A Novel Algorithm for Blind Adaptive Recognition between 8-PSK and π/4-Shifted QPSK Modulated Signals for Software Defined Radio Applications

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***Abstract*- In This paper, we propose a new method to recognizing and distinguishing among 8-PSK modulated signal and π/4-shifted QPSK, from the samples of received noisy and faded PSK signal. The proposed algorithm is based on computation of relative Euclidean distance and relative phase difference among the received symbols in a frame. Prior to recognition, the Constant Modulus (CM) equalization is performed. Based on simulation results, this method can perform recognition task with high accuracy even at low Signal to Noise Ratio (SNR) values and employing fairly small number of data samples. To the best of our knowledge in comparison with other methods of distinguishing among QPSK variants, this algorithm do well specially in practical systems which have a limited time to make the decision and use small number of samples of receiving signal.**

Keywords- Automatic Blind Modulation Recognition (ABMR); Mean Square Error (MSE); Constant Modulus Algorithm (CMA); Tapped Delay Line filter (TDL); software defined radio (SDR); relative Euclidean distance; relative phase difference

I. INTRODUCTION

Automatic modulation recognition (AMR) has become more important with the rising development in software defined radio (SDR) systems. In SDR systems we could apply automatic recognizer before the demodulation block resulting a robustly handle of multiple modulations in a single SDR system. Thus, modulation recognition is an important issue for such systems. QPSK, OQPSK and π/4-Shifted QPSK are the recommended modulation types for a large number of mobile and wireless communication standards (such as IS-54, IS-95, 802.11 and etc). To recover the message truly, a practical SDR system would require to automatically distinguishing among such variants of QPSK [1].

Modulation type classifiers play an important role in some communication applications such as signal confirmation, interference identification, Surveillance, electronic warfare and electronic counter-counter measure. Many techniques have been reported in literature for AMR. In a report by Weaver, Cole, and Krumland [2], early works on analog modulation recognition can be found. In the area of recognition of digitally modulated signal, the paper by Liedtke [3] is a well-known early work. He presented results based on a statistical analysis of various signal parameters to discriminate between amplitude shift keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK) signals. Various techniques such as Artificial Neural Network (ANN) [4], constellation shape [5], Statistical moment matrix method [6], maximum likelihood [7], and their combinations have been used for AMR. In addition, a few numbers of these methods are threshold-based techniques to estimate modulation schemes [3, 4]. For such schemes, the threshold level becomes SNR dependant so threshold setting is difficult under variable SNR scenario. A method based on Mean Square Error (MSE) decision rule to recognize different M-PSK signals have been developed in [8]. In this method the authors compute MSE between the prototype message points stored in the receiver library and the received signal points. Classification is made by computing the differences in MSE of different PSK signals against specified threshold values.

In [1], same authors proposed a method for distinguishing among different types of QPSK variants such as QPSK, OQPSK and π/4-Shifted QPSK signals among Additive White Gaussian Noise (AWGN) and multi-path fading channel. In this paper, we propose a novel algorithm to distinguish between 8-PSK and π/4-Shifted QPSK signals efficiently in AWGN and multi-path fading channels.

According to the high performance of π/4-Shifted QPSK modulation, large numbers of practical systems such as satellite communication systems, different kinds of wireless systems like IEEE 802.11, WiMax systems and GSM mobile communication systems have been employed this type of modulation. There are two principles for great performance of π/4-Shifted QPSK signal:

1) Asynchronous detection ability

2) Less amplitude variety than QPSK signal because of less phase fluctuations.

On the other hand, because of low energy level and good performance, many wireless and other communication systems may use the 8-PSK modulation for transmission the data. As we know the constellation shape of these two modulations are quite similar. So there is an important problem to distinguish π/4-Shifted QPSK signal from 8-PSK signal.

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The rest of the paper is organized as follows; In section II the effect of channel on constellation points of the received signals has been investigated. In section III we briefly describe the method developed in [1] for blind recognition of different M-PSK signals. The proposed method for recognition of 8-PSK and π/4-Shifted QPSK variants with simulation results are presented in detail in section IV. Conclusions are stated in section V.

II. CONSTELLATION POINTS PASSED FROM AWGN AND FADING CHANNELS

The received band-pass signal in the k-th signaling interval in the AWGN channel may be written as

$$r(t,k) = s_m(t,k) + n(t,k)$$
$$kT_s \le t \le (k+1)T_s \quad (1)$$

Where T_s is symbol duration, $s_m(t)$ is the message waveform corresponding to the M-PSK symbol s_m, m = 1, 2, 3...M. Assuming perfect carrier synchronization and timing recovery and employing I-Q demodulation we get

$$r(k) = [r_I(k), r_Q(k)]$$
$$= [s_{mI} + n_I(k), s_{mQ} + n_Q(k)] \quad (2)$$

Thus in the signal space the received signal points wander around signal points in a completely random fashion, in the sense it may lie anywhere inside a Gaussian distributed noise cloud centered on the message point. The effect of AWGN on signal points for MPSK signals at the receiver is shown in Fig. 1(b). For wireless communication scenarios, in addition to AWGN, there will be the effect of multi-path fading. Multi-path fading channel can be modeled by a Tapped Delay Line (TDL) [1]: the test signal is convolved with the impulse response of the TDL to account for the effect of fading induced by the channel. The TDL parameters are chosen corresponding to power delay profile of physical channels. We have considered a frequency selective channel in performing simulations. Fig. 1(c) and Fig. 1(d) respectively show the faded received signal constellation and equalized signal constellation after CM equalization.

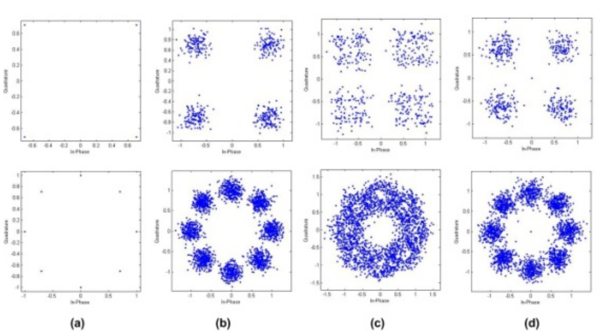

Figure 1. Effect of Noise and Fading on QPSK and 8-PSK constellation at SNR=10 dB, (A) Prototype signal points, (b) Received noisy signal constellation, (c) Received noisy and faded signal constellation (d) Equalized constellation.

III. METHOD FOR AUTOMATIC BLIND MODULATION RECOGNITION

In this section, we briefly discuss the Automatic Blind Modulation Recognition (ABMR) algorithm developed in [1, 8], for estimating modulation schemes based on MSE criterion. This discussion will be helpful in understanding the proposed algorithm for distinguishing QPSK variants.

A sequence of N received signal samples $\{r(k)\}$, k = 1, 2...N, are collected at demodulator output. Using this sequence, we check how closely the received signal samples "match" with each of the prototype constellations available at the receiver library. The degree of "closeness" or "match" is measured in terms of a Mean Square Error power defined as

$$MSE(M) = \frac{1}{N}\sum_{k=1}^{N} D_{k,M}^2, M = 2^q, q = 1,2,... \quad (3)$$

Where

$$D_{k,M} = \min_m\{|r(k) - s_m|\}, m = 1,2,...$$
$$= \min_m\{|d_{k,m}|\} \quad (4)$$

The computation of $D_{k,M}$ can be simplified by confining the search to that quadrant in which lies. For example, as shown in Fig. 2, as $r(k)$ lies in first quadrant (Q_1), we need to compute only the distances $d_{k,1}, d_{k,2}$ and $d_{k,3}$ to find $D_{k,8}$.

Recognition scheme make the following observations:

Lower-order PSK constellations are sub-sets of the higher-order PSK schemes; therefore, when lower-order PSK symbols are transmitted, the received signal sequence $\{r(k)\}$ will find a "match" not only with the corresponding prototype constellation, it will also "match" with the higher-order constellation (with more or less the same degree of accuracy).

If the transmitted signal is BPSK; the received signal points will be scattered around the symbols s_2 and s_6 shown in Fig. 2.

(a) Majority of the points will be confined in the first and the third quadrants (Q_1 and Q_3) especially at high SNR. The contribution of these points towards MSE power will be the same in both BPSK and QPSK, i.e.

$$MSE(2) = MSE(4),$$
$$\forall r(k) \in Q_1 \cup Q_3$$

However, this same set of points will result in a slightly lower MSE when matched to 8-PSK as some of these points will have closer match to 8-PSK symbols s_1 or s_3 and s_5 or s_7 shown in Fig 2. Thus,

$$MSE(8) < MSE(2), MSE(4),$$
$$\forall r(k) \in Q_1 \cup Q_3$$

(b) For a small fraction of the received points which lie in Q_2 and Q_4, their "match" with the BPSK prototype will be proper (the nearest symbols being s_2 and s_6) as compared to

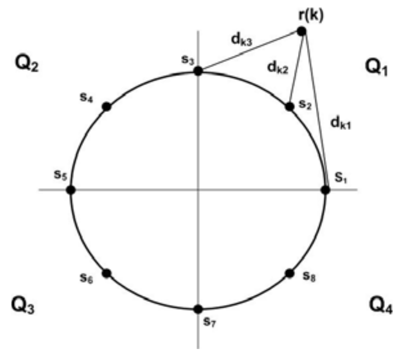

Figure 2. Euclidean distance vector calculation for M-PSK signals.

QPSK prototype (nearest symbols s_4 and s_8) and 8-PSK (nearest symbols s_3, s_4, s_5 and s_7, s_8, s_1). Thus,

$$MSE(8) < MSE(4) < MSE(2),$$
$$\forall r(k) \in Q_2 \cup Q_4$$

Conclusions:

- when BPSK is transmitted, at any SNR, we shall find MSE(8) < MSE(4) < MSE(2)
- At high SNR, the differences in MSE are negligibly small; only at low SNR, the differences are distinguishable

If QPSK is transmitted; Now $\{r(k)\}$s are scattered around the four symbols s_2, s_4, s_6, s_8. It follows that $\{r(k)\}$ will match well with QPSK and 8-PSK prototypes while there will be large mismatch with BPSK prototype. Thus,

MSE(2) > MSE(4), MSE(8) at all SNR

MSE(8) ≈ MSE(4) at high SNR

MSE(8) < MSE(4) at low SNR

If 8-PSK is transmitted, following similar reasoning we conclude:

MSE(2) > MSE(4) > MSE(8) at all SNR.

Now we review the presented approach in [1] to identify QPSK signal variants, such as QPSK, OQPSK and π/4-Shifted QPSK. OQPSK signaling is similar to QPSK signaling, except the time alignment of the odd and even bit stream by half-symbol period. This implies that the maximum phase shift of the transmitted signal at any given time instant is limited to ±90 degrees. The constellation diagram of QPSK and OQPSK is shown in Fig. 3(a) and Fig. 3(b) respectively. It is observed that, for QPSK signal there is a bidirectional phase transition from signal point s_1 to s_3 or s_2 to s_4 and vice versa. Hence the relative Euclidian distance denoted by D^r between the adjacent received signal symbols in a frame for QPSK is greater than OQPSK signal.

Therefore the signal which has greater D^r will be boosted and the signal which has smaller D^r will be minimized, with higher order even power moment. The moment M^r of received signal symbols in a frame is represented as

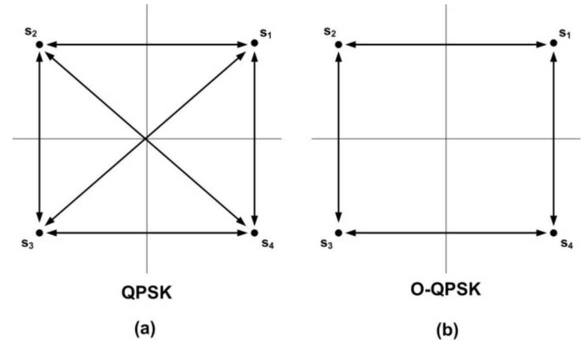

Figure 3. Constellation diagrams of a QPSK and OQPSK signals.

$$M^r = \frac{1}{N}\sum_{k=1}^{N} |D^r(k)|^4 \tag{5}$$

Where $D^r(k)$ is relative Euclidean distance between received symbols in a frame length of N symbols represented as,

$$D^r = r(i) - r(j)$$
$$1 < k < N, \quad 1 < i < N-1 \quad and \quad j = i+1$$

In a π/4-Shifted QPSK modulator, constellation is formed by superimposing two QPSK signal constellations offset by π/4 relative to each other, resulting in eight signal phases. During each symbol period a phase angle from only one of two QPSK constellations is transmitted. This results in maximum phase transient of 1350. The above mentioned constellation based ABMR algorithm does not classify π/4-Shifted QPSK and 8-PSK signals, because both schemes have eight constellation points.

An approach which developed to classify π/4-Shifted QPSK and 8-PSK signal depends on relative phase of received symbols in a frame [1]. Fig. 4(a) and Fig. 4(b) depict the relative phase distribution of 8-PSK and π/4-Shifted QPSK signal respectively.

The relative phase difference denoted by P_r between each received symbol in a frame is represented as

$$P_i^r = \left|\tan^{-1}\left(\frac{V_Q(i)}{V_I(i)}\right)\right|, \; 1 < i < N-1$$
$$V(k) = |r(i) - r(j)|, \; 1 < k < N, \; j = i+1 \tag{6}$$

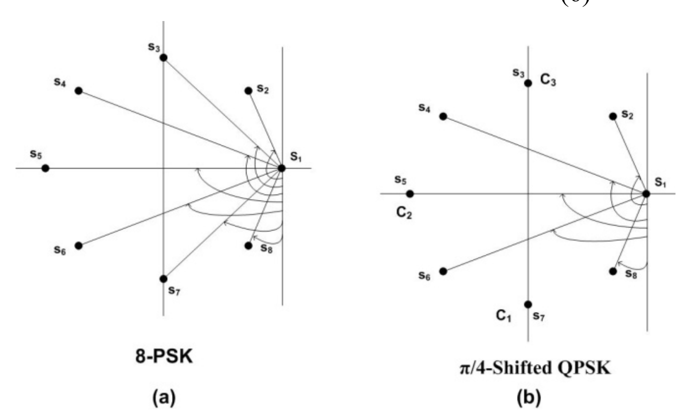

Figure 4. Relative phase distribution of a 8-PSK and π/4-Shifted QPSK signals.

The relative phase distribution of 8-PSK is $0, \frac{\pi}{8}, \frac{2\pi}{8}, \frac{3\pi}{8}, \frac{4\pi}{8}, \frac{5\pi}{8}, \frac{6\pi}{8}$ and $\frac{7\pi}{8}$. The relative phase distribution of π/4-Shifted QPSK is 0 , $\frac{\pi}{8}, \frac{3\pi}{8}, \frac{5\pi}{8}$ and $\frac{7\pi}{8}$.It is observed that, without any noise and fading, for π/4-Shifted QPSK signal there is no relative phase distribution of $\frac{2\pi}{8}, \frac{4\pi}{8}$ and $\frac{6\pi}{8}$. Hence, to identify the modulation type authors have placed three counters C1, C2 and C3 at $\frac{2\pi}{8}, \frac{4\pi}{8}$ and $\frac{6\pi}{8}$ phase locations respectively. The basic function of counters is to count the number of received symbols falling with these phase angle over a frame. Without any noise, these three counter values are zero for π/4-Shifted QPSK signal and there is some value in each counter for 8-PSK signal. By computing the average value of three counters, the modulation type can be identified.

If $\left(\frac{C1+C2+C3}{3}\right)_{8-PSK} > \left(\frac{C1+C2+C3}{3}\right)_{\frac{\pi}{4}-ShiftedQPSK}$, declare the modulation type as 8-PSK, else the modulation type declared as π/4-Shifted QPSK. It should be mentioned here that since π/4-Shifted QPSK signal has 8 constellation points, the MSE criterion based tests will classify it as 8-PSK signal. The procedure described above can distinguish π/4-Shifted QPSK from 8-PSK based on the relative phase difference.

IV. NEW ALGORITHM FOR RECOGNITION BETWEEN 8-PSK AND Π/4-SHIFTED QPSK WITH SIMULATUIN RESULTS

In this section we propose our new method for efficiently distinguishing 8-PSK signal from π/4-Shifted QPSK signal. For clear compare with previous paper results, we first simulate the algorithm proposed in [1]. To distinguishing between 8-PSK and π-Shifted QPSK signals, we considered 2000 symbols per frame of received signal. Fig. 5 and Fig. 6 show the relative phase difference distribution in an AWGN and multi-path fading channel respectively. We could set a threshold on the average of occurrence of two signals. It is seen that the two curves are not well separated specially at SNR lower than 15dB.

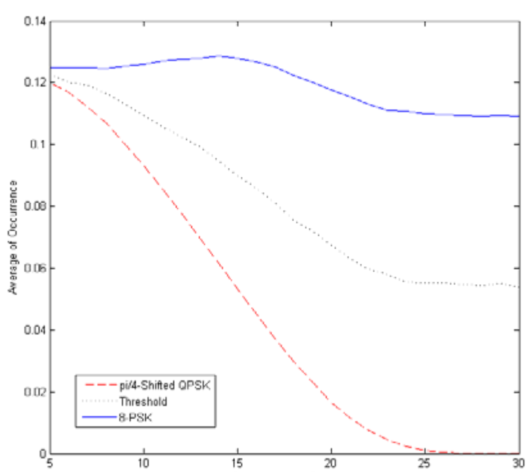

Figure 5. Average of occurrence of 8-PSK and π/4-Shifted QPSK signal vs. SNR in an AWGN channel. (Recognition method used in [1])

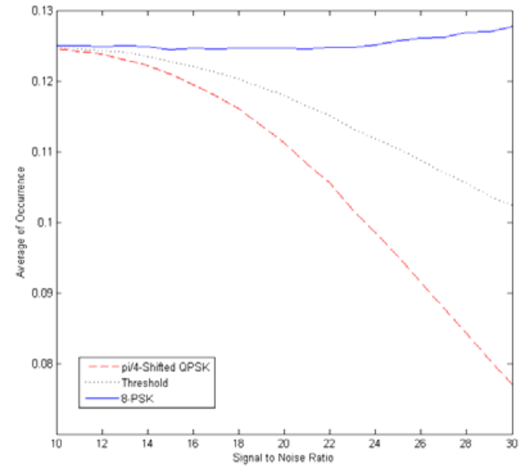

Figure 6. Average of occurrence of 8-PSK and π/4-Shifted QPSK signal vs. SNR in Multi-path fading channel.

For better detection of π/4-Shifted QPSK signal from 8-PSK signal it is necessary to mark both amplitude and phase varieties of neighboring symbols of received signal. In prior methods (among [1]), the emphasis is only on phase difference of neighboring symbols. For the sake of clarity of new method, we should attend on phase changing diagram of 8-PSK and π/4-Shifted QPSK signals as in Fig. 7.

With defining the difference of two neighboring symbols signal as $V(i) = r(i) - r(i+1)$, we can depict each sample of the signal $V(i)$, as a vector in signal space. After depicting all vectors in signal space, we find that the difference vector illustration of π/4-Shifted QPSK signal is a sub-set of the difference vector illustration of 8-PSK signal (see Fig.8).

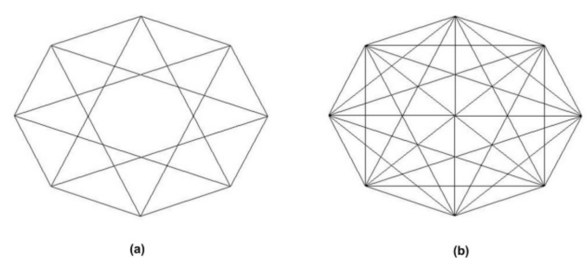

Figure 7. Phase changing diagram of (a) π/4-Shifted QPSK, (b) 8-PSK

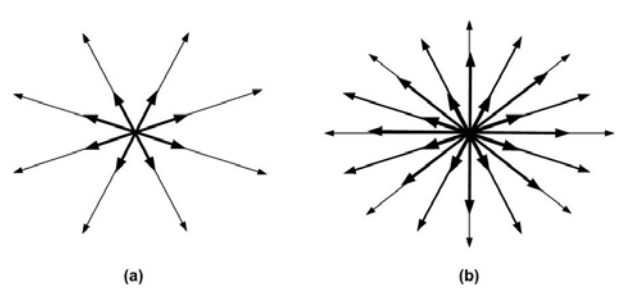

Figure 8. Phase difference vectors of neighboring symbols for (a) π/4-Shifted QPSK and (b) 8-PSK signals

So we set π/4-Shifted QPSK points in signal space as constants in receiver's library and calculate the minimum Euclidean distance between each received symbols from these fixed points. Then we save the mean of these distances in an accumulator for each signal. Finally we compare the value of accumulators and make the decision; the one which has minimum value is π/4-Shifted QPSK signal and the other is 8-PSK signal.

With this method, detection ability is well improved. Fig. 9 and Fig. 10 show the simulation results of this method in AWGN and multi-path fading channels respectively. To set a constant threshold we have run extensive simulations in various conditions of SNR and various number of received signal samples. It is seen that the two curves are well separated in both channels except in very low SNRs in multi-path fading channel. Also, we must note that these results are achieved in small numbers of received signal samples which is relatively the same as the circumstances in real operations, where we have limited numbers of signal samples and little time to make correct detection.

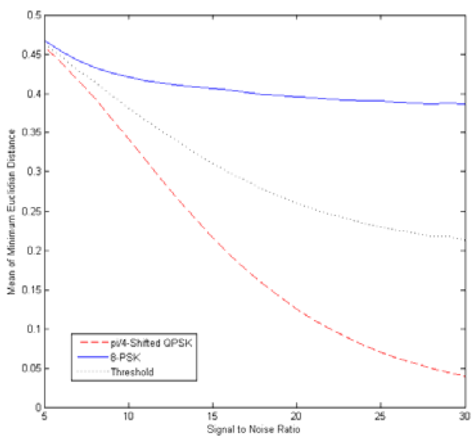

Figure 9. Mean of minimum Euclidean distance of 8-PSk and π/4-Shifted QPSK signal vs. SNR in AWGN channel.

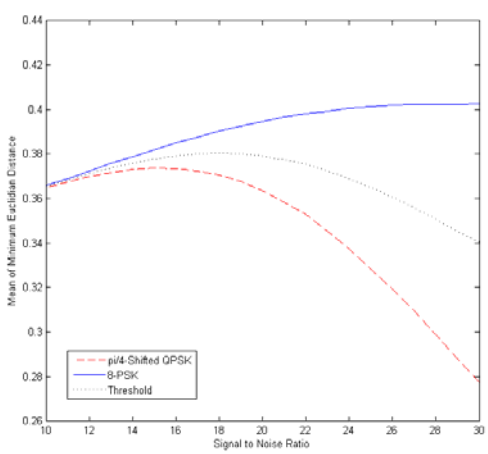

Figure 10. Mean of minimum Euclidean distance of 8-PSk and π/4-Shifted QPSK signal vs. SNR in multi-path fading channel.

We have an extended comparison of recognition accuracy of our new method to distinguishing π/4-Shifted QPSK signal from 8-PSK signal, against the older method [1, 8]. The results have been shown in table 1 and table 2 for AWGN and multi-path fading channels respectively.

From tables 1 and 2 it is observed that in old method, recognition accuracy depends on number of samples while in our new method the recognition accuracy approximately become independent from number of samples. Also it is observed that in new method, in the AWGN channel and in SNR above 7dB, the recognition accuracy become independent of SNR. This rate is SNR above 15dB for multi-path fading channel. Therefore when knowledge about the SNR is available, an adaptive scheme can be designed to change the samples to attain higher accuracy.

TABLE I. RECOGNITION ACCURACY IN AWGN CHANNEL

SNR (dB)	No. of Samples	% Recognition Accuracy		Modulation Type
		Old	***New***	
7 dB	200	67.25	77	8-PSK
		73.87	77.25	π/4-Shifted QPSK
	500	78.5	88.87	8-PSK
		81.62	89.12	π/4-Shifted QPSK
	1000	86.25	93.62	8-PSK
		90.12	94.5	π/4-Shifted QPSK
10dB	200	91.75	99.87	8-PSK
		94	100	π/4-Shifted QPSK
	500	99	100	8-PSK
		99.37	100	π/4-Shifted QPSK
	1000	99.87	100	8-PSK
		100	100	π/4-Shifted QPSK
12 dB	200	99.12	100	8-PSK
		99.5	100	π/4-Shifted QPSK
	500	100	100	8-PSK
		100	100	π/4-Shifted QPSK
	1000	100	100	8-PSK
		100	100	π/4-Shifted QPSK

TABLE II. RECOGNITION ACCURACY IN MULTI-PATH FADING CHANNEL

SNR (dB)	No. of Samples	% Recognition Accuracy		Modulation Type
		Old	***New***	
10 dB	500	51.87	68.75	8-PSK
		54.87	41.75	π/4-Shifted QPSK
	1000	46.5	64.12	8-PSK
		61.62	54.12	π/4-Shifted QPSK
	2000	47.25	57.5	8-PSK
		62.75	62.87	π/4-Shifted QPSK
15 dB	500	66	71.5	8-PSK
		61.25	76.25	π/4-Shifted QPSK
	1000	69	78.37	8-PSK
		65.75	85.62	π/4-Shifted QPSK
	2000	78.37	89.37	8-PSK
		75.62	92.5	π/4-Shifted QPSK
20 dB	500	84.5	97.5	8-PSK
		81.25	97.75	π/4-Shifted QPSK
	1000	93.62	99.75	8-PSK
		91.75	99.87	π/4-Shifted QPSK
	2000	98.37	100	8-PSK
		97.75	100	π/4-Shifted QPSK

V. CONCLUSION

In this paper we have presented a novel approach to automatic recognizing and distinguishing π/4-Shifted QPSK signal from 8-PSK signal. We also reviewed automatic blind recognition of different QPSK signals. Ability of blindly distinguishing among the QPSK variants will have useful application in SDR. The performance of the proposed scheme has been tested in AWGN and fading channels. Simulation results show that the proposed scheme gives very good recognition performance at low SNR values in AWGN as well as fading channel. The proposed scheme has been found to be attractive both in terms of computational complexity and accuracy of recognition. Also it has been obtained through simulation results that at a fair SNR, this method could act independently from SNR and number of samples so the SDR system could set a constant threshold for recognition.

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