Improve BER Performance of QPSK-Alamouti's STBC's Decoder using Source Extraction Method Based on ($\mathcal{R}$-$\mathcal{I}m$) Decomposition Model

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Abstract

The popular Alamouti orthogonal Space Time Block Code (STBC) attains full transmit diversity in two transmitter multiple input multiple output channel systems. Maximum ratio combiner (MRC) performance depends mainly on the quality of channel estimator, which depends mainly on the number of training symbols. The aim of this paper is to improve performance of MRC of QPSK-Alamouti's STBC's decoder without increasing number of training symbols. This paper gives an introduction to the basic concepts of training based channel estimator and explains the implementation of least square error (LS) channel estimator with diagonal and orthogonal training matrix. The kurtosis based source extraction method based on using real imaginary ($\mathcal{R}$-$\mathcal{I}m$) decomposition of MRC was fully described. Finally the benefit of using at least four training symbols for initialization de-mixing vector and removing source ambiguity was illustrated.

Computer simulation for QPSK Alamouti STBC's in flat fading MIMO channel was implemented using MATLAB2012. First MRC decoder with LS channel estimator technique analyzes according to their number of training symbols (Nt=2,4,…10) and type of training matrix (diagonal or orthogonal). We found that: orthogonal training matrix for any sequence length provides superior performance than diagonal training matrix. Finally the proposed decoding technique was implemented and it's BER performance were analyzed using only four training symbol with illustration for number of iteration at each SNR.

Keywords: Alamouti STBC; ($\mathcal{R}$-$\mathcal{I}m$) decomposition ,MRC; Source extraction; Kurtosis

تحسين خصائص معدل الأخطاء لمنظومة (QPSK-Alamouti)للترميز الفضاء الزمني باستعمال طريقه استخلاص المصدر المبنية على أساس نموذج تجزئه الحقيقي خيالي

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الخلاصة

لترميز الفضاء الزمني المتعامد الشائع يوفر تعدديه إرسال كاملة خلال قناة متعددة الإدخال و الإخراج ذات هوائيي Alamouti إرسال. خصائص المازج ذو النسبة الكبرى تعتمد بصوره أساسيه على كفائه مخمن القناة الذي بدوره يعتمد على عدد عينات التدريب. الهدف الأساسي من هذه الورقة هو تحسين خصائص المازج ذو النسبة الكبرى لنظام QPSK-Alamouti لترميز الفضاء الزمني بدون زيادة عدد عينات التدريب. هذه الورقة تعطي مقدمه لمفاهيم الاساسيه لمخمن القناة المبني على أساس عينات التدريب وتوضح بناء مخمن القناة ذو مربع الخطأ الأقل مع مصفوفة التدريب القطرية و المتعامدة . طريقه استخلاص المصدر

المبنية على أساس الكرتوزز باستعمال تجزئه الحقيقي خيالي للمازج ذو النسبة الكبرى تم شرحها بالكامل. أخيرا تم توضيح فائدة استعمال مالا يقل عن أربعه عينات تدريب لتهيئه متجه الفصل وأزاله الشك بالمصدر.
لترميز الفضاء الزمني خلال قناة متعددة الدخل و الخرج ذات خفوت منتظم تم بنائها QPSK-Alamouti محاكاة حاسوبيه ل بالبدء المازج ذو النسبة الكبرى مع مخمن القناة ذو مربع الخطأ الأقل تم تحليله تبعا لعدد عينات MATLAB2012باستعمال التدريب (2, 4,...,10 عينات) و نوع مصفوفة التدريب (قطريه أو متعامدة) . وجدنا انه مصفوفة التدرب المتعامد لأي طول تعطي خصائص أفضل من مصفوفة التدرب القطرية. بالنهاية تم بناء التقنية المقترحة وتم تحليل خصائص معدل الأخطاء لها باستعمال أربعه عينات التدريب مع إيضاح عدد التكرارات اللازمة لكل نسبه اشاره- ضوضاء
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1. Introduction

Multiple-input multiple-output (MIMO) channel has recently become an area of intense development in the wireless communication industry. In MIMO channel, the received signal is usually distorted by the channel characteristics. In order to recover the transmitted bits, the channel effect must be estimated and compensated in the receiver. In general, the channel response can be estimated by using ***training*** or ***pilot*** symbols that known to both transmitter and receiver. In order to keep track of the time-varying channel characteristics, the pilot symbols must be placed as frequently as the coherence time (*Yong et al,2010;Rose,2004*). However, training symbols reduce the throughput and such schemes are inadequate when the bandwidth is scarce. Several strategies have been proposed recently to avoid these limitations:

- If receiver has no prior information about Channel State Information (CSI) this type will called blind channel estimator. ICA(*Chekuri,2012; Kohei et al,2009*) Second order Static SOS(*Adriana et al,2010*) High Order Static (*Vincent et al,2011*), iterative signal separation (*Mihai,2002),*…etc., were used to build blind channel estimator. This type need no training symbol that made it provide full throughput but the main two weakness point in blind estimator is its huge complexity and latency.
- If receiver have full knowledge about CSI this called known channel. This can be obtain either by using extra receiving antenna or long training sequence period that reduces throughput and increase system complexity. This technique used widely in military application (since it need short massages, and there is no limitation in system cost)
- If receiver has fractional CSI then this type called semi-blind channel estimator. LS,MAP,MMSE estimator *(Rose,2004, Yong et al,2010)*, Practical Swarm Optimization PSO(*Chen et al,2010*) and ANN(*ZHANG et al,2007*),… etc. were used in implementation such estimator. This type until this day is open topics since it provides acceptable throughout and complexity. Estimation latency and error depend on the optimization techniques that used to estimate the left behind CSI.

1.1 System Model

Figure (1) shows the ***baseband*** representation of QPSK Alamouti STBC encoder with MIMO channel have two antennas at the transmitter and two antennas at the receiver. Massage bits arrive at the modulator [$a_1 b_1$, $a_2 b_2$,…..] mapped to complex symbols s_1 ,s_2,….. where [$a_t b_t$] $\in$ {+1,-1} are the odd and even bits arrive at the modulator at time t mapped and $s_t=\frac{A}{\sqrt{2}}\times(a_t + jb_t) \in$ QPSK constellation . The space time block code proposed by Alamouti map the input complex symbols into two orthogonal sequences X_1 and X_2 where (*Muhammad et al,2010*):

$$X=\begin{pmatrix} X_1 \\ X_2 \end{pmatrix}=\begin{pmatrix} s_1 & -s_2^* & s_3 & -s_4^* & .. & ... \\ s_2 & s_1^* & s_4 & s_3^* & .. & ... \end{pmatrix} \quad (1)$$

These two sequences transmitted simultaneously from antennas one and two, respectively as shown in **Figure** (1). In this paper, 2×2 MIMO channel is used, where only two antenna elements at the receiver side where received signal from each one are Y_1 and Y_2 respectively where (*Muhammad et al,2010)* :

$$Y=\begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix}=\begin{pmatrix} y_1^1 & y_1^2 & y_1^3 & .. & ... \\ y_2^1 & y_2^2 & y_2^3 & .. & ... \end{pmatrix}=\begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix}\times\begin{pmatrix} X_1 \\ X_2 \end{pmatrix}+\begin{pmatrix} N_1 \\ N_2 \end{pmatrix} \tag{2}$$

Where h_{ij} is the complex channel fading coefficient between j_{th} transmitted antenna and i_{th} received antenna, and N_i is complex white Gaussian noise symbol added at i_{th} received antenna .

For quasi- stationary MIMO channel the channel varies randomly between block to block, but fixed within a transmission time this time called ***coherence time*** (*Luis, 2009*). Therefore the block length should choose equal or less than coherence time.

Figure (2) illustrates the STBC decoding process. First the fading components should be recovered at the receiver side using channel estimator then Maximum Ratio Combiner (MRC) combine received signal from antenna 1, 2 at time slot t $\left(y_1^t \quad y_2^t\right)$ (where t=1,3,5,..) with complex conjugate of received signal from antenna 1, 2 at time slot t+1 $\left(y_1^{t+1} \quad y_2^{t+1}\right)$ to produce s_t and s_{t+1} as given(*Yong et al,2010*):

$$\begin{bmatrix} y_1^t \\ y_2^t \\ \left(y_1^{t+1}\right)^* \\ \left(y_2^{t+1}\right)^* \end{bmatrix}=\begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix}\times\begin{pmatrix} s_t \\ s_{t+1} \end{pmatrix}+\begin{bmatrix} n_1^t \\ n_2^t \\ \left(n_1^{t+1}\right)^* \\ \left(n_2^{t+1}\right)^* \end{bmatrix} \quad t=1,3,5,...$$

$$Y_{MRC}(t)=H_{MRC}\times\begin{pmatrix} s_t \\ s_{t+1} \end{pmatrix}+\mathit{Noise} \tag{3}$$

The key feature of designing MRC that the selected encoding matrix X is orthogonal, that made H_{MRC} also orthogonal i.e. : $(H_{MRC})^H \times (H_{MRC}) = \frac{1}{\|H_{MRC}\|^2} I_2$.

Where $(.)^H$ is the Hermitian operator and I_2 is 2×2 identity matrix. To solve **Equation 3** multiply both sided by $(H_{MRC})^H$ and re-arrange the resulting terms we deduce that the decoded symbols at t and t+1 are (*Yong et al,2010*):

$$\begin{pmatrix} \tilde{s}_t \\ \tilde{s}_{t+1} \end{pmatrix}=([(H_{MRC})^H\times(H_{MRC})]^{-1}\times(H_{MRC})^H)\times Y_{MRC}(t) \quad t=1,3,5,.. \tag{4}$$

1.2 **Training Symbol-Based Channel Estimation**

In all non-blind channel estimators a ***training symbols sequence*** (T) must be placed at a beginning of each transmitted symbols frame where channel estimator use this sequence to estimate the fading coefficient (H) during estimation period and feed them to MRC to decode the received signal as shown in **Figure** (**2**).

The least-square (LS) technique is widely used for channel estimation when training symbols are available. The least-square (LS) channel estimation method finds the estimated channel matrix H_{LS} in such a way that the minimized cost function $\| R-H_{LS}T\|^2$. When cost function is equal to zero then (*Rose,2004*; *Yong et al,2010*):

$$H_{LS}=\frac{R\times T^H}{\left(T\times T^H\right)^{-1}} \tag{5}$$

There are two popular forms for training sequence.

A. Diagonal Training Symbol

In this case the training symbols matrix chosen as a diagonal matrix:

$$\mathbf{T}=\begin{pmatrix} S_1 & 0 \\ 0 & S_2 \end{pmatrix} \tag{6}$$

At the first time slot training symbol (or N symbols) S_1 transmitted through antenna 1 while transmitted antenna 2 is idle, therefore the received signal at j_{th} antenna is ($h_{j1}\times S_1+N_j$). At the second time slot training symbol (or symbols) S_2 transmitted antenna 2 while transmitted antenna 1 is idle (*Yong et al,2010*).

B. Orthogonal Training Symbol

In this case the training symbols matrix chosen as $2\times N_t$ orthogonal matrix ($T\times T^H=\frac{I_2}{\|T\|}$) therefore $H_{LS}=\frac{R\times T^H}{\|T\|}$ (*Rose,2004*). This process is very efficient for quasi- stationary MIMO channel since H is constant on other hand this technique reduces the transmission efficiencies due to the required overhead of training symbols such as preamble or training tones that are transmitted in addition to data symbols therefore we must reduce number of training symbols, but short training sequence produce poor performance .

2. Signal Extraction using ($\mathcal{R}$- $\mathcal{Im}$) Decomposition Model

Blind signal extraction (BSE) is essentially a method for extracting individual ***one source signal*** from ***noisy mixtures*** received signals. Kurtosis based BSE use a simple criteria that: *the sum of two independent random variables usually has a distribution that is closer to Gaussian than any of the two original random variables* (Central Limit Theorem). Therefore BSE is based on the assumption that source signals must have ***non-Gaussian*** distributions. The classical measure of non-Gaussianity is normalized kurtosis where for real random variable y it could be define as (*Xiang et al,2009; Wei et al,2006*):

$$\text{kurt}(y)=\frac{E\{y^4\}}{\left(E\{y^2\}\right)^2}-3 \tag{7}$$

Thus, kurtosis is ***zero*** for a Gaussian random variable. For most (but not quite all) non-Gaussian random variables, kurtosis is nonzero. Random variables that have a negative kurtosis are called ***sub-Gaussian***, and those with positive kurtosis are called ***super Gaussian*** (*Aapo et al,2000 ;Andrzej et al,2002*).

Most of the previous works stars with **Equation 2** by assuming X as independent sources ,Y as mixtures received signals and H is mixing matrix (*Adriana et al,2010; Chekuri,201; Kohei et al,2009;…*). In this work we will start with **Equation 3** by considering H_{MRC} is mixing matrix**.** Usually all statistical methods deals with complex number are not favorable and give poor performance therefore we will use ***Real Imaginary*** (***ℜ- ℑm***) decomposition for MRC model, i.e. the **Equation 3** become in the form:

$$\begin{pmatrix} \mathrm{Re}\{Y_{MRC}(t)\} \\ \mathrm{Im}\{Y_{MRC}(t)\} \end{pmatrix} = \begin{bmatrix} R\{H_{MRC}\} & -\mathrm{Im}\{H_{MRC}\} \\ \mathrm{Im}\{H_{MRC}\} & R\{H_{MRC}\} \end{bmatrix} \times \begin{pmatrix} \mathrm{Re}\{\begin{pmatrix} s_t \\ s_{t+1} \end{pmatrix}\} \\ \mathrm{Im}\{\begin{pmatrix} s_t \\ s_{t+1} \end{pmatrix}\} \end{pmatrix} + [\psi] \tag{8}$$

Where $[\psi]$ is real valued white Gaussian noise matrix. If we assume that: $s_t=U_1+jU_3$, $s_{t+1}=U_2+jU_4$, $[z_1\ z_2\ z_3\ z_4]^T$ are the real part of $Y_{MRC}(t)$ and $[z_5\ z_6\ z_7\ z_8]^T$ are the imaginary part of $Y_{MRC}(t)$ at t=1,3,5,…. then :

$$\begin{pmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \\ z_6 \\ z_7 \\ z_8 \end{pmatrix} = \begin{bmatrix} h_{11}^R & h_{12}^R & -h_{11}^I & -h_{12}^I \\ h_{21}^R & h_{22}^R & -h_{21}^I & -h_{22}^I \\ h_{12}^R & -h_{11}^R & h_{12}^I & -h_{11}^I \\ h_{22}^R & -h_{21}^R & h_{22}^I & -h_{21}^I \\ h_{11}^I & h_{12}^I & h_{11}^R & h_{12}^R \\ h_{21}^I & h_{22}^I & h_{21}^R & h_{22}^R \\ -h_{12}^I & h_{11}^I & h_{12}^R & -h_{11}^R \\ -h_{22}^I & h_{21}^I & h_{22}^R & -h_{21}^R \end{bmatrix} \times \begin{pmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{pmatrix} + [\psi] \tag{9}$$

This decomposition was chosen carefully to ensure that H_{MRC}^{R-I} after decomposition still in orthogonal form i.e.:

$$\left(H_{MRC}^{R-I}\right)^T \times \left(H_{MRC}^{R-I}\right) = \frac{1}{\left\|H_{MRC}^{R-I}\right\|} I_4 \tag{10}$$

First advantage of this decomposition that only ***one column of*** H_{MRC}^{R-I} ***need to be estimated***, other column could be evaluated intuitively. The second advantage that according to this decomposition and **Equation 1,** sources for QPSK Alamouti STBC will be:

$$\begin{pmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} a_1 & a_3 & a_5 & a_7 & .. & . & ... \\ a_2 & a_4 & a_6 & a_8 & .. & . & ... \\ b_1 & b_3 & b_5 & b_7 & .. & . & ... \\ b_2 & b_4 & b_6 & b_8 & .. & . & ... \end{pmatrix} \qquad (11)$$

Since $[a_t\ b_t] \in \{+1,-1\}$, that made all source has a binomial distribution (***sub-Gaussian***) with normalized kurtosis =-2 for any sequence length. That mean kurtosis based BSE technique could apply for this model efficiently (*Wei et al,2006 ;Xiang et al,2009)* .

To extract one of the sources, we apply a de-mixing operation given by vector $W^T=[w_1\ w_2\ ,..,\ w_8]$ to the mixtures Z, which yields the extracted source y, given by (*Andrzej et al,2002; Wei et al,2006)*:

$$y = W^T Z = \left[[w_1 \quad w_2 \quad .... \quad w_8] \times H_{MRC}^{R-I} \right] \times \begin{pmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{pmatrix} + W^T \psi = G \begin{pmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{pmatrix} + W^T \psi \qquad (12)$$

Where G denotes the ***global de-mixing vector***, which is related to the quality of the performance of the BSE algorithm i.e. if we want to extract source first source ($y=U_1$), G should equal to [1,0,…0] (*Andrzej et al,2002;Wei et al,2006).*

Since H_{MRC}^{R-I} orthogonal matrix, optimum value of de-mixing vector W_{opt} ***should equal to the first column of*** H_{MRC}^{R-I} .

Since all source are identical distribution (kurt=-2) that present ***source ambiguity*** problem in BSE, that mean we cannot determine which source has been extracted(*Aapo et al,2000 ;Xiang et al,2009*). To remove ambiguity problem, first two bits of each source in **Equation 11** could be used to **identify** each source i.e. sources should be in the form:

$$\begin{pmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} -1 & -1 & a_5 & a_7 & .. & . & ... \\ -1 & +1 & a_6 & a_8 & .. & . & ... \\ +1 & -1 & b_5 & b_7 & .. & . & ... \\ +1 & +1 & b_6 & b_8 & .. & . & ... \end{pmatrix} \qquad (13)$$

That mean for QPSK Alamouti STB, we need ***at least four*** training symbols to remove ambiguity problem .The second advantage of these training symbol that give a prior knowledge of H_{MRC}^{R-I} using LS channel estimator. Now W need to update iteratively to come close to W_{opt}, several algorithms to update the value of de-mixing vector, we modify algorithms in (*Andrzej et al,2002*; *Wei et al,2006; Vicente et al,2010*) with our system model the resulting kurtosis based semi blind signal extraction using (***ℛ- ℐm***) decomposition for MRC model will be:

1- Initialize de-mixing vector W as first column of (***ℛ- ℐm***) decomposition of H_{LS}.
2- *it*=1 (number of iteration)
3- Find extracted sequence $y=W^T \times Z$
4- Source signals are typically sub-Gaussian, the nonlinear function $\varphi(U^{it})$can be chosen as:

$$\varphi(y) = \frac{y}{E\{y^2\}} - \frac{y^3}{E\{y^4\}} \quad (14)$$

5- Update the de-mixing vector using(*Andrzej et al,2002; Vicente et al,2010*):

$$W_p^{it+1} = W^{it} - \mu \times \varphi(y) \times Z \quad (15)$$

Where μ is the learning rate.

6- Normalized the weighting vector using(*Andrzej et al,2002 ;Wei et al,2006; Vicente et al,2010*):

$$W^{it+1} = \frac{W_p^{it+1}}{\left\| W_p^{it+1} \right\|} \quad (16)$$

7- The algorithm can be stopped(go to step 9)

if

1- it > maximum number of iteration.

2- or W^{it+1} converge to specific value i.e $\left| 1 - \left| \left(W^{it+1}\right)^T \times W^{it+1} \right| \right| \le 10^{-5}$ *(Aapo et al,2000; Vicente et al,2010*):

else: it=it+1,Go to step 3.

8- At end of iteration specify which source was extracted by looking to sign of first two values of y.

9- If $y=U_i$ then i^{th} column of new MRC decoder matrix is $H_{SE}(:,i)=W^T$ and other columns could calculate intuitively by looking to **Equation 9**.

10- Finally use H_{SE} instead of H_{MRC}^{R-I} to decode received sequence.

3. Simulation and Result

In this paper MATLAB2012 program was used to implement QPSK Alamouti STBC in 2×2 MIMO channel. BER and normalized mean square (NMSE) error were used to measure of the estimation and decoding performances. In this system, a random data generator generates digital information bits, frame-by-frame, where each frame is 200 bits length. Each frame was modulated using QPSK modulator to produce 100 symbols. First N_t symbols will used as training symbols (known for receiver side) while the remaining 100- N_t will be the data symbol that encoded by Alamouti STBC. The encoded symbols are transmitted by two antennas through MIMO Rayleigh fading channel where the complex AWGN is added to the transmitted signal.

At receiver end, first the LS channel estimator use training symbols to estimate the channel coefficient where the normalized mean square error NMSE can be found using:

$$NMSE = \frac{1}{N_{frame}} \sum^{N_{frame}} \frac{\left\| H - H_{LS} \right\|}{\left\| H \right\|} \quad (17)$$

The other received symbols are decoded, using MRC and feed them to QPSK demodulate. Decoded bits are compared with originally generated data bits frame to compute BER corresponding to a given SNR. Total number of frames used is about 1×10^4 frames.

3.1 Influence of Training Sequence Length

Figures (3,4) show the BER performance of MRC of QPSK Alamouti STBC's and NMSE of LS-estimator with diagonal and orthogonal training matrix. It's obvious that increasing number of training symbols provides significant coding gain but the throughput rate will reduced.

Although the diagonal training matrix is easy in design and low estimation complexity but by comparing with orthogonal training matrix we can see that orthogonal training matrix for any sequence length provides superior performance than diagonal training matrix

3.2 Performance of the Proposed Decoder

QPSK Alamouti STBC with 4 training used to as evaluation of the new algorithm BER performance with comparison with classical MRC. Training bits [0 1 0 1 0 0 1 1] are prefixing with each data frame with 192 random bits then feed them to QPSK Alamouti decoder, therefore the first 4 symbols can consider as training symbols .This procedure used to assign each source U as given in **Equation 13**. First the 4-training symbols used to evaluate H_{LS} then performing the proposed algorithm. In this algorithm we set [max. number of iteration = 20, learning rate =0.001] **Figure** (5) shows the BER performance and number of iteration needed at each SNR for this algorithm.

4. Conclusions

In this paper, first we evaluate the BER performance of conventional MRC of QPSK Alamouti STBC system based on its training symbol length and type of training matrix. We found that orthogonal training matrix for any sequence length provides superior performance than diagonal training matrix.

Good BER performance can be obtain when training sequence length is high, but this technique reduces the transmission efficiencies .This paper proposed a new technique to improve the BER performance of QPSK Alamouti STBC system without increasing its training sequence length by applying iterative semi blind kurtosis based signal extraction. We found that using (**$\mathfrak{R}$-$\mathfrak{Im}$**) decomposition model we need to extract ***only one source*** to estimate the overall channel coefficient and that reduces decoding complexity. The problem of source ambiguity was solved by using only four training symbols, where these symbols also used to initialize the de-mixing vector. Although the new decoder model is more complex than MRC but it's provide high data rate and its BER performance could adopted easily using another updating strategy for de-mixing vector.

Finally, by comparing the complexity of this new decoder with previous works like high order static or complex based ICA or PSO,… we can conclude easily this model is more easy in design and low latency.

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Nomenclature

BER	Bit Error Rate	NMSE	Normalize Mean Square Error
BSE	Blind Source Extraction	PSO	Practical Swarm Optimization
CSI	Channel State Information	QPSK	Quadrate Phase Shift Keying
HOS	High Order Static	$\mathcal{R}$-$\mathcal{I}m$	Real Imaginary
ICA	Independent Component Analysis	SNR	Signal to Noise Ratio
LS	Least Square	SOS	Second Order Static
MIMO	Multi input multi Output	STBC	Space Time Block Code
MRC	Maximum ratio Combiner		

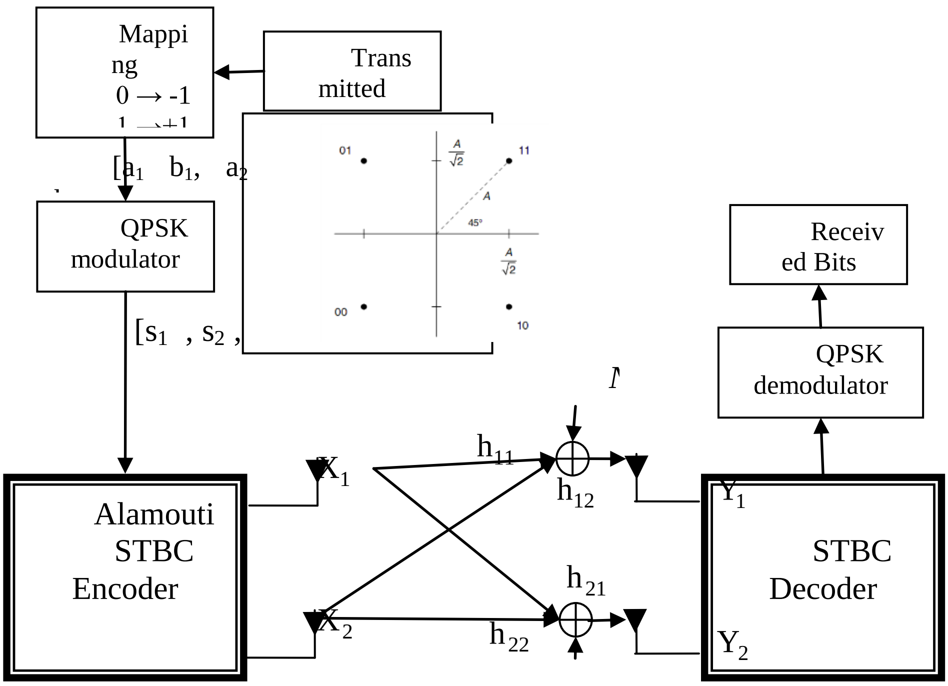

Figure (1) 2 × 2 MIMO channel with Alamouti STBC Encoder and Decoder

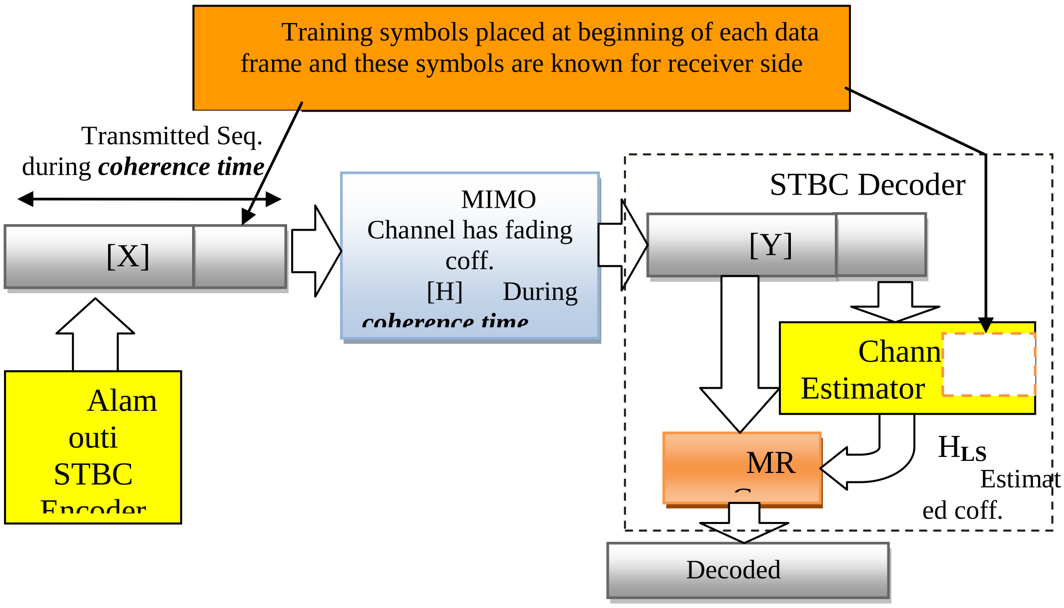

Figure (2): Non Blind Training Symbol-Based Channel Estimation

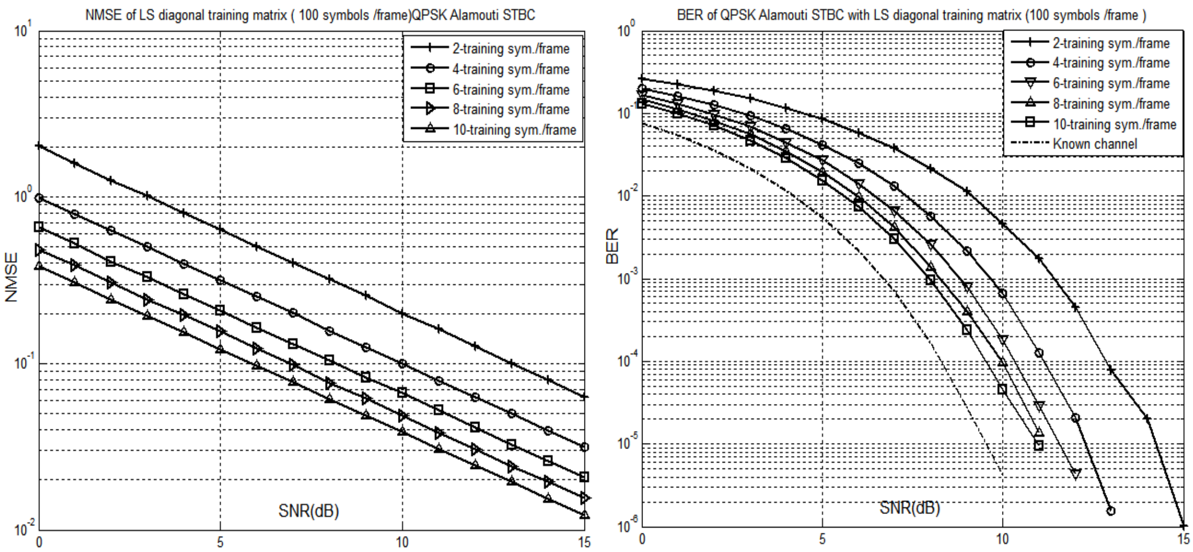

Figure (3): Performance of QPSK Alamouti STBC with diagonal training matrix LS estimator with different training symbol length with 100 symbols / frame

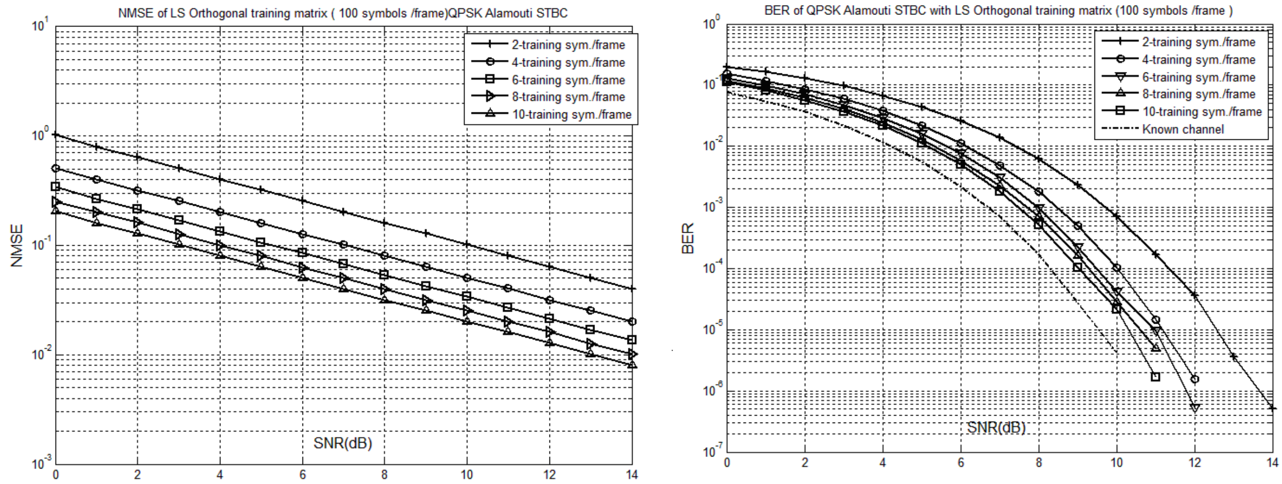

Figure (4) Performance of QPSK Alamouti STBC with orthogonal training matrix LS estimator with different training symbol length with 100 symbols / frame

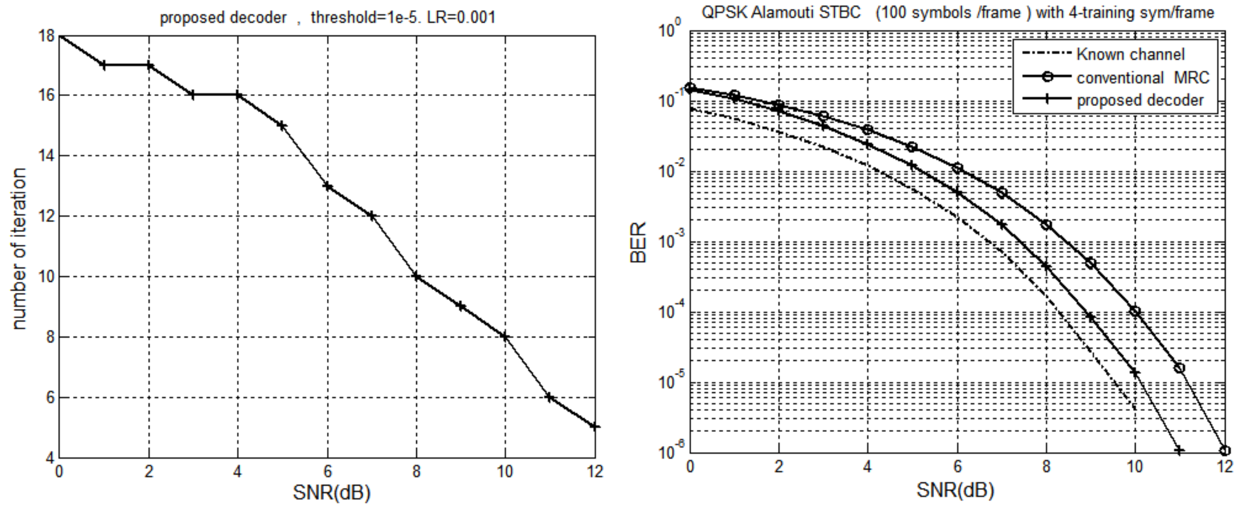

Figure (5) BER performance of proposed decoder with its number of iteration