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THE EFFECT OF IMPERFECT SYMBOL TIMING ESTIMATION ON THE PERFORMANCE OF SPACE-TIME CODED SYSTEMS

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ABSTRACT

This paper addresses the effects of errors in symbol timing estimation on performance of space time coded systems. Fixed and uniformly distributed timing errors w different variances are assumed. Furthermore, the improvement of timing estimates w increase in signal to noise ratio is modeled to yield practical expectations of performan This symbol timing–error is applied to a simple transmit diversity scheme using QPSK 8PSK modulations. This paper could be useful guide for definition of requirement in syml timing systems used in space time coding systems.

I. INTRODUCTION

Multiple-antenna wireless systems have received considerable attention over the p several years as it can offer substantial performance improvement to a wirel communication system by providing spatial diversity and supporting high data rate servic These systems can provide significantly higher capacity as compared with single-anter systems without requiring an increase in system bandwidth [1]. Capacity of single anter systems increase with the logarithm of SNR. Multiple antenna systems classicaly employ multiple antennas at the reciever, forming a reciver diveristy system. Such a system increa capacity with the log of the number of recive antennas and mitigates multipath fading. [2],[3], Emre Telatar & Foschini calculate the capacity of Multiple-Input Multiple-Out (MIMO) antenna systems. A means to achieve near capacity results were demonstrated in [In which it was shown that, MIMO systems have an extraordinary high spectral efficien and support large fade level reduction due to exploitation rather than mitigation of multip effects. Furthermore it achives co-channel interference reduction. In [5], a simple transı diveristy scheme was perposed, these space–time codes (STCs) achieve significant error r improvements over single-antenna error-correcting codes. Space-Time-Coding (STC) is method of transmitting multiple data beams on multiple transmitters to multiple receive There are two main types of STCs, namely space-time block codes (STBC) and space-ti trellis codes (STTC). Space-time block codes operate on a block of input symbols, produci a matrix output whose columns represent time and rows represent antennas. On the otl hand, space-time trellis codes operate on one input symbol at a time, producing a sequence vector symbols whose length represents antennas. The original scheme of (STC) was based trellis codes but the simpler block codes were utilised by Alamouti in [6]. Later Tarokh et. in [7], [8] devloped space–time block-codes (STBCs).

For simplicity, previous proposed papers, for both space-time block coding (STBC) a space-time trellis coding (STTC) schemes, assumed known or perfect estimated syml

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timing to evaluate the performance [6], [9]. Timing estimation errors between the transmit and received signals could degrade the system performance. This paper focuses on illustrat the effect of imperfect symbol timing estimation on the performance of Alamouti's spa time-coding MIMO transmission model. The results are presented for two antenna system.

Symbol timing recovery is critical for reliable data detection in modern digi communications, the continuous-time received signal is sampled and these samples are us to make the decisions on the transmitted symbols. The receiver has to know the starting a finishing time instants of the individual symbols in order to correctly determine the perf sampling instant. There are a number of techniques to recover the symbol timing. In gener

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they can be categorized as [10]; pure analog timing recovery, mixed (analog-digital) timi recovery, and all-digital timing recovery. The first two techniques require voltage control oscillator (VCOs) to create synchronized timing clocks, these techniques are mainly used conventional receivers, where the symbol synchronization is performed using a feedback lo which controls the phase of the sampling clock. In The third technique the continuous-ti received signal is sampled using a fixed oversampling clock that is not synchronized to incoming symbols. Consequently, timing adjustment must be done by digital methods af sampling. There are two approaches to implement these digital adjustments [11], Data-Aic (DA) timing recovery approach, and Non-Data-Aided (NDA) timing recovery approach.

In data-aided timing recovery systems [12-14], training sequences are transmitted alo with the data-bearing signal, in the receiver, these training sequences are oversampled a these samples are used in extracting the symbol timing through different timing recove algorithms. Such an approach minimizes the time required to synchronize the receiver to transmitter, and is typically used in mobile communication systems where the chan characteristics are rapidly changing, and the transmission is bursty. However, the traini symbols reduce bandwidth and power efficiencies. Furthermore, the epoch of the orthogo training sequences has to be correctly identified, if errors occur in identifying the epoch, performance of symbol timing synchronization degrades.

In Non-Data-Aided (NDA) timing recovery [15], [16], the use of training sequences avoided and the receiver carries out the task of timing extraction using the sampled da bearing signal. Both throughput and power efficiency are improved but at the expense of increase in time taken to establish timing synchronization.

Although there is a small loss of performance (increase in timing-error variance for same SNR) in (DA) approach compared to (NDA) approach, the advantage of the (ND approach is that it does not require any training sequences so that transmission efficiency increased. Furthermore, symbol timing estimation can be performed any time during transmission and no epoch of training sequences needs to be identified, thereby savi computation power and eliminating the risk of performance degradation due to incorr identification of training sequences' epoch [15].

Following, Signal Model is given in section II. The performance study of Alamou space-time-coding transmission systems under the effect of imperfect symbol timi estimation is given in section III, different timing-error pattern are considered (fixed , vari bounded, diminishing variant timing error). Results are given for two different modulati schemes; QPSK, and 8-ary PSK. Conclusion comes in section IV.

II. SIGNAL MODEL

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The simplified base band equivalent model for G2 Alamouti's space-time coding wirel system is shown in Fig 1.

Consider an information source which generates frames of length L symbols dro from certain constellation as shown in Fig 1.

$$\mathrm{F} = \left(x_1 \,,\ x_2 \,,\ \ x_3 \ \cdots \ x_L \right) \qquad (1)$$

Each frame is then space-time encoded. For simplicity we consider a simple tw transmitter-based scheme associated with $p = 2$ proposed by Alamouti in [6]. For such encoder, the transmitted symbols are arranged into pairs

$$(x_i, x_{i+1}) \quad where \quad i=1,3,\ldots L-1 \tag{2}$$

During the j^{th} symbol period, the two symbols are simultaneously transmitted from t different antennas. Then, during the $(j+1)^{th}$ symbol period, the first antenna transmits − while the second antenna transmits $\bar{x}_1$ where $\bar{x}$ denotes the complex conjugate of x. Thus, transmitted sequences from the first and the second antennas, denoted Seq_1 & S respectively, can be written as

$$Seq_1 = (x_1, -\bar{x}_2, \ldots, x_j, -\bar{x}_{j+1}, \ldots, -\bar{x}_L) \tag{3}$$

$$Seq_2 = (x_2, \bar{x}_1, \ldots, x_{j+1}, \bar{x}_j, \ldots, \bar{x}_{L\_1}) \tag{4}$$

In [6], the model was derived under assumption of perfect timing information. Therefore, o the outputs of the matched filters were considered and no ISI is modeled. Such a model is adequate for the purpose of this paper. Thus, we rederive the continuous time model, tak the pulse shape into consideration. The model presented in [6] becomes a special c obtained at the correct sampling instant. Thus, each stream of encoded symbols is t independently pulse-shaped and transmitted from the corresponding antenna, *i=1, 2*

$$S_i(t) = \sqrt{E_S}\sum_{l=1}^{L} Seq_i(l)\,p(t - lT_S) \tag{5}$$

Where $T_s = 1/R_s$ is the symbol period, and $p(t)$ is the transmit filter pulse shaping function Without loss of generality, assume that $p(t)$ is a square root raised-cosine pulse shape

$$p(t) = \frac{4\varepsilon}{\pi\sqrt{T_s}} \cdot \frac{\cos((1+\varepsilon)\pi t/T_s) + \dfrac{\sin((1+\varepsilon)\pi t/T_s)}{(4\varepsilon t/T_s)}}{(4\varepsilon t/T_s)^2 - 1} \tag{6}$$

where ε is the bandwidth expansion or roll-off factor, $p(t)$ is truncated to $\pm 3T_s$ around t= The two signals, $s_1(t)$ and $s_2(t)$ produced from the pulse-shaping are transmit simultaneously from the two transmitters, namely, Tx_1 and Tx_2

The fading channel coefficients among various transmitters and receivers are denoted $h_{ji}(t)$, where $h_{ji}(t)$ is the channel impulse response (CIR) between the receiver j, and transmitter i. $h_{ji}(t)$ is modeled by a complex random variable with Rayleigh distribu amplitude and uniform phase. Moreover we assume that the coherence time of the channe larger than the $2T_s$, so that the channel does not change over the period of transmission of x_{j+1}. Therefore, it can be written as

$$h_{ji}((2l-1)T_s) = h_{ji}(2lT_s) \tag{7}$$

where $l = 1, 2 \ldots L/2$, L = the frame length

Fig. 1 shows the block diagram of a mobile receiver equipped with two receive antennas. T received signal at the j^{th} receiver can be modeled as

$$r_j(t) = \sum_{i=1}^{2} h_{ji}(t)\, s_i(t) + n_j(t) \tag{8}$$

where $n_j(t)$ = time varying additive white Gaussian noise at receiver j.

Substituting from (5) then,

$$r_j(t) = \sqrt{E_s}\sum_{i=1}^{2} h_{ji}(t) \sum_{l=1}^{L} Seq_i(l)\, p(t - lT_s) + n_j(t) \tag{9}$$

The output of the matched filter is

$$y_j(t) = \sqrt{E_s}\sum_{i=1}^{2} h_{ji}(t)\sum_{l=1}^{L} x_i(l)\,\rho(t - lT_s) + \bar{n}_j(t) \qquad (10)$$

Where $\rho(t) = p(t) * p(t)$ *is the autocorrelation function of the square root raised cos pulse shape, and* $\bar{n}_j(t) = n_j(t) * p(t)$ *is the colored noise.*

The receiver is assumed to employ an all-digital timing recovery mechanism. Thus, outputs of the matched filters are over sampled with $f_{o.s}$ which is Q times faster than symbol rate R_s,

$$f_{o.s} = Q \,.\, R_S \qquad (11)$$

Then, the time instant of the k^{th} sample within the l^{th} matched filter output symbol, $t_{l,k}$ v be

$$t_{l,k} = lT_S + \frac{k}{Q}T_S + \delta T_S \qquad (12)$$

where δT_s *is the timing error, l=1, 2 ... L symbol index, and k=1, 2 ... Q the sample index.*
Then, the received samples at the j^{th} antenna matched filter output will be

$$y_j(t_{l,k}) = \sqrt{E_s}\sum_{i=1}^{2} h_{ji}(t_{l,k})\sum_{l=1}^{L} Seq_i(l)\rho(t_{l,k} - lT_s) + \bar{n}_j(t_{l,k}) \qquad (13)$$

These samples are first, used for timing extraction and frequency synchronization us one of the known timing and channel estimation algorithms mentioned above. Then, samples corresponding to the information symbols, at the optimum sampling instant, with channel estimation are fed to an ST channel decoder, which consists mainly of a combi and a maximum likelihood detector.
Optimum sampling instant for symbol l'

$$t_{opt}(l') = l'T_s \qquad (14)$$

Then, the j^{th} optimum timing sampled received signals is

$$y_j(t_{opt}) = \sqrt{E_s}\sum_{i=1}^{2} h_{ji}(l'T_s)\sum_{l=1}^{L} Seq_i(l')\rho((l'-l)T_s) + \bar{n}_j(t_{opt}) \qquad (15)$$

Considering the properties of the square root raised cosine pulse shape

$$\rho(0) = 1 \qquad (16)$$

$$\rho(kT_s) = 0 \qquad (17)$$

Then,

$$y_j(l') = \sqrt{E_s}\sum_{i=1}^{2} h_{ji}(l'T_s)Seq_i(l') + \bar{n}_j(t_{opt}) \qquad (18)$$

Which is the equation used in [6]

At the combiner, the two optimum-timing sampled received signals along with channel estimation, are combined producing (18), (19)

$$\tilde{y}(2l-1) = \sum_{i=1}^{2}\left(\bar{h}_{i1}(2l-1)y_i(2l-1) + h_{i2}(2l)\bar{y}_i(2l)\right) \qquad (19)$$

$$\tilde{y}(2l) = \sum_{i=1}^{2}\left(\bar{h}_{i2}(2l-1)y_i(2l-1) + h_{i1}(2l)\bar{y}_i(2l)\right) \qquad (20)$$

where l=1, 2 ... L/2
Taking into consideration (7), then

$$\tilde{y}(2l-1) = \sum_{i=1}^{2}\left[\left(|h_{i1}(2l)|^2 + |h_{i2}(2l)|^2\right)Seq_i(2l-1) + \bar{h}_{i1}n_i(2l-1) + h_{i2}\bar{n}_i(2l)\right] \qquad (21)$$

$$\tilde{y}(2l) = \sum_{i=1}^{2} \left[\left(\left| h_{i1}(2l) \right|^2 + \left| h_{i2}(2l) \right|^2 \right) Seq_i(2l) + \bar{h}_{i2} n_i(2l-1) - h_{i1} \bar{n}_i(2l) \right] \quad (22)$$

Finally, the combined signal $\tilde{y}(l)$ is fed to the maximum likelihood detector where most likely transmitted symbol is determined based on the minimum Euclidean distan between the combined signal and all possible transmitted symbols.

III. SIMULATION RESULTS

The Alamouti's STBC described in the previous section is simulated under vari conditions representing timing errors. The simulation model assumes a root raised cos pulse shaping with a roll-off factor ε=0.3. Since the timing offset are in practice drown fr continues distribution, an excessive over-sampling with Q=100 is used to generate tim error with a resolution of $0.01T_s$. Timing errors are modeled in three different methods. Fi the effect of a fixed timing shift is considered. Second, the timing error is assumed to random variable with uniform distribution. In practice, timing error variance is reduced due improvement in its estimation with the increase of SNR. Such improvement is taken i consideration in the third method

In the First method the effect of fixed error in timing estimation, is carried out by add different fixed timing offsets Δt to the ideal timing instant (t_{opt}). These timing offsets are se be a certain percentage of T_s.

In the second method, the timing-error Δt is assumed to be a random varia uniformly distributed between $[-\alpha, +\alpha]$ where $0 \le \alpha \le 0.5T_s$. The model adds a bounc random variable timing offset, Δt to the ideal timing instant (t_{opt}). These random timing offs are set to be bounded by certain percentage of T_s.

In the third method, which is the most realistic case, the timing-error is assumed to uniform distributed random variable, having a diminishing variance with increasing in SN In order to form a diminishing variance characteristic of the timing error, a simulation squaring timing recovery technique-one of the Non-Data-Aided (NDA) timing recov techniques-is used to determine the appropriate timing-error variances corresponding different SNR. A simulation model for Squaring Timing Recovery technique was carried in order to estimate different variances of timing error estimation in accordance to SNR. T simulation was carried out as in [15], using two transmitters and two receivers MIMO syst with oversampling ratio =4. Results are given in Fig. 5, 10 which show the dependence timing error estimation variances on SNR for both QPSK and 8PSK modulation schen respectively.

Taking into consideration that the variance of a uniform distributed random variable given by,

$$\mathrm{var}(\Delta t) = \frac{1}{12}(a-b)^2 \qquad as\ \Delta t\ varies\ over\ [a,b] \qquad (25)$$

Each SNR is assigned to its corresponding varying time offset bounders, then the simulati model adds these different-bounded variant timing offsets, Δt to the matched filter out sampling clock in correspondence to SNR.

In each case of modeling the timing error, the results will be compared with performance under perfect timing recovery. Moreover the results for the power loss will given for each case.

It is assumed that the timing estimate is calculated and used over a frame length $L=100$ symbols. Hence, each timing error is kept constant over 100 symbols, results averaged over 10^5 loops. The simulation is carried over SNR range (0 - 26 dB) for QP

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modulation scheme and. (*0 - 20* dB) for 8PSK modulation scheme, for each value of SNR, . random values of the timing error are used to calculate the average BER.

Fig. 2, 3 shows the performance of Alamouti's STBC using QPSK modulation sche under the effect of fixed, and bounded variant timing error compared with the performa under perfect timing, respectively. Fig. 2 shows the performance under a fixed timi offset $\Delta t = (0.05, 0.1, 0.15, 0.2, 0.25)T_s$. Fig. 3 shows the performance under a random variat uniformly distributed timing offset Δt, which is bounded by $[-\alpha, +\alpha]$, wh $\alpha = (0.05, 0.1, 0.15, 0.2, 0.25)T_s$.

It is clear that the performance degrades significantly under both schemes with ea increasing in the amount of timing offset, and the major drawback of the imperfect timi estimation is that the performance (BER) suffers from an error floor behavior, which could be overcome with any further increasing in SNR. Fig. 2 shows that these error floor are *1* 5×10^{-6}, 6×10^{-5}, 5×10^{-4} and 3×10^{-3} for $0.05T_s$, $0.1T_s$, $0.15Ts$, $0.2T_s$, $0.25T_s$ fixed timing er respectively. Fig. 2 shows also that fixed timing error results in an excessive amount of pov loss in order to achieve certain performance level, for example to achieve BER=10^{-4} $0.05T_s$, $0.1T_s$ fixed timing errors cause a power loss equal to 0*.9, 2.8 (dB),* respectively a equal to *2.5, 6.2 (*dB) for BER=10^{-5}

Fig. 3 shows that these error floor are 6×10^{-7}, 2×10^{-6}, 9×10^{-6}, 8×10^{-5} and 3×10^{-4} *[-5%, 5%]Ts, [-10%, 10%]Ts, [-15%, 15%]Ts, [-20%, 20%]Ts*, and *[-25%, 25%]Ts* bounc variable timing error respectively. Fig. 3 shows also that bounded variable timing error resu in an excessive amount of power loss in order to achieve certain performance level, example to achieve BER=10^{-4}, a *[-5% ,5%]Ts, [-10%, 10%]Ts, [-15%, 15%]* *[-10%, 10%]Ts* bounded variable timing error cause a power loss equal to *0.7, 1.8, 3* a *10* (dB), respectively.

Fig. 3 also shows that, these timing errors prevent systems from achieving cert performances, for example systems suffer from *[-10%, 10%]Ts, [-20%, 20%]Ts* bounc variant timing error are not able to achieve 10^{-6}, 10^{-5} respectively, even with any increasing SNR.

Fig. 4 shows the power loss due to bounded timing error. For example it shows that, order to achieve BER=10^{-5} in a wireless communication employing an Alamouti's STI using QPSK modulation scheme that suffers from *[-5%, 5%]Ts, [-10%, 10%]Ts* bounc variant timing error, an additional SNR = *1.8, 3.6* (dB) must be used, respectively, and t amounts increases to be *2.2, 4.2* (dB) at BER = 5×10^{-6}

Fig.5 shows the improvement in timing error estimation (decreasing of timing er variance) with increasing in SNR for Alamouti's STBC using QPSK modulation scheme. F 6 shows the most realistic case, the performance under the effect of diminishing-variai variant timing – given in Fig. 5 – compared with the performance under perfect timing. It clear that the two performances are identical for low SNR, as the effect of noise is m dominant, for high SNR the effect of noise vanishes and the effect of imperfect timi estimation degrades the performance significantly.

Fig.7, 8 shows the performance of Alamouti's STBC using 8PSK modulation sche under the effect of fixed, and bounded variant timing error compared with the performa under perfect timing, respectively. Fig. 7 shows the performance under a fixed timing off $\Delta t = (0.05, 0.1, 0.15, 0.2, 0.25)T_s$. Fig. 8 shows the performance under a random variat uniformly distributed timing offset Δt, which is bounded by $[-\alpha, +\alpha]$,wh $\alpha = (0.05, 0.1, 0.15, 0.2, 0.25)T_s$.

It is clear that the performance degrades significantly under both schemes with ea increasing in the amount of timing offset, and the major drawback of the imperfect timi estimation is that the performance (BER) suffers from an error floor behavior, which could be overcome with any further increasing in SNR.

Fig. 7 shows that these error floor are 2×10^{-4}, 10^{-3}, 6×10^{-3}, 3×10^{-2} and 7×10^{-2} for *0.05* $0.1T_s$ $0.15T_s$ $0.2T_s$, $0.25T_s$ fixed timing error respectively. Fig. 7 shows also that fixed timi error results in an excessive amount of power loss in order to achieve certain performa level, for example to achieve BER=10^{-2}, a $0.05T_s$, $0.1T_s$ fixed timing error cause a pov loss equal to *1.2, 3.9 (dB),* respectively and equal to *5, 17.6 (*dB) for BER=10^{-3}

Fig. 8 shows that these error floor are 3×10^{-4}, 6×10^{-4}, 2×10^{-3}, 6×10^{-3} and 10^{-2} *[-5% ,5%]Ts, [-10%, 10%]Ts, [-15%, 15%]Ts, [-20%, 20%]Ts*, and *[-25% ,25%]Ts* bounc variable timing error respectively. Fig. 8 shows also that bounded variable timing error resu in an excessive amount of power loss in order to achieve certain performance level, example to achieve BER=10^{-2}, a *[-5%, 5%]Ts, [-10%, 10%]Ts, [-15%, 15%]Ts, [-20 20%]Ts* bounded variable timing error cause a power loss equal to *1, 2, 5.6* and *12.5* (d respectively. Fig. 8 also shows that, these timing errors prevent systems from achiev certain performances, for example systems suffer from *[-10%, 10%]Ts, [-20%, 20%* bounded variant timing error are not able to achieve 10^{-4} , 10^{-3} respectively, even with a increasing in SNR. Fig. 9 shows the power loss due to bounded timing error, which sho that in order to achieve BER=10^{-3} in a wireless communication employing an Alamou STBC using 8PSK modulation scheme that suffers from *[-5%, 5%]Ts, [-10%, 10%* bounded variant timing error, an excessive bit SNR = *1.5, 3.8* (dB) must be used, respective and this amounts increases to be *2.8, 7* (dB) at BER = 5×10^{-3}. Fig.10 shows, the improvem in timing error estimation (decreasing of timing error variance) with increasing in SNR Alamouti's STBC using 8PSK modulation scheme. Fig. 11 shows the most realistic case, performance under the effect of diminishing-variance variant timing – given in Fig. 1(compared with the performance under perfect timing. It is clear that the two performances identical for low SNR where the effect of noise is more dominant, for high SNR the effect noise vanishes and the effect of imperfect timing estimation degrades the performa significantly.

IV. CONCLUSIONS

Symbol timing estimation error causes significant degradation in system performance Alamouti's STBC wireless communication systems using both QPSK, and 8PSK modulat schemes. The major drawback of symbol timing estimation errors is that it causes the syst performance to suffer from an error floor behavior that prevents the system from achievi certain BER, even with any increasing in SNR. Results in this paper could be a useful gu for definition of requirement in symbol timing systems used in space time coding wirel systems that are designed to achieve certain performance level

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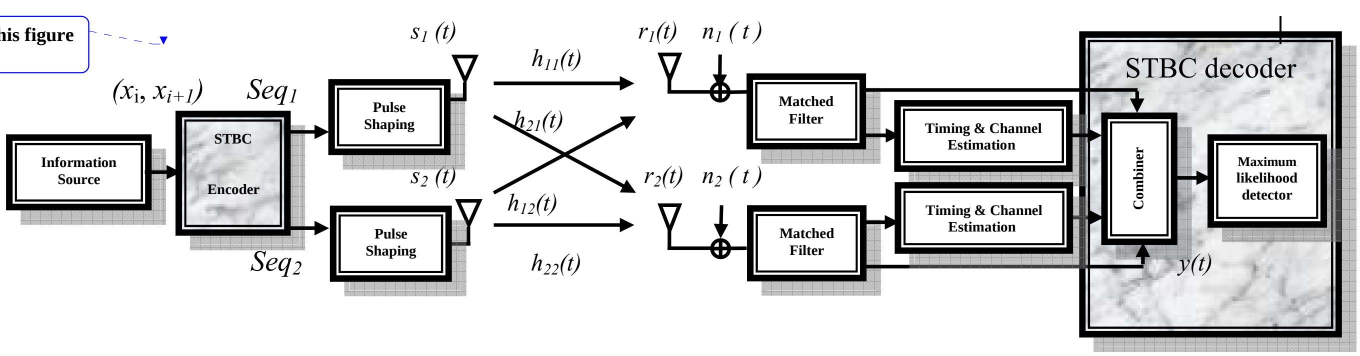

Fig.1. Simplified base band equivalent model for G2 Alamouti's space-time coding wireless system

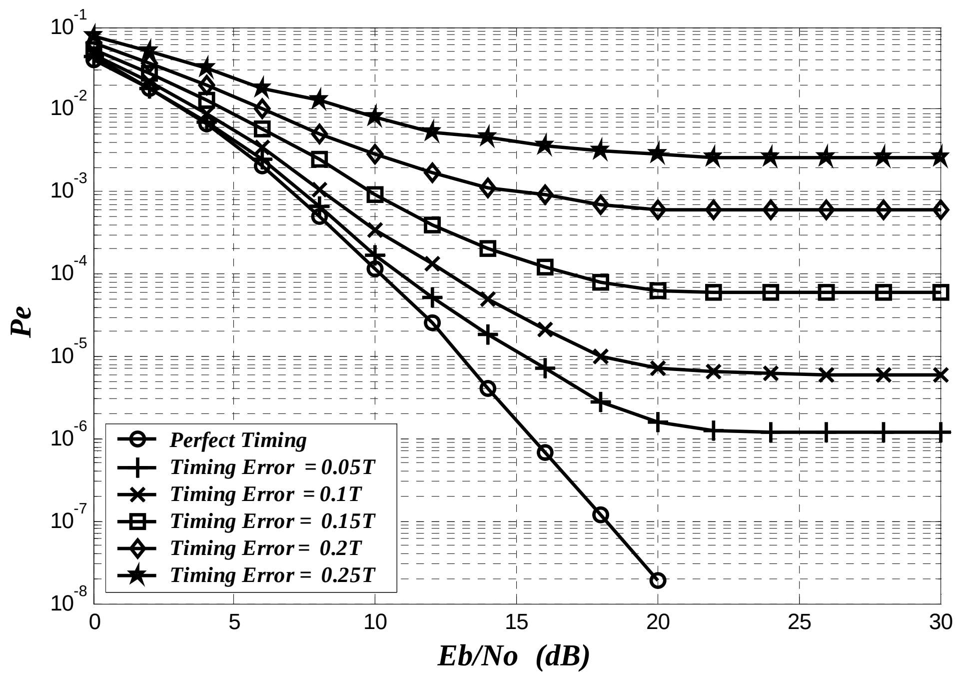

Fig.2 The performance of Alamouti's STBC using QPSK modulation scheme under the effe of different fixed timing error

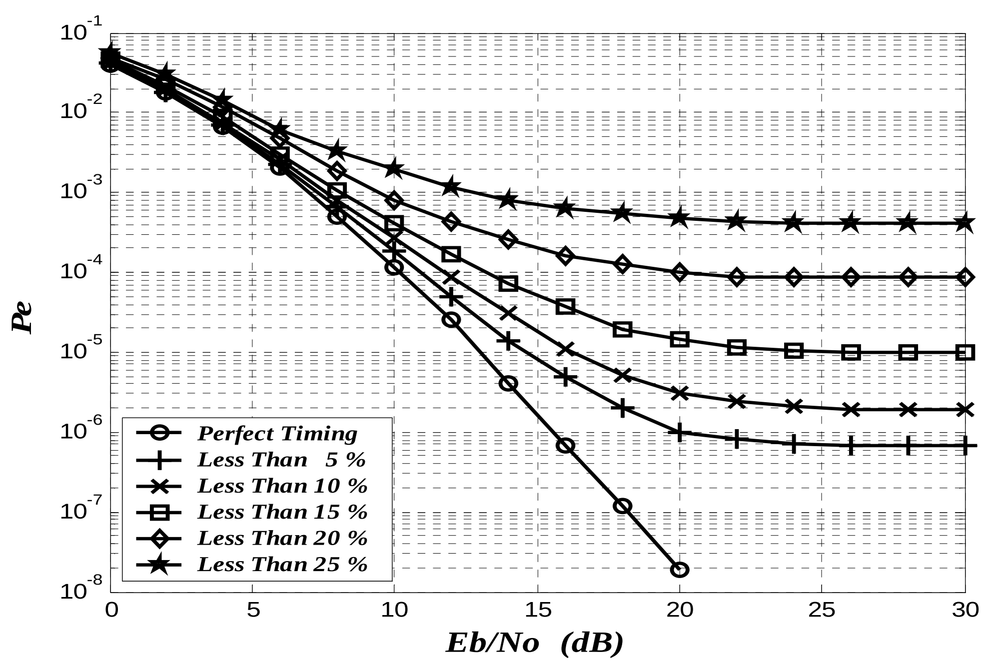

Fig.3 The performance of Alamouti's STBC using QPSK modulation scheme under the effe of different bounded variant timing error

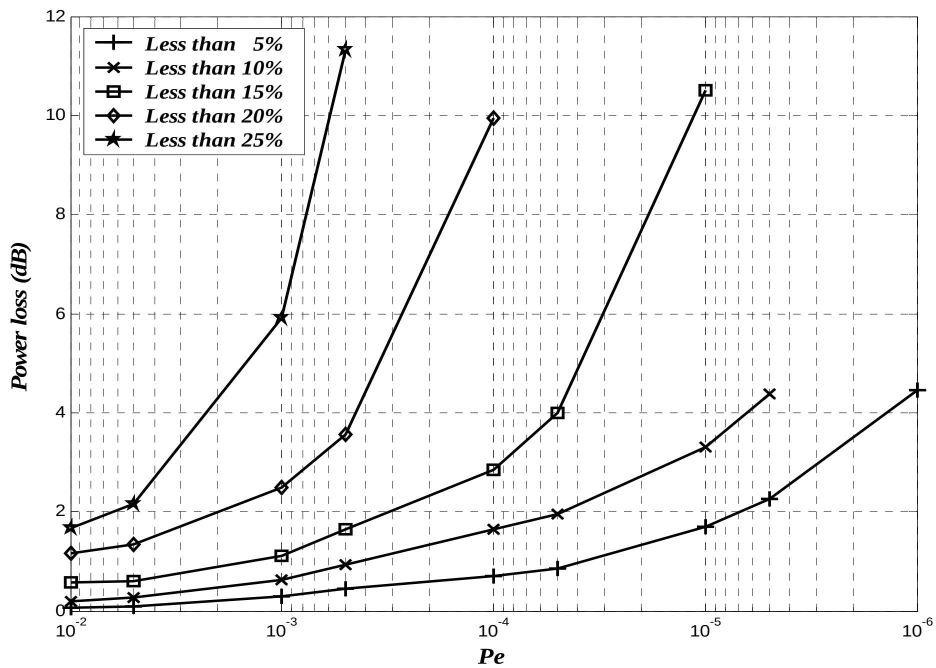

Fig.4 Power losses effect of different bounded variant timing error over Alamouti's STBC using QPSK modulation scheme

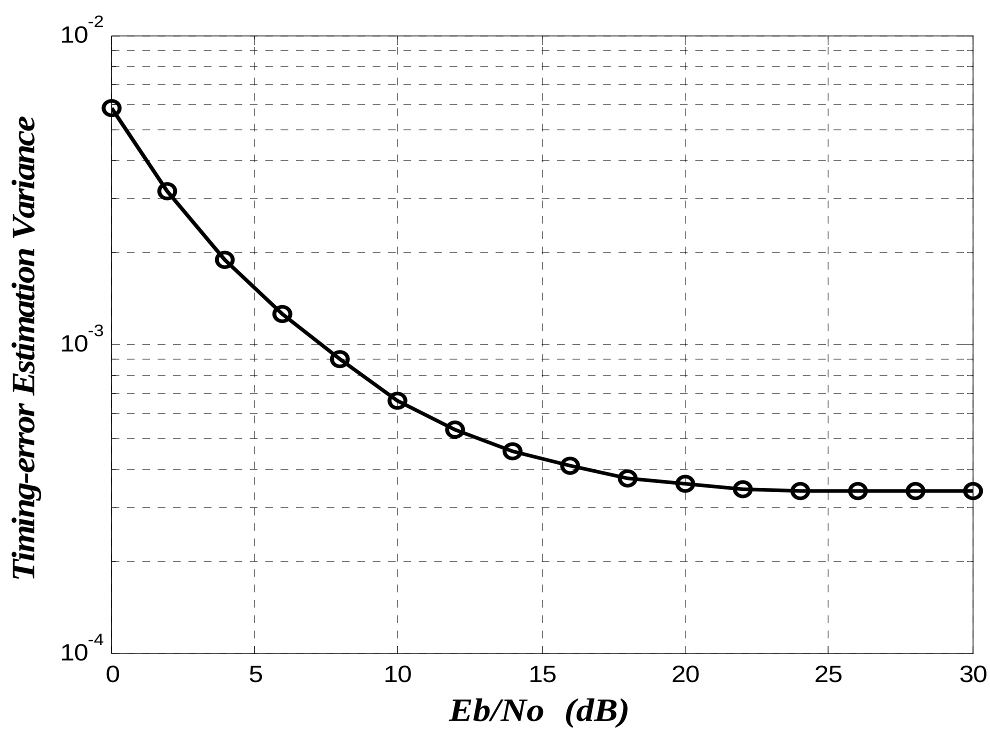

Fig.5 QPSK Timing error estimation diminishing variance

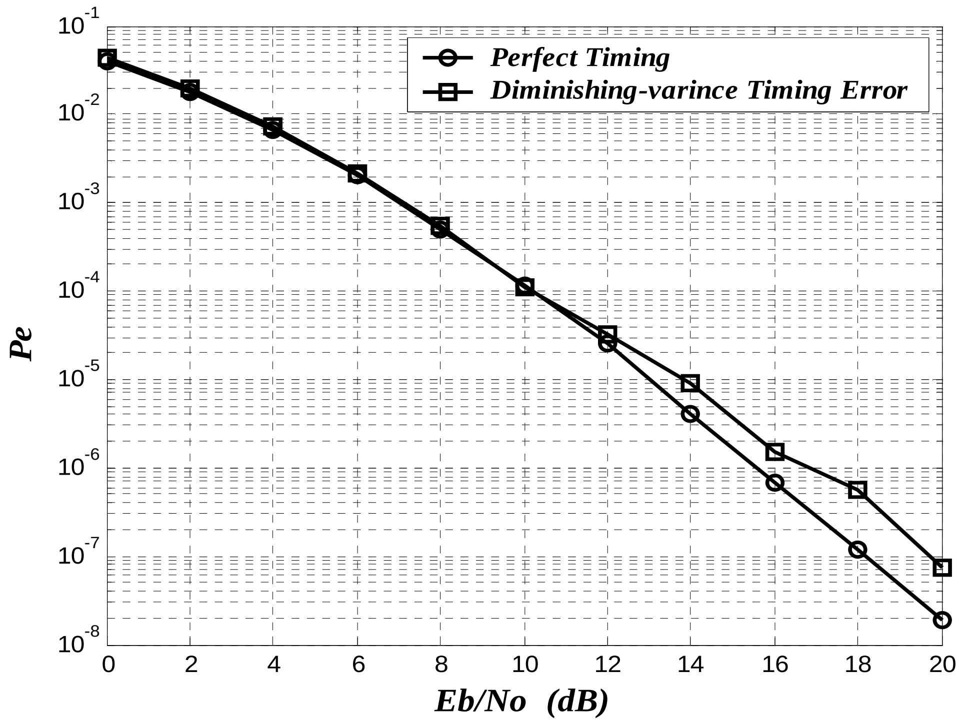

Fig 6 The performance of Alamouti's STBC using QPSK modulation scheme under the effe of a diminishing-variance variant timing error

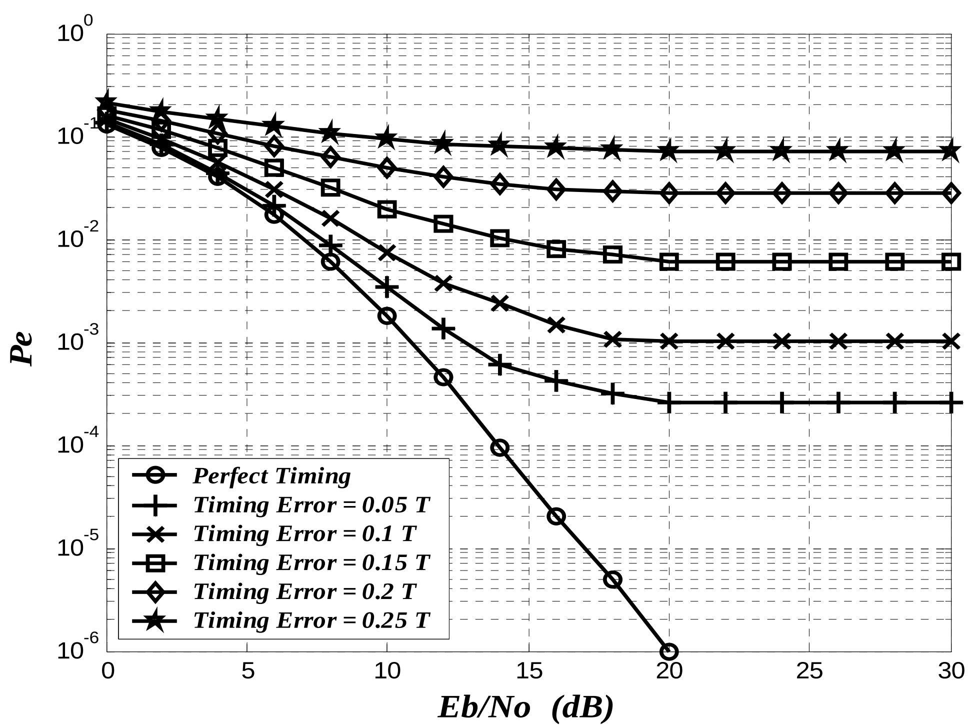

Fig.7 The performance of Alamouti's STBC using 8PSK modulation scheme under the effect of different fixed timing error

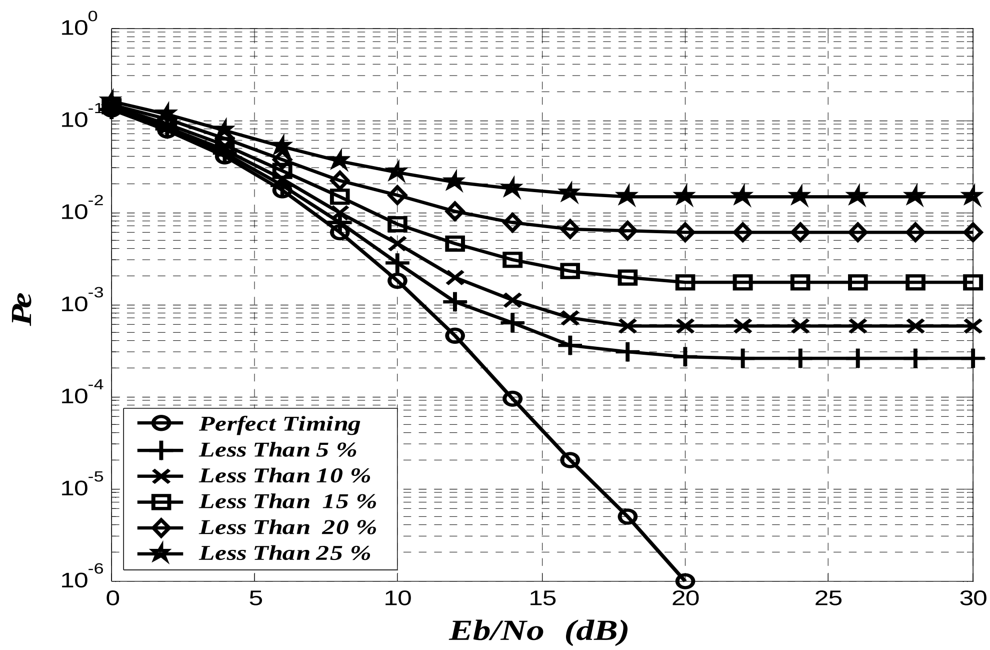

Fig.8 The performance of Alamouti's STBC using 8PSK modulation scheme under the effe of different bounded variant timing error

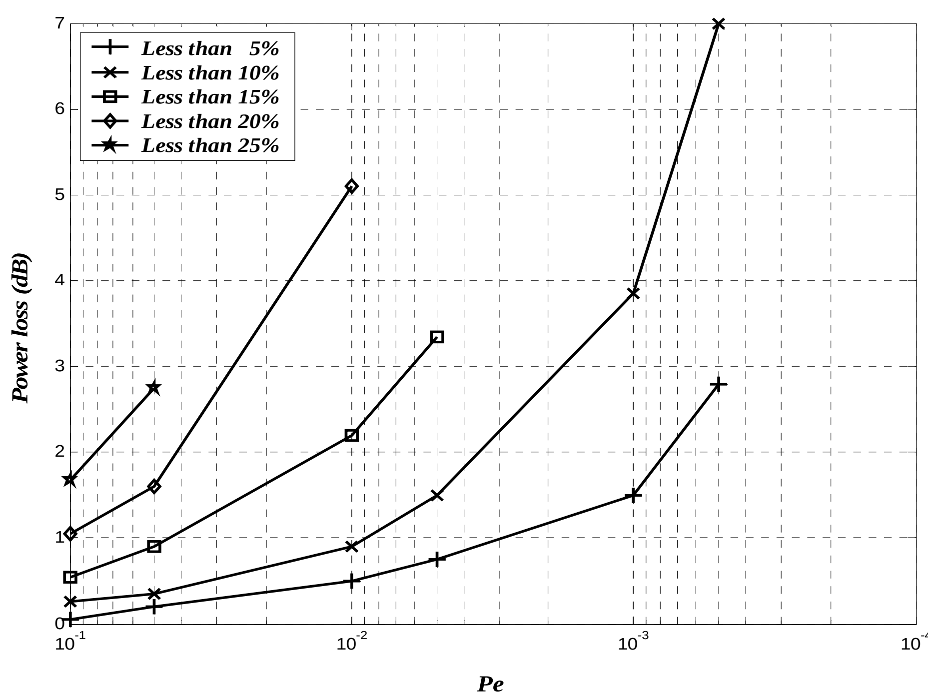

Fig.9 Power losses effect of different bounded variant timing error over Alamouti's STBC using 8PSK modulation scheme

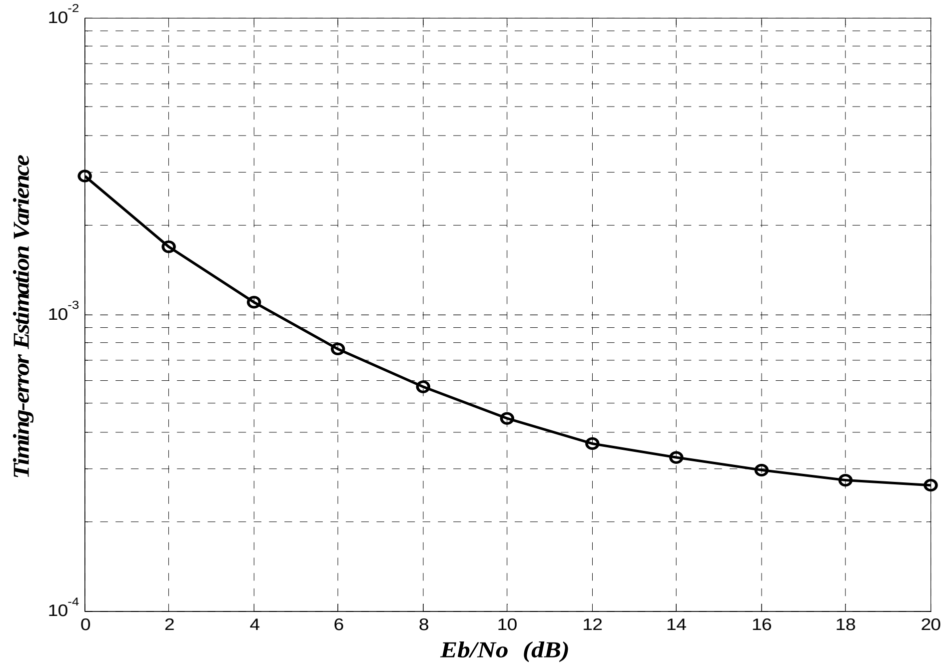

Fig.10 QPSK Timing error estimation diminishing variance

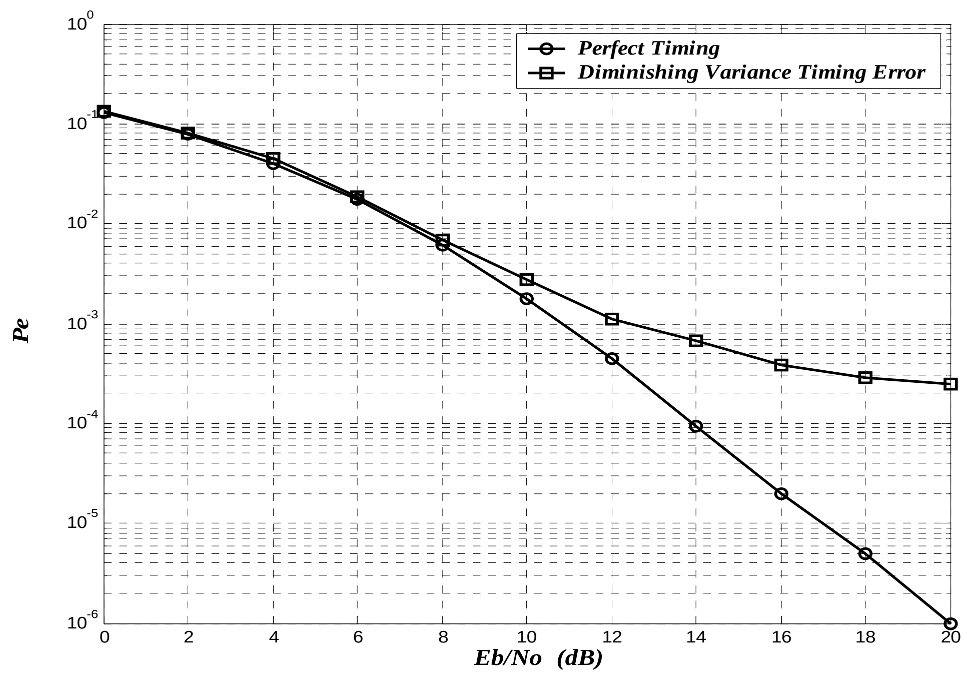

Fig.11 The performance of Alamouti's STBC using 8PSK modulation scheme under the effect a diminishing-variance variant timing error

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