Uplink-Downlink Heterogeneous Routing Protocol for Wireless Sensor Network

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Abstract—**This paper proposes and implements a wireless sensor network system with UDHR (uplink-downlink heterogeneous routing) protocol according to the characteristic of data flows in WSN. The proposed routing protocol can be applied to multi-purpose mode such as time-driven mode, event-driven mode and query mode. The simulation results show that the protocol is effective, scalable and robust. Finally the routing protocol is realized in the self-development testbed platform, which can monitor the entire network topological changes, network overhead, energy consumption of each node, data collection and so on.**

Keywords—WSN, UDHR, Testbed

I. Introduction

Wireless sensor networks (WSNs)[1][2] consist of hundreds of low-power nodes that form dynamic ad-hoc multi-hop networks. WSNs can be applied in a variety of fields such as environmental monitoring, military purposes and gathering sensing information in inhospitable locations. WSNs pose a number of unique technical challenges due to the following characteristics: distribution, large-scale, high redundancy, unattended operation, limit resources and dynamic topological changes.

Routing protocol is one of its core technologies of WSNs. Routing protocol will be responsible for transmitting data packets from the source node to the destination node. There are two main functions: finding the optimal path between the source node and destination node and transmitting data packets correctly along the optimal path. When the energy of some nodes depleted and network topology changed, the routing protocol can quickly and accurately find the routing to sink nodes, and ensure data transmission reliable. The existing routing protocols can be classified into three categories—proactive, reactive, and hybrid protocols depending on how the source finds a route to the destination. Proactive protocols attempt at maintaining consistent updated routing information between all the nodes by maintaining one or more routing tables. In reactive protocols, the routes are only created when they are needed. Hybrid protocols use a combination of these two ideas.

In WSN there are three types of information gathering modes: event-driven mode, time-driven mode and query mode. In event-driven networks, data is sent to the sink only when an event occurs. In time-driven networks, every node periodically sends data to the sink. In query mode network, the sink node disseminates a query and collects responses from the sensors over pre-established links.

The paper proposed an uplink-downlink heterogeneous routing protocol, which can support the different kinds of information gathering modes.

The remainder of the paper is structured as follows: Section 2 discusses the characteristic of data flows in WSN. The uplink-downlink heterogeneous routing protocol is presented in Section 3. The protocol simulation, implementations and experimental results are included in Section 4. Section 5 closes with a summary and directions for future work.

II. Information flow analysis

The analysis of information flow demonstrates that there are two types of information transmission methods. First, the data information is usually transmitted from a sensor node to sink node. Second, the control information is usually transmitted from sink node to sensor node. To facilitate interpretation, the transmission from sensor nodes to sink node is called uplink transmission. Routing through the uplink transmission is called uplink routing. The transmission from sink node to sensor nodes is called downlink transmission. Routing through the downlink transmission is called downlink routing. As a data collection network, the information of uplink transmission is much more than that of downlink transmission.

Many new algorithms[3] such as SPIN, Directed Direction, and LEACH have been proposed for the routing problem in WSNs. These routing mechanisms have taken the inherent features of WSNs (for example, energy restrictions and sudden changes in node status (e.g., failure) cause frequent and unpredictable topological changes.) along with the application and architecture requirements into consideration. However, few routing protocol [4][5] distinguished uplink and downlink routing. Most protocols which use the same strategy for uplink and downlink are not beneficial to improve the efficiency of data transmission. In this paper, an uplink-downlink heterogeneous routing protocol is designed. The results of network simulation and UDHR testbed show that the protocol is correct and effective.

III. Uplink-Downlink heterogeneous routing protocol

A）The key idea of uplink routing protocol

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1）When new nodes join in the network or routing is invalid or routing lifetime expires, the nodes will establish or update uplink routing.

2）A node sends URREQ (uplink routing request) packet to search a routing to sink. If the node has established uplink route to sink and has less hop than that in URREQ packet (see Fig.1), then it sends uplink routing reply (URREP) packet back. Otherwise the node doesn' t relay the URREQ packet and doesn't transmit URREP (see Fig.2) packet. If a node can't receive URREP packet in 100ms, the node would retransmit the URREQ packet (set $Hop=2*Hop_{origin}$).

3) The protocol selects an uplink routing as backbone based on the minimum number of hop.

4）The lifetime cycle is a random number between Tmax and Tmin.

5）The protocol adopts hop by hop acknowledgement.

Type	Reserved	Hop	Source address

Fig.1 URREQ packet format

Type	Reserved	Hop	Source address	Current address

Fig.2 URREP packet format

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Sensor nodes establish the uplink routing:
If route table(rt) is empty or lifetime expires
or the link is invalid then
   Send URREQ, wait URREP;
   if receive URREP (T< 100ms) then
     record route;
     //record the father node
     //set lifetime=rand(Tmin, Tmax)
     //set hops
     if receive more than one URREP then
      update route;
     // record the route with hops_min;
     end if
       else
     retransmit URREQ;
   end if
End if
```

Fig.3 establish the uplink routing

The process of the uplink routing establishment can be seen in Fig.3. When a node initializes or the lifetime of routing expires or the link is invalid, the node will send URREQ packet. If the node receives URREP packet in 100ms, the node will record the route information including the father node, the lifetime routing which is a random number between Tmax and Tmin, and the number of hop in route table. If the node doesn't receive URREP packet in 100ms, the node will retransmit the URREQ packet (Note: set $Hop=2*Hop_{origin}$). If the node receives more than one URREP packets, the node will select an uplink routing as backbone based on the minimum number of hop and backup an alternate routing which is inferior to the backbone one in route table.

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Sensor nodes deal with the received URREQ:
  Receive URREQ;
  Compare the hops  between URREQ and
self node;
  If  the node has route to sink and
          hop_URREQ > hop_node  then
   transmit URREP;
  else
    drop the URREQ;
  End if
```

Fig.4 dispose URREQ packet

When the sink receives URREQ packet, it directly replies URREP packet to the node. In Fig.4, when sensor node receives URREQ packet, the node which has the route to the sink compares the number of hop from URREQ and that from route table of the node. If $Hop_{URREQ} > Hop_{node}$, the node transmits URREP packet. If the node does not have the route to the sink or $Hop_{URREQ} < Hop_{node,}$ the node will drop the URREQ packet.

B）The key idea of downlink routing protocol

When the WSN consists of a large number of the sensor nodes, an on-demand routing strategy is adopted to establish downlink routing. The downlink routing has the same path as the uplink routing (the opposite direction). So the downlink routing is very simple and adopts end-to-end acknowledgement to ensure data transmission reliable. When there are fewer nodes in WSN, the sink node directly broadcasts inquiry information to sensor node.

IV. Network simulation and testbed

A. Simulation and analysis

Table 1 simulation condition

node number	100
communications distance	100m
data rate	250kbps
simulation area	400×400
MAC protocol	SMAC Tactive=0.3s Tsleep=0.7s
Lifetime	300+300×rand(1)
RREQ、RREP、DATA length	224bit
traffic generation	0.3 packet /s
simulation time	3600 s

The routing protocol has been coded by using the OMNET++[6] modular simulation environment based on the object oriented C++ computer language. Simulation condition showed in table 1.

The simulation results show that the uplink routing algori thm is accurate and effective. Fig 5 shows the relationship b etween the total of control packets (RREQ, RREP) of the w hole network which is 7,603(Packets*Hop) and time. DAT A packets accumulate 334,963 (Packets*Hop). So the routi ng overhead is low (2.3%).

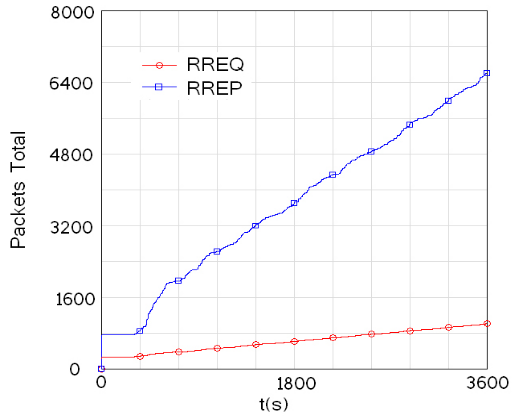

Fig.5 the relationship between the total of control packets and time

B. UDHR testbed

- Protocol stack

The testbed protocol stack contains Physical, MAC, routing, and application layers.

1) Physical layer

Physical layer adopts the physical layer standard of IEEE802.15.4[7], which is supported by RF transceiver chip CC2420[8]. The functions of IEEE802.15.4 are realized by configuring the register of CC2420.

2) MAC layer

MAC layer uses CSMA/CA protocol [9]. Since the traffic of the designed network is not heavy, the maximum transmission rate is 250kbps and the length of data packet is often short, the probability of conflicts between the nodes is small.

3) Routing layer

Uplink routing algorithms is based on the minimum number of hop routing algorithms. Downlink directly broadcasts inquiry information to sensor node. As the routing algorithm is relatively simple, it is suitable for a node with 8-bit MPU ATmega128[10] to operate. Meanwhile, the Network Layer Protocol provides a simple software interface to application layer.

4) Application layer

The application layer of sensor node gathers light intensity sensor data, which is sent by the lower layer. And the task of sink node is to transfer the collected information from sensor node to the server through serial port.

- Network demo experiment

A sensor network consists of 11 nodes (see Fig.6). The distance between each node is 1-2 meters (output power -25dbm). The sink node connects with the servers. We perform the experiments by adding new nodes, shutting down some nodes, and changing nodes' position. And then we check whether the network automatically changes routing topology and maintains network communications. In Fig.7, testbed software can show the data collection, network topology, the number of data packets, the number of control packets, retransmission number, packet loss, the energy of each node and so on in time.

The experiment has verified the accuracy of the protocol. The nodes can rapidly build up self-organization and self-management wireless sensor network depending on the uplink-downlink heterogeneous routing protocol. The sink sends the collected data to the server through serial port. We can observe the collected data about light intensity on screen (see Fig.8).

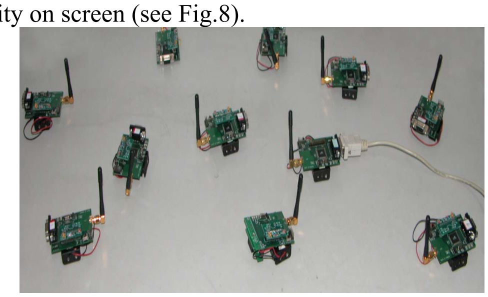

Fig.6 network demo experiment with 11 nodes
（RF Output Power=-25dbm）

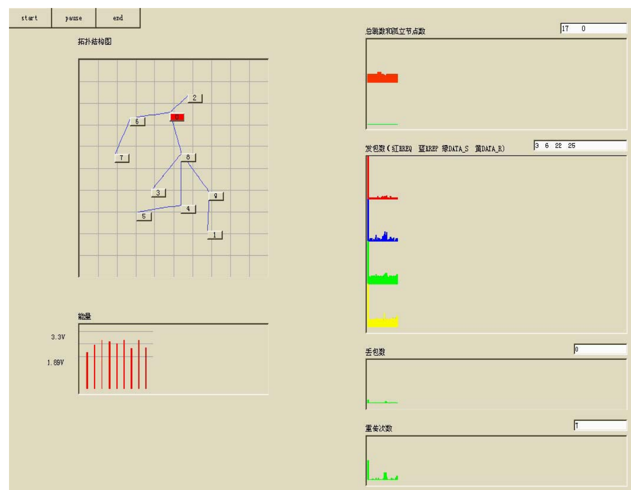

Fig.7 monitor network status

V. Conclusions and future direction

This paper presents the uplink-downlink heterogeneous routing protocol, which is applied to time-driven, event-driven and inquiry data collection mode. The protocol has high practical value. The uplink routing is selected according to the minimum number of hop instead of considering energy consumption problems. In the future, the routing protocol will be optimized through the energy consumption of nodes, and selects the best path to extend the lifetime of network.

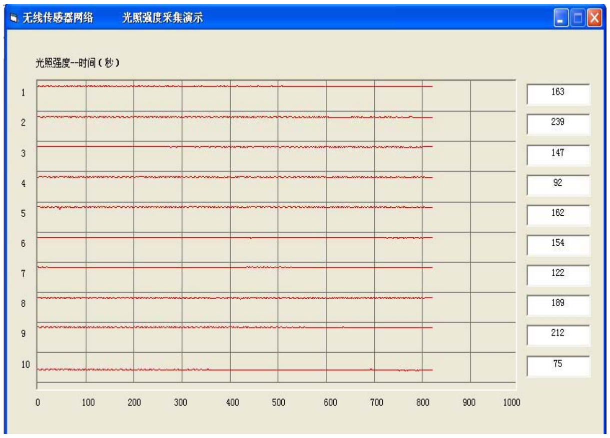

Fig.8 display collected data

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