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A Fast Adaptive Tomlinson-Harashima Precoder for Indoor Wireless Communications

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Abstract— A fast adaptive Tomlinson Harashima (T-H) precoder structure is presented for indoor wireless communications, where the channel may vary due to rotation and small movement of the mobile terminal. A frequency-selective slow fading channel which is time-invariant over a frame is assumed. In this adaptive T-H precoder, feedback coefficients are updated at the end of every uplink frame by using system identification technique for channel estimation in contrary with the conventional T-H precoding concept where the channel is estimated during the starting of the uplink frame via Wiener solution. In conventional T-H precoder it is assumed the channel is time-invariant in both uplink and downlink frames. However assuming the channel is time-invariant over only one frame instead of two, the proposed adaptive T-H precoder yields better performance than conventional T-H precoder if the channel is varied in uplink after receiving the training sequence.

Keywords— Tomlinson-Harashima precoder, Adaptive channel estimation, Indoor wireless communication, Bit error rate.

I. INTRODUCTION

MULTIPATH environment within time disruptive channels introduces intersymbol interference (ISI) [1] when modulation bandwidth is greater than the coherence bandwidth of the radio channel, resulting into increased bit error rate (BER). The performance of communication links under such hostile conditions could be improved by employing an equalizer at the front end of the demodulator [2]. A decision feedback equalizer (DFE) [3]-[5] is one such equalizer which operates with the principle that once the value of the current symbol is determined, the ISI contribution of that symbol to future symbols can be estimated and removed. However, DFE is not suitable for the portable communications where the implementation complexity of receiver should be less than the base station. Transmission adaptivity has recently emerged as powerful technique for such cases, where the modulation, coding rate, and other signal transmission parameters are dynamically adapted to the changing channel conditions, for increasing the data rate and spectral efficiency in wireless communication systems [6]. Among the different transmitting techniques that can be dynamically adjusted, focus here has been on precoding methods to combat the ISI, which is an idea dating back to the early works of Tomlinson and Harashima [7][8], where “modulo channel inverse” was used as a pre-equalizer at the transmitter. In Tomlinson-Harashima (T-H) precoding, the feedback filter is placed at transmission thereby avoiding the error propagation drawback in DFE. Such a technique has been widely used in many applications, such as, DSL systems, voice band and cable modems [9]. T-H precoding, however, requires knowledge of the channel transfer function in advance, imposing a limitation to its usage in wireless channels that are randomly time-varying. To avoid this drawback, it is necessary to update the channel status information (CSI) continuously by means of a feedback channel, which is usually available in currently standardized wireless communication systems.

We present here a fast adaptive T-H precoder within slow fading wireless channels, which can be assumed as a practical consideration for indoor wireless communications [10]. The proposed adaptive T-H precoding scheme employs a variant variable step size least mean square algorithm (LMS) to adjust its parameters dynamically, within a short time span, according to channel coefficient variations. Here, the channel is estimated at the end of the reverse link using system identification technique with an a-priori known training sequence and the obtained channel coefficients are fed to the precoder. The entire scheme is shown in Fig. 2. It is observed that the proposed adaptive T-H precoder with variable step size algorithm converges very fast than least mean square (LMS) counterpart and it is found that the BER performance of conventional T-H precoder and the proposed adaptive T-H precoder are approximately same but with advantage of low transmitter complexity of the proposed adaptive T-H precoder.

This paper is organized as follows. Section II describes about the conventional Tomlinson Harashima precoder. Section III is devoted to proposed adaptive Tomlinson Harashima model and channel estimation in uplink, used in this paper. Simulation results are presented in Section IV and finally, conclusions are drawn in Section V.

II. DESCRIPTION OF TOMLINSON-HARASHIMA PRECODER

Tomlinson Harashima precoding was proposed for quadrature amplitude modulation (QAM). Here we consider a conventional $L \times L$, where modulo arithmetic operation (with parameter $2L$) is performed on both in-phase and quadrature components of the signal. For slowly fading channel the channel impulse response is approximately time-invariant over each-symbol interval. If $\tau_k = kT$, then the channel impulse response over $t \, \epsilon \, [iT, iT + T]$ is shown as

$$h(t) = \sum_{k=0}^{K} h_k \delta(t - kT) \tag{1}$$

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where $h_k = \alpha_k(iT)e^{j\Phi_k(iT)}$. In the case $h_o = 1$, if the desired received sample at $t = iT + T$ is at baseband and the corresponding ISI is $I_i = \sum_{k=1}^{K} h_k x_{i-k}$ (where x_{i-k} is the previously transmitted signals at baseband) then ISI free transmission can be achieved by transmitting (equivalent signal at baseband)

$$x_i = d_i - I_i. \tag{2}$$

The operation of the precoder is then to map the desired signal d_i to the transmitted signal x_i , which can be described by the transfer function of the precoder

$$\frac{X(z)}{D(z)} = \frac{1}{1 + [H(z) - 1]} = H^{-1}(z) \tag{3}$$

where $H(z) = \sum_{k=0}^{K} h_k z^{-k}$ is the channel transfer function. As long as $H(z)$ has all its zeros inside the unit circle of the complex z-plane. $H^{-1}(z)$ is stable and so is the precoder. However, if the channel is not minimum phase, the above condition is no longer valid and the precoder becomes unstable.The sequence x_i will tend to increase or diverge infinitely. In order to stabilize the precoder, T-H precoding uses a nonlinear modulo-arithmetic operation Fig.1 shows the structure of a T-H precoding system. The precoder is basically an inverse filter $H^{-1}(z)$ of the channel transfer function $H(z)$, except that output of the filter undergoes modulo-arithmetic operations before being transmitted and being applied back to the feedback filter. That is, in order to achieve stability, the T-H precoder sends (instead of $x_i = d_i - I_i$)

$$x_i^{'} = [(d_i - I_i)\text{mod}2L] = d_i + 2Lk_i - I_i. \tag{4}$$

For some complex integer k_i such that $|Re(x_i^{'})| < L$ and $|Im(x_i^{'})| < L$. The corresponding z-transform of the transmitted sequence $\{x_i\}$is

$$X^{'}(z) = D(z) + 2LK(z) - X^{'}(z)[H(z) - 1] \tag{5}$$

where

$$X^{'}(z) = \frac{[D(z) + 2LK(z)]}{H(z)} \tag{6}$$

with $D(z)$ and $K(z)$ being the z-transforms of the sequence $\{d_i\}$ and $\{k_i\}$ respectively. The received sequence $\{r_i\}$ in a noise-free situation has the following z-transform

$$R(z) = X^{'}(z)H(z) = D(z) + 2LK(z) \tag{7}$$

which corresponds to $r_i = d_i + 2Lk_i$. The desired signal d_i is recovered at the receiver by applying the same modulo operation to the received signal. Since $|Re(x_i^{'})| < L$ and $|Im(x_i^{'})| < L$, $[r_i\text{mod}2L]$ should give d_i. A general Tomlinson-Harashima precoding system is shown in Fig.1. Assuming channel is time-invariant over the uplink and downlink frame channel is estimated at the base station by using the priori known training sequence in the uplink via wiener solution and the so obtained channel coefficients are normalized with respect to h_0 and then they are fed in to the precoder. Again the output of the precoder is divided by h_0.

$$h_i = R_{xx}^{-1} r_{yx}, \qquad i = 0, 1...n. \tag{8}$$

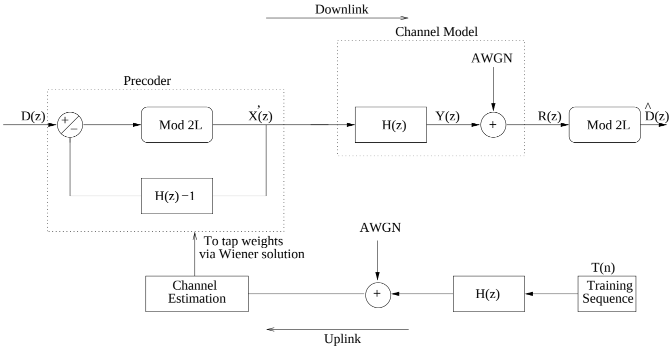

Fig. 1. Tomlinson-Harashima precoding system.

The $L \times L$ QAM can be represented by its square signal constellations(centered at the origin with side length equal to $2L$) defined on a two-dimensional Euclidean space. The desired signal d_i which is also the input signal of the precoder, can be represented by the corresponding point in the constellation. Because of the feedback path in the precoder, the input signal applied to the modulo-2L operator of the precoder is defined on the whole Euclidean space. Hence, the two-dimensional Euclidean space is referred to as the signal space.

With reference to the above Euclidean space a T-H precoder can be viewed as an operator with following three functions:

1) Dimension partitioning.
2) Selecting a shifted desired constellation point.
3) Precoding the transmitted signal i.e transmitting the difference between the shifted desired constellation point and ISI.

After the precoded signal is propagated through the frequency-selective fading channel, the received signal is represented by the shifted constellation point in the signal space in the absence of additive white Gaussian noise. The decoder at the receiver which is a modulo 2L operator moves the shifted desired constellation back to the base partition and gives the desired signal as the output. This can be observed from Fig. 2 [11].

III. PROPOSED FAST ADAPTIVE T-H PRECODER WITH A VSLMS ALGORITHM

The precoder in section II assumes the channel is time-invariant in uplink and downlink frame. With this assumption in conventional T-H precoding the channel coefficients which are calculated in starting of the uplink frame are used in downlink frame for precoding. The channel estimation in the conventional T-H precoder has to be done at the starting of the uplink frame only because for calculation of autocorrelation and inverse of autocorrelation needs all the training sequence. Suppose if their is variation in the channel after getting all the training sequence in the conventional T-H precoder in the uplink the estimated channel will not be exactly equal. This results in the increased BER and also calculation of autocorrelation and its inverse is included with huge complexity

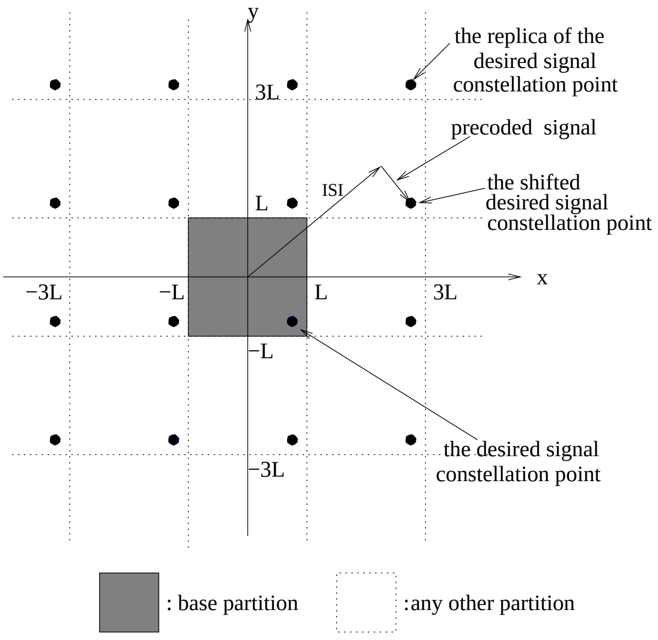

Fig. 2. Dimension partition of TH precoding.

and makes slow adaptation. To overcome all this problems here we have developed a fast adaptive T-H precoder which estimates the channel at the end of the uplink frame using system identification technique. Here the estimation of the channel is started while the training sequence is receiving, at the end of the training sequence it converges approximately to the channel coefficients. Thus it decreases the complexity. And also it improves the BER performance if the channel is varied in the uplink. The structure of a fast adaptive T-H-precoding is shown in Fig. 3.

Usually the channel is estimated by using adaptive algorithms. Here we have used variant of variable step size LMS (VSLMS) algorithm [12] for estimating the channel. Where the adaptation step size is adjusted using the energy of the instantaneous error. The complex weight update recursion of this VSLMS algorithm is given as

$$\mathbf{w}(n+1) = \mathbf{w}(n) + \mu(n) * conj(e(n)) * \mathbf{x}(n) \tag{9}$$

and the step size recursion expression is

$$\mu(n+1) = \alpha\mu(n) + \gamma e(n)^2 \tag{10}$$

where $0 < \alpha < 1$, $\gamma > 0$. Here $\mu(n+1)$ is set to either μ_{min} or μ_{max} when it falls below or rises above these lower and upper bounds respectively. The constant μ_{max} is normally selected near the point of instability of the conventional LMS to provide the maximum possible convergence speed. The value of μ_{min} is chosen as a compromise between the desired level of steady state misadjustment and the required tracking capabilities of the algorithm. The γ controls the convergence time as well as the level of misadjustment of the algorithm The algorithm has preferable performance over the fixed step-size LMS. At early stages of adaptation, the error is large, causing the step size to increase, thus providing faster convergence speed. When the error decreases, the step size decreases, thus yielding smaller misadjustment near the optimum.

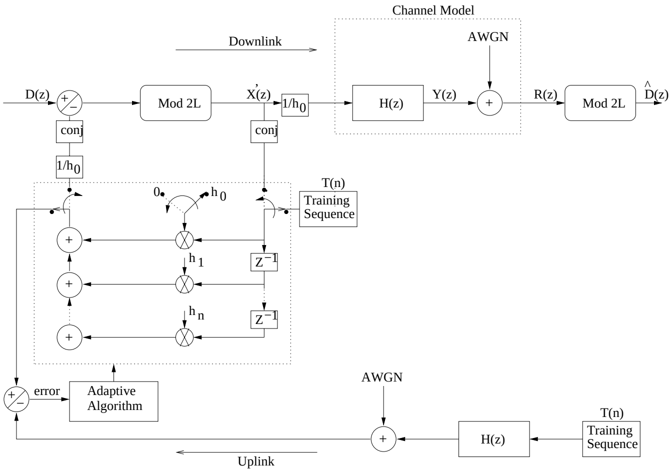

Fig. 3. Proposed Fast Adaptive Tomlinson-Harashima precoding system.

By the end of the training sequence the channel coefficients converges to the optimum value and the switches moves to the corresponding positions as shown in Fig. 3. The block *conj* in figure does conjugation because the coefficients so obtained after system identification are complex conjugate of the channel coefficients, to make similar to that of channel coefficients conjugation is applied. If $h_0 \neq 1$ then the remaining coefficients has to be normalized by h_0 and output of the precoder should also be divided by h_0.

IV. Results and Discussions

The simulation model of the above transceiver system was built and simulated with the following assumption: channel is time-invariant over a frame and the impulse response of the channel is h=[1 .8+.5i .5+.3i]. The feedback coefficients of precoder are calculated using LMS and VSLMS algorithms. And corresponding mean square error (MSE) plots for Eb/No of 10 dB are shown in Fig. 4. It is observed that for same MSE the convergence speed of the variable step size algorithm is greater than that of the conventional LMS algorithm. Here for training sequence we used QAM symbols.

For estimating the channel coefficients during LMS algorithm we have taken μ value as 0.01 and in VSLMS we have taken μ value as 0. 01, μ_{min}=0. 0001, μ_{max}=0. 1, α=0. 2 and γ =0. 01.

And in downlink by using the estimated channel coefficients the signal is precoded and transmitted and the corresponding BER performance of the proposed T-H precoder where the channel is estimated by using LMS , VSLMS algorithms and via wiener solution methods are shown in Fig. 5.

It is observed that the BER of LMS and adaptive alogorithms are approximately same because the MSE of both the algorithms are same but with fast convergence of VSLMS than that of LMS counterpart. And the complexity of the transmitter is also reduced by using the VSLMS algorithm for channel estimation than that of the conventional T-H precoder

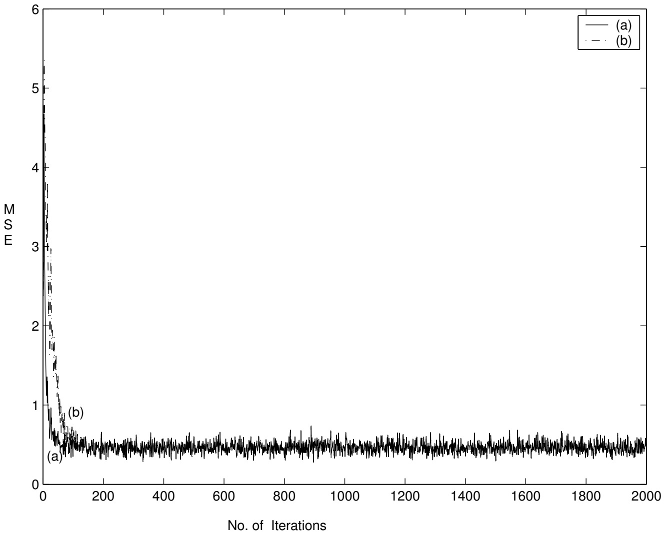

Fig. 4. Mean Square Error of (a) Proposed Adaptive T-H Precoder with VSLMS algorithm, (b) Proposed Adaptive T-H precoder with LMS algorithm.

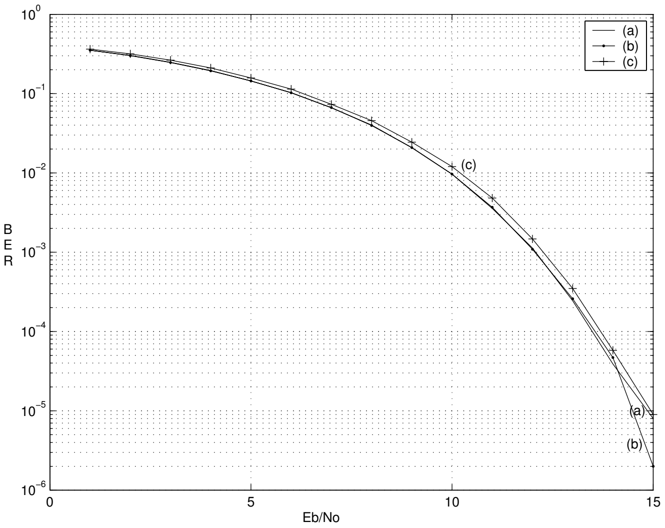

Fig. 5. BER performance of (a) Proposed Adaptive T-H Precoder with VSLMS algorithm, (b) Proposed Adaptive T-H precoder with LMS algorithm and (c) Conventional T-H precoder.

where the complexity is more than proposed one. And it is obvious that the BER performance will be better than that of conventional T-H precoder because in the proposed T-H precoder the channel is estimated at the end of the uplink frame.

V. CONCLUSIONS

The simulation shows that the adaptive T-H precoder with VSLMS algorithm has BER similar to that of the LMS algorithm but with fast convergence and also it is found that the conventional T-H precoder can be replaced by the proposed adaptive T-H precoder which has less complexity and fast adaptivity to channel variations. It has low BER if the channel is varying in the uplink. It is also found from the observations that small variations in the channel impulse response due to movement or rotation of the mobile terminal will not have drastic effect on the BER performance.

The authors are now trying to implement modified Tomlinson Harashima Precoding with this fast adaptive algorithms by considering the associated effects of the finite precision.

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