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New Solution for Reducing Doppler Shift in the MB-OFDM System Over High Mobility Multipath Channel for V&I Communication

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Abstract: The MB-OFDM has been proposed as a good candidate to ensure Vehicle to Infrastructure communication (V&I). Fast moving vehicles present challenges for the proposed system especially for high mobility (250 km h^{-1}). The main objective in this study is to study and investigate the impact of Doppler shift on the quality of transmitted/received signal in terms of Bit Error Rate (BER) and the transmission range. A new solution based on the association of Maximum Likelihood (ML) and Extended Kalman Filter (EKF) algorithmis proposed and computer simulations are performed to confirm the reduction of Doppler impact on the signal quality. Also it is shown that for high value of speed, the new solution can effectively improve the transmission range of the MB-OFDM system.

Keywords: MB-OFDM, Multipath Channel, Doppler Effect, Performance Analysis, EKF, ML

Introduction

The MB-OFDM has been selected by several key industry organizations: Multiband OFDM Alliance, WiMedia, Wireless Universal Serial Bus (USB), because of its very good technical characteristics for the diverse set of high performance that are eagerly anticipated for different applications (Kabil *et al*., 2014; 2011). However, in the wireless mobile environment, Doppler shift emerges due to the motion of a transmitter relative to a receiver (Albarazi *et al*., 2011; Kabil *et al*., 2013). When a vehicle transmits/receives a signal while moving, the transmitted/received signal is subjected to an offset in its frequency. The higher the vehicle speed, the larger frequency distortion (Albarazi *et al*., 2011) as a result, frequency shifting increases and leads to a loss in orthogonality between subcarriers causing Inter-Carrier Interference (ICI) (Albarazi *et al*., 2011; Kabil *et al*., 2013).

For higher values of speed especially for 250 km h^{-1}, the signal restoration becomes extremely difficult (Kabil *et al*., 2013). Therefore, several methods have been proposed to provide an estimation of Doppler shiftfor OFDM communication systems (Kabil *et al*., 2013; Kumar and Pandey, 2013; Kumar *et al*., 2009; Rahman *et al*., 2012). Previously in article (Kabil *et al*., 2013), the Extended Kalman Filter (EKF) has been proposed as a good method for the MB-OFDM system. Significant gains of the performance can be achieved using EKF method for high and low speeds in terms of BER (Kabil *et al*., 2013).

The critical limitation in the MB-OFDM system is their relatively short range (Qiyue *et al*., 2007; Batra *et al*., 2004). The desired range is around 20 m for 200 Mbits/s, it can be reduced in the presence of Doppler shift (Kabil *et al*., 2014). To push the MB-OFDM as a good candidate to ensure V&I communicationas proposed in (Kabil *et al*., 2013), it is important to improve the extremely short transmission range limit. The main objective of this article is to study and investigate the performance of the MB-OFDM system with the new solution for reducing the ICI Effect based on the association of EKF and ML over radio channelin terms of BER and transmission range.

This paper is organized as follows: We give a brief review of the MB-OFDM system. Then, we illustrate how the new compensation of Doppler Effect can be exploited and also analyzed it performance in terms of BER and transmission range.

Materials and Methods

MULTIBAND-OFDM System

The available spectrum (3.1-10.6 GHz) (Avila and Thenmozhi, 2014) is divided into 14 sub-bands (Qiyue *et al*., 2007), each one occupying 528 MHz (Kabil *et al*., 2011; Avila and Thenmozhi, 2014). The structure of the MB-OFDM solution is very similar to that of a conventional wireless OFDM physical layer, the main difference is the use of Time-Frequency Codes (TFC) (Kabil *et al*., 2013). The structure of the MB-OFDM system offers data rates of [55, 80, 110, 160, 200, 320 and 480] Mbits/s (Kabil *et al*., 2014).

The fundamental transmitter and receiver structure of an MB-OFDM system is illustrated in Fig. 1. At the transmitter, the bits from information sources are first encoded by the convolution encoder. To exploit time-frequency diversity and combat multi-path fading, the coded bits are further interleaved according to some preferred time-frequency patterns and the resulting bit sequence is mapped into constellation symbols and then converted into a block of N symbols by the serial-to-parallel converter (Qiyue *et al*., 2007; Kabil *et al*., 2011).

The IFFT size is 128 and the total number of used subcarriers is 122. The useful duration of each OFDM symbol is 242 ns, leading to subcarrier frequency spacing of Δf = 4.125 MHz (Kabil *et al*., 2013). In order to avoid inter-symbol interference between two consecutive OFDM symbols, a Zero Padding (ZP) guard interval of 70.08 ns duration is added at the end of each OFDM symbol.

To provide increased performance for low data rates, the MB-OFDM system includes support for frequency and time spreading, which provide repetition of the same data symbols over multiple subcarriers and/or OFDM symbols. Frequency-Domain Spreading (FDS) repeats the same data symbol over two different subcarriers in the same OFDM symbol, while Time-Domain Spreading (TDS) repeats the entire OFDM symbol in two consecutive time slots (Kabil *et al*., 2013; Christopher, 2003). The OFDM symbol is passed through a Digital-to- Analogue Converter (DAC) resulting to an analogue baseband OFDM signal (Sadough, 2008).

At the demodulator, the used of ZP requires to make the operation called Overlap and Add (OLA) before the Fast Fourier Transform (FFT) in order to restore the orthogonality between subcarriers (Kabil *et al*., 2014). The obtained N symbols are then mapped into bits and the resulting bit sequence is de-interleaved and decoded to get back the information bits (Mohammad, 2007).

Results and Discussion

New Solution for Reducing the ICI Effect

The section covers the new solution's studies for MB-OFDM system over high mobility multipath channel in order to improve the signal quality and the transmission range for 200 Mbits/s.

Improving the Performance of MB-OFDM System in Terms of BER

An OFDM signal represented in the time domain as in Equation 1:

$$x(t) = \sum^{N-1} X_k e^{j\pi f_k t}\ 0 \le t \le T_u \quad (1)$$

With:

- X_k = The complex signal modulating for the kth subcarrier
- $f_k = f_0 + k\Delta f$ = The frequency of the kth subcarrier, f_0 is the starting frequency of the MB-OFDM signals
- Δf = The frequency separation between two adjacent subcarriers, $\Delta f = \frac{1}{T_u}$
- T_u = Useful duration

The complex baseband representation of the time variant impulse response model of the multipath channel in mobile radio environments is defined as (Albarazi *et al*., 2011):

$$h(t,\tau) = \sum_{i=0}^{\infty} \alpha_i e^{j2\pi f_{d,k} t} \delta(t - \tau_i) \quad (2)$$

$$f_{d,k} = (f_0 + k\Delta f)\frac{v}{c} - \cos\theta_i \quad (3)$$

Where:

- a_i = The multipath gain coefficients of i-th scatter
- τ_i = the delay of i-th scatter
- $F_{d,k}$ = Doppler shift of the kth subcarrier received from the i-th scatter in the direction θi
- v = The speed difference between the source and receiver
- c = Speed of light

We have been proposed a multipath channel model with two paths. The model of Saleh-Valenzuela (SV) has been adopted as the reference model of Outdoor UWB channel specified in the IEEE802.15.4a (Albarazi *et al*., 2011).

For the proposed channel with two paths and in the presence of the shadowing, the impulse response becomes:

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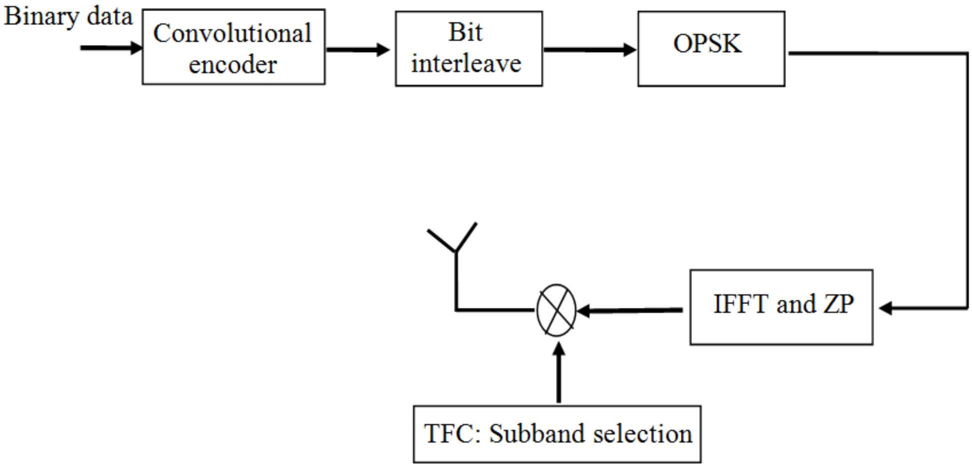

Fig. 1. Block diagrams of the transmitter of an MB-OFDM system

$$h(t,\tau) = X\sum_{i=1}^{2}\alpha_i e^{j2\pi f_{d,k}t}\delta(t-\tau_i) \quad (4)$$

where, the X represents the lognormal shadowing with the parameter of shadowing is σ_x.

The received signal with the proposed channel is:

$$y(t) = X\sum_{i=1}^{2}\alpha_i \sum_{k=0}^{N-1} X_k e^{j2\pi f_k(t-\tau_i)} e^{j2\pi f_{d,k}t} + w(t) \quad (5)$$

$$y(t) = e^{j2\pi f_{d,k}t}(X\sum_{i=1}^{2}\alpha_i \sum_{k=0}^{N-1} X_k e^{j2\pi f_k(t-\tau_i)} + w(t) \quad (6)$$

If the y(t) is sampled by Nyquist rate, the Equation 6 becomes.

The normalized Frequency Offset (FO) is $\varepsilon = f_{d,k}T$ (Kabil *et al*., 2013):

$$y(n) = e^{j2\pi\varepsilon\frac{n}{N}}(X\sum_{i=1}^{2}\alpha_i \sum_{k=0}^{N-1} X_k e^{j2\pi f_k}\left(n\frac{T_u}{N} - n\frac{\tau_i}{N}\right) + w(n) \quad (7)$$

$$y(n) = z(n)e^{j2\pi\varepsilon\frac{n}{N}} + w(n) \quad (8)$$

$$z(n) = X\sum_{i=1}^{2}\alpha_i \sum_{K=0}^{N-1} X_k e^{j2\pi f_k}\left(n\frac{T_u}{N} - n\frac{\tau_i}{N}\right) \quad (9)$$

The problem with OFDM systems are sensitive to the Frequency Offset (FO) between transmitter and receiver signals caused by the relative motion between transmitter and receiver and scattering environment, induces Doppler spread (Albarazi *et al*., 2011; Sreekanth and GiriPrasad, 2012). These frequency errors causes the loss of orthogonality between the subcarrier and signal transmitted on each carrier are not independent to each other, leading to the Inter-Carrier Interference (ICI), so that system performance may be considerably degraded (Albarazi *et al*., 2011). The degradation of the performance for the MB-OFDM in terms of BER is important and becomes worse with high speed (250 km h^{-1}) (Kabil *et al*., 2013).

Kabil *et al*. (2013), the Extended Kalman Filer (EKF) and the Maximum Likelihood (ML) estimation with ZF equalizer have been proposed and have been compared in order to combat the ICI effect. It is seen that the use of EKF or ML gives good results for 50 km h^{-1} and 150 km h^{-1}, however, for 250 km h^{-1}, the EKF gives a good results then the ML method and is about E_b/N_0 = 9.617 dB at BER = 10^{-3} compared to ML method we need E_b/N_0 = 20 dB for the same BER.

To increase the performance of the MB-OFDM system in terms of BER, we propose a new solution based on the association of the EKF and ML methods as shown in Fig. 2. These ICI cancellation methods are used without ZF equalizer.

The Equation 8 becomes:

$$y(n) = (z(n)e^{j2\pi\varepsilon\frac{n}{N}} + w(n))e^{-j2\pi(\hat{\varepsilon}_{EKF}+\hat{\varepsilon}_{ML})\frac{n}{N}} \quad (10)$$

$$y(n) = (z(n)e^{j2\pi(\varepsilon-(\hat{\varepsilon}_{EKF}+\hat{\varepsilon}_{ML}))\frac{n}{N}} + w(n))e^{-j2\pi(\hat{\varepsilon}_{EKF}+\hat{\varepsilon}_{ML})\frac{n}{N}} \quad (11)$$

Replacing $\varepsilon-(\hat{\varepsilon}_{EKF}-\hat{\varepsilon}_{ML})$ by $\varepsilon = \varepsilon-(\hat{\varepsilon}_{EKF}-\hat{\varepsilon}_{ML})$, the Equation 11 becomes:

$$y(n) = (z(n)e^{j2\pi\varepsilon\frac{n}{N}} + w(n)e^{-j2\pi(\hat{\varepsilon}_{EKF}+\hat{\varepsilon}_{ML})\frac{n}{N}} \quad (12)$$

Figure 3 illustrates the BER simulation results as function of Eb/N0 for 200 Mbits/s for the EKF algorithm and ML method and the new solution based on the association of the EKF and ML over the proposed channel with Doppler Effect of 250 km h^{-1}. The Eb/N0 is varying between -6 and 50 dB.

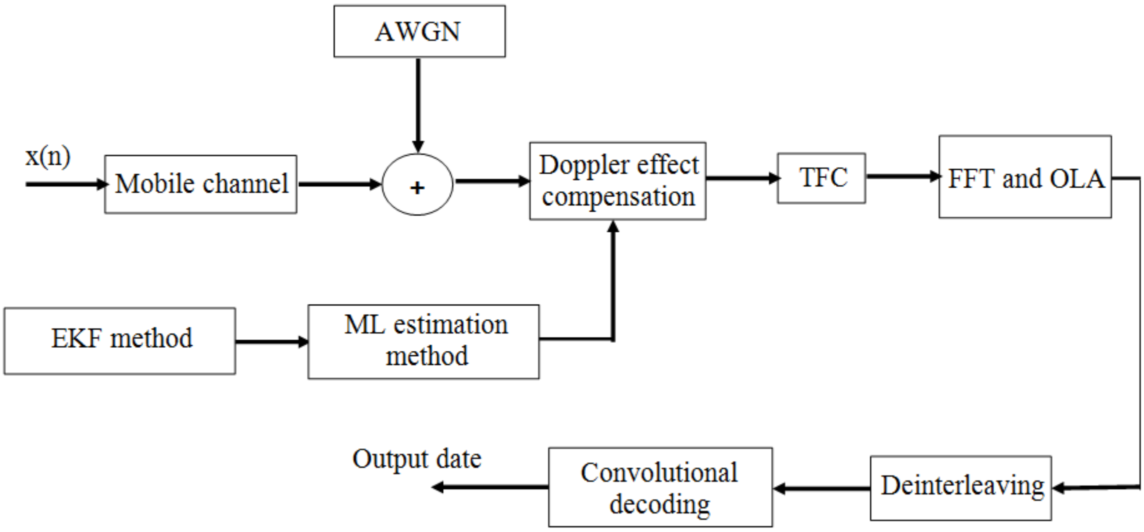

Fig. 2. Receiver bock diagram for the MB-OFDM system with the new solution

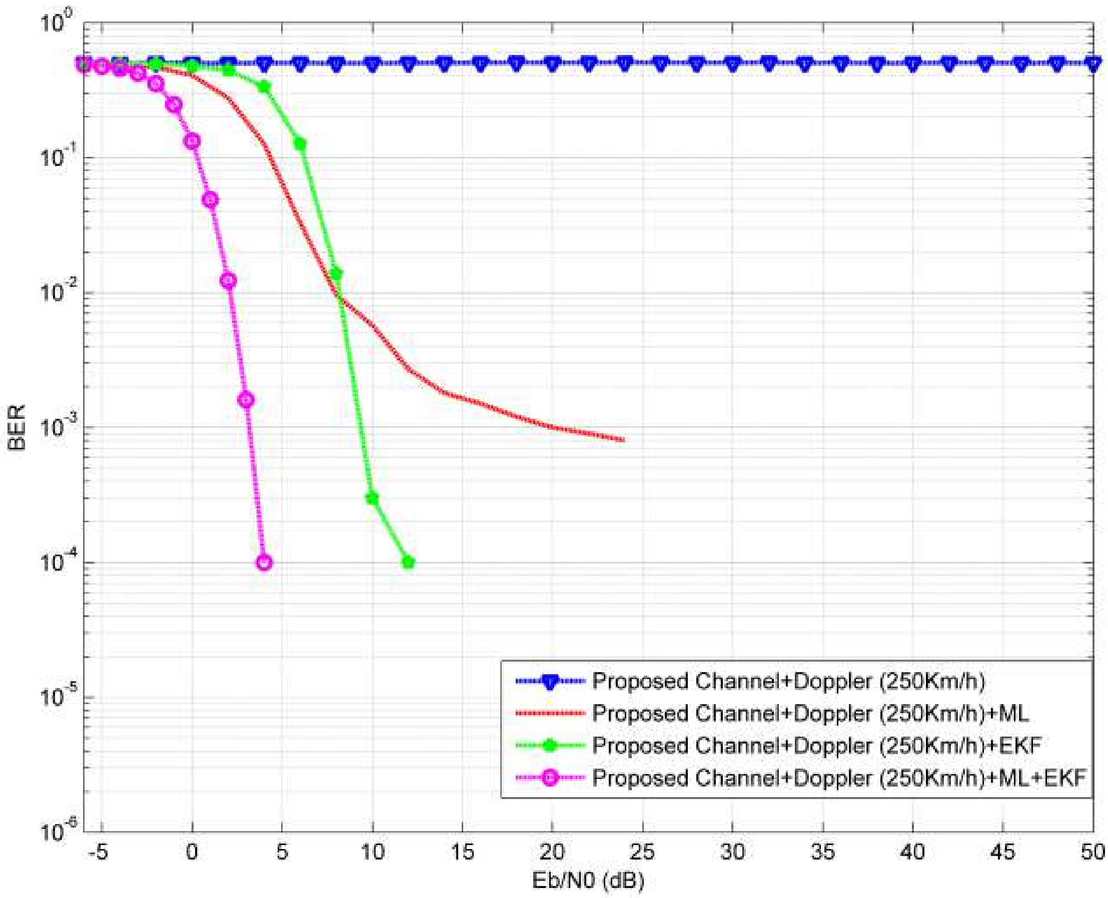

Fig.3. Curves of the BER performance with the MB-OFDM system as function of Eb/N0 for multipath channel with and without the reduction algorithms for 250 km h^{-1}

According to the simulation results of the Fig. 3, it is observed that the new solution gives good results in terms of BER compared to EKF and ML methods. At BER = 10-3, the association of the EKF and ML algorithms gives a $\frac{E_b}{N_0} = 3.169\text{dB}$ however, with EKF algorithm we need $\frac{E_b}{N_0} = 9.371\text{dB}$ for the same BER.

Range Improvement

Range Improvement with ICI Reduction Methods

The equation of the SNR as function of the transmission range for multipath channel with Doppler Effect as (Qiyue *et al.*, 2007; Sathananthan *et al.*, 2000) is Equation 13:

$$\begin{aligned} \text{SNR} &= P_{TX} - 20\log_{10}\left(\frac{4\pi f_g d}{c}\right) - (-174 + 10\log_{10}(R_b)) \\ &-6.6 - 2.5 + 10\log_{10}(E\{|H[k]^2|\}) + 10\log_{10}(\operatorname{sinc}^2(\varepsilon)) \\ &-10\log_{10}\left(1 + \frac{4}{3}\sin^2(\pi\varepsilon)\frac{E_b}{N_0}\right)(\text{en dB}) \end{aligned} \tag{13}$$

With:

- The term 10 $\log_{10}(E\{|H[k]^2|\})$is the fading gain that is captured by the IEEE 802.15.4a channel model and calculated as (Qiyue *et al.*, 2007):

$$E\{|H[k]^2|\} = \exp(0.0265\sigma_x^2) \tag{14}$$

- $10\log_{10}(\operatorname{sinc}^2(\varepsilon)) - 10\log_{10}\left(1 + \frac{4}{3}\sin^2(\pi\varepsilon)\frac{E_b}{N_0}\right)$: The degradation due to the Doppler Effect in dB as shown in (Sathananthan *et al.*, 2000)
- f_g: The geometric average of the lower and upper frequencies defined as $\sqrt{f_U f_L}$ with is the lower frequency and is the upper frequency

The transmitted signal power is equal to (Qiyue *et al.*, 2007; Batra *et al.*, 2004):

$$P_{TX} \le -41.25 + 10\log_{10}(f_U - f_L)(\text{dBm}) \tag{15}$$

G_{TX}, G_{RX} Gains of the transmitting and receiving antenna respectively and are assumed equal to 0 dBi (Btra *et al.*, 2004).

At the receiver, the average noise power can be calculated using the formula: -174+10$\log_{10}(R_b)$ (in dBm). Here, R_b is the data rate in bits per second and equal to 200 Mbits/s and -174 comes from k_BT calculated at room temperature as the thermal noise power per hertz, where $K_b = 1.38*10^{-23}$J/K is the Boltzmann's constant and T is the temperature in Kelvin. We assume that the noise figure of the antenna and the receiver RF chain is 6.6 dB and the implementation loss in the digital baseband is 2.5 dB (Qiyue *et al.*, 2007):

c = Speed of light
d = Distance between transmitter and receiver measured in meters

After adding the reduction algorithms: ML or EKF, the equation of SNR as function of the distance for an AWGN channel with Doppler Effect is as:

$$\begin{aligned} \text{SNR} &= P_{TX} - 20\log_{10}\left(\frac{4\pi f_g d}{c}\right) - (-174 + 10\log_{10}(R_b)) \\ &-6.6 - 2.5 + 10\log_{10}(E\{|H[k]^2|\}) + 10\log_{10}(\operatorname{sinc}^2((\varepsilon - \hat{\varepsilon}))) \\ &-10\log_{10}\left(1 + \frac{4}{3}\sin^2(\pi(\varepsilon - \hat{\varepsilon}))\frac{E_b}{N_0}\right)(\text{en dB}) \end{aligned} \tag{16}$$

The Fig. 4 illustrates the evaluation of the BER curves as function of the distance for the MB-OFDM system over the proposed channel with Doppler Effect for 250 km h^{-1} with the algorithms: ML, EKF in comparison with the results of the BER for the proposed channel with Doppler Effect and without reduction algorithms. The distance varies between 1 and 25 m.

By comparing the results of the BER curves as a function of the distance presented in Fig. 4, we note that despite the using of the ICI reduction methods, the transmission range is still extremely short, the distance is d = 3.325 m for a BER = 10^{-3} in the case of EKF filter.

Range Improvement with new Solution for Reducing ICI Effect

After adding the new solution based on the association of the ICI reduction algorithms: ML and EKF, the Equation 13 of SNR as function of the transmission range over the multipath channel with Doppler Effect becomes:

$$\begin{aligned} \text{SNR} &= P_{TX} - 20\log_{10}\left(\frac{4\pi f_g d}{c}\right) \\ &-(-174 + 10\log_{10}(R_b)) - 6.6 - 2.5 + 10\log_{10} \\ &(E\{|H[k]^2|\}) + 10\log_{10}(\operatorname{sinc}^2(\varepsilon - \hat{\varepsilon}_{EKF} - \hat{\varepsilon}_{ML})) \\ &-10\log_{10}\left(1 + \frac{4}{3}\sin^2(\pi(\varepsilon - \hat{\varepsilon}_{EKF} - \hat{\varepsilon}_{ML}))\frac{E_b}{N_0}\right)(\text{en dB}) \end{aligned} \tag{17}$$

The Fig. 5 illustrates the simulation results for the MB-OFDM system over the proposed channel with Doppler shift for 250 km h^{-1} with ICI reduction algorithms: ML and EKF. The distance is between 1 and 25 m.

It will be seen that with the new solution, the transmission range can be enlarged from d = 3.325 m to d = 13.960 m for the MB-OFDM system with data rate of 200 Mbits/s over high mobility multipath channel.

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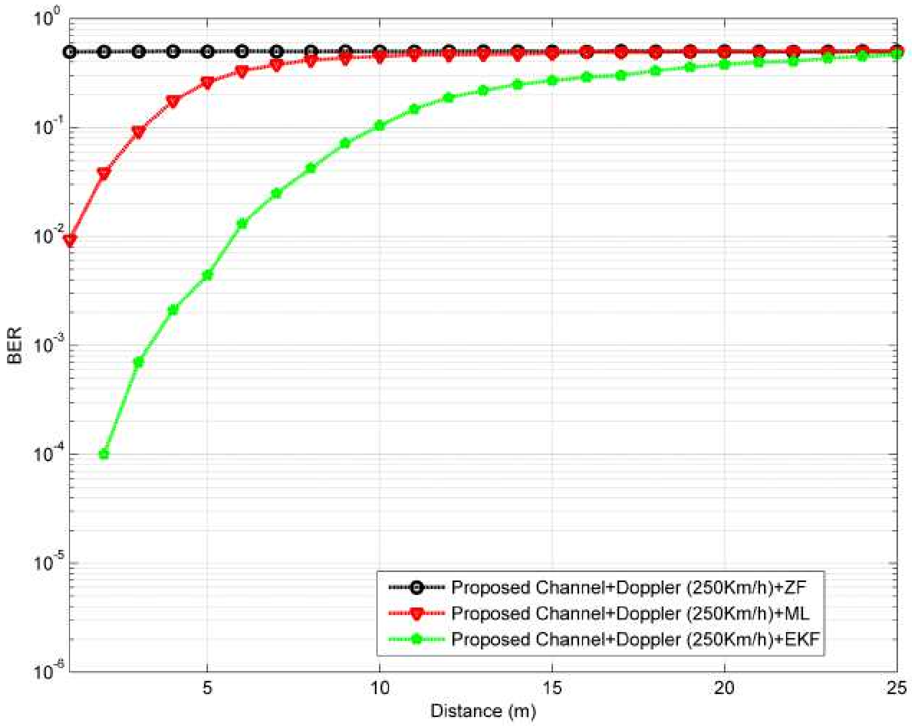

Fig. 4. Curves of the BER performance with the MB-OFDM system as function of distance for multipath channel with and without the reduction algorithms for 250 km h^{-1}

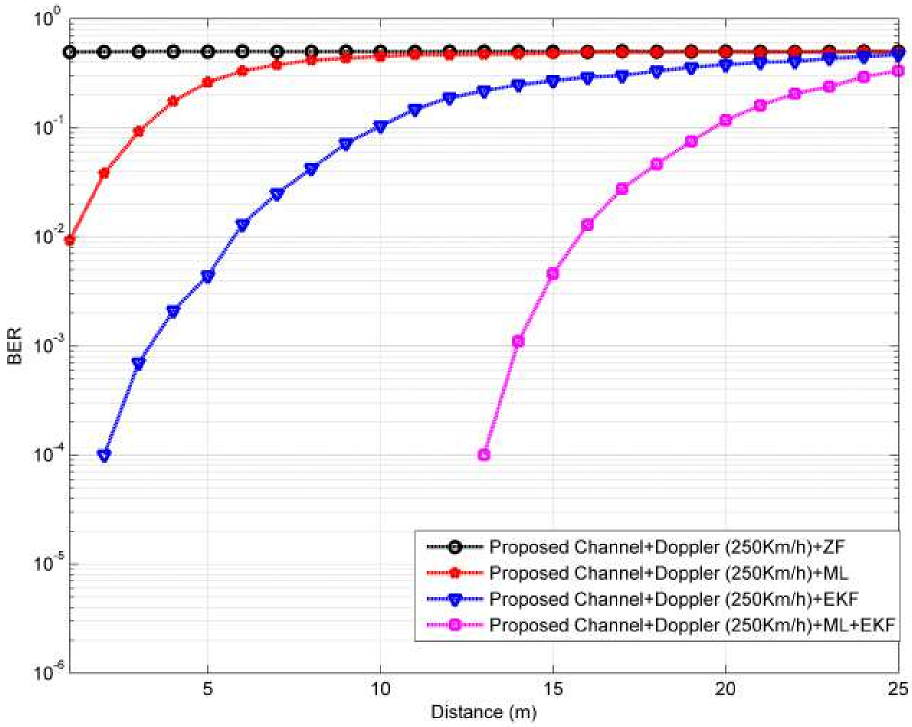

Fig. 5. Curves of the BER performance with the MB-OFDM system as function of distance for multipath channel with and without the reduction algorithms for 250 km h^{-1}

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Conclusion

In this study, we have proposed a new solution based on the association of the EKF and ML methods for reducing ICI Effect in the MB-OFDM system over high mobility multipath channel especially for 250 km h^{-1}, to improve the signal quality and the transmission range. The new solution has been compared to the EKF and to the ML with ZF equalizer. It is shown that the new solution performs better than the EKF and ML methods and offers much improvement in the performance in terms of BER and transmission range. It will be seen that the transmission range can be enlarge to 13.960 m for 250 km h^{-1}.

Perspectives

In the future work we plan to:

- Study the effect of multi-user associated with the Doppler Effect
- Optimizing the receiver for reducing the processing time with good performance required by the application of transport

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Author's Contributions

Sanaa Kabil: Participated in all experiments, coordinated the data-analysis and contributed to the writing of the manuscript.

Raja Elassali: Designed the research plan and organized the study.

Fouzia Elbahhar: Coordinated the data-analysis and contributed to the writing of the manuscript.

Brahim Ait Essaid: Participated in all experiments, coordinated the data-analysis and contributed to the writing of the manuscript.

Abdellah Ait Ouahman: Coordinated the data-analysis and contributed to the writing of the manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of other authors have read and approved the manuscript.

References

Albarazi, K., U. Mohammad and N. Al-holou, 2011. Doppler shift impact on vehicular ad-hoc networks. Canadian J. Multimedia Wireless Netw., 2: 46-56.

Avila, J. and K. Thenmozhi, 2014. Filter based interference mitigation in Multi Band-OFDM. Res. J. Applied Sci. Eng. Technol., 7: 1252-1255.

Batra, A., J. Balakrishnan, G.R. Aiello, J.R. Foerster and A. Dabak, 2004. Design of a multiband OFDM system for realistic UWB channel environments. IEEE Trans. Microwave Theory Techniques, 59: 2123-2138. DOI: 10.1109/TMTT.2004.834184

Christopher, S., 2003. Multiband orthogonal frequency division multiplexing for ultra-wideband wireless communication: Analysis, extensions and implementation aspects. Thesis B.Sc., University of Western Ontario.

Kabil, S., R. Elassali, F. Elbahhar, A.A. Ouahman and B.A. Essaid, 2013. Analysis and solution for multi-band orthogonal frequency-division multiplexing ultra wide band system in real environment for vehicle to infrastructure application. J. Comput. Sci., 9: 1305-1317.
DOI: 10.3844/jcssp.2013.1305.1317

Kabil, S., B. AitEssaid, A. AitOuahman, R. Elassali and F. Boukour, 2011. Analysis of UWB -OFDM system for vehicle to infrastructure communication. Proceedings of the 4th International Conference on Logistics (LOGISTIQUA), May 31-Jun. 3, IEEE Xplore Press Hammamet, pp: 430-433.
DOI: 10.1109/LOGISTIQUA.2011.5939438

Kabil, S., R. Elassali, F. Elbahhar, A.A. Ouahman and B.A. Essaid, 2014. Performance Analysis of doppler shift impact on the MB-OFDM system applied for vehicle to infrastructure communication. Proceedings of the IEEE International Conference on Ultra-WideBand (ICUWB), Sept. 1-3, IEEE Xplore Press Paris, pp: 433-437.
DOI: 10.1109/ICUWB.2014.6959021

Kumar, A. and R. Pandey, 2013. A spectrally efficient intercarrier interference reduction scheme for orthogonal frequency division multiplexing systems in low signal-to-noise ratio environment. IETE J. Res., 59: 74-82.

Kumar, B.S., K.R. S. Kumar and R. Radhakrishnan, 2009. An efficient intercarrier interference cancellation schemes for OFDM systems. Int. J. Comput. Sci. Inform. Security, 6: 141-148.

Mohammad, A.H., 2007. Performance evaluation of WiMAX/IEEE 802.16 OFDM Physical Layer.

Rahman, M., P.K. Dey and M.F.R. Ur Rashid, 2012. Improved ICI Self cancellation scheme for phase rotation error reduction in OFDM system. Int. J. Inform. Electronics Eng., 2: 509-511.
DOI: 10.7763/IJIEE.2012.V2.149

Sadough, S.M.S., 2008. Ultra wideband OFDM systems: channel estimation and improved detection accounting for estimation inaccuracies. Thesis University of Paris-Sud, France.

DOI: 10.3844/ajassp.2015.166.173

Sathananthan, K., R.M.A.P. Rajatheva and S.B. Slimane, 2000. Analysis of OFDM in the presence of frequency offset and a method to reduce performance degradation. Proceedings of the Global Telecommunications Conference, Nov. 27-Dec. 1, IEEE Xplore Press, San Francisco, CA, pp: 72-76. DOI: 10.1109/GLOCOM.2000.891691

Sreekanth, N. and M.N. GiriPrasad, 2012. BER Analysis of mitigation of ICI through ICI Self cancellation scheme in OFDM systems. Int. J. Comput. Netw. Wireless Commun., 2: 298-304.

Qiyue, Z., A. Tarighat and A.H. Sayed, 2007. Performance analysis of multiband OFDM UWB communications with application to range improvement. IEEE Tran. Vehicular Technol., 56: 3864-3878. DOI: 10.1109/TVT.2007.901957