ASSESSMENT OF WIRELESS COMMUNICATION QUALITY BASED ON INDUSTRIAL NOISE

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ABSTRACT

Owing to noise in industrial environment, wireless signal is seriously interfered in industrial environment, and wireless communication quality will be affected seriously. Requirements of industrial wireless network and the wireless network standards are analyzed in this paper. The wireless communication quality model of IEEE 802.15.4 and IEEE802.11b is deduced. The simulation system based on this wireless communication quality model is established by Matlab. The simulation presents and compares communication quality of IEEE 802.15.4 and IEEE802.11b at the industrial noise range (typically between 20dB and 80 dB) and security level (IEC61508 defined standard- SIL1, SIL2 and SIL3).

Keywords: Communication Quality, Wireless Communication, Industrial Noise, IEC61508

1. INTRODUCTION

Wireless communication technology has become a hot spot in the study field of industrial network control system based on wireless (WNCS). Wireless technology can bring many benefits to industrial network control system. However, wireless technology have not gained widespread acceptance at the factory floor. One reason is the difficulty in achieving the real-time and successful transmission of packets by error-prone wireless channels [1, 2].

Wireless industrial networks have created interest in both academia and industry. The first publications date back to 1988. One of the earliest projects, the European Union OLCHFA project, started in June 1992 with the goal to provide wireless spread-spectrum transmission for the WorldFIP (formerly just FIP) fieldbus. Today, several companies and consortia are active, for example, the wireless industrial networking alliance (WINA). They are considering the use of standardized wireless technologies like IEEE 802.11, BT, or IEEE 802.15.4 in a fieldbus-controlled industrial network. But the communication quality of the existing wireless communication technologies will decline seriously in the worst industrial environments. So the wireless technology is not used widely in the industrial field.

For the purpose of improving the performance of wireless signal transmission, it is important that the wireless communication quality based on industrial noise is discussed. So, we summarize requirements of industrial wireless network, and establish communication quality model, and discuss wireless communication quality based on industrial noise by simulation in this paper, which will be useful to engineer and researchers.

2. REQUIREMENTS OF INDUSTRIAL WIRELESS NETWORK

The requirements of the industrial wireless network are included as follows:

(a)Reliability: Reliability includes real-time, deterministic, redundancy etc., it is far more important than others.

(b)Security: The wireless medium is an open medium. Attacker is easy to eavesdrop it, and to insert malicious packets, or to jam the medium. These ways will affect system operation.

(c)Robustness: it included housing protection level, temperature range, energy consumption, simple installation and operation etc. In addition, protocol scalability and energy efficiency is also required.

3. WIRELESS NETWORK STANDARDS

The existing standards of wireless network technology (defined by the IEEE) are divided by network coverage. A brief overview of the various standards is as follows [3, 4]:


case study or empirical research


discussion


textbook or reference book
1) Wireless WAN (IEEE802.20): IEEE802.20 is a new mobile wireless standard for data communications, known as 4G challenger. The coverage of the standard is the same with the existing mobile phone systems. They are on a global scale. The transmission rate has reached at the level of Wi-Fi.

2) Wireless MAN (IEEE802.16): IEEE802.16 is establishing a wireless access path between the user region and the backbone network. The backbone network may be a public telephone network or Internet.

3) Wireless LAN (IEEE802.11): IEEE802.11 defined that wireless LAN can be operated in the 2.4GHz band, this band is defined the spread spectrum band by the global radio regulations entity. On August 1999, IEEE802.11 standard had been further improved and revised. A SNMP protocol based on MIB is used to replace the original OSI protocol based on MIB. It adds two elements. One is IEEE802.11a standard, which extends the physical layer standard. Its working frequency band is 5GHz, and QFSK modulation is used. The transmission rate is between 6Mb/s and 54Mb/s. The other is IEEE802.11b standard. It works at 2.4GHz frequency band, and uses compensation code keying (CCK) modulation. Its transmission rate is 11Mb/s.

4) Wireless PAN (IEEE802.15): IEEE802.15 commission has developed three different WPAN standards. IEEE802.15.1 standard is a wireless network technology of moderate rate, and it adapts to the short communication. Its QoS mechanisms are suitable for voice services. IEEE802.15.3 is a high-rate WPAN standard, and is suitable for multimedia applications. It has a higher QoS, and it uses UWB technology in physical layer. IEEE802.15.4 standard is a wireless network technology of low-power and low-cost, its target markets are industry, families, medical industry and others.

Basic parameters of the above standards [5]-[9] are shown as Table 1:

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Modulation/spread spectrum</th>
<th>Frequency</th>
<th>Transmission Rate</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11</td>
<td>DSSS, FHSS</td>
<td>2.4GHz</td>
<td>2M</td>
<td>100m</td>
</tr>
<tr>
<td>802.11a</td>
<td>OFDM</td>
<td>5G</td>
<td>6-54M</td>
<td>100m</td>
</tr>
<tr>
<td>802.11b</td>
<td>CCK/DSSS</td>
<td>2.4GHz</td>
<td>2-11M</td>
<td>100m</td>
</tr>
<tr>
<td>802.11g</td>
<td>OFDM</td>
<td>2.4GHz</td>
<td>11M,54M</td>
<td>100m</td>
</tr>
<tr>
<td>802.15</td>
<td>FHSS</td>
<td>2.4GHz</td>
<td>1Mbps</td>
<td>10m</td>
</tr>
<tr>
<td>802.15.1</td>
<td>Multiband OFDM and DS-CDMA</td>
<td>2.4GHz</td>
<td>100Mbs</td>
<td>10m</td>
</tr>
<tr>
<td>802.15.4</td>
<td>DSSS</td>
<td>868/915MHz</td>
<td>20-250K/5</td>
<td>30-100m</td>
</tr>
<tr>
<td>802.16</td>
<td>Single carrier and many carriers OFDM</td>
<td>2-11GHz</td>
<td>74Mbs</td>
<td>50km</td>
</tr>
<tr>
<td>802.20</td>
<td>OFDM</td>
<td>3.5GHz below</td>
<td>1Mbps/user</td>
<td></td>
</tr>
</tbody>
</table>

4. WIRELESS COMMUNICATION QUALITY MODEL

Assuming that the signal propagates in free space, the attenuation coefficient AFS in free space can be defined as below:

\[ A_{FS}(f) = \frac{\alpha(4\pi)^2 D^2 f^2}{G_r G_e c^2} + \partial \]  

(1)

In the formula, \( G_r \) is the gain of omnidirectional antenna; \( C \) is the speed of light: \( 3 \times 10^8 \) m/s; \( G_e \) is the effective area of the receiving antenna. \( \alpha \) is correction parameter. \( \partial \) is a parameter for different wireless network standard.

Now, we suppose that \( P_s(f) \) is the power spectral density, therefore, the total transmits power \( P_s \) is equal to quadrature of \( P_s(f) \) in the range of transmission frequency. If \( f_u \) and \( f_l \) are the upper and lower frequency in the range, the total transmits power \( P_s \) is:

\[ P_s = 2\int_{f_l}^{f_u} P_s(f) df \]  

(2)

When the given formula (1) is used for attenuation coefficient in free space, by the method of P.H. Sheng et al [10], signal power \( P_s \) received by receiver can be shown as follow:
The system margin of the receiver is $S_M$. If the requirements of $\text{SNR}_{\text{spec}}$ are met, the signal power $P_r$ may be expressed:

$$P_r = S_M \cdot \text{SNR}_{\text{spec}} \cdot P_P$$

(4)

Receiver receives signals by receiving energy $E$ in the limited interval time, $E$ is mainly composed of two components: signal energy $E_s$ and noise energy $E_n$. Noise energy may come from a lot of noise sources. These noise sources are uncorrelated and independent, such as thermal noise, multi-user interference and external interference. So the expression of $E$ is shown as Equation 5.

$$E = E_s + \sum_{i=1}^{N} E_i = E_s + E_{\text{noise}}$$

(5)

Where, $\text{SNR}_{i} (i = 1, \ldots, N)$ is corresponding to different noise sources.

$$\text{SNR}_{i} = \frac{E_s}{E_i}$$

(6)

According to channel model and parameters of IEEE 802.15.4 and IEEE 802.11b in physical layer, we can model and analysis by Matlab.

5. SIMULATION AND RESULT ANALYSIS

5.1 Simulation

First, we calculate spectral density of Gaussian [10]. Secondly, we must obtain the $\text{PSD}$ and frequency (limited range $[f_1,f_n]$) by the function ($n_{ \text{Gaussian}_P S D}$) [11]. Finally, using the above results and formula (3), we obtain link budget under a certain noise and error rate. The realization is as follows:

```matlab
function [f_vector, PSD_vector] = threshold_fr_PSD_vectors(fr, PSD, threshold)
    L = length(fr);
    f = fr(length(fr))/length(fr);
    P_high, index = max(PSD);
    f_peak = index * f;
    P_threshold = P_high*10^(threshold/10);
    index_max = index;
    P0h = PSD(index);
    while (P0h>P_threshold) & (index_max<=L)
        index_max = index_max + 1;
        P0h = PSD(index_max);
    end
    f_high = (index_max-1) * f;
    index_min = index;
    P0l = PSD(index);
    while (P0l>P_threshold) & (index_min+1<=L)
        index_min = index_min + 1;
        P0l = PSD(index_min);
    end
    f_low = f_high - f_low;
    BW = f_vector = f(index_min:index_max);
    PSD_vector = PSD(index_min:index_max);
end
```

Where, the parameter $f_i$ is vector of frequency range. The parameter $\text{PSD}$ is the power spectral density of transmitting wave. This function returns value $f_{\text{vector}}$, and it is the calculated frequency range of bandwidth. The parameter $\text{PSD}_{\text{vector}}$ included the initial value of power spectral density in the scope of bandwidth. The parameter $\text{link\_M}$ is link margin. The parameter $F_{\text{noise}}$ is noise exponent of the receiver. The parameter $x_1$ and $x_2$ is range of transmission rate.

5.2 Result Analysis

Using the above procedure, we have simulated. According to the defined industry standard [12] (security level SIL1, SIL1 and SIL3 in IEC61508,
the data error rate is from $10^{-6}$ to $10^{-5}$ in SIL1, the data error rate is from $10^{-7}$ to $10^{-6}$ in SIL2, the data errors rate is from $10^{-8}$ to $10^{-7}$ in SIL3). We can calculate the relationship curves between the maximum transmission distance and data rate under the error rate $P_{re} (10^{-5}, 10^{-6}$ and $10^{-7})$ and the noise exponent (20dB, 40dB, 60 dB and 80dB) based on IEEE 802.15.4 and IEEE 802.11b. The curves are shown in Figure 1-4.

Figure 1: Relationship of data rate and distance in the noise exponent 20dB

Figure 2: Relationship of data rate and distance in the noise exponent 40dB

Figure 3: Relationship of data rate and distance in the noise exponent 60dB
6. CONCLUSION

The wireless channel can influence the design of industrial network control system. With the success of wireless technologies in consumer electronics, wireless network technologies are envisioned for the deployment in industrial environments as well. Wireless network is, beyond all questions, an appropriate approach to obtain flexibility and mobility in the factory. Nevertheless, industrial wireless network often has stringent requirements on reliability, robustness, security and so on. In wired environments, industrial network system can satisfy requirements, such as reliability, real-time, robustness and security. For example, fieldbus is a mature technology, and it is designed to accomplish communication between digital controllers and sensors. When wireless network technologies are included, due to the adverse properties of the radio channels, the requirements of reliability, robustness and security are significantly more difficult to be met. So we discuss wireless communication quality based on industrial noise, Simulation data will be reference to research on industrial wireless network, and it will be helpful to researcher.

REFERENCES:


