Method of Non-Data-Aided Carrier Recovery with Modulation Identification and its An Application as Adaptive Modulation Scheme

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ABSTRACT

This paper shows a novel approach to the "Adaptive Modulation Scheme (AMS)" by using Multimode Phase Locked Loop (PLL), which can recover the carrier with the modulation identification without any supplementary information. The conventional AMS always uses the supplementary information to aid the modulation identification. The supplementary information is a redundancy part, therefore, to decrease such part, this paper proposes the application of multimode PLL in AMS. On the other hand, multimode PLL has drawbacks in the modulation identification, which are "initial phase offset" and "the positions of the transmitted signals bias in I-Q plane". This paper proposes two methods Sub-Phase lock Detectors (S-PLDs) and improved Status Transition Model (STM) to solve the problems. The proposed methods are evaluated by computer simulations and the efficiency of the proposed methods are shown.

1. INTRODUCTION

One of the important characteristics of the Software Defined Radio (SDR) is that SDR is a multimode Radio. Because, SDR can reconfigure the modules by changing the software, SDR can adapt the environments and user's needs dynamically and widely. To catch up with the channel environment, adaptive modulation scheme that is one of the key applications of SDR has been studied. On the other hand, in the SDR research area, the modulation identification techniques have been studied to realize the multi demodulation receiver without the supplementary information. However, researches relating to the modulation identification only mentioned the applications without concrete evaluations in the applications. This is a significant problem of the modulation identification techniques in SDR. Recent researches have focused on the accuracy of modulation identification. Nevertheless, the evaluations cannot prove directly that the modulation identification is effective for the applications noted by above researches.

The multimode PLL has been proposed to identify the modulation scheme and recover the carrier offset which deteriorates the modulation identification ability [1], [2]. A noteworthy characteristic of multimode PLL is that there is no supplemental information to identify the modulation schemes. The previous researches of the multimode PLL mainly focus on the basic characteristics analysis, e.g. lock probability, acquisition time, and the modulation identification success rate [1]. The main contribution of this paper is the evaluation of the multimode PLL in AMS. Using the multimode PLL in AMS, this paper establishes the drawbacks "Initial Phase Offset" and "Positions of the Transmitted Signals Bias in I-Q plane" which causes the modulation identification errors in multimode PLL. At first, the model of the modulation identification errors is shown. By considering the model of the modulation identification errors, this paper proposes "Sub-PLD" and "new STM". Sub-PLD prevents the modulation identification error due to both the initial phase offset and the positions of the transmitted signals bias in I-Q plane, and STM prevents the positions of the transmitted signals bias in I-Q plane.

To evaluate the multimode PLL in AMS, there are two parameters which are "modulation identification success rates" and "non-lock rates" which is equivalent to the training period of the modulation identification with supplementary information in the conventional AMS.

The rest of this paper is organized as follows. In section 2, the system block diagram of basic multimode PLL is described. Section 3 shows the model of the modulation identification error, and in section 4, the proposed methods SUB-PLD and STM are proposed and explained. The conclusions are drawn in section 5.

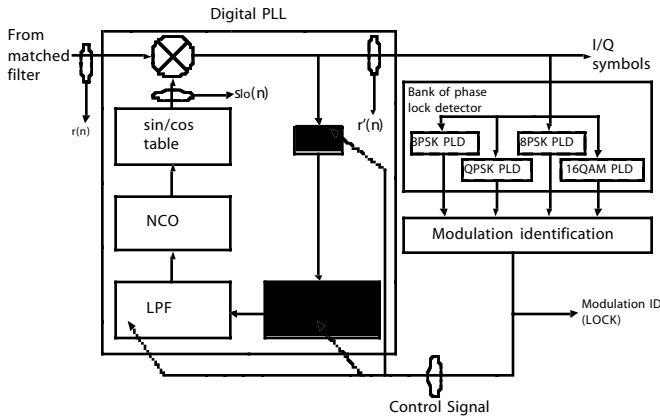## 2. SYSTEM BLOCK DIAGRAM OF MULTIMODE PLL AND ASSUMPTIONS

Fig.1 Multimode PLL

A simplified block diagram of the proposed multi-mode PLL is shown in Fig.1, where the two main functions, modulation identification and carrier recovery are illustrated. *SW* denotes a switch that opens or blocks the carrier recovery loop. Here, NCO is a Numerically Controlled Oscillator that outputs the signal $s_l(n)$ used to cancel the frequency offset. The received complex baseband signal $r(n)$ is shown as follows,

$$r(n) = \exp[-j(\phi + 2\pi\Delta f T_s)]s(n) + g(n) \tag{1}$$

where ψ, Δf and $h(t)$ are the phase offset, the frequency offset and channel impulse response, respectively. ψ is the initial phase offset which is a phase difference between the received signal and the correct constellation position. Here, $s(n)$ is the n-th symbol baseband data, T_s is the symbol interval, and g(t) is Additive White Gaussian Noise (AWGN). We assume the channel's amplitude to 1. From equation (1) the received points $r(n)$ rotate at an angular speed of radians every T_s seconds with respect to the phase ψ. Furthermore, the PED and Low Pass Filter (LPF) are designed to adapt to the transmitted modulation format. In this system the possible modulation schemes are BPSK, QPSK, 8PSK and 16QAM. Therefore, the modulation identification logic allows the frequency and phase offset. This system operates in two states, (1) initial lock acquisition and (2) tracking. The initial state (1) is the Initial Lock Acquisition state, where the switch *SW* is open and the incoming signal symbols rotate with *normalized frequency offset* $\Delta f T_s$. The carrier lock detection, obtained by using the bank of PLDs, works in a window of size *N* (=50) symbols. The PLDs output is either "1" or "0" meaning "Lock" or "Non-LOCK", respectively. If any PLD outputs "1", the modulation identification logic obtains the modulation identification result using outputs of the PLDs.

Upon successful identification of the modulation type, the state is changed to (2). The PLL parameters, which are PED and LPF, are reconfigured to adapt the modulation format and *SW* is closed so that the PLL can start to work. If every PLD outputs "0", the state does not change, and window the bank of PLDs work for initial acquisition in the next. In state (2), the bank of PLDs and modulation identification logic still play a role in the tracking stage, by monitoring the carrier recovery subsystem through the lock. If lock is lost in state (2), the state is changed back to the initial lock acquisition state (1) and *SW* is open. The configurations of PLDs for each modulation schemes are shown in Fig. 2. there are lock area and non-lock area.
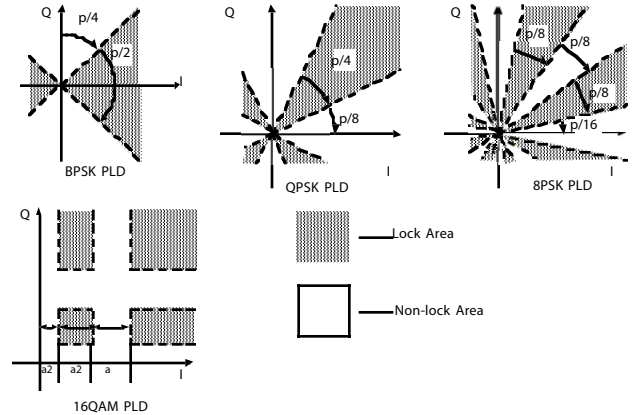

Figure 2. Each Phase Lock Detectors (PLD) configuration

The function of PLDs is to count the symbols which are in lock area of every window, the counted result denoted as N_L. If the number of symbols in lock area N_L is greater than the threshold value N_t, this PLD outputs "1". In addition, the modulation identification result also corresponds to *MOD* where *MOD* represents the modulation type. In the case that multiple PLDs output "1" at the same time, the decision is based on an order of priority which are 16QAM, 8PSK, QPSK and BPSK, respectively. In this paper we denote above described multimode PLL as basic multimode. In following sections, the improved methods for basic multimode PLL are discussed.

3. MODULATION IDENTIFICATION ERROR CHARACTERISTICS

The modulation identification error characteristics of the basic multimode PLL is useful when consider the methods which can solve the modulation identification error problem. The main causes of the identification errors are initial phase offset and the positions of the transmitted signals bias in I-Q plane. In Fig.3 the initial phase offset vs modulation identification error rate *ER* representing the number of errors over number of trials is shown, where

Es/No=30, normalized carrier offset is 0.001, threshold N_T is set to 27 symbols, and the number of trials is 500,000. It is further assumed that the threshold value and window size are fixed in this paper.
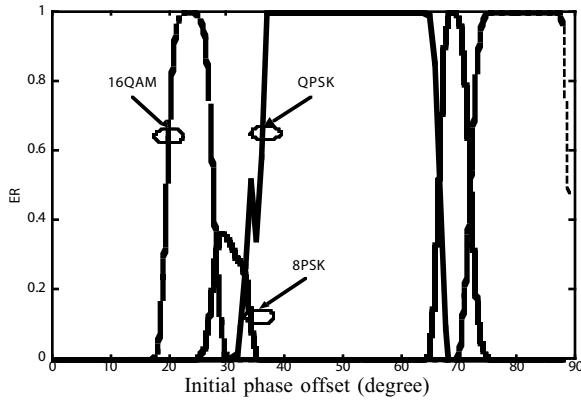

Fig.3 initial phase offset (degree) vs Modulation identification error rate

In Fig.3, BPSK is used in the transmitted signals. Here, the error characteristics from BPSK to other modulation schemes are shown. *ER* depends on the initial phase offset, as it is in other modulation schemes. By using *ER* characteristics, the error model which is shown as follow can be obtained. There are four types of error model denoted as $ER - MODEL_i$ where *i= 1, 2, 3, 4*.

- $ER - MODEL_1$: Error model at switching from 16QAM to M-PSK

  The case where there is modulation identification error from 16QAM to any PSK modulation scheme.

- $ER - MODEL_2$: Error at switching from a lower M-ary modulation schemes to a higher M-ary modulation scheme

  The cause of this error is initial phase offset. For example, if the correct modulation scheme is BPSK, and the initial phase offset is about , the modulation wrongly identified is QPSK, according to the PLD constitutions which are shown in Fig. 2.

- $ER - MODEL_3$: Identification error model for switching from a higher M-ary modulation scheme to a lower M-ary modulation scheme\

  The correct modulation scheme's number of the M-ary is higher than the identified modulation scheme's number of M-ary. The cause of error is the positions of the transmitted signals bias.

- $ER - MODEL_4$: Identification error model at switching from M-PSK to 16QAM

4. SUB-PLD AND STM

Based on described error model, this section shows two methods Sub-PLD and STM. At first, Sub-PLD which recognizes the fine characteristic among the modulation schemes to identify the correct modulation scheme is explained. Here, one of the examples Sub-PLD which prevents the error from BPSK to QPSK corresponding to $ER - MODEL_2$ is shown in Fig.4. In this Sub-PLD, there are two lock areas and two counters $N_{C,SUB}^i$. In basic PLD, the "Lock" can be obtained by observing N_C. On the other hand, by using Sub-PLD, new lock rule in QPSK is changed to $N_C > N_T$ and $N_{C,SUB}^i > N_{T,SUB}$ (*i=1,2*).
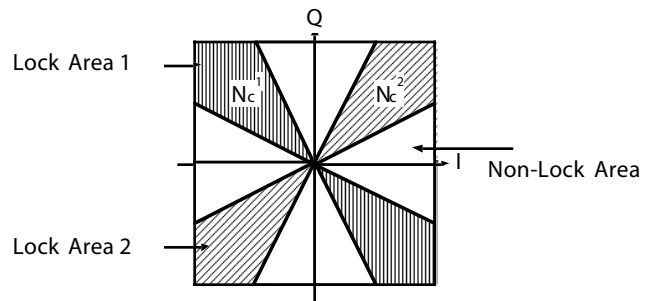

Fig.4 Sub-PLD of QPSK for $ER - MODEL_2$

By using not only the above Sub-PLD but also other Sub-PLDs, if there is initial phase offset, the error form BPSK to QPSK is prevented. Actually, in the same conditions in Fig. 3, *ER* of BPSK is 0. In other modulation schemes, *ER* characteristics are bounded less than *0.01*.

Another reason of the modulation identification error is positions of the transmitted signals bias due to the reason that the length of window is not long enough. To obtain the better performance of identification, window size has to be longer. The size of window is deeply linked to both the accuracy of the identification and robust for the carrier offset. If the window size is longer, the sustainable maximum carrier offset has to be smaller. This tradeoff is a significant problem in multimode PLL. The new STM, where the tentative lock state is, is proposed to solve this problem.

#1 MOD ID (i) = 0
(i=0,1, ...)

Initial Lock Acquisition

#2 MOD ID (i)=MOD

#3 MOD ID (i+1) = MOD ID(

Tentative Lock

Tracking

#3 MOD ID (i+1) = MOD ID(i)

#4 MOD ID (i+k+1) = MOD(i+k)

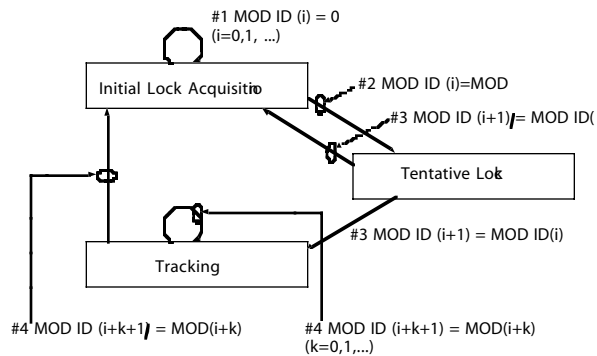#4 MOD ID (i+k+1) = MOD(i+k)
(k=0,1,...)

Fig.5 New STM diagram

The detail performance and configuration of STM is shown in Fig.5. The effect of tentative lock can compare with increasing the observation period while keeping sustainable maximum carrier offset. To confirm this effect, in next section the numerical results are shown.

5. NUMERICAL RESULTS

The channel condition is shown in Fig.6, where the SNR is changed linearly with time. Here, SNR is corresponding to Es/No. The proposed multimode PLL is evaluated in the adaptive modulation scheme where the modulation type is changed to adapt Es/No. The modulation-switching rule is shown in Table.1.
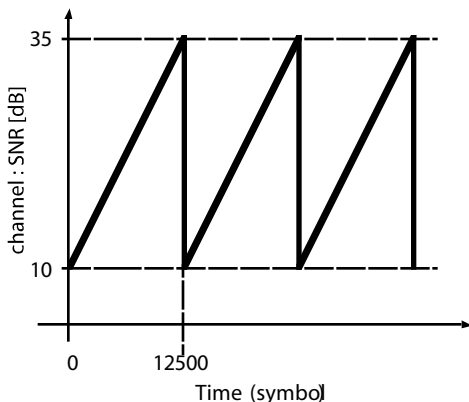

Fig.6 Time vs channel variance

Table .1			
MOD changing	BPSK ⇄ QPSK	QPSK ⇄ 8PSK	8PSK ⇄ 16QAM
Threshold Es/No	15dB	20dB	31dB

Under this conditions, two parameters which are "Modulation identification error rate" *ER* and "Non lock rate"　　are evaluated. The Non-lock rate can be obtained by the number of cases that all PLD outputs "Non-lock" during a window over the number of all trials. On the other hand, *ER* can be obtained by the number of the

identification errors over the number of case that any PLD outputs 1 during a window. Therefore, in *ER* characteristics shown in Fig.7, the case that all PLDs outputs "Non-Lock" is excluded. In this figure, two cases, with and without new STM are compared. The effectiveness of the new STM can be confirmed. In the region where carrier offset is less than 0.0003, the *ER* characteristic is deteriorated due to the slow rotation.

In Fig.8, the Non-lock rate T_{NonL} characteristics of the above two cases are evaluated. As ER characteristic, the case with new STM has better performance than the case without the new STM in the region where carrier offset is less than the sustainable maximum frequency offset *0.001* [1].
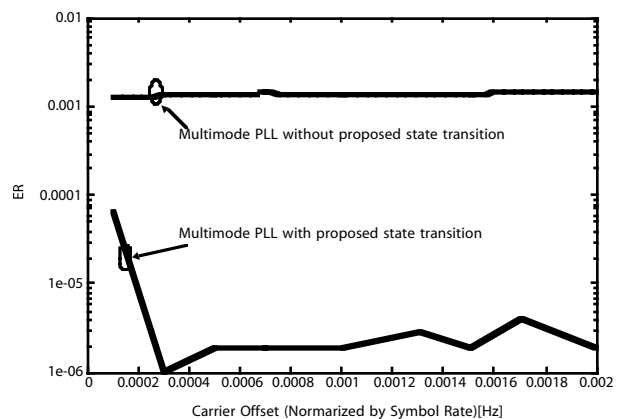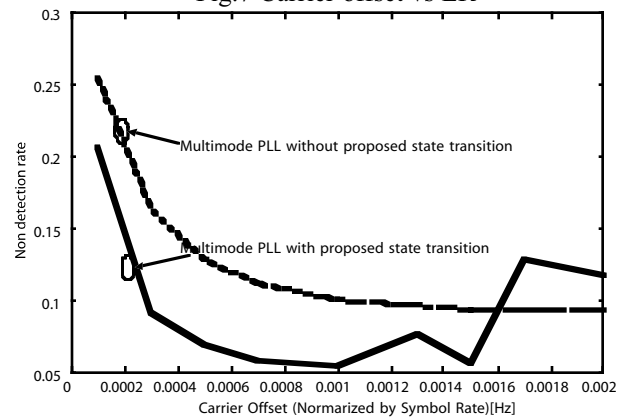

Fig.7 Carrier offset vs ER

Fig. 8 Carrier offset vs Non-lock rate

6. CONCLUSION AND FUTURE WORKS

This paper shows the multimode PLL which can not only recover the carrier but also identify the modulation schemes without aided data. Considering the adaptive modulation scheme, there are drawbacks of the multimode PLL, this paper shows the modulation identification error model which corresponds to the drawbacks. To prevent the identification error, two methods Sub-PLD and STM are proposed and evaluated with computer simulations in the

adaptive modulation schemes. As the conclusion, these methods can improve the performance of multimode PLL in the adaptive modulation scheme.

7. REFERENCES

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