MMSE Equalized Rake-Receiver Using Adaptive Filter with a Family of Partial Update Algorithms in Wireless Communication Systems

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Abstract. **For high data rate propagation in wireless ultra-wideband (UWB) communication systems, the inter-symbol interference (ISI), multiple-access interference (MAI), and multiple-users interference (MUI) are influencing the performance of the wireless systems. In this paper, the adaptive MMSE equalized rake-receiver was presented with the spread signal by direct sequence spread spectrum (DS-SS) technique. The adaptive rake-receiver structure was shown with adjusting the receiver tap weights using least mean squares (LMS), normalized least mean squares (NLMS), and affine projection algorithms (APA) to support the weak signals and mitigate the interferences. To minimize the data convergence speed and to reduce the computational complexity by the previous algorithms, a well-known approach of partial-updates (PU) adaptive filters were employed with algorithms, such as sequential-partial, periodic-partial, M-max-partial, and selective-partial updates (SPU) in the proposed system. The simulation results of symbol error rate (SER) versus signal-to-noise ratio (SNR) are illustrated to show the performance of partial-update algorithms that have nearly comparable performance with the full update adaptive filters. Furthermore, the SPU-partial has closed performance to the full-NLMS and full-APA while the M-max-partial has closed performance to the full-LMS updates algorithms.**

Keywords: LMS, NLMS, and APA algorithms, equalized rake-receiver, MMSE equalizer, adaptive filter using partial-update algorithms.

I. INTRODUCTION

In communication link, multiple links and mutiple users researches have been focused on multiuser wireless communication systems. The current networks, such as mobile, cellular, satellite, and underwater acoustic networks are dealing with mutiple access systems in which a several number of users are sharing a common channels for reception and transmission of digital information. For reception of ultra-wideband signals (UWB), a rake receivers are used to ensure the high performance of symbol error rate (SER) related to signal-to-noise ratio (SNR).The most technique to generate UWB signals is impulse radio, so that, a train of narrow pulses with less than one nanoseconds width and low duty-cycle are transmitted through short range channel models (CM1, CM2, CM3, and CM4) that presented by [1].The Federal Communications Commission (FCC) has mentioned the power spectral density (PSD) at level -41.3 dBm/MHz for spectral range of 3.1—10.6 GHz as shown in Fig.1 which is dealing with lower operating voltage and the UWB power less than 100 mW [2]. This low PSD caused the UWB systems coexist with devices such as cellular systems, global positioning systems (GPS), and wireless local area networks (WALN) that based on penetration ability to overcome the obstacles for operation under both line of sight (LOS) and non line of sight (NLOS) conditions [3]. There are multi-paths in LOS and NLOS of indoor propagation to be resolved by rake-receiver of several correlators to overcome the channel fading and reflections [4]. In rake receiver, the energy capturing of resolvable paths are done by three diversity combining schemes, all-rake, selective-rake, and partial-rake receivers [5]. Partial-rake rceiver was based in this research to combine the first arriving L paths out of multi-path components (MPCs).

As the wireless communication systems are required to be small in size and light in wieght, the number of correlators need to be minimized with improvng the performance of rake-reciver at short range channel models. Adaptive filters are playing an important role in digital communication fields, such as noise cancellation, channel equalization, system identification [6]. The application of adaptive filter in noise cancellation requires the utilization of adaptive algorithms to be suitable for convergence rate. These algorithms are Least Mean

Sequares (LMS), Normalized Mean Sequares (NLMS), affine projection (AP), Euclidean Direction Search (EDS), and Recursive Least Sequares (RLS) [7]. The RLS algorithm has been established by [8] to improve the convergence behavior instead of LMS and NLMS algorithms. Variable Step-Size NLMS and Variable Step-Size APA algorithms were used by [9] in adaptive filter for channel equalization to mitigate the inter-symbol intereference (ISI) compared with standard NLMS and AP algorithms. Fast affine projection and fast Euclidean direction search algorithms were proved by [10] to attenute the noise in speech signals. A family of partial update EDS algorithms were presented in [11] to enhance the equalization performance by illustrating the symbol error rate (SER) with signal-to-noise ratio (SNR) of the system.

In this paper, the equalized MMSE rake-receiver was implemented using three individual adaptive algorithms LMS, NLMS, and APA. A family of partial-updates algorithms were implemented to reduce the signal processing complexity and increase the data convergence speed of the main algorithms. Additionaly, the paper was orgenized to represent the transmission signal and channel model of indoor wireless propagation in Section II. Section III shows the related equalized rake-receiver to receive the multi-path components which is working in DS-UWB wireless systems. In Section IV, the proposed adaptation filter algorithms are presented to be related with rake-receiver structure.. Partial-update algorithms are given in Section V. Finally, Sections VI and IIV appropriate the discussion of simulation results and conclusions, respectively.

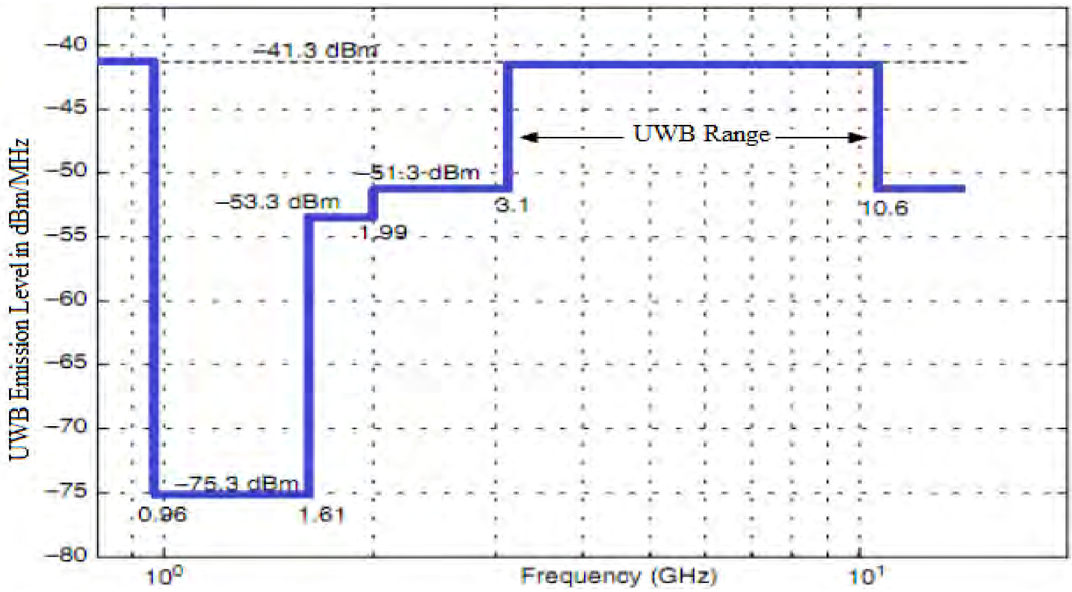

Fig. 1. UWB frequency range approved by FCC for indoor propagation [3]

II. UWB TRANSMITTER AND CHANNEL MODEL

We consider a DS-UWB system with binary pulse position modulation (PPM). The information is generated randomly by binary source and the pulses are shown in Fig. (2) of gaussian monocycle pulse and doublet pulse that can be described by the following gaussain function {g(t)} [12]:

$$g(t) = ke^{-(\frac{t}{\tau})^2} \tag{1}$$

where τ is the pulse duration and k is the factor to maintain the signal energy after each deviation.

$$g^{//}(t) = k\frac{-2t}{\tau^2}(1-2\frac{2t^2}{\tau^2})e^{-(\frac{t}{\tau})^2} \tag{2}$$

a train of generated pulses are modulated by pulse position modlation as:

$$w_{PPM}(t) = \sum_{n=-\infty}^{\infty} g(t - nT_f - T_c - D\delta) \tag{3}$$

where Tf is the pulse repition time, D represents the binary data [0, 1], $\boldsymbol{\delta}$ is the PPM parameter, Tc is the chip duration or the pseudo-random shift delay for binary sequence that is applied to spread the pulses by DS-UWB. The generated and modulated pulse sequence is transmitted over line-of-sight (LOS) indoor channel model (CM1). This channel model was proposed by IEEE 802-15 [13] which is based on modified Saleh-Valenzuela model [14] and the channel multi-path gain distribution is log-normal distribution as shown in Fig. (3). The main parameters of channel are described as: Λ is the cluster arrival rate of 0.0233 (1/ns), λ is the ray arrival rate of 2.5 (1/ns), Γ is the cluster delay factor of 7.1, and γ is the ray delay factor of 4.3. A ssuming the channel is time-invarant through the transmission, so that, the channel impulse responce {h(t)} with log-normal shadowing (X) can be modeled as in [2].

$$h(t) = \sum_{k=0}^{K} \sum_{l=0}^{L} \alpha_{k,l} \delta(\tau - T_k - \tau_{k,l}) \tag{4}$$

where $\alpha_{k,l}$ is the multi-path gain coefficients for the k-th cluster within the lth multi-path ray, T_k is the arrival time of the k-th cluster, and $\tau_{k,l}$ represents the delay of the k-th culster path within the *l*-th ray. The multipath gain is based on channel coefficients which are used to mitigate the effect of path loss on UWB signals. Hence, at the input of rake receiver, the received signal {r(t)} is given by

$$r(t) = w_{PPM}(t) * h(t) + n(t) \tag{5}$$

where * denots the covalution between modulated signal and channel impolse response and n(t) is the additive white gaussian noise (AWGN) of zero mean and two sided PSD $N_0/2$. Since there are common several users using the same broad band, there will be interfences in users called multiple user interference (MUI), inter-symbol interference (ISI), and multiple access interference (MAI), the recieved signal is expresed as

$$r(t) = w_{PPM}(t) * h(t) + I_{MUI}(t) + I_{MAI}(t) + ISI + n(t) \tag{6}$$

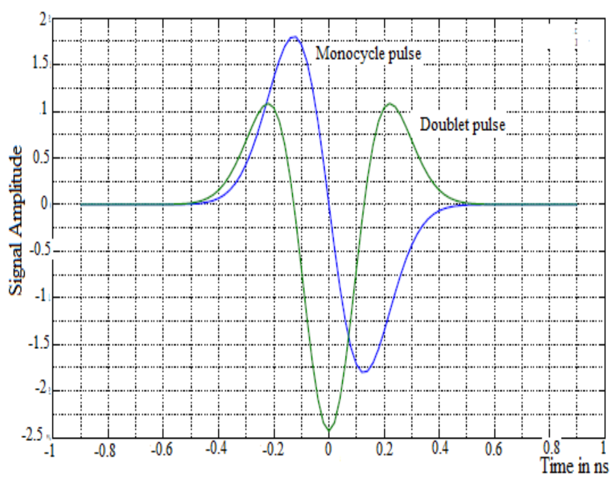

Fig. 2. Gaussian pulses

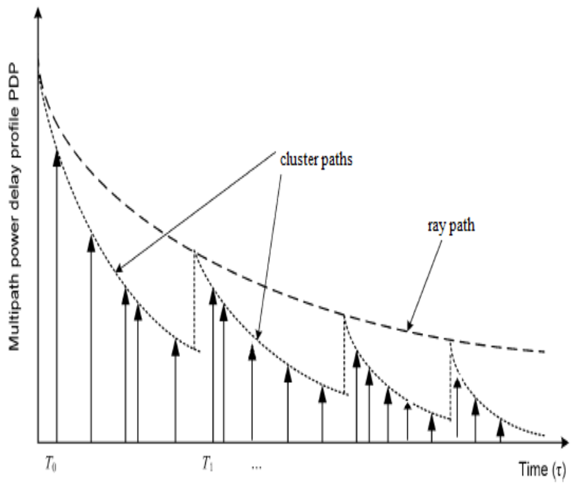

Fig. 3. Exponential power distribution for cluster and rays

III. THE EQUALIZED MULTI-PATH RAKE RECEIVER MODEL

Due to indoor reflections, diffractions, and scattering from obstacles, a radio signal channel can consist of many copies of originally signals having different amplitudes, phases, and delays.

The equalized rake receiver structure consists of L fingers (correlators) to deal with multi-path reception and followed by MMSE standard to achieve the interference suppression rather than maximal ratio combiner (MRC) that used to cupture most of the signal energy coming from generated by template signal generator as shown in Fig. (4) of equalized rake receiver. The reference waveform signals are delayed at delay time to be agree with received multi-path delay time. After that, the multiplied signals is integrated over a symbol time (T_s) to demodulate the desired signal. A sampler of 100 GHz sampling frequency was used to sample the output of each correlator to produce sampled $r_l[n]$ when l = 0, 1, 2,....L-1.

Assuming the taps vector of the l^{th} correlator output signal is

$r_l[n] = [r_1(n), r_2(n), r_3(n),........r_L(n)]^T$ (7)

and the receiver tap weights vector is $\beta_l = [\beta_1, \beta_2, \beta_3,.......\beta_L]^T$ (8)

With MMSE receiver, we assumed a perfect synchronization between receiver and transmitter. The receiver system output {x[n]} and the update equations for rake-receiver tap weights are considered as follows [15].

$$x[n]^{(n)} = r_l^{(n)}[n](\beta_l^H)^{(n)} \tag{9}$$

$$e[n]^n = x[n]^n - d[n] \tag{10}$$

$$(\beta^H)^{(n+1)} = (\beta^H)^n + \frac{(r_l^H)^n e[n]^n}{\left|r^n\right|^2} \tag{11}$$

where d[n] is the desired signal and e[n] is the deffirence between the desired data symbol and the output of rake receiver system. The e[n] should be reduced with many iterations to get $e[n]^{(n)} < e[n]^{(n+1)}$ and this computtion update the receiver tap weights to obtain more accurate performance by suppressing the noise components at several iterations.

As the MMSE channel equalizer before dicission circiut, the equalizer coefficients (c_l) [l = 1, 2, 3,....L] are estimated to minimize the mean sequre error (MSE) at the output of the system that lead to overcome the inter-symbol interference of the detected n-th data. So that, $E[\left|b_n - \hat{b}[n]\right|^2]$ has to be minimized for DS-UWB system for number of estimated equalizer tap $\tilde{c} = (c_{-J}........c_J)$ [16].

$$\hat{b}[n] = \sum_{j=-L}^{L} c_j x[n-j] \tag{12}$$

$$\tilde{c} = \arg\min E[\left|b_n - \hat{b}[n]\right|^2] \tag{13}$$

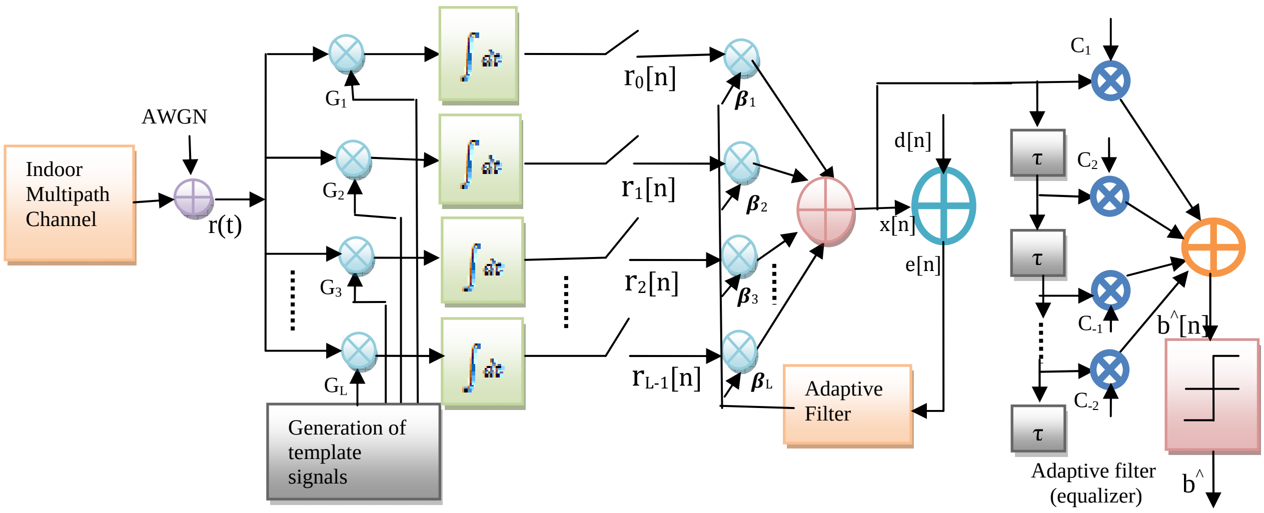

Fig.4. Block diagram of the Equalized rake-receiver with L correlators

IV. THE PROPOSED ADAPTIVE FILTER ALGORITHMS IN THE RAKE RECEIVER STRUCTURE

The adaptive rake-receiver system identification model is shown in Fig. (5) and the adaptive filter algorithms are LMS, NLMS, and APA and their partial update versions that used to minimize the cost function $\xi = E[\left|e[n]\right|^2]$ by updating the tap weights vector. From [6], the LMS algorithm was represented as

$$\beta(n+1) = \beta(n) + \mu X(n)e(n) \tag{14}$$

where $X(n) = [x(n), x(n-1), ...x(n-N+1)]^T$, $\beta(n)$ is the $N \times 1$ column filter coefficient vector at n iterations, $[\cdot]^T$ is the matrix transponse of a vector, and μ is the step-size that computes the grouping speed at steady-state MSE. The error signal is described by

$$e(n) = d(n) - \beta^T(n)X(n) \tag{15}$$

As NLMS and AP algorithms are stated in [17], NLMS and APA are used to increase the grouping speed.

For NLMS algorithm $$\beta(n+1) = \beta(n) + \frac{\mu}{\varepsilon + \left\|x(n)\right\|^2} x(n)e(n) \tag{16}$$

For APA algorithm $$\beta(n+1) = \beta(n) + \mu X^T(n)[\varepsilon I + X(n)X^T(n)]^{-1} e(n) \tag{17}$$

where e(n)=d(n)-X(n)β(n) , d(n)=[d(n), d(n+1), d(n+2),.......d(n-N+1)], is the coefficients deviation factor, $\|x(n)\|^2$ is the squared Euclidean norm of rake receiver output vector, $[\cdot]^{-1}$ is the matrix inverse or scaler inverse, and I is the matrix.

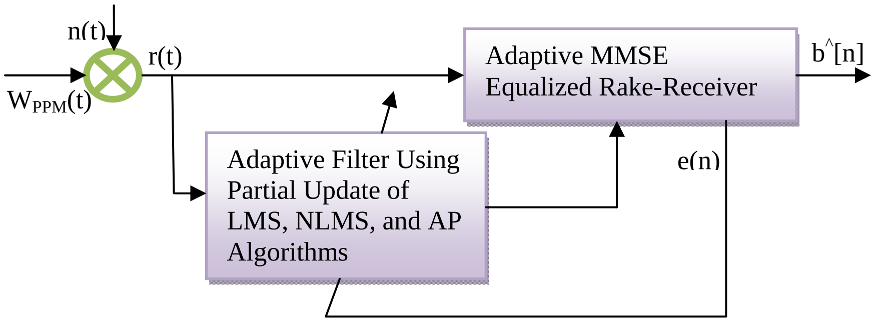

Fig. 5. Adaptive rake-receiver system identification

V. PARTIAL-UPDATE ALGORITHMS

A. Selective partial update (SPU)

The application of this algorithm requires more prudence under consideration and it is aplicable to APA and NLMS adaptive filtering methods. The PSU-APA algorithm is represented by [7]:

$$\beta(n+1)=\beta(n)+\mu I_M(n)X^T(n)[\varepsilon I+X(n)X^T(n)]^{-1}e(n) \tag{18}$$

And the PSU-NLMS algorithm is defined by:

$$\beta(n+1)=\beta(n)+\frac{\mu}{\varepsilon+x(n)I_M(n)x^T(n)}e(n)I_M(n)x(n) \tag{19}$$

where $I_M(n)$ is the coefficient matrix at M number of coefficients that selected for update.

B. M-max algorithm

The idea of this algorithm technique is to find the M-largest vector magnitude for updating requirements. This algorithm uses data that depends on coefficient selection matrix $[I_M(n)]$ of short distance between the full coefficient updates and partial coefficient updates. The M-max algorithms are represented by [18]:

For M-max APA $\beta(n+1)=\beta(n)+\mu I_M(n)X^T(n)[\varepsilon I+X(n)X^T(n)]^{-1}e(n)$ (20)

For M-max LMS $\beta(n+1)=\beta(n)+\mu I_M(n)e(n)x(n)$ (21)

For M-max NLMS $\beta(n+1)=\beta(n)+\dfrac{\mu}{\varepsilon+\|x(n)\|_2^2}e(n)I_M(n)x(n)$ (22)

where n = 0, 1, 2,....... and the coefficient selection ranks are $\|x(n)\|_2^2$, $\|x(n-1)\|_2^2$, $\|x(n-2)\|_2^2$,............, $\|x(n-N+1)\|_2^2$

C. Periodic-partial-update algorithm

The periodic-partial update method ia used to spread the update complexity over a number of iterations in order to obtain the reducing average update complexity per iteration. The periodic-partial update APA, LMS, and NLMS algorithms are given by [19]:

for periodic-partial update APA $\beta((n+1)p)=\beta(np)+\mu X^T(np)[\varepsilon I+X(np)X^T(np)]^{-1}e(np)$ (23)

for periodic-partial update LMS algorithm $\beta((n+1)p)=\beta(np)+\mu x(np)e(np)$ (24)

for periodic-partial update NLMS algorithm $\beta((n+1)p)=\beta(np)+\dfrac{\mu}{\varepsilon+\|x(n)\|_2^2}x(np)e(np)$ (25)

where p is the period of coefficient update, n = 0, 1, 2,....,

D. Sequential-partial update algorithm

The aim of this algorithm is to decrease the computantional complexity by subset the filter coefficients at each iteration and this decreasing reduces the adptation process. By this algorithm, the updating is processed to M coefficients from the total adaptive filter coefficients (N) at each iteration. The convergence rate updating by sequential-parial update is slower than the full apdative algorithm by N/M times which can be periodically selected by matrix $I_M(n)$ in every iteration, so that, the complexity reduction effects on the performance of convergence rate.

The sequential-partial updates for LMS, NLMS, and APA are given by equations (26), (27), and (28), respectively [19].

$$\beta(n+1) = \beta(n) + \mu e(n) I_M(n) x(n) \tag{26}$$

$$\beta(n+1) = \beta(n) + \frac{\mu}{\varepsilon + \|x(n)\|_2^2} e(n) I_M(n) x(n) \tag{27}$$

$$\beta(n+1) = \beta(n) + \mu I_M(n) X^T(n)[\varepsilon I + X(n) X^T(n)]^{-1} e(n) \tag{28}$$

VI. PERFORMENCE ANALYSIS AND SIMULATED RESULTS DISCUSSION

MATLAB software was used for simulation of the proposed equalized rake-receiver with adaptive classical LMS, NLMS, and APA algorithms and thier partial-updates algorithms.The simulations were performed in UWB channel model CM1 of short indoor range with modulation format for DS-UWB was PPM. The simulated system parameters were assumed to be: pulse duration Tp of second derivative gaussian was 0.39 ns, pulse shape factor was 0.22 ns, chip duration Tc was 0.5 ns, number of frames per symbol was eight, number of exsistance users was six, number of rake correlators was four, step-size (μ) to determine the convergence speed was 0.1, and number of generated symbols by the source was 40,000 symbols. The simulations evaluate the SER after averaging of 50 channels and they were performed to confirm the system performance with the MMSE equalized partial-rake receiver based on LMS, NLMS, and APA algorithms. The four correlatoers enhanced to reduce the complexity of rake-receiver and decrease the optimization time. The evaluations and comparisons of using partial-updates algorithms are illustrated in the following figures:

Fig. 6 presents SER behavior agenst SNR of the DS-UWB system established on the IEEE-UWB CM1 model for the perfect channel estimation with rake-receiver of four correlators. The adaptive filter of LMS algorithm was used to update the reciever tap weights by maximizing these weights at the fading signals. Three partial-update: periodic-partial, M-max-partial, and sequantional-update algorithms were simulated to compare with the full LMS algorithm application in adaptive filter. These partial-update algorithm were used to reduce the computational complexity and decrease the convergence speed time compared with LMS. Hence, we can see that M-max LMS has close performance to the full LMS algorithm, that mean it has better noise cancellation than the periodic and sequantional update algorithms.

Fig. 7 shows the performance of SER for equalized rake-receiver of four correlators technique under CM1 channel parameters (line of sight channel). The curves are clearly seen the improved performance of symbol error rate over 0 to 20 dB signal-to-noise ratio for the adaptive filter using NLMS algorithm. Four partial-update: periodic-partial, M-max-partial, SPU, and sequantional-update algorithms were simulated to compare with the full NLMS algorithm that applied in the adaptation process. The curves are shown in Fig. 7 in the presence of six user interferences and the SPU partial-update is the closest performance than the others to the full NLMS algorithm adaptation.

Fig. 8 provides the SER performance for channel model CM1 of less than ten meters range along the SNR of 0 to 20 dB. From simulated results, the full-APA application find out the prformance was better compared with full-LMS and full-NLMS applications. Four partial-update: periodic, M-max, SPU, and sequantional updates algorithms were simulated to compare their performances with that of classical APA in the adaptation of filter process. The SPU partial update algorithm has the closest behavior to that of full APA.

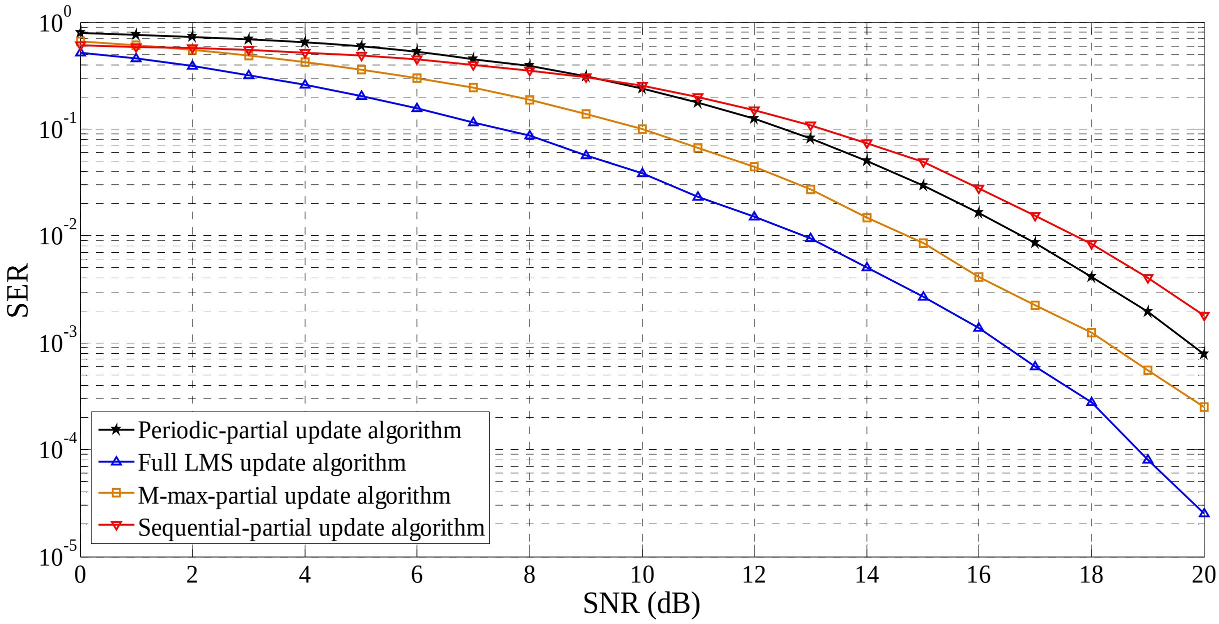

Fig. 6. Comparison of SER among partial-update LMS algorithms at six users through CM1

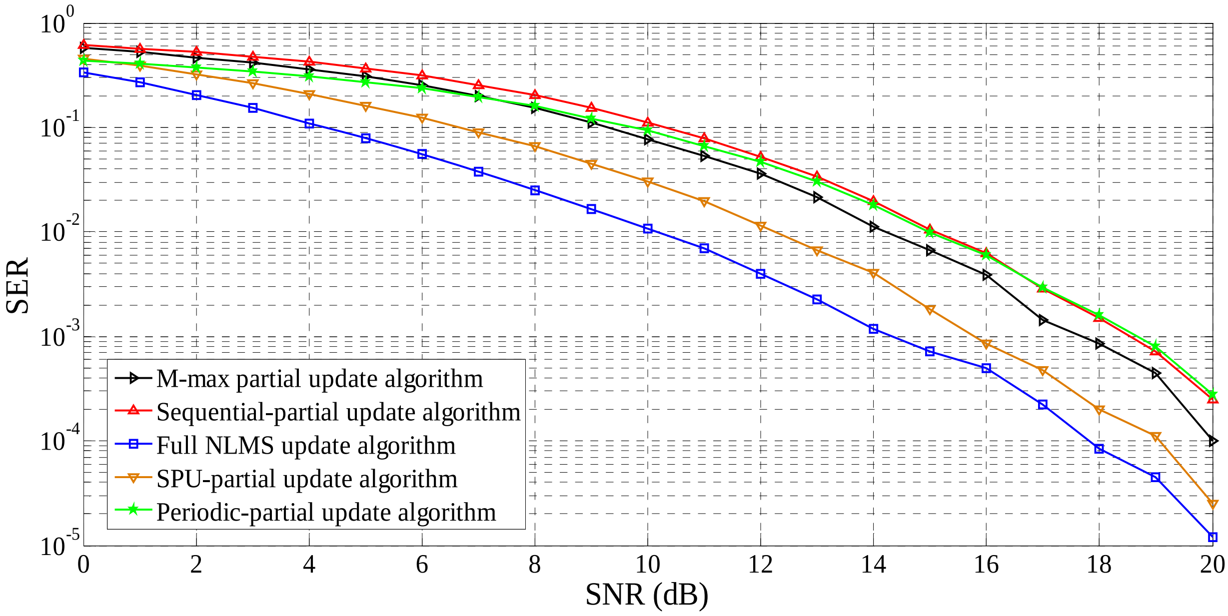

Fig. 7. Comparison of SER among partial-update NLMS algorithms at six users through CM1

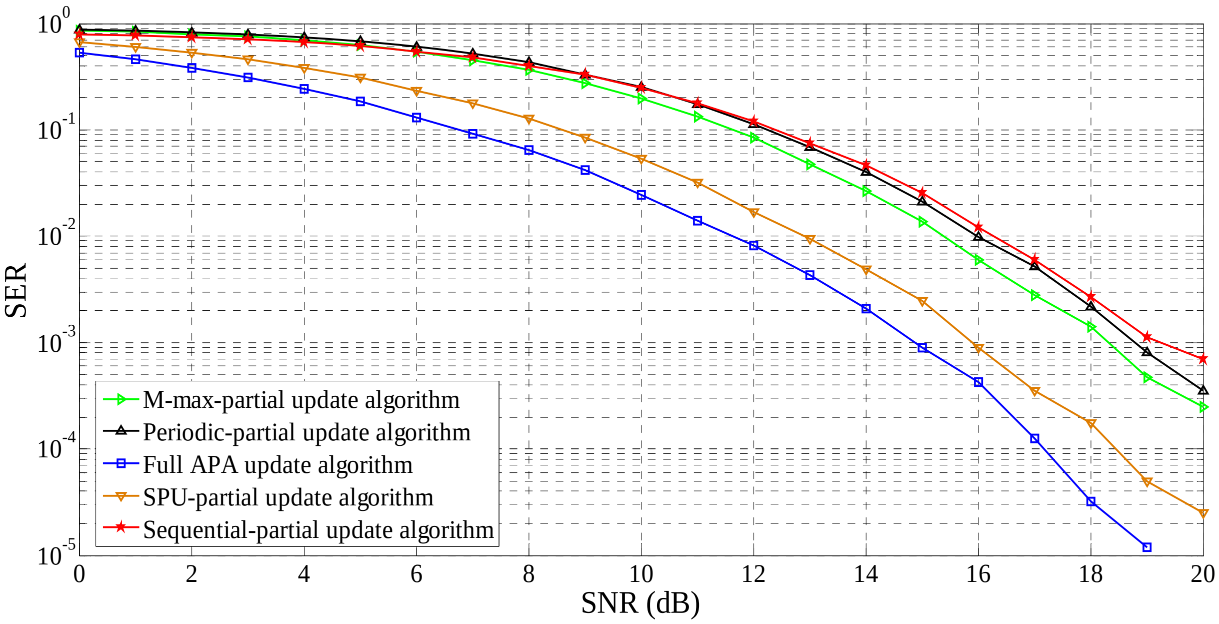

Fig. 8. Comparison of SER among partial-update APA algorithms at six users through CM1

For comparison with work done by [11], the system was simulated again at one user using full-LMS, full-NLMS, and full-APA algorithms. Fig. 9 shows the SER curves versus SNR at the output of the rake-receiver and Fig. 10 shows the SER curves using Euclidean Direction Search (EDS) and its partial-updates algorithms in system identification model. The main comparison is between full-APA in Fig. 9 and full-EDS in Fig. 10. The SER is 0.001625 at SNR of 0 dB and 0 at SNR more than 5 dB when using APA in adaptive filter while SER is 0.022 at SNR of o dB and 0 at SNR more than 11 dB.

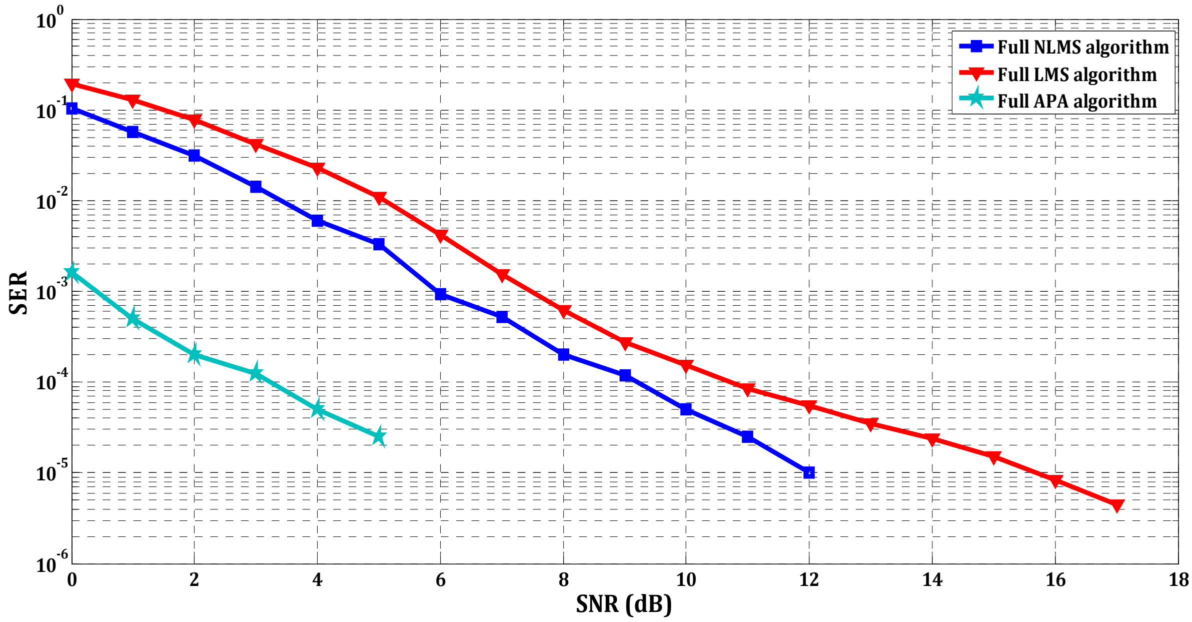

Fig. 9. SER comparison using full LMS, NLMS, and APA agorithms in CM1 UWB channel with one user

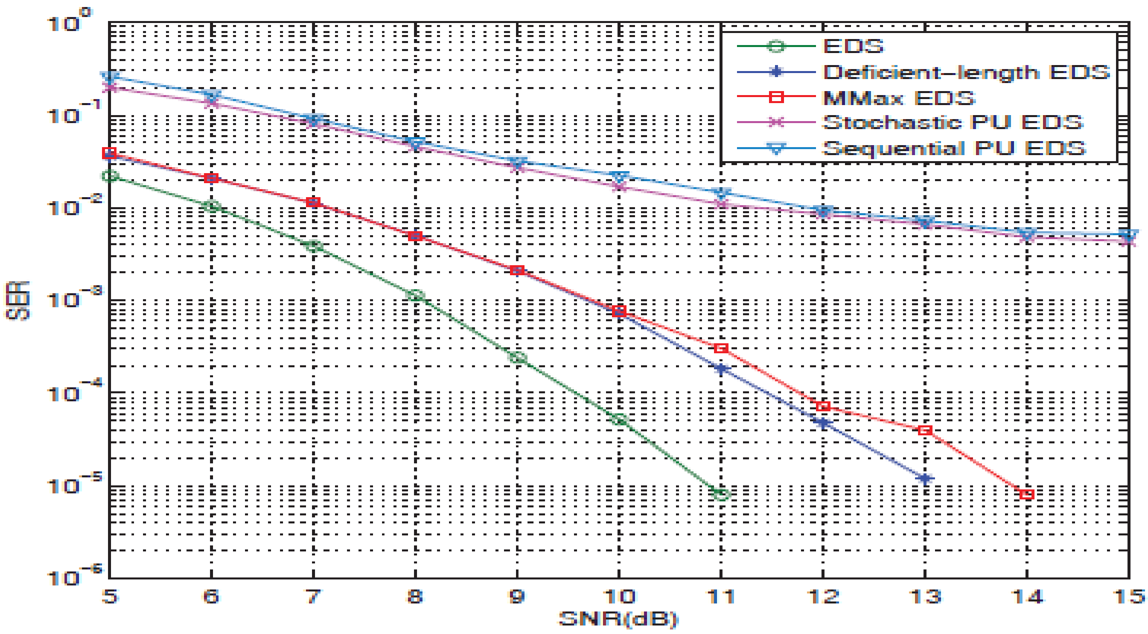

Fig. 10. Comparison of SER among partial-update EDS algorithms [11]

VII. CONCLUSIONS

In this work we have applied full-LMS, full-NLMS, and ful-AP algorithms in adaptive filters that used in MMSE equalized rake-receiver for DS-UWB wireless systems to reduce the interferences and for noise cancellation. Also partial-update algorithms such as periodic, M-max, SPU, and sequantial updates algorithms were applied in this paper for decreasing the computational complexity in adaptation process. Simulation results discover that the MUI, MAI, noise, and ISI are alleviated effectively with rake-receiver based on the ordinary algorithms through high data rate reception of UWB wireless indoor systems. The partial-update algorithms have a simulated results performance close to that of ordinary algorithms. The close performances indicate that the partial-update algorithms are suitable in implementation of the receiver adaptive filters.

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