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Performance & analysis of hybrid overlay underlay Cognitive Radio waveform in fading Channel

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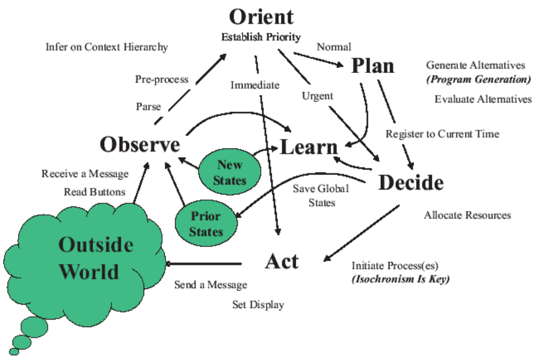
ABSTRACT: Spectrum Overcrowding continues to present a fundamental challenge for both military and commercial communications as earlier concerns over spectrum congestion and inefficient usage are manifest with 4G system emergence. Interest in Cognitive radio (CR) remains strong as the communication community strives to solve the spectrum congestion problem. In conventional CR Implementation, interference to primary users is minimized using either overlay or underlay waveforms.The overlay waveform that exploit unused spectrum holes and the underlay waveforms that spread their power spectrum density over an ultra-wide bandwidth. The proposed hybrid overlay underlay waveform that exploits both unused and underused waveform which effectively utilize the spectrum and improve spectrum efficiency.

KEYWORDS: Cognitive Radio Overlay, Orthogonal Frequency Division Muliplexing (OFDM-BPSK).

INTRODUCTION

The term Cognitive is usually associated with human thought process and reasoning abilities. It is defined as a mental processing to analyze given situation utilizing aspects such as, awareness perception, reasoning and judgement.Cognition in Cognitive radio sense is defined as, monitoring and structuring the knowledge of self, other users, and the environment to provide Information services[1,2]. It is also defined as learning from experience to tailor services user requirements, scenarios and environments. Similar to cognitive radios, there does not seem to be commonly accepted definition of cognition cycle. As a reference to cognition cycle in relation to cognitive radios, Mitola version of cognition cycle provides a good example. Mitola's cognition cycle in fig1.5 stems from the OODA loop concept [3-5]. The OODA loop is a concept that originated from the military strategies Col.Jonh Boyd of the United States Air Force. It main outline consists of four overlapping and interacting process: Observe, Orient, Decide and Act. In the cognition cycle of Fig.1, a radio gathers information regarding its operating scenario by observation (OBSERVE).The information is then analyzed (Orient) to determine its importance. Based on this evaluation, a radio sorts through its various options (Plan) and chooses the best option (Decide) suitable for that situation and radio scenario[6-9].. Finally, assuming a waveform change is necessary, the radio adapts, implementing the alternative solution (Act) by adjusting its resources and applying appropriate signaling. There are a number of different cognition cycles in the literature depending on one's need and interpretation of a cognitive radio. A cognition cycle can be as elaborate as the one in Fig1.5or as simple as the shown in Fig 2.



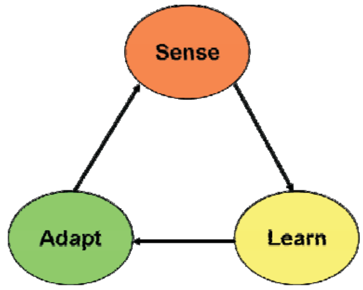


Fig.1: Cognition Cycle as defined by Mitola Fig 2: cognition cycle

PROPOSED SYSTEM

In the hierarchal access model, interactions between primary and secondary users are considered to achieve spectrum efficiency. The basic idea here is to open up the licensed spectrum to secondary users while inducing minimum acceptable interference into the primary users. Spectrum overlay and spectrum underlay are two approaches under consideration to accomplish this. Spectrum overlay allows unlicensed secondary users to utilize unused spectrum simultaneously with primary users on a noninterference basis. This overlay approach was first adapted and subsequently researched under DARPA's Next Generation (XG) program as an "opportunistic spectrum access" approach. Similarly, spectrum underlay allows unlicensed secondary users to simultaneously operate in primary user bands but under strict transmit power constraints. Of all the spectrum access models presented, the hierarchical access model is perhaps the most compatible with current FCC policies and legacy wireless systems. As proposed CR technology fits within the hierarchical access method. Even though the present CR definition only considers overlay approaches, the research trend suggests that a hybrid technique combining overlay/underlay concepts can be employed to maximize spectral efficiency by using both white and gray spectral regions. Therefore, CR can be further categorized as being either overlay-CR or underlay- CR depending on the spectral region being used.

CHANNEL CAPACITY

According to Shannon's channel capacity condition given by channel capacity can be optimized by increasing the signal-to-noise ratio (S/N) and/or channel bandwidth (W).

$$C=W\log(1+S/N) \qquad (1)$$

In the current CR framework, the transmitter continuously monitors the radio spectrum and identifies frequency bands as being in one of two categories, either used or unused. The unused frequency bands are identified as CR bands for secondary users as shown in Fig.3. The channel capacity when utilizing unused CR bands can be written :

$$C_{CR} = \left(\sum_{k=1}^{N} W_{u_k}\right) \log\left(1 + \frac{\sum_{k=1}^{N} \Phi_{CR_k} W_{u_k}}{n_0 \sum_{k=1}^{N} W_{u_k}}\right) \qquad (2)$$

where N is the total number of unused spectral bands in the total CR monitored bandwidth W, W_{uk} is the bandwidth of the k^{th} unused band and Φ_{CRk} is the power spectral density of the CR transmission in the k^{th} unused band.

UWB signaling can be used as underlay technique to support CR transmission. In UWB signaling, a very large contiguous bandwidth is used in a coexistence manner such that the spectrum is simultaneously shared with primary narrow band transmissions as shown in Fig 4. In this way, the total bandwidth W in (1) is maximized. However, to avoid interferences to primary (licensed) users, UWB transmissions are regulated by the FCC which limits the UWB transmitted power spectral density to a very low level. Hence, the channel capacity of UWB transmission is extremely limited and is given by (2). where n_0 is the additive Gaussian noise power spectral density, Φ_{UWB} is the average power spectral density of the UWB transmission is the total number of primary users operating within total bandwidth W, Φ_{pi} is the narrow band average power spectral density of the i^{th} primary user and W_{pi} is the corresponding bandwidth of i^{th} primary user.

$$C_{UWB} = W \log \left(1 + \frac{\Phi_{UWB} W}{n_0 W + \sum_{i=1}^{M} \Phi_{p_i} W_{p_i}} \right) \quad (3)$$

The coexistence of an UWB transmission with primary narrow band transmissions Suggests that most of the narrow band transmission can tolerate a certain level of interference, i.e., even though some frequency bands are occupied by primary users they are likely to be underused. To maximize channel capacity, the so called used bands also need to be considered, this concept is illustrated in Fig. 5. Accounting for both unused and underused bands, the new SDCR channel capacity for a given Cognitive Radio transmitter can be written as,

$$C_{SDCR} = W \log \left(1 + \frac{\sum_{k=1}^{N} \Phi_{CR1_k} W_{u_k} + \sum_{i=1}^{M} \Phi_{CR2_i} W_{p_i}}{n_0 W + \sum_{i=1}^{M} \Phi_{p_i} W_{p_i}} \right) \quad (4)$$

Where Φ_{CR1k} is the CR transmitted power spectral density in the k^{th} unused band, and Φ is the CR transmitted power spectral density in the i^{th} underused band. Fig.6 illustrates a conceptual view of the unused and underused spectrum utilization using an arbitrary interference threshold (IT). IT is assumed to be a limit set forth by the primary users based on the measured power spectrum density in a given bandwidth.Two cases of under-utilized spectrum are demonstrated: 1) when the spectral assignments based on a binary decision the bands adjacent to the primary users are unavailable to overlay CR users and 2) primary users bands which are below the IT are also unavailable to the CR users. A soft decision CR (SDCR) will be able to exploit these underused frequency bands to increase channel capacity and improve performance. To support the envisioned SDCR system, the original SMSE framework is extended to account for both unused and underused frequency bands.

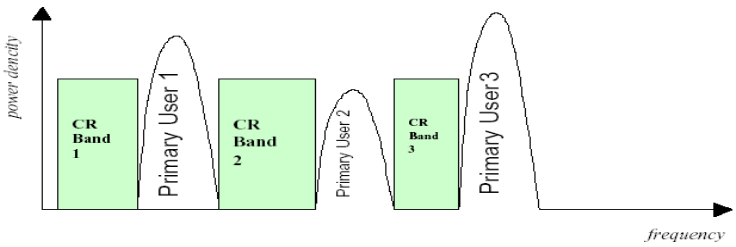


Fig 3 Illustration of Cognitive Radio Overlay Concept

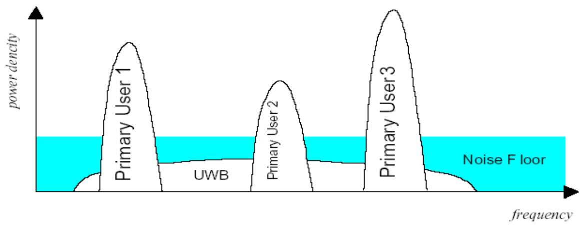


Fig 4 Illustration of Cognitive Radio Underlay Concept

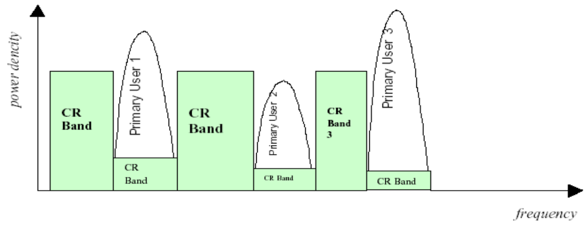


Fig 5 Illustration of Cognitive Radio Hybrid Overlay/Underlay Concept

INTERFERENCE THRESHOLD

Spectrum sensing techniques are helpful in detection of spectrum holes and identification of other primary and secondary users. In order to know if a certain portion of the spectrum is unused or underused, the power spectrum density (PSD) in a given bandwidth needs to be compared to a predetermined threshold called interference threshold. This interference threshold can be set forth by primary users or in conjunction with primary and secondary users.The concept of noise floor provides a means for evaluating the background noise in Over-utilized portions of the spectrum. Secondary user (SU) usage of the spectrum will raise the noise floor of the primary user (PU). To quantify this interference phenomenon, FCC spectrum policy task force has recommended interference temperature (IT) as a new performance metric. In May 2007 FCC issued another notice stating that it has terminated the IT concept. Even though, there are few supporters for adopting the IT approach to measure or set a threshold, there appears to be no clear cut method or rules to implement IT. The community in general (technical as well as user) argued that the IT approach is not practical and would only result in increased interference in its operating ranges. Even though FCC has temporarily abandoned the interference temperature concept, research community in general still considering IT as a viable metric, since IT is basically a measure of PSD in a receiver.

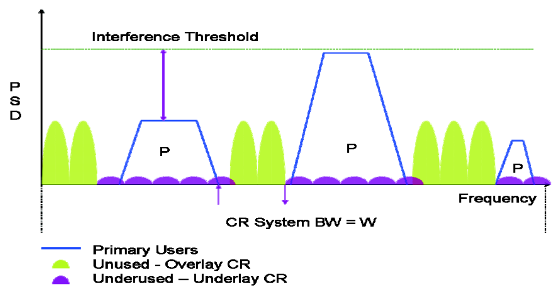


Fig 6: Identification of primary users, unused and underused spectral regions

SIMULATION RESULTS AND DISCUSSION

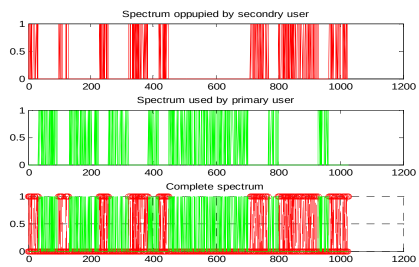


Fig 7 Cognitive Radio Spectrum Access

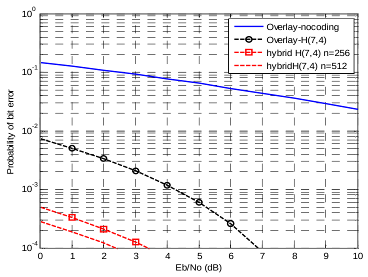


Fig8 Performance of Hybrid overlay/underlay waveform using Hamming codes in Frequency selective Fading channel

To maximize both spectrum efficiency and channel capacity, we have to take advantage of both unused and underused portion of the spectrum. In this section we demonstrate performance enhancement utilizing both unused and *underused* spectrum using a hybrid underlay/overlay waveform. The block diagram representation illustrates the conceptual view of the hybrid overlay/underlay approach. Systematic block channel coding is introduced to demonstrate the performance improvement gained by combining overlay and underlay techniques. Two popular block codes, namely a (7, 4) Hamming code with t = 1 error correction capability and a (15,5) BCH code with t = 3 error correction capability were chosen for demonstration purposes. In general, channel coding improves performance by adding redundant or parity bits. For a given communication system this translates into increased transmission bandwidth or a decrease in effective data rate. For example, a fixed bandwidth overlay system experiences a reduction in effective date rate where k and n represent the number of output encoded and input information bits, respectively.

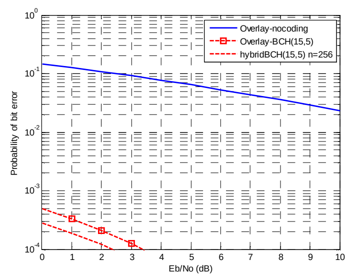


Fig 9 Performance of Hybrid overlay/underlay waveform using BCH codes in Frequency selective Fading channel

However, in the proposed hybrid overlay/underlay system, the information bits are transmitted using an overlay waveform (over unused frequency bands) while the redundant bits are transmitted using an underlay waveform (over underused frequency bands). Thus, both unused and underused frequency bands are exploited. When compared with a pure overlay system, the hybrid overlay/underlay system achieves channel coding gain without sacrificing data rate. More importantly, the hybrid overlay/underlay system possesses an increased degree of flexibility in receiver design: if preferred, no channel decoding has to be implemented and the receiver could simply demodulate the data from the overlay transmission; on the other hand, with channel decoding implemented the overlay/underlay receiver can significantly improve performance. Figure 8 shows the simulation results of overlay and overlay/underlay concept using hamming .The top solid line represents the OFDM-BPSK overlay system without channel coding. The bottom two dashed lines represents OFDM-BPSK overlay systems using H(7,4) channel coding respectively. The dashed lines represent the overlay/underlay combinations. The underlay waveform spread length was a t= 512. Figure 9 shows the simulation results of overlay and overlay/underlay concept using BCH codes illustrated in. The top solid line represents the OFDM-BPSK overlay system without channel coding. The bottom two dashed lines represent OFDM-BPSK overlay systems using BCH (7, 4) channel coding respectively. The dashed lines represent the overlay/underlay combinations. . It is evident from results in the figure that applying channel coding improves performance significantly but at the cost of reduced effective data rate. Performance of the proposed overlay/underlay system approaches that of the channel coded overlay system without experiencing the reduced data rate.

CONCLUSION

To maximize spectrum efficiency and channel capacity both *unused* (white) and *underused* (gray) spectral regions need to be exploited. Using a previously developed SMSE framework based on hard decision spectrum usage, The proposed extended soft decision SMSE framework (SD-SMSE) to support soft decision CR applications. The SD-SMSE CR implementation is capable of dynamically generating spectrally efficient overlay, underlay and hybrid overlay/underlay waveforms. Performance is evaluated here for Hybrid overlay/underlay and overlay without coding and with coding. Channel coding increases performance at the cost of decreasing data rate whereas the hybrid overlay/underlay achieves channel coding gain without loss of data rate.

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