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ANFIS-Based Rate Compatible Punctured Turbo Code for Fixed Broadband Wireless Access Networks

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Abstract- **This paper investigates the application of adaptive neuro-fuzzy inference system-based rate compatible punctured Turbo code to compensate for inter-cell interference and rain attenuation and then to effectively improve the system performance on fixed broadband wireless access system. Fixed broadband wireless access systems, for instance the local multipoint distribution service (LMDS), provide wireless multimedia services to several fixed terminal stations and offer various advantages over the wired networks services, for example the low cost and the flexibility for the deployment of the system compared to the deployment of DSL and cables ones. LMDS system is a two-way digital cellular system operating at 10-60 GHz. Operating at such high frequency band, rain attenuation and inter cell interference are two significant influential factors of the system performance. In order to combat the impacts of rain fading and of intercell interference on LMDS networks, we propose a new criterion for the choice of the puncturing patterns, in which rain rate and the cross polarization discrimination (*XPD*) are put into fuzzy inference system and the output is referred to as quality of channel. In accordance with the system situation, the channel quality will be adopted to determine the puncturing pattern, and then to reduce redundant bits as well as improving the bandwidth efficiency. Simulation results indicate that the bit error rate of two schemes are equally well; moreover, the proposed scheme indeed has improved the bandwidth efficiency of the without punctured Turbo Code scheme for LMDS network.**

Index Terms -- LMDS, rain fade, QoS, Turbo code.

I. INTRODUCTION

The requirement for broadband services was augmented by the increasing of deregulated telecommunication market. During the last decade, a vast amount of research has been done into broadband wireless access (BWA) technologies. Fixed broadband wireless access (FBWA) systems, for instance, local multipoint distribution service (LMDS) [1] provide wireless multimedia services to several fixed terminal stations and offer various advantages over the wired networks services, for example, the low cost and the flexibility for the deployment of the system compared to the deployment of DSL and cables ones. It can deal with an effective last mile communication services.

LMDS system is a fixed digital cellular point to multipoint system that offers a wireless access of broadband interactive service. LMDS networks, operating in millimeter wave radio spectrum, have large bandwidth from 0.1 to 2 GHz with multi-access schemes such as TDMA, CDMA, and OFDM etc. that can support various data, voice service, interactive TV, and multimedia service etc. Due to the high operating frequency of millimeter wave, LMDS systems suffer from a requirement for a clear line-of-sight (LOS) link between the base station (BS) and the terminal station (TS). The LOS confinement and large propagation losses, particularly free-space loss and rain attenuation, limit the coverage area of LMDS systems. Inter cell interference (ICI) is another major problem of LMDS systems, limiting frequency reuse in LMDS systems [1]-[3].

Turbo codes [4], introduced in 1993 by Berrou etc., have been studied as the error correction code and have been shown to enhance the system performance for mobile radio applications[5], [6]. Turbo code employs the same code rate in any transmitting situation, causing a lot of redundant bits and leading to bandwidth waste. To get variable rates and to enhance the reliability of the channel, the code rate of Turbo code can be adjusted by applying the puncturing scheme. In 1995, rate compatible punctured turbo code (RCPTC) was proposed by Barbulescu and Pietrobon in [5]. RCPTC can provide unequal error protection to radio fading channels. Some practical applications of the radio communication [6]-[8] have been proposed in the literature. The rate compatible codes are indeed more useful than the fixed rate code ones while the channel state changes. The scheme must select and adjust the puncturing patterns, there are some incremental steps and repetition numbers according to the given service requirements and channel conditions. However, they give little attention to the environment conditions of the transmitting channel. In [8], the authors gave the attention on rain attenuation, applied rain rate to adjust the puncturing patterns. A comparison between the performances of different puncturing patterns shows that their proposed puncturing pattern outperforms other patterns and their proposed scheme can improve the performance of LMDS system.

In addition, the adaptive neuro-fuzzy inference system (ANFIS) was proposed by Jang in [9], which combines the fuzzy inference system with the neural networks, inherits the advantages of both neural networks and fuzzy systems, avoiding the disadvantages of these two schemes, widely used in fuzzy control and pattern identification.

Rain attenuation and interference are two of the significant influential factors on LMDS networks performance, the effects are nonlinear and difficult to express in mathematical formula, so we adopt ANFIS into RCPTC for LMDS systems to guarantee a specific bit error rate (BER) and quality of services (QoS). Here, we provide a new criterion to choose the puncturing patterns, according to the quality of environment conditions to judge whether the RCPTC is punctured or not, which results in a systematic rate-compatible codes to effectively improve the performance of LMDS systems [5]. In the proposed ANFIS-based RCPTC, rain rate and *XPD* are the inputs of fuzzy inference system (FIS) and the output of FIS will be referred to as channel quality (*dq*). Thereupon, *dq* is used to judge whether puncture is carried out, for instance, the better the system situation is, the puncture is carried out resulting in the relatively higher code rates are adopted; on the other hand, the worse the system situation is, the puncture is not carried out resulting in the relatively lower code rates are used.

The remainder of this paper is organized as follows. The system model and the related propagation characteristics are described in Section II. In section Ⅲ, we describe the dynamic modulation first. Then we provide a description of the basic ANFIS scheme. Next applying ANFIS scheme to rate compatible punctured Turbo code. The simulation results and the performance of ANFIS-based RCPTC are described in section IV. Section Ⅴ is conclusions.

II. System Model

The system model and propagation characteristics used in this paper are similar to those are described in [8]. Under cellular environment, the existing intercell interference will reduce the signal-to-interference ratio (*SIR*). To minimize intercell interference and then maximize the link capacity, a well-designed cell planning is a key point. Our analysis is focused on downlink channel interference under the cellular planning. The typical LMDS system, which consists of base stations (BS) and fixed terminal stations (TS), with rectangular cellular cell patterns of a given cell width $2D$ is illustrated in Fig. 1 Each cell is further subdivided into four equally 90° spaced sectors, BS station is located at the central of each cell, and TS stations are distributed randomly within each cell sector. Carrier frequencies can be reused with appropriate cell planning in cellular system. The frequency reuse factor denotes the number of times that the whole bands are used in a cell [10]. In addition, since deployments of TS stations are fixed in a sector, antennas are designed to be highly directional and the beamwidth is typically within 2° to 5° at the TS [11]. Moreover, the BS station employs an omni-directional antenna covering the entire cell or forms a combination of several sector antennas covering the entire cell, i.e., one sector with a sector antenna. On the other hand, the TS employs a highly directional antenna pointed toward the serving BS.

The inter-cell interference is caused by the common use of the same channel, resulting in a restriction on frequency reuse. As shown in Fig.1, the cellular pattern for downlink LMDS network is employed to analysis the inter-cell interference. For LOS microwave and millimeter-wave radio systems, rain attenuation, gains of antennae, and path loss should be considered into inter-cell interference calculation procedure. Furthermore, considering the system is with dual-polarization, it is necessary to incorporate depolarization into the calculation procedure. Hence, the average received power (P_R) for LMDS system can be expressed as follows.

$$P_R = P_T\, G_T G_R (PL)\ \ (A_R)\begin{cases} \dfrac{1}{XPD} & \text{for a cross - polarized source} \\ \dfrac{XPD-1}{XPD} & \text{for a co - polarized source} \end{cases}, \quad (1)$$

where P_T denotes the transmitted power, G_T and G_R represent gains of BS and TS antennae, respectively. *PL* signifies the path loss and A_R indicates the rain attenuation. *XPD* is the cross polarization discrimination [2]. The relevant items are described as follows.

The path loss for a particular area can be characterized as two variables, that is loss exponent (α) and the path distance (d_0). Therefore, the *PL* can be given by following formulas.

$$PL(dB) = 20\log(4\pi d_0/\lambda) + 10\alpha\log(d/d_0)\,, \quad (2)$$

where λ denotes the wave length and d is the distance between TS and BS. The choice of α is depended on the existence of a clear LOS link or the degree of having a non-line-of-sight (NLOS) link.

Whenever the effects of noise are considered, e.g., obstruction of building, the *SIR* plus noise ratio (*SINR*) is given by

$$SINR = P_S \,/\, (P_I + P_N)\,, \quad (3)$$

where P_S is the signal power at the receiver, P_I is the interfering signal power at the receiver, and P_N is the noise power. The values of P_S, P_I and P_N can be calculated from the link budget as listed in Table I of [12]. Furthermore, 28.35 GHz frequency is taken to perform the system analysis for this LMDS system.

Rain attenuation dependent on the rain rate and the drop size distribution will restrict communication link distance, limits the use of higher frequencies and affects communication performance. The high rain attenuation at LMDS frequencies, leads to a major trade-off between cell size and system availability, is determined by the rain expectancy for a given geographical area. To evaluate the effect of rain attenuation on LMDS systems, the ITU-R model can be applied to predict the rain attenuation [2]. According to ITU-R model, the following simple algorithm can use for estimating the long-term statistics of rain attenuation.

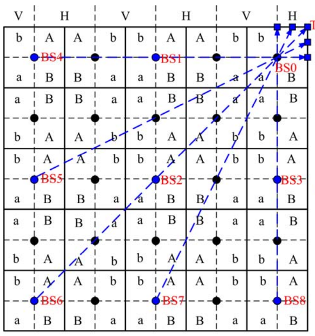

Fig. 1 Cellular pattern for downlink LMDS network.

The ITU-R 530-10 rain attenuation prediction model can be applied to predict the rain attenuation and given by

$$A_{0.01} = a \cdot R_{0.01}^{b} \cdot L \cdot r_{0.01}, \tag{4}$$

where $R_{0.01}$ is the rain rate exceeded for 0.01% of the time, $A_{0.01}$ is the total path attenuation exceeded for $R_{0.01}$, L is the actual path distance, $r_{0.01}$ is a distance fading factor, a and b are the model coefficients.

Polarization, a fundamental feature of millimeter wave signals, is used to express the orientation of the signal's electric field. In a well designed cell planning, two signals can be transmitted at the same frequency band with orthogonal polarization to double the capacity of LMDS system. The non-spherical raindrops induce the differential attenuation and depolarization. The cross polarization discrimination (*XPD*) is the ratio of co-polarized received signal power ($P_{\parallel}$) to the cross-polarized received signal power ($P_{\perp}$). The value of *XPD* quantifies the separation between two transmission channels in consequence of different polarization orientations [2]. The higher the *XPD,* the more effective orthogonal frequency reuse is. The *XPD* is a weak function of co-polarized polarization attenuation. The value of *XPD* can be given by the following equation,

$$XPD(dB) = 10\log\frac{P_{\parallel}}{P_{\perp}} \ . \tag{5}$$

III. ANFIS-BASED RATE COMPATIBLE PUNCTURED TURBO CODE

The noise and free space propagation affect the channel quality resulting in the received data may be losing or error. The Turbo code, correlates with convolution code and block code, is adopted to enhance the efficiency and accuracy of information transmitted at LMDS network [8], and the code rate can be adjusted by applying the puncturing scheme. Here, RCPTC scheme takes ANFIS to administer a choice of puncturing scheme, and the relevant statements are giving in the following subsection. In Turbo code, the information bits encoding by two or a lot of parallel recursive systematic convolutional (RSC) code with an interleaver which laid between these RSC codes. The code sequences are generated by the information bits, and then followed by the parity check bits caused by both encoders. The typical Turbo encoder consists of two constituent encoders operate on the same set of inputs and the input bit are grouped into the same finite-length as the interleaver. A soft–input soft–output (SISO) decoder based on the SOVA algorithm is employed for decoding the component codes [13], [14].

A. *Rate compatible punctured Turbo code*

The RCPTC has been introduced in [5] to achieve unequal error protection, in which parallel concatenated convolutional codes with two ingredient encoders were represented with an adjustable rate of 1/2 to 1/3 using the same origination encoder. The rate is adjusted by puncturing, with M puncturing matrices, an underlying rate $1/M$ turbo encoder, where the M-1 is a number of ingredient encoder, consisting of one rate 1/2 recursive systematic convolutional (RSC) encoder cascaded in parallel with $M-2$ rate 1 RSCs. The puncturing scheme is periodic, but not limited to parity bits; consequently, both systematic and partially systematic RCPTC can be obtained.

B. *Adaptive neuro-fuzzy inference system*

This section introduces the concept of ANFIS, which is applied to RCPTC for LMDS systems. The further details of ANFIS can be found in [9]. ANFIS technique combines neural networks with fuzzy inference system, which has the advantage of easy implementation and learning ability, was proposed by Jang in [9].

For simplicity, assume that the fuzzy inference system has two inputs x and y, one output dq, and the rule base contains two fuzzy if-then rules of Takagi and Sugeno's (T–S) type (type-3) fuzzy model. The corresponding equivalent ANFIS architecture for the RCPTC scheme, as depicted in Fig. 2, is a class of adaptive networks which are functionally equivalent to fuzzy inference systems. It is a multilayer feed-forward network in which each node carries out a special work on incoming signals and a set of parameters relating to this node.

In order to reflect the different adaptive capability, the node is represented by the shape of a square or a circle. The square node with parameters is called adaptive node whereas the circular node is a fixed node without any parameter. The node functions in the same layer have the same function are described as follows.

In layer 1, each node is an adaptive node with node function, which computes the degree of membership functions of each input, the function of this layer is the fuzzification of the input parameter. As shown in Fig. 2, x and y are the inputs of nodes. A_i and B_i (i=1, 2…) are the linguistic labels, i.e., large, small, etc, associated with the node functions, and the outputs of the nodes are the membership functions which denoted the degrees to which the given inputs satisfy the quantifier A_i or B_i. The number of nodes represented the number of fuzzy sets. Usually, the bell-shaped membership functions are chosen for this layer and all membership functions take on the values of the interval [0, 1]. Parameters in this layer are named premise parameters and defining the membership function of the node.

Layers 2 and 3 are with fixed nodes, which have no parameters, are separately labeled Π or N. The nodes of layer 2 multiply the incoming signals and send out the outputs to the nodes of layer 3, which give the firing strength for each rule.

In layer 3, each node is normalizing the firing strength of each rule, in which the node calculates the firing strength ratio of each rule to the sum of all rules, according to the outputs of the nodes of layer 2. The outputs of layer 3 will feed forward to layer 4.

Each node in layer 4 is an adaptive node with node function. The node makes a simple linear combination from the system inputs and a set of consequent parameters to the outputs of layer 3, and then calculates the contribution of each rule toward the overall output. In layer 5, the single node is a fixed node labeled Σ, and calculates the sum of the outputs from layer four to get the system output by means of the summation of all incoming signals.

In the proposed ANFIS-based RCPTC scheme, the T-S type fuzzy if-then rules are developed to generate membership functions which are used in processing the fuzzy reasoning. The output of each rule is a linear combination of the preconditions. The hybrid learning procedure is employed batch mode to update the parameters in an adaptive network, each epoch is consisted of a forward pass and a backward pass, given the values of premise parameters, the overall outputs can be expressed as linear combinations of the consequent parameters. In the forward pass, provide input data to each node, functional signals go forward to calculate each node output layer by layer till layer 4, and the consequent parameters are identified by the least squares estimate, this process is repeated for all the training data entries and the error measure is obtained. In the backward pass, the error rates derived from the error measures, which propagate backward from the output end to the input end, and the premise parameters are update by the gradient descent. The structure of ANFIS is assumed to be fixed and the parameters are adjusted through the hybrid learning rule. The hybrid learning rule not only decreases the dimension of the search space in the gradient method, but also accelerates the convergence.

IV. Simulation Results

For analyzing the BER of this system, we assumed that the subscribers are randomly located in the sector; the distance between the TS and the BS is *d* km. In this simulation, the block interleaver is used and the SOVA method is used to decode. The parameters of LMDS systems are set up, where the radius of a cell is 6km, the Frame size is 400, the number of iteration is 5, and implements on the rain rate $R_{0.01}$.

To calculate the *SINR* of the TS that randomly locates on the upper right corner sector of BS0. Please refer to the Fig.1, considering the TS1 is located at the upper-right corner point of the upper-right sector. The value of *SINR* varies with various rain rates is simulated, and the results are shown in Fig.3. Obviously, we can find that the system has supreme SINR value as rain rate is 10 mm/hr.

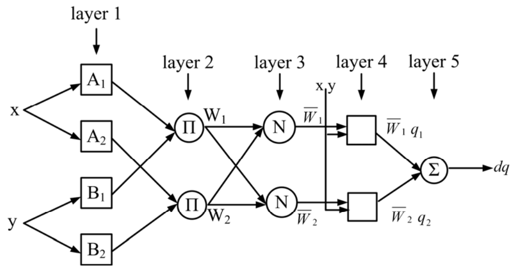

Fig. 2 ANFIS architecture

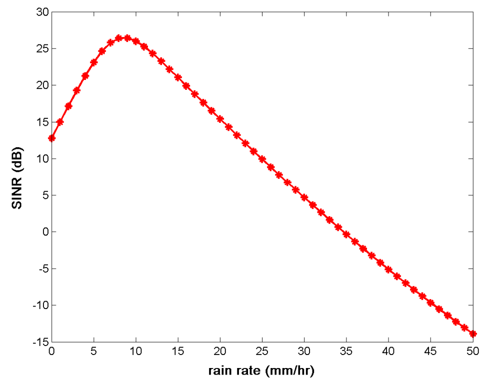

Fig. 3 SINR vary with rain rates for TS1.
(rain rate=0mm/hr, TS antenna's beamwidth=3°)

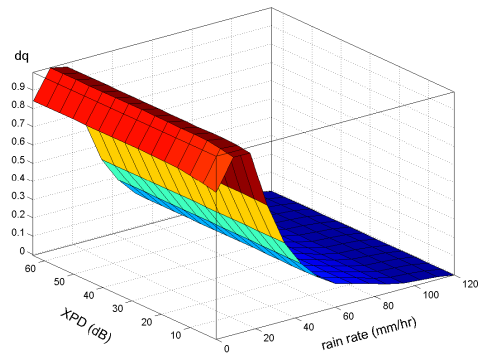

Fig. 4 Input-output mapping of ANFIS.

The application of ANFIS scheme for RCPTC is used to compensate for rain and other attenuations and enhance the capacity of downlink LMDS networks. In this paper, the SINR for downlink LMDS network which vary with rain rate and *XPD* are employed in the hybrid learning rule to generate the data base.

The proposed scheme employs a batch of inputs and output the quality of channel, which is used to adjust the puncturing scheme. The ANFIS convert the fuzzy inference engine into an adaptive network that learning the relationship between the inputs and the outputs. For our simulation, the number of membership functions for each input variable is determined by means of a trial and error process for simplicity; rain rate and *XPD* are the two input parameters, and four linguistic variables for each input parameters are used to obtain the desired performance. Here, the ANFIS contains 16 fuzzy rules and the total number of parameters is 72, including both premise and consequent parameters. A total of 7744 training data pairs are obtained, storing the training data and the corresponding operating conditions. Accordingly, we apply the stored data to train the ANFIS system. The ANFIS input-output mapping is plotted in Fig. 4, which illustrates the relationship between the two inputs (rain rate and *XPD*) and one output (*dq*). The output of ANFIS is quality of channel that is referred to as *dq*, where the value of *dq* must be in the interval [0, 1].

In practice, this system adopts the weather forecast data provided by the weather bureau to predict the rain rate. The RCPTC is performed once after the data of *dq* is obtained. And then, we applied the values of *dq* to judge whether the Turbo code is punctured or not. In case *dq* is not less than 0.5, meaning that the quality of channel is good and the system can use higher code rate. Accordingly, the system performs the RCPTC operation, that is, the Turbo code is punctured and the code rate is equal to 1/2. In case *dq* is less than 0.5, meaning that the quality of channel is worse and the system should use lower code rate. Hence, the system performs no punctured operation and the code rate is equal to 1/3.

A comparison between the performances of different puncturing scheme shows that the proposed ANFIS-based RCPTC outperforms without punctured Turbo code ones and the proposed ANFIS-based RCPTC scheme can improve the performance of LMDS system; the results are shown in Figs. 5 and 6. Fig. 5 illustrates that the both BER of ANFIS-based RCPTC and without punctured Turbo code ones are equal well. Fig. 6 shows that the bandwidth efficiency of ANFIS-based RCPTC LMDS system is higher than that of not punctured LMDS system.

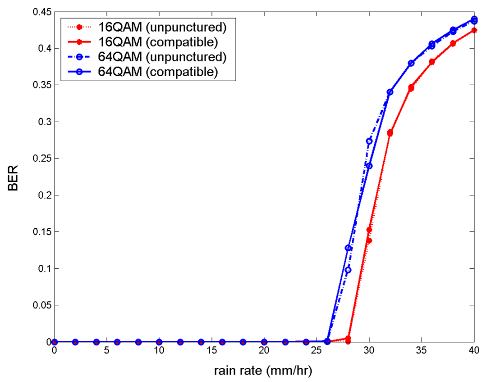

Fig. 5 BER vary with rain rates for un-punctured Turbo code and rate compatible Turbo code (*XPD*=35dB).

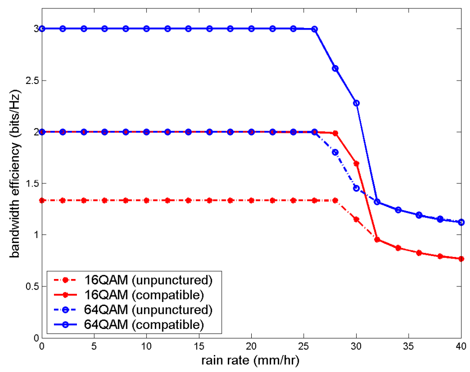

Fig. 6 Bandwidth efficiencies vary with rain rates for un-punctured Turbo code and rate compatible Turbo code (*XPD*=35dB).

V. CONCLUSIONS

The rain attenuation and inter-cell interference are the two major factors of limiting system performance in LMDS systems. In this paper, we investigate the ANFIS-based rate compatible punctured Turbo code which adopts the rain rate and *XPD* to be as the inputs of fuzzy inference system and then output the channel quality, which is applied to adjust the puncturing rule for effectively enhancing the system performance. The typical Turbo code employs the same code rate all over the channel and the existence of the redundant bits will waste in bandwidth. Rate compatible punctured Turbo code adopts the channel quality to adjust the puncturing rule, which can reduce the redundant bits when the quality of channel is better. On the other hand, when the quality of channel is bad, the system performs no punctured Turbo code to guarantee the system against outage menace. Simulation results show that the proposed ANFIS-based rate compatible punctured Turbo code for LMDS systems has higher bandwidth efficiency than that of no punctured Turbo code scheme, at the same time the BER of the two systems are equal well.

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