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Enhancement of Hierarchy Cluster-Tree Routing for Wireless Sensor Network

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Abstract

Many protocols such as clustering are proposed to minimize and balance energy consumption of the network because WSN (wireless sensor network) is energy-limited. In clustering protocols, CHs (cluster head) consume much more energy than its CMs (cluster member) which leads to the faster death of CHs. Many traditional protocols are designed to solve the problem, but they have some drawbacks respectively. In this paper, EHCT (enhancement of hierarchy cluster-tree routing for WSN) is proposed to further balance the energy consumption. The simulation results show that the performance of EHCT has an improvement of 41% over LEACH and 14% over UDACH in the area of 500m*500m, 28% over LEACH and 18% over UDACH in the area of 1000m*1000m.

Keywords: WSN, Cluster-tree enhancement, EHCT

1. Introduction

Fast development of technologies such as low-power wireless communication and inbuilt computing enables that many low-price sensors can be organized to be a WSN (wireless sensor network). The sensors are distributed in the open and powered by batteries. They need to work lots of months and can not be powered again. By this token, the difference of WSN from traditional networks is energy-limited. To solve this problem, many clustering protocols have been proposed in recent years.

LEACH (Heinzelman W., 2000, pp.1-10) is a representative clustering protocol where CHs are selected randomly and rotated in each round. The energy consumption is reduced because of the decreasing of the number of nodes which communicate with BS directly.

LEACH-C (Heinzelman W., 2002, 4, pp.660-670) is an improvement of LEACH. In this protocol, CHs are not selected randomly but according to the residual energy. The node whose residual energy is more than the average energy of all nodes may be selected as a CH, so CHs can not die untimely. However, the deficiency of LEACH and LEACH-C is that the distribution of CHs is uneven and the data is transmitted by single hop.

PEGASIS (Lindsey S., 2002, 3, pp.1-6) makes all nodes form a chain and specifies one node to communicate with BS directly. Each node only communicates with its neighbors and sends data to BS in turn, but it requires the location of all nodes.

UDACH (Chen Jing etc., 2007, pp.628-632), a uniformly distributed adaptive clustering hierarchy routing protocol, enables that CHs are uniformly distributed, which balances the energy consumption and prolongs the lifetime of the network compared with LEACH and LEACH-C. But CHs in UDACH communicate with each other directly, when the distance of two CHs is long, the sending CH consumes much energy.

In this paper, EHCT is designed to further balance energy consumption and prolong lifetime of the network. It selects CHs based on a Master/Slave method. When a CH needs to send data, it selects a RN which is a member of the previous cluster to forward data to the next CH. The total distance of RN to previous CH and RN to next CH is minimum and less than the distance of previous CH to next CH.

2. Wireless network model

The sensor nodes are randomly distributed in a square area and monitor the environment unceasingly. We assume that all nodes are energy-limited. The location of each node is unknown and fixed. The BS is stationary and located far away from the monitored area. Each link is symmetric and the approximate distance of two nodes can be evaluated according to the received signal intensity.

We use the energy model (HeinzelmanW., 2000, pp.83-86) to analyze the radio energy consumption (Figure.1). Two channel models are used in the energy model. One is free space model, the other is multi-path fading model. The distance between transmitter and receiver determines which model is used.

d is transmitting distance of L-bit packet, multi-path fading model is selected when d is greater than d_0, and the energy spent for the radio is

$$E_{TX}(l,d) = l * E_{elec} + l * \varepsilon_{amp} d^4 \tag{1}$$

Free space model is selected when d is less than d_0, and the energy consumption is

$$E_{TX}(l,d) = l * E_{elec} + l * \varepsilon_{fs} d^2 \tag{2}$$

E_{elec} in equation (1) and (2) represents the electronic energy, ε_{fs} and ε_{amp} are transmitter amplifier, d_0 is a constant.

The energy for receiving this packet is

$$E_{RX}(l) = l * E_{elec} \tag{3}$$

The energy for fusing n packets with L-bit is

$$E_{DA}(n,l) = n * l * E_f \tag{4}$$

E_f in equation (4) is the energy consumed by the node to fuse one bit.

3. EHCT design

An enhancement of hierarchy cluster-tree routing EHCT is proposed in this paper. It is an energy efficient clustering protocol which is divided into several rounds. Each round is composed of three phases: cluster formation, cluster-tree construction, data transmission. CHs are selected in cluster formation phase and aggregate the data collected from its CMs in data transmission phase. If the cluster-tree is constructed, CHs forward the aggregated data to BS.

At the beginning of the network construction, BS broadcasts a HELLO packet to all the nodes at a certain power level. Each node can compute the approximate distance to BS according to the received signal intensity.

3.1 Cluster Formation

The cluster formation is based on a Master/Slave method. There is a MCH (master CH) and two SCHs (slave CHs) in each cluster. MCHs are not selected randomly but according to the residual energy. Each node generates a random number and compares it with a specified threshold. The node whose random number is greater than the threshold becomes a candidate MCH. Only the candidate MCH has the right to be a MCH. The candidate MCH which has the max residual energy is the final MCH. Each MCH then selects two SCHs which have the maximum residual energy among its neighbors. The two SCHs then join this cluster. Other neighbors join clusters according to the principle of proximity.

After each cluster is constructed, the MCH sends the TDMA packet to each CM to assign the slot time. The two SCHs have the last two slots. CMs send collected data to the closest one among the MCH and two SCHs.

3.2 Cluster-tree Construction

A cluster-tree is built to link MCHs with BS in this phase. Each MCH broadcasts a WEIGHT packet including its own ID and the square of d(CH, BS) in a certain power level. The node receiving the WEIGHT packet computes the approximate distance to the sending MCH based on the received signal intensity.

We introduce a distance function f(d) to select the next MCH to BS. If the MCH_x receives a WEIGHT packet from MCH_y and $d^2(MCH_x,BS)$ is great than $d^2(MCH_y,BS)$, it computes $f^{xy}(d)$ and selects the MCH which has the minimum f(d) to be the next hop to BS.

$$f^{xy}(d) = |d^2(MCH_x,BS) - d^2(MCH_y,BS)|, (x,y = 0,1,...N) \tag{5}$$

N is the number of nodes. When a MCH can not communicate with any other MCH in its transmission range, it sends the data to BS directly.

The MCH which has selected the next MCH further selects a RN to forward the aggregated data. After a certain time, each CM sends a DIST packet to its MCH in its assigned slot time. The DIST packet includes the square of the distance of the CM to its near MCHs.

We assume that MCH_m selects MCH_n to be the next hop. If a CM_i whose MCH is m receives a WEIGHT packet from a MCH_n, it computes the approximate distance d(CM_i->MCH_m, MCH_n). If a MCH_m receives a WEIGHT packet from a MCH_n, it computes the approximate distance d(MCH_m, MCH_n).

We give the following formula:

$$d^2_{comp}(CM_i) = d^2(CM_i \to MCH_m, MCH_n) + d^2(CM_i \to MCH_m, MCH_m) \quad (6)$$

The MCH_m compares d^2_{comp} of all its CMs and selects the CM which has the minimum d^2_{comp} to be the candidate RN. Assuming that CM_j is selected and $d^2_{comp}(CM_j)$ is less than $d^2_{comp}(MCH_m,MCH_n)$, which is

$$d^2_{comp}(CM_j) < d^2(MCH_m, MCH_n) \quad (7)$$

CM_j becomes the RN to forward the data from MCH_m to MCH_n. Otherwise MCH_m forwards the aggregated data to its next MCH_n directly.

Our method of building cluster-tree can decrease the energy consumption of the MCHs and balance the energy consumption of the whole network on the ground that the energy consumption is relative to square distance in free space or four-square distance in multi-path fading space. The flowchart is shown in figure.2.

3.3 Data transmission

Each node collects the data unceasingly and sends it to its MCH or two SCHs in its transmission slot time. The two SCHs send the data aggregated by them to the MCH in the last two slots. The MCH aggregates all the received packets to one single packet and then sends it to its RN which forwards the aggregated packet to the next MCH. If there is not an eligible RN, the MCH sends the packet to next MCH directly.

4. Evaluated performances

To evaluate the performance of EHCT and compare it with LEACH and UDACH, the protocols are simulated in two environments 500m*500m and 1000m*1000m, the simulation tool is OMNET. There are 100 nodes and the BS is located far away from the monitored area. The simulation parameters are listed in table 1.

We analyze the three protocols from two aspects: total energy consumption and death time of half nodes. Figure.3 and figure.4 show the total energy consumption over time in 500m*500m and 1000m*1000m respectively. The simulation results show that EHCT consumes the least energy and UDACH takes the second place, while LEACH consumes maximum energy. CHs in LEACH communicate with BS and the distribution of CHs is uneven. CHs in UDACH communicate with each other directly. The distance between the two CHs is longer, and the energy consumption of the sending CH will be more. In EHCT, we select a CM in the previous cluster to be a RN which forwards the aggregated data from the previous CH to the next CH. It decreases the energy consumption of CHs, thus it reduces the energy consumption of the whole network.

Figure.5 and figure.6 illustrate the number of dead nodes over time in 500m*500m and 1000m*1000m respectively. The simulation results show that the fewer the dead nodes are, the better the performance of the protocol is. As shown in the two figures, LEACH has the worst performance while EHCT is best.

We usually evaluate the performance of a protocol based on the death time of half number of nodes which represents the lifetime of network. As shown in table 2, the longer the death time of half number of nodes is, the better the protocol is.

The performance of our protocol compared with UDACH and LEACH is shown in table 3. The performance of EHCT has an improvement of 41% over LEACH and 14% over UDACH in the area of 500m*500m, and 28% over LEACH and 18% over UDACH in the area of 1000m*1000m.

The simulation results show that EHCT balances the energy consumption of the nodes and prolongs the lifetime of network. It performs best of the three protocols.

5. Conclusion

To balance the energy consumption and prolong the lifetime of the network, EHCT is proposed. It is composed of three phases: cluster formation, cluster-tree construction and data transmission. After clusters are built, a previous MCH further away from BS may forward the aggregated data to a RN, and then the RN forwards the data to the next MCH nearer to BS. The RN is a CM whose MCH is the previous MCH. The simulation results show that EHCT has the best performance compared with LEACH and UDACH.

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Table 1. Simulation parameters

Parameter	Value
Initial Energy	200J
Transmitting Radius	150m
Simulation Time	36000s
ε_{fs}	10pJ/bit/m^2
ε_{amp}	0.0013pJ/bit/m^4
E_{elec}	50nJ/bit
E_f	5nJ/bit/signal

Table 2. Death time of the three protocols

Area	Algorithm	Death time
500m*500m	EHCT	31069s
	UDACH	26692s
	LEACH	18198s
1000m*1000m	EHCT	25457s
	UDACH	20960s
	LEACH	18437s

Table 3. Improvement of EHCT

Area	Comparer	Improvement
500m*500m	UDACH	14%
	LEACH	41%
1000m*1000m	UDACH	18%
	LEACH	28%

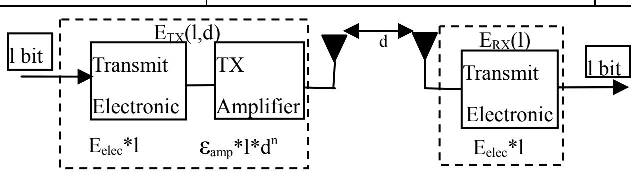

Figure 1. Energy Model

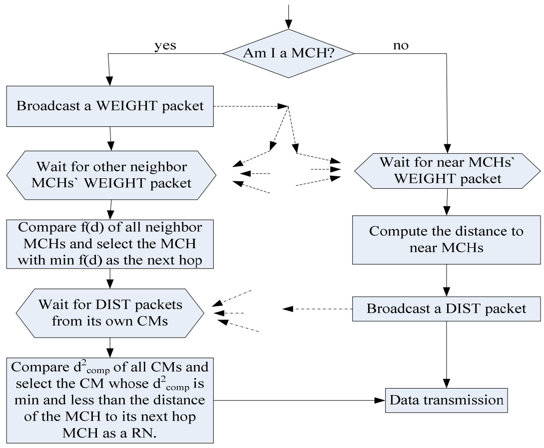

Figure 2. Flowchart of cluster-tree construction

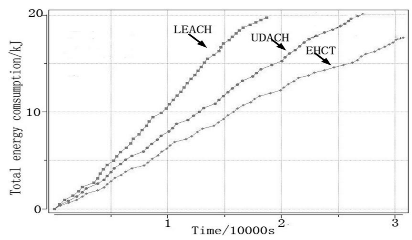

Figure 3.Total energy consumption in 500m*500m

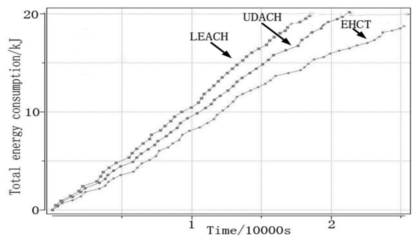

Figure 4. Total energy consumption in 1000m*1000m

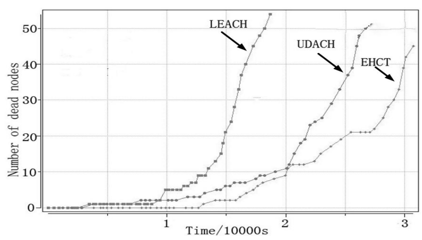

Figure 5. Number of dead nodes in 500m*500m

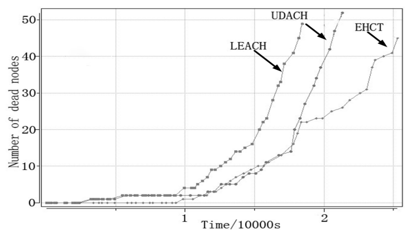

Figure 6. Number of dead nodes in 1000m*1000m