An Improved Directed Diffusion Protocol based on Opportunistic Routing

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Abstract—Researchers are paying more and more attention to the application of wireless sensor networks (WSNs), where routing is one of the vital techniques. An advanced Directed Diffusion protocol, named DDOR, is presented in this paper based on Opportunistic Routing to improve the disadvantage of mono-forwarder of traditional routing protocol. Packet head has been modified in order to implement a forwarder list in DDOR. Instead of fixed next-hop forwarding in transmission, DDOR selects the optimal node to forward. DDOR mechanism can effectively save energy of WSNs by decreasing the hops from sources to sinks, thereby extends the life of WSNs. A large number of simulations prove that DDOR is feasible. Compared with Directed Diffusion, DDOR does decrease the energy consumption on packets forwarding.

Index Terms—WSNs; Directed Diffusion; Opportunistic Routing; Forwarder List; ETX; Energy Consumption

I. INTRODUCTION

Recent advance in processor, memory, and radio technology enables small and cheap sensing nodes to perform wireless communication and significant computation. Sensor networks [1-3] may contain hundreds or thousands of sensing nodes. It is desirable to make these nodes as cheap and energy-efficient as possible and rely on their large numbers to obtain high quality results. Sensor networks should be reduced in its energy-consumption to minimize its maintenance, which thereby can be applied in inhospitable terrain inaccessible to any service and embedded structures.

Network protocol is one of the significant techniques of sensor networks, and also the field received with most attention of network researchers. Network protocols must be designed to avoid the early failure of individual node. In addition, since the limited wireless channel bandwidth must be shared among all the sensors in the network, routing protocols for these networks should perform local collaboration to reduce transmission collision.

Eventually, the data sensed by the nodes in the network must be transmitted to the sink node. In this work, we consider wireless sensor networks where the unique sink node is fixed and all the other nodes located in a large area where communication between the sensor nodes and the sink node is expensive. Traditional routing faces difficulties in coping with reliable and energy-efficient communications. It is imperative to design protocols in wireless sensor networks which will implement efficient measures to enhance communications reliability and minimize energy loss. Our work takes inspiration from one class of promising techniques known as opportunistic routing (ExOR) [4], which takes advantage of the broadcast nature of wireless communication to increase throughput and save energy in retransmissions. We propose an improved directed diffusion protocol based on opportunistic routing (DDOR). The main contributions of DDOR are summarized as follows:

1. DDOR proposes a novel transmission strategy. Intermediate nodes forward packets to their next nodes dynamically, which are determined opportunistically by the priorities of reinforced nodes.

2. DDOR solves the problem of retransmission caused by packets mission.

This paper is organized as follows: Section II surveys related works on routing of wireless sensor networks and describes their characteristics and application areas. Section III presents the mechanism of DDOR and the form of data and ACK packets. Section IV evaluates the performance of DDOR, and compares with directed diffusion. Section V concludes this paper.

II. RELATED WORK

In this section, we provide a brief overview of some related research work.

SPIN attempts to reduce the cost of flooding data [5]. The advantage of SPIN is that topological changes are localized since each node needs to know only its single-hop neighbors. However, the data advertisement mechanism of SPIN can not guarantee the delivery of data.

Intanagonwiwat et al. introduced a data dissemination paradigm called directed diffusion (DD) for sensor networks [6]. It includes three phases, interests diffusion, gradients establishment and paths reinforcement in that
energy consumption and results in high energy consumption. 

Table I summarizes all the above protocols discussed.

### III. DDOR Protocol

#### A. Introduction of Opportunistic Routing

Suppose data forward through a fixed path, such as Source - 1 - 2 - 3 - 4 - Sink, as demonstrated in Fig. 1. In WSNs, sensor nodes communicate with other nodes by broadcasting, and broadcasting communication is under influence of the environment. If source node broadcasts a message to node 1, it is possible that node 2 or 3 which is not far from node 1 also receives the broadcasting message. The ratio of successful reception of node 2 or 3 is lower than node 1 undoubtedly. If node 2 or 3 instead of node 1 sends the message to the sink, it will save the energy of broadcasting from node 1. Through the fixed path Source - 1 - 2 - 3 - 4 - Sink, there may be one or more opportunities to skip an intermediate node so as to save more energy. Especially in a large scale and distribution-intensive WSNs, the more hops from sources to sinks, the more energy will be saved by skipping intermediate nodes.

From the analysis above, we have introduced opportunistic routing [4] into directed diffusion. We take two-phase-pull directed diffusion as an example. In the phase of reinforcement, sinks send the reinforcement...
messages to sources hop-by-hop, and the intermediate nodes with the shortest delay will be marked as reinforced neighbors. We modify the reinforcement messages, so that the nodes received reinforcement messages will write their information into forwarder lists contained in the messages. When source nodes receive the reinforcement messages, the forwarder lists which contain all the reinforced nodes are established simultaneously. Every reinforced node maintains its own forwarder list and data packet map, and the following packet will be transmitted in term of DDOR.

B. Forwarder List

Through the phases of interests diffusion and gradients establishment, elementary gradients between all the nodes have been established, as shown in Fig. 2(a). In the path reinforcement phase, a sink node broadcasts a message with reinforcement information, and announces that the neighbor who sends data to sink earliest will become the next hop of the path reinforced. After the chosen node receiving the message, ID and priority of the node will be written into the message, and forwarder list will be duplicated in the local storage. Then, the message will be forwarded to neighbors as the above rules. The whole forwarder list will be stored as in ExOR. In this paper, we shorten the length of a forwarder list to save storage resource. The length of a forwarder list stored in every node is \( K \) Byte, which is composed of \( K-1 \) nodes with higher priority and the node itself. The other nodes which are not chosen as reinforcement nodes will go dormant.

![Figure 2. Gradients establishment and paths reinforcement](Image)

When an intermediate node \( i \) receives a reinforcement message, forwarder list in the message will be checked primarily. The maximum length of a forwarder list is \( N \), which is decided by the storage of every node. If the number of nodes stored in a forwarder list is less than \( K \), node \( i \) will write its own ID and priority into forwarder list, and duplicate the forwarder list in local storage, and then broadcast the message to neighbors. If there are \( K \) nodes in the forwarder list, all of which have a higher priority than node \( i \), node \( i \) will write its own ID and priority into forwarder list to replace the node with the highest priority, and make a duplication and broadcast as well.

When a source node receives the reinforcement message, it updates and duplicates the forwarder list as other intermediate nodes do, therefore, a reinforced path has been established, as shown in Fig. 2(b). Source nodes set up a threshold \( N (N<K) \) according to its transmitting power, and \( N \) nodes with the highest priorities will be written into the forwarder list in the message to be broadcast. Suppose every node has the same transmitting power except sinks, the value of \( N \) is fixed.

C. Cooperation Mechanism

In consideration of QoS, ACK mechanism is introduced in this paper. When an intermediate node receives a data packet for the first time, it checks the forwarder list before it makes a decision.

1. If this node has the highest priority in the forwarder list, it updates local data packet map before sending an ACK to the node \( i-1 \). As has mentioned above, \( N \) nodes with the highest priorities in local forwarder list will be written into the forwarder list in the packet, and the packet will be forwarded to next hop.

2. If this node does not have the highest priority in the forwarder list, it keeps monitoring for an interval \( T \). During the monitoring time, if the node receives an ACK from node \( i+1 \) (the node with higher priority), it will update local data packet map and send an ACK to node \( i-1 \) after interval \( T \). During the monitoring time, if the node does not receive an ACK from any node with higher priority, it will operate as situation 1 after interval \( T \).

Data packet map records a group of nodes, every of which has the highest priority corresponding to different packet, sources and the sink are also contained in this group. Interval \( T = kT_i \), \( k(k<N) \) is the number of nodes which have higher priorities than the current node. \( T_i \) is a time margin, which should be longer than the sum of time to process and transmit a packet.

When a source node receives an ACK from the node with the lowest priority in its forwarder list, the last packet will be confirmed to have been received by a node with higher priority. Then, packets will be transmitted one by one following the same rule.

When the sink node receives a data packet, it updates the data packet map and broadcasts an ACK immediately. After receiving the ACK from the sink, intermediate nodes update their data packet maps and drop the packets received by the sink. The process will last until all the packets have been received by the sink.

D. Data packet Head and ACK Packet Head

During the transmission of data from sources to the sink, as data are based on interests from the sink, which differ from ExOR, the data packet head in ExOR should be modified, as shown in Fig. 3. The differences of the data packet head between ExOR and DDOR are as follows:

1. Interest type takes the place of Batch ID. Every forwarder can match packets with interests to decide which packets should be received and forwarded.

2. Data packet map takes the place of Batch map. As Interest type indicates the forwarding direction of a packet, Data packet map shows which packets have been received. DPMSz is similar to BatchSz, which means the size of packets.
After receiving a packet, a node will transmit an ACK packet. The form of an ACK packet head is shown in Fig. 4. The expression of every part in this packet head is the same as data packet head.

<table>
<thead>
<tr>
<th>Ethernet Header</th>
<th>Ver</th>
<th>HdrLen</th>
</tr>
</thead>
<tbody>
<tr>
<td>PktType</td>
<td>PktData</td>
<td>DPMsz</td>
</tr>
<tr>
<td>Data Packet Map</td>
<td>Checksum</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. ACK packet head

![Flow chart of DDOR](image)

Figure 5. Flow chart of DDOR

### E. Retransmission

Retransmission mechanism remedies the shortage of ExsOR. In our work, after transmitting a data packet, if an ACK from node $i+1$ is not received, the intermediate node $i$ will retransmit the latest data packet. The reasons of retransmission may be as follows:

1. This packet is not received by nodes with higher priorities than node $i$.
2. This packet is received by one node at least with higher priority, but the ACK is missing.

A robust routing protocol has to deal with all the possible problems.

When the data packet is missing, suppose node $i$ retransmits the latest packet, the node $j$ with higher priority receives the packet for the first time. In this case, node $j$ will check the forwarder list to determine whether it will transmit the packet immediately or keep monitoring for an interval $T$, as introduced in section III. C.

When the ACK is missing, suppose node $j$ receives the retransmitted data packet from node $i$, it will check the local storage to see whether the packet has been received. If the packet has been received by node $j$ or other nodes with higher priorities, node $j$ will understand that the latest ACK is missing and will retransmit an ACK to node $j-1$. If the packet has not been received before, node $j$ will check the forwarder list to determine whether it will transmit the packet immediately or keep monitoring for an interval $T$, as introduced in section III. C.

### F. Flow of DDOR

The flow chart of DDOR is shown in Fig. 5.

### IV. PERFORMANCE ANALYSIS

Reference [12] describes the probability of reception with Rayleigh fading channel, which is:

$$p_r = p_r^N \cdot p_r^F$$

(1)

$p_r^N$ is the reception probability in a zero-interference network as it depends only on the noise, $p_r^F$ is the reception probability in a zero-noise network. For a well-designed routing protocol, interference can be ignored, and therefore the probability of reception is:

$$p_r = \exp \left( -\frac{\theta N_0}{P_d d_{ij}^{-\alpha}} \right)$$

(2)

$P_T$ is the transmission power of node $i$, $d_{ij}$ is the distance between node $i$ and node $j$, $N_0$ denotes the noise power, $\alpha$ is the channel attenuation factor, $\theta$ is a certain threshold of the signal-to-noise-and-interference ratio (SINR) that is determined by the communication hardware.

Suppose the reinforced nodes are distributed as Fig. 6. The reinforced path between a source and the sink is composed of twelve hops. Transmission power is set to $P_T = 660mW$ as in Ref. [6]. According to Ref. [12], channel attenuation factor $\alpha$ has a value between 2 and 4, and the other two parameters are $N_0 = 0.1mW$ and $\theta = 1$.

Suppose the threshold $N = 3$, the distance between two neighbors is fixed $d_{ij+1} = d_{ij}$. When $d_{ij+1}$ and $\alpha$ change, the ETX of forwarding a packet from a source to the sink is shown in Fig. 7.

![Nodes deployment of reinforced path](image)

As known in Fig. 7, the longer distance between two neighbors, the larger ETX is needed to transmit a packet from a source to the sink. The larger channel attenuation factor $\alpha$, the larger ETX is needed to transmit a packet from a source to the sink as well. We choose a common environment with $\alpha = 2.5$, and compare the performance of DDOR with direction diffusion, as shown in Fig. 8.

As known in Fig. 8, when the distance between two neighbors satisfies $d_{ij+1} < 30m$, DDOR is superior to directed diffusion obviously.

We implement DDOR protocol in NS-2 simulator. Our 50-node sensor field is generated by randomly placing the nodes in a $200 \times 200$ m square. The ns-2 simulator implements a 1.6 Mb/s 802.11MAC layer. Our simulations use a modified 802.11 MAC layer. To more closely mimic realistic sensor network radios, we altered the ns-2 radio energy model so that the idle-time power
dissipation was about 35 mW, which is nearly 10% of its receiving power dissipation (395 mW) and about 5% of its transmitting power dissipation (660 mW). Every node has 1000J energy initial, and the simulation lasts 20000s.

As the number of sources changes, Fig. 10 shows the average residual energy with directed diffusion and DDOR, respectively. As shown in Fig. 10, DDOR can save more energy than directed diffusion, for its efficiency in choosing the next-hop nodes.

V. CONCLUSION

This paper focuses on the problem of simplex and fixed next-hop nodes in traditional routing protocols, and presents an energy-efficient routing protocol based on directed diffusion and opportunistic routing. In data transmission, a forwarder list instead of a fixed next-hop destination is implemented to choose an optional next-hop node. Plenty of experiments prove that DDOR can save more energy in transmission, and prolong the life of WSNs. Comparing with directed diffusion, DDOR is more energy-efficient.

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REFERENCES


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