Single-carrier Hybrid ARQ Using Joint Iterative Tx/Rx MMSE-FDE & ISI Cancellation

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Abstract—**Recently, we proposed a joint iterative transmit/receive (Tx/Rx) minimum mean square error (MMSE) frequency-domain equalization (FDE) & inter-symbol interference (ISI) cancellation (ISIC) for single-carrier (SC) block transmissions. In this paper, we extend the previously proposed joint iterative Tx/Rx MMSE-FDE & ISIC to the SC hybrid automatic repeat request (HARQ) packet access to exploit the retransmission of the same packet for improving the throughput. We optimize the set of Tx/Rx MMSE-FDE weights by taking into account the packet retransmission/combining as well as ISIC. We show by computer simulation that the proposed scheme significantly improves the packet error rate (PER) and throughput performances in a severe frequency-selective fading channel.**

Keywords; SC-FDE, ISI cancellation, HARQ

I. INTRODUCTION

The broadband wireless channel comprises many propagation paths having different time delays [1]. The minimum mean square error frequency-domain equalization (MMSE-FDE) provides good bit error rate (BER) performance for broadband single-carrier (SC) transmission in a severe frequency-selective fading channel [2-4]. However, the performance of SC using the MMSE-FDE is still a few dB away from the matched filter bound due to residual inter-symbol interference (ISI) after the MMSE-FDE. The use of iterative receive (Rx) MMSE-FDE & inter-symbol interference (ISI) cancellation (ISIC) has been extensively studied [5,6]. The Rx FDE weight is updated based on the MMSE criterion by using the reliability information of data detection at the previous iteration. In [6], iterative Rx FDE & ISIC was studied for SC-hybrid automatic repeat request (HARQ).

Recently, we took different approach from the iterative Rx processing and proposed a joint transmit/receive (Tx/Rx) MMSE-FDE [7]. A set of Tx and Rx FDE weights was derived based on the MMSE criterion. Although the derived weight set is suboptimal, the proposed scheme provides better performance than the conventional Rx MMSE-FDE. More recently, we proposed a joint iterative Tx/Rx MMSE-FDE & ISIC that is an extension of joint Tx/Rx MMSE-FDE [8]. In this scheme, ISIC is incorporated into joint Tx/Rx MMSE-FDE. At the receiver, Rx FDE & ISIC is iterated. In each iteration stage, the Rx FDE weight is updated based on the MMSE criterion. At the transmitter, Tx FDE is carried out before transmitting the signal based on the predicted degree of residual ISI after the ISIC at the receiver. The joint iterative Tx/Rx MMSE-FDE & ISIC provides much better performance than the conventional iterative MMSE-FDE & ISIC.

In this paper, we extend the previously proposed joint iterative Tx/Rx MMSE-FDE & ISIC suitable to SC-HARQ to exploit the retransmission of the same packet for improving the throughput. HARQ using the Chase combining (CC) strategy [9,10] retransmits the same packet until it is correctly received. Before transmitting the packet, Tx FDE is applied. At the receiver, every time the same packet is received, the Rx FDE, packet combining, and ISIC are jointly iterated. We optimize the set of Tx/Rx MMSE-FDE weights by taking into account the packet retransmission/combining as well as ISIC. In our scheme, the Rx FDE weights are the same as the one presented in [6] except that the concatenation of transmit FDE and channel is viewed as an equivalent channel. The Tx FDE weight is optimized for each retransmission. For the initial packet transmission, the Tx FDE weight is computed based on the predicted degree of residual ISI after the ISIC at the receiver. For the packet retransmission, the Tx FDE weight is computed for the given channel conditions of previous retransmissions of the same packet as well as the predicted degree of the residual ISI after packet combining and the ISIC at the receiver. We show by computer simulation that the proposed scheme significantly improves the packet error rate (PER) and throughput performances.

The rest of this paper is organized as follows. Section II describes the system model of SC-HARQ using joint iterative Tx/Rx MMSE-FDE & ISIC. In Sect. III, the set of MMSE-Tx/Rx FDE weights is derived. Section IV shows the computer simulation results. Section V concludes this paper.

II. SC-HARQ SYSTEM MODEL

The transmitter/receiver structure is illustrated in Fig. 1. Below, symbol-spaced discrete-time signal representation is used. We consider SC-HARQ using CC that retransmits the same packet until it is correctly received. The (M–1)th packet retransmission is considered (i.e., transmission of the Mth copy of the same packet). In our scheme, both transmitter and receiver require the channel state information (CSI) for computing their MMSE-FDE weights. In this paper, we assume the perfect knowledge of CSI at both the transmitter and the receiver.

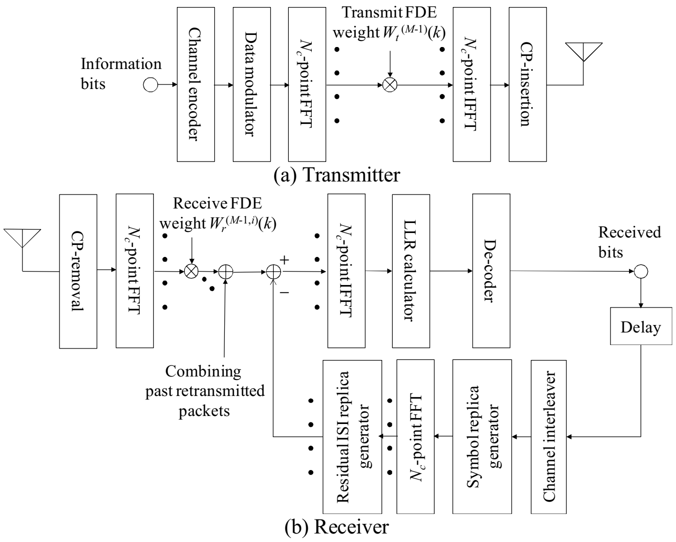


Fig.1 Transmitter/receiver structure.

A. Transmit signal

A packet is generated by data-modulating the coded bit sequence. The data sequence of the packet is grouped in a sequence of N_c-symbol blocks, where N_c is the size of fast Fourier transform (FFT) and inverse FFT (IFFT). Without loss of generality, we consider one N_c-symbol block in a packet (which consists of multiple blocks) and thus, the block number in a packet is omitted for the sake of simplicity.

The N_c-symbol block is represented as $\mathbf{d}=[d(0),\ldots,d(t),\ldots,d(N_c-1)]^T$. N_c-point FFT is carried out on $\mathbf{d}$ to obtain the frequency-domain transmit signal $\mathbf{D}=[D(0),\ldots,D(k),\ldots,D(N_c-1)]^T$, where $\mathbf{D}$ is given by

$$\mathbf{D}=\mathbf{F}\mathbf{d} \tag{1}$$

with

$$\mathbf{F}=\frac{1}{\sqrt{N_c}}\begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & e^{-j2\pi\frac{(1\times 1)}{N_c}} & \cdots & e^{-j2\pi\frac{(1\times(N_c-1))}{N_c}} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & e^{-j2\pi\frac{((N_c-1)\times 1)}{N_c}} & \cdots & e^{-j2\pi\frac{((N_c-1)\times(N_c-1))}{N_c}} \end{bmatrix} \tag{2}$$

being an $N_c\times N_c$ FFT matrix.

The Tx FDE weight, which is multiplied to the kth frequency component $D(k)$ of a block in the $(M-1)$th retransmitting packet, is denoted by $\{W_t^{(M-1)}(k);\ k=0\sim N_c-1\}$. Before transmitting the $(M-1)$th retransmitting packet, $\{W_t^{(M-1)}(k);\ k=0\sim N_c-1\}$ is multiplied to $\{D(k);\ k=0\sim N_c-1\}$ as

$$\begin{aligned}\mathbf{S}^{(M-1)} &= [S^{(M-1)}(0),\ldots,S^{(M-1)}(k),\ldots,S^{(M-1)}(N_c-1)]^T \\ &= \mathbf{W}_t^{(M-1)}\mathbf{D},\end{aligned} \tag{3}$$

where $\mathbf{W}_t^{(M-1)}=diag\{W_t^{(M-1)}(0),\ldots,W_t^{(M-1)}(k),\ldots,W_t^{(M-1)}(N_c-1)\}$ is an $N_c\times N_c$ diagonal Tx FDE weight matrix for the $(M-1)$th retransmitting packet. $tr[\mathbf{W}_t^{(M-1)}\mathbf{W}_t^{(M-1)H}]=N_c$ is met to keep the transmit power intact.

An N_c-point inverse FFT (IFFT) is applied to $\mathbf{S}^{(M-1)}$ to obtain a block $\mathbf{s}^{(M-1)}=[s^{(M-1)}(0),\ldots,s^{(M-1)}(t),\ldots,s^{(M-1)}(N_c-1)]^T=\mathbf{F}^H\mathbf{S}^{(M-1)}$ in the time-domain $(M-1)$th retransmitting signal packet. After the insertion of N_g-sample cyclic prefix (CP) into the guard interval (GI), the packet is transmitted.

B. Received signal

The propagation channel is assumed to be an L-path frequency-selective block fading channel. The complex-valued path gain and time delay of the lth path of the mth retransmitting packet are denoted by $h_l^{(m)}$ and $\tau_l^{(m)}$, $l=0\sim L-1$, $m=0\sim M-1$, respectively. The CP-length is assumed to be equal to or longer than the maximum channel time delay τ_{L-1}. The received signal block $\mathbf{r}^{(m)}=[r^{(m)}(0),\ldots,r^{(m)}(t),\ldots,r^{(m)}(N_c-1)]^T$ after the CP-removal in the mth retransmitted packet can be expressed as

$$\mathbf{r}^{(m)}=\sqrt{\frac{2E_s}{T_s}}\mathbf{h}^{(m)}\mathbf{s}^{(m)}+\mathbf{n}^{(m)}, \tag{5}$$

where E_s and T_s are the average transmit symbol energy and symbol duration, respectively, $\mathbf{h}^{(m)}$ is an $N_c\times N_c$ circulant channel matrix given by

$$\mathbf{h}^{(m)}=\begin{bmatrix} h_0^{(m)} & & & h_{L-1}^{(m)} & \cdots & h_1^{(m)} \\ h_1^{(m)} & \ddots & & & \ddots & \vdots \\ \vdots & & h_0^{(m)} & \mathbf{0} & & h_{L-1}^{(m)} \\ h_{L-1}^{(m)} & & h_1^{(m)} & \ddots & & \\ & \ddots & \vdots & & \ddots & \\ \mathbf{0} & & h_{L-1}^{(m)} & \cdots & \cdots & h_0^{(m)} \end{bmatrix}, \tag{6}$$

and $\mathbf{n}^{(m)}=[n^{(m)}(0),\ldots,n^{(m)}(t),\ldots,n^{(m)}(N_c-1)]^T$ is the noise vector with $n^{(m)}(t)$ being a zero-mean additive white Gaussian noise (AWGN) having variance $2N_0/T_s$ (N_0 is the one-sided noise power spectrum density).

An N_c-point FFT is carried out on M copies of the same packet, $\mathbf{r}^{(m)}$, $m=0\sim M-1$, to obtain the frequency-domain received signals $\mathbf{R}^{(m)}$, $m=0\sim M-1$. $\mathbf{R}^{(m)}=[R^{(m)}(0),\ldots,R^{(m)}(k),\ldots,R^{(m)}(N_c-1)]^T$ is given as

$$\mathbf{R}^{(m)}=\mathbf{F}\mathbf{r}^{(m)}=\sqrt{\frac{2E_s}{T_s}}\mathbf{H}^{(m)}\mathbf{W}_t^{(m)}\mathbf{D}+\mathbf{N}^{(m)}, \tag{7}$$

where $\mathbf{N}^{(m)}=\mathbf{F}\mathbf{n}^{(m)}$ and $\mathbf{H}^{(m)}=\mathbf{F}\mathbf{h}^{(m)}\mathbf{F}^H$. Due to the circulant property of $\mathbf{h}^{(m)}$, the channel gain matrix $\mathbf{H}^{(m)}$ of size $N_c\times N_c$ is diagonal. The kth diagonal element of $\mathbf{H}^{(m)}$ is given by

$$H^{(m)}(k)=\sum_{l=0}^{L-1}h_l^{(m)}\exp(-j2\pi k\tau_l^{(m)}/N_c). \tag{8}$$

C. Iterative Rx MMSE-FDE, packet combining, and ISIC

At the receiver, MMSE-FDE, packet combining, and ISIC are carried out in each iterative stage. The number of iterations is denoted by $I(>0)$. Below, the ith iteration stage $(0<i\leq I)$ is described.

M copies of the frequency-domain received signals $\mathbf{R}^{(m)}$, $m=0\sim M-1$, are multiplied by the Rx FDE weights $\mathbf{W}_r^{(m,i)}=diag\{W_r^{(m,i)}(0),\ldots,W_r^{(m,i)}(k),\ldots,W_r^{(m,i)}(N_c-1)\}$, $m=0\sim M-1$, and are packet combined in frequency-domain. Then, the residual

ISI replica, generated using the decision result at the (i–1)th iteration stage, is subtracted from the frequency-domain signal after packet combining. The resultant frequency-domain received signal block, $\hat{\mathbf{D}}^{(M-1,i)}=[\hat{D}^{(M-1,i)}(0),\ldots,\hat{D}^{(M-1,i)}(k),\ldots,\hat{D}^{(M-1,i)}(N_c-1)]^T$ after carrying out the packet combining and ISIC is given as

$$\hat{\mathbf{D}}^{(M-1,i)}=\sum_{m=0}^{M-1}\mathbf{W}_r^{(m,i)}\mathbf{R}^{(m)}-\mathbf{\Theta}^{(M-1,i-1)}, \quad (9)$$

where $\mathbf{\Theta}^{(M-1,i-1)}$ is the frequency-domain residual ISI replica.

In Eq. (9), $\mathbf{\Theta}^{(M-1,i-1)}$ is computed as

$$\mathbf{\Theta}^{(M-1,i-1)}=\sqrt{\frac{2E_s}{T_s}}\left\{\sum_{m=0}^{M-1}\mathbf{W}_r^{(m,i)}\mathbf{H}^{(m)}\mathbf{W}_t^{(m)}-\mathbf{I}\right\}\tilde{\mathbf{D}}^{(M-1,i-1)} \quad (10)$$

where $\tilde{\mathbf{D}}^{(M-1,i-1)}$ is the frequency-domain soft symbol replica given as

$$\tilde{\mathbf{D}}^{(M-1,i-1)}=\mathbf{F}\tilde{\mathbf{d}}^{(M-1,i-1)} \quad (11)$$

with $\tilde{\mathbf{d}}^{(M-1,i-1)}=[\tilde{d}^{(M-1,i-1)}(0),\ldots,\tilde{d}^{(M-1,i-1)}(n),\ldots,\tilde{d}^{(M-1,i-1)}(N_c-1)]^T$ being the soft symbol replica block. The nth element $\tilde{d}^{(M-1,i-1)}(n)$ of $\tilde{\mathbf{d}}^{(M-1,i-1)}$ is given as [6]

$$\tilde{d}^{(i-1)}(n)=\begin{cases}\frac{1}{\sqrt{2}}\left\{\tanh\left(\frac{\lambda_n^{(i-1)}(0)}{2}\right)+j\tanh\left(\frac{\lambda_n^{(i-1)}(1)}{2}\right)\right\} & \text{for QPSK,}\\ \frac{1}{\sqrt{10}}\left\{\tanh\left(\frac{\lambda_n^{(i-1)}(0)}{2}\right)\left(2+\tanh\left(\frac{\lambda_n^{(i-1)}(1)}{2}\right)\right)\right\} & \\ +\frac{j}{\sqrt{10}}\left\{\tanh\left(\frac{\lambda_n^{(i-1)}(2)}{2}\right)\left(2+\tanh\left(\frac{\lambda_n^{(i-1)}(3)}{2}\right)\right)\right\} & \text{for 16QAM,}\end{cases} \quad (12)$$

where $\lambda_n^{(i-1)}(x)$ is the log-likelihood ratio (LLR) associated with the xth bit of the nth data symbol in a block, computed using the decoder output in the (i–1)th iteration stage (note that x=0~$\log_2 M$–1 and n=0~N_c–1 (M is the modulation level) and $\tilde{\mathbf{d}}^{(M-1,0)}=\mathbf{0}$ for the first iteration stage).

$\hat{\mathbf{D}}^{(M-1,i)}$ of Eq. (9) is transformed into the time-domain signal block by IFFT. The decoding is carried out using the resultant time-domain signal block. After the decoding, the output LLR is used to compute the updated residual ISI replica to be used in the next iteration stage.

III. SET OF TX/RX MMSE-WEIGHTS

In this section, we derive the set of Tx and Rx FDE weights assuming that M copies of the same packet have been received. First, we derive the Rx FDE weights for packet combining, for the given Tx FDE weight. Then, the Tx FDE weight is derived assuming that the derived receive FDE weights are used.

A. Rx MMSE-FDE weight

A concatenation of the transmit FDE and the propagation channel is treated as an equivalent channel. We define the expanded received signal vector $\mathbf{R}$ of size $MN_c\times 1$ as

$$\mathbf{R}=\left[\mathbf{R}^{(0)}\quad\cdots\quad\mathbf{R}^{(M-1)}\right]=\sqrt{\frac{2E_s}{T_s}}\overline{\mathbf{H}}\mathbf{D}+\mathbf{N}, \quad (13)$$

where

$$\overline{\mathbf{H}}=\begin{bmatrix}\mathbf{H}^{(0)}\mathbf{W}_t^{(0)}\\ \vdots\\ \mathbf{H}^{(M-1)}\mathbf{W}_t^{(M-1)}\end{bmatrix},\quad \mathbf{N}=\begin{bmatrix}\mathbf{N}^{(0)}\\ \vdots\\ \mathbf{N}^{(M-1)}\end{bmatrix}. \quad (14)$$

Using Eq. (13), Eq. (9) can be rewritten as

$$\hat{\mathbf{D}}^{(M-1,i)}=\mathbf{W}_r^{(i)}\mathbf{R}-\sqrt{\frac{2E_s}{T_s}}\{\mathbf{W}_r^{(i)}\overline{\mathbf{H}}-\mathbf{I}\}\tilde{\mathbf{D}}^{(M-1,i-1)}, \quad (15)$$

where $\mathbf{W}_r^{(i)}=[\mathbf{W}_r^{(0,i)},\ldots,\mathbf{W}_r^{(m,i)},\ldots,\mathbf{W}_r^{(M-1,i)}]$.

When M copies of the same packet are received, the error vector $\mathbf{e}^{(M-1,i)}=[e^{(M-1,i)}(0),\ \ldots,\ e^{(M-1,i)}(t),\ \ldots,\ e^{(M-1,i)}(N_c-1)]^T$ between $\mathbf{d}$ and $\hat{\mathbf{d}}^{(M-1,i)}=\mathbf{F}^H\hat{\mathbf{D}}^{(M-1,i)}$ at the ith iteration stage is given as

$$\begin{aligned}\mathbf{e}^{(M-1,i)}&=\mathbf{d}-\hat{\mathbf{d}}^{(M-1,i)}/\sqrt{2E_s/T_s}\\ &=\mathbf{F}^H\{\mathbf{W}_r^{(i)}\overline{\mathbf{H}}-\mathbf{I}\}\{\mathbf{D}-\tilde{\mathbf{D}}^{(M-1,i-1)}\}+\gamma^{-1}\cdot\mathbf{F}^H\mathbf{W}_r^{(i)}\mathbf{N},\end{aligned} \quad (16)$$

where $\gamma=(E_s/N_0)$. The total MSE $e^{(M-1,i)}=tr[E(\mathbf{e}^{(M-1,i)}\mathbf{e}^{(M-1,i)H})]$ is given as

$$\begin{aligned}e^{(M-1,i)}&=\rho^{(M-1,i-1)}\cdot tr[\{\mathbf{W}_r^{(i)}\overline{\mathbf{H}}-\mathbf{I}\}\{\mathbf{W}_r^{(i)}\overline{\mathbf{H}}-\mathbf{I}\}^H]\\ &\quad+\gamma^{-1}\cdot tr[\mathbf{W}_r^{(i)}\{\mathbf{W}_r^{(i)}\}^H],\end{aligned} \quad (17)$$

where [6]

$$\rho^{(M-1,i-1)}\cdot\mathbf{I}=E\{(\mathbf{D}-\tilde{\mathbf{D}}^{(M-1,i-1)})(\mathbf{D}-\tilde{\mathbf{D}}^{(M-1,i-1)})^H\}. \quad (18)$$

From Eq. (18), we obtain the MMSE solution of $\mathbf{W}_r^{(i)}$ that minimizes $e^{(M-1,i)}$ as

$$\mathbf{W}_r^{(i)}=\overline{\mathbf{H}}^H\{\overline{\mathbf{H}}\overline{\mathbf{H}}^H+(\gamma\rho^{(M-1,i-1)})^{-1}\cdot\mathbf{I}\}^{-1}. \quad (19)$$

Using the matrix inversion lemma [1], the MMSE solution of $\mathbf{W}_r^{(m,i)}$ can be derived as

$$\mathbf{W}_r^{(m,i)}=\left\{\sum_{m'=0}^{M-1}\mathbf{H}^{(m')}\mathbf{W}_t^{(m')}\{\mathbf{H}^{(m')}\mathbf{W}_t^{(m')}\}^H+(\gamma\rho^{(M-1,i-1)})^{-1}\mathbf{I}\right\}^{-1}\times\{\mathbf{H}^{(m)}\mathbf{W}_t^{(m)}\}^H. \quad (20)$$

If error is detected after the Ith iteration, the same packet retransmission is requested. Then, after receiving the retransmitted packet, receiver computes Rx FDE weights for all the same packets to combine them based on the MMSE criterion.

B. Tx MMSE-FDE weight

The transmitter assumes that the residual ISI will be partially reduced by a factor of $1-\rho^{(M-1,tx)}$ at the receiver, where $\rho^{(M-1,tx)}$ indicates the reliability of the ISI cancellation at the receiver, which is predicted by the transmitter, and takes a value between 0~1. Assuming that $\mathbf{W}_r^{(tx)}$ is used in the receiver, the error vector $\mathbf{e}^{(M-1,tx)}$ corresponding to Eq. (16) can be given as

$$\mathbf{e}^{(M-1,tx)} = \sqrt{\rho^{(M-1,tx)}} \cdot \mathbf{F}^H \{\mathbf{W}_r^{(tx)}\overline{\mathbf{H}} - \mathbf{I}\}\mathbf{D} + \gamma^{-1} \cdot \mathbf{F}^H \mathbf{W}_r^{(tx)}\mathbf{N} \,. \quad (21)$$

Similar to the derivation of Eq. (18), the MMSE solution that minimizes $e^{(M-1,tx)}=tr[E(\mathbf{e}^{(M-1,tx)}\mathbf{e}^{(M-1,tx)H})]$ can be derived as

$$\mathbf{W}_r^{(tx)} = \overline{\mathbf{H}}^H \{\overline{\mathbf{H}}\overline{\mathbf{H}}^H + (\gamma\rho^{(M-1,tx)})^{-1} \cdot \mathbf{I}\}^{-1}. \quad (22)$$

Substituting Eq. (22) into Eq. (21), we obtain

$$\begin{aligned} e^{(M-1,tx)} &= \gamma^{-1} \cdot tr[\{\overline{\mathbf{H}}^H\overline{\mathbf{H}} + (\gamma\rho^{(M-1,tx)})^{-1}\}^{-1}] \\ &= \sum_{k=0}^{N_c-1} \frac{\rho^{(M-1,tx)}}{\rho^{(M-1,tx)}\gamma\sum_{m'=0}^{M-1}|W_t^{(m')}(k)|^2|H^{(m')}(k)|^2+1}. \end{aligned} \quad (23)$$

We derive the MMSE solution $\mathbf{W}_t^{(M-1)}$ using the Lagrange multiplier method [1] under the transmit power constraint $tr[\mathbf{W}_t^{(M-1)}\{\mathbf{W}_t^{(M-1)}\}^H]=N_c$ for the given $\{\mathbf{H}^{(m)};\ m=0\sim M-1\}$ and $\{\mathbf{W}_t^{(m)};\ m<M-1\}$. The solution is given as (derivation is omitted for the sake of brevity)

$$W_t^{(M-1)}(k) = \max\left[\left\{\begin{array}{l}\frac{1}{\mu}\frac{\gamma^{-1/2}}{|H^{(M-1)}(k)|} - \frac{\gamma^{-1}}{\rho^{(M-1,tx)}|H^{(M-1)}(k)|^2} \\ -\frac{\sum_{m<M-1}|W_t^{(m)}(k)|^2|H^{(m)}(k)|^2}{|H^{(M-1)}(k)|^2}\end{array}\right\}^{\frac{1}{2}},\ 0\right] , \quad (24)$$

where μ is chosen so as to satisfy $tr[\mathbf{W}_t^{(M-1)}\mathbf{W}_t^{(M-1)H}]=N_c$.

The parameter $\rho^{(M-1,tx)}$ appears in the second term of the first component. If the transmitter believes that the receiver can almost perfectly cancel the residual ISI, $\rho^{(M-1,tx)} \to 0$. On the other hand, if the transmitter believes that the receiver cannot cancel the residual ISI at all (or when the iterative ISIC is not employed), $\rho^{(M-1,tx)}$ is set to be 1. It is quite difficult to analytically find $\rho^{(M-1,tx)}$ and hence, in this paper, by computer simulation, we find $\rho^{(M-1,tx)}$ such that the average PER (or the throughput) is minimized (or maximized) for the given average transmit E_s/N_0.

IV. PERFORMANCE EVALUATION

The performances of SC-HARQ using the joint iterative Tx/Rx MMSE-FDE & ISIC are evaluated by computer simulation. The number of iterations is set to I=6. N_c=256 and CP length of N_g=32 are considered. QPSK and 16QAM are assumed for data modulation. The channel is assumed to be an L=16-path frequency-selective block Rayleigh fading channel having uniform power delay profile ($E[|h_l^{(m)}|^2]=1/L$). Independent channel is assumed for each retransmission. A turbo encoder [11] with the original coding rate 1/3 using two (13,15) recursive systematic convolutional encoders is used. 2048 bit length codeword with the coding rate R=1/2 is generated by puncturing the parity bit sequences. The decoder consists of two log-MAP decoders. We assume ideal ACK/NACK transmissions.

A. Average PER performance

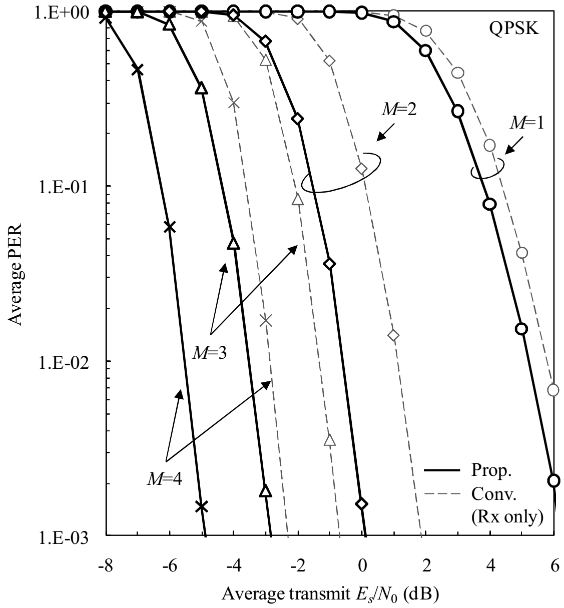
The PER performance when the same packet has been retransmitted M times (i.e., the number M is fixed here) is plotted in Fig. 2 as a function of average transmit symbol energy-to-noise power spectrum density ratio (E_s/N_0) with M=1~4 as a parameter. For comparison, the PER performance with the conventional iterative Rx MMSE-FDE & ISIC is also plotted. It can be seen from Fig. 2 that the proposed scheme outperforms the conventional one. As M increases, the proposed scheme provides much better PER performance than the conventional one. This is because, before retransmission of the same packet in our proposed scheme, the transmit FDE for M>1 is computed for the given channel conditions of previous retransmissions of the same packet as well as the predicted degree of the residual ISI after packet combining and the ISIC at the receiver. For example, when M=1 (4) and QPSK is used, the joint iterative Tx/Rx MMSE-FDE & ISIC can reduce the required E_s/N_0 for achieving PER=10^{-2} by about 0.8dB (2.8dB) from the conventional receive MMSE-FDE.

B. Throughput performance

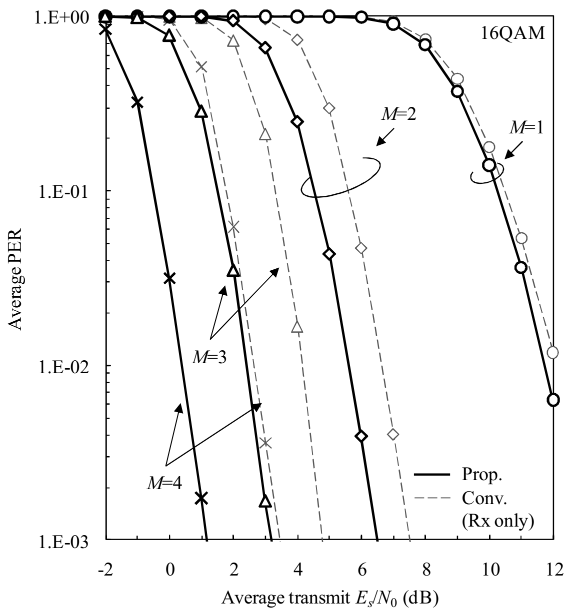
Figure 3 plots the achievable throughput performance of SC-HARQ using joint iterative Tx/Rx MMSE-FDE & ISIC. The throughput performance using the conventional iterative Rx MMSE-FDE & ISIC is also plotted for comparison. It can be seen from Fig. 3 that the proposed scheme always provides better throughput performance than the conventional scheme. In the low E_s/N_0 region, the packet is more likely retransmitted. However, the proposed scheme offers higher packet combining gain than the conventional scheme and therefore, the throughput significantly improves. In the high E_s/N_0 region, the first packet transmission is most likely successful. Even in this region, the proposed scheme provides higher throughput than the conventional scheme.

V. CONCLUSION

In this paper, we proposed the joint iterative Tx/Rx MMSE-FDE & ISIC for SC-HARQ. We derived a set of Tx/Rx MMSE-FDE weights. In the proposed scheme, the Rx MMSE-FDE weight for packet combining and the residual ISI replica for ISIC are updated based on the MMSE criterion. Before retransmission of the same packet, Tx MMSE-FDE is done based on the predicted degree of residual ISI after joint MMSE-FDE, packet combining, and ISIC. The computer simulation results showed that the joint iterative Tx/Rx MMSE-FDE & ISIC provides significantly better performance than the conventional iterative Rx MMSE-FDE & ISIC.

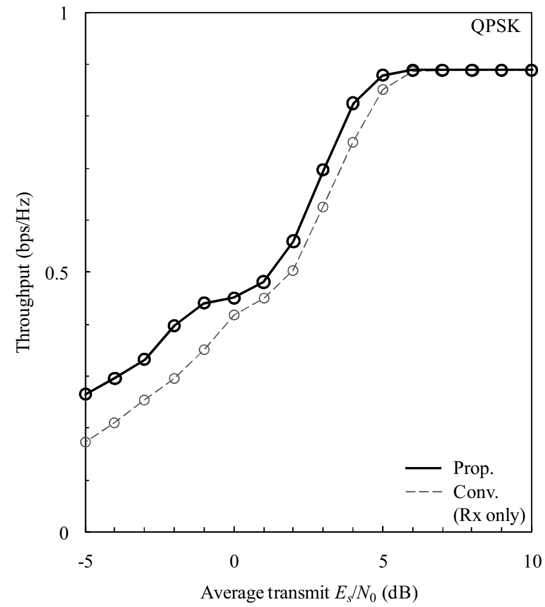


(a) QPSK

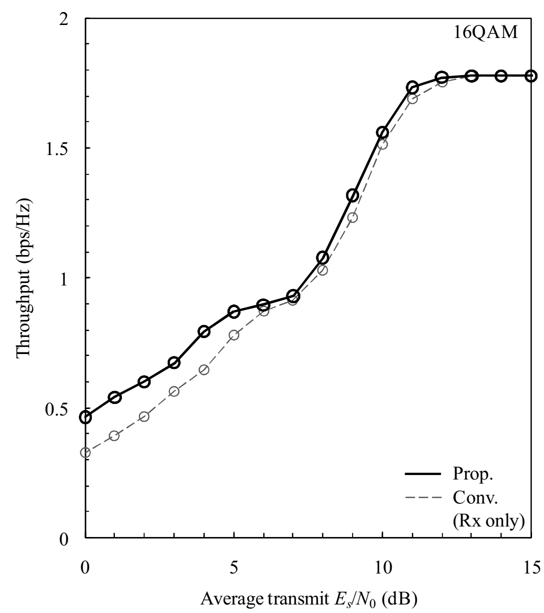


(b) 16QAM

Fig. 2 Coded PER performance.



(a) QPSK



(b) 16QAM

Fig. 3 Throughput performance.

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