Optimal Medium Access Control Protocol in Cognitive Radio Ad-hoc Networks: A Cross-Layer Design

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Abstract

In this paper, we consider the impact of power control on contention–based medium access control (MAC) for all secondary users (**SU**s) in cognitive radio ad-hoc networks (CRAHNs). Firstly, we formulate the optimization framework of joint power control and medium access control addressing maximum overall throughput. Then we propose a distributed MAC to achieve an optimal throughput. Finally, the numerical results demonstrate that our proposed protocol achieves higher utility when comparing to existing works.

1. Introduction

CRAHNs have been recently investigated by many researchers to enhance wireless high-speed addressing spectrum shortage. In fact, some IEEE standardization activities have been issued for opportunistic spectrum access applications [1]. However, transmissions from cognitive devices can make physically collisions to primary users (PUs)' transmissions. Hence, in this paper we propose a novel constraint of collision probability to adequately protect PUs' transmission.

In wireless ad-hoc networks, Lee at al. [2] also shows that unfairness in contention at MAC layer is one of the major reasons for inefficiency of back-off based existing MAC protocols. Moreover, interference among SUs [3,4,5] due to insufficient power usage seriously degrades overall performance of CRAHNs. Hence, to achieve an optimal throughput for CRAHNs, we need a novel MAC protocol addressing all above issues.

2. Network Model and Optimization Problem

We consider a multi-hop CRAHN consisting of a set of N pairs of secondary nodes with one primary channel. The availability of primary channel is modeled using two-state Markov Chain with idle probability π. Let

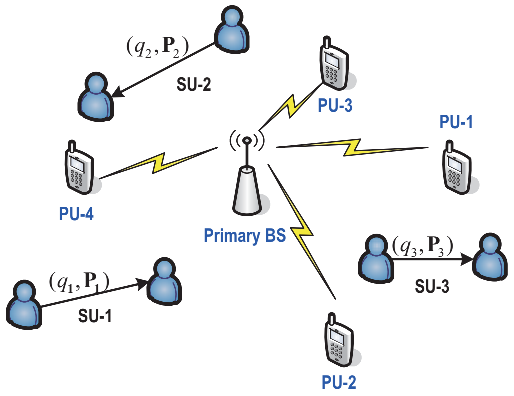

Fig. 1: CRANs with 3 SUs and 4 PUs

$\mathbb{N}=\{1,2,...,N\}$ denote the set secondary links in network hops With an allocated power P_n, SU n transmits with persistence probability q_n. Then SU n attains a utility $C_n(\mathbf{P},\mathbf{q})$ which is the instant protocol capacity which SU n can achieve:

$$C_n(\mathbf{P},\mathbf{q}) = \underbrace{W\log\left(1+K\times SIR_n(\mathbf{P})\right)}_{\Psi_n(P)}\times \Pr_n^{idle} \qquad (1)$$

Here K is constant depending on the modulation, coding scheme and bit-error rate (BER). $SIR_n(\mathbf{P})=G_nP_n/N_0$ is signal-to noise at SU- receiver n. And in SU n viewpoint, the probability of idle channel is derived as:

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$$\Pr_n^{idle} = q_n \times \prod_{k \in L_n^I} (1 - q_k) \times \pi \tag{2}$$

To protect its transmission and maintain quality of service (QoS), primary system requires its collision probability to stay below a certain threshold η_{th}:

$$\prod_{n=1}^{N} (1 - q_n) \times (1 - \pi) \le \eta_{th} \tag{3}$$

Our optimal MAC problem with PU QoS is formulated:

Problem $\mathfrak{M}$:

$$\max_{\mathbf{q},\,\mathbf{P}} \sum_{n=1}^{N} W \log\left(1 + K \times SIR_n(P) \times \Pr_n^{idle}\right) - \alpha_n \sum_{n}^{N} P_n$$

$$\text{subject to} \quad \prod_{n=1}^{N} (1 - q_n) \times (1 - \pi) \le \eta_{th};$$

$$\Pr_n^{idle} = q_n \times \prod_{k \in L_n^I} (1 - q_k) \times \pi$$

$$P_n^{\min} \le P_n \le P_n^{\max}; q_n^{\min} \le q_n \le q_n^{\max}.$$

Solving above problem using heuristic method, we have the optimal MAC protocol as following

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Algorithm1: Optimal MAC Protocol

At each time slot, SUs perform

Power Control:
$$P_l^{(t+1)} = \left[\frac{1}{\Pr_n^{idle,(t)}} \left(\frac{\alpha_n}{W} - \frac{1}{\Gamma_n} \right) \right]_{P_n^{\min}}^{P_n^{\max}}$$

where $\Gamma_n = KG_n / N_0$.

MAC control:

$$q_n^{(t+1)} = \left[\frac{\mu}{\prod_{k \ne n} (1 - q_k^{(t)})} + \beta_t \left(\Psi_n^{(t)} \prod_{k \in L_n^I} (1 - q_k^{(t)}) - \sum_{l \in \mathbb{N}} a_l^n \Psi_l^{(t)} q_l^{(t)} \prod_{m \in L_l^I \setminus n} (1 - q_m^{(t)}) \right) \right]_{q_n^{\min}}^{q_n^{\max}}$$

where $a_l^n = \begin{cases} 1 & \text{if } l \in L_n^I; \\ 0 & \text{otherwise} \end{cases}$

Proposition 1: Optimal MAC Protocol converges to global optimum with step size $0 \le \beta_t \ll 1$.

3. Simulation Results

The simulation results are shown in Fig.2. We observe that the proposed MAC protocol for CRAHNs with power control converges to the unique fixed point with an acceptable convergence speed. The optimally allocated link powers are [39, 18.9, 28.9]mW because $\alpha = [3, 7, 5]$. This shows that the transmit power of an SU depends on not only the mutual interference levels among SUs but also its cost per unit of consumed power. Furthermore, proposed MAC protocol outperforms the existing MAC protocol [2].

4. Conclusion

We propose a novel MAC protocol for CRAHNs addressing shortage of existing MAC protocol with proportional fairness. Our proposal is to maximize overall throughput while adequately protect PUs' QoS.

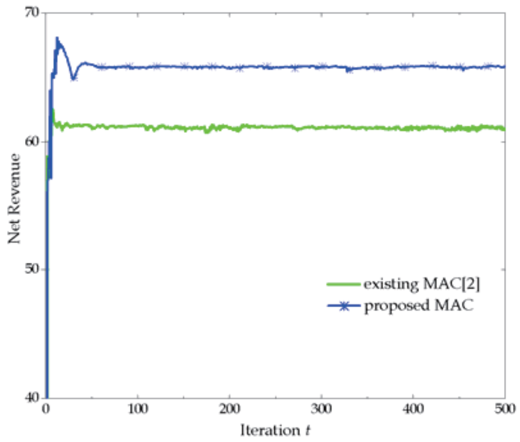

Fig. 2: Performance comparison of proposed MAC protocol and [2].

References

[1] FCC, "Spectrum Policy Task Force Report", Nov. 2002.

[2] J.-W. Lee, M. Chiang, and A. R. Calderbank, "Utility-optimal random access control," IEEE Trans. Wireless Commun., vol. 6, no. 7, pp. 2741-2751, July 2007.

[3] S. Huang, X. Liu, Z. Ding, "Distributed Power Control for Coginitive User Access based on Primary Link Control Feedback", IEEE Infocom, 2010.

[4] M. V. Nguyen, C. S. Hong, and S. Lee, "Cross-layer optimization for congestion and power control in OFDM-based multi-hop cognitive radio networks," IEEE Trans. Commun., vol. 60, no. 8, pp. 2101-2112, August 2012.

[5] M. V. Nguyen, Duong T.Q., Hong C.S., Lee S., Zhang Y., "Optimal and sub-optimal resource allocation in multi-hop cognitive radio networks with primary user outage constraint," IET Networks, vol.1, no.2, pp.47-57, June 2012