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Dual Turbo MIMO-OFDM Channel Estimation Based on Puncher Technique via UWA Channels

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Abstract: In this study, various techniques of UWA (Underwater Acoustic, UWA) channel estimation for underwater MIMO-OFDM system are studied. Dual turbo channel estimation algorithm based on channel puncture technique is proposed. In order to judge the criteria of channel compensation, difference between the raw received signal and the re-coded information signal is carried out. The uncertain sub-channels are punched by using channel puncture technique and replaced by the responses estimated by MMSE (Minimum Mean Square Error, MMSE) or OMP (Orthogonal Matching Pursuit, OMP) algorithms. Compared with the conventional existing algorithms, the proposed algorithm can effectively reduce the occupancy of pilots, offer confined error propagation and significantly increase the stability of the system with Monte Caro simulation. The results of in-tank-experiment further indorse the reliable performance with improved efficiency of 1.51 bits/s/Hz.

Keywords: Dual turbo channel estimation, MIMO-OFDM, MMSE, OMP, puncture technique, underwater acoustic channel

INTRODUCTION

In underwater acoustic communication, oceanic channel imposes a great challenge in terms of extremely limited bandwidth and respective low data rate such that it couldn't be improved even with increasing transmitting power. In this background, MIMO-OFDM regarded as the best possible solution which can improve the spectral efficiency and has become one of the hottest spots in recent years for high speed UWA communication (Carrascosa and Stojanovic, 2010; Baosheng *et al*., 2009; Gang *et al*., 2012). The UWA channel is usually considered to be a time-space coherent multi-path channel. In dealing a finite time domain channel, the UWA channel can be modeled on an invariant filter (Li, 2007). Compress sensing (Shenguo and Xiang, 2011; Maohua *et al*., 2011), as already being used in signal processing fields such as image compression, is used to acquire and reconstruct the signals which are supposed to be sparse or compressible. In this study, a novel turbo estimation algorithm, that have capability to handle complex MIMO-OFDM channels is proposed. Both STBC (Space-Time Block Code, STBC) and CC (Convolution Code, CC) is used to encode the information. The channel estimation is taken as a decoding process and the properties of UWA channel are utilized for the definition of decoding rule. The punched OFDM symbols are used as new input source for the channel turbo decoder, whereas, the difference between the raw received signal and the re-coded information signal is considered as a criterion to judge the reliability of signal compensation. Compared with the methods mentioned in Song (2008) and Huang (2010), concatenated code combined with channel estimating algorithm and the channel puncture technique are adopted here to compose a channel dual turbo decoder for confined propagation of error. The aim of this research is to realize reliable high speed MIMO-OFDM UWA communication. It has been verified that the channel can be effectively reconstructed and long distance MIMO communication can be realized with the results from Monte Carlo simulation. Moreover, the results from tank experiments in the underwater acoustic channel simulation lab of Harbin Engineering University are also used for the performance evaluation and MIMO_OFDM communications at an effective data rate of 6.04 kbits/s are achieved.

MAJOR TECHNIQUES USED IN MIMO-OFDM

MIMO-OFDM: MIMO technique is usually combined with OFDM modulation in high-speed UWA communication to solve the problems created by complex UWA channels.

CP-OFDM (Circulation Prefix OFDM, CO-OFDM) is considered in this study. An OFDM symbol duration is T' and the pre-positive guard interval is T_g. So the real duration T of a whole OFDM symbol should be:

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$$T = T' + T_g \tag{1}$$

Let f_c denote the first sub-carrier frequency and Δf the space of successive sub-carriers. The j^{th} sub-carrier frequency f_j can be written as:

$$f_j = f_c + (j-1)\Delta f \tag{2}$$

The MIMO channels are considered as frequency selected fading channels. The fading coefficients are independent and identically distributed between the antennas with no spatial correlation between them. The channel matrix H based on multipath propagation channels is given as Anwar and Matsumoto (2010):

$$H = \begin{bmatrix} H_{11} & H_{12} & \cdots & H_{1K} \\ H_{21} & H_{22} & \cdots & H_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ H_{I1} & H_{I2} & \cdots & H_{IK} \end{bmatrix} \tag{3}$$

H_{ik}, I = 1, 2,… I, K = 1, 2,… K is sub-matrix, K and I is the total number of transmit and receive elements respectively, whereas, each sub-array is a Toeplitz matrix as expressed in (4). Because of the multipath channel response, cyclic prefix is added to the sub-matrix H_{ik} that make it become a circulant. Its first column can be written as:

$$h_{ik} = [h_{ik}(0), h_{ik}(1), \cdots, h_{ik}(L-1), 0, \cdots 0]^T \tag{4}$$

where,

L-1 = The length of channel

$h_{ik}(l)$ = The impulse response between the K^{th} transmitters and i^{th} receive antennas. Since the matrix H is a cyclic block matrix, the frequency domain channel matrix is given (Feng and Sui, 2010):

$$\Omega = F_I^H H F_K = \begin{bmatrix} \Omega_{11} & \Omega_{12} & \cdots & \Omega_{1K} \\ \Omega_{21} & \Omega_{22} & \cdots & \Omega_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ \Omega_{I1} & \Omega_{I2} & \cdots & \Omega_{IK} \end{bmatrix} \tag{5}$$

where,

$F_I = P_I \otimes F$

P_I = An identity matrix

$\otimes$ = The Kronecker product

F = Discrete Fourier matrix as given by:

$$F_{\varepsilon,\upsilon} = \frac{1}{\sqrt{K}} e^{\Gamma \cdot \frac{2\pi}{K} \cdot \varepsilon \cdot \upsilon} \tag{6}$$

$\Gamma = \sqrt{-1}$, $\varepsilon, u = 0, \ldots K-1$. In (4) and (6), the symbol H_k and Ω_k stand for the same column of k^{th} transmit antenna. So Ω_k can be also given by:

$$\Omega_k = F_I^H H_k F_K$$

(7)

When the signal 'x' is transmitted over the frequency selective fading channel, the received signal can be expressed as:

$$y = Hx + n \tag{8}$$

where,

n = A white Gaussian noise vector, with a zero mean and covariance

$E\{nn^H\} = \sigma^2 p_I$

σ^2 = a noise variance given as $\sigma^2 = 10^{-SNR[dB]/10}$ which is further defined by the specified signal to noise ratio per antenna path in decibel.

Alamouti transmit diversity scheme: Alamonti transmit diversity scheme is a typical design based on orthogonal space-time block codes (Roy, 2007) and it is a simple transmit diversity method which is suitable only for array of two transmitting antennas. It is necessary to have multiple transmit antennas, however, multiple receive antennas is not necessary, although it can improve performance.

Assuming that there are two symbols x_1, x_2 which are transmitted by antenna array at two successive time slots. At the first slot, x_1 is transmitted from transmitter 1 and x_2 is from transmitter 2, in the very next slot, $-X_2^*$ is transmitted from transmitter 2 and X_1^* is from transmitter 1.

In the case of one single receiving antenna, the received signal $y_1(1)$ of the first slot can be expressed as:

$$Y_1(1) = \left(\Omega_{1,1}X_1 + \Omega_{2,1}X_2\right) + N_1(1) \tag{9}$$

In the second slot, the received signal can be expressed as:

$$Y_1(2) = \left(-\Omega_{1,1}X_2^* + \Omega_{2,1}X_1^*\right) + N_1(2) \tag{10}$$

where,

$N_1(1)$ & $N_1(2)$: The sample of complex AWGN (additive white Gaussian noise)

The received signal Y can be written as:

$$Y = \begin{bmatrix} Y_1(1) \\ Y_1^*(2) \end{bmatrix} = \begin{bmatrix} \Omega_{1,1} & \Omega_{2,1} \\ \Omega_{2,1}^* & -\Omega_{1,1}^* \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} N_1(1) \\ N_1^*(2) \end{bmatrix} \tag{11}$$

Assuming that the receiver has reconstructed the channel successfully, the decision variables are formed with the maximum likelihood detection rule as follows:

$$\left(\hat{X}_1, \hat{X}_2\right) = \arg\max_{(X_1, X_2)} P\left(X_1, X_2 \middle| X, \Omega_{1,1}, \Omega_{2,1}\right) \tag{12}$$

It can also be expressed as:

$$\left(\hat{X}_1, \hat{X}_2\right) = \arg\max_{(X_1, X_2)} P\left(X_1, X_2 \middle| \Omega^H Y, \Omega_{1,1}, \Omega_{2,1}\right) \tag{13}$$

where,

$$\Omega = \begin{bmatrix} \Omega_{1,1} & \Omega_{2,1} \\ \Omega_{2,1}^* & -\Omega_{1,1}^* \end{bmatrix} \tag{14}$$

If all the input symbols are equiprobable, according to the Bayesian criterion, the best solution can be written as:

$$\left(\hat{X}_1, \hat{X}_2\right) = \arg\max_{(X_1, X_2)} P\left(\Omega^H Y \middle| X_1, X_2, \Omega_{1,1}, \Omega_{2,1}\right) \tag{15}$$

where,

$$\Omega^H Y = \begin{bmatrix} \left|\Omega_{1,1}\right|^2 + \left|\Omega_{2,1}\right|^2 & 0 \\ 0 & \left|Y_{1,1}\right|^2 + \left|Y_{2,1}\right|^2 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} N_1'(1) \\ N_1'(2) \end{bmatrix} \tag{16}$$

$$\begin{bmatrix} N_1'(1) \\ N_1'(2) \end{bmatrix} = \begin{bmatrix} \Omega_{1,1}^* & \Omega_{2,1} \\ \Omega_{2,1}^* & -\Omega_{1,1} \end{bmatrix} \begin{bmatrix} N_1(1) \\ N_1^*(2) \end{bmatrix} \tag{17}$$

It is clear that $N_1'(1)$ and $\acute{N}_1(2)$ are the linear combination of $N_1(1)$ and $N_1(2)$ respectively. So, $N_1'(1)$ and $\acute{N}_1(2)$ are joint Gaussian distribution and independent to each other.

Therefore, in order to find out the optimized solution of $\hat{X}_1, \hat{X}_2$, the following formulas should be satisfied to chase down the minimum Euclidean distance between the received symbols and the ones which are likely be transmitted:

$$X_1 = \arg\max_{X_1} \left| \Omega_{1,1}^* Y_1(1) + \Omega_{2,1} Y_1^*(2) - \left(\left|\Omega_{1,1}\right|^2 + \left|\Omega_{2,1}\right|^2 \right) X_1 \right| \tag{18}$$

$$X_2 = \arg\max_{X_2} \left| \Omega_{2,1}^* Y_1(1) - \Omega_{1,1} Y_1^*(2) - \left(\left|\Omega_{1,1}\right|^2 + \left|\Omega_{2,1}\right|^2 \right) X_2 \right| \tag{19}$$

Compressed sensing: Nyquist sampling theorem has the flaw of being independent of the signal's form and it will bring in abundant information redundancy inevitably. In 2004, David Donoho proposed the theory of Compress Sensing (Donoho, 2006) to fix this problem.

The methods of recovering the sparse signal are reported in Berger (2009), Wu (2006) and Figueiredo (2008). In this study, OMP is taken as the method to solve the problem. Matching pursuit is a type of numerical technique which involves finding the "best matching" projections of multidimensional data onto an extremely redundant dictionary. Let φ_n denoted the indexes of the elements which have been chosen in the dictionary Ψ and ω_n is the weighting factor for φ_n. The steps of the OMP algorithm are listed below:

- **Initialization:** Let residual signal R = Y
- Find the element φ_n that has the biggest inner product with the residual signal R_n and its weighting factor ω_n:

$$s_n = \arg \max_{n=1,2,\dots Q, n \notin S_n} \frac{\left\langle \varphi_n, R_{n-1} \right\rangle}{\left\| \varphi_n \right\|^2} \tag{20}$$

$$\omega_n = \frac{\left\langle s_n, r \right\rangle}{\left\| s_n \right\|^2} \tag{21}$$

- Refresh the weighting factor matrix $W_n = [W_{n-1}, \omega_n$ and the φ_n position $S_n = (S_{n-1}, s_n)$
- Subtract the contribution due to that element and refresh the residual signal R_n:

$$R_n = R_{n-1} - \omega_n^T R_{n-1} \omega_n \tag{22}$$

- Repeat the process until the signal is satisfactorily decomposed

With these steps above, we can get the whole channels responses correctly in frequency domain

Channel puncture technique: Channel puncture technique is a method that uses some criteria for valuing the reliability of the channel's response. The uncertain sub-channels' responses are punched (with low weighting factor) and the dependable sub channels' responses are used as new information source to estimate and fill-in the punched blank.

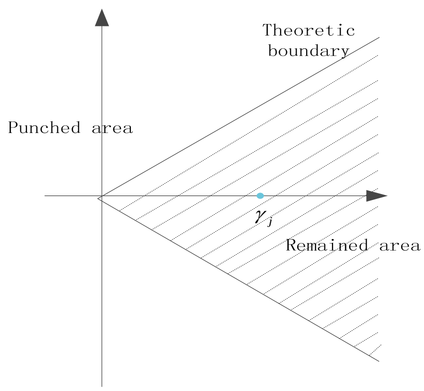


Fig. 1: The sketch of puncture technique

To find out the unbelievable sub-channels easily, we define the believable factor γ:

$$\gamma_j = X_j / X'_j \tag{23}$$

where,
X_j = The original data
X'_j = The corrected data
γ_j = A phase information

Take QPSK mapping for example, the theoretic boundary of the remained area which are shown in Fig. 1 is $\left[-\frac{\pi}{4}, \frac{\pi}{4}\right]$. If γ_j is in the shadow area, we assume that the checked data X'_j is right in all probability, if γ_j is not in the shadow area, we deal X'_j as an unbelievable data and we punch the corresponding sub-channel.

In other word, the less the differences, the more stable the communication.

DUAL TURBO CHANNEL ESTIMATION ALGORITHM

The method of using the corrected information as the new block pilot symbols can track the time varying channel and lowers the possession of the pilots dramatically. Moreover, MIMO turbo decoding method can improve the performance. However, both of these methods suffer with the problem of the error propagation that may harm to communication system, especially in low SNR (Signal-to-Noise Ratio) condition like UWA channel. In this regards, dual turbo channel estimation algorithm which can deal with the problem of the error propagation is proposed in this section. The algorithm flow chart is shown in Fig. 2.

The channel turbo decode algorithm is based on channel puncher technique. We judge reliability of the

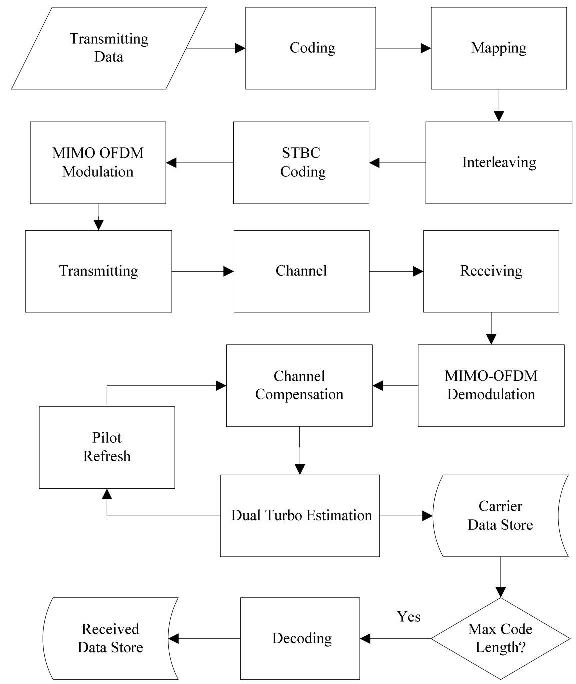


Fig. 2: The sketch of the algorithm

channel responses to give out the most proper values for communication.

Let $Y_{i,t}$ denote the STBC decoded information that received by I^{th} receiver at t time. The joint soft information Y_t which is provided to the CC decoder as the input information is:

$$Y'_t = \sum_{i=1}^{I} Y_{i,t} \tag{24}$$

Turbo channel decoding with soft decision is adopted. The differences between the information corrected by concatenated code Y''_t and Y'_t are taken as the criterion of reliability.

The turbo decoder's structure is the same as in Fig. 3(a). The channel turbo decoder's structure is figured in Fig. 3(b). Let H_c denote the prior information and H is the channel intrinsic information. The initial information of H_{c2} is provided by the pilots. Then H_{c1} is satisfied with the expression (25):

$$H_{c1} = f_1(Y''_t, H_{c2}) \tag{25}$$

where,
$f(.)$: The relationship in function
H_c : The measurement of the channel
Y''_t : The input information provided by the Turbo code decoder

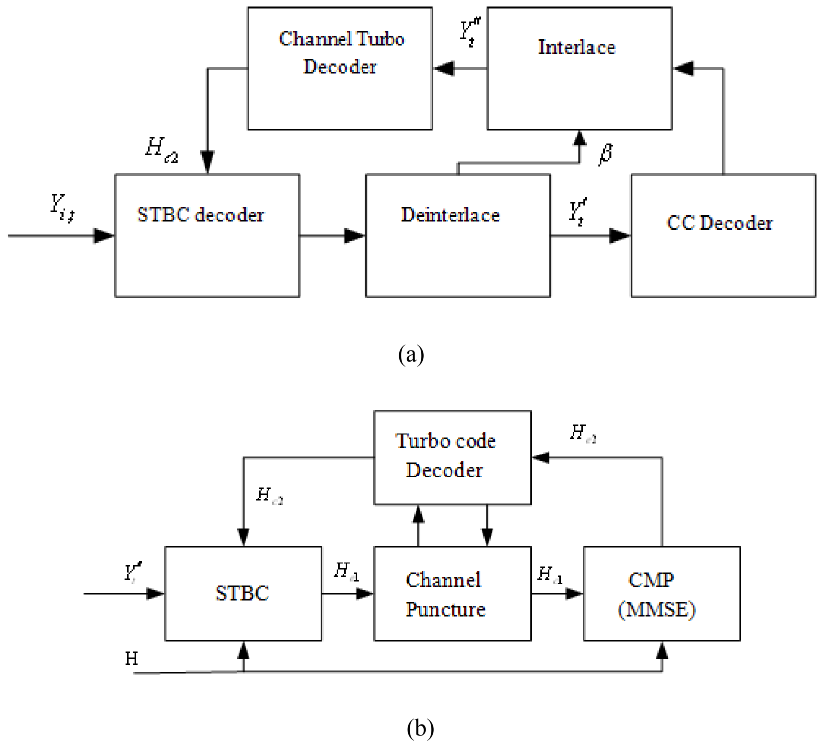


Fig. 3: Dual turbo estimation, (a) turbo code estimation, (b) channel turbo estimation

The noise on H_{c1} and on H_{c2} is of different character. So H_c can be taken as the new input value to channel equalizer. Thus, the dual recursive process can be written as:

$$Y_t' = f_{\mathrm{STBC}}\left(Y_{i,t}, H_{e2}\right) \tag{26}$$

$$Y_t'' = f_{\mathrm{CC}}\left(Y_t'\right) + \beta Y_t' \tag{27}$$

$$H_{e1} = f_{\mathrm{STBC}}\left(Y_t'', H_{c2}, \mathrm{H}\right) \tag{28}$$

$$\begin{aligned} H_{e2} &= f_{\mathrm{OMP}}\left(H_{c1}, \mathrm{H}\right) \\ &= f_{\mathrm{OMP}}\left(\alpha_1 H_{e1}, \mathrm{H}\right) \end{aligned} \tag{29}$$

where, α and β is the weighting factor.

In the channel turbo decoder, we estimate the channel response with the theory of Shannon and CS alternately. The error distribution of H_{c1} is effected by additive noise, but the error distribution of H_{c2} mainly depends on multiplicative noise residue which is nearly independent from the noise on H_{c1}. In this way, the channel turbo decoder can restrain the propagation of error and enhance the performance of communication.

The method we proposed here is able to use the difference between the received signal before checking and after checking as the criterion to judge the reliability of signal compensation. The undetermined sub-channels responses are punched and replaced by blank or estimated response. The whole channels responses are recovered by combined channel estimation. Finally, the most likely transmitted information is saved and relevant channels responses are delivered in the next slots of channels responses.

It must be pointed out that in the first slot, the transmitted symbols including comb pilots take a possession of $1/\mu$. The channels response H_0 in the first slot is estimated by these pilots. The overall pilots' possession P can be calculated using the following formula:

$$\rho = \frac{1}{\mu Z} \tag{30}$$

where, Z is the number of the OFDM symbols.

EXPERIMENTAL RESULTS

Simulation experimental results: Consider a MIMO-OFDM communication system with two transmitters

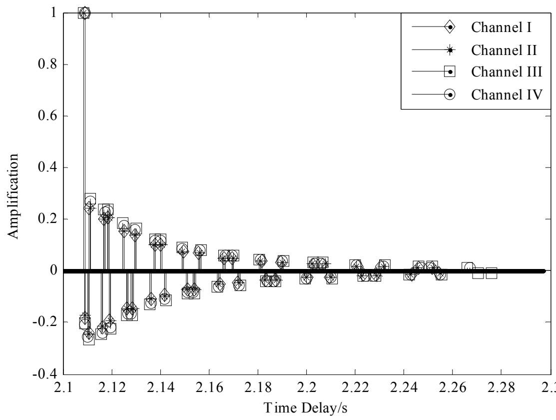


Fig. 4: The impulse response of the simulation channels

Table 1: Parameters of MIMO-OFDM system

FFT length	8192	Code pattern	STBC and CC
Sampling rate/kHz	48	MIMO structure	2×2
Effective sub-carriers	768	Mapping	QPSK
Δf/Hz	5.86	T/ms	171
Band range/kHz	6-12	T_g(CP) /ms	43
J	1025	T_b(CS) /ms	6
Pilot	Comb	$\hat{T}$/ms	220

and two receivers. Four sparse channels are generated from channel simulation software to evaluate the performance. Transmitter I and II are respectively 17 and 20 m below the water surface with a distance of 3150 m and the receiver I and the receiver II are 6 and 9 m. The average depth of the channel is 55 m. The impulse response of the channel obtained from the simulation channel is shown in the Fig. 4 (Table 1).

In the simulation, we use OMP with MMSE as the channel interpolation method to fill-in the punched sub-channel. CC code with generator polynomial of (1167, 1545) is used here and the track length of CC code is five times of its constraint length long. All the information are coded together and interleaved in one OFDM symbol only. The decisions are calculated following the maximum likelihood detection rule.

To figure out the performance of these channel estimating methods, a Monte Carlo simulation is conducted. The result of channel dual turbo estimation algorithm compared with the OMP and MMSE (MMSE algorithm is used to track the channels' variety but no feedback) channel compensation methods is drawn in Fig. 5. The possession of comb pilots adopted in OMP method and the possession of block pilots in MMSE algorithm both are $\rho_1 = 25\%$.

The relationship between LS and MMSE are studied in Feng and Sui (2010):

$$\hat{\Omega}_{MMSE} = R_{\Omega\Omega}\left(R_{\Omega\Omega} + \sigma^2\left(XX^H\right)^{-1}P_I\right)^{-1}\hat{\Omega}_{LS} \tag{31}$$

where,

$$R_{\Omega\Omega} = E\{\Omega\Omega^H\} \tag{32}$$

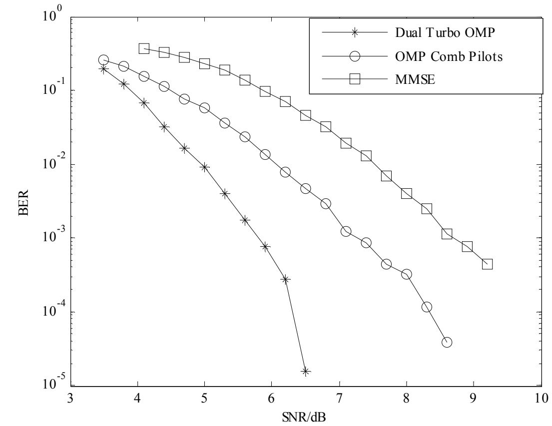


Fig. 5: The BER comparison of dual turbo, OMP and MMSE

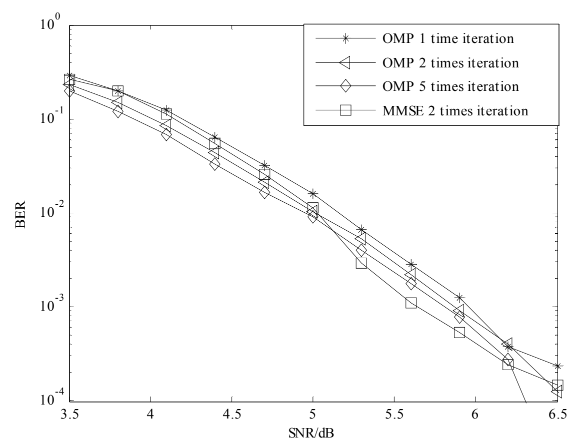


Fig. 6: The BER comparison of different time's interaruon

$$\Omega_{LS} = Y / X \tag{33}$$

Figure 5 shows that the performance of dual turbo channel estimation algorithm is much better than other methods such as OMP and MMSE. At 6.2 dB, the proposed algorithm gives over 2 dB gain more than the other two methods. Comparing with OMP algorithm, the performance of turbo estimation is better when SNR is higher.

Figure 6 gives out dual turbo equalizers simulation results of different punched channel filling methods. In this simulation, the additive noise subjects to Gaussian distribution.

From Fig. 6 we can find that both of the channel filling methods can realize reliable communication at high SNRs condition.

At 5 dB SNR condition, dual turbo OMP with 5 times iteration yields 0.3 dB gain higher than dual turbo OMP with single iteration. With more times iteration, the system stability can be enhanced and the performance of the communication can is increased.

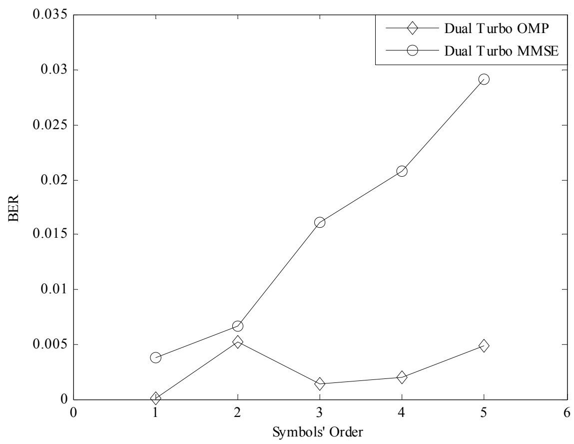


Fig. 7: The BER comparison of different punched channel filling methods

Dual turbo MMSE performances almost the same as dual turbo OMP at high SNRs, however, it need more pilots to confine the error propagation. In this simulation, the possession of block pilots in dual turbo MMSE algorithm is $P = 14.29\%$ and the possession of comb pilots in dual turbo OMP algorithm is $P = 3.57\%$.

Figure 7 provides the analysis of anti burst noise capability of two channel filling methods. The burst noise which subjects to Alpha stable distribution is generated by the following formula:

$$N' = A_{a,b} \frac{\sin\left(a\left(V^* - B_{a,b}\right)\right)}{\left(\cos\left(V^*\right)\right)^{1/a}} \left(\frac{\cos\left(V^* - a\left(V^* - B_{a,b}\right)\right)}{W^*}\right)^{(1-a)/a} \quad (34)$$

where,

$$B_{a,b} = -\frac{\arctan(b\tan\frac{\pi a}{2})}{a} \quad (35)$$

$$A_{a,b} = \left[1 + \left(b\tan\frac{\pi a}{2}\right)^2\right]^{1/2a}$$

(36)

V^* is a uniform distribution random variable in $\left(-\frac{\pi}{2}, \frac{\pi}{2}\right)$. W^* is random variable of exponential distribution and the average of W^* is 1. Here we take a = 1.95 and b = 0.

It can be revealed from Fig. 7 that dual turbo MMSE algorithm has the problem of error propagation, whereas, dual turbo OMP algorithm confined the error propagation. The OMP algorithm subjects to Compress Sensing theory, we can reconstruct the channel with only a few correct information and that information is actually supplied by channel puncture technique.

Table 2: Parameters of MIMO-OFDM system

FFT length	8192	Pilot	Comb and block
Sampling rate/kHz	48	Code pattern	STBC and TCM
Effective sub-carriers	510	T/ms	171
Δf/Hz	5.86	T_g(CP) /ms	43
Band range/kHz	4-8	$\acute{T}$/ms	220
J	681	MIMO structure	2×K

Table 3: Error rate of different algorithm

	Receiver I	Receiver II
OMP	$1.6*10^{-2}$	$2.8*10^{-2}$
MMSE	$2.1*10^{-2}$	$6.2*10^{-2}$
Dual turbo MMSE	$6.2*10^{-3}$	$6.3*10^{-2}$
Dual turbo OMP	$5.3*10^{-3}$	$6.5*10^{-3}$

Therefore, the error rate inside a slot is usually independent from the error rate in the very last symbol in the same frame. We calculated the symbols' average EBR in different slots inside a frame. And in this simulation, the error rates of many symbols of 2^{nd} slots in total a hundred frames are very high but do not harm to the symbols of the 3^{rd} slot. Moreover, this is also the same reason that dual turbo MMSE algorithm does not perform as good as dual turbo OMP algorithm in low SNRs.

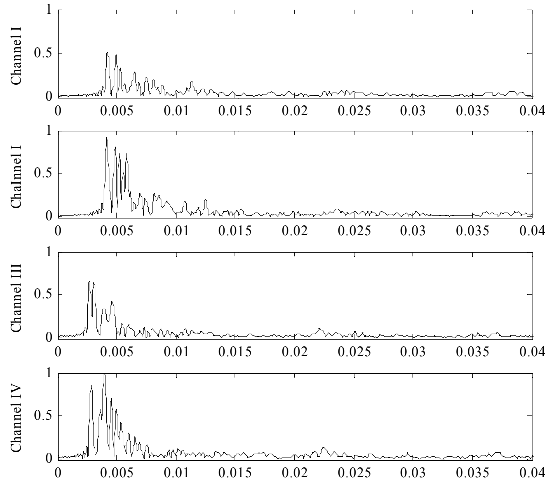
Pool 11 experimental results: In order to validate the feasibility of the channel estimation algorithms, the experiment is also carried out in the underwater simulation channel lab of Harbin Engineering University in December in 2011.

The average depth of the water was 4 m. Two transmitting transducers were placed in the depth of 1.5 and 2.5 m, whereas, the receiving hydrophones were placed at 1.5 and 3 m, respectively depths. The horizontal distance between transmitters and receivers was 7.8 m.

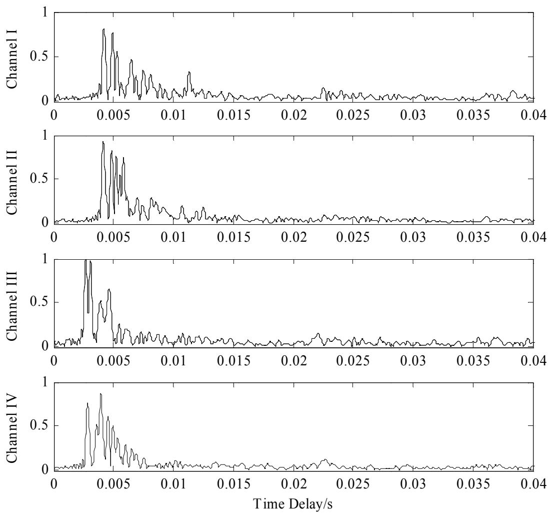
The communication parameters are listed in Table 2. We adopted STBC combined with TCM-8PSK as the concatenated code. Each OFDM symbol is coded separately.

The channel impulse responses of one pool channel estimated by MMSE channel examination algorithm and by dual turbo channel examination algorithm are shown in Fig. 8. We can see the channel responses are very complex, the maximal time delay of the channel is over 12 ms. Compare Fig. 8 (b) with (a), we can see that dual turbo channel examination algorithm can reconstruct the channel quite well.

One of the tank experiment results along with BER using different channel compensation methods are listed in Table 3. This experiment is carried out in low SNRs and the channels' time domain responses shown in Fig. 8 are sparsely, hence, the OMP which is suitable for spares channel estimation performances better than MMSE. From the results comparison, dual turbo OMP estimation method is found to be better than the other three methods. The receiver I's result of dual turbo



(a)



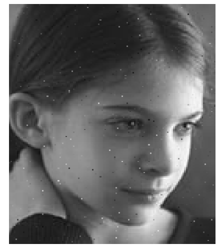
(b)

Fig. 8: The impulse response of the channels, (a) the channel MMSE estimated by block pilot, (b) the channel estimated by dual turbo algorithm

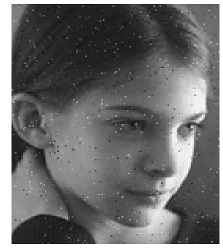
MMSE estimation algorithm is almost the same with the results of dual turbo OMP estimation algorithm. Nevertheless to the receiver I, receiver II with dual turbo MMSE is worse than MMSE algorithm due to the problem of error propagation. Besides, dual turbo OMP algorithm can restrict the propagation of error and can enhance the performance compared with the dual turbo MMSE algorithm.

Let J' denote the effective Sub-carriers number in an OFDM symbol and ρ_{code} stand for the code rate, the efficiency of these methods can be calculated by formula (37):

$$\eta = \frac{T \times J'}{T' \times J} \rho_{code} \tag{37}$$



BER $1.5*10^{-3}$



BER $6.4*10^{-3}$

BER $8.4*10^{-4}$

BER $5.2*10^{-4}$

BER $8.0*10^{-5}$

BER $8.0*10^{-5}$

Fig. 9: The comparison of different compensation methods, (a) OMP, (b) MMSE, (c) dual turbo MMSE 1 time (d) dual turbo MMSE 5 times, (e) dual turbo OMP 1 time (f) dual turbo OMP 5 times

The efficiency of OMP, MMSE and dual turbo MMSE estimation algorithm are same and equal to 1.36 bits/s/Hz while, the efficiency of dual turbo OMP estimation algorithm is at least 1.51 bits/s/Hz.

Figure 9 (a) and (b) explained the combined results of OMP and MMSE, the error rate of both the conventional methods are greater than 10^{-3}, and it is not quality for UWA communication.

Figure 9 (c) and (d) explain that dual turbo MMSE estimation algorithm had better performance than the conventional methods, the communication quality and stability will be enhanced with more times iterations. But the overall performance is still not good enough due to the error propagation and low SNR conditions. With this experiment, dual turbo OMP estimation algorithm is endorsing the best performance among other four algorithms as it controlled the error propagation in low SNR condition.

From the comparison of Fig. 9(e) with (f), we found that the 5 times iteration of dual turbo OMP did not enhance the performance compared with 1 time iteration. The reason is that the system's quality is limited by the performance of TCM code. Thus it can be justified to say that the stability of dual turbo OMP estimation algorithm is satisfying and realizable.

CONCLUSION

In this study, dual turbo channel estimation algorithm based on channel punching technique is studied. Comparing with the conventional estimation algorithm, the proposed algorithm can reduce the occupancy rate of the pilots and improve the communication performance significantly. Two sub-algorithms are presented and their performance was evaluated in different noise modes. Dual turbo OMP estimation algorithm gives better performance on anti burst noise than dual turbo MMSE estimation algorithm in sparse UWA channel, but in high additive white gauss noise environment, dual turbo MMSE estimation algorithm is better.

At last, we realized the reliable communication with the efficiency of 1.51 bits/s/Hz in the tank experiments.

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