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To cite this article: M I Youssef *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **610** 012083

IOP Conf. Series: Materials Science and Engineering **610** (2019) 012083 doi:10.1088/1757-899X/610/1/012083

ICI and PAPR enhancement in MIMO-OFDM system using RNS coding

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Abstract. The Inter-Carrier-Interference (ICI) and the Peak-to-Average-Power Ratio (PAPR) of the transmitted signal are considered as bottlenecks in the utilization of Multiple-Input-Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) systems, which caused a significant performance degradation. In this paper Residue Numbers as a coding scheme is impeded in MIMO-OFDM systems, where the PAPR values are analysed and compared to non-RNS coding systems, and the ICI levels are measured and evaluated with respect to the conventional ICI mitigation techniques as pulse shaping, windowing and self-cancellation techniques implemented in MIMO-OFDM system. The ICI errors, Bit-Error-Rate (BER) and the Complementary Cumulative Distribution Function (CCDF) for MIMO-OFDM system with Residue Number System (RNS) coding are analysed and evaluated. The results demonstrated a performance enhancement of the transmission model over the system without RNS implementation.

1. Introduction

In MIMO communication systems, the transmitted data is distributed through the usage of various Space–Time Block Coding (STBC) algorithms to achieve either higher transmission data rates or enhance system BER performance for the same data rate [1]. The OFDM as a multi-carrier modulation scheme has shown its ability to provide high transmission rates, due to its unique features as robustness to multipath fading overcoming Inter-Symbol-Interference (ISI), high spectral efficiency, immunity to impulse interference, overcoming time dispersion problems, flexibility and simple equalization over wireless communication channels.

For MIMO-OFDM systems [2], orthogonality between sub-carriers lost due to the OFDM sensitivity towards frequency offset generated from the Doppler shift between the transmitter and the receiver. This results in an ICI between the transmitted symbols that degrade the overall performance [3].

Different ICI cancellation techniques are currently available like time-domain widowing, pulse shaping and frequency equalization, which reduce the ICI levels and improves the BER for MIMO-OFDM communication system. Still, these techniques are costly and high complex either on the transmitter or receiver side. This paper proposes an efficient ICI cancellation technique based on the utilization of Residue coding scheme; where the system is analysed and compared to current mitigation techniques.

In section 2 and 3, RNS background and analysis on ICI errors are presented respectively. Section 4 summarize existing mitigation techniques, present relation between frequency offset and number of sub-carriers and give theoretical rational about RNS coding effect on ICI reduction. Section 5 describes the proposed MIMO-RNS-OFDM communication system. In section 6 the conducted simulations are illustrated to measure the overall performance and in section 7, a conclusion is stated.

Analysis of inter-carrier-interference
In MIMO-OFDM systems, the loss of orthogonality indicated in section 1 result in signal amplitude reduction and increasingly ICI errors as presented in figure 1, which would degrade the system performance.

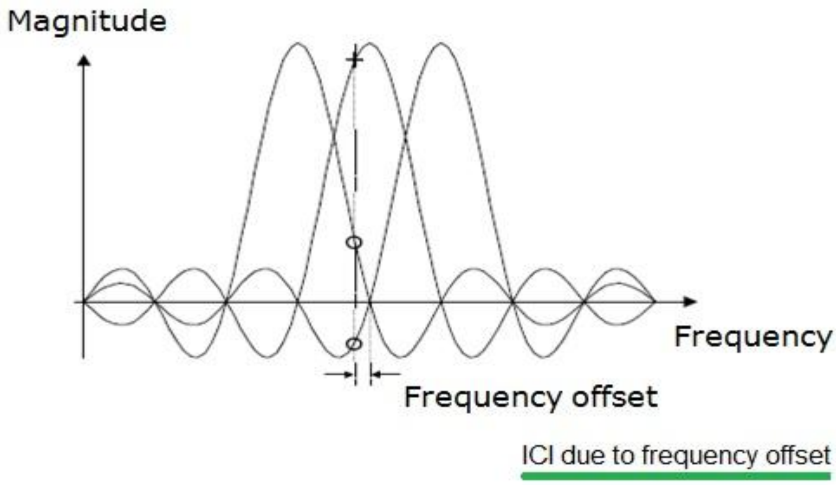

Figure 1. Representation of Signal Frequency Offset

2. Residue system background

2.1. RNS tutorial
Through binary to RNS conversion, data is represented through smaller integers, with two exclusive features. A carry-free arithmetic that enables parallel mathematical activities and no weight-information carried between sub-carriers that prevent error propagation [4].

Through the RNS scheme, a ‘v’ positive pair-wise relative primes moduli are selected, where the residue digit is the reminder of division of the binary information to each of the residue moduli [4]. Then, at the receiver side to recover the information, Mixed Radix Conversion (MRC) method [5] is utilized.

2.2. Redundant residue number system
The Redundant Residue Number System (RRNS) scheme use additional moduli that are greater than any other chosen moduli set and even not used in defining the associated dynamic range. These additional moduli are referred to as the “redundant modulus”, while the initial moduli set are referred to as the “information moduli”.

Through this technique the received symbol transmission error is detected [6], which is followed by correcting the erroneous symbols and retrieve the correct data using the MRC technique. This algorithm is based on testing each of the information moduli with the two redundant moduli and through this test it is able to identify and correct the bit which generated the error [7].

The frequency offset (ε) modelled as shown in figure 2, where the received signal represented as;

$$Y(n) = x(n)e^{\frac{j2n\varepsilon}{N}} + w(n) \quad (1)$$

where;
x(n) A sequence data in a discrete time domain

w(n) The FFT of the samples of the noise signal
N Total number of sub-carriers

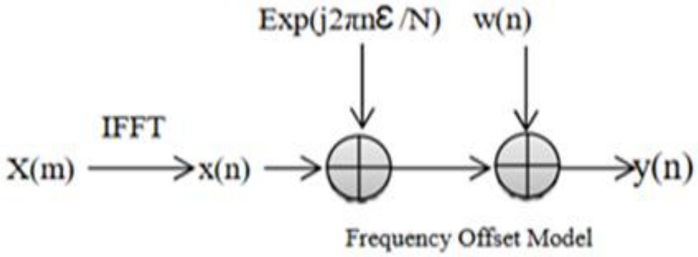

Figure 2. Frequency offset model

The received symbols are affected by this frequency offset as represented in equation (2).

$$Y(k) = X(k) \, . \, S(0) + \sum_{l=0, l\neq k}^{N-1} X(l) . S(l-k) + w(n) \tag{2}$$

where;
X(k) Transmitted symbol for k^{th} sub-carrier,
n_k FFT of w(n).
S(l-k) ICI components for received signal
where, the complex coefficients of the ICI signal components transmitted on sub-carriers is shown in equation (3).

$$S(l\text{-}k) = \frac{\sin(\pi\,(l+\varepsilon-k)}{N \sin\{\frac{\pi\,(l+\varepsilon-k)}{N}\}} \exp\{j\pi\left(1-\frac{1}{N}\right)(l+\varepsilon-k)\} \tag{3}$$

3. RNS as ICI mitigation technique

The frequency offset factors as attenuation and rotation of sub-carriers causes loss of orthogonality among sub-carriers, which generate ICI errors, that degrades the efficiency of the system.

In this section a summary for the research conducted to mitigate the ICI errors, as well as the theoretical behind ability of RNS as a coding scheme to reduce the ICI errors in the communication system is provided as seen next.

3.1. ICI current mitigation schemes

A lot of researchers [8, 9] have proposed numerous ICI mitigation techniques to resolve this problem which is categorized as; self-cancellation, frequency-domain equalization, time–windowing, and Pulse shaping techniques [10, 11, 12, 13].

These techniques are employed as well for the reduction of the PAPR through the reduction of side lobes in each carrier, permitting higher power to be transmitted to for a constant peak power, and making enhancement in the overall Signal-to Noise Ratio (SNR) at the receiver.

The Frequency Offset and Number of Sub-carriers

The impact of Carrier Frequency Offset (CFO) on the degradation of the SNR in OFDM systems [14] is seen in equation (4);

$$D_{freq} = \frac{10}{3 \ln 10} (\pi \Delta f T)^2 SNR \tag{4}$$

where;
Δf, T, E_b, N_o frequency offset, symbol duration, energy per bit and the noise respectively.
SNR is Signal-to-Noise Ratio.

Figure 3 illustrates the impact of the sampling offset on the degradation of SNR, where it is seen a degradation in the OFDM system when increasing the number of sub-carriers.

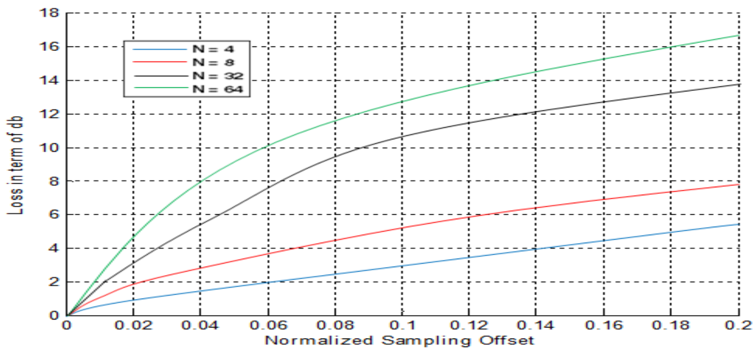

Figure 3. Effect of Number of Sub-carriers on SNR

3.2. RNS Coding as ICI Reduction Approach

The OFDM use a dedicated sub-carrier for each data symbol, so for N-data samples it is required an N sub-carrier frequencies used in the IFFT/FFT stage at both transceiver sides. The Residue Number System on the other hand uses only 'v' sub-carriers, each with N-sample data bits. These 'v' sub-carriers are equivalent to the selected number of RNS moduli.

Moreover, in sub-section 4.2, the system degradation due to frequency offset that generates ICI is function of the number of sub-carriers in the transceiver system. So, when number of sub-carriers are duplicated the ICI increased by 3 dB. Thus, as the selected number of RNS moduli is always less than the N-samples, the conversion to RNS is able to mitigate the effect of ICI seen in OFDM system.

4. Proposed system model

The MIMO-RNS-OFDM system is shown in figure 4. Where, the input binary data is converted to residue numbers, modulated, coded using Space-Time Block Code (STBC) encoder, converted to a set of parallel streams through a Serial-To-Parallel (S/P) converter, going to an IFFT block for data multiplexing, and finally transmitted over the communication channel. At the receiver end the system blocks are the reverse of that indicated in the transmitter side.

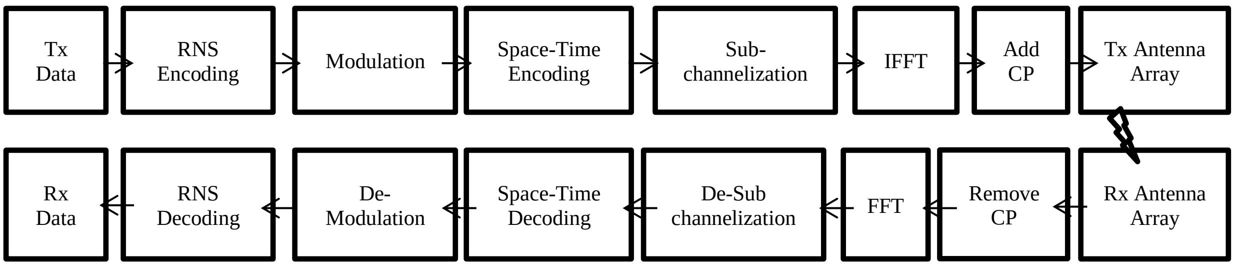

Figure 4. MIMO-OFDM System model

The above system, shown in figure 4 is evaluated by measuring the CIR given in equation (5), and the BER of the signal shown in equation (6), respectively.

$$\mathrm{CIR} = \frac{|S(k)|^2}{\sum_{l=0,l\neq k}^{N-1} |S(l-k)|^2} \tag{5}$$

And; the probability of error for M-PSK modulated transmission [15] is given by:

$$P_{ERR} = \frac{2}{\max(\log 2\, M, 2)} \sum_{k=1}^{\min(2,\left[\frac{M}{4}\right])} Q\left\{ \sqrt{2\sigma . x} \, . \sin\left(\frac{(2k-1)\pi}{M}\right)\right\} \tag{6}$$

where;

M, is constellation size.

σ, SNR per symbol.
x, chi-square distributed random variable.

5. Simulation results

Transmitting 1000 symbols in a MIMO-OFDM communication system using RRNS moduli's set (17, 13, 11, 7, 5, 3), where (17, 13) are the redundant moduli's.

5.1. BER vs. SNR for various offset values for MIMO-RNS-OFDM system

In figure 5, the performance of communication system in the presence of varies frequency offset values between the transmitter and the receiver is evaluated and discussed.

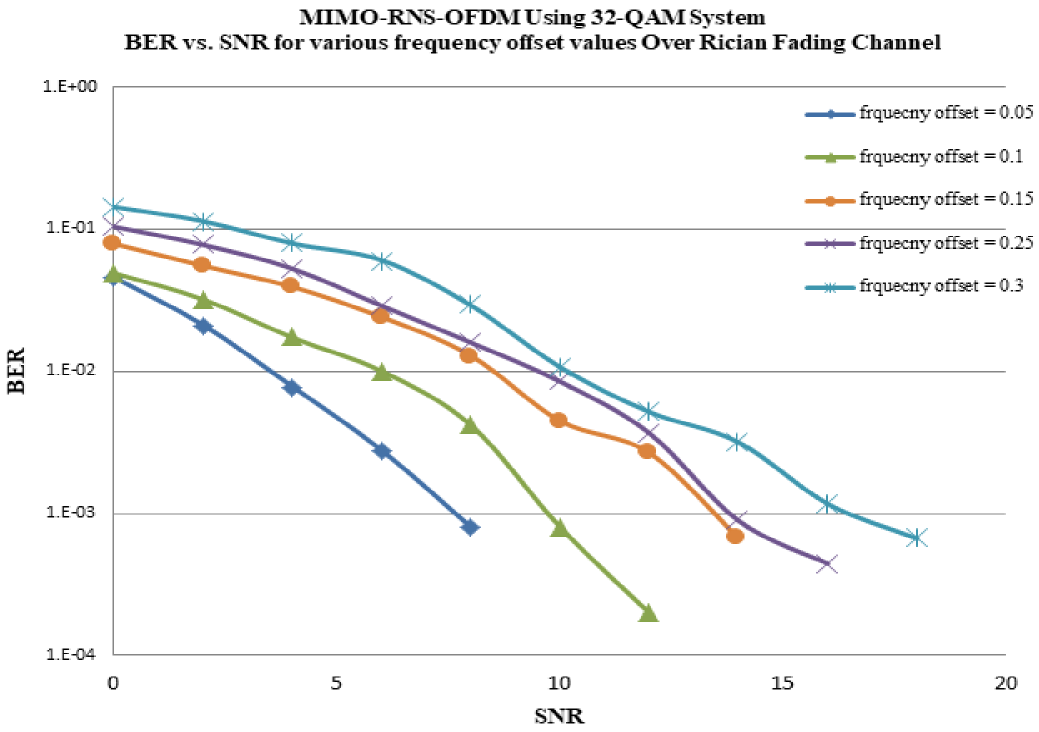

Figure 5. Frequency offset Effect on the System BER

From figure 5, it is shown that the performance is degraded with the increase in the frequency offset as it goes from 0.05 to 0.3.

5.2. ICI measurements for MIMO-RNS-OFDM system

For a SNR value (80), the transmission signal error is plotted versus the frequency offset as seen in Figure 6 for OFDM system with and without RNS moduli's (13, 11, 7, 5, 3) as coding scheme;

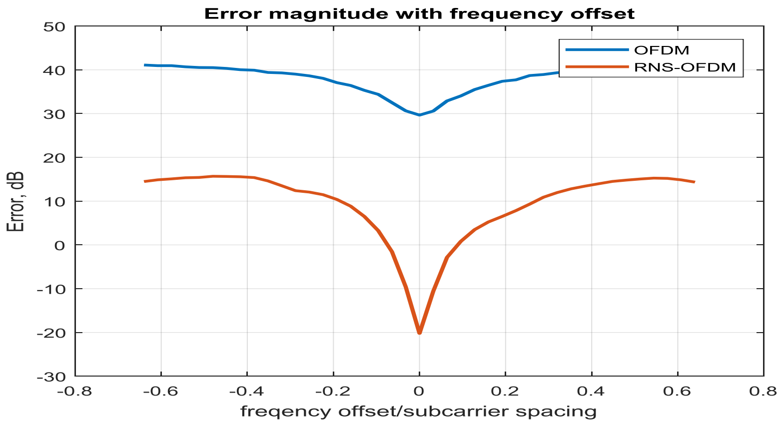

Figure 6. Error vs. Normalized Frequency Offset

In figure 6, absolute 25 dB improvement using RNS scheme is achieved, which is better than that obtained using self-cancellation scheme [10]. In addition, as the frequency offset increase the error increases due to the increasingly loss of orthogonality between carriers. While, with low offset values the RNS coding performance is enhanced due to the inherent properties of RNS that does not allow the transmission of error between different moduli.

5.3. ICI Error for MIMO-RRNS-OFDM system

Using RNS coding technique (17, 13) with redundant moduli's (11, 7, 5, 3), and recording the ICI error with respect to the normalized frequency offset and comparing its evolution with OFDM and RNS-OFDM systems without error detection and correction scheme.

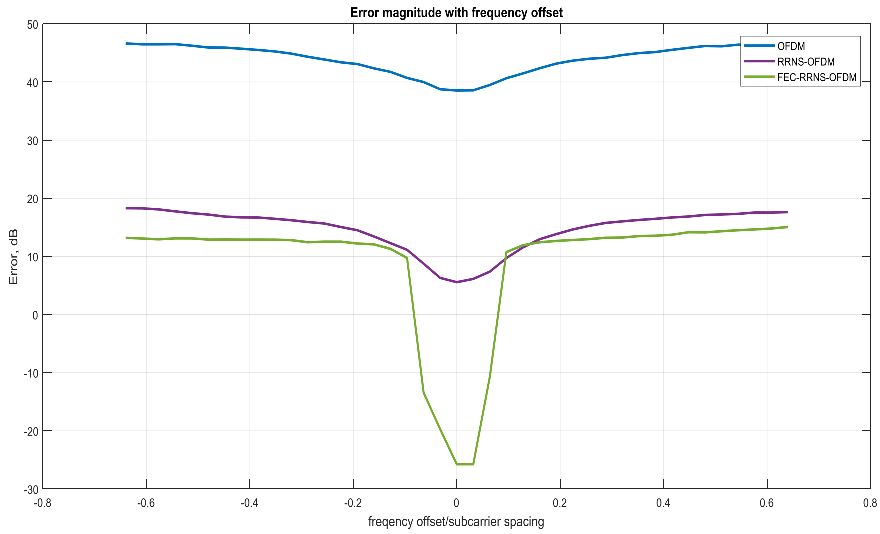

Figure 7. Error for MIMO-RRNS-OFDM Systems

In figure 7 the improvement is more than 30 dB, which is better than self-cancellation scheme [10] and RNS coding. Moreover, the system exhibits similar performance as that shown when using RNS as a coding scheme only, as seen in section (6.2).

5.4. Effect of RNS moduli selection on ICI performance

Increasing the order of RNS moduli set and measures the system performance to see the effect of the selection of the RNS on ICI reduction.

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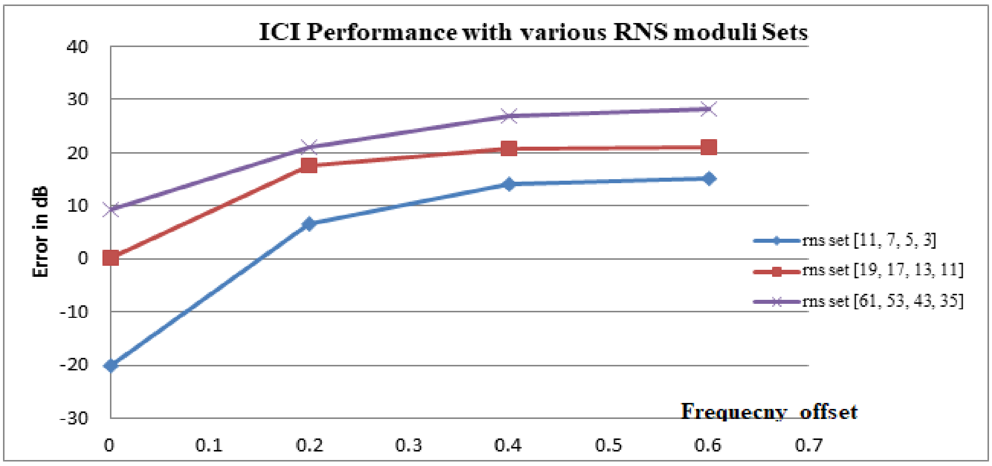


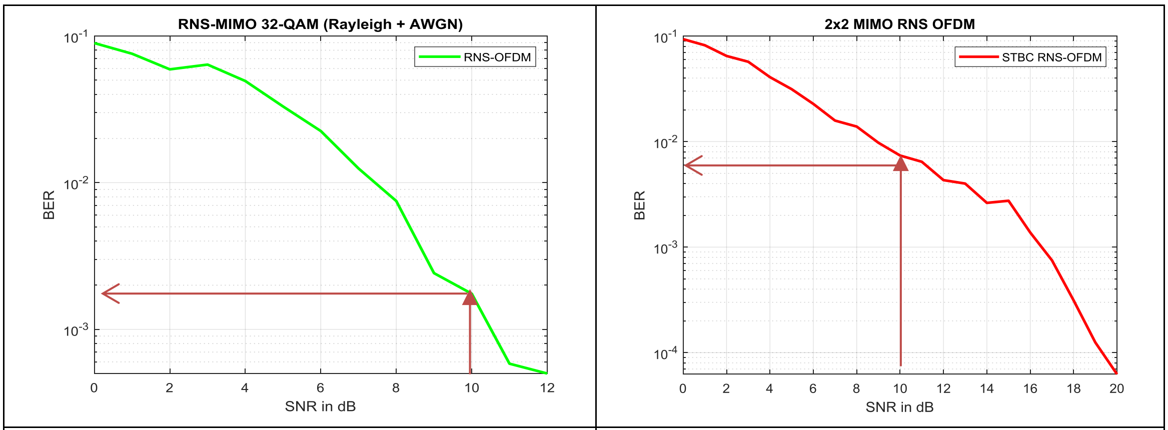
Figure 8. ICI vs. RNS moduli set

From figure 8, it is noted that each time the amplitude of the RNS set increased this would increase the ICI error, and thus the increased signal amplitude would increase directly the interference between adjacent sub-carriers.

Now; in the comings sub-sections (6.5) to (6.8) various mitigation schemes are implemented and analysed in the MIMO-OFDM communication system to study and evaluate its performance in combination with Residue coding technique.

5.5. MIMO-RNS-OFDM with "Frequency domain equalization" Scheme

The frequency equalizer is located at receiver side, where the system performance is evaluated as seen in figure 9 over a Rayleigh fading channel.



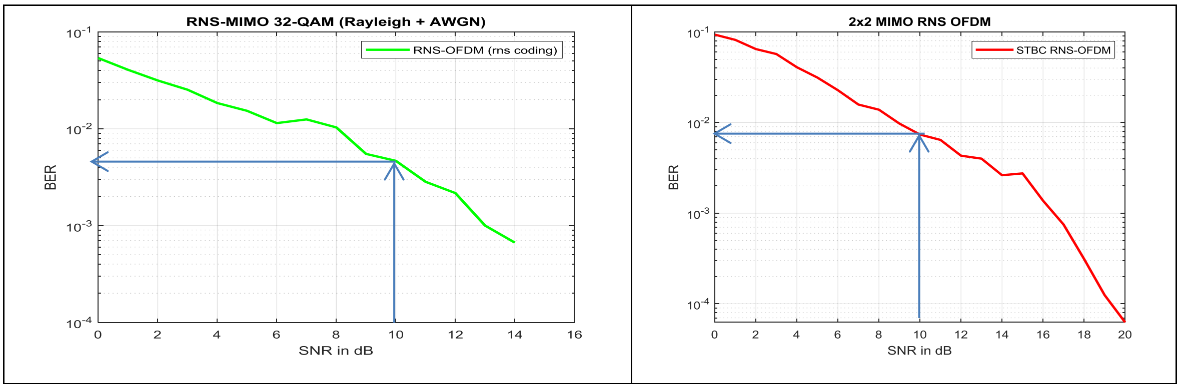
(a) With Equalization (b) Without Equalization

Figure 9. MIMO-OFDM RNS system with/without Equalizer

In a 32-QAM system and over Rayleigh channel @ SNR=10 dB, the BER seen in figure 9 (a) is ~$2*10^{-3}$ while in figure 9 (b) it reaches $6*10^{-3}$. Also, for a BER = 10^{-3} the SNR is reduced by ~ 5.5 dB when using Equalization mitigation scheme.

6.6 MIMO-RNS-OFDM with "Self-Cancellation" scheme

A data conjugate type of self-cancellation scheme is implemented, where the system performance is evaluated as seen in figure 10 over a Rayleigh fading channel.



(a) With mitigation scheme (b) Without mitigation scheme

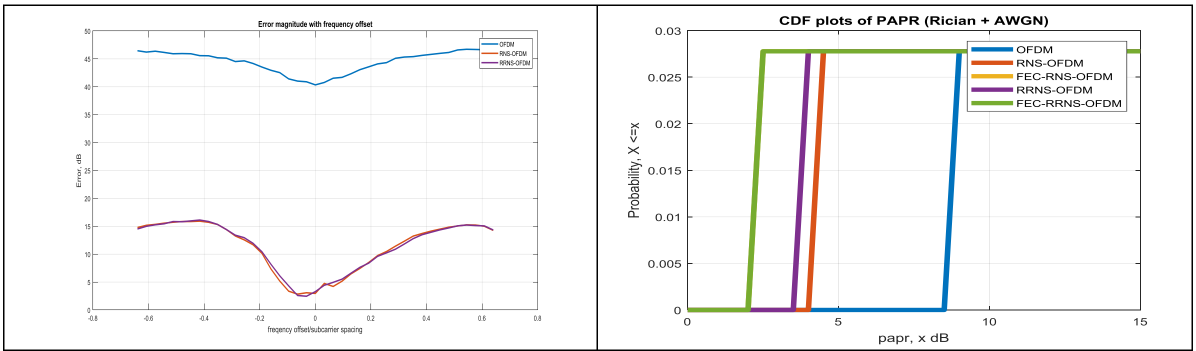
Figure 10. MIMO-OFDM RNS system self-cancellation Scheme

In a 32-QAM system and over a Rayleigh channel @ SNR = 10 dB, the BER seen in figure 10 (a) is $3*10^{-3}$, while in figure 10 (b) it reaches $7*10^{-3}$. Also, for a BER = 10^{-3} the SNR is reduced by ~3 dB when using Self-cancellation mitigation scheme.

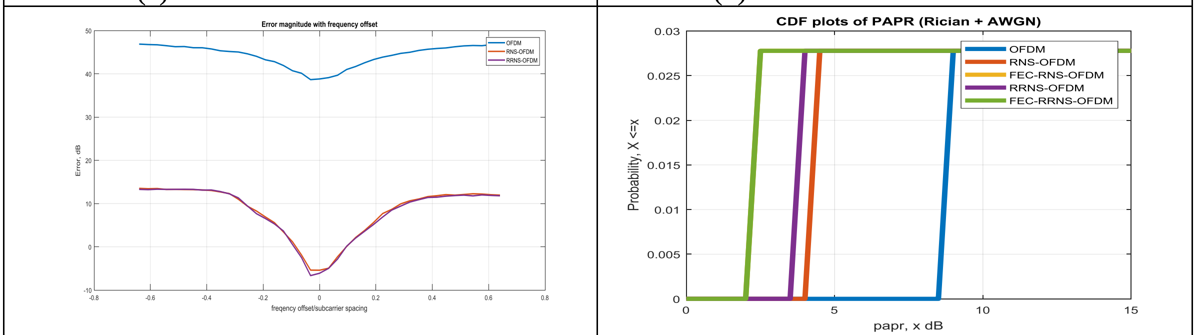
5.6. MIMO-RNS-OFDM with "Pulse Shaping" scheme

A Raised Cosine (RC) pulse shaping is implemented in 512-QAM communication system, where system performance is measured over Rician + AWGN channel. The selected RRNS moduli set is (3, 5, 7, 11, 13), where information moduli are (3, 5, 7, 11) and redundant moduli is (13).

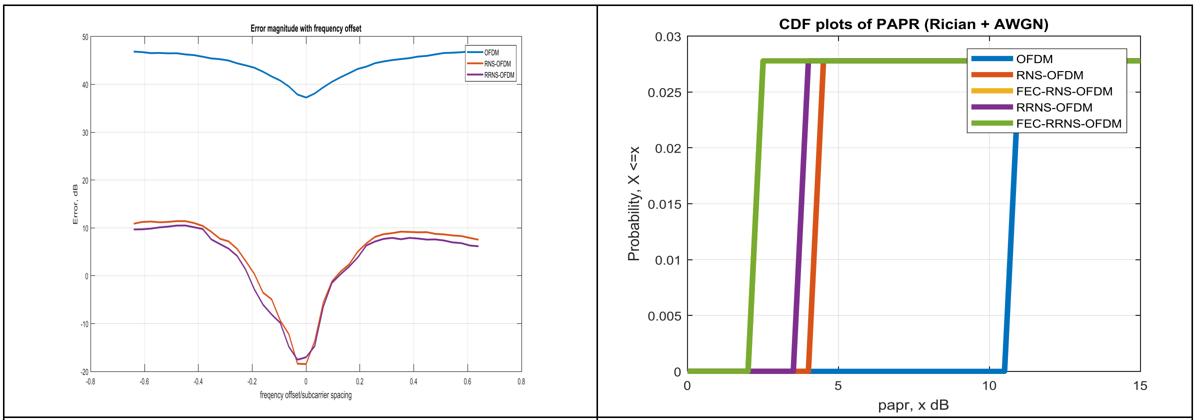
5.6.1. Pulse Shape Design. Prior to testing the communication system with pulse shaping mitigation scheme, it is essential to set-up the pulse filter to obtain the optimum performance. Thus, the pulse roll-off parameter is adjusted, as seen in figure 11.



(a) ICI with Roll-OFF = 0.0 (b) PAPR with Roll-OFF = 0.0



(c) ICI with Roll-OFF = 0.25 (d) PAPR with Roll-OFF = 0.25



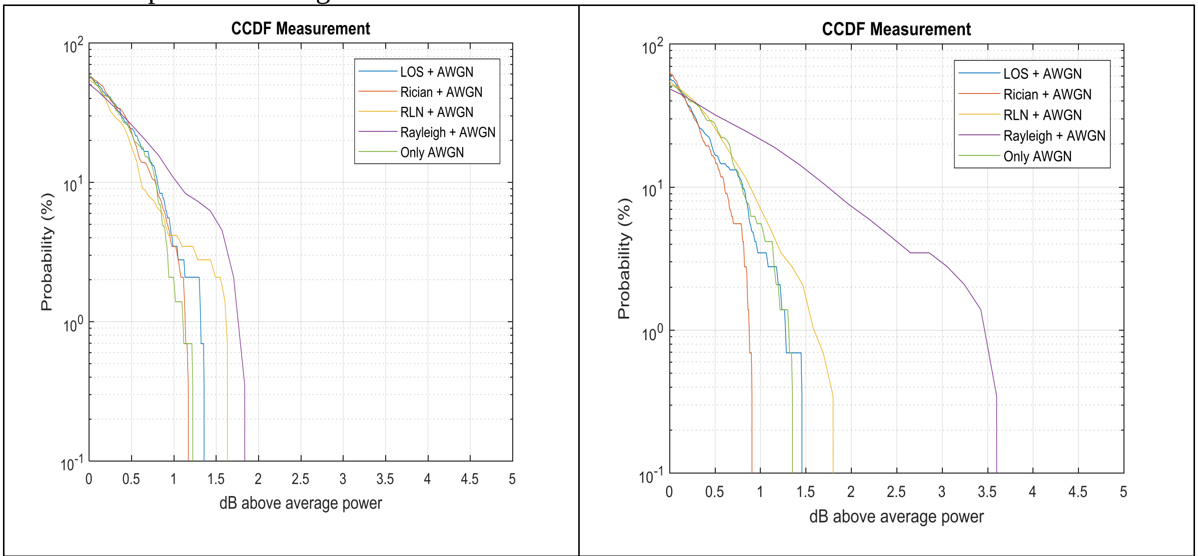
(e) ICI with Roll-OFF = 0.8 | (f) PAPR with Roll-OFF = 0.8

Figure 11. ICI and PAPR for various Roll-off

From figure 11, the shape of the filter affects the system performance through decreasing or increasing the PAPR and ICI values. In figures 11 (a), 11 (c), and 11 (e), the ICI errors decrease with increase of roll-off.

While as seen in figures 11 (b), 11 (d), and 11 (f) the PAPR increases with increase in roll-off. Therefore, the selection of the optimum roll-off is a trade-off between the ICI and PAPR required.

5.6.2. CCDF Measurement. Plotting the CCDF to measure and evaluate the signal amplitude variations as presented in figure 12.

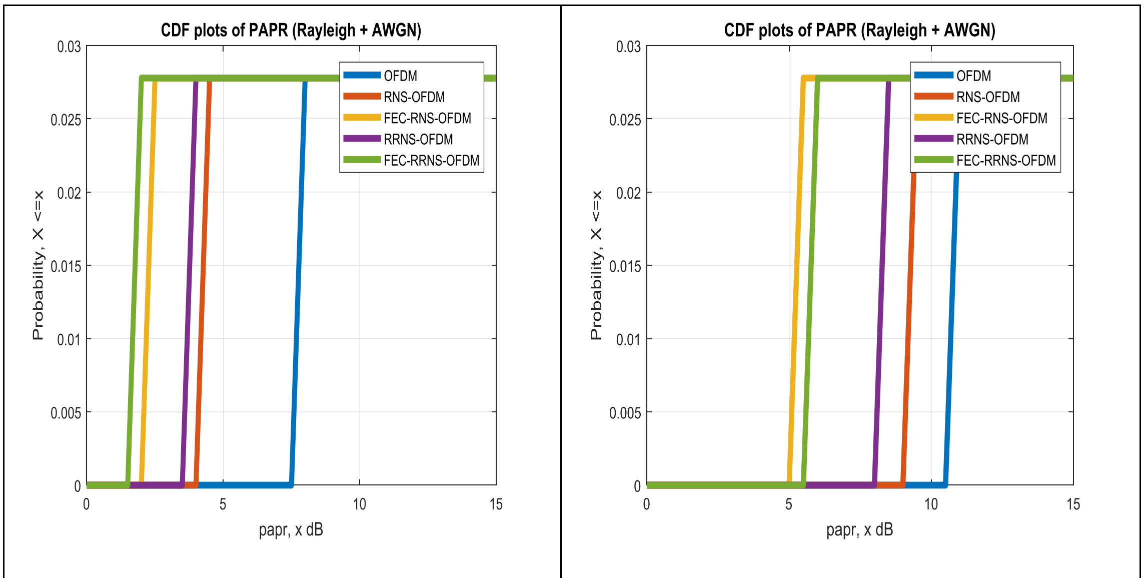


(a) With pulse shaping mitigation | (b) Without pulse shaping mitigation

Figure 12. CCDF Measurements

It figure 12 (a), the CCDF measured for the system with a raised cosine pulse scheme was lower than that foreseen in figure 12 (b) which was measured without a mitigation scheme. This is attributed to the condensation in signal spectrum resulted from RC filter that decrease of the symbol shape.

5.6.3. PAPR measurement. Perform recurrent measurement to evaluate the PAPR of the communication system with and without pulse shaping mitigation scheme as seen in figure 13.

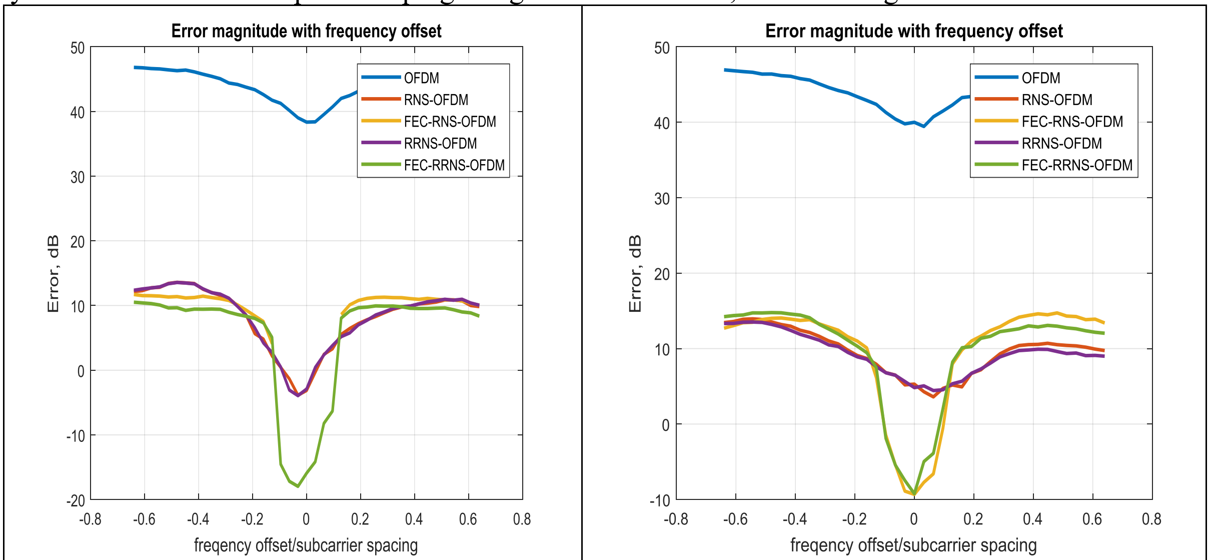


(a) With mitigation scheme	(b) Without mitigation scheme

Figure 13. PAPR Measurements

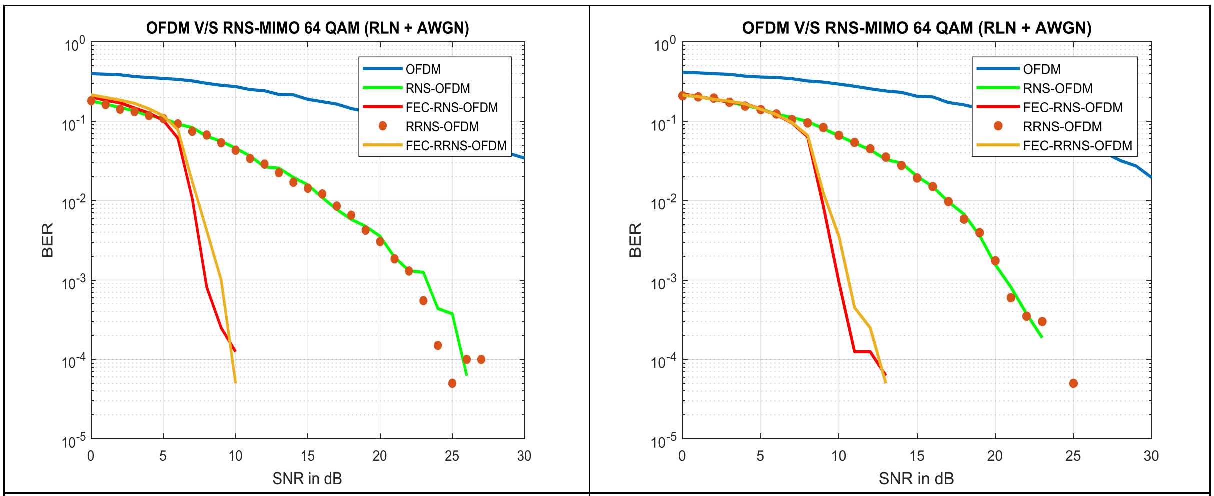
From figures13 (a) and (b), it is shown that reduction in PAPR seen over a Rayleigh fading channel for wireless communication with residue system and error control when using pulse shaping mitigation scheme in comparison to that without the mitigation scheme.

5.6.4. ICI and BER Measurement. Measure the ICI error and overall BER performance for the system with and without pulse shaping mitigation is measured, as seen in figure 14 and 15.



(a) With mitigation scheme	(b) Without mitigation scheme

Figure 14. ICI errors vs. Frequency Offset



(a) BER With pulse shape (b) BER Without pulse shape

Figure 15. BER vs. SNR for RNS coding with/without pulse shaping

It is shown that using the mitigation scheme in figure 14 (a) the ICI reduction using RNS coding is around 40 dB while without mitigation scheme as seen in figure 14 (b) the reduction is only 30 dB. The improved features seen in figure 14 (a) is attributed to the use of pulse shaping scheme as a mitigation technique in the communication system.

Also, the BER performance seen in figure 15 (a) is better than that seen in figure 15 (b). Where, at SNR = 10dB, the BER for the RRNS system with mitigation scheme seen in figure 15 (a) is 10^{-4} while for the same system without mitigation scheme as seen in figure 15 (b) is 10^{-3}. This result is coherent with that obtained in figure 14, indicating the decrease of ICI when implementing mitigation scheme.

5.7. MIMO-RNS-OFDM vs. ICI Reduction Techniques

In this subsection a comparisons of ICI cancelation schemes that are implemented within the MIMO-RNS-OFDM system are studied and analysed as seen in figure 16, to determine the best choice of ICI mitigation techniques that is suitable of RNS coding scheme.

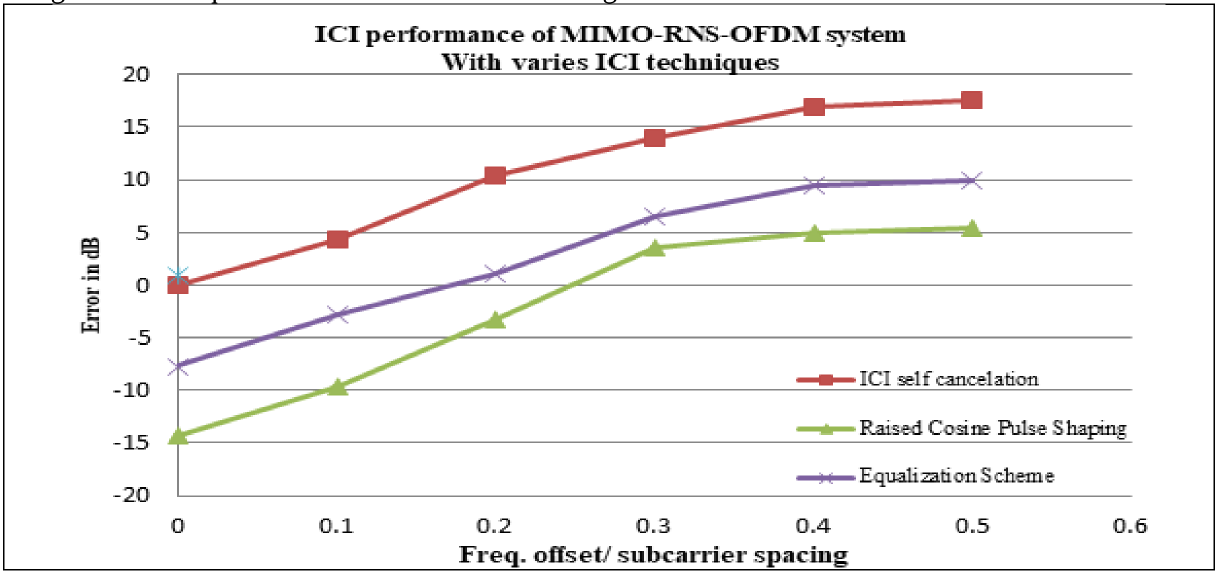


Figure 16 (a). ICI for MIMO-RNS-OFDM with varies mitigation schemes

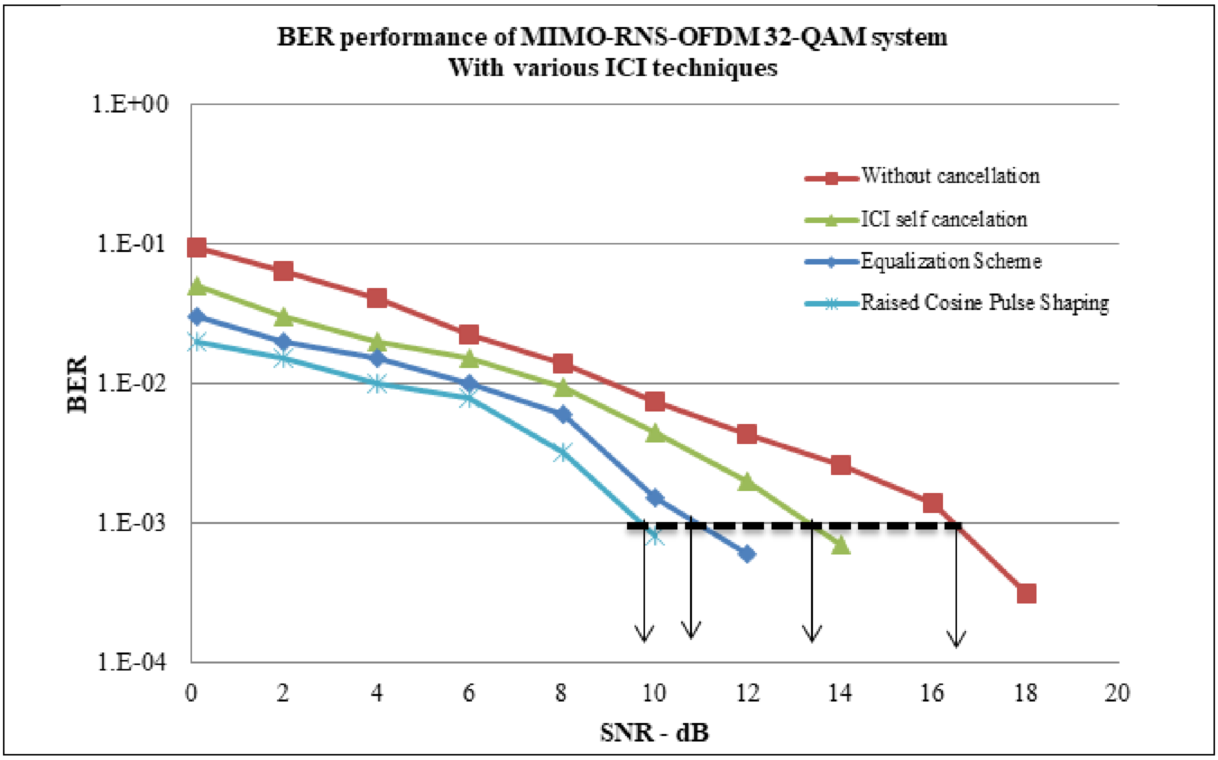


Figure 16 (b). BER for MIMO-RNS-OFDM with various mitigation schemes

From the above figure 16, the equalization considers the channel information and hence gives more accurate results compared to self-cancellation scheme. Windowing/pulse shaping on the other hand would provide the best performance with respect to the other schemes.

The rationale behind this is that conventional technique for ICI Reduction like time domain equalization, self-cancelation, does not properly reduce ICI at the receiver side as through these techniques, ICI reduces only band limited channel which is not the main source of ICI. Where, the main source of ICI is due to frequency mismatch between transmitter and receiver that is corrected and reduced through pulse shaping mitigation method.

6. Conclusion

In this paper, a review for MIMO-OFDM system performance using ICI self-cancelation, pulse shaping, windowing mitigation techniques had been provided and discussed.

An RNS coding insertion in MIMO-OFDM communication system has been proposed, and evaluated with respect to ICI, PAPR and BER performance. The usage of residue system had showed its advantage in improving the communication system features through decreasing the ICI errors, reducing PAPR and improving the BER performance.

The MIMO-OFDM with RNS coding scheme further enhanced through the insertion of ICI mitigation technique in the communication system, where the pulse shaping mitigation scheme had proven its enhanced performance with the residue system over the equalization and self-cancelation schemes; through the recorded improvement in the BER and ICI parameters.

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