CrossMark

Efficient MAI Cancellation Scheme in MC-DS-CDMA Using SIC

A. K. Gnanasekar[1] ⬤ · **V. Nagarajan[1]**

Abstract As of late, the group of multi carrier direct sequence code division multiple access (MC-DS-CDMA) transmission technologies has drawn a considerable measure of consideration in giving broadband wireless communication services. It stands as a promising procedure to help multiple clients with secured high speed wireless communications. In any case, the limit of the MC-DS-CDMA is restricted via multiple access interference (MAI) as of different clients and furthermore it influences the CDMA frameworks performance. To beat such disadvantage, a proficient wireless transmission plot that mitigates the MAI for dual tree complex wavelet transform centered MC-DS-CDMA frameworks is proposed by this given paper. In the proposed conspire, total mean square error equalizer is utilized to presents the initial appraisal of clients' data and the successive interference cancellation plot is after that utilized to regenerate and call off the MAI from the desired client. In this proposed scheme, MAI is revived; subsequently as of the signal that was received it is subtracted in time domain ahead of equalization. The proposed system successfully maintains a deliberate distance from the MAI and also enhances the limit is revealed in experimental outcomes.

Keywords Wireless communication · Multiple access interference · Dual tree complex wavelet transform · Peak signal to noise ratio · Mean square error

✉ A. K. Gnanasekar
   kgnanshek@gmail.com

   V. Nagarajan
   nagarajanece31@gmail.com

1   Department of Electronics and Communication Engineering, Adhiparasakthi Engineering College, Melmaruvathur, India

1 Introduction

In the modern globe, the requirement of individuals to convey and get associated with one another is expanding gradually. Thus a wireless communication system's limit has become vital. This issue can be settled with multiple access schemes' utilization that productively uses the constrained radio range [1]. The FDMA and also TDMA, utilized through the 1G/2G technology are constrained in either frequency or else time. Consequently, the number of clients which can be suited is restricted. The CDMA technology utilized by the 2G/3G technology allocates a pseudorandom code to every client rather than frequency and also time slots. Consequently the limit offered by this framework is enhanced than those frameworks [2]. In 2G and also 3G wireless mobile systems, CDMA framework was regarded as fundamentally alluring multiple access systems. This is intended for the principle reason that the framework stands as a proficient way to handle battle channel fading and also a variety of sorts of narrowband obstruction in multiple-access situations [3].

CDMA is equipped for offering a 384 kbps of maximum data rate. The present necessity for data range for exponentially expanded clients is around 2–10 Mbps [4]. By regarding the CDMA along with OFDMs properties, a hybrid multiple access system is proposed. This procedure is called MC-CDMA. It acquires the upsides of both [5]. It is otherwise called OFDM stand as a multi-client multi-carrier data communication method wherein various clients can get to a channel all the while and non-concurrently, utilizing all around stated spreading sequences [6]. In a multicarrier communication, serious MAI and ISI emerge due to multiuser multipath propagation when the channel delay surpasses the time of a symbol [7]. In general, a major problem with the interference cancellers is the maintenance of simplicity. Parallel interference cancellation and successive (serial) interference cancellation are the popular interference cancellation schemes. The serial structure is simple and robust when compared to parallel interference cancellation scheme. Successive interference cancellation (SIC) is a multi-user detection technique that uses the structured nature of interference to decode multiple concurrent transmissions. Consequently, the multicarrier framework's limit is constrained. It stands as a multicarrier multiplexing technique, which has a high spectral efficiency, is safe against frequency-selective fading impacts and furnishes data transmission with high bit rate. Notwithstanding giving fast data transmission, another vital advantage of this strategy is it permits multiuser access contrasted with other multiplexing strategies [8].

The most imperative kinds of multicarrier framework is called MC-DS-CDMA framework, which has the data sequence multiplied by means of a spreading succession of modulating disjoint multiple carriers [9]. In contraction with the other multicarrier plans without utilizing DS spreading, it utilizes a high quantity of degrees of opportunity aimed at high-adaptability outline and reconfiguration [10]. It is outstanding that, inferable from the work of DS spreading, it can utilize an altogether brought down quantity of subcarriers than the multicarrier plans, which don't utilize DS spreading. Besides, it utilizes the adaptability to design its quantity of subcarriers as per the wireless channels' frequency-selectivity, with the goal that each subcarrier encounters independent fading [11]. With the guide of DS spreading, it can utilize a

noteworthy lower quantity of subcarriers and, henceforth, can relieve the PAPR issue [10].

Problem Statement:

- MAI that occurs due to multiple access delays.
- Limited capacity.

Objective:

- To propose a proficient wireless transmission scheme for dual tree complex wavelet transform based MC-DS-CDMA (DTCWT-MC-DS-CDMA) systems.
- To mitigate MAI using SIC.

2 Literature Survey

Hossein and Ahmad [12] projected to implement proportional fairness like an anti-jamming strategy when the downlink of a solitary cell MC-CDMA network was the jamming target. They required the BS to implement proportional fairness on its transmissions to consumers in the jammer presence. Interactions betwixt the BS and the jammer were designed by a non-cooperative zero-sum generalized game. The game was unraveled through quasi-variational inequality (QVI) and ideal strategies (transmit power levels) were acquired in closed structures, which were not as water-filling formula. Furthermore, they likewise proposed another gradient-cenetered algorithm to unravel the QVI, demonstrated its convergence, and got the ideal systems. The suggested technique expanded the SINR of high-priority clients and diminished the SINR of different clients to the acceptable level to implement the fairness amongst each users was established from the Experimental results. That expanded the transmission rate of the top-priority clients and diminished that of alternate clients. Though this model achieved proportional fairness among all the users, the proposed algorithm is quite complex.

Li et al. [13] proposed a MC-CDMA downlink communication, in which usual sparse signatures were conveyed on frequency domain. Picking the symbol discovery perspective, they defined an issue proper aimed at downlink with discrete alphabets as their inputs. The answer for the issue gave a power-effective pre coding algorithm aimed at base station, contingent on minimum SEP prerequisites at the mobile stations. In the algorithm, signature sparsity was exhibited to be pivotal for decreasing pre coding intricacy. Numerical outcomes affirmed system-load-dependent power decrease gain from the proposed pre coding above the zero forcing pre coding and also the regularized zero-compelling pre coding with upgraded regularization parameter under a similar SEP targets. Cost intricacy is high whilst considering BER [Bit Error Rate] performance metrics and also flawed channel estimation. For a settled framework stack, it was likewise shown that scanty MC-CDMA with an appropriate decision of sparsity level achieved nearly similar power proficiency and connection throughput as that of thick MC-CDMA yet with diminished pre coding intricacy.

Vishvaksenan and Raj [14] formulated minimum mean-square-error (MMSE) supported TP matrix utilizing noisy feedback of vector quantized assessed channel information (CI) for FDD framework. Obviously, they evaluated the CI and performed

VQ at every MS and transmit the index of the quantized value through committed low rate noisy channel. Lastly, they obtained CI of every active client utilizing known estimation algorithm so as to manufacture TP. They realized Time–Frequency (TF) domain signature sequence to assist more user population. Specifically, they broke down the ER execution of coded MC-CDMA framework with TP for Stanford University Interim (SUI) channel model. The ER curve demonstrated that coded MC-CDMA framework centered upon TP approach gave better execution less flag signal-to-noise ratio (SNR) while offering low complexity of MS. Moreover, performance curve demonstrated that there was an enhancement in the ER performance when perfect CI was used to assemble TP matrix contrasted with noise tainted VQ-CI.

Silva et al. [15] joined iterative IA precoding on the transmitter with IB-DFE centered dealing out at the receiver aimed at MC-CDMA frameworks. The proposed receiver structure was planned in two stages: initial a linear filter was considered to moderate the inter-user aligned interference, and after that an iterative frequency-domain equalizer was intended to proficiently isolate the spatial streams. The matrices were gotten by reducing the general MSE of every part of data streams on every subcarrier. They additionally proposed a basic; yet accurate analytical approach for getting the receiver structure's performance. The outcomes revealed that the suggested receiver structure was vigorous to the residual inter-user aligned interference in addition very effective to isolate the spatial streams, whereas enabling a near-to-optimum space-diversity gain. The proposed residual inter-user aligned interference permitted noteworthy diminishment in the amount of iterations of the IA procedure, and hence decreased the data should have been traded between the diverse transmitter–receiver pairs. Although it gives excellent receiver structure, implementation procedure is intricate and also time-consuming.

Wang et al. [16] formed a JTCE scheme centered upon the RWBS optimization algorithm intended for band constrained long code-supported MC-DS-CDMA frameworks that required neither the transmission of known pilots nor the supposition that the channel state stays constant within the entire observation window. An ad-hoc filling algorithm named the PODR was proposed to work in association with the RWBS procedure, which was capable of effectively avoiding local minima of the CF, and was exhibited to be more effectual than the existing generation initialization options for the current issue. The CRLB equivalent to the JTCE task of interest had been procured as a performance benchmark. Quantitatively, for the instance of K = 10 clients, *Eb/N0* $\geq$ 3 dB and a 10 dB NFR, the RWBSPODR estimator utilizing a observation window of 20 Tb was appeared to approach the CRLB at a complexity which was 10 orders of magnitude lower in contrast with its full ML-based counterpart depending centered upon exhaustive grid-based search. Subsequently the solution strikes an exceptionally proficient and practical near-optimal low complexity contrasting option to the ML-based estimator.

Chang [17] proposed an Interference Avoidance [IA] code task methodology aimed at the hierarchical 2-D spread MC-DS-CDMA frameworks. They characterized the white, black and gray spreading codes and also the code task system was intended to use the gray and white spreading codes to augment the spectrum effectiveness without hurting macrocell clients. A recently characterized MAI coefficient was utilized to assess every candidate code and in view of that coefficient, the projected strategy can

allocate the fewer interfered gray and white spreading codes to the microcell clients in addition kept up the received flag quality. Through a simulation analysis, they found that this strategy realized an additional of 55% call admissions, furthermore, brought down the call dropping rate by 25% for the microcell. The SIC [successive interference cancellation] method was as well implemented, additionally improve the framework performance. It was discovered that when SIC was implemented and a proliferation of femtocells were conveyed, the entire framework gave a capacity that was more than the aggregate capacity.

Benrami et al. [18] developed a easy method centered upon Wavelet Networks to compute the Weighted Despreading Sequences, by stepping chip weighting waveforms based determination when operating in MC-DS-CDMA system. The presented technique was an ideal substitute for MAI cancellation with BPSK modulation in AWGN channel. The intricacy of the presented scheme was much reduced and there was no degradation in bit error rate (BER) performance.

Karthipan et al. [19] investigated the performance of a multi-user cognitive radio based MC-CDMA system (MC-DS-CDMA) for downlink communication using Transmitter Preprocessing. The capability of the multipath environment to trigger an irreducible mistake in the system performance was shown in their simulation results. The proof that a better BER performance was achieved for a MC-DS-CDMA system by the incorporation of SVD based TP techniques was also explicated in their analysis. Restricted number of computations at the receiver end and reduction of the effects of MAI were the additional advantages offered by the considered system.

3 Proposed DTCWT-MC/DS-CDMA System Model

In the given section portrayed the proposed stream for the proposed SIC based DTCWT-MC-DS-CDMA framework model. The proposed model's principle goal stands to moderate the MAI impact and to augment the limit in MC-DS-CDMA frameworks utilizing successive interference cancellation. A MAI cancelation plan proposed to transfer images through a DTCWT transform. Here the TMSE is employed to present the initial evaluation of clients' data and the serial interference cancelation scheme is after that utilized to regenerate and call off the MAI from the desired client.

3.1 System Model

Consider a K-user synchronous Multi Carrier DS-CDMA framework (an asynchronous framework can likewise be thought about similarly). Let's assume a solitary cell and K-active users over a transmission channel. The conceptual transmitter along with receiver block diagram of MC-DS-CDMA to transmit images across DTCWT is exhibited in Fig. 1.

3.1.1 Transmitter

On the transmitter half, the serial to parallel converted input data of the kth user is modulated, spreaded and scrambled. The input data symbols to be transmitted at a rate
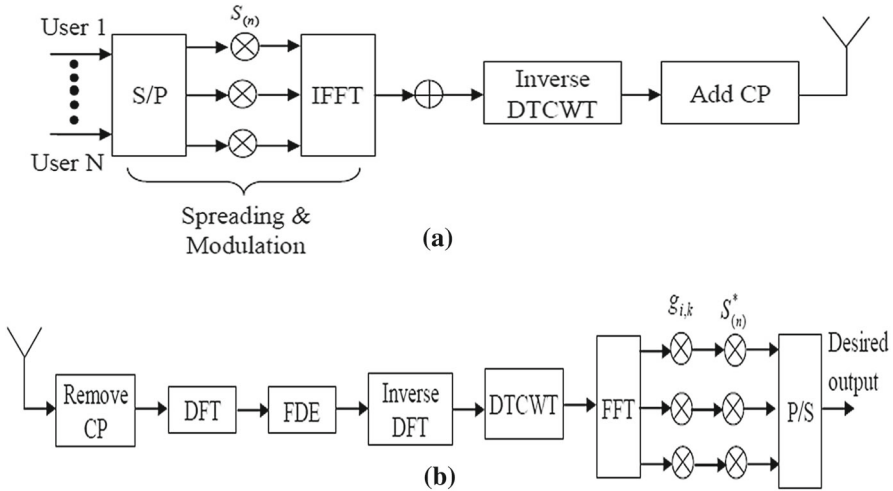
Fig. 1 Baseband downlink MC-DS-CDMA. **a** Transmitter, **b** receiver

R_d to respective client are part into N symbol sequences, every one comprise a rate R_d / N as well each one modulating a distinct carrier of the multicarrier system.

Modulation and Spreading The modulation of the spread data symbols on the carriers is performed through an inverse FFT. The input data symbol $a_{i,k}$ stands multiplied with a spreading sequence $S_{(n)}$ with a spreading code length L which is specified in (1). Consider m is the quantity of subcarriers. The subsequent multiplied signals of the spread data symbol $a_{i,k}$ are transmitted on the mth carrier. Each transmitted block has duration of $(N/L) / R_d$. We indicated the input data symbol as $a_{i,k}$ i.e., ith symbol sent on carrier m to the desired user k.

$$W^{-1} = IFFT(a_{i,k} \times S_{(n)}) \tag{1}$$

where $a_{i,k}$ is the input datum symbol, and $S_{(n)}$ is a spreading sequence.

After that each FFT output block is recurrently stretched out with a prefix samples indicated by C_p to stay away from interference between successive transmitted FFT blocks. In multi client situation, every client is provided a different spreading sequence.

3.1.2 DTCWT

After modulation Inverse DTCWT is applied, which is signified as trails.

$$i[k] = W^{-1}CS_{(n)}h \tag{2}$$

Where W^{-1} is the modulated signal, C is an scrambling code matrix with dimensions $LT \times LT$, $S_{(n)}$ is an Spreading sequence with dimensions $LT \times KT$, h is a $KT \times 1$
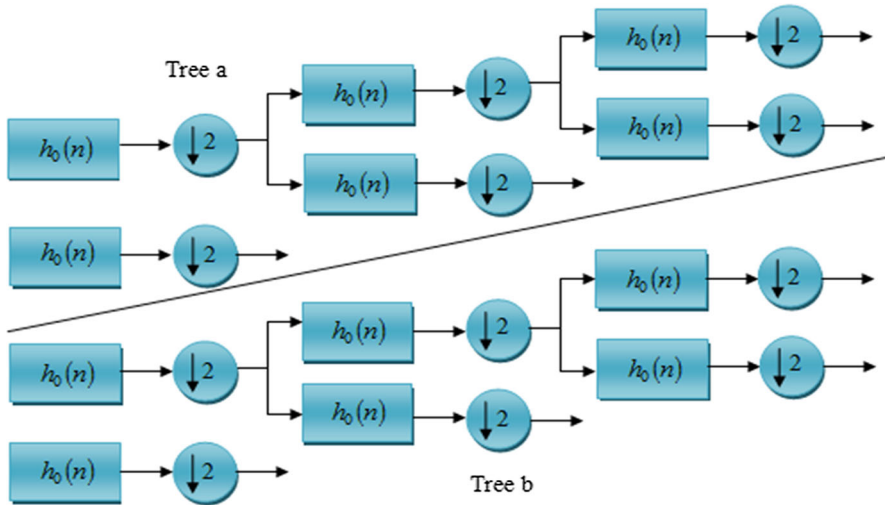
Fig. 2 Structure of DTCWT

vector comprising of the modulated symbols of the kth client. T stands as the quantity of transmitted symbols from every client.

When all is said in done the DTCWT of a specific signal is employed utilizing two critically-sampled DWTs in parallel on same data, exhibited in the Fig. 2.

It utilizes two distinct discrete wavelet transform (explicitly, Tree a, Tree b) with low pass along with high pass sub band filters, to compute complex signal transform. Two DWT's can deliver real together with imaginary coefficients independently, if simply, both the filters are designed particularly unique in relation to one another. Upper DWT creates real part whilst lower DWT creates imaginary part. In the event that both are same there stands no gain. The implementation has two stages. To start with, the input image decomposition is performed via two branches 'a' and 'b' in which upper DWT stands as Hilbert transform (approximate) associated with lower DWT. subsequent, same pass bands of equivalent two sub bands joined linearly either via differencing or else averaging.

At the point when designed like so, the DT-CWT stands almost shift-invariant, rather than the classic DWT. Also, to accomplish the correct relative signal delay, the aggregate delay difference intended for a provided level and every single preceding level must total to one sample period at the input sample rate of the specified level. Thus the filters beneath level 2 in one tree have to give delays which are half a sample different (at every filter's input rate) from those in the opposite tree. Advance there stands no intricate arithmetic engaged with any trees. The complex coefficients are essentially acquired as

$$X_k^c = X_a + kX_b \tag{3}$$

where, X_a—coefficients gotten from tree a, X_b—coefficients gotten from tree b

The inverse DTCWT is computed via two normal inverse wavelet transforms, one equivalent to every tree accompanied by the consequences of every single of the two inverse transforms are after that averaged to furnish the reconstructed signal.

3.1.3 Receiver

The receiver block diagram is exhibited in Fig. 1. After getting the transmitted signal, the receiver expels the cyclic prefix C_p from the transmitted block of samples at the receiver side. The subsequent C_p removed signal is specified in Eq. (4).

$$r = H_c i[k] + n_f \tag{4}$$

Equation (4) can be composed concerning the MAI as takes after:

$$r = H_c i[k]_{des} + H_c i[k]_{int} + n_f \tag{5}$$

where H_c is a circulant matrix, n_f is the noise factor, and $i[k]$ is the transmitted signal.

To expel the Inter Symbol Interference (ISI) and to lessen the noise impacts, *DFT* and *FDE* are applied on the received signals. *DFT* is applied on the rest of the samples prior to applying Frequency Domain Equalization (*FDE*). In the proposed model, FDE is utilized to boost the transmission rate and in addition to attain a excellent BER performance. After *FDE*, the inverse *DFT* is implemented to recuperate the transmitted signal. After that *DTCWT* procedure is accomplished to attain the preferred user's signal. Then demodulation is performed as follows: the *FFT* outputs are applied to one-tap equalizers $g_{i,k}$ that scale and rotate the kth *FFT* in the respective ith symbol interval. De-spreading is performed through multiplying the equalizer yields with the relating spreading sequence of the specific client and after that parallel to serial conversion is done to attain the preferred output sequence.

TMSE-SIC: The proposed TMSE-SIC scheme's algorithm meant for downlink DTCWT-MC/DS-CDMA framework can be outlined as takes after: The proposed MAI Cancelation scheme intended for downlink MC-DS-CDMA has the accompanying stages. To begin with, the TMSE equalizer utilized to afford the first data appraisals of all clients. At that point SIC equalizer is employed to regenerate besides drop the MAI before equalization. At last, the TMSE equalizer is utilized to afford the gauge of desired client's data. This is depictd in Fig. 3.

- Elimination of Cyclic Prefix from the transmitted block.
- DFT is employed on the received signal. The subsequent signal is specified as

$$R_T = \Lambda D + N_f \tag{6}$$

Equation (6) likewise be composed concerning MAI

$$R_T = \Lambda D_{des} + \Lambda D_{int} + N_f \tag{7}$$

where N_f is the Fourier transform of the noise vector and Λ diagonal matrix holding the DFT of the circulant sequence of H_c.
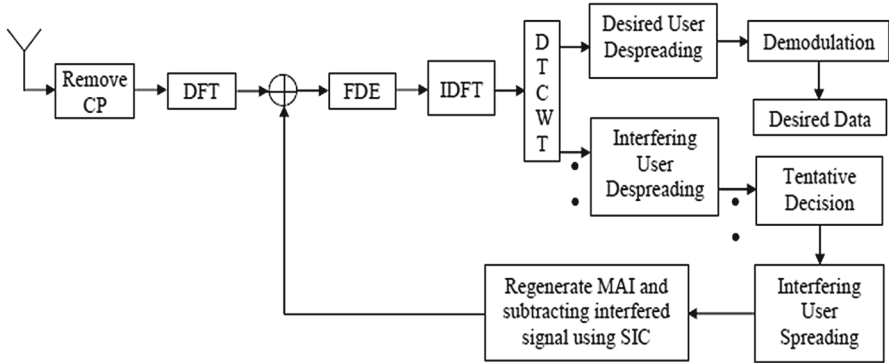
Fig. 3 Proposed MAI cancellation scheme using SIC and TMSE

- FDE (Frequency Domain Equalization) is implemented for evacuating inter-symbol interference.
- IDFT and DTCWT are applied on the subsequent symbols from FDE.
- The subsequent yield is descrambled, despreaded and the speculative decision is then implement to achieve the gauge of the interfering symbols as takes after:

$$b_{des} = f(\overset{\wedge}{F^{-1}} DWR_T) \tag{8}$$

where f stands as the decision function. F^{-1} is the IDFT matrix. D is the DTCWT matrix. W is the FDE matrix.

- At that point regeneration of MAI is done to acquire an interference free signal. The regenerated MAI is after that subtracted to get an interference free signal as takes after:

$$R_{free} = R_T - R_{MAI} \tag{9}$$

where R_{MAI} is the regenerated MAI signal.

At last a superior gauge of the symbol of intrigue can be acquired utilizing SIC. Initially TMSE equalizer utilized to give starting appraisal of the considerable number of clients by calculating TMSE values for all the active clients. The minimization of the MMSE Sum is called as TMSE values which can be implied as takes after:

$$TMSE = \sum_{k=1}^{K} MMSE \tag{10}$$

After TMSE equalization SIC is done. In SIC we identify and call off the contribution of the principal selected interfering client as of the received signal, at that point detection and cancelation of contribution of the second chosen client takes
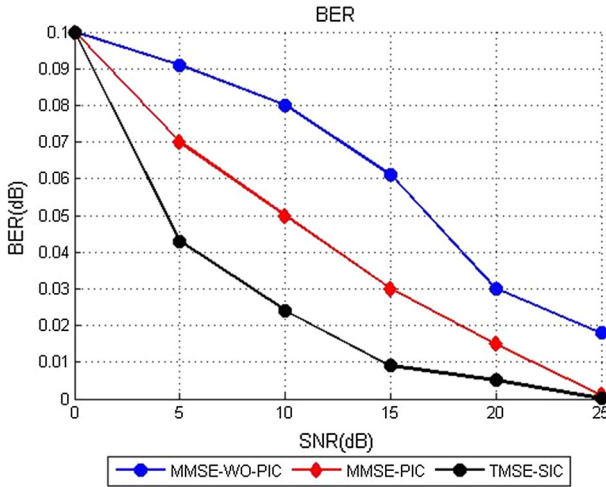
Fig. 4 BER comparisons for proposed TMSE-SIC for MC-DS-CDMA with existing techniques

after, et cetera. A particular ordering must be enforced. On account of SIC, interferers are ordered centered upon their diminishing received power levels. In every iteration of SIC, the whole clients signal is evaluated and also the signal with the biggest power is regenerated in addition subtracted as of the buffered received signal.

4 Results and Discussions

The proposed work's primary object is to moderate the multiple access interference's effect, which restricts the limit of the wireless transmission frameworks. At the moment, the simulation outcomes are exhibited to typify the obtainable performance of TMSE-SIC scheme. Let's consider, the proposed process have 6 active clients $k=6$ with BPSK modulation on every subcarrier. The CDMA codes stands as the Gold codes of length 32.

4.1 Performance Analysis

In the given section, the BER got with proposed TMSE-SIC equalizer and the BER got with the current procedures are analyzed. Figure 4 displayed the performance contrast betwixt the proposed TMSE-SIC with the existing techniques. The proposed TMSE-SIC equalizer technique is contrasted and existing MMSE and MMSE-PIC systems. From Fig. 4 it can actually be inferred that the result acquired with the proposed process has low error rate when contrasted with the existing systems.

Fig. 5 Original transmitted image

Table 1 MSE and PSNR values for the received camera man image on different SNR values

SNR (dB)	MSE		PSNR	
	MMSE-PIC (existing scheme)	TMSE-SIC (proposed scheme)	MMSE-PIC (existing scheme)	TMSE-SIC (proposed scheme)
0	0.058	0.055	12.8	12.10
5	0.024	0.020	14.08	14.13
10	0.009	0.002	21.22	21.25
15	0.01	0.001	28.22	28.34
20	0.01	0.001	32.99	33.12
25	0.005	0.0	40.99	42.21

4.2 Comparative Analysis

Image along with multi-media transmission with CDMA technology has pulled in the interest of a few researchers. Here utilizing 2 metrics to gauge the reconstructed image's quality to contrast the original transmitted image MSE along with PSNR. The image appeared in Fig. 5 has been sent and got for all the active clients. Here contrasting the proposed algorithm with the MMSE-Parallel Interference Cancelation (PIC) Scheme. Table 1 reveals the MSE and also PSNR correlations for the existing and proposed schemes with various SNR values.

Discussion The proposed TMSE-SIC scheme for MAI cancelation gives higher PSNR values when contrasted with existing interference cancelation scheme can be stated from Table 1 and furthermore the proposed process present less MSE values contrasting with MMSE-PIC scheme. The MSE together with PSNR values intended for the proposed and also existing schemes are around measure up to at low SNR values
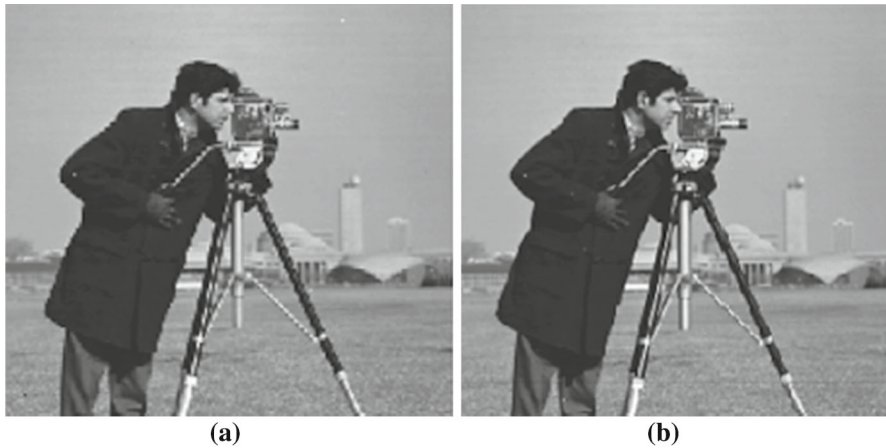
Fig. 6 Received transmitted images with 6 active users on transmission channel for existing MAI cancellation scheme **a** received images with SNR = 20 dB, **b** received images with SNR = 30 dB
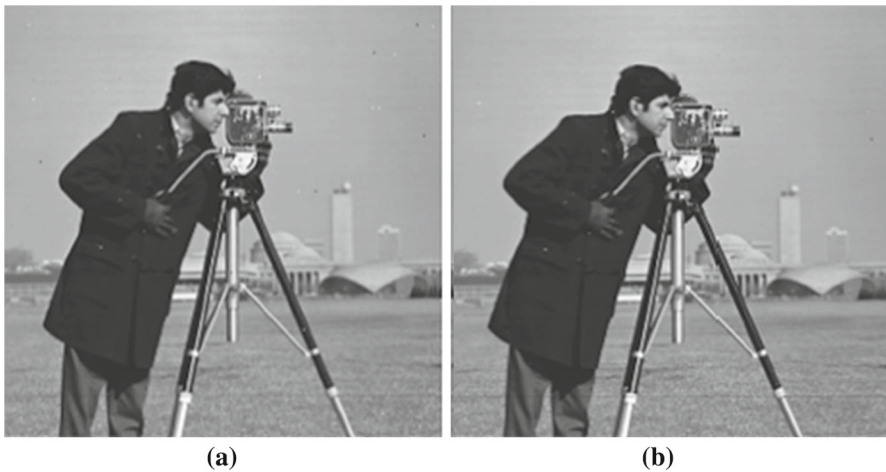

Fig. 7 Received transmitted images with 6 active users on transmission channel for proposed MAI cancellation scheme **a** received images with SNR = 20 dB, **b** received images with SNR = 30 dB

since at low SNR the noise is dominating. On high SNR, the proposed process indicates better MSE together with PSNR when contrasted with existing scheme. Figure 6 along with Fig. 7 reveals the received images under various SNR values. Figure 8 reveals the MC DS/CDMA framework's performance regarding PSNR and MSE values for image transmission.

The PSNR employed to calculate the reconstructed image's quality on the receiver. It is characterized as the ratio betwixt the maximum possible signal power and the
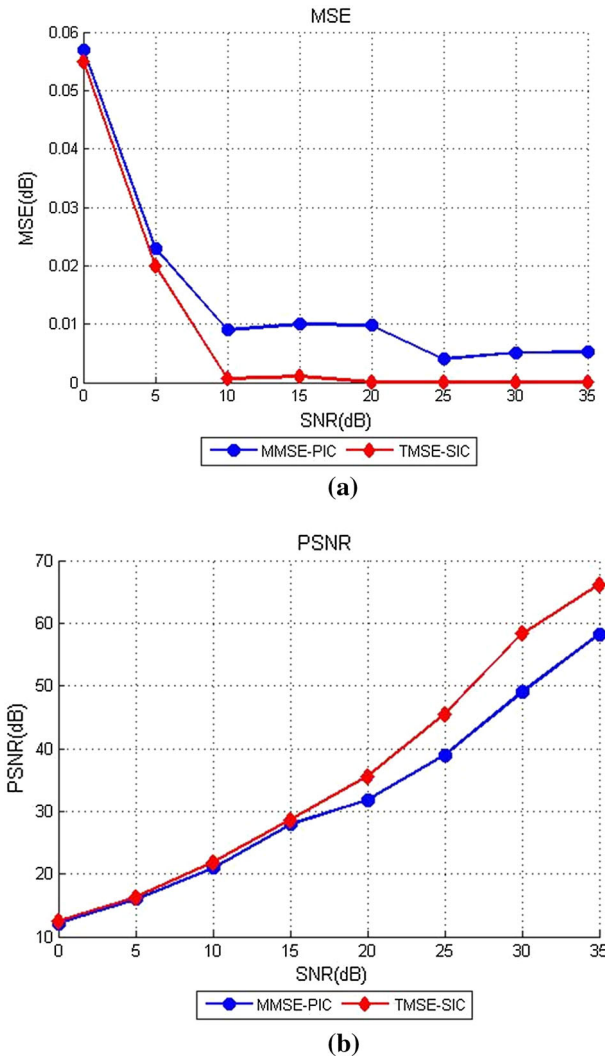
(a)

(b)

Fig. 8 Comparison graph for MMSE-PIC (existing scheme) and TMSE-SIC (proposed scheme) on different SNR values. **a** MSE, **b** PSNR

tainting noise that impacts the fidelity of the same signal. PSNR gauged utilizing the accompanying equation.

$$PSNR = 10 \log(f_{\max}^2/MSE^2) \tag{11}$$

MSE is another performance metrics that is employed to gauge the reconstructed image's quality contrasted with the actual image. The MSE values can compute utilizing (12)

$$MSE = \frac{\sum_{k=1}^{M} \sum_{l=1}^{M} (I_O\,[m-n] - l_r[m,n])}{p^2} \tag{12}$$

where p^2 is the aggregate number of pixels in the transmitted image, and I_o and I_r are the original together with the recovered images, individually.

Figure 6 exhibits the received transmitted images utilizing MMSE-PIC scheme. Figure 7 exhibited the received transmitted images utilizing TMSE-SIC scheme. The correlation graph for the proposed and also existing strategy is appeared in Fig. 8. The proposed process gives enhanced interference cancelation when contrasted with existing algorithm can be presumed from Figs. 7 and 8. Consequently because of MAI lessening and furthermore because of time domain implementation of all filters, this proposed scheme will have high capacity and effectiveness.

5 Conclusion

In this given paper, a proficient time-domain interference cancelation scheme intended for downlink DTCWT based MC-DS-CDMA framework through a multipath wireless channels is proposed. TMSE equalizer is utilized to gives the initial assessment of clients' data and the SIC scheme is after that utilized to regenerate and call off the MAI from the desired client. The proposed process is contrasted with the existing MMSE-PIC concerning peak signal to noise ratio (PSNR) values and also MSE values. The proposed process enhances the capacity and furthermore adequately shuns the MAI which is demonstrated from Experimental outcomes.

References

1. Rohini, S., Suriyakala, C.D.: An overview of performance evaluation of MC-CDMA system. IOSR J. Electron. Commun. Eng. (IOSR-JECE) 92–97 (2016)
2. Rohini, S., Suriyakala, C.D.: Performance evaluation of MC-CDMA system—a survey. Int. J. Comput. Sci. Commun. (IJCSC) **6**(2), 56–65 (2015)
3. Chen, J.I.Z., Kuo, W.C.: On the impact of CFO for an MC-DS-CDMA system in weibull fading environments. Wirel. Pers. Commun. **63**(4), 785–805 (2012)
4. Nelson, I., Annadurai, C., Kalidoss, R., Partibane, R.: Mitigation of co-channel interferences in cognitive multi-carrier code division multiple access system by singular value decomposition techniques. Cluster Comput. (2017). https://doi.org/10.1007/s10586-017-0997-y
5. Carvajal, H., Orozco, N., de Almeida, C.: Mean spectral efficiency evaluation of the uplink of MC-CDMA cellular systems. Wirel. Pers. Commun. **96**(3), 1–17 (2017)
6. Sheikh, J.A., Parah, S.A., Bhat, G.M.: A new multiple input multiple output multi-carrier direct sequence code division multiple access system using T × T spreading with link budget analysis. Int. J. Wirel. Mobile Comput. **10**(2), 148–158 (2016)
7. Kabaoglu, N.: SAGE based suboptimal receiver for downlink MC-CDMA systems. IEEE Commun. Lett. **15**(12), 1381–1383 (2011)
8. Seyman, M.N.: Adaptive arrangement of cyclic prefix length for MC-CDMA systems via multi-objective bat algorithm. Neural Comput. Appl. (2017). https://doi.org/10.1007/s00521-017-3188-0

9. Chen, J.I.Z., Hsieh, T.W.: Another view point on the performance evaluation of an MC-DS-CDMA system. J. Commun. Netw. **11**(3), 240–247 (2009)
10. Shi, J., Song, Z., Ni, Q.: Distributed resource allocation assisted by intercell interference mitigation in downlink multicell MC DS-CDMA systems. IEEE Trans. Wirel. Commun. **16**(2), 1250–1266 (2017)
11. Shi, J., Yang, L.L.: Novel subcarrier-allocation schemes for downlink MC DS-CDMA systems. IEEE Trans. Wirel. Commun. **13**(10), 5716–5728 (2014)
12. Noori, H., Sharafat, A.R.: Proportional fairness in MC-CDMA networks in the presence of jammers: a game theoretic approach. Iran. J. Sci. Technol. Trans. Electr. Eng. **41**(4), 267–282 (2017)
13. Li, M., Liu, C., Hanly, S.V.: Precoding for the sparsely spread MC-CDMA downlink with discrete-alphabet inputs. IEEE Trans. Veh. Technol. **66**(2), 1116–1129 (2017)
14. Vishvaksenan, K.S., Raj, P.T.V.: Coded downlink multi-user MC-CDMA system using transmitter pre-processing: performance results. IEEE Access **4**, 4534–4542 (2016)
15. Silva, A., Teodoro, S., Dinis, R., Gameiro, A.: Iterative frequency-domain detection for IA-precoded MC-CDMA systems. IEEE Trans. Commun. **62**(4), 1240–1248 (2014)
16. Wang, S., Chen, S., Wang, A., An, J., Hanzo, L.: Joint timing and channel estimation for bandlimited long-code-based MC-DS-CDMA: a low-complexity near-optimal algorithm and the CRLB. IEEE Trans. Commun. **61**(5), 1998–2011 (2013)
17. Chang, C.W.: An interference-avoidance code assignment strategy for the hierarchical two-dimensional-spread MC-DS-CDMA system: a prototype of cognitive radio femtocell system. IEEE Trans. Veh. Technol. **61**(1), 166–184 (2012)
18. Benrami, T.A., Jabrane, Y., Antari, J., Iqdour, R.: Wavelet networks for MAI cancellation in MC-DS/CDMA. In: 2016 5th International Conference on Multimedia Computing and Systems (ICMCS), pp. 519–522. IEEE (2016)
19. Karthipan, R., Vishvaksenan, K.S., Kalidoss, R., Krishan, A.: Performance of cognitive radio based MC-DS-CDMA system for downlink communication. In: International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), pp. 401–404. IEEE (2016)