Performance of Adaptive Beamforming Algorithm for LMS-MCCDMA MIMO Smart Antennas

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Abstract: *We propose a downlink multiple-input multiple-output multi-carrier code division multiple access system with adaptive beamforming algorithm for smart antennas. The algorithm used in this paper is based on the least mean square, with pilot channel estimation and the zero forcing equalizer in the receiver, requiring reference signal and no knowledge channel. multi-carrier code division multiple access is studied in a multiple antenna context in order to efficiently exploit robustness against multipath effects and multi-user flexibility multi-carrier code division multiple access and channel diversity offered by multiple-input multiple-output systems for radio mobile channels. Computer simulations, considering multi-path Rayleigh Fading Channel, interference inter symbol and interference are presented to verify the performance.Simulation results demonstrate a significant performance improvement using our proposed receiver structure for a multiple-input multiple-output system with the presence of large Interferences. Therefore, the BER performance of the proposed system is much better than STBC- multi-carrier code division multiple access system with RMSE algorithm. In the other hand it can be seen that, as a number of antennas at transmitter and receiver increases, the performance also improves and the number of interferences decrease the performance of the system with the same Rayleigh fading environment.*

Keywords: *Adaptive beamforming, LMS algorithm, MC-CDMA, MIMO system, smart antenna.*

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1. Introduction

In recent years, adaptive antennas have been considered to be one of the most expected technologies, which are adapted to the demanding high-bit-rate or high-quality in broadband commercial wireless communication such as mobile internet or multi-media services [3, 4]. Currently, Multiple-Input Multiple-Output (MIMO) systems, where array antennas are equipped at both the transmitter and receiver, have emerged as significant break-through in wireless communication systems. It has been improved to provide high-bit-rate transmission and increase system performance over multipath fading channels and interference [6, 8].

In this paper, we propose a new MIMO scheme, namely Least Mean Square (LMS)-MIMO- Multi-Carrier Code Division Multiple Access (MCCDMA). The LMS-MIMO-MCCDMA is intended to use the adaptive beamforming algorithm based on the LMS criterion [2, 11]. Here MC-CDMA modulation scheme has already proven to be a strong candidate as an access technique for the downlink of broadband cellular systems, as it benefits from the advantages of both MC and CDMA techniques: high spectral efficiency, robustness in frequency selective channels with a low-complexity at receiver considering a simple one-tap equalization, multiple access capability with high flexibility, narrow-band interference rejection [4]. On the other hand, it is well-known that a MIMO system is one of the most promising approaches, which provides a considerable increase in throughput at relatively small cost in terms of bandwidth. One of the most important aspects of the MIMO system is that its capacity increases linearly with the number of antenna arrays on both transmitter and receiver sides.

Our proposed scheme is based on the beam forming approach to excluding interference emanating from a direction other than that of the desired signal. For MIMO system, there are a total of three different types of interference, which are Co-Cannel Interference (CCI), Interference Inter Symbol ISI and Multiple Antenna Interference (MAI). The MAI defined here is the interference from different transmits antennas in the MIMO system. We are targeting on the three interferences sources and aiming to provide a solution to the problems of resolving all ISI and MAI and canceling CCI effectively by employing LMS algorithm by adjusting both transmitter and receiver weights in the MIMO system.

Coherent MIMO MCCDMA requires channel state information at the receiver, when the channel is not known [9]. Thus, pilot symbols are often periodically inserted into the transmitted signal to support Channel Estimation (CE). It is performed using the Zero

Forcing (ZF) equalizer on pilots only. The computer simulation with the AWGN, interference and multi-path Raleigh Fading channel are presented to verify its performance [2].

2. Proposed LMS MIMO MCCDMA Configuration

Figure 1 represents the block diagram of the downlink MIMO MC-CDMA system with LMS Algorithm. At the transmitter, the data symbols $\mathrm{U} = [\mathrm{u}_1, \ldots \mathrm{u}_i, \ldots \mathrm{u}_{\mathrm{N_u}}]^{\mathrm{T}}$ of the N_u users are multiplied by their specific orthogonal Walsh-Hadamard spreading code $\mathrm{C} = [\mathrm{c}_1, \ldots \mathrm{c}_i, \ldots \mathrm{c}_{\mathrm{N_u}}]^{\mathrm{T}}$ where c_i is the ith chip, and $[.]^{\mathrm{T}}$ denotes matrix transposition; the spread vector is simply expressed as:

$$S = C \cdot X \qquad (1)$$

The result signals are summed and multiplexed together with pilot symbols where are inserted at the beginning of each frame. These result symbols S' are next QAM modulated and serial-to-parallel converted into N_c *data* symbols per user in an OFDM symbol using the IFFT operator. In order to combat the effect of multipath, the cyclic prefix is added to an OFDM symbol after parallel to serial conversion, the cyclic prefix maintains orthogonality between the subcarriers in a multipath channel.

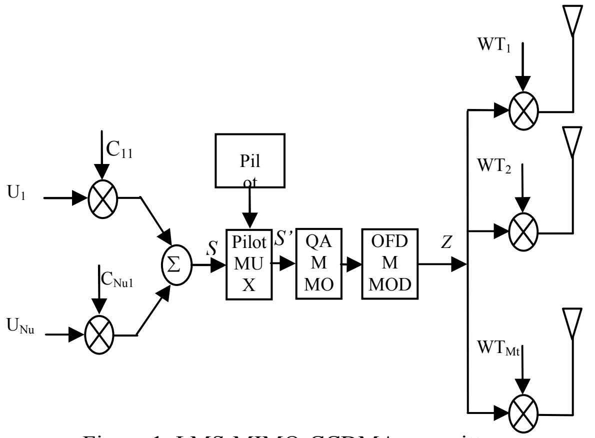

Figure 1. LMS-MIMO-CCDMA ransmitter.

Each data symbol is then transmitted by a MIMO beamforming combining system with M_t transmit antennas and *Mr* receive antennas. Assuming a narrowband channel, the combining vector at the transmitter is denoted as *Z* and the receiver is denoted by *Y* while the Additive White Gaussian Noise (AWGN) at the receiver is denoted as *N* with zero mean and power σ_n^2. The uncorrelated Rayleigh channel assumption implies that the entries of *H* are distributed as (O, 1). Let h_{ij} be the coefficient of *H* representing the link between antenna *i* and antenna *j*. In order to detect the transmitted signal at the receiver we multiplied the transmitted and the received signal by transmitted weights W_T and received weights W_R respectively, the received signal is given as

$$Y = W_R \cdot H \cdot W_T \cdot Z + W_T \cdot N \qquad (2)$$

The calculation of the weights is explained in the section III. The result symbols are shortened by the GI and OFDM demodulated by an FFT operation of the received symbols and brings them back to the frequency domain. Then, the received pilot symbols are separated from the received data symbols, and fed into the Channel Estimation (CE). The CE only uses pilot symbols to estimate the CSI (channel symbol Interference) using Zero Forcing Equalizer (ZFE) given as in [12]

$$Z_{ZF}(k) = \frac{1}{G(k)} \qquad (3)$$

where $G(k)$ is the multipath channel estimation. The N_c results sequence are then, parallel to serial converted and QAM demodulated. The pilots symbols are then demultiplexing from the demodulated signal and the output of the pilot DEMUX is dispreading with Walsh code c_1, representing the code of the desired signal.

3. LMS MIMO Algorithm

Figure 3 is the model of MIMO system considered in this paper. The number of antennas of the transmitter array and the receiver array are M_t and M_r respectively. The received signal is expressed as in equation 4 [7].

$$x(t) = H \cdot W_T \cdot z(t) + \sum_{l=1}^{L} H_l \cdot W_{Tl} \cdot z_l(t) + n(t) \qquad (4)$$

The received signal $x(t)$, the channel matrix *(H)*, and transmission weight vector (W_T) are defined as the following vector equations

$$x(t) = \left[x_1(t), x_2(t), \ldots, x_{Mt}(t)\right]^T \qquad (5)$$

$$H = \begin{bmatrix} h_{11} & h_{12} & . & . & . & h_{1Mr} \\ h_{21} & h_{22} & & & & h_{2Mr} \\ . & . & . & & & . \\ . & . & & . & & . \\ . & . & & & . & . \\ h_{Mt1} & h_{Mt2} & . & . & . & h_{MtMr} \end{bmatrix} \qquad (6)$$

$$W_T = \left[W_{T1}, W_{T2}, \ldots, W_{TMr}\right]^T \qquad (7)$$

where, h_{nm} is the channel response between m^{th} transmitter antenna and n^{th} receiver antenna. And, *z(t)* is source data signal, *n(t)* is AWGN (additive white Gaussian noise). L is the number of interferences. H_l, is the channel matrix of the 1^{th} interference signal similarly composed of equation 6 and W_{Tl} is the transmitter weight vector of l^{th} interference composed of the same manner as equation 7. And, in this paper, the symbols, $[.]^*$, $[.]^{\mathrm{T}}$, and, $[.]^{\mathrm{H}}$, are conjugate, transpose and, conjugate transpose operators, respectively.

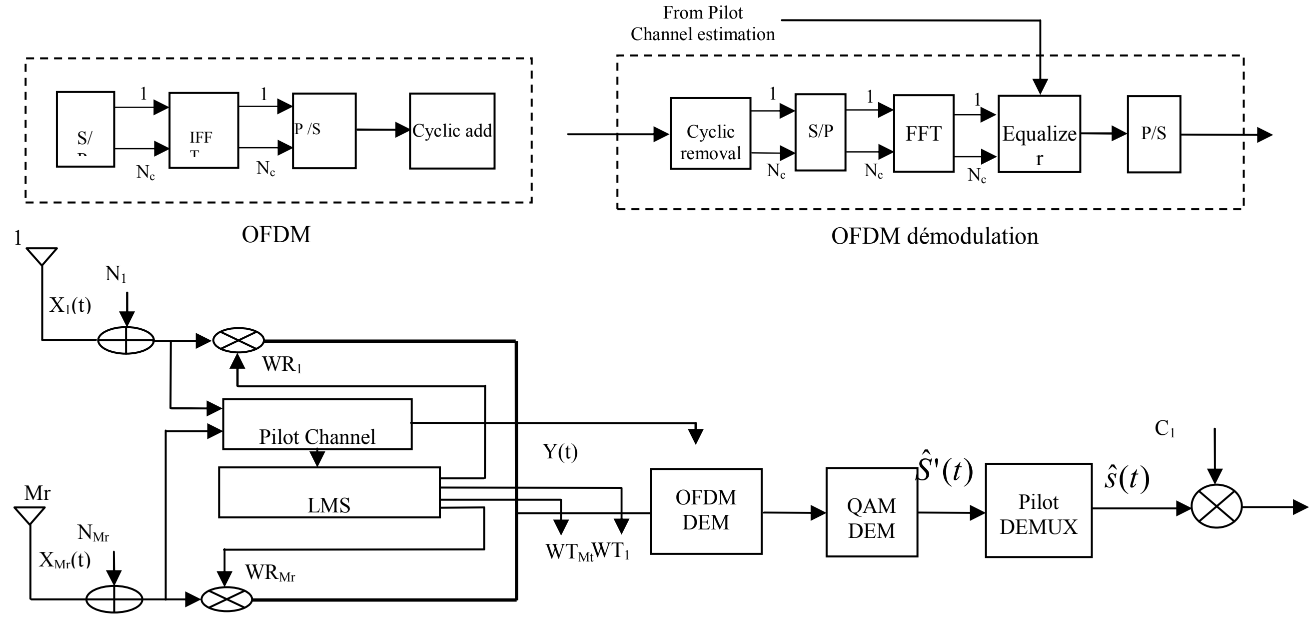

Figure 2. LMS-MIMO-MCCDMA receiver.

3.1. Receiver Antenna Weight Vector

Basically, the algorithm is based on the conventional LMS algorithm. Considering a simplified MIMO model in Figure 3. The received signal is as following

$$x(t) = H \cdot W_T \cdot z(t) + n(t) \quad (8)$$

By the receiver adaptive beamforming, the output signal is

$$y(t) = W_R^H \cdot H \cdot W_T \cdot z(t) \quad (9)$$

Here the noise component is omitted for the simplicity of calculation. The error signal of the *k-th* sample is defined by following

$$\varepsilon_k = d_k - y(k) = d_k - W_R^H(k) \cdot H \cdot W_T(k) \cdot z(k) \quad (10)$$

Here, d_k is reference signal defined by projecting the output signal *y(k)* to the nearest signal constellation.

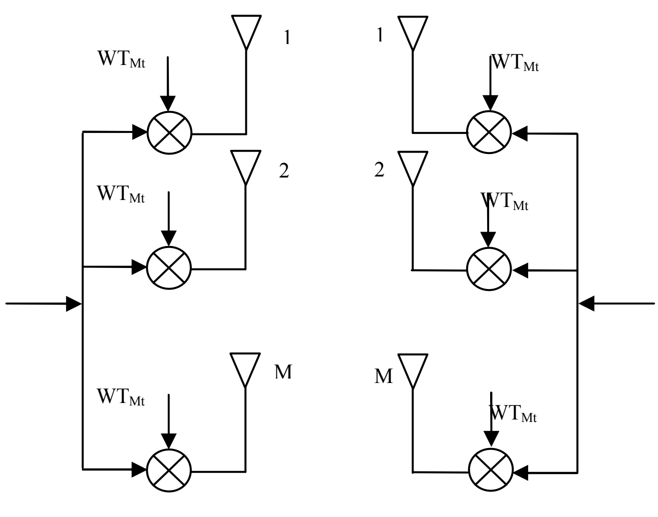

Figure 3. A MIMO system model.

Now, the gradient is obtained by differentiating the square error by the receiver antenna weight,

$$\frac{d\varepsilon_k^2}{dW_R^*(k)} = -2\varepsilon_k \cdot x(k) \quad (11)$$

Consequently, the weight of the receiver antenna is upgraded by following [10]

$$W_R(k+1) = W_R(k) - 2\mu\varepsilon_k x(k) \quad (12)$$

3.2. Transmitter Antenna Weight Vector

Differentiating the square error by the transmitter antenna weight is,

$$\frac{d\varepsilon_k^2}{dW_T(k)} = -2\varepsilon_k \frac{d\varepsilon_k}{dW_T(k)} \quad (13)$$

Here, $\varepsilon_k = d_k - W_R^H(k) \cdot H \cdot W_T(k) \cdot z(k)$, the error signal is differentiated as following:

$$\frac{d\varepsilon_k}{dW_T(k)} = -z(k) \cdot H^T \cdot W_R^*(k) \quad (14)$$

Therefore the transmitter antenna weight vector is,

$$W_T(k+1) = W_T(k) - 2\mu\varepsilon_k z(k) H^T W_R^*(k) \quad (15)$$

Multiplying the transmitter weight by the equation 8:

$$x(k) W_T^H(k) = H \cdot z(k) \cdot W_T(k) \cdot W_T^H(k) \quad (16)$$

Applying vector inversion to the equation 16, the following equation is obtained

$$H \cdot z(k) = x(k) w_T^H(k) \quad (17)$$

Taking transpose operation and multiplying by the receiver weight vector to the equation 17,

$$z(k) \cdot H^T \cdot W_R^*(k) = y(k) \cdot W_T^*(k) \qquad (18)$$

Finally, the transmitter antenna weight vector of equation 15 is modified as following [5]

$$W_T(k+1) = W_T(k) - 2\mu \cdot \varepsilon_k \cdot y(k) \cdot W_T^*(k) \qquad (19)$$

4. Simulations

This section presents simulation results for a downlink MIMO MC-CDMA system applying WH spreading and the LMS beamforming algorithm with five transmit and five receive antennas, spaced *d= 0.5* wavelengths apart.

In this section, we provide some simulation results of our proposed MIMO Beamforming, which we briefly call, LMS-MIMO-MCCDMA and compare its performance to an STBC-MIMO-MCCDMA, the most important difference is that the proposed hybrid LMS-MIMO-MCCDMA technique is capable of performing CCI and multiple antenna interference cancellation and ISI equalization. The performance is also evaluated over number of antennas at transmitter and receiver.

4.1. Simulation Parameters

At a carrier frequency of *fc* = 5.2 GHz, the MC-CDMA systems transmits 32 OFDM symbols per frame divided into 768 useful data subcarriers over a bandwidth of 46.2 MHz resulting in a subcarrier spacing of f = 60 kHz. The size of the fast fourier transforms in the OFDM modulation and demodulation is 1024. The Guard Interval (TGI) is set to 256 Tspl, where the sampling duration is *Tspl* = 1/61.44 MHz =16.276 ns. The system uses a modulator of 16-QAM symbols and WH spreading codes of length L = 32. A 128 pilot symbols are inserted into the frame.

We consider the received desired signal arrive at angle 45° with 16 multi-path Rayleigh fading channel and interferences at 135° and 300°. We plot the simulation results in terms of Bit Error Ratios (BER) versus Signal to Noise power Ratio (SNR).We consider for all simulation the channel coefficients for individual users $h_{ij}(k)$ are generated using uncorrelated Rayleigh channel distributed as (O, 1). In order to apply LMS algorithm we assume that the channel is stationary over each block of 768 symbols and is different from block to block. Also, for simplicity we assume that the transmitted data are known.

The initial transmit weight vector is used to calculate the optimal receive and transmit weight vectors w_R^{opt}, w_T^{opt} alternately by using the iterative update weight LMS algorithm. The updated w_T^{opt} is used in the transmitter as a fixed weight vector and updated w_R^{opt} is used in the receiver to detect the received signal *X(t)* at the receiver. Although the received weight vectors are estimated based on an iterative update LMS algorithm to overcome the interferences, only the error between the reference and the output signal obtained from the received signal *Y(t)* is less than all the rest. It is clear that the DOA of both the transmitter and the receiver antennas sides are exploited to suppress interferences for the received signal *X(t)*.

In our simulations, 3 iterations are sufficient to obtain the best performance. As shown in the Figure 4 in Rayleigh fading channel, the BER performance of the proposed system is much better than STBC-MCCDMA system with RMSE algorithm [1]. However, at high SNR, the degradation gets down above 5 dB for BER $\leq 10^{-3}$.

Figure 5 show the system performance in term of the beampattern of the LMS-MCCDMA algorithm in the presence of two interferences. It is noted that patterns main lobes exactly oriented toward the direction of the desired user (45°) and nulls toward the interferers (135°, 300°).

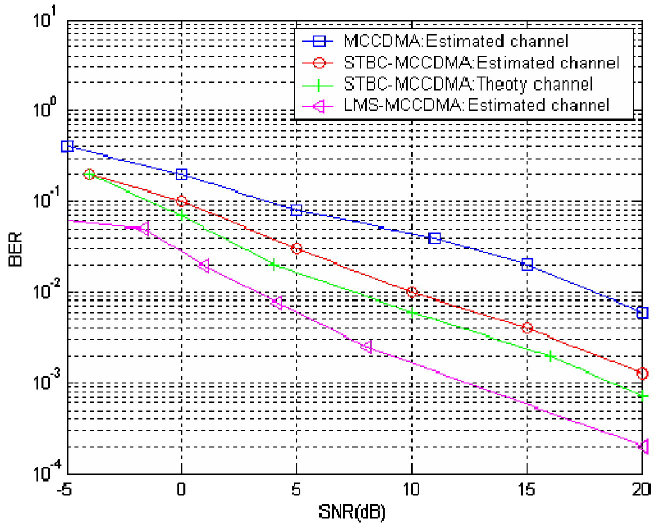

Figure 4. Performance comparison between LMS-MIMO-MCCDMA system and STBC-MIMO-MCCDMA system (for MIMO M_t=M_r=3).

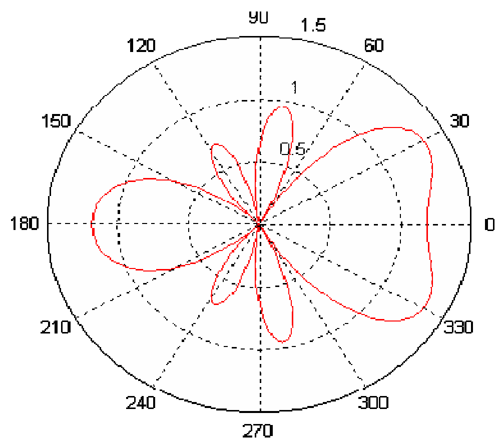

Figure 5. Beampattern response for two interferences (at 135° and 300°) and desired signal at 45°.

Figure 6 shows that as a number of antennas at transmitter and receiver increases, the performance also improves with the same Rayleigh fading environment. Therefore, the two receive antenna system does not have sufficient degree of freedom to fight multipath and interference. However, the results of link level performance show clearly that 6 transmitter and receiver antennas provide significant result. The performance improvement of our proposed scheme belongs to the number of transmitter and receiver antennas because the DOA of both the transmitter and receiver antennas is used to suppress the interferences of the signal *X(t)*.

From the Figure 7, it can be seen that, as the number of interferences increase as the performance of the system is less than that obtained without interferences.

For the multipath Rayleigh fading environment used in our simulations, it is shown that the 5x5 system can support properly four interferences with 16 multipaths and AWGN, the desired signal is well separated from the rest of the signals. In contrast, for tree interferences with 16 multipaths, the system causes performance improvement (around 4dB at 10^{-2} of BER). Therefore, the four receive antenna system does not have sufficient degree of freedom for nulling; part of array gain has been spared to suppress each of interferences leading to reduced performance. However, the results of the link level performance show clearly that the proposed LMS-MIMO-MCCDM provides significant achievement while a failure occurs to a normal MIMO detection without the adaptive array to cancel the interferences [7].

Compared with the Gaussian channel, Rayleigh fading introduces severe performance degradations to the receiver system, introducing multiuser diversity, enhances the performance of LMS-MIMO with 4Tx-4Rx antenna array configuration for example. Since the spatial diversity order of this scheme is 16, the MIMO Rayleigh fading channel has been approximately transformed to an equivalent single-input single-output AWGN channel. It is well known that by increasing the spatial diversity order of LMS-MIMO further, performance in terms of BER improved. In the other hand, we have applied the Rayleigh fading compensation technique using the FFT method for MC-CDMA signal. Pilot chips are inserted before the IFFT block at the transmitter. The zero forcing equalizer estimates of the pilots is obtained in the receiver by dividing those corrupted pilots with the known pilot symbols. To obtain the channel coefficients for the data symbols interpolation is performed in the frequency domain. But when increasing the number of interferences, The LMS MIMO algorithm does not provide very good interference suppression. The result can be improved using the minimum mean square error equalizer.

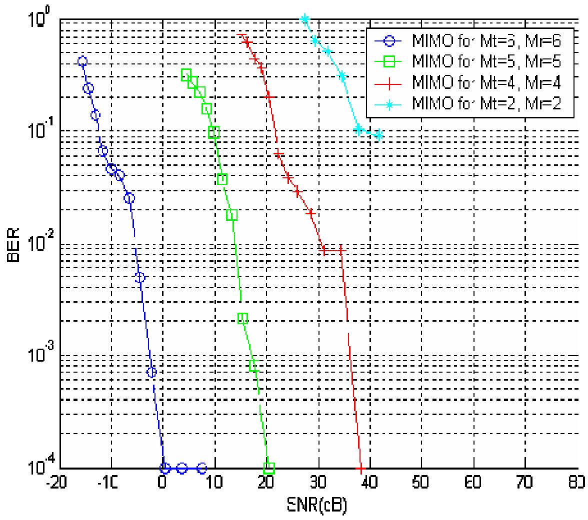

Figure 6. LMS-MIMO-MCCDMA performance in the AWGN with multi-path Rayleigh fading channel (with the variation of the transmitter and receiver antenna elements).

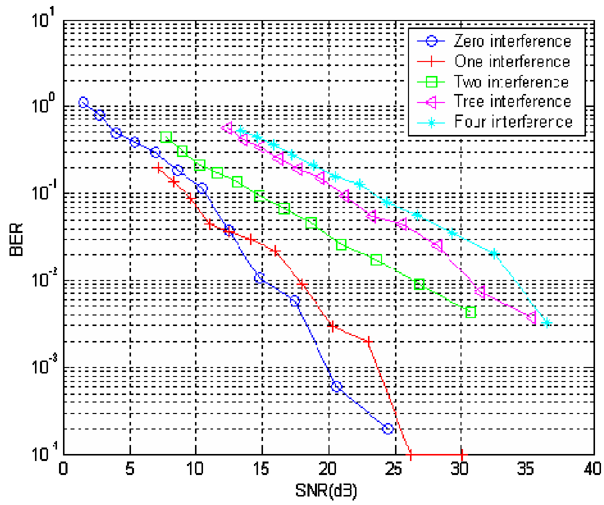

Figure 7. LMS-MIMO-MCCDMA performance in the AWGN with multi-path Rayleigh fading channel (with increase number of interferences).

5. Conclusion

In this paper, we have proposed a MCCDMA MIMO adaptive beamforming LMS algorithm for smart antennas. The performance of the proposed system is much better than STBC-MIMO-MCCDMA system with RMSE algorithm. The performance also improves as the array antennas at the transmitter and receiver have more elements.

The proposed scheme is to target multipath and interference for efficient interference cancellation. The simulation results demonstrate a significant performance improvement using our proposed system with the presence of large interferences. It is worthwhile to note here that more receive antennas will be required to provide the degree of freedom to mitigate a higher number of effective multipath for improved system performance. The complexity of the proposed system is another issue for future investigation.

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