Performance Analysis of Energy Efficient Dynamic Multilayer Cluster Designing Routing Protocol in Wireless Sensor Network

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Abstract

Objective: Reliability and Energy conservation are two main factors to be considered in wireless sensor networks. Wireless Sensor Networks (WSN) is widely used in time-critical applications. WSN are resource constrained, so developing energy efficient protocols is a major concern in sensor networks. Multilayer clusters are preferred for sensors used in Remote Monitoring applications. When the position of sensor changes then it becomes very difficult to conserve energy as the cluster head is mainly responsible for delivery of the data. Protocols like EADUC, TLPER follows Multilayer clustering approach. The main aim of this paper is to develop dynamic clusters with less energy consumption.

Methods/Statistical Analysis: The proposed method D-MCDA is efficient when the location of nodes varies dynamically and the clusters are formed based on their locations which proves efficient when compared to other protocols. First all the nodes are involved in the formation of the cluster and then the Cluster head is selected. The actual data packet is sent from the source to destination and the consumption of energy is calculated for various protocols and their results are compared.

Findings: As energy consumption was the main motivation, use of multilayer and additional cluster heads have reduced the energy consumption by 0.019. The Proposed D-MCDA algorithms have performed better in terms of average energy consumption per node and in the process of designing a cluster. The proposed algorithm is compared with the existing algorithm like TLPER and MCDA. Applications/Improvements: Energy Consumption is very essential in applications like Remote monitoring, process control and automations. Reliability is another issue to be considered as it is another major reason for energy depletion. Reliability on the basis of congestion avoidance scheme, acknowledgement mechanisms can be considered which can reduce the energy consumption to a major level.

Keywords: Cluster Analysis, Cluster Head, Energy Consumption, Sensor Networks

1. Introduction

Wireless Sensor Network (WSN) is widely used now-days in industrial monitoring systems. Clustered architecture is best suited for WSN compared to Flat layer because it is energy efficient. Grouping of nodes in a convenient manner is called clustering where a node with high energy is elected as Cluster Head (CH) and other nodes as cluster members that communicate data to its cluster head. The CH aggregates the data to the base station. Communication among the cluster members and between the CH and its members is called intra cluster and communication between CH of one cluster to the CH of the other is called inter cluster. Two different
architectures have been proposed. They are cluster-based network and flat network. Communication between the CH and Base Station (BS) can be done based on single hop model or multihop model which depends on the size of the network. The size of the network determines the transmission range of the network. Every cluster member needs to provide the following information to its CH namely energy level of the node, geographic location, node density and so on. Cluster-based network follows centralized and distributed approaches. In centralized approach, the CH is decided based on K-means, nearest neighbour approach. In distributed method, the cluster formation is based on some selective metrics. The CH is chosen which as the highest value of the selective metrics and other nodes use their RSSI and join CH as cluster members. LEACH follows cluster based centralized approach. Many Cluster based protocol like EELBCRP, TLPER have been proposed that effectively chooses CH. Many additional CH have been proposed to assist CH in data aggregation and data forwarding.

2. Background

Mobility of sensor nodes can cause packet losses to a greater extent. Some applications may demand both fixed and dynamic nodes in the same network. So a cross layer design approach is used in between MAC layer and Network layer for some applications. MAC protocols have been proposed to solve the problem of mobility. Routing protocols like LEACH are also proposed. But they are not energy efficient and synchronization between the neighbouring nodes is also important. The mobility of nodes also causes problems in synchronization. Cross layer design is a solution to achieve reliability and energy efficiency. Network layer uses the information provided by the MAC layer and establishes a successful route. Cross layer technique is also used in physical layer. When retransmission is initiated, transmission takes place at maximum power level; otherwise transmission takes place at normal level.

Many clustering algorithm does not take into account mobility of nodes. CBR protocol takes into account of mobility of sensor nodes and it uses cross layer optimization techniques. When any nodes move out of cluster or does not have any data to send then that time slot is assigned to any other node.

LEACH is the earliest cluster designing protocol proposed in the architecture. LEACH protocol has two phases: Setup phase and Steady phase. Initially the CH is chosen. Then the nodes choose their CH according to the Received Signal Strength (RSS). They send a join message to the CH. After it receives all join messages it establishes a Time Division Multiple Access (TDMA) and broadcast to all its members. The nodes remain in their sleep state till its allocated time slot. When it receives a data request message from its CH, it sends data in its time slot; otherwise it continues to be in sleep state until its next time slot. Even in the second round if it doesn’t get the data request message from CH it sends a join request message to the nearby CH. Also if the CH does not get any join request message from the nodes or doesn’t receive any data, then it assumes that the node is dead or it has moved to another cluster. The problem of overhearing and idle listening is solved in protocols like S-MAC and CBR since it is scheduled MAC protocols. Fairness cannot be achieved in WSN. So the design goal of fairness does not apply to these protocols. CBR (Cluster Based Routing Protocol for Mobile nodes) avoids most of the drawback found in LEACH. LEACH-M has to wait for two timeslots to detect loss. Moreover, it does not have packet avoidance technique. CBR is a cluster based cross layer protocol that supports mobility and avoids packet loss. CBR sends data request message to the node, if it does not get data within its allocated time, it sends data request message to Alternative Owner (AW) i.e. the new joining node. If the node does not have any data to send, then it sends a ‘no data message’ to the CH. If AW also doesn’t have any data to send, it also sends a ‘no data message’ and the time slot is wasted. CBR works in both Contentions based and scheduled based approach. In scheduled based, time slots are reserved, whereas in contention based the nodes have to content for a period of time. CBR also uses tow phase just like LEACH. CH can be stationary or a node that has little mobility can be chosen as CH. For advertisement CSMA/CA MAC protocols are used.

DEEAC protocol uses a distributive approach compared to LEACH and its variants. In LEACH, the residual energy level of the node is sent to the base station which consumed more time. In DEEAC, the residual energy of the node is sent to the CH along with the data join message which is then sent to the base station. The residual energy of the entire cluster along with the CH is known to the base station. This distributive approach is better than the centralized
approach followed in LEACH. DCP (Dynamic Clustering protocol) was proposed that performs better than LEACH. It follows sleep /wait technology and CH is chosen dynamically and role of CH is rotated. EADUC is a clustering routing algorithm that uses unequal cluster size. Every cluster consists of a setup stage followed by transmission phase. The cluster formation process starts with the BS broadcasting the signal at a particular power level. All the nodes calculate their distance from the base station using RSSI. All nodes within the radio range of the BS calculate their residual energy and compare it with the neighbouring nodes. The nodes having the higher residual energy broadcast to be the cluster head. All the nodes compare their residual energy with the neighbouring CH and choose the CH which is nearer to them.

3. Existing Protocols

3.1 Threshold based Load Balancing Protocol for Energy Efficient Routing (TLPER)

Threshold Based Load Balancing Protocol for Energy Efficient Routing (TLPER)\(^2\) aims at fault tolerant and load balancing by making use of Role Transfer Threshold and Multi Assistant Cluster Heads (ACH). The sensor nodes are homogeneous and TLPER follows preselected cluster heads (CH) and preselected ACHs. Each node may know its neighbouring nodes as well as its Vicinity Head (VH). The term Vicinity Head applies to CH and ACH. At initial stage, selection of CH and ACH is on hand. Due to the homogenous nature of nodes, the node having more neighbours is designated as Vicinity Head (VH). Cluster Head is the main head of the vicinity of cluster while ACH is the assisting head of sub vicinity of the same cluster. Later the rotation of VHS (CH and ACH) communicates their designation to neighbouring nodes. Each node attaches itself to the VH on the basis of received signal strength (RSSI). But the problem with TLPER is that the boundary area nodes difficult to access the vicinity heads. This issue may arise with the boundary cluster nodes as the inner cluster’s central positions creep along with relevant nodes. This process focuses on less energy routing mechanism and doesn’t focus on timely delivery and packet loss.

3.2 Multilayer Cluster Designing Algorithm

Multilayer Cluster Designing algorithm\(^{10,11}\) (MCDA) is a hybrid algorithm that comprises of both flat and cluster design architecture. Moreover, it follows both centralized and distributed approach that helps in energy savings.

The basic equation for a CH selection in LEACH protocol is:

\[
T(n) = \left\{ \frac{P}{1-P} \cdot \left( \frac{1}{r \mod \frac{1}{p}} \right) \right\} \text{ if } n \in G
\]

where,

- \(P\) is the percentage of Cluster head nodes
- \(r\) is the current round
- \(G\) is the number of nodes not been elected as cluster head so far

Various improvements have been made to this equation with various parameters and MCDA was proposed. Clustering has many benefits that include load balancing, less energy consumption, reusability of networks. Hierarchical cluster-based routing protocols include LEACH, TEEN, and APTEEN. Location based protocol are GAF and GEAR. MCDA assumes that all nodes are homogenous i.e. nodes have same communication range, sensing and other capabilities.

MCDA algorithm consists of setup phase, steady phase and routing phase. CH selection, CM selection and route establishment are all done in setup phase. This stage is called passive phase since no data is send during this phase. Everything is done through control packets. The remaining phase involves data transaction.

Cluster designing involves three stages:

1. Self Organizing
2. Flat Layer
3. Cluster Layer

Generally, when the nodes are randomly deployed, they enter into active stage and send a beacon message to their neighbours through flooding or gossiping method\(^12\). All the neighbours set up a table consisting of information about is neighbours. Specifically, in MCDA algorithm, the number of neighbours is maintained instead of the whole detail. This saves time and energy. In clustered network, the nodes near the base station consume more energy since it is involved
in forwarding data to the BS. Rotation of CH is also a major issue. Therefore, two layers are proposed in MCDA. The first layer called flat layer consist of nodes for BS that serve as Decision Maker nodes for the selection of CH in the second layer. Second layer involves in clustering and the data aggregated by the CH is forwarded to the BS by the DM nodes in the first flat layer. They also perform the function of load balancing for CH. The cluster based model is shown in Figure 1.

![Cluster based model](image)

**Figure 1.** Cluster based model.

In case of centralized cluster approach normally all the nodes need to communicate their decision metric to the BS which is a tedious and energy consuming process in case of large networks and involves multi hop routing. In distributed cluster approach, inter node communication is much involved selecting the CH and CM nodes. Lot of factors are involved in designing a cluster. Nodal density, energy of nodes, neighbour count is all essential. Once the CH with high energy is chosen by DM, then communication of CH with CM is done on TDMA basis. CH sends join request message to its neighbour nodes which respond with join accept msg. If some nodes are near to more than one CH, then its membership with CH depends on the load of the CH.

The most energy consuming task is the CH selection. In homogenous network, all the nodes have equal cluster size, have same residual energy. A number of cluster head techniques are available to rotate the cluster head. CH may be single hop away or multi-hop away from BS. The nodes that are close to BS may be elected as the cluster head. In case of homogenous network, the residual energy is the metric for choosing the CH.

CH rotation depends on two threshold levels:

1. **Load Balancing Threshold (LBT)**
   - When the energy level of the CH becomes 50% less than the initial threshold, Backup forwarding node shares the workload of the CH. There is a high probability of this Backup Forwarding Node (BFN) to be the next CH. BFN shares the job of CH by aggregating the data and forwarding the data to BS and so on. Thereby it shares the workload of the CH.

2. **Role Transfer Threshold (RTT)**
   - When the energy level of the CH becomes 20% less than the initial threshold, then the role of CH is shifted to another CH. A CH rotation message is then sent to all CM to note their energy levels. The decision maker node selects the node with highest energy level and acknowledgment is received from the node to become CH and then the information is sent to all CM.

### 4. Proposed System

Even though the existing MCDA algorithm has many metrics it also has some de- metrics as dynamic clusters are difficult to design using MCDA. So cost-effective routing is added by making some changes to the existing MCDA. In the neighbour node prediction unlike existing MCDA it takes the number of nodes in its neighbour with their geographic coordinate so that it will help us to find the distance and direction of corresponding neighbour node. At the clustering phase (i.e.) at layer-2 instead of using sequence number for clustering it uses distance to create the clustering region which is more accurate than previous technique. The cluster member selection routing process is more effective because of dynamic routing because it will choose the best path to transfer data according to its current location. There are many algorithms to solve the problem of clustering. One such method is Modified K-means. The nodes in WSN are generally distributed in a given area of interest. The location information of
each node is required, because it is essential to know where the information is sensed in the sensor network. This method needs all the nodes to know the location information. Some applications may require accurate localization of nodes. So location based algorithms or GPS-enabled nodes can be used. But it is quite costly.

The coordinates \((x_i, y_i)\) computes the distance between two sensor nodes. The distance between reference nodes is computed by using this formula,

\[
\text{Euclidean Distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}
\]

where, \((x_1, y_1)\) and \((x_2, y_2)\) are the coordinates of the two nodes that are taken into consideration.

The parameters us to cluster the algorithms are mainly based on two factors. They are minimum distance and highest energy. The sensor nodes that satisfy these criteria are clustered by using the chosen clustering algorithm.

Basically the location of the cluster head is to be known. The coordinate position of the cluster head is compared with the other nodes. The nodes which are in close proximity with the cluster head and with the highest energy is selected for further processing.

Using the concept of centroid method, the sum of all X coordinate of the sensor node is divided by the number of cluster nodes. The same procedure is repeated for Y coordinate also.

**4.1 Cluster Head Selection**

The sensor nodes are arranged into several clusters and in each clusters, one of the sensor nodes is chosen to be cluster head (CH). After the formation of cluster, the centroid of the clusters is computed again. In general, a cluster head is not repeated again in the next round. So, this new coordinate cannot be selected as a cluster head, because it is a location based clustering scheme. The current position of the cluster head should be known. After finding the centroid position, find the minimum distance between the centroid position and the cluster members. The sensor nodes which have the minimum distance from the centroid point is a new cluster head.

In some cases, the energy level of the CH can go low. In that case it becomes necessary to repeat the same procedure and choose a Cluster head with high energy node present in the cluster. This selected high energy will serve as CH for that particular cluster for a period till the node energy reaches a minimum threshold value. Once the minimum threshold value is reached, selection of CH is performed in the same cluster. Now, selection of cluster is based on residual energy of the node. That is node having high residual energy is elected as CH and the process continue.

Calculate the new cluster centre using the following equations:

\[
C(x) = \frac{1}{cl} \sum_{j=1}^{cl} (x_i)
\]

Similarly, for Y coordinate.

\[
C(y) = \frac{1}{cl} \sum_{j=1}^{cl} (y_i)
\]

where, \(C(x)\) and \(C(y)\) is the x and y coordinates of the cluster centre.

**4.2 K-AODV**

Routing plays a very important role in any network. A proper route selection strategy may lead to high energy consumption and reliable data delivery. Improper or long routes often leads to network complexity. Ad-hoc On Demand Distance Vector (AODV) is a distance vector routing protocol. It is a reactive routing protocol; therefore, routes are determined only when needed. The modified K means Clustering algorithm is added to the existing AODV protocol, to form a new K-AODV where K represents the K means clustering algorithm. Routing can be of two types namely Inter-clustering and Intra-clustering. Normally the cluster members communicate only with the Cluster Head. The Cluster heads are involved in communication with the Base station which is a good technique in preserving energy. The Cluster members forward the packets to the respective cluster heads and the cluster head will forward the packets to the base station. If the base station is far away from the cluster head, multi-hop communication will take place. The cluster head will forward the packets to the nearest cluster head and this nearest cluster head will send the packets to the base station.

**5. Simulation Results**

The parameters for simulation are tabulated below in Table 1.
### Table 1. Simulation parameter

| Parameter                      | Description               |
|-------------------------------|---------------------------|
| Routing Protocols             | D-MCDA                    |
| Channel Type                  | Wireless Channel          |
| Network Interface Type        | Phy/wirelessphy           |
| MAC type                      | 802.11                    |
| Max packet in IFQ             | 50                        |
| No of mobile nodes            | 25                        |
| Simulator                     | NS 2.35                   |
| Data Rate                     | 4 Packets/S               |
| TCP/IP Layer                  | Network Layer             |
| Node to Node Distance         | Random                    |
| Node Type                     | Homogenous                |
| Propagation Model             | Two ray Ground            |
| Ground Initial Energy of Node | 100J                      |

Simulation was performed with NS2 to decide the energy consumption for the following

1. Average Energy consumption for a node
2. Average Energy consumption for transmitting a single packet from source to destination
3. Total energy consumption in designing an entire cluster

The present nodes need to know the neighbouring node and it has to select a neighbouring node as the forwarding node. The energy consumed at this process is taken and are plotted in the graph. Figure 2 show that D-MCDA consumes low power.

The data transmitted from source to destination needs to keep in consideration the following criteria's like route selection, forwarding node selection, distance of the nodes etc. These aspects are included in this measurement and are plotted in the graph. Figure 3 shows that the proposed protocol consumes less than the existing systems.

![Figure 2. Average energy consumption for a node.](image)

![Figure 3. Average Energy consumption for transmitting one packet from source to destination.](image)

![Figure 4. Total energy consumption in cluster design.](image)

### 6. Conclusion and Future work

In this paper D-MCDA protocol has been proposed that consumes less energy in all phases when compared to other protocols in the literature. This protocol will be very much useful when the nodes are dynamic in nature. Dynamic clusters are used now-days in remote monitoring applications. The concept of reliability and packet priority can be considered as a future work. Improvements
and suggestion about MAC layer can also be included as duty cycle approach also contributes much to the conservation of energy.

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