A Cross-layer Delay Taming Method with Conflict Avoiding in WirelessHART Networks

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Abstract

Mesh network routing and TDMA scheduling are core techniques at the network and data link layers to provide reliable real-time data delivery. In standard WirelessHART, these works are left to the network manager. This paper addresses the issue of establishing a lower latency, smaller conflict and more stable WirelessHART network. Methods are proposed to address the problems respectively. The concept of Conflict Crisis is put forward creatively, which greatly reduces the amount of calculation. Results show that delay is controlled within 1.5 seconds in a 50-node network while our method ensures a 99% success rate of the whole network even if the success rate of a single link is down to 80%.This meets the needs of most industrial environment.

Keywords

WirelessHART, TDMA Scheduling, Mesh Network Routing, Conflict avoiding.

1. Introduction

Wireless sensor network (WSN) is a multi hop, self organizing network system formed by a large number of sensor nodes deployed in the monitoring area. The purpose of the wireless sensor network is to collect and process the information of the objects in the area and send it to the observer in collaboration. WirelessHART is the first open wireless communication standard to meet the needs of building a reliable, stable, and real-time wireless sensor network for the process industry.

WirelessHART adopts a multiple layer structure. The physical layer of WirelessHART network is based on the IEEE 802.15.4 standard. The data link layer is based on time synchronization. Communication slot is strictly defined as 10ms, and TDMA technology is used to support conflict avoidance and deterministic communication. At the network layer, in order to support the ad-hoc mesh network structure, each WirelessHART device can forward data for other devices. Source routing, graph routing and super frame routing are three routing methods set up at the network layer.

In WirelessHART, communication between devices and the gateway is based on command and response. In graph routing, we maintain an uplink and a downlink from each node to the gateway. By TDMA scheduling, we allocate slots and channels for each segment of the links. How to configure communication time and path is left to the network manager. Thus, the graph routing problem and TDMA scheduling problem can be combined to take into consideration as a cross-layer problem.

In the industrial environment nowadays, we urgently need to strike a balance between success rate ensuring and delay taming. This paper addresses the issue of establishing a lower latency, smaller conflict and more stable communication network.

For the gateway has the ability to record success rates of all the links, we convert success rates into conflicts. After transforming the model of the cross-layer method, a routing problem is defined as optimizing uplinks with minimized conflict and a scheduling problem is considered as allocating channels and slots for the uplinks with minimized time delay. We analyzed the complexity of both the routing and the scheduling problems. K-shortest Conflict Path Routing Algorithm and Conflict Avoiding Scheduling Method are proposed to solve the problems.

Although the solutions are aimed at the characteristics of WirelessHART, the model we proposed in this paper is also applicable to routing and scheduling in other analogous wireless sensor networks.

2. Model Discussion

Given an unweighted undirected graph G=(V,E),where V represents the set of (n+1) nodes which has the only one access point connected to the gateway and E represents the set of all links in the network.

Assume that all the nodes are homogeneous,the amount of channel c is expanded, each uplink and downlink is contrary. We use t to define time slot. In order to discuss network conflicts, in this model, all nodes sends a packet to the access point when t=1.

Define P as uplinks of each node. For the uplink is directed, we put them in direction. There is only one wireless transceiver for each node in the network. The same node can be dispatched only once in the same time slot. If two connections are arranged in the same time slot regardless of sending or receiving, dominant conflicts will occur. Moreover, implicit conflict occurs when a node sending data has a connection with an other node receiving data in the same time slot. Figure 1 shows the two kinds of conflicts.

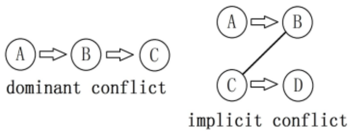

Fig. 1 Two kinds of conflicts

We sometimes take the direction (v_s,v_d) of P into consideration. If P is discussed as a part of the uplink, it actually has a direction. In subsequent paragraphs and sections, whether P has a direction depends on what we are talking about. Let F be a table with C rows and T columns if P needs T slots and C channels to complete TDMA Scheduling. For each t in T and c in C,

$$F(t,c)=p(b,x)$$

$$p_{x=}(v_s,v_d)$$

According to WirelessHART networks, only one p can be scheduled in one block. Dominant conflict may occur at slot when any two different c satisfy

$$F(t, c_1)=p(b_1, x_1)=\{v(b_1, s_1),v(b_1, d_1)\}$$

$$F(t, c_2)=p(b_2, x_2)=\{v(b_2, s_2),v(b_2, d_2)\}$$

$$s_1= s_2 \text{ or } s_1=d_2 \text{ or } d_1=s_2 \text{ or } d_1=d_2$$

Implicit conflict may appear but we do not need to take it into consideration at first. This doesn't matter if we cut down the dominant conflit.

Besides, a TDMA scheduling problem is widely discussed. In this paper, we use the usual model.

3. Complexity Analysis

3.1 Analysis for Routing Problem

Using the given definitions and formulations above, a routing problem is described as following: Given an undirected weighted graph G=(V,E,W), find an optimal uplink set P to minimize total delay T, which avoids all the dominant conflicts including all transmissions.

After calculation, conflict has transformed from edges to nodes. Each node is only able to reduce 1 conflict per slot. Obviously, if a set of P is optimal, owing to the extensible channels, we change the question into a 0-1 programming problem which is widely proved NP-complete. In classical 0-1 programming model, the size of matrix grows at liner rate. However, simple path between two points in an undirected graph may be up to factorial. Thus, this model has a factorial growth such that the routing problem surpasses exponential complexity.

3.2 Analysis for Scheduling Problem

The TDMA scheduling problem is described as distributing all the transmissions and retransmissions to each slot per channel in this paper. Define an undirected and unweighted graph H=(M,N). In H the amount of nodes is M and the amount of links is N. By taking the edges in G as nodes in H and by connecting two nodes in H when there is a common point in G, we transform G into H. As we all know, a retransmit link conflicts with any other links which also transmits on the same link. Thus, we put the retransmissions into the definition of dominant conflict.

In G, there are n nodes and m links. If there are D transmissions at most for one link, M will be less than (1/2)Dn(n-1). In complexity analysis, we take the worst condition M=(1/2)Dn(n-1) into consideration. Similarly, N=(1/2)M(M-1).

A problem is set up to fill each node in M into F with any two connected node not in the same column. Define each column as a color, the problem finally transformed into a Graph Coloring Problem which is widely proved as an NP-complete problem. For the amount of nodes in M is polynomial level times larger than N, this problem is NP-hard.

4. Algorithm and Method

4.1 Algorithm for Routing Problem

Input: Undirected and unweighted graph

Output:The set P which represents all the links of transmissions and retransmissions.

1:Find K-shortest paths from each node to the access point.

2:Initialize the shortest path from each node to the access point.

3: Change the next shortest path.

4:change the path, goto 1 until no better path is found.

4.2 Method for Scheduling Problem

Recently, A problem with more complexity broadly than we discuss in this section called Real-time Scheduling problem for WirelessHART networks has been researched by article [1]. Schedulable ratio is greatly improved in the paper. However, we now have a graph with more complexity and a scheduling problem with uncertain deadline. In this section, we proposed a scheduling method called Conflict Avoiding Method, which based on a theory proved by the article.

Input: An optimized set of all the transmissions P;

Output: Schedule F;

1:For each t in T

2:Give F the largest set of transmissions p in P including no conflicts (If there is a tie, schedule the links without implicit conflicts first);

5. Conclusion

Fig.2 to Fig.4 shows the simulation which is separated to 3 blocks based on low, medium, and high connect qualities. Conflict Crisis represents to the maximum of the conflict the experiment may give out. The simulation results show that delay is controlled within 1.5 seconds in a 50-node network while our method ensures a 99% success rate of the whole network even if the success rate of a single link is down to 80% if the nodes are not far away from each other. This meets the needs of most industrial environments.

TDMA scheduling and mesh network routing are two core techniques at the data link and network layers to provide reliable real-time data delivery. They are adopted by industrial wireless sensor network standards such as WirelessHART. In WirelessHART, how to configure communication time and path is left to the network mananger.

This paper addresses the issue of establishing a smaller conflict and more stable communication network.

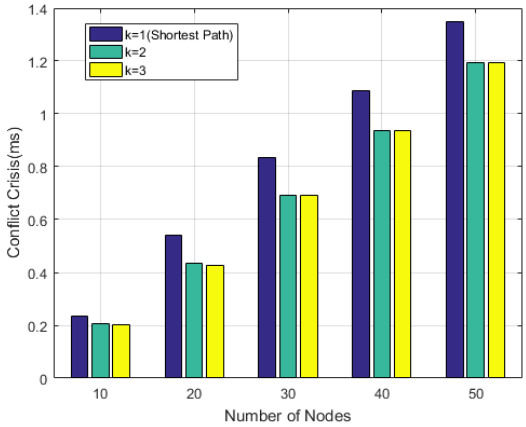

Fig.2 Result of simulation on low connect quality

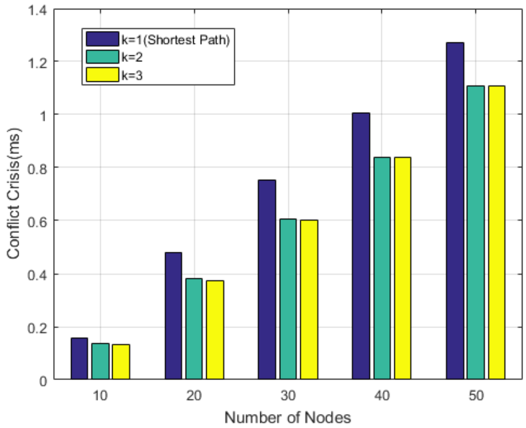

Fig.3 Result of simulation on medium connect quality

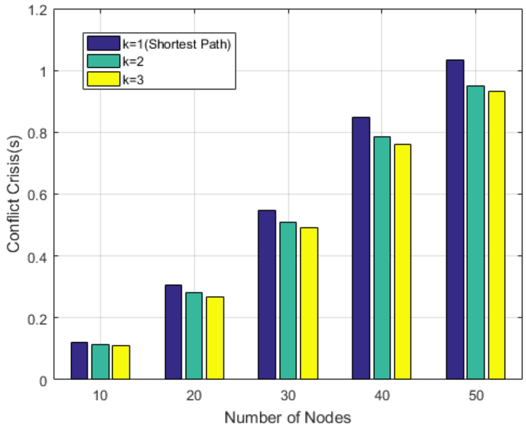

Fig.4 Result of simulation on high connect quality

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