Distributed Synchronization Protocol For Secondary Overlay Access In Cognitive Radio Networks

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***Abstract*—A secondary distributed synchronization protocol in the Overlay based Hybrid Automatic Repeat request cognitive radio has been proposed. A detailed description for our protocol is given and simulation runs have been carried out. Our results show how secondary users can achieve synchronous reception on the primary receiver with the transmission from the primary transmitter. This synchronization represents a key functioning in the Overlay access scheme in cognitive radio networks.**

Keywords—Cognitive Radio; Overlay; HARQ.

I. INTRODUCTION

Recently, new regulatory model has been considered to open licensed (Primary) frequency spectrum to unlicensed (Secondary) access, with the aim to improve spectrum utilization, as well as, finding space for new radio technologies. This new model requires the development of Cognitive Radio (CR) devices that are able to access the primary bands without causing any harmful interference to Primary Users (PUs). Several secondary access schemes were suggested to allow harmless access to primary spectrum. These schemes can be classified under the Interweave, Underlay and Overlay access paradigms [1].

The Overlay access scheme authorizes secondary and primary concurrent access over the same channel, in which the secondary power is split for two parts, one for secondary link and the other part of the power to relay (assist) primary communication[2][3][4]. Through a conscious choice of the power splitting ratio, the increase in a PU Signal to Interference plus Noise Ratio (SINR) due to the relaying part from SUs is exactly balanced by the drop in the PU's SINR due to the interference from the secondary other transmission part.

Even though the Overlay access paradigm can outperform other paradigms in terms of capacity, it suffers from several practical limitations [3][5][6]. On top of these limitations comes the synchronization problem. Where Secondary User (SU) has to keep kind of synchronization with the primary system to guarantee seamless secondary co-existence within it. Such synchronization requirement is already achieved for the DVB-T Single Frequency Network (SFN) based Overlay CR in [4], where the primary signal is sent via satellite to some major transmitters, which need to apply the corresponding delay to keep the synchronization required by the SFN model. Thus, a potential secondary transmitter might also gain access to the primary signal, keeping time and frequency synchronization with the primary transmitters and, therefore, join the primary network using the Overlay scheme [7].

The recent works about overlay CR access paradigm in [1-6][8-9] assume perfect synchronization between secondary and primary users. In contrary, in this paper we propose a distributed synchronization protocol. Where in our case study, no prefect synchronization is assumed and we are targeting the secondary Overlay access to primary spectrum, in which PUs are utilizing Hybrid Automatic Repeat Request (HARQ) and Orthogonal Frequency Division Multiplexing with Cyclic Prefix (OFDM-CP).

The rest of the paper is organized as follows. Description of the system model is presented in section two. In section three, we describe our proposed synchronization protocol. We present the performance of our proposal in section four. Finally, in section five we draw some conclusions.

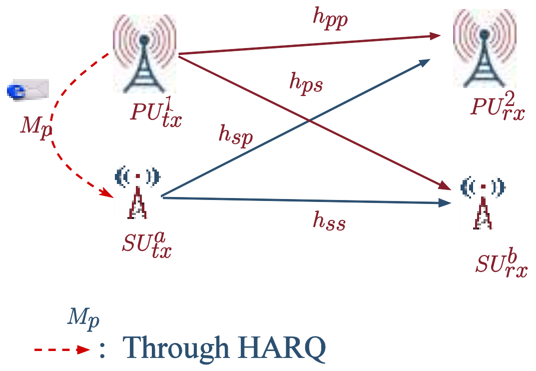

Fig. 1. Network scenario with a couple of primary and secondary pairs is presented. The dotted line indicates a priori knowledge of the PU's message M_p at the SU transmitter.

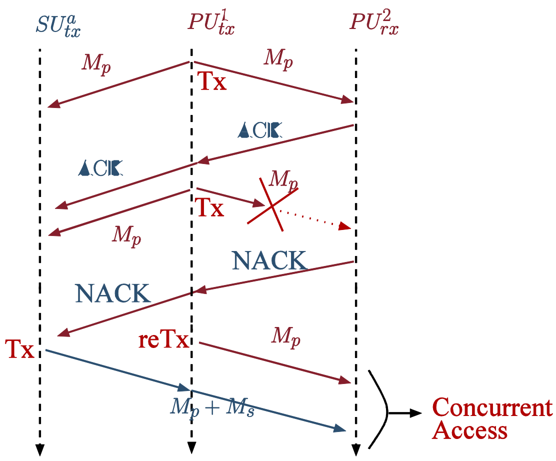

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Fig. 2. Message transmission using HARQ protocol is presented between a primary pair (PU_{tx}, PU_{rx}), while a SU_{tx} is listening and trying to access the primary spectrum concurrently with the primary retransmission, using an overlay access scheme. (M_p, M_s) are the PU's and SU's messages, respectively.

II. SYSTEM MODEL

Figure 1, describes the basic network setup under which we will perform our study. All users are assumed to be within the same transmission range of each other. The fading between the users is of the flat quasi-static Rayleigh type; where per block-fading channel model is used with effective channel gains $|h_{ij}|^2$ are exponentially distributed. We assume that SU applies no rate control and uses a fixed transmission powerP_s. Moreover, a feedback channel exists between the secondary pair.

We adopt the Overlay based HARQ protocol in figure 2, for obtaining the prior knowledge about the PU's message [2]. Where, each secondary transceiver will compensate for its interference by relaying the primary message. Moreover, PUs are assumed to use OFDM-CP. On contrary to the work in [2], we do not assume perfect synchronization between the primary and secondary transceivers.

As the transmitted signal travels over the medium as it is been received by the antenna it experience different manifestations. Due to the interaction of the physical environment over the transmitted signal which creates multiple wavefronts, also known as multipath. As consequence of the multipath mechanisms, the variations on the received signal power strength will be characterised by path loss and shadowing effects. The signal is said to experience flat or Frequency selective fading is dependent upon the estimated delay spared value. The proposed model was tested over different values of delay spread depending on the propagation environment.

Next, we describe our proposed distributed synchronization protocol.

III. SYNCHRONIZATION BETWEEN PRIMARY AND SECONDARY TRANSCEIVERS

Table 1, describes the terminologies that are used in this paper. Given the system model described in section 2 and assuming that SUs have an access to a geolocation[1] database [9]. In addition, SUs have a full knowledge about the PU's HARQ MAC protocol information. SU starts the synchronization protocol by following the flow graph in figure 3, where it obtains the initialization parameters $\{d_{1a}, T_m, T_w, T_{ACK}, T_{Msg}\}$ from the PU's MAC protocol and the geolocation database as an initialization step. Following this step, SU keeps listening for the primary channel that it would like to access and sees if a PU's message is transmitted. If yes, it will store this message and record the start reception time t_{rx}^{1a}, then it waits for an ACK/NACK from the PU receiver.

[1] Geolocation data base will offer only a location information about the primary user transmitter (usually a base station), but no information about primary receivers.

TABLE I: TABLE OF TERMINOLOGIES.

Symbols	Description
T_{ACK}, T_{NACK}	Time required for receiving an ACK/NACK
T_{Msg}	Time required for receiving a PU's message
d_{ij}	The Euclidean distance between user i and j
$T_{p_{ij}}$	The propagation delay between user i and j
C	Speed of light
ΔT	Time difference between the primary and secondary start transmission
T_w	Time between receiving a message and transmitting an ACK/NACK back
T_m	Time between receiving an ACK/NACK and transmitting/retransmitting a message
t_k^0	Primary start transmitting /retransmitting message time and k is the message sequence number
t_k^{ja}	Secondary start receiving time from user j
$\hat{T}$	Secondary estimated waiting time after receiving a NACK and before start transmission
α	Secondary power splitting ratio

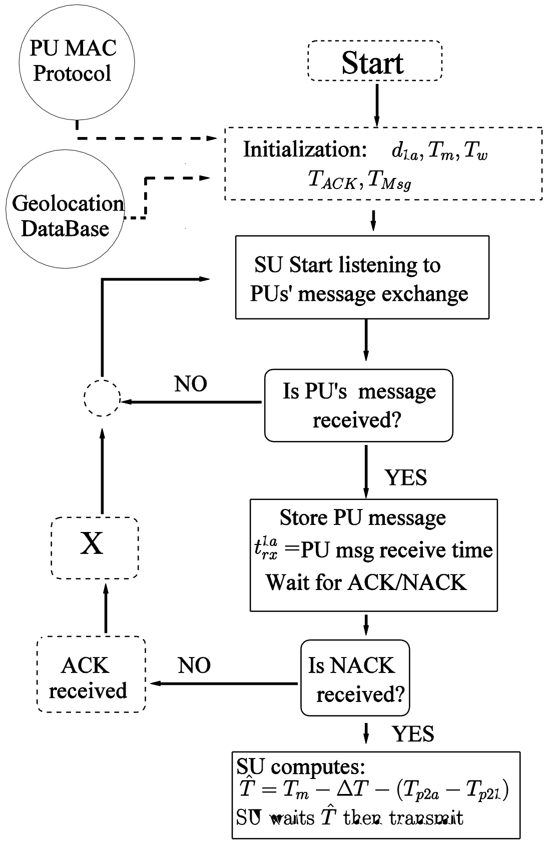

Fig. 3. Synchronization protocol flow chart.

In case of an ACK is received then SU knows that there will be no retransmission for the previously stored PU's message, for that SU deletes the stored message and do the required computations as in figure 4. Eventually, if a NACK is received from the PU side, then SU computes time $\hat{T}$ that it should waits before starting its concurrent transmission, to guarantee synchronous reception on the PU receiver with the message from the PU transmitter. This is true as long as we maintain a relative delay between the secondary relaying signal and primary signal that does not exceed the duration of the cyclic prefix of the primary transmitter signal [11].

X

SU deletes PU's message

$t_{rx}^{2a} =$ PU ACK receive time

SU computes:

$$\Delta T = T_m - (t_{rx}^{1a} - T_{p1a} - t_{rx}^{2a} - T_{ACK})$$

$$t_2^0 = t_{rx}^{1a} - T_{p1a}$$

$$T_{p_{21}} = T_{p_{12}} = \frac{(t_2^0 - T_m - T_{ACK} - T_w) - (t_1^0 + T_{Msg})}{2}$$

$$T_{p2a} = T_{p12} + \Delta T$$

Fig. 4. Computations required by the SU before start transmission.

IV. PERFORMANCE EVALUATION

Given the system model described in section 2 and assuming two transmission scenarios as in figures 5 and 6. In figure 5, the SU transceiver SU_{tx}^{a} is assumed to be closer to primary transmitter PU_{tx}^{1} than to primary receiverPU_{rx}^{2}, (i.e; $d_{2a} > d_{21}$). On the other hand, in figure 6, the SU_{tx}^{a} is closer to PU_{rx}^{2} than to PU_{tx}^{1}, (i.e; $d_{2a} < d_{21}$).

Simulating the two example scenarios with PU's failure probably of 10% in figure 7 and 8, respectively. One can see how a SU can have the right estimate of time $\hat{T}$, that is required to achieved synchronous reception on the PU receiver. Where in figure 7 and 8 (a), the reception time of the transmission from the PU transmitter on the PU receiver is shown, while in figure 7 and 8 (b), the reception time of the transmission from the SU transmitter on the PU receiver is shown. Synchronous reception from both PU and SU is achieved through our proposed protocol.

V. CONCLUSION

In this paper we proposed a distributed synchronization protocol to solve the synchronization problem in the HARQ based Overlay access scheme in cognitive radio network. We assumed that primary users are using OFDM-CP. A detailed description is provided and two scenarios are studied and simulated to evaluate the performance of our proposal. Our results show how secondary users can achieve synchronous reception on the primary receiver with the transmission from the primary transmitter. This synchronization represents a key functioning in the Overlay access scheme in cognitive radio networks.

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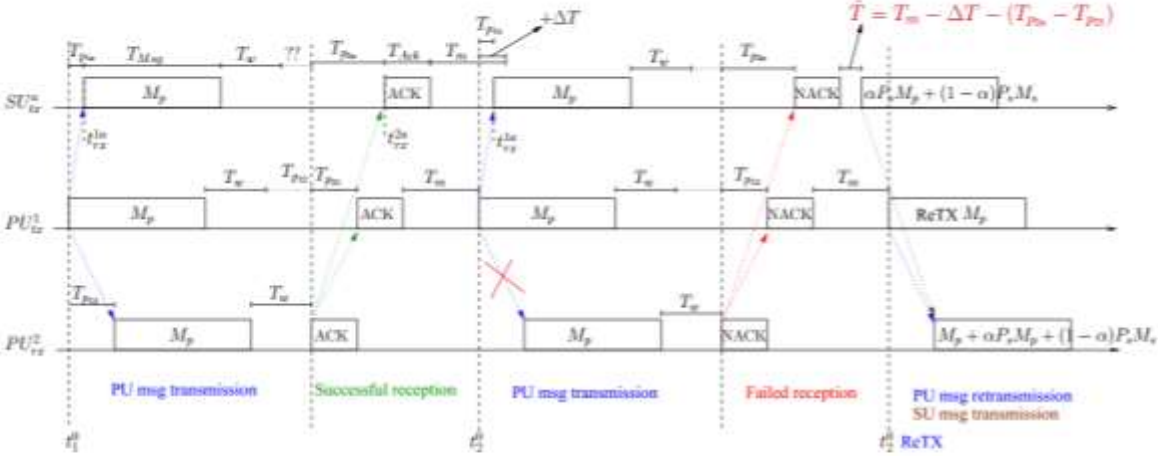

Fig. 5. Transmission scenario no.1: $d_{2a} > d_{21}$.

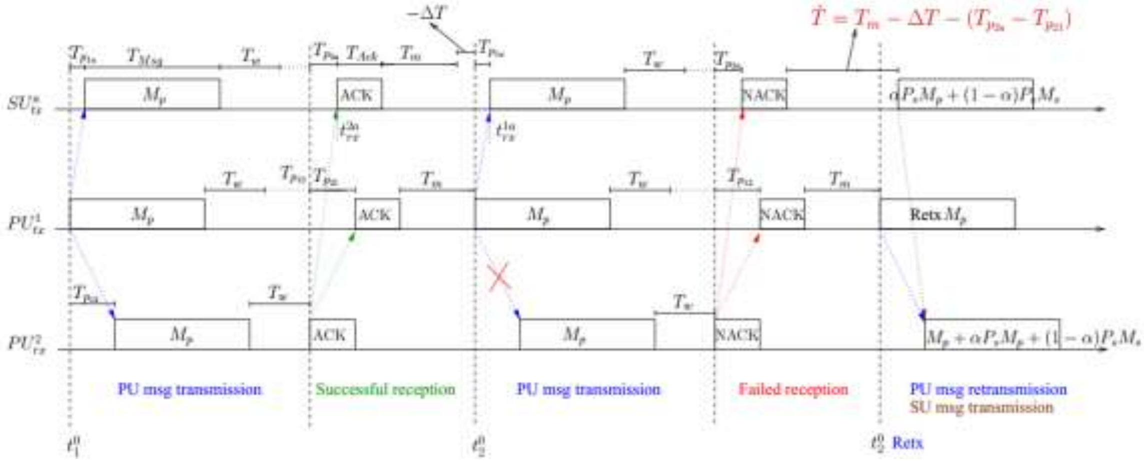

Fig. 6: Transmission scenario no.2: $d_{2a} < d_{21}$.

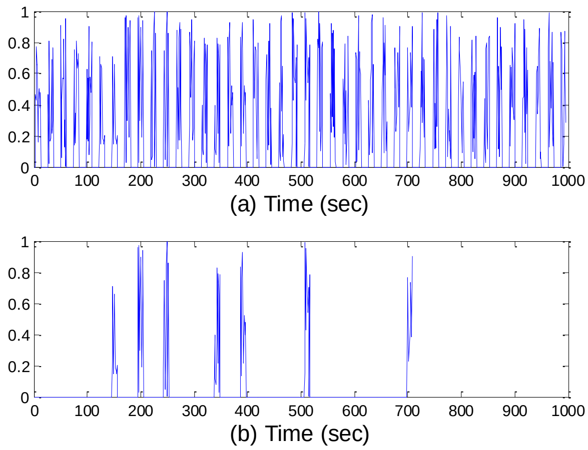

Fig. 7: Simulation results for transmission scenario no.1. (a) Reception time from PU's transmission and (b) Reception time from SU transmission.

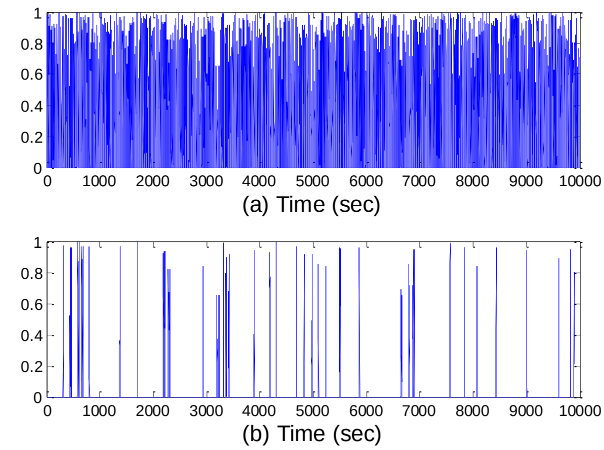

Fig. 8: Simulation results for transmission scenario no.2. (a) Reception time from PU's transmission and (b) Reception time from SU transmission.