SPECTRUM SENSING ALGORITHM BASED ON ATSC DTV SIGNAL STRUCTURE

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Abstract- In order to improve spectrum utilization rate, people need a method to sense the spectrum hole. This article puts forward a spectrum sensing algorithm, which uses ATSC DTV signal structural characteristics. First, we should sample the input signal based on structural characteristics. Second, these signal samples should be separated into different sets and accumulate these samples. Third, we execute the correlation operation to accumulation result and synchronization. Finally, decision can be got by comparing the test statistics with threshold. According to the simulation result, we can get the conclusion that signal structural characteristics based on spectrum sensing method can realize spectrum sensing well enough.

Index terms: Cognitive radio, spectrum sensing, ATSC DTV, signal structure, energy detection.

I.   INTRODUCTION

With the development of wireless communication and mobile Internet, more devices need the ability of wireless access. Thus it is very important to provide the new equipment with wireless spectrum resource. However, as a kind of non-renewable resources, radio spectrum is very limited. Moreover, the traditional spectrum allocation method which distributes the specific frequency spectrum to fixed business cannot ensure sufficient utilization of spectrum resources. In fact, the report of Federal Communications Commission (FCC) pointed out that in some places the spectrum utilization rate was very low [1][2]. Even though spectrum resources have been utilizing as planned in these places, 15% to 85% of spectrum resources are still idle in most of the daytime. In order to improve the utilization rate of wireless spectrum, the FCC selected cognitive radio technology to solve this problem.

Cognitive radio is an intelligent wireless communication system. It can sense its surrounding environment (for example, the outside world), and uses the methodology of understanding-by-building to learn from the environment.   Some parameters (for example, transmit- power, carrier-frequency and modulation strategy and so on) are changing from time to time so that the cognitive radio equipment's internal state can adapt the statistics changes of input RF stimuli. In the process of changing parameters, highly reliable communication and the spectrum utilization efficiency need to be achieved meeting demands no matter when and where [3][4].

As the earliest agency engaged in the research of cognitive radio, Berkeley Wireless Research Center (BWRC) at the University of California has begun the study of cognitive radio since 2004. Their major research was spectrum sensing. They conducted simulation experiments in the 2.4 GHz ISM band using its own building BEE2 simulation platform, and published a series of papers [5][6]. Georgia tech Information Transmission Processing Laboratory (ITPL) and Broadband Wireless Network Laboratory (BWNL) worked together supported by the national natural science foundation to study spectrum sensing and cognitive radio spectrum access to the next generation of dynamic spectrum and so on. Supported by the national natural science foundation, Rutgers University Wireless Information Network Laboratory (WINLAB), Kansas University, Carnegie Mellon University and Blossom Company worked

together for the study of spectrum sensing algorithm, and they created USRP2 experiment platform for testing the perception algorithm. Singapore institute of information and communication also did a lot of work, such as spectrum sensing, design of cognitive radio network across layer protocol, cognitive radio network throughput, detection efficiency and so on. They published several new spectrum sensing algorithms. The telecommunication research center of king's college in London University did a lot of research on spectrum allocation, dynamic reconfiguration protocol stack, the application of game theory in spectrum redistribution, intelligent cross layer optimization scheme and so on. In addition, wireless innovation alliance including Google and Microsoft is also committed to the development and utilization of blank TV spectrum [7].

Cognitive radio technology must satisfy the requirement that there is no interference for the main users who buy the spectrum, thus the first step is to test the main user's existence in the case of low signal-to-noise ratio (SNR). Thus the spectrum sensing technology is one of the most important technologies in cognitive radio area. The protocol set by the IEEE 802.22 working group is used for 54 MHZ to 862 MHZ VHF/UHF frequency band of TV signal channel; therefore the spectrum sensing of ATSC DTV signal in this frequency is very important.

II. THE ENERGY DETECTION ALGORITHM

Energy detection algorithm was proposed by Harry Urkowitz in 1967. The block diagram of energy detector system is shown in figure 1.
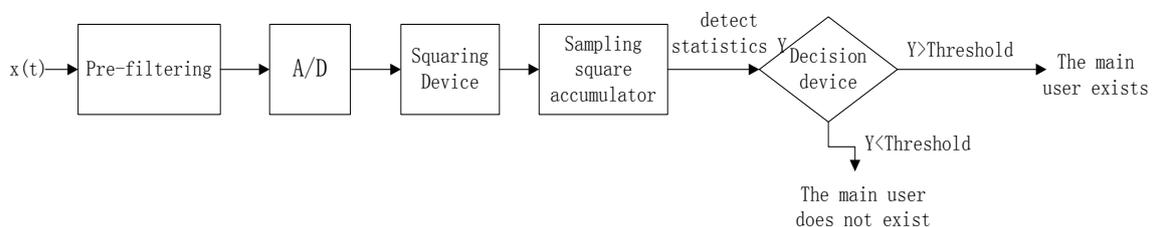

Figure 1. The block diagram of energy detector system

When the noise is Gaussian white noise and the signal has a known waveform, the appropriate processing is a matched filter or its correlator equivalent [8]. When the signal has an unknown

waveform, it's appropriate to consider the signal as a random process function. We can make use of the signal statistics which are known to design energy detectors.

The detector will prefilter the received signal firstly, and get signal within the detecting frequency band. The noise within the detection frequency band's scope is additive White Gaussian noise, and the average of noise is zero. And then do digital processing to the signal. Calculate the energy of signal in the sensing time, and compare it with the detection threshold. The result can be used to judge whether there is a signal.

However, there are some factors that can affect the noise power, such as temperature and system calibration. The lack of noise power's information is called noise uncertainty [9]. The threshold is closely linked with the energy of the noise. The uncertainty of noise energy has a great effect on the energy detection algorithm. It is impossible to keep the noise energy remain the same all the time. So the energy detection algorithm cannot complete the spectrum sensing of cognitive radio network task very well.

III.   THE STRUCTURE OF ATSC DTV SIGNAL

The Advanced Television Committee (ATSC) released the ATSC DTV signal standard in September 1995. The ATSC DTV signal data frame format is shown in figure 2 [10].
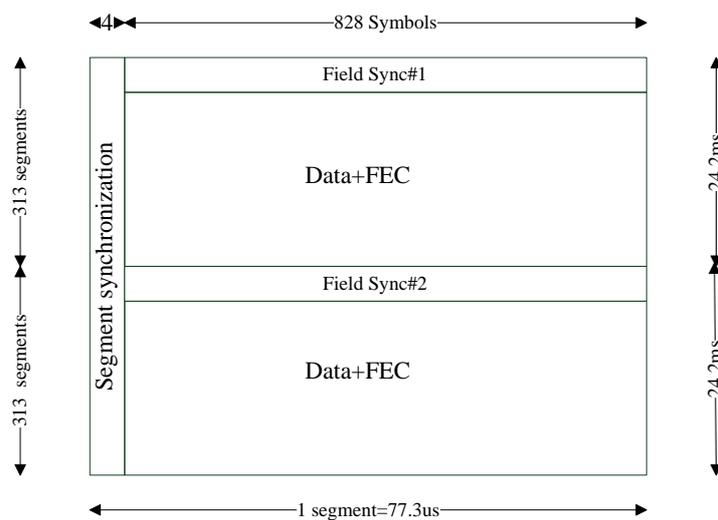

Figure 2. VSB data frame without extra field sync

Figure 2 shows how the data are organized. We can see that each signal Data Frame consists of two Data Fields. Each data field contains 313 data segments. The first Data Segment of

each Data Field is a unique synchronizing signal (Data Field Sync) that contains training sequence for the receiver equalizer [11]. The remaining 312 Data Segments in each Data Field are all carrying the same amount of data from one 188-byte transport packet plus its associated RS-FEC overhead. Each Data Segment contains 832 symbols. The first four symbols are transmitted in binary form and provide segment synchronization [10].
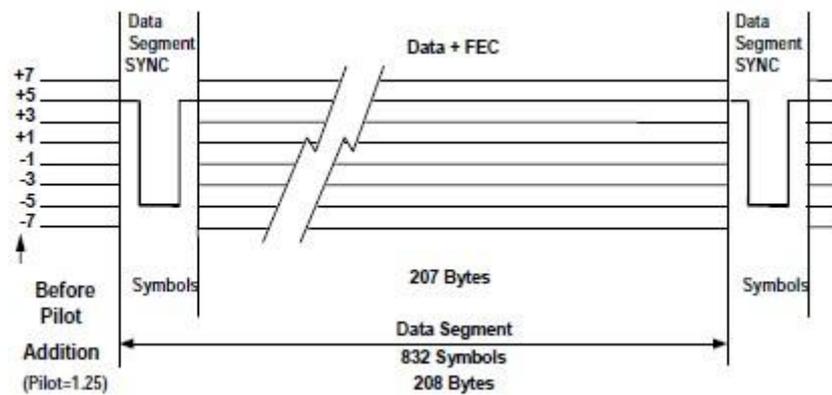

Figure 3. 8-VSB ATSC DTV signal Data Segment

The Data Segment Sync embedded in random data is illustrated in Figure 3 [10]. It can be seen from figure 3 that a complete data segment consists of 832 symbols. The first four symbols are for Data Segment Sync and the rest of the 828 symbols are parity symbols. The Data Segment Sync is in binary (2-level).The same sync pattern occurs regularly at 77.3 μs intervals, and is the only signal repeating at this rate. Unlike the data, the four symbols for Data Segment Sync are not Reed-Solomon or trellises encoded, nor are they interleaved. The Segment Sync pattern shall be a '1001' pattern, as shown in Figure 3[10].

The data are not only divided into Data Segments, but also into the Data Fields, and each Data Field contains 313 Data Segments. Each data field (24.2 ms) shall start with a complete Data Segment of Data Segment Sync. Each symbol represents 1 bit of data (2-level). The 832 symbols of data are in the corresponding format, that is, the first four symbols are synchronization of data segment, the second PN63 symbol in the other parts of the data and 128 symbols in the end are not fixed, while PN511and the other two PN63 symbols are fixed. The structure of the synchronous of Data Field is shown in figure 4[10].
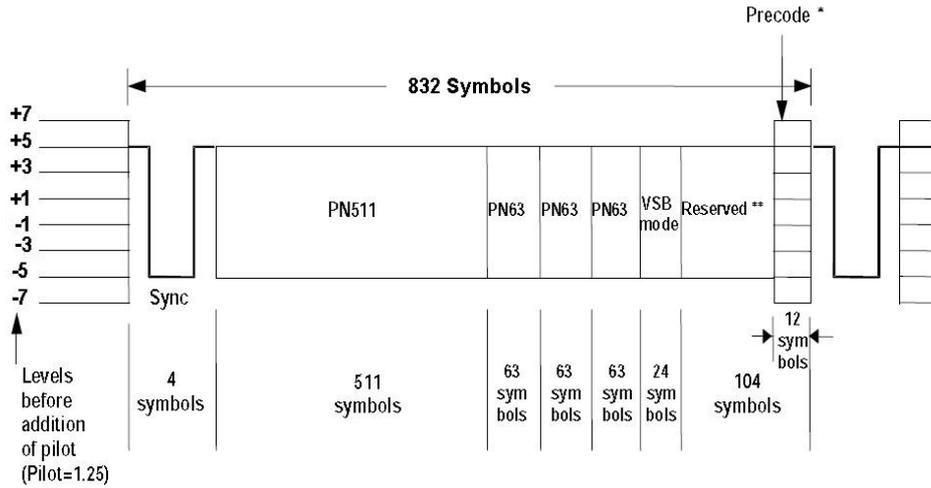
Figure 4. The synchronization of VSB Data Field

IV.   THE SPECTRUM SENSING SIMULATION MODEL BASED ON SIGNAL FEATURE

Figure 5 shows the simulation model of the perception algorithm based on the signal feature. This model was put forward by Steve Shellhammer et al [12]. The real value of DTV signal data r[n] gets sampled by frequency f_s=21.524476M sample/second and conversed to intermediate frequency f_{IF}=5.38MHz of the DTV signal channel. Because of using embedded data transmission for signal spectrum sensing, the baseband complex envelope $\hat{r}[n]$ of the signal must be calculated. The parameter f_c in figure 5 is 2.69 MHz. $\hat{r}[n]$ does scale transform according to the power of the wanted signal $s[n]$,

$$s[n]=\frac{\hat{r}[n]}{\alpha} \qquad (1)$$

In which α is the power scaling factor, and α equals,

$$\alpha = 10^{\frac{P_{Desired} - P_S}{20}} \qquad (2)$$

The parameter $P_{Desired}$ is the power of the wanted signal $s[n]$ and the parameter P_S is the power of the signal $\hat{r}[n]$. Finally, additive White Gaussian noise $\eta[n]$ after preliminary

filtered is added to the wanted signal $s[n]$ to get the required experimental data, thus the following formula is available,
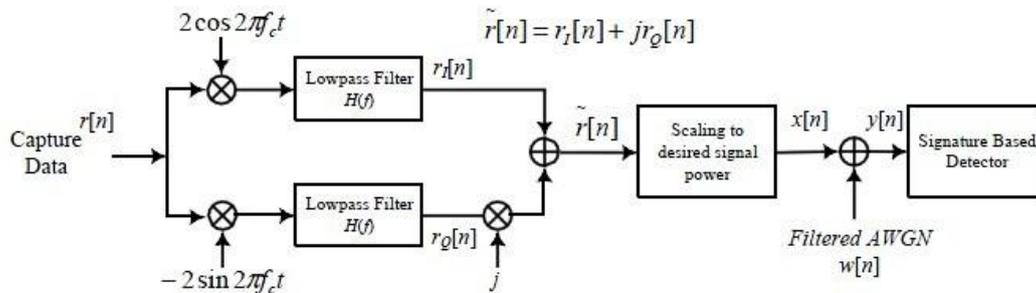
$$x[n] = s[n] + \eta[n] \qquad (3)$$

Figure 5. The simulation model of spectrum sensing algorithm based on signal feature

V. SEGMENT ACCUMULATION SYNC CORRELATION DETECTOR ALGORITHM

Literature [13] introduced the SSAD algorithm and FSCD algorithm, and this paper introduces a new algorithm, the Segment Accumulation Sync Correlation Detector Algorithm (SASCD), which uses synchronous portion of data segment for testing.

a. The theoretical analysis

From figure 3, it can be seen that the beginning of each segment is synchronous elements composed of four symbols '1001' and the rest are data after the randomization process. The signals are sampled according to the Nyquist sampling theorem. The sampling frequency is $832 \times 2 \times M$, which is a total of $1664 \times M$ sampling points. The received signal x[n]is as follows,

$$x = [x(1), x(2), \ldots, x(1664 \times M)] \qquad (4)$$

Make the $1664 \times M$ sampling points into M groups equally, so each group has 1664 sampling points. The number 1664 is the same with the sampling frequency of this very data segment according to the Nyquist sampling theorem. Then accumulate the M group data segments and get a data set of 1664 sampling points.

There are two hypotheses: H_0, the signal doesn't exist; and H_1, the signal is present. The received signal at receiver is given by

$$H_0: \quad x(n) = \eta(n) \qquad (5)$$

$$H_1: \quad x(n) = s(n) + \eta(n) \qquad (6)$$

Where s(n) is the received signal component by receiver.

When the primary user signal dose not exist, which is to say, when the White Gaussian noise exists alone, the received signal is as follows,

$$x = \eta = [\eta(1), \eta(2), \dots, \eta(1664)] \qquad (7)$$

When accumulating the received signal after grouping, the accumulation results are as follows,

$$\begin{aligned}
X &= [x_{acc|H_0}(1), x_{acc|H_0}(2), \dots, x_{acc|H_0}(1664)] \\
&= [\eta_{acc}(1), \eta_{acc}(2), \dots, \eta_{acc}(1664)]
\end{aligned} \qquad (8)$$

In which,

$$x_{acc|H_0}(i) = \eta_{acc}(i) = \sum_{j=0}^{M-1} \eta(i + 1664 \times j) \qquad (9)$$

Because $\eta(i)$ is the Gaussian White noise with mean 0 and variance σ_η^2, then the joint distribution of the random variable $x_{acc|H_0}(i)$ is a normal distribution with mean $\sum_{j=1}^{M} 0 = 0$ and variance $\sum_{j=1}^{M} \sigma_\eta^2 = M\sigma_\eta^2$.

SCSAD adds M sets of data together. Because of the sync part have the same symbols, we can consider that one sync part multiple a number M. After to be added together the randomized data part value tends to be zero. If there is a window whose pattern is as follows,

$$h_{sync} = [+1, +1, -1, -1, -1, -1, +1, +1] \qquad (10)$$

A test statistics Y can be got from the correlation calculation between h_{sync} and X,

$$\begin{aligned}
Y = \sum h_{sync} * X &= x_{acc|H_0}(j) + x_{acc|H_0}(j+1) - x_{acc|H_0}(j+2) - x_{acc|H_0}(j+3) - x_{acc|H_0}(j+4) \\
&- x_{acc|H_0}(j+5) + x_{acc|H_0}(j+6) + x_{acc|H_0}(j+7)
\end{aligned} \qquad (11)$$

By probability theory, the mean of Y is,

$$
\begin{aligned}
E[Y] &= E[\, x_{acc|H_0}(j) + x_{acc|H_0}(j+1) - x_{acc|H_0}(j+2) - x_{acc|H_0}(j+3) - \\
&\quad x_{acc|H_0}(j+4) - x_{acc|H_0}(j+5) + x_{acc|H_0}(j+6) + x_{acc|H_0}(j+7)] \\
&= E[x_{acc|H_0}(j)] + E[x_{acc|H_0}(j+1)] - E[x_{acc|H_0}(j+2)] - E[x_{acc|H_0}(j+3)] - \\
&\quad E[x_{acc|H_0}(j+4)] - E[x_{acc|H_0}(j+5)] + E[x_{acc|H_0}(j+6)] + E[x_{acc|H_0}(j+7)] \\
&= 0
\end{aligned} \tag{12}
$$

The variance of Y is,

$$
\begin{aligned}
Var[Y] &= Var[x_{acc|H_0}(j) + x_{acc|H_0}(j+1) - x_{acc|H_0}(j+2) - x_{acc|H_0}(j+3) - \\
&\quad x_{acc|H_0}(j+4) - x_{acc|H_0}(j+5) + x_{acc|H_0}(j+6) + x_{acc|H_0}(j+7)] \\
&= 8 \times \sum_{j=1}^{M} \sigma_\eta^2 \\
&= 8M\sigma_\eta^2
\end{aligned} \tag{13}
$$

So it can conclude that Y is accord with normal distribution, that is $Y \sim N(\,0\,, 8M\sigma_\eta^2\,)$.

According to the basic theory of probability, the accumulation normal distribution function is,

$$
F(x \mid \mu,\sigma) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi\sigma^2}}\, e^{-\frac{(t-\mu)^2}{2\sigma^2}}\, dt \tag{14}
$$

Where μ is mean and σ is variance.

The probability of false alarm for secondary user is,

$$
p_{fa} = P\{Y > Th_{SASCD} \mid H_0\} = 1 - F(Th_{SASCD} \mid \sqrt{8M\sigma_\eta^2}) \tag{15}
$$

Thus the threshold of SASCD algorithm can be obtained as follows,

$$
Th_{SASCD} = F^{-1}\{1 - p_{fa} \mid \mu,\sigma\} \tag{16}
$$

If primary user exists, both signal and noise are received by the receiver,

$$
x = s + \eta = [s(1) + \eta(1)\,, s(2) + \eta(2)\,, \cdots, s(1664 \times M) + \eta(1664 \times M)\,] \tag{17}
$$

Then we can get a vector X, which is as follows,

$$
\begin{aligned}
X &= [\, x_{acc|H_1}(1)\,, x_{acc|H_1}(2)\,, \cdots, x_{acc|H_1}(1664)\,] = [\, s_{acc}(1) + \eta_{acc}(1)\,, s_{acc}(2) \\
&\quad + \eta_{acc}(2)\,, \cdots, s_{acc}(1664) + \eta_{acc}(1664)\,]
\end{aligned} \tag{18}
$$

In which,

$$
s_{acc}(i) = \sum_{j=1}^{M-1} x(\,i + 1664 \times j\,) \tag{19}
$$

$$\eta_{acc}(i) = \sum_{j=1}^{M-1} \eta(i + 1664 \times j) \qquad (20)$$

$$x_{acc|H_1}(i) = \sum_{j=1}^{M-1} (s_{acc}(i) + \eta_{acc}(i)) \qquad (21)$$

$\eta_{acc}(i)$ is accord with normal distribution whose mean is $\sum_{j=1}^{M} 0 = 0$ and variance is

$\sum_{j=1}^{M} \sigma_\eta^2 = M\sigma_\eta^2$.

Because these 8 symbols of ATSC DTV signal appear with equal probability, the expectation of signal and the variance of signal are, respectively,

$$E[s] = \frac{1}{8}(-7-5-3-1+1+3+5+7) = 0 \qquad (22)$$

$$\begin{aligned} Var[s] &= \frac{1}{8}[(0-7)^2 + (0-5)^2 + (0-3)^2 + (0-1)^2 + \\ &\quad (0+1)^2 + (0+3)^2 + (0+5)^2 + (0+7)^2] \qquad (23) \\ &= 21 \end{aligned}$$

The data part of ATSC DTV signal is accord with discrete uniform distribution whose mean is 0 and variance is 21.

The correlation calculation result of and data part of data segment is,

$$\begin{aligned} Y &= \sum h_{sync} * X = x_{acc|H_1}(j) + x_{acc|H_1}(j+1) - x_{acc|H_1}(j+2) - x_{acc|H_1} - (j+3) - x_{acc|H_1}(j+4) - \\ &\quad x_{acc|H_1}(j+5) + x_{acc|H_1}(j+6) + x_{acc|H_1}(j+7) = \sum h_{sync} * s_{acc} + \sum h_{sync} * \eta_{acc} \end{aligned} \qquad (24)$$

We can get two values $Y_{H_1,s} = \sum h_{sync} * s_{acc}$ and $Y_{H_1,\eta} = \sum h_{sync} * \eta_{acc}$.

By probability theory, it can conclude that $Y_{H_1,s}$ is accord with normal distribution whose mean is 0 and variance is $8M\sigma_s^2$. $Y_{H_1,\eta}$ is accord with normal distribution whose mean is 0 and variance is $8M\sigma_\eta^2$.

$$Y = Y_{H_1,s} + Y_{H_1,\eta} \qquad (25)$$

Because Y is composed of random variables that have different distribution functions, it is hard to compute the Y's distribution function.

If we use h_{sync} do correlation calculation separately with signal and noise, we can know that

Y is accord with normal distribution whose mean is 0 and variance is $8M\sigma_\eta^2 + 8M\sigma_s^2$.

Assumes that noise power is P_n and the signal power is P_s, SNR is $10 \times \log_{10}\left(\dfrac{P_s}{P_n \times C^2}\right)$. C

is coefficient which is used to adjust the SNR in simulation. If we accumulate sync part of data segment M times, we can obtain a vector,

$$s_{acc\_sync} = [\ +\frac{5M}{C}, +\frac{5M}{C}, -\frac{5M}{C}, -\frac{5M}{C}, -\frac{5M}{C}, -\frac{5M}{C}, +\frac{5M}{C}, +\frac{5M}{C}\ ] \qquad (26)$$

If we use h_{sync} do correlation calculation with sync part, we can get another random variable. This random variable is the threshold of SASCD, that is,

$$
\begin{aligned}
Y &= \sum h_{sync} * X_{H_1} = \sum h_{sync} * (s_{acc\_sync} + \eta_{acc}) \\
&= \{[\frac{1 \times 5M}{C} + \frac{1 \times 5M}{C} - \frac{(-1) \times 5M}{C} - \frac{(-1) \times 5M}{C} - \frac{(-1) \times 5M}{C} - \\
&\quad \frac{(-1) \times 5M}{C} + \frac{1 \times 5M}{C} + \frac{1 \times 5M}{C}]\} + \{[1 \times \eta_{acc}(j) + 1 \times \eta_{acc}(j+1) + \\
&\quad (-1) \times \eta_{acc}(j+2) + (-1) \times \eta_{acc}(j+3) + (-1) \times \eta_{acc}(j+4) + (-1) \times \eta_{acc}(j+5) \qquad (27) \\
&\quad + 1 \times \eta_{acc}(j+6) + 1 \times \eta_{acc}(j+7)]\} \\
&= \frac{40M}{C} + [\eta_{acc}(j) + \eta_{acc}(j+1) - \eta_{acc}(j+2) - \eta_{acc}(j+3) - \eta_{acc}(j+4) \\
&\quad - \eta_{acc}(j+5) + \eta_{acc}(j+6) + \eta_{acc}(j+7)]
\end{aligned}
$$

If primary user exists, the expectation and variance of Y are, respectively,

$$
\begin{aligned}
E[Y] &= \frac{40M}{C} + 1 \times [\eta_{acc}(j) + \eta_{acc}(j+1) - \eta_{acc}(j+2) - \eta_{acc}(j+3) \\
&\quad - \eta_{acc}(j+4) - \eta_{acc}(j+5) + \eta_{acc}(j+6) + \eta_{acc}(j+7)] \\
&= E[\frac{40M}{C}] + E[\eta_{acc}(j) + \eta_{acc}(j+1) - \eta_{acc}(j+2) - \eta_{acc}(j+3) \qquad (28) \\
&\quad - \eta_{acc}(j+4) - \eta_{acc}(j+5) + \eta_{acc}(j+6) + \eta_{acc}(j+7)] \\
&= \frac{40M}{C}
\end{aligned}
$$

The variance of Y is,

$$Var[Y] = 8M\sigma_\eta^2 \qquad (29)$$

Then the probability of detection of SASCD is,

$$p_d = \{Y > Th_{SASCD} \mid H_1\} = 1 - F\left(Th_{SASCD} \mid \frac{40M}{C}, \sqrt{8M\sigma_\eta^2}\right)$$

$$= \int_{Th_{SASCD}}^{+\infty} \frac{1}{\sqrt{2\pi \times 8M\sigma_\eta^2}} e^{-\frac{\left(t - \frac{40M}{C}\right)^2}{16M\sigma_\eta^2}} dt \qquad (30)$$

No matter whether primary user exists or not, the test statistics have the same variance and different means. Figure 6 shows the probability distributions of these two types of test statistics.
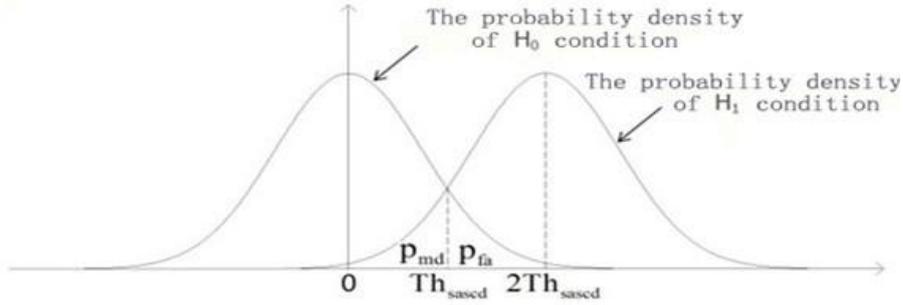

Figure 6. Probability density function of two kinds of condition

The secondary user probability of false alarm is,

$$p_e = p_{fa}P(H_0) + p_{md}P(H_1) \qquad (31)$$

If the usage percent of primacy user is 50% which is to say that $P(H_0) = P(H_1) = 0.5$, it can be seen that $Th_{SASCD} = Th_{min\_error}$. The secondary user probability of false alarm is smallest. Secondary user probability of false alarm and probability of miss detection is equal, and the threshold is,

$$Th_{SASCD} = \frac{20M}{C} \qquad (32)$$

$$p_{fa} = 1 - F(Th_{SASCD} \mid 0, \sqrt{8M\sigma_\eta^2}) = 1 - F(\frac{20M}{C} \mid 0, \sqrt{8M\sigma_\eta^2}) \qquad (33)$$

$$p_{md} = F(Th_{SASCD} \mid 2 \times Th_{SASCD}, \sqrt{8M\sigma_\eta^2}) = F(\frac{20M}{C} \mid \frac{40M}{C}, \sqrt{8M\sigma_\eta^2}) \qquad (34)$$

Because there are 1664 elements in the vector, correlation calculation will get 1664 results. Set the false alarm probability as p_{fa}, therefore we can calculate that the number of false alarm is about $N_{H_1 \mid H_0} \approx p_{fa} \times 1664$.

Even if the primary user signal does not exist, there will be $N_{H_1 \mid H_0}$ values bigger than

threshold. We know that $p_{fa} = 0.01$ is small enough probability of false alarm, but it can concludes that $N_{H_1|H_0} \approx 17$. So it is impossible to judge whether primary user exists or not by comparing the maximum value of correlation calculation and threshold.

Formula 30 shows that no matter whether primary user exists or not, the variance of random variable changes little, because SNR is small enough. It is obvious that the threshold almost keeps unchanged and the primary user probability of false alarm and the secondary user probability of false alarm are almost equal. There will be $N_{H_1|H_1}$ results of correlation calculation bigger than threshold. The number is about $N_{H_1|H_1} \approx p_d \times 1 + N_{H_1|H_0} \approx 1 + N_{H_1|H_0}$.

We still cannot judge whether primary user exists or not by comparing $N_{H_1|H_1}$ and $N_{H_1|H_0}$, because $N_{H_1|H_1} \approx N_{H_1|H_0}$.

Assumes that receiver samples are $1664 \times M \times N$ points, and we divide these points into N big vectors and each big vector has $M \times 1664$ points. Then we divide each big vector into M small vectors and each small vector has 1664 points. Then we accumulate these M small vectors into one final vector, so there are N final vectors. We use h_{sync} do correlation calculation with these N final vectors separately. And the results are Ψ_i $(1 \leq i \leq N)$,

$$\psi_i = [\psi_{i,1}, \ldots, \psi_{i,k}, \ldots, \psi_{i,1664}] \qquad (35)$$

To compare each value in Ψ_i with threshold, it gets a vector V_i $(1 \leq i \leq N)$ which contains 1 and 0 only.

$$V_i = [v_{i,1}, \ldots, v_{i,k}, \ldots, v_{i,1664}] \qquad (36)$$

In which,

$$\begin{cases} v_{i,k} = 1 & \psi_{i,k} > Th \\ v_{i,k} = 0 & \psi_{i,k} < Th \end{cases} \qquad (37)$$

Finally, it has a matrix that,

$$R = \begin{bmatrix} v_{1,1} & v_{1,2} & \cdots & v_{1,1664} \\ v_{2,1} & v_{2,2} & \cdots & v_{2,1664} \\ \vdots & \vdots & \ddots & \vdots \\ v_{N,1} & v_{N,2} & \cdots & v_{N,1664} \end{bmatrix} \qquad (38)$$

If primary user exists, $v_{i,k}$ will be 1 with the probability p_d.

The sum of each column is,

$$\phi_k = \sum_{i=1}^{N} v_{i,k} \qquad (39)$$

We can get a vector that,

$$\Phi = [\phi_1, \ldots, \phi_k, \ldots, \phi_{1664}] \qquad (40)$$

ϕ_k is the biggest number in vector Φ with maximum probability, and the value range of

ϕ_k must $1 \leq \phi_k \leq N$. So we can choose a integer Th_{INT} $(1 \leq Th_{INT} \leq N)$ as the final

threshold. We can conclude that,

$$\phi_k \geq Th_{INT} \quad H1 \qquad (41)$$

$$\phi_k < Th_{INT} \quad H0 \qquad (42)$$

If primary user exists, the secondary user probability of detection is,

$$P_D = \sum_{Th_{INT}}^{N} \binom{N}{Th_{INT}} (p_d)^{Th_{INT}} (1-p_d)^{N-Th_{INT}} \qquad (43)$$

If primary user does not exist, the ith element probability of false alarm is,

$$P_{fa,i} = \sum_{Th_{INT}}^{N} \binom{N}{Th_{INT}} (p_{fa,i})^{Th_{INT}} (1-p_{fa,i})^{N-Th_{INT}} \qquad (44)$$

Totally, there are 1664 elements, so the composite probability is,

$$P_{FA} = 1 - \prod_{j=1}^{1664} (1 - P_{fa,j}) \qquad (45)$$

By choosing a rational value, the probability of detection will be $P_D \geq 0.95$ and the

probability of false alarm $P_{FA} \leq 0.05$.

Compared with SSAD algorithm introduced in the literature [13], SASCD algorithm has

carried superposition on the grouping of received signal before related operations. According

to the nature of the Additive White Gaussian noise, the influence of the primary user signal after superposition can be effectively reduced. When the primary user signal exists, the synchronous part of the primary user signal can also be overlaid to reinforce this part of the signal. SSAD algorithm requires the autocorrelation calculation. When SASCD algorithm does relevant operation with h_{sync} , we can know SASCD algorithm only need to change the symbol of accumulative signal to do relevant operation. So the multiplier of SASCD algorithm can be much easier.

When cognitive radio network uses cooperative spectrum sensing, "K" rank fusion rules is a kind of general fusion rules, yet "and" and "or" fusion rules are special cases of it[14]. Literature [14] proved that when $p_{fa} = p_{md}$, the majority of the voting rules is optimal fusion rule of "K" rank. Thus SASCD algorithm can satisfy the conditions of the optimal fusion rules "K" rank.

b. The Results

The simulation results of the experiments are shown in figure 7, figure8 and figure 9. Figure 7 shows the performance Receiver Operating Characteristics (ROC) curves of SASCD and ED. It assumes that the noise is AGWN. Accumulation coefficient M is 100. SNR decreases from 0dB to -20dB. With the decrease of SNR, the ROC curve of ED would decrease sharply when SNR is smaller than -7dB. But as can be seen in figure 7, for SASCD $P_d = 0.9$ can still be achieved when SNR is -18 dB. A conclusion can be got that SASCD performs better than ED when SNR is smaller than -7dB. The ROC curve of SASCD decreases slowly.
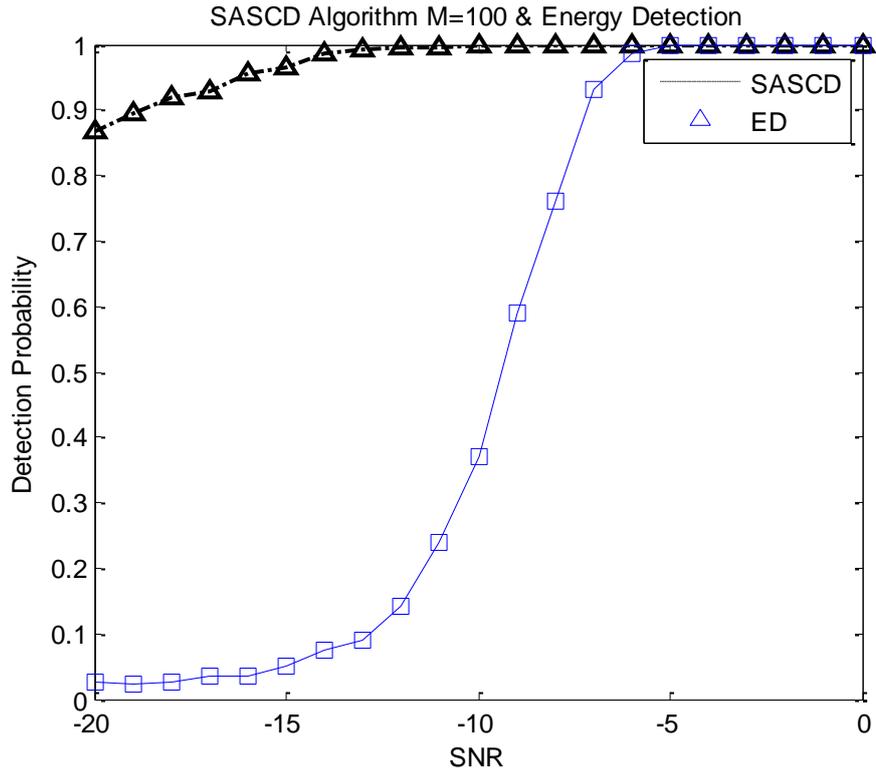
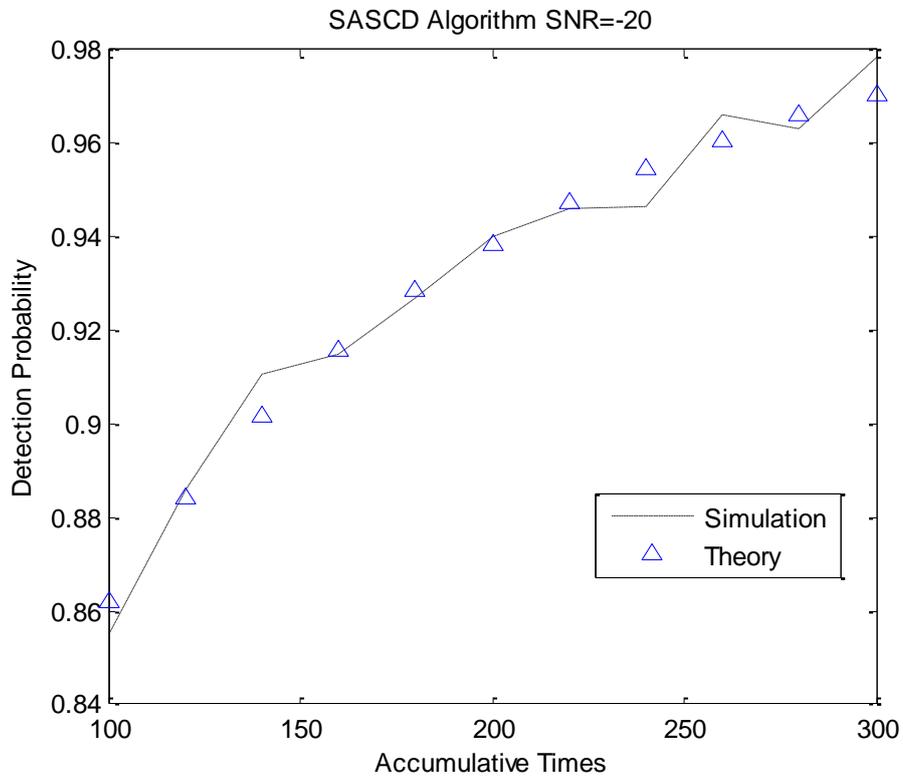Figure 7. Contrast of SASCD algorithm and energy detection algorithm

Figure 8. The results of detection propability with fixed SNR

Figure 8 shows the relationship of detection propability and accumulative coefficient when SNR is fixed as -20dB. It can be concluded from the figure when the accumulative coefficient increase, the detection probability of the secondary users increase, too. The theoretical results and simulation results is coincident very well.
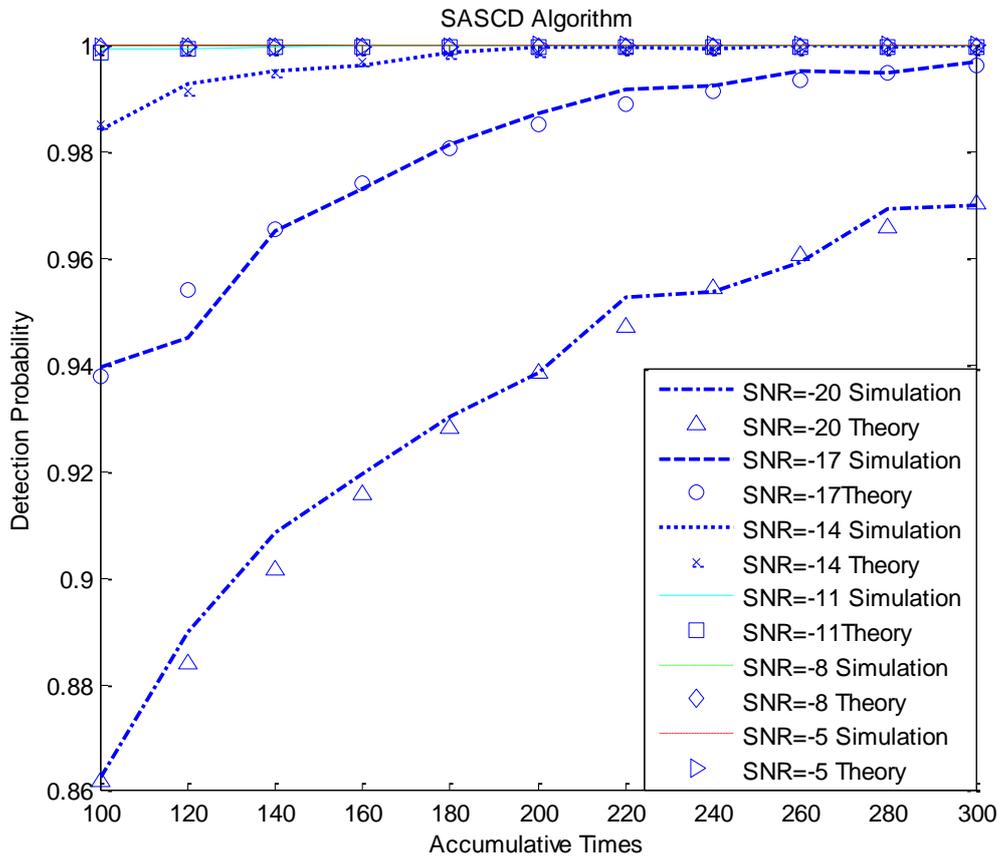

Figure 9. SNR and accumulate more often to the simulation results of the dynamic value

Figure 9 shows the simulation results and theoretical analysis results of SASCD when given different SNR and different accumulative coefficient. The accumulative coefficient increases gradually from 100 to 300 and the SNR changes from - 20 dB to -5 dB in this simulation. We can see that it can detect the signal with small accumulative coefficient when SNR is high enough. We can increase the accumulative coefficient in response to SNR reducing, but this will obviously increase the sensing time.

VI. CONCLUSIONS

At the beginning this paper introduces ATSC DTV signal structure, and we can make use of the ATSC DTV signal structure characteristics to do spectrum sensing for its perception of TV signal frequency band. Based on the point, this paper presents the SASCD algorithm and analyzes the derivation process of the false alarm probability. Given the false alarm probability, we can calculate the threshold of SASCD algorithm which can be used to calculate the detection probability of the cognitive users. The impact of false alarm probability on the correlation detection algorithm is also analyzed, and a solution is presented, too. When the structure of the other signals is known, the spectrum sensing algorithm based on the structure of signal can also be used for other digital signal perception.

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