A Study on Communication Channel Estimation for Emergency Networks in Underground Mining Environment

Jin-cheng HUANG1,a,* , Ya-heng ZHANG1, Rui CAO1, Gang ZHOU1, Yuan MA1 and Ze-ming DONG2

1Department of Information Engineering, Yancheng Institute of Technology, No.1 Middle Xiwang Avenue, Yancheng, Jiangsu Province 224051, P.R. China
2Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi, 755-8611, Japan

a huangjincheng@163.com
*Corresponding author

Keywords: Monitoring, Networks, Emergency.

Abstract. Monitoring networks in underground mining environment should provide many of mobile devices with the same time multi-access communications, high speed data transmission, and low transmit power capability. Bandwidth limitations, propagation loss, noise, interference, time variance, and frequency selective fading caused by multipath propagation can bring high symbol error ratio in high rate transmission. Communication systems can enhance their performance by using anti multi-path fading techniques only when they could make precise and real time estimation of fading coefficients of multipath channel. The purpose of this paper is for optimizing the wireless network system designs, and providing theoretical guides and technology programs for promoting the anti-multipath fading performance of wireless emergency networks.

Introduction

With the development of wireless network communication technology, ubiquitous mobile emergency communication systems, such as intelligent transportation system and network robot system, have attracted [1].

The communication channel is the physical medium that is used to send the signal from the transmitter to the receiver. It provides the connection between the transmitter and the receiver. The physical channel may be a pair of wires that carry the electrical signal, or an underwater ocean channel in which the information is transmitted acoustically, or free space over which the information-bearing signal is radiated by use of an antenna.

Wireless communication devices to be applied to the ubiquitous mobile system are desirable to possess good characteristics with high reliability, rapid access, and multiple access communications. Emergency networks in underground mining environment should provide many of mobile devices with the same time multi-access communications, high speed data transmission, and low transmit power capability. However, Bandwidth limitations, propagation loss, noise, interference, time variance, and frequency selective fading caused by multipath propagation can bring high symbol error ratio in high rate transmission [2]. Communication systems can enhance their performance by using anti multipath fading techniques only when they could make precise and real time estimation of fading coefficients of multipath channel. However, the transmitted signal is corrupted in a random manner by a variety of possible
mechanisms, such as additive thermal noise generated by electronic devices; man-made noise, e.g., automobile ignition noise; and atmospheric noise, e.g., electrical lightning discharges during thunderstorms. Other types of signal degradations are signal attenuation, amplitude and phase distortion, and multi-path distortion.

The frequency correlation characteristics are important parameters of multipath channel and the researches on frequency correlation characteristics have attracted much attention of experts and scholars. However, the frequency correlation characteristics have rarely been investigated with respect to transmission distance, radio carrier frequency and the speed of mobile station for monitoring networks with mobiles devices [3]. In this paper, the multipath fading channel models based on electromagnetism scatter theory will be proposed over wireless network channels, and comprehensive theoretical analysis of frequency correlation characteristics over the models will be discussed on the basis of the influence of transmission distance, radio carrier frequency and the speed of mobile devices.

Fading Cannel

In many typical situations without line of sight between communication stations, the received signal is a superposition of a large number of reflected rays because of scattering and reflections from buildings and obstructions, as shown in Fig. 1. These reflected and scattered paths have random amplitudes. The phase for each path is uniformly distributed between $0$ and $2\pi$ and the phases of different paths are independent.

![Figure 1. Rayleigh fading channel.](image)

As a result, the average signal level received at any time remains virtually constant, but its instantaneous value varies randomly about the mean level with a Rayleigh distribution. This multi-path fading phenomenon is called Rayleigh fading. Rayleigh fading gain distributions on different frequency bands may be mutually independent as long as the both frequencies are sufficiently apart. Fading cross-correlation versus keying frequency deviation characteristics should be examined. Rayleigh fading characteristics have been analyzed with a synthetic radio wave model consisting of many scattered path-waves made by reflection at objects arranged in a transmission route [4].

The central limit theorem holds that, if there are sufficiently many scattered waves, the channel impulse response will be well-modeled as a Gaussian process irrespective of the distribution of the individual reflected components. If there are no dominant components made by a few scattered waves, then such a process will have a Gaussian
distribution characterized by zero mean and phase evenly distributed between 0 and $2\pi$ radians [5]. The envelope of the channel gain response will therefore be Rayleigh distributed.

**Channel Model**

A multi-path channel model is shown in Fig. 2, where $S$ denotes a transmitter, $R$ a receiver, $d_0$ a straight-line distance between $S$ and $R$. In this model having more than one path, a signal propagates on the paths between the transmitter and receiver. Although Fig. 2 shows only three paths for simplicity, it should be practically generalized to $J$ paths.

Respective paths may be made by transmit-angles $\phi'_j(j=1,2,3,\cdots,J)$, and receive angles $\phi_j$, where respective path-waves reflect at reflection wall surfaces $\omega_j(i=1,2,3,\cdots,J)$. As a result, each path distance is calculated with above parameters $\phi'_j$, $\phi_j$ and $d_0$.

By allocating random variables to the respective parameters $\phi'_j$ and $\phi_j$, a propagation wave set consisting of $J$ pieces of path-waves denoted by $(d_1,d_2,\cdots,d_J)$ can be obtained.

Let $A_j$ be signal amplitude whose distribution is Gaussian with an average. At the $t$-th time, it is assumed that a path-wave set defined by $A_j$ and $d_j(t)$ ($j=1,2,3,\cdots,J$) is thus obtained. $d_j(t)$ may be used for all the frequencies.

Let $f_r$ be a carrier frequency and $c$ a light speed. The carrier wavelength is defined by $\lambda_r=c/f_r$. $N'_j$ is a number of wavelength comprised in the $j$-th path, given by $N'_j=d_j/\lambda_r$, and $\Theta'_j$ the phase of the signal on the $j$-th received path-wave given by $\Theta'_j=2\pi[N'_j]$, where $[N'_j]$ is a decimal part of $N'_j$.

Let $R_j$ be the $j$-th received path-wave defined by

$$R_j = A_j \exp(j\Theta'_j), \quad (1)$$

where $A_j$ is the amplitude of the $j$-th received signal of frequency $f_r$. Let $x_j = A_j \cos(\Theta'_j)$ and $y_j = A_j \sin(\Theta'_j)$ be the in-phase and quadrature components, respectively.

The average envelope amplitude of a synthetic wave obtained by summing pieces of the receive-path-waves is written as

$$R = \frac{1}{\sqrt{J}} \sqrt{\left(\sum_{j=1}^{J} x_j\right)^2 + \left(\sum_{j=1}^{J} y_j\right)^2} \quad (2)$$

where $R$ accords to Rayleigh distribution when each of the synthetic waves is composed of more than about 10 waves (that is $J \geq 10$).

Let $P'_r$ be the power of a synthetic wave on frequency $f_r$ at the $t$-th time. The path-waves composing the wave set varies random. The power is expressed by $P'_r = (R(f_r,t))^2$ which is a function of a path-wave set composed of $A_j$ and $d_j(j=1,2,3,\cdots,J)$. Consider such a discrete frequency range for $f_r$ as defined by $(r=1,2,3,\cdots,r^*)$ and $f_{r+1} - f_r = 1[\text{MHZ}]$. 

141
The result of power of synthetic waves over different straight-line distance channels on the condition of each channel using the same time. It shows that when the frequency changes the synthetic wave power also changes even over the same straight-line distance channel on the condition of each channel using the same time, and when the straight-line distance changes becomes longer, the change of synthetic wave power becomes more intense. However, the cross-correlation characteristics between different frequencies cannot be observed clearly here. On the other hand, the power changes at different time. However, the cross-correlation characteristics between different frequencies are invisible. Therefore the covariance properties must be discussed strictly and the cross-correlation will be investigated furthermore.

Simulation

Let \( P_t \) be a frequency related power sequence set at the \( t \)-th \( (t = 1, 2, \ldots, T) \) time defined by \( P_t = (P'_t, \ldots, P'_r, \ldots, P'_T) \). Let \( f_r \) be a centre frequency, \( f_r' \) be an adjacent frequency expressed by \( f_r' = f_r + \Delta f' \), where \( \Delta f \) is frequency deviation. Let \( P' \) be a time related power sequence set on the \( r \)-th frequency \( f_r' \). Sequence \( P' \) is denoted by

\[
P' = (P'_1, \ldots, P'_r, \ldots, P'_T)
\]  

(3)

Correlation between the times related power sequence set \( P' \) on \( f_r \) and \( P' \) on \( f_r' \) can be calculated [6]. Thus the correlation coefficient between \( P' (f_r) \) and \( P' (f_r') \) is defined by

\[
\rho(\Delta f) = \frac{E[(P'_r - E(P'_r))(P'_{r'} - E(P'_{r'}))]}{\sigma_{P'_r} \cdot \sigma_{P'_{r'}}}
\]  

(4)

where \( \sigma_{P'_r} \) and \( \sigma_{P'_{r'}} \) are the standard deviations of \( P' \) and \( P' \) with respect to the time \( t \).
The fading correlation versus frequency deviation characteristics are obtained with Eq. 4 under the following conditions: \( d_0 = 10, 20, 50, 100, 200, 500 \) meters; \( f_r = 10, 1000 \text{MHZ}, 0 \leq \Delta f \leq 100 \text{MHZ} \).

![Figure 4. Centre frequency \( f_r = 1000 \text{MHZ} \).](image)

The results shown in Figs. 3 and 4 indicate that the longer the transmitter to receiver distance \( d_0 \) is, the narrower correlation bandwidth \( B_c \) is. \( B_c \) may be recognized as a function of distance \( d_0 \). Consequently, by designing the carrier frequencies \( f_0 \) and \( f_1 \) to be apart by higher than \( B_c \), independent fading condition can be satisfied.

Let us choose some relation between fading correlation \( \rho \) and frequency deviation \( \Delta f \) for centre frequency \( f_r = 1000 \text{MHZ} \) which may be observed in Fig. 4, and the major results are shown in Table 1.

![Figure 5. Bit error rate characteristics for BFSK-MRC with fading correlation \( \rho(\Delta f) \) in Table 1.](image)

BER Performance using MRC calculated with system parameters in Table 1 is shown in Fig. 5. As a result, for \( \rho(\Delta f) \leq 0.7 \), the BERs for BFSK approaches to those in the case of independent fading.

Table 1. Simulated results on fading correlation versus bandwidth (\( f_r = 1000 \text{MHZ} \)).

<table>
<thead>
<tr>
<th>Straight-line Distance (meters)</th>
<th>( \rho(\Delta f) )</th>
<th>( \Delta f (\text{MHZ}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.9</td>
<td>13</td>
</tr>
<tr>
<td>50</td>
<td>0.8</td>
<td>54</td>
</tr>
<tr>
<td>100</td>
<td>0.7</td>
<td>5</td>
</tr>
<tr>
<td>200</td>
<td>0.2</td>
<td>6</td>
</tr>
</tbody>
</table>

This advantage results from the capability of utilizing SC or MRC technique, because, unlike BPSK or ASK, BFSK receiver only can provide two branch soft-outputs conveyed via respective keying frequencies, without using two receive-antennas. In addition, this modulation principle may be applied to systems operating even for a system of emergency communication networks by properly selecting design parameters so as to satisfy the independent fading condition.
Summary

This work provides a valuable reference for designing the wireless emergency communication systems with high spectral efficiency and high tolerance to multipath fading. In this paper, the theory based on multipath channels is summarized and a very simple multipath channel model is presented. Then the frequency correlation characteristics were investigated with the respect to transmission distance and radio carrier frequency in theory and the frequency correlation coefficient were conducted. As a result, by optimizing the wireless network system, providing theoretical the guides and technology programs for promoting, the anti-multipath fading performance of wireless emergency networks can be designed.

Acknowledgement

This work was supported by the Scientific Research Foundation of Jiang Su Industry-University-Research Collaboration under the Grant No. BY2016065-02 and the Project Sponsored by the Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry under the Grant No.14KJB430023.

References