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CUMULANT APPROACH FOR MODULATION RECOGNITION

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ABSTRACT
In this paper, cumulant approach is used in MQAM modulated signal recognition. This method uses the characteristics of higher-order cumulants and higher-order statistics to identify different kinds of MQAM signals. We focus on the modulation identification using statistical properties of MQAM signals. The reason of using this method is the ability of higher-order statistics to reflect the distribution characteristics of the constellation diagram. There are many benefits of using this method. This method needs only small amount of computations. It can effectively inhibit the effects of White Gaussian Noise. In many applications, the cumulants are applicable to distinguish between different amplitude or phase modulated signals like MQAM, MPSK, MASK. Different modulated signals have different cumulant values. Whenever we use higher order cumulants, we will get higher degree to distinguish the type of modulation scheme; the higher order cumulants require a large amount of data. A good characteristic of this method is that: the value of higher order cumulants (more than two orders), for the Gaussian noise is zero, so the use of higher-order cumulants characteristics can effectively remove the impact of the Gaussian noise. Simulation results reflect the validity of proposed algorithm.

INTRODUCTION
There is a critical need of communication recognition nowadays, because it has a very important application in many civil and military aspects. In civil life, it is used in spectrum management and radio monitoring. It is used to manage the legal use of radio channels, to determine whether the operating stations comply with predefined operating rules. Modulation Recognition is also used in the military applications. It is counted as an important task in the communication confrontation phase of the electronic warfare. It is an important tool to defeat the enemy communications and to control the electromagnetic spectrum [1].
Quadrature Amplitude Modulation or QAM is one of the most used forms of digital modulation techniques. It is a digital communication technique with a wide range of applications. It is widely used because it has got many features and advantages over other forms of digital modulation such as PSK [2]. It has got low spectrum utilization, anti-multipath fading resistance, power spectrum attenuation is slow.
Proposed method is practically and robust against noise with high probability of correct recognition. It works in very low SNR environment, with good confidentiality. This method is also very quick in recognition process.

SIGNAL MODEL
In QAM signal there exist two carriers shifted by 90 degrees in phase. These carriers are modulated. The resultant output contains variations in both amplitude and phase. It can be seen as a mixture of phase and amplitude modulation because there are variation in both amplitude and phase[3].
Equivalent low-pass signal of MQAM signals is given by the equation:

$$S(t)=\sum_k a_k g_t\left(t-KT_b\right)-\sum_k b_k g_t\left(t-KT_b\right)$$

where, a_k and b_k are the discrete information symbol sequence, T_b is the symbolic cycle, g_T is the shaping pulse. Assume that the channel attenuation factor is $\alpha(t)$, channel delay is $\xi(t)$. MQAM received signal can be seen as:

$$s(t)=\sum_K \alpha\, a_k g_T\left(t-KT_b-\xi T_b\right)Cos\left(2\pi f_c t+\phi_i\right)$$
$$-\sum_K \alpha\, b_k g_T\left(t-KT_b-\xi T_b\right)Sin\left(2\pi f_c t+\phi_i\right)+n(t)$$

After assuming that changes in $\xi(t)$ and $\alpha(t)$ are not too much relative to the symbol rate. So, they are considered as constants. f_c is the carrier frequency, ϕ_i denotes the carrier initial phase. $n(t)\sim N(0,\sigma^2)$ Alternatively, the QAM signal waveforms may be expressed as:

$$s(t)=\sqrt{E_i}\,g_T Cos\left(2\pi f_c t-\phi_i\right)$$
$$\text{Where, } E_i=\sqrt{(a_k)^2+(b_k)^2} \text{ and } \phi_i=\tan^{-1}\left({b_k}/{a_k}\right)$$

From this expression, it is apparent that the QAM signal waveforms can be viewed as a combined amplitude and phase modulation.[22]

MQAM SIGNAL PROPERTIES

The following figure shows the basic block diagram of QAM modulation

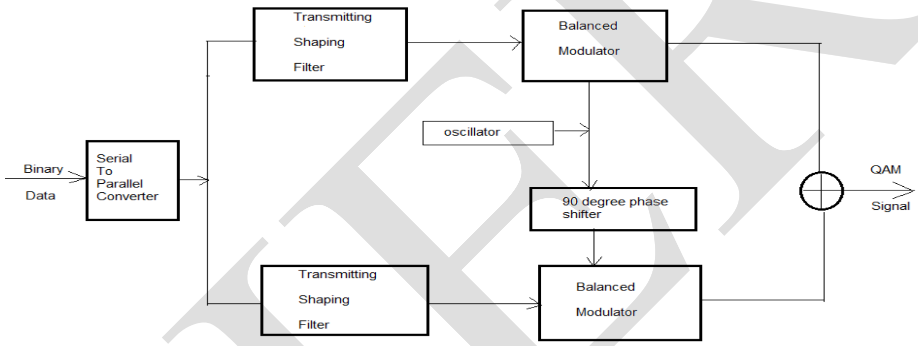

Figure 1: Basic Block Diagram of QAM Modulator

The output of the QAM modulator consists of two orthogonal signals; the orthogonal signals are modulated in phase and in amplitude. The output is the binary bits have been mapped in a different amplitudes and different phases. MQAM has a high information transmission rate because it is a multi-level transmission technique [4].

The relationship between MQAM output pulse rate R_N and MQAM input pulse rate R_C is given by the following equation:

$$R_N={R_C}/{\log_2 \log_2 N}$$

Whenever, M is high, then R_C will also be high. As MQAM input pulse rate R_C is reduced by the factor $\log_2 N$ that implies high band utilization [5].

SHAPING MQAM SIGNAL

In real QAM before sending the signal is passed through a shaping filter, to send the signal in a band limited channel. Using the shaping filter introduces ISI (Inter symbol interference). To compensate the ISI at the

receiving end we use a matched filter technique. Practically matched filter and shaping filter uses Raised Cosine Roll-off filter. The roll-off determines the filter specifications.
Generally, the frequency response of the shaping pulse is given by the following equation:

$$G(f)=\begin{pmatrix} \sqrt{T_b} & ; & |2fT_b|\le 1-\alpha/2T_b \\ \sqrt{T_b}Cos\left[\pi/4\alpha(|2fT_b|-1+\alpha)\right] & ; & 1-\alpha/2T_b \le |2fT_b| \le 1+\alpha/2T_b \\ 0 & ; & elsewhere \end{pmatrix}$$

α denotes the roll-off factor.

CYCLIC CUMULANT FEATURE

Due to the presence of carrier frequency and symbol rate, the digital modulation signals will have stable repeated features [11,12]. The best way to represent these repeated features is the use of high order cumulants, because it is well describing the characteristic distribution in the signal. The cumulants can effectively suppress noise, with a need to small amount of calculations [6]. In the modulation identification process, the usage of higher-order cumulants of the signal has many reasons: the constant zero value for the Gaussian noise; multi-spectral (higher moments and cumulants spectrum) contains the phase information of the signal which can help much in the identification process.
Practically, different order of the higher-order statistics contains different information about the signal, this is very useful in signal classification. The required classification feature will be extracted from the higher-order cumulant domain [7, 8,9]. In low SNR cases, there exist low recognition rate using other recognition methods. To get better results we have to use the cumulant approach to achieve high recognition rate in low SNR cases.
The high order moment represented using the following equation:

$$M_{p+q,p}=E\left[X^p\left(X^*\right)^q\right]$$

Higher order cumulants are represented using the following equation:

$$C_{p+q,p}=cum\left[X,....,X,X,X^*,....,X^*\right]$$

There are some commonly used cumulants in most researches and papers; the importance comes from the good specifications they have in relation to each other [10]. The ration between two specific cumulants leads to differentiate between two kinds of MQAM signal. Following equations show the relationship between different cumulants and corresponding moments:

$$C_{20}=M_{20}$$

$$C_{21}=M_{21}$$

$$C_{40}=M_{40}-3\left(M_{20}\right)^2$$

$$C_{41}=M_{41}-3M_{21}M_{20}$$

$$C_{42}=M_{42}-|M_{20}|^2-2\left(M_{21}\right)^2$$

$$C_{60}=M_{60}-15M_{40}M_{20}+30\left(M_{20}\right)^3$$

$$C_{63}=M_{63}-9M_{42}M_{21}-6\left(C_{21}\right)^3$$

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THEORETICAL CALCULATED CUMULANTS

Using the above equations, we can calculate the theoretical values for different MQAM signals as shown in Table3-1 below. Define the following parameters as follows:

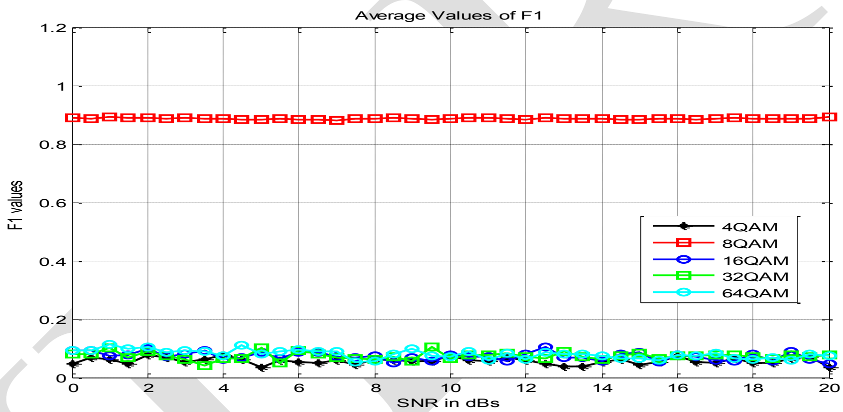
$$F_1 = \left|\frac{C_{41}}{C_{42}}\right| \qquad F_2 = \frac{\left|C_{63}\right|^2}{\left|C_{42}\right|^3} \qquad F_3 = \left|\frac{C_{40}}{C_{42}}\right| \qquad F_4 = \left|C_{21}\right|$$

Table 1. Theoretical Cumulants Values for MQAM modulated signals.

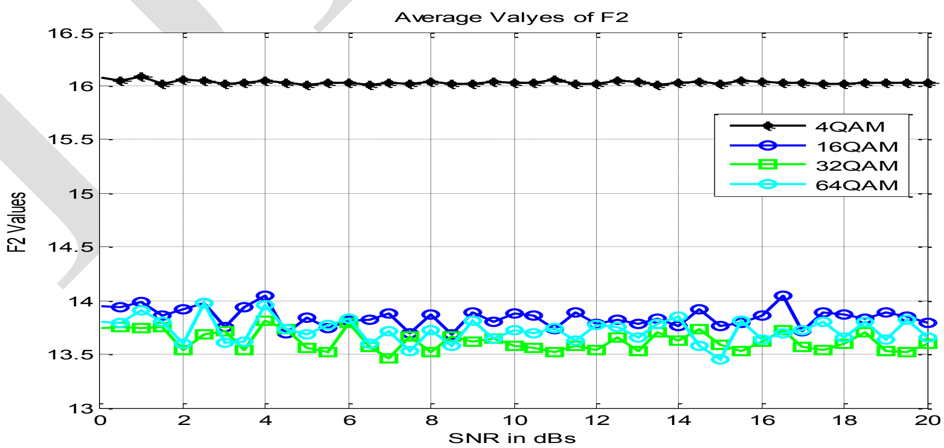
MQAM	$F_1 = \lvert C_{41}/C_{42}\rvert$	$F_2 = \lvert C_{63}\rvert^2/\lvert C_{42}\rvert^3$	$F_3 = \lvert C_{40}/C_{42}\rvert$	$F_4 = \lvert C_{21}\rvert$
4QAM	0	16	0	2
8QAM	0.8889	28.4444	1	6
16QAM	0	13.7594	1	10
32QAM	0	13.5524	0.2754	20
64QAM	0	13.6153	1	43

SIMULATION ANALYSIS

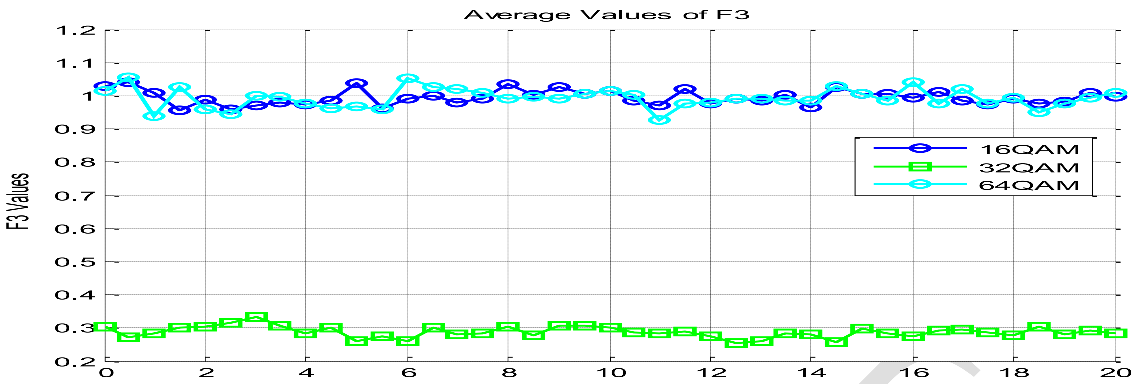
Applying the aforementioned parameters on different MQAM signals we will be able to differentiate between different MQAM signals. The following figure shows the average values of high order cumulants high order cumulants when applied on MQAM signals for recognition purposes.



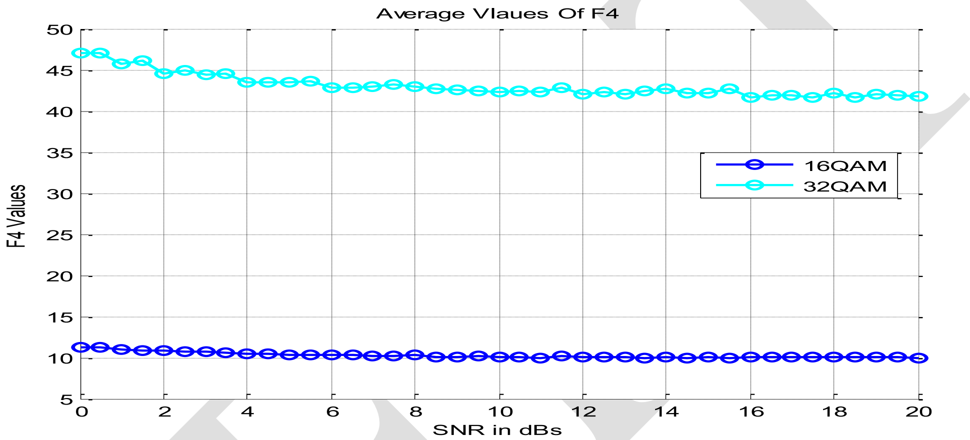
(a) Average values of F1



(b) Average values of F2



(c) Average values of F3



(d) Average values of F3

Figure 2: This figure shows the simulation results of proposed method.

CONCLUSION

From above results, we see that, MQAM signals can be recognized using the cumulant approach with good confidentiality in low SNR. This method is practically and robust against noise with high probability of correct recognition. This method is also very quick in recognition process. The problem is that it is not applicable when M is high. So, it only works until 64QAM.

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