Collision Problem Solving in FH-CDMA by Multi Linear Chirp Technique

Phichet Mougnoul, Surachate Disapirom, Sutouch Junpong, Tawil Paungma

Faculty of Engineering and Research Center for Communication and Information Technology
King Mongkut’s Institute of Technology Ladkrabang, Chalongkrung Road, Bangkok 10520, THAILAND
Phone: +66-2-3264242, Fax: +66-2-3264554, E-mail: phichet@telecom.kmitl.ac.th

ABSTRACT
This paper proposes a new modulation technique for Frequency Hopping Code Division Multiple Access (FH-CDMA) system for solving the collision problem and improving the system performance. The FH system uses a small part of the bandwidth when it transmits, but the location of this path differs in time. When the collision problem occurred, there is more than one signal from different users assigned to use that small part of bandwidth at the same time. So, at the receiver, the demodulator cannot estimate the correct value of data bit for each user. This paper presents the use of Multi Linear Chirp (MLC) technique, which can solve the collision problem and increase the performance of the FH-CDMA system. For the result, the performance of the proposed technique are compared with the frequency shift keying (FSK) FH-CDMA and presented in form of Bit Error Rate (BER).

Keywords: Multi Linear Chirp, FH-CDMA, Collision

1. INTRODUCTION
Various kinds of CDMA, there are two of them, which are frequently used: Direct Sequence CDMA (DS-CDMA) and Frequency hopping CDMA (FH-CDMA). In the RADAR system, there are many modulation techniques which have been used e.g. continuous wave (CW), Linear Frequency modulation (LFM or Linear Chirp), Non-linear frequency modulation (NLFM) and V-frequency modulation (V-FM) [1]. Linear Chirp is one of the most popular modulation methods because of its ability of Interference rejection [2]. Chirp modulation was introduced by Winkler in 1962. After that, Linear Chirp technique was continuously applied in many areas of wireless communication and radar system.

2. FREQUENCY HOPPING-CDMA SYSTEM AND COLLISION PROBLEM
In the general FH-CDMA, BFSK technique has been used as the modulation technique. In this system, 2 sinusoid signals with different frequencies are used as data bit ‘1’ and ‘0.’ Both signals must be in the data modulation band or frequency hop band (Wd). A PN code pattern must be generated identically for each user. It can be divided into intervals of length k and this code in the interval are used to synthesize the frequency of BFSK signal according to the frequency level lm. By this way, the frequency band Wd will hop by the sub code in each interval of PN code. This relation can be expressed by the formula shown below.[2]

\[ f_{ch} = f_{ch1} + (l_m - 1)W_d, \quad l_m = 1, 2, \ldots, L \] (1)

\[ L = 2^k \] (2)

Where \( l_m \) is hop level of user \( m \), \( L \) is number of all hop levels, \( f_{ch} \) is center frequency of hop band and \( f_{ch1} \) is center frequency of hop level 1. All hopping frequencies of \( W_d \) are in the spread spectrum band (ws), which their relations can be expressed as shown next[3].

[Fig. 1: Signal of BFSK-FH-CDMA system in time-frequency domain and represent collision problem in user A and B]
Where \( G_p \) is processing gain, \( W_d \) is data modulation band, \( k \) is number of code bit in hop duration. There is a problem, which always occurs when there are many users in the system that is a collision problem [4]. The reason, why this problem occurred is, when there are many users in the system, the code, which is used to synthesize the frequency, of two or more users are the same at some periods. So, at that period, there are two or more data bit signals hopped into the same data modulation band \( (W_d) \). For example, as shown in Fig 1, define the data pattern and PN code Pattern of length \( k = 3 \) of user A are ‘11101’ and ‘110 111 101 011 101’ respectively. And on, The data pattern and PN code Pattern of user B are ‘01010’ and ‘111 101 011 101’ respectively. And so on, The result of collision may be noticed that, at time period \( T_2 \) and \( T_3 \), The interval codes '011 111 001 011 110' respectively. From the example, it shown in Fig 1, define the data pattern and PN code Pattern of length \( k = 3 \) of user A are ‘11101’ and ‘110 111 101 011 101’ respectively. At period \( T_2 \), The users’ data bit are same, because the data bits of both users are the same. At period \( T_4 \), The result of collision may be noticed that, at time period \( T_2 \) and \( T_3 \), The interval codes '011 111 001 011 110' respectively. From the example, it shown in Fig 1, define the data pattern and PN code Pattern of length \( k = 3 \) of user A are ‘11101’ and ‘110 111 101 011 101’ respectively. And so on, The result of collision may be noticed that, at time period \( T_2 \) and \( T_3 \), The data bit of each user even they are in the same hopping frequency at the same time. Another key factor of MLC modulation is time-bandwidth product \((TB)\). This product represents the area of frequency sweeping. The relation of this product to the other factors is shown below [3].

\[
TB = (M + 1)\Delta f
\]

Where \( TB \) is Time-bandwidth Product, \( M \) is Number of user and \( \Delta f \) is Separation frequency

### 3. MULTI LINEAR CHIRP FH-CDMA

#### 3.1 Multi Linear Chirp Modulation

This technique, a linear chirp signal is compressed with 2 compression rates. In another words, each signal is characterized by two different slopes as shown in Fig. 2.

\[
G_p = \frac{W_r}{W_d} = 2^k
\]  (3)

\( W_r \) is bandwidth of \( \Delta f \) and time interval of \( T_c \). By the values of \( \Delta f \) and \( T_c \), the values of \( \mu_f \) and \( \mu_b \) can be varied to \( 2m \) sets, \( m \) sets of positive slope (up chirp) for data bit ‘1’ and \( m \) sets of negative slope (down chirp) for data bit ‘0’.

So, for \( m \) users, each user will have its own two levels of compression (slope) signal. The users have their own pattern of signal, so the receiver can easily separate the data bit of each user even they are in the same hopping frequency at the time same. This paper, the Multi Linear Chirp (MLC) technique is proposed as a new modulation technique instead of BFSK technique because of the good advantage that it can provide the unique pattern of signal for each user. To generate the MLC-FH-CDMA signal, the center frequency of hop band \( (f_c) \), in equation (1), is adjusted according to the PN sequence of each user. This process can express in form of the equations as shown below [1]:

\[
\sum_{n=-\infty}^{\infty} \sum_{m=-1}^{M} P_{tx}(t-nT_b)s_{m}(t)
\]

\[
s_m(t) = s_m(t) + s_{\mu_f}(t)
\]

\[
s_{m}(t) = A \cos \left[ 2\pi \left( f_{ch} + \left( \frac{t_m - 1}{2} \right) W_d \right) + b(t) \mu_m \pi^2 \right]
\]

\[
\mu_m = \frac{(M + 1 - m)\Delta f}{mT_c}
\]

\[
s_{\mu_f}(t) = A \cos \left[ 2\pi \left( f_{ch} + \left( \frac{t_m - 1}{2} \right) W_d - b(t)m\Delta f \right)(t - mT_c) \right] + b(t)\mu_m \pi^2 (t - mT_c)
\]

\[
\mu_m = \frac{m\Delta f}{(M + 1 - m)T_c}
\]

\[
T_c = \frac{T_b}{(M + 1)}
\]

\[
\Delta f = \frac{W_d}{(M + 1)}
\]

\[
b(t) = \begin{cases} 1, \text{Data bit is "1" (up chirp)} \\ -1, \text{Data bit is "1" (down chirp)} \end{cases}
\]

\[0 \leq t \leq T_h\]

Where \( \mu_f \) is front chirp slope of user \( m \), \( \mu_b \) is back.
chirp slope of user \( m \), \( m \) is user sequence, \( T_h \) is hop bit duration, \( T_c \) is separation time and \( p(t) \) is unit amplitude pulse of duration \( T_c \).

![Fig. 3: Block diagram of MLC-FH-CDMA system (a) Transmitter and (b) Receiver](image)

The process as of the proposed system can be described by block diagrams shown in Fig 3. This system consists of two parts, transmitter part and receiver part. In the receiver part, the MLC demodulator has a correlator with different signal patterns to be references for each user. The symbols \( \phi_1 \) and \( \phi_0 \) in Fig 4 are the references of data bit ‘1’ and bit ‘0’, respectively, for user \( m \). This is a main point that differ from the BFSK demodulator which has only 2 references, \( \phi_1 \) for data bit ‘1’ and \( \phi_0 \) for data bit ‘0,’ as shown in Fig 4. In Fig 5, the despreading signal which must be sent to compare with the references and estimate the data bit value at the demodulator, is shown. It is shown that the patterns of signals of user A and B are obviously difference. So, the value of data bit of each user can be estimated correctly.

![Fig. 4: (a) BFSK Demodulator [5] and (b) MLC Demodulator for user sequence \( m \)](image)

3.3. Performances of MLC-FH-CDMA system

Multi Linear chirp modulation is binary communication system, so, the performance of the system can be expressed by the equation as shown below.

\[
P_e = Q \left( \frac{\bar{e}(1-\rho_s)}{2\sigma^2} \right)
\]

Where \( P_e \) is probability of error, \( Q \) is Gaussian distribution function, \( \bar{e} \) is average signal energy, \( \rho_s \) is signal correlation coefficient and \( \sigma^2 \) is variance. From the equation, the performance of the system is directly depended on factor \( \rho_s \) \( (P_e \propto \rho_s) \). And from [6], we realize that \( \rho_s \) will increase when the Time-Bandwidth Product decreases and when the number of user (\( m \)) increases. So, two factors must be considered as the performance factor.

4. SIMULATION RESULTS
This paper, we simulate the BFSK-FH-CDMA and MLC-FH-CDMA system with Processing gain equal to 32, i.e. the number of code bit in hop duration (k) equal to 5. The length of PN code used in this simulation is 255 and the m-sequence algorithm is used to generate the code at the receiver. The demodulator with a correlator is used. Both systems are simulated on AWGN, which the results are shown in Fig 6 and 7, and on Multipath Fading Channel with Maximum Doppler Shift equal to 185 Hz, which the result is shown in Fig. 8. From Fig. 6, Time-Bandwidth Product makes no effect to BFSK-FH-CDMA system. But, when compare between BFSK and MLC, the performance of MLC is better at every value of TB and it much better at the high value of TB. Fig. 7 shows the effect of number of users. Number of users affects both BFSK and MLC system. When number of user increase, the performances of both BFSK and MLC decrease. However, at every numbers of users, the performance of MLC system is better. On multipath fading channel in Fig 8, the performance of both systems decrease, but all main characteristics of the systems are the same such as the performance is down when the number of users increase and the performance of MLC is still better.

5. CONCLUSION

All the results conclude that the new modulation technique, multi linear chirp modulation, give the better performance (lower Bit Error Rate) than the traditional technique, BFSK modulation, for Frequency Hopping CDMA system. This dues to the ability to generate a unique signal pattern in the data modulation band for each user. So, the probability of error when occur the collision problem is decrease. The system parameters that must be considered are Time-Bandwidth Product and number of users. The performance of this system will increase when the Time-Bandwidth Product increase or when the number of users decrease.

6. REFERENCES