Cooperative spectrum sensing for satellite communication systems based on cognitive radio

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Abstract

Cognitive radio has attracted more attention due to its merit of making full use of the spectrum resources for wireless terrestrial communication network. Also for the satellite communication scenario, which has the requirements of transparent air interface to Integrated/Hybrid Satellite-Terrestrial communication systems and is supplement for more multimedia services will cause frequency scarcity. And satellite communication systems based on cognitive radio can be available under the transmission with changing communication scenario. In this paper, a cooperative spectrum sensing algorithm based on time-based cooperative spectrum sensing model of Integrated/Hybrid cooperative satellite communication system is proposed. Moreover, the proposed weighed cooperative spectrum sensing is introduced. It can solve the problem of interference to primary user (PU) caused by secondary user (SU) when it is compared to the traditional time spectrum sensing algorithm. And multiple SUs which use some part of the bandwidth cooperatively perform spectrum sensing throughout the whole frame can detect the presence of PU in time. Numerical results demonstrate the performance of the proposed algorithm.

1. Introduction

Satellite communication system is one of the key components of space segment, which acts the necessary supplement of terrestrial communication systems is playing more important role for the future information transmission implement, especially when the scenario of emergency communication or gusty terrestrial communication systems paralysis. Nowadays 5G of wireless terrestrial communication is coming to satisfy the requirements of high speed broadband and multimedia services. With the developing of wireless terrestrial communication network, satellite communication is meeting the challenges of transparent air interface and the demands of more kinds of services for the flexible broadband access of Integrated/Hybrid Satellite-Terrestrial (S-T) communication systems.

Cognitive radio (CR) which emerges as a promising technology for enhancing the efficiency of spectrum and making full use of available spectrum resources. Moreover, the application of CR to Integrated/Hybrid S-T communication systems is very attractive to the researchers all over the world. S. Bayhan introduced satellite-assisted smart radio network architecture and the satellite to finish the job of spectrum allocation, based on the information gathered from smart base stations [1]. In 2008, Didem Gozupek proposed a novel protocol which focused on to solve the problem of hidden incumbent for satellite based on cognitive radio [2]. In 2009, Yeo Hun Yun etal. from POSTECH found a jointly optimal transmitter and receiver pair of a secondary system to minimize the mean squared error which overlays a secondary-user signal over a satellite communication channel occupied by a primary user [3]. In 2010, S. Kandeepan etal. introduced the concept of cognitive satellite terrestrial radios with dynamic spectrum access on the ground for hybrid satellite-terrestrial systems [4]. In 2011, four researchers from Japan introduced Satellite System for optimal transmission control method in cognitive wireless network when the severe disaster comes and studied a proper wireless link for optimal transmission control [5]. In 2012, Ezio Biglieri from UCLA summarized the research papers associated to the applications of cognitive radio to satellite communications, especially to the implementation of spectrum sensing technique [6]. In 2012, 4 researchers from Oulu of Finland introduced three scenarios about satellite acts PU or SU respects to the terrestrial system and defined operational limits for interference management regarding spectrum sensing [7]. To the industry aspect, in Oct. 2012, Project CoRaSat (Cognitive Radio for Satellite Communications)[8] which aimed at implementing flexible and smart spectrum usage or management to exploit unused or underused frequency resources assigned to satellite services as primary or secondary allocation kicked-off by the

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researchers from European universities [9]. In 2013, Greece Vassaki, etal. taken an efficient resource management mechanism for the terrestrial network acting as the secondary system for consideration [10].

There are two motivations of this paper. Firstly, it can be seen that some researchers has studied some aspects about the application of cognitive radio for satellite Communications, and the component of space segment is almost one independent GEO satellite is mentioned. Thus, the coverage of shared spectrum is insufficient for the communication of all over the world. Therefore, the cooperative framework about space segment which is composed of three GEO satellites is introduced in this paper. Furthermore, the other motivation is that it is known that spectrum sensing as the key technique of cognitive radio context has been studied much more [11-13], it is natural to extend the research of spectrum sensing to S-T based CR systems, but it also brings new challenges. No matter what the exact model will be through 7 scenarios has been studied in [9], the interference caused secondary user (SU) to primary user (PU) cannot be avoided in the cognitive radio context, since it is difficult to locate primary receivers nearby without any change to the primary system. The secondary user (SU) need avoid causing harmful interference to primary user (PU) via spectrum sensing. However, SU which yields terrible interference to PU cannot detect PU's presence during its transmission for the traditional time spectrum sensing algorithm [14-16]. Therefore, a weighed bandwidth-based spectrum sensing is proposed in this paper, which allows multiple SUs to use part of the bandwidth to cooperatively perform spectrum sensing throughout the whole frame, in order to detect PU's reappearance in time. The SU's spectrum efficiency is maximized by jointly optimizing the sensing bandwidth proportion, the number of cooperative SUs, and the detection probability, subject to the constraints on the SU's interference and false alarm probability.

2. System Model Descriptions

In 2010, a integrated system based on space and terrestrial segment was proposed[17]. It is natural that we extend cognitive radio concept applied to this model, and cooperative model of satellites with Inter-satellite Link (ISL) for space segment is proposed to satisfy the coverage requirement. The integrated/Hybrid cooperative satellite communication system models can be described as Fig.1.

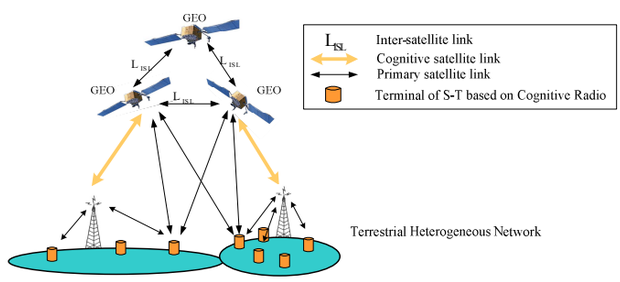

Fig. 1 Scenario of S-T communication network with terrestrial heterogeneous network

As shown in Fig.1, we take three GEO satellites as the example to describe the cooperative model, and the terrestrial segment is Heterogeneous network. Whereas the primary services can be either terrestrial or satellite, and satellite can be provided on a secondary basis. For the downlink or uplink of satellite, there are various frequency bands can be considered, such as Ka-band, Ku-band, C-band and S-band. Importantly, it should depend on the different application scenarios which have different demands or requirements.

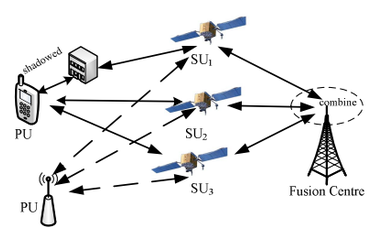

Fig.2 Cooperative spectrum sensing model

3. Cooperative Spectrum sensing

As shown in Fig. 2, we consider a CR network where there are 3 SUs that act as the relay nodes to cooperatively detect the PU's state (presence or absence). Although the SU1's single detection performance is inaccurate because of the shadowed PU, with the help of SU_2 to SU_N, SU_1 can obtain an accurate decision by sharing other sensing information. In cooperative spectrum sensing, each SU detects the PU's transmitted signal by energy detection, and then reports its local detection result to the fusion centre that manages these SUs and processes the received sensing information [15]. In local sensing, the SUi's received signal (i=1,2,…,N) is built as a binary hypothesis problem as follows

$$y_i(m) = \begin{cases} n(m), & \Omega_0 \\ h_i s(m) + n(m), & \Omega_1 \end{cases}, \quad m = 1,2,...,M \tag{1}$$

where $s(m)$ is the PU's transmitted signal with the power σ_s^2, $n(m)$ is the Gaussian noise with the power σ_n^2, h_i is the channel gain between PU and SUi, hypotheses Ω_0 and Ω_1 denote the absence and presence of the PU, respectively, and M is the number of the received signal's samples.

z_i is reported to the fusion centre by SUi as the local detection result, and the aggregate energy statistic Z obtained by summing z_i with the corresponding weight ω_i for i=1,2,…,N, as follows

$$Z = \sum_{i=1}^{N} \omega_i z_i \tag{2}$$

Z obeys the Gaussian distribution, which is the weighed sum of a series of Gaussian functions. From (4), the means and variances of Z at Ω_0 and Ω_1 are, respectively, given as follows

$$\begin{cases} \mathrm{E}(Z\,|\Omega_0) = \sigma_n^2 \sum_{i=1}^{N} \omega_i, & \mathrm{var}(Z\,|\Omega_0) = \frac{2}{M}\sigma_n^4 \sum_{i=1}^{N} \omega_i^2 \\ \mathrm{E}(Z\,|\Omega_1) = \sigma_n^2 \sum_{i=1}^{N} \omega_i (1 + h_i^2 \overline{\gamma}), & \mathrm{var}(Z\,|\Omega_1) = \frac{2}{M}\sigma_n^4 \sum_{i=1}^{N} \omega_i^2 (1 + h_i^2 \overline{\gamma})^2 \end{cases} \tag{3}$$

In the fusion centre, Z is compared with a specific threshold λ, and Ω_0 is decided with $Z < \lambda$, while Ω_1 is determined with $Z \geq \lambda$. Noting $\sum_{i=1}^{N} \omega_i^2 = 1$, the false alarm probability P_f and the detection probability P_d of weighed cooperative spectrum sensing can be given as follows

$$P_f = Q\left(Q^{-1}(P_d)\sqrt{\sum_{i=1}^{N} \omega_i^2 \left(1 + h_i^2 \overline{\gamma}\right)^2} + \overline{\gamma}\sqrt{tw}\sum_{i=1}^{N} \omega_i h_i^2 \right) \tag{4}$$

where function $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{+\infty} e^{-\frac{y^2}{2}} \mathrm{d}y$. By optimizing ω_i for i=1,2,…,N, minimizing P_f is equal to maximizing $\sum_{i=1}^{N} \omega_i h_i^2$ when $\omega_i = h_i^2 \Big/ \sqrt{\sum_{i=1}^{N} h_i^4}$. Hence, the minimal $P_f^{\min}$ is given as follows

$$P_f^{\min} = Q\left(Q^{-1}(P_d)\left(1 + \overline{h}^2 \overline{\gamma}\right) + \overline{\gamma}\sqrt{tw\sum_{i=1}^{N} h_i^4} \right) \tag{5}$$

The traditional time-based cooperative spectrum sensing [13,14] means time slot is allocated for the purpose of spectrum sensing. Before data transmission, cooperative spectrum sensing is firstly performed by SUs at the beginning of the frame, wherein after local sensing, each SU's sensing result is reported to the fusion centre in a single time slot in order to avoid transmission conflicts. In the proposed bandwidth-based cooperative spectrum sensing, and it means bandwidth is allocated for spectrum sensing. SUs use part of the bandwidth to perform cooperative spectrum sensing and the left bandwidth to transmit data, as shown in Fig. 3. For avoid transmission conflict, each SU reports its sensing result to the fusion centre in a single sub-band. Since the spectrum sensing and data transmission are implemented synchronously in bandwidth-based cooperative

spectrum sensing, SU may detect the PU's state momentarily during the whole frame. Once the PU's presence is found, SU can vacate the PU's channel immediately, in order to avoid causing any interference to the PU.

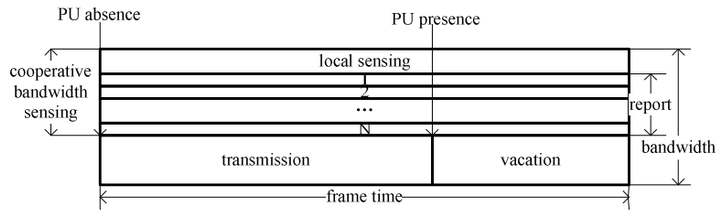

Fig. 3 Bandwidth-based cooperative spectrum sensing model

4. SIMULATION RESULTS

In the simulations, for verifying the sensing performance of the proposed weighed bandwidth-based cooperative spectrum sensing, we suppose that the PU's power is very low with σ_s^2=-10dBmW. We also assume that the frame time T=5s, the channel bandwidth W=1MHz, the reporting bandwidth W=0.05MHz, the transfer rates $u_0 = u_1 = 0.5$, the channel gains obey the Rayleigh distribution with the means $\bar{h} = \bar{g}$=10dB, the noise power σ_n^2=0dBmW, the SU's transmission power p=10dBmW, the total number of the SUs K=10, and the upper bound of false alarm probability $\varepsilon = 0.5$. Fig. 4 compares the detection probability P_d versus un-weighed and weighed cooperative sensing methods, with various false alarm probability P_f .

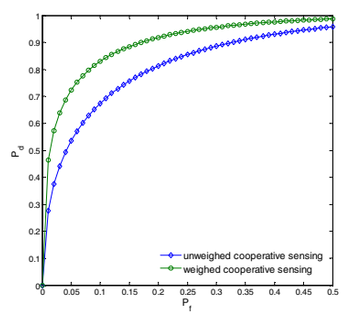

Fig. 4 Detection probability comparison versus different cooperative sensing methods

From Fig. 4, P_d improves as P_f increases, because from because from (7) P_d and P_f have the same monotony in λ; P_d of weighed cooperative sensing is larger than that of un-weighed cooperative sensing, which denotes that our proposed method can obtain better performance obviously. Fig. 6 shows the interference probability P_I versus cooperative time and bandwidth sensing methods, with various P_f . It is observed that P_I decreases with the increase of P_f , which denotes that the interference to PU decreases with the debasement of SU's spectrum utilization.

5. Conclusion

In this paper, a cooperative spectrum sensing model based on the cooperative model of satellites for space segment is proposed. Moreover, a weighed bandwidth-based cooperative spectrum sensing is proposed to detect the PU's presence in time throughout the whole frame. Simulation results have been shown that compared with the traditional time-based cooperative spectrum sensing, the notable decrease of the interference can be obtained by the weighed bandwidth-based spectrum sensing. By searching through the number of cooperative SUs, it has been proven to be a convex optimization problem about sensing bandwidth proportion. The optimization problem about this algorithm will be further done in future work.

6. References

1. S. Bayhan, G. Gur, and F. Alagoz, "Satellite Assisted Spectrum Agility Concept", Military Communications Conference," *IEEE MILCOM* 2007, pp. 1-7.

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