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Enhancing Multi-User Detection in Multicarrier 5G and Beyond: A Space-Time Spreading Approach with Parallel Interference Cancellation

Sumayh S. Aljameel, Atta-ur Rahman*

Department of Computer Science, College of Computer Science and Information Technology, Imam Abdulrahman Bin Faisal University, P.O. Box 1982, Dammam 31441, Saudi Arabia

Corresponding Author Email: aaurrahman@iau.edu.sa

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ABSTRACT

This study explores a composite space-time and frequency-domain spreading strategy, designed to augment the capacity of multicarrier 5G systems operating over frequency-selective Rayleigh fading channels. The focus is directed towards a comprehensive analysis of the Bit Error Rate (BER) performance of the proposed system, with adjustments made to various parametric values. In tandem, receiver optimization techniques are meticulously studied, and their outcomes are positioned against existing literature. Within this context, the Parallel Interference Canceller (PIC) emerges as a viable alternative to the De-correlating Detector (DD), a shift primarily driven by the latter's heightened complexity and noise amplification. Additionally, this study demonstrates the acquisition of a larger number of users exclusively employing transmission diversity, thereby eliminating the need for receiving diversity and additional code sets. This approach incrementally augments hardware complexity at both ends of the transmission link, a minor trade-off for the benefits garnered. The efficacy of this scheme is substantiated through MATLAB simulations, indicating a promising avenue for improving the capacity of multicarrier 5G systems. The findings pave the way for significant advancements in the development of efficient and robust communication systems for the 5G era and beyond.

1. INTRODUCTION

Multi-Carrier Code Division Multiple Access (MC-CDMA) [1-3], a prominent transmission technique that amalgamates Direct Sequence CDMA (DS-CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) [4-7], is presently incorporated in Non-Orthogonal Multiple Access (NOMA) systems [8]. In the quest for delivering high-speed multimedia services and wireless Internet, broadband mobile wireless systems are expected to provide high data rates. However, numerous factors impede system capacity and data rate, necessitating strategies such as Space-Time Spreading (STS) to mitigate the effects of fading [3]. It has been demonstrated that STS can achieve a substantial diversity gain, thereby enhancing system throughput.

In this work, a novel STS-assisted multi-carrier direct sequence code division multiple access system is proposed, designed to support a wide range of bit rates. The study examines the concept of Single-User Detection (SUD) where, amid simultaneous communication of multiple users, only the signal of the user of interest is treated as useful information while the remaining users' data is considered noise. Conversely, Multi-User Detection (MUD) considers the data of other users as useful information [9-11]. Various MUD schemes have been proposed, including a Maximum Likelihood (ML) MUD for MC-CDMA [12] and an Interference Cancellation (IC) based MUD.

A physical perspective reveals that the Minimum Mean Square Error (MMSE) detector strikes a balance between the need to eliminate Multiple Access Interference (MAI) and the necessity to avoid enhancing background noise [13-15]. Despite the MMSE detector's superior performance over the Decorrelating detector, its complexity remains an issue [16]. Therefore, this study investigates the Parallel Interference Canceller (PIC), which promises to mitigate noise enhancement and complexity in 5G networks. Owing to its parallel nature, it proves equally effective in Orthogonal Multiple Access systems (OMA) and NOMA [17-20]. This proposed scheme serves as a receiver optimization approach when the number of users is excessive.

While traditional multiuser detection and interference cancellation schemes exist, computational intelligence techniques proposed in the last decade promise improved detection efficiency [21-25]. These techniques employ meta-heuristic and stochastic algorithms to reduce the multiuser search space, utilizing Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), Chaotic Firefly Algorithm (CFA), and Ant Colony Optimization (ACO), among others.

In addition to space-time transmit-receive antenna topology and diversity, adaptive communication is a leading technique in modern communication systems, including 5G and beyond, facilitating both OMA and NOMA systems [26-30]. This approach adapts transmission parameters, such as the modulation symbol, code rate, and transmit power, in response to the ever-changing and hostile Channel State Information (CSI). At the same time, optimizing system throughput while fulfilling Signal-to-Noise Ratio (SNR) constraints as widely used in serval studies in the literature for various OFDM based adaptive communication systems [31-40].

A thorough review of the literature reveals a scarcity of studies that explore the role of the PIC detector over other counterparts in an STS-based MC-CDMA system. While research exists comparing various detectors in a multiuser environment, they do not operate under STS or within an MC-CDMA environment. Likewise, studies investigating STS and MC-CDMA seldom feature PIC detectors or contrast them with other detectors. Consequently, this research emphasizes the role of PIC for varying numbers of users in STS-based MC-CDMA systems, conducting multiple experiments to investigate the impact of transmitting/receiving antennas under various conditions. The proposed study aims to examine the effectiveness of PIC in the current settings, compared to other detectors like SIC and DD, which exhibit relatively more complexity. The proposed scheme is a receiver optimization scheme with reduced complexity and better bit error rate.

The remainder of the paper is structured as follows: Section 2 provides a background; Section 3 details the proposed scheme. Simulation results are discussed in Section 4, and Section 5 offers a conclusion.

2. BACKGROUND

2.1 Space time spreading

Space-Time Spreading (STS) is a technique in which each user's data is being spread in a different fashion using a common set of orthogonal codes and is transmitted on their respective transmit antennas. This technique known as STS improves the downlink performance of the broadband direct sequence code division multiple access by using a small number of antenna elements at the base and one or more antennas at the handset, in conjunction with a novel spreading scheme inspired by space-time codes. Each signal is spread uniquely over the transmitter antennas to get maximum path diversity at the receiver end. It is a practical way to increase the bit rate, quality, and range in the case of many users. When Space Time Spreading is being invoked for spreading the signal of each subcarrier, the fading of each sub-carrier is mitigated and hence the system becomes capable of significantly reducing the effects of the time-variant channel fading, provided that the number of transmitting antennae is higher than one. In other words, we can say that the system will achieve higher throughput and a higher transmitted bit rate with the advent of transmit diversity. For easy understanding, we will consider two transmit and one receive antenna (Figure 1). Let the signal transmitted on one antenna i.e., T_1 is:

$$T_1 = \left(\frac{1}{\sqrt{2}}\right)(b_1c_1 + b_2c_2) \tag{1}$$

Similarly, the one transmitted on T_2 is:

$$T_2 = \left(\frac{1}{\sqrt{2}}\right)(b_2c_1 - b_1c_2) \tag{2}$$

where, c_1 and c_2 are any set of orthogonal *2Px1* unit norm spreading sequences and $c_1.c_2=0$. Observe that we are using two spreading codes of length 2P each but are employing both codes with both data symbols. Hence no extra resources are needed. Consequently, it can be written as:

$$[t_1, t_2] = [c_1, c_2]\begin{bmatrix} b_1 & -b_2 \\ b_2 & b_1 \end{bmatrix} \tag{3}$$

The received signal after dispreading will be:

$$d_1 = \left(\frac{1}{\sqrt{2}}\right)(h_1b_1 + h_2b_2) + c_1n$$
$$d_2 = \left(\frac{1}{\sqrt{2}}\right)(-h_2b_1 + h_1b_2) + c_2n \tag{4}$$

Here the d can be defined as:

$$d = \frac{1}{\sqrt{2}}Hb + v$$
$$where \tag{5}$$
$$H = \begin{bmatrix} h_1 & -h_2 \\ h_2 & h_1 \end{bmatrix}, b = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}, v = \begin{bmatrix} c_1n \\ c_2n \end{bmatrix}$$

To recover the symbol streams the mobile of interest simply must multiply its de-spread signal d by h_1 or h_2 respectively. At this point, the recovered symbols will be ready for hard or soft decoding. We call this approach STS since each user data is spread differently on each transmitter antenna. Similarly, for 4 transmitter antennas, we can write:

$$S = [c_1 \quad c_2 \quad c_3 \quad c_4].\begin{bmatrix} b_1 & b_2 & b_3 & b_4 \\ b_2 & -b_1 & b_4 & -b_3 \\ b_3 & -b_4 & -b_1 & b_2 \\ b_4 & b_3 & -b_2 & -b_1 \end{bmatrix} \tag{6}$$

Here the vector C = $[c_1 \quad c_2 \quad c_3 \quad c_4]$ refers to the orthonormal spreading sequences against the four considered users and b_i are the user data bits. The b_i's are arranged according to the very famous Almouti scheme as given in the study [3]. Further, the S is the baseband equivalent representation of the signals on the 4 respective antennas.

This scheme is valid only for M=2, 4, 8, etc. because the principle of orthogonality imposed by means of the sequences. The essence of the scheme is for sub-streams of each user's data to share a common set of spreading codes differently on each transmitter antenna. Possible extra benefits of STS that remain to be quantified are the mitigation of both the power control problem, as well as the inter-cell interference problem. Increased diversity implies that power adjustments do not have to occur as frequently.

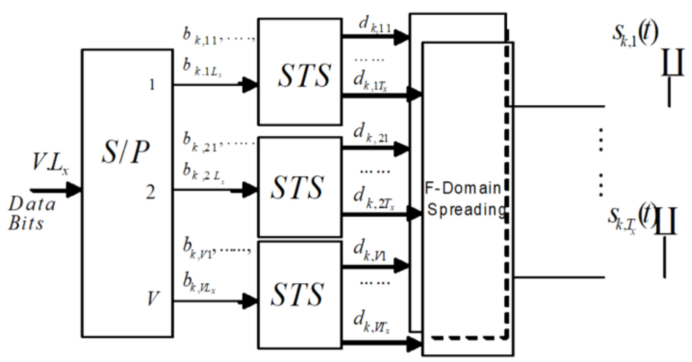

Figure 1. Proposed transmitter model

2.2 Parallel interference cancellation and MUD

In contrast to the single interference canceller (SIC) based multi-user detector (MUD), the parallel interference cancellation (PIC) aided detector estimates and subtracts the Multiple Access Interference (MAI) imposed by all interfering users from the signal of the desired user in parallel. In SIC, in each cancellation stage, the signal of each user is reconstructed by invoking the data estimates from the previous cancellation stage. Then, for each user, the reconstructed signals of all the other users are subtracted from the received composite signal and the resultant signal is processed by the matched filter or RAKE receiver, as shown in Figure 2. So that a new set of data for each of the K users to be used in the next interference cancellation stage can be obtained. The reconstruction, cancellation, and re-estimation operations are repeated as many times as the affordable complexity of the system allows. The advantages of PIC in comparison to SIC are that it does not require the power estimates of all users to be updated after each cancellation stage and that all the users have the same processing delay.

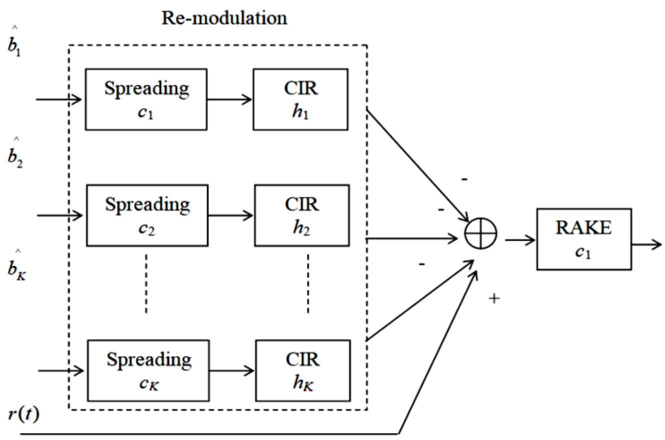

Figure 2. Schematic for PIC

3. PROPOSED 5G SYSTEM MODEL

This section introduces the transmitter and receiver models assumed for the study.

3.1 Transmitter

We consider an orthogonal bit-synchronous MC DS-CDMA system illustrated in Figure 1.

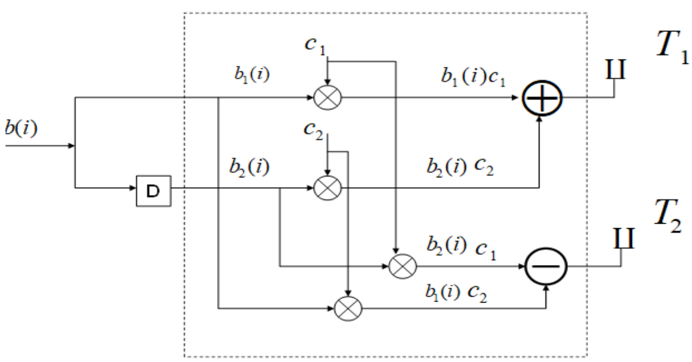

Figure 3. A (2,1) STS scheme

In the system model, we are using single receiving antenna, T_x number of transmitting antennas and $V*S$ number of frequency subcarriers. K user signals are transmitted synchronously in this MC DS-CDMA scheme. Per the Figure 1, we are investigating the kth user where real-valued data symbol using binary phase shift keying (BPSK) modulation and real-valued spreading is considered. A block of $V.L_x$ data bits each having a bit duration of T_b is serial to parallel converted to V parallel subblocks. Each parallel sub-blocks have L_x data bits which are space-time spread using the scheme described in Figure 3. With the aid of M_x number of orthogonal spreading codes e.g.,

Walsh codes = $\{c_{k,1}(t), c_{k,2}(t), \dots, c_{k,M_x}(t)\}, 1 \le k \le K$

Subsequently, it is represented on set of aforementioned transmitting antennas. The interval of the symbol used as the STS signal can be calculated as:

$$\frac{UL_xT_b}{T_c} = UL_xN \text{ as } \frac{T_b}{T_c} = N$$

Here T_c correspond to the chip interval of the Walsh spreading codes in our case. Now it can be shown from Figure 1 that the output coming out from the STS blocks is then mapped on the T_x transmit antennas. These V STS signals that are frequency domain spread can be expressed as:

$$\{c^{II}{}_k[0], c^{II}{}_k[1], c^{II}{}_k[2], \dots\dots\dots\dots, c^{II}{}_k[S-1]\} \quad (7)$$

Consequently, each signal spread over the space-time is communicated over the mentioned subcarriers. The main idea of spreading the signal in the frequency domain is to achieve maximum frequency spacing to avoid potential fading. Inverse fast Fourier transform (IFFT) is then applied on the STS and F-domain spread signals to carry out multicarrier modulation. The IFFT block output is then transmitted using one of the transmitter antennas. The composite transmitted signal over all the transmitters can be represented as:

$$s(t) = \sum\nolimits_k s_k(t) \quad (8)$$

$$s_k(t) = Re\left\{\sqrt{\frac{2E_b}{VT_bSM_xT_x}}[C_kB_k]^T Gw * \exp\big(j2\pi f_c(t)\big)\right\} \quad (9)$$

where, $\frac{E_b}{VT_b}$ is the transmitted power per sub-carrier. Here G in Eq. (3) represents V×VS dimensional frequency domain spreading matrix:

$$G = \left[C_K{}^{II}[0], C_K{}^{II}[1], C_K{}^{II}[2], \dots\dots\dots, C_K{}^{II}[S-1]\right] \quad (10)$$

Here,

$$C_k{}^{II}[s], where\ s = 0,1,\dots\dots, S-1$$

It is the set of rank V matrices and can be further be represented as:

$$C_k{}^{II}[s] = diag\{c_k{}^{II}[s], c_k{}^{II}[s], c_k{}^{II}[s], \dots\dots, c_k{}^{II}[s]\} \quad (11)$$

The expanded form of the equivalent transposed matrix can be expressed as diagonal matrix of dimension $V \times VM_x$:

$$C_k{}^T = \begin{pmatrix} c_{k,1}(t) & 0 & \cdots & \cdots & 0 \\ c_{k,2}(t) & 0 & \cdots & \cdots & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ c_{k,M_x}(t) & 0 & \cdots & \cdots & 0 \\ 0 & c_{k,1}(t) & 0 & \cdots & 0 \\ 0 & c_{k,2}(t) & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & c_{k,M_x}(t) & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & \cdots & c_{k,1}(t) \\ 0 & 0 & \vdots & \vdots & c_{k,2}(t) \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & \cdots & c_{k,M_x}(t) \end{pmatrix}$$

B_k is a $VM_x \times T_x$ is dimensional matrix mapping the data of V sub-blocks to T_x antennas. This is done according to the requirements space-time spreading described earlier. The matrix B_k can be expressed as:

$$B_k = \left[B_{k1}{}^T, B_{k2}{}^T, \ldots\ldots\ldots, B_{kV}{}^T\right]^T \quad (12)$$

where, B_{ku}, u=1, 2, ..., V are $M_x \times T_x$ dimensional matrices. The matrix structure of this matrix is as follows:

$$\begin{pmatrix} a_{11}b^{/}_{k,11} & a_{12}b^{/}_{k,12} & \cdots & a_{1L_x}b^{/}_{k,1T_x} \\ a_{21}b^{/}_{k,21} & a_{22}b^{/}_{k,22} & \cdots & a_{2L_x}b^{/}_{k,2T_x} \\ \vdots & \vdots & \ddots & \vdots \\ a_{M_x1}b^{/}_{k,M_x1} & a_{M_x2}b^{/}_{k,M_x2} & \cdots & a_{M_xL_x}b_{k,M_xT_x} \end{pmatrix} \quad (13)$$

In the above-given matrix a_{ij} is the sign of the element in the i^{th} row and j^{th} which is determined by the STS design rule.

Here in the currently setting, the variable w in equation represents the IFFT multi-carrier modulated vector of length VS and it can be written as:

$$w = [exp(j2\Pi f_1 t), exp(j2\Pi f_2 t), \ldots\ldots\ldots, exp(j2\Pi f_{SV} t)]^T \quad (14)$$

Eq. (3) shows the general form of the transmitted signal regardless of the values L_x, M_x, T_x. The study of space time spreading shows that L_x=M_x=T_x gives the best results as this combination provides maximum transmit diversity utilizing a common set of codes.

Hence no extra set of codes is required. Now talking about the number of users supported by this broadband multicarrier direct sequence code division multiple access system using space time and frequency domain spreading the analysis is given as follows. The total number of orthogonal codes used by the space time spreading VL_xN with the overall quantity of users accommodated by the system are:

$$Kmax = \frac{VL_xN}{M_x}$$

As compared to this the number of orthogonal codes used by frequency domain spreading is S. This shows that the S number of signals can share a common set of space time spreading codes. These S users are distinctly separable with the help of S number of frequency domain codes. It means that the total number of users supported by this multicarrier direct sequence code division multiple access system using space time spreading and frequency domain spreading are:

$$SKmax = \frac{VSL_xN}{M_x}$$

Now the orthogonal code assignment can be done as follows: If the total numbers of users are in the range of maximum user limit, they will be assigned the same number of orthogonal space time spreading codes and the same S number of frequency domain spreading codes. However, if the number of users increased sufficiently that is if they are in the range $sK(s+1)_{max_{max}}$.

Consequently, these s(s+1) users are assigned the same set of space time spreading codes but the s+1 users are assigned different frequency domain codes. In doing so multi-user interference is introduced which affects the overall bit error rate performance of the system.

Nonetheless, this where the receiver's optimization plays its role in reducing the multiuser interference by employing the proposed parallel inference cancelation assisted multiuser detection scheme. It will combat with the induced interference by adequately mitigating it with a relatively lower imposed computational complexity compared to the other state of the art detectors.

3.2 Channel

The channel assumed in this context is a slowly varying frequency non-selective Rayleigh flat fading channel. Each sub-carrier signal will experience flat fading. Now let us assume that $0 \le K^{/} \le S$ corresponds to the count of users communicating with the same group of space time spreading codes. Here it can also be stated that the number of space time spreading codes are shared among same set of users as mentioned above.

The moment these mentioned set of signals are transmitted over a frequency nonselective Rayleigh flat fading channel as utilized in several studies in the literature for similar type of the assumed OFDM systems [41-48], the received equivalent low pass signal can be written as:

$$R(t) = \sum_{k=1}^{K^{/}K_{max}} \sum_{i=1}^{T_x} \sqrt{\frac{2E_b}{VT_bSM_xT_x}} \left(\left[C_kB_k\right]^T G\right)_i Hw + N(t) \quad (15)$$

where, $N(t)$ represents additive white Gaussian noise (AWGN) having a double-sided spectral density of N_0 and single sided spectral density of $N_0/2$.

The idea of assuming this channel is to assure that the simulation environment is aligned to the fifth-generation systems as previously investigated in the studies [49-51].

3.3 Receiver

A comprehensive schematic of the receiver of the proposed scheme is shown in Figure 4. The sequence of the steps taken by the receivers are successive as well as parallel in nature depending on the respective block. The blocks employed are frequency demodulation block, followed by space time de-spreading block and finally the detectors are employed.

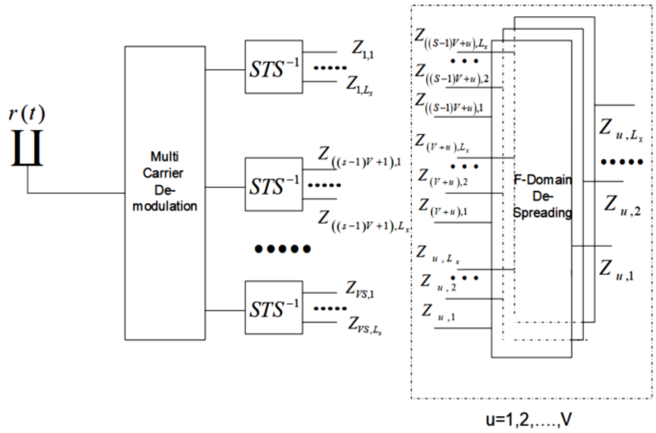

Figure 4. Receiver of the proposed 5G system

On the receiver side, the inverse operations are being carried out. As can be seen in the Figure 4 the received signal is first down converted using demodulation in the FFT multi-carrier block. Consequently, we received equivalent parallel outputs to be fetched to the subsequently blocks.

After performing the de-spreading operation in space time a outcome argument is obtained against each transferred bit of data after performing de spreading in the frequency domain as well. It is worth mentioning that we are assuming the transmitter and receiver diversity with two, four and eight antennas, respectively.

Hence the output of the overall system can be readily expressed as:

$$z_{u1} = \left[Z_{u,1}, Z_{(V+u),1}, \ldots\ldots\ldots\ldots, Z_{(S-1)V+u,1}\right]^{\mathrm{T}} \quad (16)$$

The intermediate operations are expressed by means of segregating different components as given in Eq. (17) with all the effects and then combining them in the form of Eq. (18).

$$\begin{aligned}
A &= diag\left\{\sum_{L=1}^{T_x} h_{uL,}^2, \sum_{L=1}^{T_x} h_{(V+u)L,}^2, \ldots\ldots\ldots, \sum_{L=1}^{T_x} h_{((S-1)V+u)L,}^2\right\} \\
Q &= \begin{pmatrix} q_1^{II}[0] & q_2^{II}[0] & \cdots & q_{K/}^{II}[S-1] \\ q_1^{II}[1] & q_2^{II}[1] & \cdots & q_{K/}^{II}[S-1] \\ \vdots & \vdots & \ddots & \vdots \\ q_1^{II}[S-1] & q_2^{II}[S-1] & \cdots & q_{K/}^{II}[S-1] \end{pmatrix} \\
b &= \left[b_{1,u1}, b_{2,u1}, \ldots\ldots\ldots\ldots\ldots\ldots, b_{K/,u1}\right]^T \\
n &= Re\left[N_{u,1}^{/}, N_{(V+u),1}^{/}, \ldots\ldots\ldots\ldots\ldots, N_{((S-1)V+u),1}^{/}\right]
\end{aligned} \quad (17)$$

By considering all the parameters given in the equations, now the decision variable can be expressed as:

$$z = \sqrt{\frac{2VE_bT_b}{S}} AQB + n^{\mathrm{T}} \quad (18)$$

3.4 Detection with parallel interference canceller

In the detection of Space-Time Spreading STS-based MC DS-CDMA signals, we investigate correlation-based single-user detector, de-correlation-based multi-user detector, and parallel interference canceller. The decision statistics are obtained after both STS and F-domain dispreading. In contrast to the SIC-based multi-user detector, the parallel interference cancellation (PIC) aided detector estimates and subtracts the MAI imposed by all interfering users from the signal of the desired user in parallel. Based on the discussion we can express as:

$$Z = \left[z_{u1}, z_{u2}, z_{u3}, \ldots\ldots\ldots, z_{uK/}\right]^{T\,\mathrm{T}} \quad (19)$$

We can define this $z_{u,k}$ as:

$$z_{uk} = \sqrt{\frac{2VE_bT_b}{S}} AQb + n^{\mathrm{T}} \quad (20)$$

$$z_{uk} = A_{u,k}b_{u,k} + \sum_{\substack{j=1 \\ j\neq k}}^{K/} A_{u,j}b_{u,j}\rho_{uj,k} + n^{\mathrm{T}} \quad (21)$$

So, for the conventional PIC we can write:

$$\hat{b}_{uk} = sgn\left[z_{uk} - \sqrt{\frac{2VE_bT_b}{S}} \sum_{\substack{j=1 \\ j\neq k}}^{K/} A_j b_j \rho_{j,k}\right]^{\mathrm{T}} \quad (22)$$

We can see that there is parallel cancellation of interference. This is the required proposed scheme for PIC. The signum (sign) function represents the sign of the detected bit as the originally transmitted binary phase shift keying (BPSK) signal from the user.

4. SIMULATION RESULTS

The proposed system is simulated in MATLAB 14a software with system configuration as Intel Core i7 and 8GB of RAM. Figures below show compare the BER versus SNR per bit or performance of the STS-assisted MC DS-CDMA system. Figure 5, Figure 6, and Figure 7 show the performance of different detectors with the increasing number of supported users that is 10, 20, and 30, respectively.

We can see from Figure 5 that PIC based detector performs better compared to a Decorrelating detector which is further better than a simple co-relator with a simple maximum ratio combiner followed by a hard decision detector. Since the noise factor is not circumvented in this scheme. In the Decorrelating detector, results are good for higher SNR, since the problem associated with the Decorrelating detector of noise amplification makes it less charming. Also, with the increase in the number of users, due to multiuser interference (MUI), the detection in all three detectors is somewhat decreased as can be shown in the subsequent figures. Moreover, if we fix the BER as 10^{-3}, the proposed scheme is less than 2dB away from the single-user detection case (lower bound), in terms of the SNR value. Further, this factor is similar in the case of 20 and 30 users, respectively.

Another aspect can be seen by the increase in the number of transmit antennas (also known as the transmit diversity); we can see there is a significant betterment in performance. So even with the high number of users (30) results are identical to that of 10 users. So, we can readily deduce that by increasing the number of transmit antennas and PIC-based detector number of supported users can be increased significantly. It is also evident that the BER of 10^{-4} can be achieved at 20dB in the case of 4 Tx antennas while in the case of 2 Tx antennas at 20dB, the BER achieved is 10^{-3}. That means by adding two more Tx antennas, there is an order difference in BER. This is evident in Figure 8 and Figure 9, respectively.

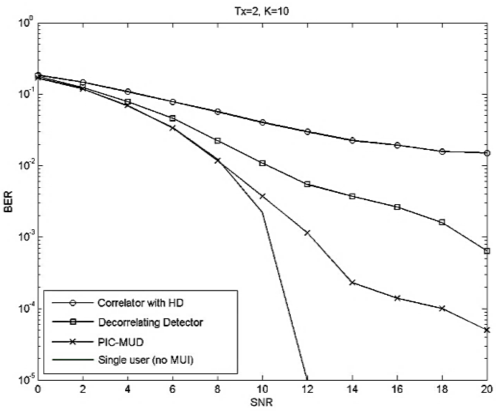

Figure 5. Schemes with two transmit antennas and 10 users

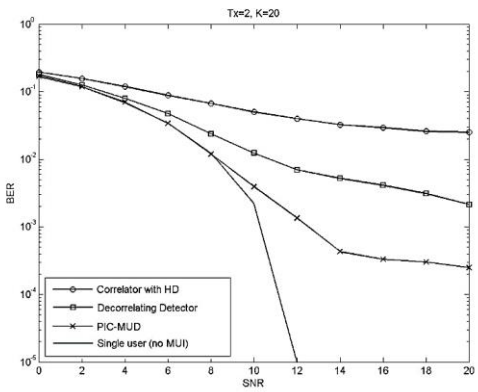

Figure 6. Schemes with two transmit antennas and 20 users

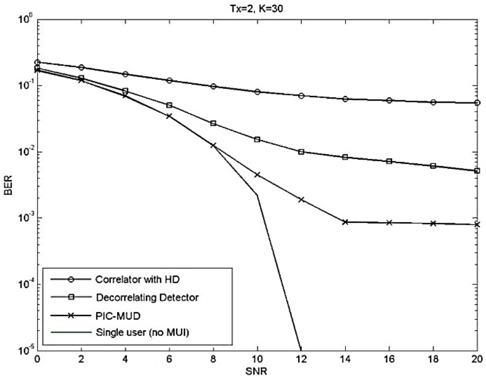

Figure 7. Schemes with two transmit antennas and 30 users

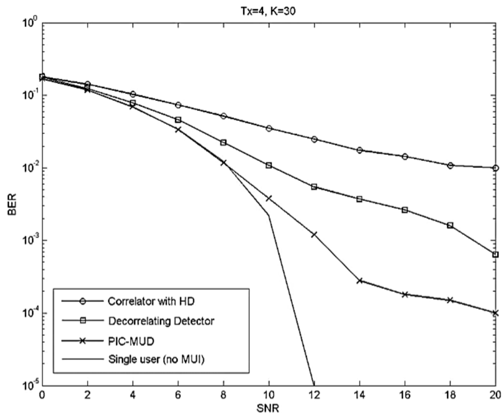

Figure 8. Demonstration of all schemes with four transmit antennas and K=30

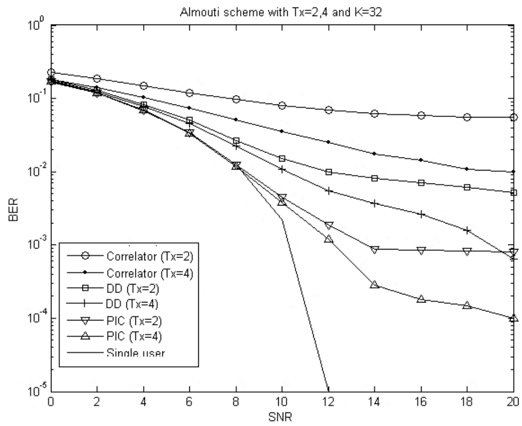

Figure 9. Demonstration of all schemes with Tx=2, 4 transmit antennas and K=32

Table 1 presents a comprehensive comparison of all the schemes with various transmit antennas, against the BER. It is apparent that PIC outperforms DD and the correlator detector. Similarly, DD outperforms the correlator detector. Without loss of generality, it can be safely stated that there is an order difference in the performance of PIC over the DD and an almost similar difference can be observed in the case of DD and correlator detector. The transmit diversity, increasing from two transmit antennas to four transmit antennas pays exceptionally well in terms of BER and more relatively accommodation of supported users. It can be forecasted, that for a fixed BER (say 10^{-3}), if the supported users need to be doubled, roughly double the transmit diversity. No receiver diversity has been used in the analysis.

Table 1. Comparison with other detectors

#	Tx	Users	Detector	BER
1	2	20	PIC	$9x10^{-3}$
2	2	30	PIC	$2x10^{-3}$
3	4	30	PIC	$1x10^{-4}$
4	4	32	PIC	$1x10^{-4}$
5	2	20	DD	$9x10^{-2}$
6	2	30	DD	$3x10^{-2}$
7	4	30	DD	$3x10^{-3}$
8	4	32	DD	$3x10^{-3}$
9	2	20	Correlator	$8x10^{-1}$
10	2	30	Correlator	$5x10^{-1}$
11	4	30	Correlator	$1x10^{-2}$
12	4	32	Correlator	$1x10^{-2}$

5. CONCLUSIONS

The paper presents a novel approach to multiuser detection in multicarrier 5G systems with a parallel interference cancellation-based receiver. From the comparative study of different MUD schemes, following is concluded. The PIC-assisted MUD outperforms the De-correlating detector and correlator with hard decision; the comparison is more significant for higher SNR values. With an increase in the number of users, the performance is reduced due to MUI, but PIC-based MUD gives still a reasonable comparison; further, this issue can be overcome by an increase in the number of transmit antennas (transmit diversity). So, a greater number of users can be entertained by using PIC-assisted MUD, changing the length of frequency domain spreading codes, increase in SNR, or increasing the number of transmit antennas for more power propagation and good signal recognition, and relatively lesser BER. In the future, this scheme can be investigated with different detectors like multiple interference canceller, successive interference canceller assisted MUDs. Moreover, receiver diversity can also be investigated. Channel coding can be used to entertain a greater number of users with low BER and relatively easy decoding. Also, different channel models can be investigated with various other parameters to fine-tune. Moreover, artificial intelligence, machine, and deep learning-based approaches such as transfer learning etc. as already utilized in several studies in the literature [52-60]. Moreover, these schemes are quite promising in terms of addressing the similar type of engineering problems, can be investigated for performance improvement in terms of channel capacity enhancement mitigating bit error rate.

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NOMENCLATURE

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CSI	Channel State Information
DD	Decorrelating Detector
FDMA	Frequency Division Multiple Access
GA	Genetic Algorithm
ISI	Inter Symbol Interference
MMSE	Minimum Mean Square Error
MUD	Multi User Detection
NOMA	Non Orthogonal Multiple Access
PIC	Parallel Interference Canceller
SIC	Successive Interference Canceller
SNR	Signal to Noise Ratio
SUD	Single User Detection
STS	Space Time Spreading