

# Channel and Power Allocation in Cognitive Radio Network using Iterative Water-filling Method

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**ABSTRACT:** Radio spectrum is the backbone of wireless communication system. Cognitive Radio is a revolutionary technology which has helped in improvement of spectrum usage efficiently. The cognitive user (CU) can not only use the free spectrum, but is capable of sharing a channel with primary user (PU). In this paper, a power allocation algorithm, known as “iterative water filling algorithm” is used to investigate the power allocation in between the channels of cognitive radio network. Here, the PUs and CUs will coexist in the same spectrum but with the condition that the interference caused by CU will not exceed a certain threshold and will not affect communication for PUs. Simulation results showed that the use of proposed algorithm helps in improvement of overall system capacity.

**KEYWORDS:** Cognitive Radio, Power allocation, Cognitive User, Water-filling algorithm.

## I. INTRODUCTION

Cognitive response and artificial intelligence is the key transformer of the present digital civilisation. For most of our machines adaptability, optimal usability and the power to evolve are the major factors that set apart an evolutionary machine. Cognition is defined to be the set of all mental abilities and processes related to knowledge, attention, memory and working memory, judgment and evaluation, reasoning and computation, problem solving and decision making, comprehension and production of language, etc. The natural electromagnetic radio spectrum is licensed to several bodies for various applications. With increasing applications there is suddenly a severe shortage of spectrum. It is found that very little of the licensed spectrum is actually utilized. The unutilized part of the spectrum results in Spectrum holes or White Spaces. Therefore, recently it has been proposed to allow utilization of the unused spectrum at a time to other users who do not hold the license. This is possible by the Cognitive Radio.

The ever-increasing pace of technology advancement and the related increases in the demands for the various applications the technology has enabled have rendered this “studied opinion”-based allocation scheme virtually impossible to manage in the developed countries of the world. Therefore, since mid-1980s, most regulatory bodies have moved from the strict assessment of public interest value, to the use of a market-based approach for new spectrum assignment, especially for commercial assignments such as cell phone bands [1].

## II. SYSTEM MODEL

### Cognitive Radio Architecture:

The infrastructure-based CRNs have one central network entity, such as the base station for communication control. Examples of such networks are cognitive radio cellular networks and wireless regional area networks. A CRN may have a spectrum broker that maintains and distributes the spectrum resources among various CRNs.

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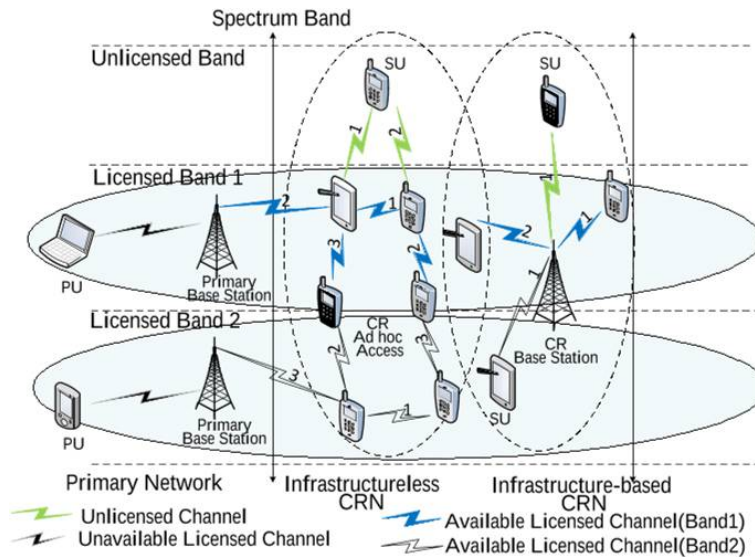


Fig. 1 Cognitive Radio Network Architecture [6]

**OFDM Architecture:** The idea behind the analog implementation of OFDM can be extended to the digital domain by using the Discrete Fourier Transform (DFT) and its counterpart, the Inverse Discrete Fourier Transform (IDFT). In practice, OFDM systems are implemented using a combination of Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) blocks that are mathematically equivalent versions of the DFT and IDFT, respectively, but more efficient to implement. An OFDM system treats the source symbols (e.g., the QPSK or QAM symbols that would be present in a single carrier system) at the transmitter as though they are in the frequency domain.

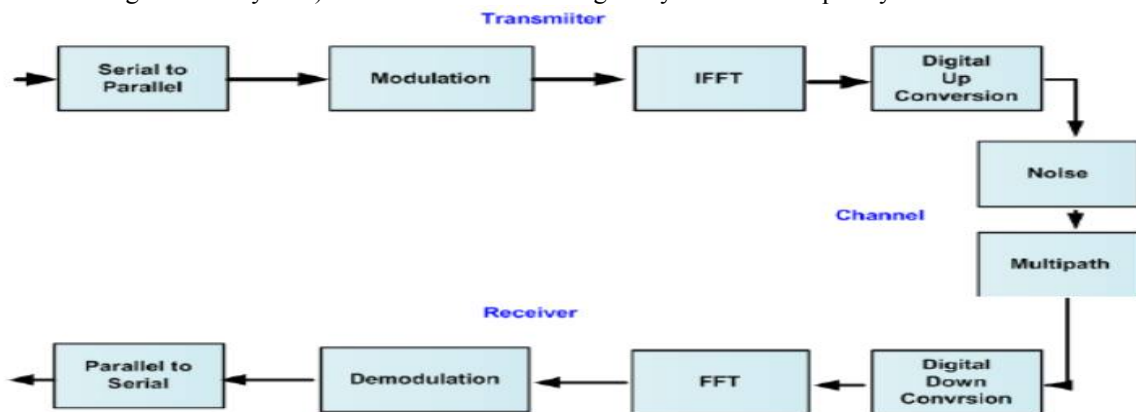


Fig. 2 OFDM Architecture

These symbols are used as the inputs to an IFFT block that brings the signal into the time domain. The IFFT takes in  $N$  symbols at a time where  $N$  is the number of subcarriers in the system. Each of these  $N$  input symbols has a symbol period of  $T$  seconds. Recall that the basic functions for an IFFT are  $N$  orthogonal sinusoids. These sinusoids each have a different frequency [2-4]. Each input symbol acts like a complex weight for the corresponding sinusoidal basis function. Since the input symbols are complex, the value of the symbol determines both the amplitude and phase of the sinusoid for that subcarrier. The IFFT output is the summation of all  $N$  sinusoids. Thus, the IFFT block provides a simple way to modulate data onto  $N$  orthogonal subcarriers.

The block of  $N$  output samples from the IFFT make up a single OFDM symbol. The length of the OFDM symbol is  $NT$  where  $T$  is the IFFT input symbol period mentioned above. After some additional processing, the time-domain signal that results from the IFFT is transmitted across the channel. At the receiver, an FFT block is used to process the

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received signal and bring it into the frequency domain. However, there is no notion of a constellation for the time-domain signal [2-4]. When plotted on the complex plane, the time-domain signal forms a scatter plot with no regular shape. Thus, any receiver processing that uses the concept of a constellation (such as symbol slicing) must occur in the frequency- domain.

## CRN Channels:

A communication channel or simply channel refers either to a physical transmission medium, such as a wire, or to a logical connection over a multiplexed medium such as a radio channel in telecommunications and computer networking. A channel is used to convey an information signal, for example a digital bit stream, from one or several senders (or transmitters) to one or several receivers. A channel has a certain capacity for transmitting information, often measured by its bandwidth in Hz or its data rate in bits per second.

Most common types of channels in communication systems are [7]:

- (i) Discrete Memory-less channel (DMC)
- (ii) Additive White Gaussian Noise channel (AWGN channel)
- (iii) Multiple Input Multiple Output channel (MIMO channel)
- (iv) Multi-access channel
- (v) Broadcast channel
- (vi) Cognitive Channel

**Channel Assignment:** Channel assignment defines the mapping of channels to the radio interfaces to attain optimal channel utilization while minimizing the channel interference. With respect to the mapping nature [5], channel assignment is generally classified into three categories:

- (i) Fixed or Static
- (ii) Dynamic
- (iii) Hybrid

The channel assignment scheme can also be categorized based on the following implementation methods [6]:

- (i) Centralized
- (ii) Distributed.
- (iii) Decentralized

## III. PROPOSED METHODOLOGY

Current research on CR systems is still at an early stage. Most of the existing work focused on achieving the Nash Equilibrium allocation of power. The power control itself cannot meet the full QoS and fairness requirements, where those diverse requirements are needed to be considered in the optimization formulation. Furthermore, as the channels on each subcarrier are likely independent for different users, the subcarriers experiencing the deep fade for one user may not be in deep fade for other users. [6]

### Optimum Power Allocation Algorithms:

#### For Cognitive User:

**METHOD 1: All Removed :** After perform control assignment calculation for subjective clients, the entrance point will check whether the impedance in the channels that essential clients exist is underneath  $Q$  and reject all solicitations of using that channel from psychological clients with  $I_{cp}(s,k) \geq Q$ . Then the cognitive users will allocate transmit power iteratively. This algorithm is fast because we remove "violated channels" in only one step. Therefore, we only need to solve this power allocation problem at most two times.

**METHOD 2: One-by-One Removal:** At the point when the entrance point finds the impedance surpass the foreordained edge  $Q$ , it will expel the auxiliary client that makes most obstruction essential clients. In the event that the main evacuation influences the impedance to drop to a sane edge  $Q$ , at that point wrap up. Else, one more subjective client will be evacuated until the point that we meet this prerequisite.

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## For Primary User:

**Fixed Channel Allocation:** This is the most conventional method that each primary user allocates all the transmit power just in one fixed and unique channel, e.g. the first user allocates all its power  $P_0$  in channel one and the second distributes  $P_0$  in channel two, etc. Note that, here we assume there are more channels than the primary users, i.e.  $m \geq t$ , according to the low spectrum efficiency of the current wireless communication systems.

**Dynamic Channel Allocation:** The  $t$  Primary users choose the best  $t$  channels, according to the  $SINR_{pi}$ , to allocate all their transmit power initially. After that, the cognitive users will allocate their power under the interference constraint  $Q$  using the “cognitive modified waterfilling” method. And this process is carried out iteratively for several times.

**Modified Water Filling Method:** The primary users allocate the transmit power according to the “cognitive modified water-filling” method, and then cognitive users allocate their power under the interference constraint  $Q$  using the same algorithm. The flow chart of the proposed channel and power allocation scheme for the cognitive radio network in a cellular environment is shown in Fig. 3

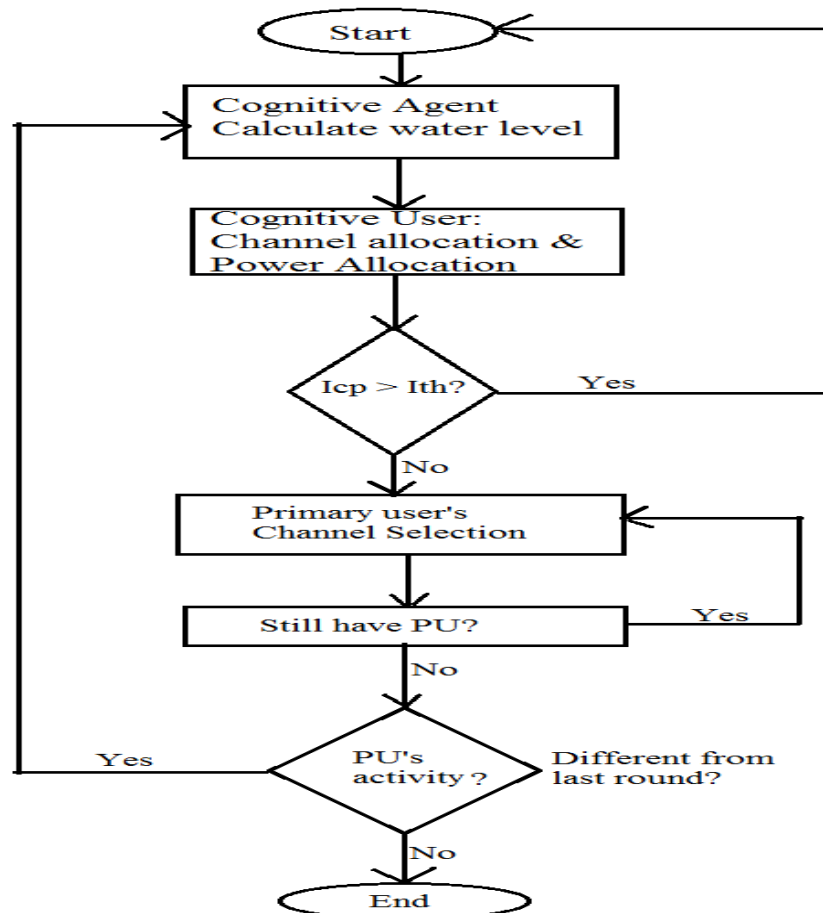


Fig. 3 Flow chart of the proposed channel and power allocation scheme for Cognitive Radio network

## IV. RESULTS

The results obtained by proper use of “Iterative Water-Filling Algorithm” used for optimum power allocation in secondary users without disturbing the power levels in primary users. The methodology has been explained in previous chapters, which is implemented on MATLAB (version R2011b).

Fig. 4 (a), (b) & (c) show the Secondary User 1, Secondary User 2 & Secondary User 3, respectively. They are generated randomly so that there is more generalization in the simulation.

MIMO systems has the power to improve the spectral efficiency drastically with the use of multiple antenna as both ends of communication channel. They have the ability to reduce fading to a great extent and increase data rates. In Cognitive radio network, they are of special importance as they allow the MIMO cognitive users to transmit in the null space of primary channels [1]. Also, interference caused in the communication channel can also be avoided with the help of MIMO configuration

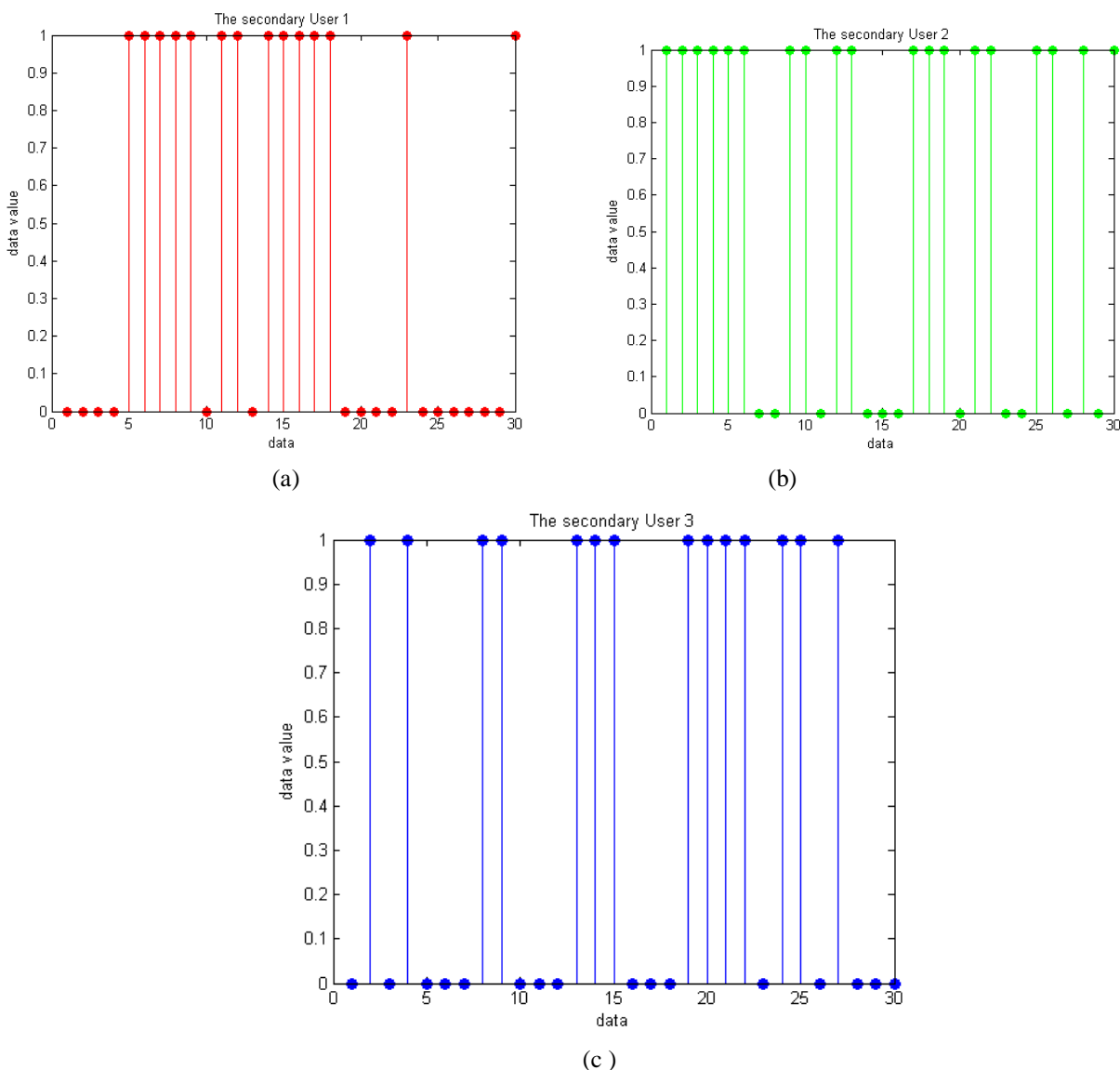


Fig. 4 Secondary users in Cognitive Radio network

In general, throughput means highest rate at which anything can be produced. But in communication system, throughput is the rate of rate of message delivery over the communication channel, efficiently. Here, we will compare the MIMO-OFDM Cognitive users (Primary and Secondary) with OFDM Cognitive users (Primary and Secondary) in Fig. 5

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As we can see, the average throughput is better if we use MIMO-OFDM Cognitive system instead of simply OFDM Cognitive system. It is because, the MIMO-OFDM systems helps in achieving greatest spectral efficiency.

MIMO-OFDM is an especially capable mix in light of the fact that MIMO does not endeavor to relieve multipath spread and OFDM keeps away from the requirement for flag balance. MIMO-OFDM can accomplish high ghostly productivity notwithstanding when the transmitter does not have channel state information (CSI). At the point when the transmitter possesses CSI, it is conceivable to approach the hypothetical channel limit. CSI might be utilized, for instance, to distribute distinctive size flag groups of stars to the individual subcarriers, influencing ideal utilization of the interchanges to channel at any given snapshot of time.

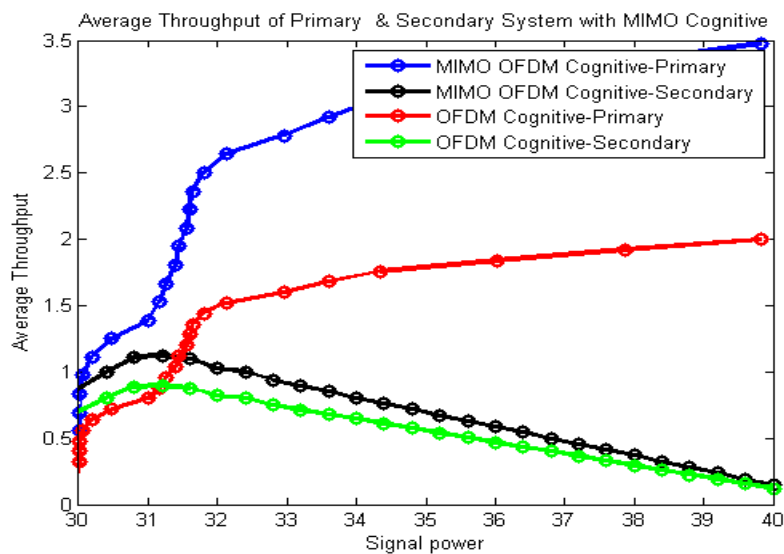


Fig.5 Average Throughput of Primary & Secondary System

Now, we will see the results obtained for optimum power allocation for Primary and Secondary users by the algorithms mentioned in Chapter 6.

Fig. 6 shows the capacity of cognitive and primary system respectively using the “cognitive modified water-filling” method for the CU and the power allocation explained in Chapter 6, (Section 6.3.1 Fixed Channel Allocation). It is interesting that when the interference threshold is at a high level, e.g.  $Q=-9\text{dB}$ , the total capacity of cognitive system will drop from a larger value to a small one at a certain SNR (here is 16dB). All cognitive users can allocate their transmit power according to the cognitive modified water-filling scheme without any removal at low SNR region, however, some cognitive users can't keep the channels where primary users exist due to the interference constraint with SNR increasing, which results in capacity fall of cognitive system. When the interference threshold is at a low level, e.g.  $Q=-11\text{dB}$ , the interference constraint will restrict the power allocation of cognitive users to ensure the primary users' communication quality. The result also shows that one by one removal method has a better effect on system capacity than all removal case. The former one can maximize the capacity of cognitive system to the highest degree and this also leads to the largest whole system capacity.

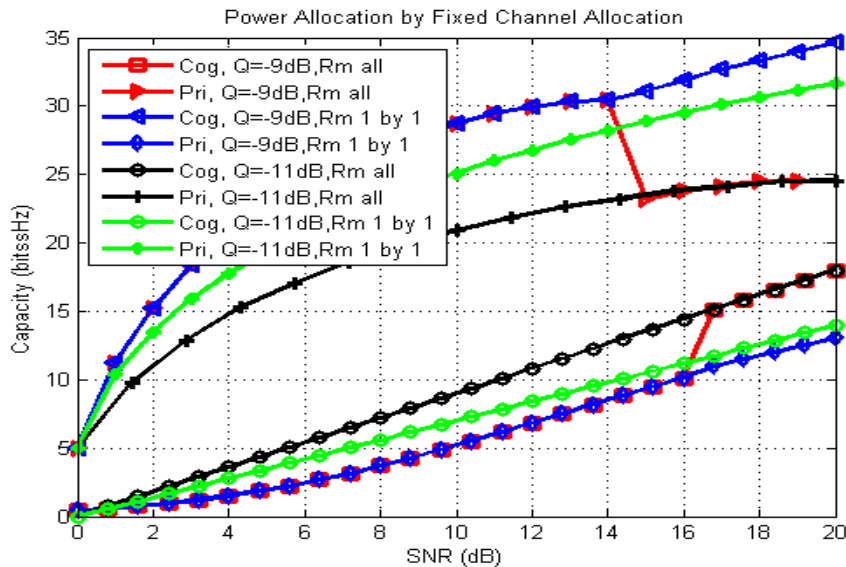


Fig. 6 Power Allocation by Fixed Channel Allocation

Fig. 7 shows the capacity results by using the “cognitive modified water-filling” method for the CU and the power allocation method mentioned in Chapter ^ (Section 6.3.2 Dynamic Channel Allocation). In most cases, the capacity curve in this method has the same trend with that of Fixed Channel Allocation. The capacity of cognitive users will also drop at a certain SNR with the decreasing of the interference constraint Q. The only difference is that the absolute capacity amount of primary system is a little bit larger while that of cognitive users has a touch of reduction. This result shows the priority of the primary users, so that the primary users choose the best channels in every iteration.

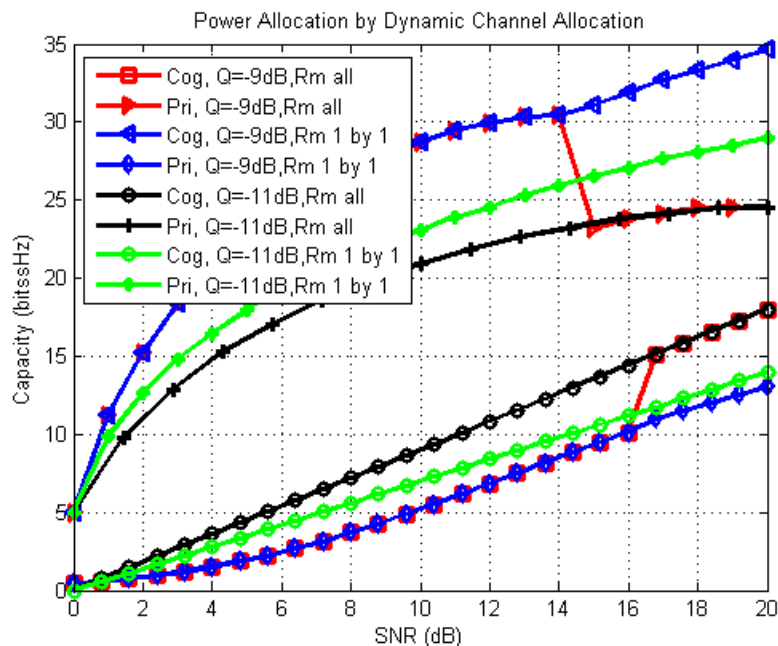


Fig. 7 Power Allocation by Dynamic Channel Allocation

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We have discussed that both the primary and cognitive system use the so-called “modified water-filling” to maximize the system capacity. When  $Q=-9\text{dB}$ , both the cognitive and whole system can achieve the largest capacity. At this time, the two removal methods are the same because interference to primary users does not go beyond the threshold  $Q$ . Compared to method B, the capacity of the whole system increases about 15%. And this algorithm won't permit the cognitive users utilizing the channels when  $Q\leq-10\text{dB}$  if only all removal method is used, because that the primary system uses all the available channels to maximize the capacity of his own. But if we use one by one removal algorithm, some cognitive users still can communicate in the channels which have not been fully occupied and the capacity of whole system increases 40% than that in all removal case at  $\text{SNR}=20\text{dB}$ . It is shown in Fig. 8 below.

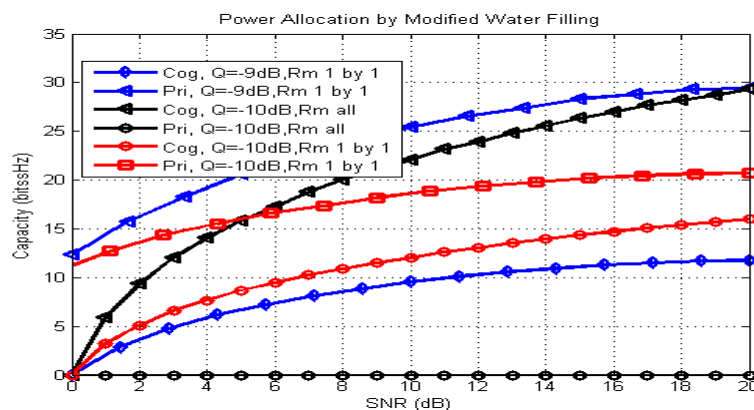


Fig. 8 Power Allocation by Modified Water-Filling Algorithm

## V.CONCLUSION

In this thesis, a channel and power allocation between channels in a cognitive wireless network, using the spectrum underlay strategy has been proposed, to maximize the capacity of the overall system under the constraint that the interference to the PUs due to the CUs will not exceed a certain threshold, so that the communication of the PUs will not be affected. The optimization of the overall system capacity has been investigated, with the cognitive users using the “cognitive modified water-filling” method and the primary users using different power allocation scheme. Simulation results show that the proposed scheme provides a significant improvement on the system capacity, and the most significant system capacity improvement is achieved when the primary and the secondary users all use the dynamic “cognitive modified water-filling” method.

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