Reliable Energy-Aware Routing Protocol for Heterogeneous WSN Based on Beaconing

Li Ya, Wang Pengjun, Luo Rong, Yang Huazhong, Liu Wei

Department of Electronic Engineering, Tsinghua University, P.R. China

Rohm Building 4-205, Tsinghua University, Beijing, P.R. China

qhcjly@126.com, wangpj@tsinghua.edu.cn, luorong@tsinghua.edu.cn, yanghz@tsinghua.edu.cn, liu-wei@mails.tsinghua.edu.cn

***Abstract*—Heterogeneous WSN(wireless sensor network) is widely used in environmental monitoring, infrastructure monitoring, animal monitoring and smart building. Since nodes in heterogeneous WSN have different power supply and operational capability, routing protocols could make the most of the nodes' heterogeneity to make the network reliable, robust, simple and energy-efficient, but by now, protocols designed can't achieve all these goals. CTP(collection tree protocol) made a good practice to provide a reliable protocol based on beaconing for data collection. But it doesn't consider about energy balance and it doesn't provide an efficient dissemination scheme. In this paper, we present a novel routing protocol for heterogeneous WSN based on beaconing. We introduce EARBB(a Energy-Aware Routing Based on Beaconing) which can provide a reliable and energy-efficient routing scheme for both information collection and dissemination with beaconing packets exchanged between nodes and their neighbour. At the same time, EARBB also support node-to-node routing scheme besides node-to-sink routing scheme. Simulation experiments show that EARBB establish a reliable network which can quickly recover from node failure. During downstream data transmission, 80% less packets need to be sent using EARBB than using flooding. Its average lifetime is at least 20% longer than that of CTP.**

***Keywords*—static heterogeneous WSN, energy-aware, routing, beaconing, reliability, CTP**

I. Introduction

For sensor network used in infrastructure monitoring, smart home, environment monitoring and animal monitoring, heterogeneous WSN is always preferred because it can largely alleviate the workload of the nodes by using some powerful header nodes.

An efficient routing protocol can make heterogeneous WSN better to provide a reliable and energy efficient connectivity between nodes and the sink. When designing a routing protocol for heterogeneous WSN, five goals should be considered.

Reliability: Under normal circumstances, more than 90% end to end packets should be sent successfully.

Robustness: Network can quickly react to the change of network condition and topology.

Energy-efficiency: minimum energy should be consumed and energy-consumption should be even among all nodes.

Bidirectional-support: Both upstream and downstream routing should be efficient.

Simplicity: Complex protocol requires more hardware resources and energy consumption.

Many protocols achieve some of these five goals. LEACH based protocols[1]–[3] are quite energy efficient and can support bidirectional transmission because LEACH based protocols construct single-hop network. However, LEACH based protocols can't guarantee 100% connectivity between nodes and header nodes that largely decreases its reliability. RSNP[4] is a very simple protocol. It provides reliable and energy efficient upstream link, but its downstream traffic consumes too much energy and this protocol can't quickly react to node failure. REAR[5] is another good practice for heterogeneous WSN. It introduces energy-reservation mechanism and back-up path mechanism to achieve reliability and energy efficiency, but REAR reacts slowly to network condition change.

CTP[6]–[8] is considered the most reliable and robust routing protocol among all those routing protocols for heterogeneous WSN. It is well designed and fully tested. Adaptive beaconing mechanism makes it very robust while simple path validation scheme makes it very energy efficient. Reliability is achieved by single hop Ack, route loop avoid and packet repetition suppression scheme. But CTP doesn't support bidirectional transmission and its unbalanced energy consumption among nodes is a big constraint to the lifetime of the network.

In this paper, we propose an energy-aware routing protocol based on beaconing that improves CTP. By modifying the beaconing scheme, we make the sink maintain a routing table containing the whole topology of the network. Thus, the new protocol support bidirectional transmission and the downstream traffic can be the same robust, reliable and energy-efficient as the upstream traffic. By introducing a new path validation metric, the route selection is based on not only the link quality, but also the residue energy of the route. Therefore, energy consumption among node is much more balanced and the lifetime of the whole network is prolonged. Overcoming the drawbacks of CTP, the new protocol achieves all five goals as reliability, robustness, energy-efficiency, bidirectional-support and simplicity.

II. PROPOSED PROTOCOL

A routing protocol should build and maintain a routing table that contains the minimum-cost tree from every node to the sink. The cost metric is a very important parameter to depict the quality of the route. Once the routing table is established, minimum-cost route can be selected between every node and the sink. In this part, the new path validation metric that helps balance the nodes' energy consumption in the network will be introduced. Then routing table establishment process will be described.

A. Energy Aware Path Validation

In order to find the minimum cost route for nodes, every node should evaluate the cost of the route to the sink. To evaluate the cost of the route, a cost metric should be picked first. Usually, cost metric is set to be a parameter related to the packet loss rate. In CTP, expect transmission which is in proportion to packet loss rate is selected to be the cost metric[7]. Such cost metric can objectively depict the link quality of the radio channel. But using such cost metric makes the nodes in the best quality routes bear most of the transmission tasks. Therefore, these nodes will quickly exhaust their energy. The energy consumption is even faster on those nodes near the sink.

To counter this problem, we assume another cost metric to evaluate the path quality which is called expect transmission hops and energy residue (ETHER). Single hop ETHER is calculated using the following equation.

$$\mathrm{ETHER} = E^{\alpha} \cdot L$$

where, E is the energy residue of the node. L is the packet loss rate of the channel. α is a constant, here it is recommended α to be 1.5. The ETHER of the route is the sum of ETHER of each hop along the route. Because energy residue can be easily got from the power curve of the source, ETHER is very easy to get.

Since ETHER takes energy residue into account, the route with less energy residue will not be selected as the best route. Thus nodes on the route with the best link quality will not run out of energy so fast. The workload of the network is distributed more evenly. This solution may slightly influence the delay and the quality of transmission, but it will largely prolong the lifetime of the network. According to the simulation in part 3, the lifetime can be prolonged at least 30% under different network size.

B. Route Computation and Selection

EARBB adopts the adaptive beaconing scheme[7] which extends the Trickle algorithm[9]. So the network could quickly react to network topology and condition change while consuming least energy on beacon packets transmission. But EARBB introduces a new route computation and selection procedure to support efficient bidirectional transmission.

In EARBB, minimum-cost routing tree will be established as beacon packets exchanged between nodes and their neighbours. Beacon packets are also exchanged between nodes and the sink. Beacon frame contains information of the node's cost to the sink. The detail of the beacon frame is in table 1.

The function of *P* bit and *C* bit is the same as that in CTP[7]. *PARENT* field and *ETHER* field record the cost from the node to the sink. *ORIGIN* field record the node's own address. *NEIGHBOUR COUNT* field, *NEIGHBOUR ADDRn* field and *ETHERn* field record the cost from the node to its neighbours.

TABLE 1. BEACON FRAME DETAIL

1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
P	C	RESERVED						PARENT							
PARENT								ORIGIN							
ORIGIN								ETHER							
ETHER								NEIGHBOUR COUNT							
NEIGHBOUR ADDR 1															
ETHER1															
NEIGHBOUR ADDR 2															
ETHER1															
……															

Every node in the network maintains a cost table that records the cost between the node and its neighbours as well as the neighbours' cost to the sink. Node in the network also maintains its own cost to the sink and its parent address. When node receives beacon packet from its neighbours, it updates the cost table, calculates the best route according to the new cost table and then refreshes its own cost to the sink and its parent address. As beacon packet exchanged between nodes in the network, every node in the network finds its best route and its parent. After that, the upstream route tree is formed within the network.

When a node receives a beacon packet whose *ORIGIN* field equals its own address, it immediately forwards the beacon packet to the sink as a normal data packet through its route to the sink. When the sink receives the beacon packet, it updates its route table, which contains nodes' address and their parent address in the network. The sink can find the best route to the node in the network through the route table.

Figure 1 shows an example of how the sink finds the route to a specific node in the network. Assume the sink's address is 1 and the route table contains three nodes 2, 3 and 4. The sink wants to find the route to node 4. It first goes through the route table to find node 4, then goes through the route table to find node 4's parent which is node 3. Repeat the above steps until the sink find the node whose parent is the sink itself. In this case, it should be the node 2. Now, the sink discovers the route from the node 4 to the sink. The route is 4-3-2-1. So the route from the sink to the node 4 is just the opposite route which should be 1-2-3-4. So the route table maintained by the sink make it possible to find route to any node in the network.

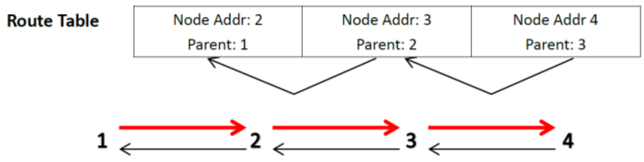

Figure 1. Downstream route discovery procedure

The downstream data packet header structure is shown in table 2. The header contains all node address along the route in sequence. When node on the route receive a downstream data packet, it delete its own address in the header and forwards the packet to the next hop, thus guarantee that the first address in the header is the address of the next hop.

TABLE 2. DOWNSTREAM DATA PACKET

1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
HOPS COUNT															
RELAY NODE1 ADDRESS															
RELAY NODE2 ADDRESS															
……															
RELAY NODEn ADDRESS															
DATA PAYLOAD															

Since EARBB adopt route loop avoidance and duplicate suppression mechanism[7] in CTP, EARBB is very reliable and robust. As the new route discovery scheme is introduced, EARBB support bidirectional transmission.

C. Node to Node route discovery

EARBB is able to support node to node communication. This is useful under many situations.

Since Beacon packet includes details about the connectivity between node and its neighbours, after all the nodes send beacon packet to the sink, the sink becomes aware of the whole topology of the network. So the sink can find the best route between two ordinary nodes.

Using the footer part of the beacon packet, the sink establishes a $n \times n$ matrix to describe the topology of the whole network. n equals to the network size. The element in the i for column j record the ETHER values from node i to node j. Once the matrix is established, the sink can find the best route between any two nodes using Dijkstra Algorithm.

Any node which needs to frequently communicate to another node in the network can request the sink for the route. Then the sink computes the best route according to the topology matrix and sends the route information back to the node. The node sending the request stores the route information and then it is able to communicate to the node it is interested in through the best route.

III. SIMULATION

A. Simulation Platform

We use TOSSIM[10] as the simulation platform for the test of the proposed protocol. TOSSIM is a useful simulation tool for TinyOS applications. TOSSIM can do packet-level simulation and it's able to simulate the behaviour of a whole network of different size.

B. Reliability Test

To test the overall performance of EARBB, a 20-minute long simulation of a network with 50 nodes is conducted. A comparison with CTP is made. For EARBB condition 1, the sink is made to transmit a downstream packet to a random node in the network every 500ms and other node in the network is made to transmit an upstream packet every 500ms to the sink. For EARBB condition 2, the sink is made to transmit a downstream packet to a random node in the network every 500ms and other nodes do not send upstream packet at all. For CTP, node in the network is made to transmit an upstream packet every 500ms to the sink. During simulation, 30% of the nodes in the network are down at 10 minutes. Figure 2 shows the delivery ratio for both protocols.

The simulation result indicates that EARBB is almost as reliable as CTP. EARBB can quickly recover from node failure just as CTP does. The downstream transmission of EARBB reacts a little bit slower than upstream transmission of EARBB because the sink need more time to update the topology change than ordinary node.

C. Energy Efficiency Comparison

It is stated in part 1 that CTP has a problem of energy consumption distribution. EARBB solves this problem by introducing energy aware path validation mechanism.

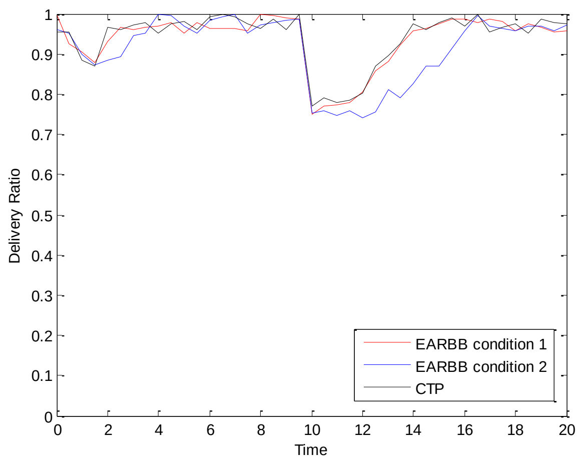

Figure 2. Delivery ratio test result

To test the energy efficiency of EARBB, Simulation under different network size is made. Network size varies from 10 nodes to 80 nodes, 10 as interval. To simplify the energy consumption evaluation model, assume the packet sending and receiving quantity as the energy metric. Moreover, assume every node can total send or receive packets of 4GB. In the simulation, each node in the network sends an upstream packet every 500ms. When 10% of the nodes run out of energy, the network is broken down. Figure 3 shows the result of the simulation.

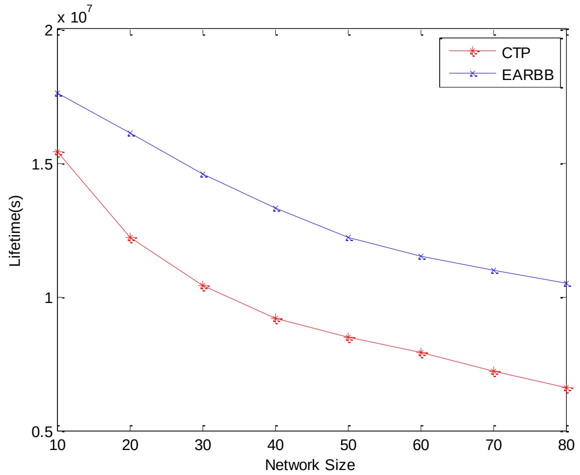

Figure 3. Lifetime of the network

The figure shows that EARBB prolongs the lifetime of the network by at least 20%. And the effect is even greater when network size become larger. That illustrates the effectiveness of the new path validation mechanism of EARBB.

D. Downstream Transmission Test

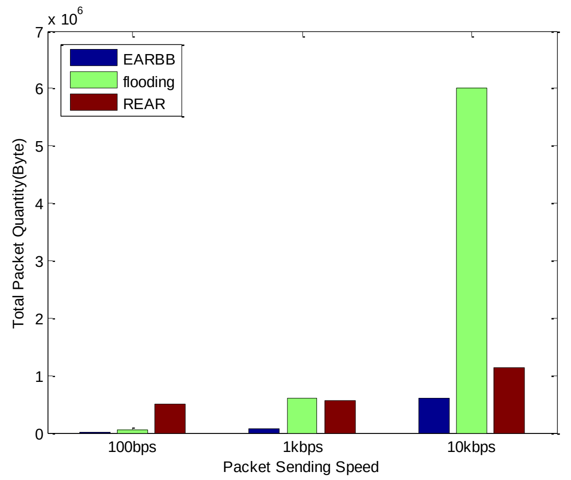

Figure 4. Downstream transmission simulation result

In order to test the performance of downstream transmission of EARBB, a simulation is conducted to compare the efficiency of downstream transmission of EARBB, flooding and REAR protocol. The network size is 50 nodes and the node will send packet under different speed. The sink sends a packet to a specific node every 500ms. For REAR, assume that the route tree is updated every 2 minutes. The simulation period will be 20 minutes and the total packet quantity will be the metric to evaluate the efficiency of the protocols. Figure 4 shows the result of the simulation.

It is obvious that the downstream transmission of EARBB is much more efficient than flooding and REAR. Flooding protocol need to send at least 80% more packets to disseminate information than EARBB and since EARBB need less packet transmission to maintain the routing tree, thus it's more efficient than REAR too.

IV. CONCLUSION

CTP is a very good practice for heterogeneous network. It is fully tested under various platforms. It's very reliable, robust and energy efficient. But CTP is constrained by its energy consumption distribution and single direction transmission. In this paper, an energy aware routing protocol based on beaconing is proposed to counter the problems that CTP has. New path validation mechanism prolongs the lifetime of the network and new beaconing schedule support efficient downstream transmission and node to node transmission. In the future, the new protocol is expected to implement on the Micaz hardware platform to perform some hardware tests.

REFERENCES

[1] Heinzelman W. Chandrakasan A. Balakrishnan H.,"energy-Efficient Communication Protocol for Wireless Microsensor Network"s, Proceedings of the 33rd Hawaii International Conference on System Sciences, January 2000.

[2] Meenakshi Sharma, Kalpana Sharma. An Energy Efficient Extended LEACH (EEE LEACH), 2012 International Conference on Communication Systems and Network Technologies, 2012

[3] Arezoo Yektaparast, Fatemeh-Hoda Nabavi, Adel Sarmast. An Improvement on LEACH Protocol(Cell-LEACH), Advanced Communication Technology (ICACT), 2012 14th International Conference on, Feb. 2012.

[4] Scow Guther, CertCo, "Wireless Relay Networks", IEEE Network, November 1997.

[5] Ke Liu, Nael Abu-Ghazaleh, "Reliable Energy Aware Routing in Wireless Sensor Networks", Proceedings of the Second IEEE Workshop on Dependability and Security in Sensor Networks and Systems, 2006.

[6] R. Fonseca, O. Gnawali, K. Jamieson, S. Kim, P. Levis, and A. Woo. TEP 123: The Collection Tree Protocol, Aug. 2006

[7] Kyle Jamieson, David Moss and Philip Levis. "Collection Tree Protocol", Proceedings of the 7th ACM Conference on Embedded Networked Sensor Systems, 2009.

[8] Joakim Flathagen, Erlend Larsen, Paal E. Engelstad, etc. O-CTP: Hybrid Opportunistic Collection Tree Protocol for Wireless Sensor Networks, Local Computer Networks Workshops (LCN Workshops), 2012 IEEE 37th Conference on, Oct. 2012.

[9] P. Levis, N. Patel, D. Culler, and S. Shenker. Trickle: A selfregulating algorithm for code maintenance and propagation in wireless sensor networks. In Proc. of the USENIX NSDI Conf., San Francisco, CA, Mar. 2004

[10] http://tinyos.stanford.edu/tinyos-wiki/index.php/TOSSIM, Sept, 2013