OPTIMAL RESOURCE ALLOCATION FOR FLEXIBLE AND RELIABLE SPECTRUM USE IN HYBRID COGNITIVE GAUSSIAN RELAY CHANNELS

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ABSTRACT

Recent advancements in communication systems has suggested the benefits of Hybrid Cooperative Communication System which focuses on the integration of licensed radio and cognitive radio. This paper investigates the fundamental properties of such hybrid systems by studying the mathematical model of hybrid cooperative communication system called Hybrid Cognitive Gaussian Relay channel (HCGRC), which uses licensed Radio Resource (RR) and Cognitive RR for forward and relay transmissions respectively. The fundamental difference between Conventional relay channels from HCGRC is that the licensed and Cognitive Radio Resources are not Subject to a total resource Constraint. we derive the optimal power-bandwidth allocation strategies for the Cognitive relay to maximize the capacity, spectrum efficiency (SE), and energy efficiency(EE) analytically. The analytical derivation of optimal EE-SE trade off curve is done and the optimal design allocation strategies are discussed.

Keywords: *Cognitive radio, energy efficiency, spectral efficiency, trade-off*

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1. INTRODUCTION

Due to advance in wireless communication systems, available wireless spectrum resource is becoming increasingly scarce. However, a large portion of the allocated spectrum is found to be underutilized. The concept of cognitive radio is introduced to ensure opportunistic access of the underutilized spectrum to improve efficiency of the overall spectrum utilization. The licensed radio resource (RR)[4] is provided to the incumbents has a relatively small bandwidth, high transmit power and high reliability. The cognitive radio resource has broad bandwidth, low transmit power, and low reliability. To take advantage of the broad bandwidth of cognitive radio networks various models are specified. But pure CR networks are unreliable because they are opportunistic in nature. So a hybrid cognitive radio network is proposed to overcome the drawbacks of pure CR networks and to increase the reliability. These are called Hybrid CR networks which operate by exploiting the complementary natures of licensed and cognitive RRs. There are two basic architectures of hybrid CR networks: non cooperative and cooperative [9], [10]. Non-cooperative architecture creates two separate radio interfaces whereas cooperative architecture creates a single integrated physical layer. The result is a hybrid cooperative CR network. The cooperative architecture has significant performance gains when carefully designed taking in mind the resource constraints and the allocation strategies for the network under consideration. For example the RR is better for long range because of high transmit power and cognitive RR is better for short range because of high bandwidth.

Previous works on hybrid cooperative CR networks [5] focused on system level studies. They are mainly focused resource allocations and concentrated on large scale networks. However the link level study of hybrid cooperative CR networks has so far achieved less attention. The link level study consists of mathematical modelling of the channel and is mainly information theoretic.it mainly focuses on the bounds of transmit power and bandwidth under different conditions for the transmit receive pair. For pure CR networks the link level study is considerably well done compared to hybrid cognitive CR networks and there is still a wide research gap.

This paper makes systematic extensions in three aspects. First the upper bound performance and resource allocation schemes are presented. Second, the energy efficiency(EE)-spectral efficiency(SE) trade-off for optimal resource allocation is studied. Third the limiting values regarding performance metrics and resource allocation were presented.

2. MOTIVATION AND SYSTEM MODEL

The motivation application scenario consists of two models is illustrated in Fig.1.In scenario 1 the cognitive relay[7] deployed communicates with the BS using the licensed RR and provides local coverage using the cognitive RR. It is able to work in a duplex fashion to outperform conventional relays.in scenario 2 the cognitive relay uses cognitive radio resource for backhaul and the licensed radio resource for local coverage.

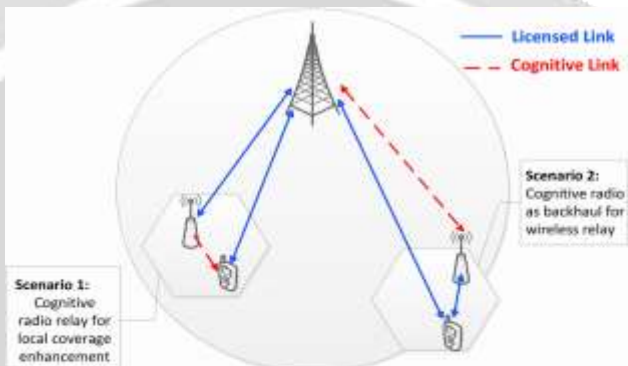

Fig.1.Hybrid cooperative CR network in cellular systems

Three metrics are used for the evaluation of a wireless communication system namely capacity, spectral efficiency(SE) and energy efficiency(EE). The energy consumption is measured by EE ,The efficiency of bandwidth utilization is measured by SE. It is well known that both can not be achieved at the same time [1],[6] so a trade-off exists between them. Of the above three metrics capacity is the most important because the main purpose of using CR is for capacity enhancement while the EE-SE trade off study also has a unique practical value.

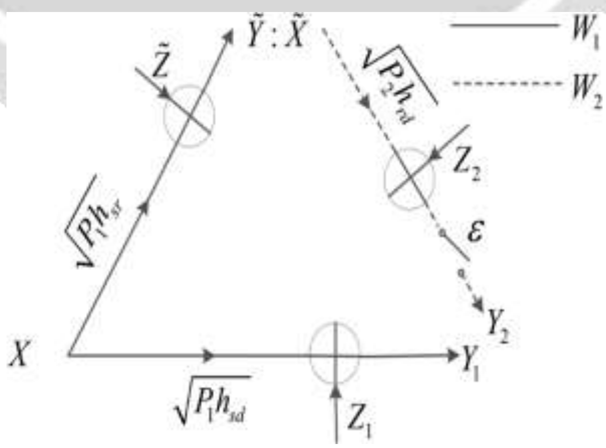

Fig.2 Heterogeneous cognitive Gaussian relay channel (HCGRC) model.

The EE and SE bills are two significant parts of the operational expenditure of a real hybrid cooperative CR system[5]. We consider a simple three node HCGRC[8] with source, a destination, and a relay. The source uses licensed RR while the relay makes use of cognitive RR. We assume the relay node works in full duplex fashion It should be noted that the characteristics of cognitive RR depend on the primary system/incumbent as well as the coexisting mechanism, which includes transmitter-oriented (sensing and database) approaches and receiver-oriented (interference temperature) approaches [3].The model of HCGRC is illustrated in Fig.2 The solid and dashed lines indicate transmissions in the licensed and cognitive bands, respectively. We are interested in the capacity, SE, and EE of the HCGRC. The transmitted power in the licensed and cognitive bands are denoted as P1 and P2 and bandwidths as W1 and W2.We define bandwidth ratio and power ratio to indicate the relationship between licensed and cognitive RRs.

Bandwidth ratio $$\theta = \frac{W_1}{W_2} \qquad (1)$$

Power ratio $$\phi = \frac{P_1}{P_2} \qquad (2)$$

The HCGRC signaling is characterized by the following equations

$$Y_1 = \sqrt{P_1 h_{sd}}\, X + Z_1 \qquad (3)$$

$$Y_2 = \varepsilon(\sqrt{P_2 h_{rd}}\, \ddot{X} + Z_2) \qquad (4)$$

$$\ddot{Y} = \sqrt{P_1 h_{sr}}\, X + \ddot{Z} \qquad (5)$$

where X and $\ddot{X}$ are inputs of the licensed and cognitive channels, respectively h_{sr} , h_{rd} and h_{sd} are channel gains from source-to-relay, relay-to-destination and source-to-destination, respectively. Moreover, Z_1, Z_2, and Z are zero-mean intimation, respectively. Moreover, Z_1, Z_2, and Z are zero-mean independent white Gaussian noises, whose variances are given by W_1N_0, W_2N_0, and $W_1 \ddot{N}_0$, respectively. Here, N_0 and $\ddot{N}_0$ are the noise power spectrum densities at the destination and relay, respectively. They are treated as different to reflect the potential difference in receiver noise figures at the destination and relay[2]. The transmit signal-to-noise ratios (SNRs) of the source-to destination link and source-to-relay link can be written as

$$\rho_1 = \frac{P_1}{N_0 W_1} \qquad (6)$$

$$\rho_3 = \frac{P_2}{N_0 W_2} \qquad (7)$$

respectively, and the transmit SNR of the relay-to-destination link can be expressed as $\rho_2 = \rho_1\phi/\theta$. In (3), ε is a binary random variable defined on probability space [0,1] to represent the opportunistic nature of the cognitive channel[4]. When the cognitive band is unavailable, we have $\varepsilon = 0$. In this case both the CR transmitter and receiver in the cognitive band stop working and do not consume any extra power. When the cognitive band is available, we have $\varepsilon = 1$ to give a conventional Gaussian channel. The mean of ε is $\bar{\varepsilon}$, which can be interpreted as the reliability measure of the cognitive channel or the fraction of time that the cognitive channel is available[8]. The signaling procedure of the HCGRC takes four steps.

1) When the source initiates a connection, bandwidth W_1 and power P_1 are allocated to the source from the licensed band. This allocation is independent of the cellular relay and is done in the cellular network.

2) As the source communicates to the destination in the licensed band, a CR relay also receives the user's transmitted signal and stores the information;

3) Meanwhile, the CR relay senses the cognitive band for secondary access. When this band is available (i.e., $\varepsilon = 1$), the CR relay decides a bandwidth W_2 and power P_2 to relay information to the destination. Otherwise the CR relay transmits nothing.

4) The destination receives both the continuous signal from the licensed band and the intermittent signal from the cognitive band Based on the above procedure, this paper aims to address a unique research problem: given W_1, P_1, and ε, how should the cognitive relay adjust W_2 and P_2 to optimize the overall performance? This problem differs from the classic problems of CR resource allocation[7] because we consider the overall performance over both licensed and cognitive RRs.

3. NUMERICAL RESULTS AND DISCUSSIONS

This section presents numerical results based on our previous analysis. For purpose of illustration, we assume that $h_{sr} = r_{sr\,\alpha}$, $h_{sd} = r_{sd\,\alpha}$, $h_{rd} = r_{rd\,\alpha}$, where α is the path-loss exponent, r_{sr}, r_{sd}, and r_{rd} are distances between the source-to-relay, source to destination, and relay-to-destination, respectively. Without loss of generality, we set $W_1 = 1$, $P_1 = 1$, $r_{sd} = 1$, and $\alpha = 4$. We also assume that the relay lies on the line between the source and destination for simplicity.

First of all, to give readers an intuitive understanding on the nature of our problem, Fig.3, Fig.3(a), shows the capacity, SE and EE as functions of bandwidth ratio θ and power ratio ϕ for different values of bounds on capacity and relay distances. Fig.3(b),Fig.3(c) shows the bandwidth and power ratio for different reliability values and source to destination relay distances .Fig.4,Fig.4(a) shows the spectral efficiency and energy efficiency in the presence and absence of relay and under the condition of unlimited power ratio.Fig.4(b) shows the theoretical upper and numerical bounds of energy efficiency EE and spectral efficiency SE.Fig.4(c) shows the energy efficiency EE and spectral efficiency SE when there is unlimited power ratio and no relay.

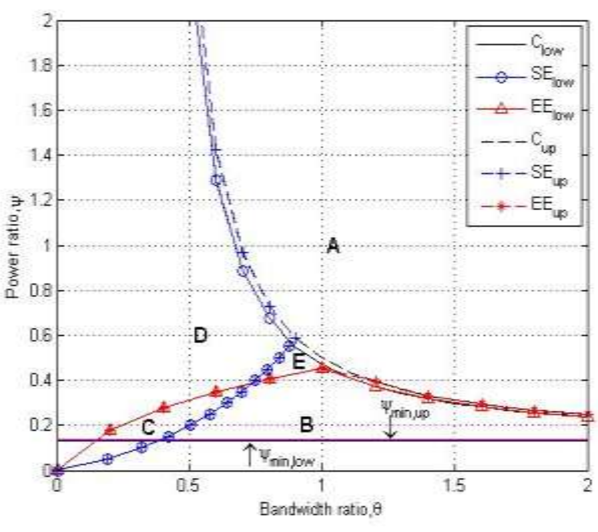

Fig.3

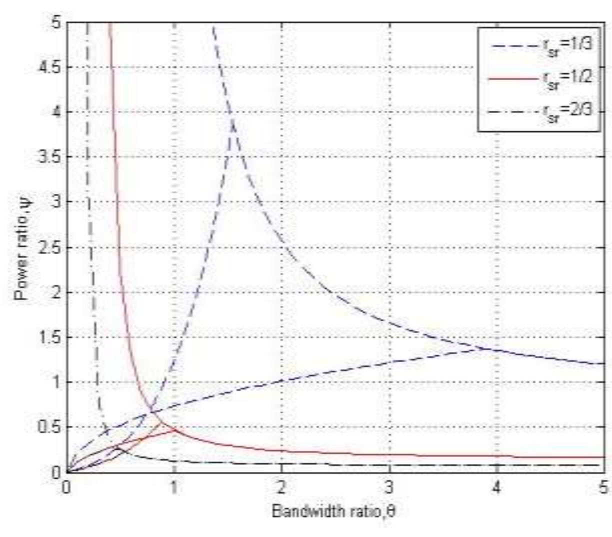

Fig.3(a)

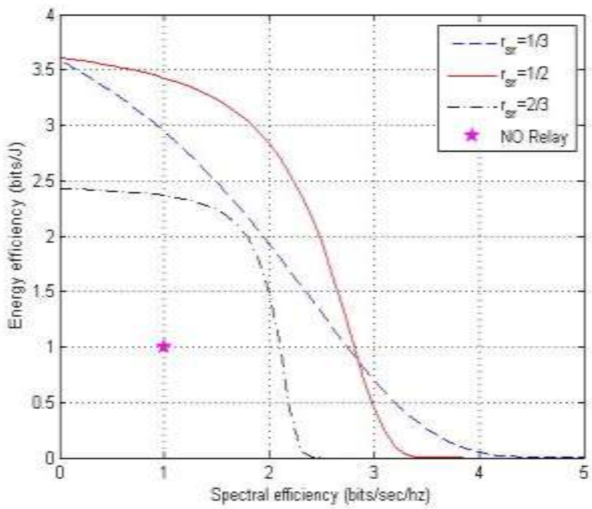

Fig.4(a)

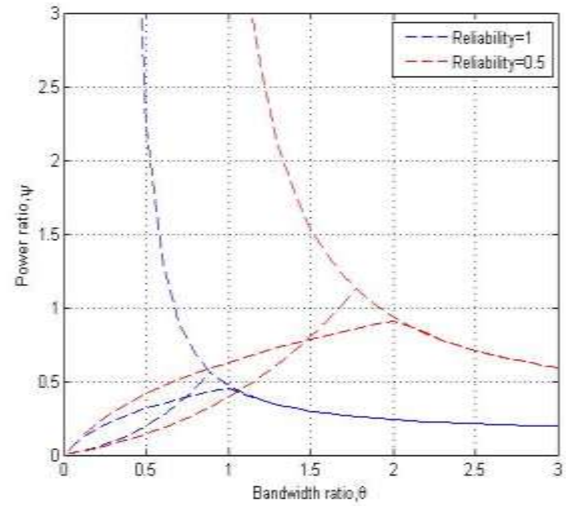

Fig.4(b)

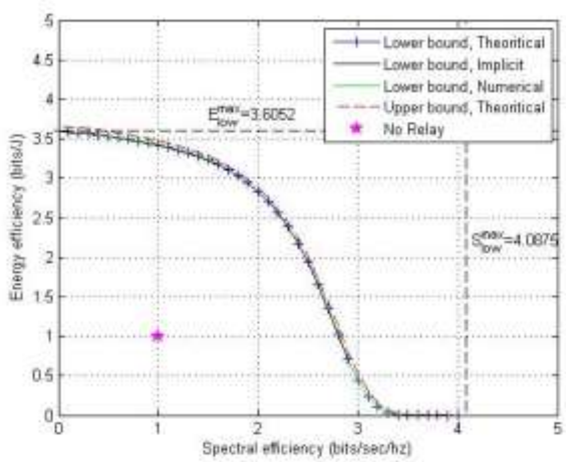

Fig.4(c)

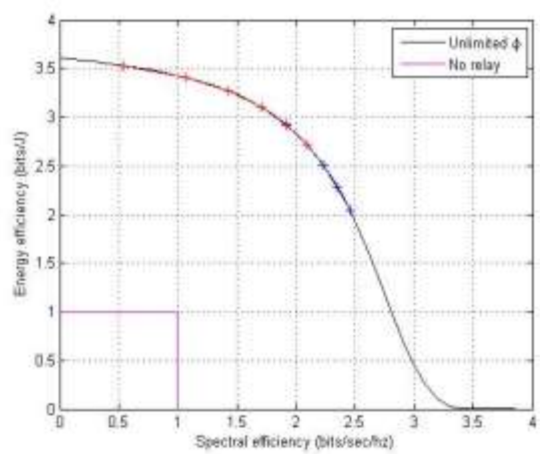

Fig.3(c)

6. CONCLUSION

The multi objective power bandwidth allocation problem in HCGRC is studied in this paper. The optimization objectives are to maximize the capacity, SE, and EE with respect to their upper or lower bounds. The optimal power bandwidth allocation strategies are done with respect to each single objective. The optimal EE-SE tradeoff curve has been characterized analytically for the proposed model of the CR network. The impact of relay location on resource allocation and EE-SE tradeoff has been studied. Our results are useful in providing basic guidelines for the design of hybrid cooperative cognitive radio systems. Future work can seek to extend the result from this paper to Rayleigh fading channels, multi-antenna scenarios, and multi-user multi-relay scenarios.

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