A Cooperative Spectrum Sensing Scheme Based on Trust and Fuzzy Logic for Cognitive Radio Sensor Networks

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Abstract

This paper proposes a cooperative spectrum sensing scheme based on trust and fuzzy logic for Cognitive Radio Sensor Networks (CRSN). The CRSN nodes use the T-S fuzzy logic to make local decisions on the presence or absence of the primary user's (PU) signal, and then use a censoring method to only allow the relatively reliable decisions sent to the fusion center. Utilizing a trust evaluation scheme based on the factors such as local sensing difference, sensing location factors, and sensing channel conditions for each node. Combing the majority rule and the trust values of the nodes, the fusion center makes the final decision. Simulation results show that the proposed scheme could improve the detect probability effectively.

Keywords: *Cognitive Radio Sensor Networks, trust, fuzzy logic, Cooperative Spectrum Sensing.*

1. Introduction

Most Wireless Sensor Networks (WSNs) operate in the unlicensed ISM (Industrial, Scientific and Medical) frequency band, for example, the 2.4 GHz band. While such bands are also used by other wireless applications such as WiFi, Bluetooth, cordless phones, RFID, microwave ovens, etc. And in a large-scale wireless sensor network, due to the event-driven nature, when an event occurs many WSN nodes need to transmit the event signal data simultaneously. Therefore, the interference or collision probability increases. The Cognitive Radio (CR)[1] that enables higher spectrum efficiency by dynamic spectrum access [2][3]can be exploited by WSN to solve this problem. The WSN comprised of sensor nodes equipped with CR is defined Cognitive Radio Sensor Networks (CRSN)[4].

To mitigate the problem of uncertainty in spectrum sensing in a cognitive radio network, cooperative spectrum sensing can be used. Different techniques were proposed for cooperative spectrum sensing. The simplest method is to use an OR or AND operation among the received sensing results [5]. Combing techniques based on maximal ratio combining (MRC) and equal gain combining (EGC) were investigated in [6], an optimal linear cooperation scheme base on a likelihood ratio test (LRT) has been proposed in [7]. In [8], the censor-based cooperative spectrum sensing has been proposed to save energy. And a censor-based cooperative spectrum sensing scheme using Takagi and Sugeno's (T-S) fuzzy logic for cognitive radio sensor networks was proposed in [9]. But in these schemes, the CRSN nodes are often assumed to be trustworthy. In practice, there are malicious CRSN nodes sending false reporting values to the Fusion Center (FC) [10], which will induce the FC to make wrong decisions. Based on the previous work in [9] and [11], we proposed a cooperative spectrum sensing scheme based on trust and fuzzy logic for CRSN. The nodes use the T-S fuzzy logic to make local decisions on the presence or absence of the primary user's (PU) signal, and then use a censoring method to only allow the relatively credible decisions sent to FC. And a trust scheme on the basis of the factors such as local sensing difference, sensing location factors, and sensing channel conditions for each node is implemented. The FC makes the final decision according to the majority rule and the trust weights of the nodes. This method can improve the sensing performance while saves the node's energy.

2. Cooperative Spectrum Sensing Scheme

2.1 Local Spectrum Sensing and Decision

Suppose each CRSN node using the energy detection. The hypotheses if the primary user is present (H_1) or not (H_0) are as follows:

$$x_i(t)=\begin{cases} n_i(t): & H_0 \\ h_i(t)s(t)+n_i(t): & H_1 \end{cases} \quad (1)$$

Where $x_i(t)$ is the received signal by the i -th node, $n_i(t)$ is the thermal noise, $h_i(t)$ is the channel gain from the PU to the i -th node, and $s(t)$ is the transmit signal from the PU.

The local test static of the i -th node using energy detection is:

$$x_{Ei}=\sum_{k=0}^{N-1}\left|x_i(k)\right|^2, i=1,2,\cdots,M \quad (2)$$

Where $x_i(k)$ is the k -th sample of received signal at the i -th node, M is the number of nodes, and N is the number of samples, $N=2TW$, where T and W are detection time and signal bandwidth, respectively[12].

Let the two fuzzy sets Low and High depict the i -th node detected energy x_{Ei} , and their membership functions are[12]:

$$\mu_{Low}(x_{Ei})=\begin{cases} 1 & ,if\ x_{Ei}\le \mu_{0i} \\ e^{\frac{(x_{Ei}-\mu_{0i})^2}{2\sigma_{0i}^2}} & ,otherwise \end{cases} \quad (3)$$

$$\mu_{High}(x_{Ei})=\begin{cases} 1 & ,if\ x_{Ei}\ge \mu_{1i} \\ e^{\frac{(x_{Ei}-\mu_{1i})^2}{2\sigma_{1i}^2}} & ,otherwise \end{cases} \quad (4)$$

And the Fig. 1 shows the shapes of the above functions [9] [12].

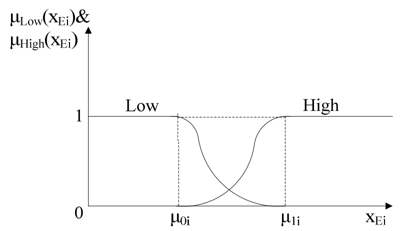

Fig.1 The membership functions of the two fuzzy sets

Based on the T-S fuzzy method, the local decision of the i -th node [9] is:

$$Ld_i=\frac{-\mu_{Low}(x_{Ei})+\mu_{High}(x_{Ei})}{\mu_{Low}(x_{Ei})+\mu_{High}(x_{Ei})} \quad (5)$$

And the fuzzy rule sets are [9] [12]:

Rule 1: IF (x_{Ei} is *Low*) THEN ($Ld_i=Ld_{\min}$)

Rule 2: IF (x_{Ei} is *High*) THEN ($Ld_i=Ld_{\max}$)

Where Ld_i is the local decision of the i -th node, $Ld_{\max}$ and $Ld_{\min}$ are the maximum and minimum value of Ld_i respectively. $Ld_{\max}=1$ means the PU is present and $Ld_{\min}=-1$ means the PU is absent.

Given the censoring threshold value $C\in(0,1)$,the local soft decision Ld_i is transmitted to the FC if and only if $Ld_i<-C$ or $Ld_i>C$.

2.2 The Trust Value of CRSN Nodes

Combine the factors such as the difference of local sensing; sensing location, sensing channel condition [11], the FC establishes trust value for each node.

The difference of local sensing is the difference of the sensing value of a single node with the average value of all nodes. The smaller the difference, the more reliable of the node. The difference of local sensing of the l -th node is:

$$D_l=\left|Ld_l-\frac{1}{Ns}\sum_{l=1}^{Ns}Ld_l\right| \quad (6)$$

Where Ns is the number of nodes that sent the local decision to the FC.

The sensing location factor includes two aspects: the distance of the l -th node to PU, the distance of the l -th node to the FC, and denoted by LO_a and LO_b respectively. The sensing location factor is:

$$LO_l=LO_a^l\times LO_b^l \quad l=(1,2,\cdots,Ns) \quad (7)$$

Because the sensing channel is non-ideal, so the information transmission is prone to error. Based on the channel SNR, define the sensing channel condition factor of the l -th node:

$$CC_l=SNR_l \quad l=(1,2,\cdots,Ns) \quad (8)$$

Carry out the standardizing to the three factors, and get the following expressions [11]:

$$D_l^{'} = \frac{D_{\max} - D_l}{D_{\max} - D_{\min}} \quad (9)$$

$$LO_l^{'} = \frac{LO_{\max} - LO_l}{LO_{\max} - LO_{\min}} \quad (10)$$

$$SC_l^{'} = \frac{SC_{\max} - SC_l}{SC_{\max} - SC_{\min}} \quad (11)$$

Where $D_{\max}$ and $D_{\min}$ is the maximum and minimum value of the sensing location factor respectively, and the others are similar.

The trust value of the l -the node is:

$$T_l = \alpha D_l^{'} + \beta LO_l^{'} + \gamma SC_l^{'} \quad (12)$$

Where $\alpha + \beta + \gamma = 1$.

2.3 Data Fusion at the FC

The FC receives Ns local decisions from CRSN nodes. According to the majority rule[9], the final decision fusion rule is:

$$H = \begin{cases} H_1 : \sum_{j=1}^{Ns} Ld_j T_j > 0 \\ H_0 : otherwise \end{cases} \quad (13)$$

3. Simulation Results and Analysis

To evaluate the performance of the proposed cooperative spectrum sensing algorithm for CRSN and compare the performance with some exiting methods, the Monte-Carlo simulations are carried out with 100,000 samples under the following conditions: The number of CRSN nodes M is 7, the PU signal is likely-equally BPSK signal, The noises at the sensing and control channels are Gaussian with zero mean and unit variance, The number of samples N is 300.

The performance of the scheme is compared with the performance of the OR/AND fusion rules, the equal gain combination (EGC) based scheme [6], and the fuzzy logic scheme [9].

Firstly, the performance of the factors that local sensing difference, sensing location factors, and sensing channel condition is evaluated. Let the SNRs for the nodes are -20,-18,-16,-14,-12, -10,-8 dB, respectively, and $C = 0.2$. From Fig.2, it can be seen that the three factors all have the effect on the detection performance, and the local sensing difference has the minimum effect while the sensing channel condition factor has the greatest effect. The scheme has the best sensing performance when the $\alpha = \beta = \gamma = 1/3$.

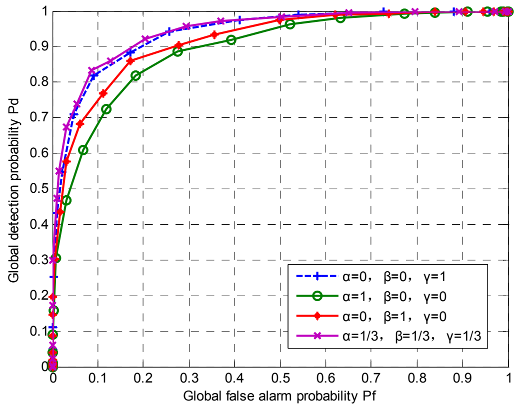

Fig.2. The effect of the α, β, γ

Secondly, the impact of the SNR on the performance is evaluated. The simulation was carried out under conditions that the SNRs of the first six nodes are -15,-14,-13,-12,-11,-10 dB, respectively, and the SNR at the 7th node is -14,-12,-10,-8,-6 dB respectively, $\alpha = \beta = \gamma = 1/3$,and $C = 0.2$. From Fig.3, it can be seen that P_M increases while the SNR at the 7th node decreases.

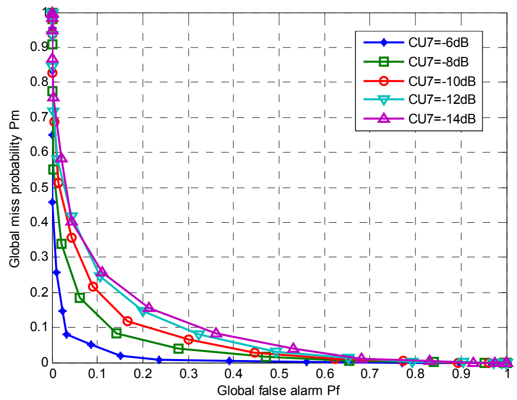

Fig.3. The impact of the SNR

Finally, the simulations are conducted under the $\alpha = \beta = \gamma = 1/3$, the SNRs for the nodes are -20,-18,-16,-14,-12,-10,-8 dB, respectively, and $C = 0.2$. The ROC curves of our scheme and compared schemes are depicted in Fig. 4. It can be seen that the proposed scheme has the highest detection probability than the OR/AND fusion rules based scheme, the EGC based scheme, and the fuzzy logic scheme. It means that the method of node trust evaluation improves the FC decision accuracy.

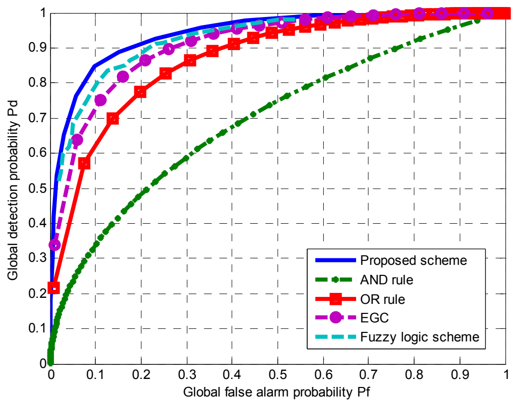

Fig.4 ROC curves of proposed scheme vs. comparison schemes

4. Conclusions

By introducing the trust scheme into the fuzzy logic scheme to represent the reliability of the nodes, a cooperative spectrum sensing scheme based on trust and fuzzy logic for CRSN was proposed in this paper. Analysis and simulations show that while keep the merits the fuzzy logic scheme that reduce the number of nodes reporting its local decision to the FC and save the energy of the CRSN nodes, the proposed scheme can improve the detection probability effectively compared with the OR/AND fusion rules based scheme, the EGC based scheme, and the fuzzy logic scheme. It is useful for the CRSN because the hardware, low energy restriction and the performance are favorable.

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References

[1] J. Mitola, G. Q. Maguire, "Cognitive Radios:Making Software Radios More Personal",IEEE Personal Communications,Vol. 6,No. 4, 1999,pp. 13-18,.

[2] Chaoub, Abdelaali; Ibn-Elhaj, Elhassane, "Comparison between Poissonian and Markovian Primary Traffics in Cognitive Radio Networks ",International Journal of Computer Science Issues, Vol.9, No .2, 2012, pp. 63-73.

[3] Yadav, Shrikrishan;Roy, Krishna Chandra, "Tradeoff Analysis of Bit-Error-Rate (BER) in Cognitive Radio Based on Genetic Algorithm",International Journal of Computer Science Issues, Vol. 9, No. 1, 2012 , pp.390-394.

[4] O.B. Akan,O.B.Karli,O.Ergul, "Cognitive Radio Sensor Networks",IEEE Networks,Vol.23, No.4, 2009,pp.34-40.

[5] Tevfik Yucek, Huseyin Arslan, "A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications",IEEE Communications Surveys & Tutorials, Vol. 11, No.1, 2009, pp. 116-130.

[6] J.Ma,G.Zhao,Y.Li, "Soft Combination and Detection For Cooperative Spectrum Sensing in Cognitive Radio Networks", IEEE Transactions on Wireless Communications, Vol.7, No.11, 2008 , pp:4502-4507.

[7] Z. Quan, S. Cui, and A. H. Sayed, "Optimal Linear Cooperation for Spectrum Sensing in Cognitive Radio Networks", IEEE Journal of Selected Topics in Signal Processing, Vol. 2, No.1, 2008, pp. 28-45.

[8] S.Maleki, A.Pandharipande, G.Leus,"Energy-Efficient Distributed Spectrum Sensing for Cognitive Sensor Networks", IEEE Sensors Journal, Vol.11, No.3,2011, pp.565-573.

[9] T.K.XUAN,I.KOO , "A Censor-Based Cooperative Spectrum Sensing Scheme Using Fuzzy Logic for Cognitive Radio Sensor Networks", IEICE Transctions on communications, Vol. E93-B, No.12, 2010, pp.3497-3500.

[10] W.Lang, Y.Zhu, H.Li,"Trust Level Based Byzantine Attack-Exclusion Cooperative Spectrum Sensing Scheme for Wireless Cognitive Sensor Networks in Smart Grids",in 2012 IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent Systems (CYBER), 2012, pp:21–25.

[11]Zhang Guanghua, Ding Renshuang, Huang Lijing, "Using Trust to Establish Cooperative Spectrum Sensing Framework",Procedia Engineering, Vol.15, 2011,pp.1361–1365.

[12]T.K.XUAN,I.KOO , "Cooperative Spectrum Sensing using Kalman Filter based Adaptive Fuzzy System for Cognitive Radio Networks", KSII Transctions on Internet and Information System,Vol. 6, No.1, 2012, pp.287-304.

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