

Research Article

A Novel Ultra-Wide Band Signal Generation Scheme Based on Carrier Interference and Dynamics Suppression

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This paper initiatively puts forward a novel synthesis design for generating UWB narrow pulse by using CI (Carrier Interference) subcarrier waveform synthesis and Bessel function expansion. Through adaptively adjusting the initial phases of multiple sub-carriers according to the location information, CI (Carrier Interference) sub-carrier waveform synthesis signal could achieve better performance. More specifically, when the carrier arrives at the receiver with a particular phase, the dynamic change of this signal amplitude can be significantly reduced by introducing sinusoidal frequency modulation signals. The method has significance for improving the overall performance of UWB communication system. This paper gives theoretical analysis and computer simulation results as well as the functional block diagram.

1. Introduction

Ultra-wide band CI pulse waveform method is one of the current UWB signal generation methods based on the idea of multiband UWB signal design. In sensor networks, there is always a large dynamic change on the communication signals between cluster head and inner-cluster node when multiple wireless sensors communicate using UWB signals because of the uncertainty of node location distribution [1]. This dynamic change of signal amplitude can be significantly reduced by introducing sinusoidal frequency modulation signals which has very important significance on improving the transmission performance of wireless sensor networks and reducing the device costs of nodes. CI can produce narrow pulse signals synthesized by multiple coherent carriers, and adaptively adjust the initial phase of multiple sub-carriers by location information so that the carrier amplitude could get the maximum when the carrier arrives at specified location which means the carrier amplitude may be too low when the carrier arrives at distant specified location.

The low dynamic interference telecommunication signal methods based on BESEL function expansion, which has the advantage of low dynamic and multicarrier interference

superposition, has a strong penetrating and low intercept probability.

CI waveform corresponds to the overlapping of the N carriers on the uniform frequency intervals ($\Delta f = 10$ MHz). The pulse waveform is given by [2]

$$h(t) = \sum_{n=1}^N A \cos(2\pi n \Delta f t). \quad (1)$$

The pulse waveform could be achieved perfectly using IFFT. Figure 1 shows the pulse waveform in one period $h(t)$ and its duration is T_f . Figure 2 shows CI waveform in frequency domain. Obviously, the pulse waveform is the result of superposition of N sinusoidal waveforms.

The frequency-domain sampling results in repetition in time-domain and the repetition period of the waveform is T_f . The final CI waveform is limited to one time-periodic signal which can be represented by [3]

$$h(t) = \sum_{n=1}^N A \cos(2\pi n \Delta f t), \quad (2)$$

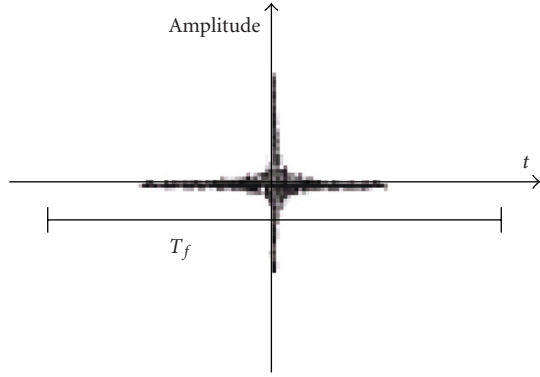


FIGURE 1: CI waveform in time-domain.

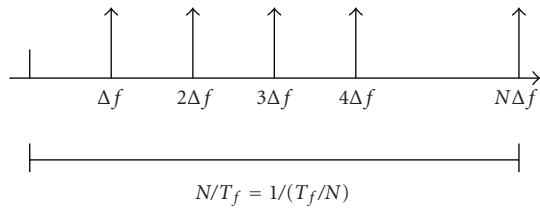


FIGURE 2: CI waveform in frequency-domain.

that is,

$$CI(t) = \sum_{n=1}^N A \cos(2\pi n \Delta f t) \cdot g(t), \quad (3)$$

where $g(t)$ represents the unit amplitude gate function with the period T_f , A is a scale factor in order to ensure the unit energy. The Interferometry CI time-domain pulse waveform is simplified as CI waveform because it is introduced by Interferometry method.

2. Proposed UWB Signal Generation Scheme

The UWB signal has a relationship with primary users in spectrum reuse. Thus, the transmit power of UWB signal is strictly limited in order to avoid the interference to primary users, which requires low Bit Error Rate (BER) in the situation of low Signal to Noise Ratio (SNR) [4]. This invention proposes a scheme of UWB signal generation based on distance awareness. We should determine the distance between transmitted end and its intended end in order to adaptively adjust multiple sub-carriers' initial phases and assemble their peak in a specified location. The scheme adds sinusoidal frequency modulation signal while adjusting sub-carriers' phases and introduces the first-order Bessel function in order to cancel out space spread channel fading. Receiver receives signals in specified location in order to get an excellent BER performance even in the situation of low SNR.

The steps and diagram of the proposed UWB signal generation scheme are as follows:

- (1) The transmitter, which employs the distance-aware module, measures the distance L between the transmitter and its intended receiver.
- (2) Based on L , we can calculate the time that the carrier arrives at the receiver t_p , that is, $t_p = L/C$, where C is the electromagnetic wave transmission speed.
- (3) We can adjust the initial phase of n th subcarrier as $\theta_n = -2\pi f_n t_p$, and generate the pulse signal, followed by the process of frequency modulation. Thus, the initial phase of n th subcarrier is modified as $\theta'_n = \theta_n + \beta \sin(2\pi f_d t)$, where β is the modulation index, the term $\sin(2\pi f_d t)$ is the baseband frequency modulation signal, and the related parameters must satisfy the inequalities; $f_d \ll f_n$ and $\beta \sin(2\pi f_d t) \ll \theta_n$.
- (4) We adopt the IFFT transform for the signals which have finished the phase and frequency modulation. The transformed time-domain signal can be expressed as follows [2]:

$$a(t) = \sum_{n=k}^{k+N} e^{j(n2\pi\Delta f t + \theta'_n)}. \quad (4)$$

- (5) We perform the OOK modulation by the procedure of sending data c multiplying by $a(t)$, that is, $d = c * a(t)$.
- (6) Then through the multicarrier-tuned filter, we can derive the first-order Bessel function expansion components, thus mitigate the transmission attenuation for the UWB transmission scheme.
- (7) At the intended receiver, we can demodulate the received signal $r(t)$ as follows: first we sample the received signal $r(k)$ at the time $t = t'$, if $r(k) > \tau$, where τ is a predefined threshold, then we determine the received data $c' = 1$, otherwise, $c' = 0$.

The Figure 3 depicts the details about the above discussion.

The scheme of UWB signal generation is based on distance awareness. The distance awareness module is used to measure the distance between transmits end and its intended end. UWB signal generation module is used to generate the signal which is available to the communication between transmits end and its intended end.

Multiple sub-carriers' initial phases are adjusted adaptively according to the result of distance awareness module. At the same time, the scheme introduces the first-order Bessel function in order to generate multicarrier signals with sinusoidal frequency modulation.

The distance awareness module can be obtained by UWB distance measure system. UWB pulse has a strong ability to be time-resolved for the duration is as short as nanoseconds because of its very high bandwidth. The UWB distance measure system usually gets the distance between transmit

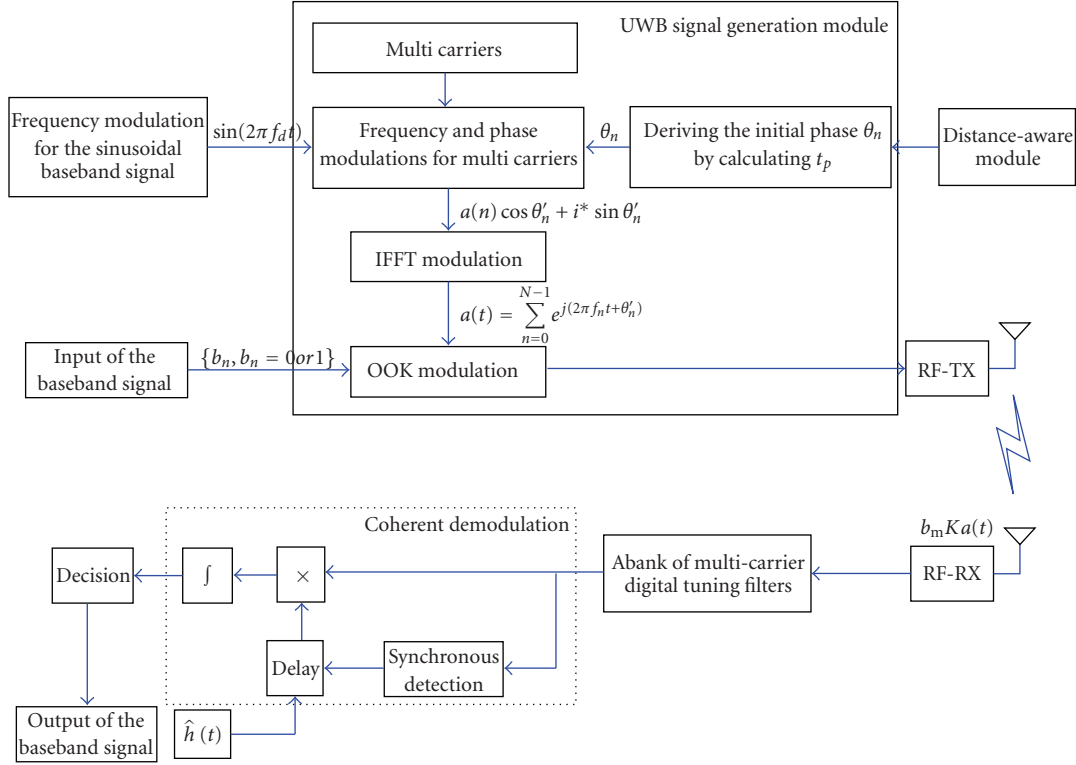


FIGURE 3: The diagram of the UWB signal modulation and demodulation.

end and its intended end by estimating the time of arrival (TOA) of first component among receiving signals and then calculates the distance of two ends. The TOA algorithm gets the transmission time interval between two ends by estimating the direct path (DP) of receiving signals and thus calculates the distance. According to the recent research, the TOA algorithm can reach centimeter-level accuracy.

In the following subsection, we give the details about the above signal generation scheme.

First, it is assumed that the carrier signal consists of N sub-carriers, and the frequency interval is Δf . Therefore, the n th sub-carrier $f_n(t)$ can be expressed as

$$f_n(t) = \cos(2\pi f_n t + \theta_n), \quad f_n = (k+n)\Delta f, \quad n \in [0, N-1], \quad (5)$$

where θ_n is the initial phase, $k\Delta f$ and $(k+N-1)\Delta f$ denote the frequency lower bound and upper bound of the transmitted signal, respectively. Here we adjust the initial phase according to the distance-aware based information, thus ensure each sinusoidal sub-carrier to reach the peak value at the intended receiver.

Since the expression $\cos[2\pi f_n t - 2\pi f_n t_p]$ reaches its maximum value at $t = t_p$, the initial phase is set as $\theta_n = -2\pi f_n t_p$.

Moreover, if we adjust the initial phase of the n th sub-carrier to θ_n , followed by the frequency modulation, as discussed above, the initial phase can be calculated by $\theta'_n =$

$\theta_n + \beta \sin(2\pi f_d t)$. From the frequency-domain points of view, let the n th sub-carrier be denoted by

$$a(n) = \cos \theta'_n + i * \sin \theta'_n. \quad (6)$$

Thus, we can derive the time-domain expression about $a(n)$ by the help of the IFFT, given as

$$a(t) = \sum_{n=0}^{N-1} e^{j[2\pi(k+n)\Delta f t + \theta'_n]}. \quad (7)$$

It is noted that, using (7), we can modulate the transmitted information $\{b_m, b_m = 0 \text{ or } 1\}$.

At the receiver, the received signal is denoted by $b_m K a(t)$ with the channel attenuation coefficient $K < 1$. In what follows, we give some insights about the effect of the term $\beta \sin(2\pi f_d t)$ which can be viewed as the baseband frequency modulation component introduced by θ'_n . First, $b_m K a(t)$ can be represented as

$$\begin{aligned} b_m K a(t) &= b_m K \sum_{n=0}^{N-1} e^{j(2\pi f_n t + \theta_n + \beta \sin(2\pi f_d t))} \\ &= b_m K e^{j\beta \sin(2\pi f_d t)} \sum_{n=0}^{N-1} e^{j(2\pi(n+k)\Delta f t + \theta_n)}. \end{aligned} \quad (8)$$

Moreover, the complex exponential term of (8) $e^{j\beta \sin(2\pi f_d t)}$, can be further denoted by

$$e^{j\beta \sin(2\pi f_d t)} = \sum_{n=-\infty}^{+\infty} J_n(\beta) e^{j2\pi n f_d t}, \quad (9)$$

where $J_n(\beta)$ is the n -order Bessel function.

Substituting (9) into (8), after some manipulation, we have

$$b_m K a'(t) = b_m K \sum_{n=-\infty}^{+\infty} J_n(\beta) e^{j2\pi n f_d t} \sum_{n=0}^{N-1} e^{j(2\pi f_n t + \theta_n)}. \quad (10)$$

Note that since (10) contains all frequency component $f_n + n f_d$ ($n = 0, \pm 1, \pm 2, \dots$), the bandwidth of the received signal should be infinite. However, the amplitude for the $f_n + n f_d$ corresponding to the large n can be neglected. Thus the bandwidth in which contains 98% or 99% signal total power is finite, and the finite bandwidth value is viewed as the effective bandwidth. In order to calculate the effective bandwidth, we expand the Bessel function as

$$J_n(\beta) = \sum_{k=0}^{+\infty} \frac{(-1)^k (\beta/2)^{n+2k}}{k!(k+n)!}. \quad (11)$$

We take the first-order Bessel function of the expansion to filter out multiple harmonics, which is given as

$$J_1(\beta) = \sum_{k=0}^{+\infty} \frac{(-1)^k (\beta/2)^{1+2k}}{k!(k+1)!}. \quad (12)$$

Since $f_d \ll f_n$, by substituting (12) into (10), we have

$$\begin{aligned} b_m K a(t) &= b_m K \sum_{n=-\infty}^{+\infty} J_n(\beta) e^{j2\pi n f_d t} \sum_{n=0}^{N-1} e^{j(2\pi f_n t + \theta_n)} \\ &\approx b_m K J_1(\beta) e^{j2\pi f_d t} \sum_{n=0}^{N-1} e^{j(2\pi f_n t + \theta_n)}, \end{aligned} \quad (13)$$

It is noted that from (13), the signal attenuation is sufficiently reduced.

3. Simulation Results

The UWB signal has flexible spectrum characteristics. The carriers of the UWB signal consists of multiple sub-carriers which results in flexible spectrum characteristics. This feature makes the UWB signal available to the flexible spectrum allocation strategy of Cognitive Radio. We can adjust the parameters of sub-carriers such as number, distribution, frequency interval and other parameters according to the available spectrum hole, the distance between two ends, the requirements of ranging accuracy the information transmission rate and so on. Thus the UWB signal can be better applied to realistic communication environment.

By adjusting the initial phase of transmitted signal, the overlap of peak values of each sub-carrier at the distance corresponding to the specified time delay can be easily achieved. Suppose that the distance-aware module measures the distance between transmitter and receiver, by calculating, we have

$$t_p = \frac{L}{c} = 0.8 * 10^{-6} (s) \quad (\text{take } c = 3 * 10^8 \text{ m/s}). \quad (14)$$

By adjusting the initial phase, we can get the coherent UWB time-domain waveforms from receivers at different position as shown in Figure 4.

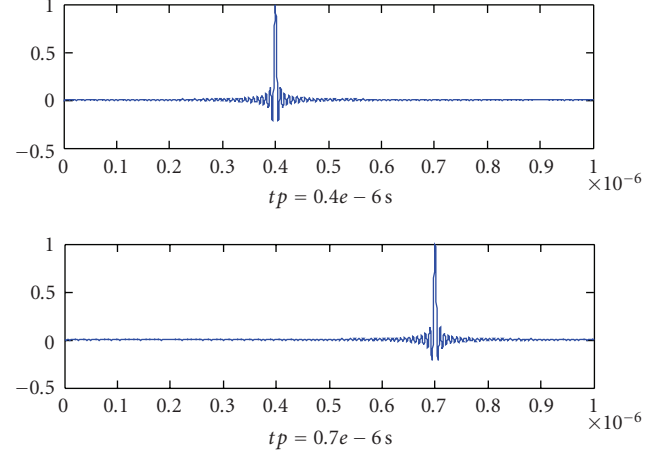


FIGURE 4: Receiving signal waveform corresponding to different distance after initial phase adjustment.

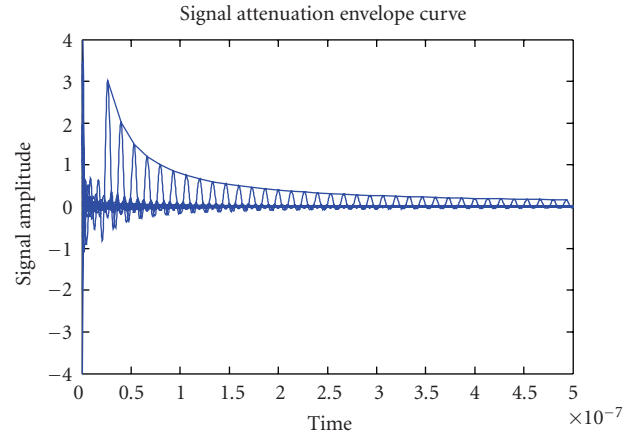


FIGURE 5: Channel fading signal envelope curve without sinusoid FM signal.

For this new type of multicarrier interference synthesis UWB signal communication system, if no low frequency sinusoid FM signal at the transmitter end, the received signal strength will get attenuation with the square of distance. As shown in Figure 5, the horizontal axis represents the distance and transmission delay between transmitter and receiver, and vertical axis represents the strength of received multicarrier interference synthesis signal at the same multicarrier transmitting signal power. The figure shows several multicarrier interference synthesis signals with equal delay interval in case of no sinusoid frequency modulation. It can be seen that the strength of received signal gets attenuation with the square of distance or time delay as shown by the envelope curve, and the received signals suffer high wireless transmission attenuation in case of a certain of distance (delay) between transmitter and receiver.

For this new type of multicarrier interference synthesis UWB signal communication system, if a low frequency sinusoid FM signal is added on each sub-carrier at the transmitter end as shown in Figure 3. At the receiver end, using a bank

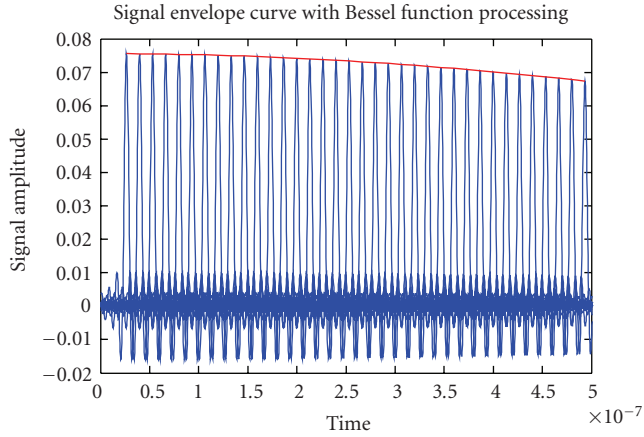


FIGURE 6: Channel fading signal envelope curve with sinusoid FM signal.

of multicarrier digital tuning filter to take the first-order Bessel expansion components, the attenuation dynamics of correlation demodulation signal are suppressed, as shown in Figure 6. Same as the Figure 5, the horizontal axis represents the transmission delay between the transmitter and receiver, as well as the distance between them and the vertical represents the strength of the normalized multicarrier interference synthesis signal at the receiver end. The figure shows several sinusoid FM multicarrier interference synthesis UWB signals with equal delay interval, after passing through a digital tuning filter, the first-order Bessel expansion components of each sub-carrier are taken out. The amplitude of equal-interval multicarrier interference synthesis UWB signal is shown as the envelope curve in Figure 6, and obviously the attenuation is better suppressed.

For general multicarrier CI synthesis method, even though the multicarrier signals are overlapped at the receiver end, still the space fade exists and have a high dynamics requirement to receiver. Through adding sinusoid FM signal at the transmitter end and make linear filtering of the first-order FM components to get the first-order Bessel function expansion components at the receiver end, the receiving space attenuation of multiple carrier components synthesis signals can be suppressed effectively, as shown in Figure 7.

The peak value overlap of multiple sub-carriers based on distance measuring greatly improve the BER performance of communication system.

By adjusting the initial phase, the peak values of multiple sub-carriers are overlapped at the receiver end, and the sub-carriers at any location between transmitter and receiver are cancelled each other. Modern distance measuring technique can achieve centimeter order precision, and the correlation demodulation at receiver end can greatly increase the processing gain, so the system BER performance can be significant improved on the basis of precise distance measurement.

In case of Gaussian white noise interference, the BER performance on the basis of precise distance measurement is shown in Figure 8.

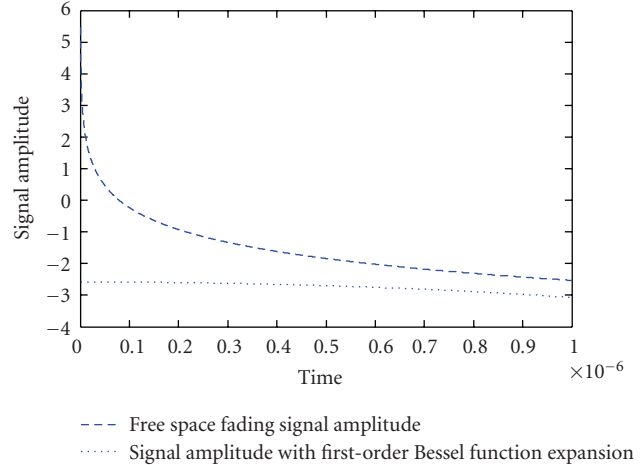


FIGURE 7: amplitude comparison between free space fading signal and the signal with first-order Bessel function expansion.

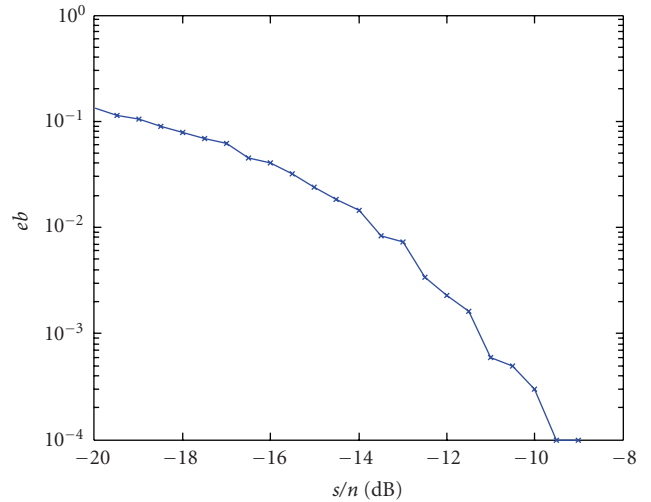


FIGURE 8: BER curve on the basis of precise distance measurement.

Moreover, the proposed scheme can be tolerance of the distance error. When there exists distance error, the BER of the system is depicted in Figure 9. We show that when the distance error is m , the performance of the proposed scheme is significantly decreased.

4. Conclusion

Through the adjustment of multiple sub-carriers' initial phases, the interference UWB signals based on distance awareness enable receiver to receive maximum amplitude of synthetic signals which brings great benefits for reducing interception probability and improving the received signal to noise ratio (SNR). The UWB signals can inhibit channel fading and reduce the dynamic changes of received signals as well as costs of receiver by introducing low frequency sinusoid frequency modulation signals and first-order Bessel function expansion. The simulation results have verified

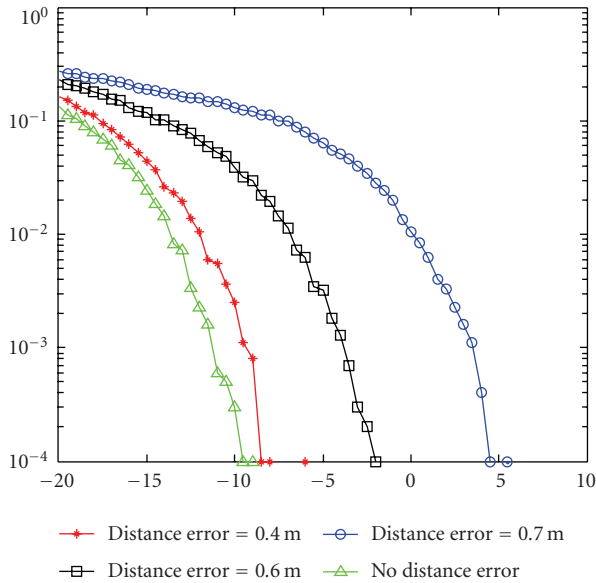


FIGURE 9: BER performance when exists distance error.

the theoretical analysis in this paper. The further research includes relationship between parameter design and realistic communication environment and improvement of whole system performance to make it more flexible and adaptive.

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