Chapter 3

TV Signal Classification Using Fuzzy Inference Fusion

3.1 Introduction to TV Signals and The Proposed Classification Approach

In cognitive radio networks (CRNs), for successful and efficient spectrum access, a secondary user (SU) is required to perform spectrum sensing prior to and during the spectrum access process. Spectrum sensing is vital to detect spectrum white spaces, that is the portions of the spectrum where the primary user (PU) is absent, and to vacate the channel as soon as the PU claims it back [1] in case of adopting the interweave paradigm. Additionally, in case of underlay paradigm, continuous monitoring of the PU's activity is necessary to guarantee keeping the interference over its transmission to be minimal and to quickly switch to another spectrum band when interference is harmful [3]. A survey of the existing spectrum sensing techniques is presented in [2].

A significant portion of the frequency spectrum (54-890 MHz) is licensed to the television (TV) operators. However, these TV dedicated portions are under-utilized and can potentially be used for other important purposes while not used by the TV operators. Those under-utilized portions are called television white space (TVWS) bands. Solving the white spaces problem is from the main interests of the Federal Communications Commission (FCC) [4] and the National Telecommunication Regulatory Authority in Egypt (NTRA). In this chapter, a technique for classifying TV signals is proposed. The presented approach is capable of classifying the detected signal to decide whether it is a TV signal or another secondary signal. This classification is useful from many perspectives. First, knowing the characteristics of the active user helps monitoring their performance and reaching efficient spectrum utilization. Second, this classification can lead in some kind of cooperation among cognitive (secondary) nodes to schedule the dynamic spectrum access and efficiently share the frequency bands. Third, knowing the nature of the active user allows the cognitive node to modify its transmission parameters so as to efficiently access the spectrum with interference avoidance.

The presented approach here depends on two of the existing sensing techniques in literature. The first one is the most famous and simplest sensing technique, that is the Energy Detection Method (EDM) [6] which depends on estimating the energy of the sensed signal. However, it is incapable of differentiating between a TV signal, a secondary signal or noise. Therefore, a more specific method that can classify the detected signal is needed.

In [7], a sensing technique is presented that depends on correlating the detected signal with a waveform that resembles the main form of the TV signal (a reference template). This Correlation Based Method (CBM) results in a high value only if the received signal is highly correlated with the reference template, which is not the case if a secondary signal or noise only is present. The CBM is the second technique on which this work depends.

In this work, EDM and CBM are aggregated to combine the benefits of both. The CBM results in a high decision metric (average correlation coefficient) only if a TV signal is present. On the other hand, the EDM will detect any signal whose energy is above the threshold. Combining the two results enables the algorithm to classify the type of the present signal.

The main contribution in this chapter is the combination of EDM and CBM results via a Fuzzy Inference System (FIS). FIS is based on a set of IF-THEN rules to control the relation between outputs and inputs. FIS was also used in [8] in a related manner.

As can be noticed from the block diagram in Fig. 3.1, the presented classification approach consists of two phases, the sensing phase which consists of two sensing techniques (EDM and CBM) operating in parallel and the fusion phase which depends on fuzzy fusion. The outputs of the sensing phase (EDM and CBM decision metrics) are fed into the fusion phase as inputs. The output of this phase is a decision whether a TV signal, a secondary signal, or noise is present.

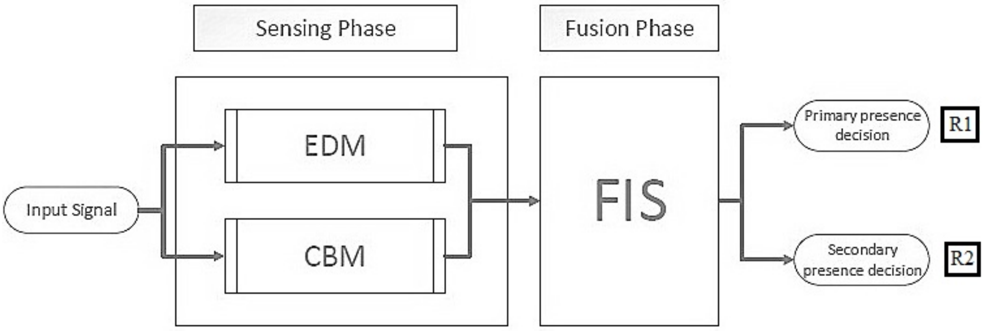

FIGURE 3.1: Block diagram of the presented classification technique.

3.2 Model of The Signal Classification Approach

Consider a cognitive radio that operates in TV frequency bands. The signal of interest here is the TV signal, whether PAL or DVB-T.

3.2.1 PAL Signal As a Primary User

PAL stands for Phase Alternating Line. It is an Analog TV standard used in many countries. In PAL signals, moving pictures are produced by flashing 25 pictures per second. Each picture is presented by horizontally scanning it in 625 lines, where odd and even lines of a picture are shown alternately. Each horizontal line is 64 microseconds long and is composed of several segments including a horizontal synchronization pulse that has the highest amplitude normalized to unity or 100%. In the receiver, this helps in synchronization and decoding of each video line. Fig. 3.2 shows the main components of a TV PAL horizontal line. More details about the PAL standard can be found in [15].

3.2.2 DVB-T Signal As a Primary User

European Telecommunications Standards Institute (ETSI) has standardized the terrestrial Digital Video Broadcasting (DVB-T) system for the terrestrial broadcasting of digital TV

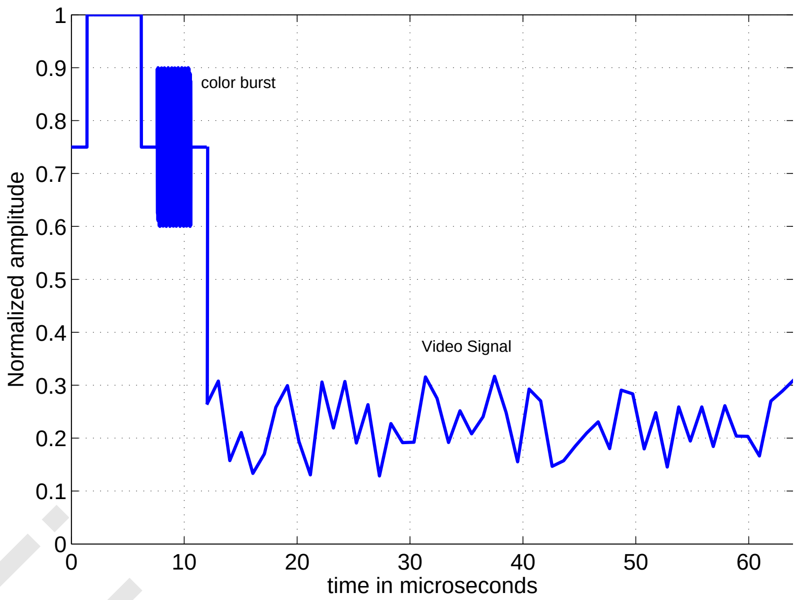

FIGURE 3.2: Components of a TV PAL signal horizontal line

[16]. DVB-T uses orthogonal frequency division multiplexing (OFDM) as a multiple access technique. More details about the DVB-T standard can be found in [17].

3.2.3 Assumed Hypothesis

The system model in this work can be represented by a ternary hypothesis [18] as follows,

$$x(t) = \begin{cases} n(t) & in\ case\ of\ H_0 \\ h_1 * s(t) + n(t) & in\ case\ of\ H_1 \\ h_2 * r(t) + n(t) & in\ case\ of\ H_2 \end{cases} \tag{3.1}$$

where $x(t)$ is the signal received by the cognitive radio, $n(t)$ is Additive White Gaussian Noise (AWGN), $s(t)$ is the transmitted TV signal, $r(t)$ is the transmitted signal of the secondary user (SU), h_1 is the channel between the active TV transmitter and the sensing node and h_2 is the channel between the active SU and the sensing node. H_0 indicates the case of a vacant channel, H_1 indicates the case of TV transmission and H_2 indicates the case of secondary transmission.

In the following section, a description of the two phases of the proposed system is presented.

3.3 Sensing Phase

The sensing phase consists of an Energy Detection Method (EDM) and a Correlation Based Detection Method (CBM) operating simultaneously.

3.3.1 Energy Detection Method

EDM is commonly used because of its simplicity in addition to the fact that it requires no prior knowledge of the primary signal [6]. Fig. 3.3 depicts the block diagram of the energy detector. The received signal $x(t)$ is passed over a bandpass filter for channel selectivity and noise bandwidth limitation. The output of the bandpass filter is squared and integrated over the sensing interval which produces an estimate of the received signal energy.

One of the main shortcomings of EDM is that it cannot discriminate between signal and noise power and thus, it exhibits high probability of false alarm under low SNR.

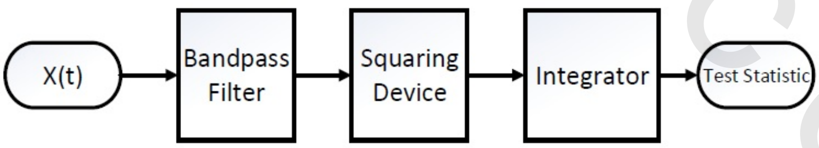

FIGURE 3.3: Block Diagram of Energy Detector

3.3.2 Correlation Based Method

The main idea behind the CBM is performing time-domain correlation between the received signal and a prior-stored reference waveform.

In case of analog TV (PAL) signal, as declared in [7], the received signal is correlated in time domain with a reference template which has mainly a similar waveform of the PAL horizontal line as shown in Fig. 3.4. Only a PAL signal is highly correlated to this reference template and therefore, the performed correlation will result in a high value only if a PAL signal exists.

The aforementioned process is performed multiple times (multiple horizontal lines are detected) and then the average or the maximum is chosen to be the output.

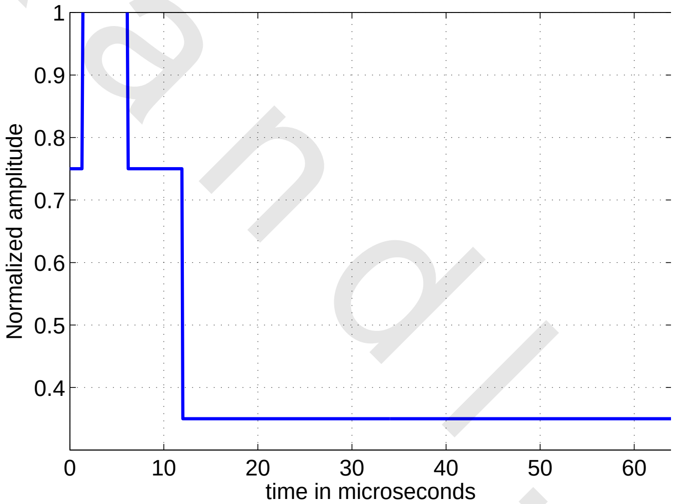

FIGURE 3.4: Baseband equivalent reference template for analog TV signal sensing based on CBM.

Fig. 3.5 shows a brief block diagram of the CBM operation. The RF IN block receives the existing signal. Noise bandwidth is limited via the bandpass filter. Signal is converted to baseband prior performing correlation. After sampling, time domain correlation is performed with the reference template. The buffer is used to save the results of the multiple correlation before taking the test statistic as the maximum or the average of the multiple correlation results.

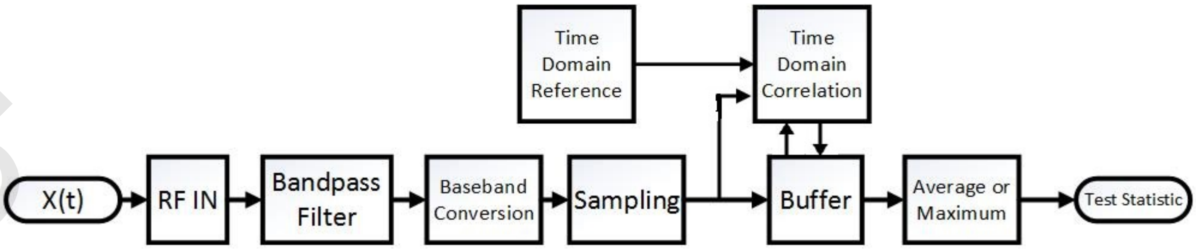

FIGURE 3.5: Block diagram of analog TV signal sensing CBM system.

In case of digital TV (DVB-T) signal, as discussed in [16] and [19], the received signal is correlated in time domain with a waveform that resembles the pilot signals' main characteristics [17], [20].

DVB-T pilots (scattered pilots) are transmitted at a boosted power level. They are modulated -as shown in equation 3.2[17]- according to a pseudo-random binary sequence (PRBS) depending on their respective carrier index. The generating polynomial is $x^{11} + x^2 + 1$ with an initial seed of all ones. In time domain, scattered pilots repeat every four OFDM symbols (There are only four possible scattered pilots patterns).

$$SP = 4/3 * 2(1/2 - w_k) \tag{3.2}$$

Where, SP is the scattered pilots, w_k is the PRBS corresponding to the carrier index k.

Scattered pilots are defined in frequency domain. That is why Inverse Fourier Transform (IFFT) is applied first before the time-domain correlation.

In Fig. 3.6 we can see the generation of PRBS which includes a group of linear feedback shift registers and an XORing process between the outputs of registers depending on the generating polynomial.

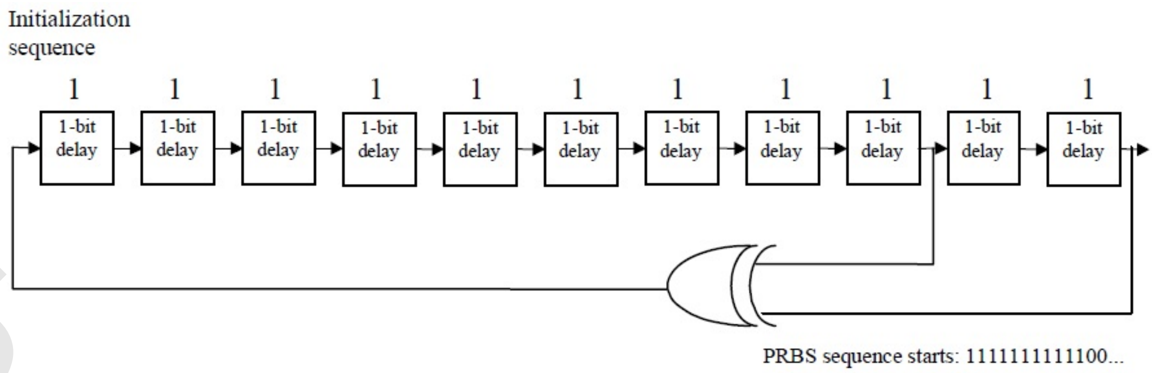

FIGURE 3.6: Generation of PRBS

3.4 Fusion Phase

The main contribution in this chapter is using a Fuzzy Inference System (FIS) in the fusion phase. FIS is a popular computing framework in literature based on the concepts of fuzzy set theory, fuzzy IF-THEN rules and fuzzy reasoning [5].

The fuzzy fusion phase of the presented technique takes the outputs of EDM and CBM as inputs with three membership functions each (low, medium and high) and two outputs with five membership functions each (least, less, moderate, more and most) which indicate the combined possibility of TV signal presence and secondary signal presence. Input and output membership functions are chosen, for simplicity, to be a mix of triangular and trapezoidal functions as shown in Figures 3.7, 3.8 and 3.9. There are many shapes of membership functions that we can select from (Gaussian, bell-shaped,..etc). They are a little more complex, that is why triangular and trapezoidal functions are chosen in this work, especially that they give similarly accurate results [8].

The outputs from the fuzzy fusion system are normalized, each, between 0 and 1 and compared to predetermined thresholds which are set to 0.5 [8]. For TV signal detection, if the decision metric is larger than the threshold, the cognitive radio will assert the presence of TV signal, otherwise, it will deny TV signal presence. Similar criterion is applied for secondary user detection.

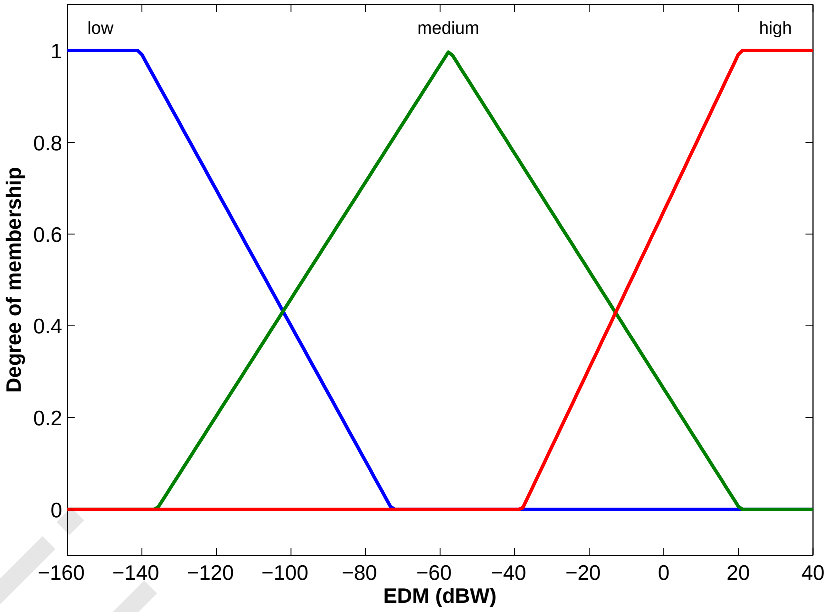

FIGURE 3.7: Membership functions of the EDM output value.

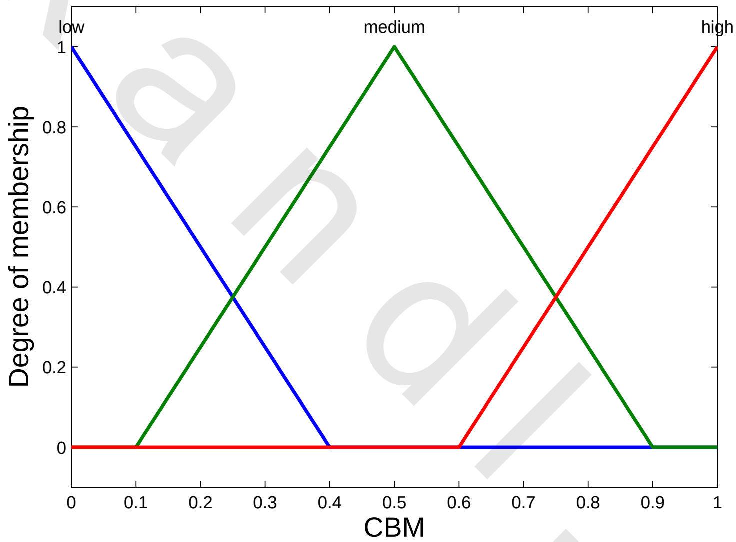

FIGURE 3.8: Membership functions of the CBM output value.

The set of IF-THEN rules that are used in the fuzzy inference fusion are shown in Table 3.1. R1 and R2 represent the possibility of TV signal and secondary signal presence respectively. The choice of rules is controlled by the relation of EDM and CBM outputs in each hypothesis. For instance, in rule 1, if both input values are low, then it is most probably that the channel is vacant. In rule 6, if EDM output is high and CBM output is low, this means that a signal is present but it is not highly correlated with the reference template of TV signal, then it is most probably that it is a secondary signal. Also in rule 8, if both inputs are high, this

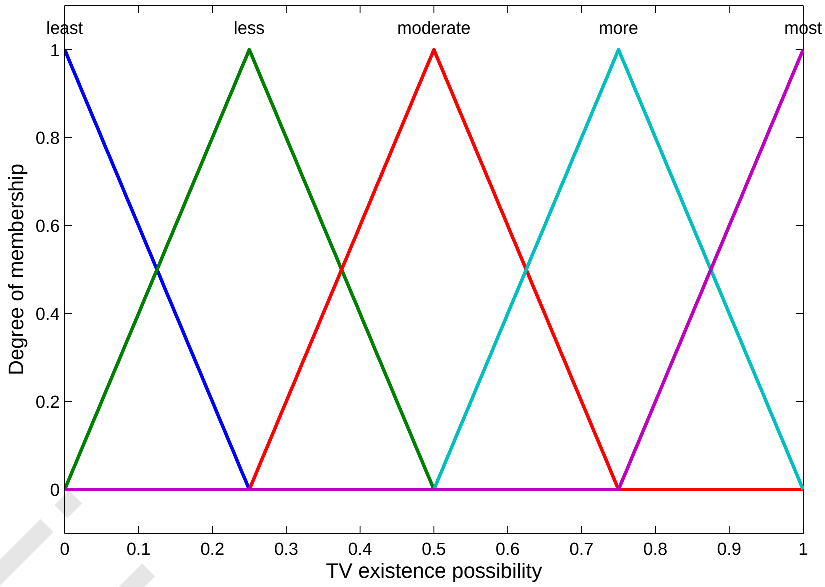

FIGURE 3.9: Membership functions of the final output values.

means that the channel is occupied by a signal that is highly correlated with the TV template. That is, a TV signal is present.

No.	EDM output	CBM output	R1	R2
1	low	low	least	least
2	low	medium	less	least
3	medium	low	least	moderate
4	medium	medium	moderate	less
5	medium	high	more	least
6	high	low	least	most
7	high	medium	more	less
8	high	high	most	least

TABLE 3.1: IF-THEN RULES

Fig. 3.10 shows the fusion process:

- CBM and EDM output values are fed to the fusion phase and then mapped to the corresponding membership functions (Fuzzification).

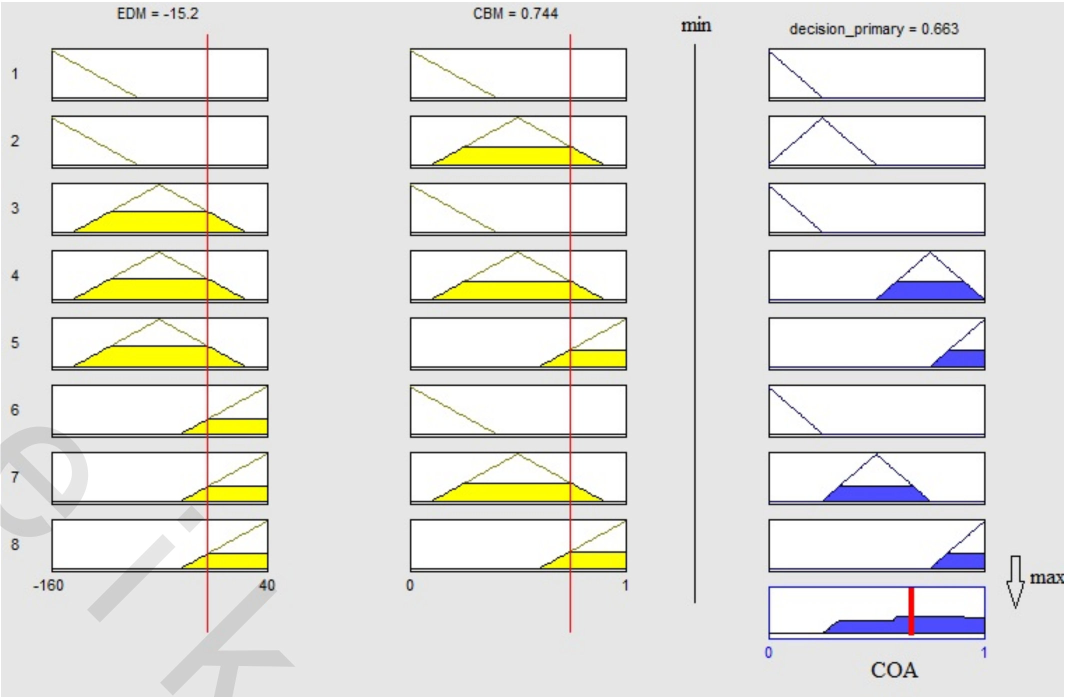

FIGURE 3.10: Fusion Process of the classification algorithm

- T-norm is applied to generate the firing strength of rules.

- IF-THEN rules are used to find the consequences.

- T-conorm aggregates the consequences of all rules.

- Crisp outputs (R1 and R2) are then found by the defuzzification method (COA).

- Finally, the decision that judges channel activity consists of two bits (R1 and R2). It has four states as shown in Table 3.2. It is noticed that, if an erroneous decision is taken in which both R1 and R2 are ”1”, this is considered in favor of TV signal existence due to its higher priority.

Decision	State
00	Vacant channel
10	TV transmission exists
01	SU transmission exists
11	TV transmission exists

TABLE 3.2: Final Decision

3.5 Performance Evaluation

In this work, performance evaluation of the proposed classification technique was conducted via MATLAB simulations. Rayleigh fading channel is applied. TV PAL signal and its reference template are imitated as shown in the waveforms of Fig. 3.2 and Fig.3.4. DVB-T signal is imitated as described in [17] and [19]. Secondary signal applied is a Binary Phase Shift Keying (BPSK) modulated signal. It is assumed that the sensing node has prior knowledge about noise power and TV signal power. Perfect channel (h_1 and h_2) estimation is also assumed at each node.

The metric that was used to evaluate the classification capability of the presented approach is the percentage of classification [21]. It is the percentage of times that the system correctly decides the type of the present signal, whether it is a TV signal, a secondary signal or just noise.

Fig. 3.11 and Fig. 3.12 show the percentage of TV signal classification and percentage of secondary signal classification in case of PAL and DVB-T signals being the primary signal respectively. We can see that -at the same SNR value- the system is capable of classifying TV signals with higher accuracy than secondary signals. This is because the TV signal classification depends on getting high outputs from the correlator and the energy detector which will not be achieved unless a TV signal is present. On the other hand, secondary signal classification depends on getting high output from the energy detector while the correlator output remains low. This later case is reached in case of secondary signal presence but also, in some cases, noise can be confusing.

We can also see in Fig. 3.13 the system's overall percentage of classification plotted versus SNR. It is compared to the case of fusing EDM and CBM results by comparing to crisp

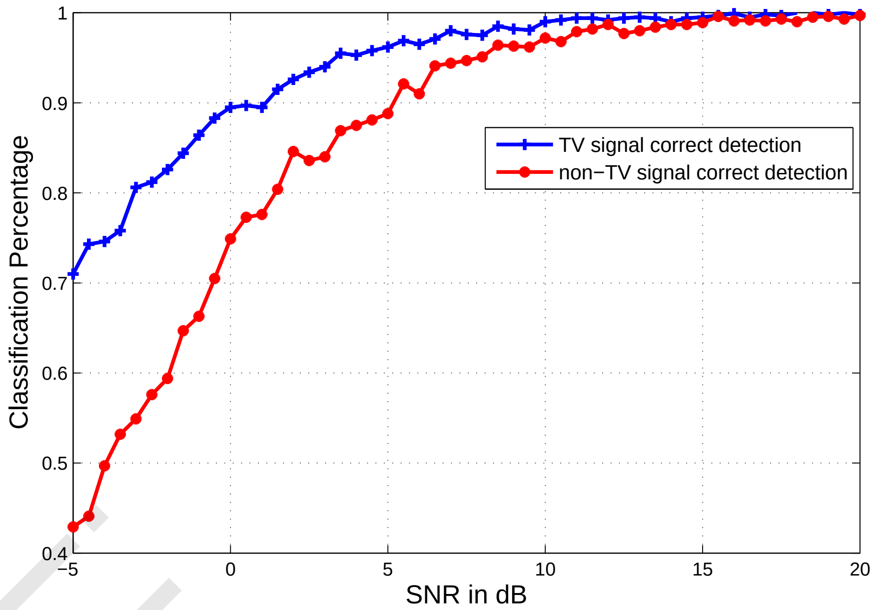

FIGURE 3.11: Percentage of TV Signal and Secondary Signal Classification versus SNR when PAL Primary Signal is of Interest

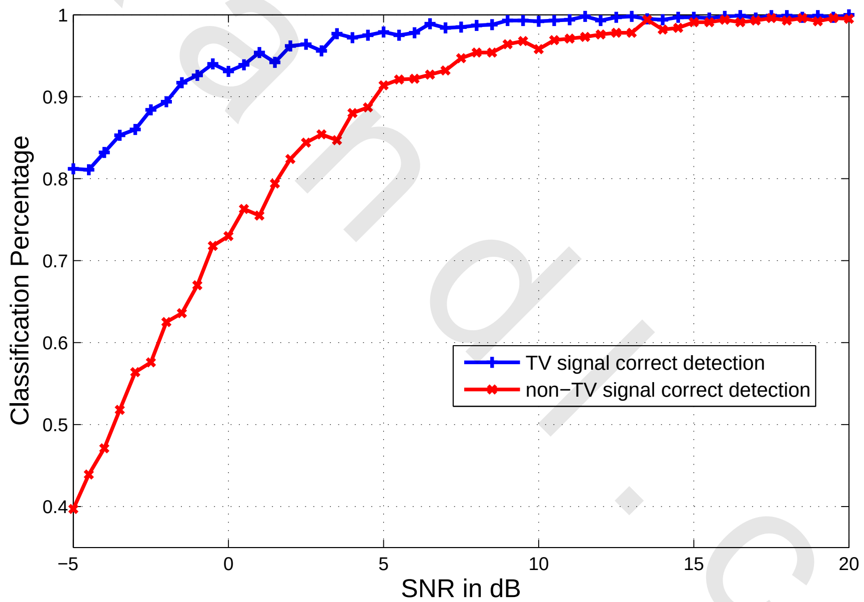

FIGURE 3.12: Percentage of TV Signal and Secondary Signal Classification versus SNR when DVB-T Primary Signal of Interest

thresholds instead of fuzzy fusion. It is noticed that fuzzy fusion gives much better classification accuracy.

Fig. 3.14 shows a comparison between the TV signal detection of this work, that of the CBM

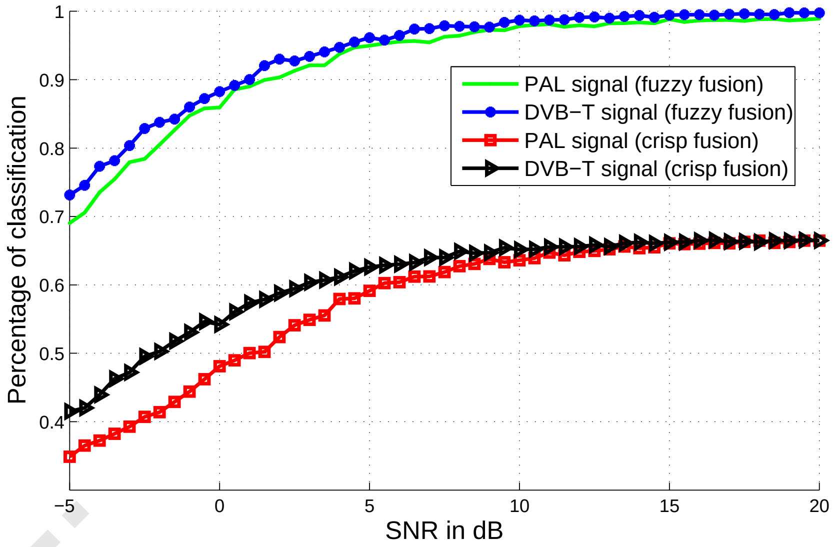

FIGURE 3.13: Overall Percentage of Classification versus SNR

when applied alone [7] and that of the crisp fusion case at SNR = 20 dB in case of DVB-T being primary signal. Fig. 3.14 represents the ROC (Receiver Operation Characteristics) curve of both systems under comparison. ROC curve is the plot of probability of detection versus the probability of false alarm which are important evaluation metrics for any sensing technique. It can be noticed that this work does not outperform the CBM but it is accurate enough. However, the main advantage of this work is the ability to classify between TV and secondary signals and not only detect their presence. It can also be noticed that crisp comparison between EDM and CBM results doesn't give accurate detection performance.

3.6 Conclusion

In this chapter, we have presented a signal classification technique to monitor the transmission activity in TV bands. It has been proven through simulations that the presented approach is able to accurately differentiate between TV and secondary transmission using the fuzzy fusion between the results of the energy detection method and the correlation based method.

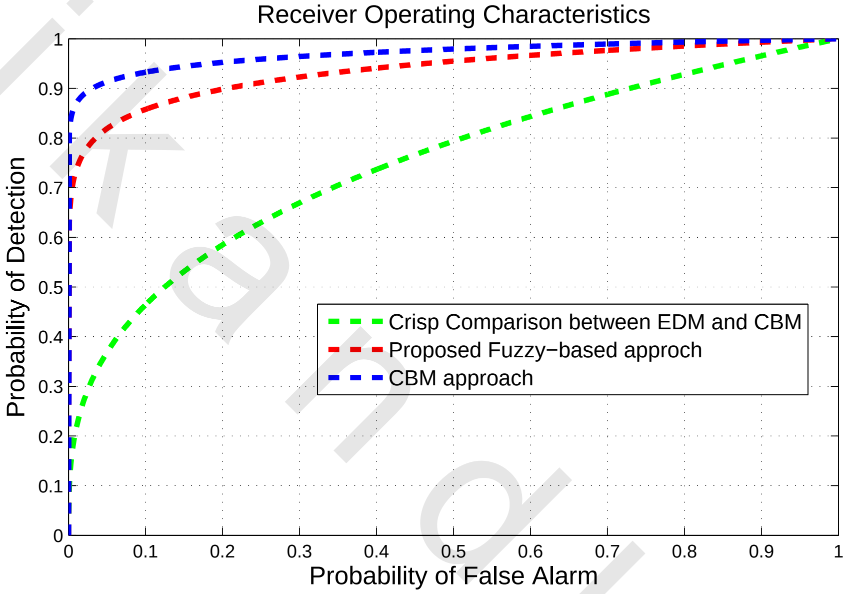

FIGURE 3.14: Comparison between the ROC of DVB-T signal detector of the new technique and the CBM at SNR = 20 dB.