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Hybrid Directional CR-MAC based on Q-Learning with Directional Power Control

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HIGHLIGHTS

- A cognitive radio concept is used to utilized channels in a more accurate way .
- Directional Hybrid control channel with GPS is used to exchange cognitive control information.
- Experimental results are carried out in context of proposed method in comparison with other existing schemes.

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ABSTRACT

In this paper, we investigate the Hybrid Directional CR-MAC based on Q-Learning with Directional Power Control in cognitive radio (CR) systems. In CR systems, nodes can switch to heterogeneous non-overlapping channels opportunistically which offer higher achievable throughput. However, the random channel selection policy in existing CR-MAC protocol has problems like delay, packet collisions, and quality of service. The proposed channel selection scheme which is quite different from the traditional scheme is adopted by nodes to achieve context awareness and intelligence for adaptive channel selection. The nodes select a channel based on the results learned by interactions with the other nodes and channels. The directional transmission power control scheme allows the nodes to reuse the channels subject to interference constraints. The simulation results show that nodes using the proposed algorithm can select channels adaptively and optimal transmission power which helps to achieve high throughput and minimized power consumption.

1. Introduction

Fixed spectrum policies have led to underutilization of spectrum resources, one of the answers to spectrum scarcity problem in a wireless network is Cognitive radio. Cognitive radio technology enables nodes to dynamically access unused or underutilized licensed spectrum opportunistically [1]. Therefore, spectrum utilization significantly increases with spectrum aware CR network. SU's exploit space, frequency and time domains of radio spectrum using models like opportunistic access [2–4] and concurrent access [5–12]. CR devices can maximize throughput [2–4], minimize energy consumption [10,11] and reduce interference [5–8] by adjusting their radio constraints. Spectrum sharing is important in CR networks to answer scarcity problem. CR nodes can use Time Division Multiple Access, Frequency Division Multiple Access or Code Division multiple access or their combinations. But, there exists fundamental question of competent channel selection and optimal transmission power in the dynamic time-varying environment, i.e. channel characteristics, the mobility of the wireless sources, the wireless nodes unpredictability in joining the network or leaving the network etc. The MAC protocols in the literature [13] can work as guidelines for Channel switching according to environmental changes in cognitive radio networks. However, the cost of frequency changes in current manufactured wireless devices is not considered by most of them. On an average channel, switching can cause packet loss ratio up to 3% exclusively, which can be even worse in cognitive radio networks due to dynamic nature of primary users. Thus optimal channel selection strategy which fluctuates less frequently is favorable. In [14] power control policies are devised for cellular networks with QoS as primary criteria, where transmitters increase power to deal with interference and

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channel impairments. However, it is not suitable for primary user's QoS if secondary users transmit with arbitrarily high power. Thus it is natural that power control should rely on the interference levels. In this paper, we propose "Hybrid Directional CR-MAC based on Q-Learning with Directional Power Control" where learning algorithm is used for channel selection and a new Directional transmission power control scheme (DTPC) for enhancing the throughput and energy efficiency of the directional hybrid CR MAC protocol. The main contributions of our work are twofold. First, using channel selection algorithm we try to select the best channel based on SU's observation of PU's traffic, channel characteristics like throughput achieved, packets lost. Second we investigate the problem of channel reuse in directional communication, where CR user has the power control capability. That is, CR user can transmit at any transmit power in the allowable power range that to achieve maximum concurrent transmissions. The organization of the rest of the paper is as follows. In Section 2, we present related work. In Section 3 we present system model. Overview of the Q-learning algorithm is presented in Section 4. The proposed Hybrid Directional CR-MAC based on Q-Learning with Directional Power Control Scheme is presented in Section 5. Simulation results for different network topologies are shown in the Section 6 to establishes the substantial throughput and energy gains that can be attained under the investigated scheme. Finally, we present our conclusions and future work.

2. Related work

Game theory based CR

In CR networks Game theory has recently been the most popular method for attaining context-awareness and intelligence. In which, SU's interact to maximize their individual objective such as delay, throughput etc. however, there are several limitations in game theory which are addressed using RL approach. Firstly, GT based CR requires a complete set of information to compute the Nash equilibrium; hence it is more suitable for centralized CR networks [15,16].

Secondly, GT assumes a single type of objective function throughout the CR network, and hence a homogeneous learning mechanism in all the SUs. Thirdly, SU's might converge to sub optimal action due to miss-coordination even when optimal action exists. Although the GT has been successfully applied in CR networks [17–26], the RL approach is a good alternative which addresses the issues above associated with GT. For instance, the RL supports heterogeneous learning mechanism in each agent because each agent can represent distinctive performance metrics as local rewards.

Omni directional Power control

SU's vary their transmit power depending on interference at primary receiver and maximum secondary transmit power constraint [27]. Concurrent transmission region is maximized in [6] using optimal power control. The number of concurrent transmissions are maximized in [7] using dynamic spectrum sharing. With objectives of maximizing sum-rate, achieving rate fairness, minimizing power consumption using power control are studied in [28–32]. The necessary and sufficient condition for the feasible region using Power controlled MAC consisting of only two transmission links is derived in [33]. Channel hopping sequence is used to allocate the control channel to one-hop neighbor nodes [25]. The basic drawback of sequential CCC based CR-MAC is longer channel rendezvous delays [26–31]. Channel rendezvous is more challenging for increased availability of PU channels.

Directional power control

For reusing spectrum in the macro cell, underlying microcell uses Antenna beamforming and power allocation schemes to maximize multiuser sum rate [34]. Capacity and power consumption of wireless network using directional antennas is studied in [35]. In [36], the achievable throughput of mobile *ad hoc* network with the directional antenna is addressed. Directional Medium Access Control is studied in [37], it suffers from deafness and hidden terminal problems. First Power control with a directional antenna over packet radio network was considered in [38]. Power control built on D-MAC with Directional RTS, Omni Directional CTS and optimal power for the data packet is studied in [39], increased network capacity and reduced power consumption. An optimization problem for selecting the range of channels for transmission with the control channel and aggregated data channel was employed in statistical channel allocation MAC (SCA-MAC) [40] which outperforms random scheme. DSA-MAC [41], DCRMAC [42], HC-MAC [43], DDMAC [44], SMA [45] are the protocols which are similar to IEEE802.11 DCF standard for reserving a channel.

3. System model

In this study, users with CR capabilities, referred to as secondary users, can communicate with other CR nodes utilizing the primary networks available spectrum spatially and/or temporally. When the secondary network doesn't have enough resources CR nodes form an ad-hoc network without a central controller or dedicated control channels. Due to highly dynamic and heterogeneous networking environment, a dedicated control channel is not pre-defined for exchanging control messages. We assume that the nodes are close enough as to consider an interference-limited spectrum sharing scenario in which a CRAHN operates. The system model is composed of M licensed channels which are accessed opportunistically by K CR nodes (acts as both transmitter and receiver), D primary users. The primary transmitter, primary receiver, and the mobile CR devices are distributed in randomly within the coverage area. Similar to [46–48], the two-state continuous-time Markov process is used to model the traffic of each channel: Channel occupied by the PU (busy state) and the channel that is not occupied by the PU(idle state). These two states are referred as ON and OFF respectively. Each SU transmitter and its corresponding SU receiver, but also on the time-varying activities of the PUs. We consider the situation that several SUs may compete for the same channel, and one SU may have more than one channel for selection

Antenna model

To predict the received power, as in [49,50], we consider a general power propagation model $P_r = \frac{P_t C G_{rt} G_{tr}}{d_{tr}^{\alpha}}$ where Pt is the transmit power, dtr is the distance between transmitter and receiver, α is the path-loss exponent, G_{tr} and G_{rt} are the directive gains of the transmitting and receiving antennas toward the direction of the receiving and transmitting antennas, respectively, while C is a constant determined by other factors as antenna heights and wave length.

Time slot structure

The system model has slotted transmission structure as shown in Fig. 3 and described as follows Each secondary user executes following stages synchronously during each time slot.

- Channel Sensing: SU's sense the PU channel's to detect the activity of PU's.
- PCL-EXCHANGE: After Sensing SU's broadcasts their Primary user free Channel List (PCL) to its neighbors. After receiving PCL information from neighbors, SU's update PCL table.
- CHANNEL RESERVATION: it is divided into N slots and every slot is divided in to two sub slots sub slot (S2) for a node to send RTS directionally and sub slot (S2) for the destination node to reply with CTS or DNAV.
- DATA TRANFER: SU's which successfully reserved channel in CHANNEL RERVATION PHASE start data transmission