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Interference-aware Energy-efficient Geographical Routing for IEEE 802.15.4a Networks

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Abstract**-- This paper proposes an interference-aware energy-efficient geographical routing algorithm for the IEEE 802.15.4a networks. The proposed algorithm estimates the interference effects and sends a packet to the neighbor with the lowest energy cost to advance to the destination. Experimental results show that the proposed algorithm outperforms the previous algorithms in terms of the delivery ratio and the energy consumption.**

I. INTRODUCTION

The IEEE 802.15.4a is an amendment to the IEEE 802.15.4/ZigBee standard to support high accuracy localization [1]. If the location information is available, the geographical routing protocol is more energy efficient than the previous ZigBee routing protocols [2]. Most geographical routing protocols use the greedy forwarding algorithm which sends a packet to the neighbor geographically closest to the destination [3]. Many algorithms have been proposed to improve the greedy forwarding algorithm [4-6]. In [4], a node estimates the energy cost based on the log-distance path loss model and sends a packet to the neighbor with the lowest *energy/distance* value in order to reduce the energy consumption. However, estimating the energy cost based on the distance cannot be enough because the signal strength is heavily affected by obstacles. The greedy forwarding algorithm can perform poorly in indoor environments because it tries to forward packets through obstacles. In [5-6], a node estimates the packet reception ratio (PRR) for each neighbor and sends a packet to the neighbor with the highest *PRR*x*distance* production. The PRR based algorithms cannot adapt to the link quality changes dynamically because it has to send or overhear several packets to estimate the PRR. Moreover, the link quality can fluctuate wildly due to the interference of other wireless products. In this paper, we propose an interference aware energy efficient geographical routing algorithm (IEG) for the IEEE 802.15.4a networks. In the proposed algorithm, each node estimates the energy cost by considering the interference effects and sends a packet to the neighbor which requires the lowest energy cost to advance to the destination. Experimental results show the significant performance improvements for both the energy consumption and the delivery ratio.

II. PROPOSED ALGORITHM

A. Interference-aware Energy Cost Estimation

In the proposed algorithm, each node estimates the energy cost for neighbors by considering the interference power level and sends a packet to where the interference effects are not strong. If the receive power threshold value for a successful reception P^{TH}_{RX} is known, the minimum transmit power P^{min}_{TX} can be determined as follows:

$$P^{min}_{TX}\,(\text{dBm}) = PL\,(\text{dB}) + P^{TH}_{RX}\,(\text{dBm}) + \sigma \qquad (1)$$

where PL is the path loss between the sender and the receiver due to the distance and the obstacles; σ is the deviation of the path loss in a fading channel. The receive power threshold value can be derived from the signal-to-interference-plus-noise ratio (SINR) model as follows [7]:

$$\boldsymbol{P}_{\boldsymbol{RX-TH}} = 10\log\left(10^{P_N/10} + 10^{\zeta_{TH}/10}\cdot 10^{P_I/10}\right) \qquad (2)$$

where P_N and P_I denote the noise power and the interference power in dBm; ζ_{TH} is the SINR threshold for a successful reception in dB. The noise power depends on the hardware and can be set manually. The SINR threshold can be obtained from the BER model. For example, the BER for IEEE 802.15.4a CSS, when using 250kbps data rate, is defined as follows [1]:

$$\boldsymbol{P}_{\boldsymbol{B}} = \left[62\cdot\boldsymbol{Q}\left(\sqrt{10^{\zeta_{TH}/10}\cdot 560.01}\right) + \boldsymbol{Q}\left(\sqrt{10^{\zeta_{TH}/10}\cdot 1120.02}\right)\right]/\,2 \qquad (3)$$

From (3), we set the SINR threshold as -13dB to satisfy the IEEE 802.15.4 receive sensitivity requirement (99% PRR with 20bytes packet size). We assume that a transceiver can measure the interference power level as an IEEE 802.15.4 transceiver measures the interference power level [7]. The energy cost of sending a packet is determined as follows:

$$E = E_{TX}\cdot T_{DATA} + E_{RX}\cdot(T_{LIFS} + T_{BO} + T_{ACK} + T_{SIFS}) \qquad (4)$$

where E_{TX} and E_{RX} denote the power consumption in mW in the transmit mode and the receive mode respectively. T_{DATA}, T_{ACK}, T_{LIFS}, T_{SIFS}, and T_{BO} denote the durations of the data packet, the acknowledge packet, the long inter-frame space, the short inter-frame space, and the backoff respectively. Note that, E_{TX} value is dominant in the energy cost and $E_{TX} \propto c\cdot P^{min}_{TX}$ (c value depends on the hardware).

B. Energy-efficient Geographical Routing Algorithm

In the proposed algorithm, each node measures the interference power level periodically and determines the receive power threshold value by using (2). When a node detects the interference effects, it broadcasts the receive power threshold value periodically at the maximum transmit power, P^{max}_{TX}. When a node received the receive power threshold value, it measures the receive power P_{RX} and determines the path loss as follows: $PL(\text{dB}) = P^{max}_{TX}\,(\text{dBm}) - P_{RX}\,(\text{dBm})$. The node then determines the minimum transmit power value by using (1) and stores the value in the neighbor table. When a

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node u has a packet to transmit, it reads the packet size and estimates the energy cost, E, for each neighbor by using (4). The node u then sends the packet to the node v with the lowest E/ADV value. ADV denotes the advance to the destination and is defined as follows: $ADV = d(u, d) - d(v, d)$. $d(u, d)$ denotes the distance between the node u and the destination d. Since the energy cost value increases as the interference power level increases, the proposed algorithm can avoid the interference region. For example shown in Fig. 1, if there are no interference effects, the node u sends a packet to the node v that is closest to the distance d. When the node v is affected by the interference, it adjusts the receive power threshold value and broadcasts the value. When the node u received the receive power threshold value, it changes the minimum transmit power value for the node v. As a consequence, the node u sends a packet to the node w because the energy cost value for the node v has increased much. The proposed algorithm should send a packet to the neighbor with the positive E/ADV value to prevent the routing loop. When a packet reaches the local minima where no neighbor has the positive E/ADV value, the proposed algorithm uses the ZigBee routing protocol such as the ad-hoc on-demand distance vector (AODV) temporarily to recover from the local minima.

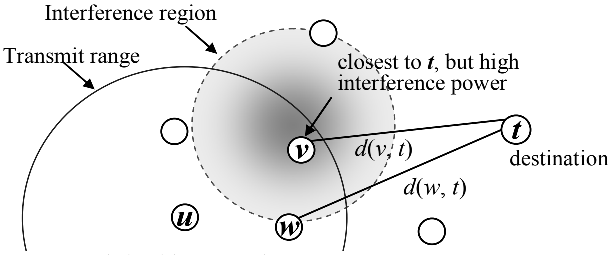

Fig. 1. Proposed algorithm example.

III. EXPERIMENTAL RESULTS

To investigate the performance of algorithms, we conduct experiments with 23 802.15.4a nodes and 2 802.11 nodes as shown in Fig. 2. The 802.15.4a nodes have the CSS-based NA5TR1 transceiver [8] and the 802.11 nodes have the 802.11a/b/g RT2870 transceiver. In the experiments, the source 802.15.4a node transmits to the destination 802.15.4a node at the rate of 1 packet per 20 seconds. In the meanwhile, a 802.11 node downloads a big file from another 802.11 node by using the file transfer protocol (FTP) program. Since the NA5TR1 transceiver cannot distinguish the interference signal from the 802.15.4a signal, we use the CC2420 transceiver to measure the interference power value and the CC2420 transfers the value to the NA5TR1.

Table 1 and 2 show the route length, the delivery radio, the energy consumption of the algorithms. Figure 2 shows routes established by different algorithms. The greedy algorithm shows the lowest delivery ratio regardless of the interference effect because it forwards packets across concrete walls and the interference region. The *PRR*x*distance* algorithm makes longer route than the greedy algorithm and thus, the effect of concrete wall is alleviated; however two links of its route are affected by 802.11 interferences and suffer around 15% packet loss each. The proposed algorithm establishes the longest route but it avoids the 802.11 interference region. Since the proposed algorithm forwards packets through good quality links, it does not waste the energy for retransmissions. From experiment results, we can observe that the proposed algorithm is robust to the interference effects.

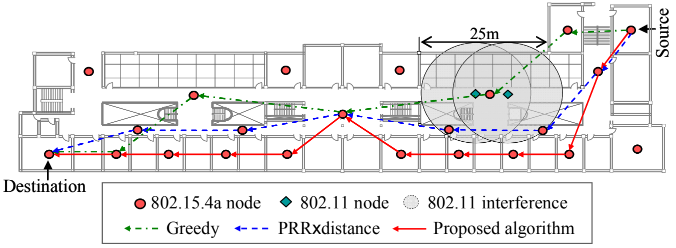

Fig. 2. Experiment scenario in building

TABLE II
EXPERIMENTAL RESULTS UNDER WLAN INTERFERENCE EFFECTS

	Greedy	PRRxdistance	IEG
Route length	6	7	11
Delivery ratio	20.32	59.83	89.27
Energy (mJ/packet)	7.95	4.13	3.12

TABLE I
EXPERIMENTAL RESULTS UNDER NO INTERFERENCE EFFECTS

	Greedy	PRRxdistance	IEG
Route length	6	7	8
Delivery ratio	81.73	94.25	95.72
Energy (mJ/packet)	3.85	2.95	2.54

IV. CONCLUSION

This paper proposes an interference-aware energy-efficient geographical routing algorithm for the IEEE 802.15.4a networks. The experimental results show that the proposed algorithm is robust to the interference effects and works energy-efficiently in real world deployments.

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