Short Paper

A Hierarchical Multiple-Choice Routing Path Protocol for Wireless Sensor Networks

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The wireless sensor networks (WSNs), a network comprising the huge number of sensor nodes, allow users to monitor a remote environment accurately by combining the data intelligently from the individual nodes. These networks require robust wireless communication protocols that are energy efficient and provide low latency. In this paper, we present a *Hierarchical Multiple-Choice Routing Path Protocol* (*HMRP*), a routing protocol for collecting data over multi-path, energy-balancing, and data aggregation to achieve good performance in terms of system lifetime and data delivery ratio. The design of the protocol aims to satisfy the requirements of sensor networks that every sensor transmits sensed data to the sink spontaneously. The sink constructs hierarchical tree by broadcasting its hop value to find the child nodes. Other nodes discover the child nodes in turn by the same way. The HMRP uses Candidates Information Table to avoid flooding and periodic updating of routing information. Moreover, the tree will automatically reconfigure according to nodes failure or adding the new nodes. The simulation results show that HMRP can increase the system lifetime by comparing with other general- purpose multi-hop clustering or tree-based approaches.

Keywords: wireless sensor network, energy-efficient, hierarchical multiple-choice routing path, clustering protocol, data aggregation

1. INTRODUCTION

Advances in micro-electro-mechanical systems (MEMS) technology, wireless communications and digital electronics allow the development of low-cost, low-power, and multi-functional small sensor nodes which are small in size and no communicatory restriction at short distances [1-3]. These multi-functional sensor nodes can be utilized in a wide range of applications such as the military, battlefield, object detection, target tracking, environment monitoring, and the civil aviation by using *Wireless Sensor Networks* (*WSNs*) [4-6]. Each sensor performs a sensing task to detect specific events and it is responsible for gathering data to return the data to the Sink or Base Station (BS). A significant difficulty in designing these networks is the battery energy, which limits the life-

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time and quality of the networks. Several good routing protocols have been well studied in [7-9, 16-23] which can help to save energy efficiently and achieve long network lifetime. However, the sensor nodes on the routing path deplete their energy very rapidly due to the use of fixed paths to transfer the sensed data back to the sink. Communication in the sensor network is based on the wireless ad hoc networking technology [9]. If the sensor nodes cannot directly communicate with the sink, some intermediate sensors should forward the data.

This investigation develops an energy-efficient hierarchical mechanism, called Hierarchical Multiple-Choice Routing Path Protocol (HMRP). The HMRP has many paths (sequential select in each transmission) to disseminate data packets to the sink. The data aggregation mechanism involves in every nodes apart from the leaf nods reducing the energy consumption in the networks. The proposed system was designed according to the following objectives:

• *Scalability*

The sensing area may include hundreds or thousands, or even more sensor nodes. The HMRP could be fit for a small or large sensing scale, since the communication overhead among sensor nodes is very low.

• *Simplicity*

The sensors have restriction to compute capability and to memory resources. Therefore, this approach attempts to minimize the numbers of operations performed and states maintained at each node. In particular, each sensor only has to maintain its candidate parents' information table to determine the routing path.

• *System Lifetime*

These networks should operate as long as possible due to recharging the battery of nodes may be inconvenient or impossible. Therefore, data aggregation and energy-balanced routing are adopted to decrease the number of messages in the network to extend its network lifetime.

The rest of this work is organized as follows. Section 2 describes the benefits and problems of existing routing protocols for sensor networks. Section 3 presents a hierarchical multiple-choice routing path protocol for wireless sensor networks. Section 4 shows the simulation results. Finally, section 5 draws conclusions and presents future research directions.

2. RELATED WORK

Several routing protocols for WSNs have been developed to establish energy-efficient and stable routes. Al-Karaki *et al*. [8] has classified protocols in two ways: One is the network structure as flat-based, hierarchy-based, and location-based routing and the other one is the protocol operation as multipath-based, query-based, and negotiation- based, QoS-based, or coherent-based. Among them, the hierarchical and multipath routing is an efficient way to lower energy consumption within a cluster, performing data aggregation and fusion to reduce the number of messages sent to the sink [7, 8].

Heinzelman *et al*. [10] introduced a hierarchical clustering algorithm for sensor networks, known as *Low-Energy Adaptive Clustering Hierarchy* (*LEACH*). LEACH is a cluster-based protocol that applies randomized rotation of the cluster heads to distribute the energy load evenly among the sensor nodes in the network. The operation of LEACH is controlled by round and each consists of a set-up phase and a steady-state phase. During the set-up phase, the network is separated into clusters, each with a randomly selected cluster head from nodes in a cluster. During the steady-state phase, the cluster heads gather data from nodes within their clusters respectively and fuse the data before forwarding them directly to the sink. LEACH provides sensor networks with many good features, such as clustering-based, localized coordination, and randomized rotation of cluster-heads, but expends much energy in cluster heads when directly forwarding data packets to the sink.

Lindsey *et al*. [11] presented an enhanced LEACH protocol. The protocol, *Power Efficient Gathering in Sensor Information Systems* (*PEGASIS*), assumes that all nodes have location information about all other nodes and each can send data directly to the base station. Hence, the chain of PEGASIS is constructed easily using a greedy algorithm based on LEACH. Each node transmits to and receives from only one of its neighbors. In each round, nodes take turns to be the leader on the chain path to send the aggregated data to the sink. To locate the closest neighbor node in PEGASIS, each node adopts the signal strength to measure the distance of all neighbor nodes. However, the global information of the network was known by each sensor node does not scale well and obtain easily.

Since a sensor network generates too much data for the end-user to process. Therefore, every sensor node has to aggregate the data before they processing. *Power Efficient Data Gathering and Aggregation in Wireless Sensor Networks* (*PEDAP*) [12] is based on a minimum spanning tree. PEDAP assumes that the sink knows the locations of all nodes that the routing information is calculated by Prim's algorithm with the sink as the root. PEDAP prolongs the lifetime of the last node in the system while providing a good lifetime for the first node. Conversely, the power-aware version of PEDAP provides a near -optimal lifetime for the first node while slightly decreasing the lifetime of the last node. Additionally, sensor nodes transmit the sensed data to the sink via the previously constructed routing path to produce a minimum energy consuming system. Nevertheless, the intermediate nodes consume energy quickly. *Hierarchy-Based Anycast Routing* (*HAR*) Protocol for Wireless Sensor Networks [13], the sink constructs a hierarchical tree by sending packets (such as CREQ, CREP, CACP, PREQ) to discover each node's own child nodes in turn. HAR avoids both flooding and periodic updating of routing information, but needs to reconstruct the tree when nodes fail or new nodes are added. The drawback of HAR is that it sends and receives too many packets in the network, expending much energy.

This investigation proposes a novel Hierarchical Multiple-Choice Routing Path Protocol (HMRP) that utilizes a hierarchical tree to discover routing paths and to perform rotation of parent node by parent's energy weight. The key ideas in HMRP are the energy-balancing of parents, each candidate parent serves appropriate times to avoid overload. The sensor network in HMRP is initially constructed as a layer network. Based on the layer level, each sensor node finds a candidate parent to send the sensed data to the

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sink, so the sensor node can always disseminate the data through a different path. In other words, the candidate parents take turns to be the routing path nodes. As shown below, HMRP yields an improved system lifetime and better energy savings over the above mentioned clustering-based routing protocols.

3. HIERARCHICAL MULTIPLE-CHOICE ROUTING PATH PROTOCOL

3.1 Network Environments and Assumptions

Fig. 1 shows an example of the system environment [24]. The sensor nodes are distributed randomly in the sensing field. A network composed of a small number of sink nodes and many wireless sensor nodes in an interesting area is considered. The sensor nodes are assuming to be fixed in their lifetimes and the identifier of sensor nodes is determined a priori. Additionally, these sensor nodes have limited processing power, storage, and energy while the sink nodes have powerful resources to perform any tasks or communicate with the sensor nodes. Once the nodes are deployed, they remain at their locations for sensing tasks and can receive messages from other nodes. The sink starts with hop value "0", while other sensor nodes are "∞".

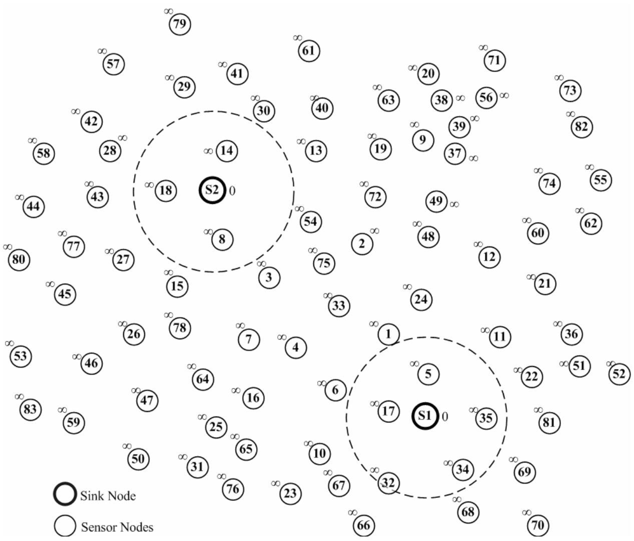


Fig. 1. Example of sensor network environment.

HMRP is a hierarchical routing protocol that can reduce the energy consumption and prolong the lifetime for sensor networks. It replies with a complete route from the source node to the sink quickly and prepares many routes path to balance the energy of each node. HMRP enables intermediate nodes to aggregate all receive packets during a short period time and transmit only one aggregated packet to the following node. There is a *Candidates Information Table* (*CIT*) to store all candidate parent(s) in each sensor node.

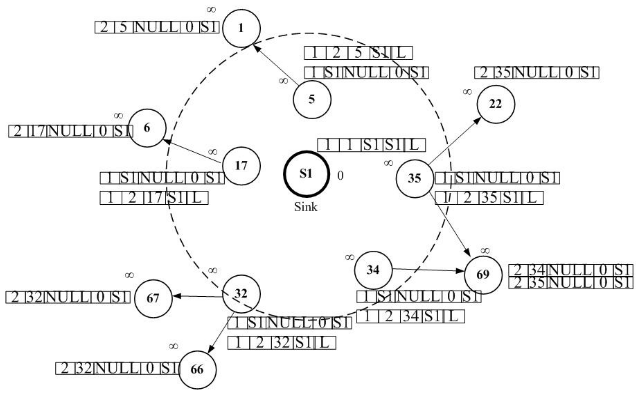
3.2 Three Phases of HMRP

HMRP is based on the hierarchical tree architecture, in which the sink nodes serve as root nodes. Each sensor node must be a member of the architecture, *i.e.*, an internal or leaf node, to communicate with the sink node. HMRP has three phases, *Layer Construction Phase* (*LCP*), *Data Dissemination Phase* (*DDP*) and *Network Maintenance Phase* (*NMP*).

3.2.1 Layer construction phase (LCP)

HMRP forms hierarchical relations with a *Network Construction Packet* (*NCP*), which allows nodes to form autonomous relationships without any centralized control. The NCP format is <*Seq_Number*, *Hop_Value*, *Source_ID*, *Sink_ID*, *Packet_Type*>. The Seq_Number field is a packet sequence. The Hop_Value field is the number of hops from the sink node. So the nodes can receive the radio signal of sink that are defined as one-hop nodes. The Source_ID denotes the ID of the node that NCP packet came from. Owing to the HMRP supports multiple sink; Sink_ID indicates which sink broadcasts the NCP packet. The Packet_Type field specifies the different type of packet, which are the *Layer Construction Request* (*LCREQ*) packet (L) and *Candidate Parents Request* (*CPREQ*) packet (C).

The major activities in this phase are hierarchy setup, candidate information table creation and routing path formation for each node. The sink node (S) first increases the Hop_Value field by one and broadcasts the LCREQ packet to discover the one-hop nodes, *i.e.*, the sink S1 broadcasts the NCP packet <1, 1, S1, S1, L> to its neighbor nodes. A node not yet attached to the layer will wait for a short period of time (T_{LCREQ}) to obtain one or more NCP packet(s) to determine its candidate parent(s) and records them in its CIT.



Network Construction Packet

Seq_Number	Hop_Value	Source_ID	Sink_ID	Packet_Type

Candidates Information Table

Hop_Value	Candidate_Parents	Transmit_Weight	Event_Range	Sink_ID

Fig. 2. Layer construction flooding.

For example, in Fig. 2, sensor node ㉞ checks the Packet_Type of a received packet (which may come from different sink nodes or other nodes). If the Packet_Type field is *L*, that means a LCREQ packet. And then, node ㉞ checks the Source_ID filed and Sink_ID field to see whether the packet comes from sink node or not. If "yes", node ㉞ stores the information of sink node into its CIT and increases the Hop_Value field of LCREQ packet by 1 and broadcasts it. Otherwise, node ㉞ compares the Hop_Value field of packet with its hop value. If Hop_Value field smaller than its hop value, then it keeps the packet in CIT during T_{LCREQ} or else drops the packet. As the time of T_{LCREQ} finished, node ㉞ begins to select the packet(s) with the lowest Hop_Value field as its candidate parent(s) and deletes other packet(s) from its CIT. Node ㉞ then raises the Hop_Value field of LCREQ packet by 1 and broadcasts it again.

Besides, node (69) additionally receives two layer packets from node ㉞ and ㉟ with the same Hop_Value field. Hence, the candidate parents are both node ㉞ and ㉟. On the other hand, node ㉞ receives an LCREQ packet from node ㉟, but the hop value of node ㉞ equals to the Hop_Value field. Therefore, node ㉞ ignores the LCREQ packet. Every node continues flooding the LCREQ packet until the network level is constructed. As shown in Algorithm 1, the *CANDIDATE_PARENT_FINDING*() procedure is used to construct the hierarchical tree.

Algorithm 1 PROCEDURE *CANDIDATE_PARENT_FINDING*()

```
/* When a node u (with a unique identification) receives a NCP packet with Packet_Type
   value L (Layer Construction Request (LCREQ) packet). */
    WHILE (Not T_LCREQ timeout)
          IF Source_ID equals to Sink_ID     // the LCREQ packet come from sink
               Candidate parent is sink node
               Store information of sink into Candidate Information Table (CIT)
               GOTO NEXT_LEVEL
          ELSE
               IF the value of Hop_Value field of LCREQ is smaller than node's hop
               value
                    Keep this LCREQ packet in Candidate Information Table (CIT)
               ELSE
                    Discard this LCREQ packet
               END IF
          END IF
     END WHILE
     FOR all record(s) in CIT
          Compare the Hop_Value field
          Find the node with minimum Hop_Value field to be candidate parent(s)
          Delete other records from its CIT
     END FOR
     NEXT_LEVEL:
          Node increases Hop_Value field by one and broadcasts the LCREQ packet
END PROCEDURE
```

3.2.2 Data dissemination phase (DDP)

After the first phase completed, sensor nodes can start disseminating the sensed data to the sink via the parent node. The packet format is as follows: <*Seq_Number*, *Source_ID*, *Dest_ID*, *Sink_ID*, *Data_Len*, *Payload*>. The Seq_Number field is a sequence number of the packet. The Source_ID, Dest_ID, and Sink_ID fields respectively are the source node of the packet, the destination node to which the packet forwards and the sink node that requests the data packet. The Data_Len field denotes the packet length and the Payload field is used to carrying the data. A Received Data Acknowledge (RDACK) packet is used to confirm that the data packet are successfully transmitted to the parent node. The parent node then replies with this packet to notice the source node and forwards the data packet to next hop.

When sensor node wishes to send a data packet to sink, it will choose a record with the minimum *Transmit_Weight* in CIT. Parent replies with a RDACK packet to confirm that the transmission is successful after it receives the data packet. If node does not obtain RDACK packet from parent node after trying two times, then it eliminates the record with this parent's ID from the CIT. As shown in Algorithm 2, the *TRANSMIT_ROUTE_CHOICING*() procedure that a node starts to transmit the data packet.

Algorithm 2 PROCEDURE *TRANSMIT_ROUTE_CHOICING*()

```
/* After the first phase is completed, the network is constructed. Sensor nodes can start
   disseminating the sensed data to the sink via the multiple-choice parent node. */
    IF Sensor node received a RDACK packet
        Increase the Transmit_Weight field of this Source_ID in node's CIT
        Call MIN_HEAP_SORT() Procedure to rearrange the sequence of candidate
        parents
    ELSE
        IF Sensor node sensed an Event
            Set Counter equals zero
            IF Node's CIT is not Empty
                Node generates data packet
    TRY_NEXT_PARENT:
                FOR all record(s) in CIT
                    Compare the Transmit_Weight value
                    Find the node with minimum Transmit_Weight value to be
                    candidate parent(s)
                END FOR
    FORWARD_PACKET:
                Node forwards this packet to parent node
                IF NOT a Received Data Acknowledge (RDACK) packet reply
                from parent during a period of time T_RDACK
                    Counter increase by one
                    IF NOT Counter equals three        //only try two times
                        GOTO FORWARD_PACKET
                    ELSE
```

```
                        Remove the parent node from CIT
                        GOTO TRY_NEXT_PARENT
                    END IF
                END IF
            ELSE
                Call CANDIDATE_PARENT_REDISCOVERY() Procedure
            END IF
        END IF
    END IF
END PROCEDURE
```

In Fig. 3, node 56, with four candidate parents, 20, 38, 39, and 37, sequentially selects a record from CIT. Node 56 first disseminates data packets to parent node 20. If node 20 replies with a RDACK packet, then the transmission is successful. Conversely, if node 20 does not reply with a RDACK packet after retransmit two times, and then it is removed from the CIT, since its energy may run out, or it is broken and data packet cannot transfer via this node later. Each node performs the same motion as node 56 until the data packet reaches the sink node.

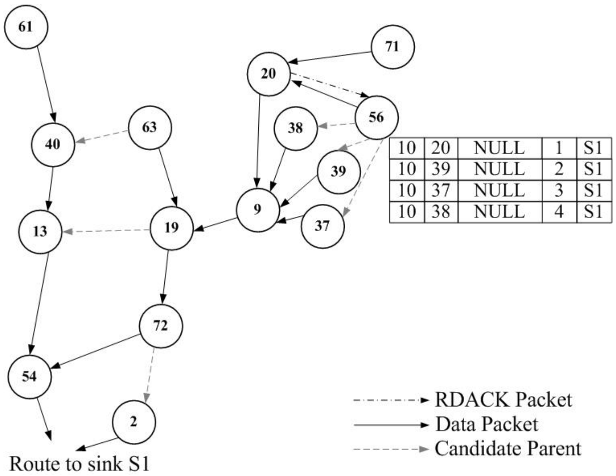


Fig. 3. Example of data dissemination.

The data packet can be forwarded to the sink via many paths. The lifetime of the network system can be extended if the sensor node always uses a different path to send data packets.

3.2.3 Network maintenance phase (NMP)

If a new sensor node attached to the network or a node had appended to the network but cannot find any candidate parent from their CIT, and then it can discover parents by using a *rediscovery mechanism* as follows. As shown in Algorithm 3, the sensor node broadcasts an NCP with its hop value and Packet_Type value C (meaning Candidate Parent Request, CPREQ) to its neighbor nodes to aware of its existence.

Algorithm 3 PROCEDURE *CANDIDATE_PARENT_REDISCOVERY*()
/* When new sensor node is attached to the network or a node is appended to the network before but cannot find any candidate parent from its CIT. */
    Node broadcasts Candidate Parent Request (CPREQ) packet
    IF the neighbor node received CPREQ and remain energy is greater than $E_{Threshold}$
        IF NOT the value of Hop_Value field of CPREQ is equal to "∞" or
        (hop_value + 1)   // ∞: new node, (hop_value + 1): sibling node
            Delete Source_ID from its Candidate_Parents field of CIT
        END IF
        Accept this CPREQ packet
        Reply node's information by unicasting a LCREQ packet
    ELSE
        Discard this CPREQ packet
    END IF
    IF the request node received a LCREQ packet from its neighbor nodes
        Keep this LCREQ packet in Candidate Information Table (CIT)
        FOR all record(s) in CIT
            Compare the Hop_Value field
            Find the node with minimum Hop_Value field to be candidate parent(s)
        END FOR
        IF Hop_Value field of other nodes is equal to its (hop_value + 2)
            Node sends the LCREQ to become their candidate parent.
        END IF
        Delete other records from its CIT (Hop_Value field is not the minimum)
    ELSE
        Node periodically broadcasts Candidate Parent Request (CPREQ) packet until getting LCREQ packet
    END IF
END PROCEDURE

Any neighbor nodes received this packet will check the remaining energy of itself whether is greater than $E_{Threshold}$ (*e.g.* 50% of the initial energy) or not. This threshold depends on the different application of sensor networks. If a neighboring node has sufficient energy, then it inspects the Hop_Value field to identify the request packet. If the request comes from a newly deployed sensor node (Hop_Value field is "∞"), then the neighboring node accepts the request and replies with a LCREQ packet to the joining node by unicasting. Otherwise, the neighboring node checks whether the Hop_Value of the requesting node equals to its own hop value + 1 or not. If "yes", the neighboring node accepts the request and replies with a LCREQ packet to the joining node by unicasting. If "no", it deletes the Source_ID of this request from its Candidate_Parents field in CIT; and replies with a LCREQ packet to the joining node by unicasting. Significantly, this LCREQ packet is same as that described in LCP, except that unicasting is adopted instead of broadcasting. If the request node does not receive any LCREQ packet after broadcasting the CPREQ packet, then either no node exist within its radio coverage, or none of its neighboring nodes have yet attached themselves to the network layer. In this case, the request node rebroadcasts the CPREQ packet periodical waiting for an incoming LCREQ packet after one of its neighbors has attached to the layer.

When the request node received a LCREQ packet from its neighbor nodes, it chooses the packet(s) with the lowest Hop_Value field as its candidate parent(s). If Hop_Value equals to hop value + 1, then the candidate parent(s) is (are) its sibling node(s). Otherwise, the candidate parent(s) must be certain of its child node(s). In Fig. 4, after a new deployed node has set its candidate parent(s), then it checks the other received LCREQ packet(s) to determine whether the Hop_Value field equals to its hop value + 2, then sends the LCREQ to become their candidate parent.

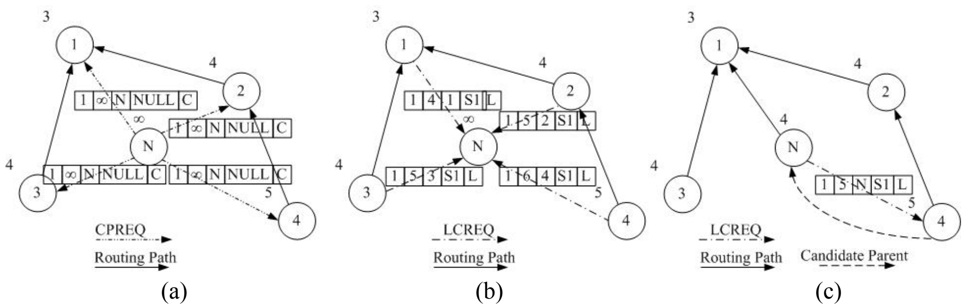


Fig. 4. (a) New node *N* broadcasts CPREQ; (b) Neighbor nodes reply LCREQ; (c) New node *N* transmits LCREQ to lower level nodes.

3.3 Data Aggregation and Fusion

Data aggregation combines responses from multiple sensors into a single message. Reducing the number of messages transmitted in a network can significantly decrease the amount of energy consumed. To save energy in the whole entire network, the aggregation is performed in their calculations that all responses received are aggregated before being propagated. The parent node waits for a period of time (T_{Wait}) to collect data packets coming from all its children. When a node receives data packets from its different lower level nodes, it will categorize the packet(s) according to the Sink_ID field of the packet. These data packets are then aggregated during a T_{Aggre} time. The parent creates an Event_Range (ER, the initial value of this field is NULL) field that indicates the stable range value of event occurrence, and then sends an RDACK packet to the children that transmitted the data packet to it with this ER value ($T_{Wait} + T_{Aggre} \leq T_{RDACK}$). The child node records the Source_ID and ER value into CIT. Finally, only one data packet is transferred to the sink node in a routing path. The sensed nodes later compare the new event value with the parent's ER value. If a new event value lies in between the ER value, then the nodes do not report the event. Otherwise, the nodes send the change value of the event. This ER field will reset to NULL after node received a new query, which is addressed by a user and dispatched from the sink node.

4. SIMULATION RESULTS

4.1 Simulation Environment

The energy costs for the various protocols discussed in the previous section were compared with those of the proposed protocol using the first order radio model [10, 14, 15]. The transmitted and received energy costs for the transmission of a *k*-bit data message between two nodes separated by a distance of r meters. To evaluate the performance of HMRP, simulations were run by using VC++. The performance of the proposed protocol was compared with the following other cluster-based routing protocols: LEACH, PEGASIS, HAR and PEDAP. The aim of the experiments was to measure the system lifetime, data delivery ratio and average energy dissipation. Networks of $100 \times 100\ m^2$ with 500 nodes and different topologies were simulated. Each node had an initial battery of 2J and sent 40 data frames in each round. Table 1 gives the parameters for the energy dissipation of the radio in order to run the transmitter or receiver circuitry.

Table 1. Parameters for simulation.

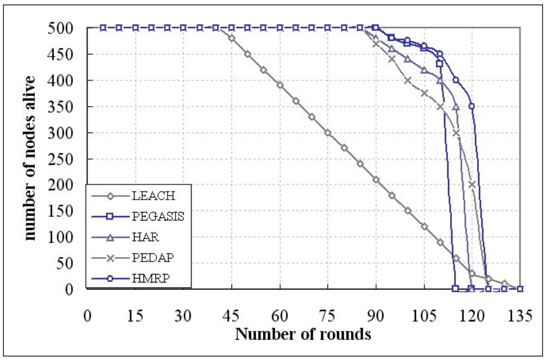
Description	Parameter	Value
Radio electronics	E_{elec}	50nJ/bit
Transmit amplifier	ε_{FS}	10pJ/b/m^2
Aggregation cost	E_{DA}	5nJ/b/message
Data size	D_{Size}	500bytes

4.2 Simulation Results

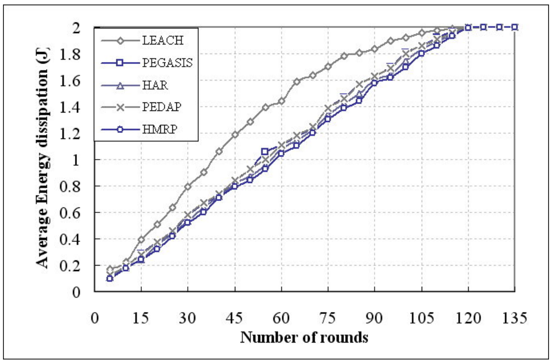
Fig. 5 (a) illustrates the system lifetime of those protocols. HMRP has a good lifetime improvement to others. Additionally, the system lifetime is defined as the number of rounds for which 75 percent of the nodes are still alive. HMRP produces a better system lifetime than the other protocols: 200 percent better than LEACH, 8 percent better than PEGASIS, 5 percent better than HAR and 14 percent better than PEDAP.

Fig. 5 (b) clearly shows that HMRP has a much more desirable energy expenditure curve than those of LEACH, PEGASIS, HAR and PEDAP. HMRP produced an average reduction in energy consumption of 35 percent over LEACH. This is because all cluster heads in LEACH send data directly to the sink, which in turn causes significant energy losses in the cluster head nodes. However, other protocols alleviate this problem so that only one cluster head node forwards the data to the sink. Nevertheless, HMRP still outperforms PEGASIS by 8 percent, due to the distances increase between neighbors. This in turn increases the communication energy cost for those PEGASIS nodes that have far neighbors. Besides, HMRP outperforms HAR and PEDAP by 4 percent and 7 percent respectively. This is because HMRP spent less cost of energy than HAR and PEDAP in constructing the hierarchy.

Next we analyze the number of data messages received by the sink for the five routing protocols under consideration. Fig. 6 shows the total number of data messages received by the sink over the number of rounds of activity. The effectiveness of HMRP in



(a)



(b)

Fig. 5. (a) The system lifetime of HMRP and other protocols; (b) The average energy dissipation of HMRP and other protocols.

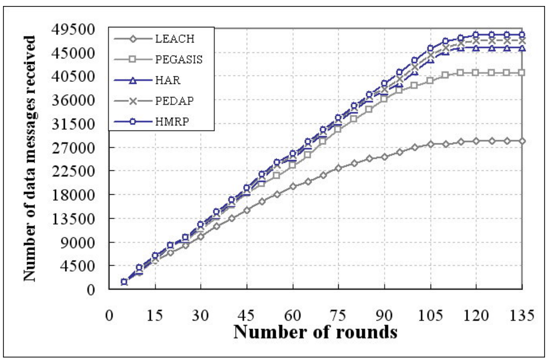


Fig. 6. The number of data message received by sink.

delivering significantly more data messages than its counterparts. HMRP offers improvements in data delivery by factors of 68, 17, 5.5, and 2.2 percent over LEACH, PEGASIS, HAR, and PEDAP, respectively. The result confirms that HMRP delivers the most data messages per unit of energy of the other schemes.

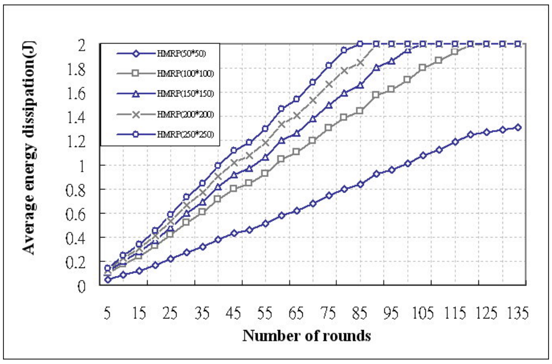


Fig. 7. Average energy dissipation over different network size.

Fig. 7 shows the average energy dissipation of the HMRP protocols over varying network area. HMRP has a stable performance as network area increases. At the end of 50 rounds of activity, LEACH will dissipate energy over 1.76 J in [14]. However, MRP uses load-balancing mechanism to share responsibility for every node to prolong the lifetime of them. We propose an alternative which is more light-weight to perform specific communication required in WSNs. Every node in HMRP broadcasts only once to discover the route which obviously incurs less overhead than other protocols.

5. CONCLUSION AND FUTURE WORK

To sum up, energy resource limitations are of priority concern in sensor networks. Distributing the load to the nodes significantly impacts the system lifetime. This investigation proposes a hierarchical multiple-choice routing path protocol called HMRP, which minimizes the path loading of the system by distributing the energy consumption among the nodes. In HMRP, the sensor nodes do not have to maintain the whole path information but just maintain their CIT. The simulation results indicate that HMRP performs better than LEACH, PEGASIS, HAR, and PEDAP.

In the future, we will further optimize the tree-based structure to improve the energy consumption in all parent nodes. We also plan to implement additional feature. For example, looking into mechanisms to prevent the faster bleeding of nodes to close to the sink nodes. This would bring a significant boost to the overall network lifetime, especially in combination with the energy awareness of the routing decisions.

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