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Fuzzy Approach based two Layered Block Coded Adaptive MC-CDMA system with FT/ST

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Abstract

The adaptive systems have been employed in nearly all future networks like 4G LTE, 5G etc in order to effectively utilize the available bandwidth, minimize bit error rate (BER) and get better convergence rate, etc. In this paper, least mean square (LMS) algorithm with adaptive step size has been applied on layered space time block coding (LSTBC) based multi-carrier code division multiple access (MC-CDMA) system. This system is studied for both transformations: Fourier transform (FT) and Slantlet transform (ST). Fuzzy rule base scheme (FRBS) has been applied for adaptation of step size. It is observed that convergence rate of proposed FRBS based MC-CDMA receiver is attractive as compare to conventional LMS receiver. Further, it has been seen that bit error rate (BER) of proposed FRBS based MC-CDMA system is better than conventional LMS receiver in both transformations mechanism FT and ST. Moreover, FRBS based MC-CDMA system with ST gives overall attractive BER.

Keywords: MC-CDMA, Two layered Block Codes, Fourier Transform, Slantlet Transform, Fuzzy System.

Introduction

In MIMO systems, Multiple Antennas are employed at both transmitter and receiver. This gives better usage of available bandwidth and thus, gives high data rate. The MIMO technology is advised for code division multiple access (CDMA) systems very frequently[1].

The CDMA systems allow frequency reuse in each cell of cellular system. The two CDMA based improved systems are: multi carrier (MC)-CDMA and Direct Sequence (DS)-CDMA[2]. The MC-CDMA scheme is adopted in this paper. The MC-CDMA systems employ CDMA and orthogonal division multiple access (OFDM) compositely which results in advantages of both CDMA and OFDM. The MC-CDMA systems are adopted in almost all future generation networks like 4G, MotoA4, etc.

In MC-CDMA communication, numerous user symbols are received for various fading channels. So, multiple access interference (MAI) arises which degrades system performance. The MAI is overcome by the use of layered block codes [3-4]. The two layered spreading-CDMA (TLS-CDMA) codes proposed by Peng are used in his paper[5]. These codes are further referred as layered space time block codes (LSTBC) for writing ease.

The commonly used transformation for frequency domain spreading is Fourier transform (FT). But, recently Slantlet transform (ST) proposed by Selesnick is also getting good attention due to 25% better utilization of available bandwidth as compare to FT[6]. The proposed system is studied for both transformation FT and ST separately.

Another important cause of performance degradation is multiuser interference (MUI). The MUI is overcome by the use of any suboptimal receiver like minimum mean square error (MMSE) receiver. The MMSE receiver improves bit error rate (BER) of system.

For further improvement of BER, the MMSE receiver should be implemented adaptively. Bangwon implemented MC-CDMA receiver adaptively by using least mean square (LMS) algorithm with static step size[7-8]. He tried to maximize the signal to interference and noise ratio (SINR) but ignored BER and convergence rate of MC-CDMA receiver. The receiver convergence rate can be improved by adaptive step size of LMS algorithm. A fuzzy rule base scheme (FRBS) is built in order to adaptively decide step size of LMS algorithm in each cycle for stabilizing the system. This system is further compared with different fixed step sizes of LMS algorithm in MC-CDMA system. The MC-CDMA system proposed with FRBS gives attractive performance as compare to traditional MC-CDMA system based on LMS.

The paper is further organized as following: section 2 explains system model, section 3 derives the minimum mean square error (MSSE) based cost function, section 4 thoroughly explains layered space time block codes (LSTBC), section 5 explains proposed fuzzy rule scheme (FRS), section 6 discusses simulation and results and section 7 gives final conclusion.

Lastly, references are given in end.

System Model

We use two transmitter antenna and one receiver antenna as Alamouti's space time coding is to be employed at MC-CDMA system. However, the number of antennas can be adjusted as per requirements.

The Figure-1 represents the MC-CDMA transmitter. Let kth user uplink transmission is to be applied. Suppose two transmitter antenna's are A and B respectively. In STBC block, Alamouti's space time coding is employed. The two consecutive symbols $a_k(2i-1)$ and $a_k(2i)$ are sent from antenna A and B. The symbols $a_k^*(2i)$ and $a_k^*(2i-1)$ are to be sent in next symbol interval according to Alamouti's space time coding. The spreading code pair $(c_{k,1}, c_{k,2})$ with dimension $N \times 1$is used for frequency domain spreading from antenna A and B. The $c_{k,m}$ is

$$c_{k,m} = \left[c_{k,m,1}, c_{k,m,2}, \dots, c_{k,m,N}\right]^T \quad (1)$$

A two layered space time block codes (LSTBC) mechanism is applied to these data symbols further whose explanation is given in section 4. The LSTBC data is further applied to both Fourier Transform (FT) and Slantlet Transform (SLT) separately. In case of FT, the N-point Inverse Fast Fourier Transform (IFFT) is applied with N is the number of subcarriers. Further, it is imposed that number of subcarriers and processing gain of spreading code are equal. The cyclic prefixes are added and signal is parallel to serial (P/S) converted. Then, this processed signal is transmitted to the channel. In case of SLT, the N-point Inverse Slantlet transform (ISLT) is applied. The signal is parallel to serial (P/S) converted. There is no need of cyclic prefixes addition due to extra orthogonality of SLT which saves the bandwidth by 25%. This P/S signal is simply transmitted to the channel.

The Figure-2 represents MC-CDMA receiver. In case of FT, the signal is serial to parallel (S/P) converted. Afterwards, the cyclic prefixes are eliminated. The N point Fast Fourier Transform (FFT) operation is performed. The multi-path reflection causes delay spread. It is supposed that cyclic prefixes length of all users is more than delay spread. In case of SLT, the received signal is serial to parallel (S/P) converted. The N-point SLT operation is performed. Further, this data is applied to LSTBCde-spreading mechanism. The LSTBC de-spreading mechanism is explained in section 4. Afterwards, the received signal vectors are:

$$y(2i-1) = \sum_{k=1}^{K}\left\{b_{k,1}a_k(2i-1) + b_{k,2}a_k(2i)\right\} + z(2i-1) \quad (2)$$

$$y(2i) = \sum_{k=1}^{K}\left\{-b_{k,1}a_k^*(2i) + b_{k,2}a_k^*(2i-1)\right\} + z(2i)$$

Cost Function

We used batch processing system that works on batches of data. The received signal vector for first two consecutive symbols is

$$r(i) = [y^T(2i-1)y^H(2i)]^T = \sum_{k=1}^{K}\{\alpha_{k,1}a_k(2i-1) + \alpha_{k,2}a_k(2i)\} + \eta(i) \quad (3)$$

The symbols $a_k(2i-1)$ and$a_k(2i)$ can be detected by defining filter weights $w_1$and $w_2$of size $2N \times 1$ for detecting. Then, the filter output based on mean square error (MSE) is

$$J(w_1, w_2) = E[|W^H y(i) - a_1(i)|^2] = E[|w_1^H y(i) - a_1(2i-1)|^2] + E[|w_2^H y(i) - a_1(2i)|^2] = J_1(w_1) + J_2(w_2) \quad (4)$$

where: $W = [w_1 w_2]$ and $J_1(w_1) = E[|w_1^H y(i) - a_1(2i-1)|^2]$

$$J_2(w_2) = E[|w_2^H y(i) - a_1(2i)|^2] \quad (5)$$

The cost function give in (4) and (5) is further improved by Bangwon which is further verified by Muhammad on MC-CDMA systems[9]. There was a simple relationship drawn between optimal weight vectors $w_{O,1}$ and $w_{O,2}$. The brief detail of it is as following:

Let N_y is a matrix with dimension $N \times N$

$$N_y = \begin{bmatrix} N_1 & N_2 \\ N_3 & N_4 \end{bmatrix} \quad (6)$$

N_y has a exceptional relation in its diagonals. It was shown that $N_4 = N_1^*$and $N_3 = -N_2^*$.

This $N_y$diagonalsrelationship was also satisfied on optimal weights vectors $w_{O,1}$ and $w_{O,2}$of MMSE receiver [9]. If the relationship

$$w_{O,1} = \begin{bmatrix} w_{1,1} \\ w_{1,2} \end{bmatrix}, w_{O,2} = \begin{bmatrix} w_{2,3} \\ w_{1,4} \end{bmatrix} \quad (7)$$

The relationship is:

$$w_{1,2} = w^*_{2,3}, \; w_{1,4} = -w^*_{1,1} \quad (8)$$

Thus, the convergence rate is increased by updating only those weights vectors in (4) satisfying (8). Further, the detail on it can be checked[10].

Layered Space Time Block Coding

Spreading at Transmitter: We used mutual orthogonal codes like Walsh–Hamdard codes for spreading. The channel must be flat over time and frequency for keeping the codes perfectly orthogonal as codes are to be applied in two layers. But, frequency selective channel may distort the code words spreading from the first layer. The time selective fading channel may distort the second layer. In LSTBC, the code words are places on time and frequency grid. The difference in between them is such that code words chips reduces according to channel propagation conditions like delay spread, Doppler's shift, etc. The time and frequency domain concept is explained by Paerson and Maeda very gently[11-12].

The spreading mechanism is explained in Figure-3. The spreading in first layer is similar to frequency domain spreading and spreading in second layer is similar to time domain spreading. The advantage of such is that second layer strengthens the multiple users against multiple access interference (MAI) and first layer eliminate multiple path interference (MPI).

There is channel distortion among chips in MMSE which destroys codes orthogonality in first layer. As discussed in section A, this does not suppress MAI but improves MPI. The second layer prioritized to combat MAI.

The dispreading mechanism is explained in Figure-4. At receiver, we first de-spread the second layer and then first layer. The de-spreading of second layer at receiver removes the MAI. After that, the de-spreading of first layer is performed which restrain the MPI which is similar to the case of rake receiver. Therefore, it is needed to select codes with moral autocorrelation possessions.

Fuzzy Rule Base Scheme FOR Updating Step Size μ: A Fuzzy rule base scheme is proposed which is able to choose the step size of LMS algorithm. This enhances the performance of MC-CDMA system. In order to do so, a fuzzy inference engine is developed with one output and two inputs. This selection criteria matches to Zadeh principle of Fuzzy Logic[11].

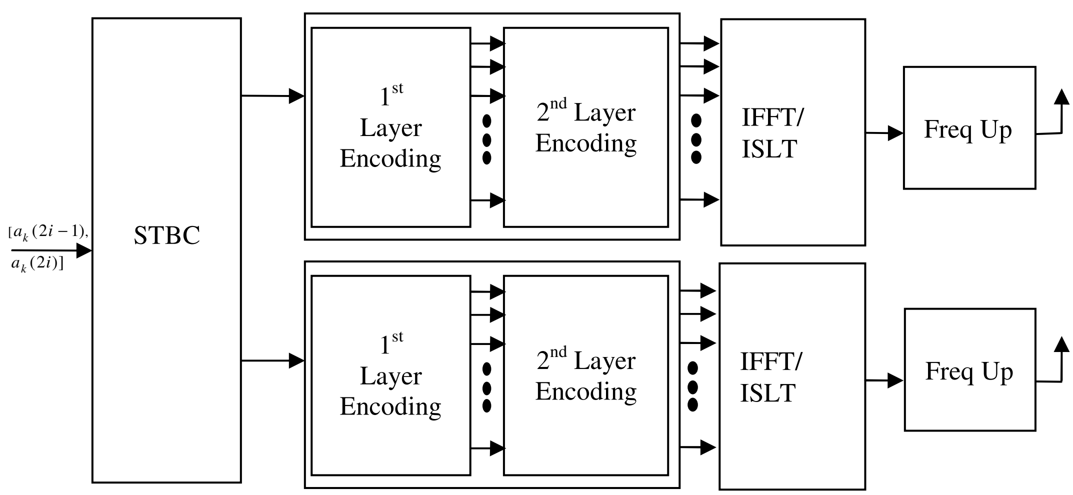

Figure-1
Two Layered Block Coded MC-CDMA Transmitter

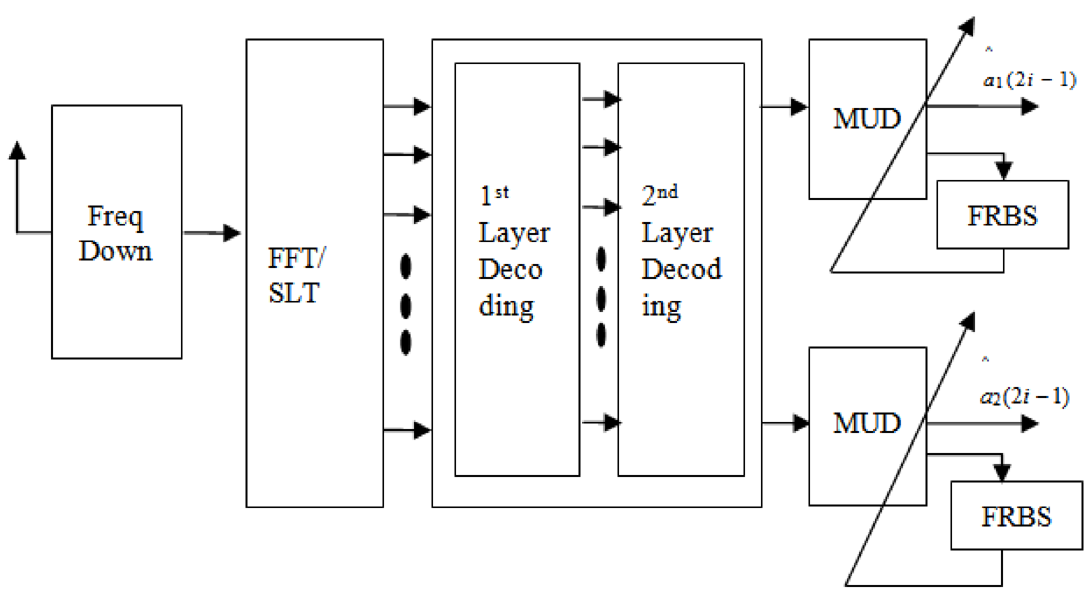

Figure-2
FRBS based MC-CDMA Receiver

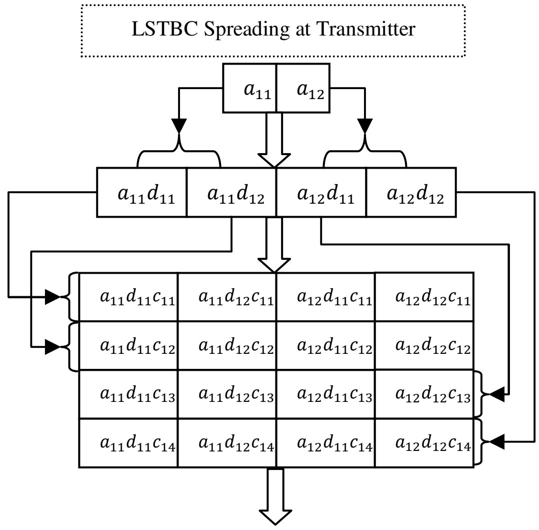

Figure-3
LSTBC procedure of Spreading in two layers at Transmitter

De-spreading at Receiver

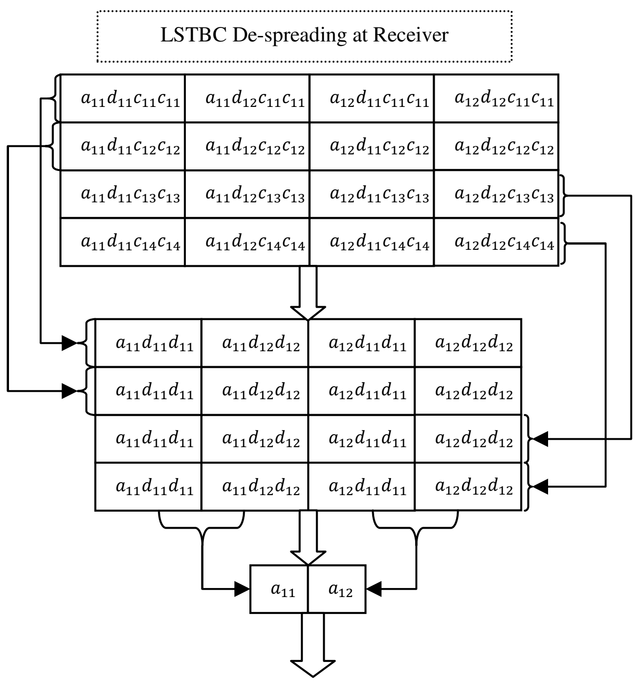

Figure-4
LSTBC procedure of De-spreading in two layers at Receiver

The two inputs are squared error $e^2[n]$ and squared error difference $\Delta e^2[n]$ of nth iteration. The output is step size $\lambda$of LMS. They are used in order to develop the lookup.Theinput to output relationship is shown in lookup table given in table 1 in order to decide μ. The input-output relationship is shown mathematically as:

$$\mu_{1,i} = FLC\left[e_1^2[i], \Delta e_1^2[i]\right] \quad (9)$$

$$\mu_{2,i} = FLC\left[e_2^2[i], \Delta e_2^2[i]\right]$$

Where: $e_m^2(i) = \frac{1}{N+1}\sum_{l=0}^{N} || \, e_m^2(l)||$ with $m = 1,2$
and $\Delta e_m^2[i] = [e_m^2(i) - e_m^2(i-1)]$.

The updated step size μ in (9) is used in updating weights selection given below
$\mathrm{w}_m(i+1) = \mathrm{w}_m(i) + \mu_{m,i}\mathrm{y}_i$ with $m = 1,2$

There are four different inputs on the basis of values of $e^2[n]$ and $\Delta e^2[n]$. These are small (S) 0.0001, medium (M) 0.001, large (L) 0.01 and very large (VL) 0.1.Secondly, the output parameter μ has five variations which are very small (VS) 0.00001, small (S) 0.0002, medium (M) 0.006, large (L) 0.09 and very large (VL) 0.1.

Table-1
Lookup table for decision of step size μ

μ		$e^2[n]$			
		S	**M**	**L**	**VL**
$\Delta e^2[n]$	S	VS	VS	M	L
	M	VS	S	M	VL
	L	VS	S	M	VL
	VL	VS	VS	M	VL

The look up Table-1 is used in order to select step size. The input and output pairs are shown in figure 5 and 6. Their mathematical form is

$(e^2[n], \Delta e^2[n];\ \mu_m)$ with $m = 1,2$

Where $e^2[n]$, $\Delta e^2[n]$ and μ_m are conferred above in (9). The sample fuzzy rule base on the basis of IF-Then is
{if($e^2[n]$ is small and $\Delta e^2[n]$ is small Then μ_m is very small}
{if($e^2[n]$ is very large and $\Delta e^2[n]$ is medium) Then μ_m is very large}

The step size μ decided on the basis of these criteria will be affective in improving stability of LMS in MC-CDMA system. The implementation of this FRBS is done using Fuzzy tool box of Matlab 7.0.

Fuzzy Sets: There is a number of fuzzy sets for covering input-output pairs. The input and output pairs are already discussed above. There are total 4, 4, 16 fuzzy sets that are used.

Fuzzifier: The triangular fuzzifier approach is used with "AND" as Min and "OR" as Max respectively.

Rule Base: There are total 16 output rules in rule base. The rules are shown in Table-2.

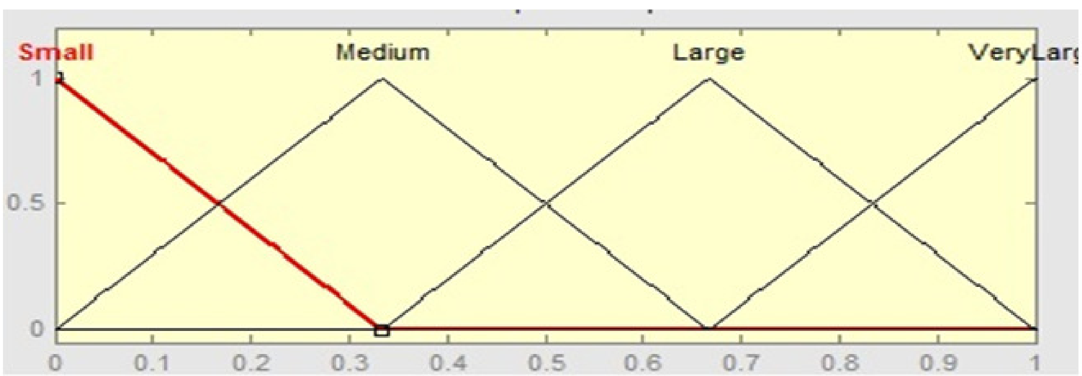

Figure-5
Fuzzy sets for input variable squared error $e^2[n]$ and squared error difference $\Delta e^2[n]$

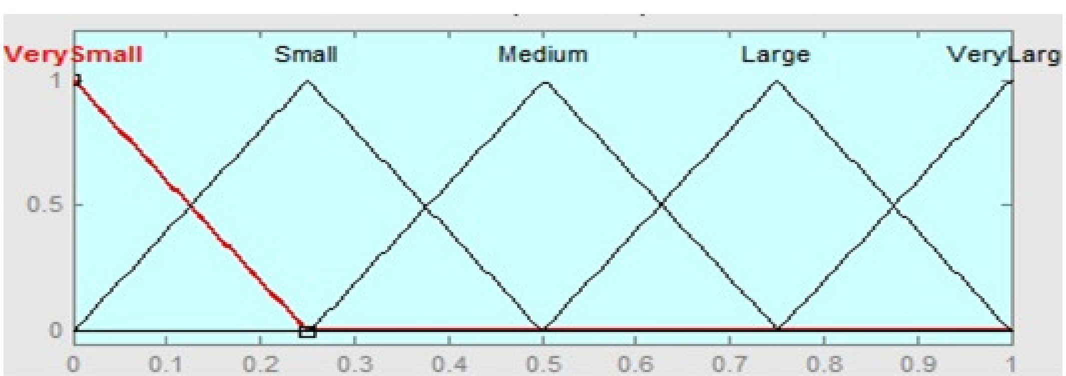

Figure-6
Fuzzy sets for output variable averaged step size μ

Table-2
Rule base for deciding step size μ with VS as Very Small, S as Small, M as Medium, L as Large and VL as Very Large

Rule Base
1.$If\ \Delta e^2[n] and\ e^2[n] are\ S\ then\ \mu\ is\ VS$
2.$If\ \Delta e^2[n]\ is\ S\ and\ e^2[n]\ is\ M\ then\ \mu\ is\ VS$
3.$If\ \Delta e^2[n]\ is\ S\ and\ e^2[n]\ is\ L\ then\ \mu\ is\ M$
4.$If\ \Delta e^2[n]\ is\ S\ and\ e^2[n]\ is\ VL\ then\ \mu\ is\ L$
5.$If\ \Delta e^2[n] and\ e^2[n] are\ M\ then\ \mu\ is\ S$
6.$If\ \Delta e^2[n]\ is\ M\ and\ e^2[n]\ is\ S\ then\ \mu\ is\ VS$
7.$If\ \Delta e^2[n]\ is\ M\ and\ e^2[n]\ is\ L\ then\ \mu\ is\ M$
8.$If\ \Delta e^2[n]\ is\ M\ and\ e^2[n]\ is\ VL\ then\ \mu\ is\ VL$
9.$If\ \Delta e^2[n] and\ e^2[n] are\ L\ then\ \mu\ is\ M$
10. $If\ \Delta e^2[n]\ is\ L\ and\ e^2[n]\ is\ S\ then\ \mu\ is\ VS$
11.$If\ \Delta e^2[n]\ is\ L\ and\ e^2[n]\ is\ M\ then\ \mu\ is\ S$
12.$If\ \Delta e^2[n]\ is\ L\ and\ e^2[n]\ is\ VL\ then\ \mu\ is\ VL$
13. $If\ \Delta e^2[n] and\ e^2[n]\ are\ VL\ then\ \mu\ is\ VL$
14.$If\ \Delta e^2[n]\ is\ VL\ and\ e^2[n]\ is\ S\ then\ \mu\ is\ VS$
15.$If\ \Delta e^2[n]\ is\ VL\ and\ e^2[n]\ is\ M\ then\ \mu\ is\ VS$
16.$If\ \Delta e^2[n]\ is\ VL\ and\ e^2[n]\ is\ L\ then\ \mu\ is\ M$

Inference Engine: The Mamdani Inference Engine (IE) is used for mapping two inputs to one output as shown in Figure-7.

De-Fuzzifier: The center average De-fuzzifier is used. The figure 8 shows rule surface of FRBS. It can be seen that when both $\boldsymbol{e^2[n]}$ and $\Delta\boldsymbol{e^2[n]}$ are small then μ is very small. However, If both $\boldsymbol{e^2[n]}$ and $\Delta\boldsymbol{e^2[n]}$ are large then μ is very large respectively.

Results and Discussion

The MC-CDMA system is employed with M=32 subcarriers such that number of subcarriers is equal to spreading code length. The Walsh-Hamdard codes are used for selecting spreading code real and imaginary parts from 1 and -1 randomly. The Rayleigh flat fading channel is implemented using three paths. The channel coefficients are fixed along spreading codes in all cycles.

The Figure-9 shows number of cycles Vs mean square error (MSE) of conventional least mean square (LMS) system with different step sizes μ's and fuzzy rule system (FLS) with adaptive LMS step size μ. The topmost curve (blue) represents conventional LMS with step size μ=0.00001. The second curve (green) represents conventional LMS with step size μ=0.0001. The third curve (red) represents conventional LMS with step size μ=0.01. The fourth curve (aqua) represents conventional LMS with adaptive step size μ. It has been noted that adaptive μ based LMS give MSE = 0.0315 as compare to other μ's based LMS at 100^{th} cycle. Further, adaptive μ based LMS give a MSE=0.0035 which is also minimum as compare to other μ's based LMS at 250^{th} cycle. Lastly, adaptive μ based LMS give a MSE=0.0011 which is minimum as compare to other μ's based LMS at 500^{th} cycle. It is also seen that other μ's= 0.00001, 0.0001, 0.01 give MSE= 0.0019, 0.0055, 0.0164 only at 500^{th} cycle. Therefore, it is can be said that adaptive step size based LMS based MC-CDMA system converges fast as compare to other schemes.

The Figure-10 shows SNR Vs BER in Fourier transform (FT) based conventional least mean square (LMS) system and proposed fuzzy logic system (FLS). The top curve represents conventional FT-LMS system. While, the second curve represent proposed FT-FLS system. The FT-LMS system achieves a BER of 0.006 at SNR=25dB. While, the FT-FLS system achieves a BER of 0.003 at SNR=25dB. It is noted that proposed FLS system gives good BER as compare to conventional LMS system for all SNR.

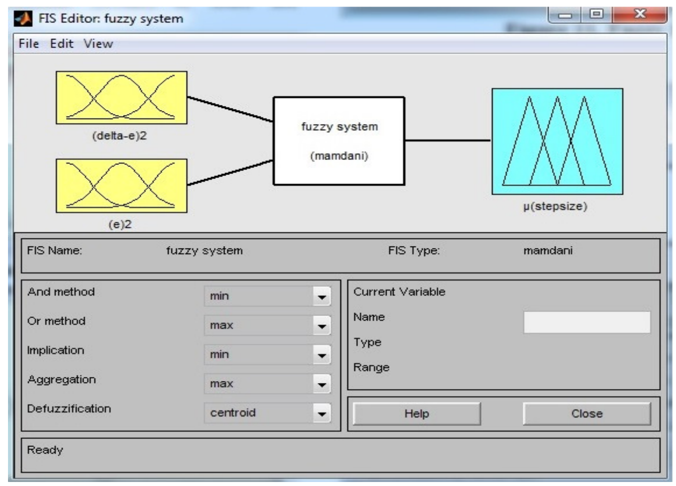

Figure-7
Mamdani Fuzzy Rule base System

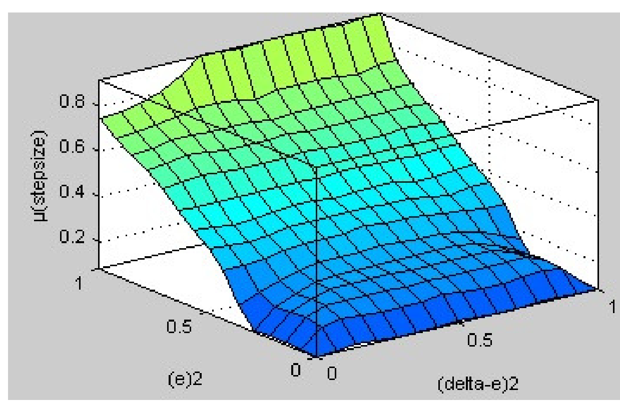

Figure-8
Rule Surface

The Figure-11 shows SNR Vs BER for Slantlet transform (SLT) based conventional least mean square (LMS) system and proposed fuzzy logic system (FLS). The top curve represents conventional SLT-LMS system. While, the second curve represent SLT-FLS system. The SLT-LMS system gives a BER of 0.9 at SNR=0dB. While, SLT-FLS system achieves a BER of 0.62 at SNR=0dB. The SLT-LMS gives a BER of 0.018 and SLT-FLS gives a BER of 0.0034 at SNR=10dB. The SLT-LMS gives a BER of 0.0016 and SLT-FLS gives a BER of 0.0009 at SNR=25dB. It is noted that proposed SLT-FLS system gives attractive BER as compare to conventional SLT-LMS up to medium SNR. However, it has also low BER at high SNR.

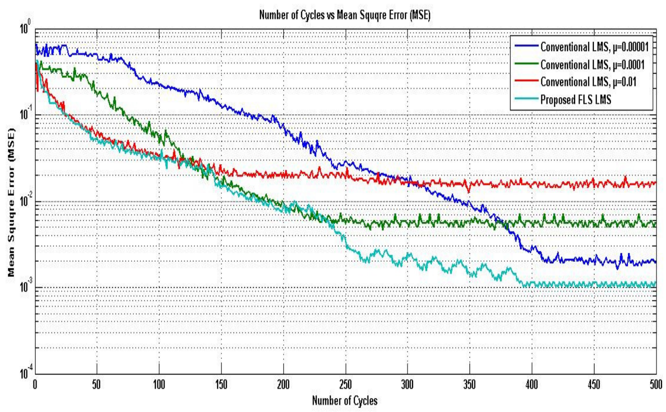

Figure-9
Number of cycles Vs Mean Square Error for different step size μ of LMS algorithm

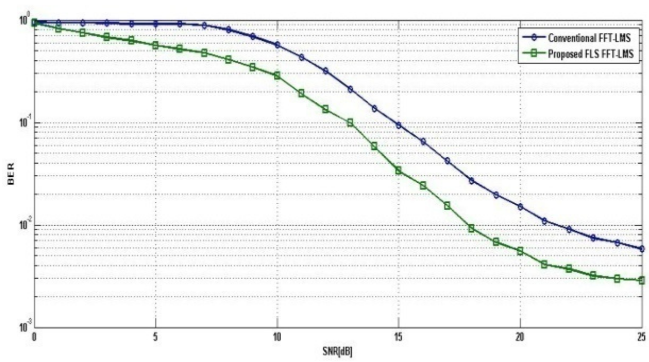

Figure-10
Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER) for FT based LMS-MC-CDMA system

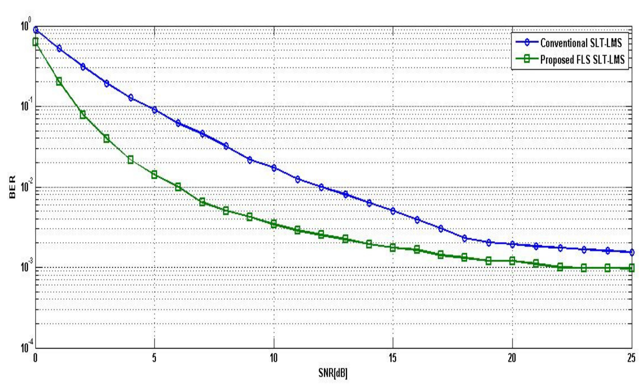

Figure-11
Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER) for SLT

The Figure-12 shows SNR Vs BER between proposed Fourier transform (FT) based fuzzy logic system (FLS) and proposed Slantlet transform (SLT) based fuzzy logic system (FLS). The top curve represents FT-FLS system. While, the second curve represent SLT-FLS system. The FT-FLS system gives a BER of 0.003 at SNR=25dB. While, the SLT-FLS system achieves a BER of 0.0009 at SNR=25dB. It is noted that proposed SLT-FLS system gives attractive BER as compare to FT-FLS system for all SNR.

The Figure-13 shows SNR Vs BER for conventional FFT/SLT-LMS system and proposed FFT/SLT-FLS system. The top curve represents conventional Fourier transform (FT) based least mean square (LMS) system. The second curve from top represents conventional Slantlet transform (SLT) based least mean square (LMS) system. The third top curve represents proposed Fourier transform (FT) based fuzzy logic system (FLS). The bottom most curve represents proposed Slantlet transform (SLT) based fuzzy logic system (FLS). It is noted from figure that proposed SLT-FLS system gives attractive BER as compare to other schemes.

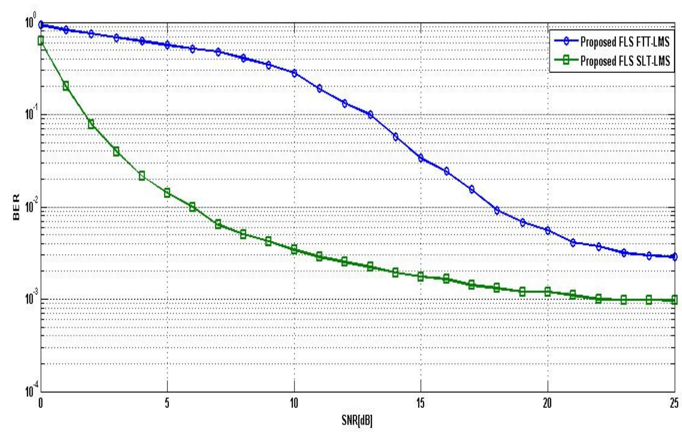

Figure-12
Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER)for FT and SLT based LMS-MC-CDMA system

Conclusion

The adaptive communication is adopting in almost all future generation networks. The least mean square (LMS) based multicarrier code division multiple access (MC-CDMA) system with adaptive step size is studied in this paper. The adaptive step size is calculated with fuzzy rule scheme (FRS). This system is implemented with layered space time block codes (LSTBC) in both transformations: Fourier transform (FT) and Slantlet transform (ST). It is observed that FRS based LMS-MC-CDMA system gives better convergence rate and minimizes BER as compare to conventional LMS based MC-CDMA system.

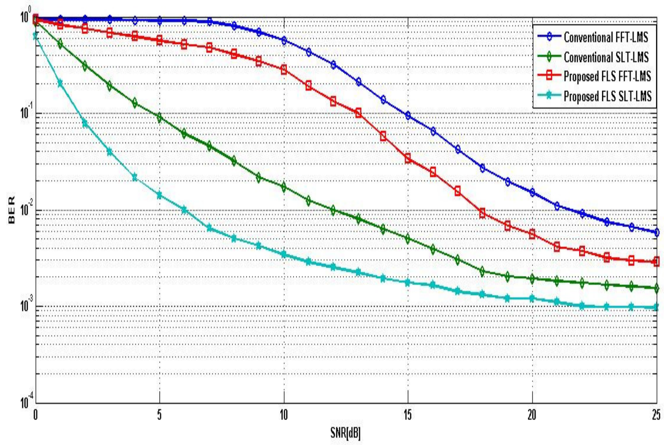

Figure- 13
Signal to Noise Ratio (SNR) Vs Bit Error Rate (BER) for FT and SLT based LMS-MC-CDMA system

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