

# An Opportunistic Routing Algorithm with Implicit ARQ for Wireless Sensor Networks

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**Abstract**—This paper presents a new multi-hop routing algorithm for wireless sensor networks. Each sensor node makes a local decision to forward or drop a packet, via a forwarding probability, either static or dynamic. This probability can be associated with local information such as residual energy of the node, packet properties, in order to optimize network performance. The direction of forwarding is guided by received signal strength indication (RSSI) relative to the sink node. Moreover, based on the characteristic of wireless communication that all packets are broadcast at the radio level, an implicit ARQ mechanism, where a receiver does not send an ACK frame explicitly to the sender, is adopted in our method. RSSI guided direction, probability based forwarding and implicit ARQ are three key points of this algorithm. The proposed algorithm reaches a good compromise between the successful delivery rate and work nodes. At last, computer simulations illustrate its effectiveness.

**Keywords**—Wireless sensor networks; opportunistic routing; RSSI; implicit ARQ; Simulation

## I. INTRODUCTION

There are a variety of routing protocols for multi-hop wireless networks. Most of these schemes have a common aspect that they attempt to find the a best path from the source to the destination and to forward packets to the next indicated hop[1]. Once a packet is lost, the nodes either retransmit the packet to the same next hop or rediscover another path. These approaches make the most sense when each pair of nodes is linked by a wire, where each link has a deterministic cost, where there will be one or more optimal routes between a source and the destination. A routing protocol which finds an optimal route and then sends data along that specific route, is likely to perform well in this case [2].

Multi-hop wireless sensor networks deviate from the wired model in following ways: first, at the radio level, nodes actually do not have to pick a particular target to forward packets, because all the packets are broadcasted into the wireless space. Second, the radio communication between a pair of nodes is not deterministic. Packets arrive

incorruptibly with some probability. The properties that make pre-determined routes work well in wired networks do not hold in wireless sensor networks [2].

Consequently, opportunistic routing schemes that exploit the broadcast nature of wireless transmissions are being actively explored [2]-[6]. In contrast to the best path routing strategies, where a packet is unicast to the predetermined next-hop, a next-hop node is determined per-packet after its broadcast transmission in an opportunistic routing scheme. It allows any node that overhears the transmission to participate in forwarding process with some probability. In [2], it was demonstrated that this more relaxed choice of next-hop significantly increases the throughput of the network, and ExOR protocol was proposed to achieve these gains. However, ExOR, ties the MAC with routing, imposing a strict schedule on node access to the medium. To overcome this problem, in [3], MORE which does not need a special scheduler to coordinate nodes was proposed. But the key point of MORE - network coding, lead to a great challenge in practical implementation. In [4]-[6] some performance analysis of opportunistic routing are given.

In this paper we propose a highly distributed opportunistic routing scheme that takes advantage of the characteristics of wireless channel. Instead of choosing a single and deterministic route before transmission, a node makes a local forwarding decision without exchanging extra information with neighbor nodes. In addition, with an ARQ mechanism, a node will get an acknowledgement in an implicit way to ensure a reliable packet transmission. To some extent, this routing scheme can be seen as a constrained flood routing. As there exist some similar routing protocols in litterateur [7]-[10], a comparison between them will be made in this paper.

## II. AN OPPORTUNISTIC ROUTING SCHEME

### A. Wireless sensor network model

The model of wireless sensor networks varies a lot depending on applications. In this part, we provide an overview concerning the network model on which our

algorithm relies. It is supposed that the sensor network consists of a unique sink node and large numbers of dense sensors. Sensors detect events and forward the information to the sink (Fig. 1). A sensor node has limited ability, including transmission power and battery energy, which means it could only cover several neighbor nodes and tends to run out of its energy easily. When a packet should be sent to the sink node, multi-hop transmission will be executed with the aid of other nodes. The coverage of the sink node is supposed to be large enough so that the entire sensor network is within its maximum transmission range. In particular, we assume that the sink is not energy constrained, which is a reasonable assumption because in practical the sink node usually connected to powerful energy supply equipments.

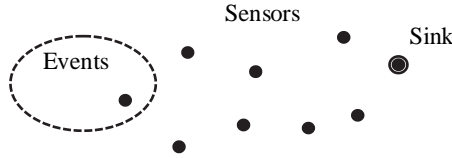


Figure 1. Wireless network model used in our paper

### B. Presentation of the protocol details

Firstly, in order to route a packet through the network, the following fields are added to the packet header (Fig. 2). The SourceID field carries the unique identifier of the source node that originates the packet. The SeqNum field carries the local packet sequence number generated by the source node. A pack is thus uniquely identified across the network by the 2-tuple {SourceID, SeqNum} as its ID. LastRelayRSSI field carries RSSI value of the precedent relay, which will be explained in detail latter.

SourceID	SeqNum	LastRelayRSSI	Others
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Figure 2. Packet Header Format

1) *RSSI guided routing*: To guide a packet towards the sink, geographic information seems to be a direct choice. However for a simple and low-cost wireless sensor network, GPS devices are probably unavailable. As a substitution, the received signal strength indication (RSSI) can be obtained with little effort with current hardware systems. With the free-space or the two-ray ground radio propagation model, RSSI decreases monotonously with the increase of the distance between two nodes. The received signal strengths can be easily translated to distances (and vice versa). With a fading channel, due to the multi-path effect and different channel gains, RSSI may not have a deterministic relation with the relative distances. However, in this case, it can be considered that RSSI provides us a logical position relationship between nodes. As with a stronger RSSI, two nodes are nearer in communication sense as the received signal power is highly related with the demodulation error rate. Another problem is that the received power may not be deterministic due to the channel variation. This kind of variation could be seemed as a disturbance of RSSI and could be alleviated using an averaged value by smoothing RSSI with several packets.

2) *Probability Based Forwarding*: In the initialization phase, the sink node broadcasts a control

message. Once a sensor node receives such a message, it consequently knows the received RSSI value relative to the sink node. The sink will broadcast such a message periodically so that sensor nodes are able to update their RSSI information. Unlike some other routing algorithm, there is no need for any sensor node to exchange information with their neighbors. There is even no need for a sensor to make a discovery of its one-hop neighbor nodes, which undoubtedly reduces the network burden.

A source node that originates a packet writes its information, including its own ID, the sequence number of this packet and its RSSI value in the fields SourceID, SeqNum and LastRelay respectively. Any neighbor node that receives this packet compares its own RSSI value obtained in the initialization phase with the RSSI value marked on the packet. If the former is larger, which indicates the current node is nearer to the sink node, the node may participate in transmission task. Moreover, as it is not necessary to involve all the nodes within the coverage into the routing task, we introduce a probability  $p$  with which a node will forward this packet.

The task to determine the value of probability  $p$  is a subtle work. The simplest way is to set this probability to a proper constant between 0 and 1 for all the sensor nodes in the network. The larger  $p$  is, the more reliable the end-to-end transmission will be, but evidently more nodes will be involved into the transmission task. In contrast, the smaller  $p$  is, the less reliable the end-to-end transmission will be, but fewer nodes will be involved. Therefore, there is a compromise between the reliability and the number of nodes involved during the transmission.

More work can be taken to calculate a dynamic probability  $p$  for optimizing the network performance. In this way, each node will have a local probability which provides a better description of the node ability or traffic properties. When residual energy is taken into consideration, nodes with less energy will have less chance to forward a packet to avoid depleting their energy. In this way, the energy consumption in the network will be balanced to some extent. For example, assume that the initial energy of a node is  $E_0$ , and the current residual energy is  $E$ , then the normalized residual energy can be defined by

$$E_N = E/E_0$$

with  $E_N \in [0,1]$ . The relation between the forwarding probability  $p$  of node  $n$  and the normalized residual energy should be described with a function  $p_n = f(E_N)$ . We can design a curve  $f(\cdot)$  with the following principles: firstly,  $p_n = f(E_N)$  should increase monotonously as  $E_N$  increases. Secondly, the full energy state should be corresponding to an upper-bound probability  $p_{max}$ , and a lower bound  $p_{min}$  should be also indicated to avoid that that no node forwards a packet when most nodes are in a poor energy state. With such principles, the following function can be given

$$p_n = \max\{p_{min}, p_{max}(1 - (1 - E_N)^y)\}$$

Such a design of dynamic forwarding probability gives possibility to balance the energy consumption of the network. Some QoS mechanisms can also be partially supported. According to the priority level marked on the

packet, a node may adjust its probability by multiplying a weight factor  $\eta_j$  associated with its priority. More parameters such as traffic load on the node etc, can be also considered to determine the  $p$  value.

3) *Implicit ARQ Mechanism*: During the classical acknowledgement process, once a node receives a packet, it will send an ACK frame to the sender to confirm the transmission. However, as we mentioned in the introduction section, in wireless sensor network all packets are broadcast at the radio level. Considering the reciprocity of channels, two nodes with the same transmission power can cover each other. A forwarding process can be also regarded as an acknowledgment to the sender, since the sender considers that another node has taken over the task and its mission has been accomplished. In this way, no ACK frame is sent in the explicit way. So we call this acknowledgment mechanism *implicit ARQ*.

On the last hop, the sender can not be simply acknowledged by implicit ARQ mechanism because the sink node, which is the destination, does not forward a packet. So it is necessary for the sink to broadcast an ACK frame to declare the arrival of the packet. This ACK is able to cover the whole network due to the adequate transmission power of the sink. On receiving this ACK, all the nodes in the network can clear their actions with respect to this packet. Moreover, this ACK can be also served as an end-to-end ACK between the source and the sink.

4) *Summary of Algorithm*: The presented routing scheme is simple but efficient. It consists of three key points: RSSI guided transmission, the probability based forwarding and implicit ARQ mechanism. We now summarize the routing process hereinbelow.

#### Routing initialization and update

- Establish the RSSI gradient field: the sink broadcasts control packets periodically
- Each node updates its RSSI value relative to the sink

#### Origination of a packet

- Add source ID and packet sequence number on the packet header.
- Add its RSSI on the packet header.

#### Processing a receiving packet in a normal node

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if current node RSSI  $\geq$  RSSI on the packet
    if this packet was forwarded
        then drop the packet;
    else
        Replace the field LastRelayRSSI by the current node RSSI;
        Calculate local forwarding probability  $p$ ;
        Forwarding the packet with probability  $p$ ;
    end
else
    if this packet is forwarded
        then this is an implicit ACK;
    else
        Drop the packet;
    end
end

```

### III. SIMULATION EXPERIMENTS

#### A. Coverage Area Study

In this part, we shall evaluate the number of nodes which are involved in a transmission task, with respect to the forwarding probability. Firstly, a topology of 256 nodes located on a  $16 \times 16$  uniform grid mesh was generated. A source node was located at (2,8) and the sink node was located at (9,8). The communication range of the node was set to  $\sqrt{2}$ , i.e. each node was able to have a direct communication with its 8 neighbors. The forwarding probabilities were set to  $p = 1$ ,  $p = 0.8$  and  $p = 0.6$  respectively. The results are illustrated in the first row of Fig. 3. It can be observed that a larger probability leads to more nodes involved in the transmission task. Similar conclusion could also be reached with a random topology with the same number of nodes was generated (See the second row of Fig. 3). The compromise between reliability and efficiency is controlled by this forwarding probability.

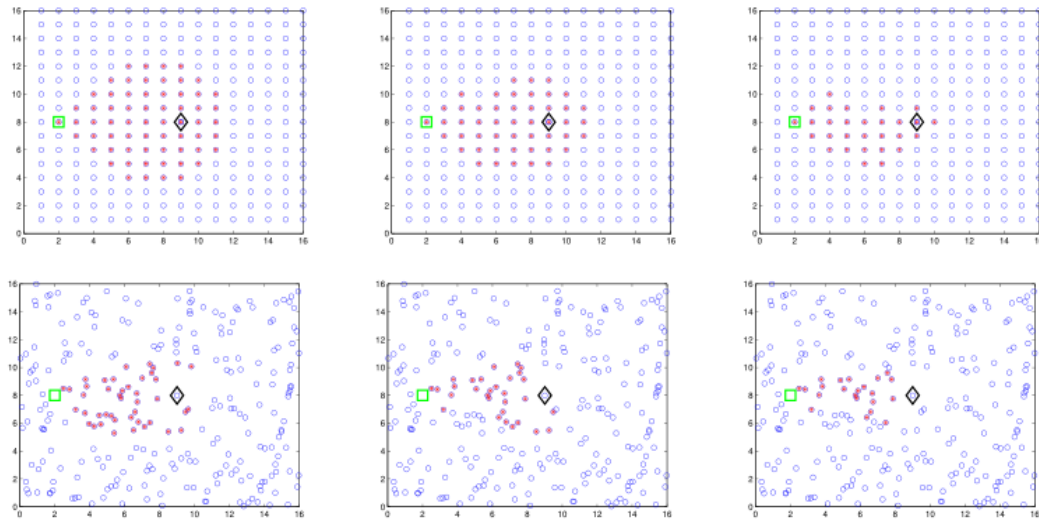


Figure 3. Coverage of nodes in a transmission task. Red '\*' are nodes involved in the transmission task. The green square represents the source node. The black diamond represents the sink node. The first row: uniformly distributed nodes with  $p = 1$ ,  $p = 0.8$  and  $p = 0.6$ , from left to right. The second row: a random topology with  $p = 1$ ,  $p = 0.8$  and  $p = 0.6$ , from left to right.

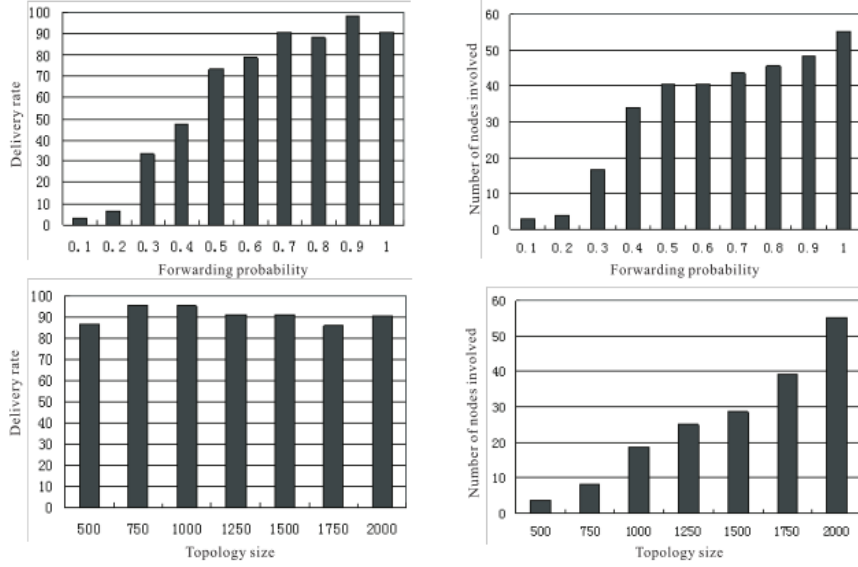


Figure 4. Performance results of the algorithm

### B. Performance Study

The object of this study is twofold. Firstly, we studied show how the forwarding probability  $p$  and the topology size effected the performance of the proposed protocol. Secondly, we compared the proposed routing protocol with some exiting ones.

We implemented our protocol and performed simulations using Network Simulator 2 (NS2). The results are illustrated in Fig. 4. For the first study, a network with 250 nodes was studied. The nodes are uniformly deployed over a  $2000m \times 2000m$  field. The sink was located at one corner of the field and one source node was located at the diagonal corner. Radio propagation model was set to two-ray ground model and transmission range was set to 250m. Network dynamics - transmission error was also considered in our simulation, where a packet error occurred at the rate of 10% during the transmission process. The forwarding probability was set to 0.7 for all nodes. From the results in the first row of Fig. 4, we can see that a successful delivery ratio greater than 0.9 could be obtained with a forwarding probability above 0.5. The network performance becomes poor if the forwarding probability is below 0.4. According to this result, if we want to set a static forwarding probability for each node in the network, this value should be larger than 0.4 for a reliable transmission with a successful delivery ratio greater than 0.7. And with a greater forwarding probability, the number of nodes involved during the routing process increases, meaning that a compromise should be made between these two factors.

For the second study, we fix the node density as 250 nodes over  $2000m \times 2000m$ , the topology size varies from

500 to 2000. From the results in the second row of Fig. 4, we see that the successful delivery rates vary little with the increase of the topology size, which indicates the stability of this routing method. With the increase of the topology size, more nodes are involved in the transmission task, which is the evident result due to the topology size.

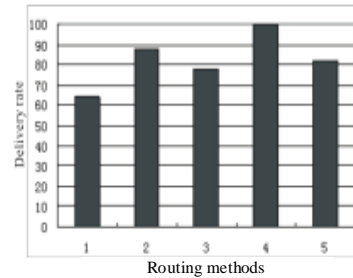


Figure 5. Comparison of delivery rate

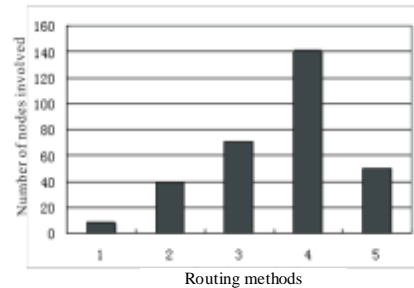


Figure 6. Comparison of involved nodes

After that, we compare the proposed protocol with other four routing methods, the number 1 to 5 represent respectively: single-path RSSI guided routing method in [8], the proposed method, a variant of the Beamstar in [7], basic flooding method, Beamstar protocol in [7]. The results of the simulations are shown in Fig. 5 and Fig. 6. We can see that the proposed algorithm reaches a good compromise between the successful delivery rate and work nodes.

#### IV. CONCLUSION

In this paper, we present an opportunistic routing protocol, which is characterized by RSSI guided transmission, the probability based forwarding and implicit ARQ mechanism. This protocol has a very low computational complexity and has good scalability. Simulation studies showed the effectiveness of this protocol.

Future works include further design and simulation on the dynamic forwarding probability. We also plan to implement it on a hardware test-bed and to investigate its performance of a real implementation.

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