J. Basic. Appl. Sci. Res., 4(3)1-12, 2014
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ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Automatic Digital Modulation Recognition Technique using Higher Order Cummulants on Faded Channels

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Received: January 13 2014
Accepted: February 18 2014

ABSTRACT

Nowadays, automatic modulation recognition (AMR) plays an important role in cognitive radio communication application. Modulation recognition is to recognize the signal modulation type at the receiver in the presence of various channel effects. The process of AMR is accomplished in two segments. First is feature extraction, extracts an appropriate combination of higher order cummulants up to 8th order. Second is recognition process which gives decision based upon the features extracted from higher order cummulants. An algorithm for automatic digital modulation recognition (ADMR) of different unknown modulated signals such as pulse amplitude modulated(PAM 2 to 64), quadrature amplitude modulated(QAM 2 to 64), binary phase shift keying(BPSK) and quadrature phase shift keying (QPSK) based on higher order cummulants (4th, 6th and 8th) features of received signal is analyzed. The algorithm for automatic digital modulation recognition has significant classification performance in terms of Probability of Correct Classification (PCC) under the effect of various channels such as additive white gaussian noise channel (AWGN), Rayleigh flat fading channel, rician flat fading channel and log normal fading channel. The simulation results show that proposed algorithm has high recognition accuracy at low signal to noise ratio (SNR) as compared to existing techniques.

KEYWORDS: Cognitive Radio, Automatic Modulation Recognition (AMR), Higher Order Cummulants (HOC), Probability of Correct Classification (PCC).

I INTRODUCTION

Automatic Modulation Recognition is a scheme to recognize the modulated signal by observing the received signal features. The received signal is usually corrupted by influence of various sources such as white guassian noise and fading which degrades the signal quality. Automatic modulation recognition plays an important role in Cognitive Radio communication. Due to amassed usage of digital signals in different technologies such as Cognitive Radios, the scientists are focused on recognizing these signal types. AMR would be considered to be incorporated with the upcoming communication standards including adaptive modulation [1]. The application based on adaptive modulation and spectrum sensing properties hypothetically contains AMR techniques, as important segment for overall functionality [2].

Generally, digital signal type recognition can be categorized in two major categories: decision theoretic (DT) methods and pattern recognition (PR) methods. DT method uses probabilistic and hypothesis testing arguments which is based on likelihood function of the received signal [3-5]. The process of MR in DT method can be viewed as multiple hypothesis tests, or may be considered sequence of pair-wise multiple hypothesis test. Once the likelihood function is created, average likelihood ratio test (ALRT) and generalized likelihood ratio test (GLRT) can be pragmatic to determine the modulation type. The major disadvantage of DT method is that it is computationally complex but theoretically optimal [6]. The DT is not robust to model mismatch which is due to channel effects, frequency offset, timing jitter and phase errors [7].

The PR method is feature based which is sub-optimal solution [8]. In PR method MR is done in two segments: The first segment is feature extraction, in which various features are extracted from the received signal which is corrupted by the channel noise, as well as, channel effects. In the second segment, features extracted from the received signal are compared with the theoretical values of the reference features and then determines the

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modulation type of transmitted signal. Due to robustness with respect to model mismatches and low computational complexity, PR method is widely used for modulation recognition [8-14].

The majority of existing AMR literature restricts the discussion on the AWGN channel [15-19]. In practice there exist the fading channels which degrade the performance of signal due to model mismatch. The effect of fading channel is discussed in [20-25]. In [1] author considered the AWGN channel, as well as, the fading channel using 4th order cummulants. The usage of higher order cummulants up to sixth order on fading channels are considered in [2]. The author shows that the correctness rate is 45% on fading channel.

In this paper, an algorithm for ADMR of different unknown modulated signals such as pulse PAM 2 to 64, QAM 2 to 64, BPSK and QPSK based on higher order cummulants features of received signal is analyzed. The algorithm for ADMR has significant classification performance in terms of PCC under the effect of various channels such as AWGN channel, Rayleigh flat fading channel, Rician flat fading channel and log normal fading channel. The modulation techniques are divided in three scenarios i.e. {BPSK, QPSK}, {PAM 2-64} and {QAM 2-64}. The features considered in simulation are 4th, 6th and 8th order cummulants. The performance comparison in terms of PCC using different cummulants on different fading channel and for different modulation scenario is also shown. The simulation results also show that proposed algorithm has high recognition accuracy at SNR rather than the existing techniques using only little bit features.

The rest of the paper is organized as follows. Section II presents the system model and the features extracted based on higher order cummulants for recognition purpose considering all three scenario. The theoretical values of higher order cummulants for considered modulations are also included. In section III, the simulation results of Probability of Correct Classification (PCC) curves are presented on AWGN, Rayleigh flat, Rician flat and lognormal fading channel. The performance comparison of using different cummulants on three different modulation scenarios is also shown. The simulation shows that high recognition rate is achieved at low SNR on AWGN channel as well as fading channels. Finally, section IV concludes the paper.

II SYSTEM MODEL& FEATURES USED

A. *System Model*

The generalized expression for signal received is given by

$$r(n) = x(n) + g(n) \tag{1}$$

where $r(n)$ is complex baseband envelop of received signal, $g(n)$ is the additive white guassian noise with zero mean and a variance of $\sigma_g{}^2$ and $x(n)$ is given by

$$x(n) = Ae^{i(w_o nT+\theta_n)} \sum_{j=-\infty}^{j=\infty} x(l)\, h(n\tau - j\tau + \epsilon_T \tau) \tag{2}$$

where

$x(l)$ = input symbol sequence which is drawn from set of M constellations of known symbols and it is not necessary that symbols are equi- probable

A = amplitude of signal

w_o = angular frequency offset constant

τ = symbol spacing

θ_n = the phase jitter which varies from symbol to symbol

$h(\dots)$ = channel effects

ϵ_T = the timing jitter

B. *Features Used*

As Cummulants are made up of moments, so various moments have been used as features. For the complex valued stationary random process $r(n)$, Cummulants of 2nd, 4th, 6th and 8th order have the following definitions [26]:-

$$C_{20,x} = E[y^2(n)] = \text{cumm}\{y(n), y(n)\} \tag{3}$$

$$C_{21,x} = E[|y(n)|^2] = \text{cumm}\{y(n), y^*(n)\} \tag{4}$$

$$C_{40,x} = M_{40} - 3M_{20}{}^2 = \text{cumm}\{y(n), y(n), y(n), y(n)\} \tag{5}$$

$$C_{42,x} = M_{42} - |M_{20}|^2 - 2M_{21} = \text{cumm}\{y(n), y(n), y^*(n), y^*(n)\} \tag{6}$$

$$C_{63,x} = M_{63} - 9M_{21}M_{42} + 12M_{21}{}^3 - 3M_{20}M_{43} - 3M_{22}M_{41} + 18M_{20}M_{21}M_{22}\, C_{63,x} = \text{cumm}\{y(n), y(n), y(n), y^*(n), y^*(n), y^*(n)\} \tag{7}$$

$$C_{84,x} = M_{84} - 16C_{63}C_{21} + |C_{40}|^2 - 18C_{42}{}^2 - 72C_{42}C_{21}{}^2 - 24C_{21}{}^4 = \text{cumm}\{y(n), y(n), y(n), y(n), y^*(n), y^*(n), y^*(n), y^*(n)\} \tag{8}$$

M_{pq} stands for moments of received signal and it is given by

$$M_{pq} = E[r(k)^{p-q} r^*(k)^q] \quad (9)$$

The normalized 8th order cummulants $C_{84,x}$:-

$$\hat{C}_{84,x} = C_{84,x}/(C_{21,x})^4 \quad (10)$$

In ADMR $\hat{C}_{84,x}$ is the key feature. $\hat{C}_{84,x}$ can also be estimated from the received signal $r(n)$ which is corrupted by AWGN noise and also from fading:

$$\hat{C}_{84,x} = \frac{1}{\beta} \frac{C_{84,y}}{(C_{21,y}-\sigma_g^2)^4} \quad (11)$$

$$\beta = \frac{\sum_{k=0}^{L-1} |h(k)|^8}{\left\{\sum_{k=0}^{L-1} h(k)^2\right\}^4} \quad (12)$$

The normalized 6th order cummulants $C_{63,x}$[2]:-

$$\hat{C}_{63,x} = C_{63,x}/(C_{21,x})^3 \quad (13)$$

$$\hat{C}_{63,x} = \frac{1}{\beta} \frac{C_{63,y}}{(C_{21,y}-\sigma_g^2)^3} \quad (14)$$

$$\beta = \frac{\sum_{k=0}^{L-1} |h(k)|^6}{\left\{\sum_{k=0}^{L-1} h(k)^2\right\}^3} \quad (15)$$

The normalized 4th order cummulants $C_{42,x}$[1]:-

$$\hat{C}_{42,x} = C_{42,x}/(C_{21,x})^2 \quad (16)$$

$$\hat{C}_{42,x} = \frac{1}{\beta} \frac{C_{42,y}}{(C_{21,y}-\sigma_g^2)^2} \quad (17)$$

$$\beta = \frac{\sum_{k=0}^{L-1} |h(k)|^4}{\left\{\sum_{k=0}^{L-1} h(k)^2\right\}^2} \quad (18)$$

Table I shows the theoretical values for normalized cummulants $\hat{C}_{84,x}$, $\hat{C}_{63,x}$ and $\hat{C}_{42,x}$ for the modulation techniques i.e. {BPSK, QPSK}, {PAM 2-64} and {QAM 2-64}.

Table I. Theoretical Normalized 4th, 6th & 8th order Cummulants for various Modulation Constellations

	$\hat{C}_{42,x}$	$\hat{C}_{63,x}$	$\hat{C}_{84,x}$
BPSK	-2	13	-163
QPSK	-1	4	-34
PAM2	-2	13	-163
PAM 4	-1.3586	70.7	440.60
PAM 8	-1.2368	522.26	1292.9717
PAM 16	-1.2113	3636.415	36934.8038
PAM 32	-1.2039	23019.7704	931687.15872
PAM 64	-1.1988	15363.424446	2588813.3566
QAM 2	-2	13	-163
QAM 4	-1	1.96	13.6
QAM 8	-1.0011	0.0192	0.0637
QAM 16	-0.6778	2.08	-13.9808
QAM 32	-0.6876	1.9448	-12.005
QAM 64	-0.6167	1.7972	-11.5022

III. ALGORITHM FOR AUTOMATIC DIGITAL MODULATION RECOGNITION (ADMR) USING FADING CHANNEL FEATURES

The algorithm for ADMR using fading channel coefficients (Rayleigh Flat, Rician Flat and Log-normal) can be stated as follows:-

1. Calculate the normalized channel coefficients h(k)
2. Calculate the β according to Eqs. (12), (15), (18).
3. Calculate the normalized eight-order $\hat{C}_{84,x}$, sixth-order $\hat{C}_{63,x}$ & fourth-order $\hat{C}_{42,x}$ cummulants of transmitted symbols according to the Eqs. (8), (10), (11), (7), (13), (14), (6), (16), (17).
4. Compare the $\hat{C}_{84,x}$, $\hat{C}_{63,x}$ and $\hat{C}_{42,x}$ with the theoretical values listed in Table I to determine the modulation type of the received signal.

IV ADMR PERFORMANCE EVALUATION

The Probability of Correct Classification in the presence of AWGN channel as well as fading channel such as Rayleigh Flat fade, Rician Flat fade and lognormal fade are simulated here using cummulants which includes normalized eight-order $\hat{C}_{84,x}$, sixth-order$\hat{C}_{63,x}$ & fourth-order$\hat{C}_{42,x}$. The modulation schemes considered here are divided in three scenarios i.e. and {BPSK, QPSK}, {PAM2, PAM4, PAM8, PAM16, PAM 32, PAM64} and {QAM2, QAM4, QAM8, QAM16, QAM32, QAM64}. The PCC curves are simulated based on SNR and sample size for three different modulation scenarios on fading channels. The performance comparison of using three different cummulants on different channels is also shown. The correct rate of recognition using 8th order cummulant is much higher than that of using 6th and 4th order cummulants.

Fig. 1 shows the PCC curve in scenario {BPSK, QPSK} considering AWGN channel, N=250. The curve also shows that using 8th order cummulants average PCC is 0.9 at SNR=-2dB, where using 6th and 4th order cummulants the average PCC is 0.8 and 0.7 respectively, at same SNR. The 8th order cummulants gives better correction rate. Fig. 2 shows if the number samples is increased from N=250 to N=2500, the correction rate also increases, e.g. using 8th order cummulants average PCC is approximately 0.99 at SNR=-2dB, where using 6th and 4th order cummulants, the average PCC is 0.91 and 0.82 respectively, at same SNR.

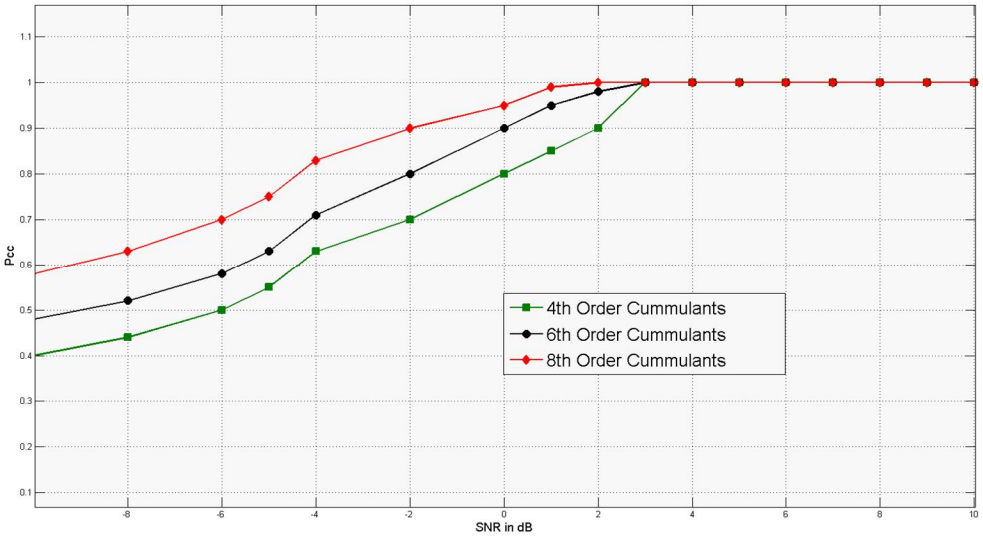

Figure.1 PCC on AWGN channel in scenario {BPSK, QPSK}, N=250

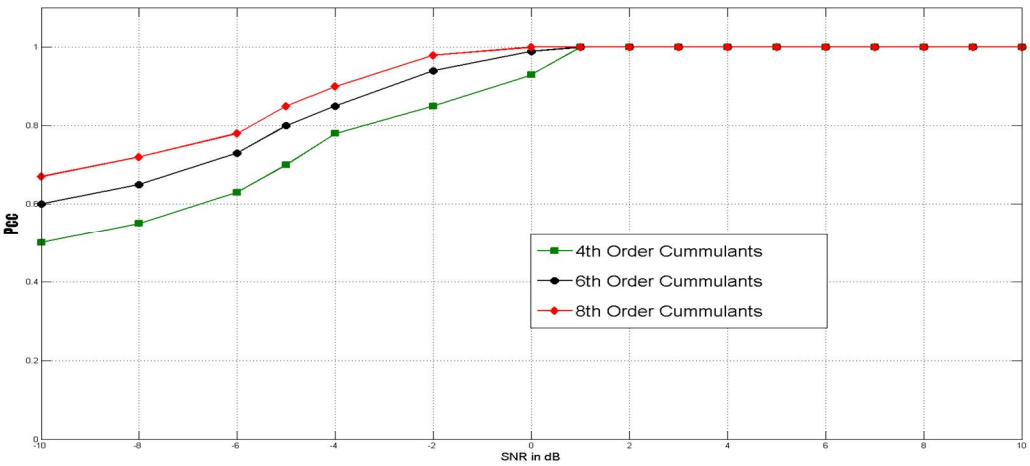

Figure.2 PCC on AWGN channel in scenario {BPSK, QPSK}, N=2500

Fig. 3 shows the PCC curve in scenario {QAM 2 to 64} considering AWGN channel, N=300. The curve also shows that using 8th order cummulants average PCC is 0.72 at SNR=0dB, where using 6th and 4th order cummulants, the average PCC is 0.6 and 0.57 respectively, at same SNR.

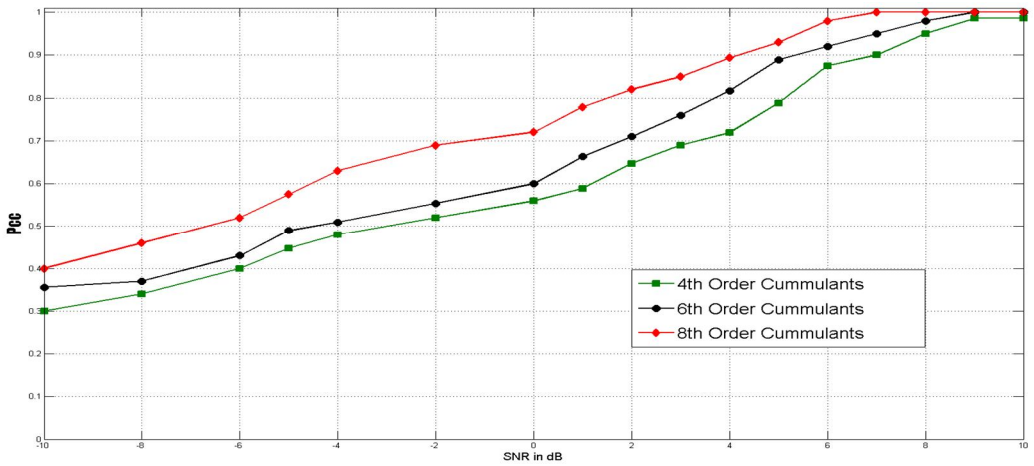

Figure.3 PCC on AWGN channel in scenario {QAM 2 to 64}, N=300

Fig. 4 shows that if the number of samples is increased from N=250 to N=3000, the correction rate also increases, e.g. using 8th order cummulants average PCC is approximately 0.85 at SNR=0dB, where using 6th and 4th order cummulants the average PCC is 0.8 and 0.77 respectively, at same SNR.

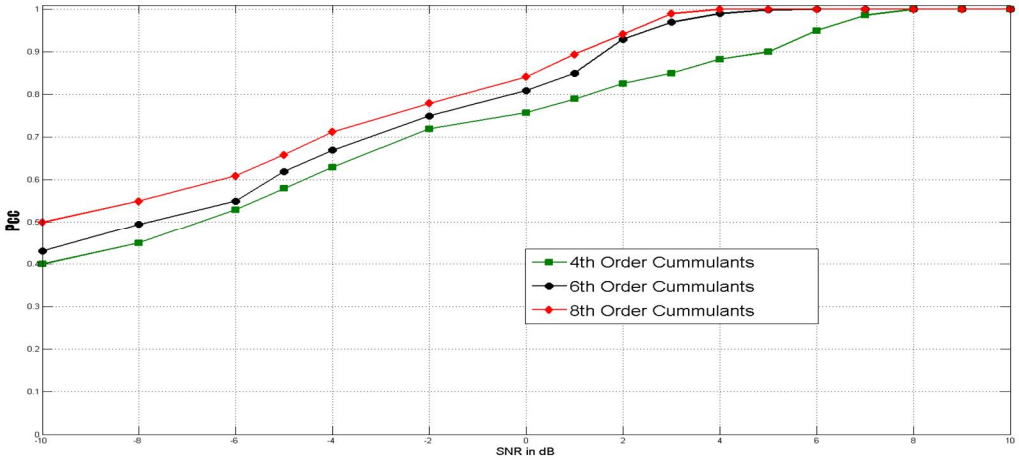

Figure.4 PCC on AWGN channel in scenario {QAM 2 to 64}, N=3000

Fig. 5 the correction rate using 8th order cummulants is approximately 1 at SNR=2dB, where using 6th and 4th order cummulants the average PCC is 0.96 and 0.84 respectively, at same SNR.

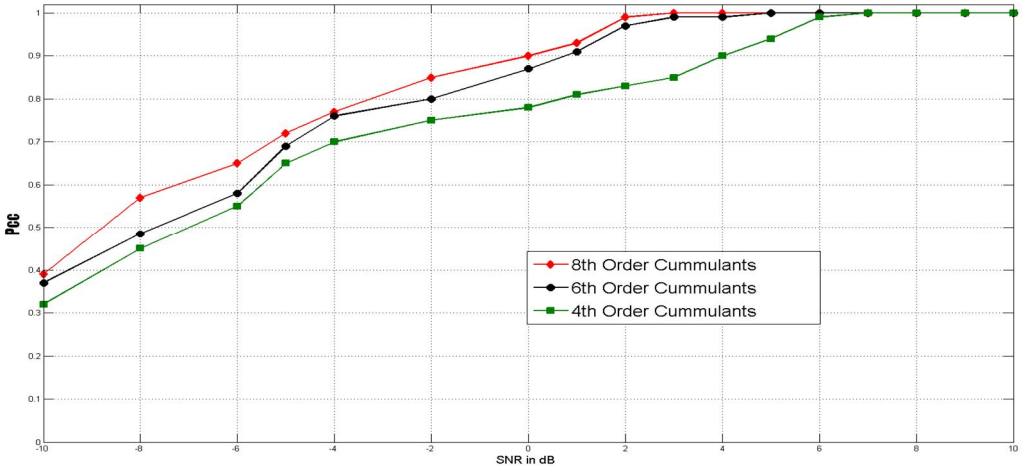

Figure.5 PCC on AWGN channel in scenario {PAM 2 to 64}, N=3000

Fig. 6, 7 & 8 show the PCC curve in scenario {BPSK, QPSK}, {PAM 2 to 64} and {QAM 2 to 64} on fading channel having number of samples 250, 2000 & 2000 respectively. The curves show that using 8th order cummulants PCC is higher than the 6th and 4th order cummulants in all three scenarios. The average PCC using 8th order cummulant for scenario {BPSK, QPSK} is 0.95, average PCC for scenario {PAM 2 to 64} is 0.7 and average PCC for scenario {QAM 2 to 64} is 0.64 at SNR=0dB.

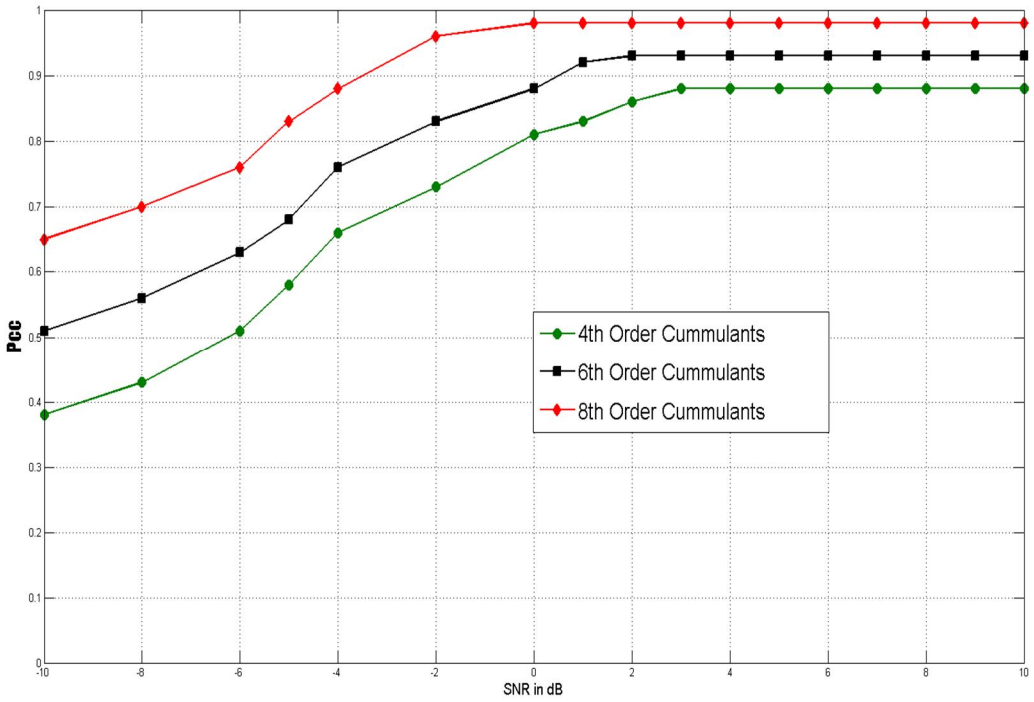

Figure.6 PCC on Fading channel in scenario {BPSK, QPSK}, N=250

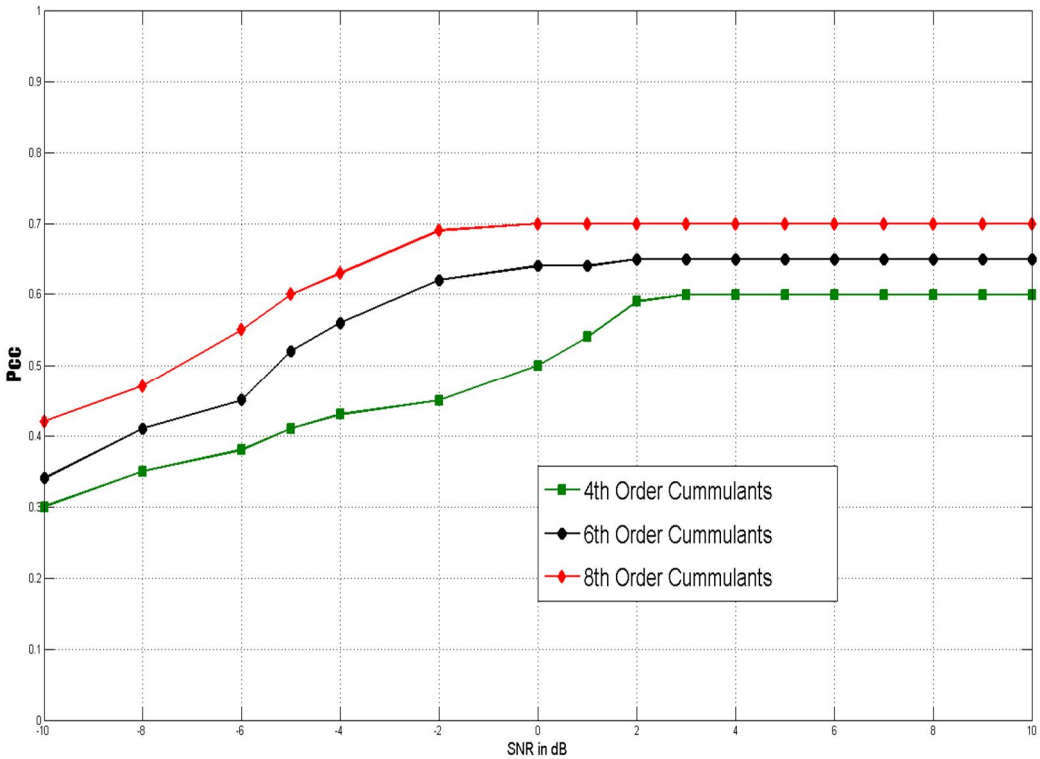

Figure.7 PCC on Fading channel in scenario {PAM 2 to 64}, N=2000

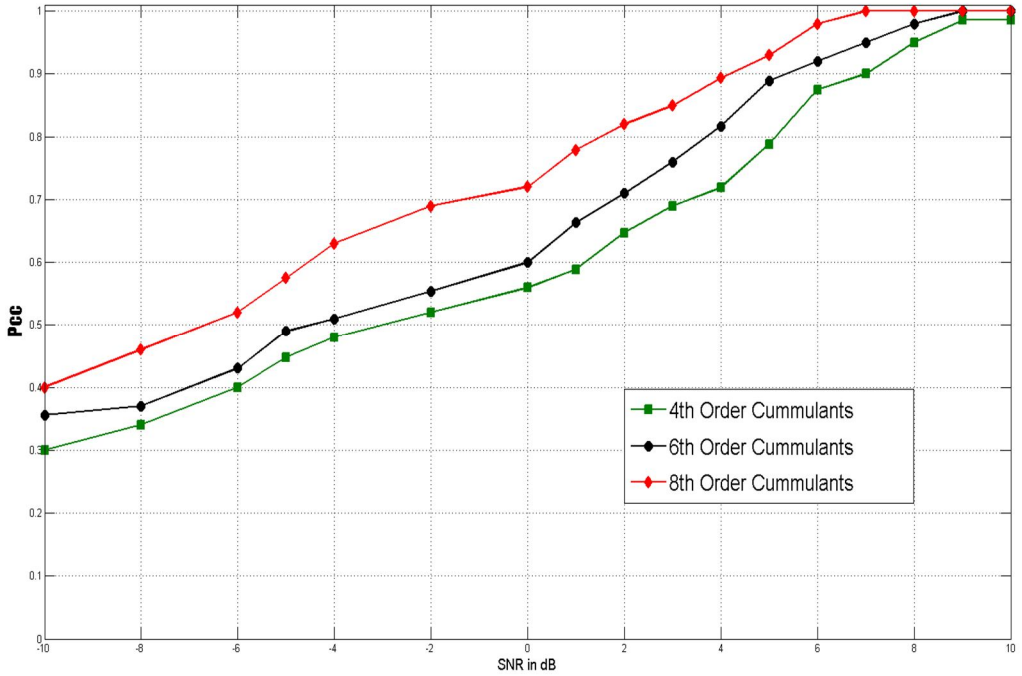

Figure.8 PCC on Fading channel in scenario {QAM 2 to 64}, N=2000

Fig. 9, 10 & 11 show the PCC curve in scenario {BPSK, QPSK} on Rayleigh flat fading, lognormal fading and Rician flat fading channel having no of samples 250. The curves show that using 8th order cummulants PCC is higher on faded channels. The average PCC in fig. 9 is 0.94 using 8th order cummulants while average PCC is 0.8 using 4th cummulant.

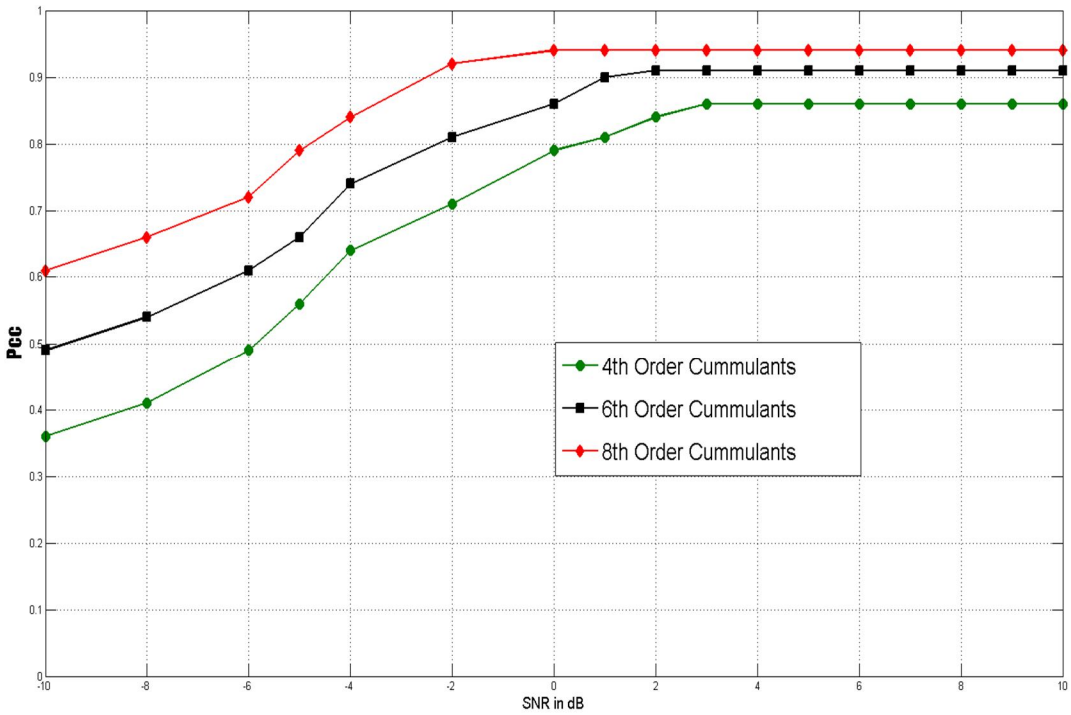

Figure.9 PCC on Rayleigh Flat Fading channel in scenario {BPSK, QPSK}, N=250

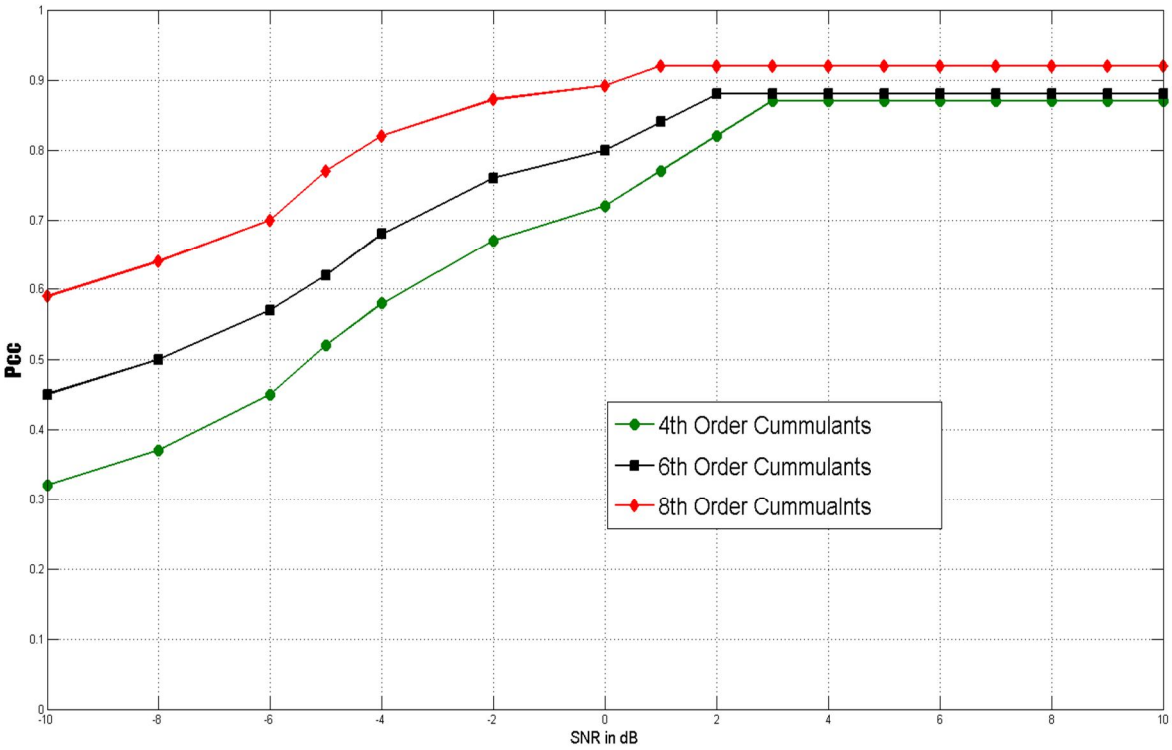

Figure.10 PCC on Lognormal Fading channel in scenario {BPSK, QPSK}, N=250

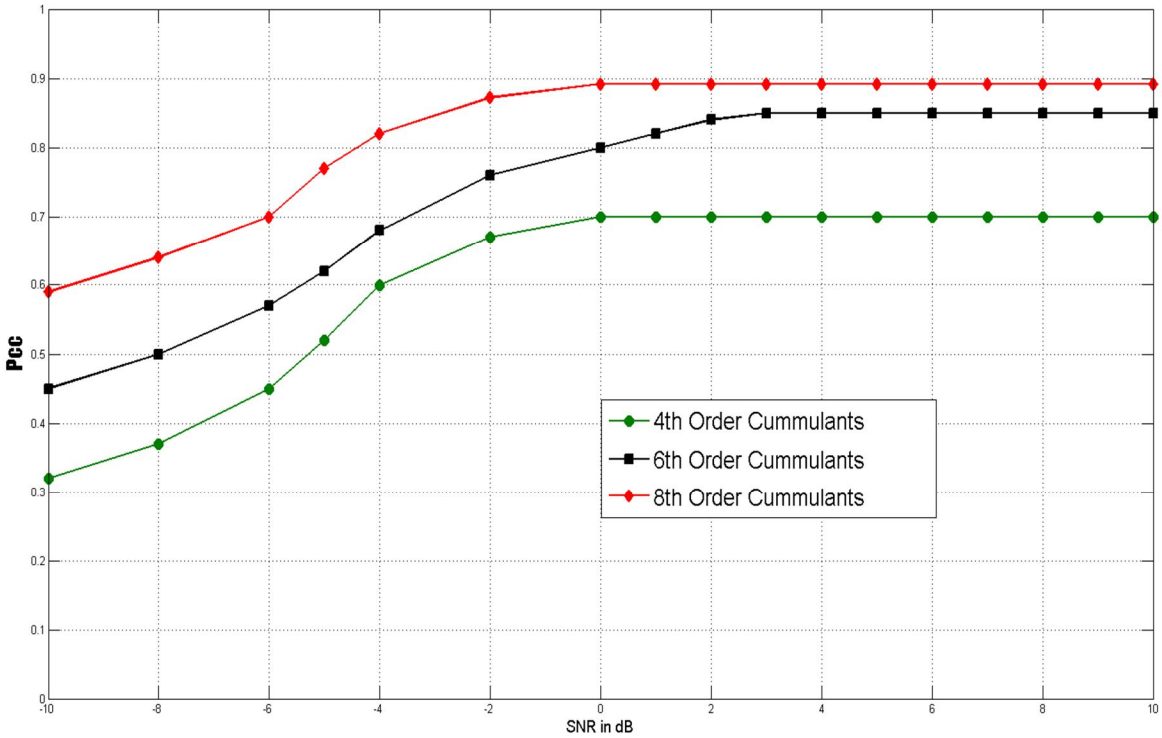

Figure.11 PCC on Rician Flat Fading channel in scenario {BPSK, QPSK}, N=250

Fig. 12 shows the performance evaluation of ADMR on faded channel and AWGN channel in the scenario {BPSK, QPSK}. The 8th order cummulants gives higher accuracy on all faded channel.

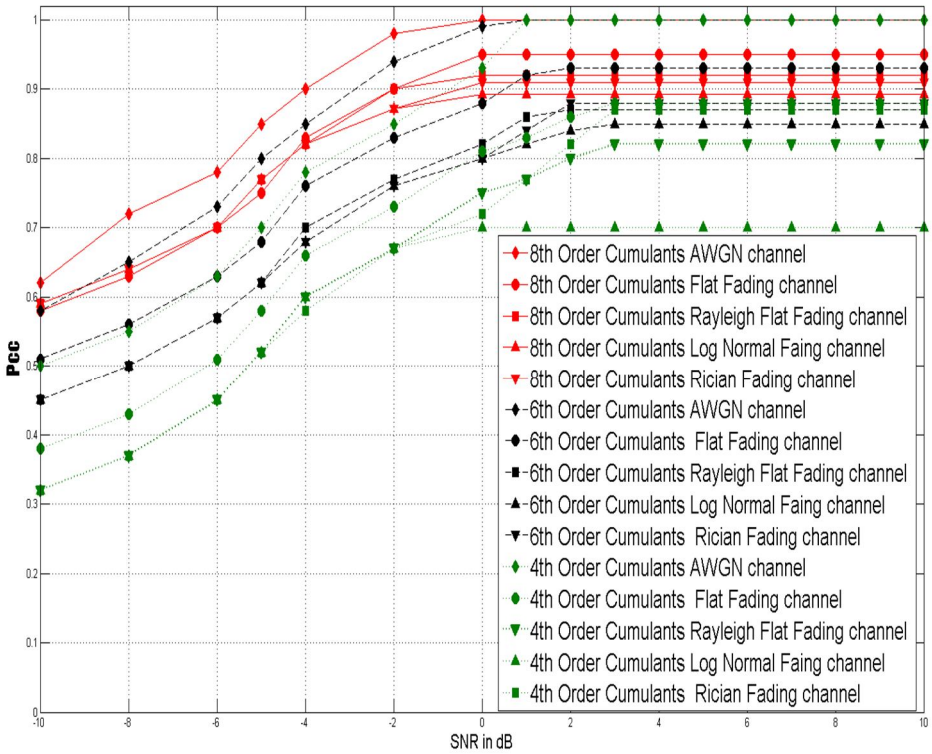

Figure.12 Performance of ADMR on Faded channel in scenario {BPSK, QPSK}, N=250

In Table II, the correct rate of recognition using 8th, 6th and 4th order cummulants on faded channels in scenario {BPSK, QPSK} is given.

Table II. PCC (%) in scenario {BPSK, QPSK}, N=250 for different Channels

8th Order Cummulants												
SNR	-10	-8	-6	-5	-4	-2	0	1	2	3	4	5
AWGN	62	72	78	85	90	98	100	100	100	100	100	100
FLAT	58	63	70	75	83	90	95	95	95	95	95	95
RAYLEIGH	56	62	68	73	80	85	90	92	92	92	92	92
LOG NORMAL	56	64	67	71	78	84	89	89	89	89	89	89
RICIAN	59	63	66	70	75	84	88	91	91	91	91	91
6th Order Cummulants												
SNR	-10	-8	-6	-5	-4	-2	0	1	2	3	4	5
AWGN	58	65	73	80	85	94	99	100	100	100	100	100
FLAT	51	56	63	68	76	83	88	92	93	93	93	93
RAYLEIGH	45	52	57	66	70	77	82	86	87	87	87	87
LOG NORMAL	44	48	58	65	68	76	80	82	84	85	85	85
RICIAN	45	46	55	63	68	76	80	84	88	88	88	88
4th Order Cummulants												
SNR	-10	-8	-6	-5	-4	-2	0	1	2	3	4	5
AWGN	50	55	63	70	78	85	93	100	100	100	100	100
FLAT	38	43	51	58	66	73	81	83	86	88	88	88
RAYLEIGH	32	36	45	52	60	67	75	77	80	82	82	82
LOG NORMAL	32	35	44	51	60	65	70	70	70	70	70	70
RICIAN	32	33	43	47	58	64	72	77	82	87	87	87

The PCC for scenario {QAM 2 to 64} on Rayleigh flat, Rician flat and lognormal fading channel is shown in fig. 13.The usage of 8th order cummulants shows the better recognition rate than that of 6th & 4th order cummulants. For example average PCC is 0.57 at SNR= -2dB on lognormal fading channel, while using 6th & 4th order cummulants the average PCC is 0.51, 0.45, respectively, at same SNR

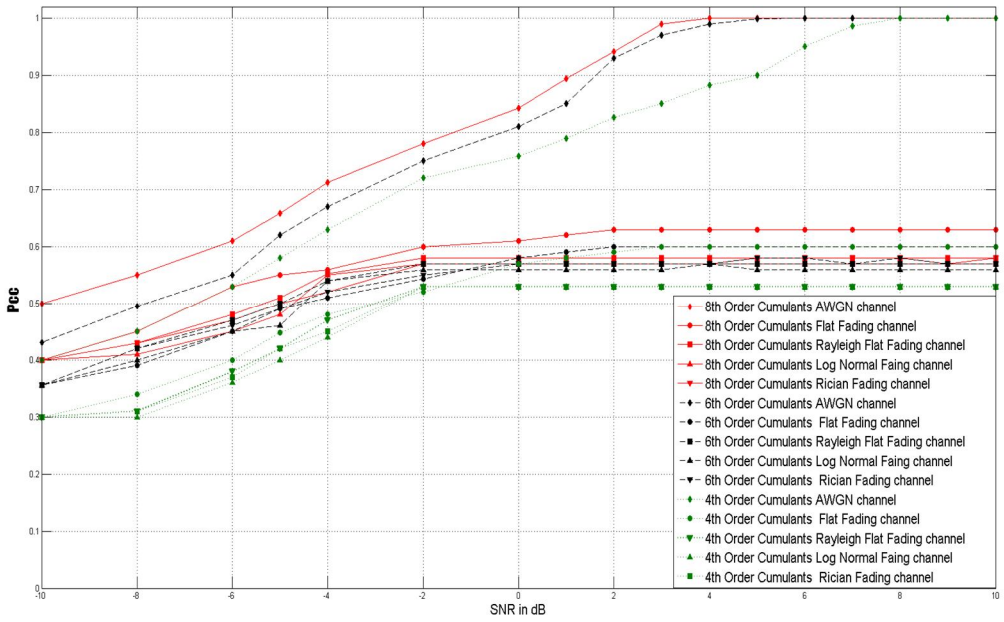

Figure.13 Performance of ADMR on Faded channel in scenario {QAM 2 to 64}, N=3000

Table III, shows the correct rate of recognition using 8th order cummulants on faded channels in scenario {QAM 2 to 64}.

Table III. PCC (%) in scenario {QAM 2 to 64}, N=3000 for different Channels

SNR	**-10**	**-8**	**-6**	**-5**	**-4**	**-2**	**0**	**1**	**2**	**3**	**4**	**5**
AWGN	50	55	61	66	71	78	84	89	94	99	100	100
FLAT	40	45	53	55	56	60	61	62	63	63	63	63
RAYLEIGH	40	43	48	51	55	58	58	58	58	58	58	58
LOG NORMAL	40	41	45	48	55	57	57	57	57	57	57	57
RICIAN	40	43	47	50	52	57	57	57	57	57	57	58

The PCC for scenario {PAM 2 to 64} on Rayleigh flat, Rician flat and lognormal fading channel is shown in fig. 14.The 8th order cummulants perform better than 6th & 4th order cummulants. For example average PCC is 0.6 at SNR= 0dB on Rician fading channel, while using 6th & 4th order cummulants the average PCC is 0.57, 0.51, respectively, at same SNR.

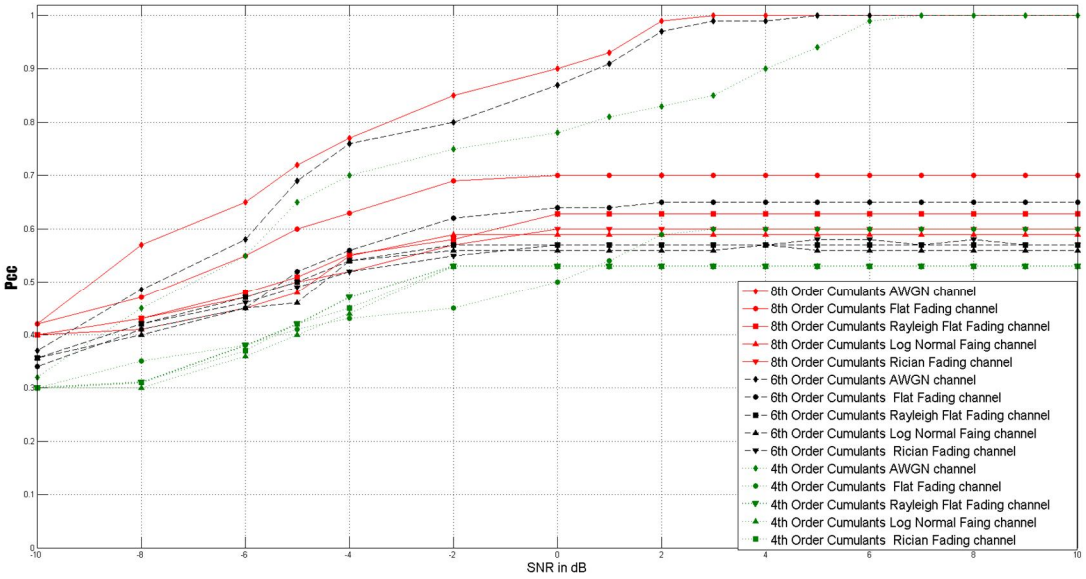

Figure.14 Performance of ADMR on Faded channel in scenario {PAM 2 to 64}, N=2500

Table IV, shows the correct rate of recognition using 8th order cummulants on faded channels in scenario {PAM 2 to 64}.

Table IV. PCC (%) in scenario {PAM 2 to 64}, N=2500 for different Channels

SNR	-10	-8	-6	-5	-4	-2	0	1	2	3	4	5
AWGN	42	57	65	72	77	85	90	93	99	100	100	100
FLAT	42	47	55	60	63	69	70	70	70	70	70	70
RAYLEIGH	40	43	48	51	55	58	63	63	63	63	63	63
LOG NORMAL	39	41	45	48	55	59	59	59	59	59	59	59
RICIAN	40	43	47	50	52	57	60	60	60	60	60	60

V. CONCLUSION

In this paper, the performance comparison of using 8th order cummulants is evaluated under the effects of channels. The considered noise throughout the simulations is AWGN. The modulations considered are divided in three scenarios i.e. {BPSK, QPSK}, {PAM2, PAM4, PAM8, PAM16, PAM 32, PAM64} and {QAM2, QAM4, QAM8, QAM16, QAM32, QAM64}. The probability of correct classification using 8th order cummulants is also compared with the 6th and 4th order cummulants and it is found that the probability of correct classification is much higher. The PCC is found for all scenarios and simulation results show that 8th order cummulants perform better for BPSK, QPSK, PAM2, PAM4, PAM8, PAM16, PAM 32, PAM64, QAM2, QAM4, QAM8, QAM16, QAM32 and QAM64 on fading channels such Flat Fading, Rayleigh Flat Fading, Rician Flat Fading, Lognormal Fading as well as AWGN channel. The average PCC is 1 for AWGN channel at SNR =-2dB using 8th order cummulants, while for fading channels average PCC approaches 0.9 for {BPSK, QPSK}.

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