A Low Complexity Interference Suppression Scheme for High Mobility STBC-OFDM Systems

Chorng-Ren Sheu[1], Jia-Wei Liu[2], Chuan-Yuan Huang[3] and Chia-Chi Huang[4]

V200, Information & Communications Research Laboratories, Industrial Technology Research Institute
Rm. 255, Bldg. 11, 195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan 310, R.O.C.[1,2,3]
Wireless Communication Laboratory, Dept. of Communication Engineering, National Chiao Tung University
No. 1001, Ta Hsueh Rd., Hsinchu, Taiwan 300, R.O.C.[4]
Tel: +886 3 5914809[1], +886 3 5914653[2], +886 3 5912315[3], and +886 3 5712121ext54510[4]
Fax: +886 3 5820279[1,2,3], and +886 3 5710116[4]
E-mail: crsheu@itri.org.tw[1], JWLiu@itri.org.tw[2], cyhuang@itri.org.tw[3], and huangcc@cc.nctu.edu.tw[4]

Abstract—**A novel low complexity scheme based on received data symbol pair reordering and optimal selection, is proposed for space time block coded (STBC) OFDM systems to suppress co-channel interference (CCI) and inter-carrier interference (ICI) caused by time-varying channels. The proposed scheme reorders the conventional received data symbol pairs to produce extra received data symbol pairs. Then, the STBC decoding is performed on all the received data symbol pairs, and the STBC decoding output signals are used to obtain multiple combined signals. Finally, the optimal combined signal with minimum interference is selected to suppress CCI and ICI, and the system performance will be improved as long as the channels are mutually uncorrelated. Our computer simulation results verify that the proposed low complexity scheme achieves good performance for high mobility 2×2 STBC-OFDM systems in the ITU Vehicular A (VA) channels.**

Keywords —received data symbol pair reordering; optimal selection; space time block code; OFDM; inter-carrier interference; co-channel interference

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is an important technology capable of high data rate transmission in wireless communications. In OFDM systems, a cyclic prefix guard interval (GI) is inserted into each OFDM symbol to overcome the inter-symbol interference (ISI) as long as the maximum channel delay is smaller than the length of GI. Then, the time-invariant multi-path channel effect can be compensated by a simple one-tap equalizer [1].

Space time block coding (STBC), an effective transmit diversity technique, was first proposed by Alamouti [2] for flat fading channels. It can provide the same diversity gain as maximal-ratio receiver combining (MRRC) when the channels are quasi-static.

Recently, OFDM systems combined with STBC (STBC-OFDM) have been investigated intensively. In an STBC-OFDM system, data symbols are encoded over space (antennas) and over time (OFDM symbol intervals). It has the advantages of both OFDM transmission and STBC technique, and hence it is a potential modulation technique to be used for the future 4G wireless communication systems such as WiMAX (IEEE 802.16m) and LTE-Advanced.

Nevertheless, an STBC-OFDM system will suffer from two kinds of interference in time-varying channels. One of them is inter-carrier interference (ICI) caused by variation of multi-path channels within an OFDM symbol. Secondly, as data symbols are coupled to each other at the receiver when the channels are time-varying over two consecutive OFDM symbols, the so-called co-channel interference (CCI) is induced. For the STBC-OFDM receiver with a one-tap equalizer, both CCI and ICI will significantly degrade the system performance in fast fading channels.

Several methods [3]-[6] have been proposed to alleviate the effects of CCI and ICI for high mobility STBC-OFDM systems. The sequential decision feedback sequence estimation (SDFSE) scheme, which is a modified maximum likelihood sequence estimation (MLSE) scheme with decision feedback, is proposed in [3]. The performance of the method is well but the computation complexity is $O(C_M^2)$ where C_M is the constellation size. A zero-forcing detection scheme is proposed in [4]. The performance of the method is also well but the computation complexity is not low because of the inverse matrix operation. A successive interference cancellation (SIC) scheme [5] based on the difference of the diversity gains is proposed to cancel CCI. The computation complexity of the method is low but the performance is not well because the ICI effect is not cancelled and the CCI reconstruction is not accurate enough due to error propagation in data symbol detection. An iteratively combined List-SIC and ICI cancellation scheme [6] is proposed to cancel both CCI and ICI. Although the performance is improved but the computation complexity is not low due to the List-SIC operation which has computation complexity $O(C_M)$ and it needs multiple iterations. Because heavy computation complexity is involved in [3], a low complexity CCI/ICI cancellation method extracted from [5,6] and the zero-forcing detection method described in [4], are adopted below as the conventional method 1 and 2 for comparison purpose.

In order to further improve the system performance of the conventional method 1 and 2, a novel low complexity interference suppression scheme with received data symbol pair reordering and optimal selection is proposed.

In the following, we first introduce the transmitter and receiver of a 2×2 STBC-OFDM system, the channel model, and mathematically analyze the CCI and ICI effects caused by the time-varying channels in Section II. Afterwards, the conventional and the proposed interference suppression methods in time-varying multi-path channels are described and analyzed in Section III and Section IV, respectively. Then, we describe the simulation parameters and discuss our simulation results in Section V. Finally, we draw some conclusions for the proposed methods in Section VI.

II. SYSTEM AND CHANNEL MODEL DESCRIPTION

An Alamouti space time block coded OFDM system is discussed in this paper. Here we consider two transmit (Tx) antennas and two receive (Rx) antennas, the 2×2 STBC-OFDM system, for notation simplicity. A schematic diagram of the 2×2 STBC-OFDM transmitter is shown in Fig. 1. In this figure, the binary input is fed into the M-ary quadrature amplitude modulation (M-ary QAM) mapper to generate the data symbol.

Every two data symbols are grouped into one data symbol pair and the data symbol pair $X(k)$ can be expressed as $X(k)=[X_s^1(k), X_s^2(k)]^{\mathrm{T}}$ where $[.]^{\mathrm{T}}$ denotes transpose, and $X_s^j(k)$ denotes the data symbol at s-th OFDM symbol period, k-th subcarrier and j-th Tx antenna. Then, the STBC encoder is applied to $X(k)$ with the encoding process $X_{s+1}^1(k)=-(X_s^2(k))^*$ and $X_{s+1}^2(k)=(X_s^1(k))^*$ to produce the encoded data symbol pairs $X_1(k)=[X_s^1(k), X_{s+1}^1(k)]^{\mathrm{T}}$ and $X_2(k)=[X_s^2(k), X_{s+1}^2(k)]^{\mathrm{T}}$ for each Tx antenna branch, where $(.)^*$ denotes complex conjugate. $X_1(k)$ and $X_2(k)$ are individually fed into the OFDM modulation sub-blocks , which include the inverse fast Fourier transform (IFFT) operation and GI insertion, and then the output signals are sent out through the Tx antennas.

The element of the frequency domain channel matrix at s-th OFDM symbol period from j-th Tx antenna to i-th Rx antenna is denoted as $H_s^{i,j}(k,m)$. Note that if $m=k$, $H_s^{i,j}(k,k)$ is the average frequency response of time-varying channel. When $m\neq k$, $H_s^{i,j}(k,m)$ is the ICI from m-th subcarrier to k-th subcarrier. In this paper, we assume that all the elements of the channel matrices are known and the channel characteristics with different antenna indices i and j are mutually uncorrelated.

A schematic diagram of the 2×2 STBC-OFDM receiver with a one-tap equalizer is shown in Fig. 2. In this figure, the OFDM demodulation sub-blocks include the GI removal and FFT operation. We assume that the length of cyclic prefix GI is longer than the maximum channel delay and perfect synchronization. Hence, after the FFT operation, two successive frequency domain received data symbols can be grouped into one received data symbol pair $Y_i(k)$, which can be further derived as follows [6],

$$Y_i(k)=H_i(k,k)X(k)+I_i(k)+W_i(k) \tag{1}$$

where

$$I_i(k)=[I_s^i(k),(I_{s+1}^i(k))^*]^{\mathrm{T}}=\sum_{m=0,m\neq k}^{\mathrm{N}-1} H_i(k,m)X(m), \tag{2}$$

$$H_i(k,m)=\begin{pmatrix} H_s^{i,1}(k,m) & H_s^{i,2}(k,m) \\ (H_{s+1}^{i,2}(k,m))^* & -(H_{s+1}^{i,1}(k,m))^* \end{pmatrix}. \tag{3}$$

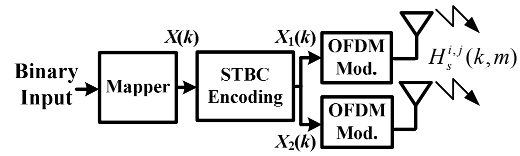

Fig. 1. A schematic diagram of the 2×2 STBC-OFDM transmitter

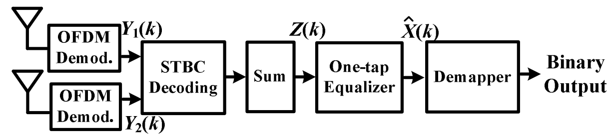

Fig. 2. A schematic diagram of the 2×2 STBC-OFDM receiver with a one-tap equalizer

$Y_i(k)=[Y_s^i(k),(Y_{s+1}^i(k))^*]^{\mathrm{T}}$ and $W_i(k)=[W_s^i(k),(W_{s+1}^i(k))^*]^{\mathrm{T}}$, wherein $Y_s^i(k)$, $I_s^i(k)$ and $W_s^i(k)$ are the frequency domain received data symbol, ICI and complex additive white Gaussian noise (AWGN) at s-th OFDM symbol, k-th subcarrier and i-th Rx antenna for i=1~2, respectively. Furthermore, the STBC decoding module is used to calculate $H_i^{\mathrm{H}}(k,k)Y_i(k)$ where $(.)^{\mathrm{H}}$ denotes the Hermitian transpose. Then, after summing the outputs of STBC decoding module, the summation $Z(k)$ can be expressed as

$$Z(k)=\sum_{i=1}^{2} H_i^{\mathrm{H}}(k,k)Y_i(k)=\Gamma(k)X(k)+I(k)+W(k) \tag{4}$$

where $I(k)=\sum_{i=1}^{2} H_i^{\mathrm{H}}(k,k)I_i(k)$ and $W(k)=\sum_{i=1}^{2} H_i^{\mathrm{H}}(k,k)W_i(k)$.

And hence, $\Gamma(k)$ can be derived as follows [5,6],

$$\Gamma(k)=\sum_{i=1}^{2} H_i^{\mathrm{H}}(k,k)H_i(k,k)=\begin{pmatrix} r_{1,1}(k) & r_{1,2}(k) \\ r_{2,1}(k) & r_{2,2}(k) \end{pmatrix} \tag{5}$$

where

$$r_{1,1}(k)=\sum_{i=1}^{2}\{|H_s^{i,1}(k,k)|^2+|H_{s+1}^{i,2}(k,k)|^2\} \tag{6}$$

$$r_{1,2}(k)=\sum_{i=1}^{2}\{(H_s^{i,1}(k,k))^* H_s^{i,2}(k,k)-(H_{s+1}^{i,1}(k,k))^* H_{s+1}^{i,2}(k,k)\} \tag{7}$$

$$r_{2,1}(k)=(r_{1,2}(k))^* \tag{8}$$

$$r_{2,2}(k)=\sum_{i=1}^{2}\{|H_{s+1}^{i,1}(k,k)|^2+|H_s^{i,2}(k,k)|^2\} \tag{9}$$

And the ICI terms $I(k)$ can be further derived as [6]

$$I(k)=\sum_{m=0,m\neq k}^{\mathrm{N}-1}\Phi(k,m)X(m) \quad \text{where } \Phi(k,m)=\sum_{i=1}^{2} H_i^{\mathrm{H}}(k,k)H_i(k,m) \tag{10}$$

We denote $Z(k)=[Z_{1,1}(k),Z_{1,2}(k)]^{\mathrm{T}}$, $I(k)=[I_{1,1}(k),I_{1,2}(k)]^{\mathrm{T}}$, and $W(k)=[W_{1,1}(k),W_{1,2}(k)]^{\mathrm{T}}$. Then, the signal $Z(k)$ is sent into the one-tap equalizer to detect the data symbol pair $X(k)$ and obtain the estimate $\hat{X}(k)=[Z_{1,1}(k)/r_{1,1}(k),\ Z_{1,2}(k)/r_{2,2}(k)]^{\mathrm{T}}$, and the $\hat{X}(k)$ can be described as follows,

$$\hat{X}(k)=X(k)+\begin{pmatrix} r_{1,2}(k)/r_{1,1}(k)\cdot X_s^2(k) \\ r_{2,1}(k)/r_{2,2}(k)\cdot X_s^1(k) \end{pmatrix}+\begin{pmatrix} I_{1,1}(k)/r_{1,1}(k) \\ I_{1,2}(k)/r_{2,2}(k) \end{pmatrix}+\begin{pmatrix} W_{1,1}(k)/r_{1,1}(k) \\ W_{1,2}(k)/r_{2,2}(k) \end{pmatrix} \tag{11}$$

The second term of the right side of (11) is the CCI because the interference comes from the other data symbol for one data symbol detection.

The system performance will be degraded due to CCI & ICI in a time-varying channel. An illustration of the bit error rate (BER) performance degradation effect at different normalized

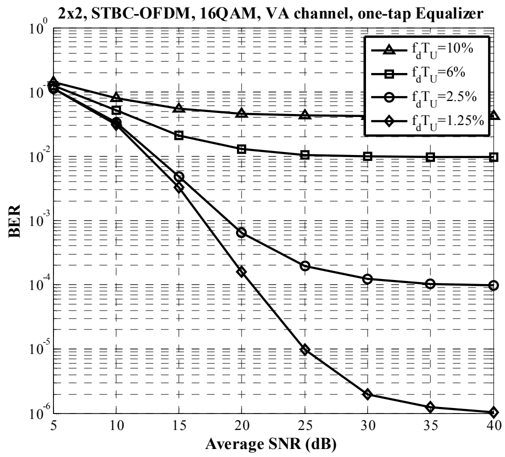

Fig. 3. An illustration of the BER performance degradation effect at different f_dT_U for 2×2 STBC-OFDM systems in the time-varying VA channels

Doppler frequency (NDF) f_dT_U for 2×2 STBC-OFDM systems in the time-varying VA channels is shown in Fig. 3. In this figure, one-tap equalizer method, as shown in Fig. 2, is used. The NDF is the product of Doppler frequency (f_d) and the useful OFDM symbol duration (T_U). From the figure, we observe that CCI and ICI effects are significant as long as f_dT_U is larger than 6% for the 2×2 STBC-OFDM systems with 16-QAM modulation.

III. Conventional Interference Suppression Methods

Two conventional interference suppression methods for 2×2 STBC-OFDM systems are introduced in this section. A schematic diagram of the two methods is shown in Fig. 4.

For the conventional method 1, CCI/ICI reconstruction and cancellation is used to suppress interference. The SIC technique based on the difference of diversity gain $r_{i,i}(k)$ is used for CCI cancellation, which can be formulated as [5,6]

1) Ordering

$$\begin{cases} \text{a=1 and b=2, for } r_{1,1}(k) \geq r_{2,2}(k) \\ \text{a=2 and b=1, for } r_{1,1}(k) < r_{2,2}(k) \end{cases} \tag{12}$$

where a and b represent the detection order.

2) Detect the data symbol with larger diversity gain

$$\hat{X}_s^a(k) = Q\{Z_{1,a}(k) / r_{a,a}(k)\} \tag{13}$$

where $Q\{.\}$ represents for hard decision.

3) Cancel the CCI and detect the other data symbol

$$\hat{X}_s^b(k) = Q\{[Z_{1,b}(k) - r_{b,a}(k)\hat{X}_s^a(k)] / r_{b,b}(k)\} \tag{14}$$

Furthermore, the ICI power in the desired subcarrier is mainly coming from the neighboring subcarriers. Hence, ICI cancellation can be simplified as [6]

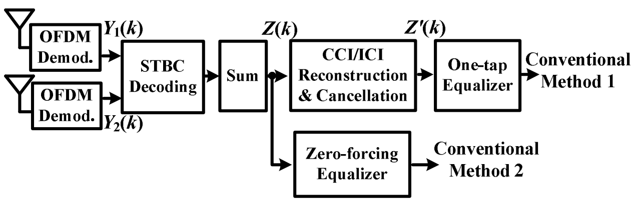

Fig. 4. A schematic diagram of the conventional method 1 and 2 for 2×2 STBC-OFDM systems

$$Z'(k) = Z(k) - \sum_{m=k-q, m\neq k}^{k+q} \Phi(k,m)\hat{X}(m) \tag{15}$$

where the second term of the right side of the (15) is the ICI and $2q$ is the number of neighboring subcarriers included in the calculation. And, $\hat{X}(m)$ can be obtained from (13) and (14). Then, the one-tap equalizer, as shown in Fig. 2, can be used to detect the data symbol pair $X(k)$.

For the conventional method 2 [4], a zero-forcing equalizer is used to obtain the detection of data symbol pair $X(k)$, which can be expressed as $\Gamma^{-1}(k)Z(k)$.

IV. Proposed Interference Suppression Methods

Two proposed interference suppression methods for 2×2 STBC-OFDM systems are introduced in this section. A schematic diagram of the two methods is shown in Fig. 5. From the figure, we observe that the two proposed methods are both composed of two parts. The first part performs received data symbol pair reordering to generate extra received data symbol pairs and it can help to obtain multiple combined signals. The second part executes optimal selection and selects the optimal combined signal to improve the performances of the following sub-blocks. The two parts will be simply described in the next two sub-sections, respectively.

A. Received Data Symbol Pair Reordering

The two first parts of the two proposed methods are the same. An illustration of received data symbol pair reordering for 2×2 STBC-OFDM systems is shown in Fig. 6. From this figure, the extra received data symbol pairs can be generated as $Y_{e,1}(k) = [Y_s^2(k), (Y_{s+1}^1(k))^*]^T$ and $Y_{e,2}(k) = [Y_s^1(k), (Y_{s+1}^2(k))^*]^T$.

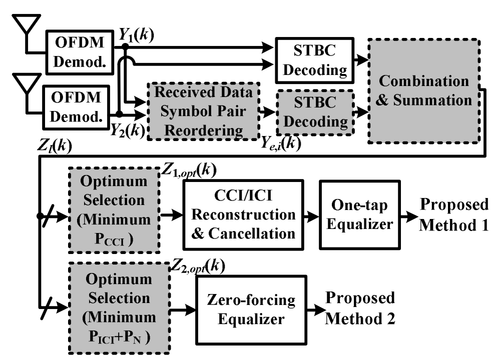

Fig. 5. A schematic diagram of the proposed method 1 and 2 for 2×2 STBC-OFDM systems

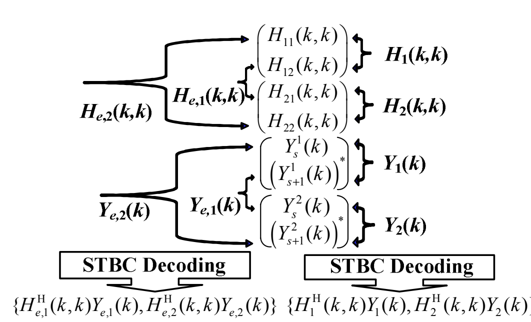

Fig. 6. An illustration of received data symbol pair reordering in the proposed methods for 2×2 STBC-OFDM systems

Similarly, if we define $H_i(k,k)=[H_{i1}^{\mathrm{T}}(k,k),H_{i2}^{\mathrm{T}}(k,k)]^{\mathrm{T}}$, the extra $H_{e,1}(k,k)=[H_{21}^{\mathrm{T}}(k,k),H_{12}^{\mathrm{T}}(k,k)]^{\mathrm{T}}$ and $H_{e,2}(k,k)=[H_{11}^{\mathrm{T}}(k,k),H_{22}^{\mathrm{T}}(k,k)]^{\mathrm{T}}$ can be generated for i=1~2. We denote $Y_{i+2}(k)=Y_{e,i}(k)$ and $H_{i+2}(k,k)=H_{e,i}(k,k)$ for i=1~2, then totally four STBC decoding outputs $H_i^{\mathrm{H}}(k,k)Y_i(k)$ for i=1~4 can be obtained. After summing any combinations of the four STBC decoding outputs, total *Num* combined signals $Z_l(k)$ for l=1~*Num* can be generated where the largest *Num* value is equal to 15 ($C_1^4+C_2^4+C_3^4+C_4^4=15$). If the set of index i's which is included in the l-th combination is named Q_l, then the combined signal $Z_l(k)$ can be expressed as

$$Z_l(k)=\sum_{i\in Q_l}H_i^{\mathrm{H}}(k,k)Y_i(k)=\Gamma_l(k)X(k)+\tilde{I}_l(k)+\tilde{W}_l(k) \tag{16}$$

where $\tilde{I}_l(k)=\sum_{i\in Q_l}H_i^{\mathrm{H}}(k,k)I_i(k)$ and $\tilde{W}_l(k)=\sum_{i\in Q_l}H_i^{\mathrm{H}}(k,k)W_i(k)$.

Hence, $\Gamma_l(k)$ can be expressed as follows,

$$\Gamma_l(k)=\sum_{i\in Q_l}H_i^{\mathrm{H}}(k,k)H_i(k,k)=\begin{pmatrix} r_{1,1}^l(k) & r_{1,2}^l(k)\\ r_{2,1}^l(k) & r_{2,2}^l(k)\end{pmatrix} \tag{17}$$

where $r_{u,v}^l(k)$ are similar to $r_{u,v}(k)$, as shown in (6)~(9), for u=1~2 and v=1~2 except the index i's in the set Q_l will replace the original index $i\in\{1,2\}$. And the ICI terms $\tilde{I}_l(k)$ can be further derived as

$$\tilde{I}_l(k)=\sum_{m=0,m\neq k}^{\mathrm{N}-1}\Phi_l(k,m)X(m) \text{ where } \Phi_l(k,m)=\sum_{i\in Q_l}H_i^{\mathrm{H}}(k,k)H_i(k,m) \tag{18}$$

Also, (16) and (18) are similar to (4) and (10), respectively, except the difference in the index i's.

B. Optimal Selection with Minimum Interference Criterion

The optimal selection criterions in the two proposed methods are different. For proposed method 1, one-tap equalizer is used and the interferences are composed of CCI, ICI and noise. Because CCI is dominant, as shown in [5], the selection criterion is minimum CCI power. The CCI power $\mathrm{P}_{CCI,l}(k)$ after the one-tap equalization can be simplified as $[|r_{1,2}^l(k)/r_{1,1}^l(k)|^2,|r_{2,1}^l(k)/r_{2,2}^l(k)|^2]^{\mathrm{T}}$, which can be calculated similarly from (11). And, the optimal l can be obtained by

$$[l_{1,opt}(k),l_{2,opt}(k)]=[\min_l|r_{1,2}^l(k)/r_{1,1}^l(k)|^2,\min_l|r_{2,1}^l(k)/r_{2,2}^l(k)|^2] \tag{19}$$

We denote $Z_l(k)=[Z_{l,1}(k),Z_{l,2}(k)]^{\mathrm{T}}$ and the p-th row of $\Phi_l(k,m)$ is $\Phi_{l,p}(k,m)$. Then, the optimal combined signal is $Z_{1,opt}(k)=[Z_{l_{1,opt}(k),1}(k),Z_{l_{2,opt}(k),2}(k)]^{\mathrm{T}}$, and the values of optimal l may be different in the two elements of $Z_{1,opt}(k)$. Compare to (12)~(14), the original SIC procedure will be modified as

1) Ordering

$$\begin{cases} \text{a=1 and b=2, for } r_{1,1}^{l_{1,opt}(k)}(k)\geq r_{2,2}^{l_{2,opt}(k)}(k)\\ \text{a=2 and b=1, for } r_{1,1}^{l_{1,opt}(k)}(k)< r_{2,2}^{l_{2,opt}(k)}(k)\end{cases} \tag{20}$$

where a and b represent the detection order.

2) Detect the data symbol with larger diversity gain

$$\hat{X}_s^a(k)=Q\{Z_{l_{a,opt}(k),a}(k)/r_{a,a}^{l_{a,opt}(k)}(k)\} \tag{21}$$

where $Q\{.\}$ represents for hard decision.

3) Cancel the CCI and detect the other data symbol

$$\hat{X}_s^b(k)=Q\{[Z_{l_{b,opt}(k),b}(k)-r_{b,a}^{l_{b,opt}(k)}(k)\hat{X}_s^a(k)]/r_{b,b}^{l_{b,opt}(k)}(k)\} \tag{22}$$

Furthermore, compare to (15), the original ICI cancellation will be modified as

$$Z'_{l_{p,opt}(k),p}(k)=Z_{l_{p,opt}(k),p}(k)-\sum_{m=k-q,m\neq k}^{k+q}\Phi_{l_{p,opt}(k),p}(k,m)\hat{X}(m) \tag{23}$$

for p=1~2. Finally, the one-tap equalizer, as shown in Fig. 2, can be used to detect the data symbol pair $X(k)$.

For proposed method 2, a zero-forcing (ZF) equalizer is used to equalize channel effect and suppress CCI, so the selection criterion is minimum power sum of ICI and noise. After ZF equalization (i.e. $\Gamma_l^{-1}(k)Z_l(k)$), the power of ICI is $\mathrm{P}_{ICI,l}(k)=\|\Gamma_l^{-1}(k)\tilde{I}_l(k)\|_2^2$ and the power of noise is $\mathrm{P}_{N,l}(k)=\|\Gamma_l^{-1}(k)\tilde{W}_l(k)\|_2^2$, as calculated from (16)~(17), where $\|.\|_2$ denotes 2-norm of a matrix or a vector, and $\|X(m)\|_2^2=2\sigma_s^2$ and $\|W_i(k)\|_2^2=2\sigma_w^2$ where σ_s^2 is the average signal power and σ_w^2 is the average noise power. Then, the optimal l can be obtained by $l_{ZF,opt}(k)=\min_l\{\mathrm{P}_{ICI,l}(k)+\mathrm{P}_{N,l}(k)\}$, and the optimal combined signal is $Z_{2,opt}(k)=[Z_{l_{ZF,opt}(k),1}(k),Z_{l_{ZF,opt}(k),2}(k)]^{\mathrm{T}}$. Finally, the detection of data symbol pair $X(k)$ can be expressed as $\Gamma_{l_{ZF,opt}(k)}^{-1}(k)Z_{2,opt}(k)$.

Because we assume that the channel characteristics $H_s^{i,j}(k,m)$ with different antenna indices i and j are mutually uncorrelated, the strength of the elements in the $\Gamma_l(k)$ will be different for different combination index l. Hence, an optimal combined signal with minimum interference can be selected from $Z_l(k)$ for l=1~*Num*. And the optimal combined signal can be adopted into the conventional method 1 and 2 to further improve the system performance.

Compare to the two conventional methods, the additional complex multiplications, including the calculation of $H_i^{\mathrm{H}}(k,k)Y_i(k)$, $H_i^{\mathrm{H}}(k,k)H_i(k,k)$, $H_i^{\mathrm{H}}(k,k)H_i(k,m)$, $\mathrm{P}_{CCI,l}(k)$, $\mathrm{P}_{ICI,l}(k)$, and $\mathrm{P}_{N,l}(k)$ for i=3~4 and l=1~*Num*, are needed for the two proposed methods. Because the value of *Num* is limited and the size of all the matrices, as described above, is 2×2, the computation complexity is not heavy for the two proposed methods.

V. Simulation Results

A 2×2 STBC-OFDM system over the time-varying ITU Vehicular A (VA) channels is considered in our simulation. Perfect channel estimation and synchronization are assumed, and the system parameters are shown in TABLE I.

Each tap of the ITU VA channel is generated by Jake's model with f_dT_U of 10%, and the power delay profile of the ITU VA channel is shown in TABLE II. The parameter f_dT_U of 10% is a typical high-mobility target value. In our simulation, 5000 OFDM symbol periods are simulated, and the BER of the equalizer output data symbol is used to evaluate the system performance. In general, the BER between 10^{-2} and 10^{-3} is the range of targeted BER for system performance evaluation, and the targeted BER=2×10^{-3} is adopted here.

Fig. 7 shows the comparisons of BER performance among the conventional method 1, the proposed method 1 and the one-tap equalizer method. The CCI and ICI cancellation are used for the conventional method 1 and the proposed method 1, and the ICI terms from the 2*q* neighboring subcarriers are cancelled with *q*=1 and 2. For the proposed method 1, 9 ($C_2^4 - 1 + C_3^4 = 9$) combined signals are generated in this case. From the figure, we observe that the BER performance of the proposed method 1 is improved significantly compare to the conventional method 1 as long as the SNR is larger than 15dB. The proposed method 1 performs well because the error propagation of data symbol detection in CCI/ICI reconstruction can be alleviated through the optimal selection from 9 combined signals.

Fig. 8 shows the comparisons of BER performance among the conventional method 2, the proposed method 2 and the one-tap equalizer method. For the proposed method 2, 5 ($C_2^4 - 1 = 5$) and 9 combined signals are generated in this case. From the figure, we observe that the BER performance of the proposed method 2 is about 1.7 dB and 2.5 dB better than the performance of the conventional method 2 at BER=2×10^{-3} for *Num*=5 and 9, respectively. The improvement is not large because the dominant CCI effect has been suppressed by ZF equalizer in the conventional method 2 and proposed method 2.

Besides, the error floor phenomenon occurs in all the methods in Fig.7 and Fig.8 is caused by the residual CCI/ICI after CCI/ICI cancellation or zero-forcing equalization.

VI. CONCLUSIONS

A novel low complexity scheme for suppressing CCI and ICI caused by time-varying channels in STBC-OFDM systems has been presented in this paper. A received data symbol pair reordering module is used to generate extra received data symbol pairs, and it can help to obtain multiple combined signals. Then, the optimal selection module is used to select the optimal combined signal, and it can help to improve the performance of the following CCI/ICI cancellation and zero-forcing equalization stages. Our simulation results show that the proposed scheme performs well at low computation complexity for high mobility 2×2 STBC-OFDM systems in the ITU VA channels.

TABLE I. SYSTEM PARAMETERS

Bandwidth	**10 MHz**
Subcarrier spacing	**10.94 KHz**
FFT size	**1024**
OFDM symbol duration (T_U)	**91.43 μs**
Guard interval duration	**T_U/8**
Mapper	**16 QAM**

TABLE II. POWER DELAY PROFILE OF THE ITU VA CHANNEL

Tap delay (μs)	**0**	**0.3**	**0.7**	**1.1**	**1.7**	**2.5**
Fading gain (dB)	**0**	**-1**	**-9**	**-10**	**-15**	**-20**

REFERENCES

[1] W. Y. Zou, and Y. Wu, "COFDM: An overview," *IEEE Trans. Broadcasting*, vol. 41, no. 1, pp. 1-8, Mar. 1995.

[2] S. M. Alamouti, "A simple transmit diversity technique for wireless communications," *IEEE J. Sel. Areas Comm.*, vol. 16, no. 8, pp. 1451-1458, Oct. 1998.

[3] J. Kim, R. W. Heath Jr., and E. J. Powers, "Receiver designs for Alamouti coded OFDM systems in fast fading channels," *IEEE Trans. Wireless Commun.*, vol. 4, no. 2, pp. 550-559, Mar. 2005.

[4] D. B. Lin, P. H. Chiang, and H. J. Li, "Performance analysis of two-branch transmit diversity block-coded OFDM systems in time-varying multipath Rayleigh-fading channel," *IEEE Trans. Veh. Technol.* vol. 54, no. 1, pp. 136-148, Jan. 2005.

[5] J. W. Wee, J. W. Seo, K. T. Lee, Y. S. Lee, and W. G. Jeon, "Successive interference cancellation for STBC-OFDM systems in a fast fading channel," in *Proc. of IEEE VTC 2005-Spring*, vol. 2, pp. 841-844, May 2005.

[6] C. Y. Tso, J. M. Wu, and P. A. Ting, "Iterative interference cancellation for STBC-OFDM systems in fast fading channels," in *Proc. of GLOBECOM,* pp.1-5, Nov. 2009.

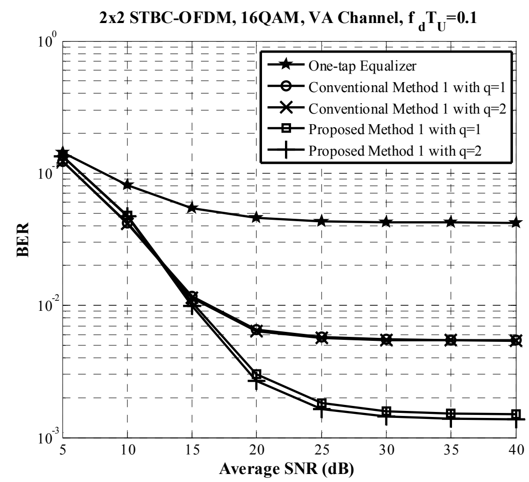

Fig. 7. Comparisons of BER performance among the conventional method 1at different *q*, the proposed method 1 at different *q* and the one-tap equalizer method for 2×2 STBC-OFDM systems in the time-varying VA channels

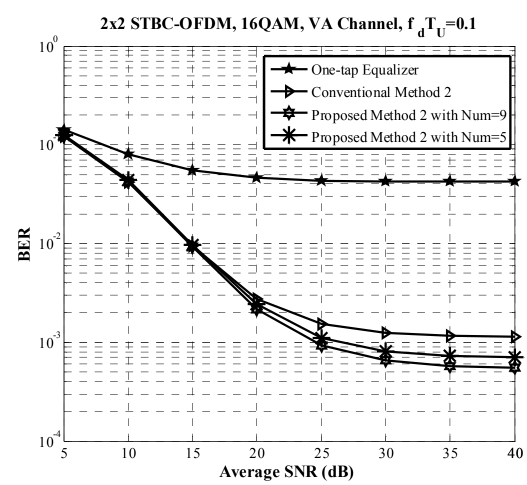

Fig. 8. Comparisons of BER performance among the conventional method 2, the proposed method 2 at different *Num* and the one-tap equalizer method for 2×2 STBC-OFDM systems in the time-varying VA channels