Performance Enhancement of Digital Communication Systems Using Fuzzy Logic

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ABSTRACT

The objective is to study the various fuzzy logic techniques being used for minimization of Multiple Access Interference (MAI) in CDMA. These techniques will be compared and their applicability for the enhancement of digital communication systems with different modulations will be explored. An attempt will be made to develop some new methods and techniques using fuzzy logic for the enhancement of CDMA based and other digital communication systems as well. Parameters common to different communication systems will be located and fuzzy logic will be applied considering those parameters for the enhancement of the system performance. Simulation will be done to show the consistency of improved efficiency.

Keywords: Code Division Multiple Access, Fuzzy Inference System, Spread spectrum, Parallel Interference Cancellation, Time Division Multiple Access

1. Introduction

CODE-DIVISION multiple access (CDMA) is a well-known scheme for multiplexing communication channels that is based on the method of direct-sequence spread spectrum [1]. The essential difference between CDMA and other multiplexing methods, such as time-division multiple access (TDMA) and frequency-division multiple access (FDMA), is that in CDMA, the resource allocated per channel is power, as opposed to time or bandwidth.

The Direct-sequence Code-division multiple access (DS-CDMA) cellular communication system is one of the favorite candidates for the third generation of radio cellular communication systems due to its high potential capacity. However, there are two main shortcomings in a CDMA system. One is multiple access interference (MAI) due to the simultaneous transmission of all users in the same band and asynchronous received signals with non-orthogonal random sequences for the uplink. The other shortcoming is the near-far problem, which can be diminished by a power control scheme or even fully eliminated by a perfect power control method. Nevertheless, the goal of perfect power control is hard to reach and even though it can be fulfilled, the MAI still degrades the performance especially for a high system load. Thus the aspect of interference suppression or cancellation is an imperative perspective.

New techniques to suppress narrow-band and multiple-access interference for spread-spectrum (SS) systems are continually being researched for use in the growing cellular CDMA market. Making CDMA system intelligent is one of them. Intelligent systems require the capabilities for evolution, adaptation and learning. Intelligent systems can be made by the different methods, such as Fuzzy Logic, Neural Networks and Evolution Computation. Each method plays specific role in intelligent systems. As one of the principal constituents of soft computing, fuzzy logic is playing a key role in what might be called high MIQ (machine intelligence quotient) systems.
Fuzzy Logic is a practical mathematical addition to classic Boolean logic. The fuzzy inference system (FIS), which is based on the principle of fuzzy logic developed by Zadeh [1], is a decision-making logic and is used to handle the linguistic concepts. The FIS has drawn a great deal of attention because of its universal approximation ability in the nonlinear problem [2].
A lot of work has been done to increase the performance of CDMA systems in wireless communication channels. It is proposed to extend this work to various guided and wireless digital communication systems.

2. Literature Review

2.1 Fuzzy Logic

The concept of fuzzy logic was first introduced by Zadeh, whose classic paper has become the philosophical bible in the field [1]. The concept is simple: set membership, and indeed reasoning of any sort, carries more information when there are a continuum of grades membership. The reasoning is based on Zadeh's Principle of Incompatibility [3], which maintains that high precision is incompatible with high complexity. The suggestion is that the complexity of a system and the precision with which it can be analyzed bears a roughly inverse relation to each other. He asserted that since real world ideas appear to be fuzzy in nature, there is reasonable cause for adapting this approach to machines.

Fuzzy logic is considered as a superset of standard logic which is extended to deal with the partial truth. It has become one of the most successful technologies for developing complex control systems. Fuzzy logic is a design methodology that can be used to solve real life problems. Fuzzy set theory resembles human decision making in its use of approximate information. It was basically used to mathematically represent uncertainty and vagueness and provide tools to deal with the imprecision in many problems [4].

A fuzzy logic controller consists of fuzzifier, inference engine, fuzzy rule base, and de-fuzzifier. The fuzzifier transforms the values of the input parameters into the fuzzy linguistic terms through a set of membership functions [4]. These fuzzy linguistic terms are the inputs of the inference engine, which will perform the logic inference according to the fuzzy rule base. The fuzzy inference machine is a decision making logic which employs fuzzy rules from the fuzzy rule base to determine fuzzy outputs of a fuzzy system corresponding to the fuzzified inputs [2]. The defuzzifier converts the results of the inference into the usable values for decisions. Having knowledge about the input-output relations, the fuzzification interface and fuzzy rule base of the fuzzy system can be established. Fuzzy logic techniques have been applied to many systems which are nonlinear, time-varying, or non-stationary [2]. A fuzzy logic system has the advantage of lower development costs, superior features and better end product performance [5-17].

2.2 Fuzzy Logic in CDMA

The application of fuzzy logic techniques has been increasing rapidly in the last few years. Its implementation can be seen in many branches of engineering. Communications and networking has been able to use the fuzzy logic for ATM network traffic modeling, management, and rate control as well as nonlinear channel equalization, telecommunication ranking and network admission control, [18-39]. In a wireless system, the channel situation could be variable caused by many factors, so the controller has to be capable of adapting to the changes of channel and to be more aggressive to upgrade the utilization. Author has studied the recent and direct applications of fuzzy logic to reduce MAI in CDMA.

2.2.1 Fuzzy Interference Cancellation

Multistage parallel interference cancellation (PIC) is an effective method to cancel the MAI for equal-power channels; nevertheless, there was a significant degradation in performance for non-equal power ones. To improve the interference cancellation effect, Divsalar et al. [40] added a weight to each interference cancellation path. When all the weights are the same, it is called the constant weight PIC (CWPIC) scheme. However, the optimal weights of interferers depend on their reliability, respectively.
Lei Xiao and Qinglin Liang [33] presented an idea for a parallel interference weighted canceller (PIWC) to mitigate the degrading effects of unreliable interference estimation that was the key shortcoming of the total interference canceller. The computational complexity of the proposed scheme was linear in the number of users and only a little more than that of the total PIC resulting in the great practicability of PIWC. The determinate weighting and fuzzy weighting were studied based on Gaussian approximation. Simulation results confirmed that the PIWC was better than the total PIC and the fuzzy weighting was better than determinate weighting.

Huang and Wen [34] proposed the adjustment of the weights of interfering users according to their reliability estimated by the fuzzy inference mechanism, so that the error propagation would be minimized. They observed from simulation results that fuzzy PIC served a better performance over a large range of system traffic; especially, it was superior to the conventional PIC in the high load while it was better than CWPIC in the light load. In addition, the fuzzy PIC was more robust to the variation of system capacity compared to the conventional PIC and the CWPIC.

Wen and Huang [35] put forward the idea that multistage PIC scheme was an effective method for the multiuser detection in the DS-CDMA systems, but the performance still suffered degradations in the near-far situations. They gave the concept of partial PIC (PPIC), which tried to reduce the cancellation error due to the wrong interference estimations in the earlier stages, and hence outperformed the conventional PIC (CPIC) when the system load was high. An adaptive fuzzy inference mechanism was proposed to generate the adequate cancellation weights for the multistage PPIC by using the measured SNR and signals' amplitudes, which reveal the reliability of the received signals. Simulation results proved that the proposed fuzzy-based PPIC (FB-PPIC) detector was more robust over the fading channels and was more near-far resistant than both the CPIC and constant weight PPIC (CW-PPIC) schemes.

Tseng et al [36] proposed a fuzzy PIC multiuser detection/vector channel prediction scheme in Rayleigh fading channels. The vector channel prediction was based on the first-order auto-regressive model and the expectation-maximization algorithm. The signal-to-interference ratio and signal-to-noise ratio were estimated from the vector channel model's parameters, and they adapted the weight of each interference cancellation path via fuzzy inference mechanism. The proposed fuzzy PIC and vector channel prediction cooperated in a way that fuzzy PIC' some input parameters came from the channel predictor and fuzzy PIC made the channel predictor more accurate at the next stage. Computing weights via the fuzzy adaptive method added insignificant complexity because it involved only table lookup. The overall complexity was still linear in the number of users. The simulation results showed that the proposed fuzzy PIC/vector channel prediction scheme performed better than previous improved PIC schemes in Rayleigh fading channels.

Shibuya and Shigeo [37] proposed a method for reducing additive narrowband signal, impulsive noise and direct sequence code division multiple access (DS-CDMA) interferences simultaneously in multi-carrier DS-CDMA (MC-DS-CDMA) communication systems. A fuzzy denoising scheme based on the Haar wavelet decomposition was applied to the interference reduction problems for MC-DS-CDMA systems. The computational load with the Haar function was very small and the interferences in time and frequency domains were effectively suppressed by selecting fuzzy reasoning parameters.

Naidoo and Rooyen [38] investigated the feasibility of using a fuzzy logic technique to adapt the MMSE detector for the suppression of narrow-band interference (NBI). The fuzzy logic adaptation (FLA) technique was described and its performance was compared to the least-mean-square (LMS) and the recursive-least-square (RLS) adaptive algorithms. It was found that the fuzzy logic technique considered gave a performance improvement over the conventional and adaptive algorithm, while it failed to match the performance of the RLS adaptive algorithm.

Seoyoung Lee and Dickerson [39] proposed Fuzzy hybrid interference suppression for DS-CDMA systems in non-Gaussian impulsive channels. From them we know that a fuzzy hybrid detector can suppress multiple-access interference (MAI) in direct-sequence code-division multiple-access (DS-CDMA) systems in the presence of additive non-Gaussian impulsive noise. They proposed hybrid detector which combined the adaptive minimum dispersion (MD) detector and the hard-limiting matched filter (HLMF) detector. They opined that the adaptive MD detector had good near-far resistance in the presence of additive non-Gaussian impulsive noise modeled as a symmetric alpha-stable (S alpha S) process where as the HLMF detector performed well when the additive impulsive noise dominated the MAI. They showed by simulations that the hybrid detector performed better than the adaptive MD detector in non-Gaussian impulsive noise-limited environments and the fuzzy hybrid detector had nearly the same performance as the adaptive MD detector in MAI-dominated environments.

2.2.2 Fuzzy Call Admission Control

In CDMA systems, number of users that each cell can support is limited by the total interference received at each base station and will vary with time. When a system is congested, admitting a new call can only make the link quality worse for ongoing calls and may result in call dropping. Thus the system needs a CAC (call admission control) policy for new calls and handoff calls to maintain acceptable connections for existing users. MUD provides a method to reduce the MAI of users in the local cell, which usually dominates the communication quality and capacity. For a WCDMA cellular system using MUD, the local cell interference will be significantly decreased by MUD and then adjacent cells' MAI takes a more dominant position in communication quality. Therefore, traffic control mechanisms for WCDMA with MUD should be reconsidered, especially when adjacent cells have accommodated more users.

Chen, Chang and Shen [10] proposed a new design for outage-based call admission control (CAC) for WCDMA systems with SIC MUD. They put forward the idea that traffic behavior turned to be different when it had been processed by MUD, and hence it was more significant to consider the traffic behavior at MUD instead of at the antenna. They considered the performance of the outage probability of each user, which was much fairer than Sin-based CAC and it inspired higher capacity of the system. The technique of fuzzy logic was also applied in the CAC; they showed that by constructing a proper rule base for the fuzzy CAC (FCAC), the efficient admission control could be achieved to maximize the system utilization. For the outage-based fuzzy call admission control, they assumed three estimators, (A)Home Cell Worst SIR Estimator, (B) Outage Probability Estimator, and (C)Adjacent Cell Worst SIR Estimator. Twenty seven rules were made in which the short-term parameter, Outage Probability Estimator was treated in a looser requirement, while other parameters were set to be stricter because they implied a mean quality of service in the system. The fuzzy inference algorithm was max-min inference method. The defuzzification method used was center of area defuzzification method to obtain the final decisions of acceptance or rejection.

Simulation results showed two subjects of comparisons. First they compared the capacities between FCAC with MUD and FCAC with the conventional RAKE receiver. The capacity improvement of FCAC with MUD over FCAC with RAKE was by an amount of 21%. They also compared with FCAC with MUD to a SIR-based CAC with MUD. It was found that the utilization of the FCAC was about 10% higher than that of the SIR-based CAC when satisfying the constraint of QoS. Besides, FCAC kept QoS guaranteed, while SIR-based CAC did not be-cause of the inadequate decision information reflecting the variety of traffic. They concluded that FCAC adopted a more aggressive and pre-cise strategy so that there was a conspicuous improvement.

Anding Zhu and Jiandong Hu[51] proposed a novel adaptive call admission control (CAC) policy, which could adjust the CAC threshold dynamically according to the current traffic load in local and neighboring cells and handoff users density by employing the equivalent capacity demand estimation and fuzzy guard channel capacity estimator. The results of computer simulation indicated the method was more efficient and simpler than previous policies.

Chung-Ju Chang et al [52] proposed intelligent call admission control for wideband CDMA cellular systems to support differentiated QoS requirements. The intelligent call admission controller (ICAC) adopted fuzzy and neural network techniques to make admission decision for a new call request by considering the QoS measures of all service types, predicted next-step existing-call interference, and estimated new-call interference. It contained a fuzzy call admission processor, a pipeline recurrent neutral network (PRNN) interference predictor and a fuzzy equivalent interference estimator. Simulation results indicated that ICAC attained better performance in keeping QoS guaranteed, blocking probability and admitted number of users. In addition ICAC was found to be more adaptive and stable than SIR-based CAC in wideband CDMA cellular systems.

Xu Li , Hu Xiaodong and Wang Jianfang [53] proposed a kind of intelligent CAC policy, which could adjust the CAC algorithm and its threshold according to the current traffic load in local and neighboring cells, and handoff user density etc. by fuzzy inference, system-level simulation and self-learning, and increased the whole system performance.

Jun Ye et al [54] proposed a novel call admission control (CAC) scheme using fuzzy interference for a wideband code division multiple access (CDMA) cellular system. The fuzzy CAC first estimated the newly arriving mobile station's (MS) effective bandwidth and its mobility information, and then made a decision to accept or reject the MS's connection request based on the estimates and the system status. Numerical results were given to demonstrate the performance of the proposed fuzzy CAC scheme in terms of new call blocking probability, handoff call dropping probability, outage probability and resource utilization.

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