Enhanced Multilayer Clustering Protocol for Wireless Sensor Network using Hierarchical and Hybrid Multilayer Architecture

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Abstract

Background/Objectives: Sensor nodes will be in fixed/mobile locations. The exchanges can also be huge that it may result in overlapping or loss of packets. This will lead to heavy overhead and less packet forwarding ratio. A layer level model will be a good solution. Methods/Statistical Analysis: In this research work, Hierarchical Hybrid Model based clustering is proposed to combines the merits of both hierarchical and hybrid approaches in routing for improving the lifetime of the network. A mathematical model is being proposed for a wireless sensor network. It consists of following phases. Layering Design, Clustering, Multilayer clustering, Region categorization. The model is improved as it has facilities for clustering and routing based on combined layered approach. Findings: For simulation, the network simulator tool (NS 2) is used. The performance of the proposed scheme has been shown in graphs for the metrics namely, Total consumed energy, control overhead, good put, throughput, delay, packet delivery ratio and lifetime. The paper provides conclusions how the longevity of the network is improved by combining hierarchical and hybrid approaches in routing. This approach can be applied for users in indoor environment.

Keywords: Clustering, Grouping, Multilayer, Routing, Sensor Network

1. Introduction

The paper provides modification by considering the functions of the sensor network as below:

- Base station: Collect all sensed data from sensors.
- Cluster head: It is used to manage to clusters. Collect the data from cluster member and select forwarding cluster head then forward data to base station via selected cluster head.
- Cluster member: It is used to sense the environment and forward the data to cluster head.
- Flat nodes. Nodes bounded inside the flat region forward without hierarchy manner.
- Layer: Heterogeneous Nodes are categorized into layer to differentiate its characteristics.

Sensor network is organized into clusters based on energy and cluster based routing model that is member forward data to cluster head and cluster head forward data to base station.

A study on two-layered heterogeneous sensor networks where two types of nodes are deployed in the network: basic sensor nodes and cluster head nodes¹. Basic sensor nodes are simple and inexpensive, while cluster head nodes are much powerful and much richer in energy. A cluster head node organizes the basic sensor nodes around it into a cluster. A basic sensor node does data collection and sends the data packet when polled by the cluster head. By introducing hierarchy, a two-layered heterogeneous sensor network has better scalability than homogeneous sensor networks.

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As in Figure 1, the large nodes are the cluster heads and the small nodes are the basic sensor nodes. In the previous work the focus is on finding energy efficient and collision-free polling schedules in the multi-hop cluster\(^2\). To reduce energy consumption in idle listening, a schedule is optimal if it uses minimum time. It is shown that the problem of finding an optimal schedule is NP hard, and then gives a fast on-line algorithm\(^3\). A cluster is divided into sectors to reduce the idle listening time of sensors. Simulation is carried out on the NS-2 simulator, and the results show that our polling scheme can reduce the active time of sensors by a significant amount while sustaining hundred percent throughput in a layered model\(^4\).

![Figure 1. A two-layered heterogeneous sensor network.](image)

Merits of the approach are:
- Cost effective, since the network functionalities are shifted from sensors to cluster head.
- As the clusters are sectored the ideal listening time of the sensors are minimized.

A new clustering algorithm that handles the concept of multi-feature sensor networks where each node reports more than one feature\(^5\). In order to handle the above task Multi-Feature LEACH based Clustering algorithm (MFLC) is used. MFLC considers the number of features reported by each node as well as the node’s residual energy during the clustering process. MFLC is a new clustering algorithm that fits the purpose of multi-feature sensor networks. In this algorithm LEACH protocol is extended to multi-hop clustering in a multi-feature environment. MFLC differs from the LEACH on the criteria used for a node to decide to be a cluster head or not\(^6\).

Step 1: The algorithm starts by the initialization phase where the Sink Node (SN) broadcasts its position and the maximum number of features expected to be reported from all nodes\(^7\). The sink node is assumed powerful enough to connect to all nodes in the monitored field. After nodes received the SN message, each node looks for its neighbors and fills its neighbor’s list \(l\).

**Step 2:** Nodes start working on the clustering where each node applies equation (1) and computes \(T(s)\). At the same time, each node runs the random generator algorithm to generate a random number between 0 and 1. Based on these two values, \(T(s)\) and the random number, the node decides to be a cluster head or not. If a node decided to be a cluster head, it sets the CHparam to true and waits for a certain period of time to hear from other cluster heads (if any). If it hears from any other cluster head, it adds it to its CH-list for further usage. If a node is not a cluster head, it decides to join one of its neighbor cluster heads based on the cluster heads residual energy. Any node without a cluster head, it is forced to be a cluster head.

\[
T(s) = \left( \frac{p}{1-p} \right) \bmod \left( \frac{1}{p} \right) \times \left( \frac{F(s)}{F_{\text{max}}} \right) \times \left( \frac{E_c(s)}{E_m(s)} \right)
\]

Where \(p\), \(r\), \(F(s)\), \(F_{\text{max}}\), \(E_c(s)\), and \(E_m(s)\) are parameters where \(p\) is the node’s desire to be a cluster head, \(r\) is the current round, \(F(s)\) is the number of features reported by node \(s\) is an element of \(S\), \(F_{\text{max}}\) is the maximum features reported by the network, \(E_c(s)\) is node’s \(s\) is an element of \(S\) residual energy, and \(E_m(s)\) is node's \(s\) is an element of \(S\) initial energy.

**Step 3:** Nodes start to report to their cluster heads using TDMA protocol. Nodes may apply a sliding window for the sensed data. Now, the cluster heads applies an appropriate aggregation method such as the average on the received similar features and tries to send the aggregated value(s) to the sink node\(^8\). A cluster head might not be directly connected to the sink node. Therefore, a multi-hop reporting must be used. As proposed the cluster head choose one of its neighbor cluster heads found in its CH-list with the highest residual energy. The CH-list might be empty; thus, the cluster head has to select one of its neighbors that it does not belong to its cluster to report to. If all of the neighbors belong to other clusters, it might select a node at random or based on the neighbors energy or number of features hoping that it will reach one of the other cluster heads\(^9\).

**Step 4:** When the round time expires and the network still alive, the clustering algorithm is repeated; otherwise, the algorithm terminates.
The merits of the approach are:

- The algorithm results in better clustering since it utilizes both sensors energy and multi-features while clustering.

A new MAC protocol, ML-MAC (Multi-Layer Medium Access Control) for dense sensor networks. If the density of nodes in a virtual cluster is high, the cluster header performs the splitting the nodes into several layers. Splitting is done by sending modified ACK messages after receiving the beacon message from the cluster header. As only the sensor nodes in the same layer communicate each other, less power is consumed and longer network life time is guaranteed. By simulation method with NS-2, the protocol is being evaluated. In dense nodes environments, ML-MAC protocol shows performs better in terms of packet delivery rates throughput and energy consumption. Mining can also be combined as a feasible solution.

The merits of the approach are:

- ML-MAC reduces energy consumption by dividing node of the cluster into several layers.
- It reduces unnecessary waste of energy, ML-MAC has extended the network lifetime.

2. Proposed Work

2.1 Hierarchical Hybrid Model based Clustering

Sensor network is organized into a multilayer as heterogeneous network and routing approach is modeled as a combined approach of both hierarchical and hybrid approaches. The improvement in the proposed model is under Layering, Clustering, multilayer clustering, boundary estimation, region categorization categorization, grouping and routing. The improvements are detailed as below:

2.1.1 Layering Design

Layering is provided for increasing the capabilities of communication of wireless sensor network. The layering levels proposed in this model is as given below:

- Multi-player is formed in terms of energy, processing power and in data generation.

- If the number of layers is defined as 1, then complete network nodes have equal characteristics.
- If the number of layers is defined as 2, then network is spitted into two layer, both layers has different characteristics while compare to each other.
- If the number of layers is defined as 3, then network is organized into three layers, which has different characteristics while compare to each other. Once layering process completes, clustering protocol is initiated.

2.1.2 Clustering

Nodes in wireless sensor network form clusters and communicate on a requirement basis. In general the nodes and stations are involved in communication. They suffer due to issues like network size, time period. The proposed approach models clustering as below:

- Base station start broadcasting bs announcement message as network wide broadcast message.
- Base station broadcasts this announcement message as periodical message which is executed by bs timer handled in base station.
- Receiver sensor nodes stores the base station id.
- Once base station id is assigned to sensor nodes then it starts info_timer.
- Info timer executed in periodical manner.
- Whenever this timer expires, sensor nodes send its node information to base station, which includes node energy, location in terms of latitude and longitude and layer at which node is placed.
- Base station receives this message and store node information in the node_list table, this table contains node id, location and probability.

2.1.3 Multilayer Clustering

- After receiving information of all sensor nodes present in the network, base station initiated the clustering timer to perform clustering process.
- This timer executed as periodical process.
- Since MLCP is the combination of hierarchal routing and flat routing, flat region boundary is estimated to divide the network into flat region and hierarchical region.

Boundary estimation is done considering the boundary range of the network.
Boundary value is calculated as follows:

Boundary = topology_area * boundary_range (boundary_rangelays 0 to 1).

2.1.4 Region Categorization

Nodes outside flat boundary is considered for clustering, remaining nodes performs only flat routing process in the proposed work.

There are two type probability mode is executed to perform clustering that combined probability and conditional probability.

Probability estimation procedure is as below:

- Combined probability is process of normalizing the node information with respect to its layer,
- Probability value of node is estimated by including node information such as energy, power and layer, which is calculated as follows,
- Probability = energy * layer/maximum layer * power * layer/maximum layer
- To execute conditional probability leach model if modified with node probability, Here conditional threshold is estimated from selection probability with round at which clustering process.
- Conditional_prob = (probability)/(1-probability*((current_round+1)%int(double(1)/probability)))
- After calculating the conditional probability clustering process is executed in two phases namely Grouping, Routing.

2.1.4.1 Grouping

- From all nodes in nodes list node with high probability which must have greater probability compare to conditional probability, selected as first cluster head, neighbours of the cluster head node is marked as cluster members.
- Once first cluster is formed, cluster head and members nodes are removed from the node list.
- After updating the list, from all nodes in nodes list node with high probability which must have greater probability compare to conditional probability selected as second cluster head, neighbors of the second cluster head node is marked as 2nd cluster members.
- Once second cluster is formed, cluster head and members of 2nd clusters nodes are removed from the node list.
- These two steps in step 3, step 4 are executed until all nodes grouped into clusters.
- At the time of cluster formation completion, base station send cluster information message to all nodes in the network.
- This message includes, cluster information such as cluster id, head id, member nodes id in the corresponding cluster.
- Sensor nodes receive this message and check node is cluster head, if so it stores its member information and cluster id.
- If node is not cluster head, then it checks the corresponding head id of its cluster and notes its head id and cluster id.

2.1.4.2 Routing Process

Flat routing is performed as below:

- Nodes within the flat region, executes route discovery process by sending route discovery message as network wide broadcast message with destination node id and seq. no. of route request message.
- Receiver node of route discovery message checks for routing loop and verify whether the packet is already received by same node. If any one of above two conditions is satisfied then it discards the route request message.
- Now node creates the forward entry in the routing table with src node id.
- Now current node matches its id with destination node id, if both ids are not same, then updates request message and rebroadcast message to all of its neighbors.
- If both ids are same, then current node is intended destination for the packet. Now it forms the reverse path of the request message, and create route reply message then it is unicasted through established reverse path to reach source node.
- During reply message, Intermediate and source node creates routing table entry to reach destination.
- Once route discovery is completed, then data forwarding is initiated and executed as follows,
- First node checks whether it is present in flat region or hierarchical region,
- If node is in hierarchical region then it checks node is cluster head or cluster member, If it is cluster member then it forwards the data packet to corresponding head node by setting next hop of packet as head_id.
- If it is cluster head then it forwards packet to next level cluster head.
• If node is in flat region then it obtains the next hop node id from the routing table forwards the packet to destination.
• In case route failure occurs, node first validate the alternate path is available or not,
• If not available then it executes route discovery process by sending route discovery message as network wide broadcast message with destination node id and seq. no. of route request message and flat routing modeled as explained above.

3. Results and Discussions

The simulation parameters for the environment are as shown in Table 1:

Table 1. Simulation parameters for the runtime environment for the Wireless Sensor Network model

| Parameter          | Value                      |
|--------------------|----------------------------|
| No of layers       | 1,2,3                      |
| Area               | 500x500, 1000x1000          |
| Nodes              | 60,100,120,240             |
| Clustering prob.   | 0.4                        |
| Cluster radius     | 50m                        |
| Transmission range | 250m                       |
| Initial energy     | 100J                       |
| Mac type           | 802.11                     |
| Queue Type         | Priority Queue             |
| Antenna Type       | Omni Directional           |
| Simulation time    | 100s                       |
| Flat region range  | 0.1                        |
| Routing model      | Flat, hierarchy, hybrid    |

From the Figure 2 it can be inferred the various stages involved in message synchronization in cluster formation.

From the Figure 3 it can be observed that the Total consumed energy is reduced with increase in nodes.

From the Figure 4 it can be observed that the control overhead lies in between the Flat and Hierarchical routing.

The performance of the wireless sensor network largely depends on the Goodput of the network. It can be observed from the Figure 5,6 that the Goodput is improved with increase of number of nodes.

From Figure 7, it can be observed that the throughput stays on 48000 bits per second and gradually reduces and stays steadily to a value closer to 46000 bits per second.
From Figure 8 it can be observed that the delay stays between 15000 to 25000 milli seconds. It is comparatively less than flat and hierachial routing.

From Figure 9 it can be observed that the PDR stays between 95000 and 100,000 for the hybrid routing. It is better compared to Flat and Hierarchical routing.

From Figure 10, it can be observed that the life time stays between 720 to 740 for hybrid that is lesser than flat and hierachial routing.

From Figure 11, it can be observed that the Total consumed energy is less than 138 Joules that is less than flat and hierachial routing.
From Figure 12, it can be observed that the control overhead of hybrid clustering stays between flat and hierarchical clustering.

From Figure 13 it can be observed that the Goodput is improved in hybrid clustering.

From Figure 14 it can be observed that the throughput is improved ranging from 77 bits per second for a hybrid clustering.

From Figure 15, it can be observed that the Delay stays less below Flat and hierarchical clustering.
From the Figure 16 it can be observed that the packet delivery ratio is close to 100% for a hybrid clustering.

From Figure 17 it can be observed that the life time stays at 1.7 initially an comes down to 0.96 and rises high to 1.8. In some cases the hybrid model stays between flat and hierarchical model.

4. Conclusion

Wireless sensor network is efficient only when the lifetime is increased. This inturn is dependent on the node behaviour, PDR and other factors. This has been considered in the network by proposing in the hybrid approach.
The results has been presented in the results section above. Hence it can be inferred that the combining the characteristic hierarchical and hybrid approaches using an intelligent routing mechanism gives better performance in terms of delay and packet delivery ratio. A cluster framework could also be developed as a complete solution in future.

5. References

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