Adaptive Modulation Method using Non-Line-of-Sight Identification Algorithm in LDR-UWB Systems

Lin Chuan Ma*, Jae Ho Hwang*, Nack Hyun Choi* ***Associate Members,***
Jae-Moung Kim* ***Lifelong Member***

ABSTRACT

Non-line-of-sight (NLOS) propagation can severely weaken the accuracy of ranging and localization in wireless location systems. NLOS bias mitigation techniques have recently been proposed to relieve the NLOS effects, but positively rely on the capability to accurately distinguish between LOS and NLOS propagation scenarios. This paper proposes an energy-capture-based NLOS identification method for LDR-UWB systems, based on the analysis of the characteristics of the channel impulse response (CIR). With this proposed energy capture method, the probability of successfully identifying NLOS is much improved than the existing methods, such as the kurtosis method, the strongest path compare method, etc. This NLOS identification method can be employed in adaptive modulation scheme to decrease bit error ratio (BER) level for certain signal-to-noise ratio (SNR). The BER performance with the adaptive modulation can be significantly enhanced by selecting proper modulation method with the knowledge of channel information from the proposed NLOS identification method.

Key Words : Ultra-wideband, NLOS Identification, Energy Capture, Adaptive Modulation, CIR

Ⅰ. Introduction

Ultra-wideband (UWB) radio technology is a promising candidate for the next generation wireless communication systems in virtue of its excellent merits such as high data rates, lowequipment cost, multi-path fading immunity, ranging and communication simultaneously, etc. These promising features allow a new scope of applications of UWB technique, including military applications, medical applications, supervision of children, search-and-rescue, control of home applications, logistics and security applications[1-4].

UWB technology is suitable for ranging and localization as a result of its ultra wide bandwidth. In the ranging and localization systems, the key issue is how to attain the reasonable and more accurate ranging results with certain ranging method, such as Time-of-arrival (ToA), Time-difference-of-arrival (TDoA), etc. All these ranging methods should calculate the delay time of the transmitted signal in the receiver. Since NLOS error is considered as the major error source in wireless localization systems, some researchers are dedicated to eliminate the NLOS effects, which is based on identifying the NLOS circumstances firstly. The NLOS mitigation methods can improve the accuracy of ranging and localization.

NLOS identification and mitigation have been discussed in cellular network area detailedly [5-9][12-14]. For instance, paper [5] shows a decision-theoretic NLOS identification framework with various hypothesis tests based on known and unknown probability density functions (PDFs) of the ToA measurements. The NLOS error identification

※ 본 연구는 2006년도 정부(과학기술부)의 재원으로 한국과학재단의 국가지정연구실사업으로 수행되었음. (No. M10600000194-06J0000-19410).
※ 본 연구는 지식경제부 및 정보통신연구진흥원의 대학IT지원센터 지원사업의 연구결과로 수행되었음. (IITA-2008-C1090-0801-0019)
* 인하대학교 정보통신대학원 무선전송연구실(anlala85@hotmail.com,hoho3676@naver.com,nack0082@naver.com, jaekim@inha.ac.kr)
논문번호 : KICS2008-08-376, 접수일자 : 2008년 8월 28일, 최종논문접수일자 : 2008년 10월 27일

and correction techniques are proposed for mobile user location in wireless cellular systems in [6], grounded on how much a prior knowledge of the NLOS error is available. Two NLOS mitigation algorithms are advanced: the NLOS state estimation algorithm and the improved residual algorithm. Furthermore in [7], a suitable distance metric between a known measurement error distribution and a non-parametrically estimated distance measurement distribution are defined to estimate whether a given base station is within LOS or NLOS transmission. All these methods assume the mobile station is moving and the channel circumstances between the base station and the mobile station are time-varying. Nevertheless, in LDR-UWB systems, the variances does not vary much since the environments are mostly residential, indoor office and industrial environments, which makes it much harder to separate NLOS and LOS environments according to this information. In such a case, we need to find other method to identify NLOS when the environment does not vary a lot between base station and mobile station.

Lately, the strongest path comparing method in [8] utilizes the percentage of the energy of the strongest part occupying the total energy of the received signal to determine whether the tested channel is NLOS or LOS. Moreover in [9], the statistics of the CIRs have been analyzed and the integration of kurtosis of the CIRs, mean excess delay and RMS delay spread of the power delay profile are contributed to NLOS identification.

In this paper, we propose an energy capture method to acquire the information of the amplitude and delay spread of the received signals, founded on analyzing the characteristics of CIRs in LDR-UWB systems. Meanwhile, LDR-UWB communication requires the channel information to perform adaptive modulation to enhance BER performance. According to the channel information obtained by NLOS identification dynamically, UWB systems can improve BER performance by choosing the proper modulation, effectively.

This paper is organized as follows. Section Ⅱ minutely presents the existing NLOS identification algorithms and proposed energy capture method. Subsequently, an application in adaptive modulation scheme with this proposed method is amply described in section Ⅲ. The simulation results which compare these NLOS detection algorithms and BER performance with the adaptive modulation are expounded in section Ⅳ. Finally, section Ⅴ concludes this paper.

Ⅱ. NLOS Identification

In this paper, we mainly consider the NLOS identification algorithms which are based on the analysis of the CIRs. In order to compare the performance of the existing NLOS identification methods and the proposed one, the investigated NLOS detection algorithms includes the kurtosis method, the mean excess delay and RMS delay, strongest path comparison, and the energy capture method, respectively. The first three have been explained in the literature, the last one is newly proposed by us.

2.1 Kurtosis of the multipath channel

The kurtosis method exploits to capture the amplitude of multipath channel. Since the kurtosis value characterizes how peaky a sample data, it is more likely that the received signal is LOS for a CIR with high kurtosis values. The kurtosis value is calculated by the following formula for a certain channel h(t):

$$k=\frac{E[(|h(t)-\mu_{|h|}|)^4]}{E[(|h(t)|-\mu_{|h|})^2]^2} \qquad (1)^{[9]}$$

where $\mu_{|h|}$ is the mean of $|h(t)|$.

The kurtosis method can distinguish between residential, indoor office or industrial environments effectively if UWB systems could wisely choose the appropriate thresholds and the SNR should be large enough to calculate the kurtosis value of the received signal. However, the kurtosis can not availably separate NLOS and LOS conditions in outdoor environments since the dispersion of the CIRs of outdoor environments.

2.2 Delay spread of the multipath channel

The mean excess delay and RMS delay spread are the delay indexes of the power delay profile of wireless communication systems, which can be considered as the methods to distinguish between NLOS and LOS environments. The mean excess delay is the first moment of the power delay profile which is defined to be:

$$\tau_m = \frac{\int_{-\infty}^{\infty} t|h(t)|^2 dt}{\int_{-\infty}^{\infty} |h(t)|^2 dt} \quad (2)^{[9]}$$

RMS delay spread is the square root of the second central moment of the power delay profile which is defined as:

$$\tau_{rms}^2 = \frac{\int_{-\infty}^{\infty} (t-\tau_m)^2 |h(t)|^2 dt}{\int_{-\infty}^{\infty} |h(t)|^2 dt} \quad (3)^{[9]}$$

2.3 Strongest path comparison method

Some one advances the strongest path comparison method utilizing the sliding window and energy detection in each window, and then setup a threshold to distinguish NLOS and LOS conditions.[8] In summary, this NLOS identification is achieved by:

$$\frac{\max|h(t)|^2}{\int_{-\infty}^{\infty} |h(t)|^2 dt} \underset{H_1}{\overset{H_0}{\gtrless}} \xi \quad (4)$$

where $0 \le \xi \le 1$ is a threshold set on the normalized strongest path. The selection of the thresholds is critical for balanced identification success probabilities of the LOS and NLOS channels. Even with a reasonable threshold setting, this method can not achieve a precise success probability of NLOS identification.

2.4 Energy Capture Method

With a view to distinguish the NLOS and LOS circumstances effectively, we propose an energy capture method which considers the diversification of the amplitude and delay spread of the transmitted signal caused by channel. The proposed NLOS identification method -- Energy Capture Method will be described in the following part.

Refer to the CIRs of LDR-UWB channel models, we analyze the difference of channel responses in LOS and NLOS cases. Firstly, the energy densities in NLOS and LOS cases are differentia since the primary energy concentrates on a few samples for LOS cases. However, for the NLOS cases, the significant portion energy of

received signal disperses in more samples due to the NLOS effects. Secondly, the maximum delay

spread of the transmitted signal for LOS cases is much shorter than that of NLOS cases (see table 1), since the NLOS case will expend the signal delay spread caused by multipath effect, by calculating the ratio of the number of paths that occupy certain percentage of the total energy of the received signal to the total number of paths of the received signal. The system blocks and the flow chart of this NLOS identification approach are shown in Figure 1 and 2, respectively. In the capture method is implemented for channel Identification (NLOS or LOS environment).

Table 1. Maximum delay spread of LDR-UWB channel models

Channel	Maximum delay spread	Channel	Maximum delay spread
Residential LOS	~100ns	Residential NLOS	~150ns
Indoor Office LOS	~ 98ns	Indoor Office NLOS	~110ns
Outdoor LOS	~ 220ns	Outdoor NLOS	~650ns
Industrial LOS	~ 80ns	Industrial NLOS	~700ns

For carrying out the energy capture method, we calculate the energy of each sample of received signal at first, and then count the total energy of the received signal. Then we compute the number of samples that occupy $m\%$ percentage of the total received energy. Therefore, a parameter ξ can be calculated by:

$$\xi = \frac{x}{L_{total}} \quad (5)$$

where ξ is the parameter to identify NLOS or LOS condition of the tested channel, it is the number of samples that captures $m\%$ of total NLOS identification part of Figure 2, the energy received energy. L_{total} is the total length of the received signal. If the parameter ξ is greater than the threshold, the tested environment is deemed as NLOS, and if

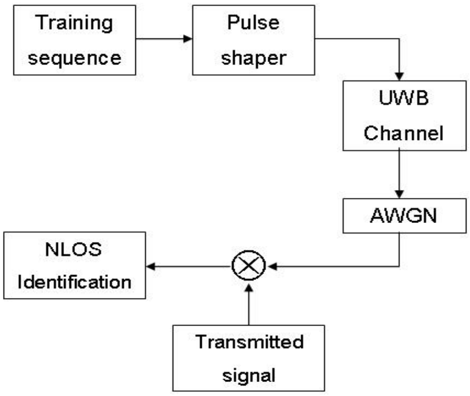


Fig. 1. System blocks for the proposed energy capture method

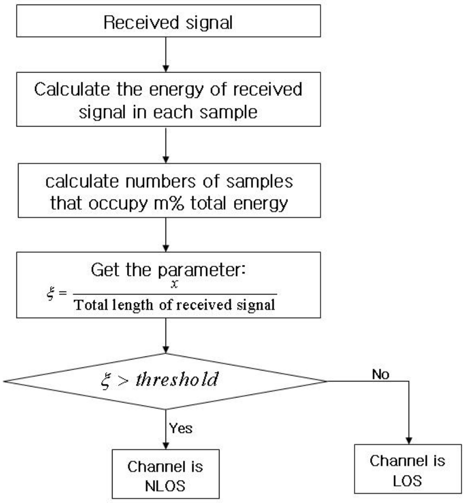


Fig. 2. Flowchart of the proposed energy capture method

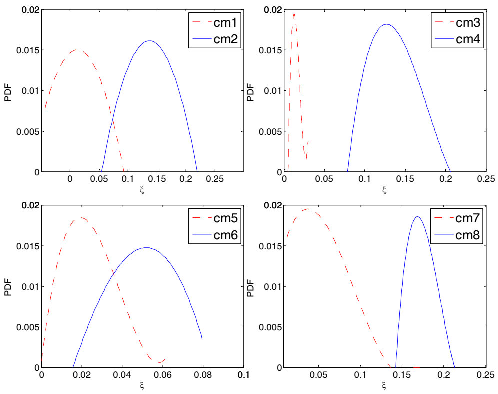


Fig. 3. The logarithm of ξ for CM1 to CM8 in LDR-UWB channel models

otherwise, LOS condition.

The PDFs of the parameter ξ can be achieved for both LOS and NLOS scenarios employing the system blocks in Figure 1, and the logarithms of ξ for the eight circumstances are depicted in Figure 3. Obviously, this energy capture algorithm can distinguish between NLOS and LOS cases effectively expect for CM5 (Outdoor LOS) and CM6 (Outdoor NLOS). The reason for this phenomena might be the highly dispersive characteristics of outdoor environments. Therefore, in order to get a more comprehensive NLOS identification for all eight channels, and whereas the mean excess delay method achieves higher identification percentage in CM5 and CM6, we integrate the proposed energy capture method with mean excess delay method to identify NLOS and LOS environments in different environments.

In [9], a joint method of kurtosis, mean excess delay and RMS delay is proposed for NLOS identification. This joint method combines the three methods together to achieve a higher success probability of identifying NLOS environments. Nevertheless, the success identification probability is still not high enough, especially for residential environments. Therefore, we propose to employ the proposed energy capture method combining with the RMS delay method as a new joint method to identify NLOS conditions.

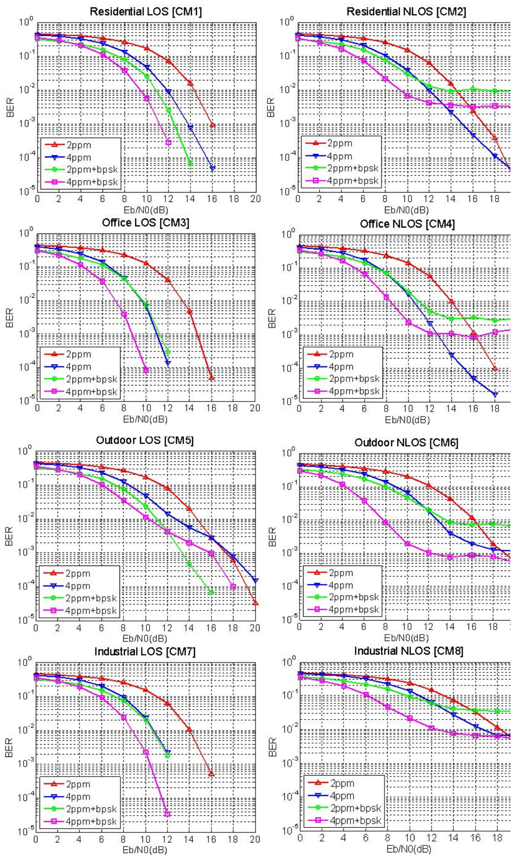
For getting the joint PDF of the energy capture and mean excess delay, to be simple, we assume the parameters from the two methods are independent. Since the joint PDF is difficult to achieve, the sub-optimal new joint PDF can be expressed as:

$$PDF_{joint} = \frac{PDF^{EC}_{los}}{PDF^{EC}_{nlos}} \times \frac{PDF^{MED}_{los}}{PDF^{MED}_{nlos}} \qquad (6)^{[9]}$$

where PDF^{EC}_{los}, PDF^{EC}_{nlos}, PDF^{MED}_{los}, PDF^{MED}_{nlos} are the PDFs of energy capture method and mean excess delay method in LOS and NLOS situation, respectively.

Ⅲ. Adaptive Modulation Algorithm

In LDR-UWB transmissions, the systems attempt to minimize the cost function by minimizing BER with an appropriate modulation. Position modulation



Fig, 4. BER performance with coherent 2PPM/4PPM and non-coherent 2PPM/4PPM in CM1 to CM8.

based on intensity modulation and direct detection, is a very suitable modulation scheme for LDR-UWB transmission since it is easy to implement data compression and error correction, and small duty-cycle pulse transmission (low power transmitter)[10]. Hence M-array PPM is employed here. For LDR-UWB systems, BER with the same modulation scheme can not achieve the best performance for all environments. The fact can be proved in Figure 4, the coherent PPM is always better than the non-coherent PPM in LOS environments (CM1,3,5,7) in respect that the

coherent modulation considers both phase diversification and position variety. Nevertheless,

for NLOS environments, such as CM2,4,6,8, the multipath effect will impact the phase of transmitted signal a lot, which makes the coherent

PPM worse than the non-coherent PPM. Hence, if

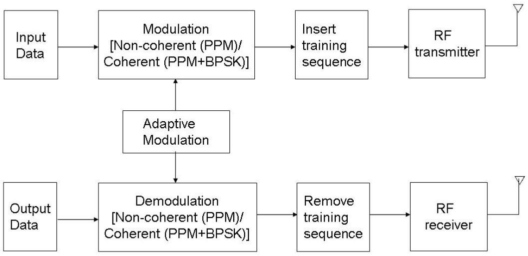


Fig. 5. System blocks for adaptive modulation scheme in UWB transmissions

UWB system can adaptively alter the modulation method according to the channel condition, it may meet various quality of service(QoS) constraints.

The system blocks for adaptive modulation are shown in Figure 5. In the adaptive control part, we utilize the channel information from the proposed new joint NLOS identification method. Therefore the BER performance can be enhanced by dynamically choosing the adaptive modulation.

Ⅳ. Simulation Results and Discussion

4.1 Simulation results for NLOS identification

4.1.1 Test rules

If a prior knowledge of the statistics of our selected parameter is available under the NLOS and LOS scenarios in a certain channel, the hypothesis tests can be utilized to perform NLOS identification. Let $PDF_{los}(\xi)$ and $PDF_{nlos}(\xi)$ are the values of PDFs of ξ in LOS and NLOS under the same ξ, respectively. Then with a given channel realization *h(t)*, the likelihood test for LOS/NLOS identification is presented by:

$$\frac{PDF_{los}(\xi)}{PDF_{nlos}(\xi)} \underset{H_1}{\overset{H_0}{\gtrless}} 1 \qquad (7)$$

where H_0 and H_1 stand for the tested channel is LOS or NLOS condition, respectively.

4.1.2 Performance comparison

For establishing the scenario close to real case implementation of the proposed new joint method (energy capture method and mean excess delay), the signal, which consists of pulses with bandwidth of

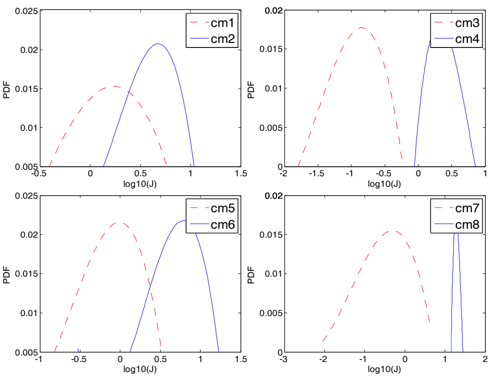


Fig. 6. The logarithm of new joint parameter in CM1 to CM8 of LDR-UWB channel models

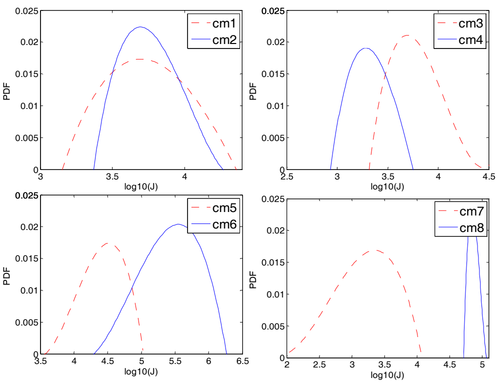


Fig. 7. The logarithm of joint parameter in [9] for CM1 to CM8 of LDR-UWB channel models

500MHz, is selected as the source. Meanwhile the IEEE 802.15.4a channel models (LDR-UWB) is used.[11] We utilize 100 channel realizations for CM1 to CM8, with central frequency of 6GHz and sampling frequency of 0.5GHz.

Figure 6 shows the logarithms of new joint parameter in different environments. And Figure 7 presents logarithms of joint parameter of kurtosis, mean excess delay and RMS delay in different environments. By all appearances, the new joint

method can differentiate NLOS and LOS channels more effectively and accurately than the joint method of kurtosis, mean excess delay and RMS delay.

For each channel realization, we apply the likelihood test given in (7), and calculate the percentage of correctly identified scenarios. 2 tabulates both LOS and NLOS identification

Table 2. LOS/NLOS Identification Percentages(%)

Channel Model	**Energy Capture**	Kurtosis	Mean excess delay	RMS delay	Strongest Path Compare	Joint (K,MED, RMS)	Joint (EC,MED)
Residential LOS (CM1)	**88.4**	80	63.6	62.1	68.5	80.4	**90.2**
Residential NLOS (CM2)	**87.1**	79.1	62.3	75.4	68	78.7	**89.3**
Indoor Office LOS (CM3)	**99.5**	99	88.9	72.3	81.8	98.3	**99.7**
Indoor Office NLOS (CM4)	**98.1**	97.2	87	88	78.1	95.9	**99.1**
Outdoor LOS (CM5)	**73.5**	62.5	98.9	91.5	79.9	97.5	**98.7**
Outdoor NLOS (CM6)	**76**	58.1	99.5	89.4	78	98.2	**99.8**
Industrial LOS (CM7)	**99.5**	98.3	89.4	97.2	99.8	93.4	**100**
Industrial NLOS (CM8)	**99.4**	95.3	99.7	97	97.6	97.8	**100**

percentages of the seven techniques. It can be seen that the energy capture method is better than kurtosis method in all cases. Thereby, the new

joint method can provide even more accurate information than the joint method in [9].

4.2 Simulation results for adaptive modulation scheme

With the channel information from new joint NLOS identification method, UWB systems can determine the appropriate modulation method according to the current channel environment. It is obvious, from Figure 4, that BER performance with coherent modulation can reach lower level than that with non-coherent modulation in LOS conditions, nevertheless, BER with noncoherent modulation is better than that with coherent modulation in NLOS conditions.

In the simulation, we firstly employ the proposed NLOS identification to identify the current channel environment, and then according to this information, choose the proper modulation scheme for UWB transmission. The rule for selecting the modulation scheme is that if the current channel is identified as the LOS environment, UWB system choose coherent 4PPM/2PPM as the modulation method, otherwise if the current channel is estimated as the NLOS environment, UWB systems employ non-coherent 4PPM/2PPM to modulate the transmitted information.

The simulations with adaptive modulation scheme in residential, indoor office, outdoor and industrial environments are shown in Figure 8 and 9. In this simulation, the environments are all mixed with almost half of NLOS and half of LOS conditions. Such as the residential environments, it consists of

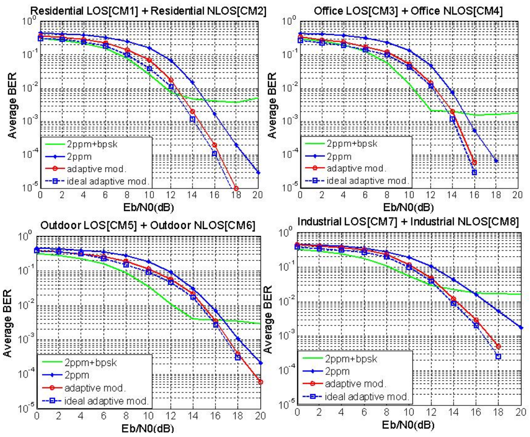


Fig. 8. BER performance with fixed modulation (coherent 2PPM/noncoherent 2PPM) and adaptive modulation in mixed environments [NLOS+LOS]

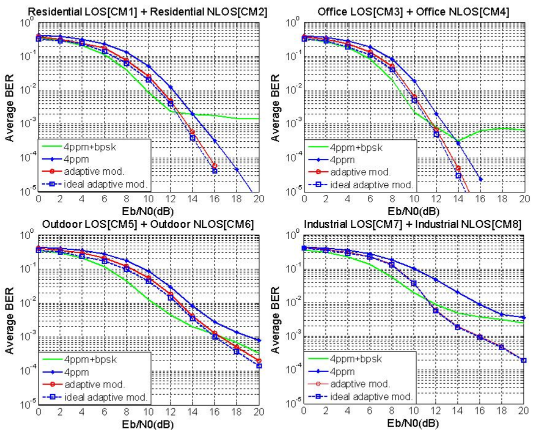


Fig. 9. BER performance with fixed modulation (non-coherent 4PPM/coherent 4PPM) and adaptive modulation in mixed environments [NLOS+LOS]

almost half percentage of residential LOS environments and the residual

percentage of residential NLOS environments, which is satisfied with the time-varying channel changing between NLOS and LOS. We also consider the ideal case that we can employ the new joint NLOS identification method with the success identification probability of 100% in this simulation.

At the target BER of 10^{-4}, the adaptive modulation can improve almost SIR of 1dB in all cases than just with fixed noncoherent 2PPM. Meanwhile, the BER with coherent 4PPM, non-coherent 4PPM and adaptive modulation in different NLOS/LOS pairs are shown in Figure 9.

Adaptive modulation also choose coherent 4PPM for LOS conditions and noncoherent 4PPM for NLOS conditions with the channel information from new joint NLOS identification method. Evidently, the adaptive modulation could enhance the BER performance effectively. Furthermore, the fact that all the BER performance are so close to the that of the ideal case proves that this new joint NLOS identification method could availably improve the BER performance in LDR-UWB systems.

V. Conclusions

In this paper, we propose an appropriate NLOS identification method with the knowledge of the characteristics of CIRs in LDR-UWB systems. Then we apply this joint NLOS identification method to the adaptive modulation scheme in a control part to improve the BER performance. Thanks to this joint NLOS identification method, an enhanced BER performance can be achieved in different channel environments. Furthermore, the proposed joint NLOS identification method can be applied in ranging and localization systems for accurate ranging and positioning.

References

〔1〕 M. Z. Win and R. A. Scholtz; "On the robustness of ultra-wideband signals in dense multipath environments"; IEEE Communication Letters, Vol.2, No.2, pp.51-53,1998.

〔2〕 M. Z. Win and R. A. Scholtz; "Characterization of ultra-wide bandwidth wireless indoor channels: a communication-theoretic view"; IEEE Journal on Selected Areas in Communications, Vol.20, No.9, pp.1633-1627, 2002.

〔3〕 D.Cassioli, M. Z. Win, and A. F. Monlisch; "The ultra-wide bandwidth indoor channel: from statistical model to simulations"; IEEE Journal on Selected Areas in Communications, Vol.20, No.6, pp.1247-1257, 2002.

〔4〕 A. F. Monlisch, D. Cassioli, C.-C. Chong, et al.; "A comprehensive standardized model for ultrawideband propagation channels"; IEEE Transaction on Antannas and Propagation, Vol. 54, No.11, pp.3151-3166, 2006.

〔5〕 J. Borras; P. Hatrack; N.B. Mandayam; "Decision theoretic framework for NLOS identification"; 1998 *Vehicular Technology Confe-rence, (VTC 98)*, May 1998, Vol.2, pp.1583-1587. 48th IEEE.

〔6〕 L. Cong; Zhuang Weihua; "Non-line-of-sight error mitigation in TDOA mobile location"; in Proc. *IEEE conference on computer communications (INFOCOM)*, Hong Kong, Ma. 2004, pp.650-659.

〔7〕 S.Gezici, H.Kobayashi, and H.V.Poor; "Non-parametric non-light-of-sight identification"; Proc. *IEEE Vehic Technol. Conference. (VTC)*, Vol.4, Orlando, FL, Otc.2003, pp.2544-2548.

〔8〕 A. Rabbachin; I. Oppermann; B. Denis; "ML Time-of-Arrival estimation based on low complexity UWB energy detection"; in Proc. IEEE *International Conference on Ultrawideband (ICU- WB)*, Waltham, MA, Sept. 2006, pp.598-604.

〔9〕 I. Guvenc; Chong Chia-Chin; F. Watanabe; "NLOS identification and mitigation for UWB localization systems"; *Wireless Communications and Networking Conference, 2007.* IEEE.

〔10〕 N. J. August, R. Thirugnanam, Ha Dong Sam; "An adaptive modulation scheme for optimization of energy, BER, and data rate"; Joint with Conference on Ultrawideband Systems and Technologies, 2004. pp.182-186.

〔11〕 A.F. Molisch, K. Balakrishnan, D. Cassioli, et al.: "IEEE 802.15.4a channel model – final report"; *Technical Report, IEEE 802.15-01-1662-01- 04a*, September 2004.

〔12〕 M. Tuchler and A. Huber; "An improved algorithm for UWB-based positioning in a multipath environment"; *International Zurich Seminar on Communications*, Zurich, Switzerland, 2006.

〔13〕 R. Caas, A. Marco, J.J. Guerrero, and H. Falco; "Robust Estimator for Non-Line-of-Sight Error Mitigation in Indoor localization" *Eurasip J. Applied Sig. Processing*, pp.1-8, 2006.

〔14〕 Chin-Der Wann; Chih-Sheng Hsueh; "NLOS mitigation with biased kalman filters for range estimation in UWB systems" *TENCON 2007 -* 2007 IEEE Region 10 Conference.

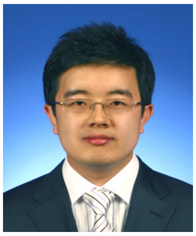
마 림 천 (Lin Chuan Ma) 준회원

2007년 2월 허베이대학교 정보컴퓨터공학과 졸업
2007년 3월~현재 인하대학교 정보통신대학원 석사과정
<관심분야> UWB, 무선인지기술

황 재 호 (Jae Ho Hwang) 준회원

2006년 2월 인하대학교 전자공학과 졸업
2008년 2월 인하대학교 정보통신 대학원 석사과정
2008년 3월~현재 인하대학교 정보통신대학원 박사과정
<관심분야> UWB, 무선인지기술

최 낙 현 (Nack Hyun Choi) 준회원



2007년 2월 인하대학교 컴퓨터공학과 졸업
2007년 3월~현재 인하대학교 정보통신대학원 석사과정
<관심분야> UWB, 무선인지기술

김 재 명 (Jae Moung Kim) 종신회원

1974년 2월 한양대학교 전자공학과 졸업
1981년 8월 미국 남가주대학교 (USC) 전기공학과 석사
1987년 8월 연세대학교 전자공학과 박사
1974년 3월~1979년 6월 한국과학기술연구소, 한국통신기술연구소 근무
1982년 9월~2003년 3월 한국전자통신연구원 위성통신연구단장 / 무선방송연구소 소장 역임
2003년 4월~현재 인하대학교 정보통신대학원 원장/교수, 현재 통신위성 우주산업연구회 회장 외 기술자문으로 다수 활동 중
<관심분야> 광대역 무선전송, 이동통신 및 위성통신, Cognitive Radio 및 UWB 무선통신분야