Impulsive Noise Cancellation for MIMO Power Line Communications

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***Abstract*—**Power line channels are often badly corrupted by impulsive noise. In this paper, an impulsive noise cancellation method for MIMO power line communication is proposed. First, the received signal is transformed into frequency domain and MIMO detection is carried out. Then, the detected signal is transformed back to time domain and the noise estimation can be obtained by subtracting detected signal from the original received signal, the result is the estimation of the noise in time domain. Finally, impulsive noise can be found out from the estimation of the noise by a threshold detector and canceled from the original received signal. The de-noised output is transformed back to space-time domain to repeat the impulsive noise cancellation process until the output is unchanged. Simulation results show that the proposed method can suppress in PLC channel impulsive noise and improve bit-error ratio performance in multi-wire power line communication.

***Index Terms*—**Impulsive noise cancellation, power line communications; multiple input multiple output; space time block code

I. INTRODUCTION

Power line communications (PLC) have gained heightened interest in the past several years. Based on widespread establishment of electrical power supply distribution systems, PLC has great advantages in constructing in-home communication networks. It can provide broadband Internet access to residential customers and has been considered as a strong candidate to facilitate Smart Grid. The multiple-input multiple-output (MIMO) techniques can greatly increase the capacity of PLC system, and have been successfully used in wireless communication. Furthermore, MIMO techniques can also be used in PLC since many power line networks deploy multi-conductor cables. In fact MIMO PLC has recently become a hot research topic for enhancing the performance of indoor PLC. HomePlug Power line Alliance considers MIMO technique as the key element of next generation PLC standard [1]. The characteristics of the MIMO power line channels has been studied in [2], [3]. The capacity of MIMO PLC has been studied in [4].

High speed PLC is a great challenge due to the fact that power lines were not designed for data communication, but for power delivery. PLC systems face several obstacles, such as frequency-selective fading, colored noise, narrowband interference and impulsive noise. Orthogonal frequency division multiplexing (OFDM) is the most acceptable technique to combat those obstacles, which provides excellent methods to handle the frequency selective attenuation of the PLC channel, colored noise, and narrowband interference. OFDM is also considered as a robust tool to fight against the impulsive noise [5]. Impulsive noise is the main interference in power line channel, which causes signal distortions and degrades the BER performance. Impulsive noise occurring in the time domain is suppressed after OFDM demodulation by spreading the impulsive noise over a large number of subcarriers. However, it was shown in [5], [13] that impulsive noise leads to an enormous loss in the BER performance in OFDM systems when the impulsive noise amplitude exceeds some extent. This is because OFDM demodulation just spreads impulsive noise energy but not reduces the noise energy. One approach to remove impulsive noise is to identify peaks of the received signal in time domain and reduce the impulsive noise by blanking or clipping the peaks. More efficient impulsive cancellation method which has simple iterative structure is proposed in [6], [13]. The characters of impulsive noise in time domain and frequency domain are exploited. Impulsive noise is cancelled in time domain, information signal is detected in frequency domain and detected signal transform back to time domain to start next iteration. For MIMO system, usually diversity techniques are used to combat impulsive noise. In [9], space-time-frequency block code (STFBC) which can obtain diversity gain was used for reducing impulsive noise effect for MIMO-PLC. It can improve the BER performance in MIMO-PLC, though the noise correlation in MIMO-PLC reduce the diversity gain which STFBC can obtain.

In this paper, an impulsive noise cancellation method for MIMO PLC is proposed. Iterative impulsive noise cancellation in [6] is extended into MIMO OFDM PLC system by using orthogonal space-time block code (STBC). First, the received signal is transformed into frequency domain and MIMO detection is carried out. Then, the detected signal is transformed back to time domain and is subtracted from the original received signal. The results of the subtraction is the estimation of the noise in time domain. Finally, impulsive noise is found out from the estimation of the noise by a threshold detector and canceled from the original received signal. STBC and iterative impulsive noise cancellation promote each other. STBC can make impulsive noise estimation

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more accurate and after impulsive noise cancellation STBC decoder outputs are more accurate in next iteration. The BER performance of the final converged outputs is promoted a lot. The simulation results show that the proposed method obtains a better performance than STBC method in impulsive noise condition.

This paper is organized as follows. In Section 2, the power line channel and impulsive noise model are given; In Section 3, space time block codes (STBC) for PLC is discussed; In Section 4, the impulsive noise cancellation method for SISO-OFDM is introduced; The impulsive noise cancellation method for MIMO PLC is proposed and discussed in Section 5; In Section 6, the performance of the proposed method is shown by simulation; Finally, some conclusions are drawn in Section 7.

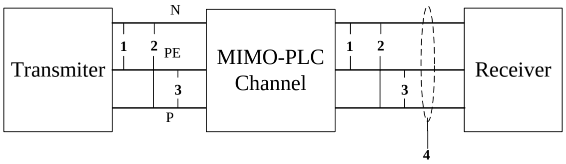

Fig. 1. MIMO PLC channel

II. Model for Power Line Channel and Systems

A. MIMO Power Line Channel Model

Three-wire power line cable is typical in power distribution grids. The wires are N (Neutral), P (Phase or Live) and PE (Protective Earth), therefore there are three different feeding possibilities, i.e. N to PE, N to P and P to PE. Fig. 1 shows the three feeding patterns. However, only two of them can be used as transmitting ports because of Kirchhoff's rule. While on receiving side, all three different receiving ports are available. Moreover, the common mode (CM) path can also be used as the fourth receiving port. CM signals are created unintentionally in unbalanced networks. Unbalanced parasitic capacities from installations or devices to ground cause a CM current returning to the source. According to multi-conductor transmission-line theory, coupling exists among different feeding channels. With the coupling transmission data from one transmitting port can reach all the receiving ports, which is just similar to a typical wireless MIMO.

Zimmermann and Dostert [10] developed a N_p-path frequency domain channel model to account for the attenuation of the signal flow as

$$H(f)=\sum_{P=1}^{N_p} g_p \mathrm{e}^{-j\frac{2\pi d_p\sqrt{\varepsilon_r}}{c}} \mathrm{e}^{-(a_0+a_1 f^k)d_p} \tag{1}$$

where g_p, N_p and d_p stand for path gain, number of paths and path length respectively; Each path is characterized by weighting factor g_p which is the product of transmission and reflection factors with path length d_p; The attenuation factor is modeled by the parameters a_0, a_1 and k, which can be obtained from measurements; c is the light speed and ε_r is the dielectric constant.

The model proposed by Zimmermann and Dostert is extended to MIMO-PLC model in [14]. For a MIMO PLC system comprising of M emitter ports and N receiver ports, the channel matrix H(f) can be written as

$$\mathbf{H}(f)=\begin{pmatrix} h_{1,1}(f) & h_{1,2}(f) & \cdots & h_{1,M}(f) \\ h_{2,1}(f) & h_{2,2}(f) & \cdots & h_{2,M}(f) \\ \vdots & \vdots & \ddots & \vdots \\ h_{N,1}(f) & h_{N,2}(f) & \cdots & h_{N,M}(f) \end{pmatrix} \tag{2}$$

where $h_{n,m}(f)$ represents the channel transfer function from the m-th emitter to the n-th receiver. Transmission channels represented by $h_{n,m}(f)$ with $m = n$ are called co-channels, and others are named as cross-channels. In the MIMO PLC model proposed in [14], Zimmermann's model is applied for PN-PN channel, and the channel transfer function of the other channels in MIMO-PLC can be obtained from PN-PN channel by assigning a random phase φ_p to each defined path. The transfer functions of the other channels are modified as follows

$$H(f)=\alpha\sum_{P=1}^{N_p} g_p \mathrm{e}^{-i\varphi_p} \mathrm{e}^{-j\frac{2\pi d_p\sqrt{\varepsilon_r}}{c}} \mathrm{e}^{-(a_0+a_1 f^K)d_p} \tag{3}$$

where φ_p follows a uniform distribution between $-\Delta\varphi/2$ and $\Delta\varphi/2$, here $\Delta\varphi$ is between 0 to 2π. $\Delta\varphi$ is selected empirically, for PPE-PPE channel, $\Delta\varphi=2\pi$; for other channels, $\Delta\varphi=\pi$; α is global frequency attenuation factor of a given channel, and its value is between 0 to 1. The attenuation of cross-channels is generally larger than co-channels. Therefore, for co-channels, $\alpha=1$, while for cross-channels, $\alpha<1$.

B. Impulsive Noise Model

A suitable model for typical PLC impulsive noise caused by switching transients in the grids is the Middleton's class A noise model [11], The probability density function (PDF) of Middleton's class A noise model is given by

$$p(x)=\sum_{m=0}^{\infty}\frac{a_m}{2\pi\sigma_m^2}\exp\left(-\frac{|x|^2}{2\sigma_m^2}\right) \tag{4}$$

where $a_m=\dfrac{A^m \mathrm{e}^{-A}}{m!}$, and

$$\sigma_m^2=\sigma^2\frac{(\frac{m}{A})+T}{1+T} \tag{5}$$

where σ^2 is the variance of the Class A noise, A is the impulsive index, which is the average number of impulses during a unit length interval. In this model, the number of impulses during the j-th unit length interval, P_j, is a Poisson distributed random variable; a_m is the probability that P_j takes the value of m. Middleton's class A noise model combines an additive white Gaussian component and additive impulsive noise component; T is the Gaussian-to-impulsive noise power ratio, and if $T\to\infty$, the Middleton's Class A noise model degenerate to a Gaussian distribution.

C. MIMO-OFDM PLC System

In OFDM, the entire channel is partitioned into many sub-channels. We consider a MIMO-OFDM PLC system with m_T transmitting ports and m_R receiving ports. At time slot k an input data block is mapped into m_T complex constellation sequences $S_i(k, 1)$, $S_i(k, 2)\ldots S_i(k, N)$, where $i=1,\ldots, m_T$, N is the number of subcarriers. The received signal after FFT processing at receiving port j is

$$R_j[k,n]=\sum_{i=1}^{2}H_{ij}[k,n]S_i[k,n]+P_j[k,n] \tag{6}$$

where $H_{ij}[k,n]$ is the channel frequency response from transmitting port i to receiving port j at the n-th tone of the OFDM block. P_j is class A noise received at receiving port j.

III. Space-Time Block Code

Non-orthogonal STBC is applied in early PLC research [7, 8, 15] and the couplings between multi-wires power lines were not taken into account. But in fact coupling does exist in power line channel [16]. If the couplings are taken into account, non-orthogonal STBC is not suitable own to its complex decoding. Orthogonal STBC is preferred for PLC. Alamouti STBC which is the simplest orthogonal STBC [12] is applied in the scheme.

The Alamouti STBC [12] system with two transmitting ports and four receiving ports for PLC was investigated in [8]. During the first time slot, two symbols [s_1 s_2] are transmitted in the two cables simultaneously. In the second time slot, the symbols [$-s_2^*$ s_1^*] are transmitted. Combined with OFDM, Alamouti encoding can be applied in two different ways. Space-time encoding indicates that every subcarrier of the same OFDM symbol uses the encoding method referred above, while for space-frequency encoding, time slots k and k+1 are not assigned in time dimension but two adjacent subcarriers of the same OFDM symbol.

Alamouti code is an orthogonal codes, which allows a simple decoding. For space-time Alamouti decoding, it is assumed that the channel is static during two successive time slots. At receiver, maximum likelihood (ML) detection is described by

$$\hat{\mathbf{s}}=\arg\max_{\mathbf{s}(l)\in C}\{\mathrm{p}[(\mathbf{r}(l)\,|\,\mathbf{s}(l)]\} \tag{7}$$

where $\mathbf{s}(l)$ is transmitted signal, $\mathrm{p}[\mathbf{r}(l)\ |\mathbf{s}(l)]$ is the conditional PDF of the received vector $\mathbf{r}(l)$, C represents all possible transmitted vectors.

The ML receiver searches all possible transmitted vectors and selects the one with the maximum value of conditional PDF for the output. The conditional PDF of the received vector $\mathbf{r}(l)$ can be further described as

$$\mathrm{p}[(\mathbf{r}(l)\,|\,\mathbf{s}(l)]=f[\mathbf{r}(l)-\mathbf{H}(l)\mathbf{s}(l)] \tag{8}$$

where $f(\cdot)$ is the noise PDF, $\mathbf{H}(l)$ is channel transfer matrix.

Substituting (8) into (7), we have

$$\hat{\mathbf{s}}=\arg\max_{\mathbf{s}(l)\in C}\{f[\mathbf{r}(l)-\mathbf{H}(l)\mathbf{s}(l)]\} \tag{9}$$

If the noise has Gaussian distribution, Eq. (9) becomes

$$\hat{\mathbf{s}}=\arg\max_{\mathbf{s}(l)\in C}(\|(\mathbf{r}(l)-\mathbf{H}(l)\mathbf{s}(l)\|^2) \tag{10}$$

IV. Iterative Impilsive Noise Cancellation Method for MIMO PLC

Because impulsive noise is sparsity in time domain and is scattered in frequency domain, it is easier to find the position of the impulsive noise in time domain. Iterative impulsive noise cancellation method exploits the nature of the impulsive noise. Impulsive noise is estimated and removed in time domain, and signal is detected in frequency domain. So the iterative impulsive noise cancellation method can efficiently reduce the energy of the impulsive noise. For MIMO PLC , impulsive noise is estimated and removed in space-time domain, and the MIMO detection is carried out in frequency domain. STBC can obtain noise diversity in MIMO PLC at each iteration which can further improve the system performance.

In the proposed scheme, indoor two-phase network is concerned, which can be considered as a 2×4 MIMO channel as described in section 2, thus 2×4 STBC is used in the scheme. The block diagram of the iterative impulsive noise cancellation method for MIMO-OFDM PLC is depicted in Fig. 2. In Fig. 2, **r** is receiving data block, l is The number of iterations, and $\mathbf{S_{out}}$ is the final output.

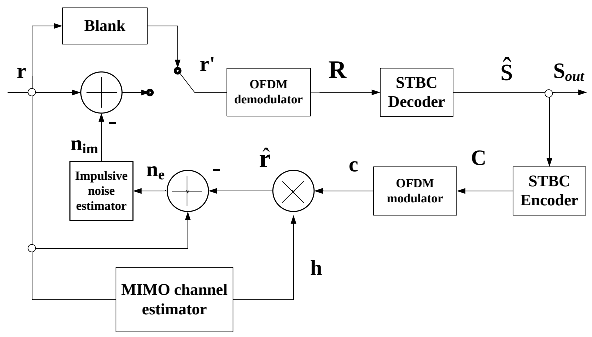

Fig. 2. Block diagram of iterative impulsive noise cancellation method for MIMO-OFDM PLC

In the following, each module of the proposed impulsive noise cancellation method for MIMO PLC are illustrated in detail.

A. Blanking

There is a blanking nonlinearity before OFDM demodulator. The received signal vector **r** with larger value which is considered as the result of impulsive noise is set to zero after blanking nonlinearity. The nonlinearity processing weakens the effect of impulsive noise, and increases the convergence speed of iterative impulsive noise cancellation. Blanking operation works just at the first iteration loop.

B. OFDM Demodulator

The received signal is transformed into frequency domain after OFDM demodulation. And impulsive noise is spread over a large number of subcarriers.

C. STBC Encode

In the proposed scheme, Alamouti code with BPSK is applied in the indoor two-phase network. Assume that $\mathbf{S}_1$, $\mathbf{S}_2$ are two successive unmodulated transmitting N-dimension vectors, N is the number of OFDM subcarriers. s_1^m and s_2^m the *m*-th entry of $\mathbf{S}_1$ and $\mathbf{S}_2$ and [s_1^m , s_2^m] are transmitted at the two cables simultaneously by *m*-th subcarrier. In the second time slot, the symbols [-(s_2^m)*, (s_1^m)*] are transmitted.

D. STBC Decode

In order to carry out STBC decoding, channel state information (CSI) is needed. Assume that the PLC receiver can get perfect CSI, $R_j^m(k)$, *j*=1, 2, 3 and 4, represents the receiving signal from the *m*-th subcarrier's channel and the *j*-th receiving port at time slot *k* after demodulation. The average transmitted power at each transmitting port is denoted by the scalar ρ . At two successive time slots *k* and *k*+1, we have

$$R_j^m(k) = \sqrt{\rho}(h_{1,j}^m s_1 + h_{2,j}^m s_2) + n_j(k), \tag{11}$$

$$R_j^m(k+1) = \sqrt{\rho}(-h_{1,j}^m s_2^* + h_{2,j}^m s_1^*) + n_j(k+1), \tag{12}$$

where $h_{i,j}^m$ represents the *m*-th subcarrier's channel factor from *i*-th transmitting port to the *j*-th receiving port. n_j represents noise at *j*-th receiving port. If *N* is large enough, noise $n_j(k)$ can be considered as Gaussian noise due to the Gaussian approximation.

Using maximum ratio combining, we can obtain

$$R^m(k) = \sum_{j=1}^{4} \sqrt{|h_{1,j}|^2 + |h_{2,j}|^2}\; y_j(k). \tag{13}$$

For BPSK, using maximum likelihood (ML) method, $\hat{s}_1$ and $\hat{s}_2$ represent the entries of decoding output $\mathbf{S_{out}}$. we have

$$\hat{s}_1 = \begin{cases} 1, & \mathrm{Re}[\sum_{j=1}^{N_r} h_{1,j}^* R_j(k) + h_{2,j} R_j^*(k+1)] < 0 \\ 0, & else \end{cases} \tag{14}$$

and

$$\hat{s}_2 = \begin{cases} 1, & \mathrm{Re}[\sum_{j=1}^{N_r} h_{2,j}^* R_j(k) - h_{1,j} R_j^*(k+1)] < 0 \\ 0, & else \end{cases} . \tag{15}$$

E. OFDM Modulator

STBC encoded signal is transformed back to time domain again by OFDM modulator. This process is exactly same with the OFDM modulator at the transmitting side.

F. MIMO Channel Estimation

Least square channel estimation is applied in the proposed method. As impulsive noise is suppressed, the channel estimation becomes more accurate.

G. Impulsive Noise Estimator

Assume that $\mathbf{n}_{\mathrm{im}}(k, j)$ is the estimation of impulsive noise at *j*-th receiving port in time slot *k* and $\mathbf{n}_{\mathrm{e}}(k, j)$ is the estimation of receiving noise at *j*-th receiving port in time slot *k*, $\mathbf{n}_{\mathrm{e}}(k, j) = \mathbf{r} - \hat{\mathbf{r}}$, where $\hat{\mathbf{r}}$ = $\mathbf{h}$*$\mathbf{c}$, $\mathbf{c}$ is the estimation of transmitting signal. The function of the impulsive noise estimator is

$$\mathbf{n}_{\mathrm{im}}(k, j) = \mathrm{E}(\mathbf{n}_{\mathrm{e}}(k, j)) = \begin{cases} 0, & |\mathbf{n}_{\mathrm{e}}(k, j)| \le D \\ \mathbf{n}_{\mathrm{e}}(k, j), & |\mathbf{n}_{\mathrm{e}}(k, j)| > D \end{cases} \tag{16}$$

where *D* is the threshold, $\mathrm{E}(\cdot)$ stands for impulsive noise estimating operation

Let $\mathbf{S}_{\mathrm{out}}^{(j)}$ stand for the *j*-th iteration loop output , if $\mathbf{S}_{\mathrm{out}}^{(j)} = \mathbf{S}_{\mathrm{out}}^{(j+1)}$, the iteration is terminated. The impulsive noise cancellation method for MIMO-OFDM PLC can be concluded as follows.

Input: **r**, **h** **Output**: $\mathbf{S_{out}}$
r'=Blanking (**r**)
l=0
$\mathbf{r}^{(0)} = \mathbf{r}'$
Repeat until stop criterion is valid
$\mathbf{R}^{(l)}$=FFT($\mathbf{r}^{(l)}$)
$\hat{\mathbf{S}}^{(l)}$=STBC_decode ($\mathbf{R}^{(l)}$)
$\mathbf{C}^{(l)}$=STBC_encode($\mathbf{S}^{(l)}$)
$\mathbf{c}^{(l)}$=IFFT($\mathbf{C}^{(l)}$)
$\hat{\mathbf{r}}^{(l)}$=$\mathbf{h}$*$\mathbf{c}^{(l)}$
$\mathbf{n}_{\mathrm{e}}^{(l)}$=$\mathbf{r}^{(l)}$- $\hat{\mathbf{r}}^{(l)}$
$\mathbf{n}_{\mathrm{im}}^{(l)}$= E ($\mathbf{n}_{\mathrm{e}}^{(l)}$)
$\mathbf{r}^{(l+1)}$= $\mathbf{r}^{(l)}$- $\mathbf{n}_{\mathrm{im}}^{(l)}$
l=*l*+1
end repeat
$\mathbf{S_{out}}$= $\hat{\mathbf{S}}^{(l)}$

In this scheme, estimating impulsive noise is applied instead of estimating the transmitting signal directly. This process has the advantage that the performance of the proposed method without optimal threshold *D* would still be better than ordinary STBC. Noise estimation is improved by STBC code then the impulsive noise estimation will be more accurate, furthermore after impulsive noise cancellation in the current iteration, STBC decoding output is more accurate at the next iteration. Therefore, the iterative impulsive noise cancellation is increased and the performance of the whole system will be improved.

V. Simulation Results and Discussion

To evaluate the performance of the proposed method, computer simulation in power-line environments was carried out. In the simulations, a 2×4 MIMO OFDM PLC system is adopted. Assume that perfect CSI is available at the receiver. The transmitted signal is generated by pseudo-random code. BPSK is applied in the simulation and the number of OFDM subcarriers is 512.

The simulations are carried out in two conditions: the impulsive parameter A = 0.1 and A=0. 25, which are well within a practical range of A. A = 0.1 corresponds to a power line channel which is heavily corrupted by impulsive noise, and A = 0.25 corresponds to a power line channel which is weakly corrupted by impulsive noise. The threshold D in (11) is crucial for the performance of the proposed method . For each SNR, we find out optimal threshold D by Monte Carlo simulation. The value of threshold D is searched from 0.0005 to 0.5, searching step is 0.0005, and optimal threshold D can be found. The threshold for different SNR in the simulation is shown in Table I and Table II.

TABLE I. OPTIMAL IMPULSIVE THRESHOLD IN UNCORRELATED IMPULSIVE NOISE CONDITION

	A=0.1, T=0.01	A=0.25, T=0.01
SNR 0 dB	0.248	0.263
2 dB	0.1975	0.2145
4 dB	0.16	0.1835
6 dB	0.124	0.148
8 dB	0.111	0.121
10 dB	0.0865	0.0995
12 dB	0.0765	0.844
14 dB	0.056	0.0625
16 dB	0.0395	0.046

TABLE II. OPTIMAL IMPULSIVE THRESHOLD IN CORRELATED IMPULSIVE NOISE CONDITION

	A=0.1, T=0.01	A=0.25, T=0.01
SNR 0 dB	0.2205	0.2515
2 dB	0.171	0.197
4 dB	0.1345	0.1675
6 dB	0.108	0.1415
8 dB	0.087	0.121
10 dB	0.0715	0.1145
12 dB	0.059	0.0965
14 dB	0.0465	0.083
16 dB	0.0345	0.0605

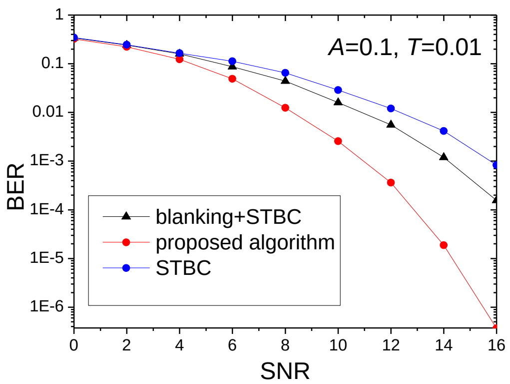

Fig. 3. BER performance comparison in multi-wire PLC, parameter A = 0.1

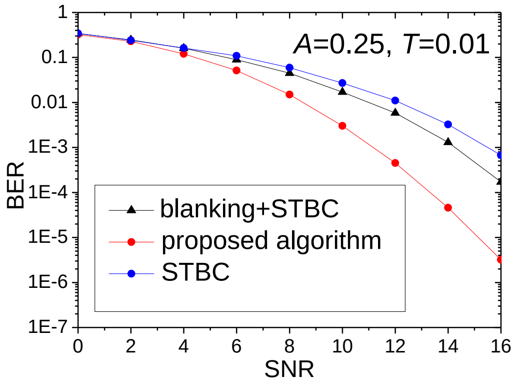

Fig. 4. BER performance comparison in multi-wire PLC, parameter A = 0.25

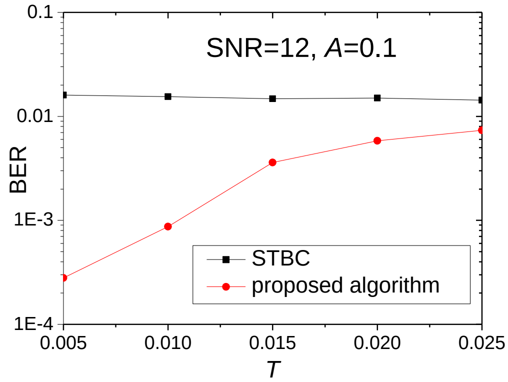

Fig. 5. BER performance comparison with different parameter T

Assume that four independent impulsive streams are added separately to four received signals. The simulation results in power line channel slightly corrupted by impulsive noise (A=0.25) are shown in Fig. 3. We can find out that STBC with blanking gives a better BER performance than common STBC-OFDM PLC system in an impulsive noise environment, and the proposed method give the best BER performance. The simulation results in power line channel highly corrupted by impulsive noise (A=0.1) are shown in Fig. 4. We can see from Fig. 4 that the BER performance has still improved a lot by the proposed method. The influence of the Gaussian-to-impulsive noise power ratio T is shown in Fig. 5. If the number of the OFDM subcarriers is large enough, the influence of T is weak for common STBC-OFDM system, while for the proposed method, if the noise power is unchanged, the smaller T is, the better BER performance is. T is much smaller than 1 means that Gaussian noise power is much smaller than the impulsive noise power, therefore, impulsive noise can be picked out more easily by threshold detector and more noise power will be reduced, so the smaller T is, the better BER performance is.

Threshold value choosing is important for system BER performance, however, the proposed method will not degrade the BER performance of MIMO PLC system even if the threshold value is far from optimal. From the Fig. 6 we can see that the optimal threshold is 0.11. When the threshold is very small, even zero, the proposed method has a similar BER performance with the STBC

MIMO PLC system. When the threshold is around optimal value, the proposed method significantly improves system BER performance. When the threshold is getting larger, the proposed method getting worse, but always better than the STBC MIMO PLC system. This is because we try to estimate impulsive noise instead of estimating transmitting signal directly, and impulsive noise is picked up from noise estimation based on STBC decoding output. Therefore, even if the threshold is not optimal, the output will not get worse than STBC decoding output.

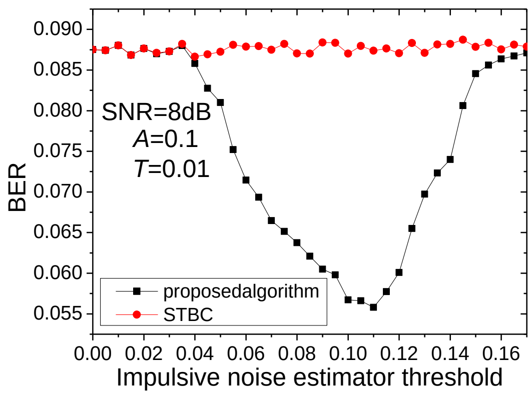

Fig. 6. BER performance comparison with different impulsive noise threshold

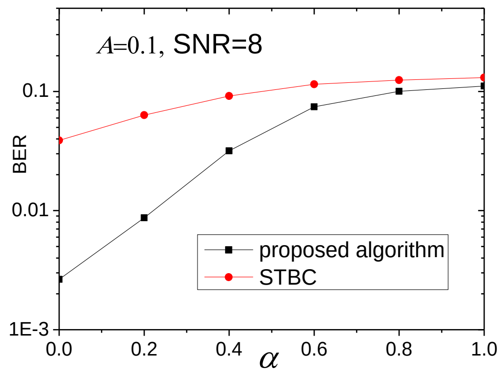

Fig. 7. BER performance comparison with different α

Coupling exists in multi-wire power line, so in practical power line condition, noises in different transmitting lines are not independent. Assume that noise correlation in power lines is only caused by coupling in power lines. Noise in simulation is generated by two independent class A noise sources transmitting through MIMO power line channel. Because of coupling, noise at receiving ports is correlated. Correlation is related to α in (3). The bigger a is, the stronger correlation is. From Fig. 7 we can see that when correlation is strong, the performance of both STBC and proposed method is degraded. The correlation of the noise reduces the diversity gain of STBC. But the proposed method gives much better performance when correlation is weak. When α is 1, there is no diversity in the channel and the proposed method has little improvement compared to STBC. However, when α is smaller than 1, both methods can obtain diversity gain from the channel and with a getting smaller, improvement of the proposed method becomes obvious compared to STBC. These results prove the superiority of the proposed method, the proposed method can obtain more benefit from the noise diversity. Noise estimation is improved by STBC, then the impulsive noise estimation will be more accurate, furthermore after impulsive noise cancellation in this iteration, STBC decoding output will be more accurate at the next iteration. Impulsive noise cancellation and STBC benefit from each other in the iteration, therefore, the proposed method can obtain more benefit from noise diversity. The system BER performance under correlated impulsive noise (α =0.2) is shown in Fig. 8 and Fig. 9. The optimal impulsive threshold used in the simulation in correlated impulsive noise is shown in Table II.

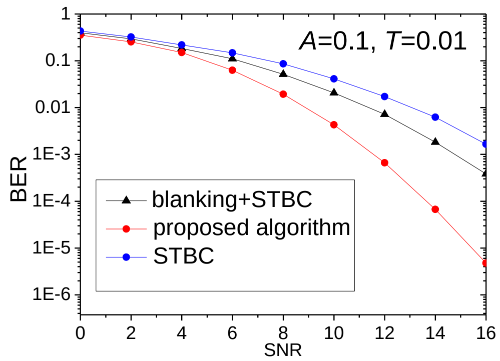

Fig. 8. BER performance comparison in multi-wire PLC with , correlated impulsive noise, parameter A = 0.1

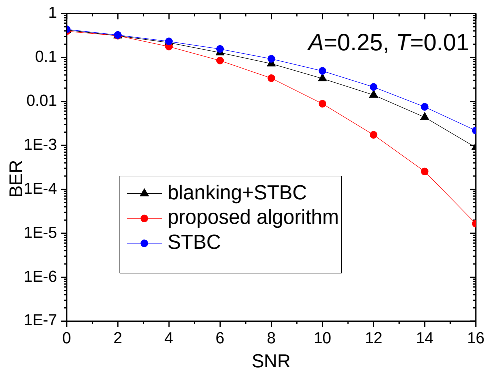

Fig. 9. BER performance comparison in multi-wire PLC with , correlated impulsive noise, parameter A = 0.1

VI. Conclusion

In this paper, an iterative impulsive noise cancellation method for MIMO PLC is presented. The proposed method exploits the nature of the impulsive noise and utilizes noise diversity of MIMO PLC. Impulsive noise can be picked out easier in time domain, so the impulsive noise is estimated and removed in time domain while MIMO detection is carried out in frequency domain. STBC is applied to obtain diversity gain from power line channels. Impulsive noise cancellation and STBC can be benefited from each other in the iteration, so proposed method can obtain more benefit from noise diversity than ordinary STBC, therefore, the BER performance is improved. Simulation results show that the proposed scheme significantly improves the BER performance of

MIMO PLC system corrupted by impulsive noise. It works efficiently in both MIMO PLC channel highly corrupted by impulsive noise and slightly corrupted by impulsive noise. Choosing optimal threshold of the impulsive noise estimator can give the best performance. In fact, if the threshold is not optimal, the proposed scheme would still give a better or at least the same performance as STBC PLC system.

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REFERENCES

[1] D. Schneider and A. Schwager, "Implementation and results of a MIMO PLC feasibility study," in *IEEE International Symposium on Power Line Communications and Its Applications*, Udine, Italy, 2011, pp. 54-59, 3-6.

[2] A. Schwager, "MIMO PLC: Theory, measurements and system," in *IEEE International Symposium on Power Line Communications and Its Applications*, Udine, Italy, 2011,pp 48-53

[3] R. Hashmat and P. Pagani, "A channel model for multiple input multiple output in-home power line networks," *IEEE International Symposium on Power Line Communications and Its Applications*, Udine, Italy, 2011, pp.48-53.

[4] D. Schneider, M. Hirano, K. Oka, and Y. Tagawa, "Potential of MIMO for inhome power line communications," in *Proc. IEEE Global Telecommunications Conference*, New Orleans, USA. 2008, pp. 23-28.

[5] S. V. Zhidkov, "Impulsive noise suppression in OFDM based communication systems", *IEEE Transactions on Consumer Electronics*, vol. 49, no. 4, pp. 944- 948, Nov 2003.

[6] A. Mengi and J. H. Vinck, "Successive impulsive noise suppression in OFDM," in *IEEE International Symposium on Power Line Communications and Its Applications*, Rio de Janeiro, Brazil, 2010, pp. 33-37, 28-31.

[7] Z. Quan and M. V. Ribeiro, "A low cost STBC-OFDM system with improved reliability for power line communications," in *IEEE International Symposium on Power Line Communications and Its Applications*, Udine, Italy, 2011, pp. 261-266, 3-6.

[8] L. C. Giovaneli, P. Farrell, and B. Honary, "Improved space-time coding applications for power line channels," in *IEEE International Symposium on Power Line Communications and Its Applications*, Kyoto, Japan, 2003, pp. 121-125.

[9] B. Adebisi and B. Honary, "Space-frequency and space-time-frequency M3FSK for indoor multiwire communications," *IEEE Transaction on Power Delivery*, vol. 24, no. 4, October 2009.

[10] M. Zimmermann. and K. Dostert, "A multipath model for the power line channel," *IEEE Transactions on Communications*, vol. 50, no. 4, pp. 553-559, April 2002.

[11] D. Middleton, "Canonical and quasi canonical probability models of class A interference," *IEEE Transactions on Electromagnetic Compatibility*, vol. 25, no. 2, May 1983.

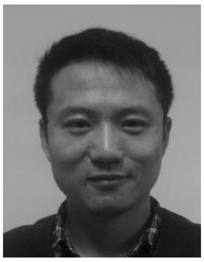
[12] V. Tarokh, H. Jafarkhami, and A. R. Calderbank, "Space-time block codes from orthogonal designs," *IEEE Transactions on Information. Theory*, vol. 45, no. 5, pp. 1456–1467, July 1999.

[13] J. Haering and A. J. H. Vinck,"OFDM transmission corrupted by impulsive noise," in *IEEE International Symposium on Power Line Communications*, Limerick, Ireland, 2000, pp. 9-14.

[14] R. Hashmat, P. Pagani, and A. Zeddam, "A channel model for multiple input multiple output In-home power line networks," in *IEEE International Symposium on Power Line Communications and Its Applications*, Udine, Italy, 2011, pp.35-41, 3-6.

[15] C. L.Giovaneli, P. Farrell, and B. Honary, "Space-time block codes with rate >=1 for power line channels," in *IEEE International Symposium on Telecommunications*, Natal, Brazil, 2002.

[16] L. Hao and J. Guo, "A MIMO-OFDM scheme over coupled multi-conductor power-line communication channel," in *IEEE International Symposium on Power Line Communications and Its Applications*, Pisa, Italy, 2007.



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