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Intelligent Wireless Communication System of Cognitive Radio

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Abstract-- Radio spectrum has become the most valuable resource of the modern era due to the advancements of wireless technologies. With modern wireless systems, providers aim at offering a wide variety of applications with high data rates. It is often overlooked that as high performance wireless data services are widely deployed, the lack of additional spectrum is becoming a serious issue. Cognitive Radios are the probable solution to the current low usage of the radio spectrum. It is viewed as a novel approach for improving the utilization of the EM spectrum. The Cognitive Radio (CR) is defined as an intelligent wireless communication system that is aware of its environment and uses the methodology of understanding-by-building to learn from the environment and adapt to statistical variations in the stimuli with highly reliable communication whenever and wherever needed and efficient utilization of the radio spectrum. It is the key wireless technology that will enable a more flexible, reliable, and efficient spectrum sharing scheme.

I. INTRODUCTION

Cognitive radio is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not, and instantly move into vacant channels while avoiding occupied ones. This optimizes the use of available radio-frequency (RF) spectrum while minimizing interference to other users. Cognitive radios are aware of their surroundings and bandwidth availability and are able to dynamically tune the spectrum usage based on location, nearby radios, time of day and other factors. This provides for a more efficient use of the spectrum as well as reducing power consumption, and enabling high priority communications to take precedence if needed. Possible functions of cognitive radio include the ability of a transceiver to determine its geographic location, identify and authorize its user, encrypt or decrypt signals, sense neighboring wireless devices in operation, and adjust output power and modulation characteristics.

There are two main types of cognitive radio, full cognitive radio and spectrum-sensing cognitive radio. Full cognitive radio takes into account all parameters that a wireless node or network can be aware of. Spectrum-sensing cognitive radio is used to detect channels in the radio frequency spectrum. The specification cycle of the cognitive cycle is clearly described below.

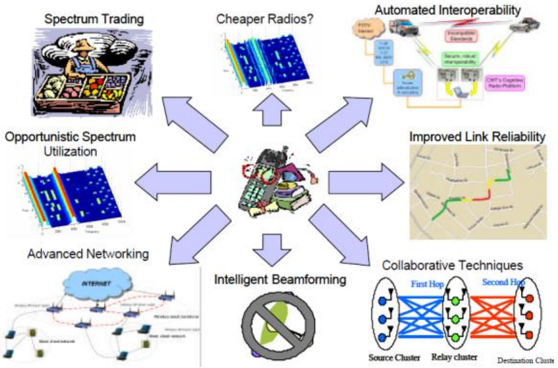

Fig 1. Cognition Cycle

II. DESCRIPTION

A. Cognition Cycle:

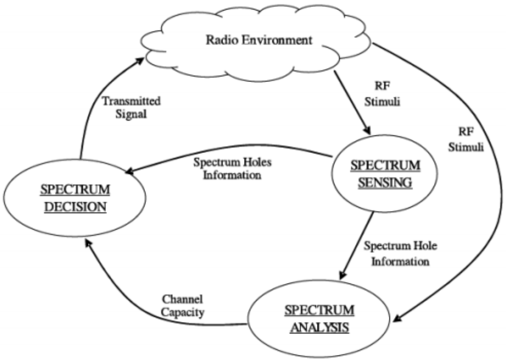

Fig 1.a. Cognition Cycle

The cognitive capability of a CR enables real-time interaction with its environment to determine appropriate communication parameters and adapt to the dynamic radio environment. The tasks required for adaptive operation in open spectrum are referred to as the cognition cycle. Three main steps of the cognition cycle are spectrum sensing, spectrum analysis, and spectrum decision.

1) Spectrum Sensing: A CR monitors the available spectrum bands, captures their information, and then detects the spectrum holes.

2) Spectrum Analysis: The characteristics of the spectrum holes that are detected through spectrum sensing are estimated.

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3) Spectrum Decision: A CR determines the data rate, transmission mode, and bandwidth of the transmission. The appropriate spectrum band is then chosen according to the RF characteristics and user requirements. Once the operating spectrum band is determined following the cognition cycle, the communication can be performed over this spectrum band. However, since the radio environment changes dynamically over time and space, thus the CR should keep track of the changes of the surrounding radio environment.

B. Physical Architecture:

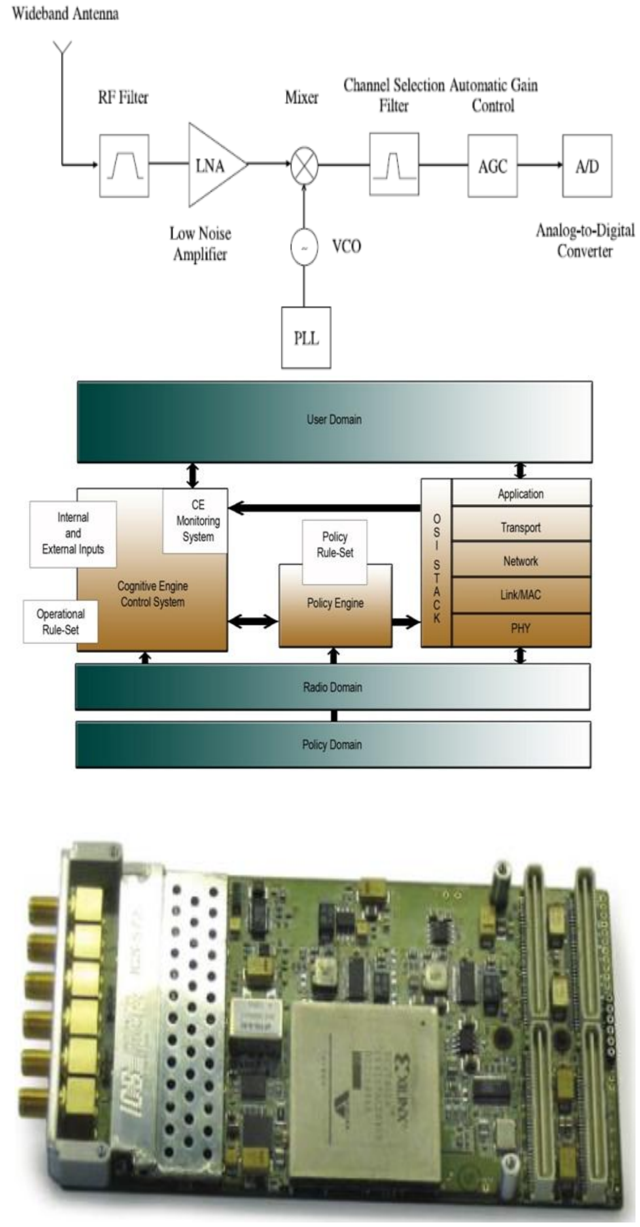

Fig 2. Architecture

The novel characteristic of CR transceiver is the wideband sensing capability of the RF front-end. This function is mainly related to RF hardware technologies such as wideband antenna, power amplifier, and adaptive filter. RF hardware for the CR should be capable of tuning to any part of a large range of frequency spectrum. Also such spectrum sensing enables real-time measurements of spectrum information from radio environment. The RF Filter selects the desired band by band-pass filtering the Rx (received) RF signal. Then the LNA (Low Noise Amplifier) amplifies the Rx signal while minimizes the noise component. The Mixer combines the Rx signal with local RF frequency (generated by VCO) to create an intermediate frequency (IF). The Channel Selection Filter is used to select the desired channel and reject the adjacent channels. The Automatic Gain Control (AGC) is used to maintain the gain or output power level constant over wide range of input signals. The key challenge of the physical architecture of the CR is the accurate detection of weak signals of licensed users over a wide spectrum range.

III. FUNCTIONS

A. Spectrum Sensing:

Although CR was initially thought of as a Software Defined Radio (SDR) extension, most of the research work is currently focusing on Spectrum Sensing Cognitive Radio (SSCR). The essential problem of SSCR is in designing high quality spectrum sensing devices and algorithms for exchanging spectrum sensing data between nodes. The term spectrum sensing implies detecting the unused frequency spectrum and sharing it with other users without harmful interference. It is an important requirement of the CR networks to sense spectrum holes (or white bands); the most efficient way to detect spectrum holes is to detect the primary user.

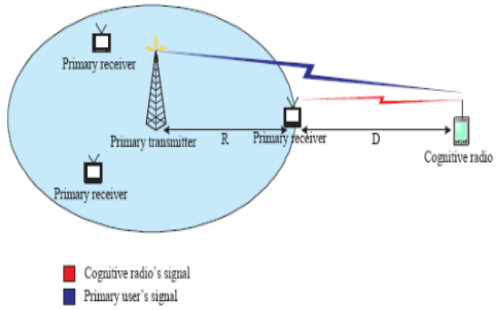

Fig 3. Spectrum Sensing

To solve this hidden-node problem as well as other CR-related issue, some spectrum sensing techniques were proposed:

1) Cooperative Sensing: In a mobile communication channel, multi-path fading effects vary significantly depending on the receiver's location; CRs with more than a few wavelengths apart are expected to experience independent fading. The uncertainty due to fading can be mitigated by allowing different users to share their sensing results and cooperatively decide on the licensed spectrum occupancy. Having multiple users cooperating over a wide area provides a possible solution to the hidden-node problem since this problem would arise only if all secondary users are shadowed away from the primary system. If the secondary users span a distance that is larger than the correlation distance of the shadow fading, it is unlikely that all of them are under a deep shadow simultaneously. Moreover, cooperation between CRs cannot always be guaranteed since a user can cooperate with others only when they are within its vicinity monitoring the same frequency band as itself.

Therefore, it was proposed that opportunistic spectrum access for a network of cooperating secondary users should be regulated based on their capabilities as a group rather than as individual users. In other words, a group of CRs should be permitted to cooperatively access a licensed band; individual accesses should be restricted.

2) Cluster Sensing:

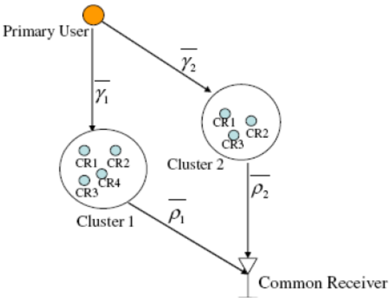

Fig 4. Cluster Sensing

This is a modified version of cooperative sensing in which two assumptions were made: First, the instantaneous channel state information of the reporting channel is available at the cognitive users. Second, the channel between any two users in the same cluster is perfect since they are close to each other. During the initiation stage, all CR users are separated into different clusters by some distributed clustering algorithm with the most favorable user selected, according to the largest instantaneous reporting channel gain, as the cluster head. Every CR in its respective cluster collects local observation and sends that information to its cluster head. The cluster head then makes a cluster decision from some fusion function. Finally, cluster decisions are reported to the common receiver for a final decision according to another fusion function. By separating all the secondary CR users into a few clusters and selecting the most favorable user (cluster head) in each cluster to report to the common receiver, the proposed method can exploit the user selection diversity so that the sensing performance can be enhanced.

3) Distributed Sensing:

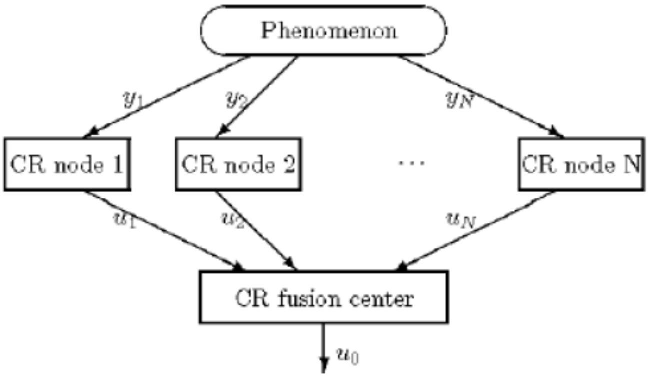

Fig 5. Distributed Sensing

An alternate approach to increase the spectral estimation reliability and decrease the probability of interference in a CR network is the distributed spectrum sensing. Under this distributive approach, the spectrum occupancy is determined by the joint work of CRs, as opposed to being determined individually by CRs in the cooperative scheme. A standard parallel fusion network is commonly used in decentralized detection problems. Each of the N CR nodes obtains some relevant channel information yi on the spectrum occupancy and then sends a summary of its own observation to a central fusion center, in the form of a message ui. The fusion center then generates a global spectrum usages decision u0 based on the N messages it has received from the CR nodes. CRs must be able to detect spectrum usage with no a priori knowledge of modulation scheme and RF characteristics of the primary systems. The traditional approach is to use a radiometer for the detection of an unknown deterministic signal in an AWGN (Additive White Gaussian Noise) channel. Radiometer simply measures the received energy in both time and frequency domains. However, this method is highly susceptible to unknown and changing noise levels and interference. In order to overcome these issues, a basic cyclic-feature detector known as a single-cycle detector is employed. This detection scheme has many advantages including signal classification capabilities and reduced sensitivity to unknown dynamic background noise.

B. Location Awareness:

A CR must know its geographical location. This knowledge may assist in sensing the surrounding environments because RF characteristics differ in rural areas from urban areas. When setting up a connection between two CRs, both partners must know about their particular location because this may help in making optimal use of the channel. The location of a CR may be determined by employing a Cognitive Positioning System (CPS).

The proposed CPS system consists of Bandwidth Determination, H-EDSM (Hybrid Enhanced Dynamic Spectrum Management), and A-TOA (Adaptive Time-of-Arrival) components as shown in the above figure. Cognitive Engine specifies the desired accuracy, which is then translated into required effective bandwidth by the Bandwidth Determination block. The H-EDSM provides the spectrum information for the corresponding required effective bandwidth to the CR while A-TOA estimates the location information from the received signal with different time resolutions. Simulation results showed that CPS provides adaptive positioning accuracy.

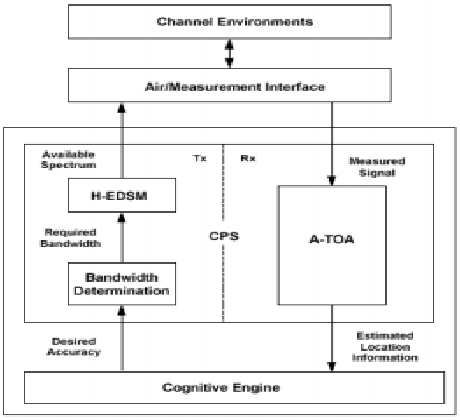

Fig 6. Location Awareness

C. Spectrum Shaping:

Another requirement for opportunistic spectrum usage is to dynamically adapt the transmission parameters to comply with the changing spectral conditions. A CR can accomplish this by modifying the shape of the transmitting pulse to fill the detected spectrum hole (or white bands) as efficiently as possible. This mechanism is known as spectrum shaping in CR.

D. Power Control:

One main characteristic for CR is the ability to adapt to the behavior of primary users. If primary user vacates its frequency band, a CR that is currently sensing the spectrum will know, and if necessary, occupy this band for signal transmission. Upon occupying the frequency band, the CR still has to monitor the spectrum in case that the primary user wants to reclaim its band. There are two options for the CR when the primary user reclaims its frequency band. First, the CR will free the band the hops to another available spectrum band. Second, the CR will still stay in the current band but altering its transmission power to avoid harmful interference to the primary user. With the two available options, it can be figured out that with immediate frequency jumping, the CR communications will be unexpectedly interrupt. The CR has to wait to be assigned a new frequency band to continue its transmission session. In other words, such interrupt will further lead to setup overhead and possibly induce transmission delay. Obviously, this will degrade the CR system performance. On the other hand, without immediate frequency hopping, the CR will have to stay in the current frequency band and adjust its transmission power without creating unwanted interference to the primary user. Many researches on this opportunistic transmit power control (TPC) scheme were done.

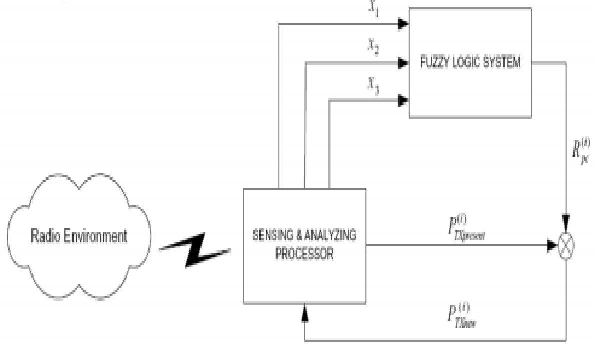

Fig 7. Power Control

E. Spectrum Management:

The under-utilized spectrum bands spread over wide spectrum range including both unlicensed and licensed bands. These unused spectrum bands detected through spectrum sensing show different characteristics according to not only the time varying radio environment but also the spectrum band information such as the operating frequency and the bandwidth. Since CR networks should select the best spectrum band to meet the QoS (Quality of Services) requirements over all available spectrum bands, new spectrum management functions are required to support the dynamic nature of spectrum characteristics. These functions are spectrum sensing, spectrum analysis, and spectrum decision as described in the cognition cycle. While spectrum sensing is primarily a PHY layer issue discussed earlier, spectrum analysis and spectrum decision are closely related to the upper layers.

IV. CONCLUSION

The concept shown in this paper is ability to access the under-utilized licensed spectrum band cognitively, CR is considered to be the future wireless communications mechanism. However, development of CR is currently still at an early stage and many challenges are awaiting researchers to look into like spectrum sensing for link and network layers, medium access control, cross-layer radio resource optimization, network layer issues, trusted access and security, hardware and software architectures. Some of the major cognitive radio provides the following applications:

1. Implementation in the 5G Communications.
2. Improving spectrum utilization and efficiency
3. Improving link reliability
4. Less expensive radios
5. Enhanced SDR techniques
6. Automated radio resource management
7. Advanced network topologies
8. Development of Cognitive Dynamic Systems.

These provides the major development in telecommunication systems.

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