SIGNAL CLASSIFICATION AND IDENTIFICATION FOR COGNITIVE RADIO

A Thesis submitted in partial fulfilment of the Requirements for the degree of

Master of Technology

In

Electronics and Communication Engineering

Specialization: Communication and Networks

By

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MAY 2015

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ROURKELA- 769008, ODISHA, INDIA

CERTIFICATE

This isto certify that the work in this thesis entitled "**SIGNALS CLASSIFICATION AND IDENTIFICATION FOR COGNITIVE RADIO"** by Mr. **MANISH KUMAR AGRAWALA**is a record of an original research work carried out by his during 2014-2015 under my supervision and guidance in partial fulfilment of the requirement for the award of the degree of Master of Technology in Electronics and Communication Engineering (Communication and Networks), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge, has been submitted for any degree or diploma elsewhere.

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ROURKELA- 769008, ODISHA, INDIA

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Manish Kumar Agrawala

213EC5236

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Manish Kumar Agrawala

ABSTRACT

From the past few decades the need for higher data rates in wireless communication has increased exponentially. The spectrum access policy has restricted the growing demand of wireless devices. Out of the total given spectrum only a small portion is given for open user and a large part is given for licensed user. But the unlicensed spectrum is used more than the licensed spectrum, which forced the FCC to design a policy so that the limited spectrum can be used efficiently. The spectral occupancy of licensed spectrum is very less as compared to the unlicensed spectrum. Cognitive radio has emerged as a solution for this inefficient utilization of licensed spectrum; it identifies the unused portion of licensed spectrum which is called white space and makes them available for unlicensed user. Before giving the white space to the secondary user for transmitting the signals, it is required to identifies and classify the signals, so that the cognitive radio can work efficiently.

so to classify the incoming signals many method are used like feature extraction method and neural network method.in feature extraction method, first we have to find out the feature value from all the signals then by comparing that with the threshold value we can find out the modulation type of the signal.In neural network method, we have to give the feature value to a neural network and that network will find out the type of the signal.

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1

Introduction to cognitive radio

From the last few decades the use of wireless communication has been increasing exponentially, because of the increase in the number of user in electronic application. The spectrum that is available is remain constant, but the users are increasing.so it will lead to spectrum scarcity. The available spectrum is divided among two kind of user i:e: licensed user and unlicensed user. The unavailability of spectrum is due to the inefficient utilization of the licensed spectrum, it is observed that around 80-85% of the licensed spectrum is not in use at any time.

Now to overcome the inefficient utilization of the spectrum and to fulfill the demand, a new concept called “Cognitive-radio “comes into the picture. The Cognitive Radio is a technology which efficiently utilizes the licensed spectrum without causing any harm to the licensed users. It searches the licensed frequency bands for unused spectrum, and uses them efficiently. The unused licensed spectrum is also known as ‘white spaces’

1.1 Cognitive Radio Concept

Cognitive Radio derives its name from the word ‘cognitive’ which means process of acquiring knowledge by the use of reasoning, intuition or perception. It is a new technology which scans the radio spectrum and searches for white spaces in it. It enables the unlicensed user to use the licensed bands without causing any significant interference to the licensed user. The licensed user is also known as primary user (PU). The users which are having no rights to access the licensed bands are known as secondary users (SU)

1.2 Characteristics of Cognitive Radio (CR)

CR is an intelligent radio system which check the availability of the spectrum and utilized them efficiently. CR has the following characteristics which help in achieving this goal [23]

1) ***Flexibility:*** Cognitive radio should able to change its parameter like data rate, modulation technique, etc.
2) ***Agility:*** CR should be able to operate in several spectrum bands in order to utilize white spaces observed in different frequency bands.
3) ***Sensing:*** CR should be able to sense the RF environment and internal working parameters in order to sense the existence of spectrum holes and to provide an overview of the radio spectrum utilization.
4) ***Networking:*** CR should be able to communicate between different nodes of the wireless communication to bring synergy in using the radio resources. Sharing of information and cooperatively passing decisions on the radio resources.

1.2.1 Terms related to Cognitive Radio Network [9]

Following are some important terms related to cognitive radio network

1. Primary user- A licensed user is called as a primary user who has the authority to use the licensed band.
2. Secondary user- A user who has no right to access the licensed spectrum is called as a secondary user. It is also known as CR user, because the CR detect the white space in the licensed band and the secondary user transmit the data in that white space..
3. White spaces- The licensed spectrum which are not in use is known as white space. It provides opportunity for secondary users to access that unused spectrum with the help of CR technology. One of the main aims of CR is to search for white spaces. It is also known as spectrum holes.

1.3 IEEE 802.22- an exclusive standard for Cognitive Radio [9]

It has been observed by FCC, spectrum scarcity is an artificial result of the way the bands are regulated. Large part of the licensed radio spectrum is used inefficiently by the licensed user adds to the problem of growing demand for additional spectrum. The commercial success of unlicensed bands has compelled FCC to provide more unlicensed spectrum. In order to increase the spectrum utilization of licensed bands, FCC has allowed unlicensed users to access the licensed bands without affecting the PU.IEEE 802.22 is a standard which gives the opportunity of utilizing the unoccupied TV bands for CR users without causing any significant interference to the licensed user. This standard is also known as WRAN standard [6]. It concentrates mainly on VHF/UHF TV bands due to their highly favorable propagation characteristics and worldwide move from analog to digital TV creating spectrum opportunities called "White Spaces". IEEE 802.22 concentrates on rural areas, which constitutes around 45% of the world's population where wireless is a viable source of communication. It specifies the PHY layer and MAC layer specification for different methods and under different operating conditions in order to exploit the unutilized licensed spectrum.

1.4 Motivation

As the wireless communication user is increases continuously, so the demand for the available spectrum is also increases but the radio spectrum that is available with us is constant, so it is required to use that available spectrum efficiently. Two kinds of user are there in wireless communication, one is licensed user and the other is unlicensed user. The licensed user uses a large portion of the spectrum whereas the unlicensed user uses only a small portion. But the licensed user utilizes that licensed spectrum inefficiently which causes the spectrum scarcity. So we need a new technology which utilizes that licensed spectrum efficiently. Cognitive radio is intelligent radios which detects the white space in licensed band and make them available for the unlicensed user. The secondary user transmit the date through cognitive radio in the white space,

For the cognitive radio to work efficiently, the classification and identification of signals that is going to transmit is required.

1.5 Thesis Organization

The thesis has been organized into five chapters. The current chapter gives theintroduction to the concept of CR, its operation, characteristics and need. It also gives a brief overview of IEEE 802.22 standard. The motivation and the objective present an essence of the dissertation

Chapter 2: It describes the Automatic Modulation Classification for the cognitive radio.

Chapter 3: The third chapter describes the AMC for analog and digital signals.

Chapter 4: The fourth chapter describes the advantage of the ANN network over the other networks.

Chapter 5: It presents the conclusion and future scope.

2

Automatic modulation classification for cognitive radio

2.1 LITERATURE REVIEW

From the past few years, cognitive radio has become a key research area in communication system. Automatic modulation classification (AMC) is an important component which improves the overall performance of the cognitive radio [5] [6], AMC is the automatic recognition of the modulation scheme of the received signal. AMC is always an intermediate step between the demodulation and detection.

Automatic modulation recognition has many application in military intelligence system, such as spectrum surveillance, counter channel jamming, threat evaluation, identification interference level [3][2].AMC is also very use full in civilian application mainly in dynamic spectrum management.

The main function of AMC [2] is detection of primary user in cognitive radio system. The AMC algorithm when combined with a software defined radio, it will form the CR.

As the numbers of user in wireless communication are increasing drastically, so the usage of radio spectrum efficiently is a very important task. The available radio spectrum is divided into two types of user licensed and unlicensed.in unlicensed spectrum, the users can transmit the data with a small amount of interference. But in the licensed band only the licensed user can transmit their data, so here the interference level is very low.

The recent studies show that the usage of the licensed band at any location is as low as 15% [6] which is very low. Now the licensed spectrum is very high than the unlicensed spectrum band. But the efficient utilization of the licensed band is less than the unlicensed band[9][11] .so the solution for this imbalanced created by the static spectrum allocation policy is to allow the other users to use the licensed band without creating any interference with the primary user, and the technology use for this purpose is CR technology. Which first check whether the band is in use or free, if the band is free then it allocate that unused band to the other user.so that the frequency band can be used efficiently.

2.2 WHY AMC

The main job of the cognitive radio is to use the available spectrum effectively. The cognitive radio first detects whether there is any primary user transmitting data in the licensed band or it is free. If the band is free, then it allows the other user to transmit their data in that vacant band. For detecting whether the band is free or not and utilizing that available band effectively, the cognitive radio required the AMC block. The AMC is placed between the demodulator and signal detector.it find out the modulation type of the signal.

Modulation is the process in which one of the characteristics of the carrier signal varies according to the variation of the massage signal. For identification of signals, modulation type is used as main characteristics. AMC is use to find out the modulation type of the detected signal automatically.

Normally two methods are used to find out the modulation type of the signal.

(1) Decision theoretic
(2) Statistical pattern recognition

Decision theoretic approach uses hypothesis and probability testing argument, based on probability and careful analysis it calculate the threshold value, and by comparing the feature value of the detected signal with this threshold value, it find out the modulation type of the signal.

However the pattern recognition approach do not required any probabilistic analysis for calculating the threshold value. This pattern recognition approach is divided into two subsystems

(a) Feature extraction subsystem
(b) Recognition subsystem

Feature extraction subsystem is responsible for extracting the feature value from the detected signals, and the recognition subsystem is used for classification of incoming signal based on feature value.

2.3 DIFFERENT TYPE OF SIGNALS:

Many type of signals used cognitive radio technique for utilization of the radio spectrum. Like IEEE 802.22 WRAN, NTSC, PAL, SECAM. The IEEE 802.22 used the unused spectrum in the television frequency band. This signal is designed to operate in the TV broadcast band. The National Television System Committee (NTSC) is an analog television system mainly used in western countries. Phase Alternating Line (PAL) is a color encoding system for analog television. Sequential Color with Memory (SECAM) is used in analog color television system.

3

AUTOMATIC MODULATION CLASSIFICATION FOR ANALOG AND DIGITAL SIGNALS

Normally all the signals that we are using is either analog or digital modulated signals. So before transmitting that signals we need to classify and identify the modulation type of all the modulated signals.

3.1 classification of analog signals

Now a days, normally digital signals are in used, but analog signals are also used in many application, so we need to classify the analog signal, here I have taken some of the analog modulated signals like AM, FM, PM, DSB, VSB, LSB, USB.

An automatic modulation classifier consist of three stage

(1) Pre processing

(2) Key feature extraction

(3) Modulation classification

The signals that are received by the receiving antenna is given to the automatic modulation classifier block. Now the classifier extracts the key feature from the given signal.

All the modulating signals have some individual feature, which are unique to that signal, so by extracting that feature and comparing that with a suitable threshold value, we can decide the type of modulation.,

In analog modulation signal, all the information are stored either in amplitude, phase, or frequency of the carrier signal. If we consider these three part, then we can decide the type of modulation.

To classify the analog signals, considered four key features.

(1) The maximum value of the spectral power density of the normalized centered instantaneous amplitude (γ_{max})

γ_{max}=max|DFT (a_{cn}(i))|2/Ns (3.1)

where

Ns: number of sample

a_{cn}(i):value of the normalized centre instantaneous amplitude

$a_{cn}(i)=a_n(i)-1$

$a_n(i)=a(i)/m_a$

m_a: average value of the instantaneous amplitude

(2) The standard deviation of the absolute value of the centered nonlinear component of the instantaneous phase (σ_{ap}) [1]

$$\sigma ap = \sqrt{\left(\frac{1}{c}\left(\sum_{a_n(i)>a_t} \Phi^2{}_{NL}(i)\right) - \left(\frac{1}{c}\sum_{a_n(i)>a_t} \left|\Phi_{NL}(i)\right|\right)^2\right)} \tag{3.2}$$

Φ_{NL} is the value of the centered nonlinear component of the instantaneous phase.

C is the number of sample in Φ_{NL}(i) for which $a_n(i)>a_t$

a_t is the threshold value.

(3) Standard deviation of the centered nonlinear component of the direct instantaneous phase (σ_{dp}) [1]

$$\sigma_{dp} = \sqrt{\left(\frac{1}{c}\left(\sum_{a_n(i)>a_t} \Phi^2{}_{NL}(i)\right) - \left(\frac{1}{c}\sum_{a_n(i)>a_t} \Phi_{NL}(i)\right)^2\right)} \tag{3.3}$$

Φ_{NL} is the value of the centered nonlinear component of the instantaneous phase

C is the number of sample in $\Phi_{NL}(i)$ for which $a_n(i)>at$

a_t is the threshold value

(4) Now to calculate the spectrum symmetry around the corner frequency, the last key feature is used that is the' p' value

These above four key feature are used to classify the incoming modulated analog signals.

The first feature is used to differentiate the FM signals from the rest of the signals. Because in FM signals, the amplitude is always constant and the frequency of the carrier signal vary according to message signal. So the normalized centered instantaneous amplitude is zero, there is no information in the amplitude of the FM signal. So the γ_{max} is less than the threshold value for the FM signal, and for rest of the signal, the amplitude of the carrier signal changes according to the message signal, means the information is present in the amplitude of the carrier signal.

The second key feature is used to differentiate the combined AM-FM signal from the DSB signals, since in the DSB signal, only the sidebands is present and no signal present at the carrier frequency, it content only two sidebands. So it phase takes two value either 0 or π.The centered value of the phase is $\pi/2$.Which is a constant, since the phase is constant, hence it does not contain any information. But in the combined AM-FM signal, the phase is continuously changes according to the message signal, hence it contain some phase information, means the σ_{ap} value is greater than the threshold value. Hence the σ_{ap} can differentiate the DSB and combined AM-FM signal.

Now the third key feature is used to differentiate the AM and VSB signal from the rest of the signal, since for an AM signal, the message is contain in the amplitude of the carrier signal, and the frequency and the phase of the modulated signal is always constant. Now the VSB signal is also like an AM signal. The only difference between the VSB and AM is that, in VSB signal, one sideband is completely present and some part of the other sideband is present. So for both the AM and VSB signal, there is no direct phase information .Hence its σ_{dp} value is less than the threshold value, and for rest of the signal, there is some direct phase information, for DSB signal also, the phase is either 0 or π, means a direct phase value is there, hence the σ_{dp} of this signal is more than the threshold value of the signal. Hence σ_{dp} can differentiate the AM-VSB signal from rest of the signal.

The fourth key feature is P value, The P value is about the power of the lower sideband and upper sideband, means it can differentiate the signals whose lower and upper side band have different amplitude, because the power is directly depend upon the square of the amplitude. The P value can differentiate the AM signal from the VSB signal. In AM signal the lower sideband and upper side band have sane amplitude value. So the power of the lower and upper side is same, hence the P value is zero. The VSB signal contain one complete sideband and some portion of the other side band. So the amplitude of the amplitude of the two sideband is different, hence the power is also different for upper and lower sideband. So the P value is not zero.SSB signal only contain one sideband, either upper sideband or lower sideband. If it contain upper side then it is called USB signal and if it contain only lower sideband, then it is called LSB signal. Power of lower and upper sideband is different, so its P value is greater thanzero. Now in FM and DSB signal, the lower and upper sideband contain some amplitude, hence the power of lower of lower and upper sideband is same, so the P value is zero. Hence the P value can differentiate the AM signal from the VSB signal and also can differentiate the SSB signal from all other signals.

The below figure shows the, signal flow graph of the analog modulated signal.

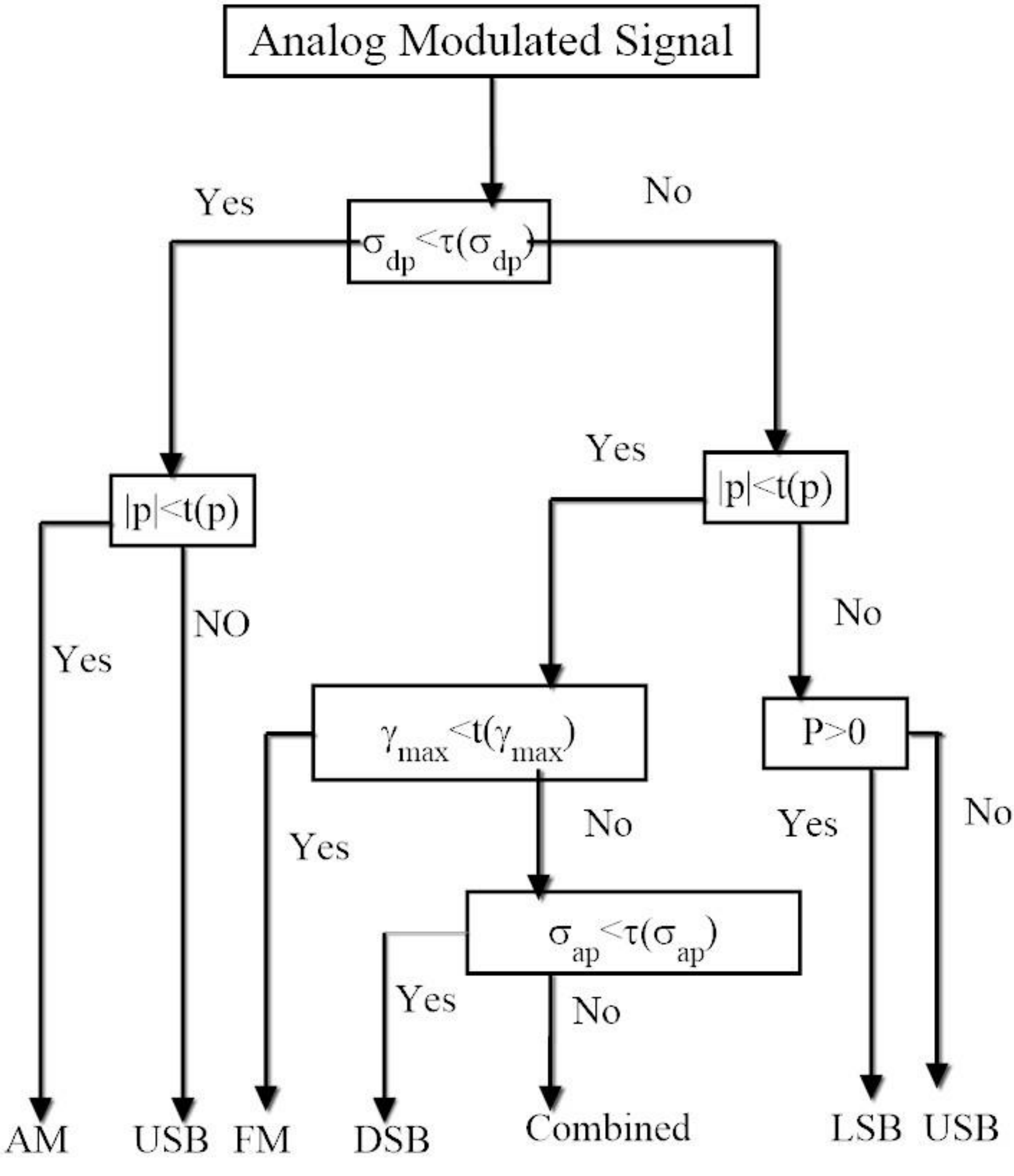

Figure 3.1: signal flow graph of analog modulated signal

3.1.2 DIFFERENT TYPE OF ANALOG MODULATED SIGNALS:

3.1.2.1 AM:

Amplitude modulation is the process in which the peak amplitude of the carrier signal will be varied linearly with respect to variation of the amplitude of message signal.

Let the message signal $m(t)=A_m \cos w_m t$

And the carrier signal $c(t)=A_c \cos w_c t$

Then the AM signal is

$S(t)=A_c[1+k_a m(t)]\cos w_c t$

$S(t)=c(t)+k_a.m(t).c(t)$

Where

K_a=amplitude sensitivity of AM modulator

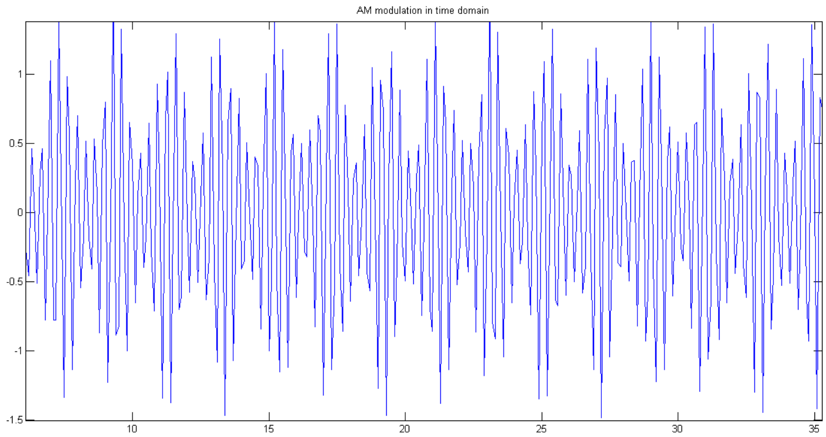

Figure 3.2: AM modulated signal

3.1.2.2 DSB:

It is the modulator process in which the amplitude of carrier signal will be varied with respect to the variation of amplitude of message signal. The only difference between AM and DSB is that, the spectrum of DSB signal does not contain any component at the carrier frequency.

The DSB signal is

$S(t)=A_c.m(t).\cos w_c t$

Where

m(t)=modulating signal

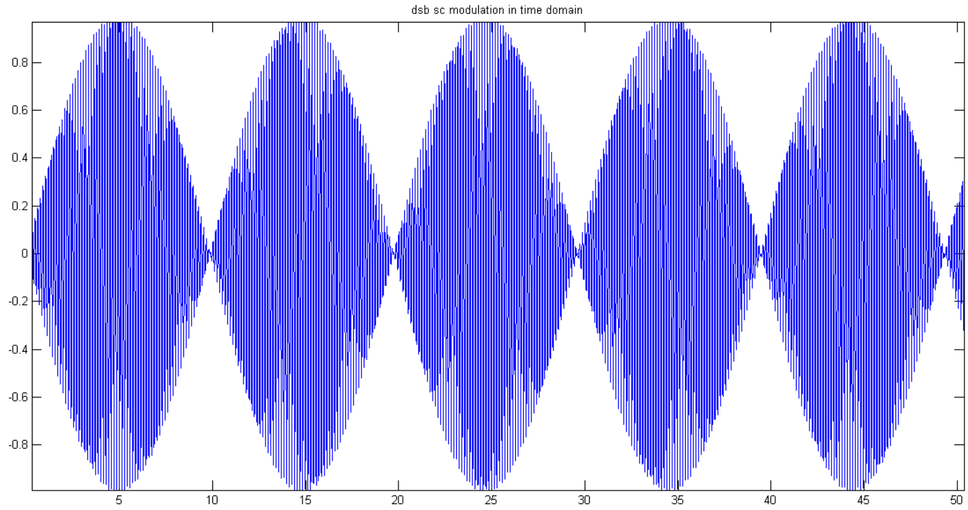

Figure 3.3: DSB-SC modulated signal

3.1.2.3 SSB:

In the SSB modulation, the modulated signal contain only one sideband, either lower sideband or upper side band and also it suppressed the carrier signal from the modulated signal.

3.1.2.4 USB:

In USB, the modulated signal suppressed the carrier signal and also the lower sideband.it contain only the component at upper sideband.

The USB modulated signal is

$S(t)=A_c.m(t).\cos w_c t-A_c.\widehat{m(t)}.\sin 2\pi f_c t$

Where

m(t)=message signal

$\widehat{m(t)}$=Hilbert transform of message signal

3.1.2.5 LSB:

In lower sideband, the modulated signal suppressed the carrier signal and also the upper sideband.

The LSB modulated signal is

$S(t)=A_c.m(t).\cos w_c t+A_c.\widehat{m(t)}.\sin 2\pi f_c t$

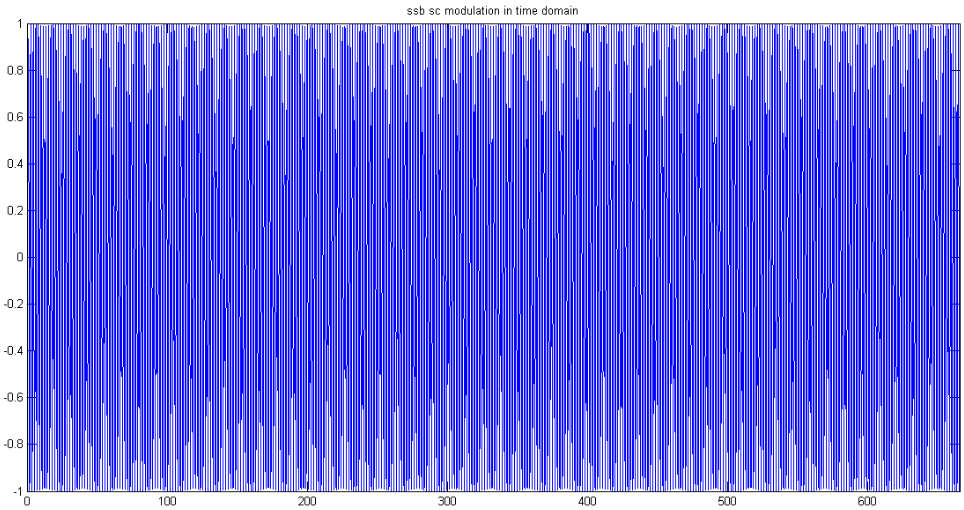

Figure 3.4 : SSB modulated signal

3.1.2.6 VSB:

In this modulation, one sideband and some portion of another sideband is transmitted.

3.1.2.7 FM:

Frequency modulation is the process, in which the frequency of the carrier signal will be varied with respect to the variation of message signal.

Let the modulating signal is $m(t)=A_m\sin 2\pi f_m t$

And the carrier signal is $c(t)=A_c\sin 2\pi f_c t$

Now the FM signal is

$S(t)=A_c\cos[2\pi f_c t+\beta\sin 2\pi f_m t$

Where

β=modulation index of FM

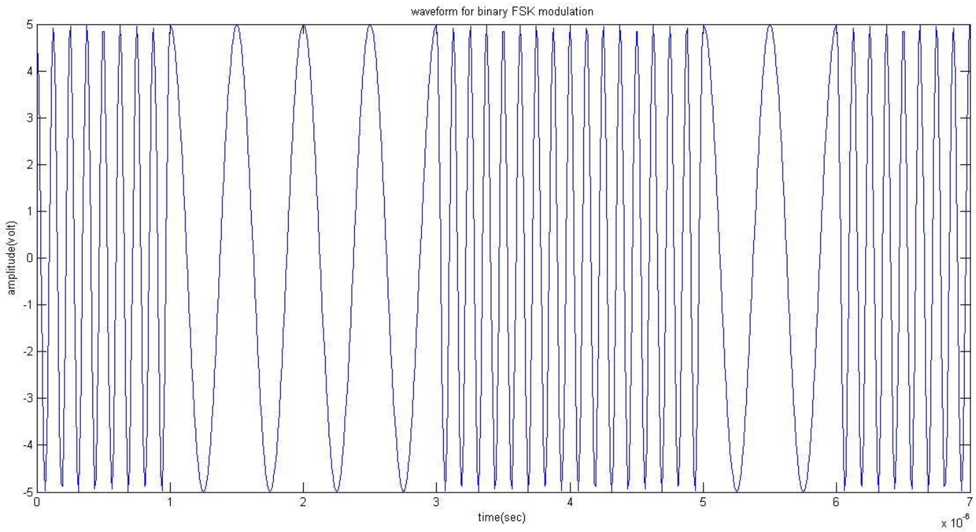

Figure 3.5: FM modulated signal.

3.1.3 RESULT:

Table 3.1: feature value of AM signal

Key feature of AM signal	**Corresponding value**
γ_{max}	59.75
σ_{ap}	0.16
σ_{dp}	0.16
p	0

Table 3.2: feature value of USB signal

Key feature of USB signal	**Corresponding value**
γ_{max}	43.87
σ_{ap}	0.74
σ_{dp}	0.74
p	-0.58

Table 3.3: feature value of LSB signal

Key feature of LSB signal	**Corresponding value**
γ_{max}	43.87
σ_{ap}	0.74
σ_{dp}	0.74
p	0.58

Table 3.4: feature value of DSB signal

Key feature of DSB signal	**Corresponding value**
γ_{max}	43.65
σ_{ap}	0.52
σ_{dp}	0.84
p	0

Table 3.5: feature value of VSB signal

Key feature of VSB signal	**Corresponding value**
γ_{max}	48.76
σ_{ap}	0.64
σ_{dp}	0.32
p	0.76

Table 3.6: feature value of FM signal

Key feature of FM signal	**Corresponding value**
γ_{max}	2.32
σ_{ap}	0.83
σ_{dp}	0.83
p	0.2

3.1.4 CONCLUSION:

The aim of AMRAS is to recognize the types of modulation in analog signals automatically. Here the decision theoretic approach has taken for identification.

3.2 CLASSIFICATION OF DIGITAL SIGNAL

Now a days digital signals are used frequently then the analog signal. In every communication device mainly digital signals are used. Because it is very easy to store the digital signal, the error correcting and error detecting is also easy for a digital signal, and it is economical also. So in almost every application digital signals are used. Because of this the classification of digital signals is very much essential then analog signal.

In the previous chapter I classify the analog signal by considering the key feature extraction method. Same method can also be used for the classification of digital signal.

In digital modulation the modulating signal is a digital signal. But the carrier signal is a high frequency analog signal, and in the modulation one of the characteristics parameter that is amplitude, phase or frequency of the carrier signal will be varied with respect to message signal amplitude variation.

Digital modulation techniques are classified as two types either linear or nonlinear, in linear modulation, the amplitude of modulated signal varies linearly with the message signal. Since in linear modulation, the frequency of the modulated signal is constant.so it is bandwidth efficient, now a days since the user are increasing exponentially, so the bandwidth efficient is the primary requirement for every system. The available spectrum is always constant and demand for that spectrum is increasing continuously, so system with less bandwidth requirement is necessary.

Like analog signal, digital signals also store information either in amplitude, phase or frequency.so we can apply the same key feature extraction method to classify the digital signals.

First the signals that are collected by the receiving antenna is given to the classifier block. Then the classifier extract the key feature from the signals and by comparing that with the threshold values, it determine the type of modulation of the signal.

3.2.1 Key features extraction:

Five key features are used to classify all the digital signal.

1) The maximum value of the spectral power density of the normalized centered instantaneous amplitude(γ_{max})

γ_{max}=max|DFT (a_{cn}(i))|2/Ns (4.1)

Where

Ns:number of sample

a_{cn}(i): value of the normalized centre instantaneous amplitude

$a_{cn}(i)=a_n(i)-1$

$a_n(i)=a(i)/m_a$

m_a :average value of the instantaneous amplitude

2) The standard deviation of the absolute value of the centered nonlinear component of the instantaneous phase (σ_{ap}) [1]

$$\sigma ap = \sqrt{\left(\frac{1}{c}\left(\sum_{a_n(i)>a_t} \Phi^2{}_{NL}(i)\right) - \left(\frac{1}{c}\sum_{a_n(i)>a_t} \left|\Phi_{NL}(i)\right|\right)^2\right)} \quad (4.2)$$

Where

Φ_{NL} is the value of the centered nonlinear component of the instantaneous phase.

C is the number of sample in Φ_{NL}(i) for which $a_n(i)>a_t$

a_t is the threshold value

3) standard deviation of the centered nonlinear component of the direct instantaneous phase (σ_{dp}) [1]

$$\sigma_{dp} = \sqrt{\left(\frac{1}{c}\left(\sum_{a_n(i)>a_t} \Phi^2{}_{NL}(i)\right) - \left(\frac{1}{c}\sum_{a_n(i)>a_t} \Phi_{NL}(i)\right)^2\right)}$$

Where (4.3)

Φ_{NL} is the value of the centered nonlinear component of the instantaneous phase

C is the number of sample in $\Phi_{NL}(i)$ for which $a_n(i)>a_t$

a_t is the threshold value

4) standard deviation of the absolute value of the normalized centered instantaneous amplitude(σ_{aa}) [1]

$$\sigma_{aa} = \sqrt{\frac{1}{N_s}(\sum_{i=1}^{N_s} a_{cn}{}^2(i)) - (\frac{1}{N_s}(\sum_{i=1}^{N_s} | a_{cn}(i) |))^2} \quad (4.4)$$

5) standard deviation of the absolute value of the normalized centered instantaneous frequency(σ_{af}) [1]

$$\sigma_{af} = \sqrt{\frac{1}{C}(\sum_{a_n(i)>a_t} f_N{}^2(i)) - (\frac{1}{C}(\sum_{a_n(i)>a_t} | f_N(i) |))^2} \quad (4.5)$$

Where

$f_N(i)=f_m(i)/r_s$

$f_m(i)=f(i)-m_f$

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

r_s= number of symbol per second

The first key feature is used to differentiate the FSK2 and FSK4 signals from rest of the signals. In the FSK signal ,the frequency of the carrier signal is changes according to the modulating signal, here the phase and the amplitude is constant, so the information placed in the frequency of the signal and ‘the amplitude and phase contain no information. In the ASK signal, the amplitude of the carrier signal is changes according to the modulating signal, and the frequency and phase of the carrier signal remain constant and contain no information. The γ_{max} value for the FSK2 and FSK4 signals are less than the threshold value. Whereas for ASK2 and ASK4 signals, the γ_{max} value is more than the threshold value.

The second key feature is used to differentiate the ASK2, ASK4, PSK2 signals from the PSK4 signal. For the ASK2 and ASK4 signals, the phase of carrier signals always remain constant, only the amplitude of the carrier signal changes according to the message signal. The Phase remain constant, so there is no phase information, hence σ_{ap} value is less than the threshold value, in the PSK2 signal, the phase of the carrier signal takes two values either 0 or π, the centered value of the phase is $\pi/2$, which is constant, hence it does not contain any information, in the PSK4 signal, the phase of the carrier signal takes 4 values, hence it contain some information and the σ_{ap} value for PSK4 signal is greater than the threshold value. Hence the σ_{ap} value can be used to differentiate the ASK4 signal from the ASK2, ASK4 and PSK2 signal.

The third key feature σ_{dp} is used to differentiate between the ASK2 and ASK4 signals from the PSK2 signals, In the ASK2 and ASK4 signals only the amplitude of the carrier is changes according to the modulation signal, and the phase and frequency is always remain constant. So it does not contain any phase information and its σ_{dp} value is less than the threshold value, but for the PSK2 signal the phase of the carrier signal takes two values rather 0 or π,so it contain some direct phase information and the σ_{dp} value is greater than the threshold value.

The fourth key feature σ_{aa} is used to differentiate the ASK2 signal from the ASK4 signals.in the ASK2 signal, the amplitude of the carrier signal takes two values according to the variation of the message signal that is either +1 or -1,so these amplitudes have same magnitude but sign is opposite.so the absolute value of the amplitude is constant and it does not contain any information.so the σ_{aa} value for ASK2 signal is less than the threshold value.in the ASK4 signal, the amplitude of the carrier signal takes four values according to the variation of message signal. Hence the absolute value of the amplitude is not constant and the σ_{aa} value is greater than the threshold value.

The fifth key feature σ_{af} is used to differentiate the FSK2 signal from the FSK4 signal.in FSK2 signal, the frequency of the carrier signal takes two values according to the variation of the message signal, and these two values have same magnitude but sign is opposite. Now the absolute value of this two frequency is constant, so there is no absolute frequency information. And the σ_{af} value is less than the threshold value in FSK4 signal, the frequency of the carrier signal takes four values, according to the variation of message signal, so it contain frequency information, so the σ_{af} value for FSK4 signal is greater than the threshold value.

3.2.2 SIGNAL FLOW DIAGRAM [1]:

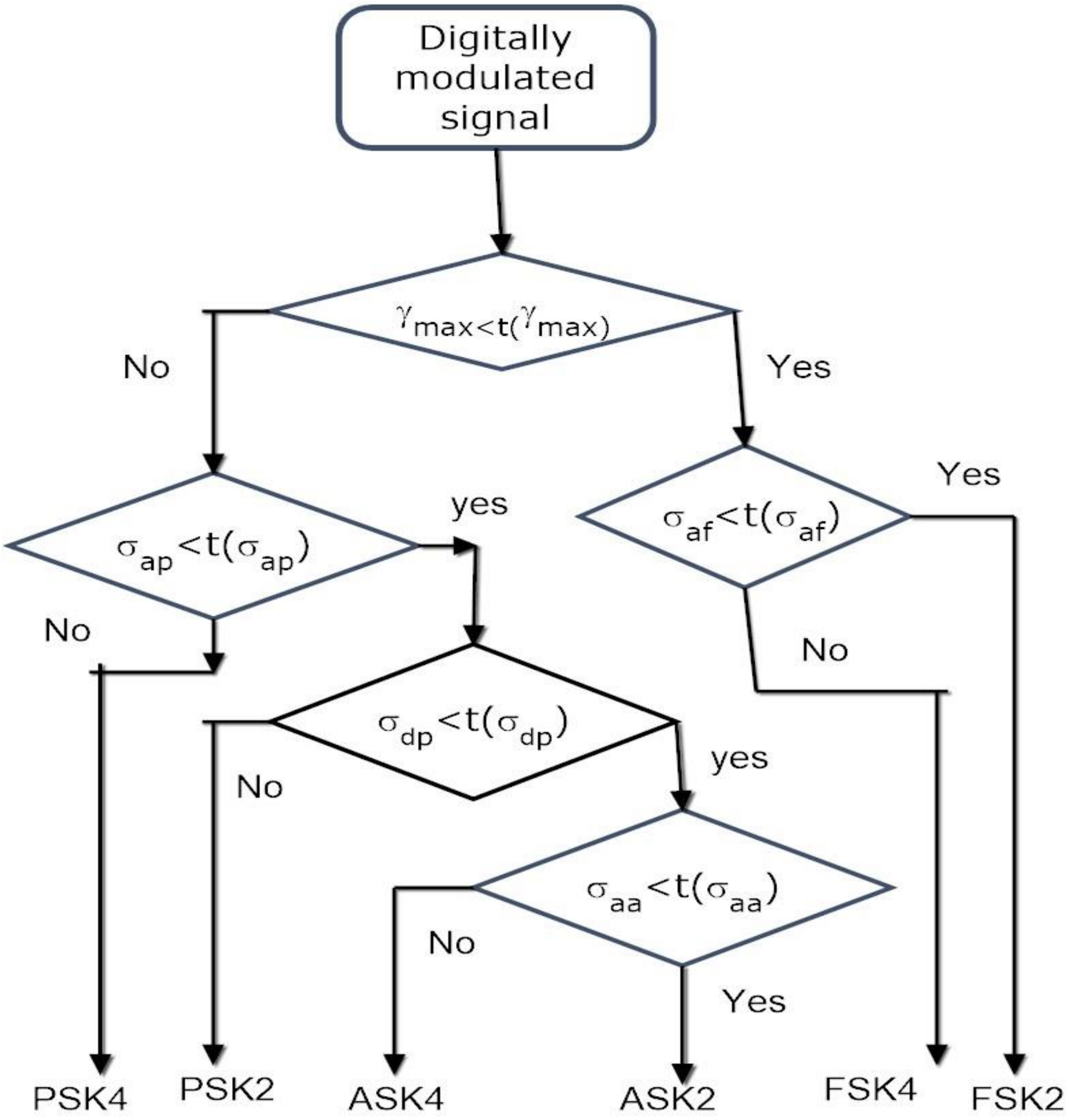

Figure 3.6 signal flow graph of digital signal

3.2.3 DIFFERENT TYPES OF DIGITAL MODULATED SIGNAL:

3.2.3.1 ASK:

ASK modulation is similar to amplitude modulation, where the carrier signal amplitude varies to the amplitude of modulation signal.in ASK, the carrier signal is transmitted when the input data bit is '1' and nothing is transmitted when input data bit is '0'.

ASK modulated signal is

$S(t)=A_c.m(t).cos2\pi f_c t$

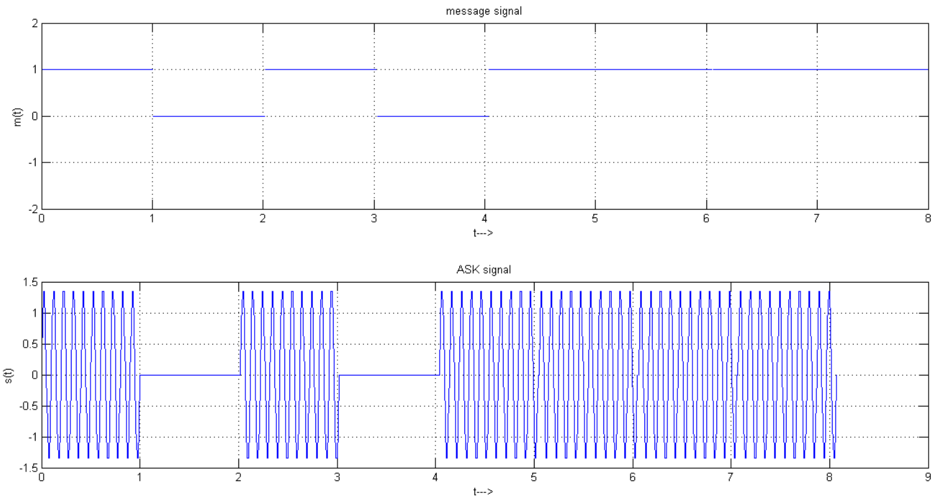

Figure 3.7: ASK modulated signal

3.2.3.2 PSK:

PSK modulation is similar to phase modulation, where the phase of the carrier signal varies to the modulating signal.

In PSK,binary 1 is represented by actual carrier and binary zero is represented by 180 degree phase shift of carrier.

If $m(t)=1$

Then $s(t)=A_c\cos(2\pi f_c t)$

If $m(t)=0$

Then $s(t)=A_c\cos(2\pi f_c t+\pi)$

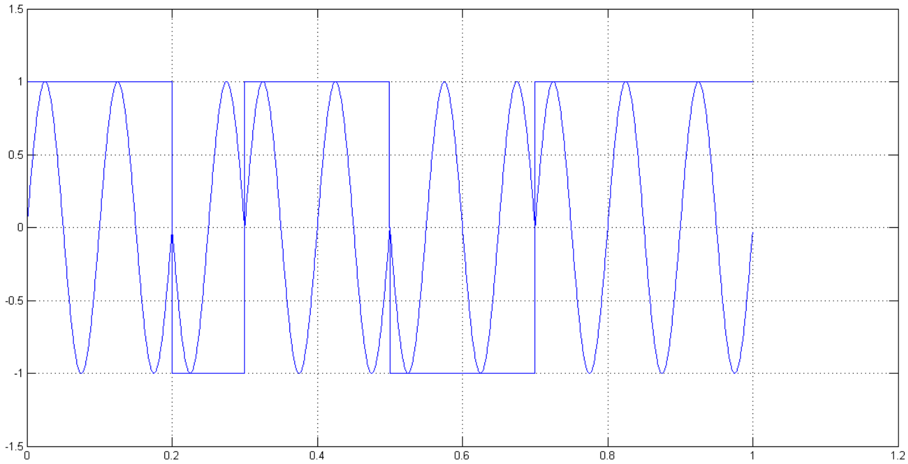

Figure 3.8: PSK modulated signal

3.2.3.3 FSK:

FSK modulation is similar to FM modulation, in which the frequency of carrier signal varies according to the message signal. In FSK modulation, the frequency of the carrier is shifted according to binary symbol. The phase of carrier is unaffected.so we have two different frequency signals according to the binary symbols.

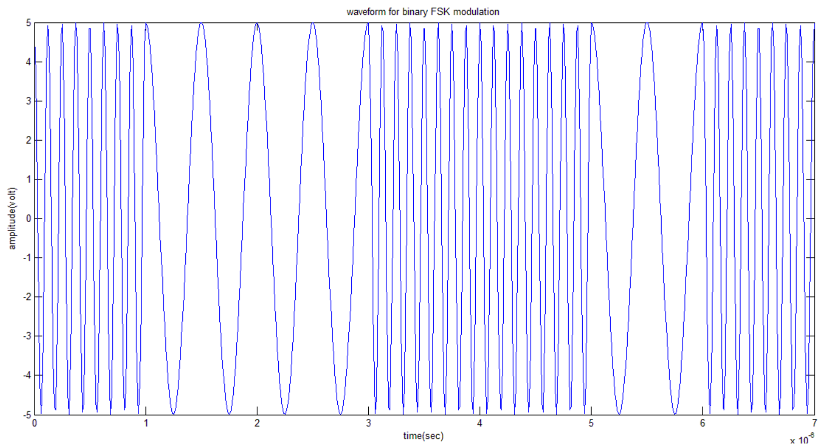

Figure 3.9: FSK modulated signal

3.2.4 RESULT:

Table 3.7 feature value of ASK2 signal

Key feature of ASK2 signal	Corresponding value
γ_{max}	28.73
σ_{ap}	0.32
σ_{dp}	0.47
σ_{aa}	0.18
σ_{af}	0

Table 3.8 feature value of ASK4 signal

Key feature of ask4 signal	Corresponding value
γ_{max}	34.65
σ_{ap}	0.37
σ_{dp}	0.29
σ_{aa}	0.63
σ_{af}	0

Table 3.9 feature value of PSK2 signal

Key feature of psk2 signal	Corresponding value
γ_{max}	22.64
σ_{ap}	0.18
σ_{dp}	0.74
σ_{aa}	0
σ_{af}	0

Table 3.10 feature value of PSK4 signal

Key feature of psk4 signal	**Corresponding value**
γ_{max}	29.63
σ_{ap}	0.84
σ_{dp}	0.23
σ_{aa}	0
σ_{af}	0

Table 3.11 feature value of FSK2 signal

Key feature of fsk2 signal	**Corresponding value**
γ_{max}	1.87
σ_{ap}	0.21
σ_{dp}	0.16
σ_{aa}	0.07
σ_{af}	0.34

Table 3.12 feature value of FSK4 signal

Key feature of fsk4 signal	**Corresponding value**
γ_{max}	2.18
σ_{ap}	0.15
σ_{dp}	0.21
σ_{aa}	0.18
σ_{af}	0.72

3.3AMC using Artificial Neural Network

Now a day's there are many methods to recognize the type of modulation of the signal. Artificial neural network is also a approach in which we can easily recognize the modulation type of the signal. In automatic modulation classification algorithm, we have chosen a threshold value for each key feature and by comparing the key feature value with the threshold value; we determine the modulation type of signal. But I neural network method the threshold value is choosing at each neuron automatically and adaptively.in decision theoretic approach many algorithms can be developed based on the same key feature. By simply applying the key feature in different order to the algorithm and the entire algorithm perform different success rate at same SNR. In decision theoretic approach only one key feature is taken at a particular point of time si the correct decision probability on the reorganization of the type if modulation in these algorithms is based on ordering of the feature value but in the artificial neural network algorithm all the feature values are considered simultaneously. So the correct decision probability does not change according the ordering of the feature value. So neural network approach for the recognitionof the modulation type of the signal is better than the automatic modulation classification algorithm.

The reorganization of the type of modulation by using the neural network involves different architecture, different training parameter, and differentlearningtechniques and toachieve good accuracy.

The network parameter selection are based on the structure that gives a sum-squared-error which is minimum in the training part. In the training part of system and theprobability of correct decision should be maximum in the test part of the system.

The artificial neural network algorithm consists of three main blocks

- Pre-processing
- Training and learning phase
- Test phase

In pre=processing stage, form every signal the key features values are extracted.

In training and learning phase, the neural network optimizes the weight and bias.

And in test phase neural network decides the type of modulation of signal.

3.3.1 Pre-processing

In the preprocessing stage we have to process the incoming signal and find out the key features. Let the incoming signal is of duration L second. Now this signal is samples at fs rate. After that the signal is divided to into many segments having Ns sample. Now total no of segment (Ms= Lf_s/N_s). Now from every segment we have to find out the key features. In artificial neural network algorithm the input data sets are nothing but the key feature value, that we are extracted from the incoming signal. For the reorganization of analog modulation same four key features are required like in automatic modulation classification and for the reorganization digital modulation same five key features are required.

From the incoming signal we have total Ms Segments, out of which some segments are used in the training part to optimize the weight and bias of the artificial neural network structure, and rest of the segment are used in test phase. In test phase the performance of the network is evaluated and the decision about the modulation type is taken.

3.3.2 Training and learning phase of ANN

To optimize the weight and bias and to minimize the error between the correct response and output of the network, training of the network in required. To minimize the error many types of methods oflearning are there.

1. Correction learning
2. Hebbian learning
3. Competitive learning
4. Boltzman learning

A main criterion of the network is the minimum min-squared-error between the correct response and network output.

May learning paradigms are also there for the ANN network like supervised, self-organized learning and unsupervised. In the supervised learning the data is provided in terms of pair like [X,T],

Where,

X is the vector consists of key features

T is the vector consists of output decision.

Now in almost all artificial neural network reorganization algorithms the learning methods used is back propagation algorithm and learning paradigm used in supervised learning.

In ANN algorithm, three types of network are considered

a) ANN with no hidden layers
b) ANN with single hidden layer
c) ANN with two hidden layer

All the networks can be used to recognize the type of modulation of the input signal. The main aim of all the ANN network is to reduce the SSE (sum squared error).SSE is defined as the difference between actual target and output for the training data.

3.3.3 SSE for networks

The SSE for all networks are

1. **No hidden layer network [1]**

$$SSE = \sum_{a=1} \sum_{b=1} E(a,b) \qquad (5.1)$$

$$E = (T - A)^2 \qquad (5.2)$$

Where,
T= actual output
A= calculated output

The calculated output is given by

A= log-sigmoid (B+W×P_{in}) (5.3)

Where,

W is weight of the output layer

B is biases of the output layer

P_{in} is input training data

2. One hidden layer network [1]

$$SSE = \sum_{a=1} \sum_{b=1} E(a,b) \tag{5.4}$$

$$E = (T - A_2)^2 \tag{5.5}$$

Where,

T= actual output

A_2=calculated output

The calculated output is given by

$A_2 = B_2 + W_2 \times A_1$

Where,

A_2 = output of output layer

W_2= weight of output layer

B_2= biases of output layer

A_1= output of hidden layer

And A_1 is calculated as

A_1= log-sigmoid ($B_1 + W_1 \times P_{in}$)

Where,

W_1= weights of hidden layer

B_1 = biases of hidden layer

3. Two hidden layers networks [1]

$$SSE = \sum_{a=1} \sum_{b=1} E(a,b) \tag{5.6}$$

$$E = (T - A_3)^2 \tag{5.7}$$

Where,

T= actual output

A_3 = calculated output

The calculated output is given by

A_3= log-sigmoid ($B_3+W_3\times P_{in}$)

Where

W_3= weights of output layer

B_3= biases of output layer

$A_{2=}$ output of second hidden layer

And A_2 is calculated as

$$A_2=B_2 + W_2 \times A_1$$

Where

W_2= weights of second hidden layers

B_2= biases of second hidden layers

A_1= calculated output of first hidden layer

And A_1 is calculated as

A_1= log-sigmoid ($B_1+W_1\times P_{in}$)

Where,

W_1= weights of first hidden layer

B_1= biases of first hidden layer

P_{in}= input training data

The training phase output are the optimum biases and weights of the ANN networks, and the test phase uses that biases and weights.

3.3.4 training phase of ANN

In the training phase of ANN network we have to choose numbers of hidden layers, number of node in each hidden layer, the training parameter, like the learning rate, the ratio of error, the learning increment rate, the learning decrement rate, andmaximum epochs. The adaptive learning algorithm is used to decrease the time of training. The adaptive learning is mainly characterized by learning rate, the decrement rate and the increment rate. Two activation function are mainly chosen for the ANN algorithm i.e. log-sigmoid activation function and linear activation function. The activation function are different for different layer like

- In ANN with no hidden layers , the activation function used for the output layer is log-sigmoid function
- In ANN with single hidden layer the activation function used for the hidden layer is log-sigmoid function and for output layer is linear function.
- In ANN with two hidden layer the activation function used for hidden layer number 1 is log-sigmoid function, the activation function used for hidden layer number 2 is linear function, and the activation function used for the output layer is log-sigmoid function.

In the presentation phase of the training stage, sum squared error is calculated as the difference between actual output and calculated output for the training data. The main aim of the training phase is to minimize the sum squared error by updating the network parameter i.e. weights and bias of the network.

In momentum learning for every epoch, the calculated SSE is compared with previously chosen error goal.

If SSE is less than error goal, than the job of the training phase is completed and optimum weights and bias are saved for test phase.

If SSE is greater than error goal, than the process is continued till the total number of epoch.

3.3.5 Test phase of ANN

At the end of the training phase the sum squared error is minimum and the weights and bias are optimized. That minimum bias and weights are used in test phase of the network. Normally for analog and digital modulation recognition algorithm training of the ANN has been done only for 50 realizations.

The below figure shows, a single hidden later neural network, having four input nodes and seven output nodes.

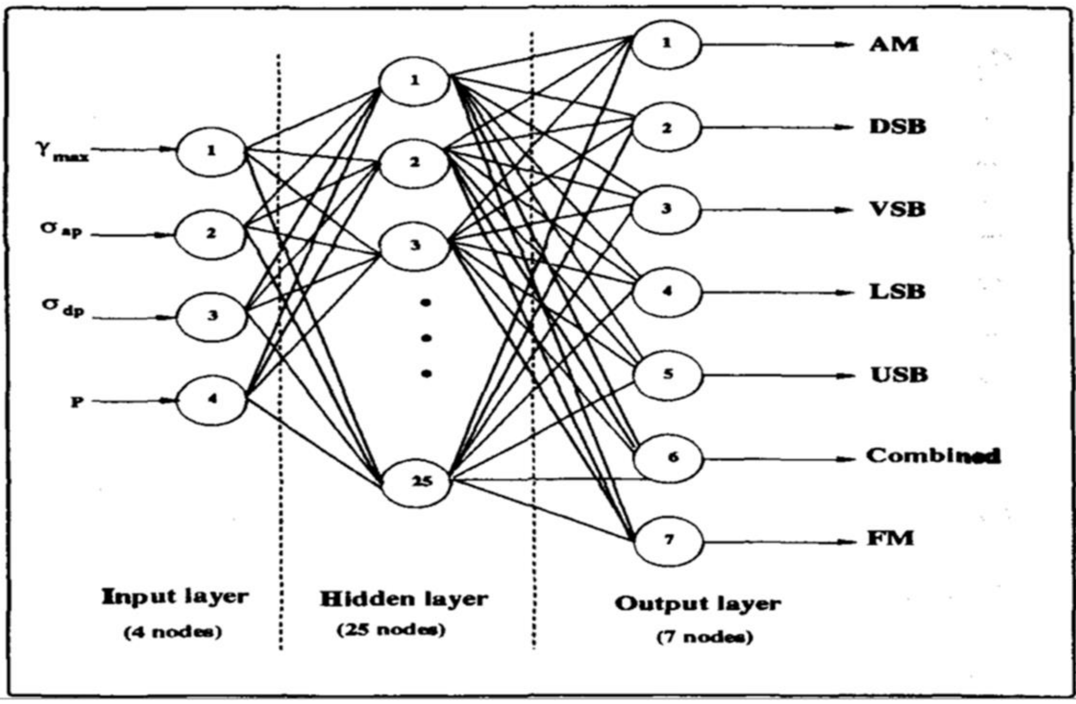

Figure 3.10 Neural networks with one hidden layer, four input node and seven output node

4

4.1 ADVANTAGE OF ANN

ANN method use pattern recognition approach, in which it does not require any probabilistic calculation to find out the threshold value. The pattern recognition approach involves extraction of feature, reduction of the feature space, and the classification based on the feature space. The ANN modulation classifier mainly consist of three main blocks, the first block is preprocessing block in which the key feature values are extracted from the input signal. The second block consists of training and learning stage, which is used to minimize the error between the actual output and the target. And in this stage the network parameters are optimized. And the third block consists of test phase, which is used to calculate the modulation type of the signal. The performance of the AMC using ANN is very good as compared to any other method.in ANN the mean square error is very less, if the number of sample taken for training is high.

4.2 RESULT

4.2.1 MSE Vs epoch graph:

The mean square of the network vs. the number of epoch graph shows that, the MSE error is gradually decreases as the number of epoch increases.

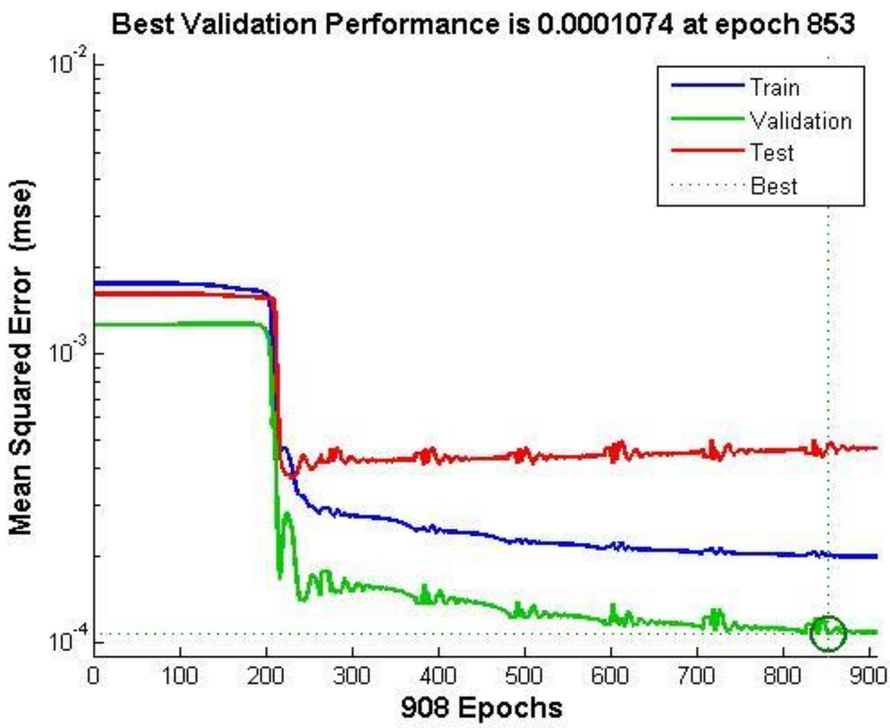

Figure 4.1:MSE Vs. Epoch plot

4.2.2 Performance graph of analog signals:

The classification of signal is mainly depends upon the noise power, that is added to the signals, if the noise power is more, then the signal to noise ratio is less and the performance of the system decreases**.**

As the SNR is increases, then the accuracy of the system is also increases.

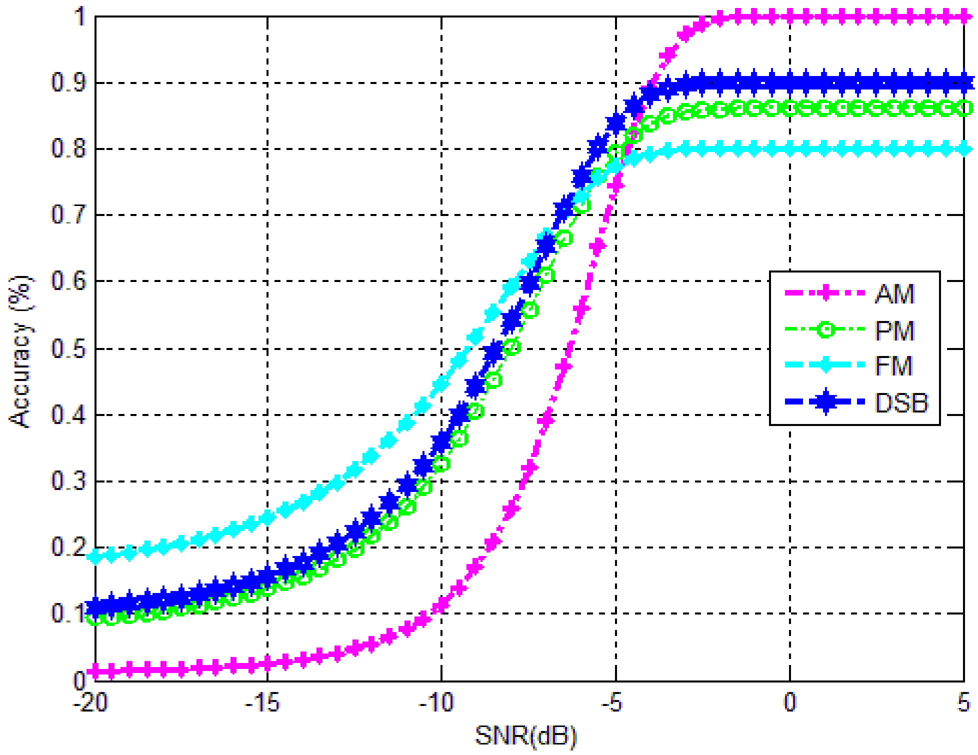

Figure 4.2: Accuracy vs. SNR plot for analog signal

4.2.3 Performance graph of digital signal:

The performance graph shows that, as the SNR of the signal is increases, than the accuracy of classifying the signal is also increases**.**

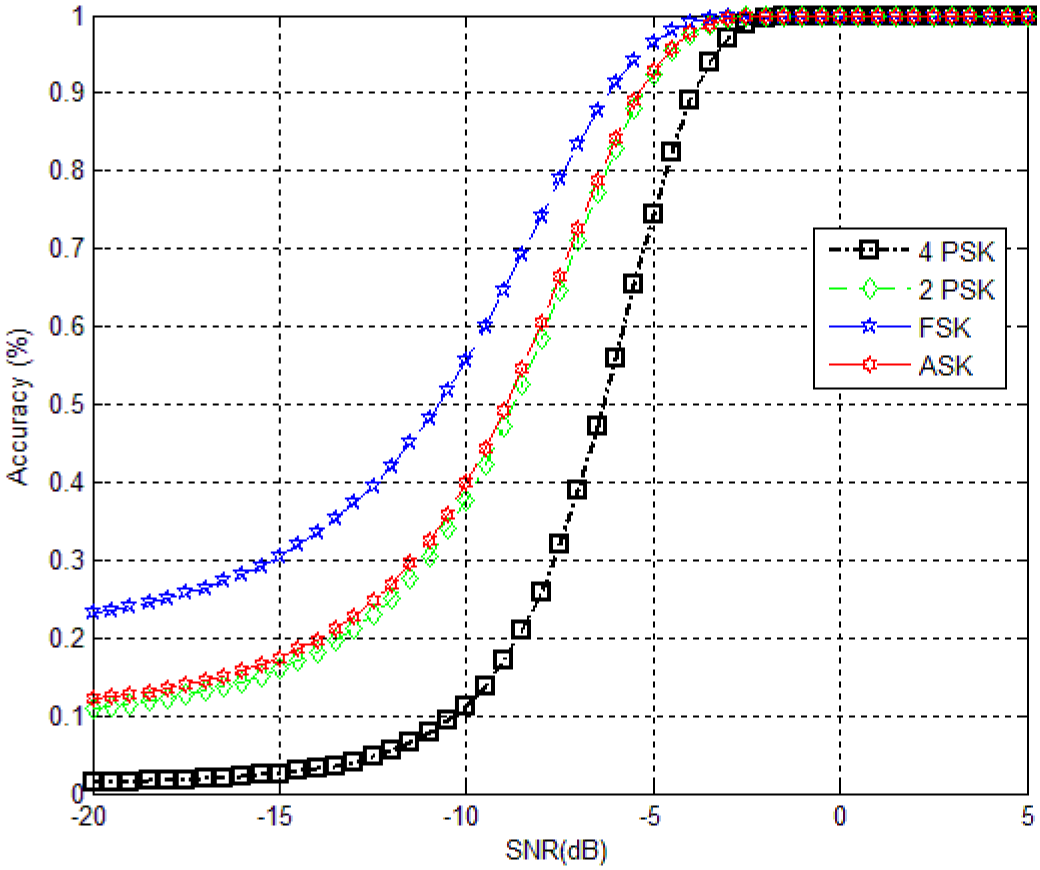

Figure 4.3: Accuracy Vs SNR plot for digital signal

5

CONCLUSION:

The AMC using decision theoretic method and statistical pattern recognition method are two widely used methods for identification and classification of signals in cognitive radio. The decision theoretic method use probability and hypothesis for calculation of the threshold values, since it require very careful analysis for calculations, so its performance is less. On the other hand the statistical pattern recognition using ANN, does not require the calculation of threshold values, the ANN first optimize the network parameter and according to that parameter values, it identifies the modulation type of the incoming signal. Hence the performance of ANN network is very high.it is shown in the performance graph that, the accuracy of ANN system is very high even at low SNR. The mean square error vs the epoch graph shows that, if the number of epoch for training of the system is more than the MSE is less.

FUTURE WORK:

Two hidden layer artificial neural network gives better performance for the identification and classification of signals for cognitive radio. The neural network methods can also be used for classification of other kind of signals like television signals, IEEE 802.22 WRAN signals, universal software radio peripheral (USRP) signals. Many other methods are also there for the classification like, fuzzy logic, genetic algorithm, GNU radio.

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