Performance Analysis of Various Interference Cancellation Schemes in CDMA Systems

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Abstract-- **In this paper, various interference cancellation techniques that are used in DS-CDMA are analyzed and their performance characteristics are simulated and evaluated. The conventional matched filter receiver, decorrelating detector, successive interference canceller and parallel interference canceller are considered. Combination of parallel canceller and decorrelating detector is been modeled for performance consideration & comparison. For spreading sequence, some portion of the long m-sequence generated from the primitive polynomial is used. This sequence doesn't hold good in terms of properties and performance. To employ better spreading sequences, the gold sequences generated from the preferred pairs are also applied for the performance evaluation and comparison. For simulation, Synchronous and AWGN (Additive White Gaussian Noise) are assumed. Performance of those interference cancellation techniques are simulated and the results are highlighted which proves to be very much suited for DS-CDMA systems.**

Index Terms—**Interference Cancellation, MAI, detector, gold sequence.**

I. Introduction

DS-CDMA is one of the most popular and widely used techniques used in wireless communication. It is chosen due to large capacity and immunity to jamming. However the performance is been limited by multiple access interference (MAI). This is caused by the cross correlation of users spreading sequences.

Although making the sequences, which are spreaded, as orthogonal among each other, could eliminate MAI multipath component and asynchronous makes them non-orthogonal. In order to overcome these types of problems many interference cancellation schemes are proposed. To evaluate, several interference techniques are reviewed and simulated. In the next section a conventional decoding method is introduced. It is a optimum receiver incase of single user, but performance degrades when multiple-users are present. In the following section the decorrelating detector, which eliminates MAI by multiplying the inverse of the cross correlation matrix of the spreading sequences, is considered [1]. The next section deals with the successive and parallel interference scheme, which eliminates MAI by subtracting from other interferers, estimated signals. The successive interference canceller is called the decision driven multiuser detector. The parallel interference canceller can be used for several stages[2][7]. The combination of this with the decorrelating detector is also simulated for grading the performance in case of multiusers. In the last section simulations are reviewed, evaluated and the final section deals with the conclusions arrived by the various schemes for the performance evaluation and suitability for the 3G cellular systems. The various interference cancellation techniques performance is compared with the DC-PIC (decorrelating detector and parallel interference canceller) performance by simulation analysis in Matlab v6.5.

II. Matched Filter (Conventional Detector)

First, a synchronous CDMA model is presented in [1]. The 'K' numbers of users are active. The users transmit by employing the modulation scheme as BPSK. The received signal will be the sum of antipodal modulated synchronous waveform as

$$y(t) = \sum_{k=1}^{k} A_k b_k s_k(t) + \sigma n(t), t \in (0,t) \quad (1)$$

Where T is the bit duration and S is the signature waveform. The signature waveform is said to be zero outside the interval (0,T) so there is no inter symbol interference.

A_k is the amplitude of the received waveform of the Kth user, $b_k \in \{-1,+1\}$ is the message bit transmitted by the user.

$$\|S_k\|^2 = \int_0^T S_k(t)^2 dt = 1 \quad (2)$$

Where n(t) is the white Gaussian noise of unit power and $\sigma^2 = N_0/2$ is the noise power. The received signal is passed through a bank of filters as shown in the figure1.

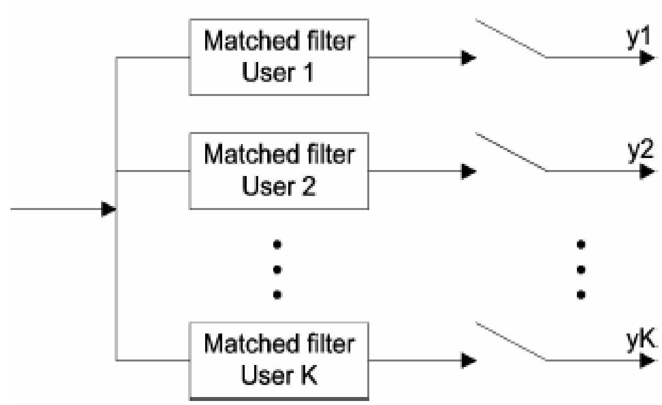

Fig 1. Conventional Matched Filter

This detector is the simple extension of matched filter for one user. The performance of the detector is optimal for single user but not for the multiuser environment. In the synchronous case the output of the Kth matched filter is y_1 to y_k as

$$y_1 = \int_0^T y(t) S_1(t) dt$$
$$y_k = \int_0^T y(t) S_k(t) dt \qquad (3\&4)$$

Alternatively, it is stated as of the form

$$y_k = A_k b_k + \sum_{j \neq k} A_j b_j \rho_{jk} n_k \qquad (5)$$

Where

$$n_k = \sigma \int_0^T n(t) S_k(t) dt \qquad (6)$$

It is convenient to represent the output of the matched filter in matrix notation. To represent we employ the cross correlation matrix is defined as

$$R = \begin{bmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1k} \\ \rho_{21} & \rho_{21} & \cdots & \rho_{21} \\ \cdots & \cdots & \cdots & \cdots \\ \rho_{k1} & \rho_{k2} & \cdots & \rho_{kk} \end{bmatrix} \qquad (7)$$

Where

$$\rho_{ij} = \int_0^T S_1(t) S_j(t) dt, wherei\ , j = 1 \ldots k \qquad (8)$$

It is convenient to state the output of the matched filter as

$$y = RAb + n \qquad (9)$$

Where

$$y = \begin{bmatrix} y_1 & y_2 & \ldots & y_k \end{bmatrix}^T$$
$$b = \begin{bmatrix} b_1 & b_2 & \ldots & b_k \end{bmatrix}^T \qquad (10)$$
$$A = diag\{A_{1,} A_2 \ldots, A_k\}$$

and n is the zero mean Gaussian random vector with covariance matrix equal to

$$E\left\lfloor nn^T \right\rfloor = \sigma^2 R \qquad (11)$$

To get the users decoded bit, we simply take the sign of each of the components as the outputs.

$$\hat{b} = \operatorname{sgn}(y) \qquad (12)$$

III. DE-CORRELATOR

In this section, the decorrelating detector is introduced. The cross correlation matrix is invertible. If we premultiply the output of the bank of the matched filter by R-1, the

$$R^{-1} y = R^{-1}(RAb + n)$$
$$= Ab + R^{-1} n \qquad (13)$$

We observe that the Kth component of R-1 y is free from interference caused by any other users. The only source of interference is the background noise. To get the users decoded bit, we can simply take the sign of the each of the components of $R^{-1} y$.

$$\hat{b} = \operatorname{sgn}(R^{-1} y) \qquad (14)$$

Figure 2 depicts the detector of this type. There are several good properties about this detector. The most important is the performance, which doesn't depend on the signal energy. There are certain drawbacks like boosting of noise power and calculation of R^{-1} which is difficult in practical implementation.

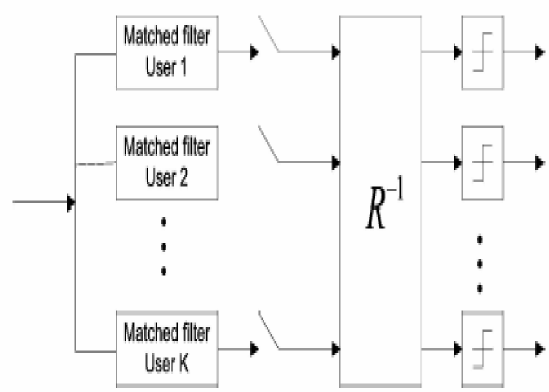

Fig 2. Decorrelating Detector

IV. SERIAL INTERFERENCE CANCELLER

SIC is one of the decision-driven multiuser detectors. Let us consider the two user synchronous case, it is demodulated by its matched filter as

$$\hat{b}_2 = \operatorname{sgn}(y_2) \qquad (15)$$

Demodulating the signal of the user2 with b2, we obtain $A_2 b_2 S_2(t)$. The estimated signal is subtracted from the received signal, which yields

$$\hat{y}(t) = y(t) - A_2 \hat{b}_2 S_2(t)$$
$$= A_1 b_1 S_1(t) + A_2(b_2 - \hat{b}_2) S_2(t) + n(t) \qquad (16)$$

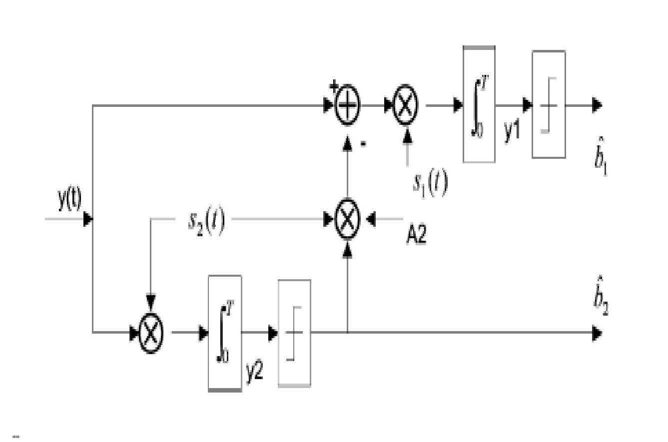

Fig 3. SIC (2 user case)

In the signal y(t) the interference from user2 is removed. This new signal y is, now processed with the matched filter for s1. So we obtain the decision as

$$
\begin{aligned}
\hat{b}_1 &= \mathrm{sgn}(y_1 - A_2\hat{b}_2\rho) \\
&= \mathrm{sgn}(y_1 - A_2\rho\,\mathrm{sgn}(y_2)) \\
&= \mathrm{sgn}(A_1 b_1 + A_2(b_2 - \hat{b}_2)\rho + \sigma < n, S_1 >
\end{aligned} \tag{17}
$$

Where <n,s1> is the cross correlation between n and s1. The 2 user successive cancellation detector is shown above in the figure. In K user successive cancellation, the users interference component is subtracted one by one at a time. When making a decision about Kth user, we assume that the decisions of users K+1, K are correct and we eliminate the presence of the users 1, K-1[8].

V. PARALLEL INTERFERENCE CANCELLER

In contrast to the SIC, the PIC detector estimates all MAI and subtracts them out for each user in a parallel manner. The detector structure is shown in the figure4 below.

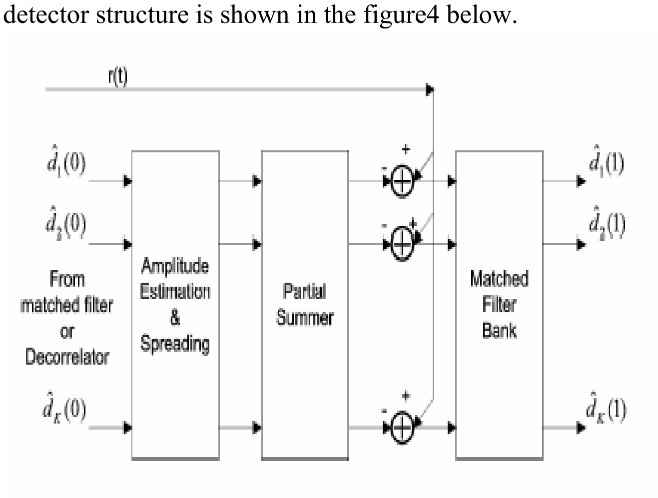

Fig. 4.PIC (Initial block as MF/DC)

VI. SIMULATIONS

Gold codes are generated from preferred pairs of <45> and <75> which was used for the comparison. The period of the code is 31. For simplicity, Synchronous and AWGN channel is considered. Without loss of generality, the error rate of a first user is plotted. Figure 5 shows the conventional filter response of gold sequence respectively. When employing m-sequence the performance degrades as the number of user increases. It is apparent that it doesn't do well due to MAI. This proves that the matched filter receiver is not optimal when multiple users are present. Its performance improves when the crosscorrelation becomes small as in figure 5. The gold codes does this since it has good crosscorrleation properties.

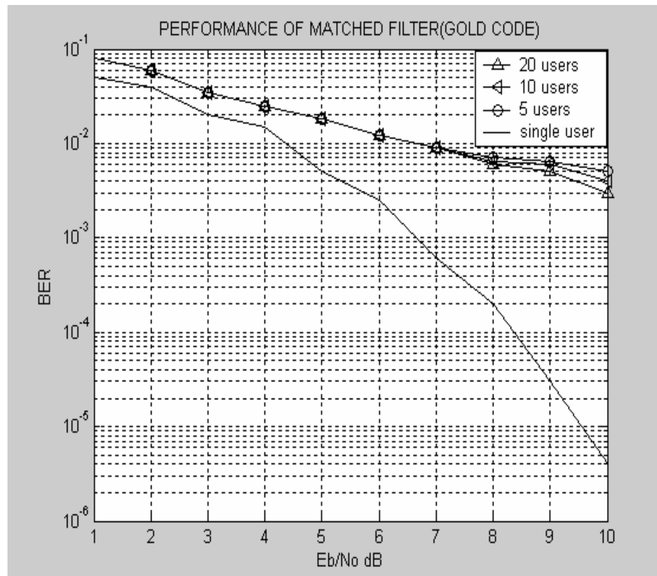

Fig.5. Performance of matched filter (Gold sequence)

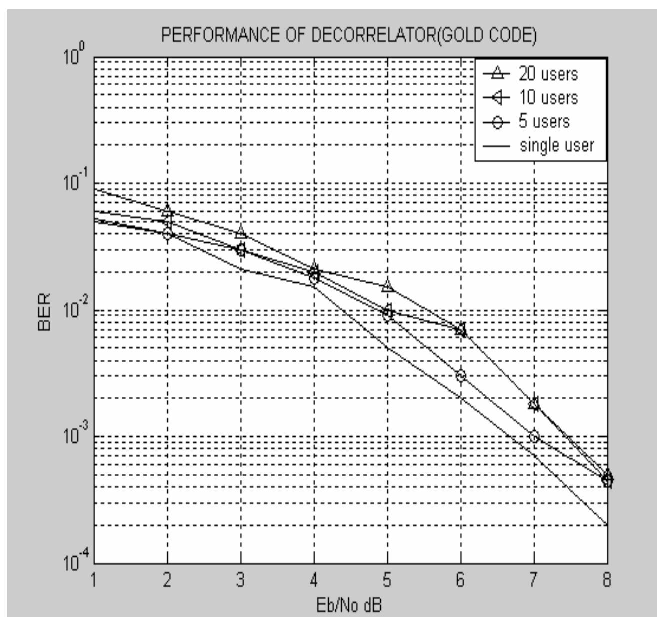

Fig 6. Performance of decorrelating Detector (gold seq)

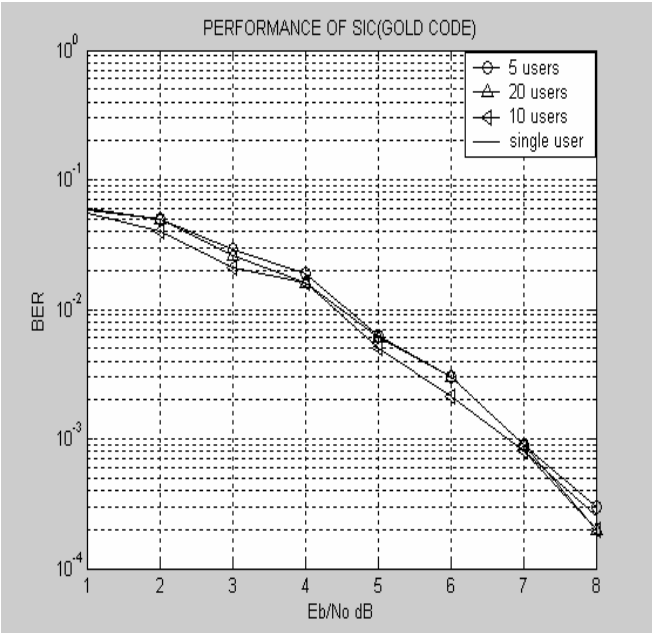

Fig 7. Performance of SIC (gold seq)

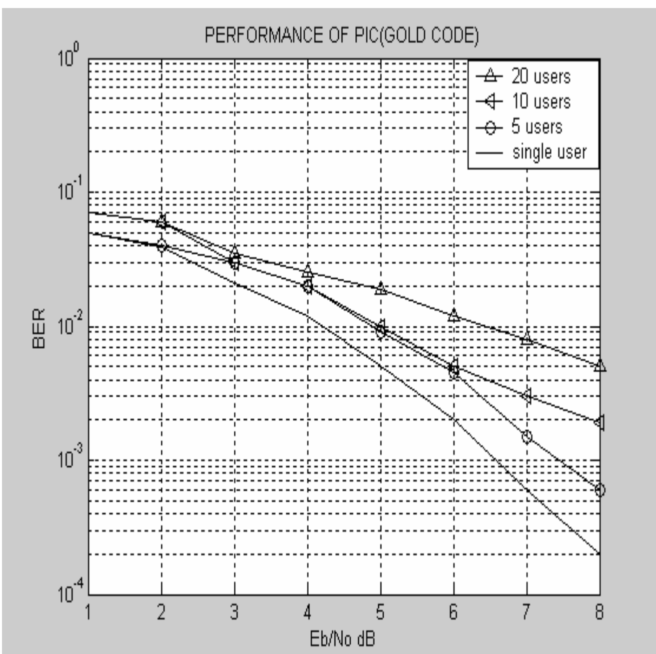

Fig.8. Performance of PIC (gold seq)

For the combiner (DC-PIC) the following model was considered. Here the decorrelator is used as the first stage and the PIC as the second stage. The figure 9 shows the performance plots which proves to be more effective, by doing so the MAI components can be removed much more effectively than the matched filter response as shown in the figures 5. The plots in Figure 6 shows the performance of decorrelator, whereas the plots in Figure 7 & 8 highlights the performance of SIC & PIC. In case of gold seq the performance of PIC is comparable to that of SIC.

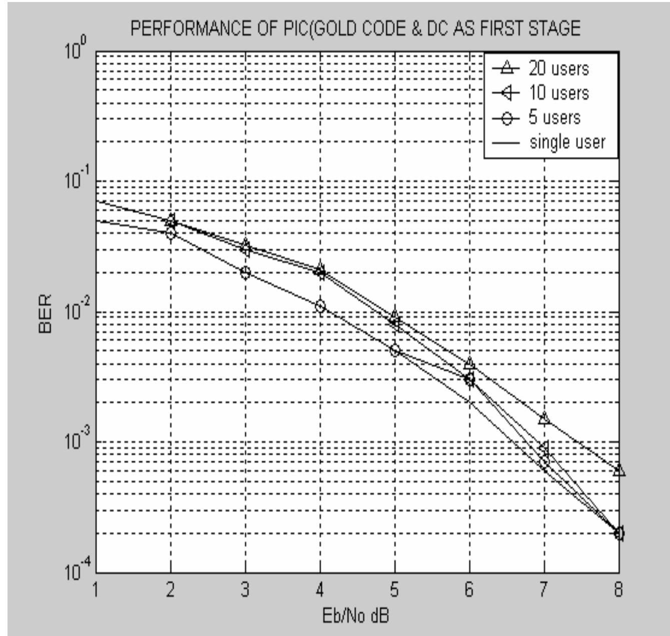

Fig 9. Combination of PIC & Decorrelator (gold seq)

VII. CONCLUSION

The various interference cancellation techniques are reviewed and simulated. The matched filter, which is optimum only when single user is present, is not necessarily optimum for the multi-user case. Other multi-user detectors are more effective. By using gold codes significant performance improvement can be obtained as it holds good cross-correlation properties when compared to the m-sequences. Finally employing good codes plays a vital role for eliminating the MAI components, Capacity increase and System performance.

VIII. REFERENCES

[1] S. Verdu, "Multiuser Detection," Cambridge University Press, 1998.
[2] S. Moshavi, "Multiuser Detection for DS-CDMA Communication" IEEE Communication Magazine, pp. 124-136, Oct.1996.
[3] S. B. Wicker, "Error Control Systems for Digital Communications and Storage," Prentice Hall, 1995.
[4] Holma, "WCDMA Handbook," 1998.
[5] Lee and Miller, "CDMA Systems Engineering Handbook," Artech House, 1998.
[6] Braun, "PN acquisition and tracking performance in DS-CDMA systems with symbol length spreading sequence, IEEE transactions on Communications, Vol. 45. pp. 1595-1601, Dec. 1997.
[7] Divalkar and Simon, "Improved parallel interference cancellation for CDMA," IEEE transactions on Communications, Vo.l46 pp. 258-268.
[8] Zie, et. al; "A family of Suboptimal detectors for Coherent multi-user communication," IEEE in J. Selected areas in Communication, Vol.8, no4, pp. 683-690.