PBER IMPROVEMENT OF IEEE 802.15.4 UNDER MULTIPATH RAYLEIGH FADING CHANNEL

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Abstract - Zigbee is a technology operates under IEEE 802.15.4 standard. It has been developed to define a specific set of communication protocols that support short-range, low cost and low power consumption wireless networking that are designed for control and monitoring applications. These applications are merely require security, reliability, in addition to a minimum possible amount of data rate and power consuming. This paper focuses on implementing a digital transceiver system for Zigbee sensor based on IEEE 802.15.4 and with a minimum possible amount of bit error rate (BER) for fading environments. As this standard does not provide channel equalization facility, an adaptive equalizer for multipath Rayleigh fading channel is equipped with Zigbee transceiver system. Two equalization algorithms are applied independently that are; least mean square (LMS) and Kalman equalizer. Simulation results have shown that the system has provided better performance in presence of LMS equalizer for signal-to-noise ratio (SNR) lies in the range -8-4 dB. However, Kalman equalizer has achieved well signal recovery in presence of noise. Based on the mean square of error (MSE), Kalman equalizer was capable of errors converging faster than the LMS equalizer.

Keywords - Adaptive equalizers; BER; IEEE 802.15.4; Kalman filter; Multipath Rayleigh Fading.

I. INTRODUCTION

Due to the rapid evolution in wireless communications and electronics over the last few years, the need for networks with low-cost, low-power, and multi-functional sensors received an increasing attention. These sensors are small in size and able to sense, process data, and communicate with each other over an RF (radio frequency) channel. A sensor network is designed to detect events or phenomena, collect and process data, and transmit sensed information for the intended users [1]. These networks have the potential of interfacing the physical world with the virtual (computing) world in an unprecedented scale and provide practical usefulness in developing a large number of applications, including the protection of civil infrastructures, habitat monitoring, precision agriculture, toxic gas detection, supply chain management, and health care [2]. Zigbee is considered one of the wireless sensor devices operating under IEEE 802.15.4 standard. This standard has been introduced by Zigbee Alliance. Zigbee standard was created to address the market need for cost-effective, standard-based wireless networking solutions that support low data rates transceivers, low power consumption, security, and reliability through wireless personal area networks (WPANs) [3]. It is known that the wireless medium is influenced by real-time conditions such as signals interference, doppler shift, and path loss; where these parameters have the effect of degrading wireless transmission performance [4]. Generally, the reliability of any communication channel depends on the BER and this greatly effects on network performance including throughput, delay, and energy [5]. During transmission over a communication channel, the transmitted signal may suffer from reflection, refraction, and diffraction. For example, the communication channel in vehicles is subjected to multiple paths as a signal travel from a transmitter to a receiver. In Line-of-Sight (LoS) transmission, the signal is able to find a direct path. In contrast, it may obstruct by an object as in Non-Line of Sight transmission (NLoS). Moreover, it is difficult for the receiver to recover the original signal because of different resultant paths delay and gains [6]

According to [7], zigbee transceiver system has been implemented based on IEEE 802.15.4 standard. The system has shown well performance, considering to BER, when it was experienced by additive white gaussain noise (AWGN) channel and in the presence of direct sequence spread spectrum (DSSS) technique. Moreover, this paper focuses on implementing 2.4 GHZ Zigbee transceiver system based on IEEE 802.15.4 and equipped with channel equalizer using MATLAB/Simulink. Equalization process has been considered for further BER improvement through applying LMS and Kalman equalization algorithms independently. The use of channel equalization is for facilitating the receiver in providing a reliable communication and especially when a signal is suffering from interference with other signals travel from multiple paths.

II. RESEARCH METHOD

It is well known that whenever channel distortions occur, the effect of inter-symbol interference (ISI) might arise despite of the correct transceiver filters design. In such cases, channel equalization must be resorted. Equalization can be defined as a technique adopted to recover channel distortions. The fixed equalizer is needed when the effect of channel distortion is not time-varying; otherwise, an adaptive

equalizer might be required [8]. In general, the concept of equalization is based on compensating signal amplitude and phase distortion using adjustable filters. Adaptive equalizer is employed in most of practical cases whenever the characteristics of the communication channel are unknown. Hence, for every channel connection, the equalizer must be updated automatically to track changes in the channel instantaneously [9]. Fig. 1 illustrates the general structure of an adaptive equalizer; where k represents the number of iteration, $x(k)$ is the input signal, $y(k)$ denotes the adaptive equalizer output, and $d(k)$ denotes the desired signal. $e(k)$ is the error signal and it can be calculated as:

$$e(k) = d(k) - y(k) \qquad (1)$$

The error signal is used to the objective function required by the adaptation algorithm for determining the suitable updating of the filter coefficients. The output signal of the adaptive equalizer should match with the desired signal in order to minimize the objective function [10].

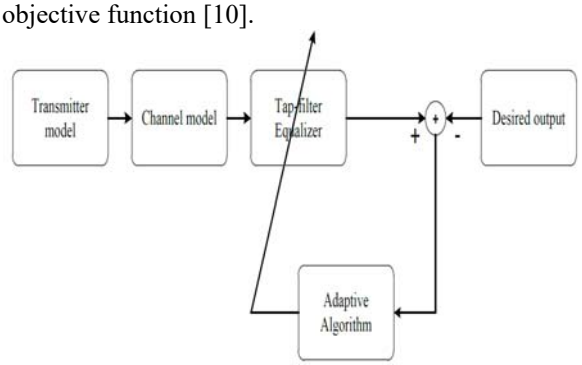


Fig.1 General structure of the suggested equalizer system

A. Least Mean square (LMS) Algorithm

LMS is an adaptive equalization algorithm that uses iterative procedure for successively corrects the weights. This algorithm is considered a stochastic gradient algorithm and it provides the function of tracking time variation of channel characteristics [11]. Because of its simplicity, LMS algorithm is widely used in many application. However, it has a drawback in having slow convergence speed unlike other complicated algorithms like Recursive Least Square (RLS) [12].

In this paper, LMS equalization algorithm is used as an adaptive multipath Rayleigh fading channel equlizer to provide further improvement in BER. A finite duration impulse response (FIR) filter is used to implement the LMS equalizer. The filter has delay elements corresponding to the symbol duration and coefficients determined by LMS algorithm adaptively. The proposed LMS equalizer includes two main processes:

Filtering process: producing filter output signal and estimation error.

Adaptive process: performing automatic adjustment of filter coefficients.

As shown in Fig. 2, the proposed LMS equalizer suggests the use of a tapped delay line equalizer consists of five tape coefficients that adaptively computed by LMS algorithm. LMS algorithm is described by the following equations:

$$y(n) = \sum_{i=1}^{M-1} c_i(n)x(n-1) \qquad (2)$$

$$e(n) = d(n) - y(n) \qquad (3)$$

Tap-coefficients adaptation:

$$c_i(n+1) = c_i + \Delta e(n)x(n) \qquad (4)$$

Computing the MSE at step $\mathbf{N}$:

$$E_N = \frac{N-1}{N}E_{N-1} + \frac{1}{N}e_N^2 \qquad (5);$$

Where $y(n)$ is the actual (current) filter output, $c_i(n)$ represents the tap filter coefficients, $x(n)$ is the tap inputs from the channel, $d(n)$ is the desired signal (transmitted modulated signal), $e(n)$ is the estimation error, M is the fitter order (number of taps), Δ represents the scale factor or step size parameter that control the rate of convergence, and e_m represents the error at step m.

The steps of the proposed LMS equalizer are depicted in the flowchart of Fig. 3. The symbols and their definitions used in this flowchart are as follow:

c: vector of LMS equalizer coefficients, nn: delay to fill equalizer, err_sq: square magnitude of LMS error (MSE), del: LMS scale factor, e: the error at step m, and esd: the estimation error.

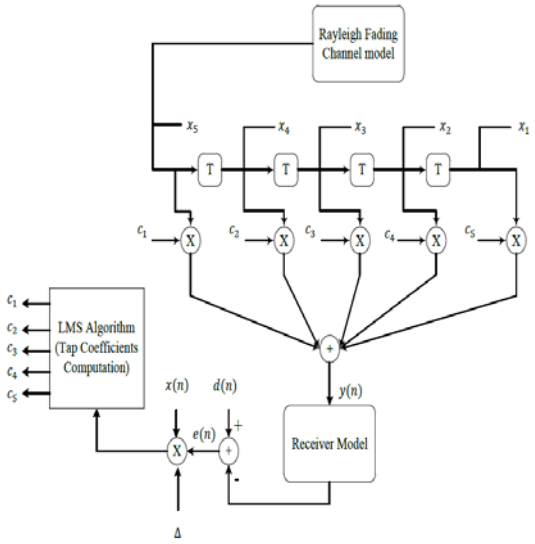


Fig. 2 Proposed LMS Equalizer

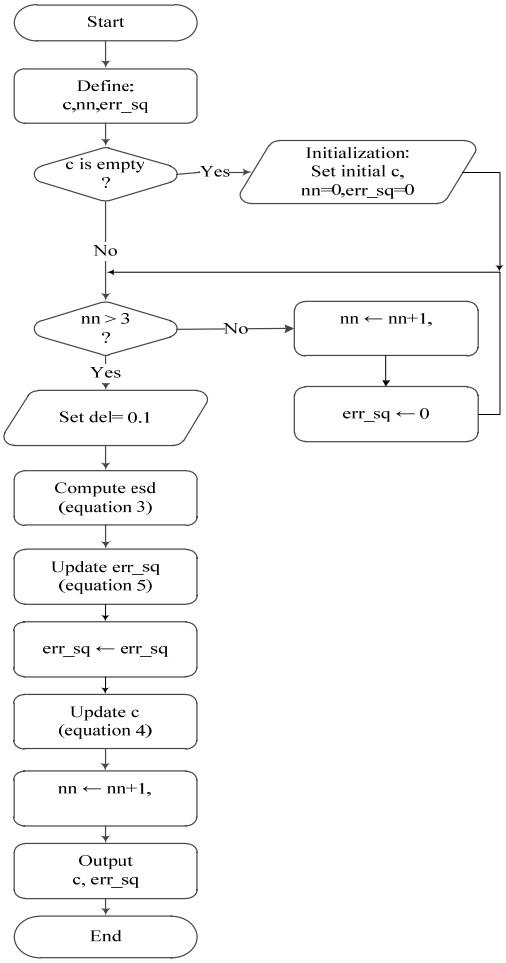


Fig. 3 Flowchart of the proposed LMS equalizer

B. Kalman Equalization Algorithm

Kalman equalizer is considered to be an optimum solution for wireless network with non-stationary signal and noise. It is based on least squares method which attempts to find an estimation that minimizes the error covariance matrix; hence it is known as kalman estimation. The recursive least square (RLS) algorithm is simplified form of the Kalman filter [13]. The Kalman filter is such a powerful equalization algorithm because it provides estimations of past, present, and even future states, in addition, it can work good with unknown system parameters [14]. In this paper, Kalman filter is used to calculate the coefficients of the equalizer needed to reduce the distortion resulted from the Rayleigh fading channel model. The following equations are used to implement a tapped delay equalizer of five coefficients using Kalman filter [15]

Computing Kalman filter equalizer coefficients recursively:

$$\vec{d}_k = \vec{d}_{k-1} + G_k(s_k - \vec{v}_k \vec{d}_{k-1}) \quad (6);$$

Where s_k denotes a known training signal, $\vec{v}_k$ is the corrupted signal at multipath channel output, and G_k represents the Kalman filter gain.

$$C_k = C_{k-1} + Q_k - G_k \vec{v}_k^T (C_{k-1} + Q_k) \quad (7);$$

Where Q_k represents the dynamic channel model noise covariance.

$$G_k = (C_{k-1} + Q_k)\vec{v}_k / [\vec{v}_k^T (C_{k-1} + Q_k)\vec{v}_k + v_{ke}] \quad (8);$$

Where v_{ke} represents the covariance of the channel model noise, and

$$Q_k = 0.01\mathrm{I} \quad (9);$$

Where I is an L×L identity matrix.

Computing the MSE at step N :

$$E_N = \frac{1}{N}\sum_{m=1}^{N} e_m^2 = \frac{N-1}{N} E_{N-1} + \frac{1}{N} e_N^2 \quad (10);$$

$$e_m = s_k - \vec{v}_k^T \vec{d}_{k-1} \quad (11);$$

The proposed Kalman equalizer is shown in the flowchart of Fig. 4. The steps of the proposed Kalman equalizer are depicted in Fig. 5. The symbols and their definitions used in this flowchart are as follow:

d: vector of Kalman equalizer coefficients, nn: delay to fill the equalizer, cov: current error covariance, err_sq: square magnitude of Kalman error (MSE), vke: channel noise covariance, q: dynamic model noise covariance, and e: the error at step m.

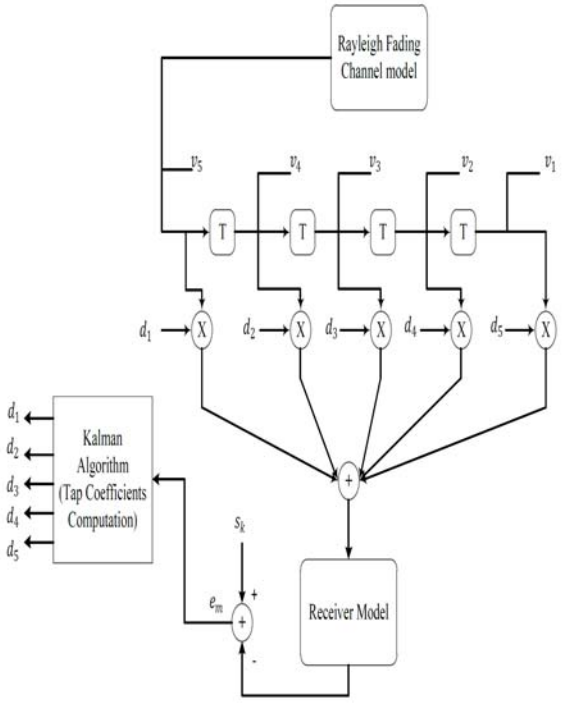


Fig.4 Proposed Kalman Equalizer

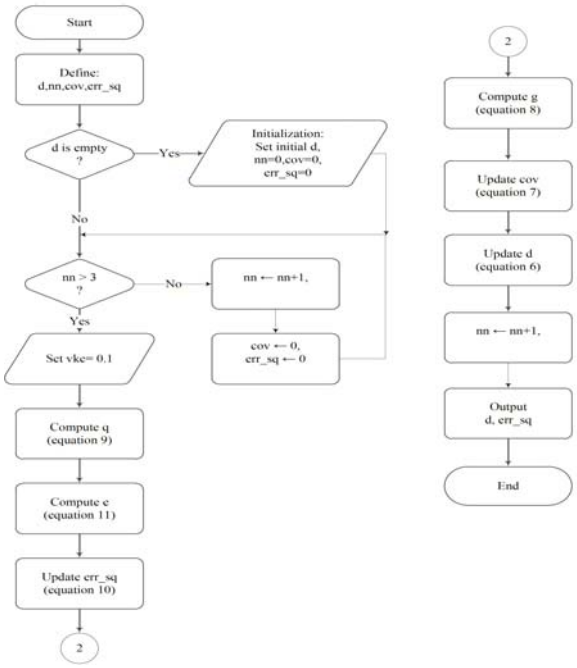


Fig. 5 Flowchart of the proposed Kalman equalizer

III. RESULTS AND SIMULATION ANALYSIS

According to the flowchart previously depicted in Fig. 3, LMS equalizer coefficients has been computed adaptively for the system with Rayleigh fading channel model.

A part of the simulation for Zigbee transmitter input and Zigbee receiver output is shown in Fig. 6, where the two signals were mostly identical due to the minimum resultant values of BER for high SNR. Values of SNR lies in the range -8-4 dB has been selected to calculate the possible BER values, where the results have shown better BER performance in presence of LMS equalizer. For comparison, when SNR was equal to 0 dB, the BER was 10-2 and 10-3 when the system was without and with LMS equalizer respectively. In Fig. 7, the real part of both of Zigbee modulated signal and LMS equalizer output are shown, and it is clear that the slower rate of convergence has introduced BER with certain E_b/N_0 values, but it was smaller than in the case the system was without LMS equalizer and as depicted in Fig 8.

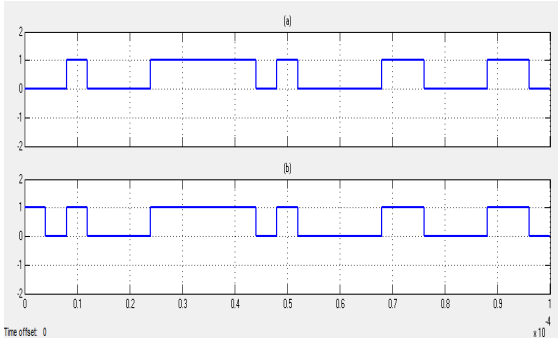


Figure 6: Zigbee transceiver input (a) and output (b) with LMS equalizer

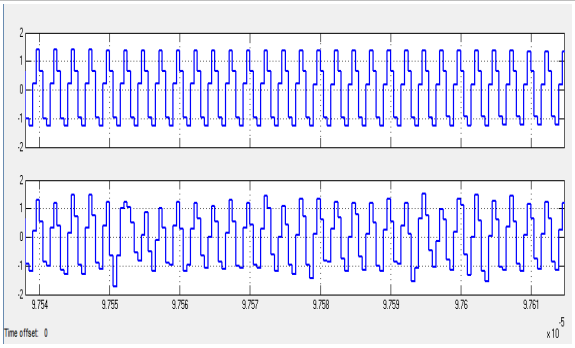


Fig. 7 Real Part of Zigbee transmitter and LMS equalizer output

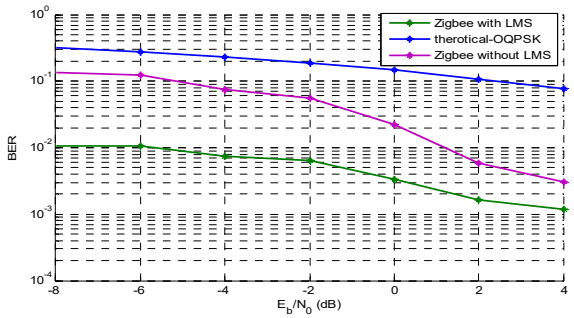


Fig. 8 BER curve of Zigbee transceiver with LMS equalizer

As LMS equalization algorithm introduced errors in the received signal, Kalman equalization algorithm has been applied to show the possibility of obtaining better BER performance. SNR values range between -8 dB to 4 dB have also been selected for BER measurement, where the results have shown that BER was equal to zero for all values of SNR and approximately for 4000 bits. Moreover, the real part of the proposed Zigbee transmitter output was identical with the output of Kalman equalizer as shown in Fig. 9, and that means, unlike LMS equalization algorithm, this algorithm provides large convergence area and the errors could be predictable in that interval. Furthermore, another comparison between the two algorithms could be made by examining the MSE and as depicted in Fig. 10 and Fig. 11, which shows that Kalman equalizer has the ability to converge for errors faster than LMS equalizer. Hence, it could be stated that Kalman equalization algorithm has improved the performance of the proposed Zigbee transceiver system by minimizing BER, when it was with multipath Rayleigh fading channel

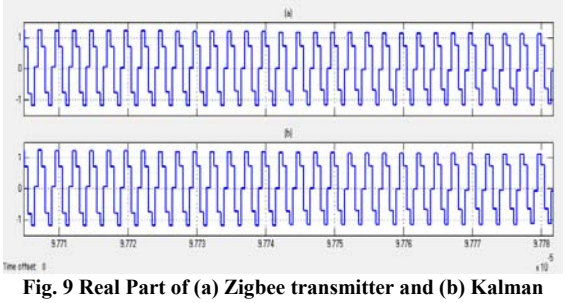


Fig. 9 Real Part of (a) Zigbee transmitter and (b) Kalman Equalizer Output.

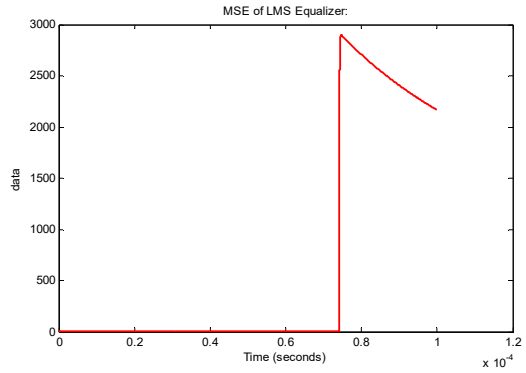


Fig. 10 MSE of LMS equalizer

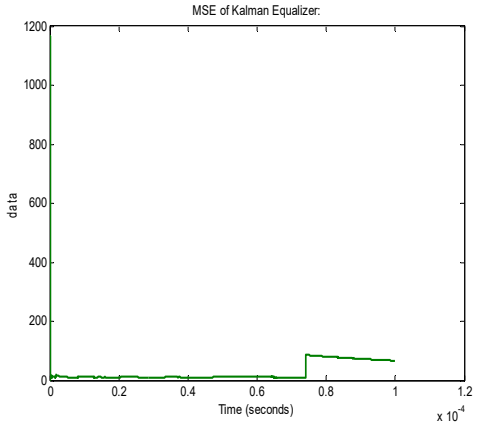


Fig. 10 MSE of LMS equalizer

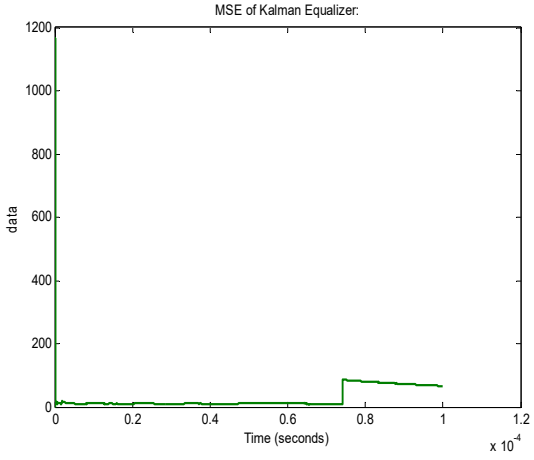


Fig. 11 MSE of Kalman equalizer

IV. CONCLUSIONS

Digital transceiver system for 2.4 GHZ Zigbee sensor based IEEE 802.15.4 has been implemented using MATLAB/Simulink. The system has been equipped with adaptive channel equalizers in order to mitigate inter-symbol interference (ISI) and/or multipath effect produced by Rayleigh fading channel and to obtain better BER performance. Two equalization algorithms have been used independently that are; LMS and Kalman equalizer algorithms. LMS equalizer has better improved BER for SNR lies in the range -8-4 dB; however, Kalman equalizer has achieved well signal recovery in presence of noise. Based on mean square of error (MSE), Kalman equalizer was capable for errors converging faster than the LMS equalizer. Hence, it could be stated that Kalman equalization algorithm has enhanced Zigbee transceiver performance when the system experienced multipath Rayleigh fading channel.

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