AN AUTOMATIC BLIND MODULATION RECOGNITION ALGORITHM FOR M-PSK SIGNALS BASED ON MSE CRITERION

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Keywords: Automatic Blind Modulation Recognition (ABMR), Mean Square Error power (MSE), Mean Square Error Difference (MSED), Threshold On Moment (TOM), Constant Modulus Algorithm (CMA), Tapped Delay Line filter (TDL).

Abstract: This paper addresses Automatic Blind Modulation Recognition (ABMR)problem, utilizing a Mean Square Error (MSE) decision rule to recognize and differentiate M-ary PSK modulated signals in presence of noise and fading. The performance of the modulation recognition scheme has been evaluated by simulating different types of PSK signals. By putting appropriate Mean Square Error Difference Threshold (MSEDT) on Mean Square Error (MSE), the proposed scheme has been found to recognize the different modulated signals with 100% recognition accuracy at Signal to Noise Ratio (SNR) as low as 1 dB in AWGN channels. The data samples required to be used for performing recognition is very small, thereby greatly reducing the time complexity of the recognizer. For fading signal Constant Modulus (CM) equalization has been applied prior to performing recognition. It has been observed that when CM equalization is used, 100 % recognition can be achieved at SNR as low as 6 dB.

1 INTRODUCTION

Automatic blind modulation recognition has its roots in military communication intelligence applications. In literature, most recognition method proposed initially were designed for recognizing analog modulations. The recent contributions in this area deal with recognition of digitally modulated signals as now a days digital modulation schemes are employed in almost all form of communication systems. With the rising development in software defined radio (SDR) systems, automatic modulation recognition has gained more attention than ever. Automatic recognizer units can act as front-end to SDR systems before demodulation takes place. Thus a single SDR system can robustly handle multiple modulations, therefore modulation recognition is an important issue for SDR systems. Many techniques have been reported in literature for AMR. Early works on modulation recognition can be found in a report by Weaver, Cole, Krumland and Miller (Weaver et al., 1969) where the authors use frequency domain parameters to distinguish between analog modulation types. In the area of recognition of digitally modulated signal, the paper by Liedtke (Liedtke, 1984) is a well-known early work. The author 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. A variety of techniques such as Artificial Neural Network (ANN) (Wong and Nandi, 2004), (Halmi and Abdalla, 2003), constellation shape (Mobasseri, 2000), Statistical moment matrix method (Azzouz and Nandi, 1996b), maximum likelihood (Wei and Mendel, 1999), (Boiteau and Martret, 1998), zero crossing detection (Hsue and Soliman, 1990), pattern recognition (Weaver et al., 1969), (Halmi and Abdalla, 2003) and their combinations have been used for AMR. Especially, there are few threshold-based techniques (Wong and Nandi, 2004), (Azzouz and Nandi, 1996b), (Soliman and Hsue, 1992) to estimate modulation schemes. For such schemes, the threshold level becomes SNR dependant and hence threshold setting is difficult under variable SNR scenario.

In this paper, we have proposed a method based on MSE decision rule to recognize received M-PSK modulated signals. In this method we compute MSE between the prototype message points stored in the

Vastram Naik M., Mahanta A., Bhattacharjee R. and Nemade H. (2005).
AN AUTOMATIC BLIND MODULATION RECOGNITION ALGORITHM FOR M-PSK SIGNALS BASED ON MSE CRITERION.
In *Proceedings of the Second International Conference on e-Business and Telecommunication Networks*, pages 13-19
DOI: 10.5220/0001419400130019

receiver library and the received signal points. Classification is made by computing the differences in MSE of different PSK signals against specified threshold values obtained through extensive simulation. The performance of the proposed algorithm has been evaluated for digitally modulated M-PSK signals. As in (Wei and Mendel, 1999), (Halmi and Abdalla, 2003) and (Umebayashi et al., 2000), we have assumed perfect symbol and carrier synchronization while evaluating the performance of the scheme. The rest of the paper is organized as follows, Section-2 describes the effect of channel on constellation points. The proposed blind modulation recognition algorithm is presented in section-3. Simulation results are presented in section-4. Conclusions are drawn in section-5.

2 EFFECT OF AWGN AND FADING CHANNEL ON CONSTELLATION POINTS

In AWGN channel, the received bandpass signal in the k-th signaling interval may be written as

$$\begin{aligned} r(t,k) &= s_m(t,\ k) + n(t,\ k), \\ & \quad k\,T_s \le\ t\ \le (k+1)\ T_s \end{aligned}$$

where T_s : 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 as in [8, 12, 14] and employing I-Q demodulation we get

$$\begin{aligned} \mathbf{r}(k) &= [r_I(k),\ r_Q(k)] \\ &= [s_{mI} + n_I(k),\ s_{mQ} + n_Q(k)] \end{aligned}$$

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 Additive White Gaussian Noise on signal points for MPSK signals at the receiver is shown in Figure 1(B). For wireless communication scenarios, in addition to AWGN, there will be the effect of multipath fading. Multipath fading channel can be modelled by a Tapped Delay Line(TDL) (Proakis, 2001): the test signal is convolved with the impulse response of the TDL to account for the effect of fading that is induced by the channel. The TDL parameters are chosen corresponding to power delay profile of physical channels (Chen and Chng, 2004). Figure 1(C) and Figure 1(D) respectively shows the faded received signal constellation and equalized signal constellation after CM equalization.

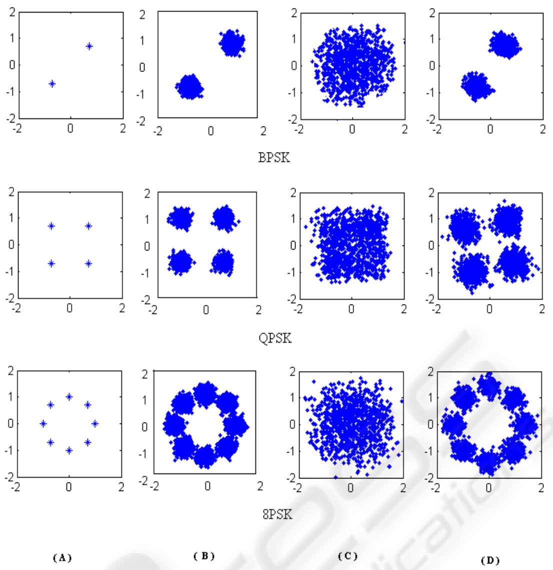

Figure 1: Effect of Noise and Fading on MPSK constellation at SNR=15 dB, (A) Prototype signal points, (B) Received noisy signal constellation, (C) Received noisy and faded signal constellation (D) Equalized constellation

3 PROPOSED METHOD FOR AUTOMATIC BLIND MODULATION RECOGNITION

A sequence of N received signal samples $\{\mathbf{r}(k)\}$, 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

$$MSE(M) = \frac{1}{N}\sum_{k=1}^{N} D^2_{k,\ M},\ M = 2^q,\ q = 1, 2, \ldots.$$

where

$$\begin{aligned} D_{k,\ M} &= \min_m\{|\ \mathbf{r}(k) - \mathbf{s}_m\ |\}, \quad m = 1, 2, \ldots M \\ &= \min_m\{|\ d_{k,\ m}\ |\} \end{aligned}$$

The computation of $D_{k,M}$ can be simplified by confining the search to that quadrant in which $\mathbf{r}(k)$ lies. For example, as shown in Figure 2, as $\mathbf{r}(k)$ 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 $D_{k,\ 8}$.

We 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 $\{\mathbf{r}(k)\}$ 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).

Case 1 BPSK is transmitted

In this case, the received signal points will be scattered around the symbols s_2 and s_6 shown in Figure1.

(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.

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

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 Figure 2. Thus,

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

(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 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,

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

Conclusions:

(i) when BPSK is transmitted, at any SNR , we shall find $MSE(8) < MSE(4) < MSE(2)$

(ii) at high SNR , the differences in MSE are negligibly small; only at low SNR , the differences are distinguishable, it is shown in Figure 3.

Case 2 QPSK is transmitted

Now $\{\mathbf{r}(k)\}'s$ are scattered around the four symbols s_2, s_4, s_6, s_8. It follows that $\{\mathbf{r}(k)\}$ 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

$MSE(8) \approx MSE(4)$ at high SNR

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

This is shown in Figure 4.

Case 3 8-PSK is transmitted

Following similar reasonings we conclude

$MSE(2) \gg MSE(4) \gg MSE(8)$ at all SNR.

The three curves are now well-separated, it is shown in Figure 5.

Proposed Algorithm

Step 1

Check for constant envelope property by computing fourth order moment of the received signal over a few samples, and compare with a Threshold On Moment(TOM), denoted by λ_M to distinguish between M-PSK and M-QAM signals.

$$m = \frac{1}{N} \sum_{k=1}^{N} |\ \mathbf{r}(k)\ |^4$$

where N is number of received signal samples considered.

Step 2

Observation space is partitioned into four quadrants, named as Q_1, Q_2, Q_3, Q_4. Check signs of received signal points $[r_I(k), r_Q(k)]$ to know to which quadrant it belongs:
If signs of real and imaginary part are $+, + \Rightarrow Q_1$
If signs of real and imaginary part are $-, + \Rightarrow Q_2$
If signs of real and imaginary part are $-, - \Rightarrow Q_3$
If signs of real and imaginary part are $+, - \Rightarrow Q_4$

Step 3

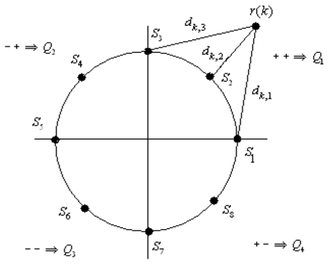

Figure 2: Distance vector calculation for M-PSK signals

(a) Compute

$$\begin{aligned}
D_{k,\,2} &= \mid \mathbf{r}(k) - \mathbf{s}_m \mid, \\
& m = 2\ if\ \mathbf{r}(k) \in Q_1 \\
& m = 6\ if\ \mathbf{r}(k) \in Q_3 \\
D_{k,\,2} &= \min_m \{\mid \mathbf{r}(k) - \mathbf{s}_m \mid\}, \\
& m = 2,6\ if\ \mathbf{r}(k) \in Q_2\ or\ Q_4 \\
D_{k,\,4} &= \mid \mathbf{r}(k) - \mathbf{s}_m \mid, \\
& m = 2\ if\ \mathbf{r}(k) \in Q_1 \\
& m = 4\ if\ \mathbf{r}(k) \in Q_2 \\
& m = 6\ if\ \mathbf{r}(k) \in Q_3 \\
& m = 8\ if\ \mathbf{r}(k) \in Q_4 \\
D_{k,\,8} &= \min_m \{\mid \mathbf{r}(k) - \mathbf{s}_m \mid\}, \\
& m = 1,2,3\ if\ \mathbf{r}(k) \in Q_1 \\
& m = 3,4,5\ if\ \mathbf{r}(k) \in Q_2 \\
& m = 5,6,7\ if\ \mathbf{r}(k) \in Q_3 \\
& m = 7,8,1\ if\ \mathbf{r}(k) \in Q_4
\end{aligned}$$

(b). Compute

$$MSE(M) = \frac{1}{N} \sum_{k\,=1}^{N} D_{k,\,M}^2,\ M = 2,4,8$$

Step 4

Compute Mean Square Error Difference(MSED)

$$MSED_{2-4} = MSE(2) - MSE(4)$$
$$MSED_{4-8} = MSE(4) - MSE(8)$$

Step 5

Decision rule (compare with thresholds determined through simulation):

(i) If $MSED_{2-4} < \lambda_{2-4}$, declare BPSK is transmitted

(ii) If $MSED_{2-4} > \lambda_{2-4}$, then check if $MSED_{4-8} < \lambda_{4-8}$. If $MSED_{4-8} < \lambda_{4-8}$, declare QPSK is transmitted.

(iii) If $MSED_{4-8} > \lambda_{4-8}$, declare 8-PSK is transmitted.

4 SIMULATION RESULTS

Manto-carlo simulation runs were carried out with N = 250 samples at SNR ranging from 0 dB to 30 dB. Average values of MSEs obtained from 800 such runs at each SNR are plotted in Figures 3-5 (in AWGN channel) and Figures 10-12 (in fading channels) for the three cases (e.g BPSK, QPSK and 8-PSK).

Determination of the thresholds λ^a_{2-4} , λ^a_{4-8}, λ^f_{2-4} and λ^f_{4-8}.

For AWGN channel:

Figure 6 shows the distribution of $MSED_{2-4}$ at SNR = 0 dB. The distribution is approximately Gaussian. We set $\lambda^a_{2-4} = \mu_{2-4} + \sigma_{2-4} = 0.2196 + 0.0369 = 0.2565$. The distribution of $MSED_{4-8}$ is shown in Figure 7, from where we obtain $\lambda^a_{4-8} = \mu_{4-8} + \sigma_{4-8} = 0.1619 + 0.0154 = 0.1773$. With these thresholds we have observed 100% recognition in all three cases at SNR $\geq$ 1 dB in AWGN channel.

For fading channel:

Figure 8 and Figure 9 show the distribution of $MSED_{2-4}$ at SNR = 3 dB and $MSED_{4-8}$ at SNR = 5 dB respectively. Following the same procedure, the thresholds obtained for fading channel are λ^f_{2-4} = $\mu_{2-4} + \sigma_{2-4} = 0.1378 + 0.0327 = 0.1705$ and $\lambda^f_{4-8} = \mu_{4-8} + \sigma_{4-8} = 0.1069 + 0.0121 = 0.1190$ respectively. With these thresholds, 100% recognition is achieved in fading channel at SNR $\geq$ 6 dB.

5 CONCLUSION

In this paper we have presented a novel approach to automatic digital modulation recognition of M-PSK signals. The performance of the proposed scheme has been tested in AWGN and fading channels. Simulation results show that the proposed scheme gives a much higher recognition performance for MPSK signals compared to the methods reported in literature (Wong and Nandi, 2004), (Azzouz and Nandi, 1996a), (Mobasseri, 1999), (Umebayashi et al., 2000)

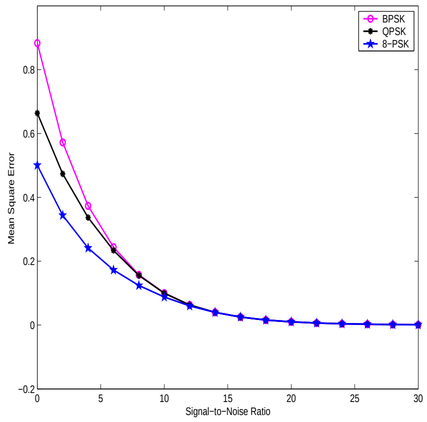

Figure 3: Characteristics of BPSK signal in an AWGN channel

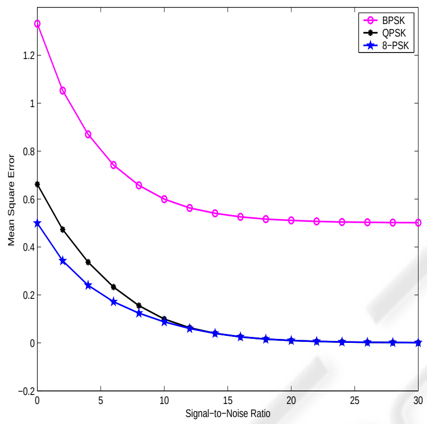

Figure 4: Characteristics of QPSK signal in an AWGN channel

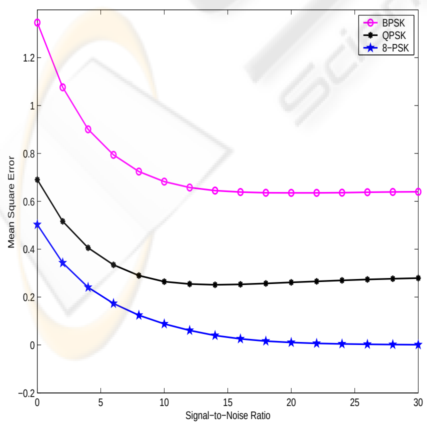

Figure 5: Characteristics of 8-PSK signal in an AWGN channel

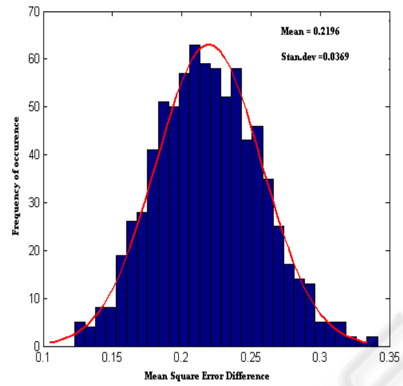

Figure 6: Distribution of $MSED_{2-4}$ at SNR = 0 dB in an AWGN channel

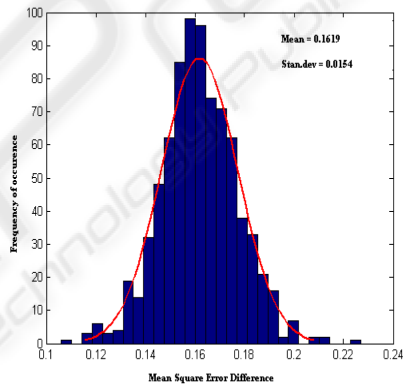

Figure 7: Distribution of $MSED_{4-8}$ at SNR = 0 dB in an AWGN channel

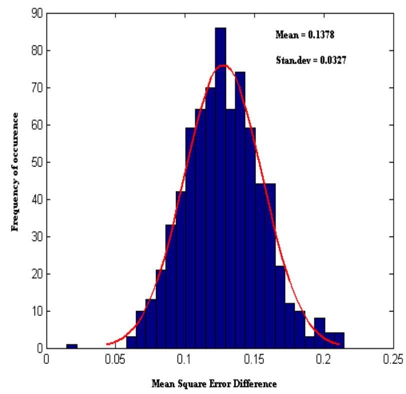

Figure 8: Distribution of $MSED_{2-4}$ at SNR = 3 dB in multipath fading channel

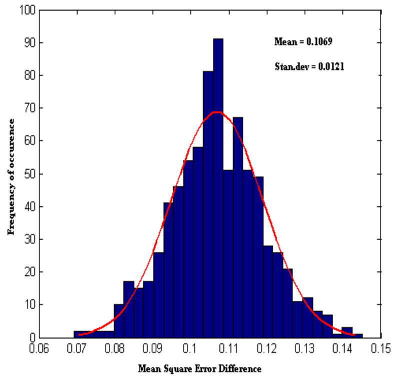

Figure 9: Distribution of $MSED_{4-8}$ at SNR = 5 dB in multipath fading channel

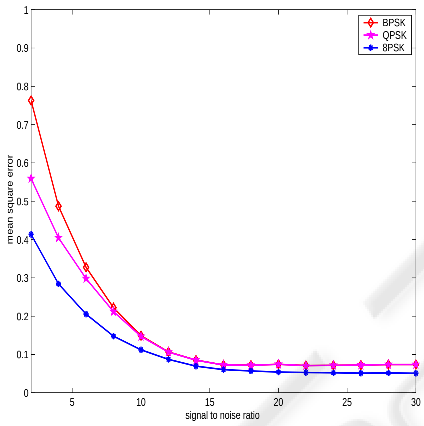

Figure 10: Characteristics of BPSK signal in multipath fading channel

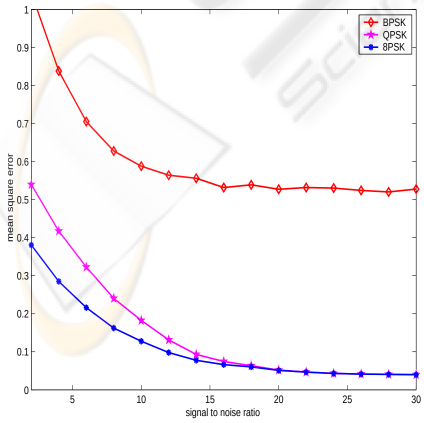

Figure 11: Characteristics of QPSK signal in multipath fading channel

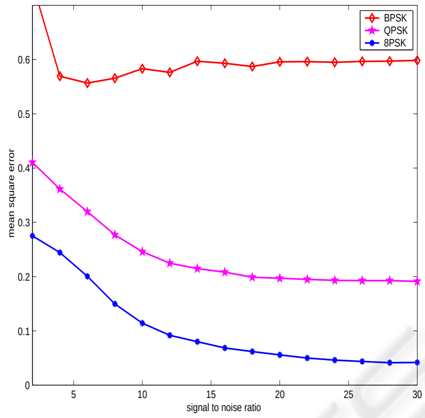

Figure 12: Characteristics of 8-PSK signal in multipath fading channel

at low SNR in fading channel. Moreover, the number of samples required by the recognizer for performing recognition task is much smaller compared to the earlier reported methods (Wong and Nandi, 2004), (Azzouz and Nandi, 1996a), (Mobasseri, 1999) and (Umebayashi et al., 2000).

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