# An Energy Efficient Opportunistic Routing Protocol for Wireless Sensor Networks

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## Abstract

In order to solve the problems that limited energy of sensor and end-to-end delay, an Energy Efficient Opportunistic Routing Protocol (EEORP) is proposed for opportunistic routing in wireless sensor networks. In EEORP, effective expected value, residual energy rate and packet reception quality are presented as metrics. During the data delivery, first forwarder and standby forwarder are selected, while reliability of link and timely of transmission are improved by collaborative forwarding which achieved through standby forwarder. Meanwhile, sleep-wake scheduling is an effective mechanism to save energy by appropriately arranging sensor nodes to sleep. Simulation results show that EEORP reduces energy consumption and latency, prolongs lifetime of networks.

## Keywords

Wireless sensor networks; Opportunistic routing; First forwarder; Standby forwarder.

## 1. Introduction

Wireless sensor networks (WSN) is deployed in monitoring area which consists of sensor nodes. Compared with traditional wireless networks, WSN is collaboratively to perceive, collect and process event information in monitoring area, and transmitting to monitor timely [1]. But nodes in monitoring area are usually supplied with energy from batteries that cannot be charged [2]. So energy saving becomes one of the main problems in WSN research [3]. In addition, network topology of WSN may changes constantly. It causes nodes wasting a lot of energy, which affects the life of the whole network [4]. The instability of the wireless link is well solves by opportunistic routing. At the same time, opportunistic routing also improves wireless network lifetime [5-6]. Compared with traditional routing, opportunistic routing creates path diversity, and balances the energy of network by selecting the next-hop node opportunistically, so it can adapts to WSN dynamic topology and reduce energy consumption [7-8].

## 2. Related Work

Recently, research of opportunistic routing protocol for WSN has proposed a variety of solutions. The EQGOR protocol is presented to solve the efficiency problem for QoS requirements in geographic opportunistic routing of WSN [1]. And ASSORT protocol is joint design of asynchronous sleep-wake scheduling and opportunistic routing [9]. The calculation of them is complex, and it will increase the energy consumption.

In R3E protocol, guide nodes and a virtual path are found and they complete the data delivery by collaboration mechanism [10]. The virtual path provided by guide node which needs to know the information about related nodes, it will increase consumption of energy. PBR algorithm determines the forward area and data transmission is completed by the highest priority node. In this process, node limits the unnecessary data forwarding through regional division [11]. But the network energy consumption increased because all nodes are always in a state of work.

Through the above analysis, we put forward energy efficient opportunistic routing protocol (EEORP). In EEORP, the next-hop relay nodes are selected by geographical information and metrics. At the same time, it selects a standby forwarder to increase timeliness and reliability of data transmission. In order to reduce energy consumption further, EEORP combines with sleep-wake scheduling to arrange nodes sleep in idle time.

## 3. Network Model and EEORP

### 3.1 Network Model

In a two-dimensional planar region, we set a multi-hop WSN. The initial energy of all nodes is same, sink node energy is infinite. Each node has plenty of neighbors, and each node knows its own location information, sink node location information, Euclidean distance between itself and sink node. Nodes employ periodic sleep-wake scheduling, in order to ensure that data can be perceived, acquired and delivered in a timely manner, nodes are required sleep at different time. So how to set sleep time $T_{sleep}$ is critical.

Monitoring area and node density are set as $S$ and $\rho$, respectively. So the number of nodes in the monitoring area is $N=S\times\rho$. According to the definition of Poisson distribution, we set probability of event is $\lambda$, and n nodes that are in the awake state should meet the requirements of $n=N\times\lambda$.

In a time period, the relationship between sleep time and wake-up time are described as:

$$T_{sleep} = \delta \cdot T_m \tag{1}$$

where $T_{sleep}$ is sleep time and $T_m$ is wake-up time.

During the $t$ time, we will discuss two different conditions of one node: 1) there are no tasks in network area, $\eta$ time periods are completed in $t$ time; 2) node has completed $\chi$ time periods when node receives a forwarding task. The two different conditions defined as:

$$\frac{n \cdot \eta T_m}{t} = \lambda \tag{2}$$

$$\frac{n \cdot \left[ \chi \left( T_m + T_{sleep} \right) + T_m \right]}{t} = \lambda \tag{3}$$

where $\chi$ is 0,1,2…. According to (1), (2) and (3), we obtain:

$$\eta = \chi \cdot \delta + \chi + 1 \tag{4}$$

In accordance with requirements of the network, the $\chi$ value is selected, and the relationship between $T_m$ and $T_{sleep}$ is determined.

### 3.2 EEORP.

In EEORP, source node informs neighbor nodes through a broadcast which contains related geographic information. Neighbor nodes which are in the work state receive the broadcast will calculate distance from sink node to themselves. When neighbor nodes are closer to sink node, they will identify themselves as candidate nodes and reply an ACK containing residual energy rate and packet reception quality. Then source node selects first forwarder and standby forwarder among candidate nodes. After first forwarder and standby forwarder are selected, data packets are transmitted by first forwarder and standby forwarder cooperates to forward data packets. Figure.1 shows the flow chart of EEORP.

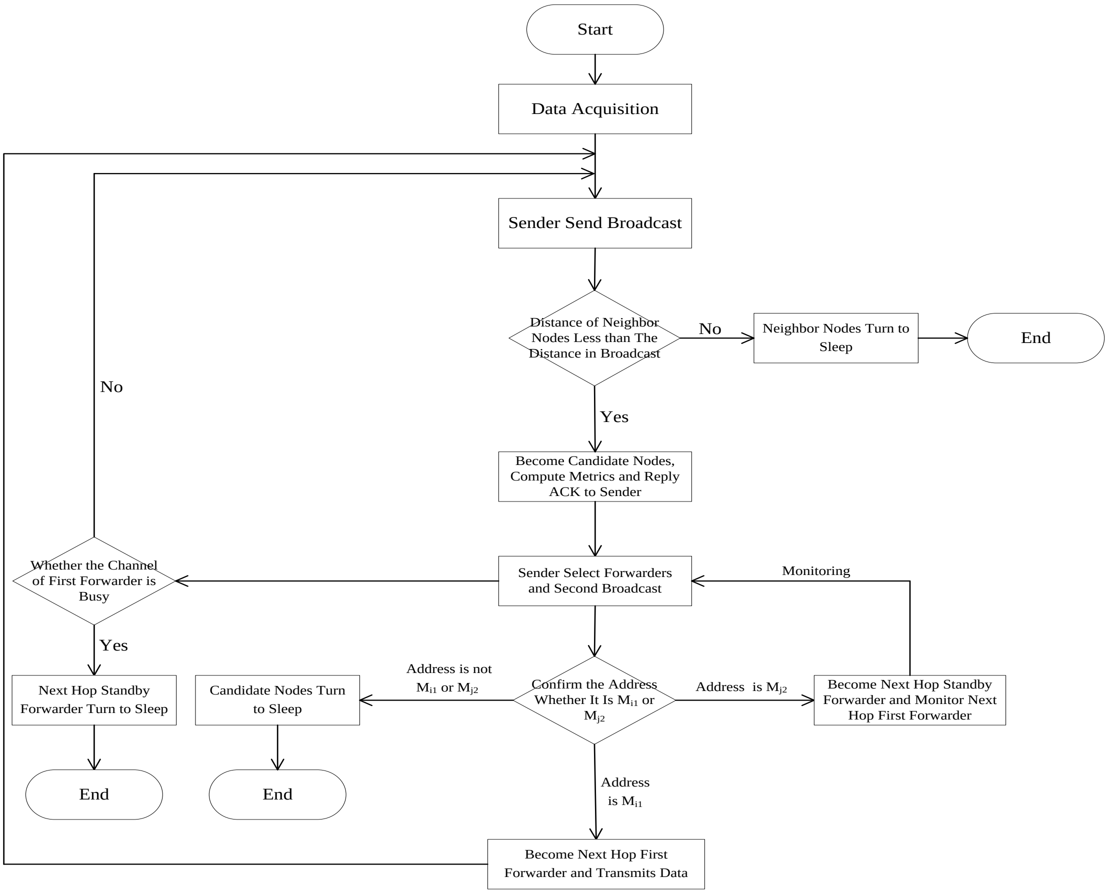


Fig. 1 The Flow Chart of EEORP

### 3.3 Metrics Calculation

Relay node is chosen from the candidate node set of source node, so the metrics of candidate node is significant. This paper defines three metrics: effective expected value $M_i$, residual energy rate $M_{i1}$ and packet reception quality $M_{i2}$ ($i$ is the identification of node), and higher priority have greater values.

Assuming $E$ is initial energy of node, total working time is $T$ , data generation rate is $\lambda$ , packet reception rate of node $i$ is $\beta$, $E_{iexpect}$ and $T_{iexpect}$ describe expected energy consumption within a time period and expected working time in a working cycle, respectively. The number of work cycle $n'$ is:

$$n' = \left\lceil \frac{T}{T_{iexpect}} \right\rceil \tag{5}$$

The expected residual energy $E_{iesurplus}$ of node $i$ is

$$E_{iesurplus} = E - n'E_{iexpect} \tag{6}$$

The residual energy and packet reception rate are normalized, $S_{is}$ is the Euclidean distance between node $i$ and sink node, and the base of logarithmic function is 0.5. At current time, effective expected value $M_i$ of node $i$ is

$$M_i = \alpha \times \frac{-S_{is}}{\log \frac{E}{E_{iesurplus}} \cdot \log \frac{1}{\beta}} \tag{7}$$

where $\alpha$ is reduction factor which makes $M_i$ compare with two other metrics.

When node *i* participates in the relay nodes competition, current actual residual energy of node *i* is Eit, residual energy rate $M_{i1}$ and packet reception quality $M_{i2}$ of node i are calculated as Eq.(8) and Eq.(9), respectively:

$$M_{i1} = \frac{\left(\frac{E_{it}}{E}\right)^{\beta}}{S_{is}} \tag{8}$$

$$M_{i2} = \frac{S_{is}}{\left(\frac{1}{\beta}\right)^{\left(\frac{E}{E_{it}}\right)}} \tag{9}$$

When the first forwarder and standby forwarder selection criteria $(M_{i1} \geq M_i) \vee (M_{i2} \geq M_i)$ is satisfied, node *i* becomes a candidate node and participates in the relay node competition

### 3.4 Sleep-Wake Scheduling

In order to reduce energy consumption of nodes, we introduce sleep-wake scheduling in EEORP. All nodes have two states in the network and they are independent of each other.

During wake-up time, node does not receive data forwarding request, time $T_{r1}$ is calculated as Eq. (10):

$$T_{r1} = T_{\text{m}} + T_{\text{sleep}} \tag{10}$$

where $T_m$ is wake-up time and $T_{sleep}$ is sleep time.

According to EEORP, node as a data receiver receives a data forwarding request during the wake-up time, time $T_{r2}$ is calculated as Eq. (11):

$$T_{r2} = T_m + (1+\gamma) T_{ACK} + T_{\text{Wb}} + T_{rDATA} \tag{11}$$

where $T_{ACK}$ is a reply ACK time, $\gamma$ is the coefficient of random back-off time, $T_{Wb}$ is waiting for the secondary broadcast time, $T_{rDATA}$ is the time of receiving data packets, the contrast of Euclidean distance and the calculation of measurement time are ignored.

As a data sender, node will broadcast among neighbor nodes. After that, there have two cases, one is sender receives an ACK, another is not. Time of the two cases is calculated as Eq. (12) and Eq. (13), respectively.

$$T_{s1} = T_{broadcast} + T_{WACK} + T_{sleep} \tag{12}$$

$$T_{s2} = T_{broadcast} + T_{WACK} + T_j + T_{sleep} + T_{sDATA} \tag{13}$$

where $T_{broadcast}$ is broadcast time, $T_{WACK}$ is the time waiting for an ACK, $T_j$ is the time of priority selection and broadcast, $T_{sDATA}$ is sending packets time.

## 4. Simulation

In this section, we evaluate the performance of EEORP through the simulations implemented in MATLAB, and we choose MICAz as the hardware setting in simulations. The detailed parameter setting is summarized in Table 1. Our simulations compare EEORP, ExOR[12] and GCF[13] protocols.

Set the initial energy of each node to 2J, figure 2 shows the first depletion in network within different number of nodes. The first depletion in ExOR and GCF has an unobvious change that because metric of next forwarder selection is distance and they do not take into account energy. In order to avoid excessive consumption of energy, residual energy of nodes is considered in EEORP. Furthermore, nodes are arranged to go to sleep in idle time to save energy.

Table1. Simulation Parameters

| | |
|---|---|
| Area of field | (500 m, 500m) |
| Coordinate of source node | (0 m, 0 m) |
| Coordinate of sink node | (500 m, 500m) |
| Number of sensor nodes | 175, 200, 225, 250, 275,300, 325, 350 |
| Transmit power | 0dBm |
| Energy cost (transmit) | 52.2mW |
| Energy cost (receive) | 59.1mW |
| Transmission data rate | 250kbps |
| Packet size | 46 bytes |

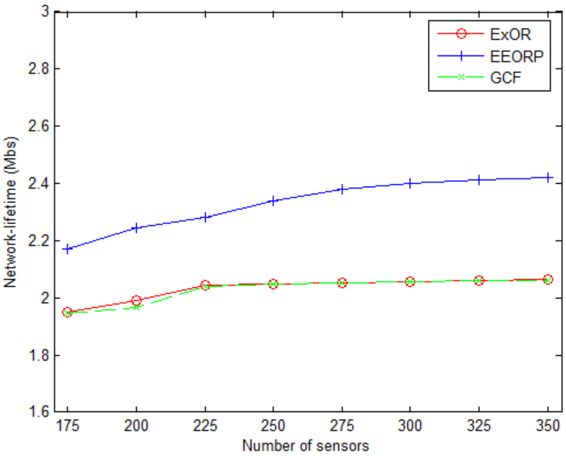


Fig. 2 The First Depletion in Network within Different Number of Nodes

Set 250 nodes in network area, network area is set to (500 m, 500m). The node density is unchanged and the network area is expanded. With expanding of the area, the distance from sender to sink node and the number of hops also increased. The increasing of hop will result in energy consumption increasing. Moreover, the increasing of nodes may produce a series of crosstalk or collision, it also consumes energy. In the case of constant density, figure 3 shows the first depletion of three protocols.

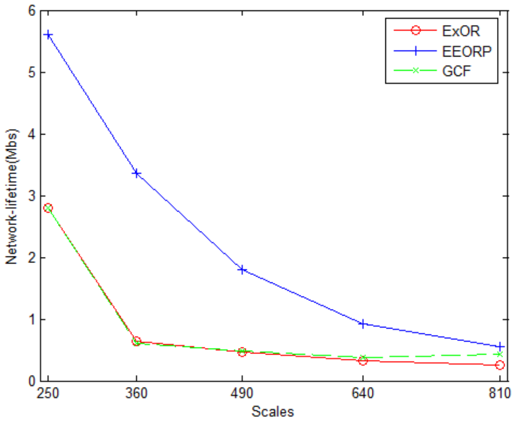


Fig. 3 The First Depletion within Same Density

Set same size of network area with different number of nodes, and figure 4 shows the end-to-end delay of three protocols. In the case of different number of nodes, end-to-end delay in EEORP is less than ExOR and GCF.

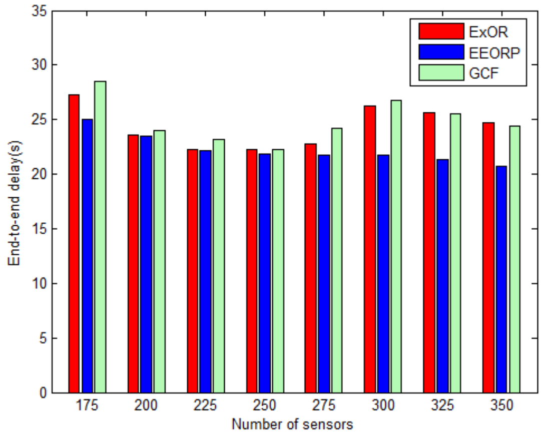


Fig. 4 The End-to-end Delay with The Increasing of Nodes

## 5. Conclusion

This paper studies opportunistic routing protocol in wireless sensor networks. In view of finite energy and end-to-end delay, EEORP is proposed. It uses the priority of metrics to select first forwarder to transmit data and standby forwarder which is base on energy to forward collaboratively. Meanwhile, it takes full advantage of sleep-wake scheduling to arrange nodes sleep in idle time. EEORP balances the energy consumption and improves the quality of link transmission. The simulation shows that the EEORP reduces energy consumption, improves the end-to-end delay and prolongs the life of network.

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