Coalitional Game Formulation for Multi-channel cooperative in Heterogeneous Cognitive Wireless Networks

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Abstract

This paper concerns about cooperative problem of mobile secondary users in heterogeneous cognitive wireless network with coexist of secondary femtocell networks, a secondary macrocell networks and a primary network. A scheme with cooperative among wireless network systems to improve capacity, reduces interference to primary system, reduces power transmission of secondary users in uplink data transmission. Specifically, our problem is formulated as coalitional game to maximize payoff of whole system. Simulation results show the effectiveness of our proposed scheme.

I. Introduction

Cognitive radio network (CRN) or cognitive wireless network (CWN) is system that licensed spectrum utilized by secondary system [1, 2]. They predicted that, in future wireless network may has many cognitive wireless network can coexist in an area with many different technology for access network. This problem has become a hot topic with cooperation problems among systems to improve utility licensed spectrum and quality of service in cooperating among femtocell and macrocell networks [3, 4].

Our main contribution are propose a new scheme for cooperative of secondary users in heterogeneous wireless network with coexistence of multiple secondary femtocells, a secondary macrocell and a primary network. Specifically, the cooperative problem is formulated as a coalitional game. The coalition is formulated among secondary macro users (SMUE), licensed channels (or PUs), secondary femtocell user (SFUEs).

The remaining of this paper is organized as follows: Section II provides system model and problem of the data transmission rate with cooperation or non-cooperation. Next, coalitional game is formulated in section III. Then Section IV performs simulation results. Finally, conclusions are in section V.

II. System and cooperation model

1. System model

Consider the heterogeneous cognitive wireless network include of a primary network and a secondary networks as in Figure 1. In primary network, all channel are occupied by PUs (N licensed channel are occupied by N primary users in uplink data) and its coverage contains all coverage of secondary system. The secondary system use underlay model (mean that, each element in secondary network has to power control to avoid interference to Primary network). In secondary network, there are M secondary femtocells, each of them contains K secondary femtocell users (SFUEs). The secondary network has a secondary macro base station (SMBS) contains L secondary macro users (SMUE). Assume that whole wireless networks are synced in one area that we consider to, all locations of elements in network are well-known, has a common control channel to exchange all information among secondary network and primary network.

We consider to system that macro secondary network has more priority than secondary femtocell when they access at the same licensed channel. All user (SFUEs and SMUE) have to perform power control to avoid interference to primary system. So, we consider interference from PBS (PU^T) to SMBS, SFBS, SFUE, and from SFUEs, SMUEs to PU (receiver).

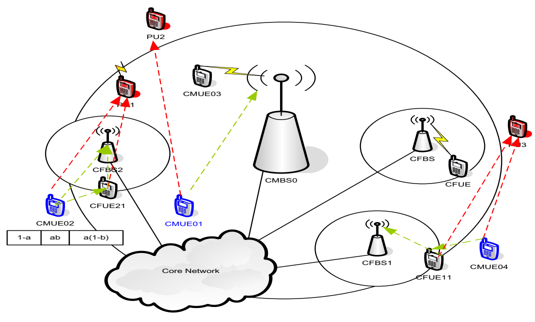

Figure 1. System model

The data transmission of secondary network is transmitted follows infraction of time as on Figure 1. In which, ($1-a_l$) is fraction of time when SMUE transmit to destination without relay, $a_l b_k$ is fraction of time SMUE transmit to destination via relay, $a_l(1-b_k)$ is fraction of time that SFUEs received reward when SFUE support as a relay for SMUEs. $0 < a_l, b_k \le 1$.

2. Cooperative model

In non-cooperative approach, if SMUEs use channel n for its transmission, the SMBS offers SMUE *m* a link transmission capacity of:

$$R_l^{NC} = B\log\left(1+\frac{\left|H_{l,0}\right|^2 P_l}{\sum_{n\in\Phi_n}\left|H_{n,0}\right|^2 P_n^T+\delta^2}\right) \quad (1)$$

Where B is the bandwidth of a sub-channel, $\left|H_{l,0}\right|^2$ is the channel gain between SMUE l and the SMBS denoted by subscript 0, P_l is the power used at SMUE l, $\left|H_{n,0}\right|^2$ is the channel gain between PU^T_ns and SMBS (receiver of secondary macro cell), P_n^T is the power used at transmitter at PMBS to PU_n by using channel n. As a matter of fact, when SMUE cannot guarantee quality of the signal received at the SMBS. In this system, each SFBS need provides a function as relaying data. The successful transmission can be computed as the maintaining the SINR above a target level γ_m, γ_k respectively for a SMUE and SFUE. In this work, we use decode and forward relay scheme, assuming that a packet is successfully received if the respective SINR satisfies the above conditions. Finally, the achievable service rates for MUEs and FUEs in the cooperative approach becomes:

$$R_l^C(a,b) = \min\left((1-a)R_l^R, ab_k R_k^R\right) \quad (2)$$

$$R_k^C(a,b) = a(1-b_k)R_k^R \quad (3)$$

With,

$$R_l^C = B\log\left(1+\frac{\left|H_{l,k}\right|^2 P_l}{\sum_{n\in\Phi_n}\left|H_{n,k}\right|^2 P_n^T+\delta^2}\right) \quad (4)$$

$$R_k^C = B\log\left(1+\frac{\left|H_{k_m,m}\right|^2 P_{k_m}}{\sum_{n\in\Phi_n}\left|H_{n,m}\right|^2 P_n^T+\delta^2}\right) \quad (5)$$

Where $\left|H_{k_m,m}\right|^2$ is the channel gain between SFUE k in SFBS m and $\left|H_{n,m}\right|^2$ is the channel between PMBS using channel n to SFBS want to use channel n. Because of our system modeled under interference that they always have interference from PU^T, so when SFUE, SMUE allocated channel and power level for its data transmission, they have to perform power control, channels assignment and cooperative between other secondary users in secondary network to maximize utility of system. Here, main contribute of this paper is applying coalitional game to this system model to maximize utility of system. By separating the transmission from SMUE and SFUE within the super-frame, the SFUE forward transmissions are affected only by interference from non-cooperative SMUEs, outside the coalition.

III. Coalitional game formulation and analysis

Coalition game is the game that players can form coalitions. Coalition is a collective decision-maker. Worth of each coalitions is the total amount that the player from the coalition can jointly guarantee themselves, it is measured in abstract units of utility. We formulate our considered our problem as a coalitional game with transferable utility (TU) [5].

In our work, the coalitional value v(S) of a coalition S is a real number defined as the maximum sum utility generated by PMUEs, SMUEs, SMBSs, SFBSs, SFUEs in coalition S, which depends only on the actions (assigned channels, allocated power levels) and locations of members in coalition S. The payoff function is defined as follows:

$$P(S): v(S) = \max\sum_{\substack{l\in L, m\in M,\\ k\in K, n\in N}}\left(\min\left((1-a_l)R_l^R, a_l b_k R_k^R\right)+a_l(1-b_k)R_k^R\right)$$

Subject to: (6)

$$0 < a_l, b_k \le 1 \quad (7)$$

$$0 < P_l^{thres\_min} P_l < P_l^{thresh\_max} < P_l^{Max} \quad (8)$$

$$0 < P_k^{thres\_min} < P_k < P_k^{thres\_max} < P_k^{max} \quad (9)$$

$$b_k P_k^R + (1-b_k)P_l^T < P_{max} \quad (10)$$

In which, $P_l^{thres\_min}$ is power level that guarantee quality of capacity for SMUE *l*, $P_l^{thresh\_max}$, $P_k^{thres\_max}$ are maximum power level of SMUE l, SFUEs to avoid interference to PMUEs, $P_k^{thres\_min}$ is power level that guarantee quality of connection from SFUE to SFBSs, condition (10) gurantee that, once a coalition S_k has formed, the SFUE k optimizes its own payoff by deciding upon b_k and the transmit power. At the SFUEs side, relaying traffic for a set of SMUEs incurs a cost that must be taken into account by the SFUE before making any cooperation decision. In this paper, we consider a cost in terms of the transmit power that each SFUE spends to transmit for SMUEs within the same coalition. Namely, an SFUE spends power for relay transmissions, while the overall transmit power is limited by P_{max}. Based on above problem and using duality theory [6], we can easy prove that the problems (6) are concave, and exist a core is non-empty. From that, by using the Shapley Function and scheduling, social analysis, our problem can solved to find optimal solution with channel assignment, power level of each SMUEs, SFUEs. Due to limitation of space so that we do not present detail about solution for this problem.

V. Simulation and numerical results

Assume that, we have system model with one MPBS has N = 8 licensed channels is allocating for PUs, number of femtocell network M = 20, each femtocell has 3 SFUEs, a mobile SMBS is moving, radius of macrocel R_{SMUE} = 1500m, R_{SFUE} = 200m, B= 1, location of PU^R_s, PU^T_s, SMBS, SMBS, SFBSs, SFUEs are random in network as shown in Figure 2. The noise power is $\delta^2 = 10^{-2}$ at receiver, and transmission power of primary user is transmitting in uplink data with power transmission = 0.5 W. The power transmission of SMUE, SFUEs are always change in each time period to avoid interference to MPBS based on optimize concave problem (5). The maximize value of transmission power of SMUE, SFUEs are P_l^{Max} = 0.1 W, P_k^{Max} = 0.01 W, respectively. Assume that the system have one controller and one common control channel for collection all information and channel assignment, power allocation for each secondary users. We simulate our problem based on mat lab software. In table 1, when SMUE is moving in its route with 1500 time periods, after perform concave problem in the header of each period of time, the SMUE perform choose different channels, different femtocells, different power levels to guarantee SMUE's data rate requirement. Table 1 showed that, the payoff of system will decrease when they do not use cooperative solution because at that time, SMUE has to reduce power to avoid interference to PUs receivers. When increase radius of femtocell, payoff of system decrease a little due to data rate from SFUEs to its SFBS are decreased.

Periods	0	33	60	98	200	300	500	700	1000	1200	1500
Channel	1	1	3	5	3	3	3	7	7	2	1
Femtocell	2	19	17	7	18	10	9	5	14	2	2
Power	0.1	0.08	0.1	0.1	0.06	0.03	0.04	0.03	0.1	0.09	0.1
Payoff(C)	23.43	16.32	20.34	20.79	15.65	13.12	16.23	12.54	20.65	22.45	23.54
Payoff(NC	23.43	12.33	16.45	15.59	14.5	12.56	13.4	8.43	18.42	20.53	23.43

Table 1. Channel assignment, Power allocation, Femto cell selection of SMUE at some period of 1500 time periods

V. Conclusions

In this paper, we proposed and analyzed a new scenario of cooperation in heterogeneous wireless network among the secondary macrocell, secondary femtocells and multiple primary users. Specifically, by applying coalitional game approach, we assigned channels, perform power control for SMUEs and SFUEs. Based on that, we achieved maximize payoff of whole system secondary users in uplink data.

Acknowledgement

This research was supported by the MSIP (Ministry of Science, ICT & Future Planning), Korea, under the ITRC(Information Technology Research Center) support program (NIPA - 2013 - H0301-13-4006) supervised by t h e NIPA (National IT Industry Promotion Agency)."Dr. CS Hong is corresponding author.

Reference

[1] I.F.Akyildiz et al., "A Survey on Spectrum Management in Cognitive Radio Networks," IEEE Commun. Mag., vol. 46, no.4, pp.40-48, Apr.2008.

[2] Maria-Gabriella Di Benedetto, Andrea Ferrante, Luca "Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneous Wireless Networks" 2012 IEEE,

[3] Yang Li, Aria Nosratinaia, "Hybrid Opportunistic Scheduling in Cognitive Radio Networks" IEEE transactions on wireless communications, Vol.11, No.1, January 2012.

[4] Rahul Urgaonkar, Michael J. Neely, "Opportunistic Cooperation in Cognitive Femtocell Networks", JSAC. Vol.30, No.3, Arpil 2012.

[5] W.Sadd, Z.Han, M.Debbah, A.Hjorungness, and T.Bassar, "Coalitional game theory for communication networks: A tutorial" IEEE signal Processing Mag., Vol.26, pp. 77-97, Sep.2009.

[6] Stephen Boyd, "Convex Optimization"