An Energy Efficient Hierarchical Clustering Protocol for Wireless Sensor Networks

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Abstract—This paper presents an innovative hierarchical clustering protocol for wireless sensor networks. In networks that mainly apply multi-hop communications, the huge amount of energy consumed by relay tasks of nodes near the sink node cause premature network death, and, so, the lifetime of these nodes needs to be improved efficiently in order to prolong the duration of network service. The aim of the proposed hierarchical clustering design is to minimize energy dissipation difference among these nodes. Furthermore, the hierarchical clustering mechanism reduces transmission delay. The energy efficiency of the proposed algorithm is verified through simulation and it demonstrates that the network lifetime has been significantly extended by 45% compared with LEACH.

Keywords—cluster-based; cross layer; energy efficient; wireless sensor networks; TDMA; multi-hop

1. INTRODUCTION

Wireless sensor networks have gained much interest in the routing protocol research field for more than one decade. It is an emerging technology that benefits from the ongoing developments of sensor techniques, low energy consumption electronics, and low-power radio frequency design [HeCh00]. In recent years, reliable and inexpensive sensors have been extensively utilized in different applications ranging from civil purpose to military applications [RaSe02] [ChCh01]. Though such sensors are not as accurate as expensive sensors, they are still popular because of their high accessibility. Furthermore, in many applications, trading low budget devices for an increased number of devices is more important. But, what is even more important is the Quality of Service (QoS).

Quality of service (QoS) of wireless sensor networks may be evaluated from two points of view. On the one hand, reliability of sensor data can be used to measure quality of service, but this implies the use of accurate and expensive sensors. The use of such high quality sensors may not be a good choice in certain applications, such as forest fire tracking and battle field monitoring, since the sensors may not be retrievable in those scenarios. In these cases, practicality demands the use of inexpensive sensors, and a compromise between QoS and expense must be made. On the other hand, maximum network lifetime is a significant goal of wireless sensor networks. If the nodes in the network prematurely cease to function, then the quality and reliability of sensor readings become irrelevant, since the nodes no longer participate in the network. Extending the lifetime of a WSN has attracted much interest in the research field of energy consumption and distribution of loads.

Since wireless sensor networks are usually deployed in fields where power supply is not available, the consumption of energy becomes the most important issue in order to maximize network lifetime. Some algorithms have been proposed to minimize energy consumption of each sensor node. Ye et al. [YeHe04] proposed S-MAC protocol to reduce unnecessary energy consumption by putting nodes into sleep mode when not working. However, this scheme results in delay when one node is trying to communicate with another node while it is in sleep mode, called sleep delay. Dam et al. [DaLa03] present a T-MAC protocol to further reduce unnecessary energy consumption. When two nodes are communicating, all neighbor nodes and their surrounding nodes enter sleep mode. Nevertheless, the sleep delay problem is still exhibited here, and it even may be potentially worse than S-MAC, since more nodes are in sleep mode at the same time, which means higher possibility of sleep delay. Furthermore, multi-hop transmission type is applied in wireless sensor networks due to its lower energy cost than single-hop transmission. Kim et al. [KiLe09] proposed a cross layer design (ECLP) and energy efficient listening window schedule to minimize energy consumption.

In general, any wireless sensor network that has one sink and applies multi-hop transmission faces the same problem called “hot spot”; this is the problem whereby the nodes near the sink node, especially those which can communicate with the sink node with one hop, may consume much more...
energy (i.e., more data relay operations, called one-hop nodes) than nodes that are farther away. This problem exists in many WSN routing protocols such as ECLP and T-MAC. Common sense dictates that the energy consumption distribution must be optimized. Unequal distribution may result in critical disconnections, which means major connection failure (alive nodes cannot reach the sink node) in the wireless sensor networks. Li et al. [LiYe05] proposed an energy-efficient unequal clustering mechanism (EEUC). This algorithm was designed to relieve energy cost pressure of nodes near the sink node by assigning distinct size of clusters. Heinzelman et al. [HeCh00] proposed low-energy adaptive clustering hierarchy (LEACH); it was intend to relieve this problem by combining clustering technique and single-hop transmission. Both EEUC and LEACH apply single-hop transmission, which may consume more energy in larger scale of wireless sensor networks. This paper proposes a hierarchical clusters approach that is designed to distribute energy consumption of nodes near the sink node as equal as possible, to reduce the likelihood of critical disconnection. Moreover, the proposed protocol aims to balance quality of service and energy consumption; a new approach of how to utilize single-hop transmission is introduced.

The remaining parts of this paper are organized as follows. The next section describes an innovative hierarchical clustering design and a few important elements. This is followed by a detailed description of different network stages. The simulation and analysis results are given in Section IV. Finally the conclusions and recommendations for future works are given.

II. HIERARCHICAL CLUSTERING

The algorithm creates hierarchical layers of clusters of nodes. Each cluster is assigned a distinct level ID, which represents the cluster-hop count between sink node and the particular cluster. Member nodes of a cluster are assigned the same level ID as the cluster in which they belong. During the data communications stage, cluster heads from higher layer clusters relay data to lower layer cluster heads until the messages are received by the sink, which is located at the lowest layer cluster. In order to improve transmission efficiency, the transmission scheme is a combination of multi-hop and single-hop routing.

The hierarchical clustering algorithm is explained in four sections. The first part describes the motivation and overview architecture, which is followed by the details of packets used for synchronization. The third section presents the procedure of hierarchical clustering. Once the whole network is set up, a description of the data communications phase is given in the last section.

In this paper, the network has similar configuration as standard wireless sensor networks. There are $V$ stationary nodes in the wireless sensor network:

$$V = N \cup S$$

The $N$ is the number of sensor nodes, and $S$ is the number of sink nodes. They are randomly distributed in the target field. To simplify the simulations, we assume one sink node, but many potential source nodes are contained in the network. Each sensor node is able to determine its approximate relative distance from other nodes by analyzing received signal strength. All nodes have the same capability and initial energy. Each node has two communications radios to allow either multi-hop or single-hop message passing, but, the single-hop option is the default mode. However, the transmission range is fixed for either case.

A. Overview of Hierarchical Clustering Design

The core idea of this hierarchical clustering design is to generate an energy efficient hierarchical cluster topology for the network. This approach is motivated by the “hot spot” problem, which is faced by many other routing protocols. It is an inevitable situation for such network configuration. The approach used to relieve this problem is to minimize energy consumption difference among cluster heads in each layer; especially those near the sink nodes (one-hop nodes), which take-on most of the burden of this problem. This approach automatically serves to prolong network lifetime. Furthermore, the proposed algorithm also intends to reduce general transmission delay, which includes sleep delay and hop delay.

In order to simplify the description, the clusters which have level ID of $n$ are referred to as Level $n$ clusters. In the network, each node can hold at most two level IDs, which are $CM_{Ln}$ and $CH_{L(n+1)}$. The $CM_{Ln}$ means the node is a cluster member of Level $n$ cluster, and $CH_{L(n+1)}$ means it is a cluster head of Level $n+1$ cluster.

As described, nodes closer to sink node are more likely to consume more energy during service. This condition also applies to clusters near the sink node. Cluster heads dissipate energy with higher rate than cluster members, due to their responsibility of managing and gathering data from cluster members. Furthermore, cluster heads near the sink node bear more relay tasks than those far away from the sink node. Therefore, this paper proposes hierarchical clustering design to balance energy dissipation by cluster heads in each layer to maximum network lifetime.

The proposed protocol consists of hierarchical clusters that mainly perform multi-hop data communications. However, such links can be terminated whenever a relay node on the link breaks down. To reduce data loss and improve network robustness against disconnection, this paper presents two options when such situation appears. One way is to choose an alternative transmission link, which may be considered as a fast recovery solution. Another way is to transmit data directly to the sink node with single-hop transmission mode. Though the former solution may cost more delay than
A single-hop, it is selected as preference option in terms of energy consumption.

In wireless sensor networks, the energy consumption for different transmission schemes is calculated as [HeCh02]:

\[
E_{\text{trans}}(I,d) = \begin{cases} 
    lE_{\text{elec}} + lE_{\text{mp}}d^2, & d < d_0 \\
    lE_{\text{elec}} + lE_{\text{mp}}d^4, & d \geq d_0
\end{cases} \tag{2a}
\]

\[
E_{\text{elec}}(I) = lE_{\text{elec}} \tag{2b}
\]

The \(E_{\text{elec}}\) is the electronics energy dissipation and it is determined by related operations during service (e.g., modulation/demodulation, filtering, and coding/decoding). The energy consumption of transmit amplifier \(E_{\text{mp}}\) and \(E_{\text{mp}}d^4\) are exclusively chosen according to the distance threshold \(d_0\). From previous work [HeCh00] [HeCh02], the difference of amplifier energy dissipation is considerable. Therefore, a proper value of \(d_0\) is important for wireless sensor network design.

The proposed protocol consists of two stages, which are network clustering stage and data communications stage. In the network clustering stage, the hierarchical layering starts from the lowest level cluster; Level 0 cluster is first created and cluster head is the sink node with level ID of 0 (\(CH_{L0}\)). Each member in the Level 0 cluster has a level ID: \(CM_{L0}\). Each \(CM_{L0}\) node is able to create, one degree higher, Level 1 cluster. By this, each \(CM_{L0}\) can also have another ID of Level 1 cluster head (\(CH_{L1}\)). In practice, whether a \(CM_{Ln}\) becomes a cluster head (i.e., \(CH_{Ln}\) ) depends on several criteria; a full description is given later in this paper. The reason of such network design is that interference and cluster overlap should be minimized in the network. Since each node is able to calculate approximate distance with another node, it is better to only let cluster members near geometrical boundary of a cluster create higher level clusters. The formation of hierarchical clusters grows like a tree. Starting from the Level 0 cluster (i.e., \(CH_{L0}\) is the sink node), potentially several branches to the next higher level clusters are created. The next level clusters, in turn, create branches to next higher level clusters. This continues until no other higher level clusters can be created.

In the data acquisition stage, time division multiple access (TDMA) technique is applied for intra-cluster communications. The time schedule is denoted by \(TS_{Ln}\), where \(n\) represents the level of cluster. Cluster head with level ID of \(CH_{L(n+1)}\) collects data from its cluster members using \(TS_{Ln}\), and then relays data to \(CH_{Ln}\) during time slot \(TS_{Ln}\). The inter-cluster TDMA slot is subdivide into \(m\) sub-slots for interference-free cluster member communications. By this approach, signal interference is minimized and sleep delay is substantially reduced.

\[B. \ Control \ Packets\]

During the network clustering stage, two packets, SYNC and SYNC_reply are utilized. These two packets are similar to SYNC packet in S-MAC [KiLe09] and ECLP [YeHe04]. The proposed protocol uses the SYNC packet for cluster formation, management and synchronization; the SYNC_reply is used for leaf node confirmation operations. Another essential component for each sensor node is the node management table. The table mainly includes elements that indicate the relation between this sensor node and its neighbor nodes.

Elements of the SYNC packet also include network routing information. \(c_{id}\) indicates the packet sender, and \(c_{lv}\) is the level of cluster created by the sender (i.e., \(CH_{Ln}\)). \(c_{parent}\) points out the parent node of sender. \(c_{cost}\) is calculated on the basis of the sender’s energy situation. It is written as,

\[
\text{SYNC}_{c_{cost}} = \frac{E_{R_{i}}}{E_{R_{j}}} \tag{3a}
\]

where

\[
E_{R} = E_{R_{i}} + E_{R_{j}} \tag{3b}
\]

The \(E_{R}\) is the sender’s residual energy, and \(E_{R}\) is the average energy cost for one round relay task. Furthermore, a SYNC_reply packet contains two items, which are \(c_{lv}\) and \(node_{total}\). \(c_{lv}\) is the maximum or deepest level of cluster that exists along one branch. The \(node_{total}\) is the total number of nodes along this branch. Both values are updated by each cluster head that relays this SYNC_reply packet to the sink node.

\[C. \ Network \ Clustering \ Stage\]

At the beginning of the network clustering stage, an initialization process is executed. Each node broadcasts its information with randomly short delay whenever it starts working. Nodes that receive the message calculate relative distance and store information in their node management table. If a new node joins the network during service, it also broadcasts its node information, and surrounding nodes then broadcast their node information to the new node. The sink node is able to broadcast to all nodes in the network. In this case, initially, each node has a node management table that stores information of surrounding nodes and the sink node.

The sink node marks itself as Level 0 cluster head (\(CH_{L0}\)), and updates the \(c_{cost}\) and \(c_{lv}\) into the SYNC packet. The sink node then sends the SYNC packet to its one-hop neighbors using the short range transmission mode. The one-hop neighbors which receive the SYNC packet choose the sink node as their cluster head, and then they store the value of \(c_{id}\), \(c_{lv}\) and \(c_{cost}\) into their node management table. In this case, the one-hop neighbors of the sink node become cluster members of the Level 0 cluster (\(CM_{L0}\)).
one sink node means there is only one Level 0 cluster in the network. Therefore, layer 0 is comprised of only one cluster. The cluster members of Level 0 then individually decide whether they should be the ones to create the next level cluster.

At the Layer n construction stage node $i$ is designed to accomplish two goals via its own SYNC packet. The first goal is to confirm to the cluster head of joining the Level $n$ cluster. The second purpose is to decide whether it should generate the next level cluster. Whether a node with level ID of CM_Ln should create another level ID of CH_L(n+1) depends on the distance between itself and its cluster head CH_Ln, called boundary distance. An equation of boundary distance is given to determine the eligible nodes,

$$ P_{CH_L}(n+1) = \begin{cases} 
0.9, & bd < \frac{d(CH_Ln, node_i)}{R} < 1 \\
0, & \text{otherwise} 
\end{cases} \tag{4a} $$

$$ bd = \min(\max_{bd}, \min_{bd} * \rho(n+1)) \tag{4b} $$

The $P_{CH_L}(n+1)$ is the possibility of a CM_Ln to be a CH_L(n+1). $R$ is the multi-hop based radio transmission range of nodes, and it is also the radius of each cluster. $d(CH_Ln, node_i)$ is the approximate distance between node $i$ and its cluster head, it is calculated by node $i$ and stored in the node management table during initialization process. The $bd$ is the boundary distance threshold that distinguishes possible cluster heads of next level from pure cluster members. The $n$ is the level of current cluster. To improve energy utilization efficiency, lower level clusters are designed to have more nodes that could be next level cluster heads by assigning looser distance restrictions. For instance, the boundary distance thresholds allow more nodes with level ID of CM_L0 to become a potential cluster head than nodes with higher level ID. Furthermore, tighter boundary distance restriction is applied to reduce redundancy of higher level clusters. If node $i$ does not meet the distance requirement, it only finishes the first SYNC packet goal, which is to confirm cluster membership to the cluster head. Otherwise, node $i$ is said to establish a higher level cluster with a certain probability.

As shown in Fig. 1, all cluster heads (denoted with solid circles) except the sink node are also cluster members of lower level clusters. The solid triangles represent pure cluster members.

A parameter $\rho$ is used to adjust the boundary distance so that the annulus of a cluster decreases with increasing layer number. Because the annulus decreases, the number of nodes that qualify for cluster head status decreases with increasing cluster layer. The reason for doing this is because the nodes that are farther away from the sink have a smaller chance of suffering from the “hot spot” problem. Accordingly, mitigation of the “hot spot” problem is decreasingly required for load balancing for cluster layers located further away from the sink. Therefore, the number of new clusters created at layers with increasing distance from the source decreases.

Fig. 1  Network clustering stage.

Similar with the sink node, node $i$ first calculates $c_{cost}$ and upgrades $c_{lv}$ by one, thus, indicating it is the cluster head of Level 1 cluster (CH_L1). $c_{parent}$ is assigned with ID of the sink node. These values are then updated into SYNC packet and broadcast, both sink node and neighbor nodes of $i$ are able to hear this packet: (i) sink node takes a look at the packet, it would add node $i$ to its cluster member group if node $i$ indicates the sink node is its cluster head. (ii) as soon as node $j$ receives SYNC packet, it set up a contention timer. Once the timer is out, $j$ chooses the SYNC packet sender that has lowest value of $c_{lv}$ as its cluster head. If more than one SYNC packets have the same value of $c_{lv}$, then $j$ selects the one that has lowest value of $c_{cost}$. It also stores another node that has the second lowest value of $c_{cost}$ as alternative parent. The value of $c_{lv}$ in the SYNC packet determines which level of cluster that node $j$ becomes a cluster member of. For instance, if node $j$ chooses node $i$ as the cluster head, it then becomes cluster member of Level 1 cluster (CM_L1). Node $j$ then adds cluster head information into node management table. By this approach, each node is a cluster member of lower level cluster and possibly to be a cluster head of higher level cluster. This procedure is executed until the leaf nodes are encountered.

If a cluster head does not hear SYNC packet that indicates this node as a parent node, it then marks itself as a leaf
cluster head and transmits a SYNC_reply packet along the formed branch. Data of \(c_{lv\_max}\) and \(node\_total\) is updated. \(c_{lv\_max}\) is the level of this leaf cluster head, and \(node\_total\) is the sum of direct and indirect child node, obviously, the value is 0 for a leaf cluster head. The SYNC_reply packet is then relayed by each cluster head all the way to sink node. Each cluster head then updates the value of \(node\_total\) of first received SYNC_reply packet by adding the number of its direct child nodes. The cluster head then compares \(c_{lv\_max}\) with its up to date highest level information. Cluster head updates its own highest level information if \(c_{lv\_max}\) is larger, otherwise \(c_{lv\_max}\) is updated. As a result, all cluster heads are able to know the highest cluster levels of this branch, and the amount of direct and indirect child nodes. Therefore, cluster heads have a sense of logical position in the network and relay load. This is for the purpose of load threshold function, which is stated in the data communications stage. When all SYNC_reply packets reach sink node, the network clustering stage is formally finished and switched to data communications stage.

D. Data Communications Stage

In the duration of data communications stage, TDMA is applied for intra-cluster communications. Each Level \(n+1\) cluster member transmits data based on local time schedule \(TS_{L(n+1)}\), and cluster head of Level \(n+1\) cluster relays data to lower level cluster head according to lower level cluster time schedule \(TS_{Ln}\). The network topological architecture looks like an inverted triangle, and data is transmitted from highest side all the way to the lowest vertex, which is the sink node.

A cluster head has two energy thresholds, one is called base threshold and another is load threshold. The load threshold reveals relay load degree of a cluster head. Cluster heads that have large number of direct and indirect child nodes and more close to sink node (i.e., lower cluster level) are likely to dissipate much more energy. In order to prevent rapid energy consumption of individual nodes, if the load threshold is breached, it means this cluster head is overloaded; it broadcast such message to all cluster members. Any cluster member that has alternative parent then broadcast message to join alternative cluster. It relays data to alternative cluster head once the request is confirmed. In the meanwhile, both the cluster head and alternative cluster heads recalculate load threshold. The load threshold is calculated as,

\[
c_{load\_thresh} = \max\_thresh \cdot (1 - \alpha \cdot \frac{n\_child \cdot c_{lv}}{node\_total \cdot c_{lv\_max}})
\]

(5)

where \(\max\_thresh\) is the maximum load threshold a cluster head can have. \(n\_child\) is the number of direct child nodes and \(c_{lv}\) is the level of this cluster head. Parameter \(\alpha\) is chosen with proper value to adjust results. From the equation, a cluster head that close to sink node or has more direct and indirect child nodes has larger load threshold. However, whenever the base threshold is violated, the cluster head disconnects all links and only sends its own data. In such situation, nodes that lost links switch cluster heads if they have alternative parent nodes. Otherwise, they automatically switch radio to single-hop transmission mode and send data to sink node in order to guarantee quality of service until next network clustering stage.

By using proposed single-hop transmission approach, a proper duration period of data acquisition is also important. A large period may degrade performance of minimize energy consumption difference. However, a small period could influence network efficiency and increase unnecessary overhead rate.

III. SIMULATION AND RESULTS

A simulation of the proposed hierarchical clustering protocol (HCP) was implemented in Matlab. Three comparison algorithms were demonstrated using the same parameters with hierarchical clusters design. The simulation was conducted to evaluate network performance that covers system survival period, link quality, and energy consumption. Parameters used in the simulation are given in Table 1. The parameters related to energy consumption are the same as those in [HeCh00]. Base threshold is set to 10% of maximum energy capacity. Max load threshold of cluster head is 30% of maximum energy capacity. Minimum and maximum boundary threshold are 20% and 80% of transmission range of multi-hop mode.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network coverage</td>
<td>(0,0)–(200,200)m</td>
</tr>
<tr>
<td>Base station location</td>
<td>(100,100)m</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>300</td>
</tr>
<tr>
<td>Initial energy</td>
<td>0.5J</td>
</tr>
<tr>
<td>R</td>
<td>30m</td>
</tr>
<tr>
<td>(E_{elec})</td>
<td>50nJ/bit</td>
</tr>
<tr>
<td>(E_{fs})</td>
<td>10pJ/bit/m²</td>
</tr>
<tr>
<td>(E_{mp})</td>
<td>0.0013pJ/bit/m⁴</td>
</tr>
<tr>
<td>(E_{DA})</td>
<td>5nJ/bit/signal</td>
</tr>
<tr>
<td>Data packet size</td>
<td>4000 bits</td>
</tr>
<tr>
<td>(\rho)</td>
<td>2</td>
</tr>
</tbody>
</table>

The simulation was conducted to compare proposed algorithm with three previous network routing algorithms. They are the low-energy adaptive clustering hierarchy (LEACH), energy-efficient unequal clustering mechanism
EEUC, and enhanced cross-layer protocol (ECLP). LEACH is selected since it is a typical clustering model for wireless sensor networks. Deep and systemic research has proved its value. The EEUC routing algorithm is designed to assign distinct cluster size to relieve energy pressure problems of nodes near sink node, which is also one of research goals of this paper. Furthermore, both LEACH and EEUC apply two radio transmission modes, which are the same as proposed by the present HCP algorithm. However, nodes in LEACH and EEUC switch radio mode to single-hop depend on distance between itself and the sink node, whereas in HCP, only nodes that loose link during service are allowed to send data directly to the sink node to maintain quality of service. Since LEACH, EEUC and HCP all belong to subcategory of clustering approach, the comparison is positive and worthy. ECLP is selected since it also applies layer design. A meaningful comparison can be given between ECLP and HCP.

As Fig. 2 illustrates the number of live nodes changes over time. HCP demonstrates significant longer service period than LEACH and EEUC. However, the ECLP shows better performance.

The reason is analyzed from a node efficiency aspect, which is shown in Fig. 3. Curves of LEACH and EEUC in Fig. 3 are the same with Fig. 2. It is because the link of these two algorithms is guaranteed since all nodes are able to reach the sink node by single-hop transmission. However, the node efficiency (percentage of nodes that are able to reach the sink node) of ECLP varies wildly, and then drops dramatically to a low level at a particular time spot. This is because that node in ECLP is link oriented. In multi-hop transmission mode, the sink node receives data from nodes closer to itself. This leads to huge energy consumption of these one-hop nodes, and obviously, the number of available one-hop nodes decrease during service. As a result, branches in the network tend to converge to one-hop nodes that are still available for data relay task. All nodes that have distance larger than one-hop distance lose links at the time the last one-hop node’s residual energy is below its threshold, i.e., disconnecting all links and only send its own data. Though some nodes are still alive in ECLP, the network cannot service any more.

The comparison between ECLP and HCP mainly concentrates on data relay efficiency, in other words, number of nodes that are hierarchical to the sink node during service. The HCP exhibits good performance on balancing energy consumption for each layer. Compared with ECLP of node efficiency, the variance of HCP is much smaller and smoother. The reason for such comparison result is that layers in ECLP categorize nodes, but layers in HCP classify clusters. Moreover, ECLP routing protocol does not apply single-hop transmission, nodes lost link broadcast error message and when reconnection attempt fails, they stop relaying data until next network configuration stage. In HCP, a node that lost link transmits data directly to the sink node.

A node efficiency comparison of one-hop nodes between ECLP and HCP is illustrated in Fig. 4. According to the simulation, the number of one-hop node is less than 10% of total number of nodes. As we can see, the percentage of available one-hop nodes in the figure decreases over time. The curve of HCP represents that the number of available one-hop nodes decreases smoothly. HCP provides longer network service time in terms of percentage of available one-hop nodes.
IV. CONCLUSIONS

This paper presents an innovated routing approach called hierarchical clusters design for wireless sensor networks. The goal of this proposed algorithm is to minimize energy dissipation difference in each layer, especially to relieve energy consumption pressure of nodes near sink node. Furthermore, a novel utilization of single-hop transmission mode is described in order to maintain node efficiency in the network. The hierarchical cluster design demonstrates promising network performance through simulation. The network lifetime is significantly prolonged compared with other algorithms. By using TDMA communications protocol and layer network architecture, the transmission delay is also reduced. The future work is needed to continue improve node efficiency, and the algorithm should be enhanced in larger scale of wireless sensor networks.

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