# An Enhancement of WirelessHART Protocol

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## 1 Introduction

Industrial facilities usually have dense infrastructure with metals that interferes with wireless transmission. There are frequent movement of large equipment and changing conditions. Numerous sources of radio-frequency and electromagnetic interference may cause communication challenges. The WirelessHART standard uses both direct sequence and frequency hopping spread spectrum techniques to spread communications among different physical channels. However, such strategy in WirelessHART is not capable enough to overcome all the possible problems in industrial wireless communication. To further solve the multipath fading problem, we have to enhance the protocol. This report presents my thoughts of improvement in frequency hopping and cooperative relay strategy.

## 2 Strategy Description

### 2.1 Directive Frequency Hopping Spread Spectrum

Frequency Hopping Spread Spectrum(FHSS) is a widely used method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver. It is highly resistant to narrowband interference. In WirelessHART protocol, frequency hopping is within a white list where channels in good condition are collected and remain the same during transmission. In this pattern, once sudden powerful interference comes, causing the white-listed channels break down simultaneously, there would be severe communication problem, which is often the case in industrial environment. Simply expanding the white list would cost too much energy during transmission. Under the concerns above, I came up with an idea of directive FHSS in which the white list can be updated regularly and the allocation of white list and slots — TDMA is generally used in industrial communication — of re-transmission is given by a method.

Suppose there is one data link with $N+1$ nodes which divide the link into $N$ sublinks. Total number of channels available in the environment is $C$. And due to the demand of transmission instance, the transmission work has to be finished in $S$ slots. The job is to allocate the slots to different sublinks and find the proper channels for each of them to make the whole data link more reliable. Here, the reliability of a link is reckon to be its success rate of transmission.

At the beginning, set up a reliability matrix as follows.

$$P = \begin{bmatrix} p_1^1 & p_1^2 & \cdots & p_1^N \\ p_2^1 & p_2^2 & \cdots & p_2^N \\ \cdots & \cdots & p_i^j & \cdots \\ p_C^1 & p_C^2 & \cdots & p_C^N \end{bmatrix} \tag{1}$$

$p_i^j$ represents the reliability of sublink j using channel i. Thus, we can find the reliability of each sublink and the whole link.

$$P^j = 1 - \prod_{i \epsilon \phi_j} (1 - p_i^j) \tag{2}$$

$$P = \prod_j p^j \tag{3}$$

$\phi_j$ is the set of the chosen channel(s) for subchannel j.

The allocation of channels and slots is done by this:

1. Initialize the white list or $\phi_j$. Add one channel which is in the best condition among all available ones to the white list. At the same time, each sublink has one slot.
2. Add a new slot and channel to the whole link. To specify the subchannel, we should find a way to bring the biggest increase to the reliability of the data link.
3. Repeat step 2 until the slots are used up.

There is a process indication of this allocation shown in figure 1.

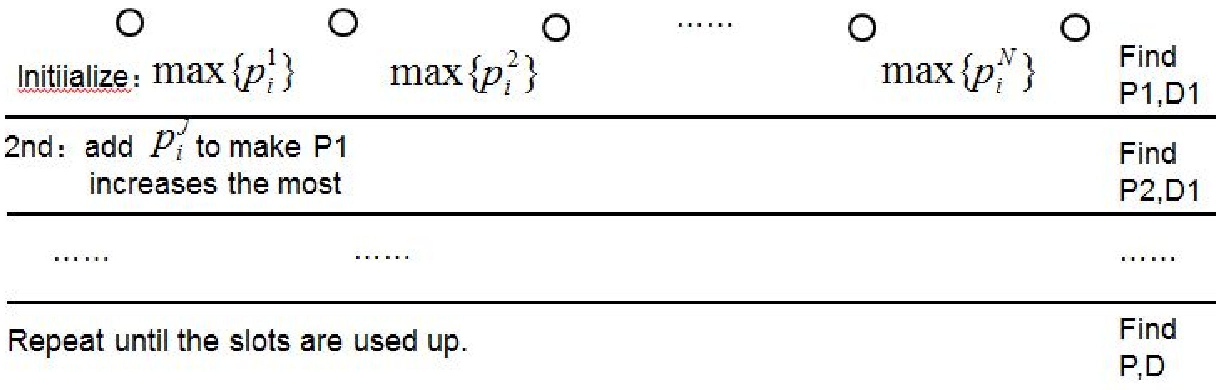


Figure 1: Channel and Slots Allocation

After allocating the slots and channels to each sublink, the white list is set up. During transmission, the exactly channel-hop order and slot limit should be followed and obeyed to maintain a reliable data link.

## 2.2 Cooperative Relay

Currently, in WirelessHART protocol, relay strategy exists in a way to achieve long-distance transmission. As a matter of fact, in recent researches, relays have already been used to enhance the reliability of communication as well as to improve data rate. However, the synchronization problem became the major obstacle in applying such technology. Our pattern is based on a 2010 infocom paper[1], in which synchronization problem is given a solution.

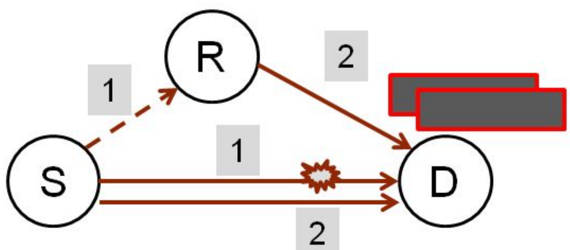


Figure 2: Non-orthogonal Cooperative Relay Strategy

Non-orthogonal cooperative relay is the best way found to fit the industrial wireless communication. A typical cooperative communication protocol allows a relay to overhear the sources transmission, and then forward the data to the desired receiver in case the direct delivery attempt failed. Such a two-stage cooperative relay protocol essentially establishes a virtual antenna array among multiple distributed single-antenna transmitters, so that the link capacity from the source to the destination may be boosted. That's how cooperative relay network achieve indirectly MIMO network, which is energy saving reliable.

Different from orthogonal relay strategy, in non-orthogonal cooperative relay strategy, the source node would transmit the same package at the same time with relay's transmission.(Figure 2) Besides further improvement of success rate, such pattern also raise up another communication problem — overlapping. How to demodulate the two packages from both the source node and the relay become the major problem of this strategy. My friend Zhang Ying find a way to do this.

Basically, the method is differential demodulation. Firstly, after receiving the overlapping package, there would be an energy excess which we can detect and locate the beginning of the overlapping part. Secondly, we use iterative subtraction based on the non-overlapped part to recover the package bit by bit, as shown in figure 3.

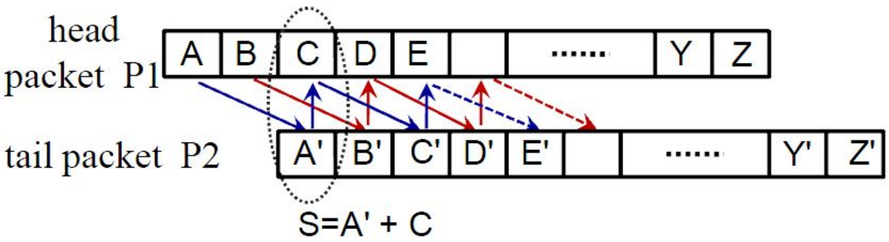


Figure 3: Differential Demodulation

## 3 Simulation Results

Based on the directive FHSS mentioned above, I made some simulation on Matlab. The simulation model is established on 6 to 16 nodes data links with slot number varying and the channel number is 16. The success rate of transmission satisfies Rayleigh distribution and other refinements of the model are left out.

| Sub | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Reliab. | 0.8644 | 0.9420 | 0.9164 | 0.9860 | 0.7706 | 0.8307 | 0.9532 | 0.7099 | 0.9745 |
| Slot | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |

| Sub | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Reliab. | 0.8644 | 0.9420 | 0.9164 | 0.9860 | 0.7706 | 0.8307 | 0.9532 | 0.9078 | 0.9745 |
| Slot | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 |

| Sub | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Reliab. | 0.8644 | 0.9420 | 0.9164 | 0.9860 | 0.9458 | 0.8307 | 0.9532 | 0.9078 | 0.9745 |
| Slot | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |

Figure 4: Allocation Process

Figure 4 shows the allocation process of slots and the enhancement of reliability of each sublink. Basing on big amount of experiment, we can interestingly find out that work is done only on the weakest sublink. So the way to find the best way to use another slot could be simplified.

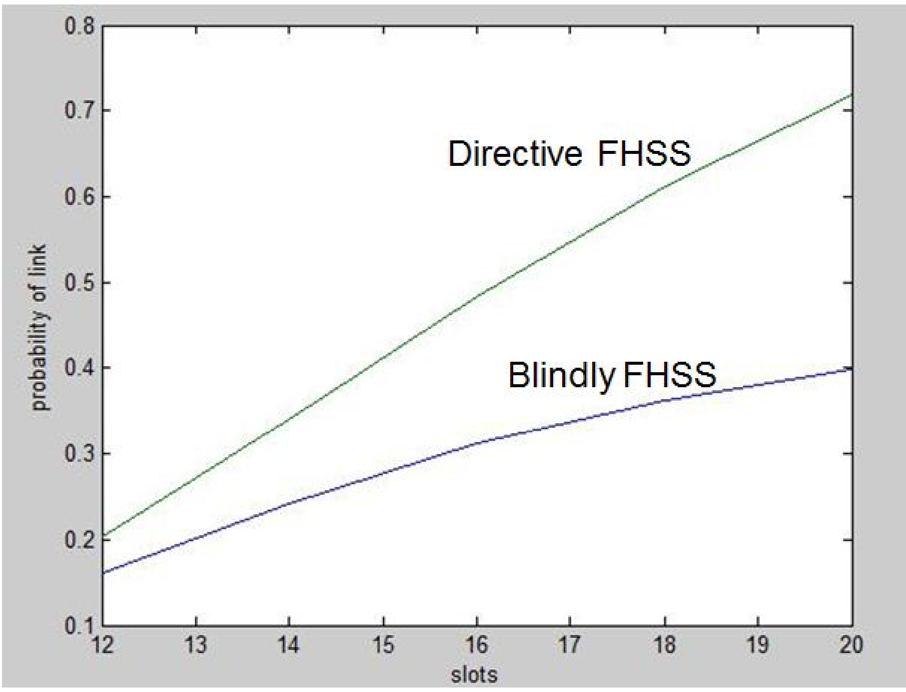


Figure 5: Reliability of Data Link with 10 Nodes

Figure 5 shows the reliability variation in each slot number when the node number is 10 and we can easily find the effectiveness of directive FHSS. Moreover, the advantage of directive FHSS is more obvious when slot number become larger. That might give us a hint that we should make full use of those slots.

Due to the time limit, simulation of cooperative relay is not accomplished. This is to be done for further verification of my strategies. However, the directive FHSS is certainly improving the reliability from the above results.

## 4 Future Work

After the software simulation, some test on hardware platform should be done as well. We choose NI USRP2 as the platform which we could already run some simple demo on it programmed by Labview.

When the simulation work is all done, we will begin to write the protocol. The difficulty is that there would be plenty of details we should conceive. Also, WirelessHART itself is complicated, it will take time to understand the entire working pattern of it.

## 5 References

[1]DAC: Distributed Asynchronous Cooperation for Wireless Relay Networks *Xinyu Zhang, Kang G. Shin*

[2]Wireless Real-Time Mesh Network for Industrial Automation HART **Springer** *Deji Chen, Mark Nixon*