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A Variable Step Synchronization Acquisition Method for UWB Systems

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Abstract: The extremely narrow pulses with the order of nanoseconds and multipath in Time Hopping Ultra Wide Band system result in long mean acquisition time as well as low acquisition precision. A novel Variable Step Acquisition scheme, which aims to improve both mean acquisition time and acquisition precision, is proposed. The proposed acquisition scheme employs nonconsecutive search and adjusts searching steps according to several thresholds, which makes the acquisition process a fast acquisition with variable steps, i.e., from large steps to small ones. The mean acquisition time performances of the proposed scheme and conventional acquisition schemes are evaluated and compared. It is evident that proposed acquisition scheme significantly outperforms the conventional ones.

Key words: Synchronization acquisition, ultra wide band, variable step acquisition, mean acquisition time

INTRODUCTION

The most challenging problem for Ultra Wide Band (UWB) synchronization is acquisition time and acquisition precision (Aedudodla *et al*., 2005). The extremely narrow UWB pulse causes larger searching area, while the low transmit power increases the difficulty of UWB acquisition. And because of presence of multipath, there will be more than one path satisfying threshold, which causes several possible phases to stop the acquisition. Considering the complexity of the hardware implementation, many approaches in the literature adopt serial or hybrid search acquisition based on detection.

A traditional coarse acquisition scheme, where the search space is searched in increments of a chip fraction for the acquisition of Time Hopping (TH) UWB signals in AWGN noise, is introduced (Blazquez *et al*., 2003). The received signals will correlate with the local template delayed and process stops at a decision variable exceeding the threshold. The scheme has the merit of simple frame but the whole acquisition process is too long. To improve the Mean Acquisition Time (MAT), several searching strategies are proposed based on Markov chains such as Truly-Random-Search, Random Permutation Search and look-and-jump-by-K-bins Search and etc. (Homier and Scholtz, 2002). This efficient search strategy specifies the order in which the candidate phases in the timing uncertainty region are evaluated by the acquisition system and it trade off the MAT for an increase in the probability of miss synchronized phase. Zhang *et al.* (2002) proposes a hybrid acquisition scheme called the reduced complexity sequential probability ratio test (RC-SPRT) for UWB signals in AWGN, which is a modification of Multihypothesis Sequential Probability Ratio Test (MSPRT) for the hybrid acquisition of spread spectrum signals. In MSPRT, the potential ideal phase will be sent to the verification stage after determined during the serial searching strategy. However, in RC-SPRT, the false hypothesis will be excluded by the searching strategy and replaced by new hypothesis and process stops when all false hypothesis are excluded. This scheme has the merit at low SNRs but lacks the improvement for acquisition precision. In CLPDI scheme, the output of a matched filter, whose impulse response is a time reversed replica of the spreading code, is integrated over successive time intervals (Soderi *et al*., 2003). Although it decreases the sampling time, it doesn't help to decrease the matching time, which contributes more to MAT. Furthermore, because the consequent searching is adopted, there is no obvious improvement for MAT. Besides this, the effect of Equal Gain Combining (EGC) on the acquisition of UWB signals with TH spreading is investigated in a multipath environment (Vijayakumaran and Wong, 2003, 2006). Two schemes based on EGC called the Square and Integrate (SAI) and the Integrate and Square (IAS) are analyzed and compared. It is shown that even though EGC improves the acquisition performance in SAI at low SNRs, the performance of IAS with no EGC is superior to SAI at all SNRs. Some acquisition schemes attempt to solve the large search space problem by employing a two-stage acquisition

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strategy (Gezici *et al.*, 2003; Reggiani and Maggio, 2003; Aedudodla and Vijayakumaran, 2005; Corazza, 1996). The basic principle behind all these schemes is that the first stage performs a coarse search and identifies the true phase of the received signal to be in a smaller subset of the search space. The second stage then proceeds to search in this smaller subset and identifies the true phase. Because the second searching step precision is limited by the first step, two-stage acquisition will result in local optimum which increases the probability of error detection. Besides this, some nonconsecutive searches are adopted to improve the MAT. An optimum serial searching strategy based on TH-UWB in a multipath environment (Vijayakumaran and Wong, 2005) and a nonconsecutive searching in a frequency selective fading channel (Shin and Lee, 2001) are introduced. These methods improve the MAT by selecting one phase from every K consecutive phase. However the performance of MAT and acquisition precision are influenced by the choice of step K.

The above mentioned schemes aim to shorten acquisition process and are evaluated by MAT. However, the acquisition precision is underestimated, which can evaluate accuracy of the fast acquisition scheme. Although the fast acquisition scheme has the advantage of MAT, quick acquisition process is gained at a cost of acquisition precision. Two-step acquisition will result in local optimum, sequential searching will be influenced by multipath and the jump-K-cells will miss the probable phases between every two K cells. Therefore, it is necessary to develop a fast acquisition scheme considering both acquisition precision and MAT. Variable Step Acquisition (VSA) is proposed in this paper and aims to improve the MAT as well as acquisition time.

PROPOSED ACQUISITION SYSTEM

Acquisition system: The acquisition system proposed in this study is shown in Fig. 1. The coherent receiver will acquire the signals with the matching template which are generated based on Time Hopping (TH) code. The correlation output is squared and compared with thresholds and the step L_p is determined by comparison result.

This system utilizes the presence of more than one resolvable path signals and includes two modes of operation, i.e., searching mode and verification mode. In the searching mode, the decision variable is compared with a decision threshold. If the decision variable exceeds the decision threshold, the corresponding cell is assumed tentatively to be an in-phase cell and the verification mode is activated to test whether the tentative decision is correct or not. Otherwise, the cell is assumed to be an out-of-phase cell and a new cell is tested. In the verification mode, the receiver performs a number of tests by comparing the decision variable with a decision threshold. If at least B out of these A decision variables exceed the new decision threshold, acquisition is declared and the tracking system is enabled. Otherwise, the tentative decision is rejected and the acquisition system goes back into the searching mode to test a new cell. Before testing a new cell, the code phase is updated by L_p cells, which makes the search procedure nonconsecutive. This nonconsecutive search strategy will be introduced in details in next subsection.

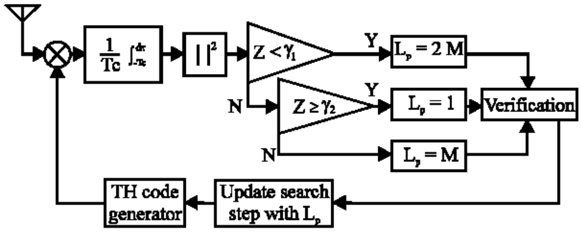

Fig. 1: Structure of an acquisition receiver employing the VSA scheme

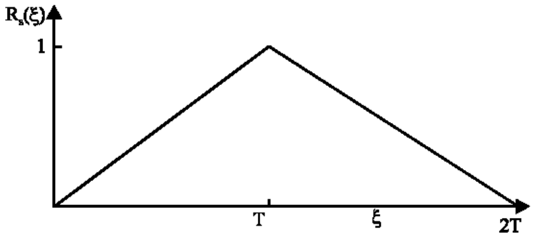

Fig. 2: Correlator output for rectangle pulse with the duration T

Variable step search: As mentioned in Introduction, UWB multipath channel results in large searching scope for the receiver. VSA search is proposed aiming to decrease the searching scope. The uncertain region is searched by L_p steps non-consecutively and the L_p is updated every search time by comparing variable decision with the threshold. For a rectangle pulse s(t) with the duration of T, the output of correlator filter is the autocorrelation of s(t), i.e., $R_s(\xi)$ which is the maximum gained at $\xi = T$. Figure 2 shows the maximum position is the ideal synchronized phase position. The output of correlator, which is in inverse proportion to the distance between corresponding phase and the ideal synchronized phase, is larger when it is closer to the ideal position.

In impulse radio TH-UWB system, the correlator output also follows the rules above. In system simulation,

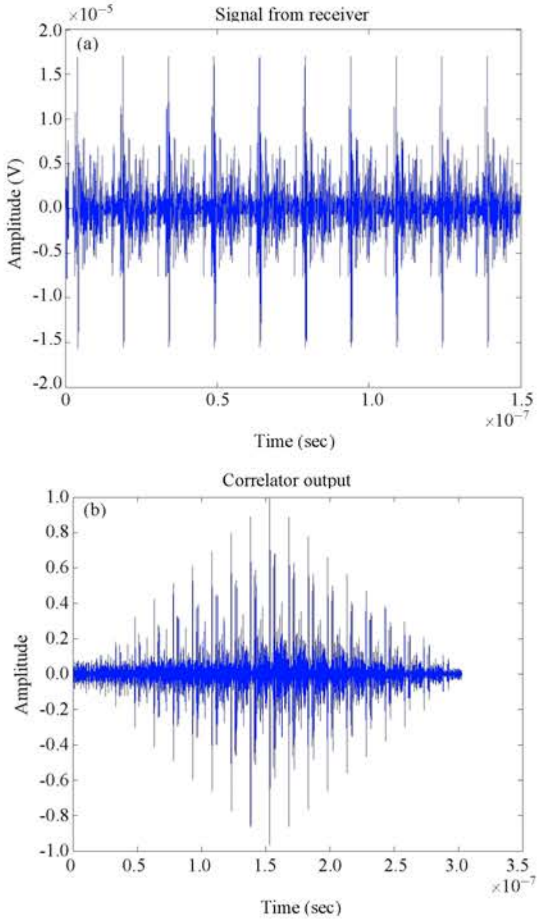

Fig. 3: Correlator output for Impulse Radio UWB Time Hopping sequences(a) TH Sequence received from UWB indoor channel 2 and (b) Correlator output for (a)

IEEE_UWB NLOS indoor model is adopted as channel model, Gaussian 2nd derivative function is used as the UWB signal and the TH sequence is used as correlator template. Input signal at the receiver is shown in Fig. 3a and correlator output of Fig. 3a is shown as Fig. 3b. Thus, step L_p can be designed and adjusted based on the correlation output $R_s(\xi)$.

The flow graph for VSA designed based on the output of correlator is shown in Fig. 4. When correlation output is relatively small, large step is adopted for searching to skip the region quickly in which low probability happens for in-phase cell. With correlation output increment, step is adjusted from large to small. Until the phase is close to the ideal synchronized cell, one single cell is adopted as the searching step. In this study, thresholds for three steps are designed and the steps are set correspondingly. Searching step L_p should satisfy the rules as follows, where Z is the amplitude of correlation output, r_1 and r_2 are comparative threshold:

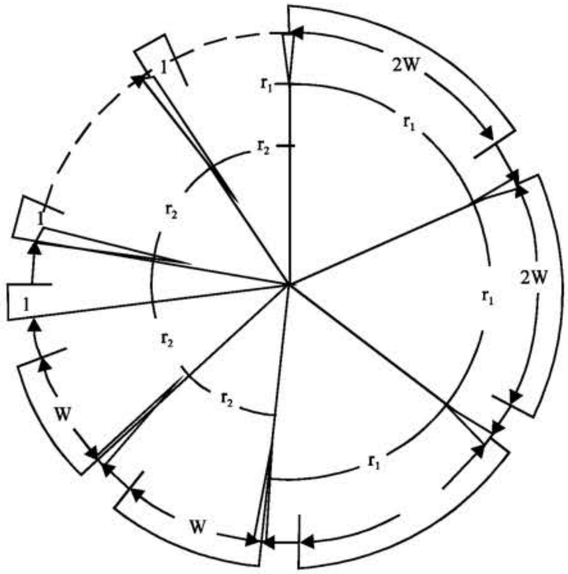

Fig. 4: Nonconsecutive search flow diagram

$$\begin{cases} Z < r_1, & L_p = 2W \\ r_1 \le Z < r_2 & L_p = W \\ Z > r_2 & L_p = 1 \end{cases} \tag{1}$$

PERFORMANCE ANALYSIS OF MEAN ACQUISITION TIME

Transfer function based on nonconsecutive L_p cells is (Shin and Lee, 2001),

$$\begin{aligned} H(z) &= \frac{1}{L}\sum_{l=1}^{Lp}\sum_{m=1}^{\Lambda_1} H(z\,|\,l,m) \\ &= \frac{1}{L(1-[H_0(z)]^{L-Lp}\prod_{l=1}^{Lp} H_{ml}(z))}. \\ &\quad \{\sum_{l=1}^{Lp}\sum_{m=1}^{\Lambda_1}\sum_{j=1}^{Lp+l-1}[H_0(z)]\sum_{k=1}^{j}\Lambda_{((k))+l-m-j}.H_D(z,l,j)\} \end{aligned} \tag{2}$$

Especially, variable step searching method is adopted in this study, thus,

$$E[Lp] = \sum_{a=0}^{N}\sum_{b=0}^{N-a} C_{Lp}^{a} C_{Lp}^{b} C_{Lp}^{Lp-a-b} (P_{r1})^{a} (P_{r2})^{b} (P_1)^{Lp-a-b} \tag{3}$$

where, $P_{r1} = \frac{2W}{N}, P_{r2} = \frac{W}{N}, P_1 = \frac{1}{N}$

So the mean acquisition time is

$$E[T_{ACQ}] = \frac{dH(z)}{dz}\Big|_{Z=1} \qquad (4)$$

PERFORMANCE ANALYSIS

Simulation setup: In system simulation, Gaussian 2nd derivative function is used as the UWB signal with pulse duration 0.5 ns. Sampling frequency is 50 GHz and the length for TH code is 5 with code duration 1 nsec. IEEE_UWB NLOS indoor model is adopted as channel model.

Simulation results: Here, the proposed Variable Step Acquisition is compared with classic acquisition schemes such as, Oh-Shin-search (Shin and Lee, 2001), CLPDI-search (Soderi *et al*., 2003), serial-sequent-search (Blazquez *et al*., 2003), Jump-K-cell search (Vijayakumaran and Wong, 2005) Truly-Random-Search and Random-Permutation-Search (Homier and Scholtz, 2002) based upon MAT and acquisition precision. The comparisons of MAT and the acquisition precision are shown in Fig. 5 and 6, respectively. Acquisition bias, which is defined as bias of ideal position and actual acquisition position, is adopted to evaluate the acquisition precision.

$$T_{Bias} = |T_{ideal} - T_{actual}| \qquad (5)$$

MAT performances of Truly-Random-Search and Random-Permutation-Search are changing because of the random position searching strategy. Although these two algorithms are quick to achieve acquisition, from the view of acquisition precision they have relatively large bias. At low SNRs, all the acquisition schemes are quick to achieve acquisition, as shown in Fig. 5, because noise makes it easier and quicker to exceed the threshold. With SNR increment, VSA improves the mean acquisition time comparing the Sequent, CLPDI, Oh Shin schemes. Jump-K-cell is quicker than VSA to achieve synchronization; however, the performance of accuracy is the worst among these searching strategies, which is because the probability of missing synchronized phase between every two steps is large. VSA utilizes the variable step searching strategy improves the acquisition accuracy and performs best among these schemes. As a whole, VSA outperforms the other algorithm in the view of MAT and precision.

However, the performance of VSA scheme is closely related to the selection of threshold and searching step W. The performances of MAT under different thresholds and with different steps are compared in Fig. 7, where the

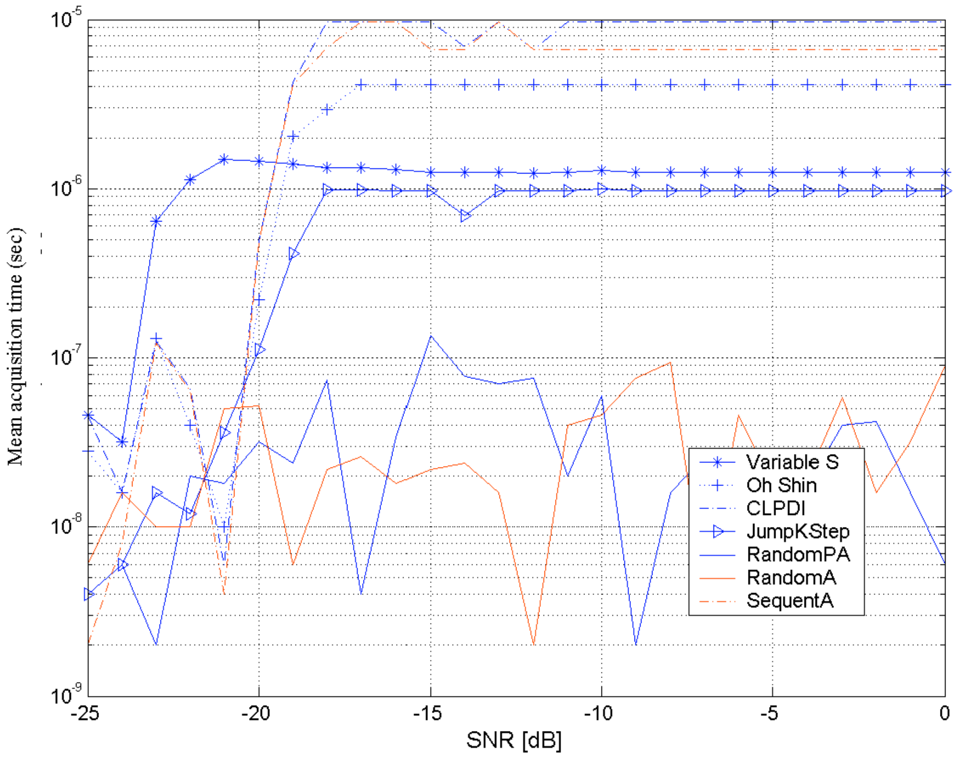

Fig. 5: The mean acquisition time comparison of VSA and several classic acquisition schemes

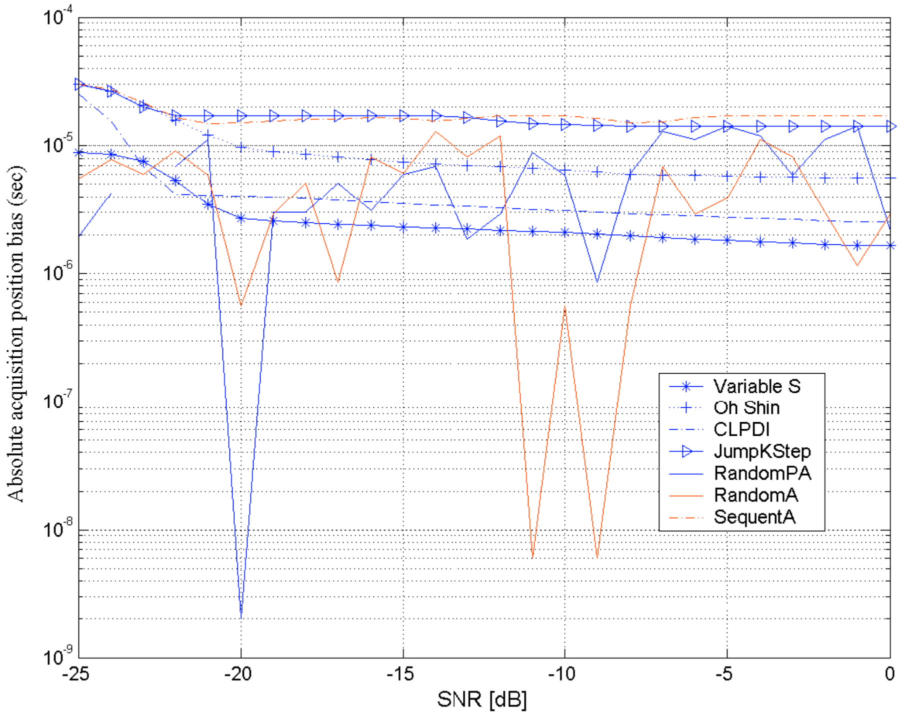

Fig. 6: The acquisition precision comparison of VSA and several classic schemes

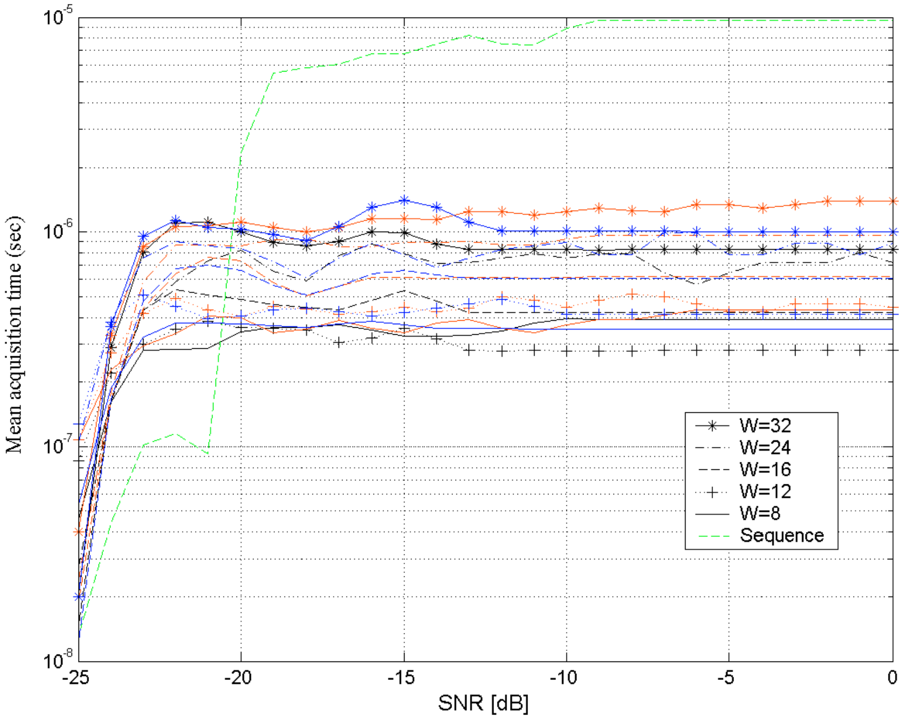

Fig. 7: MAT comparison for VSA under different threshold with different steps

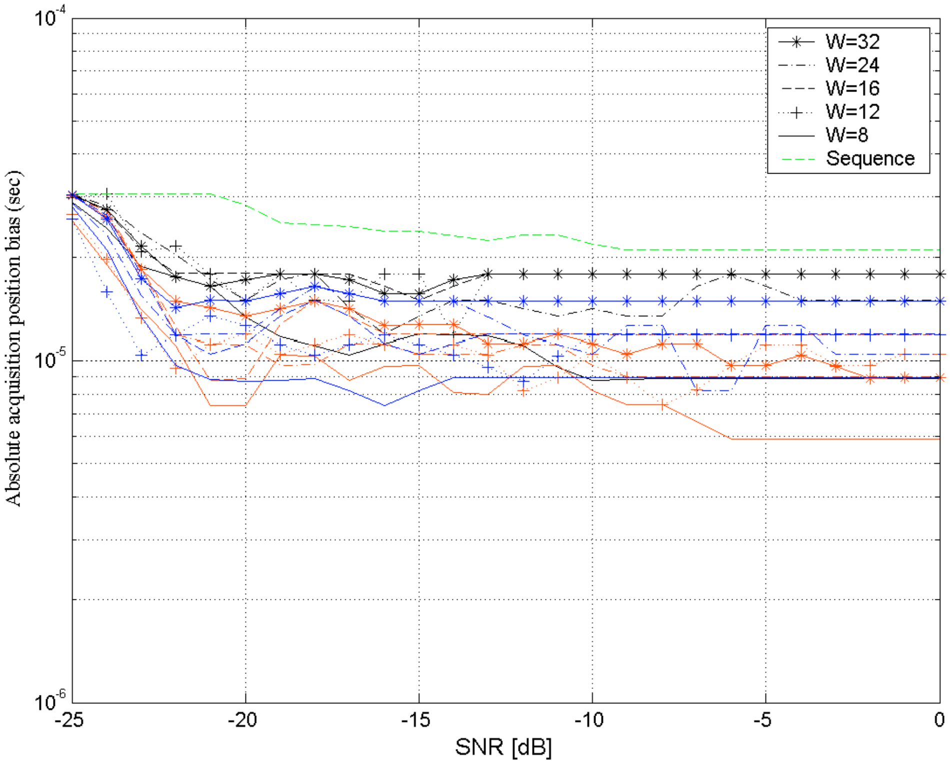

Fig. 8: Acquisition Bias comparison for VSA under different threshold with different steps

red curves, blue curves and black curves are gained under high, medium and low threshold, respectively.

Overall, acquisition is quicker to achieve under low threshold than in high threshold. To a specific threshold, different searching steps W = 32, 24, 16, 12, 8 are compared, as shown in Fig. 7. MAT performance is not perfect as W is too large or too small, in this paper W = 12 performs better than W = 32 and W = 8. The acquisition bias performance is shown in Fig. 8 with the same configurations for curves in Fig. 7. The accuracy of acquisition is higher when searching step is smaller, because the probability of missing synchronized phase between two steps is smaller. For instance, acquisition performance at W = 8 is better than W = 12 and W = 12 is better than W = 32. Overall, high threshold leads to higher accuracy of acquisition than lower threshold, because the higher correlator output, the closer it lies to ideal synchronized phase.

Although higher threshold helps to gain higher acquisition accuracy, it also brings longer MAT. And the performance of low threshold is to the contrary. Large searching step W results in error detection, while small W results in long acquisition time. Therefore, it is important to choose the acquisition step and threshold properly.

CONCLUSIONS

In this study, a new acquisition scheme, i.e., Variable Step Acquisition that effectively utilizes multipaths is proposed in IEEE NLOS channel. This scheme utilizes nonconsecutive and multi-step strategy. The performance of MAT for novel scheme is analyzed in UWB NLOS channel. Simulations for MAT performance and acquisition precision are setup and explained. As the results reveal, compared with classic acquisition schemes, VSA is quicker to achieve synchronization by using nonconsecutive searching and better at acquisition precision because of variable step choice. Simulation results about the comparison of thresholds and steps reveal that the choice of threshold and step length is important to both MAT and accuracy.

Further investigation is required for choosing proper threshold and step length to improve the MAT and accuracy performance. And the analysis of probability of a miss is also desired.

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