A Quasi-Synchronous CDMA System using Frequency Domain Multi User Detector (MUD)

Anees K A[1], D. Damodaram[2]

[1, 2]Sree Vidyanikethan Engineering College, Tirupati-517102, India

Abstract: ***In this paper, a novel frequency domain multi-user detector is proposed for a time division-code division multiple access (TD-CDMA) up-link. Unlike conventional frequency domain detectors, the proposed detector first transforms the system matrix of TD-CDMA systems into a circulant matrix by cyclic truncation. It subsequently uses a new method to convert the circulant matrix into a frequency domain block diagonalized matrix through discrete Fourier transforms and permutations. Therefore, the proposed detector can utilize the channel frequency domain coherence to further decrease its computational complexity with a controlled performance loss. Moreover, a novel approach is proposed to calculate the frequency domain correlation matrix and matched filter. With the help of this novel approach, the proposed detector expresses significant complexity advantage over other frequency domain detectors for a real TDCDMA system in a short-time-dispersive channel.***

Keywords: circulant matrix, cyclic truncation, MUD.

1. Introduction

The rapid increase in the demand for data services, primarily Internet Protocol (IP), has been thrust upon the wireless industry. Over the years there has been much anticipation of the onslaught of data services, but the radio access platforms have been the inhibitor from making this a reality. Third generation (3G) is a term that has received and continues to receive much attention as the enabler for high-speed data for the wireless mobility market. UMTS includes two of the air interface proposals submitted to the International Telecommunications Union (ITU) as proposed solutions to meet the requirements laid down for International Mobile Telephony 2000 (IMT-2000). These both use Direct Sequence Wideband CDMA (DS-WCDMA). One solution uses Frequency Division Duplex (UTRA-FDD) and the other uses Time Division Duplex (UTRA-TDD).**C**ODE division multiple access (CDMA) is a multiplexing technique whereby a plurality of users are separated in the code domain while sharing the same time and the same frequency band CDMA has been adopted by the standardization bodies, including the 3rd Generation Partnership Project (3GPP) and 3GPP2, in 3rd generation mobile systems, which have been commercially deployed world-wide. In Time Division Multiple Access (TDMA) each user is allocated a unique time slot. Time division CDMA (TD-CDMA) is a radio access scheme based on a combination of TDMA and CDMA methods. Due to the small arriving time differences among different user signals, a TD-CDMA system can be regarded as a quasi-synchronous CDMA system in the up-link. For CDMA systems, the Rake receiver, based on the correlation of the received signal with a specific user signature sequence, is popular due to its simplicity. However, by simply considering other users' signal as noise, the Rake receiver is unable to cope with multiple access interference (MAI), coming from other users' signals, which significantly reduces its performance in spectra efficiency. Another well known approach in CDMA detection is to demodulate all user signals simultaneously. This principle is referred to as multi-user detection (MUD). The optimum multiuser detectors for an AWGN channel, proposed by Verdu, consist of matched filters, followed by either forward or forward-backward dynamic programming algorithms. The complexity of the optimum receivers increases exponentially with the number of users, which makes them unsuitable for practical applications. Therefore, a number of sub-optimum receivers have been proposed to reach a good trade-off between the performance and complexity, such as the decorrelator, the decision feedback detector the group detector, the minimum mean-square-error (MMSE) detector, the multistage parallel interference cancellation detector, etc. For a time-dispersive channel, the presence of inter-symbol interference (ISI) will exacerbate the complexity of MUD receivers. In, four types of sub-optimum detectors, combating both MAI and ISI based on zero forcing (ZF) or MMSE, were presented and compared. M. Vollmer *et al* designed a number of commercially feasible MUD receivers for a TD-CDMA system in; they concluded that a Cholesky decomposition algorithm, block Levinson algorithm, and block Schur algorithm have a similar computational complexity for an acceptable bit error rate (BER). More recently, turbo MUD, which combines MUD and a powerful turbo detection principle, has received considerable attention due to its good trade-off where between the performance and complexity. However, iterations in the turbo detector might cause unacceptable delays. It is worth noting that all the aforementioned MUD receivers are time domain detectors. Motivated by the frequency domain equalization for a single user system, a block Fourier MUD receiver has been proposed in for a multiuser system. So far, the block Fourier MUD receiver has been the most popular frequency domain detector for TDCDMA systems. In contrast to time domain detectors, which jointly suppress the ISI and MAI, a block Fourier MUD receiver decouples ISI and MAI, and thus achieves a lower computational complexity compared to time domain detectors. Through the matrix reduction and well known overlap save technique, the computational complexity of a block Fourier MUD receiver can be further reduced at the expense of a controlled performance loss. However, the complexity advantage of the frequency domain multi-user detector in over time domain detectors is significant only over long-time dispersive channels, i.e., channels with long channel impulse responses (CIR). In, the maximum CIR length is 60 chips. However, in the practical TD-CDMA system, the 1.28MCps time division duplex (TDD) mode of the Universal Mobile Telecommunications

System (UMTS), the typical CIR length in the urban area is about 2.5 μs, corresponding to 4 chips. In the short CIR length case, this complexity gain is marginal and even negative. To the best of the authors' knowledge, none of the available frequency domain detectors has a significant complexity advantage over time domain detectors in real TD-CDMA systems. In order to fill the aforementioned gap, in this paper, I propose a novel frequency domain multi-user detector for real TD-CDMA systems with significantly reduced complexity over the best existing frequency domain detector in and suitable for commercial implementation in real TD-CDMA systems. Unlike the frequency domain detector in, the proposed detector first converts the system matrix of TDCDMA systems into a circulant matrix by a cyclic truncation operation and then block diagonalizes a block circulant matrix in the frequency domain by discrete Fourier transforms (DFT) and permutations. In this case, each block in the block diagonalized matrix is associated with a frequency and its corresponding equation set can be solved independently from each other by using a minimum mean square error-zero forcing (MMSE-ZF) algorithms, and Cholesky decomposition. The frequency domain solutions are subsequently transformed into the desired time-domain results by an inverse DFT (IDFT). The proposed frequency domain detector allows us to exploit the channel frequency-domain coherence property in order to reduce the computational complexity.

The frequency domain coherence means that the frequency response of a channel is flat within a certain bandwidth. This implies that, the output triangular matrices of the Cholesky decomposition at adjacent frequencies are highly correlated. In this case, the Cholesky decompositions can be carried out only at selected frequency subsets, while the triangular matrices for the other frequencies can be interpolated from those with a small amount of calculations. This significantly reduces the computational complexity of the proposed detector at the expense of a controlled performance loss. In order to further reduce the complexity of the proposed frequency domain detector on real channels, which exhibit short impulse response, a novel approach for calculating the frequency domain correlation matrix and matched filter is proposed. Unlike the conventional two-step approach, where the time domain values are transformed to the frequency domain first, and then used to calculate the correlation matrix and matched filter. In the proposed approach, we calculate the frequency domain correlation matrix and matched filter from their time domain values. Finally, the performance and complexity of the proposed frequency domain multi-user detector are compared and compared to those of the best existing frequency domain detector in [3], which has been shown to have a lower complexity than all popular time domain multiuser detectors. The rest of this project is organized as follows. In Section II, the system model is presented. Section III presents a description of the proposed novel frequency domain multi-user detector. In Section IV, the simulation results and computational complexity are presented and discussed. Finally, conclusions are drawn in Section V, VI deals with future work of this project.

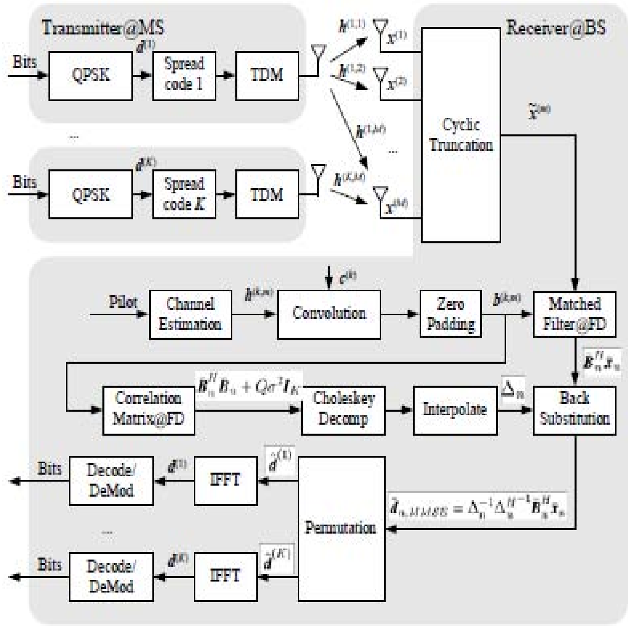

Figure 1: Block diagram of a TD-CDMA transmitter and frequency domain MUD receiver for one data block

2. System Model

At a mobile station transmitter, the coded user data signals are modulated by quadrature phase-shift keying (QPSK), and then spread by a user specific Walsh code. The spreading factor for each data symbol is denoted by Q. We assume that all users have the same spreading factor. However, it is straightforward to extend the algorithm to variable spreading factors. The output spread CDMA signals from all active users are time division multiplexed into a data block. In a time division multiplexer (TDM), a TDMA frame is divided into Nfr time slots. A time slot is shown in Fig. 2. It includes a mid-amble used for channel estimation, a guard period, and two data blocks, each of which contains N spread data symbols. We assume that there is a single transmit antenna at each mobile station and there are M receive antennas at the base station. The received signals coming from various users at the base station are assumed to be synchronized by the down- and up-link synchronization procedures during the cell search and initial up-link access.

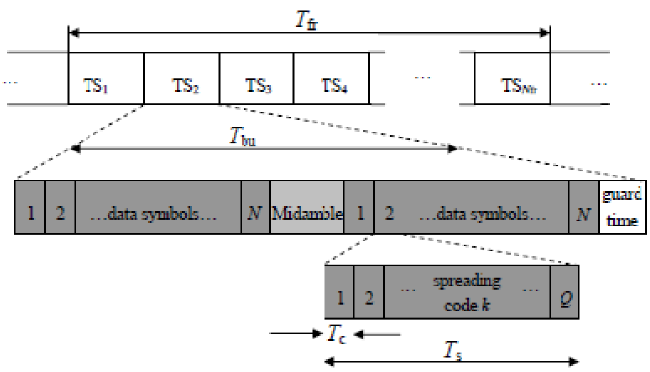

Figure 2: Frame and time slot structure of TD-CDMA system T_{fr}, T_{bu}, T_s, T_c denote the duration of a TDMA frame, a time slot, a symbol and a chip respectively.

3. A Novel Frequency Domain Multi-User Detector

Block diagonalization of the system matrix by a DFT requires converting the system matrix $\boldsymbol{H}$ (k, m) into a circulant matrix. Instead of the matrix extension technique applied in [6], we utilize a cyclic truncation technique to realize this objective. Block diagonalizing the system matrix of a TD-CDMA systems with the help of the above new block-diagonalization approach. A natural question arises: what is the essential difference between the proposed new approach and the conventional block Fourier transform approach in [6]. The answer is that for the proposed new approach, the received signal is transformed by a single DFT with the length of *NQ*, while the conventional block Fourier transform approach performs the transformation of the received signal by *Q* parallel DFTs with the length of *N*. The new approach allows us to utilize the frequency coherence of a channel to achieve approximation. This will be detailed in Subsection C, where the error property of this approximation is also analyzed.

Approximation by Interpolation

Coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered "flat" (i.e., a channel passing all spectral components with approximately equal gain and linear phase). The coherence bandwidth is inversely proportional to the root mean square delay spread of the channel. Consequently, the frequency domain correlation matrices .$\boldsymbol{R}n$ are correlated at adjacent frequencies. This is particularly pronounced in short-time dispersive. This can justify the high correlation of .$\boldsymbol{R}n$ at adjacent frequencies. Similarly, the upper triangular matrices Δn are also correlated at adjacent frequencies. Therefore, it is feasible to compute .$\boldsymbol{R}n$ and Δn on only a subset of all frequencies, referred to as sample frequencies. The matrix Δn on non-sample frequencies can be calculated from the sample frequencies, by using an interpolation algorithm with a neglectable amount of computations, e.g., zero order, linear or spline interpolation [10]. Since the Cholesky decomposition contributes a significant part to the total computations, reducing its number by interpolation can greatly decrease the complexity with controllable performance degradation.

4. Simulation Results and Computational Complexity

In order to verify the proposed frequency domain multiuser detector, a comparison, including both performance and computational complexity, between the proposed detector and the block Fourier MUD receiver is performed under the condition of a simplified practical TD-CDMA up-link with parameters shown in Table I in this section. The reason to choose the block Fourier detector in for comparison is that this detector is the best existing frequency domain detector so far and has a similar performance as time domain detectors but with lower complexity. For simplicity, the compared frequency domain detector and the proposed detector are denoted as FD-VGH and FD-Proposed, respectively. The channel is simulated as a tapped delay line with a fixed delay, based on a VA (Vehicular channel A) model and a VB (Vehicular channel B) model.

The un-coded BER curves in the VA and VB channels are shown in Figs. 5 and 6. The parameter *P* is the number of sample frequencies in the FD-Proposed method, and equals to the number of effective symbols in each data slice (*Dprelap-postlap*) [6] in FD-VGH. Parameters W = 6 and W = 24 correspond to the VA and VB channels, respectively. Simulation results show that the exact FD-Proposed and FDVGH algorithms, with *P*=32 and ideal performances, have identical BER curves in both the VA and VB channels. For the approximate algorithms, with *P* < 32 and suboptimal performances, the FD-VGH maintains a similar performance for various *P* values. The reason for this is that the burst errors caused by the approximation occur in the overlapped symbols. If the length of the overlapped symbols is greater than the time dispersion of the channel, the erroneous symbols can be largely eliminated by the overlap-save technique. In a VA channel, the FD-Proposed method has an obvious performance degradation for *P*=2, due to the approximation errors in the correlation matrices.

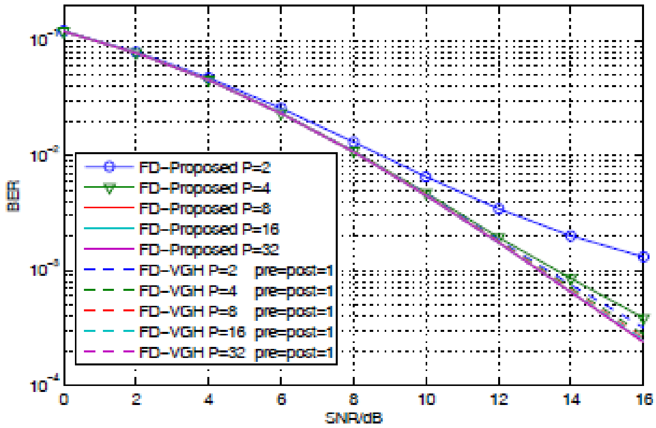

Figure 3: BER comparison of the FD-Proposed and FD- VGH in a VA channel, Doppler shift=100Hz.

When *P* is greater than 4, the FD Proposed has a similar performance as the exact algorithm. In a VB channel, *P* should be greater than 8 for the FD-Proposed to get a similar performance as the exact algorithm, because of the longer channel time dispersion and corresponding narrower coherence bandwidth, compared to a VA channel.

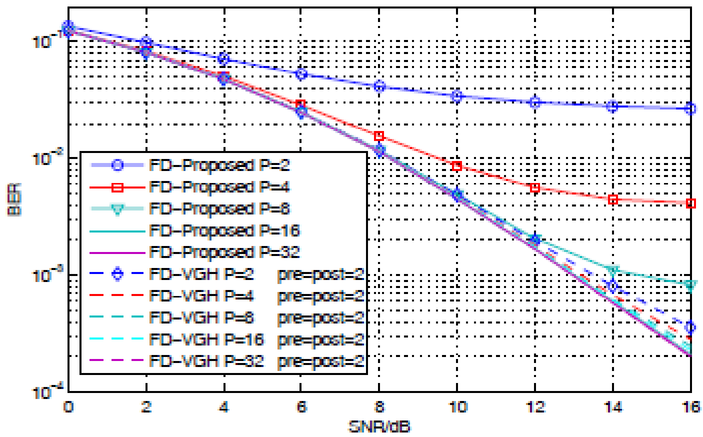

Figure 4: BER comparison of the FD-Proposed and FD-VGH in a VB channel, Doppler shift=100Hz.

5. Conclusion

In this paper, I propose a novel frequency domain multi-user detector for TD-CDMA systems. The proposed detector is based on a novel method for a block diagonalization of the system equation matrix, which enables using the channel frequency domain coherence to decrease its complexity at the expense of a controlled performance loss. The frequency domain correlation matrix and matched filter can be calculated not only in the frequency domain but also in the time domain by application of the proposed one-step time domain method.

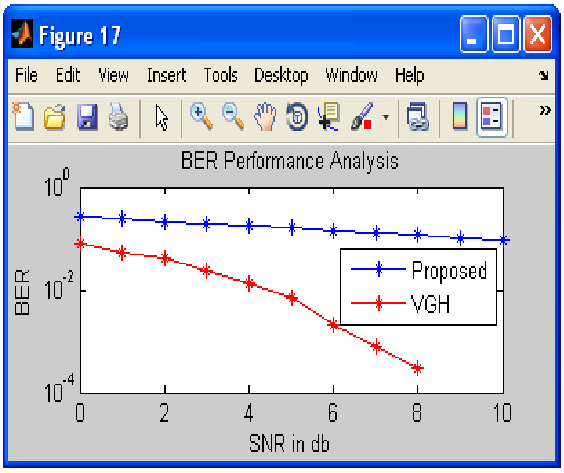

Figure 5: Bit Error Rate performance analysis of TD-CDMA system

It has been shown that the time domain method is superior in complexity to the conventional frequency domain approach, especially for short-time-dispersive channels. Numerical results have demonstrated that, with practical parameter configuration, the proposed detector has an acceptable performance and a 20% lower complexity compared to the best existing frequency domain detector for short-time-dispersive channels, typically encountered in real systems. Bit Error Rate performance analysis of TD-CDMA system is shown in the figure 5. The channel is simulated as a tapped delay line with a fixed delay. The FD-Proposed has a near optimal performance and thus out performs the FD-VGH, when the parameter $P \geq 8$, for the VA channel.

The FD-Proposed has an acceptable performance, but is even more superior in complexity over the FD-VGH than in the case of a long-time-dispersive channel. I conclude that this low computational complexity and acceptable performance in short time-dispersive channels makes the TD-CDMA system in frequency domain is suitable for wireless broadband communication. The TD-CDMA system is widely used in wireless broadband services.TD-CDMA, a proven technology that is available now for cellular operators and ISPs. TD-CDMA is part of the 3GPP umbrella, it is fully interoperable with existing UMTS-based networks and provides a migration path to mobile applications, enabling far more flexible use of available spectrum as well as the Quality of services (QoS) required by voice applications.

6. Future Enhancement

The TD-CDMA technology is well suitable for Pico n macro cell systems. TD-SCDMA is part of the 3G mobile communication standards IMT-2000 and UMTS. It is an improved narrowband variant of TD-CDMA. By introducing the advanced techniques step by step, e.g., MIMO, OFDM, AMC, distributed Antenna Array, Ad Hoc and cooperative relaying, distributed network architecture and scalable bandwidth, the evolved TD-SCDMA can provide much higher data rate with low latency, low cost with improved coverage and capacity The four key features of TD-SCDMA, which are low chip rate, uplink synchronization, smart antenna and baton handover. The TD-CDMA system uses the frequency domain concept in reducing the system matrix computational, where as the TD-SCDMA system uses the time domain signals for calculating the system matrix. Feature of the TD-SCDMA technique is Joint Detection (JD). This technique is used to combat the Multiple Access Interference (MAI) experienced in other CDMA-systems.

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Author Profile

Anees K A received the B. Tech degrees in Electronics and communication engineering from BIT Institute of Technology in 20009, respectively. During 2005-2009, He is currently pursuing Master degree, M. Tech (CMS) in Sree Vidyanikethan Engineering College, Tirupathi.