Performance Analysis of a MIMO MC-CDMA Wireless Communication System Implementing Spatial Domain Noise Reduction Techniques with MMSE Signal Detection

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***Abstract*—Multi Carrier CDMA (MC-CDMA) technique has become increasingly popular in wireless communications, mainly due to its high spectral efficiency, robustness to frequency selective fading and flexibility to support integrated applications. This paper incorporates a comprehensive BER simulation study undertaken on the effectiveness of a channel encoded multiple-input multiple-output multi-carrier code division multiple access (MIMO- MC-CDMA) wireless communication system on color image transmission. The convolutional channel encoded simulated system incorporates Minimum mean square error (MMSE) signal detection technique and two-dimensional nonlinear order statistic and median filtering for noise reduction. The extracted data are processed with QAM, QPSK and DQPSK digital modulations under Rayleigh fading and additive white Gaussian noise (AWGN) channels and two-by-two MIMO antenna configuration. It is anticipated from the simulation study that the image retrieving performance of the presently considered communication system is reasonably acceptable.**

Keywords—Color image; MMSE; Median and Order Statistic Filtering; MIMO MC-CDMA

I. INTRODUCTION

Multi-carrier code division multiple access (MC-CDMA) is an orthogonal frequency-division multiplexing (OFDM)-based multi-user wireless communication system mitigating the problem of inter symbol interference (ISI) with exploitation of frequency diversity [1-2]. With higher demands in performance and data transfer rates in modern digital wireless communication systems, the multi antenna supported (MIMO) MC-CDMA systems under implementation of space-time coding techniques are capable of achieving high spectral efficiency and high link reliability over frequency selective wireless channels and improving significantly the capacity of wireless communication systems and performance [3]. The MC-CDMA is a hybrid transmission technique employing an amalgam of Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) and is expected to combine the benefits of pure CDMA and OFDM techniques. In an comparative study on the bit error rate performance of downlink coded multiple-input multiple-output multi-carrier code division multiple access (MIMO MC-CDMA) and coded MIMO orthogonal frequency division multiple access (MIMO OFDMA) systems under frequency selective fading channel conditions, it was observed that the MIMO MC-CDMA system outperforms as compared to MIMO OFDMA system. In MC-CDMA multiplexing technique, multiple users are permitted to access the wireless channel simultaneously by modulating and spreading their input data signals across the frequency domain using different spreading sequences [4]. The CDMA technique is widely used in current Third Generation (3G) wireless communication systems providing higher data rate i.e. 64kbps –2Mbps as compared to 9.6kbps – 14.4kbps used in 2G systems. In CDMA systems, multi users share a same higher bandwidth than the modulating signal's bandwidth using different spreading codes. Due to implementation of noise-like spreading sequences, the Inter-Symbol Interference (ISI) is reduced significantly in frequency selective multi-path fading environments. Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a successful air-interface multicarrier digital modulation technique advocated by many European standards, such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting for Terrestrial television (DVB-T), Digital Video Broadcasting for Handheld terminals (DVB-H), Wireless Local Area Networks (WLANs) and Broadband Radio Access Networks (BRANs) [5, 6].

II. Signal Detection And Noise Reduction

A. MMSE Signal Detection

In order to maximize the post-detection signal-to-interference plus noise ratio (SNR), the MMSE weight matrix is given as

$$W_{MMSE} = (H^H H + \sigma_z^2 I)^{-1} H^H \quad (1)$$

Note that the MMSE receiver requires the statistical information of noise σ_z^2. Note that the ith row vector $w_{i,MMSE}$ of the weight matrix in equation (1) is given by solving the following optimization equation

$$w_{i,MMSE} = \underset{w=(w_1,w_2,\ldots,w_{N_T})}{\arg\max} \frac{|wh_i|^2 E_x}{E_x \sum_{j=1,j\neq i}^{N_T} |wh_j|^2 + ||w||^2 \sigma_z^2} \quad (2)$$

Using the MMSE weight in equation (2), we obtain the following relationship:

$$\begin{aligned} \tilde{x}_{MMSE} &= W_{MMSE} y \\ &= (H^H H + \sigma_z^2 I)^{-1} H^H y \\ &= \tilde{x} + (H^H H + \sigma_z^2 I)^{-1} H^H z \\ &= \tilde{x} + \tilde{z}_{MMSE} \end{aligned} \quad (3)$$

where, $\tilde{z}_{MMSE} = (H^H H + \sigma_z^2 I)^{-1} H^H z$ .Using SDV again , the post-detection noise power is expressed as

$$\begin{aligned} ||\tilde{z}_{MMSE}||_2^2 &= ||(H^H H + \sigma_z^2 I)^{-1} H^H z||^2 \\ &= ||(V\Sigma^2 V^H + \sigma_z^2 I)^{-1} V \Sigma U^H z||^2 \end{aligned} \quad (4)$$

Because

$$(V\Sigma^2 V^H + \sigma_z^2 I)^{-1} V\Sigma = (V\Sigma^2 V^H + \sigma_z^2 I)^{-1} (\Sigma^{-1} V^H)^{-1}$$

$= (\Sigma V^H + \sigma_z^2 \Sigma^{-1} V^H)^{-1}$, the noise power in equation (4) can be expressed as

$$\begin{aligned} ||\tilde{z}_{MMSE}||_2^2 &= ||(\Sigma V^H + \sigma_z^2 \Sigma^{-1} V^H)^{-1} U^H z||^2) \\ &= ||V(\Sigma + \sigma_z^2 \Sigma^{-1})^{-1} U^H z||^2 \end{aligned} \quad (5)$$

Again by the fact that multiplication with a uniary matrix does not change the vector norm, that is, $||Vx||^2 = ||x||^2$, the expected value of equation (5) is given as

$$\begin{aligned} E\{||\tilde{z}_{MMSE}||_2^2\} &= E\{||(\Sigma + \sigma_z^2 \Sigma^{-1})^{-1} U^H z||^2\} \\ &= E\{tr((\Sigma + \sigma_z^2 \Sigma^{-1})^{-1} U^H z z^H U (\Sigma + \sigma_z^2 \Sigma^{-1})^{-1})\} \\ &= tr((\Sigma + \sigma_z^2 \Sigma^{-1})^{-1} U^H E\{z z^H\} U (\Sigma + \sigma_z^2 \Sigma^{-1})^{-1}) \\ &= tr(\sigma_z^2 (\Sigma + \sigma_z^2 \Sigma^{-1})^{-2}) \\ &= \sum_{i=1}^{N_T} \sigma_z^2 \left(\sigma_i + \frac{\sigma_z^2}{\sigma_i}\right)^{-2} \\ &= \sum_{i=1}^{N_T} \frac{\sigma_z^2 \sigma_i^2}{(\sigma_i^2 + \sigma_z^2)^2} \end{aligned} \quad (6)$$

Noise enhancement effect in the course of linear filtering is significant when the condition number of the channel matrix is large, that is, the minimum singular value is very small. Referring to Equation (6), the noise enhancement effects due to the minimum singular value for the MMSE linear detector is:

$$E\{||\tilde{z}_{MMSE}||_2^2\} = \sum_{i=1}^{N_\tau} \frac{\sigma_z^2 \sigma_i^2}{(\sigma_i^2 + \sigma_z^2)^2} \approx \frac{\sigma_z^2 \sigma_{min}^2}{(\sigma_{min}^2 + \sigma_z^2)^2} \quad (7)$$

where, $\sigma_{min}^2 = \min\{\sigma_1^2, \sigma_2^2, \ldots, \sigma_{N_\tau}^2\}$.

Note that if $\sigma_{min}^2 \gg \sigma_z^2$ and thus, $\sigma_{min}^2 + \sigma_z^2 \approx \sigma_{min}^2$, then the noise enhancement effect of the two linear filters becomes the same[8].

B. Spatial Domain Noise Reduction Technique

Noise can be defined as any undesired artifact that contaminates an image. The presence of noise in an image can be due to several sources, resulting in different types of noise, from thermal noise in acquisition devices to periodic noise in the communication channel (8) used to transmit an image from a remote sensing location to a base station. Various techniques have been used to improve the appearance of an image that has been subject to degradation and noise.

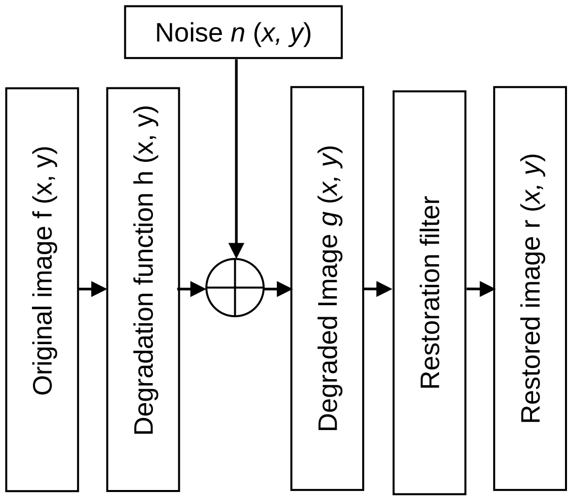

Fig. 1. *Image degradation and Restoration*

Fig. 1 shows a diagram of the degradation and restoration processes. It is assumed that an original image f (x, y) has been subject to some sort of quality degradation (e.g., blurring caused by lack of focus or camera motion, atmospheric disturbances, or geometric distortions caused by imperfect lenses) that can be modeled by a function h(x, y). The image may have been contaminated by additive noise n(x, y). The resulting degraded image g(x, y) is the input for the image restoration algorithms usually implemented as restoration filters that are able to minimize to some extent the degradation process, resulting in a restored image r(x, y) (which should be interpreted as an estimate of the original image f (x, y) and is often referred to as f̂(x, y)). In other words, the goal of restoration techniques is to obtain an image that is as close to the original image as possible.

Mathematically, the degradation and restoration problem can be described as:

$$g(x, y) = f(x, y) * h(x, y) + n(x, y) \quad (8)$$

where* denotes convolution.

The order statistic filters (also known as rank filters, or simply order filters) operate on a neighborhood around a reference pixel by ordering (i.e., ranking) the pixel values and then performing an operation on those ordered values to obtain the new value for the reference pixel. Order statistic filters perform very well in the presence of salt and pepper noise but are computationally more expensive than mean filters [7].

III. Description of Simulated System

A simulated single-user MC-CDMA communication system depicted in Fig. 2 utilizes a ½-rated Convolutional coding scheme with two transmit and two receive antennas. In this simulated system, it has been assumed that a single user is transmitting a color image data. An uncompressed RGB images in JPEG format is used as the input source. The analog image data is converted into 480×360 digital image components with R-G-B samples. These samples are contaminated with salt and pepper noise and then serially multiplexed and channel encoded using a ½-rated Convolutional encoder. The encoded bit stream is then interleaved to minimize the burst error effect. The output of the interleaver is digitally modulated using different digital modulation schemes such as Quadrature Amplitude Modulation (QAM), Quadrature Phase Shift Keying (QPSK) ,Differential Quadrature Phase Shift Keying (DQPSK) and the number of digitally modulated symbols is increased (copied) eight times (as the processing gain/ sequence length of the Walsh–Hadamard (WH) transformed orthogonal codes is eight) and subsequently multiplied with assigned Walsh–Hadamard code .The Walsh–Hadamard and Convolutionally encoded interleaved digitally modulated symbols are summed up and fed into demultiplexing section . The output of the demultiplexer is sent up into two serial to parallel converter. The serial to parallel (S/P) converted complex data symbols are fed into each of the two OFDM modulators with 1024 sub-carriers which performs an IFFT on each OFDM block of length 1024 followed by a parallel-to-serial conversion. A cyclic prefix (CP) of length Lcp (0.1*1024) containing a copy of the last Lcp samples of the parallel-to-serial converted output of the 1024-point IFFT is then pretended. The CP is essentially a guard interval which serves to eliminate interference between OFDM symbols.

However, the resulting OFDM symbols of length (1024+ Lcp) are launched from the two transmitting antenna. In receiving section, all the transmitted signals are detected with linear signal detection scheme (MMSE) and the detected signals are subsequently sent up to the serial to parallel (S/P) converter and fed into OFDM demodulator which performs FFT operation on each OFDM block. The FFT operated OFDM blocked signal are processed with cyclic prefix removing scheme and are undergone from parallel to serial conversion and are fed into multiplexing section. Its output is multiplied with assigned Walsh–Hadamard code. the complex symbols are digitally demodulated, de-copied, de-interleaved and convolutionally decoded and processed for binary to integer conversion prior to send up through noise filtering section and the filtered data are converted into R,G and B component and eventually, the noise filtered transmitted color image is retrieved [8, 9].

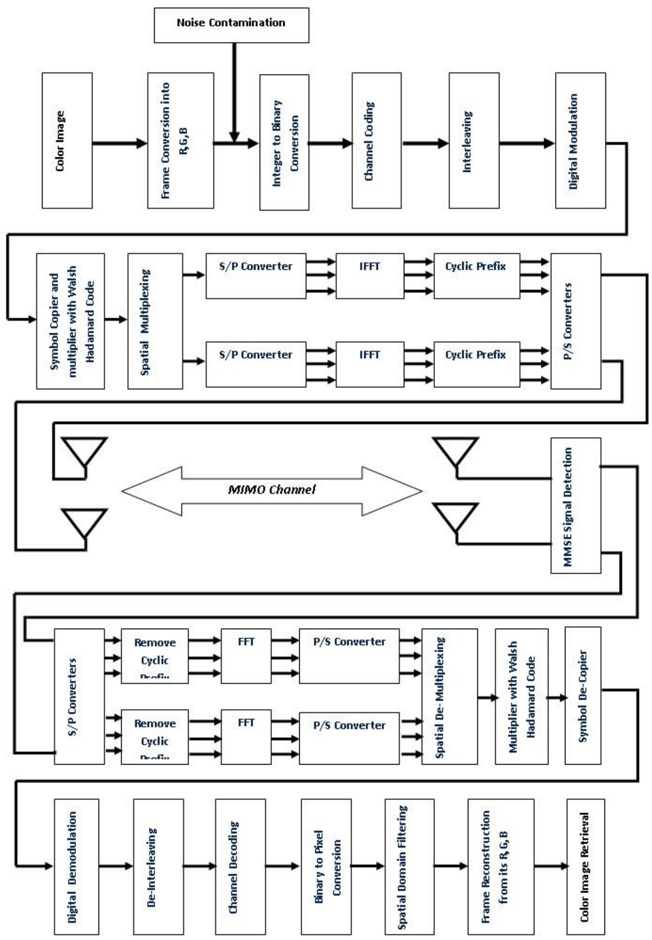

Fig. 2. *The proposed multiple antenna aided MC-CDMA Wireless communication system Model*

IV. Results and Discussions

The proposed model for the multiple antenna aided MC-CDMA Wireless communication system presented in Fig. 2 is simulated with consideration of the following simulation parameters of Table -I.

TABLE I. SIMULATION PARAMETERS

Parameters	Types
Data Type	Color image
Image size	173 pixels × 292 pixels
Orthogonal code	Walsh Hadamard
Processing Gain	8
Antenna configuration	2(Transmitting) × 2(Receiving)
Digital modulation	QAM,QPSK,DQPSK
OFDM Block Size	1024 digitally modulated symbols
SNR	0-10 Db
Channel	AWGN and Rayleigh

Computer simulations using MATLAB R2014a have been conducted to evaluate the quality of the transmitted color image in MIMO MC-CDMA Wireless Communication System on the parameters of Table-I presented in the previous chapter. It is assumed that the channel state information (CSI) of the MIMO fading channel is available at the receiver and the fading process is approximately constant during the whole period of color image transmission.

From Simulation we have found excellent Data for Bit Error Rate (BER) analysis with increasing Signal to Noise Ratio (SNR) value containing 0 dB to 10 dB. We know SNR= 10 dB means Signal power is greater than Noise power by 10 dB and SNR= 0 dB means Noise power and Signal power is identical. We have calculated total BER with increasing SNR for every condition such as QAM with MMSE and Median Filter, QPSK with MMSE and Median Filter, DQPSK with MMSE and Median Filter, QAM with MMSE and Order Statistic Filter, QPSK with MMSE and Order Statistic Filter, DQPSK with MMSE and Order Statistic Filter.

Fig. 3 shows the effects of different modulation techniques for 1/2-rated Convolutional channel encoded MIMO MC-CDMA wireless Communication system with implementation of MMSE signal detection, spatial domain noise reduction Median Filtering. It is seen from Fig. 3 that the lower bit error rate (BER) is achieved in QAM as compared to QPSK and DQPSK digital modulations. For a typical SNR value 4dB, the BERs for QAM, QPSK and DQPSK are 0.1417, 0.1421 and 0.1423 respectively. QAM improve the system performance of 0.0123dB (8.66%) than QPSK and 0.0184dB (12.93) than DQPSK at a SNR value of 4dB.

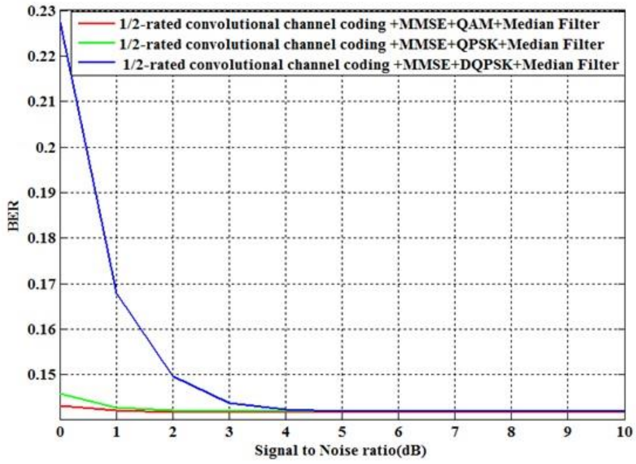

Fig. 3. *BER performance of 1/2-rated Convolutional channel encoded MIMO MC-CDMA wireless Communication system with implementation of MMSE signal detection, spatial domain noise reduction Median Filtering and various digital modulation schemes.*

Fig. 4, Fig. 5 and Fig. 6 show the Transmitted, impulsive (salt and pepper) noise contaminated (where Contamination rate is 5% viz. 2525 pixels out of 50516 pixels are contaminated with impulsive noise for each 173 pixels × 292 pixels sized Red, Green and Blue components) and retrieved color image with implementation of spatial domain noise reduction Median Filtering, MMSE signal detection and three (QAM, QPSK, DQPSK) digital modulation under signal to noise power ration of 10dB.

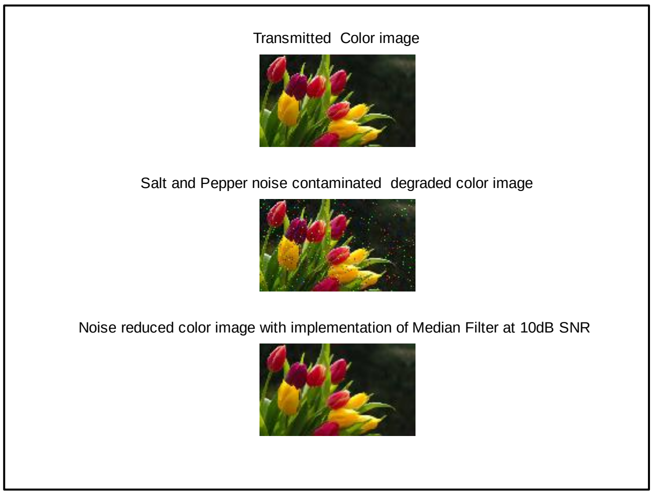

Fig. 4. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Median Filtering, MMSE signal detection and QAM digital modulation under signal to noise power ration of 10dB.*

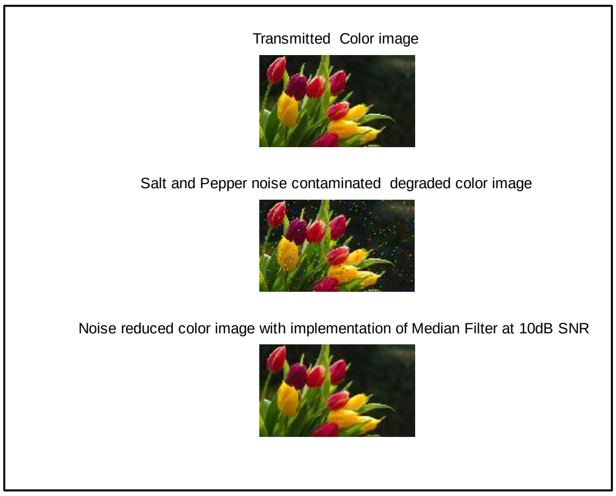

Fig. 5. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Median Filtering, MMSE signal detection and QPSK digital modulation under signal to noise power ration of 10dB.*

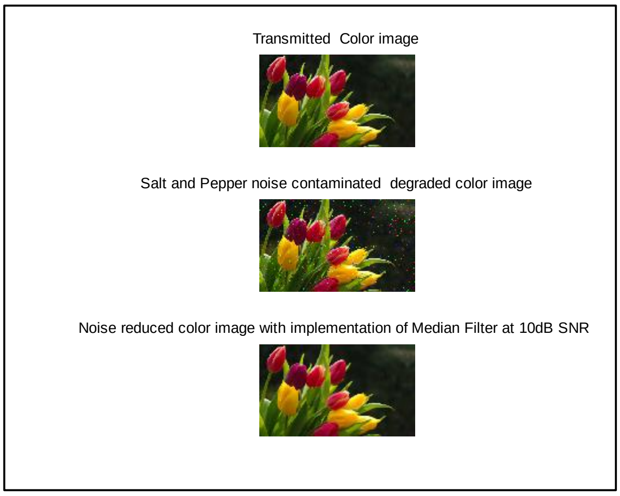

Fig. 6. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Median Filtering, MMSE signal detection and DQPSK digital modulation under signal to noise power ration of 10dB.*

Fig. 7 shows the effects of different modulation techniques for 1/2-rated Convolutional channel encoded MIMO MC-CDMA wireless Communication system with implementation of MMSE signal detection, spatial domain noise reduction Order Statistic Filtering. It is seen from Fig. 7 that the lower bit error rate (BER) is achieved in QAM as compared to QPSK and DQPSK digital modulations. For a typical SNR value 4dB, the BERs for QAM, QPSK and DQPSK are 0.2888, 0.2894 and 0.2892 respectively. QAM improve the system performance of 0.009dB (3.11%) than QPSK and 0.006dB (2.07%) than DQPSK at a SNR value of 4dB.

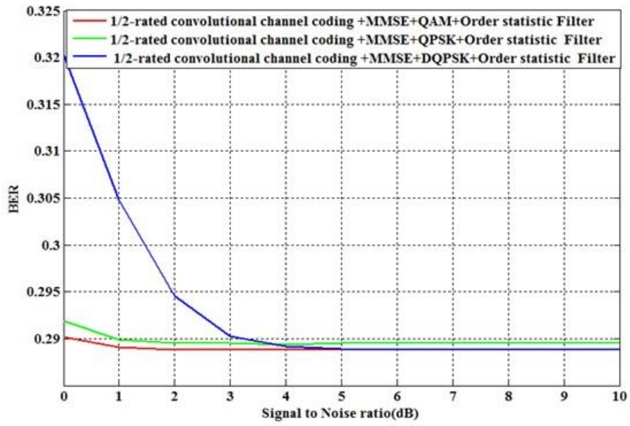

Fig. 7. *BER performance of 1/2-rated Convolutional channel encoded MIMO MC-CDMA wireless communication system with implementation of MMSE signal detection, spatial domain noise reduction Order Statistic Filtering and various digital modulation schemes.*

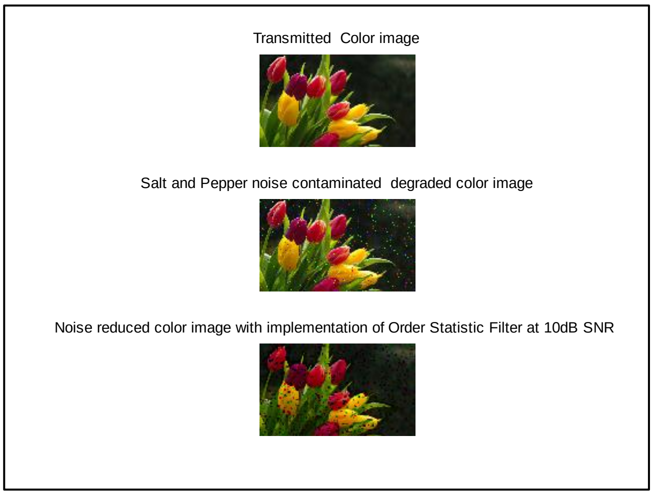

Fig. 8. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Order Statistic Filtering, MMSE signal detection and QAM digital modulation under signal to noise power ration of 10dB.*

Fig. 8, Fig. 9 and Fig. 10 show the Transmitted, impulsive (salt and pepper) noise contaminated (where Contamination rate is 5% viz. 2525 pixels out of 50516 pixels are contaminated with impulsive noise for each 173 pixels × 292 pixels sized Red, Green and Blue components) and retrieved color image with implementation of spatial domain noise reduction Order Statistic Filtering, MMSE signal detection and three (QAM, QPSK, DQPSK) digital modulation under signal to noise power ration of 10dB.

For the signal detection technique MMSE and for three modulation schemas QAM, QPSK and DQPSK, Median Filter decreases Bit Error Rate more than Order Statistic Filter. From the aforementioned figures, it is observed that Median Filter decreases BER up to 0.1417 for QAM, 0.1420 for QPSK and 0.1419 for

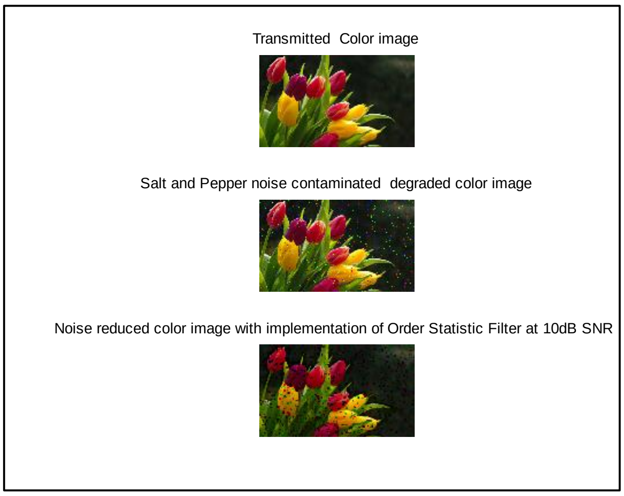

Fig. 9. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Order Statistic Filtering, MMSE signal detection and QPSK digital modulation under signal to noise power ration of 10dB.*

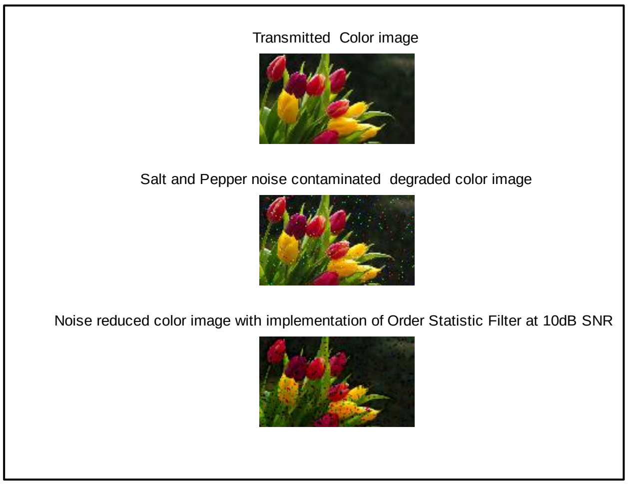

Fig. 10. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Order Statistic Filtering, MMSE signal detection and QDPSK digital modulation under signal to noise power ration of 10dB.*

DQPSK while Order Statistic Filter decreases BER up to 0.2888 for QAM, 0.2895 for QPSK and 0.2888 for DQPSK at 10dB. So Median Filter improves the system performance of 3.0923dB (10.71%) for QAM, 3.0936dB (10.69%) for QPSK and 3.0861dB (10.69%) for DQPSK. In other words, Median Filter reduces more noise than Order Statistic Filter. So the performance of Median Filter is better over Order Statistic Filter for MMSE signal detection.

V. Conclusions

The performance of a MIMO MC-CDMA wireless communication system for transmitting and retrieving of color image signal has been studied in this paper. Comparing the above results of two spatial domain Filters: Median Filter and Order Statistic Filter, it is found that with MMSE signal detection- Median Filter outperforms than that of Order Statistic Filter.

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