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Time Domain DS-UWB Channel Estimation using Maximum Likelihood Algorithm

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Abstract: This study proposed a direct sequence ultra-wideband (DS-UWB) channel estimation method using Maximum Likelihood algorithm for the indoor dense multi-path UWB channel of preamble structure suggested in the proposal of IEEE P802.15.TG3a. The Normalized Mean Square Channel Estimation Error (NMSCEE) is employed to measure the performance of the estimation method. The effect of the estimation performance influenced by different assisted-pilot numbers and the different Gaussian waveforms as UWB monocycle is discussed in different SNR conditions. Due to Federal Communications Commission (FCC)'s limits, the order of the derivative Gaussian pulse should be 5 of more. The simulation results show that the estimation algorithm can achieve satisfying performance with 60 as the pilot number. And when the pilot number is less than 50, the fifth order Gaussian pulse is the best choice. If the pilot number is more than 50, the ninth order Gaussian pulse is suitable. The results can be as the references and the basis for the practical UWB system.

Key words: DS-UWB, channel estimation, ML criterion, pilot sequence, estimation error

INTRODUCTION

Ultra Wideband (UWB) transmission is a Spread Spectrum (SS) system that is currently receiving great attention since it is a candidate for the physical layer of several applications like sensor networks and high rate Wireless Personal Area Networks (WPAN) (Yang and Giannakis, 2004). The direct sequence ultra-wideband (DS-UWB) technology has many appealing features, such as less complex hardware, high data transmission speed, low power, wide bandwidth, high multi-path resolution, as well as high-precision ranging capability (Win and Scholtz, 2000) and it is one available candidate for future short-range indoor radio communication systems (Fontana, 2004).

For the practical application of the UWB technology, channel estimation is a key technology that must be addressed (Zhaogan *et al*., 2007). According to whether using the pilot sequence, the DS-UWB system estimation algorithm can be divided into blind channel estimation and non-blind channel estimation. The maximum likelihood estimation (ML) algorithm (Lee, 2010) and the Least Squares (LS) algorithm are the most common algorithms. ML algorithm is widely used for its low complexity, low SNR and high precision. In Dilmaghani *et al.* (2004), a reverse system is employed and the flat elliptical wave is used as the input pulse. Although this method has a relatively high accuracy, it can not estimate the channel delay. So, the delay estimation must employ the other devices, which will increase the system complexity. In Alizad *et al.* (2005), a new UWB channel estimation method is provided, which uses the training sequence to design a compression filter and uses it as the input signal to get the impulse response. The performance of this method is better, but it requires a matching filter, a sampling device and a compression filter. All of these will increase the complexity of the algorithm and the system. In Ertin *et al.* (2001), the techniques of maximum-likelihood estimators of the channel parameters are proposed under the assumption of the presence of a training sequence. In Zheng and Xiao (2009), Takeda and Adachi (2005), the improved algorithms of frequency domain equalization is provided, which have a good performance in channel estimation. In addition, music algorithm is a good choice for the channel estimation as is proposed in Yung *et al.* (2001).

In this study, we employ the ML algorithm to estimate DS-UWB channel and analyze the performance of the ML algorithm. The estimation performance influenced by different assisted-pilot numbers and the different Gaussian monocycle is discussed in different SNR conditions.

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SYSTEM MODEL

DS-UWB signal model: For the DS-UWB systems, the signal is generated usually through the following processes: first, the pseudo-random code or binary PN code to is applied to code the sending binary code sequences; second, the narrow pulse is modulated by amplitude. And the emission signal can be expressed as (Yi *et al*., 2008):

$$s(t)=\sum_{j=-\infty}^{\infty}\sum_{n=0}^{N_s-1} d_j g_n p(t-jT_f-nT_c) \tag{1}$$

where, $d_j \in \{-1, +1\}$ is the user's binary information symbols, $g_n \in \{-1, +1\}$ is the user's pseudo-random code sequence, $R_s = 1/T_s$ is data rate and $T_s = N_s T_f$ is symbol period, then each binary data symbol is expressed by N_s single pulses.

S-V channel model: Channel model is used to represent the wireless transmission characteristics in a given environment. Signal propagation environment is one of the main factors to affect the performance of the wireless communication. So, it is important to estimate an accurate channel model for the transmission system, such as antenna diversity, equalization, coding and performance analysis issues.

S-V model based on this observation: Typically, the pulse from the same multi-path arrived at the receiver in the form of cluster. The arrival time of the cluster is modeled as a Poisson process with the rate of Λ:

$$p(\tau_{nk} \mid \tau_{(n-1)k}) = \Lambda e^{-\Lambda(T_n-T_{n-1})} \tag{2}$$

where, T_n and T_{n-1} are the arrival time of the n and the n-1 cluster. And the first cluster's arriving time is 0. In each clusters, the successive arrival time of multi-path components also obey the Poisson distribution with the rate of Λ:

$$p(\tau_{nk} \mid \tau_{(n-1)k}) = \lambda e^{-\lambda(T_n-T_{n-1})} \tag{3}$$

where, T_n and T_{n-1} are the arrival times of the n and the n-1 components of the kth cluster. And the first component of each cluster's arriving time is 0.

IEEE P802.15.TG3a model: In order to make the experiment data more consistent to the measurement data of UWB, IEEE Working Group modifies the S-V model. The impulse response of IEEE model can be expressed as (Wang and Chang, 2007):

$$h(t)=X\sum_{n=1}^{N}\sum_{k=1}^{K(n)}\alpha_{nk}\delta(t-T_n-\tau_{nk}) \tag{4}$$

where, X is lognormal random variable representing the channel amplitude gain, N is the observed cluster number, K(n) is the received multi-path number of the nth cluster, α_{nk} is the kth path coefficient of the nth cluster, T_n is the arrival time of nth cluster and τ_{nk} is the delay of k path of the nth cluster. Channel coefficients α_{nk} can be expressed as:

$$\alpha_{nk} = p_{nk}\beta_{nk} \tag{5}$$

where, $p_{nk} \in \{-1, +1\}$ is the equal probability of discrete random variables and β_{nk} is channel coefficient of the kth path of the nth cluster, which is lognormal distribution. β_{nk} is given by:

$$\beta_{nk} = 10^{\frac{x_{nk}}{20}} \tag{6}$$

where, x_{nk} is the Gaussian random variable and x_{nk} can be further decomposed into:

$$x_{nk} = \mu_{nk} + \xi_n + \zeta_{nk} \tag{7}$$

where, ξ_n and ζ_{nk} are the channel coefficient of each cluster and each component, respectively. Furthermore, with the characteristics of the cluster's amplitude and each multi-path component, we can get the μ_{nk}:

$$<|\beta_{nk}|^2>=<|10^{\frac{\mu_{nk}+\xi_n+\zeta_{nk}}{20}}|^2>^2$$

$$\Rightarrow \mu_{nk} = \frac{10\ln(<|\beta_{00}|^2>)-10\frac{T_n}{\Gamma}-10\ln\frac{\tau_{nk}}{\gamma}}{\ln 10}-\frac{(\sigma_\xi^2+\sigma_\zeta^2)\ln 10}{20} \tag{8}$$

Based on the S-V model, the arrival time of T_n and τ_{nk} obey the Poisson process and the rate are Γ and λ, respectively.

CHANNEL ESTIMATION ALGORITHM

ML estimate algorithm is one of the most common and effective estimation methods. The basic idea of the ML algorithm is that without a priori knowledge of the estimated variable, the variable is estimated by using the known parameters of the observations. Therefore, using the ML algorithm in estimation, the estimated parameters are random variables. But they are assumed to be constant and include the noise. For single user, the signal modulated by DS-BPSK is expressed as Eq. 1.

Practical UWB system is likely a multi-user system. And in order to demodulate one user's signal from the received signal, usually there are two methods. One is to use multi-user detective method. Although, this method does not require the estimated multi-path channel parameters, the structure of the receiver designed according to this method is complex and the amount of the computation is large. Anther method is first to estimate the channel parameters and then the RAKE receiver is employed using the estimated channel parameters to demodulated the information.

Based on the above analysis, multi-user can be reduced to a signal user situation. The received signal is expressed as:

$$r(t)=\sum_{l=1}^{L_c}\gamma_l s(t-\tau_l)+n(t) \tag{9}$$

And the estimated signal is given by:

$$\hat{r}(t)=\sum_{l=1}^{L_c}\hat{\gamma}_l s(t-\hat{\tau}_l) \tag{10}$$

Then we can get the lognormal likelihood function:

$$\log[\Lambda(\hat{\gamma},\hat{\tau})]=2\int_0^{T_0} r(t)\hat{r}(t)dt-\int_0^{T_0}\hat{r}^2(t)dt \tag{11}$$

For the UWB signal, when $l_1 \neq l_2$:

$$\int_0^{T_0} s(t-\hat{\tau}_{l_1})s(t-\hat{\tau}_{l_2})dt \approx 0 \tag{12}$$

Using (10),(11) and (12), we can get:

$$\log[\Lambda(\hat{\gamma},\hat{\tau})]=2\sum_{l=1}^{L_c}\hat{\gamma}_l J(\hat{\tau}_l)-N_{pilot}E_b\sum_{l=1}^{L_c}\hat{\gamma}_l^2 \tag{13}$$

$$J(\hat{\tau}_l)=\int_0^{T_0} r(t)s(t-\hat{\tau}_l)dt \tag{14}$$

$$E_b=\int_0^{T_0} b^2(t)dt \tag{15}$$

where N_{pilot} is the number of pilot. In order to maximize $\log[\Lambda(\hat{\gamma},\hat{\tau})]$, first $\hat{\tau}$ should be fixed and then changes the $\hat{\gamma}$ to make Eq. 13 to be max and get the $\hat{\gamma}$. So, we should get the $\log[\Lambda(\hat{\gamma},\hat{\tau})]$ partial derivative of and we get:

$$\hat{\gamma}_l=\frac{J(\hat{\tau}_l)}{N_{pilot}E_b} \tag{16}$$

According to Eq. 15 and 16, we can get $\hat{\gamma}$ and $\hat{\tau}$.

SIMULATION AND ANALYSIS

The affection of the number of pilot symbols on the channel estimation: This study uses the IEEE P802.15.TG3a model to simulate. First, the basic parameters of the impulse response should be defined, such as the average observation time and the cluster arrival rate, pulse average arrival rate, cluster power decay factor and so on. Second the arrival time of each cluster should be generated. From Eq. 2 we can know the arrival time of each cluster is exponentially distributed random variable. And then the multi-path components should be generated. According to the Eq. 3, each cluster's arrival time of multi-path components are also exponentially distributed random variables. Finally, the impulse responses of the continuous-time are normalized.

In order to measure the performance of the channel estimation algorithm based on ML criteria, normalized mean square channel estimation error (ξ_{NMSCEE}) is employed in this study:

$$\xi_{NMSCEE}=\frac{\sum_{m=1}^{M}|\gamma(m)-\hat{\gamma}(m)|^2}{\sum_{m=1}^{M}\gamma(m)^2} \tag{17}$$

where, M is the number of the data, the $\gamma(m)$ is the real multi-path information and the (m) is the estimated multi-path information. If $\xi = 0$, then the estimated information fixes the actual information exactly and the smaller the ξ is, the better performance of the algorithm is.

Figure 1~2 are the relationship of the estimate channel and actual channel of CM1~CM4. CM1 is the light of sight channel (0~4 m). CM2 and CM3 are the non light sight channels, ranging from 0~4 m and 6~10 m, respectively. And CM4 is the extreme non light sight multi-path channel. All of those are calculated in the condition of that the transmission signal is the half-wave cosine signal, the SNR is 10dB and the pilot number is 10.

It can be seen from Fig. 1 to 2, with the lower channel quality, the deviation between the estimation and the actual values is increasing. Figure 3 shows the relationship curves of the ξ_{NMSCEE} and the pilot of the four channels, with the SNR = 10 dB.

We can draw many conclusions from Fig. 3. First, the ξ_{NMSCEE} of the four kinds of the channel decreases as the pilot number increased. Take the CM1 for example, when the pilot number increased from 10 to 30, the ξ_{NMSCEE} decreased rapidly from 7.3 to 2.2%. Second, when the pilot number increased to a certain number, the decline rate of ξ_{NMSCEE} slowed significantly and closed to unchanged. For the CM2, there is only 0.47% decline of the ξ_{NMSCEE}, when

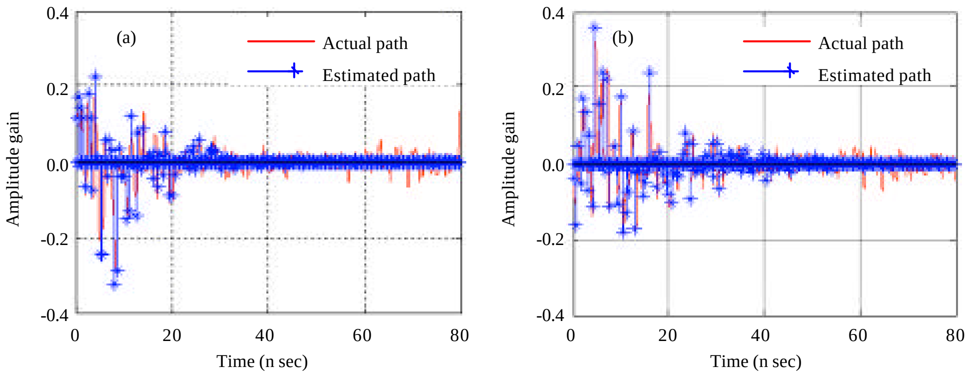

Fig. 1: (a) Comparison of the estimated and (b) comparison of the estimated the actual multi-path information the actual multi-path information in CM1 channel in CM2 channel

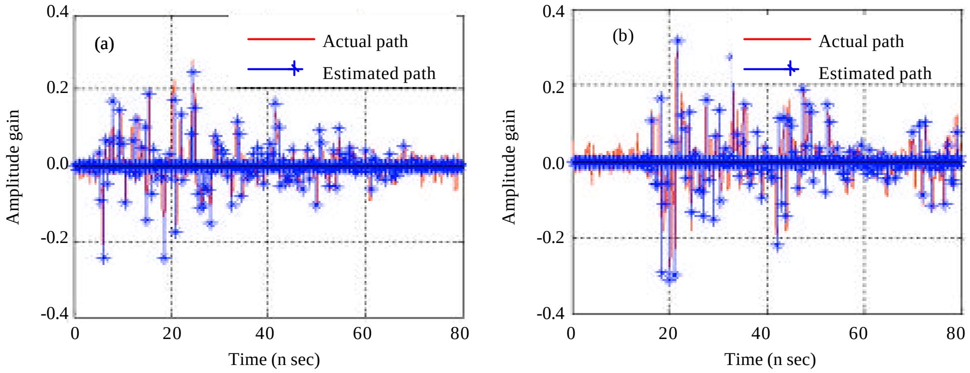

Fig. 2: (a) Comparison of the estimated and (b) comparison of the estimated the actual multi-path information the actual multi-path information in CM3 channel in CM4 channel

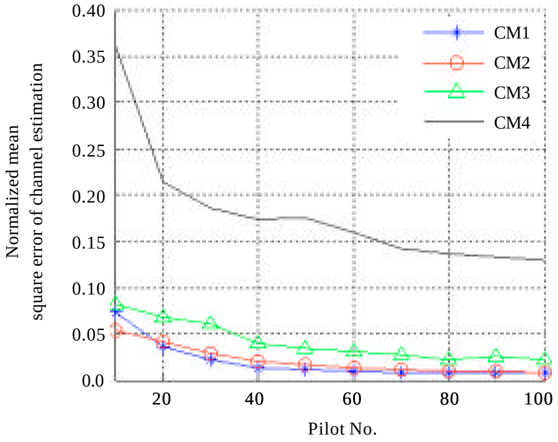

Fig. 3: The relationship of ξ_{NMSCEE} and the pilot number for CM1 to CM4, with SNR = 10 dB

the pilot number increased from 60 to 100. As a result, blindly increasing the number of the pilot can not greatly improve the performance of the algorithm, but will increase the computing complexity. In practical application, the wise number of pilot is 50 with 1.67% of the ξ_{NMSCEE}. Third, the estimate effect of the CM1 is the best among the four channels. And the CM2 is the second. For the CM1 and CM4 are the limit cases, we usually only consider CM2 and CM3 in practical application. In the following simulations, we only discuss the CM2 and CM3.

The affection of SNR on the channel estimation: Here, the changes of ξ_{NMSCEE} are discussed under different SNR. Figure 4 and 5 are the relationship of the ξ_{NMSCEE} and the SNR, respectively. And the pilot number is 10, 20, 30, 50, 70 and 90.

As is shown in Fig. 4 and 5, under the same pilot number, as the SNR increased the ξ_{NMSCEE} is gradually reduced. And the performance of the channel estimation algorithm is improved. When the pilot number is fewer (less than 30), the performance of the channel estimation algorithm is greatly improved by increasing SNR. For instance, in Fig. 5, when the SNR increased from 5 to 10 dB, the ξ_{NMSCEE} reduced 13.25% with the pilot number = 20. In addition, when the pilot number is greater than 50, the improvement of the performance by increasing the SNR can be omitted.

The affection of the waveforms of the transmitted signals: For the indoor UWB transmission, the transmitted signal power must satisfy the FCC's restrictions. Figure 6 shows the spectrums of different order Gaussian pluses which meet the FCC's limits.

We can see that the fifth order Gaussian pulse is the minimum order pulse which satisfies the FCC's limits. Figure 7 is the relationship of the ξ_{NMSCEE} and the different waveforms with SNR = 10 dB. And the waveforms are the half-wave cosine pulse, the fifth Gaussian pulse, the seventh Gaussian pulse and the ninth Gaussian pulse.

Figure 7 shows that the performance of the fifth order Gaussian pulse is the best when the pilot number is less

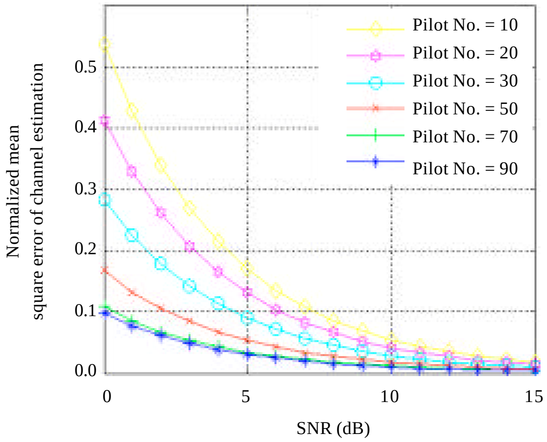

Fig. 4: The relationship of ξ_{NMSCEE} and the SNR with different pilot numbers in CM2

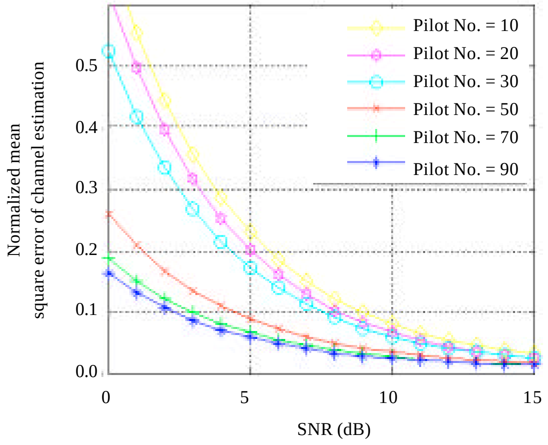

Fig. 5: The relationship of ξ_{NMSCEE} and the SNR with different pilot numbers in CM3

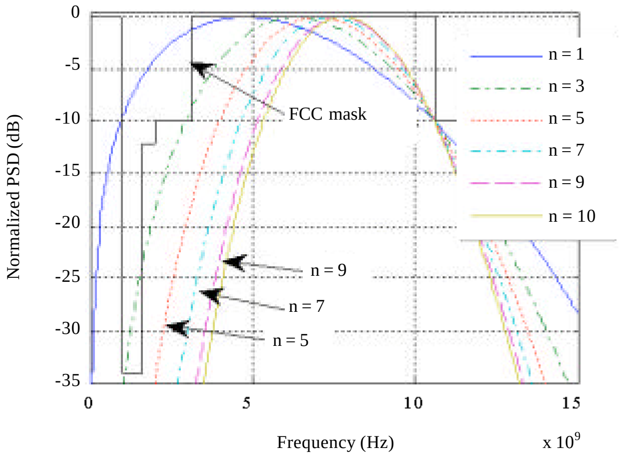

Fig. 6: PSD of the high-order derivatives of the Gaussian pulse and FCC's restrictions

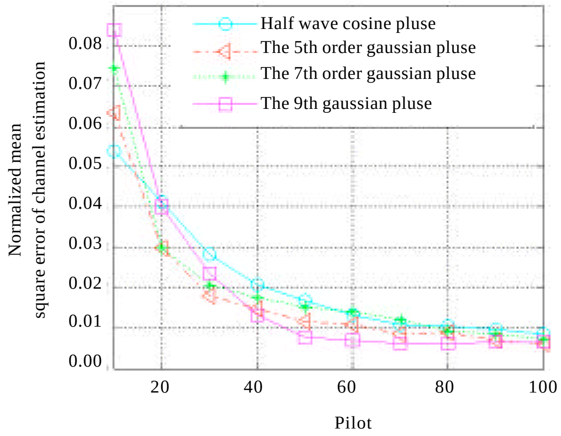

Fig. 7: The relationship of the ξ_{NMSCEE} and the different waveforms

than 30. When the pilot number is more than 50, the ninth order Gaussian pulse has a better performance. But there is only 0.3% improvement compared with fifth order Gaussian pulse. Considering the compute complexity, the fifth order Gaussian pulse is the best choice for the UWB monocycle.

All of the simulation results indicate that, compared with other methods, the performance of the paper is better. With the same SNR, the better performance can be got, comparing with the methods in (Dilmaghani *et al*., 2004; Ertin *et al*., 2001). And due to employing the ML algorithm in time domain, we can get better real time than the frequency domain algorithm (Zheng and Xiao, 2009; Takeda and Adachi, 2005). Moreover, even with the low SNR, we can get the acceptable performance, which is superior to the music algorithm (Yung *et al*., 2001).

CONCLUSIONS

In this study, the Maximum Likelihood algorithm is implemented in time domain DS-UWB channel estimation. Compared with other estimation methods, ML algorithm can establish the channel estimation information in time domain and has less complexity in calculation. The IEEE P802.15.TG3a model is selected for the estimation simulation. To measure the estimation performance, the normalized mean square channel estimation error is employed in this paper. The simulation results indicate that the performance improves with the increasing of the pilot number and the estimation algorithm can achieve significant performance when the pilot number is about 60 in CM1, CM2 and CM3 when the SNR equals to 10 dB. In the case of pilot number less than 30, the algorithm is sensitive to SNR, that is to say the performance improves obviously with the increasing of SNR. On the other hand, in the case of pilot number more than 50, the algorithm is not sensitive to SNR and the increasing of SNR almost can not improve the estimation performance. Due to FCC's PSD restrictions, the monocycle of the DS-UWB is researched and the simulation results show that the fifth order Gaussian pulse can obtain satisfying performance.

REFERENCES

Alizad, A.R., B. Alipanahi, A. Ghasemi, M. Shiva, S.H. Jamali and S. Nader-Esfahani, 2005. A new approach for UWB channel estimation. Proceedings of the Fifth International Conference on Information Communication Signal Processing, (ICSP'05), Bangkok, pp: 291-295.

Dilmaghani, R., M. Ghavami and H. Aghvami, 2004. Channel estimation technique for ultra wide band pulse transmitters. Electronics Lett., 40: 1348-1350.

Ertin, E., U. Mitra and S. Siwamogsatham, 2001. Maximum-likelihood-based multipath channel estimation for code-division multiple-access systems. IEEE Trans. Commun., 49: 290-302.

Fontana, R.J., 2004. Recent system applications of short-pulse ultra-wideband (UWB) technology. IEEE Trans. Microwave Theory Tech., 52: 2087-2104.

Lee, J.Y., 2010. Parameter estimation of the extended generalized gaussian family distributions using maximum likelihood scheme. Inform. Technol. J., 9: 61-66.

Takeda, K. and F. Adachi, 2005. Pilot-assisted channel estimation based on MMSE criterion for DS-CDMA with frequency-domain equalization. Vehicular Technol. Conf., 1: 447-451.

Wang, Y.P. and K.H. Chang, 2007. Preamble-based successive cancellation scheme for the channel estimation in the DS-UWB system. IEEE Trans. Consumer Electr., 53: 842-845.

Win, M.Z. and R.A. Scholtz, 2000. Ultra-wide bandwidth time-hopping spread spectrum impulse radio for wireless multiple-access communications. IEEE Trans Commun., 48: 679-689.

Yang, L.Q. and G.B. Giannakis, 2004. Ultra-wideband communications: An idea whose time has come. IEEE Signal Process. Maga., 21: 26-54.

Yi, H., Y.S. Wang, X.Y. Zuo and Y.N. Zhang, 2008. Ultra wideband technology for Micro Air Vehicles data links systems. Proceedings of the ICMMT International Conference on Microwave and Millimeter Wave Technology, April 21-24, Nanjing, pp: 108-111.

Yung, Y.W., J.T. Chen and W.H. Fang, 2001. Joint estimation of DOA and delay using TST-MUSIC in a wireless channel. Signal Process. Lett., 8: 58-60.

Zhaogan, L., W. Liejun, Z. Taiyi and R. Yun, 2007. A new steiner channel estimation method in MIMO OFDM systems. Inform. Technol. J., 6: 1238-1244.

Zheng, Y.R. and C. Xiao, 2009. Channel estimation for frequency-domain equalization of single-carrier broadband wireless communications. IEEE Trans. Vehicular Technol., 58: 815-823.