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論　文　名	「Self Organization Techniques for Orthogonal Frequency Division Multiplexing Wireless Communication Systems（OFDM 無線通信システムを対象とした自己組織化技術の応用に関する研究)」
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論文要旨

The rapid growth of wireless communications such as wireless multimedia, wireless Internet access and future-generation mobile communication systems have produced a strong demand for advanced wireless techniques and new methods of obtaining high capacity wireless communication systems. Orthogonal Frequency Division Multiplexing (OFDM) has emerged as one of the main modem schemes for high capacity wireless network. The main design challenge of wireless communication is the ability to combat InterSymbol Interference (ISI), a major problem in wideband transmission over multipath fading channels. There are many methods proposed to combat the ISI. Multicarrier modulation techniques, including OFDM are among the more promising solutions to this problem. The principle of Frequency Division Multiplexing (FDM) is to allow multiple messages to be sent over a single radio channel. It is however in a much more controlled manner with an improved spectral efficiency. OFDM is a highly efficient form of FDM. Carriers are more closely spaced than in conventional FDM systems because they are mathematically orthogonal. Therefore, no guard intervals are required. Inter Carrier Interference (ICI) are also avoided due to the orthogonal nature of the modulation.The broadband OFDM signal is simply a combination of many lower-rate carriers.OFDM has an excellent robustness in multi-path environments.Because the Cyclic Prefix (CP) preserves orthogonality between sub-carriers and the CP allows the receiver to capture multi-path energy more efficiently. OFDM has an inherent

robustness against narrowband interference. Narrowband interference will affect at most a couple of subchannels. Information from the affected subchannels can be recovered via the Forward Error Correction (FEC) codes. Equalization in OFDM is very simple compared to single-carrier systems.OFDM has some drawbacks. That is OFDM is sensitive to frequency, clock offsets, phase offsets and also it has a high sensitivity to ICI.The OFDM time-domain signal has a relatively large Peak to Average Power Ratio (PAPR) and it tends to reduce the power efficiency of the High Power Amplifier (HPA). Nonlinear amplification in the HPA destroys the orthogonality of the OFDM signal and introduces out-of-band radiation.

Orthogonal Frequency Division Multiple Access (OFDMA) is currently being considered as a modulation method and multiple access method for 4th generation wireless networks. OFDMA is an extension of the well known concept of OFDM, which is currently used as the modulation of the high speed data access systems. In OFDMA, the total available bandwidth is shared by a number of users. Each user is assigned a subset of the total bandwidth. Those users utilize different modulation, coding and power control methods, adaptively based on their respective channel conditions. Therefore, OFDMA has a better capacity than fixed resource allocation methods, such as Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). An another advantage of OFDMA over OFDM with TDMA and OFDM with Code Division Multiple Access (CDMA) is the elimination of intra-cell interference, avoiding CDMA type of Multiuser Detection (MUD). Adaptive resource allocation schemes in such OFDMA transmissions use perfect Channel State Information (CSI). Instantaneous CSI is obtained by the base station transmitter through feedback channels from all the users. The reliability of the CSI is a vital factor in such adaptive resource allocations. CSI is not optimal due to various impairments in a feed back path such as transmission delays, computing delays and also the noise attenuation Additive White Gaussian Noise (AWGN) in low signal power levels. Therefore, CSI should be predicted accurately, several milliseconds ahead.

Multicarrier Code Division Multiple Access (MC-CDMA) system is a combination of CDMA and OFDM resulting robustness against frequency selective channel fading. Frequency diversity in MC-CDMA is obtained by spreading a symbol to multicarriers. However, Direct Sequence Code Division Multiple Access (DS-CDMA) signals have a wide bandwidth and can be subjected to frequency elective multipath fading. If the data rates are increased to overcome this problem, then the frequency spread gets wider and a more complex RAKE receiver is required. Multi User Interference (MUI) plays an important role to degrade the performance of the above mentioned CDMA systems. MUI

can be mitigated by using MUD.

OFDM has many good properties that make it an attractive modulation for high data rate transmission. However, it has also some inherent disadvantages, as mentioned in the previous sections.The objective of this research is to provide a new self organizing approach to solve some problems in OFDM, such as nonlinear distortion caused by the HPA, CSI prediction in OFDMA and MUD in MC-CDMA.

The difficulty in system identification algorithms is the size of the possible system function space, which creates a need for the reliance of the algorithm on large amount of a priori knowledge or strong assumptions about the process which might not hold true. It is necessary therefore to create algorithms which are not dependent on this type of knowledge but rely mostly on the observed data behavior and could incorporate this knowledge when available. This leads to the adoption of self organizing structures in the design neural networks, since fixed structure algorithms present the same problems as parameter estimation algorithms, in which the assumed model is either an under or overestimation of the true process. If the elementary function of the nodes are permitted to be general enough to minimize the prior assumptions and a self organized rule is rich enough to capture the complexity of the underlying process, then the simplest model can be found. We use Self Organizing Map (SOM), neural networks, Wavelet Neural Network (WNN) and hybrid of the above methods to tackle and solve the above mentioned problems in OFDM.

Chapter 1 introduces the concept of OFDM, OFDMA and MC-CDMA. Also an outline of their advantages and disadvantages is given. The basic concept of self organizing techniques is also presented. This helps to get an overview the thesis.

Chapter 2 explains the self organizing concept in detail and gives a detail explanation of the neural networks what we have used to design the self organizing techniques. A detailed explanation of OFDM, OFDMA and MC-CDMA communication systems is given. Nonlinear distortions, CSI prediction and MUD are explained. The traditional methods and some neural network based methods to solve the above mentioned problems are explained.

Chapter 3 presents a new method of HPA independent adaptive nonlinear distortion compensator for uncoded OFDM signals, which operates at the OFDM receiver end. The compensator is based on a cascade version of a Functional Link Neural Network (FLNN) and a Self Organizing Map(SOM), which compensates the HPA nonlinearities with memory effect. Here, the SOM is used as a self organizing detector at the receiver. In general, pattern classifiers such as SOM and FLNN utilize considerable amount of training data and time in the training phase. An increase number of training data

reduces the useful data bandwidth of an OFDM system. Therefore, a combined neural network structure of a FLNN and a SOMis designed to train using minimum training symbol utilization. Practical OFDM systems use pilot symbols to do channel estimations. We use scattered pilot configuration to train the system adaptively and the equalization is done for each subcarrier. Here we plan to deploy a SOM pattern classifier as an adaptive detector with nonlinear decision boundaries. FLNN is used to preprocess the input signal and this helps to reduce the effect of ISI and the noise scattering. This governs a less probability of misclassification at the SOM. First the FLNN is trained and then, the trained output is sent to the SOM. Finally SOM is trained and labeled. This trained SOM is used in data classification. We simulated the compensator in a general time dispersive channel with the ISI effect and with the HPA nonlinear distortionswithout memory effect and with memory effect. The experimental results indicate a good performance of compensating nonlinear distortions, introduced by HPAs and memory effect under a fading channel environment.

Chapter 4 presents a SOM and Mixtures of Experts Neural Network (MENN) based channel predictor for an OFDMA system. MENN models consist of a set of experts, which models the conditional probabilistic processes and gates which combine the probabilities of the experts. We use FLNN modules as the mixtures of experts and a Radial Basis Function Neural Network (RBFNN) as the gating network. In general, a FLNN has a lesser computational complexity than a Multilayer Perceptron (MLP) network. The SOM is used to mine the local information in the input space to allocate the gates using suitable activations. We use FLNNs to construct a neural network structure like a MLP, with 30 neurons in the input layer and 5 neurons in the output layer. First, we design a SOM to represent the input outdated CSI samples (regressor space). The dimension of the input space SOM is 30 and initially 300 neurons are used. The prediction horizon is taken as 5 in the output space and we use a MENN group with SOM backing to find the predictive mapping function. We use two parallel Kalman Filters (KF) to estimate the parameters of the SOM to obtain a fast convergence and robust operation. Simulation results show that the proposed method can predict the CSI five steps ahead to maintain the target Bit Error Rate (BER) in an OFDMA system with a considerable total system delay.

Chapter 5 proposes a multi-user detector using a nonorthogonal Wavelet Neural Network (WNN). The proposed method operates in frequency domain to detect multi-users in a frequency selective fading channel environment. KF algorithm is used to estimate the parameters of the neural network fast and automatically. Nonorthogonal bases have a good resolution when constructing a wavelet network than

orthogonal basis. It is due to the difficulty of obtaining an analytical solution to generate orthogonal basis to constrict a wavelet network with better resolution. The performance of the proposed multi-used detector is evaluated on a Raleigh fading channel and it outperforms the conventional receiver where CSI is assumed to be available.The proposed detector detect multi-users in a fading channel by estimating the channel itself during the Kalman training with the help of the training patterns of each user.

Chapter 6 concludes this thesis and gives some topics for future research.

審査結果の要旨

本論文は、OFDM（Multi-Input Multi-Output Orthogonal Frequency Division Multiplexing: MIMO-OFDM）無線通信システムにおける諸問題を、自己組織化技術を応用して解決したものである。得られた主な結果は、以下の項目に要約できる。

（1）電力増幅器による OFDM 信号の非線形歪は、伝送特性の大きな劣化につながる。この問題を解決するために、受信側に関数型ニューラルネットワークと自己組織化マップを組み合わせたシステムを導入している。なお、提案手法は、サイド情報を必要とせず、良好な伝送特性を得ている。

（2）直交周波数分割多重アクセス（Orthogonal Frequency Division Multiple Access: OFDMA）システムにおいて、先見的にチャネル情報を知ることは、適応変調、適応符号化および適応電力制御等の送信技術に有効に利用することができる。本研究では、自己組織化マップとエキスパートモジュールを結合した新たなチャネル推定手法を提案し、その有効性を計算機シミュレーションにより検証している。

（3）OFDM 通信技術および符号分割多元接続（Code Division Multiple Access:ＣDMA）通信技術を融合したマルチキャリアＣDMA（Multicarrier Code Division Multiple Access:MC-ＣDMA）方式は、次世代の移動通信方式として有望な通信方式である。本研究では、マルチキャリアＣDMAにおけるマルチユーザ検出を、非直交ウェブレットニュラルネットワークを用いて実施している。また、提案手法の有効性を、レイリフェージングチャネル環境下で調査し検証している。

以上の諸成果は、OFDM 通信システムにおける諸問題を解決する基礎的な知見や基盤を与えるものであり、この分野の技術の発展に貢献するところ大である。また、申請者が自立して研究活動を行うに十分な能力と学識を有することを証したものである。学位論文審査委員会は、本論文の審査ならびに最終試験の結果から、博士（工学）の学位を授与することを適当と認める。