Flower Pollination Algorithm (FPA) Optimization based Multiuser Detection for DS-UWB Communication System

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Abstract - Ultra wideband (UWB) is a pulse based technology which is ideal for short range and low power transmission applications. UWB is spread spectrum technology. Multiuser detection has been a good approach to detect spread spectrum signals. Computational complexity is major issue with optimum multiuser detector. In this paper a novel optimization technique i.e. Flower Pollination Algorithm (FPA) has been applied to reduce computational complexity of optimum multiuser detector. Simulation results show that proposed detector performs with lesser complexity than Genetic Algorithm (GA) and Artificial Bee Colony (ABC) Optimization based multiuser detector.

Keywords - *Ultra wideband (UWB), Multiuser Detection (MUD), Flower Pollination Algorithm (FPA), Multiple Access Interference (MAI)*

I. INTRODUCTION

UWB technology has many features which make it an attractive scheme for spread spectrum communication. UWB is a pulse based system. In DS-UWB narrowband pulses of (<1ns) are transmitted [1-4]. Similar to conventional CDMA systems, Performance of DS-UWB is interference-limited. It is affected by multiple access interference (MAI), which occurs because user's signals no longer remain orthogonal in an asynchronous channel. It also gets influenced by Additive white Gaussian noise (AWGN) on the way from transmitter to the receiver, which is inherent in a wireless communication system. The MAI is usually the principal source of bit errors in a CDMA system.

MAI is a factor that limits the efficiency of a DS-UWB system [3-4]. MAI in a DS-UWB system occurs because of cross correlation between different bits of different users. In a synchronous environment, cross correlation between bits of different users is assumed to be zero when all the user's signals are perfectly orthogonal, but in a wireless environment orthogonality of different user's waveforms cannot be maintained so MAI occurs and in an asynchronous environment occurrence of MAI is inherent owing to different timing offsets between users. Frequency selective fading, non-linear power amplification and PAPR effect are some other factors which contribute to MAI. Frequently, with the change in amplitudes of different subcarriers their power levels also vary, which in turn increases inter subcarrier interference (ISI) and as a result MAI increases. We know that the best performance is given by optimum MUD which is based on maximum likelihood principle, but the biggest disadvantage with the optimum detector is that of computational complexity, because for a K number of users, it has to do 2^K comparison which is too complex[5-8]. Various other linear & sub-optimum detectors have been also proposed [9]. On the other hand evolutionary computational techniques give a more robust and less complex approach for solving complex MUD problems. Evolutionary techniques such as Genetic algorithm (GA) and Particle swarm optimization (PSO) and ABC [10-18] have been successfully applied on CDMA based systems to solve MUD problem.

In this paper a novel approach is used by applying a new optimization technique i.e. Flower Pollination Algorithm (FPA) which is based on [19-22]. Our objective here is to design an efficient and optimum detector based on FPA optimization which effectively reduces MAI. The rest of the paper has been presented as follows. In section II, multiuser detection is described. The algorithm FPA has been described in section III. DS-UWB receiver model is described in section IV. Simulation results have been discussed in section V and section VI is for conclusion.

II. MULTIUSER DETECTION

In a conventional method (matched filter detection) of detecting in a CDMA based system, MAI is not taken into account. This method is termed as single user detection where each user is detected separately and interference caused by other user is treated as noise but in multiuser detection interference from other user is used in detection of each individual user MUD [2-5] is basically a detection strategy which has been extensively researched in CDMA based systems and it has been proved to be a good technique to mitigate MAI and near far problem. Fig. 2 shows a multiuser detector where a number of matched filters are employed to detect corresponding bits and further these bits are processed by Multiuser detection algorithm which is based on maximum likelihood detection where a particular bit combination of all the users gives closest match of the estimated and received value.

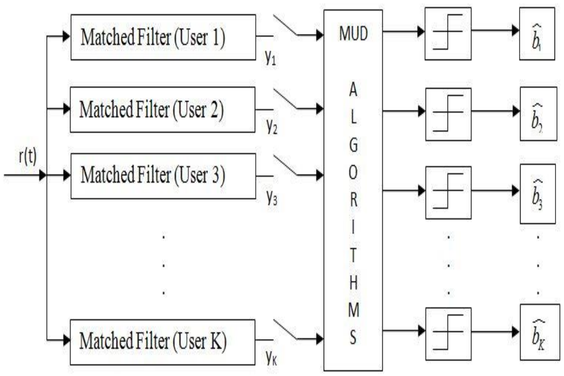

Fig.1: Multiuser Detection

A multiuser detector utilizes the information available in MAI term to detect the signal and not treat it as a noise. A multiuser detector has to do 2^K comparisons for K number of users to give the best combinations of detected bit of all users. The optimum estimate of $\hat{b}$ will minimize the probability of error. The received signal r(t) is the sum of received signals for all K users, plus noise. For K number of users in a synchronous DS-UWB system, the outputs of matched filters as shown in Fig. 1, can be given as $y = [y_1, y_2, \ldots, y_K]$.

In the matrix form,

$$y = RAb + n \tag{1}$$

where b is a vector of K user's symbols i.e.

$$b = [b_1, b_2, \ldots, b_K]^T$$

A is a diagonal K×K matrix of user's amplitudes

R is a K×K cross correlation matrix of the user's spreading sequences.

n is additive white gaussian noise (AWGN), it can be given as $n = [n_1, n_2, \ldots, n_K]^T$

Now the optimum(maximum likelihood) detector of data vector b is given as

$$\hat{b} = \arg \min_b |y - ARb|^2 \tag{2}$$

Where the notation arg $\min_b$ refers to the value of b that minimizes the quantity within braces. This method searches all possible b vectors to determine the one that minimizes the square error between matched filters outputs y and the predicted value. So we have to choose $\hat{b}$ such that estimated signal is closest to the received signal. The optimum estimate of $\hat{b}$ will minimize the probability of error. The equation above can be further written as:

$$\hat{b} = \arg_{b\in\{-1,1\}} \max\left(2b^T y - b^T ARAb\right) \tag{3}$$

III. FLOWER POLLINATION ALGORITHM (FPA)

Flowering plants has been evolving for at least more than 125 million years. It is estimated that there are over a quarter of a million types of flowering plants in nature and that about 80% of all plant species are flowering species. It still remains a mystery how flowering plants came to dominate the landscape from cretaceous period [19-21]. The primary purpose of a flower is ultimately reproduction via pollination. Flower pollination is typically associated with the transfer of pollen, and such transfer is often linked with pollinators such as insects, birds, bats and other animals. In fact, some insects and certain flowers have co-evolved into a very specialized flower-pollinator partnership. For example, some flowers can only depend on a specific species of insects or birds for successful pollination.

Abiotic and biotic pollination are two main forms in the pollination process. About 90% of flowering plants belong to biotic pollination. That is, pollen is transferred by a pollinator such as insects and animals. About 10% of pollination takes abiotic for which does not require any pollinators. Wind and diffusion help pollination of such flowering plants, and grass is a good example of abiotic pollination. Pollinators, or sometimes called pollen vectors, can be very diverse. It is estimated there are at least about 200,000 varieties of pollinators such as insects, bats and birds. Honey bees are a good example of pollinator, and they have also developed the so-called flower constancy. That is, these pollinators tent to exclusive certain flower species while bypassing other flower species. Such flower constancy may have evolutionary advantages because this will maximize the transfer of flower pollen to the same or nonspecific plants, and thus maximizing the reproduction of the same flower species such flowers constancy may be advantageous for pollinators as well, because they can be sure that nectar supply is available with their limited memory and minimum cost of learning, switching or exploring .rather than focusing on some unpredictable but potentially more rewarding new flower species , flower constancy may require minimum investing cost and more likely guaranteed intake of nectar.

By a close look into the world of flowering plants, pollination can be achieved by self-pollination or cross-pollination. Cross-pollination, or allogamy, means pollination can occur from pollen of a flower or a different plant, while self-pollination is the fertilization of one flower, such as peach flower, from pollen of the same flower or different flowers of a same plant, which often occurs when there Is no reliable pollinator available. Biotic, cross-pollination may occur at long distance, and the pollinators such as bees, bats, birds, and flies can fly a long distance, thus they can considered as the global pollination. In addition, bees and birds may behave as levy flight behavior, with jump or fly distance steps obeying a levy distribution. Furthermore, flower constancy can be considered as an increment step using the similarity or difference of two flowers. From the biological evolution point of view, the objective of the flower pollination is the survival of the fittest and the optimal reproduction of plants in terms of numbers as well as he most fittest.

A. Flower Pollination Algorithm

Following rules describe the FPA:

1. Biotic and cross-pollination can be considered as a process of global pollination process, and pollen-carrying pollinators move in a way which obeys levy flights [rule1].
2. For local pollination, abiotic and self-pollination are used [rule2].
3. Pollinators such as insects can develop flower constancy, which is equivalent to a reproduction probability that is proportional to the similarity of two flowers involved [rule3].
4. The interaction or switching of local pollination and global pollination can be controlled by a switch probability $p \in [0,1]$, with a slight bias towards local pollination [rule4].

B. Flower Pollination Algorithm with MUD

Step 1: Give input for Number of users, Number of bits per user, and power level of each user.

Step 2: Generate gold codes and signature sequence for all the users. Build cross correlation matrix on the basis of generated gold codes.

Step 3: Generate a bit stream for all the users to be transmitted and build a composite signal and transmit it using the gold codes from step 2.

Step 4: Detect the received noisy signal using the Matched filter

$$y = \mathrm{sgn}(RAb + awgn)$$

Step 5: Output from Matched filter is given to the MUD Detector. And the objective function for Flower Pollination Algorithm is equation/criterion of the detector as described below

$$b_{MUD} = \max(2b'Ay - b'ARAb)$$

Step 6: Set the parameters of FPA by considering the population size equal to number of bits per user in the problem, considering the number of parameters to be optimized equal to the number of users, lower bound & upper bound of parameters to be optimized equal to -1 and +1 respectively, number of iterations equals to 30, switch probability p equal to 0.8.

Step 7: At a time one bit of each user is considered as a parameter of objective function to be optimized. So number of parameters of problem to be optimized is considered as number of users.

Step 8: In the initialization phase of FPA, from the output of MUD Detector assign one bit of each user as an initial solution to one member of population which will be 1 X K vector having values either -1 or +1. And then assign the rest of the members of population, their initial solutions by changing randomly values in these bits.

Step 9: Then calculate fitness of all initial solutions and find best of these.

Step 10: Start iterations for flower pollination. According to the switch probability find new solutions for whole members of the population. And evaluate these new solutions and find best solution at the end of iteration.

Step 11: Repeat step 8 to 10 for whole number of bits and calculate the bit error rate after detecting the whole bits.

Step 12: Repeat step 5 to 11 for different values of signal to noise ratio.

IV. THE PROPOSED DS-UWB MULTIUSER DETECTOR

In a DS-UWB system, each bit is coded and simultaneously transmitted on multiple pulses thus achieving frequency diversity and system becomes immune to multipath fading. In this way DS-UWB system is similar to multicarrier CDMA system where each data symbol is transmitted on different subcarrier simultaneously. Equation 1 represents the binary DS-UWB system.

$$S^m(t) = \sum_{k=-\infty}^{\infty} \sum_{j=1}^{N} \omega(t - kT_d - jT_c)(C_P)_j^{(m)} d_k^{(m)} \qquad (4)$$

where k represents k^{th} bit number , $d_k^{(m)} \in \{-1,+1\}$ denotes user m^{th} information bit in the f^{th} frame, the frame duration is T_f, where $T_f = MT_C.(C_P)_j$ is the j^{th} spreading chip of the pseudorandom code. $\omega(t)$ is the pulse waveform with main-lobe duration T_C. N represents the number of pulses to be used per data bit. Bit length $T_d = NT_C$. The pseudo-random codes can take values {-1,+1} and are used to separate users.

The total received signal composed by different signals of all users is

$$r(t) = \sum_{k=1}^{K} A_k S_k(t) + n(t) \qquad (5)$$

Where A_k is the amplitude of kth received signal and n(t) is additive white Gaussian noise with zero mean and power spectral density N_0

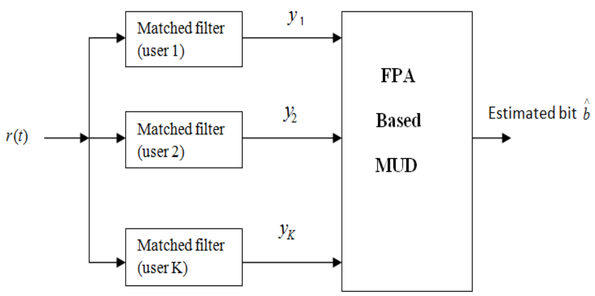

Fig.2: DS-UWB MUD Receiver with FPA

V. SIMULATIONS

For the simulation purpose, a total of 16 numbers of users are taken. Channel is AWGN and 31 bits gold sequence has been used as the spreading codes. Following parameters have been taken for evaluating the performance of a DS-UWB system.

1. Total number of subcarriers taken is 31.
2. Since the channel is asynchronous (uplink) so every subcarrier goes for independent multipath fading.
3. Perfect subcarrier synchronization with no frequency offset is assumed.
4. It is assumed that there is no non-linear distortion.
5. QPSK (quadrature phase shift keying) modulation is used.

In the simulation 10,000 bits per user has been transmitted and these bits are received by different multiuser detectors. Three parameters i.e. BER performance, computational complexity and system capacity is evaluated.

A. BER performance

As it can be observed from the Fig. 3, BER performance of optimum detector is best among all other detectors but to achieve this performance it has to perform 2^K number of iterations which is a large number with 16 users. It can be easily seen that FPA based optimum detector gives BER performance very close to optimum detector and even at some points it overlaps with optimum detector. Performance of FPA based optimum detector is superior than both GA based detector and ABC based detector. Like ABC, FPA also do not perform any selection, crossover and mutation operation as done in GA. Reason for such a performance by FPA is the 2-dimensional initial population and lesser number of control parameters as compared to GA and ABC.

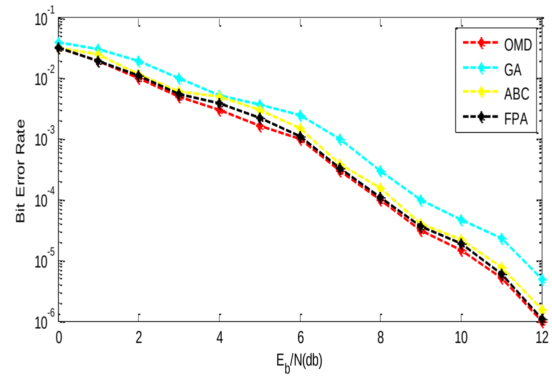

Fig.3: BER performance of GA-MUD, ABC-MUD, FPA-MUD and optimum MUD

B. Computational complexity

Computational complexity has been a major issue with the optimum detector and for this very reason this detector is not preferred for practical implementation. Optimum detector will have to perform 2^{16} number of calculations to select the desired bit vector for one bit period. It can be clearly observed from the Fig. 4 that FPA detector converge in only 30 iterations whereas ABC detector takes 40 and GA based detector takes around 50 iterations. Computational complexity is an important factor in cellular mobile communication as DS-UWB systems are meant to provide high data rates. It can be seen from Fig. 4 that by using FPA based MUD computational complexity can be reduced to around 73% as compared to optimum detector.

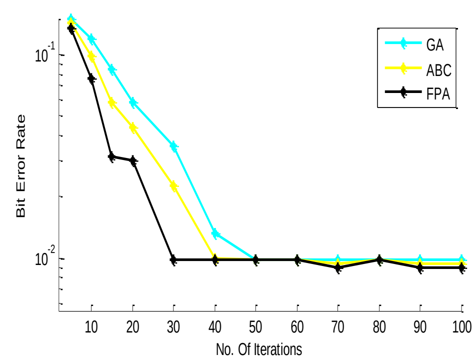

Fig.4: Computational complexity of GA-MUD, ABC-MUD and FPA-MUD

C. System capacity

System capacity of a cellular mobile system represents the maximum number of users(subscribers) supported by it and a dynamic system must support a large number of users in a cell site. Fig. 5 shows the BER comparison with different number of users. It can be observed that FPA based MUD gives near optimal performance as curve of FPA coincides with that of optimum detector at many points. It indicates that for the same amount of BER a FPA based MUD can accommodate a large number of users as compared to GA based MUD and ABC based MUD.

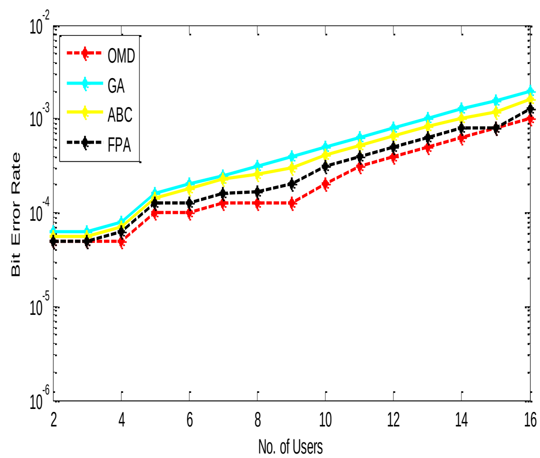

Fig.5: Convergence comparison of GA-MUD, ABC-MUD and FPA-MUD

VI. CONCLUSION

In this paper FPA algorithm has been applied on multiuser detection for a DS-UWB system. FPA based multiuser detector outperform multiuser detectors based on GA, ABC and optimum detector. Detectors are compared taking three parameters i.e. BER performance, computational complexity and system capacity. FPA is a novel optimization technique and has not been explored and exploited to its full potential yet. Moreover different versions of this algorithm should be developed to better optimize a given problem.

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