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Joint cooperative spectrum sensing and spectrum opportunity for satellite cluster communication networks

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ABSTRACT

Satellite communication networks composed of various satellites with different heights can be regarded as cooperative primary users in the space segment. Cooperative spectrum sensing as the key techniques of cognitive radio has been paid more attention to the application of satellite communications. To fully explore the potentials of the mobile satellite communication networks based on the concept of satellite cluster in supporting of heterogeneous applications, a trust-weighted cooperative spectrum sensing to primary satellite system is proposed in this paper. And the proposed algorithm allows the fusion center to combine all the 1-bit local decisions from all the secondary satellite systems through trust weights, in order to obtain a final decision on the presence of the primary satellite system. Moreover, according to the spectrum dynamics and node mobility, we propose a spectrum opportunity-based routing protocol (SORP) in which the nodes can exploit the local information and find local available channel to provide reliable routing in cluster-based satellite networks. Specifically, a novel metric which is aware of the unique properties is introduced to select the cluster head of each cluster. Simulation results show the comparison of the efficiency of proposed cooperative spectrum sensing and protocol with a few other related works.

1. Introduction

Satellite communications is one of the key components of space segment, which is playing more and more significant role in the future information transmission, especially in the case of emergency services. Moreover, the development of satellite communications should keep step with the quick development of wireless terrestrial communications to satisfy the requirements of future 5G wireless communications.

At present, the scarcity spectrum of terrestrial segment is a tricky problem which has attracted more attentions of the researchers worldwide. Cognitive radio (CR) [1–3] emerges as a promising technology to enhance the efficiency of spectrum and make full use of available spectrum resources.

Cooperative spectrum sensing [4–6], as one of the key techniques of CR, has been paid more attention, especially in the field of satellite communications. A novel protocol which focused on the problem of hidden incumbent during network entry and handover for satellite based on cognitive radio based on 802.22 is proposed in [7]. And an optimal transmission control method in cognitive wireless network for satellite networks when the severe disaster comes and a proper wireless link and route selection for optimal transmission control is studied in [8]. The applications of cognitive radio, especially the implementation of spectrum sensing technique, are introduced in [9]. And it can be concluded that CR techniques applied in satellite communication systems have obvious potential to improve the spectrum efficiency [10]. In recent three years, the Project CoRaSat (Cognitive Radio for Satellite Communications) has gained many accomplishments by making full use of the frequency resources assigned to satellites as primary users (PU) or secondary users (SU) [11].

Satellite cluster is proposed for satellites with different height in the space segment[12–18]. In [12], a conception of satellite cluster is proposed, which points out that the member of cluster is not satellite but satellite subsystem. It proposes that cluster relationship, individuation and evolution capability are three social basic characters of satellite cluster, and points out that the criterion to determine whether a certain satellite belongs to a satellite cluster is its social characters. In [13], it presents the design and development of a satellite cluster system that supports an inter-federation communication in High Level Architecture(HLA)–

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compliant distributed simulation. The inter- federation communication enables the execution of a complex, large-scale cluster system of distributed satellites that share the dispersed data assets among satellite components collaboratively. A model including computation, communication, command and control is proposed for the scenario of a space-borne remote sensing application involving a spacecraft or satellite cluster. In [14], it considers the distributed processing nature of such an application together with the highly dynamic free space optical interconnection network deployed for communications. In [15], according to the features of dynamic changes of topology of the satellite network, the limited ability and high-speed movement of the satellite node, it proposes a management cluster generation algorithm for satellite network based on contract network model to reduce the time delay of network management and communication load between the management station and the agent on the satellite node. In [16], it introduces CubeSat Torrent, which aims to increase the downlink and uplink speeds of large files by distributing pieces of the files to CubeSats in the cluster and downloading different pieces of the files simultaneously from different CubeSats. In [17], a layer-cluster-based group key management protocol is proposed. This protocol is based on the layer-cluster model and the feature of multi-layer in satellite network. Via using this protocol, the communication overhead is reduced and the flexibility and scalability are improved. In [18], a spectrum-aware cluster-based routing (SCR) protocol is proposed to overcome the formidable limitations of energy and spectrum in cognitive radio sensor networks. In this protocol, SU nodes are clustered based on their relative spectrum awareness and residual energy. It can be applied to the large scale satellite network. There is an architecture of distributed satellite cluster network (DSCN) [19]. On the basis of analyzing the acquisition approach of network status and route calculation, the heuristic algorithm Ant Colony Optimization based traffic classified routing algorithm for DSCN is proposed. It can balance network traffic effectively, and reduce end-to-end delay of every traffic class and a better performance on packet delivery ratio.

However, there are still some questions needed to be solved on the protocol. Few of existing works investigate the following aspects: (1) the topology characteristic of the mobile satellite communication networks based on the concept of satellite cluster and route discovery together. Due to the mobility of the node and time-varying of channel for each node, the topology and channel information needs to be known by spectrum sensing for selecting a reliable route; and (2) evaluating the effective approaches to route path. In addition to the changes of topology, link failure may happen when Pus activities are detected within SUs' transmission range. Therefore, both node mobility and PUs activities should be considered to establish a reliable route path.

There are two motivations of this paper. Firstly, the component of space segment is almost one independent satellite in above mentioned works. However, it can be foreseen that satellite communication networks composed of various satellites with different heights can be regarded as CR networks with cooperative PUs in the space segment. Thus, we propose a trust-weighted cooperative spectrum sensing algorithm and analyze the cooperative spectrum sensing process to the primary satellite system based on the concept of satellite cluster. Secondly, to fully explore the potentials of the mobile satellite communication networks based on the concept of satellite cluster, and support heterogeneous applications in multiple situations, it is crucial to study routing algorithm in an opportunistic spectrum access system by considering the dynamic properties of the cognitive environment. Moreover, we take the heterogeneity properties into account during the operation of the proposed scheme in channel selection and next hop relay selection.

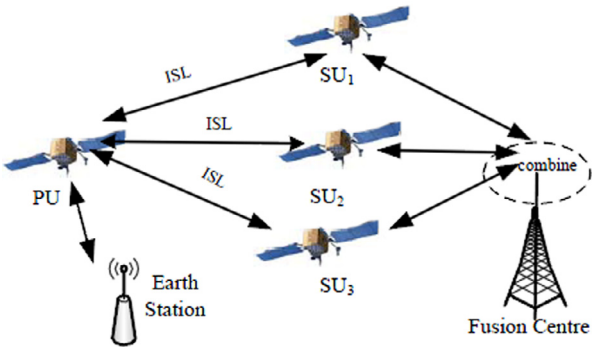

Fig. 1. Cooperative spectrum sensing model.

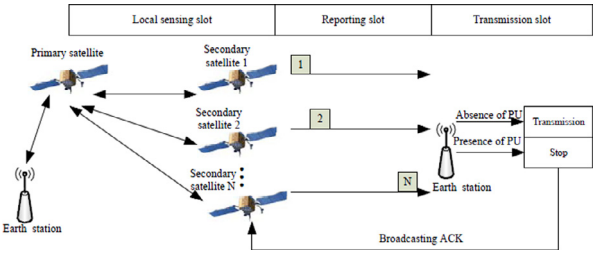

Fig. 2. Cooperative spectrum sensing process to the primary satellite system.

2. System model

The space segment is composed of satellite and aircrafts with different heights. The space segment which is composed of one GEO satellite and LEO with Inter-satellite Link (ISL) for the integrated system based on space and terrestrial segment is proposed in [17]. And the satellite component is concerned in this paper. Satellite nodes are considered as co-primary users of the cooperative spectrum sensing. And a cooperative model of satellites for space segment can be satisfied the coverage requirement and emergency applications. The models of cooperative satellite communication system is illustrated in Fig. 1.

As shown in Fig. 1, we take four satellites with different orbit heights as the example to describe the cooperative model. To explain well about the cooperative process, the cooperative spectrum sensing process to the primary satellite system is presented in Fig. 2.

According to Fig. 2, the cooperative spectrum sensing process of the primary satellite system is given as follows:

(1) Each secondary satellite system, from 1 to *N*, senses the primary satellite system by using energy detection in the local sensing slot of the frame and makes one 1-bit decision.
(2) Each secondary satellite sends their local decision to the earth station center, which can be regarded as the fusion center, in the allocated time sub-slot of the reporting slot.
(3) The earth station center collects and combines all the local decisions with the trust weights to get a final decision on the absence or presence of the PU.
(4) If the absence of the PU is confirmed, the earth station center broadcasts the transmission ACK to all the secondary satellites, and then the secondary satellites transmit data via the transmission slot.
(5) Otherwise, in the situation of the presence of the PU, the earth station center broadcasts the stop ACK to all the secondary satellites, and then the secondary satellites stop transmitting data in the transmission slot and wait until the new decision is broadcasted in the next frame.

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