NONLINEAR AMPLIFIER DISTORTIONS

IN DS-CDMA SYSTEMS

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ABSTRACT

A well-known feature of the DS-CDMA technique is its small sensitivity to nonlinear distortions with respect to multicarrier systems. Indeed, when phase-shift keying (PSK) modulations are used, the single-user DS-CDMA signal is characterized by an almost constant envelope, and therefore the transmitting high-power amplifier (HPA) can work efficiently, i.e., close to the saturation, without introducing significant distortions. In this paper, we evaluate the symbol-error rate (SER) performance of linear multiuser detectors in downlink channels, taking into account the presence of a nonlinear HPA at the transmitter. We underscore that our aim is to outline the performance degradation induced by the HPA when multiuser detectors designed for linear scenarios are employed. More sophisticated detectors specially designed for nonlinear environments [ReZh][MeGe] are not considered herein. Firstly, we present a statistical characterization of the nonlinear distortions. Successively, we extend to the linear de-correlating detector (LDD) and to the MMSE detector some of the results obtained in [CDT] for the MF in AWGN channels. Moreover, the degradation induced by the nonlinear amplifier is analyzed in fading channels. For flat Rayleigh fading channels, a closed-form SER expression for the LDD is derived. For frequency-selective fading channels, a semi-analytic SER expression is obtained. We also evaluate the total degradation (TD), which is a parameter that allows to optimize the mean output power for a given HPA and a target SER. Simulation results, which validate the analytical approach, are presented for the RAKE receiver, the LDD, and the MMSE detector.

INTRODUCTION

The communication system has challenge of accommodating many users in a small area. The wireless domain is the current area of interest. The conventional systems used either frequency spectrum sharing or timesharing and hence there was the limitation on the capacity. With the advent of spread spectrum and hence CDMA, fixed bandwidth was used to accommodate many users by making use of certain coding properties over the bandwidth. But this system suffers from MAI (Multiple Access Interference) caused by direct sequence users. Multiuser Detection Technique is going to be the key to this problem. These detection schemes were introduced to detect the users’ data in the presence of Multiple Access Interference (MAI), Inter Symbol Interference and noise. Spread spectrum CDMA systems (DS/CDMA) are becoming widely accepted and promise to play a key role in the future of wireless communications applications because of their efficient use of the channel and there allowance for nonscheduled user transmissions. Hence recent interests are in techniques, which can improve the capacity of CDMA systems.
The focus of most current research is on Wideband CDMA (W-CDMA) or NG (next generation) CDMA. In W-CDMA, the multimedia wireless network will become feasible. Not only voice, but also images, video and data can be transmitted by mobile phones or other portable devices. Achieving a higher data rate and higher capacity are two major goals for W-CDMA, which makes the multiuser interference problem more and more crucial. As Mobile communication systems based on CDMA are inherently subject to Multiple-Access Interference (MAI), since it is impossible to maintain orthogonal spreading codes in mobile environments. MAI (Multiple-Access Interference) limits the capacity of Conventional detectors and brings on strict power control requirements to alleviate the Near-Far problem.

MOTIVATION and OBJECTIVE
Direct sequence code division multiple access (DS-CDMA) system is well known wireless technology. In DS-CDMA system, all of the users signals overlap in time and frequency cause mutual interference. This system suffers from Multiple Access Interference (MAI) caused by Direct Sequence users and near –far effect. The general structure of these detectors consists of a bank of matched filters. The detection is done on the basis of a filter matched to the pseudo-random sequence of the user. We refer to this detector as the conventional matched filter detector. Since the conventional matched filter was designed for orthogonal signature waveforms, it suffers from many drawbacks due to the MAI term which it does not take into account. Multi-user Detector (MUD) techniques exploit the character of the MAI by removal of the Multi-User Interference from each user’s received signal before making data decision, and thus offer significant gains in capacity and Near-Far Resistance over the conventional receiver. Verdu's work shows that optimum Maximum-Likelihood Sequence Detector can completely eliminate MAI, thus greatly increase CDMA system capacity. However, the complexity of the Optimum detector is exponential in number of users, which is too complicate for practical implementation. There have been great interests in finding sub optimum detectors with acceptable complexity and marginal performance degradation compared with the optimum detector. Sub optimum detectors can be classified into two linear multi-user detectors and subtractive interference canceller. Two of the most cited linear multi-user detectors are Decorrelating detector and MMSE detector. This work presents comparative study between linear multiuser detectors, and conventional single user matched filter in DS-CDMA system. Analysis and simulations are conducted in synchronous AWGN channel, and Gold sequence and kasami sequence are used as the spreading codes. Multiuser detectors derivation is presented for synchronous DS-CDMA systems. The synchronous assumption considerably simplifies exposition and analysis and often permits the derivation of closed form expressions for desired performance measures. These are useful since similar trends are found in the analysis of the more complex asynchronous case. Further more, every asynchronous system can be viewed as equivalent synchronous system with larger effective user population.

MEASURE OF PERFORMANCE
The probability of error of bit error rate (BER), as a function of the signal–to–Noise Ratio (SNR), is a common and essential figure of merit for a communication system, indicating the feasibility of reliable data transfer across the channel. The BER can be used as a metric to compare different communication systems. Throughout this work we utilize the BER as a measure of performance for the multiuser detection schemes.

LITERATURE SURVEY
S.R. Sheikh Raihan and B.C.Ng proposed that Direct sequence code division multiple access (DS-CDMA) is a popular wireless technology. This system suffers from multiple Access Interference (MAI) caused by Direct Sequence users and Near–Far effect due to different power levels received. Multi-User Detection schemes are used to detect the users’ data in the presence of
MAI and Near–Far problem. In this paper, presented comparative study between linear multiuser detectors and conventional single user matched filter in DSCDMA system. Analysis and simulations are conducted in synchronous AWGN channel, and Gold sequence is used as the spreading code. Simulation results describe the performance of Conventional detector, Decorrelating detector and MMSE (Minimum Mean Square Error) detector. It shows that the performance of these detectors depends on the length of PN code used and Number of users. Linear multiuser detectors perform better than the conventional matched filter in terms of BER performance.

Kavita Khairnar, and Shikha Nema proposed that DS-CDMA system is well known wireless technology. This system suffers from MAI (Multiple Access Interference) caused by Direct Sequence users. Multi-User Detection schemes were introduced to detect the users’ data in presence of MAI. This paper focuses on linear multi-user detection schemes used for data demodulation. Simulation results depict the performance of three detectors viz- conventional detector, Decorrelating detector and subspace MMSE (Minimum Mean Square Error) detector. It is seen that the performance of these detectors depends on the number of paths and the length of Gold code used.

S. Verdu proposed Minimum Probability of Error for Asynchronous Gaussian Multiple Access Channel Spread spectrum techniques originated in answer to the needs of military communications. They are based on signaling schemes which greatly expand the transmitted spectrum relative to the data rate. A transmission technique in which a pseudorandom code.

Spread spectrum techniques originated in answer to the needs of military communications. They are based on signaling schemes which greatly expand the transmitted spectrum relative to the data rate. A transmission technique in which a pseudorandom code, independent of the data, is employed as a modulation wave form to spread the signal energy over a band width much greater than the information signal band width is called SSM. The modulated output signals occupy a much greater band width than the signals base band information band width. To qualify has a spread spectrum signal, two criteria should be met.

MMSE detector generally performs better than the Decorrelating detector because it takes the background noise into account. With increasing in the number of users, the performance of all detectors will degrade as well. This is because as the number of interfering users increases, the amount of MAI becomes greater as well. Thus there is a trade of between the performances measures (BER vs. SNR). Depending on the situations, a suboptimum receiver satisfying the implementation constrains can be chosen. Multiuser detection holds promise for improving DS-CDMA performance and capacity. Although multiuser detection is currently in the research stage, efforts to commercialize multiuser detectors are expected in the coming years as DS-CDMA systems are more widely deployed. The success of these efforts will depend on the outcome of careful performance and cost analysis for the realistic environment.

**SPREAD SPECTRUM MODULATION**

An important issue in wireless communication systems is multiple random access: communication links can be activated at any moment while several links can be active simultaneously. As multi-access and random-access are properties mainly determined by the chosen data communication technique it is important to keep these requirements in mind from the very beginning. Three possible concepts to realize multi-access communication systems are in use.

**FDMA:**

Frequency Division Multiple Access commonly used in conventional telephone systems: every user gets a certain frequency band assigned and can use this part of the spectrum to perform its communication. If only a small number of users are active, not the whole resource (frequency spectrum) is used. Assignment of the channels can
be done centrally or by carrier sensing in a mobile. The later possibility enables random access.

TDMA:
Time Division Multiple Access applied nowadays in mobile phone systems: every user is assigned a set of time slots. Transmission of data is only possible during this time slot, after that the transmitter has to wait until it gets another time slot. Synchronization of all users is an important issue in this concept. Consequently, there must be a central unit (base station) that controls the synchronization and the assignment of time slots. This means that this technique is difficult to apply in random access systems.

CDMA:
Code Division Multiple Access (spread spectrum): a unique code is assigned to each user. This code is used to „code” the data message. As codes are selected for the cross correlation properties, all users can transmit simultaneously in the same frequency channel while a receiver is still capable of recovering the desired signal. Synchronization between links is not strictly and so random access is possible. A practical application at the moment is the cellular CDMA phone system.

SPREAD SPECTRUM MODULATION
Spread spectrum techniques originated in answer to the needs of military communications. They are based on signaling schemes which greatly expand the transmitted spectrum relative to the data rate.
A transmission technique in which a pseudorandom code, independent of the data, is employed as a modulation wave form to spread the signal energy over a band width much greater than the information signal band width is called SSM. This group of modulation techniques is characterized by its wide frequency spectra. The modulated output signals occupy a much greater band width than the signals base band information band width. To qualify has a spread spectrum signal, two criteria should be met.
1. The transmitted signal band width is much greater than the information band width.
2. Some function other than the information being transmitted is employed to determine the resultant transmitted band width.
The processing gain is the ratio of the bandwidth of the spread signal to the bandwidth of information bits:

$\text{PG} = \frac{B_s}{B_i}$

Where $B_s$ is the bandwidth of the spread signal and $B_i$ is the bandwidth of the information bit.

MULTI-USER DETECTION
BASIC PRINCIPLES OF MULTI-USER DETECTION:
The practical problem that often arises in CDMA is the fact that the code sequences are not completely orthogonal, either because they are chosen not orthogonal to avoid capacity limitation, or because the signal coming from each user at the receiver have a random delay, and thus the matched corresponding to one code will not totally suppress the interference caused by other signals. A conventional DS/CDMA system treats each user separately as a signal, with other users considered as noise or multiple access interference. This yields what is referred to as the near/far effect: users near the base stations are received at higher powers than those far away. Thus, those far away suffer degradation in performance. A tight power control is needed to overcome this problem, or one can use multi-user detection techniques. Multi-user detection considers all users as signals for each others, and detects them jointly. This leads to reduced interference, and alleviates the near/far problem.
The DS/CDMA receivers are divided into Single-User and Multi-User detectors. A single user receiver detects the data of one user at a time whereas a multi-user receiver jointly detects several users” information. Single user and multi user receivers are also sometimes called as decentralized and centralized receivers respectively.
MULTIUSER DETECTION RECEIVERS

There are two types of receivers:
1. Optimal receivers
2. Suboptimal receivers

Fig 1 Multiuser receivers

Optimal detector or maximum likelihood sequence estimation detector proposed by Verdu this detector is too complex for practical DS-CDMA systems. There are two categories of the most proposed detectors: linear multiuser detectors and non-linear detectors. In linear multiuser detection, a linear mapping (transformation) is applied to the Soft outputs of the conventional detector to produce a new set of outputs, which hopefully provide better performance. In non-linear detection, estimates of the interference are generated and subtracted out.

Figure 2 shows the general structure of multiuser detection systems for detecting each K user’s transmitted symbols from the received signal, which consists of a matched filter bank that converts the received continuous-time signal to the discrete-time statistics sampled at chip rate without masking any transmitted information relevant to demodulation.

Fig 2 A typical multiuser detector for DS-CDMA system

This is followed by applying multiuser detection algorithm for optimality conditions to produce the soft output statistics. The soft outputs are passed to the single user decoders. With the statistic \([y_1 \ldots \ldots \ldots y_k]\) at the output of the matched filter, an estimate for the transmitted bits \([b_1 \ldots \ldots \ldots b_k]\) that minimizes the probability of error can be found.

MAXIMUM- LIKELIHOOD (ML) SEQUENCE DETECTION

The ML criterion is based on selecting the input bit that minimizes the Euclidean distance between the transmitted symbol (corresponding to the input bit) and the received symbol. In the case of multi-user detection, the Euclidean distance between a transmitted symbol vector corresponding to the input bit-vector \(b\) and the received symbol vector is given by

\[
d(b) = \sum_{n=1}^{N} [y(n) - \sum_{k=1}^{M} A_k b_k s_k(n)]^2
\]

Expanding the above expression, we get:

\[
d(b) = \sum_{n=1}^{N} y(n)^2 - 2\sum_{k=1}^{M} y(n)s_k(n) + \sum_{n=1}^{N} \left( \sum_{k=1}^{M} A_k b_k s_k(n) \right)^2
\]
The first term in the expression is independent of $b$ and so it can be removed from the minimization process (instead we define a likelihood function ($b$) that differs from $d(b)$ by a constant). Using the definitions of $y_j$ in equation (4) and using the definitions of $A$ and $b$, the above expression can be simplified as:

$$\Omega(b) = -2Nb^T A y + Nb^T A R A b$$

Again, removing the common factor $N$ and using the fact that maximizing the negative of a function is the same as minimizing the function, the problem of optimal multiuser detection can be stated as:

Maximize $\Omega(b) = 2b^T A y - b^T A R A b$

Subject to $b \in \{+1, -1\}^M$

The maximization problem stated above is a combinatorial optimization problem, since the variables of the optimization problem are basically limited to a finite set. The straight-forward method for solving such combinatorial optimization problem is an exhaustive search over all the possibilities. In the above case, since $b \in \{+1, -1\}^M$, there are $2^M$ possibilities. (For Q-ary modulation, have Q N possibilities!). Thus the search space increases in a geometric fashion with the number of users. In other words, the complexity required for decoding $M$ bits of data is $Q(2^M)$. It has been shown by Verdu that no-other algorithm whose computational complexity is a polynomial in the number of users exists to solve this combinatorial optimization problem. The problem with MLS approach is that here there are $2^{NK}$ possible $d$ vectors; an exhaustive search is clearly impractical for typical message sizes and numbers of users.

**VALIDATION BY SIMULATION RESULTS**

Fig. 3 shows the SER of the LDD as a function of the SNR in AWGN channels, when an IPA is used. It is noteworthy the good agreement between the theoretical curves and the simulated points for all the OBO values. On the contrary, when the Saleh HPA model replaces the IPA (Fig.4), there is a good agreement at high back-off (OBO $\approx 4$ dB), while at low OBO values (OBO =1.72 dB) the simulated performance does not perfectly match with the theoretical one. Indeed, since the PDF of the NLD noise is not exactly Gaussian, the simulated SER slightly diverges from the theoretical one only when the NLD noise is dominant with respect to the AWGN, i.e., when the SNR is high and at the same time the OBO is not too high. However, the good agreement between simulated and theoretical performance at low SNR for any OBO values proves that the signal loss induced by the HPA is correctly modeled by the coefficient $|a|$. Moreover, for very low OBO values, (i.e., OBO $\approx 1$ dB), the Gaussian approximation is accurate, despite of the increased NLD noise. Fig. 3 shows the SER performance of the MMSE receiver in AWGN channels when the soft-limiter model is used for the HPA. Similar considerations holds true. It is also of interest to check the differences between analytical and simulated performance when the operating conditions are not exactly the ones assumed in the theoretical model. Specifically, we checked the model accuracy in three different conditions:

- The powers $\{2\}$ $k$ $A$ of the users' signals are not exactly equal;
- The number $K$ of active users is not high enough to assume a Gaussian PDF for the HPA input;
- The processing gain $N$ is not high enough to assume a Gaussian PDF for the NLD noise at the output of the detector.

Particularly, we focused on the two extreme scenarios with high and very low OBO values. To begin with the first case, we consider the situation with AWGN and IPA, even though analogous considerations hold true for other channels or amplifiers. In the first scenario, we assume that the power of the $K = 40$ users' signals varies in a linear manner, in such a way that the last user has double power with respect to the first user, which is the user of interest. In this case, the simulated performance exactly matches the analytical model when the OBO is high or very low, as shown in Fig. 6. In the second scenario, we assume that 20 out of 40 users, including the one of interest, have double power with respect to the others. In this case, at low OBO values, Fig. 7 presents a little
mismatch in the saturating point of the SER curve, as in Fig. 5. Moreover, Fig. 6 shows that the analysis is still accurate when the number of active (equal power) users is reduced to $K = 20$. However, when the base station attends a smaller number of users, e.g., $K = 10$ users, the HPA input is no more Gaussian. Therefore, when $\text{SER} < 10^{-4}$, the analytical results are pessimistic if compared with the simulated ones, as shown in Fig. 7. In Fig. 9, we assume that $N = 31$ and that $K = 20$ users are active. The simulation results exhibit good agreement with the analytical model also in such a scenario.

Fig. 3. PSD of the signal at the HPA output (Saleh model, $K = 40$, $N = 63$).

Fig. 4. SER of the LDD in AWGN channels (Saleh model, $K = 40$, $N = 63$).

Fig. 5. SER of the MMSE in AWGN channels (IPA model, $K = 40$, $N = 63$).

Fig. 6. SER of the LDD in AWGN (Signals with unequal powers, first scenario).

Fig. 7. SER of the LDD in AWGN (Signals with unequal powers, second scenario).
We have presented an analytical framework to evaluate the SER performance of linear multiuser detectors for DS-CDMA downlink systems subject to the nonlinear distortions introduced by the transmitting HPA. We have derived closed form expressions for AWGN and flat Rayleigh fading channels, and we have proposed a semi-analytical SER evaluation in frequency-selective multipath fading channels. Results for QPSK mapping with square-root raised cosine pulse shaping waveforms have been presented, and the OBO that minimizes the system TD has been evaluated. Simulation results have shown that the analytical model is quite appropriate in a large number of scenarios. Therefore, the proposed approach represents a valuable tool to predict the SER performance in the presence of nonlinearities, with a dramatically reduced computation time with respect to simulations, which require signal interpolation.

REFERENCES


Author Profile

V. Ajay Kumar received the M.Tech in DECS, Department of ECE from JNTU Kakinada in 2011. He is currently working as an Assistant professor, Department of ECE in Tirumala Engineering College Guntur. His current research interests include Array antennas, communications.

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