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Recovery of Image through Alamouti Channel with Incorporation of RSA Algorithm

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Abstract

In many applications, it is necessary to transmit images at a remote station, where wired Internet service is not available. In this case, wireless local loop (WLL) can help in making wireless link between one end node of the internet and remote service center. In such link, the communication is heavily affected by large and small scale fading; hence the received signal experiences huge distortion in case of forward error correction. Otherwise, huge service delay arises due to frequent negative acknowledgements. To combat the situation, we can choose Alamouti channel of full rate and fully orthogonal space-time block code (OSTBC). Our aim is to transmit images through Alamouti channel and to observe the quality of the recovered image, in context of bit error rate (BER). We have also observed the impact of fading and additive white Gaussian noise (AWGN) on the image without application of error correction or detection technique of channel coding. To ensure security, we apply the RSA algorithm on each pixel prior transmitting and decrypt them at the receiving end, where we found no impairment from the algorithm. Finally, we observe that the relative performance of the system changes digital modulation schemes.

Keywords

Quotient and Remainder Matrix, Alamouti Simulator, Multiple-Input Single-Output (MISO), Image Encryption and Decryption, BER and Discrete Wavelet Transform (DWT)

1. Introduction

Two most important limitations of wireless communication are: the range or length of link and data rate (related to channel capacity). To overcome these limitations, researchers have given their effort on space diversity and

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multicarrier parallel transmission called orthogonal frequency division multiplexing (OFDMA) of [1] [2]. A number of algorithms are proposed on transmitting side in [2]-[7] for attaining space diversity hence getting high signal-to-noise ratio (SNR) at receiving end. A communication model, where space-time block code (STBC) at the physical layer, with channel coding (linear block code) at the data link layer is shown in [8]-[10] and performances were measured in context of BER. A diversity coding can be used in multiple-input multiple-output (MIMO) to provide high data rate without requiring additional bandwidth and transmit power. It is noted that Alamouti space-time block coding has showed good performance than other techniques comparatively. This motivates us to use Alamouti channel for transmitting different types of images like "medical images", "secured watermark", "biometric identification" at a remote station.

Several digital modulation schemes *i.e.* binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), quadrature amplitude modulation (QAM) are used to measure the performance of the system in [11] [12]. It is observed that a well-known cryptographic algorithm RSA [13] is used by researchers [7] for ensuring security of the transmitted message. Research [14]-[16] on MIMO with maximal ratio combining (MRC), selection combining (SC) and equal gain combining (EGC) diversity reception over several correlated and uncorrelated fading channels is also going on.

In this research, Alamouti space-time block coding is applied on transmission channel with incorporation of RSA, for successful recovery of an image. We summarize our key contributions as follows:

- We proposed an algorithm to transmit image through Alamouti channel because of its full spatial diversity gain and observe the quality of recovered image by measuring the bit error rate.
- Furthermore, to ensure security we apply the RSA algorithm on each pixel of the image.
- We perform a number of experiments over Rayleigh fading channels by varying SNR and by applying 16-QAM modulation schemes in order to measure the performance of the system.

The remainder of this paper is organized as follows. Section 2 presents our proposed algorithm of recovering image through Alamouti scheme with incorporation of RSA. In Section 3, we present our experimental results in details with respect to a variety of parameters. Finally, Section 4 concludes the paper with future research directions.

2. System Model

The space-time block code (STBC) is used to achieve orthogonality among transmitted symbols of individual antenna of the MIMO system [17] [18]. Alamouti scheme is a full rate OSTBC where two transmits and one receive antenna are used provided the receiver has the knowledge of channel gain. When more than two antennas are used, then orthogonality is possible but transmission rate become 1/2 or 3/4, for example, sporadic code.

2.1. Full Rate STBC

Full rate STBC is also possible for the case of transmitted antennas, $n_T = 2^k$, $k = 2,3,4,\cdots$; but full orthogonality is not possible and the scheme is called QSTBC explained in [19]-[21]. We can apply zero forcing (ZF) on QSTBC to convert its full orthogonal [21] at the expense of noise. In OSTBC the multiplication channel matrix and its conjugate transpose produces a diagonal matrix *i.e.* the off-diagonal elements are zero. In case of quasi-orthogonal, the result produces a few non-zero off-diagonal elements like below:

$$\begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3 & h_4 & h_1 & h_2 \\ h_4^* & -h_3^* & h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3 & h_4 & h_1 & h_2 \\ h_4^* & -h_3^* & h_2^* & -h_1^* \end{bmatrix}^H = \begin{bmatrix} \alpha & 0 & \beta & 0 \\ 0 & \alpha & 0 & \beta \\ \beta & 0 & \alpha & 0 \\ 0 & \beta & 0 & \alpha \end{bmatrix}$$

where, each element of the matrix h_i indicates the channel gain, $\alpha = |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2$ and $\beta = h_1 h_3^* + h_3 h_1^* + h_2 h_4^* + h_4 h_2^*$

In zero forcing decoding technique, the quasi-orthogonal reception is made fully orthogonal. Here we can eliminate interferences at the expense of noise. From MIMO scheme, the received signal vector is

$$\boldsymbol{r} = [r_1 r_2 r_3 r_4] = \boldsymbol{Hx} + \boldsymbol{n}$$

The estimated received signal vector under ZF is

$$\begin{aligned}\hat{\boldsymbol{Y}} &= \left(\boldsymbol{H}\boldsymbol{H}^{H}\right)^{-1}\boldsymbol{H}^{H}\boldsymbol{r} = \left(\boldsymbol{H}\boldsymbol{H}^{H}\right)^{-1}\boldsymbol{H}^{H}\left(\boldsymbol{H}\boldsymbol{x}+\boldsymbol{n}\right)\\ &= \left(\boldsymbol{H}\boldsymbol{H}^{H}\right)^{-1}\left({}^{1}\boldsymbol{H}^{H}\boldsymbol{H}\right)\boldsymbol{x}+\left(\boldsymbol{H}\boldsymbol{H}^{\mathrm{H}}\right)^{-1}\boldsymbol{H}^{\mathrm{H}}\boldsymbol{n}\\ &= \boldsymbol{I}_{4}\boldsymbol{x}+\left(\boldsymbol{H}\boldsymbol{H}^{H}\right)^{-1}\boldsymbol{H}^{H}\boldsymbol{n}\\ &= \boldsymbol{x}+\boldsymbol{n}';\ \text{where } \boldsymbol{n}' = \left(\boldsymbol{H}\boldsymbol{H}^{\mathrm{H}}\right)^{-1}\boldsymbol{H}^{\mathrm{H}}\boldsymbol{n}\\ &= \left[x_1x_2x_3x_4\right]^{\mathrm{T}}+\left[n_1'n_2'n_3'n_4'\right]^{\mathrm{T}}\end{aligned}$$

Now we have to go for better STBC technique, which provides orthogonality among the received symbols at the same time noise is not enhanced like ZF algorithm of above. In this case, we can choose the simplest possible orthogonal STBC of two antenna systems, called Alamouti scheme discussed in next subsection.

2.2. Alamouti Scheme

Alamouti scheme is a space-time block code under MISO, where the transmitting end uses two antennas and the receiver side has only one antenna, hence the system has no scope of using combining scheme. It is the only full rate orthogonal STBC discussed in [22]. In Alamouti scheme two symbols $\tilde{S}_1$ and $\tilde{S}_2$ are transmitted simultaneously by the antennas at instant t and $t + T$ according to **Table 1**; where T is the duration of a symbol as discussed in [23].

The gain of two wireless links or multipath fading factors is complex expressed as: $h_1 = \alpha_1 e^{j\theta_1}$ and $h_2 = \alpha_2 e^{j\theta_2}$. The entire scenario of Alamouti scheme is visualized from **Figure 1**.

The complex received signal at time $t' > t$ is expressed as

$$\tilde{x}_1 = \alpha_1 e^{j\theta_1}\tilde{S}_1 + \alpha_2 e^{j\theta_2}\tilde{S}_2 + W_1 \tag{1}$$

The corresponding received signal at time $t' + T$ is

$$\tilde{x}_2 = -\alpha_1 e^{j\theta_1}\tilde{S}_2^{*} + \alpha_2 e^{j\theta_2}\tilde{S}_1^{*} + W_2 \tag{2}$$

where W_1 and W_2 are the AWGN noise.

From (1) and (2),

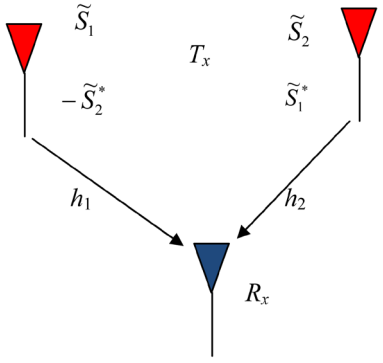

Figure 1. Alamuoti scheme in simplest form.

Table 1. Symbol sequence of two antenna elements.

Time	T_{x1}	T_{x2}
t	$\tilde{S}_1$	$\tilde{S}_2$
$t+T$	$-\tilde{S}_2^{*}$	$\tilde{S}_1^{*}$

$$\begin{bmatrix}\tilde{x}_1\\ \tilde{x}_2^*\end{bmatrix}=\begin{bmatrix}\alpha_1 e^{j\theta_1} & \alpha_2 e^{j\theta_2}\\ \alpha_2 e^{-j\theta_2} & -\alpha_1 e^{-j\theta_1}\end{bmatrix}\begin{bmatrix}\tilde{S}_1\\ \tilde{S}_2\end{bmatrix}+\begin{bmatrix}\tilde{W}_1\\ \tilde{W}_2^*\end{bmatrix} \tag{3}$$

Now, the output of the linear combiner using the concept of channel knowledge of [24] [25],

$$\begin{bmatrix}\tilde{y}_1\\ \tilde{y}_2\end{bmatrix}=\begin{bmatrix}\alpha_1 e^{-j\theta_1} & \alpha_2 e^{j\theta_2}\\ \alpha_2 e^{-j\theta_2} & -\alpha_1 e^{j\theta_1}\end{bmatrix}\begin{bmatrix}\tilde{x}_1\\ \tilde{x}_2^*\end{bmatrix} \tag{4}$$

$$\Rightarrow\begin{bmatrix}\tilde{y}_1\\ \tilde{y}_2\end{bmatrix}=\begin{bmatrix}\alpha_1 e^{-j\theta_1} & \alpha_2 e^{j\theta_2}\\ \alpha_2 e^{-j\theta_2} & -\alpha_1 e^{j\theta_1}\end{bmatrix}\left(\begin{bmatrix}\alpha_1 e^{j\theta_1} & \alpha_2 e^{j\theta_2}\\ \alpha_2 e^{-j\theta_2} & -\alpha_1 e^{-j\theta_1}\end{bmatrix}\begin{bmatrix}\tilde{S}_1\\ \tilde{S}_2\end{bmatrix}+\begin{bmatrix}\tilde{W}_1\\ \tilde{W}_2^*\end{bmatrix}\right)$$

$$\Rightarrow\begin{bmatrix}\tilde{y}_1\\ \tilde{y}_2\end{bmatrix}=\left(\alpha_1^2+\alpha_2^2\right)\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}\tilde{S}_1\\ \tilde{S}_2\end{bmatrix}+\begin{bmatrix}\alpha_1 e^{j\theta_1} & \alpha_2 e^{j\theta_2}\\ \alpha_2 e^{-j\theta_2} & -\alpha_1 e^{-j\theta_1}\end{bmatrix}\begin{bmatrix}\tilde{W}_1\\ \tilde{W}_2^*\end{bmatrix}$$

$$\therefore\begin{bmatrix}\tilde{y}_1\\ \tilde{y}_2\end{bmatrix}=\left(\alpha_1^2+\alpha_2^2\right)\begin{bmatrix}\tilde{S}_1\\ \tilde{S}_2\end{bmatrix}+\begin{bmatrix}n_1\\ n_2\end{bmatrix} \tag{5}$$

In $\tilde{y}_1$, there is no component of $\tilde{S}_2$ and in $\tilde{y}_2$, there is no component of $\tilde{S}_1$, hence the system is fully orthogonal. The simulation of entire Alamouti scheme under fading channel can be represented by the flowchart of **Figure 2**.

2.3. Algorithm

This subsection provides the algorithm of image processing and transmission of the image through fading channel.

1. Select an RGB image and convert it to grayscale. Resize the image as the size of $N \times N$.
2. Covert the image to a column vector $\mathbf{\Gamma}$ of size of $1 \times N^2$.
3. Divide the amplitude of each pixel of column vector by 16 and store the remainder $R(i)$ and quotient $Q(i)$ of ith pixel where $i = 1, 2, 3, \cdots, N^2$ using the concept of [26].
4. Since the amplitude of each pixel is in the range of 0 - 255 therefore both $R(i)$ and $Q(i)$ has the value in the range of 0 - 15 hence we can use the values as the constellation points of 16-QAM.
5. Assign each value of $R(i)$ and $Q(i)$ against a constellation point of 16-QAM.
6. Transmit the constellation points or symbols against corresponding values of $R(i)$ and $Q(i)$ thorough a Alamouti simulator with Rayleigh fading channel contaminated by AWGN. The flowchart of simulator is shown in **Figure 2**.
7. Recover each constellation points using orthogonal space diversity algorithm at the receiving end.
8. Convert the constellation points to $Q(i)$ and $R(i)$.
9. Evaluate the amplitude of pixel using $\Gamma(i) = 16 * Q(i) + R(i)$.
10. Convert the column vector $\mathbf{\Gamma}$ to the matrix $N \times N$ in the reverse way of step 2.
11. Smooth the image using DWT with a threshold value.

We can apply RSA algorithm of [27] [28] on $R(i)$ and $Q(i)$ at step 5 to achieve secured communication.

3. Results

Let us first select a test image (main gate of Jahangirnagar University campus) and apply the algorithm on it for the fading channel of average SNR of 12, 15, 20, 25 and 30 dB. The corresponding results are shown in **Figures 3-7**. The recovered image is found appreciable at a glance for 20 dB or above. The quality of received image improves at higher SNR is visualized from the figures. We can get better results by applying lower modulation scheme like, BPSK, QPSK, 8-PSK instead of 16-QAM, although throughput is higher at higher modulation scheme. We measure the BER of the same image (main gate of JU campus) for four different modulation schemes shown in **Figure 8**, where we get the conventional results, *i.e.* performance is better for lower modulation scheme. Actually the algorithm has very small effect on different images in context of BER. The phenomenon is shown in **Table 2**, where we select 6 different images and measure BER under 16-QAM taking SNR

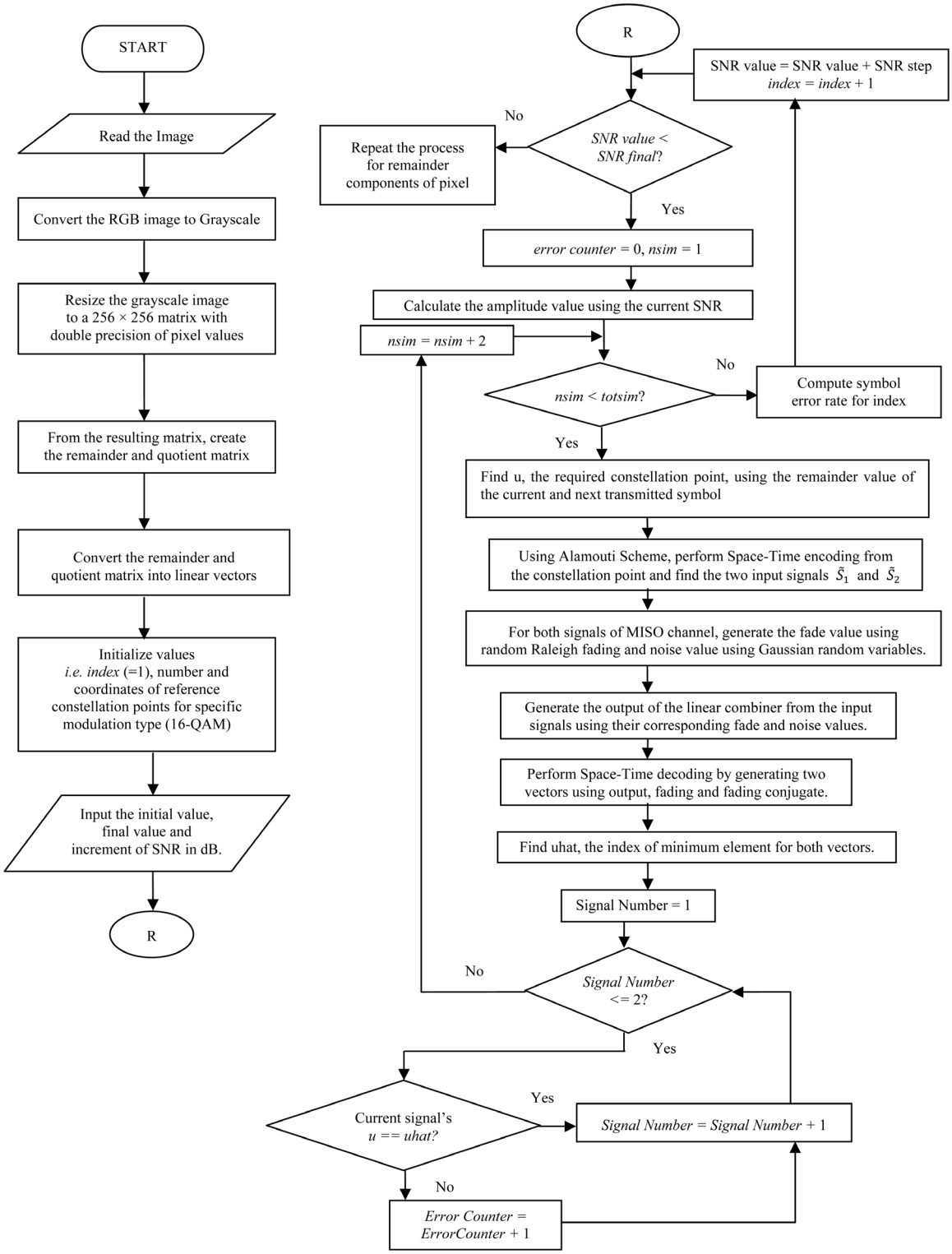

Figure 2. Flowchart of Alamouti Simulator.

from 12 to 30 dB. Finally, for secured communication we apply RSA algorithm on $Q(i)$ and $R(i)$ of four images. The corresponding results are shown in **Figure 9**, where we show the original RGB image, its grayscale version, encrypted image and recovered/decrypted image.

Figure 3. Image recovery at SNR of 12dB using 16-QAM.

Figure 4. Image recovery at SNR of 15dB using 16-QAM.

Figure 5. Image recovery at SNR of 20dB using 16-QAM.

Figure 6. Image recovery at SNR of 25dB using 16-QAM.

Figure 7. Image recovery at SNR of 30dB using 16-QAM.

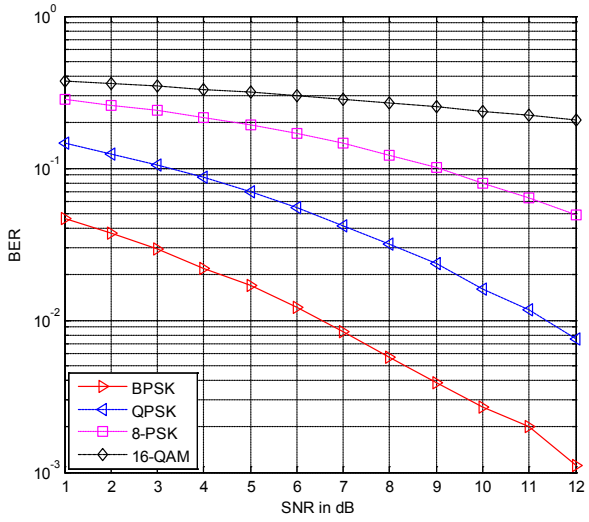

Figure 8. BER of the image of JU Gate under four different modulation schemes.

Figure 9. Encryption and decryption of image.

Table 2. BER of six test images under 16-QAM.

SNR (dB)	BER (image 1)	BER (image 2)	BER (image 3)	BER (image 4)	BER (image 5)	BER (image 6)
12	0.2082	0.2074	0.2092	0.2059	0.2076	0.2107
14	0.1835	0.1813	0.1826	0.1803	0.1830	0.1862
16	0.1598	0.1587	0.1600	0.1579	0.1612	0.1629
18	0.1370	0.1366	0.1374	0.1349	0.1386	0.1399
20	0.1158	0.1154	0.1156	0.1146	0.1158	0.1164
22	0.0920	0.0911	0.0921	0.0919	0.0930	0.0932
24	0.0692	0.0686	0.0685	0.0676	0.0695	0.0704
26	0.0490	0.0477	0.0487	0.0483	0.0486	0.0492
28	0.0310	0.0305	0.0317	0.0296	0.0304	0.0309
30	0.0179	0.0177	0.0176	0.0176	0.0178	0.0181

4. Conclusion

In this paper, we are able to recover an image transmitting through Alamouti channel with incorporation of RSA algorithm; where the quality of the image depends on the SNR of the channel. Although we reveal the results for grayscale images, we can also do the similar job for RGB images as well, sending the R, G and B components separately, then combining and at receiving end. We can apply channel coding scheme like linear block code, convolutional code or CRC (Cyclic Redundancy Code) scheme to enhance the performance of the system. MIMO and combining scheme (maximal ratio combining, equal gain, selection combining) can be considered an alternate technique of improvement of the system.

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