Novel Overlay Data Transmission Technique in Cognitive Radio Networks

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Abstract—Recently, overlay transmission access paradigm in Cognitive Radio Networks (CRNs) has gained a special attention, for its promising results in improving the overall spectral efficiency. The main contribution of this work is in introducing a novel modified version of the existing overlay transmission technique in CRNs. Our technique overcomes some of the overlay drawbacks and at the same time improves the performance of the primary and secondary systems.

I. INTRODUCTION

Cognitive Radio (CR) emerges as a new technology capable of efficiently utilizing the spectrum usage. Three different cognitive transmission access paradigms are presented: underlay, interweave and overlay [1]. The underlay approach allows concurrent primary and secondary transmissions in the manner of ultra-wide band systems [2], where the transmission stay below the noise level of other radio technologies. On the other hand, in the interweave approach, the Secondary Users (SUs) access the Primary Users (PUs) spectrum opportunistically [3], where they access the the PU spectrum holes, as long as they are available. On contrary to those two approaches, in the overlay approach the SUs are transmitting concurrently with the PUs. The key enable of the overlay system is that the SU has a-priori causal/non-causal knowledge of the PU message and the Channel State Information (CSI), that can be used to split its power for secondary communication part and the remainder of the power to assist (relay) primary transmissions [4], [5]. By careful choice of the power split, the increase in a PU’s Signal to Noise Ratio (SNR) due to the assistance from secondary relaying is exactly offset by the decrease in the PUs SNR due to the interference caused by the remainder of the secondary transmit power that is used for secondary communication, as shown in Figure (1).

Overlay approach is based originally on the idea of non-causal knowledge of the PU message and the CSI on the SUs. However, this knowledge about the PU message can causally be obtained using either one of the two following approaches: (i) As in the case of the Single Frequency Network (SFN) scenario that is used in Digital Television (DVB-T) in Europe [6]. Where several base stations cooperate to transmit the same TV data over the same frequency and simultaneously, as in Figure (2.A). Accordingly, adding a Secondary Base station (SBS) to the SFN is an applicable scenario, as shown in Figure (2.B). (ii) In [7], the authors have proposed a modified overlay model that is valid when the PU utilizes a Hybrid Automatic Repeat request (HARQ) protocol. Accordingly, the SU link is only active during PU retransmissions, as in Figure (1). Therefore, the SU pair can causally acquire knowledge of the PU message. While these scenarios offer the knowledge of the PU message to SUs, still the CSI is assumed to be an non-casual knowledge. Based on [7], a partial knowledge about the CSI through listening to the first transmission and ACK/NACK exchange between PUs can be obtained. Moreover, the work in [8] shows that the use of multiple antennas on the secondary pair will avoid the need for full CSI knowledge.

II. STATE OF THE ART

A considerable research effort has been carried out concerning the overlay paradigm, such as [4], [5], [7]. All of these works are based on the idea of splitting the SU power to transmit and relay the secondary and primary data, respectively. However, neither one of these works propose a mechanism that can improve the primary system performance. Where no actual benefit is gained by the PU from the SU coexistence, as the increase of the PU’s SNR through relaying is deceased due to SU interference. Moreover, the current overlay works suppose that the SU is using its full power and no power saving technique is proposed yet. On the contrary, our work is studying the scenario where the secondary system can improve its performance and the primary system performance from one side and the mechanism that can help the secondary system
to save power, especially for power critical systems, from another side.

These issues motivate us to study the current overlay technique and propose novel modifications that can improve the secondary and primary systems performance and allow the secondary system to save power.

![Figure 2](image.png)

**Figure 2.** (A) Typical Single Frequency Network (SFN) for DVB-T. (B) Hybrid SFN which contains an additional secondary base station. Global Positioning System (GPS) for synchronization.

### III. Novel Overlay Primary User Data Masking Technique (PUDM)

#### A. Observation

We start describing our PUDM technique by asking motivation questions: What if the PU message already contains the SU message? if yes, why the SU has to split its power in this case?

To answer the first question lets us consider that the PU message $W_p$ of size $M$ and the SU message $W_s$ of size $N$, where $N < M$. And we randomly fill both messages separately with 0’s and 1’s using a uniform binary random generator. Then we check if $W_s$ is contained within $W_p$ according to the following simple pseudo code:

**Algorithm 1 : Masking SU message within PU message**

```plaintext
while (i < N - k) do
    while (j < M - k) do
        if ($W_s[i, k + j] == W_p[j, k + j]$) then
            $W_s[j, k + j] = W_p[j, k + j]$;
            $j = j + k$;
            break; // stop the j while loop and j keeps its value
        else
            $W_s[j] = NULL$; // Keep it empty and skip
            $j = j + 1$;
        end if
    end while
    $i = i + k$;
end while
```

Where $k$ is the number of bits to scan at a time and $W_s$ is the mask that locates all or part of the SU message $W_s$ within the PU message $W_p$, as shown in Figure (3).

Figure (4), answers our motivation question, where we notice that within a PU message of size 1024 bytes we can locate an SU message of size 256 bytes with $P(W_s \subset W_p) = 1$. And sure we can locate longer SU message by considering consecutive PU messages.

#### B. PUDM Description

According to our simple observation that the PU message may contain the SU message, we can propose our novel modifications to the current overlay technique. Where if the SU current transmission data is equal to the PU data, then the SU does not need to split its power, and only can dedicate part or full of its power for relaying the PU data which is at the same time is useful for its receiver. Accordingly, if we take the system model proposed in [7] as an example, where they exploit the HARQ retransmission of the PU to obtain the required knowledge to the SU. Then, a typical message of the SU will be as follows:

$$x_s = \sqrt{(1 - \alpha)P_s}x_2 + \sqrt{\alpha P_p}h_{2,1}e^{j\theta x_1}$$

(1)

where $x_1, x_2$ are the PU and SU codewords, respectively. $\alpha \in [0, 1]$ is the power splitting ratio and is given by:

$$\alpha = \left(\frac{|h_{1,1}|\sqrt{P_p}(1 \pm |h_{2,1}|^2P_s(1 + |h_{1,1}|^2P_p))}{|h_{2,1}|\sqrt{P_s}(1 + |h_{1,1}|^2P_p)}\right)^2$$

(2)
where $h_{i,j}$ is the channel gain between transmitter $i$ and receiver $j$. $P_P$, $P_s$ are PU and SU average powers, respectively. According to the the protocol in [7], both secondary transmitter and receiver listen for the PU message and both have to decode it correctly, then the secondary transmitter waits for NACK from the PU receiver. If a NACK received by the secondary transmitter, it will split its power as in Equ (1) and then transmit concurrently with the PU retransmission of the failed message. For more details about the system model, please refer to [7].

To evaluate our PUDM technique performance, we apply it on the HARQ system model that is proposed in [7] as an example scenario. Hence, PUDM will be as the following:

1) Both SU transmitter and receiver listen for the PU message and both have to decode it correctly, then the SU transmitter waits for NACK from the PU receiver.

2) Upon reception of the NACK, the SU checks if the current codeword is equal to the PU codeword (This step can be done off line as the SU already has the PU message). If equals, SU will dedicate part $\beta < 1$ or full $\beta = 1$ of its power for relaying only.

$$x_s = \sqrt{\beta P_s h_{2,1}^2 |h_{2,1}^2|^j x_1}$$

3) If not equal then SU computes the value of $\alpha$ according to Equ (2) and splits its power using $\alpha$ as in Equ (1), then transmits according to the usual overlay technique.

4) SU repeats step number two again and so on.

The advantages of the simple PUDM technique can be summarized in three points. First, the PU performance will be improved, as for some parts of the SU transmission there will be only relaying with no interference. Accordingly, the primary system will be interested in the coexistence with the secondary system. Second, the SU performance will be improved as the probability of correct reception of the shared codewords with the PU will be higher, where here the PU can serve as a relay for the SU when transmitting the shared codewords. Figure (5) shows how our PUDM protocol improves the performance of both secondary and primary systems. Third, it is clear that by using PUDM the SU can save power, by dedicating only part $\beta < 1$ of its power in each transmission of the shared codewords.

**IV. CONCLUSIONS AND FUTURE WORK**

We have proposed simple but effective modifications to the overlay data transmission technique in cognitive radio networks. It has been shown that our PUDM technique is able to improve the performances of both primary and secondary systems, while allowing the secondary system to save power.

For future work: (i) we will explore our idea over different scenarios concerning the HARQ and SFN system models, (ii) study a hybrid protocol that exploits both interweave and overlay transmission techniques, (iii) and study the effect of SU mobility on the overlay secondary system performance.

**REFERENCES**


