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A fairness-based MAC protocol for 5G Cognitive Radio Ad Hoc Networks

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ABSTRACT

Fifth Generation (5G) technique aims at achieving high data rate and capacity for large numbers of users. Cognitive Radio (CR) is a promising technical to boost the development of 5G networks, which can significantly increase the spectrum efficiency by letting unlicensed Secondary Users (SUs) utilize the idle licensed spectrum without interfering licensed Primary Users (PUs) dynamically. Owing to dynamic available channels, SUs need firstly meet with their target SUs on common available channels to realize communications rapidly in CR Ad Hoc Networks (CRAHNs). Channel Hopping (CH) is a superior technique for achieving rendezvous in CRAHNs. Most of existing researches on CH problem focus on designing CH sequences that can make SUs rendezvous with each other quickly. For reducing congestion, the CH protocols spread the rendezvous in time and channel in general. However, the handshaking process for data link establishment is barely considered. Besides, there is few research on handshaking process in CRAHNs considering fair data link allocation among SUs. In this paper, we first propose novel structures for Request To Send (RTS) frame and Clear To Send (CTS) frame, which combined the characteristics of CRAHN. Then, we present a Fairness-based MAC (FMAC) protocol, which considers fair data link allocation among SUs. Simulation results demonstrate that our proposed protocol gains better performance in terms of time and fairness.

1. Introduction

Nowadays, devices and applications are rapidly developed for Fifth Generation (5G) wireless networks. For instance, the Internet of Things (IoT) based on the Wireless Sensor Networks (WSNs) (Han et al., 2017a, 2017b, 2017c, 2017d, 2018a, 2018b; Ahmed et al., 2016; Sharma et al., 2017; Yu et al., 2017). With the rapid development of the techniques for 5G wireless networks, the demand of spectrum increases due to the explosively increasing demand for wireless traffic (Song et al., 2017). However, the utilization of spectrum resources is inefficiency at present because the communication on unlicensed spectrum is very crowded while the licensed spectrum is underutilized (Li et al., 2017a). Hence, over the past decade, the demand of much higher spectral efficiency has driven researchers to pursue the Cognitive Radio (CR) technique which enabling unlicensed Secondary Users (SUs) to exploit licensed spectrum opportunistically without interfering licensed Primary Users (PUs) (Li et al., 2016; Nadendla et al., 2017). Meanwhile, Federal Communications Commission (FCC) has relaxed some of licensed spectrum to redistribute the underutilized spectrum (Yang et al., 2017).

In CR Ad Hoc Networks (CRAHNs), SUs should firstly rendezvous with their target SUs on common available channels for data link establishment by exchanging control information (Li et al., 2017a; Huang et al., 2017). Data links are utilized for data transmission among SUs. One practical and efficient method for SUs to set up their rendezvous process is Channel Hopping (CH) technique in CRAHNs (Chen et al., 2017a; Tan et al., 2017a). CH technique is a blind rendezvous technique. SUs can be guided rendezvous with their target SUs on common available channels within an upper bounded time by CH technique blindly. That is, infrastructure is not necessary for CH technique, which is applicable for the distributed networks (e.g., CRAHNs). SUs access available channels according to their CH sequences generated by the CH protocols. The CH sequences of SUs can guide them to rendezvous on commonly available channels within an upper bounded Maximum Time-To-Rendezvous (MTTR) (Chang et al., 2017).

Most of existing researches on CH problem focus on the design of CH sequences (Tan et al., 2017b; Chen et al., 2017b; Sahoo and Sahoo, 2016; Chang et al., 2016; Chao et al., 2015a, 2015b). The Time To Rendezvous (TTR) is usually defined as the number of time slots that SUs spend until rendezvous with their intended SUs on same available channels (Li et al., 2017b). However, SUs rendezvous with their target SUs on same available channels, which does not represent the data link can be successfully established between them. The establishment of data link may also occur

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handshaking failure owing to the competition among SUs. Although some CH protocols considered spreading the rendezvous in time and channel to reduce congestion (Bian et al., 2009), the competition among SUs during the handshaking process still exists. Only a few of researches consider the competition among SUs during the handshaking process (Liu and Xie, 2014, 2015; Liu et al., 2015). Whereas, they only focus on the congestion during handshaking process. The congestion between control information transmission and data transmission is not well considered. Besides, fair rendezvous among channels cannot guarantee fair competition among SUs for available channels due to different transmission requirements of SUs.

To address the problems above, we first propose a novel definition which is termed as Time To Successful Rendezvous (TTSR). The TTSR is defined as the number of time slots that SUs take until successful data link establishment with their target SUs. We utilize Expected TTSR (ETTSR) and Maximum TTSR (MTTSR) to denote the average and maximum TTSR under different clock drift cases between SUs. Besides, for designing appropriate control frames for CRAHNs, we propose novel frame structures for control frames which are termed as Revised Request To Send (RRTS) and Revised Clear To Send (RCTS). Furthermore, we present a Fairness-based MAC (FMAC) protocol for CRAHNs. The contributions of this paper are summarized as follows.

- We first present two novel control frame structures that are termed as RRTS andRCTS in this paper. RRTS and RCTS are designed by tailoring the RTS frame and CTS frame, and fusing the characteristics of CRAHNs.
- We propose a FMAC protocol for CRAHNs, which sufficiently considers the channel fairness. The control link and data link can be different for the same SU in our proposed FMAC protocol. SU transmitter determines whether to use the control link for data transmission or not according to its transmission requirement. Channel fairness is considered when allocating data links to SUs for the FMAC protocol.

The rest of the paper is organized as follows. Section 2 reviews the related works. Section 3 introduces the system model. Section 4 presents the new structures of RRTS and RCTS, and the FMAC protocol. Section 5 demonstrates the performance evaluation. Finally, Section 6 concludes the paper.

2. Related work

In this section, we review several CH protocols that considered the handshaking process for data link establishment in detail (Liu and Xie, 2014, 2015; Liu et al., 2015). We analysis the implementation, advantages and drawbacks for each related work.

The possible factors which may influence the successful handshaking during CH process are analyzed in (Liu and Xie, 2014). The factors include: the destination SU is not on the same channel in the current time slot, asynchronous time slots, the interference of neighbor SU, and the destination SU is also a transmitter. According to the analysis of each factor, they propose a novel CH protocol, which can shorten the time to successful handshaking. However, they consider that there exists at most one potential contender or hidden terminal SU on one channel, which is not practical when the number of SUs is much larger than that of available channels to a great extent. Besides, SU only sends an RTS frame twice during one time slot, all the rest of time is used for listening. If the available channels are idle during the listening period, they are wasted.

A fully self-adaptive CH protocol that considering the collisions on channels, congestion at SUs and intended SUs unavailability was proposed in (Liu and Xie, 2015). Two types of collision are considered, including the collision between RTS and data transmission, and that between RTSs themselves. They set a current-channel-availability checking period for eliminating the first type of collisions. The greatest challenge for the collision between RTSs themselves during the CH process is that the SU sender cannot confirm whether the collision is between RTSs, or the SU sender and SU receiver have not accessed the same channel. For solving the above challenge, they propose a corresponding reaction for the receiver to send Not-Clear-To-Send (NCTS) aiming at telling the SU sender that its target SU with RTS collision accesses the same channel with it. If SU sender can not receive the CTS or NCTS from its target SU, it will be considered as that the SU sender and its target SU are not on the same channel. In this case, SU sender will stop the handshaking process on this channel to reduce the delay. However, the self-adaptive CH protocol still faces some disadvantages. When SU is both a sender and a receiver, it will send packets as a sender. Hence, when its potential SU sender sends RTS to it, it cannot reply to its potential SU sender. This scenario will be considered as that the potential SU sender and its target SU are not on the same channel. Hence, the potential SU will stop attempting handshaking on this channel. Besides, the collision among NCTSs may also happen.

The multiuser contention problem during the handshaking process is investigated in (Liu et al., 2015). Besides, a collision avoidance (CSMA/CA) MAC is adopted properly to the operation features of existing asynchronous CH protocols by tailoring the IEEE 802.11 Distributed Coordination Function (DCF). Moreover, for alleviating the negative impact of the rendezvous failure on channel delay, they proposed an EVCS mechanism which reduce the time lengths that consist in the duration field of the RTS packet and CTS packet. However, SU density per channel is assumed identical at each time slot, which is not practical for the CH protocols under the asynchronous clock scenario with different data transmission requirements. Besides, they assume that SUs can switch among all licensed channel, which is impractical for SUs in CRAHNs.

3. System model

In this study, we consider a CRAHN with N non-overlapping licensed channels labeled as 1, 2, ⋯, N. The bandwidth of each channel is B. Denote the number of SUs in CRAHN is M. Denote C_i as the available channel set of SU_i sensed before CH process. $C_i = \{c_{i1}, c_{i2}, \cdots, c_{ix}, \cdots, c_{i|C_i|}\}$, where c_{ix} and $|C_i|$ are the x^{th} channel in the C_i and the number of available channels for SU_i, respectively. The available channels for designing CH sequences and the channel densities of the available channels are sensed once at the beginning of each round of CH process. The density of channel l sensed by SU_i is denoted as ρ_l^i, which is measured by the number of sensed SUs on channel l. The expression of ρ_l^i is given as follow.

$$\rho_l^i = \frac{M_l^i}{B}. \tag{1}$$

Where M_l^i denotes the number of SUs on channel l sensed by SU_i. The channel density set of the available channels for SU_i is denoted as ρC_i . As it is time-consuming for SUs to sense all channels, SU itself determines whether to sense all channels or not according to its data transmission requirement and TTR before data link establishment. The capacity of channel l for SU_i is denoted as C_l^i, which can be expressed as follow.

$$C_l^i = B_l \log_2\left(1 + \frac{S_l^i}{N_l}\right). \tag{2}$$

where B_l denotes the bandwidth of channel l. S_l^i denotes the average received signal power over the B_l for SU_i. N_l denotes the average power of the noise and interference over the B_l. Hence, the time for transmitting the data transmission requirement D_i of SU_i by channel l is expressed as follow.

$$T_l^{D_i} = \frac{C_l^i}{D_i}. \tag{3}$$

We define two channel sensing thresholds α and β. If $T_l^{D_i} > \alpha$, SU_i