Journal of Southeast University (English Edition) Vol. 21, No. 4, pp. 393 – 397 Dec. 2005 ISSN 1003—7985

Multi-access performance of DS UWB system under indoor dense multi-path channel

Fan Xiangning Ni Jianqiang Bi Guangguo

(National Mobile Communications Research Laboratory, Southeast University, Nanjing 210096, China)

Abstract: The performance of multi-user code to direct spreading bi-phase shift keying (DS-BPSK) direct impulse ultra wideband (UWB) systems under indoor multi-user and multi-path environment is analyzed and simulated. The system output signals with Rake receiver are derived, then a simple and practical code selection scheme is given; i. e., with a large occupation to empty ratio of the repeating pulses, directly choosing those random or pseudo-random user codes with enough length and good co-relative orthogonal features will make the performance of DS-BPSK approximate the optimum and, so there is no need to carefully design the code or its type. The system multi-access performances are simulated using Gold sequence and PN codes as multi-user codes under CM1-CM4 multi-path channels. Simulation results prove that the proposed scheme is feasible.

Key words: ultra wideband; multi-access; multi-path; Gold code; direct sequence; Rake

FCC approved that ultra wideband (UWB) communication signals could be transmitted for commercial applications in April, 2002. After that, people showed great interest in UWB communication and put forward many proposals. Now, UWB communication has become a focus in the communication field. UWB has some advantages, such as high speed, low transmitter power, low cost and no need for special bandwidth. This paper studies the multi-access and Rake receiver performances of the UWB wireless system based on pulse signals.

In many earlier communication systems, after the baseband data was processed, it was then modulated on a carrier frequency and radiated by antenna. This is generally called narrowband communication in which signal spectrum is shifted near the carrier frequency. Later, the CDMA spectrum spread communication was proposed. The signals' spectra were first spread, then modulated on a carrier frequency. However, the occupation of the bandwidth of this kind of CDMA system was still only several MHz bandwidth and the relative bandwidth was usually less than 1%. Recently, the FCC has approved that UWB communication signals can occupy more than a 500 MHz bandwidth or the relative bandwidth can be more than 20%. In the standardization process of IEEE 802. 15. 3a WPAN Task Group, two ways have been proposed to utilize the approved bandwidth, one is based on OFDM, the other is based on DS-CDMA.

Multi-access performance is an important part for the UWB system. Earlier published literature[1 – 6] discussed the multi-access code problems and system capacity of UWB wireless communications. Ref. [1] used multiple receiver antennae and modeled the multi-access interference (MAI) as a filtered Poisson shot noise rather than the usual Gaussian assumption for MAI. The multi-access capacity of M-ary pulse position modulation (PPM) for time hopping (TH) UWB systems rather than the DS scheme is studied in Refs. [2, 3]. A method for improving the capacity of the multi-carrier based DS UWB system with 256 sub-carriers is presented in Ref. [4]. In Ref. [5], code selection for enhancing pulse-based UWB multiple access performance using TH-PPM and DS-BPSK modulations is analyzed but only under AWGN channel condition while the performance with multi-path is obtained by simulation. And Ref. [6] discussed the design and performance analysis of TH sequences for TH UWB systems. In Ref. [7], the capacity of binary PPM modulated TH UWB system over multi-path is analyzed.

In this paper, the multi-access performance of the pulse-based DS-BPSK CDMA UWB system with a Rake receiver under practical indoor dense multi-path channels will be analyzed and simulated.

1 Pulse-Based UWB Wireless System

It is an important issue to distinguish different users in wireless communication systems. Generally speaking, there are three methods for users to access the system. However, it is easy to understand FDMA is not suitable in this situation.

Received 2005-03-01.

Foundation item: The National High Technology Research and Development Program of China (863 Program) (No. 2001AA123042, 2003AA123330, 2005AA123320).

Biography: Fan Xiangning(1964—), male, doctor, associate professor, xnfan@seu.edu.cn.

In the following system as shown in Fig. 1, DS-CDMA is selected. (Note: DS referred here is not spectrum spread. In fact, it is actually a direct sequence phase coding, but the process method is similar to direct sequence spectrum spread, and it is usually named as DSSS[8]). In the system, pseudo-random sequences are adopted as different users' codes, and the receiver distinguishes different users' information according to their user codes. BPSK is assumed through the whole paper.

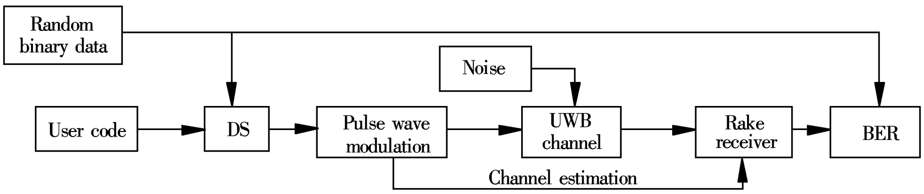

Fig. 1 Pulse-based UWB wireless system simulation block diagram

The Rake receiver will be used to improve the signal noise ratio[9]. The number of selected paths and their effect on system performance will also be discussed in the next section.

1.1 Selection of pulse waveform

In the system, the Gaussian monocycle pulse waveform is adopted[10]. Its expression is

$$V(t) = \frac{t}{\tau} e^{-\left(\frac{t}{\tau}\right)^2} \tag{1}$$

In the UWB communication system, the antenna will differentiate the transmitted signal waveform, so the transmitted waveform expression after the antenna is

$$U(t) = e^{-\left(\frac{t}{\tau}\right)^2}\left(\frac{1}{\tau} - 2\frac{t^2}{\tau^3}\right) \tag{2}$$

The different values of τ result in different pulse and spectrum widths. In this paper, $\tau = 0.5$, and the corresponding waveforms of $V(t)$ and $U(t)$ are shown in Fig. 2.

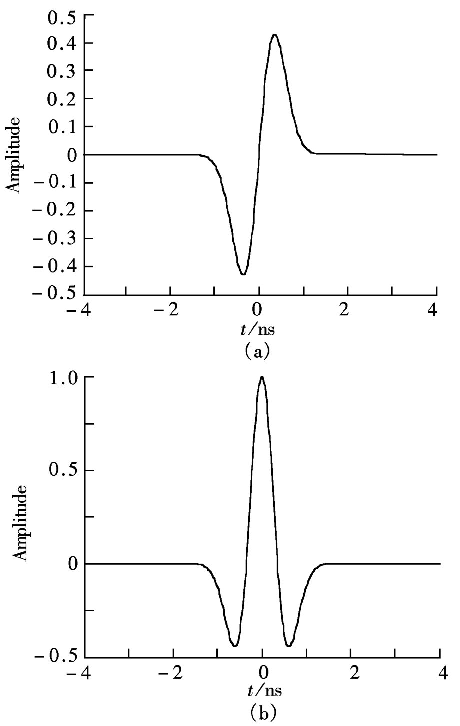

Fig. 2 Gaussian monocycle waveform and its differentiation. (a) $V(t)$; (b) $U(t)$

1.2 Analysis and simulation of user codes

Now we observe the receiver interference problem. Suppose that the system has ideal channel estimation and synchronous receiving. User A is the useful information to be acquired, and other users are interferential signals.

Suppose $C_a(t)$ is a pulse waveform of one chip, it is a low duty cycle waveform. $h_c(t)$ is a random response of the UWB channel. When the pulse waveform $C_a(t)$ passes the UWB channel, its response is expressed as

$$W_a(t) = h_c(t) * C_a(t) \tag{3}$$

where $*$ denotes convolution operation. Let a_i ($i = 0, 1, 2, \ldots, N-1$) be the code of user A, a_i is a pseudo-random sequence and its length is N. Then the expression of a spread data bit passing the channel is

$$S_a(t) = \sum_{i=0}^{N-1} a_i W_a(t - i\tau_c) \tag{4}$$

where τ_c is the chip's interval.

Similarly, the receiving signals of the other users who interfere with user A can be expressed as

$$I(t) = \sum_{j=1}^{M} \sum_{i=0}^{N-1} b_{j,i} W_{b_j}(t - i\tau_c) \tag{5}$$

where M is the number of the other users, N is the code length, and $b_{j,i}$ is the i-th code element of the j-th user.

Consider that user codes are asynchronous, $b_{j,i}$ has been adjusted; that is, the phase of the user code has been adjusted in the receiver. As shown in Fig. 3, here we obtain chip synchronization.

In Fig. 3, the upper line is the code of user A and the lower line is the code of user B. With reference to user A, user B keeps ahead by $j-1$ elements.

So the received bit data of user A is

$$R_a(t) = \sum_{i=0}^{N-1} a_i W_a(t - i\tau_c) +$$

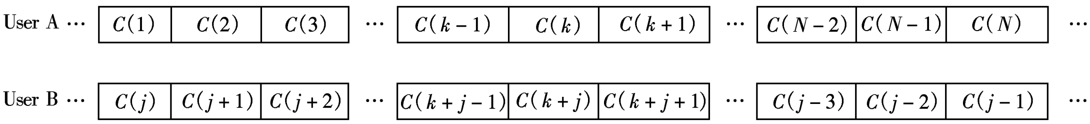

Fig. 3 Code element adjustment

$$\sum_{j=1}^{M}\sum_{i=0}^{N-1} b_{j,i} W_{b_j}(t-i\tau_c) + n(t) \tag{6}$$

In Eq. (6), the former two parts represent useful information and the interference item, respectively; $n(t)$ is the additive noise.

At the receiver, suppose that signals of user A are received with ideal channel estimation. Signal bit energy is accumulated by integration, chip by chip. It can be expressed as

$$E_b = \int_0^{T_b} R_a(t)\Big[\sum_{i=0}^{N-1} a_i W_a(t-i\tau_c)\Big]dt$$

i. e.

$$E_b = \int_0^{T_b}\Big[\sum_{i=0}^{N-1} a_i W_a(t-i\tau_c)\Big]\Big[\sum_{i=0}^{N-1} a_i W_a(t-i\tau_c)\Big]dt + \int_0^{T_b} n(t)\Big[\sum_{i=0}^{N-1} a_i W_a(t-i\tau_c)\Big]dt + \int_0^{T_b}\Big[\sum_{j=1}^{M}\sum_{i=0}^{N-1} b_{j,i} W_{b_j}(t-i\tau_c)\Big]\Big[\sum_{i=0}^{N-1} a_i W_a(t-i\tau_c)\Big]dt \tag{7}$$

It is obvious that the energy of the bit data of user A is composed of three parts: ① The useful signal energy; ② The energy generated by additive noise; ③ The interference energy of other users. Now we consider ③. Let

$$E_I = \sum_{j=1}^{M}\int_0^{T_b}\Big[\sum_{i=0}^{N-1} b_{j,i} W_{b_j}(t-i\tau_c)\Big]\cdot\Big[\sum_{i=0}^{N-1} a_i W_a(t-i\tau_c)\Big]dt \tag{8}$$

If not considering the chip interference, Eq. (8) can be rewritten as

$$E_I = \sum_{j=1}^{M}\int_0^{T_b}\Big[\sum_{i=0}^{N-1} b_{j,i} a_i W_{b_j}(t-i\tau_c) W_a(t-i\tau_c)\Big]dt \tag{9}$$

and

$$W_{b_j}(t-i\tau_c) W_a(t-i\tau_c) = C \tag{10}$$

where C is a constant, so

$$E_I = C\sum_{j=1}^{M}\Big[\int_0^{T_b}\Big(\sum_{i=0}^{N-1} b_{j,i} a_i\Big)dt\Big] \tag{11}$$

It is easy to conclude that if the codes are orthogonal, that is

$$\sum_{i=0}^{N-1} b_{j,i} a_i = 0 \tag{12}$$

Then interference between users can be eliminated. This provides a scheme for selection of user codes. That is, if the duty cycle is small enough, orthogonal codes can be used and the best performance achieved.

When chip interference occurs, suppose that current chip will affect its following $k-1$ chips, dissect the channel response into k sections. Each section's interval is τ_c. The k sections can be expressed as $P_0(t), P_1(t), \ldots, P_{k-1}(t)$.

Without considering data bit interference, we confine the chip interference within a data bit. Then one chip can be expressed as

$$U_n(t) = \sum_{i=0}^{K-1} a_{(n-i)\bmod N} p_i(t) \qquad n = 0,1,2,\ldots,N-1 \tag{13}$$

where N is the spread factor, i. e., the code length, $a_{(n-i)\bmod N}$ is the modular operation, $a_i (i=0, 1, \ldots, N-1)$ is the code element.

In Eq. (13), each chip is expressed as multi-path accumulating; that is, the effect of other chips on the current chip has been grouped together. So Eq. (7) can be changed into

$$E_b = \int_0^{T_b}\Big\{\sum_{i=0}^{N-1}\Big[U_{a,i}(t-i\tau_c)\Big]^2\Big\}dt + \int_0^{T_b} n(t)\Big[\sum_{i=0}^{N-1} a_i U_{a,i}(t-i\tau_c)\Big]dt + \int_0^{T_b}\Big\{\sum_{j=1}^{M}\sum_{i=0}^{N-1}\Big[U_{b_j,i}(t-i\tau_c) U_{a,i}(t-i\tau_c)\Big]\Big\}dt \tag{14}$$

where $U_{a,j}(t)$ is the j-th chip of user A, and $U_{b_j,i}(t)$ is the j-th chip of user b_j.

Define the interference signal ratio as

$$R = \frac{\int_0^{T_b}\Big\{\sum_{j=1}^{M}\sum_{i=0}^{N-1}[U_{b_j,i}(t-i\tau_c) U_{a,i}(t-i\tau_c)]\Big\}dt}{\int_0^{T_b}\Big\{\sum_{i=0}^{N-1}[U_{a,i}(t-i\tau_c)]^2\Big\}dt} \tag{15}$$

Using Eq. (15), we select Gold code and random binary sequence (equal probability). Suppose 2 Mbit/s baseband data rate for each user code, using the IEEE CM1-CM4 channel models[11], the Monte Carlo calculation value of Eq. (15) is between

$$R \in (0,\ 0.05) \tag{16}$$

The results indicate that the interferences between chips are not serious in the supposed conditions. Although the response waveforms of CM1-CM4 channels vary greatly, the performance of receiver with ideal channel estimation is quite close. The whole system simulation confirmed the conclusion. In contrast, Fig. 4 and Fig. 5 show the BER curve. Fig. 4 indicates Gold sequence as user codes with code length $N=63$. Fig. 5 indicates random binary sequence as user codes with the same code length $N=63$. The two figures are both the simulation results under 3-user conditions.

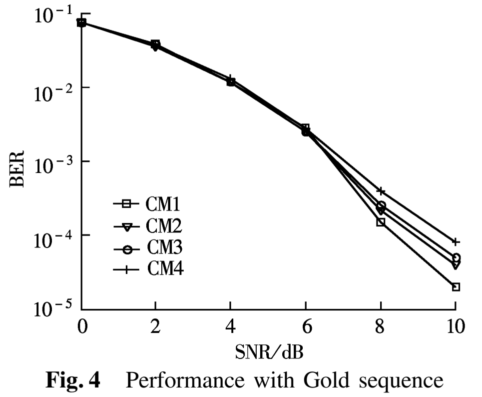

Fig. 4 Performance with Gold sequence

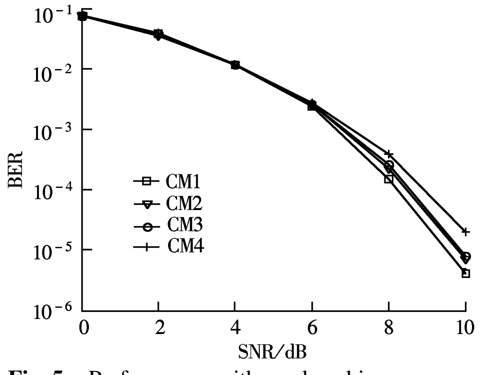

Fig. 5 Performance with random binary sequence

It can be seen that the results are similar when adopting Gold or random binary sequence. It indicates that, with the above channel conditions and parameters, if the orthogonal user codes are random and equal probability, the receiver's performance is quite similar.

In contrast, Fig. 6 shows the BER curve of Gold sequence and random binary sequence in channel CM1 and CM4.

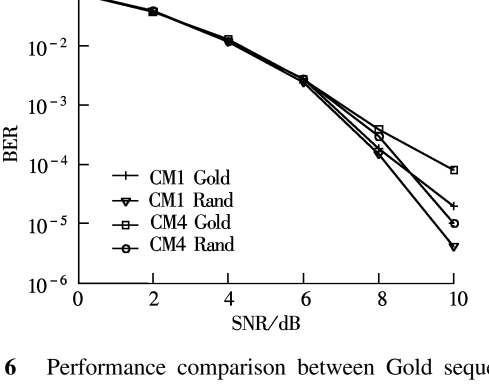

Fig. 6 Performance comparison between Gold sequence and random binary sequence

2 Performance of Rake Receiver

In our simulation system, low a duty cycle pulse is adopted. It is propitious to collect multi-path energy. Although we can use a low duty cycle to reduce interference between chips, the channel response is so long that it causes severe interference between chips. It is necessary to know how many paths are needed to reach the receiver's performance. There will be tradeoff between system and receiver cost.

Fig. 7 shows the simulation results under the system conditions of three users, Gold sequence, and CM2 channel. It indicates that proper receiving paths can reach the performance.

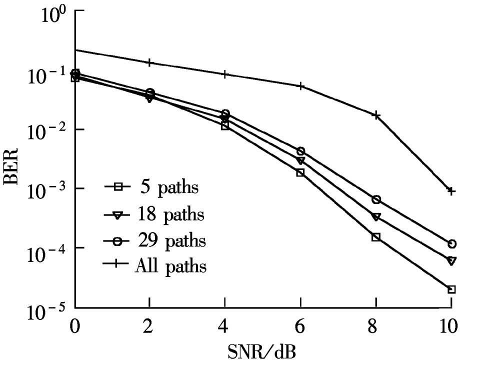

Fig. 7 Performance of Rake receiver in CM2 channel

Suppose that there is a path within a chip interval. Then the statistical results show that channel model CM2 can be divided into two sections according to the receiving energy. The first section is the main energy section from path 1 to path 18 which concentrates most of the energy of the channel response. The second section from path 19 to path 29 contains lower energy. Energy of paths beyond the 30th path can be omitted.

From Fig. 7, it need only receive the main energy so that the system can achieve quite good performance. The result provides reference to receiver design under this channel circumstance.

It can also be concluded from Fig. 7 that when the received paths are not numerous enough, the performance is poor (e. g. 5 paths in Fig. 7). When main energy is received (18 paths in Fig. 7), the performance is improved greatly. Furthermore, when main energy and sub-energy are both received (29 paths in Fig. 7), the performance is close to that of the ideal receiver (all paths in Fig. 7).

3 Conclusion

The UWB wireless communication system has a special channel that has a dense multi-path feature. The selection of orthogonal user codes does not affect system performance deeply under the condition of low duty cycle. The simulation results indicate that user codes which have random feature are similar in performance and orthogonal codes can achieve the best performance. As for the receiver, it does not need to acquire energy from all paths. The proper selection of receiver taps will simplify the design of receiver structure and maintain system performance.

References

[1] Bi C, Hui J. Multiple access capacity for ultra-wide band radio with multi-antenna receivers[A]. In: *Proceedings of the IEEE Conference on Ultra Wideband Systems and Technologies* [C]. Maryland, USA, 2002. 151 – 155.

[2] Zhang J, Kennedy R, Abhayapala T. New results on the capacity of *M*-ary PPM ultra-wideband systems[A]. In: *Proceedings of the IEEE International Conference on Communications* [C]. Anchorage, USA, 2003. 2867 – 2871.

[3] Pasand R, Nielsen J, Sesay A. Capacity of PPM ultra-wideband communications with inter pulse interference [A]. In: *Proceedings of the IEEE Canadian Conference on Electrical and Computer Engineering*[C]. Toronto, Canada, 2004. 2355 – 2358.

[4] Nassar C, Zhu Fang, Wu Zhiqiang. Direct sequence spreading UWB systems: frequency domain processing for enhanced performance and throughput[A]. In: *Proceedings of the IEEE International Conference on Communications* [C]. Anchorage, USA, 2003. 2180 – 2186.

[5] Canadeo C, Temple M, Baldwin R, et al. Code selection for enhancing UWB multiple access communication performance using TH-PPM and DS-BPSK modulations[A]. In: *Proceedings of the IEEE Wireless Communications and Networkings*[C]. New Orleans, USA, 2003. 678 – 682.

[6] Guvene I, Arslan H. Design and performance analysis of TH sequences for UWB-IR systems[A]. In: *Proceedings of the IEEE Wireless Communications and Networkings* [C]. Atlanta, USA, 2004. 914 – 919.

[7] Ramirez-Mireles Fernando. On the capacity of UWB over multipath channels [J]. *IEEE Communications Letters*, 2005, **9**(6): 523 – 525.

[8] Win Moe Z, Scholtz Robert A. Ultra-wide bandwidth time-hopping spread-spectrum impulse radio for wireless multiple-access communications [J]. *IEEE Trans Commun*, 2000, **48**(4): 679 – 690.

[9] Li Qinghua, Leslie A. Multiuser receivers for DS-CDMA UWB[A]. In: *Proceedings of the IEEE Conference on Ultra Wideband Systems and Technologies*[C]. Maryland, USA, 2002. 163 – 168.

[10] Taha Ali, Chugg Keith M. On designing the optimal template waveform for UWB impulse radio in the presence of multipath[A]. In: *Proceedings of the IEEE Conference on Ultra Wideband Systems and Technologies*[C]. Maryland, USA, 2002. 41 – 46.

[11] Foerster Jeff. Channel modeling sub-committee report final[R]. USA: IEEE Press, 2002.

直扩超宽带系统在室内密集多径下的多址性能

樊祥宁　倪剑强　毕光国

（东南大学移动通信国家重点实验室，南京 210096）

摘要：分析了脉冲方式直扩二相相移键控超宽带无线通信系统在室内多用户和密集多径环境下用户码对系统性能的影响，推导了采用 Rake 接收时系统的输出信号，并为直扩超宽带系统提供了一种简单而切实可行的用户码方案，即：在大的脉冲波形占空比的条件下，直接选用码长足够长的、具有良好的互相关正交特性的随机或伪随机用户码即能使脉冲方式直扩超宽带无线系统获得接近最佳的性能，从而不必精心设计和选择用户码. 仿真了 Rake 接收时 CM1 ~ CM4 多径信道下采用 Gold 序列与随机二进制 PN 序列作为用户码时的多用户性能，验证了提出的用户码方案的可行性.

关键词：超宽带；多用户；多径；Gold 码；直接序列；Rake

中图分类号：TN92