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Interference-aware Topology Control for Wireless Personal Area Networks

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***Abstract*-- Recently, many wireless devices operate in the 2.4GHz ISM band. Wireless personal area network (WPAN) can suffer significant performance degradation due to the interference of WLAN and Bluetooth. This paper proposes an interference-aware topology control algorithm for WPANs. In the proposed algorithm, each node adjusts the transmission power dynamically by considering the interference effect. In the meanwhile, each node maintains its local topology adaptively to minimize the interference effect. The experiment results show that the proposed algorithm outperforms the previous algorithms in terms of the energy and the delivery performances in WLAN and Bluetooth interference environments.**

I. INTRODUCTION

The topology control protocols try to maintain the lowest possible transmission power to increase the channel capacity and reduce the energy consumption [1]. Maintaining the lowest possible transmission power is vulnerable to the interferences due to the bad signal-to-interference-plus-noise ratio (SINR). There are many topology control studies in wireless networks [1-3] but these studies do not consider carefully the interferences. Recently, many wireless products such as WiFi laptop and IP-phone generate more interference for supporting multimedia services. The dynamic channel allocation algorithms have been proposed [5, 6]. However, these algorithms can generate control overhead unnecessarily because the interferences are spatially and temporarily correlated [7].

The SINR is the best channel quality indicator theoretically. However, current WPAN radio such as CC2420 doesn't provide the SINR [9]. Our experimental results show that the packet reception rate (PRR) is close to 100% when the received signal strength indicator (RSSI) is above a certain target (see. Fig. 1). Thus, we use the RSSI as channel quality indicator. Again, in Fig. 1, as the interference power, P_I, increases, the RSSI target is increased. This means that the RSSI target has to be adjusted according to the interference power. This paper proposes an interference-aware topology control for WPANs. In the proposed algorithm, each node maintains the transmission power dynamically by considering the interference. In the meanwhile, each node maintains its local topology adaptively to minimize the interference effect.

II. PROPOSED ALGORITHM

In the proposed algorithm, each node first establishes its local topology based on the modified relative-neighborhood-graph (RNG) [2]. Initially, every node broadcasts a BEACON message at the maximum transmission power. When the node *u* received a BEACON message from the node *v*, it determines the transmission power as follow:

$$ {}^{u\to v}P_{TX} = {}_{MAX}P_{TX} + (\, {}_{INIT}RSSI_{TARGET} - RSSI\,) + M. \quad (1) $$

where ${}_{INIT}RSSI_{TARGET}$ and M denote the initial RSSI target and margin respectively. After a node received BEACONs from its all neighbors, it establishes the neighbor list in increasing order of the transmission power and then, broadcasts the neighbor list. When a node received the neighbor lists from its all neighbors, it establishes the local topology. In Fig. 3-(b), the node *u* selects the node *v* and discards the node *g* because ${}^{u\to v}P_{TX} < {}^{u\to g}P_{TX}$ and ${}^{g\to v}P_{TX} < {}^{g\to u}P_{TX}$. This algorithm can preserve the network connectivity in the obstructed environment because the transmission power depends on both distance and obstacles between a sender and a receiver.

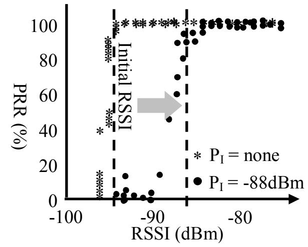


Fig. 1. RSSI vs. PRR under difference interference conditions

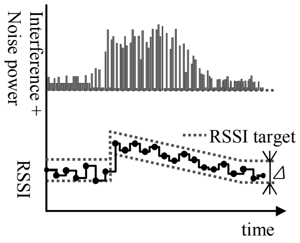
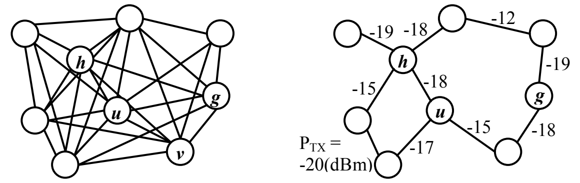
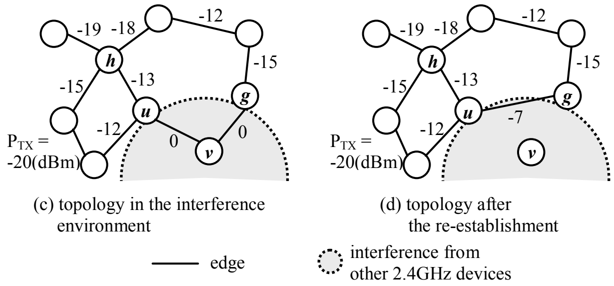


Fig. 2. RSSI adjustment operation



(a) topology with the maximum transmission power

(b) topology with the controlled transmission power



(c) topology in the interference environment

(d) topology after the re-establishment

Fig. 3. The proposed topology control operations.

After the topology is established, each node adjusts the RSSI target and the transmission power dynamically by considering the interferences (see Fig. 2 and Fig. 4). *Δ* and *σ* denote the length of the RSSI target region and the number of downward steps which satisfies a certain PRR. When the

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After the packet is transmitted (RSSI is returned through an ACK)
1: if ( transmission is successful ) {
2:     $RSSI_{TARGET}$ = MIN( $_{INIT}RSSI_{TARGET}$, $RSSI_{TARGET}$ -= $\Delta / \sigma$ );
3:     if ( $RSSI < RSSI_{TARGET}$ ) {    $P_{TX}$++;    }
5:     else if ( $RSSI > RSSI_{TARGET} + \Delta$ ) {    $P_{TX}$--;    }
7: } else { // transmission failed
8:     $RSSI_{TARGET}$ += $\Delta$ ; $P_{TX}$ += $\Delta$ ; }
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Fig. 4. Pseudo-code of the power control.

transmission fails due to the interference, the RSSI target and the transmission power are increased by Δ immediately. The increased RSSI target is gradually returned to the initial RSSI target after σ consecutive successful transmission. If p is the desired PRR, σ can be determined as follows [7]: $\sigma = p/(1-p)$. By considering the determined RSSI target, the transmission power is adjusted slightly in the fixed size of 1dB as shown in lines 3 and 4 in Fig. 4. That is, the proposed algorithm adjusts the RSSI target and the transmission power dynamically to provide the appropriate SINR.

In the meanwhile, the proposed algorithm maintains the topology adaptively to minimize the interference effect. For example shown in Fig. 3-(b) and (c), the transmission powers for node *u* and *g* are increased slightly due to the interference. Whereas, the transmission powers for node *h* are increased close to the maximum transmission level, 0 dBm, because the interference is too strong. As we stated above, in the proposed algorithm, each node establishes its local topology by using the transmission-power-based RNG algorithm. After the topology re-establishment, the topology will be changed as shown in Fig. 3-(d). That is, the proposed algorithm can minimize the interference effect and maintain good network connectivity.

III. EXPERIMENTAL RESULTS

To evaluate the performance of the proposed algorithm, we conducted testbed experiments with 13 WPAN nodes [9], 2 WLAN nodes, and 2 Bluetooth nodes (see. Fig. 5). In the experiments, the WPAN *node-1* periodically generates a 50 bytes message and the messages are transferred to the *node-13* through the route. In the meanwhile, two WLAN nodes and two Bluetooth nodes generate interferences randomly. WPAN nodes and WLAN nodes use the frequency channel 26 and 13 respectively. We set Δ and σ as 3dB and 19 to provide above 95% PRR. As stated above, the previous algorithms doesn't consider the interference effect and uses the static lowest transmission power that is determined by analytical model [1].

Figure 6-(a) shows the average physical node degree. The proposed algorithm has much smaller node degree than the MAX (using the maximum transmission power). This means that the proposed algorithm can reduce the energy consumption and increase the channel capacity. The Static Lowest shows slightly smaller node degree than the proposed algorithm, but the energy consumption performance of the Static Lowest is much worse than the proposed algorithm (See Fig. 6(b)). The reason is that the packet delivery rate (PDR) performance of the Static Lowest is very low (see. Fig. 6(c)). The SINR of the Static Lowest can be decreased much below the threshold when the interference becomes strong. As stated above, the proposed algorithm adjusts the RSSI target dynamically to provide the appropriate SINR. The proposed algorithm shows good PDR performance around 96.5% and saves much transmission energy by around 33% compared to the MAX.

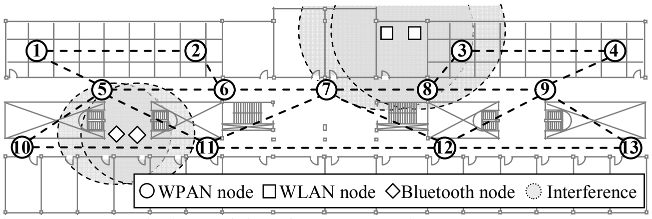

Fig. 5. WLAN and Bluetooth interference scenario.

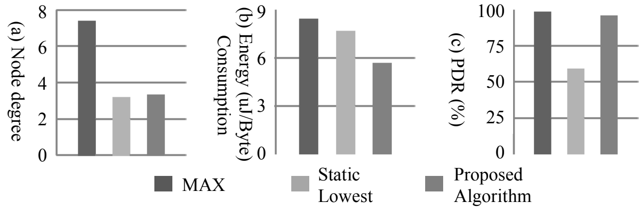

Fig. 6. Experimental results with the WLAN and Bluetooth interferences.

IV. CONCLUSIONS

In the real-world deployments, the WPAN often suffers significant performance degradation due to the interference of other 2.4GHz devices. This paper proposes the interference-aware topology control algorithm for WPANs. In the proposed algorithm, each node adjusts the transmission power dynamically by considering the interference. In the meanwhile, each node maintains its local topology adaptively to minimize the interference effect. From the experimental results, we can observe that the proposed algorithm outperforms the previous algorithms in terms of the energy and the PDR performances.

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