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Application of DFT Precoding With Repeated Clipping and Filtering For Minimizing Peak to Average Power Ratio in OFDM System

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Abstract- With the increasing growth of digital wireless communication in recent decades, the demand for high-speed data transmission has grown. OFDM techniques are at present being implemented to sustain the demand for more communication capacity. As a promising system for future wireless broadband communication, MIMO-OFDM has attracted more interest recently. It should be noted that despite the advantages offer by MIMO-OFDM technology, it still suffers from the high fluctuations of the transmitted signal called the peak-to-average power ratio (PAPR). Investigation on the performance of precoding with clipping and filtering technique, for the reduction of PAPR in OFDM signal has been conducted. An algorithm for minimizing PAPR of OFDM signal performance usingDiscrete Fourier Transform (DFT) precoding with repeated clipping and filtering (RCF) was developed and implemented. The developed algorithm was integrated with conventional OFDM system for LTE standard. Simulations were conducted in MATLAB environment to study the effectiveness of the developed algorithm. The result indicated that the introduction of precoder makes the original signal of the OFDM to be equal to 7.557 dB before the application of clipping and filtering for four iterations. Hence, the overall improvement achieved considering the value of PAPR at fourth iteration is 46.91%.

Indexed Terms- LTE Standard, OFDM, PAPR, Precoding, RCF

I. INTRODUCTION

The transmission of signal in wireless communication system makes use of various techniques like Time Division Multiplexing Access (TDMA), Code Division Multiplexing Access (CDMA), Frequency Division Multiplexing Access (FDMA), and Orthogonal Frequency Division Multiplexing (OFDM). In the TDMA process, data is transmitted into time slots such that only one user is allowed to either transmit or receive in each slot. In the CDMA technique, several users may transmit at the same time however a problem of near-far occurs [1]. In the FDMA method, each channel is assigned to individual users, that is, a user is allocated a unique frequency band. On the other hand, the OFDM process uses a multicarrier advance modulation technique to transmit a single data stream over a number of lower rate orthogonal subcarriers.

The OFDM technique is a digital modulation that has been around for about 40 years and was first introduced in 1960s and 1970s. This technique was conceived from research aimed at minimizing interference among channels near each other in frequency [2]. It has been presented as a technique to enable high-speed data transmission over wireless communication links in multi-path networks.

The need for high data rates transmission at high Quality of Service (QoS) in terms of effective utilization of available limited spectrum, has led to the adoption of Multi Input Multi Output (MIMO)-OFDM technology in wireless communication systems [3]. However, with the increasing demand for multimedia services and the growth of internet related activities, there is increasing concern for high speed communications [4]. In order to meet the demand for high speed and reliable communication, MIMO techniques are implemented.

In modern wireless communication systems using MIMO-OFDM technique, a significant improvement in performance for OFDM systems has been observed. There is intensive research in MIMO-OFDM [4]. This paper intends to minimize peak to average power ratio (PARR) in MIMO-OFDM LTE network by precoding the OFDM signal with clipping and filtering algorithm.

II. LITERATURE REVIEW

A. Application of OFDM

Wireless communication technology has been growing from time to time, with the size of system devices reducing, but with increased power processing capability. With advances in wireless communication technology, there has been increasing demand for improved and promising standards. This has brought about the need for improvement in capacity of the available wireless spectrum. Several technologies have been developed to meet customer demands. Long term evaluation (LTE) standard is a promising technology that will offer high data rate and capacity. Long Term Evolution (LTE) system is implemented by using advanced techniques like MIMO, scheduling algorithms etc. on both uplink and downlink to achieve high peak data rates and higher system throughput [5].

OFDM has been adopted by a number of wired and wireless standards. For instance, in asymmetric digital subscriber line (ADSL), digital audio broadcasting (DAB), and Digital Video Broadcasting (DVB), OFDM is the basis for the global standard [6]-[8].OFDM has been adopted as modulation standard for IEEE 802.11a/ n/ ac and HiperLAN/2. The same goes for new generation cellular telecommunications standard LTE / LTE-A. Furthermore, it is being considered as the standard modulation for 5G communication [9] and Internet of Things (IOT) [10] [11].

It offers numerous advantages such selective fading immunity, resilience to inference, efficient utilization of available spectrum, resilient to inter-symbol and inter-frame interference (ISI), resilient to narrow-band effects, and reduction in equalization complexity. However, some drawbacks are associated with the use of OFDM and these include: carrier offset and drift sensitivity, high peak to average power ratio (PAPR), receiver complexity, and demand for complex computation scheme. This has prompted the need for PAPR reduction in OFDM system. The next sub-section considers PAPR reduction techniques.

B. Peak to Average Power Ratio Reduction Techniques

In order to address the impact of PAPR in transmitted signal at the receiving end, many techniques have been proposed in literature. Reduced computational complexity Partial Transmit Sequence (PTS) technique based on firework algorithm (FWA) was proposed by Amhaimar et al [12] and was tested on IEEE 802.11a and 802.16e standards with results obtained outperforming other well-known evolutionary algorithms such simulated annealing (SA), particle swarm optimization (PSO), and genetic algorithm (GA). A technique that combines tone reservation (TR) techniques and phase information of the pilot tones for PAPR reduction such that by combining the dummy symbols and pilot phase information the PAPR of the MIMO-OFDM signals can be effectively reduced was proposed by Manasseh et al. [13]. The fact that the amplitudes of PAPR signals are nonlinearly and non-monotonically increasing was exploited by Anoh et al. [14] to develop a root-based nonlinear companding scheme for the reduction of PAPR in precoded OFDM signals. A variation of repeated clipping and filtering (RCF) and tone reservation/injection techniques for PAPR reduction was carried out by Singh et al [15] and being aware of the possibility of the peak of the time-domain signal re-growing, after the filtering operation, recursive clipping and filtering (RCF) was used to curb both the out-of-band energy and the PAPR. Using repeated clipping and filtering (RCF) and selective mapping (SLM) techniques, Manjula and Muralidhara [16] were able to reduce the PAPR to significant level in OFDM system.A combination of precoding with repeated clipping and filtering (RCF) was used by Dubey and Gupta [17] to carry out PAPR reduction of OFDM signal. Six precoding matrices namely Walsh-Hadamard Transform (WHT), Discrete Cosine Transform (DCT), Zadoff-Chu Matrix Transform (ZCT), Discrete Hartley Transform (DHT), Discrete Fourier Transform (DFT), and Square-root Raised Cosine (SRC), found in the literature were examined by Mounir et al. [18] for PAPR reduction in OFDM system. All precoding matrices, except the one which is based on square-root raised cosine function (SRC), were not effective in terms of BER performance in presence of nonlinear power amplifier (PA), especially in high modulation order schemes such as 6-QAM and 64-QAM. ZCT and DFT precoding matrices were found to have the best PAPR reduction gain among the six (N × N) predefined matrices. Repeated frequency domain filtering and clipping (RFC) was proposed by Devi and Ramprabhu [19] to reduce PAPR of OFDM signal. Reduction of PAPR by using amplitude clipping and filtering was in LTE downlink system was proposed by Haque and Mowla [20]. Infinite Impulse Response (IIR) band pass elliptic filter was used after amplitude clipping to reduce the PAPR.

The study so far shows that the issue of peak-to-average-power ratio (PAPR) is a major challenge in MIMO-OFDM networks. Many approaches and intelligent algorithms have been proposed by various researchers to decrease PAPR and yet improvement in terms of reduced computational complexity occasioned by increase in number of sub-carriers (or sub-blocks) is required.

III. METHODOLOGY

A. PAPR Problem in MIMO-OFDM System

This subsection presents the basic mathematical concept of PAPR. The output waveform of an OFDM system is usually associated with large fluctuations compared to conventional Single Carrier (SC) systems. It therefore means that devices of the system, like power amplifiers, Analogue-to-Digital (A/D) converters, and Digital-to-Analogue (D/A) converters, are to have high linear dynamic ranges. Otherwise, a series interference which is not desirable occurs at any time the amplitude (or peak) signal is driven into the nonlinear region of the devices at the transmit end. The result in this case is high out of band radiation and inter-modulation distortion [21]. Hence, a technique for reducing PAPR is of great importance for OFDM system.

MIMO-OFDM is a generalized case of OFDM systems based on space time block code (STBC) [22][23][12] for two, three, and four antennas. The encoder signal with two transmitting antennas, using Alamouti code and an input signal $X = [X(0), X(1), ..., X(N-1)]$ is given as:

$$\begin{aligned} X_1 &= \left[X(0), -X^*(1), ..., X(N-1), -X^*(N-1)\right]^T \\ X_2 &= \left[X(1), X^*(0), ..., X(N-1), -X^*(N-2)\right]^T \end{aligned} \tag{1}$$

where N is the number of independent modulated and orthogonal subcarriers whose peak (or PAPR) values are large. The signals X_1 and X_2 are transmitted by antennas 1 and 2, respectively.

At each antenna of MIMO-OFDM system, the peak-to-average power ratio (PAPR) is given by:

$$\mathrm{PAPR}\{x_i\} = \frac{\max\left\{|x_i(n)|^2\right\}}{E\left\{|x_i(n)|^2\right\}}, \; 0 \le n \le LN-1, \tag{2}$$

where i = 1, 2… N_T number of transmit antennas and L is the oversampling factor (OF). The time domain signal at each transmit antennas can be presented by:

$$x_i(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k^i e^{(j2\pi nk/LN)} \tag{3}$$

The expression that characterizes the peak power variation of MIMO-OFDM systems is defined as:

$$\mathrm{PAPR}_{\mathrm{MIMO-OFDM}} = \max\{\mathrm{PAPR}(x_i)\}, \tag{4}$$
$$i = 1, ..., N_T$$

B. Probability Distribution Function of PAPR

Using central limit theorem, given a large number of subcarriers in multicarrier signal, the real and imaginary part of sample values in time domain will conform to Gaussian distribution with mean and variance values of 0 and 0.5 respectively. Thus, the amplitude of multicarrier signals follows Rayleigh distribution with zero mean and a variance of N times the variance of one complex sinusoid [24]. The multicarrier signal power value obeys a x^2 distribution with mean of zero and two degree of freedom (2DOF) [21]. The expression for the Cumulative Distribution Function (CDF) is given by:

$$F(Z) = 1 - \exp(-Z) \tag{5}$$

where Z is the independently and identically distributed Rayleigh random variables and F(Z) is the probability density function of Z.

If the sampling values of different sub-channels are assumed to be mutually independent, and that are free of oversampling operation, the Probability Distribution Function (PDF) for PAPR less than a certain threshold value is given by:

$$P(\mathrm{PAPR} < Z) = F(Z)^N = (1-\exp(-Z))^N \tag{6}$$

However, the probability of PAPR exceeding a threshold as measurement index is preferably used in practice to represent the distribution of PAPR. This probability can be defined as Complementary Cumulative Distribution Function (CCDF), and it is mathematically give by:

$$\begin{aligned} P(\mathrm{PAPR} > Z) &= 1 - P(\mathrm{PAPR} \le Z) = 1 - F(z)^N \\ &= 1-(1-\exp(-Z))^N \end{aligned} \tag{7}$$

C. Conventional OFDM System Model

The conventional OFDM system model used in this work is shown in Fig.1. The parameters of the OFDM used in the simulation test are those of LTE network. The performance test of the system was carried out under multipath fading channel compromised by Additive White Gaussian Noise (AWGN).

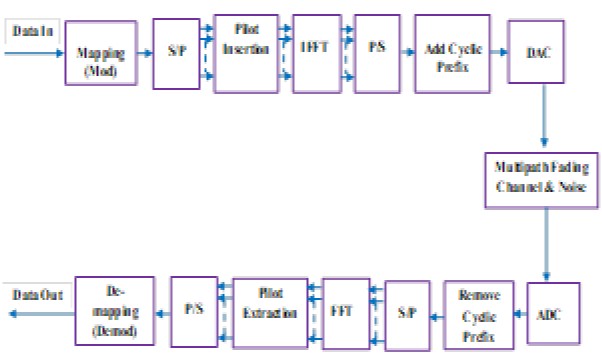

Fig. 1 Conventional OFDM System Model

The block diagram model of OFDM system shown in Fig.1 is such that the first binary data are grouped and mapped into multi-amplitude-multi-phase signals. The pilot carrier insertion is carried out and after that, the modulated $X(k)$ are sent to an Inverse Discrete Fourier Transform (IDFT) or Inverse Fast Fourier Transform (IFFT) block, and then transformed and multiplexed into $x(n)$ [25]:

$$x(n) = \mathrm{IFFT}\{X(k)\} = \sum_{k=0}^{N-1} X(k) e^{j2\pi nk} \tag{8}$$

for $n =$ 0, 1, …, N-1, where N is the number of sub-carriers. The guard interval N_g is inserted to ensure that inter-symbol interference in OFDM system is prevented. The resulting samples with $n = N_g$, $N_g - 1, \ldots, -1$ guard band can be expressed as $x_g(n)$ [25]:

$$x_g(n) = \begin{cases} x(N+n) \\ x(n) \end{cases} \tag{9}$$

$n = 0,1.....,N-1$

where N_g is the number of samples in the guard interval. The transmitted signal is afterward sent to the channel. The received signal is given by [25]:

$$y_g(n) = x_g(n) \otimes h(n) + w(n) \tag{10}$$

where h(n) is the Channel Impulse Response (CIR) and w(n) is the Additive White Gaussian Noise (AWGN) and $\otimes$ is the circular convolution. Having removed the guard interval from Eq. (10), the received samples y(n) are sent to a Fast Fourier Transform (FFT) block to demultiplex the multi-carrier signals [25]:

$$Y(k) = \mathrm{FFT}\{y(n)\} = \frac{1}{N}\sum_{n=0}^{N-1} y(n) e^{-j2\pi kn/N} \tag{11}$$

For $k = 0$, 1, …., N-1.

A. Repeated Clipping and Frequency Domain Filtering

The Repeated Clipping and Frequency Domain Filtering simply referred to as Repeat Clipping and Filtering (RCF) is a signal distortion based scheme. In this technique, the input vector $S_i = s_0, s_1, s_2, \ldots s_{N-1}$ is first transformed using an oversized IFFT, where N is the number of subcarriers in each OFDM symbol. For every L time oversampling, the input vector S_i is extended by adding $N(l-1)$ zeros in the middle of the input vector.

Generally, the clipping and filtering techniqued is carried out iteratively until the amplitude of the OFDM signal is set to a threshold value level to avoid out of band peak and regrowth of peak. Also, in LTE downlink, to reduce PAPR, the RCF is applied to OFDM signal considering different clipping ratio and oversampling factors, and their impact on PAPR and BER are noted. The selection of this technique is due to the fact that the filter improves the BER if the oversampling is high and clipping get rid of PAPR. Figure 2 shows the basic OFDM structure integrating an RCF for PAPR reduction.

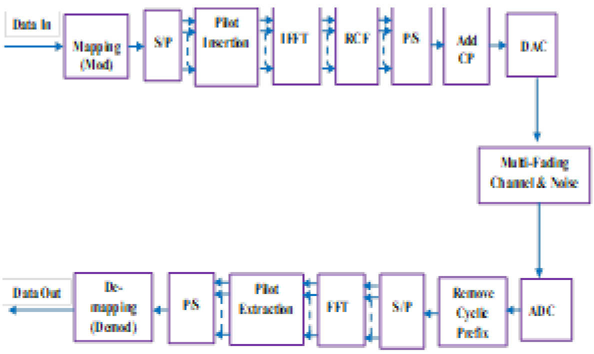

Fig. 2 OFDM system model with RCF for PAPR reduction

D. Repeated Clipping and Filtering with Precoding

The combination of precoding (P) and repeated clipping and filtering (RFC) improves PAPR reduction in OFDM system. First, PAPR reduction is achieved by the precoding process after which the signal is passed to RFC block as shown in Fig. 3. The amplitude, that is the signal strength, is clipped by using clipping technique. However, one of the disadvantages of clipping process is undesirable frequency which can be addressed by applying frequency domain filtering method. On the other hand, filtering method introduces peak re-growth. This problem can be taken care of by using iterated clipping and filtering. In this developed system, Discrete Fourier Transform (DFT) precoding is implemented.

The use of clipping and filtering is a suitable choice in the case of signal distortion (Dubey and Gupta, 2016). The RCF is only applied at the transmit end of the OFDM system PAPR reduction. However, its influence the performance of the received signal at the receive end in terms of BER. As shown in Fig. 3, after precoding, IFFT is applied to N sub-carrier, digital up conversion is used with carrier frequency and RCF process is then applied.

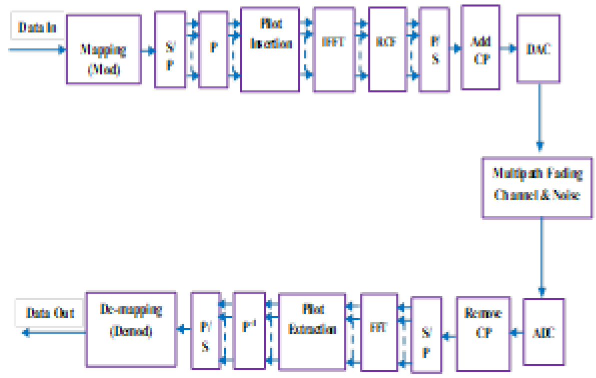

Fig. 3 Precoding with clipping and filtering method for PAPR reduction in OFDM

E. LTE Parameter for Simulation

In order to effectively study the proposed OFDM system model for PAPR reduction, the parameters of the MIMO-OFDM used in this work are that of LTE standard given in Table 1.

Table 1 LTE Simulation Test Parameter

Parameter	Description /value
Modulation	QPSK
FFT Size	256
Spacing	15KHz
Band Width (BW)	1250KHz
Cyclic Prefix (CP)	1/4 of FFT Size
Number of Symbol (nsym)	1×10^3
Sampling Frequency (f_s)	192MHz
Sampling Period (T_s)	192µs
Max. Doppler Frequency Shift (F_{Dmax})	0.01Hz

IV. RESULT S AND DISCUSION

A. Results and Analysis

In this work, extensive simulations were conducted in MATLAB in order to evaluate the performance of conventional OFDM system, OFDM system with repeated clipping and filtering (RCF) technique, precoding with RCF. In order to conduct the simulation test, the RCF with OFDM, and precoded OFDM signal with RCF was studied by selecting clipping ratio (CR) = 3, four iteration process (clipping and filtering, CF1, CF2, CF3, CF4) for effective RCF performance, and oversampling factor (OF), L = 4.

Figure 4 is the simulation result of the conventional OFDM system shown in Fig. 1. In this case, the OFDM simulated assuming no algorithm was included as part of the transmit process. This was done to enable easy understanding of how the system was performing when no technique was included in the transmit end to reduce the effect of PAPR. The value of the PAPR as shown in Fig. 4 is 10.51 dB at CCDF of 10^{-3} and it is taken as the reference value for PAPR of OFDM signal.

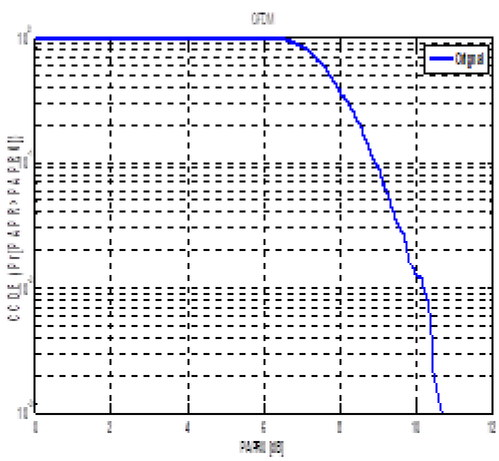

Fig. 4 PAPR of conventional OFDM system model

The simulation performance of PAPR in OFDM system model integrating RCF algorithm is shown in Fig. 5. This was conducted using the block diagram in Fig. 2. The essence of this simulation is to show the effectiveness of the RCF technique when combined alone with OFDM. The performance analysis is shown in Table 2.

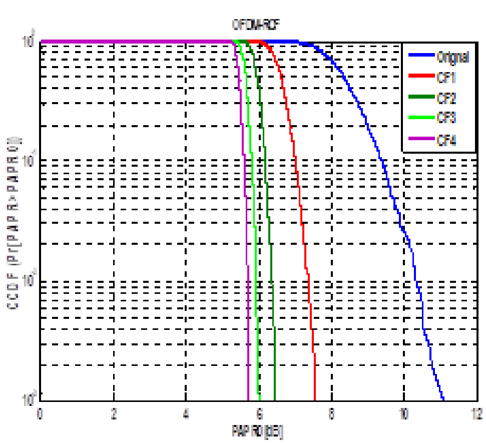

Fig. 5 PAPR of OFDM signal with RCF with four clipping and filtering process

In order to calculate the percentage improvement of PAPR, the reference value is taken as that obtained (10.51 dB) from the conventional OFDM system, that is the model without a technique for PAPR reduction. Hence the calculation is done as follows:

$$\%PAPR_{improvement} = \frac{PAPR_{OFDM\_Without} - PAPR_{OFDM\_With}}{PAPR_{OFDM\_Without}} \times 100 \quad (13)$$

Table 2 Performance analysis of OFDM system model with RCF technique

Parameter	PAPR Value (dB)	Improvement in PAPR value
Original	11.08	-5.42%
One Clipping and Filtering (CF1)	7.557	28%
Two Clipping and Filtering (CF2)	6.46	38.5
Three Clipping and Filtering (CF3)	6.003	42.88%
Four Clipping and Filtering (CF4)	5.739	45.39%

In Fig. 6, the simulation performance of PAPR in OFDM system model with precoding and RCF algorithms is presented. This was conducted using the block diagram in Fig. 3. This simulation is conducted to show the effectiveness of precoding with RCF technique in reducing PAPR in OFDM system model. Table 3 shows the analysis of the simulation result.

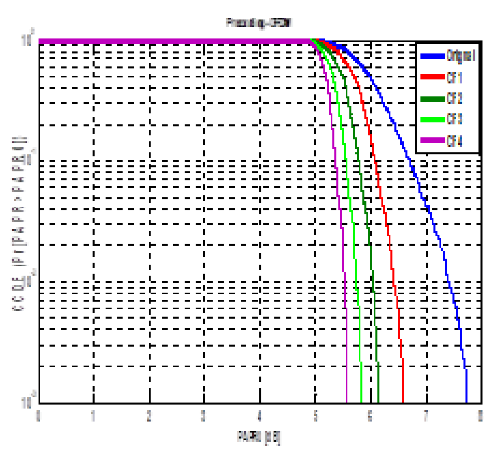

Fig. 6 PAPR of preocded OFDM signal with RCF

Table 3 Performance analysis of precoding with RCF technique

Parameter	PAPR Value (dB)	Improvement in PAPR value
Original	7.557	28%
One Clipping and Filtering (CF1)	6.585	37.3%
Two Clipping and Filtering (CF2)	6.131	41.67%
Three Clipping and Filtering (CF3)	5.821	44.6%
Four Clipping and Filtering (CF4)	5.58	46.91%

A. Discussion

The simulations are carried out for 256 data points with QPSK modulation scheme. The size of the OFDM symbol used is equal to 256. With the computation of Complementary Cumulative Distribution Function (CCDF), this work has examined PAPR performance in OFDM using precoding with RCF.

In Fig. 4 with the simulation of conventional OFDM system model, the value of PAPR at CCDF 10^{-3} is 10.51dB. With the addition of RCF in the OFDM system, the number of iterations is increased from one to four as shown in Fig. 5. It can be seen that the PAPR reduces as the iterations increases for both clipping and filtering (CF). The plot shows that the more the PAPR reduces the CCDF moves toward the origin. Table 4.1 shows that the PAPR is reduced to a value of 5.739dB at the fourth iteration (CF4) which is an improvement of 45.39%.

Figure 6 shows the CCDF performance analysis of precoded OFDM with RCF using QPSK modulation for clipping and filtering (CF) with four iterations. The performance in terms of PAPR improves as the number of iterations increases. It can be seen from Table 2 that the introduction of precoder makes the original signal of the OFDM to be equal to 7.557 dB before the application of clipping and filtering for four iterations. Hence, the overall improvement achieved considering the value of PAPR at fourth iteration is 46.91%.

CONCLUSION

Investigation on the performance of precoding with clipping and filtering technique, for the reduction of PAPR in OFDM signal has been conducted. In carrying out simulations to study and analyse the effectiveness of the proposed algorithm, the modulation scheme used was QPSK and the number of subcarrier N, used was 256. The performance of precoding with clipping and filtering technique considering oversampling factor (OF) of 4 and 4 clipping and filtering iterations using the QPSK modulation scheme of LTE network has been analysed. Simulation results have shown that PAPR reduces more on using the proposed scheme by ensuring that an improved PAPR reduction was achieved. System and time delay were obtained. The system has been fully designed and analysed using MATLAB Software. Results from the simulations showed that the compensator effectively compensates for the time delay and improved general characteristics of dish antenna response within the network.

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