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Color Image Retrieval with ZF Signal Detection under Spatial Domain Noise Reduction Techniques over a MIMO MC-CDMA Wireless Communication System

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***Abstract*—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 Zero Forcing (ZF) signal detection technique and two-dimensional nonlinear order statistic and median filtering for noise reduction. Computer simulation tests are performed with a color image downloaded from a website and 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 evident from the simulation study that the image retrieving performance by the proposed communication system is reasonably acceptable and the applicability of noise reduction technique has an impact to remove the added noise in various forms (Salt and Peeper and AWGN) from the transmitted color image with a significant development of image quality.**

Keywords—Color image; ZF; Spatial Domain Noise Reduction; MIMO MC-CDMA

I. INTRODUCTION

Linear processing techniques are very important tools that are used extensively in digital signal / image processing. However, many digital image processing problems cannot be efficiently solved by using linear techniques. An example where linear digital image processing techniques fail is the case of non-Gaussian or signal-dependent noise filtering (e.g. impulsive noise filtering). Such types of noise appear in a multitude of digital image processing applications. Impulsive noise is frequently encountered in digital image transmission as a consequence of man-made noise sources or decoding errors. Signal dependent noise is the photoelectron noise of photo sensing devices and the film-grain noise of photographic films [l].Speckle noise that appears in ultrasonic imaging and in laser imaging is multiplicative noise; i.e. it is signal-dependent noise. Another example where linear techniques fail is the case of nonlinear image degradations. Such degradations occur during image formation and during image transmission through nonlinear channels [1], [5]. The human visual perception mechanism has been shown to have nonlinear characteristics as well [2], [5]. Linear filters, which were originally used in image filtering applications, cannot cope with the nonlinearities of the image formation model and cannot take into account the nonlinearities of human vision. Furthermore, human vision is very sensitive to high-frequency information. Image edges and image details (e.g. corners and lines) have high frequency content and carry very important information for visual perception. Filters having good edge and image detail preservation properties are highly suitable for digital image filtering. Most of the classical linear digital image filters have low-pass characteristics [3]. They tend to blur edges and to destroy lines, edges, and other fine image details. These reasons have led researchers to the use of nonlinear filtering techniques. Nonlinear techniques emerged very early in digital image processing. However, the bulk of related research has been presented in the past decade. This research area has had a dynamic development. This is indicated by the amount of research presently published and the popularity and widespread use of nonlinear digital processing in a variety of applications. Most of the currently available image processing software packages include nonlinear techniques (e.g. median filters and morphological filters). A multiplicity of nonlinear digital image processing techniques has appeared in the literature. Each class of nonlinear processing techniques possesses its own mathematical tools that can provide reasonably good analysis of its performance. For example, mathematical morphology and order statistic filters have been efficiently integrated in one class, although they come from completely different origins. We shall focus our presentation on digital image processing applications, in order to render it more concise. We shall also give links to other nonlinear filter classes, whenever applicable. The class of filters based on order statistics is very rich. The best known filter is the median filter [4-5]. It originates from robust estimation theory. It was suggested by Tukey for time series analysis [6]. Since its first use, several modifications and extensions of the median filter have been proposed [7-9]. 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 [10]. A new generation of cellular system appears every 10 years or so, with the latest generation (4G) being introduced in 2011. Following this trend, the 5G cellular system is expected to be standardized and deployed by the early 2020s. The standardization of the new air interfaces for 5G is expected to gain momentum after the International Telecommunication Union Radio Communication Sector's (ITU-R) meeting at the World Radio communication Conference (WRC), was held in 2015. However, we have reported recently the comparison of performance of spatial-domain noise reduction techniques with MMSE detection in another paper [11] and now in this paper we will see the performance with ZF detection for color image retrieval over a wireless communication system.

II. SIGNAL DETECTION AND NOISE REDUCTION

Spatially multiplexed MIMO (SM-MIMO) systems can transmit data at a higher speed than a MIMO systems using antenna diversity technique. Spatial de-multiplexing or signal detection at the receiver side is a challenging task for SM-MIMO system. Consider the $N_R \times N_\tau$ MIMO system in Figure 1. Let H denotes a channel matrix with it (j,i)th entry h_{ij} for the channel gain between the ith transmit antenna and the jth receive antenna, j=1,2, ... ,N_R and i=1,2, ... ,N_T. The spatially-multiplexed user data and the corresponding received signals are represented by $x = [x_1, x_2, \ldots, x_{N_T}]^T$ and $y = [y_1, y_2, \ldots, y_{N_R}]^T$, respectively, where ,$x_i$ and ,y_j denote the transmit signal from the ith transmit antenna and the received signal at the *j*th receive antenna, respectively. Let ,z_j denote the white Gaussian noise with a variance of σ_z^2 at the *j*th receive antenna, and h_i denote the ith column vector of the channel matrix H. Now the $N_R \times N_\tau$ MIMO system is represented as

$$y = Hx + z$$

$$= h_1x_1 + h_2x_2 + \ldots\ldots + h_{N_T}x_{N_T} + z \qquad (1)$$

where, $z = [z_1, z_2, \ldots\ldots, z_{N_R}]^T$

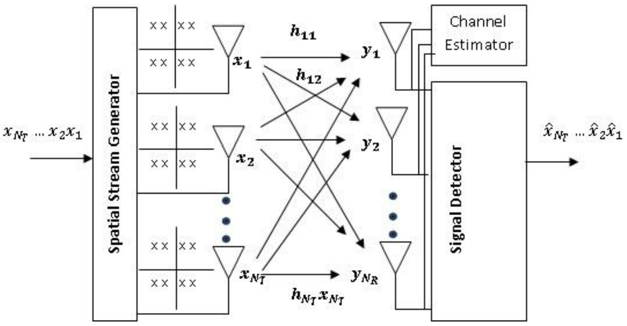

Fig. 1. *Spatially multiplexed MIMO system*

A. ZF Signal Detection

Noise enhancement effect in the course of linear filtering is significant when the The Zero Forcing technique nullifies the interference by the following weight matrix:

$$W_{ZF} = (H^H H)^{-1} H^H \qquad (2)$$

where $(\,.\,)^H$ denotes the Hermitian transpose operatio. In other words, it inverts the effect of channel as

$$\tilde{x}_{ZF} = W_{ZF}y$$

$$= x + (H^H H)^{-1} H^H z$$

$$= x + \tilde{z}_{ZF} \qquad (3)$$

where, $\tilde{z}_{ZF} = W_{ZF}z = (H^H H)^{-1} H^H z$. Note that the error performance is directly connected to the power of $\tilde{z}_{ZF}$ (i.e.,$||\tilde{z}_{ZF}||_2^2$). Using the SDV, the post-detection noise power can be evaluated as

$$||\tilde{z}_{ZF}||_2^2 = ||(H^H H)^{-1} H^H z||^2$$

$$= ||(V\Sigma^2V^H)^{-1}\ V\sum U^H z\,||^2$$

$$= ||V\Sigma^{-2}V^H V \Sigma\, U^H z\,||^2$$

$$= ||V\Sigma^{-1}U^H z||^2 \qquad (4)$$

Since $||Qx||^2 = x^H Q^H Q x = x^H x = ||x||^2$ for a unitary matrix Q, the expected value of the noise power is given as

$$E\{\big||\tilde{z}_{ZF}|\big|_2^2\} = E\{||\Sigma^{-1}U^H z||_2^2\}$$

$$= E\{tr(\Sigma^{-1}U^H zz^H U\Sigma^{-1})\}$$

$$= tr(\Sigma^{-1}U^H E\{zz^H\}U\Sigma^{-1})$$

$$= tr(\sigma_z^2\Sigma^{-1}U^H U\Sigma^{-1})$$

$$= \sigma_z^2\ tr(\Sigma^{-2})$$

$$= \sum_{i=1}^{N_T} \frac{\sigma_z^2}{\sigma_i^2} \qquad (5)$$

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 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 contamination is discussed bellow.

Median and Order Statistic Filters: nonlinear filters also work at a neighborhood level, but do not process the pixel values using the convolution operator. Instead, they usually apply a ranking (sorting) function to the pixel values within the neighborhood and select a value from the sorted list. For this reason, these are sometimes called rank filters. Examples of nonlinear filters include the median filter and the max and min filters. The median filter is a popular nonlinear filter used in image processing. It works by sorting the pixel values within a neighborhood, finding the median value and replacing the original pixel value with the median of that neighborhood which is shown Fig. 2.

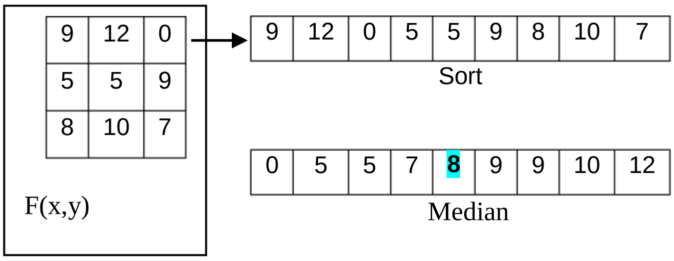

Fig. 2. *Median filter*

The median filter works very well (and significantly better than an averaging filter with comparable neighborhood size) in reducing “salt and pepper” noise (a type of noise that causes very bright- “salt” and very dark- “pepper” isolated spots to appear in an image) from images.

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]. We will compare the results obtained using median and order statistic filtering for the case of an image contaminated with salt and pepper noise in the Results and Discussions section of this paper.

III. DESCRIPTION OF SIMULATED SYSTEM

A simulated single-user MC-CDMA communication system depicted in Fig. 3 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 L_{cp} (0.1*1024) containing a copy of the last L_{cp} 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+ L_{cp}) are launched from the two transmitting antenna. In receiving section, all the transmitted signals are detected with ZF linear signal detection scheme 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.

IV. RESULTS AND DISCUSSIONS

The proposed model for the multiple antenna aided MC-CDMA Wireless communication system presented in Fig. 3 is simulated with consideration of the following simulation parameters of Table -I.

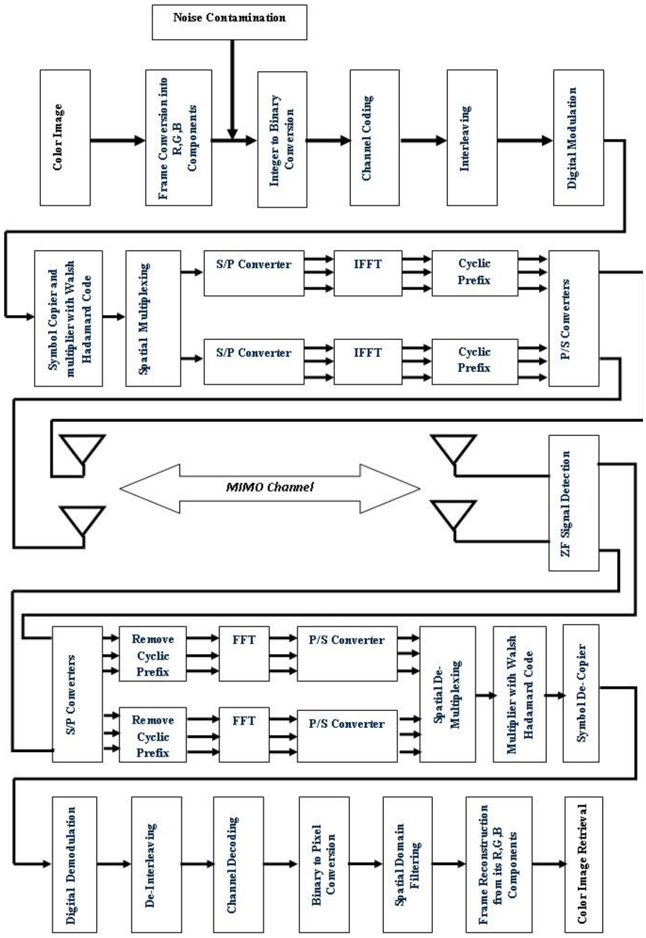

Fig. 3. *The proposed multiple antenna aided MC-CDMA Wireless communication system Model*

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
Signal Detection	ZF
Channel	AWGN and Rayleigh

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 ZF and Median Filter, QPSK with ZF and Median Filter, DQPSK with ZF and Median Filter, QAM with ZF and Order Statistic Filter, QPSK with ZF and Order Statistic Filter, DQPSK with ZF and Order Statistic Filter.

Figure 4 shows the effects of different modulation techniques for 1/2-rated Convolutional channel encoded MIMO MC-CDMA wireless communicated system with implementation of ZF signal detection, spatial domain noise reduction Median Filtering. It is seen from Figure 4 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, 0.1419 and 0.1425 respectively. QAM improve the system performance of 0.006dB (4.23%) than QPSK and 0.0245dB (17.19%) than DQPSK at a SNR value of 4dB.

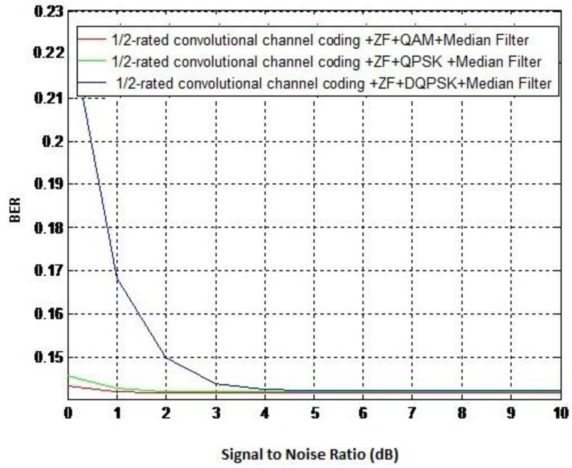

Fig. 4. *BER performance of 1/2-rated Convolutional channel encoded MIMO MC-CDMA wireless Communication system with implementation of ZF signal detection, spatial domain noise reduction Median Filtering and various digital modulation schemes.*

Figure 5, Figure 6 and Figure 7 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, ZF signal detection and three (QAM, QPSK, DQPSK) digital modulation under signal to noise power ratio of 10 dB.

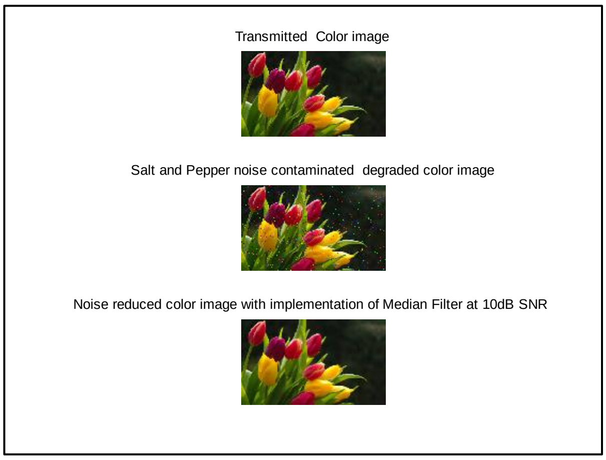

Fig. 5. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Median Filtering, ZF signal detection and QAM digital modulation under signal to noise power ratio of 10 dB.*

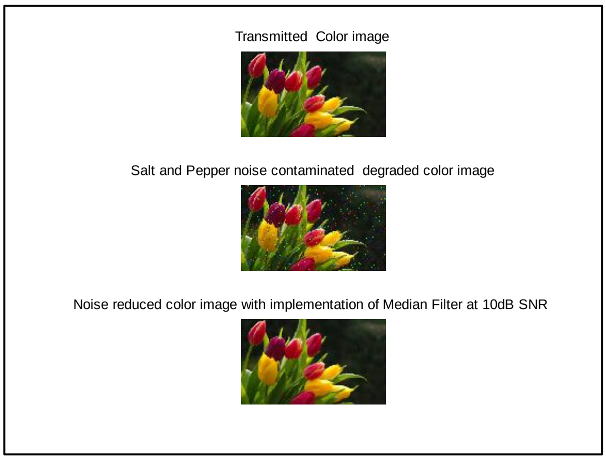

Fig. 6. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Median Filtering, ZF signal detection and QPSK digital modulation under signal to noise power ratio of 10dB.*

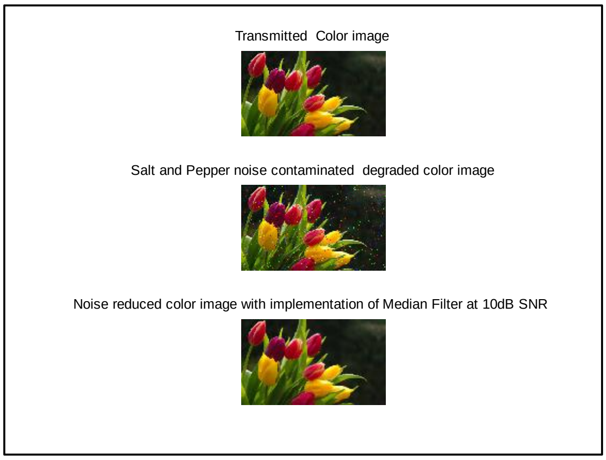

Fig. 7. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Median Filtering, ZF signal detection and DQPSK digital modulation under signal to noise power ratio of 10dB.*

Figure 8 shows the effects of different modulation techniques for 1/2-rated Convolutional channel encoded MIMO MC-CDMA wireless communicated system with implementation of ZF signal detection, spatial domain noise reduction Order Statistic Filtering.

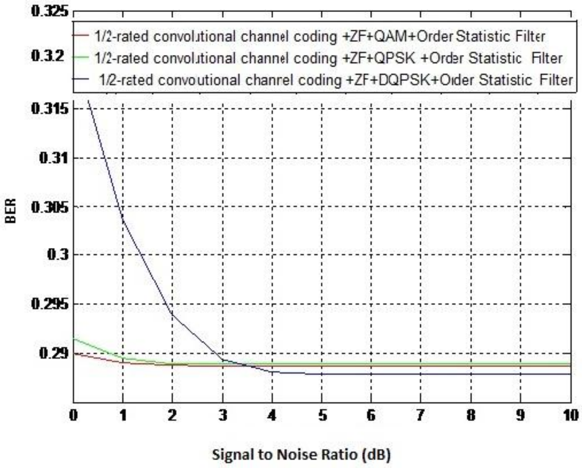

Fig. 8. *BER performance of 1/2-rated Convolutional channel encoded MIMO MC-CDMA wireless communication system with implementation of ZF signal detection, spatial domain noise reduction Order Statistic Filtering and various digital modulation schemes.*

It is clear from the Figure 8 that the lower bit error rate (BER) is achieved in DQPSK as compared to QPSK and QAM digital modulations. For a typical SNR value 4dB, the BERs for QAM, QPSK and DQPSK are 0.2887, 0.2889 and 0.2881 respectively. Here the performance of DQPSK is better than other two modulation schema. DQPSK improve system performance of 0.009 dB (3.13%) over QAM and 0.012 dB (4.17%) over QPSK at a SNR value of 4 dB.

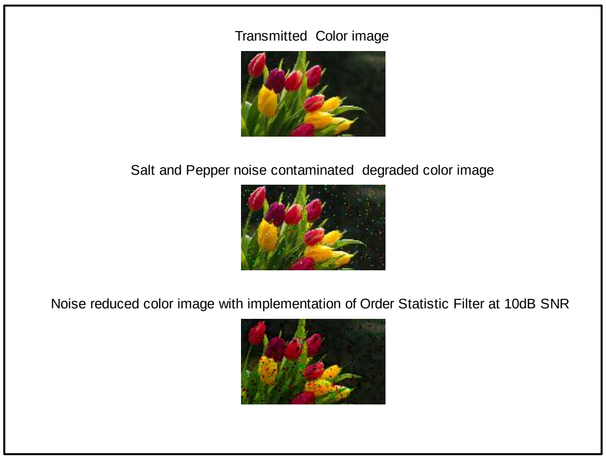

Fig. 9. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Order Statistic Filtering, ZF signal detection and QAM digital modulation under signal to noise power ratio of 10 dB.*

Figure 9, Figure 10 and Figure 11 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, ZF signal detection and three (QAM, QPSK, DQPSK) digital modulation under signal to noise power ratio of 10 dB.

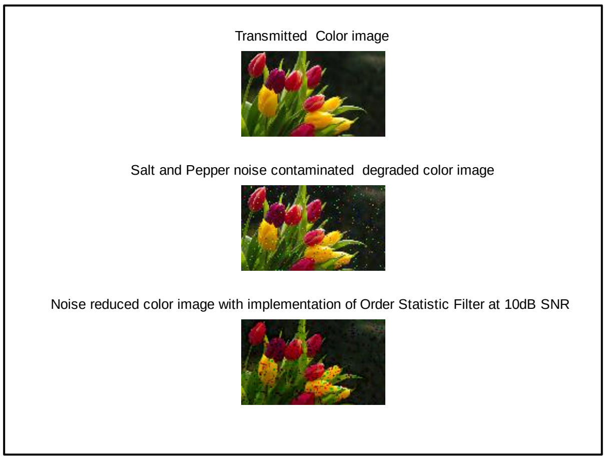

Fig. 10. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Order Statistic Filtering, ZF signal detection and QPSK digital modulation under signal to noise power ratio of 10 dB.*

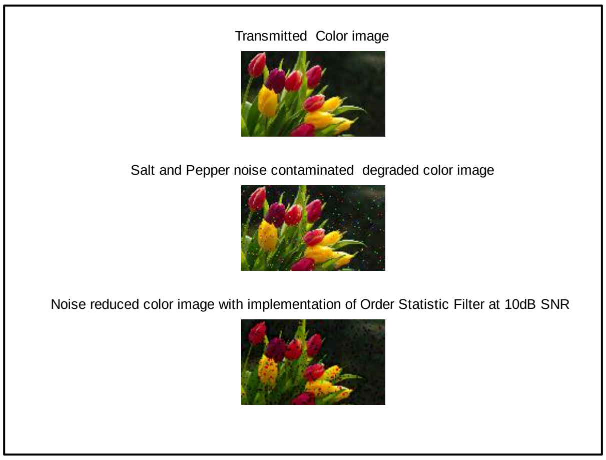

Fig. 11. *Transmitted, noise contaminated and retrieved color image with implementation of spatial domain noise reduction Order Statistic Filtering, ZF signal detection and DQPSK digital modulation under signal to noise power ratio of 10 dB.*

For the signal detection technique ZF and for three modulation schemas QAM, QPSK and DQPSK, Median Filter decreases Bit Error Rate more than Order Statistic Filter. Our results also show that Median Filter decreases BER up to 0.1417 for QAM, 0.1419 for QPSK and 0.1422 for DQPSK while Order Statistic Filter decreases BER up to 0.2887 for QAM, 0.2889 for QPSK and 0.2879 for DQPSK at 10 dB. So Median Filter improves the system performance of 3.0908 dB (10.71%) for QAM, 3.0876 dB (10.69%) for QPSK and 3.0634 dB (10.64%) 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 ZF signal detection that can also be observed from Figure 5, Figure 6, Figure 7, Figure 9, Figure 10 and Figure 11. So the performance of Median Filter is better with ZF signal detection under all QAM, QPSK, and DQPSK digital modulation schema than that of Order Statistic Filter. These results are also valid for our previous study with MMSE detection [11].

V. CONCLUSIONS

In this paper we have made a comprehensive study on the performance evaluation of a simulated digital communication system utilizing 1/2-rated convolutional channel encoded MIMO-MC-CDMA radio interface technology. The performance evaluation is mainly based on the critical examination of the effects of color image transmission through its various signal processing (modulation / demodulation, FEC, noise contamination and noise reduction etc) sections. Our results reveal that the performance of Median Filter is much better than that of Order Statistic Filter with ZF signal detection.

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