Journal of Applied Sciences, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.

Performance Analysis and Evaluation of UWB Wireless Computer Network for Multi-users and Dynamic Channel Environment

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Abstract: Ultra wideband (UWB) technology has been widely used for wireless communication systems including long and short ranges. Wireless computer network is a short range communication system. The present study provides a detailed analysis and performance evaluation of an Ultra-Wideband wireless computer network in a dynamic environment. This includes multi-users state, various modulation schemes and different channel models. Time-Hopping multiple access technique (TH) has been selected to evaluate the network performance in multi-users environment. In addition, three modulation techniques including Pulse Position Modulation (TH-PPM), Binary Phase Shift Keying (TH-BPSK) and Quadrature Amplitude Modulation (QAM) have been used in this analysis. Two types of channel models for each modulation scheme have been used to simulate dynamic environment. The channel models are CM1 (line-of-sight) and/or CM3 (Non-line-of-sight) along with AWGN (IEEE 802.15.3a). Simulation results show that performance of the local area wireless computer network is highly dependent on the channel environment, the maximum allowable number of active users and the receiver structure. Therefore, prior information of the channel model as well as maximum number of active users is required to optimize the desired performance of the wireless computer network for a specific receiver model.

Key words: UWB wireless communication systems, multiple access techniques, modulation schemes

INTRODUCTION

In the recent years, ultra wideband impulse radio communication system offers a good solution for multiuser communication problem in presence of multipath. Ultra wideband technology is emerging the lead for designing a robust wireless communication system. In addition, they also have the advantages of low cost, low power, less system complexity and high speed in short-range. UWB signal consists of a train of very short pulse duration in order of nanosecond. The resulting signal spectrum has an extremely wide ranging from near zero to a few gigahertzes. Multiple access techniques, modulation schemes and transceiver structure are fully characterized the overall UWB system performance. There are several multiple access techniques and modulation schemes have been used for UWB communication systems. This includes Direct Sequence Spread Spectrum (DSSS), Frequency Hopping (FH), Time Hopping (TH) and Orthogonal Frequency Division Multiplexing (OFDM) as a multiple access technique. On the other hand, Pulse Position Modulation (PPM), binary phase shift keying (Bpsk), Pulse Amplitude Modulation (PAM) and On-off Keying (OOK) as modulation types. Recently, Time Hopping (TH) is the current multiple access technique used in UWB communication systems along with PPM (or BPSK) scheme. Spread spectrum technique along with TH-multiple access is commonly used for an impulse radio system (Win and Scholtz, 2000). The main criterion to distinguish between users is the arrival time of each respective user pulse sequences.

In this study, a complete UWB wireless computer network with time hopping technique and three different modulation types are considered. These modulation schemes are PPM, BPSK and QAM. The assumed UWB system has been analyzed in detail and its performance has been evaluated. A dynamic channel environment as well multiple users are considered in this study. Also,

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different receiver structures have been assumed to study the main system parameters effects on its overall performance. The present study is organized among three sections. The UWB system model is discussed in detail and the assumed system parameters are presented in the first section. Simulation results are investigated, analyzed and presented in second section. Performance comparison between ideal and real channel models for multiple users is also presented this section. Performances of three different UWB receiver models are also evaluated, compared and presented in second section. Finally, the presented study is concluded in the last section.

SYSTEM MODELS

The asynchronous TH-PPM and TH-BPSK UWB systems are described in (Win and Scholtz, 2000; Taha and Chugg, 2002; Handi and Gu, 2003).

A typical TH-PPM UWB signal takes the form:

$$S_{PPM}^{(k)}(t,i) = \sqrt{\frac{E_b}{N_s}} \sum_{j=iNs}^{(i+1)Ns-1} p(t - jTf - C_j^{(k)}Tc - d_i^{(k)}\delta) \quad (1)$$

And a TH-BPSK UWB signal with antipodal data modulation is written as:

$$S_{BPSK}^{(k)}(t, i) = \sqrt{\frac{E_b}{N_s}} \sum_{j=iNs}^{(i+1)Ns-1} d_i^{(k)}\ p(t - jTf - C_j^{(k)}TC) \quad (2)$$

where, t is time, $s^{(k)}(t, i)$ is the K^{th} user's signal conveying the i^{th} data bit and p (t) is the signal pulse with pulse width Tp. The parameters employed in these UWB models are described as follows:

- E_b is the bit energy common to all signals
- N_s is the number of pulses required to transmit a single data bit, called the length of the repetition code (Durisi and Benedetto, 2003)
- T_f is the time duration of a frame and thus, the bit duration $T_b = N_s * T_f$
- $\{C_j^{(k)}\}$ represents the TH code for the k^{th} source
- $d^{(k)}_i$ represents the i^{th} binary data bit transmitted by the k^{th} source and different bits are assumed to be equiprobable. In antipodal TH-BPSK UWB systems, $d^{(k)}_i \in (1,-1)$
- δ is the time shift associated with binary PPM

In TH-PPM UWB systems, the data bits can conveniently be {0, 1} or {1,-1}, as explained in the following. In the case of QAM, four bits per impulse can be encoded in one possible amplitude; hence a set of four possible amplitudes or UWB symbols (Chen and Kiaei, 2002) is given as:

- Bits : 00 01 10 11
- Symbols: A1 A2 B1 B2

This can be expressed in mathematical form as:

$$s(t) = \sqrt{E_p} \sum_{n=-\infty}^{\infty} s_n p_2\left(\frac{t - iT_b}{T_b}\right), s_n \in \{s_1, s_2, s_3, s_4\} \quad (3)$$

The UWB signal is now a sequence of four possible UWB symbols. It can be viewed as a combination of two BPSK signals each with different amplitude and the binary signaling is defined by the polarity of the impulse. This can be expressed mathematically as:

$$s(t) = s_1(t) + s_2(t)$$
$$s_1(t) = \sqrt{E_p} \sum_{n=-\infty}^{\infty} s_n p_2\left(\frac{t - iT_b}{T_b}\right), s_n \in \{s_1, s_2\} \quad (4)$$
$$s_2(t) = \sqrt{E_p} \sum_{n=-\infty}^{\infty} s_n p_2\left(\frac{t - iT_b}{T_b}\right), s_n \in \{s_3, s_4\}$$

Where:

$$S_1 = -S_2 \text{ and } S_3 = -S_4$$

This resulting PAM signal is called QAM signal. The word "Quadrature" here does not mean a phase quadrature as in conventional PQSK; rather it reveals the quaternary nature of the symbols used for modulation. Many pulse shapes have been proposed for UWB impulse radio systems. This includes the Gaussian pulse, Gaussian monocycles and Gaussian doublet (Chen and Kiaei, 2002). The Gaussian pulse has the form:

$$po(t) = \exp[-2\pi\left(\frac{t}{\tau p}\right)2] \quad (5)$$

And its nth derivative, named the *n*th-order Gaussian monocycle, is (Zhang *et al*., 2003):

$$p_n^{(t)}\varepsilon_n \frac{dn}{dt^n} \exp[-2\pi\left(\frac{t}{\tau p}\right)^2] \quad (6)$$

where, τ_p represents time normalization factor. The most widely reported pulse in UWB systems is the second-order Gaussian monocycle (Win and Scholtz, 2000):

$$p(t) = [1 - 4\pi(\frac{t}{\tau_p})^2]\exp[-2\pi(\frac{t}{\tau_p})^2] \quad (7)$$

The autocorrelation R(x) of the Gaussian monocycle is:

$$R(x) = [1 - 4\pi\left(\frac{x}{\tau_p}\right)^2 + \frac{4\pi^2}{3}\left(\frac{x}{\tau_p}\right)^4]\exp[-\pi\left(\frac{x}{\tau_p}\right)^2] \quad (8)$$

Assuming N_u users are transmitting asynchronously over an AWGN channel, thus:

$$r(t) = \sum_{k=1}^{Nu} A_k s^{(k)} p(t - \tau_k) + n(t) \quad (9)$$

where, n(t) the additive noise and $\{\tau_k\}$ represent time shifts. Consider $S^{(1)}(t)$ to be the desired signal and $d_0^{(k)}$ to be transmitted. In addition, assume $C_j^{(1)} = 0$ for all j (Durisi and Benedetto, 2003). All the other N_u-1 signals are interference signals. Assuming perfect synchronization with the reference signal, the single-user correlation receiver computes the following decision statistic:

$$r = \sqrt{\frac{N_s}{E_b}} \sum_{j=0}^{Ns-1} \int_{jTf}^{(j+1)Tf} r(t)v(t - \tau 1 - jTf)dt \quad (10)$$

where, v (t) is the correlation template waveform, which takes different forms in the TH-PPM and TH-BPSK UWB systems correspondingly (Hu and Beaulieu, 2004; Hussein *et al*., 2012).

RESULTS AND DISCUSSION

The effects of the number of multi-user interferences on the UWB system Performance have been investigated and evaluated. A perfect power control and time synchronous between the transmitter and the receiver (τ = 0) are assumed in system simulation. The simulation parameters and their values of the transmitted binary data stream of useful users are presented in Table 1. Simulation result is presented in Fig. 1 in presence 10 interfering users. It has been reported several studies (Herceg *et al*., 2010; Craciun *et al*., 2011) of Pulse position modulation (PPM) only with additive Gaussian nose. In this study, Pulse position modulation (PPM), binary phase shift keying (BPSK) and quadrature amplitude modulation (QAM) are assumed. In the case of TH-PPM and TH-QAM, a less performance has been obtained as compared to the TH-BPSK. This due to that the BPSK is more efficient and robust than the PPM and the QAM.

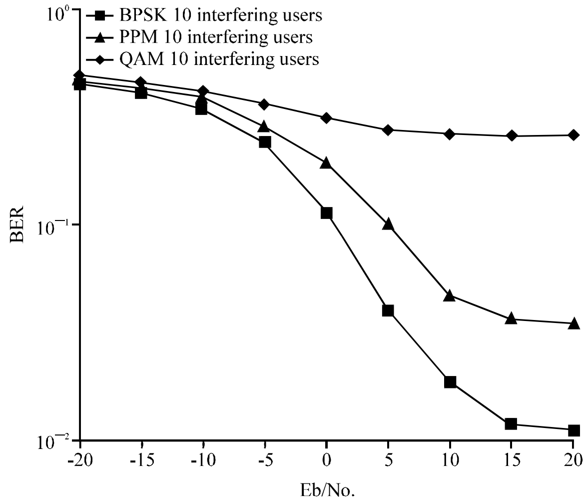

Fig. 1: Performance comparison of BPSK, PPM and QAM modulation schemes in the presence of MUI

Table 1: Transmitted UWB Binary data for multi-user simulation

Parameter	Symbol	Value
Bit duration	T_b	3^{ns}
Code repetition	Ns	5
Multi-user interfering	MUI	5, 10, 20, 30
PPM shift	δ_{shift}	0.5^{ns}
Chip duration	T_c	1^{ns}
Frame duration	T_f	3^{ns}
Pulse duration	T_m	0.5^{ns}

Also, BPSK has a less susceptibility to distortion since the difference between any two successive pulse levels is twice the pulse amplitude.

From the figure above, it can be observed that there is large BER gap between the PPM /QAM and BPSK for higher SNR (Eb/No. ratio). Rake receiver is used in time-hopping impulse radio systems for parallel matched filtering of the received signal. Another receiver types are partially rake (P-Rake) and selective rake (S-Rake). As mentioned before, the simulations were conducted for both the CM1 and the CM3 channel. First CM1 channel is assumed and then, performance of the system for different receiver types is evaluated. Simulation results are presented in ascending order from Fig. 2a through Fig. 2c. This includes performance evaluation of TH-BPSK, TH-PPM and TH-QAM in presence of 10 interfering users respectively for three different receiver types. The ideal rake collects all the multipath contributions and it has better performance as compared to both the partial and the selective rake receivers. On the other hand, this receiver is extremely complex and it is difficult to implement in practice. This is due to the large number of the rake fingers used to compensate all multipath components. Furthermore, performance of P-Rake with 7 branches is relatively the same as the S-Rake with

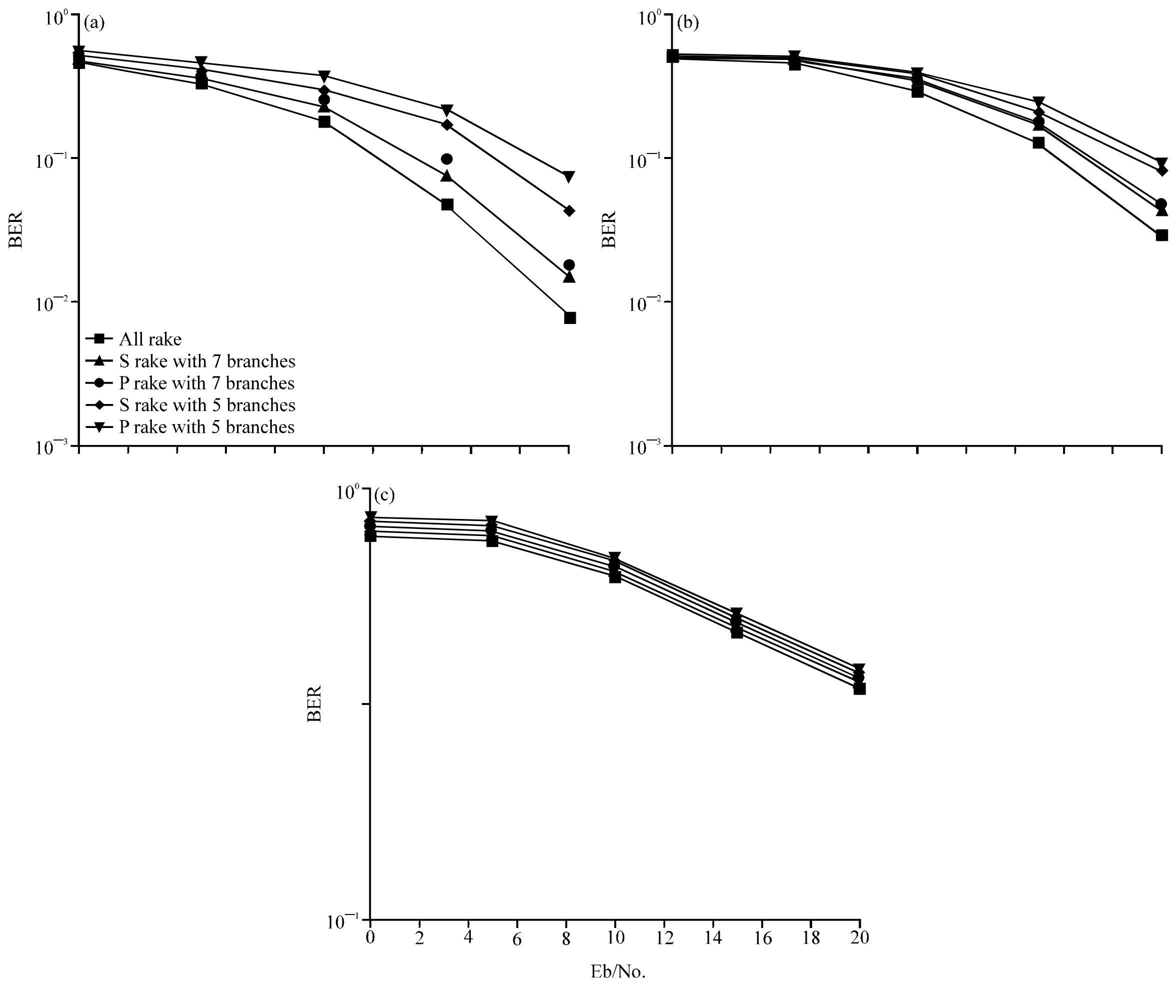

Fig. 2(a-c): (a) BER versus Eb/No. for BPSK modulation in the presence of 10 interfering users (CM1), (b) BER versus Eb/No. for PPM modulation in the presence of 10 interfering users (CM1) and (c) BER versus Eb/No. for QAM modulation in the presence of 10 interfering users (CM1)

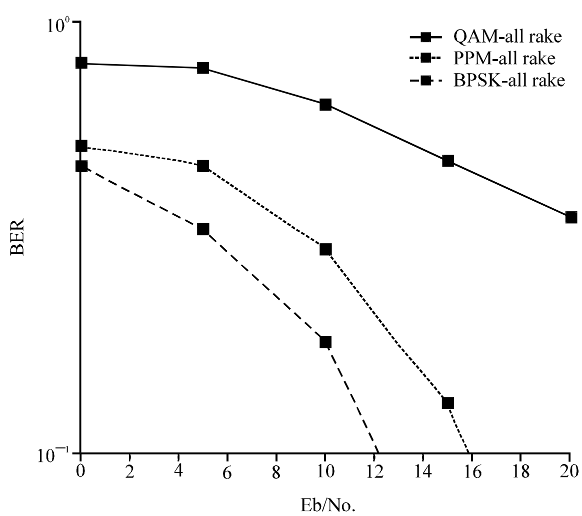

Fig. 3: PPM, BPSK and QAM performance in the presence of 10 MUI (CM1)

5 branches. The main reason is due to the difference in the collected energy of branches captured by the receiver. Furthermore, a general comment on Fig. 2b and c, is that the All-Rake receiver performance has the better performance followed by S-Rake then P-Rake either with 5 fingers or 7 fingers. This order emphasis the importance of increasing the number of fingers whose effect appears in decreasing the BER. In case of (multi-users) the BER is increased as compared to single user (Hussein *et al*., 2012).

As it is clear from the simulation results above and from Fig. 3, the worst performance was QAM modulation. The best type of modulation which provides better performance is the BPSK (First BPSK, Second PPM and Third QAM).

The second channel model has been assumed to evaluate the performance of UWB systems (IEEE 802.15.3a (CM3) channel model). Simulations results are presented in ascending order from Fig. 4a to c. Again, the

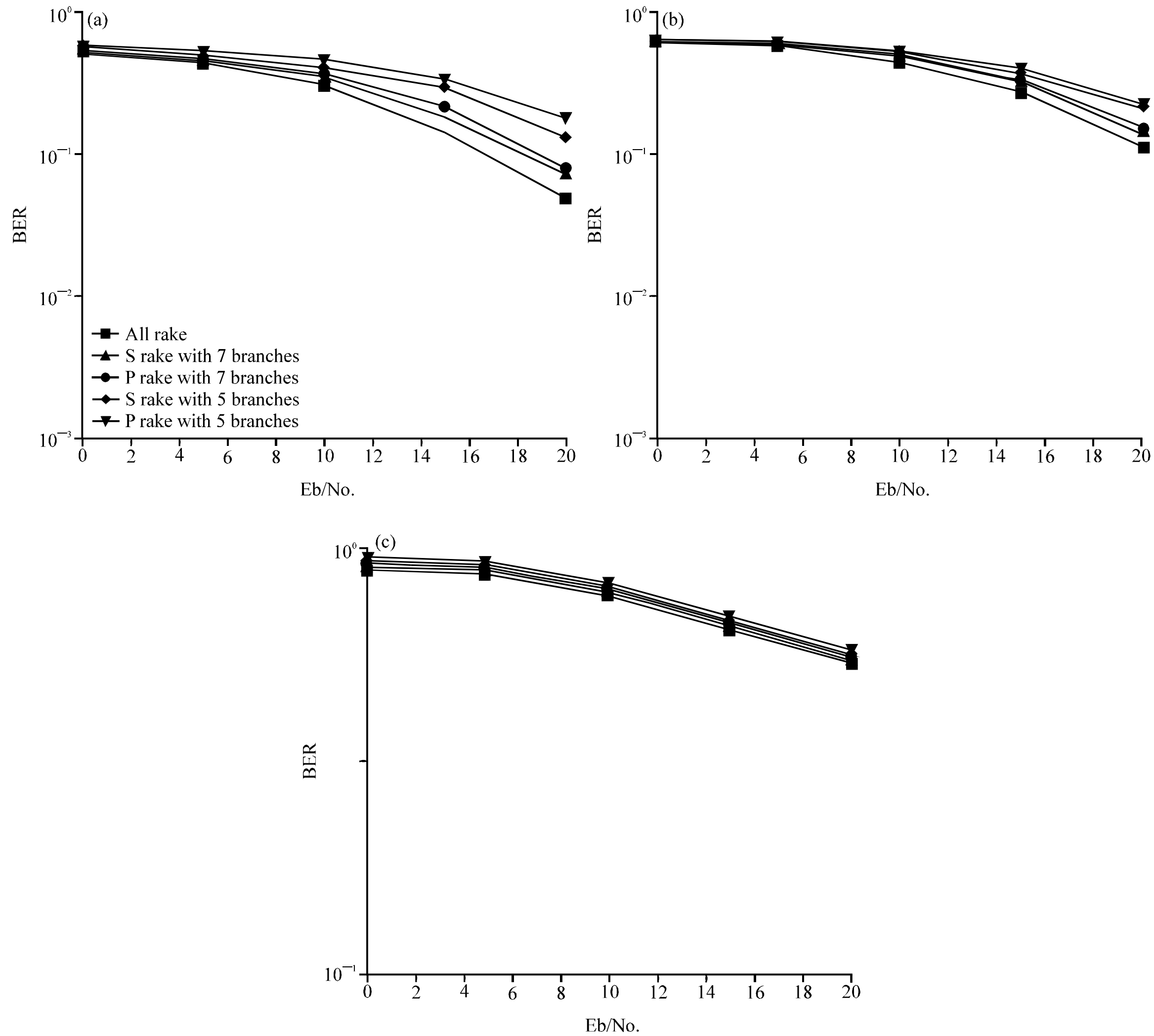

Fig. 4(a-c): (a) BER versus Eb/No. for BPSK modulation in the presence of 10 users (CM3), (b) BER versus Eb/No. for PPM modulation in the presence of 10 users (CM3) and (c) BER versus Eb/No. for QAM modulation in the presence of 10 interfering users (CM3)

three modulation schemes are considered (TH-BPSK, TH-PPM and TH-QAM) along with the presence of 10 interfering users. In fact, the complexity of the Rake receivers ranges from the most complex structure (All-Rake) down to the simplest one (P-Rake). This based on the arbitrarily picked multipath component arriving at the receiver structure.

As it clear from these figures, best performance has been achieved in case of BPSK. This can be explained as follows, the S-Rake receiver, as its name reveals, selects the strongest paths to be combined, this serves maximizing the SNR at the receivers output. In a P-Rake receiver, the fingers are selected according to the first arrival rule which may or may not destructively interfere with each other. Hence, this contributes to lower the SNR at the receiver output. The more interfering users are added, the higher will be the BER at the intended user terminal.

As a final comment on this study, less system performance has been obtained over CM3 channel model as compared to the performance CM1 channel model. This is due to the obstacles and the larger distance between the transmitter and the receiver. Figure 5 shows PPM, BPSK and QAM performances in the presence of 5 MUI between (CM1 and CM3).

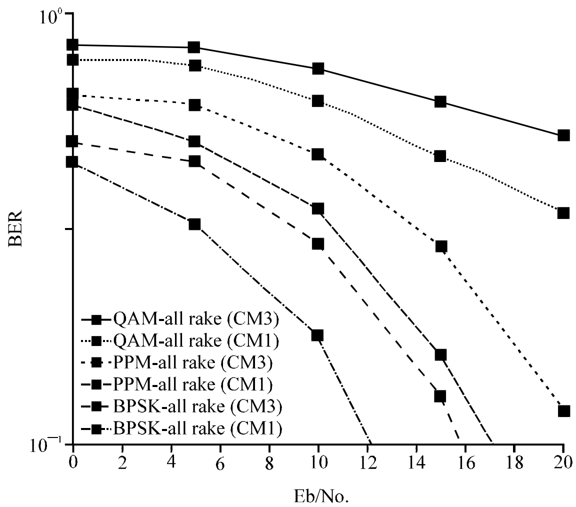

Fig. 5: PPM, BPSK and QAM performance in the presence of 10 MUI between (CM1 and CM3)

CONCLUSION

In this study, performance of UWB wireless computer network has been investigated and evaluated under multi-users and dynamic channel environment. This includes the channel model, the maximum allowable number of active users and the multiple access technique. First, time-Hopping is considered along with, three modulation schemes (PPM, BPSK and QAM). Second, three different receiver structures are considered (All-Rake, P-Rake and P-Rake). The obtained results indicate that a significant reduction in UWB network performance has been obtained in case of multipath as compare to AWGN. It has been observed that the presence of the multi-user interference has a draw back on the network performance. In other words, less performance has been obtained with increasing the number of the MUI. Finally, performance of the UWB wireless computer network is highly dependent on three main issues. First, the channel environment including the fading effects has major impact on the network performance. The second issue is the number of active users within the computer network. Finally, the receiver structure determines the quality of the network performance. Thus, these prior knowledge are very practical issues in designing a good wireless computer network.

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