IQI Problem in Discrete Sine Transform Based FDMA Systems

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Abstract: - In this paper, in-phase and quadrature-phase imbalances (IQI) problem in the recent discrete sine transform based Orthogonal frequency division multiple access (DST-OFDMA) and discrete sine transform based single-carrier frequency division multiple access (DST-SC-FDMA) is investigated and compensated. IQI problem is investigated in three scenarios, transmitter IQI scenario (TX IQI scenario), receiver IQI scenario (RX IQI scenario) and transmitter- receiver IQI scenario (TX-RX IQI scenario), with different subcarriers mapping for both FDMA systems. The simulation results show that the mismatch in the phase and amplitude between the two branches of local oscillator in the receiver scenario introduces a significant performance degradation of the both FDMA systems more than transmitter scenario. Thereby, a correction scheme is proposed in this paper in the RX IQI scenario to face the degradation in the performance.

Key-Words: - IQI, DCR, DST-OFDMA, DST-SC-FDMA.

1. Introduction

In the past few years, Orthogonal Frequency Division Multiple Access (OFDMA) system has gained more attention for its robustness to multipath fading and reducing inter symbol interference (ISI) of wideband wireless channels. Currently, it is used in wireless LAN, broadband wireless access. Thus, it has been chosen as a downlink transmission technique not uplink in third generation partnership project long-term evaluation (3GPP LTE) standards [1].However, OFDMA system has drawbacks such as high peak-to-average power ratio (PAPR) and carrier frequency offset (CFO) [2]. Recently, single-carrier frequency division multiple access (SC-FDMA) technique has received a lot of attention for its advantages [3].The main advantages of SC-FDMA system are the low PAPR and low sensitivity to CFO [1]. These advantages motivate the manufacturers to introduce this system in the uplink of LTE and LTE advanced. Beside the aforementioned impairments, the IQI induces further degradation when the direct conversion receiver (DCR) is used.

The implementation of OFDMA and SC-FDMA based physical layers experience IQI in the front-end analog processing [4,5]. A low-cost implementation of such physical layers is required in view of mass deployment, but challenging due to defects associated with the analog components, IQI. The incompleteness of quadrature causing the signal deterioration frequently generates amplitude and phase imbalances between an In-phase and Quadrature-phase components. The amplitude and phase imbalances are generated because the respective elements' insulation and signal generation do not provide a complete 90-degree phase and the same amplitude between the two branches of the local oscillator. In [5, 6], It is shown that the IQI can cause a serious intercarrier interference (ICI) and multiple access interference (MAI) in FDMA systems. IQI can severely limit the achievable operating signal-to-noise ratio (SNR) at the receiver and increase the number of bit errors for a given data rate. IQI problem is studied widely in the literature. The transmitter IQ in the OFDMA system is presented in [7]. In [4], the TX IQI imbalance is analyzed and compensated in the uplink of the OFDMA and SC-FDMA systems. Different correction schemes are proposed to compensate the IQI problem in the multicarrier discrete Fourier transform (DFT) systems, OFDMA and FDMA [7,8]. The authors in [9] propose estimation technique to remove the phase noise and IQ-imbalance problem in the multiple input multiple output (MIMO) OFDMA. However, the IQI problem in the recent discrete sine transform OFDMA (DST-OFDMA) and discrete sine transform SC-FDMA (DST-SC-FDMA) is not studied in the literature so far. This motivates us to study this problem in the recent DST based FDMA systems. There are various methods available to map the subcarriers in the FDMA systems. The commonly used methods are Interleaved FDMA (IFDMA) and Localized FDMA (LFDMA). In IFDMA, the symbol of the first user is sent followed by the symbol of the second user and so on till the last user with equal distance between symbols. In LFDMA, the whole symbols of the user are sent sequentially. [2].The localized DST-OFDMA and DST-SC-FDMA are indicated as DST-LOFDMA and DST-SC-LFDMA, respectively. Similarity, the interleaved DST-OFDMA and DST-SC-FDMA are indicated as DST-IOFDMA and DST-SC-IFDMA, respectively.

Our contribution in this work is to study the IQI problem in the recent DST-OFDMA and DST-SC-FDMA systems with three scenarios, TX IQI, RX IQI and TX-RX IQI. Moreover, our investigation takes into account the impacts of the mismatching in the amplitude and phase simultaneously. An efficient correction scheme to compensate the effect of the RX IQI problem in the recent DST systems is introduced.

The simulation results show that the IQI causes considerable degradation of the performance of the DST based FDMA systems especially with the RX IQI and TX-RX IQI scenarios. Vectors and matrixes are indicated in bold and scalar parameters in normal font. The remainder of this paper is organized as follows: Section 2 introduces IQI problem in DST-OFDMA system. Section 3 describes the IQI problem in DST-SC-FDMA system. The correction scheme in the RX IQI scenario is presented in section 4. Simulation results are shown in Section 5. Finally, Section 6 concludes the paper.

2. IQI Problem in DST-OFDMA System

In this section, the recent DST-OFDMA system is studied in the presence IQI problem. For more details about the DST-OFDMA system see the [2].The transceiver block diagram of the DST-OFDMA system with the TX IQI and RX IQI imbalance scenarios is shown in Fig.1. The system supports U users. After modulation process, The complex symbols stream are passed through a serial-to-parallel converter whose output is a set of N parallel QPSK or 16QAM complex symbols.

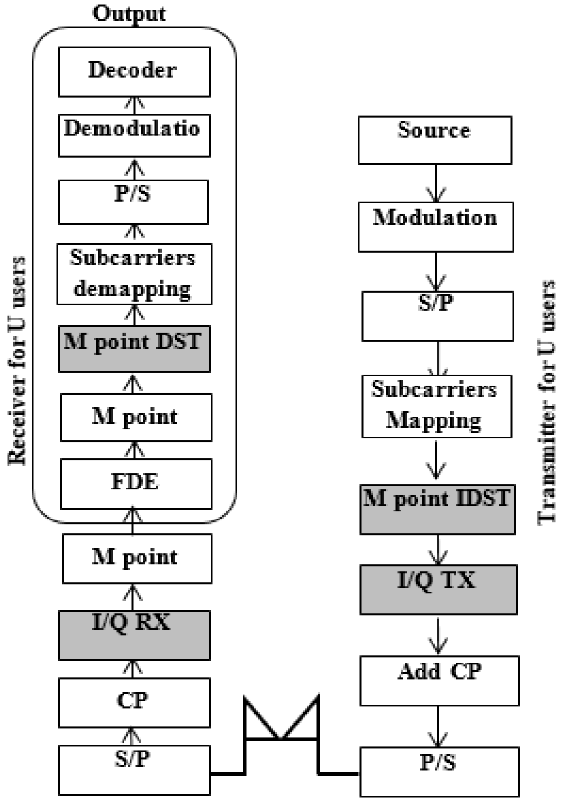

Fig.1: Transceiver structure of the DST-OFDMA system with TX-RX IQI scenario

The M symbols are produced by subcarriers mapping block and IDST is applied and the transmitted signal is expressed as follows:

$$\bar{\bar{\mathbf{x}}}_{\mathbf{u}}\mathbf{P}\ \mathbf{S}_{\mathbf{M}}^{-1} \coprod{}_{\mathbf{T}}^{\mathbf{u}}\ \bar{\mathbf{x}}_{\mathbf{u}} \quad (1)$$

where $\bar{\mathbf{x}}_{\mathbf{u}}$ is a vector N×1 of symbols of a user. $\mathbf{S}_{\mathbf{M}}^{-1}$ is an M×M inverse DST (IDST) matrix. $\coprod{}_{\mathbf{T}}^{\mathbf{u}}$ is an M × N matrix describing the subcarriers mapping of the U users. M = Z ⋅N, where Z is the number of users in the system. P is an (M+ L) ×M matrix, which adds a CP of length L. The CP is added to the head of the transmitted signal to prevent inter block interference (IBI) and in the same time make the linear convolution as a circular convolution [1]. Then the TX IQI is added to the transmitted signal as follows [5]:

$$\boldsymbol{x}_{\boldsymbol{u}} = \alpha_{\mathrm{u}}\bar{\bar{\boldsymbol{x}}}_{\boldsymbol{u}} + \beta_{\mathrm{u}}\bar{\bar{\boldsymbol{x}}}_{\boldsymbol{u}}{}^{*} \quad (2)$$

where $\bar{\bar{\boldsymbol{x}}}_{\boldsymbol{u}}{}^{*}$ is the conjugate of $\bar{\bar{\boldsymbol{x}}}_{\boldsymbol{u}}$ .The two complex scalars α_{u} and β_{u} are given by (3) and (4), respectively.

$$\alpha_{\mathrm{u}} = \cos\emptyset_{\mathrm{u}} + j\varepsilon_{\mathrm{u}}\sin\emptyset_{\mathrm{u}} \quad (3)$$

$$\beta_u = \varepsilon_u \cos\emptyset_u - j\sin\emptyset_u \quad (4)$$

where $\boldsymbol{\varepsilon_u}$ and $\boldsymbol{\emptyset_u}$ are the amplitude and phase imbalances between I and Q branches of the transmitted signal of the U user, respectively. When the $\varepsilon_u = 0$ and $\emptyset_u = 0$, then $\alpha_u = 1$ and $\beta_u = 0$ and this means that there is no mismatch between amplitude and phase. The received signal at the receiver side after remove CP is given by

$$\mathbf{r} = \sum_{\mathbf{u=1}}^{\mathbf{U}} \mathbf{H_c^u}\, \mathbf{x_u} + \mathbf{n} \quad (5)$$

where **r** is a base station received signal of vector M×1. $\mathbf{H_c^u}$ is an M × M multipath channels between the user and the base station. **n** is a vector of size M × 1 describing the noise. The RX IQI problem distorts the ideal received signal as follows:

$$\overline{\boldsymbol{r}} = \alpha\boldsymbol{r} + \beta\boldsymbol{r}^* \quad (6)$$

The signal after applying the DFT can be expressed as follows:

$$\mathbf{R} = \sum_{\mathbf{u=1}}^{\mathbf{U}} \mathbf{D^u}\, \boldsymbol{\mathcal{F}_M} \left(\alpha_u \overline{\overline{\boldsymbol{X}}}_{\boldsymbol{u}} + \beta_u \overline{\overline{\boldsymbol{X}}}_{\boldsymbol{u}}^{\,*}\right) + \mathbf{N} \quad (7)$$

where $\mathbf{D^u}$ is an M × M diagonal matrix containing the DFT of H_C^u. $\overline{\overline{\mathbf{X}}}_{\mathbf{u}}$, $\overline{\overline{\boldsymbol{X}}}_{\boldsymbol{u}}^{\,*}$ and **N** are the DFT of $\overline{\overline{\mathbf{x}}}_{\mathbf{u}}$,$\overline{\overline{\boldsymbol{x}}}_{\boldsymbol{u}}^{\,*}$ and **n**, respectively. $\boldsymbol{\mathcal{F}_M}$ is a DFT matrix of size M × M. The estimation of the modulated symbols will be deduced after the FDE, the M-points IDFT, M-point DST and the DST-OFDMA demodulation operations as follows:

$$\overleftrightarrow{\mathbf{X}}_{\mathbf{u}} = \coprod\nolimits_{\mathbf{R}}^{\mathbf{u}}\ \mathbf{S_M}\ \boldsymbol{\mathcal{F}}_{\mathbf{M}}^{-1}\, \mathbf{E_u}\, \mathbf{R} \quad (8)$$

where $\mathbf{E_u}$ is the M × M FDE matrix of U users. $\coprod_{\mathbf{R}}^{\mathbf{u}}$ is the N × M subcarrier demapper matrix of the U users. $\mathbf{S_M}$ is an M×M DST matrix . $\boldsymbol{\mathcal{F}}_{\mathbf{M}}^{-1}$ **is a** M × M inverse DFT(IDFT) matrix. The separate detection is performed for each user.

2. IQI Problem in DST-SC-FDMA System

DST-SC-FDMA system is presented recently to improve the conventional DFT-SC-FDMA system. More details about this system are presented in [10]. Fig.2 depicts the transceiver structure of the DST-SC-FDMA system with IQI problem. The system works with U users and each user has N subcarriers. The bits stream is modulated using one of the modulation formats to generate the complex symbols. These symbols are fed to N-point DST and then mapped to M subcarriers of assigned sub channels by using one of the subcarriers mapping techniques. Then the signal is applied to M-point inverse DST (IDST) block return it to the time domain. The transmitted signal of the U users is given by

$$\overline{\overline{\mathbf{x}}}_{\mathbf{u}} = \mathbf{P}\, \mathbf{S_M^{-1}} \coprod\nolimits_{\mathbf{T}}^{\mathbf{u}}\ \mathbf{S_N}\, \overline{\mathrm{x}}_u \quad (9)$$

where $\mathbf{S_N}$ is N×N DST matrix .The TX I/Q imbalance problem distorts the ideal transmitted signal as in (2). The received signal at the receiver side after DFT is given in (7).

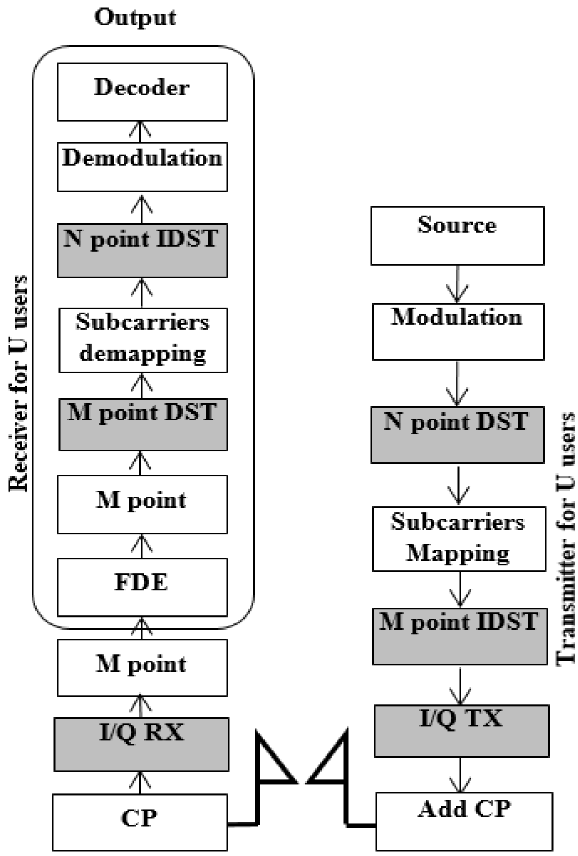

Fig.2: Transceiver structure of the DST-SC-FDMA system with TX-RX IQI scenario

After which, the frequency domain equalization (FDE), and the IDFT operations are performed to feed M-point DST, followed by the Subcarriers demapping and the IDST operations are performed to provide the estimate of the modulated symbols as follows:

$$\overleftrightarrow{\mathbf{X}}_{\mathbf{u}} = \mathbf{S_N^{-1}} \coprod\nolimits_{\mathbf{R}}^{\mathbf{u}}\ \mathbf{S_M}\ \boldsymbol{\mathcal{F}}_{\mathbf{M}}^{-1}\, \mathbf{E_u}\, \mathbf{R} \quad (10)$$

The received signal in frequency domain **R** includes the IQI mismatching. At last, the demodulation and the decoding processes are performed.

3. Correction Scheme in the RX IQ Scenario for Both DST Based FDMA Systems

DCR is widely used physical layers receiver. A low-cost implementation of such receiver is required in view of mass deployment, but challenging due to defects associated with the IQI. The effects of this problem lead researchers to compensate this effect. The correction of IQI problem in the DFT based OFDMA and SC-FDMA systems is extensity studied in the literature [7-9,11]. The IQI issue is studied and compensated in the improved discrete cosine transform based SC-FDMA (DCT-SC-FDMA) system and compared to conventional DFT-SC-FDMA system [5]. The best of our knowledge, the IQI is not studied corrected in the recent DST systems. In this section we introduce correction scheme that used to compensate the effects of the IQI in the DCR. As the simulation results show, the effect of RX IQI scenario is very clear on the performance of the both recent systems and this motivates us to introduce a correction scheme in the RX IQI scenario. This scheme is modified of the correction scheme in [12]. We formulate the $\mathcal{C}$ from IQI parameters as follows:

$$\mathcal{C} = \frac{\beta}{\alpha^*} \tag{11}$$

Where the $\mathcal{C}$ is the correction parameter and the estimation of received signal $\bar{\boldsymbol{r}}$ is given by

$$\tilde{\boldsymbol{r}} = \alpha^*\boldsymbol{r} - \beta\boldsymbol{r}^* \tag{12}$$

The correction of the IQI is given by

$$\boldsymbol{r} = \frac{\alpha^*\boldsymbol{r} - \beta\boldsymbol{r}^*}{|\alpha^*|^2 + |\beta|^2} \tag{13}$$

From (13), the $\mathcal{C}\boldsymbol{r}$ vector can be written as follows:

$$\mathcal{C}\boldsymbol{r} = \frac{\boldsymbol{r} + \mathcal{C}\boldsymbol{r}^*}{1 - |\mathcal{C}|^2} \tag{14}$$

The values of β and α^* must be known in the receiver. If this condition is found, $\mathcal{C}$ is known at the receiver, the (14) is utilized to correct the effect of the IQI in the receiver said. The rest of the receiver process are performed to estimate the IQI corrected signal at the end of the receiver.

4. Simulation Results

This section introduces the effects of the IQI problem on the DST based FDMA systems by using computer simulation only. The simulation parameters that is used to simulate the DST-OFDMA and DST-SC-FDMA systems are shown in Table 1. 10^4 iterations are used to simulate three IQI scenarios

In the following subsections we study the effect of the IQI problem on the DST based FDMA systems with three TX IQI, RX IQI and TX-RX IQI scenarios.

Table 1: Simulation parameters

parameter	characterization
Simulation method	Monte Carlo
Bandwidth	5 MHz
Modulation	QPSK
L	20 samples
M	512
N	128
Number of users	M/N=4
Subcarriers spacing	9.765625 KHz
Coding Method	Convolutional code with rate=1/2
Subcarriers mapping	Localize and interleaved
Channel model	Vehicular A outdoor channel
Equalization	MMSE
IQI scenarios	TX IQI,.RX IQI and TX-RX IQI

5.1 Impact of the TX IQI Scenario on the DST Based FDMA Systems

Figs 3 and 4 present the performance of DST-SC-FDMA and DST-OFDMA systems with the TX IQI scenario .It can be seen that the performance of the systems declines with an increase of both amplitude ε_u and phase $\emptyset_u$ values, especially with the interleaved subcarriers mapping. At zero mismatch, the performance of DST-SC-FDMA is better than DST-OFDMA systems, especially with interleaved subcarriers mapping. From zero to the moderate values of both amplitude and phase the performance remains nearly stable for both systems , but from middle to high values the BER rise dramatically especially with amplitude mismatching. It is noticeable also that the performance of the DST-SC-LFDMA and DST-LOFDMA systems remains nearly constant with increase the mismatching in the amplitude and phase. In other words, the localized of two systems is insensitive to the TX I/Q imbalance scenario. In general, the both systems have the same trend for the both interleaved and localized subcarriers mapping.

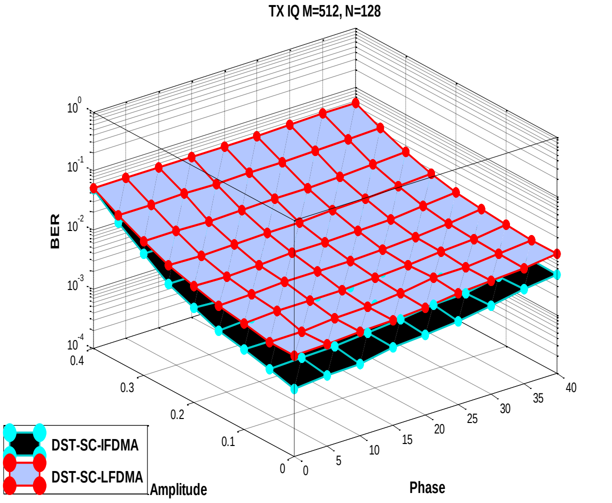

Fig.3: BER against amplitude and Phase of DST-SC-IFDMA and DST-SC-LFDMA systems with TX IQI scenario.

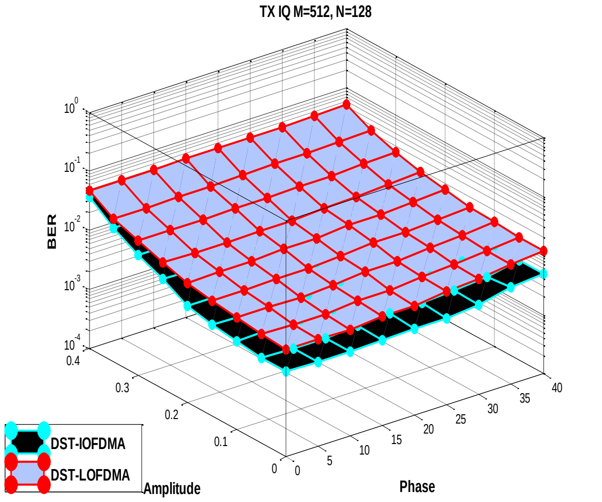

Fig.4: BER against Amplitude and Phase of DST-IOFDMA and DST-LOFDMA systems with TX IQI scenario.

4.2.Impact of the RX IQI Scenario on the DST Based FDMA Systems

Figs 5 and 6 show the effects of the RX IQI scenario on the performance of the DST-SC-FDMA and DST-OFDMA systems for different subcarriers mapping and QPSK modulation format. The figures show seriously drop in the performance of the both systems at high values of the amplitude ε_u and phase $\emptyset_u$, especially with the DST-SC-FDMA system. At no mismatch, the interleaved subcarriers mapping of the two systems provides low BER values, but for the localized subcarriers mapping the BER values are much more. From zero to moderate values of both amplitude and phase, a little increase in the BER is obvious for both systems while the substantial rise occurs from moderate to high values. It is clear that the effects of the RX IQI scenario on the performance of the DST-based FDMA systems are greater that of the TX IQI scenario due to the effect of multipath and noise and the impact of the RX I/Q imbalance scenario on the DST-SC-FDMA systems is greater than that on the DST-OFDMA system

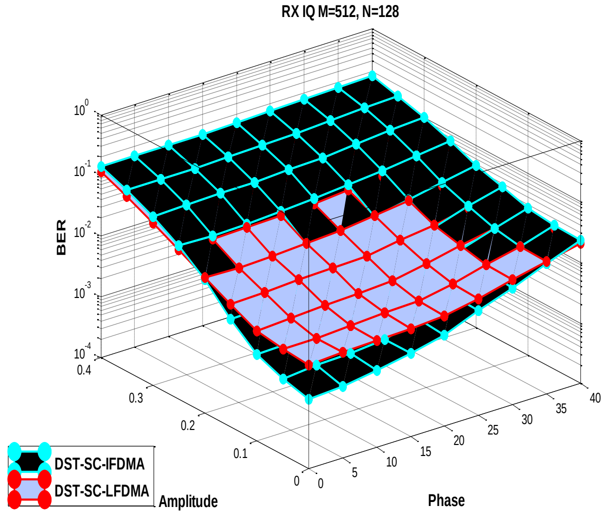

Fig.5: BER against Amplitude and Phase of DST-SC-IFDMA and DST-SC-LFDMA systems with RX IQI scenario.

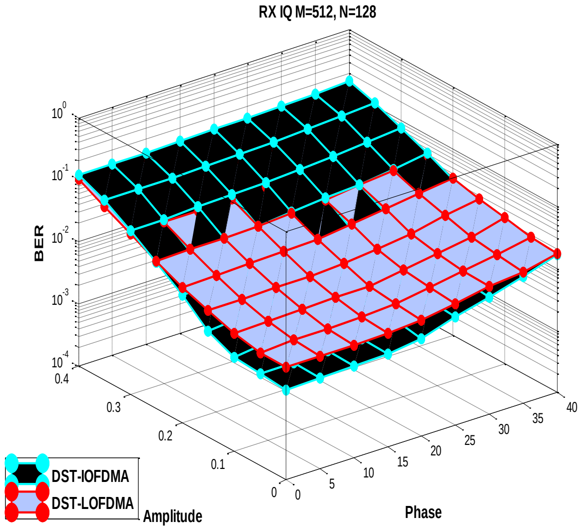

Fig.6: BER against Amplitude and Phase of DST-IOFDMA and DST-LOFDMA systems with RX IQI scenario.

4.3.Impact of the TX-RX IQI Scenario on the DST Based FDMA Systems

The impact of the TX-RX IQI scenario on the performance of the DST-SC-FDMA and DST-OFDMA systems for different subcarriers mapping is investigated in the figs 7 and 8, respectively.

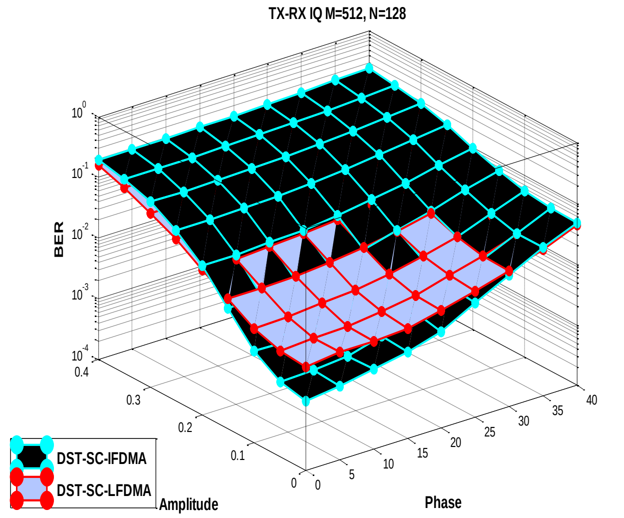

Fig.7: BER against Amplitude and Phase of DST-SC-IFDMA and the DST-SC-LFDMA systems with TX-RX IQI scenario.

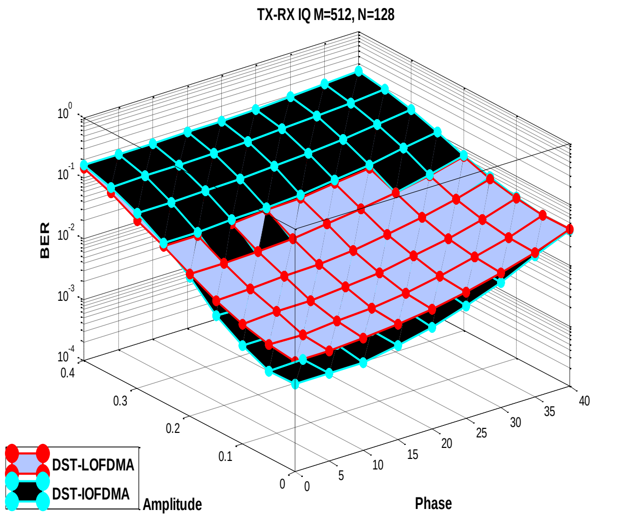

Fig.8: BER against Amplitude and Phase of DST-IOFDMA and the DST-LOFDMA systems with TX-RX IQI scenario

The figs show considerable degradation in the performance of both systems at high values of the amplitude and phase, especially with interleaved subcarriers mapping. It can be seen that the impact of the TX-RX IQI scenario on the DST-SC-FDMA system is greater than that on the DST-OFDMA system. In general, from figs 3 through 8, the effect of the TX-RX IQI scenario on the performance of the both systems is the highest when compared to TX IQI and RX IQI scenarios. Generally, the DST-OFDMA system provides the best achievement in the presence of the I/Q imbalance for all three scenarios.

4.4. Correction Scheme

In this subsection, the correction scheme is applied to the both systems with RX IQI scenario.

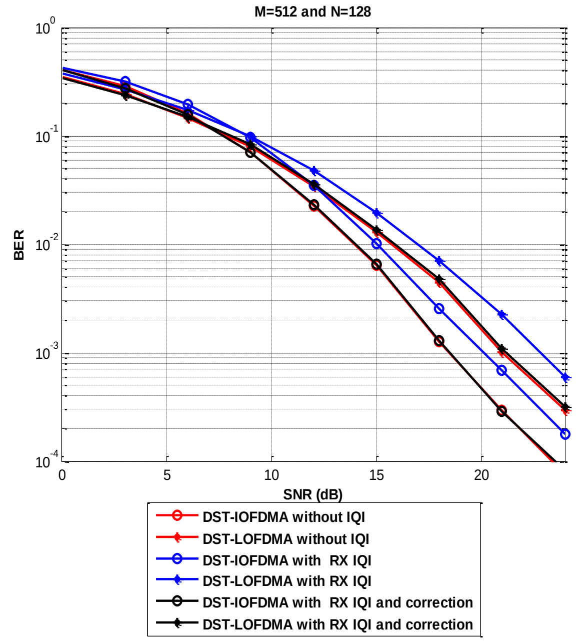

Fig.9: BER against SNR for DST–OFDMA system with RX IQI correction scheme

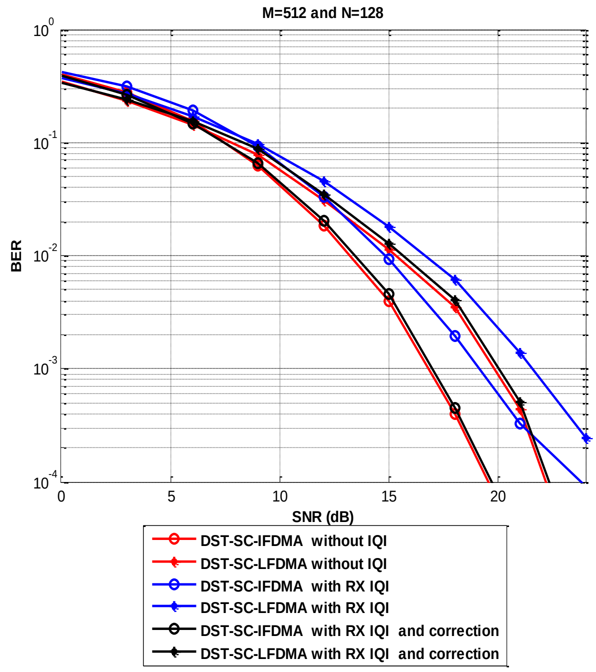

Fig.10: BER against SNR for DST-SC-FDMA system with RX IQI correction scheme

Figs 9 and 10 depict the performance of the DST–OFDMA and DST-SC-FDMA systems, respectively with RX IQI correction scheme and different subcarriers mapping. It can be noticeable that the proposed correction scheme is roughly cancelled the impacts of the RX IQI scenario. When the correction scheme is applied the performance of the systems acts as free RX IQI problem.

5. Conclusion

The problem of IQI in the DST-OFDMA and DST-SC-FDMA systems is studied for three scenarios and different subcarriers mapping. The investigation shows that the IQI problem causes tremendous degradation in the performance of the both systems. The TX-RX IQI scenario distorts the performance of the systems more than the other scenarios due to the effect of multipath and noise of the link. Moreover, the impact of the IQI problem on the performance of the DST-SC-FDMA system is more than that on the performance of the DST-OFDMA system. it is noticeable that IQI problem is effected more on interleaved subcarriers mapping and the impact of the amplitude mismatching is more than the impact of the phase mismatching in the three scenarios. The proposed correction scheme is roughly cancelled the impacts of the RX IQI scenario in the both FDMA systems.

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