



An Energy-Efficient Routing Protocol for Internet of Underwater Things

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Abstract. By using underwater acoustic sensor networks (UWSNs) as a backbone, Internet of Underwater Things (IoUT) have developed rapidly due to their applications, such as environmental monitoring, marine resources development, and geological oceanography. Frequently changing or recharging the batteries of underwater sensor nodes may not be realistic due to the harsh marine environment and high cost of underwater equipment. In this paper, we propose an energy-efficient routing protocol for IoUT for marine environmental monitoring. Our simulation results show that the proposed routing protocol can prolong the network lifetime for IoUT compared with other published routing protocols.

Keywords: Routing metric · Internet of Underwater Things · Residual energy

1 Introduction

By using underwater acoustic sensor networks (UWSNs) as a backbone, Internet of Underwater Things (IoUT) have developed rapidly due to their applications, such as environmental monitoring, marine resources development, and geological oceanography [1–8]. Unlike the conventional wireless sensor networks (WSNs), IoUT has several distinct features. First of all, underwater nodes utilize limited battery power to collect data and to communicate with each other. It is difficult to frequently recharge the batteries. Furthermore, a fairly high transmitting

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power may required when the distance between a source node and a destination node is large. Therefore, underwater communications with multiple hops is always used in IoUT [9–14], efficient underwater communication is a challenging issue when designing routing scheme. In this paper, we proposed an energy-efficient routing protocol for IoUT by jointly considering the power levels of the acoustic modem and the residual energy of each sensor node. We demonstrate the novel performance of the proposed routing protocol by comparing with other published routing protocols.

2 Routing Protocol

In this section, we propose a routing protocol for IoUT. Specifically, a sensor node send data to the sink by using different paths and different transmitting power levels. As we know, the energy consumption during underwater communications is controlled by the transmitting and receiving power levels in IoUT. Only using the minimum cost paths results in quick batteries depletion. An efficient route between a source node to a destination node should contain underwater acoustic link with lower transmitting power with underwater sensor nodes with relatively high residual energy. Denote $\mathbb{E}_r^{(u)}$ and $\mathbb{E}_r^{(v)}$ as the residual energies of node u and v , respectively. Suppose p_{tmax} as the maximum transmitting power. We express the cost of an underwater acoustic link \mathbb{C} between u and v as:

$$\mathbb{C}^{(u,v)} = w_p \frac{t \times (p_t^{(u,v)} + p_r)}{t \times (p_{tmax} + p_r)} + w_e \left(\frac{\mathbb{E}_0^{(u)} - \mathbb{E}_r^{(u)}}{\mathbb{E}_0^{(u)}} + \frac{\mathbb{E}_0^{(v)} - \mathbb{E}_r^{(v)}}{\mathbb{E}_0^{(v)}} \right), \quad (1)$$

where t is the transmission time of a data packet, w_p and w_e are the weights for power level and energy consumption, respectively. The latter in Eq. (1) represents the energy consumption of nodes u and v .

3 Performance Evaluation

3.1 Simulation Settings

We consider the IoUT with grids topology to evaluate the performance of the proposed routing protocol. We suppose that 600 m is the average distance between any two adjacent sensor nodes. At the beginning of simulation, each underwater sensor node's battery energy is $(N^2 - 1) \times 10^6$ J, where N is the number of sensor nodes in IoUT. The traffic intensity is 100 packets per day per node. In our simulation, data packets are collected by underwater sensor nodes and then are transmitted to the sink node. The sink node will send the collected data to the sea surface. To evaluate the proposed routing scheme under different energy consumption, we employ the operation parameters of the EvoLogics modem. In general, we suppose three transmitting power with to different efficient range [15]. The energy consumption can be calculated as follows [7].

$$\mathbb{E}_t = p_t^{(u,v)} \times t, \quad (2)$$

where \mathbb{E}_t is the energy consumption of node u when it transmits a data packet to node v . Equation (2) is employed to compute the energy consumption when sensor nodes are in receiving and idle listening. The data rate of the acoustic modem is 13900 bit/s.

Parameter settings are presented in Table 1.

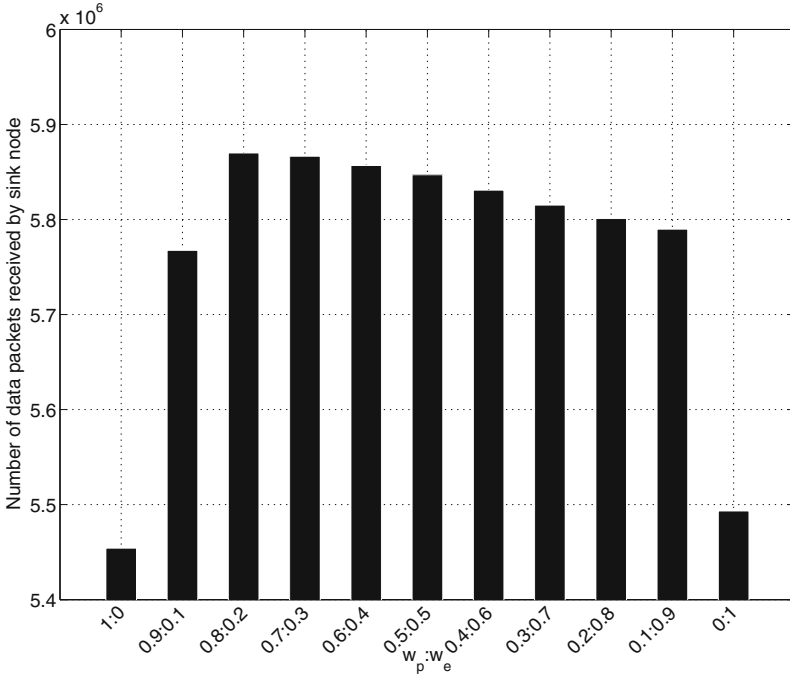
Table 1. Simulation parameters of the proposed routing protocol

Parameters	Value
Network size	11×11 , 13×13 , 15×15 , and 17×17
Initial energy of node u $\mathbb{E}_0^{(u)}$	10^6 J
Data rate	13900 bit/s
Distance between two closest adjacent nodes d_c	600 m
Traffic $i^{(u)}$	100 packets/day
Transmitting power $p_t^{(u,v)}$	2.8 W, 8 W, and 35 W
Corresponding transmission range	1000 m, 2000 m, and 3500 m
Receiving power p_r	1.1 W
Idle listening power p_l	0.08 W
Sleeping power p_s	0 W
Packet size	1200 bytes

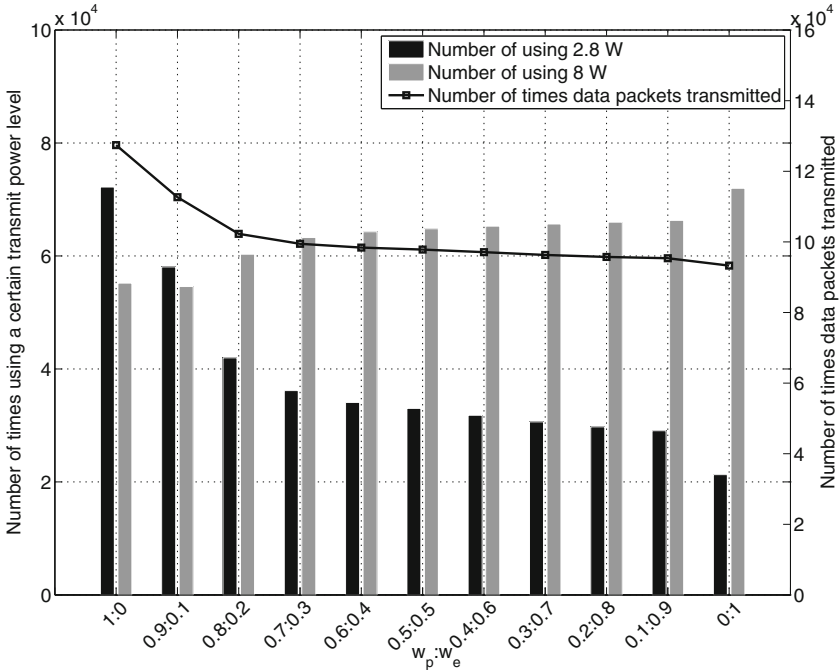
3.2 Routing Protocol Performance with Different Weights of Power and Energy Consumption

In this section, we consider two sets of transmitting power. One set has two transmitting power, i.e., 2.8 W, 8 W. The other set includes three transmitting power, i.e., 2.8 W, 8 W, and 35 W. The network size is set to a 11×11 grid IoUT to present the performance of the proposed routing protocol. As shown in Fig. 1(a) and Fig. 2(a), for both two sets of transmitting power, we can obtain the best ratio of w_p to w_e to generate the maximum received number of data packets in the sink node. When the weight of energy consumption increases and the weight of transmitting power decreases, the number of received packets by the sink node appears at 0.6:0.4 for the set of two transmitting power and 0.5:0.5 for the set of three transmitting power.

In Figs. 1(b) and 2(b), we observe that, for two or three transmitting power, according to the proposed routing metric (as shown in Eq. (1)), the transmitting power and the residual energy mainly control the performance of the proposed routing protocol. As the ratio of the weights of power and energy, i.e., $w_p:w_e = 1 : 0$, the number of times using the lowest transmitting power reaches the maximum value, which represents that the nodes frequently select routes with lowest transmitting power. It is worth to note that these nodes close to the sink

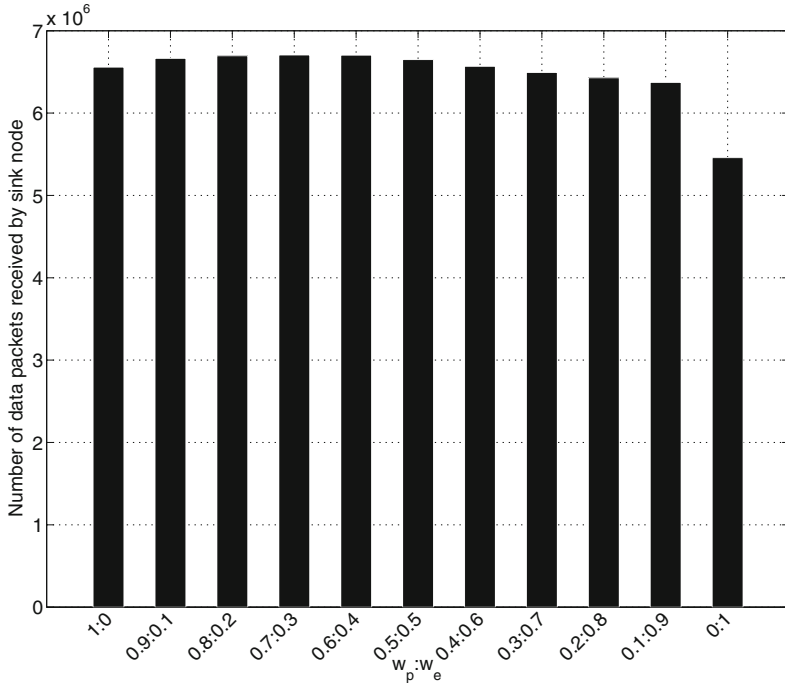


(a) Number of received data packets vs. $w_p : w_e$

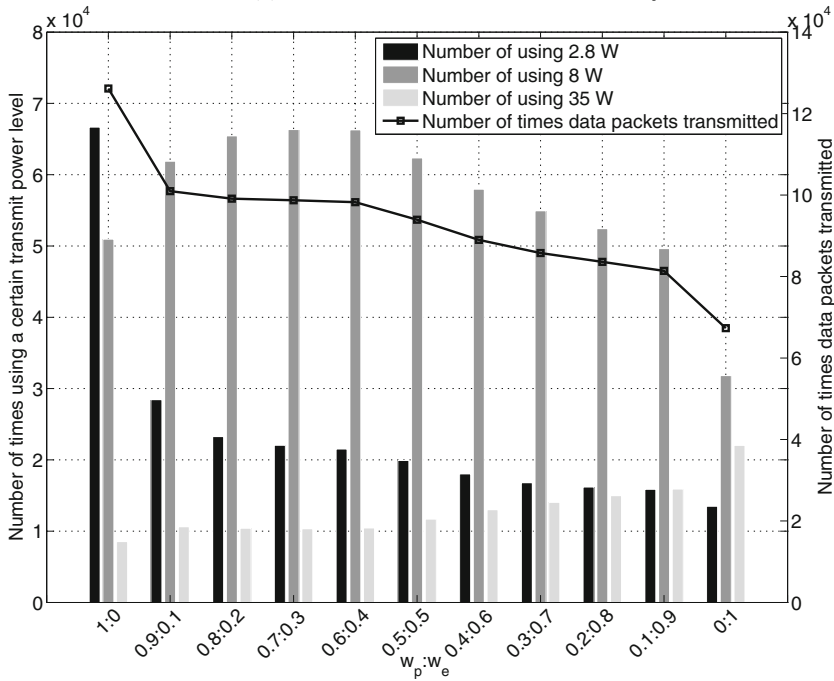


(b) Usage frequency of transmitting power levels vs. $w_p : w_e$

Fig. 1. Two transmitting power levels, network size: 11×11



(a) Number of received data packets vs. $w_p : w_e$



(b) Usage frequency of transmitting power levels vs. $w_p : w_e$

Fig. 2. Three transmitting power levels, network size: 11×11

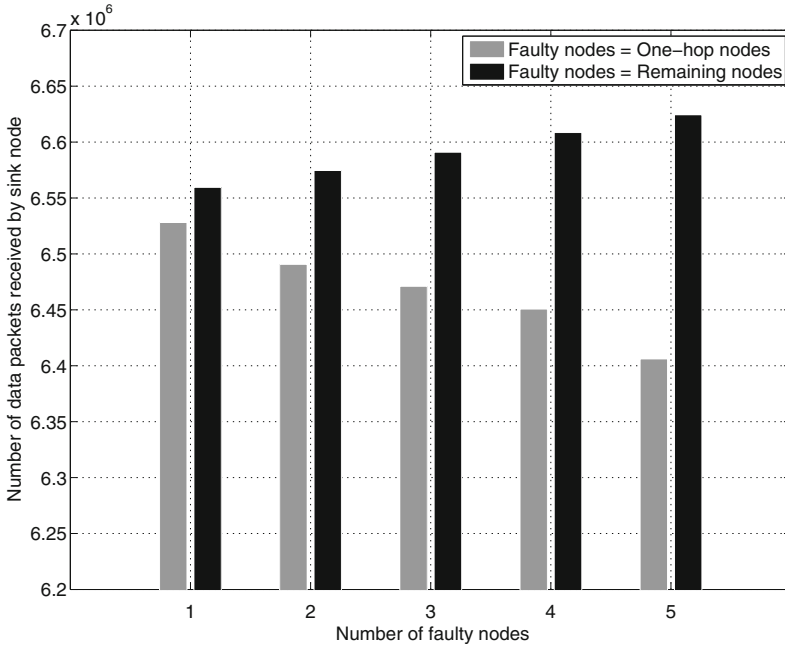


Fig. 3. Performance versus number of faulty nodes: two transmitting power, network size: 11×11

can be overloaded due to frequently forwarding data for other underwater sensor nodes. Consequently, their battery energy quickly deplete. When those nodes are close to out of energy, the proposed routing protocol prefer higher transmitting power to maintain data delivery. On the other side, when $w_p:w_e = 0 : 1$, many nodes tend to employ high transmitting power without using underwater sensor nodes with low energy. Thus, data packets forwarded via fewer hops leads to the lower energy consumption and prolongs network lifetime.

3.3 Performance with Faulty Nodes

In this section, we present the performance of the proposed routing protocol when the faulty nodes appear in IoUT. The faulty nodes in this section represents that the sensor node cannot transmit, receive, and forward data packets. The numbers of received data packets by the sink node are corresponding to the best ratios as presented in Sect. 3.2. As shown in Figs. 3 and 4, the number of data packets decreases with the increasing of number of faulty one-hop nodes. The reason is that the sensor nodes (except the one-hop nodes) have to use more hops to report data to the sink node when the faulty one-hop nodes appear. The remaining one-hop nodes (which can transmit, receive, and forward data) must forward a larger amount of data compared with that without faulty one-hop nodes. Additionally, we observe that the number of data packets received by the

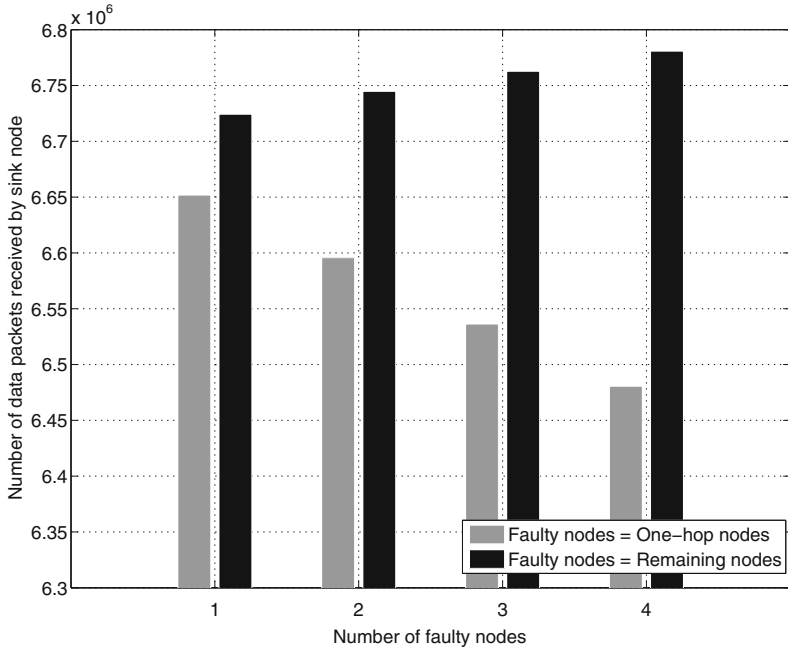


Fig. 4. Performance versus number of faulty nodes: three transmitting power, network size: 11×11

sink node increases when the number of faulty nodes increases. The reason is that the amount of forwarding data decreases when the number of faulty nodes increases. The one-hop nodes can transmit their own data to the sink node directly and reduce energy consumption.

4 Conclusions

In this paper, we propose a routing protocol for IoUT. The simulation results show that the network lifetime can be prolonged under different network sizes. Furthermore, we can get the best ratio of the weight for the transmitting power to the weight for the energy consumption, which can lead to the maximum number of received data packets by the sink node. We also evaluate the performance of the proposed routing protocol when the faulty nodes appears in IoUT. In the future, we will consider the scenario of dynamic network topology of IoUT to evaluate our proposed routing protocol and will figure out any possible improvement.

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