# Channel States Information Based Energy Detection Algorithm in Dual Satellite Systems

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**Abstract.** Satellite communication which is a crucial part in wireless communication field faces the spectrum scarcity problem. Therefore, exploring a suitable spectrum sharing mechanism has become a key issue in ensuring the full utilization of satellite users while improving the spectrum utilization of existing spectrum. Cognitive communication is an emerging solution to solving spectrum problems in wireless systems. An important part of cognitive radio is spectrum awareness, which is used for acquiring information about the spectral opportunities. One of the spectrum sensing methods is spectrum sensing, which utilizes spectrum holes in multiple fields to sense the presence or absence of primary users by using signal processing techniques. This paper studies some cognitive scenarios and systems for satellite communication, and then proposes a spectrum sensing algorithm based on the channel states information to solve the problem of large transmission loss in satellite cognitive scenarios.

**Keywords:** Satellite communication · Cognitive radio · Spectrum sensing · Channel states information

## 1 Introduction

Satellite communication (satcom) plays a key role in wireless communications because of its wide coverage and the ability to provide new services that are different from terrestrial networks. It extends the coverage of services on land-based fixed and mobile networks today. Like ground systems, satellite systems are facing spectrum scarcity due to increasing demand for communications services [1].

Cognitive communication is a new solution, which can solve the problem of spectrum scarcity in wireless systems. Although the solution started with software defining the concept of radio, it allows primary and cognitive users to coexist. The concept of Cognitive Radio (CR) was firstly proposed by Mitola in the late 1990's [2]. He defines CR as "a very intelligent radio with self and perception, including language and vision and cognitive ability of radio environment". The main task of CR is to sense the radio environment near CR, find the free spectrum resources, and allocate these spectrum resources reasonably, while not interfering with the primary user. An important part of CR is spectrum awareness [3], which is used for acquiring information about the spectral opportunities. Spectrum awareness methods include spectrum sensing, database, beacon transmission-based methods and so on. The information of


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the surrounding spectrum can be obtained by spectrum sensing. Spectrum sensing uses digital signal processing technology to detect whether the surrounding spectrum is idle. According to the different digital signal processing technologies used, spectrum sensing technology can be divided into the following categories [4], such as energy detection, eigenvalue based spectrum sensing and so on. The application of energy detection algorithm in satellite communication is an important topic.

SatCom's research on CR technology is still in its infancy. In the terrestrial wireless system environment, CR has been tested and studied, but its application in satellite communications is facing great challenges. Therefore, the CoRaSat project studies and develops CR technology in SatCom system to make more effective use of spectrum. Considering the following two main categories, CoRaSat studies the importance of cognition in SatCom and possible coexistence scenarios: hybrid satellite-ground systems and dual satellite systems [5]. Because of large transmission loss in satellite communication systems, the signal received by secondary user has a very small power, this will lead to poor performance of energy detection [6]. Therefore, when applying CR to satellite communication, energy detection algorithm must be modified. This paper proposes a spectrum sensing algorithm based on the channel states information, which can solve the above problem well.

The rest of this paper is organized as follows. Section 2 describes some cognitive systems for satellite communication. Section 3 proposes a spectrum sensing algorithm based on channel states information in dual satellite systems. The simulation results and discussion are presented in Sect. 4. Then Finally the conclusions are offered in Sect. 5.

## 2 Cognitive Systems for Satellite Communication

In this part, we study the possible coexistence scenarios considering the following two main categories: Hybrid satellite-terrestrial systems and dual satellite systems. The hybrid systems can be beneficial to both terrestrial and satellite operators depending on which system is primary.

### 2.1 Hybrid Satellite-Terrestrial Systems

Cognitive hybrid systems include two main categories: (a) Primary satellite system with the secondary terrestrial system; (b) Secondary satellite system with the primary terrestrial system. Cognitive hybrid system (a) is shown in Fig. 1.

In this system, the satellite uplink is primary communication link, the terrestrial uplink is secondary communication link. The interference of the system mainly comes from the interference of the primary user's signal to the base station and the secondary user, and the interference of the satellite from the base station and the secondary user's signal. According to Ref. [7], The intelligent CR method can only be used for ground transmission and satellite up-link transmission. Because of the wide coverage of satellites, satellite downlink can't share dynamic spectrum. Because the earth station carries out highly directional transmission, satellite upstream links cause less interference to the ground system. However, the upstream link with low elevation has stronger interference than the upstream link with high elevation. Terrestrial communication systems share the same spectrum band as satellite uplink.

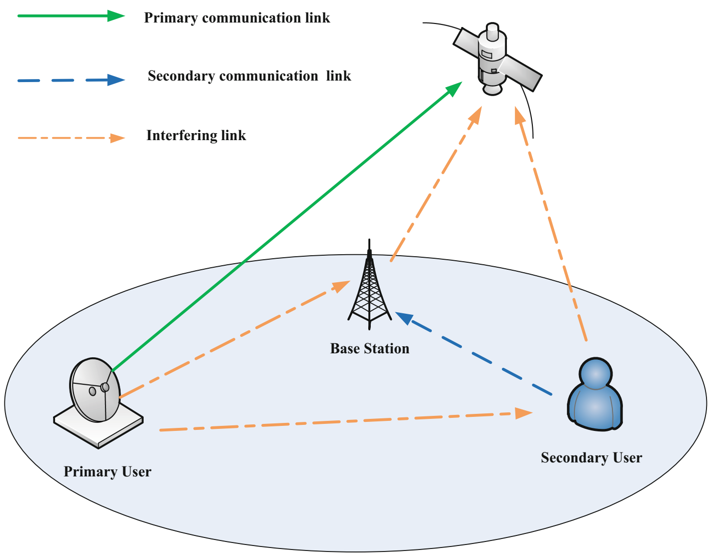


**Fig. 1.** Cognitive hybrid system

## 2.2 Dual Satellite Systems

In the dual satellite system (DSS), two satellites work in the same frequency band and share space and spectrum resources. DSS models a satellite scenario as follows (Fig. 2):

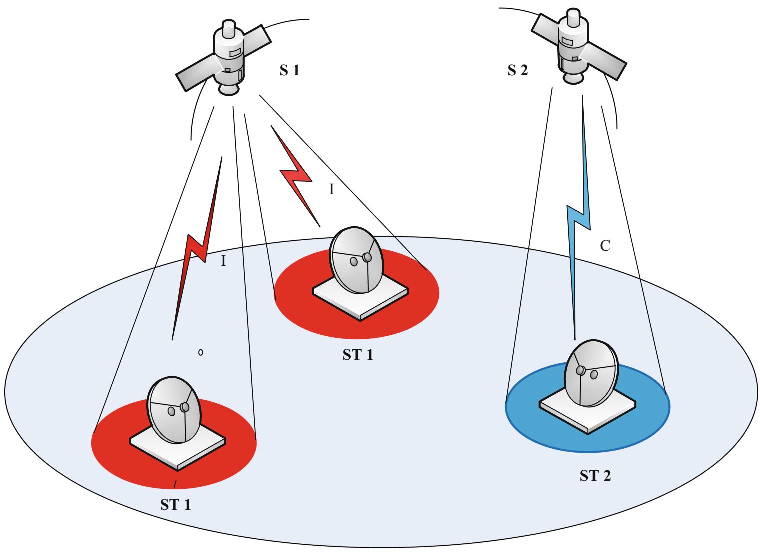


**Fig. 2.** Cognitive dual satellite system (C: cognitive, I: incumbent, S: satellite, ST: Secondary Transmitter)

In this system, S1-ST1 communication link is primary communication link, S2-ST2 communication link is secondary communication link. The system has very strong interference, which can be classified in two categories. Firstly, the wireless signals of the two coexisting networks will interfere with each other. We need to adopt appropriate technology to reduce this interference. Secondly, the interference is observed in DSS formed by geostationary earth orbit (GEO) and non-geostationary earth orbit (NGEO) satellites when the NGEO satellite falls within the signal coverage of the GEO satellite and its ground terminal.

### 2.3 Challenges Faced by Cognitive Satellite Communication

Challenges faced by CR application in satellite communication systems are quite different from those faced by terrestrial communication systems. (1) The transmission link of satellite communication system is long and the transmission delay is large. It is difficult to share dynamic spectrum in a short time. (2) Long transmission path leads to low received signal strength. In order to get enough SINR(signal-to-interference-plus-noise ratio), the receiver needs to install high gain antenna. This makes it very difficult to sense the spectrum of such signals [8]. (3) In satellite communication systems, the coverage of satellite beams is larger than that of ground cells. If there are multiple transmitters working in the same frequency band, such as cellular base stations, the sum of the interference generated by these devices will increase the interference level of the satellite, which will result in the inability to receive useful signals from the beam area.

## 3 Channel States Information Based Energy Detection Algorithm in Dual Satellite Systems

### 3.1 Scenario

In the proposed scenario, GEO satellite link is primary communication link, LEO satellite link is secondary communication link. Because of large transmission loss, the signal power received by secondary user is very small, this will lead to poor performance of energy detection. This paper proposes the channel states information based energy detection (CSI) algorithm to solve the problem (Fig. 3).

### 3.2 Model

Spectrum sensing can be considered as a binary hypothesis to judge whether a signal exists or not: $H_0$ indicates that the primary user does not exist; $H_1$ indicates that the primary user exists.

$$y(n) = \begin{cases} w(n) & n = 1, \cdots N \quad H_0 \\ s(n) + w(n) & n = 1, \cdots, N \quad H_1 \end{cases} \tag{1}$$

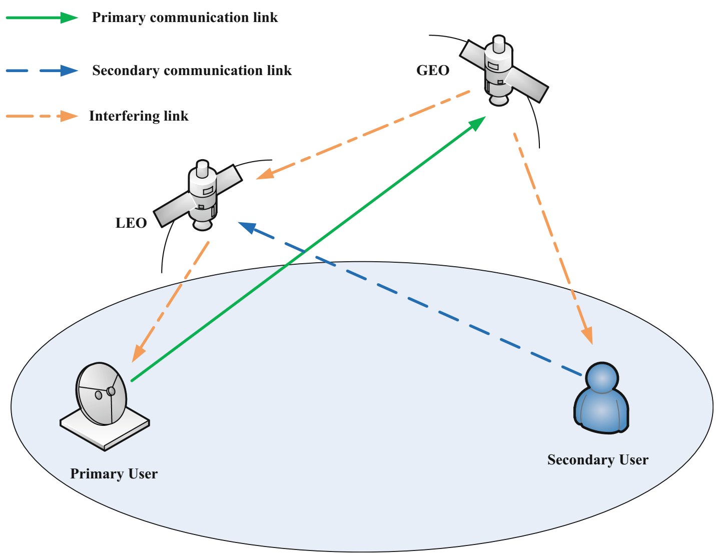


**Fig. 3.** GEO-LEO dual satellite system (LEO: low earth orbit, GEO: geostationary earth orbit)

Where $y(n)$ is received signal, $s(n)$ is useful signal, $w(n)$ is noise signal, $N$ is the number of samples. Probability of Detection $(P_d)$ and Probability of False-alarm $(P_f)$ are two main indexes to measure spectrum sensing performance. Detection probability indicates that spectrum is occupied and the spectrum sensing result is $H_1$, that is, $P_d = P(H_1|H_1)$. False alarm probability indicates that spectrum is not occupied and the spectrum sensing result is $H_1$, that is, $P_f = P(H_1|H_0)$. Obviously, the larger the $P_d$, the smaller the interference from secondary users to primary users is, and the larger the $P_f$, the greater the probability that secondary users will miss the available spectrum resources. Therefore, the influence of spectrum sensing parameters on the performance of the algorithm can be measured by the receiver operating characteristic curve (ROC) corresponding to $P_d$ and $P_f$.

### 3.3 Channel States Information Based Energy Detection Algorithm

The principle of the algorithm is to accumulate energy in a certain frequency band to get the energy detection statistic $Y$. If the value of $Y$ is higher than the selected threshold lambda, the signal exists; otherwise, only noise signal exists. We assume that the interference noise is Gaussian white noise $w(t)$ and its amplitude obeys the normal distribution of mean zero and variance $\sigma_w^2$, and then assume that the amplitude of the primary user's signal $s(t)$ obeys the normal distribution of mean zero and variance $\sigma_s^2$, finally, we assume that the noise sampling values are independent and identically distributed, and are independent of the sampling values of the signals. We sampled $w(t)$ at $N$ points and regarded the sampling result $w(1), \cdots, w(N)$ as a random variable. Obviously, these $N$ random variables will obey the normal distribution of mean zero and variance $\sigma_w^2$. Similarly, because the amplitude of $w(t) + s(t)$ obeys the normal distribution of mean zero and variance $\sigma_w^2 + \sigma_s^2$, the $N$ random variables of $w(1) + s(1), \cdots, w(N) + s(N)$ obtained by $N$-point sampling also obey the normal distribution of mean zero and variance $\sigma_w^2 + \sigma_s^2$. The statistic $Y$ obtained after sampling and summation can be expressed as (Fig. 4):

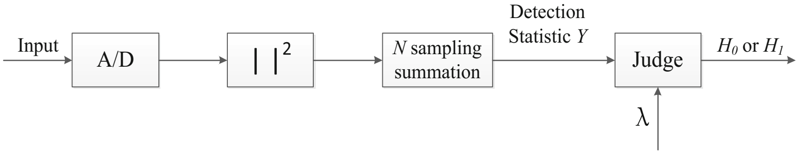


**Fig. 4.** The principle of energy detection algorithm

$$Y = \sum_{n=1}^{N} y(n)^2 \tag{2}$$

Through calculation, we can get the expression of $P_f^{ED}$ and $P_d^{ED}$ as follows:

$$P_f^{ED} = Q\left(\frac{\lambda - N\sigma_w^2}{\sqrt{2N}\sigma_w^2}\right) \tag{3}$$

$$P_d^{ED} = Q\left(\frac{\lambda - N(\sigma_w^2 + \sigma_s^2)}{\sqrt{2N}(\sigma_w^2 + \sigma_s^2)}\right) \tag{4}$$

Where $Q(x) = \int_x^{\infty} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}t^2\right) dt$.

When applying spectrum sensing algorithm to this satellite cognitive system, energy detection algorithm must be modified. This paper proposes the CSI algorithm which maps the current channel state statistic $\widetilde{Y}$ by the channel statistics of the previous $L$ detections. The previous $L$ detections are $Y_i = \{Y_1, Y_2, \ldots Y_L\}$, in which $Y_L$ represents the state closest to the current channel state (Fig. 5).

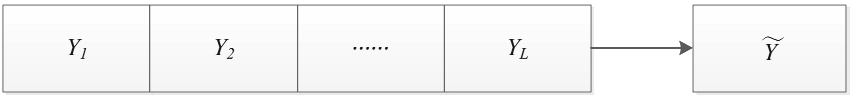


**Fig. 5.** Inference of the current channel state statistic

The current statistic $\widetilde{Y}$ can be described as follows:

$$\widetilde{Y} = \sum_{i=1}^{L} Y_i \tilde{f}(L - i + 1) = \sum_{i=1}^{L} \frac{Y_i e^{-\eta(L-i+1)}}{\sum_{j=1}^{L} e^{-\eta j}} \tag{5}$$

Where, $\tilde{f}(k) = \frac{e^{-\eta k}}{\sum_{j=1}^{L} e^{-\eta j}}$ is an attenuation function, $\eta = \log(1/(1-\theta))$ stands for the forgetting factor, the value of which depends on the transition probability $(\theta)$ of the primary user's channel state. In the following simulation, the value of $\theta$ is 0.5, which means that whether the primary user's channel is occupied or not is completely random.

Through calculation, we can get the expression of $P_f$ and $P_d$ as follows:

$$P_f = P_f^{ED} + \left(1 - P_f^{ED}\right) Q((\lambda - \tilde{\mu})/\tilde{\sigma}) P_f^{ED} \tag{6}$$

$$P_d = P_d^{ED} + \left(1 - P_d^{ED}\right) Q((\lambda - \tilde{\mu})/\tilde{\sigma}) P_d^{ED} \tag{7}$$

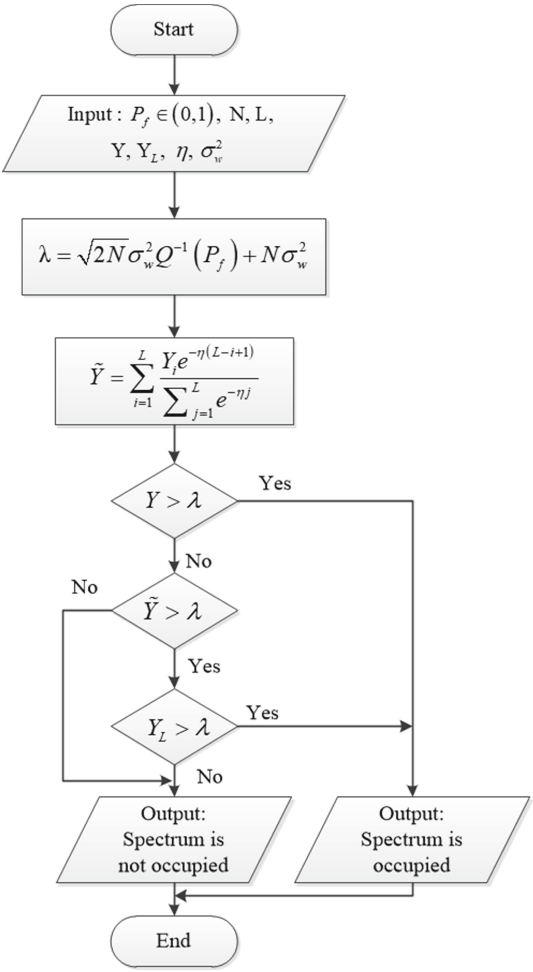


**Fig. 6.** The flowchart of CSI algorithm

Where,

$$\tilde{\mu} = \sum_{k=1}^{L} \tilde{f}(L+1-k)Y_c(k)N\left(\sigma_s^2 + \sigma_w^2\right) + \sum_{k=1}^{L} \tilde{f}(L+1-k)(1-Y_c(k))N\sigma_w^2 \tag{8}$$

And $Y_c(k) = \{Y_c(1), Y_c(2), \ldots Y_c(L)\}$ is the state vector of the former L channels. The flowchart of CSI algorithm is as follows (Fig. 6):

## 4 Simulation Results and Discussion

Simulation analysis of receiver operating characteristic should be carried out to get the performance of the algorithm. The simulation conditions are as follows: The number of sampling points is 1000 (N = 1000), SNR = −10 dB.

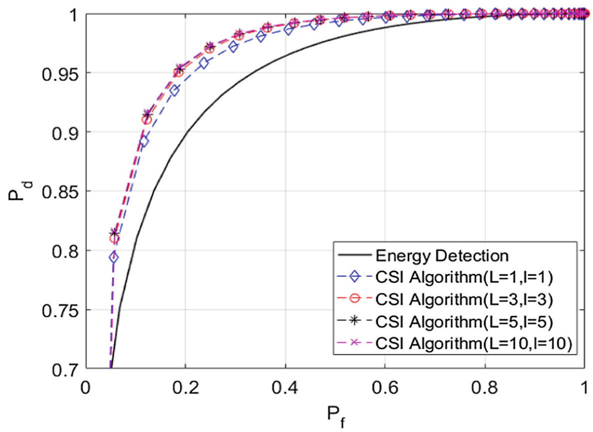


**Fig. 7.** The CSI algorithm's ROC ($l$ is the number of 1 in $Y_c(k)$)

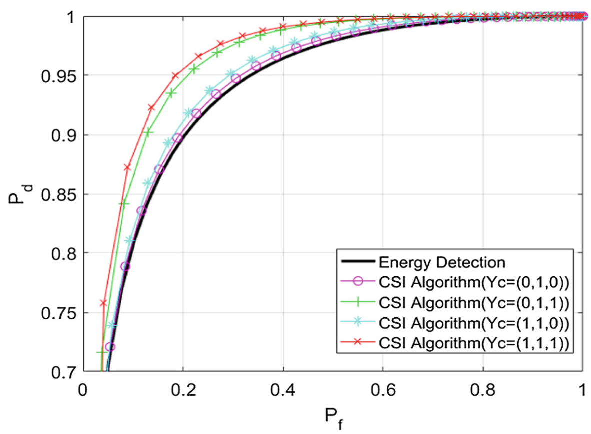


**Fig. 8.** The CSI algorithm's ROC

Figure 7 shows that the performance of the modified algorithm increases slightly with the increase of L. This is due to the fact that the current channel state statistic $\widetilde{Y}$ calculated by channel states can more accurately reflect the real average energy of the signal. However, when the number of L increases to a certain extent, the value of the signal power can be accurately estimated, which makes the increase of L can't bring about further improvement of the performance. Figure 8 shows that the performance of CSI algorithm is better than that of energy detection. And the performance will be better when the state closest to the current channel state is occupied.

## 5 Conclusions

Satellite communication which is a key part in wireless communication field faces the spectrum scarcity problem due to continuously increasing demand for broadcast, multimedia and interactive services. Applying cognitive radio to satellite communication can deal with the above problem well. After analyzing some cognitive scenarios and systems for satellite communication, we know that the energy detection algorithm should be modified in satellite cognitive communication systems. This paper proposes a spectrum sensing algorithm based on the channel states information. Simulation results show the performance of the proposed algorithm is better than that of the energy detection, and CSI algorithm solves the problem that the signals are weak at the reception point because of large transmission loss in satellite cognitive scenarios.

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