

## 子計畫三：協力式感知無線網路之規約架構與服務品質管理

### Publication:

1. H.H. Juan, H.C. Huang, **C.Y. Huang**, and Tihao Chiang "Cross-layer Mobile WiMAX MAC Designs for the H.264/AVC Scalable Video Coding," ACM Wireless Networks, vol.16, no. 1, 2010
  2. Hung-Hui Juan and **ChingYao Huang**, "Analytical Model for Wireless Communication Systems," IEEE Communication Letters, vol. 14, no. 6, JUNE 2010
  3. YungLan Tseng and ChingYao Huang, "Femto BS Network Deployment Analysis," accepted for publication, IEEE Trans. On Vehicular Technology , 2012
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1. Hsuan-Li Lin and ChingYao Huang, "Downlink Interference Mitigation for Multi-user MIMO by utilizing user scheduling and power allocation, " Jeju, ITC CSCC 2009, July 2009
  2. Chieh Yuan Ho and ChingYao Huang, "Energy Efficient Subcarrier-Power Allocation and Relay Selection Scheme for OFDMA-based Cooperative Relay Networks," ICC 2011, Kyoto, Japan, June 5-9, 2011
  3. Chieh Yuan Ho and ChingYao Huang, "Energy-Efficient 2-D Resource Allocation with Fairness Constraints for OFDMA Networks," VTC 2011, September 5-8, 2011, San Francisco, United States

### Technology Transfer:

400K to Global Mobile: Remote Healthcare Traffic Control System in WiMAX System

## **Abstract (based on studies on (1) Cognitive Radio Spectrum Sharing and (2) Energy Efficient Uplink Resource Allocation for OFDMA Cooperative Radio Network)**

In this project, we investigate various interesting research topics in the area of cognitive and wireless cooperative networks, which focus on spectrum sensing, spectrum sharing in cognitive radio network, and energy-efficient uplink resource allocation for OFDMA cooperative relay network. Novel schemes for improving spectrum utilization are proposed for the first two topics, and another resource allocation and relay selection scheme for maximizing bits-per-joule is proposed for the third one. Numerical results show dramatic improvement on our proposed schemes, and the contributions are also highlighted..

## **Introduction**

Cognitive radio (CR) technology attracts significant research attention [1][2] in the wireless communication recently, since there is a lot of licensed spectrum which is sparsely utilized. As the demand of wireless service growing, the improvement of spectrum utilization is always a challenge. We study the case that multiple wireless systems may use the same spectrum and proceed with concurrent transmission, which is called spectrum sharing problem. In this case, interference caused by other user is the barrier to achieve higher capacity, which can be dealt with by proper power allocation strategy. Wireless node with cognition capability, called unlicensed or secondary users (SU), can sense the channel, learn from the channel, and utilize the channel without interfering with the primary users (PU). More specifically, once SU has data to transmit, SU needs to sense the primary band first. To achieve that, several basic functionalities that each SU should have are spectrum sensing, spectrum decision and spectrum sharing [3][4]. In this joint work, both of spectrum sensing and spectrum sensing techniques are investigated separately.

Spectrum sensing is basically a detection problem. It is to detect the primary user appearances on the primary band. Several detection techniques of primary transmitter have been developed, such as matched filter detection, energy detection, and feature detection [5]. These techniques are belongs to physical layer issues. Nevertheless, there are some MAC layer issues, such as optimal searching sequence of primary bands and sensing period decision [6]. In this work, we focus on the sensing period decision especially during the OFF period. First, we have identified the objective, or cost function  $c(t)$ , in term of expected collision time, given sensing period is  $t$ . Based on that, the maximum sensing period can be found if it requires the expected collision time is under predefined threshold.

For interference channel (IC) [7], which models a multipoint-to-multipoint transmission scenario, iterative water-filling (IWF) [8] is one of the well-known

power allocation algorithms. The feature of IWF algorithm is that it can achieve Nash equilibrium if it converges. At Nash equilibrium, each user acts as the best response in terms of maximum capacity of himself given all the others' action is known [9]. However, since each user is selfish, that is maximizing its own capacity regardless all the others, it would cause interference, which limits the capacity improvement of IWF. To achieve higher capacity, an orthogonal power allocation method, which removes interference, is proposed. We provide a mathematic model first to compare the capacity of orthogonal with non-orthogonal or overlapping power allocation, where the non-orthogonal power allocation is based on the consequence of IWF. After that, we propose a subchannel splitting algorithm, such that the subchannel is exclusive owned by each user and no interference anymore. The results show that both individual and aggregate capacity outperforms the result of IWF. In addition to the splitting algorithm, we also propose an overlapping criterion. The overlapping criterion identifies the condition that the spectrum is suitable to be overlapping used in terms of higher capacity.

Moreover, in this joint work, another research focuses on uplink energy-efficient resource allocation is studied in an OFDMA cooperative relay network. Uplink energy-efficient communication is an important issue due to the limited battery power for Mobile Stations (MSs). The average 'Bits-per-Joule' is defined as the energy efficiency metric, and the optimal joint power allocation for both MS and RS is derived for maximizing MS' energy efficiency. Based on that, we developed a low-complexity subcarrier-power allocation and relay selection scheme for maximizing energy efficiency per user in an OFDMA cooperative relay network, assuming full channel state information (CSI) is available at both relay and BS nodes. The numerical result demonstrates that the energy efficiency performance of cooperative relay networks can be better in the range of 15% to 30% as compared to that of single BS networks. It also shows our proposed scheme has significant improvement on the energy efficiency performance as compared with conventional max-throughput and fairness-based Equal-Power Allocation (EPA) schemes which allocate equal transmit power to the assigned subcarriers. Furthermore, the proposed scheme can achieve similar performance in much lower computational complexity as compared with the exhaustive search scheme.

## **Research Approach and Results**

- Spectrum Sensing in MAC Layer: Sensing Period Decision [24]

To obtain the optimal sensing period is indeed an important topic under cognitive radio networks. This subject provides an accurate and simple model to describe the relationship of expected collision time and sensing period. This model is based on the

assumption that the arrival of PU is modeled as Poisson random process and the OFF period  $T_{OFF}$  obeys exponential distribution. It can be useful to look for the largest sensing period subject to the expected collision time under certain threshold. However, the distribution of ON period  $T_{ON}$  does not have an exponential characteristic, determining the sensing period in the ON period should not use the same method as in the future work.

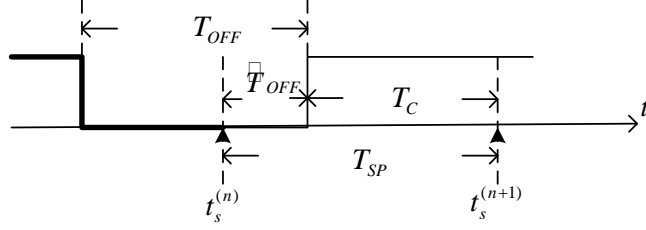


Fig. 1. The relationship of three different random variables:  $T_{OFF}$ ,  $\bar{T}_{OFF}$  and  $T_C$ . Here  $T_{SP}$  is a deterministic variable, and the randomness of  $T_C$  is contributed by  $\bar{T}_{OFF}$ .

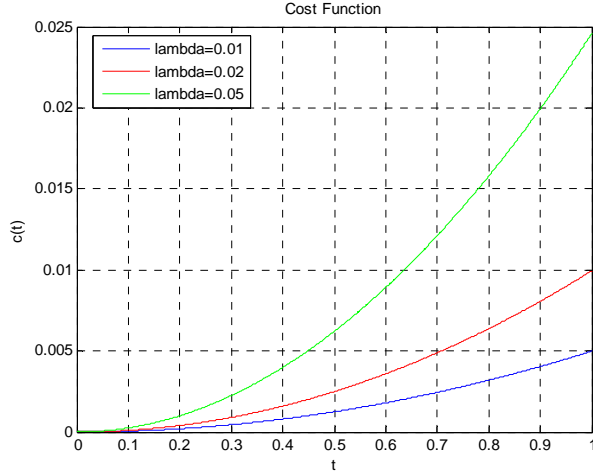


Fig. 2. The plot of cost function  $c(t)$  with respect to different rate parameter  $\lambda$ . Since the SU intend for the primary band which is sparsely utilized, the cases with small  $\lambda$  are shown. The time units can be in second, minute or even hour. Both horizontal and vertical axis should have the same unit.

### ● Spectrum Sharing: Power Allocation in Interference Channel

In this work, we study the power allocation method in spectrum sharing problem. Based on the IWF, we have developed a subchannel splitting algorithm to further improve the capacity. First, we have provided the analytic model for capacity difference between overlapping and orthogonal power allocation in user-centric and subband-centric viewpoint. Then we have proposed the subchannel splitting algorithm and verified the improvement through simulation. Finally, we provide the overlapping usage criterion to specify the channel condition which is suitable for simultaneously occupying the same spectrum.

The results show that the subchannel splitting algorithm has 30~40% capacity gain over

IWF. In this simulation, the power budget of both users is 10 mW. Noise power of each subchannel is set to be -100dBm. The results have been average over 100 trials. The vertical axis of Fig.3 is in unit of bit per second per Hz. The degradation of the curve as  $N_c$  increase is because the power is spread over wider spectrum and the unused port increase as  $N_c$ . As Fig. 3 shown, by applying subchannel splitting, both users can gain the capacity improvement simultaneously, given the same power budget.

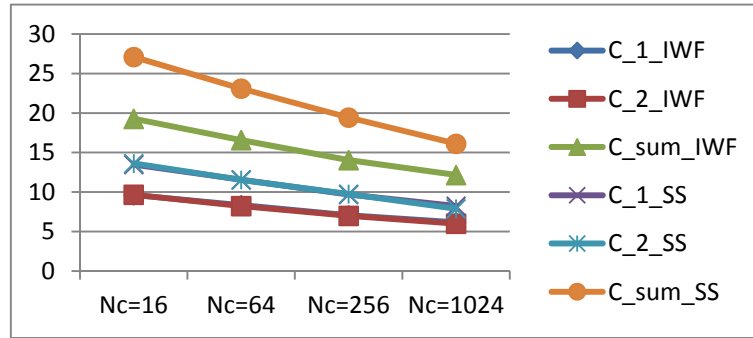
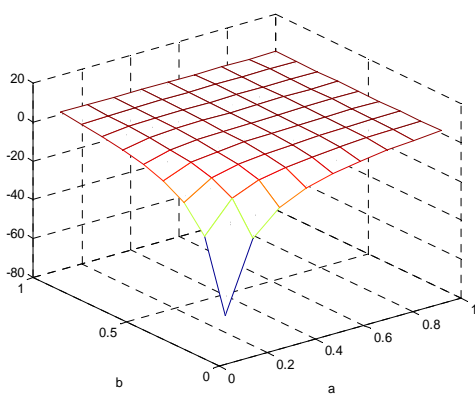
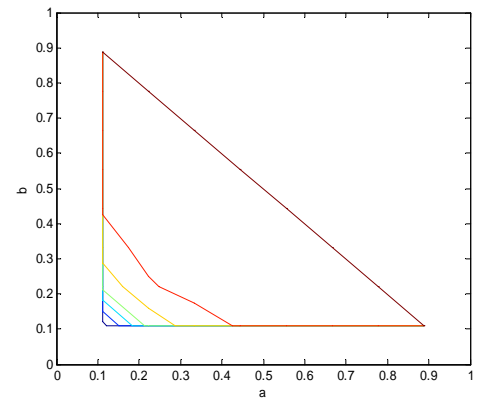


Fig. 3

Remember that notation  $a$  and  $b$  are small when cross gain is small relative to direct gain. Also,  $P_1$  and  $P_2$  are the receive power at receiver 1 and 2, respectively. Actually, the above inequality specifies the SSS region. Given  $P_1$  and  $P_2$ , for the case that  $a$  and  $b$  lie in the SSS region, overlapping usage brings more capacity than TDM/FDM does. More specifically, fig. 4 (a) shows the function plot of  $f(a,b) = \frac{a+b-1}{ab}$  and fig.4 (b) is its contour plot.



(a)



(b)

Fig.4 (a) Function plot of  $f(a,b) = \frac{a+b-1}{ab}$ . (b) Contour plot of  $f(a,b) = \frac{a+b-1}{ab}$ .

- Energy Efficient Resource Allocation and Relay Selection Scheme [25]

In this subject, the subcarrier-power allocation and relay selection scheme for maximizing the average energy efficiency per user has been addressed for uplink

transmission. We consider a multi-user OFDMA DF relay network, and utilize the additional transmission opportunity provided by cooperative relaying with Maximum Ratio Combining (MRC) to further improve the energy efficiency of the network. In order to maximize the energy efficiency for the relay link, the optimal joint power allocation for MS and RS is derived. Based on that, we proposed the Max-Energy-Efficiency (*MaxEE*) scheme which jointly performs subcarrier allocation, MS-RS joint power allocation, and RS selection, and achieves very similar performance in much lower complexity as compared to the exhaustive search. The numerical result also demonstrates that the *MaxEE* scheme with cooperative relaying outperforms that with no relay node in the range of 15% to 30%, and has more than 50% improvement as compared to the conventional EPA schemes in terms of energy efficiency per user. The following figures show the dramatic improvement on bits-per-joule with the implementation of our proposed algorithms.

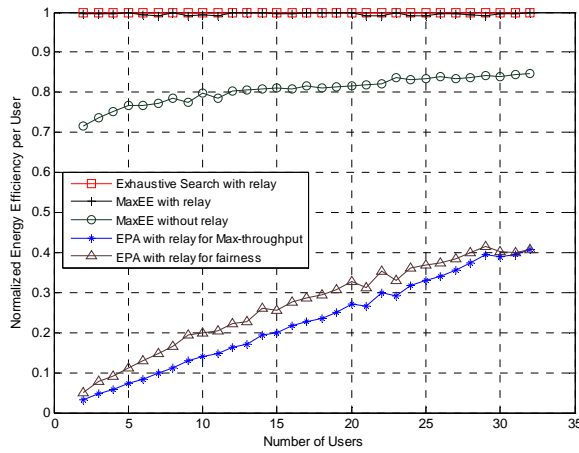


Fig. 5 Performance of energy efficiency per user in percentage (%)

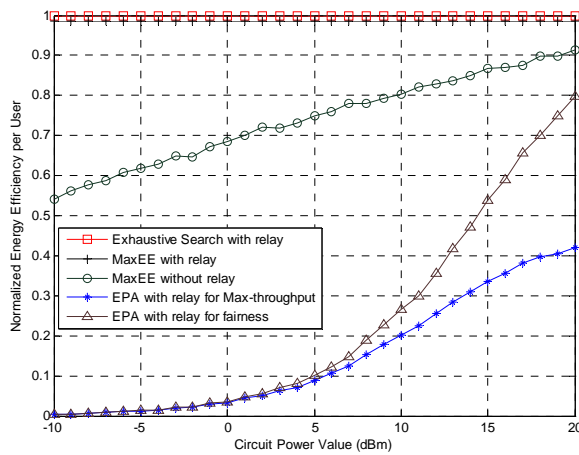


Fig. 6 Performance of energy efficiency per user in percentage, the outcome of normalizing the original result with the best one, for different circuit power; Number of users = 25, number of subcarriers = 32, and  $w=20$ .

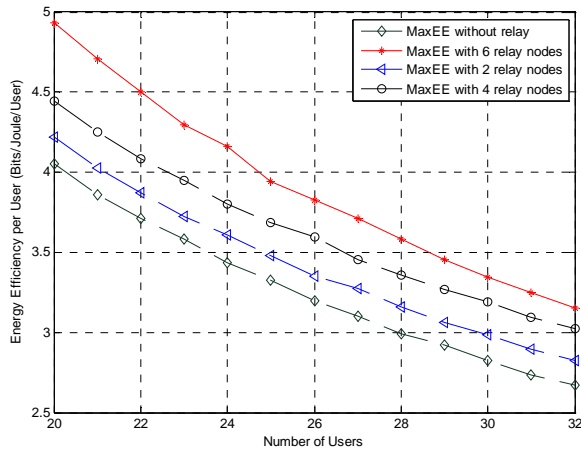


Fig. 7 Performance of energy efficiency per user for different number of relay nodes deployed in the cell. Number of subcarriers = 32, circuit power=12 dBm, and  $w=20$ .

## Conclusion

In this project, we have achieved 2 conference paper submission [24][25] in the areas of the cognitive and wireless cooperative network. The topic of our contributions includes spectrum sensing in MAC Layer, in which the relationship of expected collision time and sensing period are derived and modeled in cognitive radio networks, spectrum sharing and power allocation in the interference channel, in which a subchannel splitting algorithm to further improve the capacity is proposed, and the improvement of 30~40% capacity gain is achieved, and resource allocation for cooperative relay networks, in which the optimal joint power allocation for both MS and RS is derived for maximizing MS' energy efficiency, and a low-complexity subcarrier-power allocation and relay selection scheme for maximizing bits-per-joule in an OFDMA cooperative relay network is proposed. The numerical experiments show the improvement on bits-per-joule achieved by the proposed scheme is about 15~60% compared to other existing schemes.

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