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# Non Spectrum Handover Link Maintenance Performance in Cognitive Radio

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*Abstract*—**Cognitive Radio (CR) is a promising wireless communications technology. When using NC (Non Contiguous)-OFDM to transmit data, CU (Cognitive User) promptly evacuates the channel reused for communication once PU's (Primary User's) reappearance is detected, and needs to acquire new channel. One way is to increase modulation rate on remainder uninterfered channels, while the other is to acquire new channels. Acquiring new subcarriers takes a great portion of the link maintenance time. This paper proposes using increased modulation mode to keep the same transmission data rate so that CU can save the time of acquiring new channel. Numerical result shows that the goodput of increased modulation rate method is 14 Mb/s advantageous over that of acquiring new channel.**

***Keywords—cognitive radio, link maintenance, spectrum handover, increased modulation, primary user reappearance***

## I. INTRODUCTION

With the advance of wireless technologies, various wireless systems simultaneously exist in our daily lives. To avoid interference, each communication system usually operates at a designated non-overlapped frequency spectrum. However, the fixed spectrum allocated may not be always effectively used. To effectively utilize frequency spectrum, cognitive radio (CR) is to establish unharmful and temporary connections by reusing the spectrum of the existing systems for other unlicensed users [1]-[5]. To establish a temporary connection without the interference to the Primary User's (PU's) transmission, the Cognitive User (CU) has to be equipped with three capabilities: (1) the wideband radio sensing [6]-[8]; (2) multi-channel cognitive medium access control (MAC) protocol [9]-[14]; and (3) spectrum handover to return the channel back to the PU [4][15].

Spectrum handover is required on CU when the PU reappears or the condition of the channel reused by CU becomes worse. In these situations, the CU has to suspend its transmission and evacuate the reused channel for PUs. CR devices may either wait to resume sending data in the original channel or change to another channel. Apparently, the probability of maintaining the CU's link and the handover latency are two important performance metrics for spectrum handover.

[16] identifies PHY (Physical) and LINK layer challenges of cognitive radio networks. Most of research regarding spectrum handover is focused on the physical-layer impacts without considering the effect in the MAC layer. [17][18] discuss the impacts of the number of redundant channels on the link maintenance probability. An efficient spectrum allocation scheme has an effect on dynamic link maintenance [19]. [20] studies spectrum scan method. As for the latency issue, [21]-[23] investigate the goodput of the CU's transmission for the spectrum exchanged OFDMA system. [24][25] examine the MAC protocol design for spectrum handover.

On the other hand, the CR device may change to other channel(s). In this case, a CR device can select one target channel only when the PU reappears. In the scheme, radio sensing also wastes time. Therefore, for CUs, changing channel requires extra time and lowers the effective transmission rate.

A fundamental question is whether a CU should use the remainder channel available or acquire new channel to proceed with its data transmission when the PU reappears to the reused frequency. Thus this forms the motivation to develop an analytical model to investigate the performances of these transmission scenarios. Specifically, we investigate the link maintenance probability that at least a subcarrier is reclaimed by PU, and propose to use the remainder subcarriers to keep the same transmission rate.

## II. SYSTEM TRANSMISSION MODEL

In principle CR can work in any frequency band. Here we consider CR technology based on UWB frequency band. We divide 3.1GHz 10.6GHz bandwidth into 4.125MHz forming $128\times14$ subcarriers. All subcarriers form a spectrum pool. CUs use temporarily available spectral resources to satisfy their communication needs. Adjacent subcarriers form a band whose start and end frequencies are unfixed, but successive 128 subcarriers constitute a band with bandwidth of 528 MHz. These subcarriers are either contiguous or non-contiguous. This transmission technology is so called NC-OFDM (Non Contiguous - Orthogonal Frequency Division Multiplexing). All or part of subcarriers in a bandwidth of 528 MHz combine to create a Cognitive User Link (CUL) to transmit data and control message of CUs by OFDM technology. A CUL is a set of subcarriers, changing dynamically depending on the PUs' activity on the reused spectrum.

When a PU wants to make use of its spectrum, all the CUs have to immediately evacuate the corresponding subcarriers, giving precedence to the PU. The question with this scenario is how to achieve a reliable continuous communication among CUs despite the loss of the subcarriers caused by the reappearance of a PU so that the effect from PUs reclaiming their spectral resources is decreased. Both band movement window and change of modulation method can mitigate the loss of subcarriers caused by PU's reappearance.

Band movement window: In order to maintain the data rate requested by the CU, the CUL needs to compensate the loss of spectral resources caused by the reappearance of PUs to the subcarriers currently being reused. Every time a subcarrier has to be excluded from the CUL, a link rebuild period is executed during which some new subcarriers are immediately acquired in order to maintain the data rate of the CUL. Band movement window means the start and the end frequencies of the band are varying with the number of subcarriers (128) or bandwidth (528 MHz) unvarying. It looks as if a band window moves back and forth in system bandwidth B as shown in Figure 1. Through band window shift new channels available can be brought in.

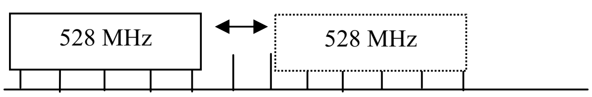


Figure 1. Band movement window.

Change of modulation method: Once an available frequency band is identified for a session, a modulation selection protocol must choose a modulation technique according to the capabilities of the radios, the established etiquette for transmission in the network, and the Quality-of-Service (QoS) priorities for the session. Using high order modulation to compensate the data rate loss caused by subcarriers being excluded, instead of handover to new subcarriers, can decrease link goodput performance loss.

Apart from QPSK modulation (Quadrature Phase Shift Keying) on single carrier, QAM modulation (Quadrature Amplitude Modulation) can be used to keep the same rate and services, namely modulation method on subcarriers in the band must be changed due to the reduced number of subcarriers available. When the number of subcarriers available is less than the pre-set number (128), more high order modulation method on subcarriers with more information bits is potentially taken to keep QoS, and different subcarriers in a band may be modulated by different method. OFDM modulation conveniently enables the vision. Alternative modulation methods to subcarriers include QPSK, 16QAM, 64QAM and also their combination with different modulation on different subcarriers.

The effective bandwidth in the band movement window, which is greater than 128 MHz and less than 528 MHz because the latter corresponds to UWB bandwidth defined by ECMA and the former to 53.3 Mbit/s lowest rate in UWB communication with QPSK modulation method, varies based on the transmission rate with QoS. The effective bandwidth is generally 128 MHz, 161 MHz, 231 MHz, and 528 MHz.

Unselected subcarriers in the band movement window will be closed on using OFDM modulation. The effective subcarrier means that they can actually be used for data, guard, and pilot in a band movement window bandwidth. According to ECMA-368, the band movement window includes effective subcarriers greater than 31 and less than 122, 31 subcarriers corresponding to 53.5 Mb/s and 80 Mb/s with 64QAM, 122 subcarriers corresponding to 480 Mb/s with QPSK modulation. Using effective subcarriers transmitting data, parameters are as in Table I.

TABLE I. PAYLOAD DATA RATE VS NUMBER OF SUBCARRIERS.

| Payload data rate (Mb/s) | Modulation method | Coding rate | data subcarriers | effective subcarriers |
|---|---|---|---|---|
| 53.3 | 64QAM | 1/3 | 9 | 31 |
| 80 | | 1/2 | | |
| 106.7 | | 1/3 | 17 | 39 |
| 160 | | 1/2 | | |
| 200 | | 5/8 | | |
| 320 | | 1/2 | 34 | 56 |
| 400 | | 5/8 | | |
| 480 | | 3/4 | | |
| 53.3 | QPSK | 1/3 | 25 | 47 |
| 80 | | 1/2 | | |
| 106.7 | | 1/3 | 50 | 72 |
| 160 | | 1/2 | | |
| 200 | | 5/8 | | |
| 320 | | 1/2 | 100 | 122 |
| 400 | | 5/8 | | |
| 480 | | 3/4 | | |

## III. ANALYTICAL MODEL

For the investigation of this paper, we assume a cognitive usage model using opportunistic spectrum sharing. It is the sole responsibility of the cognitive system to detect primary usage of the spectrum and to ensure the unimpaired operation of the PU. This is achieved locally in each CU by sensing the spectrum to detect if any PU is using its spectrum and by exchanging these sensing results between the communication peers. This model implies that a PU can interfere with CUs' communication, resulting in packet errors on the CUL.

Once reclaiming a reused subcarrier, a PU interferes with the CUs' communication, which most likely results in a corruption of the data sent on this subcarrier. As the session continues, the communications environment may change, so an adaptive transmission protocol must modify the modulation and coding as needed to maintain reliable communications without increasing interference to other radios. At the end of the session, the adaptive transmission protocol can supply information to the modulation-selection and power-adjustment protocols if there is to be another session in the same frequency band involving the same source and destination.

Assume there is only one point-to-point CUL. We do not study the effect of different CU communications within the same spectrum pool (i.e., no multi-user scenario). Control information between CUs is transferred on a dedicated control channel, i.e., dedicated subcarriers. Assume the CUL is already established, i.e., link setup is not studied. In our scenario it is assumed that the transmitter always has data to send and payload data are transmitted only from one peer to the other, but the receiving peer does not have payload data to send.

The process of link maintenance takes time, which is not usable for data transmission and thus degrades the performance of the CUL. In our system model, time is slotted into frames of length $t_{\text{frame}}$. For the general model we use a frame structure as shown in Figure 2.

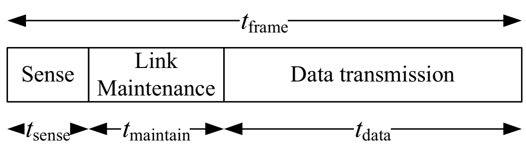


Figure 2. Frame structure.

$t_{\text{maintain}}$ denotes the time reserved for link maintenance. Each time a subcarrier has to be excluded from the CUL, a new modulation method or band movement needs to be executed in order to maintain the data rate of the CUL. In other words, every time a new modulation method or band movement needs to be selected, $t_{\text{maintain}}$ has to be taken.

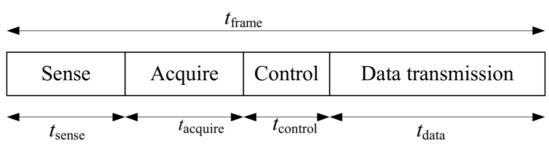


Figure 3. Detailed frame structure.

In this frame structure, as shown in Figure 3, the overhead is divided into three portions, namely $t_{\text{sense}}$, $t_{\text{acquire}}$, and $t_{\text{control}}$. During $t_{\text{sense}}$ the whole spectrum pool is scanned and learnt in order to detect PU activity. $t_{\text{acquire}}$ denotes the time reserved for the selection of new subcarriers, rate encode mode, modulation method and so on. Subsequently, within $t_{\text{control}}$, the sensing, learning and reconfiguring information has to be exchanged between the communication peers, to achieve a consistent view and to implement specific requirements. These requirements include which subcarriers have to be excluded, which subcarriers can be used for communication, and which subcarriers new modulation method can be utilized on. Note that $t_{\text{acquire}}$ and $t_{\text{control}}$ are only necessary if one of the sensing and learning messages acquired during $t_{\text{sense}}$ indicates that some subcarriers get interfered by a PU. If no subcarrier has to be excluded from the CUL, consequently $t_{\text{acquire}}$ and $t_{\text{control}}$ is not needed. In this case the next data message can be sent right away after sensing PU's free channels.

$t_{\text{data}}$ is the period of the frame reserved for payload data transmission. Payload data transmitted during one time frame is referred to as a message whereas the payload data transmitted on a single subcarrier is referred to as a packet. In other words, $t_{\text{data}}$ is the length of time for the transmission of one message on the current CUL. Note that in case no subcarriers get lost, the link does not have to acquire new subcarriers and to control sensing results, so a time frame mainly consists of $t_{\text{sense}}$ and $t_{\text{data}}$.

Acquiring new channel involves selecting subcarriers and RF transmitting power level. NC-OFDM can be allowed larger than -41.3 dBm/MHz and less than PUs' power level, for example, Power Spectrum Density (PSD) of IEEE 802.11a or IEEE 802.16e because IEEE 802.11a and IEEE 802.16e as PU will always interfere in peer to peer CUs' communication. Reconfiguration is useful to adapt encode rate, data rate, and modulation method in order to adapt to the carrier environment.

The transmission and modulation scheme used at the physical layer is assumed to dynamically adapt to the changing conditions of the wireless channel. Assume some new coding scheme is applied to the payload data in order to make the transmission robust against bit errors.

The above defined scenario represents a simplified model for link maintenance. The reappearance of a PU is the only reason that a subcarrier has to be excluded from the CUL. Furthermore, as the CU system operates with a quite low Signal-to-Noise Ratio (SNR) in general, PUI (Primary User Interference) (the reappearance of a PU to a subcarrier) completely corrupts the signal. Consequently the data sent on the subcarriers get lost.

Assume Pm is the probability that the CUL has to be maintained, i.e., the probability that at least one of the subchannels reused by the CUL is returned back to a PU during the last frame period, resulting in the need to acquire new channel for uninterrupted CR communications. Pm for our scenario can be computed as:

$$P_m = 1 - (1 - p)^N \tag{1}$$

where $p$ is the probability of PU reappearance, $N$ is the number of all the subcarriers in the band movement window. Using Equation 1, the average length of a frame, $E$[t], can be computed as:

$$t_0 = t_{sense} + t_{data} \tag{2}$$

$$E[t] = t_0 + P_m \cdot t_{control}$$ , only with increased modulation rate, (3)

$$E[t] = t_0 + P_m \cdot (t_{acquire} + t_{control})$$ , when acquiring new channel (4)

The goodput of this approach can be computed as:

$$G = \frac{\eta \times R \times t_{data}}{E[t]} \text{(Mb/s)} \quad (5)$$

where $\eta$ and $R$ are transmission factor and data rate in data transmission period, respectively.

## IV. NUMERICAL RESULT

Parameters for the numerical computation are $N$=122, $t_{sense}$ =50 ms, $t_{acquire}$=40 ms, $t_{control}$=10 ms, $t_{data}$ =900 ms, R=480 Mb/s. Subcarriers include 100 for data, 12 for pilot, 10 for guard. Overhead of data transmission period includes preamble length, head length, Frame Check Sequence and Short Interframe Space. $\eta$ is 0.7087 when Immediate Acknowledgement is considered in the transmission.

Figure 4 shows the computation result. The red line (at the bottom of the figure) denotes the goodput with acquiring new channels, while the black line (on the top) denotes the goodput with non-handover to new channels. The goodput of the black line is 14 Mb/s greater than that of the red line. The result shows that non-handover to new channel is advantageous over acquiring new channel. So, increased modulations will be taken when remainder subcarriers available are more than 56 subcarriers. This is because adequately making use of increased modulation rate, instead of acquiring new channel, can save the time taken for acquiring new channel including frequency analysis, frequency decision, reconfiguring parameter and frequency handover. Also Figure 4 shows good goodput when the PUs interfering probability p is less than 0.05, i.e., PUs use their licensed spectrum by 5%. The goodput in either non-handover to new channel or acquiring new channel method does not vary while the probability of PU reappearance is more than 0.05. That means the probability of PU reappearance does not affect the goodput much.

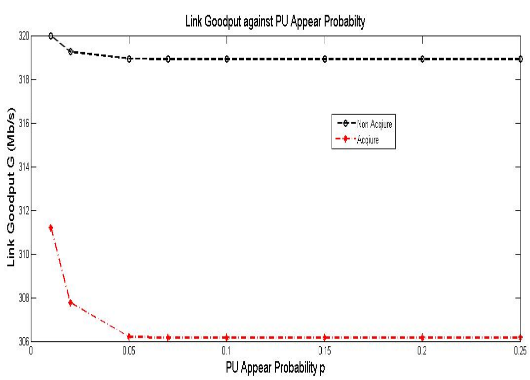


Figure 4. Link goodput against PU reappearance probability.

## V. SUMMARY

A frame of CR operation time is divided into sense time, link maintenance time and data transmission time. CU must evacuate the channel reused and return it back to PU. CU has to find out a method to deal with the channel loss. One way is to increase modulation rate, while the other is to acquire new channel available without changing modulation rate. Acquiring new channel takes much more time on spectrum analysis, spectrum selection, parameter reconfiguring and spectrum handover, resulting in CU link goodput performance degradation. This paper has studied improving on modulation method to keep the same operation rate and save the time of acquiring new channel when there is channel loss. Numerical result shows that increased modulation rate method keeping same operation rate is 14 Mb/s advantageous over searching for a new channel method.

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