCDCP	Centralized	Iterative-Cluster Splitting	Schedule Creation ID (SCID)-based	Multi-Hop
BIDRP	Pre-Determine (Centralized)	Static (Fixed throughout network Life time)	TDMA Scheduling	Multi-Hop

TABLE 1: Clustering-HierarchicalProtocols

A brief comparison of various Cluster-based hierarchical protocols is given in table 1.

In the above table, a brief comparison has been made between various Cluster-based routing protocols in terms of Cluster Head Selection, Cluster Head selection algorithm, Intra-Cluster communication and the communication pattern being employed by the CHs to route the data to the Base Station.

4. Conclusion and Future Work

In this paper a brief overview of various Cluster-based routing protocols is presented along with their comparison. These routing protocols differ in terms of data transmission, Cluster-Head selection, Cluster formation, Slots scheduling and other characteristics. Both homogeneous and heterogeneous clustering protocols are being discussed. Selection of a specific protocol depends on the nature and requirements of the application. Cluster-based routing protocols are of unique characteristics, particularly suit the resource - constraint nature of WSN and hence require particular attention and research.

Cluster Formation and Cluster-Head selection in these protocols is both random and centralized (selected by Base Station). During both these phases, considerable amount of energy is consumed due to Cluster overhead and CHs selection. Currently, we are working on this issue: To reduce the consumption of energy in CHs selection and achieve better throughput, minimize latency and packet loss.

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