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3-Dimensional Topology Control for Wireless Sensor Networks in Presence of Interference

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***Abstract*-- This paper proposes a novel 3-dimensional (3D) topology control algorithm to reduce the interference effects by removing the links affected by the interferences. The proposed algorithm uses the regular polyhedron to construct the 3D topology. Experimental results show the significant performance improvements for both the delivery ratio and the energy consumption.**

I. Introduction

The topology control is one of the effective power-saving techniques in the wireless sensor networks (WSNs). The topology control has been widely investigated in 2-dimensional space [1, 2], and a few topology control algorithms are introduced for the 3-dimensional space applications [3, 4]. The neighbor every theta (NET) [3] and the fixed partition yao graph (FIYY) [4] are the 3D extensions of the cone based topology control (CBTC) and the yao graph (YG) respectively. However, these algorithms can fail to deliver the messages due to the various obstacles and the strong interferences of WLAN or Bluetooth devices. In this paper, we propose an interference-aware 3D topology control algorithm by considering the practical implementation of the WSNs. In the proposed algorithm, each node determines the minimum transmit power based on the estimation for the interference effects. For the 3D topology construction, the minimum transmit power is used as the edge cost, and each node divides the 3D space into k equal cones by using the regular k-hedron and selects a neighbor that requires the lowest transmit power for each cone.

II. Proposed Algorithm

A. Minimum Transmit Power Estimation

The minimum transmit power from the node u to the node v, ${}^{min}P_{TX}(u, v)$, is determined as follows [6]:

$${}^{min}P_{TX}(u, v) = PL(u, v) + {}^{v}P_{RX\text{-}TH} \qquad (1)$$

where $PL(u, v)$ is the path loss between the node u and v; and ${}^{v}P_{RX\text{-}TH}$ is the receive power threshold of the node v for a successful reception in dBm. The receive power threshold value can be derived from the signal-to-interference-plus-noise-ratio (SINR) model as follows [6]:

$$P_{RX-TH} = 10\log\left(10^{P_N/10} + 10^{S_{TH}/10} \cdot 10^{P_I/10}\right) \qquad (2)$$

where P_N and P_I are the noise power and the interference power in dBm; and S_{TH} is the SINR threshold value required for a successful reception. We use the CC2420 radio chip. The noise power depends on the hardware and can be set manually [6]. The interference power can be measured by reading the received signal strength indicator (RSSI) register of the radio [5]. We can distinguish the interference signal from the IEEE 802.15.4 signal by checking the start of the frame delimiter (SFD) pin, that is, the SFD pin goes high when the radio receives the IEEE 802.15.4 signal [7]. We set the SINR threshold value as 0.4dBm from the bit-error-ratio (BER) model to satisfy the IEEE 802.15.4 receive sensitivity requirement. Note that, the minimum transmit power depends on the effects of the distance, the obstacles, and the interference.

B. Interference-aware 3D Topology Control

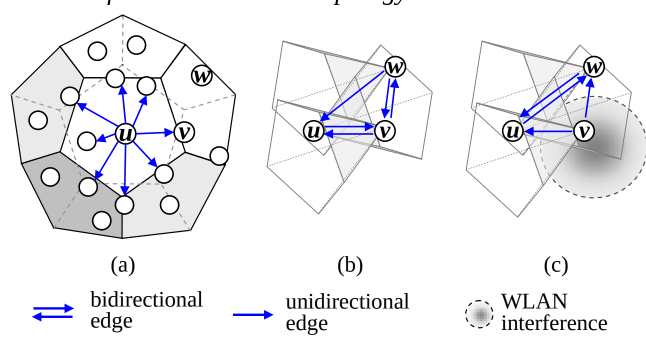

Fig. 1. Neighbor selection with regular 12-hedron (a), edge establishment in free space (b) and under WLAN interference (c).

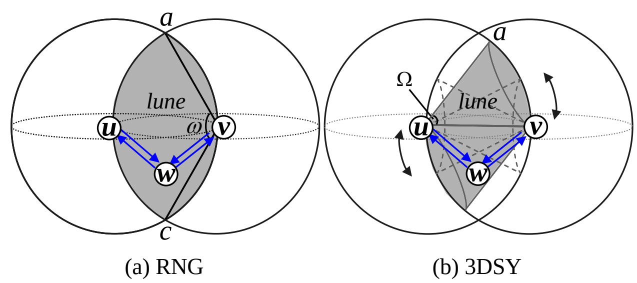

Fig. 2. Comparison of RNG and 3DSY.

We expand the symmetric yao graph [2] into the 3D topology construction, namely the 3D symmetric yao graph (3DSY). In the proposed algorithm, each node uses the regular k-hedron to divide the 3D space into k cones and selects a neighbor node that requires the lowest transmit power for each cone as shown in Fig. 1(a). The edges are selected if both node u and v select with each other, that is, only bidirectional edges are used. As shown in Fig. 2, an edge (u, v) can be selected by the relative neighborhood graph (RNG) if $lune(u, v)$ does not contain any other node, where $lune$(u, v) is formed as the intersection of two spheres centered at the node u and v. Note that ω ($\angle avc$) = π *steradian* in Fig. 2(a). Ω ($\angle auv$) = $4\pi/k$

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steradian is the solid angle of a cone in Fig. 2(b). The *lune*(*u*, *v*) of the RNG encloses that of the 3DSY when $\pi \geq 2\Omega = 8\pi/k$. That is, the 3DSY with $k \geq 8$ can preserve the network connectivity [1, 4].

In the proposed algorithm, each node estimates the interference power and determines the receive power threshold value, $P_{RX\text{-}TH}$, by using (2). The $P_{RX\text{-}TH}$ value is broadcasted at the maximum transmit power, ${}^{max}P_{TX}$. When the $P_{RX\text{-}TH}$ value is received, a node measures the receive power, P_{RX}, and estimates the path loss, $PL = {}^{max}P_{TX} - P_{RX}$. The minimum transmit power value, ${}^{min}P_{TX}$, is determined by using (1). After determining ${}^{min}P_{TX}$ values for neighbors, the node *u* establishes the neighbor set, *N{}*, for each cone as follows: $v \in N\{\}$ if ${}^{min}P_{TX}(u, v) < {}^{min}P_{TX}(u, w)$ for $\exists$w in each cone. Then, each node broadcasts *N{}*. After receiving *N{}* from neighbors, each node constructs the local topology by selecting bidirectional edges only (in which both nodes select with each other).

In the operation, each node estimates the interference power periodically. When $P_{RX\text{-}TH}$ value is changed much because of the interference, the node broadcasts the updated $P_{RX\text{-}TH}$ value. As a consequence, ${}^{min}P_{TX}$ and *N{}* of neighbors will be updated. For example, in Fig. 1(b) and (c), when the node *v* is affected by the interference, the node *u* selects the node *w* and the edge (*u*, *w*) becomes the bidirectional edge. Then, the proposed algorithm changes the route from $u \rightarrow v \rightarrow w$ to $u \rightarrow w$ by cooperating with the routing protocol. However, in the worst case, the node *v* can be isolated in Fig. 1(c). The proposed topology control algorithm will use both the unidirectional and bidirectional links, if the route cannot be connected to the destination node by using only the bidirectional edges under the interference environments.

III. Experimental Results

We first evaluate the proposed algorithm by using the Matlab-based simulator with large scale scenario: 100 nodes are randomly deployed in 100x100x100m space. Table 1 shows the physical / logical node degree and the stretch factor of the NET, the FIYY, and the 3DSY. The physical node degree is the average number of neighbors that are within the transmit range of a node. The logical node degree is the average number of edges in the edge set of a node. The stretch factor is the maximum ratio between the length of the path obtained without the topology control and the length of the path obtained with the topology control. As shown in table 1, the proposed algorithm reduces the physical / logical node degree by removing the unidirectional links. That is, the proposed algorithm can increase the channel capacity by reducing the MAC-level contention and reduce the energy consumptions for the overhearing situations.

To investigate the interference effects on algorithms, we placed 20 WSN nodes and 2 WLAN nodes in 3 stories building as shown in Fig. 3. The source WSN node transmits 50-byte message to the sink node every 10 seconds. In the meanwhile, one WLAN node downloads a big file from another WLAN node through FTP application to generate the interferences. As shown in table 2, the proposed algorithm outperforms other algorithms in terms of the delivery ratio and the energy consumption. When the interference is detected, the proposed algorithm increases the transmit power to provide the appropriate SINR level. When the interference becomes strong, the proposed algorithm removes links affected by the interference as shown in Fig. 3, and it detours messages around the interference region.

TABLE I
SIMULATION RESULTS

	NET	FIYY	3DSY, *k*=8	3DSY, *k*=12
Physical node degree	20.09	21.82	5.67	8.76
Logical node degree	8.00	11.29	3.58	5.07
Stretch factor	1.68	1.23	2.59	2.12

TABLE II
EXPERIMENTAL RESULTS UNDER WLAN INTERFERENCE

	NET	FIYY	3DSY, *k*=8	3DSY, *k*=12
Stretch factor	1.99	1.75	2.65	2.22
Delivery ratio (%)	69.53	67.30	93.08	95.02
Energy (uJ/byte)	90.40	95.18	42.12	40.21

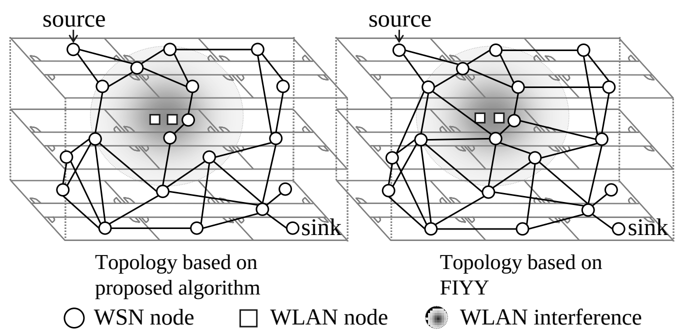

Fig. 3. Experiment scenario in building

IV. Conclusion

This paper proposes the interference-aware 3D topology control algorithm. Experimental results show that the proposed algorithm is robust to the interference effects and works energy efficiently in the 3D topology constructions.

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