Pre-Equalized QPSK-Signal with Turbo Codes for Wireless-ISI Channel

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Abstract: *In this paper, a proposed wireless-transmission model by concatenation of turbo code and precoding of Spiral curve and Dimension Partitioning techniques on QPSK signal through multipath fading channel is introduced. It is a novel method to decrease ISI effect in wireless communications. Simulation results show that Spiral curve precoding with turbo code achieves the best gain at high SNR compared to those of considered equalizations with the same turbo code scheme.*

Keywords: *Pre*-Equalization, Intersymbol Interference, Turbo Codes

1. Introduction

Efficient equalization techniques have been devised to decrease ISI effect in wireless communications such as the Viterbi or maximum likelihood equalizer (VE), optimum or sub-optimum soft output equalizer (OSE,SSE) [1], decision feed back equalizer (DFE), and *pre*-equalizer by using *precoding* technique. The first well known version of that precoding is Tomlinson-Harashima (TH) precoding which precoded on only amplitude modulated signal [2][3]. Consequently, Spiral curve-phase precoding [4] has been devised to avoid the disadvantage of TH-precoding of dealing with only that amplitude. This was done by proposing *Spiral*-based phase precoding method. Its performance and its application on *M*- PSK signal have been shown recently in [5] which achieving better performances than those of classical *post*-equalization techniques. Recently, another precoding technique, *Dimension Partitioning* [6], has been published with the same purpose. The results applying these precoding techniques show improvements in the slow varying fading channels.

In the previous works [5], Spiral precoding has been concatenated with error control coding of Trellis Coded Modulation (TCM). They have presented an efficient ISI-combating method using this combined model. Considering precoding as an ideal DFE equalizer at the transmitter [5], it can be expected of achieving a further outcome by proposing Turbo code [7] in this model in a straightforward way. To decode this turbo precoded-signal, it should has no effect of the error propagation and inherent decision delays as it occurred when using DFE. Morever, the combination of this turbo code and precoding is expected to improve the overall performance substantially compared to results of the previous works.

In this paper, a proposed wireless-transmission model by concatenation of turbo code and precoding (Spiral and Dimension Partitioning) on QPSK signal through multipath fading channel, is introduced. In section two, system description of this concatenation is presented. Next, details of soft-detection method of each precoded signals is shown in the section three. Simulation is carried out for verifying this proposed model. Its performance is compared to another well-known *post*-equalization technique of VE/SSE with the same code in section four. Finally, conclusion and discussion of this work is shown at the last including the investigation for further works.

2. System Description

In Figure 1, the proposed transmission model with full-duplex two signal links is presented. Initially, in the forward link binary turbo encoder transfers encoded signal of input sequence d_i with rate ½ and to be the codeword $\left(c^0_{p,i}, c^1_{p,i}\right)$ by using the method from [8]. This codeword is passed to QPSK mapper in order to provide related format of signal for each precoding method. As a result, a complex coded symbol $\vec{S}_i = Ae^{j\beta_i}$ with Gray-codes mapping is obtained, where A is a constant amplitude and β_i is phase of the i^{th} information signal. After interleaving to avoid burst error of fading, signal symbol $\vec{S}_i$ cooperating with the channel-estimated parameters $\vec{I}_i$ of the reverse link from slow fading channel in the same data frame of TDD multiplexing systems, are used to compute precoded signal $\vec{P}_i = Ae^{j\theta_i}$ (where θ_i is the precoding phase). This is done with the same assumption as in [5]. That is the channel fades so slowly such that it is assumed to be the time invariant over two adjacent frames of the forward and reverse link. In addition, the channel impulse response can be modeled as a linear and time-invariant over two adjacent data frames so that the radiation patterns are reciprocal in both forward and reverse links. Moreover, channel parameters are estimated perfectly on the reverse link. Due to the limitation of size and power consumption of the mobile unit, precoding is used only at the transmitter of base station.

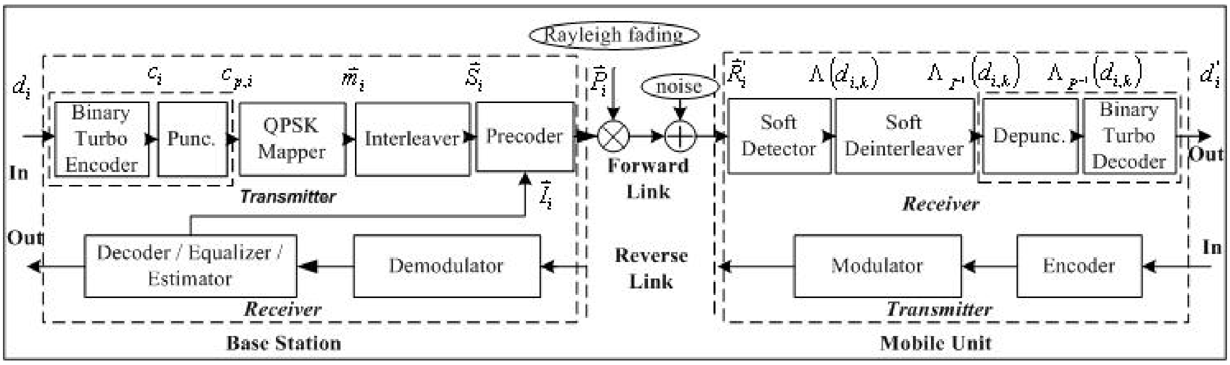

Figure 1: Proposed Model of Turbo Codes on *Pre*coded-QPSK Signals

At the receiver, signal $\vec{R}_i'$ that passed from the multipath Rayleigh fading channel is detected and computed for the Logarithm of Likelihood Ratio (LLR); $\Lambda(d_i)$. It is defined as

$$\Lambda(d_i) = \log\left[\frac{P\{d_i = 1 \mid \vec{R}_i'\}}{P\{d_i = 0 \mid \vec{R}_i'\}}\right] \tag{1}$$

Subsequently, LLR $\Lambda(d_i)$ is deinterleaved and transmitted to the turbo decoder to recover information data d_i'. In order to have the proper information for turbo decoder, soft-detection of each precoding method will be defined in the next section. Obviously, this *pre*-equalization technique is done similarly to those of the classical *post*-equalization (VE or SSE) but this *pre*-equalization is processed on the transmitter instead of working at the receiver.

3. *Pre* - Equalization

In this section, main equalization techniques that used in this paper are presented. Specially, the computation of LLR for detection of precoded signals is discussed in detail.

3.1 Modified Spiral Curve-Phase Precoding

Pre-equalization by Spiral curve phase precoding [4] has been devised to combat ISI for phase modulated signal based on Spiral curve technique. This Spiral has been modified and improved for achieving the optimum performance in the previous work of [9]. Therefore, that latest version is used in this work.

To consider Spiral precoding detection, the received signal $\vec{R}_i' = r_i' e^{j\phi_i'}$ is then computed having the received information carrying phase β_i' from [5]

$$\beta_i' = \phi_i' + \psi_0' + \left(r_i' - C\right)\pi \tag{2}$$

where r_i' is the received signal amplitude with phase ϕ_i', ψ_0' is the ISI vector's phase, and *C* is the Spiral curve constant. Because ISI is combated by precoding prior to transmission to the channel, an *equivalent*-AWGN channel assumption from [5] is used in the detector. Then, β_i' is a *simplified* Gaussian random variable with zero mean and variant σ_β^2. As a result, a *posteriori* probability $p(\vec{S}_i = \vec{x} \mid \beta_i')$ can be calculated by

$$p(\vec{S}_i = \vec{x} \mid \beta_i') = \left(1/\sqrt{2\pi\sigma_\beta^2}\right)\exp\left(-\left|\beta_i' - \beta_x\right|^2 / (2\sigma_\beta^2)\right) \tag{3}$$

where $\vec{x}$ and β_x are the referenced QPSK-signal and its phase respectively. Thus, LLR is computed by

$$\Lambda(d_{i,k}) = \log\left[\frac{\sum_{j=1}^{2} p\left(S_i = S_{d_{i,k}=1,j} \mid \beta_i\right)}{\sum_{j=1}^{2} p\left(S_i = S_{d_{i,k}=0,j} \mid \beta_i\right)}\right]$$
$$= \log\left[\frac{\sum_{j=1}^{2^{M-1}} (1/\sqrt{2\pi\sigma_\beta^2})\exp\left(-\left|\beta_i - \beta_{d_{i,k}=1,j}\right|^2 / (2\sigma_\beta^2)\right)}{\sum_{j=1}^{2^{M-1}} (1/\sqrt{2\pi\sigma_\beta^2})\exp\left(-\left|\beta_i - \beta_{d_{i,k}=0,j}\right|^2 / (2\sigma_\beta^2)\right)}\right] \tag{4}$$

where $S_{d_{i,k}=0,j}$, $S_{d_{i,k}=1,j}$ signals (with phases $\beta_{d_{i,k}=0,j}$ and $\beta_{d_{i,k}=1,j}$) represent the received data signal which the k^{th} data bit of this signal equal to *"0"* and *"1"* respectively. Finally, the variant σ_β^2 of β_i' is then calculated from

$$\sigma_\beta^2 = \frac{\sum_{i=1}^{L}\left(\left|\beta_i' - \beta_s\right|^2\right)}{L} \tag{5}$$

where *L* is the number of blocksize and β_s is the nearest signal phase to each of β_i'.

3.2 Soft Detection of Dimension Partitioning-Precoded Signals

Dimension partitioning is another generation of *pre*-equalization method [6]. Generally, it is devised

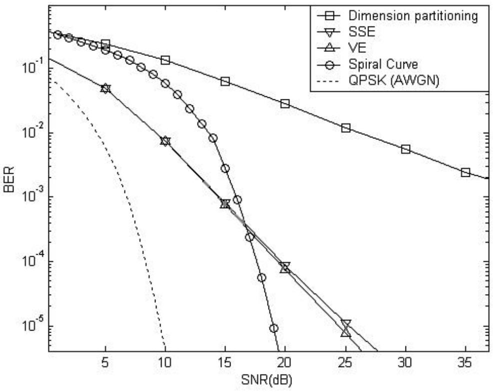

Figure 2: Performance of Uncoded-QPSK with *Pre* and *Post*-equalization

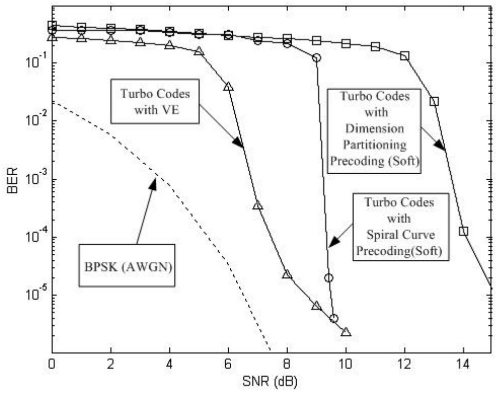

Figure 3: Performance of Concatenation of Turbo Codes with *Pre* and *Post*-equalization on QPSK Signals (Iteration : 15)

for only QPSK signal. In order to apply it with turbo code as mentioned previously, soft detection of this precoded signal is required at the detector. In this section, a calculation technique for soft output detection is described.

A *posteriori* probability of each signal in QPSK constellation $p\left(\vec{S}_i = \vec{x} \mid \vec{R}_i^{'}\right)$ can be calculated from the comparison of that received signal with all possible center of the region in dimension partitioning. This signal is named as $\vec{x}$. To simplify this method for simulation, the nearest center of received signal is used in above calculation. Hence, $p\left(\vec{S}_i = \vec{x} \mid \vec{R}_i^{'}\right)$ is computed by

$$p\left(\vec{S}_i^{'} = \vec{x} \mid \vec{R}_i^{'}\right) = \frac{1}{\sigma_N \sqrt{2\pi}} \exp\left(-\left|\vec{R}_i^{'} - \vec{C}_{\vec{s}_i = \vec{x}}\right|^2 / 2\sigma_N^2\right) \quad (6)$$

where $\vec{C}_{\vec{s}_i = \vec{x}}$ is the nearest center of the region which represents the information signal $\vec{x}$. Finally, LLR of Dimension Partitioning-precoded signal is taken by

$$\Lambda\left(d_{i,k}\right) = \log\left[\frac{\sum_{m=1}^{2}\left(1/\sqrt{2\pi\sigma_N}\right)\exp\left(-\left|\vec{R}_i^{'} - \vec{C}_{d_{i,k}=1}\right|^2 / (2\sigma_N^2)\right)}{\sum_{m=1}^{2}\left(1/\sqrt{2\pi\sigma_N}\right)\exp\left(-\left|\vec{R}_i^{'} - \vec{C}_{d_{i,k}=0}\right|^2 / (2\sigma_N^2)\right)}\right] \quad (7)$$

where $\vec{C}_{d_{i,k}=1}$ and $\vec{C}_{d_{i,k}=0}$ is the nearest center of the region that shows the received data k^{th} bit of the signal S_i. They are *"0"* and *"1"* respectively.

4. Simulation Results

The simulated ISI channel of this paper is modeled by two equal strength rays of Rayleigh fading on the τ-spaced discrete-time model where the delay $\tau = \left|\tau_1(t) - \tau_0(t)\right|$ is one symbol period *T*. In this work, Doppler effect is not taken into account.

Equalization/Precoding	**Parameters**
Spiral Curve	*$A=1$, $C=1/a_0$*
Dimension Partitioning	*$A=1$, $L_D=1/1.3$*
SSE	Decision delay = 10
VE	-

Table 1: Initial Parameters
(*A* is the normalized signal amplitude, *C* and *LD* are constants, and a_0 is the first path fading amplitude)

In this section, the performance of the modified spiral curve precoding, Dimension Partitioning compared with those of VE/SSE is presented including their concatenation with turbo codes. Initially, necessary parameters for these simulations are set in Table 1.

To consider on pure equalization performance, the comparison of each precoding and equalization method on uncoded-QPSK signal is shown first in Figure 2. At high signal to noise ratio (SNR), precoding by Spiral curve method gives the best performance compared to VE/SSE while precoding with Dimension Partitioning shows the lowest efficiency.

Next, performances of turbo code with precoding and classical equalization method are presented in Figure 3. Turbo code for this simulation is (37,21), rate 1/2 (throughput 1 bit/sec/Hz) with 1024 bit / block and a pseudo-random interleaver. The external interleaver works in block style. Results at fifteen iterations show that they are all much better than those of without coding from Figure 2. Similarly, Spiral precoding with turbo code achieves the best gain at high SNR compared to those of other equalizations with the same turbo code scheme. However, its performance is still poor at low SNR.

Finally, simulation results to find the optimal solution of using of soft-decision spiral curve with turbo codes are shown in Figure 4 and Figure 5. Their performances by using various constraint length *K* and block size are discussed. Results show that the better performance can be obtained by increasing constraint length or having better codes as mentioned in [10]. Due to the effect of estimation of σ_β^2 in equation (5),

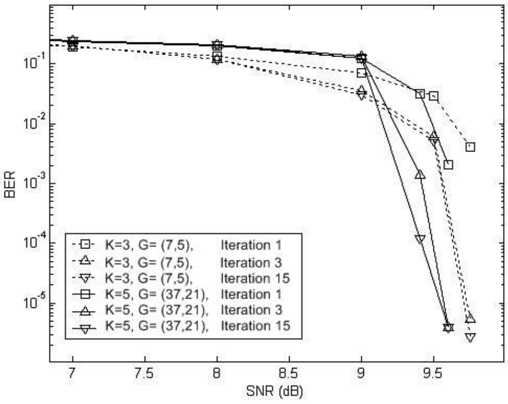

Figure 4: Performance of Various Turbo Codes with Spiral Precoding

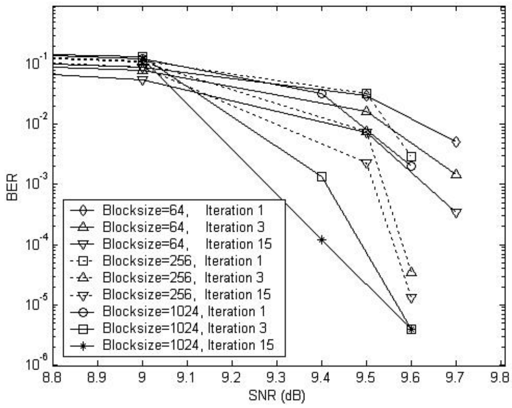

Figure 5: Performance of Different Block Size-Turbo Codes with Spiral Precoding

larger block size also gives better performance as general.

5. Conclusion and Discussion

In this paper, a proposed model by concatenation of turbo code and precoding on QPSK signal is introduced. This is to combat ISI effect for signal transmission through the multipath fading wireless channel. For turbo decoding of each precoded signal, soft detection method is described in detail. At high SNR, simulation performances show that Spiral precoding with and without turbo code gives the best performance compared to those of other illustrated equalization techniques with the same turbo code. However, it still performs poor at low SNR. Generally, this confirms the success of the proposed model to use for combating ISI in wireless communication channel.

In the future, improvement on Spiral precoding performance at low SNR will be considered. In addition, other ISI combating techniques under the same condition will be investigated and compared. Specially, the joint transmitter of turbo encoder with precoder compared to those joint receiver or turbo equalizer will be studied at the next.

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