Digital Modulation Scheme Recognition using Fuzzy Logic

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Abstract- *Automatic modulation scheme detection is the intermediate step between signal detection and information recovery. Coherent detection uses priori knowledge of received signal. In commercial and military application, two parties do not want to share their information to third party. In non-coherent detection, receiver does not use knowledge of transmitted parameters. At that time automatic modulation recognition is used. AMC is used to detect modulation type of received signal. previously many algorithms are used to classify the modulated signal. In this paper, I used fuzzy logic system to detect modulated signal. Fuzzy logic classifier uses parameters of received signal to detect the signal. Fuzzy classifier works successfully without any prior knowledge. In this paper digital modulation schemes are classified by extracting all possible parameters. This paper work is done using mathematical software MATLAB version R2012a.*

Keywords- AMC, AMR, modulation detection, fuzzy application, fuzzy classifier, feature based modulation classifier

I. INTRODUCTION

As we all know that any information signal is a low frequency signal. So it cannot travel up to longer distance. To transmit it to longer distance, modulation is done. Modulation is the process of varying some features of one signal according to the other signal. at transmitter, signal is modulated over carrier signal. this modulated signal is transmitted via channel. Receiver gets noisy received signal. The goal of receiver is to recover information signal back. There are lots of modulation schemes for modulation. So without any prior knowledge, receiver is not able to demodulate the signal. also in commercial and military application two parties do not want share their information to third party because of secure communication. Second problem of this convenient modulation scheme is that it reduces data. This technique sends pilot data along with the transmitted signal. This pilot data contains information of the transmitted signal. By using this pilot signal, data is lost. So to overcome this problem, automatic modulation scheme detection is used. AMC detects modulation scheme without any prior knowledge. It uses parameters of modulated signal. It provides valuable insight into its structure, origin and properties.

Now a day's technological work is moving towards fast and secure communications. There are many communication signals with different modulation types at different frequencies. It is required to identify and monitor these signals for some applications. Some of these applications are for civilian purposes such as signalconfirmation, interference identification and spectrum management. The other applications are electronic warfare (EW), surveillance and threat analysis. In electronic warfare applications, electronic support measures (ESM) system plays an important role as a source of information required to conduct electronic counter measures (ECM), electronic counter-counter measures (ECCM), threat detection, warning, target acquisition and homing at military application. In these type of application, it is necessary to make the signal secure. So AMC is used in these applications.

Automatic modulation scheme recognition uses parameters of transmitted signal. these parameters are given to the fuzzy classifier. Fuzzy classifier uses these parameters as membership function and classify the modulation type as output. According to these output of FC, received signal is given to the particular demodulator. An appropriate demodulator can be selected to demodulate the signal and then recover the information.[4]

II. PROBLEM STATEMENT AND PROPOSED SOLUTION

When a data is transmitted through the transmitter, it is important to modulate the data signal to some particular frequency. Here data signal is modulated into high frequency carrier signal. This modulated signal is transmitted through the transmitter. At the receiver first the received signal is demodulated. But it is necessary to know the receiver that which modulation scheme is used at transmitter. Using that knowledge receiver can demodulate the data signal from received signal. In coherent technique, the receiver has prior knowledge about modulation scheme used at receiver. But in non-coherent technique, receiver does not know which modulation scheme is used. So at that time we cannot get theexact data. To overcome this problem, we can use automatic modulation scheme detection technique.

Algorithm for proposed solution is as follow.

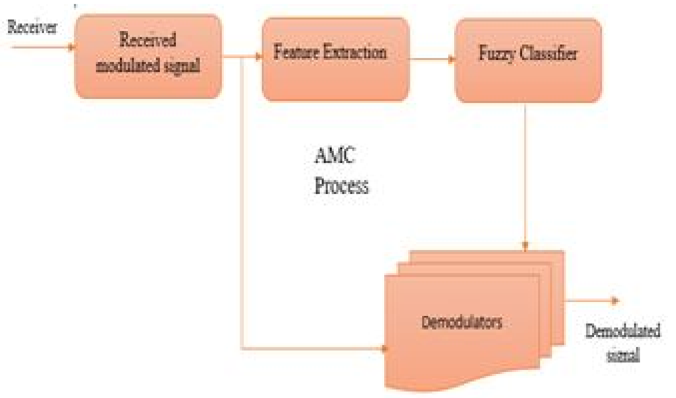

Figure 1: Flow of proposed work

Process of AMC consists 4 steps. In the first step, receiver receives modulated information signal. This signal is given to second step, which is feature extraction block. In the third step, extracted features are given to the fuzzy classifier block. The output of fuzzy classifier identifies the type of modulated signal. According to this output, the received signal is given to the particular demodulator at fourth stage. Finally, the output of demodulator is demodulated information signal.

III. SIGNAL MODEL

Equation for the received signal at receiver is given as follow:

$$rx(t) = tx(t)e^{j\Theta c} + n(t) \quad \text{.............. (1)}$$

where, rx(t) is received signal, tx(i) is transmitted signal and n(t) is complex white Gaussian noise signal which is added during transmission. Θc is the phase of carrier signal.
In this paper, digital modulation schemes ASK, FSK and PSK are classified.

Equation for ASK signal is,

$$Tx_{ASK}(t) = \sum A_i u(t-iT) \quad \text{................ (2)}$$

where, $A_i \in \{2m-1-M, M=1,2....M\}$

Equation for PSK signal is,

$$Tx_{PSK}(t) = S^{1/2} e^{j\Theta i} u(t-iT) \quad \text{..................(3)}$$

Where, $\Theta i \in \{2\Pi/M, M=1, 2....M\}$

Equation for PSK signal is,

$$Tx_{FSK}(t) = S^{1/2} e^{j(\omega i(t) + \Theta i)\, u}(t-iT) \quad \text{..................(4)}$$

Where, $\Theta i \in (0,2\,\Pi)$

$\omega i \in \{\omega 1,\omega 2,.....\omega_M\}$

In above equations, Sis the signal power, *N* is the number of observed symbols, *T* is the symbol duration and u(t) is the pulse shape of duration *T.*

IV. FEATURE EXTRACTION

From above equations, it is clear that for particular modulation type, one or more than one parameters are being changed. For example, in ASK modulation, amplitude of a signal is changed, in PSK modulation, phase of a signal is changed and in FSK modulation, frequency of a signal is changed. Number of parameters and the way in which they are changed are specific to each modulation type. They may be described by a set of statistical parameters which are used as membership functions of fuzzy classifier. After initial selection, chosen parameters are described as follow.

4.1 Kurtosis of a signal

The first feature of modulation type is kurtosis of a signal envelop. Kurtosis is defined as a measure of how outlier-prone the distribution is. It is also a measure of the "peakedness" of the probability distribution of a real-valued random variable. Higher kurtosis means more of the variance is due to infrequent extreme deviations, as opposed to frequent modestly-sized deviations. According to signal processing theory, kurtosis for a normal distribution is 3. Value of the kurtosis for the distributions which are more outliner prone than normal distribution is greater than 3. Theoretically the envelope for FSK and PSK signal has Rician distribution. Practically for SNR>10 dB, Rician distribution is approximately same as Gaussian distribution. So for PSK and FSK signals, Kurtosis is nearly 3. The envelope distribution of ASK signal is combination of both Rician and Rayleigh distribution. So the kurtosis value of ASK signal is nearly 1. [10]

4.2 Amplitude, phase and frequency

As stated in previous section, in ASK modulated signal, amplitude is changed. Same as in PSK modulated signal, phase of signal is changed. In FSK modulated signal, frequency of a signal is changed. So at primary stage we can classify signal according to these three basic parameters. [9]

4.3 Number of points of partitioned magnitude of constellation diagram

The constellation diagram is taken from the analytic form of the signal after down sampling to the baseband. From this feature, we can classify PSK and FSK in one class and ASK in other class. Noise free normalized constellation points of PSK and FSK modulation lie on the unit circle and the noise free constellation points of ASK modulation lie on, inside, and/or outside the unit circle. Thus, this feature is useful in separating near constant amplitude modulation from amplitude varying modulations. [9]

4.4 Standard deviation

Standard deviation is a measure of dispersion of a set of data from its mean. The more spread apart the data, the higher standard deviation. Basically standard deviation is a square root of variance. It is the root mean square (RMS) deviation of the values from their arithmetic mean.

For example, in the population {3, 9}, the mean is 6 and the standard deviation is 3. This may be written: {3,9} ≈ 6±3. In this case 100% of the values in the population are at one standard deviation of the mean.

(1) Sigma- AP (σap):

σap is the standard deviation of the absolute instantaneous phase, given as

$$\sigma_{ap} = \sqrt{\frac{1}{C}\sum_{a_n(i)>a_t}\phi_{NL}^2(i) - (\frac{1}{C}\sum_{a_n(i)>a_t}|\phi_{NL}(i)|)^2} \quad \ldots\ldots\ldots\ldots\ldots(5)$$

Where σNL (i) is the value of the normalized centered component of the instantaneous phase, C is the number of samples in σNL(i) for which an(i)>at, where it is the threshold for a(i) below which the estimation of instantaneous phase becomes very difficult due to noise or in other words we can say it becomes noise sensitive. [13]

(2) Sigma-DP (σdp):

σdp is the standard deviation of the direct instantaneous phase, given as

$$\sigma_{dp} = \sqrt{\frac{1}{C}\sum_{a_n(i)>a_t}\phi_{NL}^2(i) - (\frac{1}{C}\sum_{a_n(i)>a_t}\phi_{NL}(i))^2} \quad \ldots\ldots\ldots\ldots\ldots(6)$$

It is the standard deviation of the direct phase and not absolute phase, calculated over the non-weak intervals of the signals. [13]

(3) Sigma-AA (σaa):

σaa is the standard deviation of the normalized centred absolute amplitude given as

$$\sigma_{aa} = \sqrt{\frac{1}{N_s}[\sum_{i=1}^{N_s}a_{cn}^2(i)] - [\frac{1}{N_s}\sum_{i=1}^{N_s}|a_{cn}(i)|]^2} \quad \ldots\ldots\ldots\ldots(7)$$

It can be noted that acn's absolute standard deviation is being calculated and not of acn directly. [13]

(4) Sigma-AF (σaf):

σaf is the standard deviation of the normalized centred absolute frequency given by

$$\sigma_{af} = \sqrt{\frac{1}{C}[\sum_{a_n(i)>a_t}f_N^2(i)] - [\frac{1}{C}\sum_{a_n(i)>a}|f_N(i)|]^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Now it is noted that normalization of the frequency can be done by many ways but the method of normalization chosen is given below. [13]

$$f_N(i) = \frac{f_m(i)}{r_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Where, $f_m(i)=f(i) - m_f$ and

$$m_f = \frac{1}{N_s}\sum_{i=1}^{N_s}f(i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Classification according to these above parameters are defined as follow:

1. First, minimum and maximum values of basic parameters like amplitude, phase and frequency are measured by using software.
2. In the second step of classification, classification of digital modulated signals is done by using number of points on constellation diagram parameter. For ASK signal, points of constellation diagram lie on, inside and/or outside the unit circle. For PSK and FSK, points of constellation diagram lie on unit circle. So by this way we can classify signals as ASK in one class and PSK and FSK as other class.
3. In the third step of classification, kurtosis value is measured. As stated before, kurtosis value is more for amplitude modulated signal and less for phase and frequency modulated signal. So at basic stage we can classify ASK modulation as one class and PSK and FSK modulation as other class. So at this stage, we can get ASK modulation signal.

4. Now the third step is used for classification of PSK and FSK modulated signal. these signals are angle modulated type. So standard deviation of instantaneous frequency is calculated. These values are compared with threshold value to know if it is FSK or PSK signal.
5. It is clear that, FSK signal has ore frequency variation than PSK signal. so value standard deviation of instantaneous frequency is more in FSK as compared to PSK. Thus we can classify signal as PSK or FSK.
6. For PSK signal, by using frequency domain techniques we can classify signal as BPSK or QPSK signal. [13]

V. METHOD USED FOR AUTOMATIC MODULATION SCHEME DETECTION

In previous researches, automatic modulation scheme recognition is done using various methods. Some of them are as follow:

- AMC using Neural network
- AMC using information theoretic similarity measures
- AMC using support vector mechanism(SVM)
- AMC using fuzzy logic [3]

The reason for choosing fuzzy logic for AMC in this paper is given as below.

- The fuzzy logic system enables the inclusion of linguistic knowledge in a systematic way. But in artificial neural networks, the non-transparent network design prevents the inclusion of linguistic knowledge so we need a random selection of initial parameters which prolongs the learning phase.
- All parameters of the fuzzy logic system have a physical meaning. There is no such clear connection between inputs, individual parameters, and outputs in artificial neural networks.
- In some experiments, we do not have the basic knowledge about the process available. In such cases, it is possible to construct a fuzzy logic system with an adaptive algorithm which functions in the same way as the artificial neural network. The knowledge gained later can be included in the form of initial setting of parameters from the fuzzy logic system or in the form of the rule base change.
- Fuzzy logic system is less extensive and thus it requires less processing time compared to other techniques.

5.1 Fuzzy Logic

In Boolean logic, the truth values of variables may only be 0 or 1 By contrast, Fuzzy logic is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1. The range of value of fuzzy logic falls between completely true and completely false with partially truth and partially false. It is a simple, rule-based IF X AND Y THEN Z approach to solve control problem rather than attempting to model a system mathematically.[16]

5.2 Fuzzy Logic Classifier

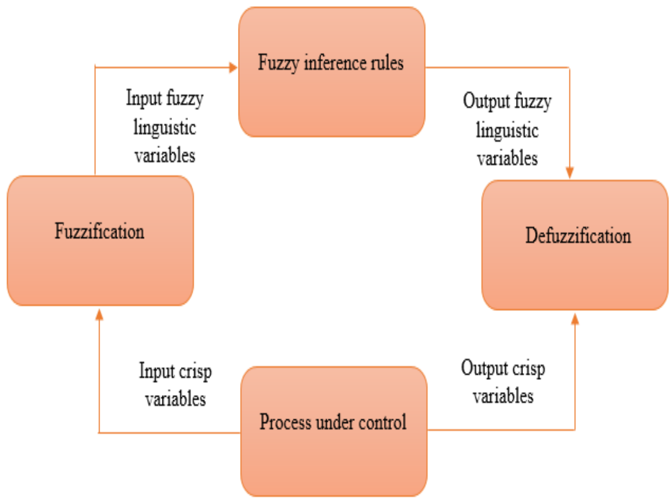

Figure 2: Block Diagram of Fuzzy Classifier

Block diagram of fuzzy logic classifier is shown in this figure. FC contains blocks such as fuzzification, defuzzification, rule sets and processing. First the output of pre- processing is given to the fuzzification block. These values are known as input crisp variables. Then the output of fuzzification block is given to the rule set. According to the rules output of FC is generated. This value of output is called output fuzzy linguistic variable.

After this result, we can get proper output by using defuzzification process. By this way, fuzzy classifier works.

VI. IMPLEMENTATION AND SIMULATION RESULTS

In this paper, AMC for digital modulation schemes is developed using fuzzy logic. For this, first I produced all type of modulators and demodulators are generated using MATLB software. A random number generator has been used to generate the signals.

6.1 Generation of fuzzy logic classifier for digital modulation techniques with 3 parameters:

For deriving the range of membership function, we must have any one parameter as variable. According to that variable, we can define the range of all other parameters. In these following experiments, I have taken carrier signal frequency as variable frequency. For different values of carrier signal frequency, we get different values. So according to those range of values, all other parameters are derived.

(i) Carrier Frequency1: 2 MHz
(ii) Carrier Frequency2: 4 MHz
(iii) Number of Signal Samples: 2001
(iv) Features Extracted: Amplitude, Phase, Frequency
(v) Fuzzy Model Used: name: 'ask_psk_fsk_18_3_rules'
type: 'mamdani'
input: [1x3 struct]
output: [1x1 struct]
rule: [1x27 struct]
(vi) Modulators: ASK, FSK, PSK

The membership functions for all parameters like amplitude, phase and frequency are as follow:

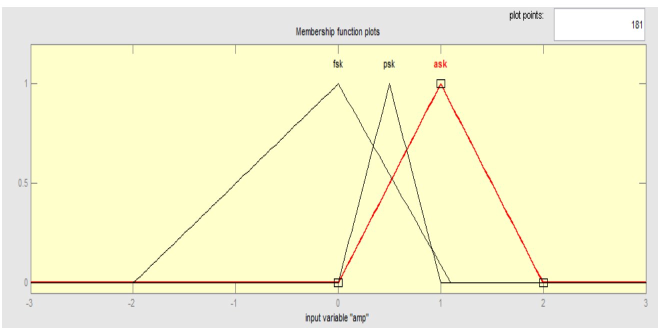

Figure 3: Membership function of amplitude

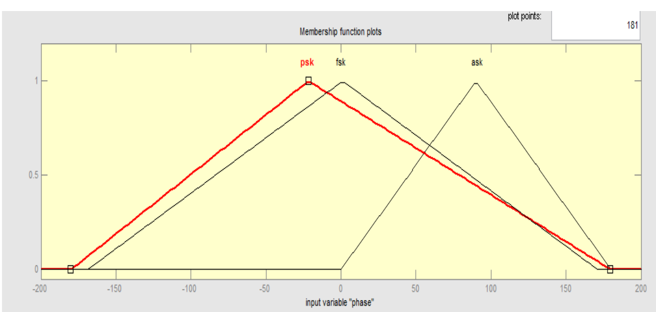

Figure 4: Membership function of phase

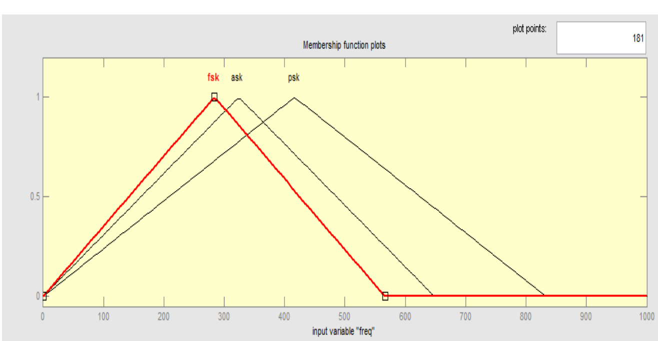

Figure 5: Membership function of frequency

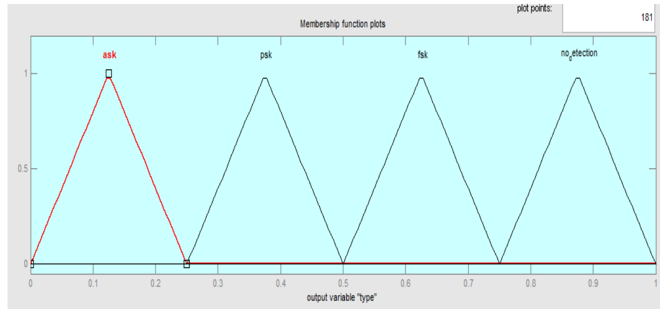

Figure 6: Membership function of Output (Type)

Rule editor:

Here, there are 3 inputs and 3 membership functions in this FC. So total 27 rules are defined.
Rules used for defining fuzzy classifier are as follow:

1. If (amplitude is ask) and (freq is ask) and (phase is ask) then (type is ask)
2. If (amplitude is ask) and (freq is ask) and (phase is psk) then (type is ask)
3. If (amplitude is ask) and (freq is ask) and (phase is fsk) then (type is ask)
4. If (amplitude is ask) and (freq is psk) and (phase is ask) then (type is ask)
5. If (amplitude is ask) and (freq is psk) and (phase is psk) then (type is psk)

Likewise, 27 rules can be defined.

Fuzzy Classifier Output:

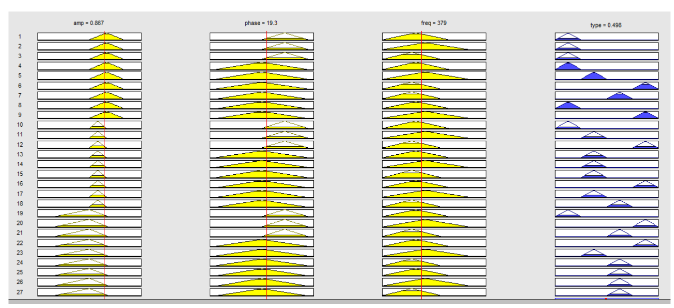

Figure 7: Fuzzy Classifier Output

Result table:

Table 1: Results for digital modulation fuzzy classifier

Sr. No.	Amplitude	Phase	Frequency	Fuzzy output
1	0.200	120	270	1.30(ask)
2	1.65	19	240	4.95(fsk)
3	1.3	66	4.5	3.1(psk)

Similarly, we can find values of this table for all 27 rules.

6.2 Generation of fuzzy logic classifier for digital modulation techniques with more parameters:

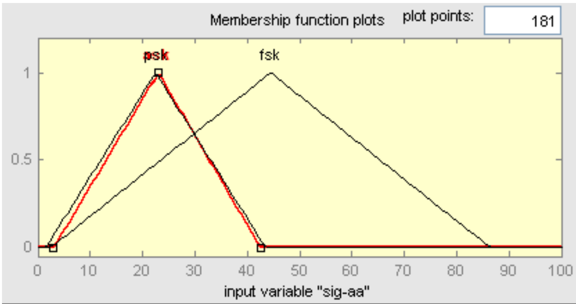

Figure 8: Membership function of sigma-aa

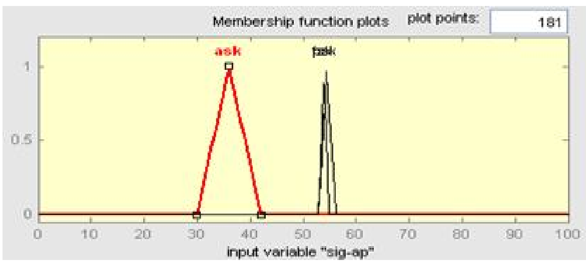

Figure 9: Membership function of sigma-ap

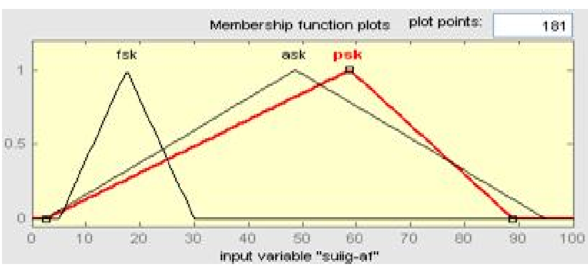

Figure 10: Membership function of sigma-af

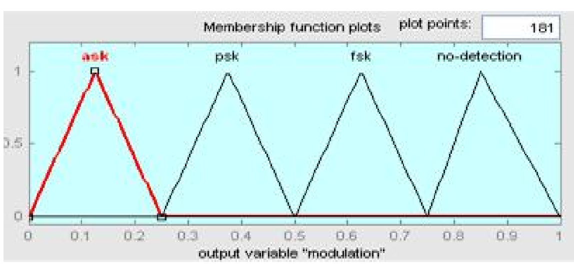

Figure 11: Membership function of Output (Type)

Rule editor:

1. If (sig-aa is ask) and (sig-af is ask) and (sig-ap is ask) then (type is ask)
2. If (sig-aa is fsk) and (sig-af is fsk) and (sig-ap is fsk) then (type is fsk)
3. If (sig-aa is psk) and (sig-af is psk) and (sig-ap is psk) then (type is psk) ….

Likewise, further 27 rules can be defined as below.

Fuzzy Classifier Output:

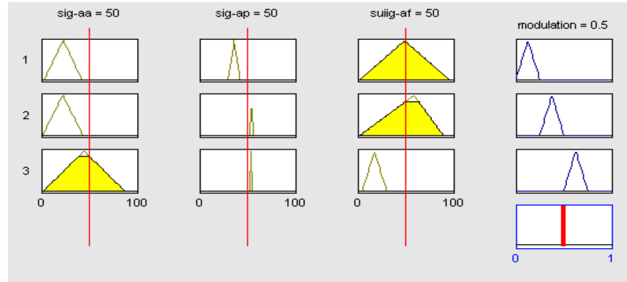

Figure 12: Fuzzy Classifier Output

Result table:

Table 2: Results for digital modulation fuzzy classifier (6 parameters)

Sr. No.	Sigma-aa	Sigma-af	Sigma-ap	Fuzzy output
1	23.5	36.7	58.4	0.125 (ask)
2	22.3	54.8	50	0.375 (psk)
3	45.2	54.8	18.7	0.625 (fsk)

Similarly, we can find values of this table for all 27 rules.

Demodulation of the received signal:

As stated, according to the output of fuzzy classifier, we can decide the type of modulation scheme. After knowing this the signal is given directly to that particular demodulator.

6.3 Efficiency Calculation:

For different modulation schemes like ASK,PSK& FSK , Using different values of SNR , Accuracy is measured. Efficiency is measured by performing multiple number of iteration of the algorithm. The more number of iterations, the better result is obtained. It can be seen that for higher values of SNR , accuracy increases. Efficiency in terms of % is calculated as below.

Table 3: Efficiency of a fuzzy classifier

Scheme	SNR : 5 dB		SNR : 10 dB		SNR : 20 dB	
	No. of iterations	No. of iterations	No. of iterations	No. of iterations	No. of iterations	No. of iterations
	10	100	10	100	10	100
ASK	86%	81%	96%	90%	100%	98%
PSK	83%	83%	95%	93%	99%	93%
FSK	83%	80%	100%	88%	97%	100%

VII. CONCLUSION

A classification system which does not require prior knowledge of the signal parameters has been introduced in this paper. It includes digital modulation techniques. MATLAB software is used to create AMC using fuzzy logic. Simulation results proved that the algorithm, using proposed set of the features is very robust with respect to SNR. Fuzzy classifier requires various parameters of the modulated signal from which they can be identified. This method allows creating intelligent radio links, efficient monitoring and control systems. This work is another small milestone in a large body of research conducted in this area. From this paper, it is proved that, with increase in SNR value , accuracy of AMC is increased.

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