Level Based Path Selection Technique in Large WSN for Hierarchical Architecture

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Abstract

One of the main design issues of wireless sensor network (WSN) is to prolong the network lifetime and prevent connectivity degradation by employing energy management techniques. But a single route does not make any solution of in terms of energy because it rapidly drains energy of relay nodes. As a result these nodes die quickly than others. In this paper, we present a novel level based path selection and data forwarding techniques for large WSN for hierarchical architecture. In this structure cluster head (CH) is responsible for data fusion and data forwarding. So CHs expense more energy than other nodes. In this work base station constructs multiple routes among the CHs based on the path cost. In the data forwarding phase a CH selects a path from its route cache by considering both path cost and residual energy. Simulation result shows that our proposed technique achieves much higher performance than the classical routing protocols such as LEACH, flooding.

Keywords: *WSN, flooding, LEACH, energy efficiency, multipath, hierarchical routing.*

1. Introduction

Wireless sensor networks contain hundreds or thousands of sensor nodes equipped with sensing, computing and communication abilities. The nodes detect events or phenomena, collect and process data and transmit sensed information to interested users [1][2][3][4]. Each node is battery powered and communicates among its peers or directly to an external Base Station (BS) or sink node. The BS collects data from all nodes and process for future use [5]. Sink node are special node act as gateways to other networks. Sensor networks have received great importance due to its diverse application area particularly in hostile environment where human involvement is difficult or sometimes impossible.

There are some constraints in sensor networks due to simple node architecture [15]. Major issue of WSNs is energy because in most applications replacement of power resources not possible or infeasible [9]. Sensors are deployed highly dense fashion in large or small area for sensing the environment. The major problem of highly dense sensor network is overhearing, collision and redundant transmission. So the energy is the challenging subjects and design factor of WSNs. Furthermore in hierarchical routing [15], CH acts as intermediate router to the sink node or BS. Since CHs play the dual role of data originator and data router in WSNs, they exhaust energy much faster than other nodes. Therefore the node failure results in reducing the availability of paths to the destination and cause serious problems in the sensor network.

In this paper, we propose a path selection and data forwarding techniques in large sensor network for hierarchical architecture to balanced energy consumption and extend network lifetime. In proposed technique, first BS initiates a route construction phase by disseminating a packet throughout the network for creating paths between BS and CHs. The path cost of a route is measured by assigning a level to each CH. The level is assigned when a route construction packet disseminate throughout the network. In the data forwarding phase a CH select a path from its route cache by considering both path cost and energy issues. A CH sends its data to a route if the nodes in route have more energy and lower path cost. If the nodes in route have low energy CH selects another route from its route cache.

The remainder of this paper organized as follows: section II describes some closely related work on multipath routing. Section III represents wireless sensor network model. Section IV provides proposed work in detail. In Section V, the simulation results are explained and finally, some concluding remarks are given in Section VI.

2. Related Work

There are many research work has been performed on routing as well as energy consumption of nodes. In particular, routing problem has received an enormous interest from the research community. The protocols in [10][11][12] uses multiple paths and choose the network reliability as their design priority. The authors of [10] proposed the use of sub-optimal paths occasionally to provide substantial gains in network lifetime. The sub-optimal paths are chosen by means of a probability depending on how low the energy consumption of each path is. In addition, the network may be very energy expensive when data are routed through the path with the largest residual energy. So, there is a tradeoff between minimizing the total power consumption and the residual energy of the network. Abawajy [12] proposed the use of multipath routing for energy-efficient recovery from node failures in wireless sensor networks. It has been found that when a small number of multipath are kept alive, failures on the primary path can usually be recovered from without invoking network-wide flooding for path discovery. They evaluate two kinds of multipath designs- the classical node-disjoint multipath and a braided multipath that consists of partially disjoint alternate paths.

R. Shah [13] proposed an algorithm which route data through a path whose nodes have the largest residual energy. The path is altered whenever a better path is discovered. Using this approach, the nodes in the primary path will not drain their energy through repeated use of the same route, therefore achieving longer life. However, the path switching cost is high. K. Wu and J. Harms [14], proposed a routing algorithm which combines with hierarchical routing and geographical routing. Based on the hierarchical network architecture, the process of forwarding packets between the source nodes in the target region and the BS consists of two phases: *inter-cluster routing* and *intra-cluster routing*, a greedy algorithm is adopted in the process of the inter-cluster routing and an multi-hop routing algorithm based on the forwarding restriction angle is designed for the intra-cluster routing.

3. Network Model

In this work, we consider hierarchical architecture of WSN [15]. This types of network more energy efficient for periodic monitoring [15]. We assume that all nodes in the network field are homogeneous and static. We also consider that there are some special nodes that are called sink nodes placed outside the sensor field. These nodes do not have any power constraint and have high quality link to the BS. Base station is located outside from the sensor field in a safe place for processing the sense data. BS is the master controller of WSNs.

4. Proposed Route Selection Technique

Proposed work finds the best route between CH to BS and selects another route when a route breaks due to node failure or other causes. Our proposed scheme composed of two phases:

A. Route Construction Phase

B. Data Forwarding Phase

A. Route Construction Phase

In this phase BS sends a packet named route construction packet (RCP) to sink nodes to disseminate the packet throughout the network. During this dissemination process route request packets are exchanged between sink nodes to CHs or CH to CH and after this process route is created between CHs and sink nodes. In this work, we assign a level to each CH when the RCP disseminate through the network. The packet contains the following information as shown in Fig. 1.

Sender_ID	*HopCount*	*Sender_level*

Figure 1: RCP Frame Format

Initially the level of all nodes is assign to a high value; and the level and hop count of all sink nodes are assign to 0. When the sink nodes receive such RCP from the BS; it updates the packet information by assigning its own ID, hop count and own level shown in fig-1 and broadcast the packet to their neighbor CHs (neighbor CH can be one hop or multihop distances). The CH that receives the packet from sink node again updates the packet information by increasing the packets sender level by one. The hop count of the packet increases as the packet moves from one node to another. But the level is only increases when packet moves from CH to CH shown in Fig. 2

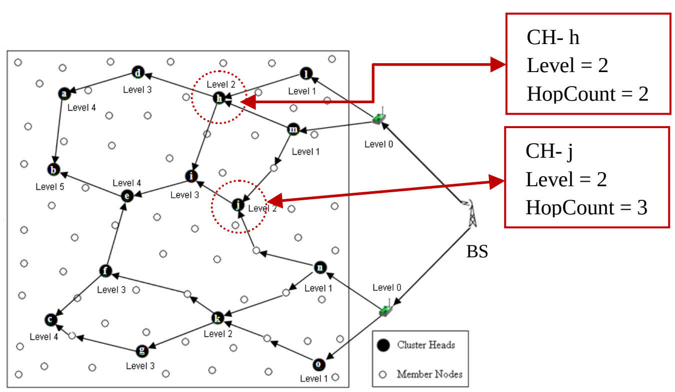

Figure 2: Dissemination of RCP

The CHs that received the RCP increases the packet's level and hop count by one and updates its routing table by using the RCP information shown in table-1. After updating its routing table the CH re-broadcast the packet to its neighbor CHs. The neighbor CHs does the same process and this process is going on until the RCP travels the whole network. If a CH receives a RCP later from the same level or lower level's CH, it simply discards the packet. Each CH broadcast the RCP once and maintains its own routing table.

Our major contribution in this phase is to create a routing table for each CH which consist of two fields namely *Next_Hop* and *Path_cost.* An example of routing table is shown in the Table I.

TABLE I: Routing Table

Next_Hop	Path_cost
1	5
2	6
…	…

Next_Hop field contains the address of the next hope address and the *Path_cost* field contains the cost to reach the BS which is measure as follows:

$$Path\_Cost = Hop\_Count \times Sender\_level$$

At first an intermediate node checks the *Sender_level*, if it is found to be lesser than itself, then the intermediate node increments the sender level by one and assigns this level as its own level. After that the intermediate node calculates the path cost to the BS and updates its routing table using this *Sender_ID* and *Path_cost*. Now the intermediate node increments the sender hop count and updates the RCP's *Sender_ID*, *Hop_Count* and *Sender_level* filed and broadcast the RCP to its all neighbor CHs. After broadcasting the packet the node sort its routing table based on the *Path_cost*. If the intermediate node found that the *Sender_level* not lesser than itself, it simply drop the packet. As the sensor node has limited memory we assume that it keeps only first *n-level* entry of the routing table as next-hop and discards all remaining entry. If a normal node, which acts as a relay node between two CHs, receives the RCP, just increment the *Hop_Count* by one of the packet and forwards the packet towards the next CH.

Our proposed scheme of acquiring multiple low-cost route construction mechanism is described in Algorithm 1.

Algorithm 1: *Route Construction Mechanism*

1. Set *Level = 0* and *Hop_Count = 0* to every Sink nodes. Assign a Level of high value to every CH.
2. BS initiates **RCP** (Route Construction Packet) to the every Sink node periodically.
3. Each Sink node assigns its ID, hop-count and level to the packet's ***Sender_ID***, ***HopCount*** and ***Sender_level*** field respectively and disseminates the **RCP** to its Neighbors CH.
4. **if** (**RCP** is Received by *CH*) **then**

   if (*Sender_Level < Own_Level*) **then**

   a) Assign *Own_Level = Sender_Level + 1*;

   b) Calculate *Path_Cost = Hop_Count* × *Sender_level*;

   c) Insert ***Sender_ID*** and ***Path_Cost*** into its Routing table as next-hop node;

   d) Hop_Count = Hop_Count + 1;

e) *Insert* the *Node_ID*, *Hop_Count* and *level* to the packet's ***Sender_ID, Hop_Count*** and ***Sender_Level*** field respectively; and broadcast the **RCP** to its every Neighbor CH;

f) Sorting the Routing table ascending order based on the ***Path_Cost**;* Keep entry upto *n-level* from the beginning as **Next_Hop** and discard all the remaining entry;

else

Drop the packet;

end if

end if

5. **if** (**RCP** is Received by a *relay node*) **then**

a) Hop_Count = Hop_Count + 1;

b) Forward the **RCP** toward the next CH;

end if

B.Data Forwarding Phase

BS initiates route construction phase periodically and create multiple low cost shortest paths. However, we also consider the residual energy at each CH because only using the shortest path forces the nodes with low residual energy over the path to exhaust their energy, so that they cannot participate as a router in forwarding data any more. Therefore, the small number of nodes alive in the network results in reducing the availability of multiple paths and finally whole network becomes inoperable.

To address the problem, when a CH picks up a next-hop node, it first checks the residual energy of the next-hop node. The CH selects a path with the next-hop node whose residual energy higher than a threshold energy value. If several next-hop nodes have same lowest path cost then it selects a next-hop node whose residual energy is the largest among the same path cost nodes towards the sink node. Each CH performs the periodic exchange of *hello* packet to inform its neighbor CHs of its residual energy. If a neighbor CH nodes residual energy goes to lower than the threshold energy then it cannot participate as a router in forwarding data over a path. It just acts as a normal CH in the environment and can send only sense data of itself to the next-hop.

If a CH recognizes that all next-hop nodes over the paths in its route cache lack their residual energy below the threshold energy that is they cannot take part as a router in forwarding data, the CH broadcast a *Failure* packet to its neighbor CHs. On receiving the *Failure* packet to the neighbor CH, it will exclude the next-hop node from its routing table using the sender of the packet as its next-hop node.

When a CH transmit a data packet to its next hop, it keeps the data packet for a pre-defined time and wait whether the data packet is successfully deliver to the next hop. If the CH receives a *Failure* packet within that pre-defined time, it recognizes that there is a broken path on that next-hop. Then the CH re-transmits the data packet to another next-hop according to its route cache and removes the *Failure* packet sender from its routing table as a next-hop. When the CH chooses another next-hop it must satisfy the condition of *path cost* and *energy* that we described before. If the CH doesn't receive such *Failure* packet within that pre-defined time it recognizes that the data packet is successfully delivered to the next-hop and it simply discard the data packet.

Now if a source CH receives such Failure packet and there is no another available path to the sink node then it try to acquire a route to the sink node from itself using flooding or broadcast a request to sink node or BS to setup a route construction phase for this CH by sending the RCP again.

We divide the following section in two parts:

i. Data forwarding mechanism

ii. Next hop selection conditions

i. Data Forwarding Mechanism

In this section we describe how a CH transmits data packet to sink node. The data forwarding mechanism is described in Algorithm 2.

Algorithm 2: *Data Forwarding Mechanism*

1. **if** (CH receives a data packet) **then**

    Transmit the data packet to its ***Next_Hop***;

    Keeps the data packet for a pre-defined time period and wait for whether a failure occurs or not;

   end if

2. **if** (*Failure* packet Received by the CH within that pre-defined time) **then**

    Re-transmit the data packet to another ***Next_Hop*** which satisfy the *pathcost* and *energy* condition;

    Keeps the data packet for another time period and wait;

    Remove the ***Failure*** packet sender from its routing table;

   end if

3. **if** (*Failure* packet is received by a Source CH and there is no another ***Next_Hop*** entry in its routing table) **then**

    Try to acquire a route to the sink node from itself using flooding and broadcast a request to the BS to setup a route construction phase for this CH by sending ***RCP***.

   end if

4. **if** (There is no Failure packet is received by the sender CH within that pre-defined time) **then**

    Discard the data packet since it is successfully received by the ***Next_Hop***;

   end if

ii. Next Hop Selection Conditions

This section, we describe the conditions how a CH select a next hop base on path cost and residual energy. The condition how a CH selects a next-hop is described in the Algorithm 3.

Algorithm 3: *NEXT-hop Selection Mechanism*

1. **if** (*All entry of* ***Next_Hop*** *nodes residual energy < Threshold Energy*) **then**

    Broadcast ***Failure*** packet;

    end if

2. **if** (Several *Next_Hop* node has equal lowest *Path_cost* and their *Residual_Energy > Threshold Energy*) **then**

    a) Find the node with highest residual energy among the same ***Path_cost*** nodes;

    b) Set the highest residual energy node as ***Next_Hop***;

    else

    a) set *index = 1* (where *i* is the row index of the routing table);

    b) **if** (*index* entry's *Next_hop Residual Energy > Threshold Energy*) **then**

    Set the *index* entry as ***Next_Hop****;*

    else

    index = index +1;

    repeat step *b* until *index* reaches at the last entry in the routing table;

    end if

    end if

5. Performance Analysis

In this section, we evaluate the effectiveness of the proposed scheme through experiments. We use MATLAB as simulator and compare our proposed routing protocol with LEACH and flooding through simulation experiments.

The radio wave propagation follows Two-Ray Ground Model (Equ. – 1) [17], which specify how receive power related with transmit power, antenna height and gain, and the distance between the transmitter and the receiver.

$$P_r = \frac{P_t \times G_t \times G_r \times h_t^2 \times h_r^2}{L \times d^4} \quad (1)$$

Where, P_t and P_r are transmitted and received power respectively, G_t and G_r are Antenna Gain of the transmitter and receiver, H_t and H_r are Antenna Height of the transmitter and receiver, L is the system loss and d is the distance between transmitter and receiver.

To transmit an l-bit message a distance d, the radio expends [18]

$$E_{Tx} = lE_{elect} + le_{fs}d^2 \quad for \quad 0 \le d \le d_{crossover} \quad (2)$$

$$E_{Tx} = lE_{elect} + le_{mp}d^4 \quad for \quad d > d_{crossover} \quad (3)$$

Where e_{fs} and e_{mp} is the energy consumed by amplifier for short and long distance respectively. E_{elect} is the electrical transmission/reception energy and $d_{crossover}$ is the limit distance for it parameters must be changed.

The energy expended in receiving an l-bit message is given by

$$E_{Rx} = lE_{elect} \tag{4}$$

We consider the Mica2 mote for our simulation to bring the reality in simulation. After randomly deployment of homogeneous sensor nodes, we randomly select some node as CH. We considered static clustering technique because we do not change CH with respect to time as it is not related with our work. In the simulation, the source is randomly chosen and we consider a CH collect and transmit data packets at intervals of 5 second. All experiments are repeated several times with different random seeds and different random node topologies. When a packet arrives the algorithm will be invoked to compute the paths. The simulation parameter is shown in Table II.

TABLE II: Simulation Parameters

Sensor Deployment Area	500 × 500
Number of Nodes	2500
Packet Size	29 bytes
Initial Energy	0.5 J
E_{elect}	50 nJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
Transmission Power (P_t)	-5 dBm
RSSI Threshold	-98 dBm
BS Location	(520, 250) m
No of Sink	25
Antenna Height	0.082 m

Fig. 3 shows the average residual energy of each CH between our proposed technique and LEACH with respect to time. From the figure we observe that as time increases proposed model consumes less energy than the LEACH.

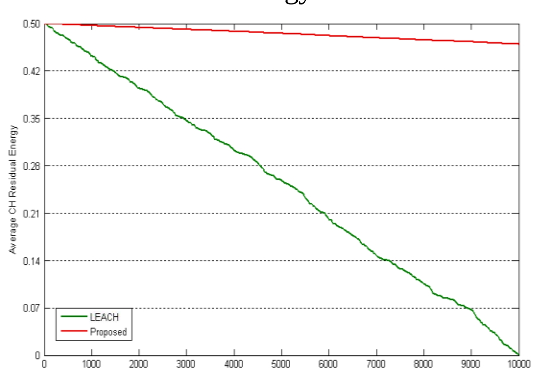

Figure 3: Average CH Residual Energy Vs Time

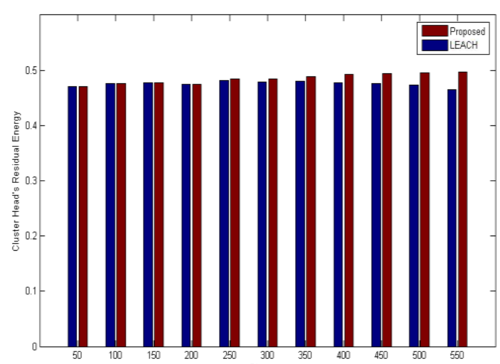

Figure 4: CH Residual Energy Vs Distance

In Fig. 4 we compare proposed technique with LEACH. In the figure proposed work perform much better performance as the distance increases and there is balanced residual energy in all cluster head.

Fig. 5 demonstrate average energy consumption with respect to number of cluster heads. Here we compare our proposed technique with flooding. The simulation is run for 2000 seconds for each topology therefore each protocol has enough time to discover the route. The flooding is the most costly protocol because the number of hops tends to increase as the node density increases. From the Figure 5.6 we observe that almost linear energy consumption increase as the network becomes denser but the energy consumption of flooding increases faster than our proposed model. On the other hand, in our proposed model the energy consumption increases very slowly. Such experimental result demonstrates that the energy efficiency of our proposed routing algorithm is stable and has little impact by the increase of the network size, while the performance of other schemes degrades with larger network size.

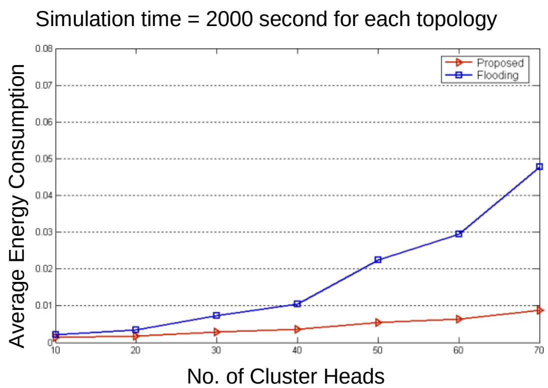

Figure 5: Average energy consumption with respect to number of Cluster Heads

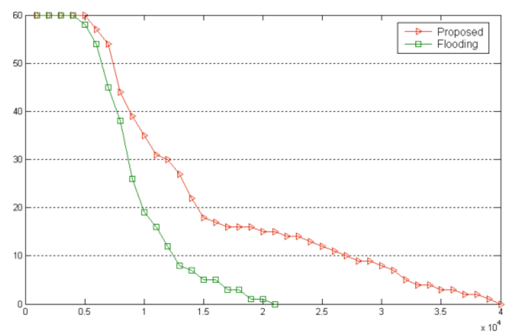

Figure 6: Network life in data Collection Round Vs Number of active Cluster Head

Fig. 6 demonstrates the network life in data collection rounds plotted against the number of active cluster heads. We compare proposed algorithms with the flooding which disseminate data to its entire neighbor. As shown in Figure-5.2, our proposed algorithm enhances the network life time by almost 50% to the flooding measured to the death of first node.

6. Conclusion

In the vast field of research related to wireless sensor network, our focus has been on the problem of level based path selection technique in large wireless sensor network for hierarchical architecture. We propose a hierarchical routing protocol which creates sink rooted tree. Energy resource limitations are the priority concern in sensor networks. Distributing the load to the nodes enhance the system lifetime significantly. In our research work, our goal is to search multiple low cost paths and utilize those paths in a balanced manner so that this prolong the network lifetime.

We simulate our proposed model and compare it to LEACH and flooding. The results show that proposed technique save much energy of cluster head that perform data fusion and act as router. So cluster heads do not died soon due to lack of energy. So it prolong the life time of sensor network. From simulation we also find that our proposed technique performs better when sensor field is large enough. There are several future works we would like to focus on including improve the algorithm by integrating sink mobility feature and how to guarantee the delivery of packets under situations when the transmission path break due to power and other nodes distance more than transmission range.

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