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FPGA Implementation of IEEE 802.22 WRAN Super frame structure with cognitive radio capabilities

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ABSTRACT

Cognitive radio is viewed as a novel approach for improving the utilization of a precious natural resource: the radio electromagnetic spectrum. The cognitive radio, built on a software-defined radio, 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 input stimuli, with two primary objectives in mind: highly reliable communication whenever and wherever needed and efficient utilization of the radio spectrum.

Cognitive radio technology gets much attention of wireless network research environments as a new way to utilize the precious spectrum efficiently. IEEE 802.22 wireless regional area network, is the first international standard based on cognitive radio technology which intends to provide broadband access by utilizing unused TV channels, also known as TV white spaces. This standard provides PHY and MAC layers functionalities in an infrastructure-based wireless access network.

The objective of this paper is to represent the simulation of IEEE 802.22 WRAN super frame structure with cognitive radio capabilities and to test the simulation on FPGA board and logic analyzer.

INTRODUCTION

The development of the IEEE 802.22 WRAN standard (802.22 or 802.22 WRAN herein) is aimed at using cognitive radio techniques to allow sharing of geographically unused spectrum allocated to the television broadcast service, on a non-interfering basis, to bring broadband access to hard-to-reach low-population-density areas typical of rural environments, and is therefore timely and has the potential for wide applicability worldwide. IEEE 802.22 WRANs are designed to operate in the TV broadcast bands while ensuring that no harmful interference is caused to the incumbent operation (i.e., digital TV and analog TV broadcasting) and low-power licensed devices such as wireless microphones.

DYNAMIC SPECTRUM ACCESS

A cognitive radio observes its environment and modifies its transmission characteristics accordingly. The cognitive radio concept was initially introduced in the software defined radio research community but has since become its own field of study. These cognitive radio networks use a cognition cycle that includes radio scene analysis, channel state estimation and predictive modeling, and transmit power control and spectrum management commands . In 2005 the IEEE began holding the annual Conference on Dynamic Spectrum Access Networks (DySPAN).

A specific area of the cognitive radio field is the area of dynamic spectrum access in which a cognitive radio network dynamically identifies

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and uses portions of the spectrum that are not being used by other systems. These unused portions of the spectrum are often referred to as *white space* in the literature. The white space may consist of unused frequencies or unused fragments of time in a given location. In IEEE 802.22, since the white space is unused television channels over a given area, it is primarily frequency white space; however, there is a time component, since if the spectrum availability changes, the 802.22 network must adapt quickly so as not to cause harmful interference to the licensed transmissions. This is particularly so for protecting licensed wireless microphone operations.

There are several methods that can be used by a cognitive radio network to be aware of its spectral environment. The two methods used with IEEE 802.22 for spectral awareness are geo-location/database and spectrum sensing. In the first method, knowledge of the location of the cognitive radio devices combined with a database of licensed transmitters can be used to determine which channels are locally available for reuse by the cognitive radio network. Spectrum sensing consists of observing the spectrum and identifying which channels are occupied by licensed transmission.

The 802.22 network quickly modifies its operating frequency so as to only operate on channels unused by licensed transmissions. Thus, the 802.22 network must both quickly identify which channels are allowed for use and move to a new unused channel, if the current operating channel becomes occupied by a licensed transmission.

System Aspects

Figure 1 illustrates the place 802.22 WRANs are intended to occupy in the family and evolution of the various wireless data communication standards developed by the IEEE 802 LAN/MAN Standard Committee (LMSC).

The application for the IEEE 802.22 WRAN standard will be providing wireless broadband access to a rural area of typically 17–30 km or more in radius (up to a maximum of 100 km) from a base station (BS) and serving up to 255 fixed units of customer premises equipment (CPE) with outdoor directional antennas located at nominally 10 m above ground level, similar to a typical VHF/UHF TV receiving installation. The minimum peak throughput delivered to CPE at the edge of coverage will be equivalent to a T1 rate (1.5 Mb/s) in the downstream (DS) direction (BS to CPE) and 384 kb/s in the upstream (US) direction (CPE to BS), allowing for videoconferencing service.

Due to the extended coverage afforded by the use of these lower frequencies, the physical layer (PHY) parameters must be optimized to absorb longer multipath excess delays than accommodated by other 802 wireless standards. An excess delay of up to 37 μs can be absorbed by the orthogonal frequency-division multiplexing (OFDM) modulation used.

Beyond the 30 km for which the PHY layer has been designed, the medium access control (MAC) layer will absorb additional propagation delays for coverage distances of up to 100 km through intelligent scheduling to cover cases where advantageous topography allows coverage to such distances.

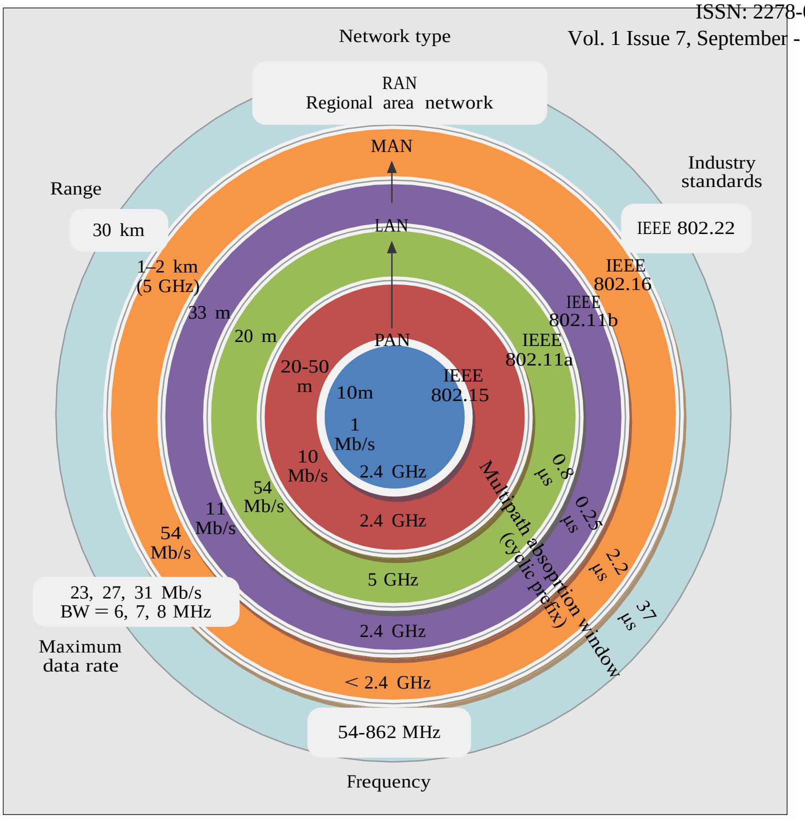

Figure 1. *The IEEE 802.22 standard relative to other IEEE 802 wireless data transmission standards.*

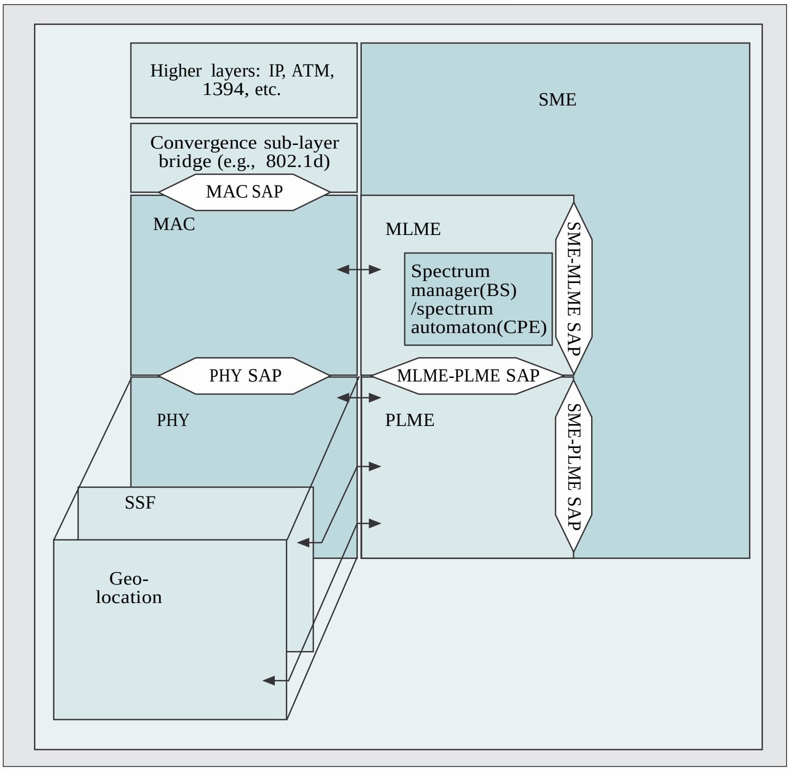

Figure 2. *The IEEE 802.22 reference architecture.*

As shown in Fig. 2, the reference architecture

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	IEEE 802.22
Air interface	OFDMA
Fast Fourier transform	Single mode (2048)
OFDMA channel profile (MHz)	6, 7, or 8 (according to regulatory domain)
Burst allocation	Linear
Subcarrier permutation	Distributed with enhanced interleaver
Multiple-antenna techniques	Not supported
Superframe/frame structure	Support a superframe structure based on groups of 16 frames. Frame size: 10 ms
Coexistence with incumbents	Spectrum sensing management,geolocation management, incumbent database query, and channel management.
Self-coexistence	Dynamic spectrum sharing
Internetwork communications	Over-the-air coexistence beacon or over-the-IP-network.

Table 1. *IEEE 802.22 features*.

for IEEE 802.22 systems addresses the PHY and MAC layers, and the interfaces to a station management entity (SME) through PHY and MAC layer management entities (MLMEs), as well as to higher layers such as IP, asynchronous transfer mode (ATM), and IEEE 1394 through an IEEE 802.1d compliant convergence sublayer.

At the PHY layer there are three primary functions: the main data communications, the spectrum sensing function (SSF), and the geolocation function, with the latter two providing necessary functionality to support the cognitive abilities of the system.

The PHY interfaces with the MAC through the PHY service access point (SAP), as well as to the MLME and the SME through the PHY layer management entity (PLME) and its SAPs.

PHYSICAL LAYER

IEEE 802.22 compliant WRANs will provide broadband access similar to asymmetrical DSL (ADSL) and cable modems, but will support more economical deployment over sparsely populated areas. The frequency range used in the VHF/UHF TV broadcast bands extends from 54 to 862 MHz depending on the various regulatory domains around the world.

PHY FEATURES

Table 1 tabulates the typical IEEE 802.22 features. IEEE 802.22 will define a single air interface based on 2048- carrier orthogonal frequency-division multiple access (OFDMA) to provide a reliable end-to- end link suitable for NLOS operation. A general description of OFDMA is easily found in the literature.

Since it is not always possible to have paired TV channels available, IEEE 802.22 is initially defining a single time-domain duplex (TDD) mode, with plans to define a frequency-division duplex (FDD) mode as a future amendment to the standard.

The granularity of frequency spectrum for WRAN is a TV channel as shown in Table 1. To support the various TV channel bandwidths in use in the world (6, 7, and 8 MHz channels), the sampling frequency, carrier spacing, symbol duration, signal bandwidth, and data rates will be scaled by the channel bandwidth for worldwide operation. IEEE 802.22 systems will use a common oversampling factor and the same frame/symbol structure, coding schemes, interleaving, and so on.

Four different lengths of cyclic prefix are defined as 1/4, 1/8, 1/16, and 1/32 of symbol duration to allow for different channel delay spreads while utilizing the spectrum efficiently. Due to the physical size of antenna structures at these lower frequencies, IEEE 802.22 will not support multiple-antenna techniques such as multiple-input multiple-output (MIMO) or beamforming.

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Transmitting a cluster of adjacent subcarriers is not supported in the IEEE 802.22 standard because it would increase the potential for harmful interference to narrowband wireless microphones.

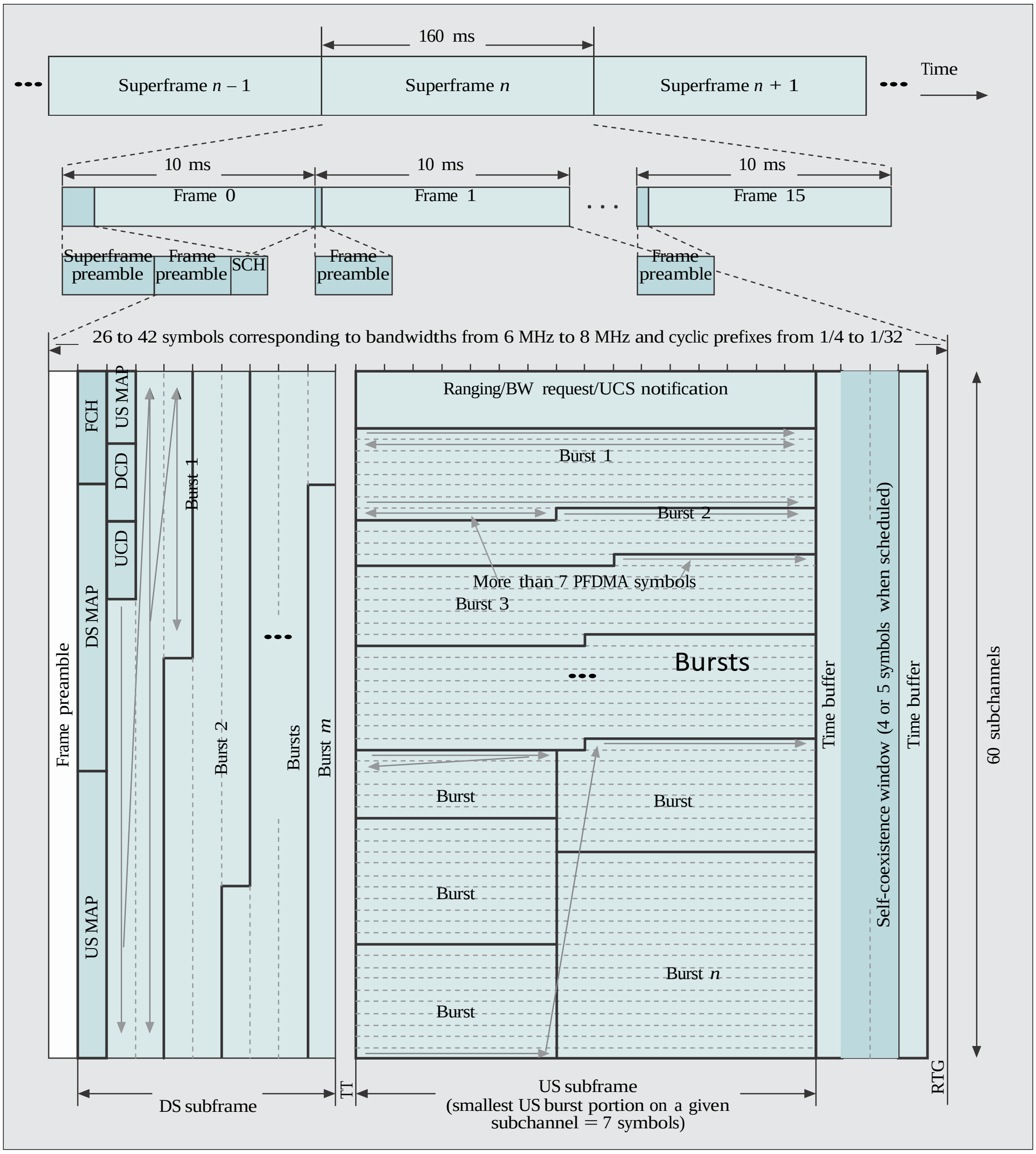

Figure 3. *Superframe and frame structure.*

Since WRAN systems are for fixed operation, transmission channels are expected to change very slowly, so there is little time diversity gain to be achieved through burst allocation across different symbols. Therefore, the downstream bursts in IEEE 802.22 will be allocated progressively across subchannels in the frequency domain, as depicted in Fig. 3, to minimize overhead by simplifying the downstream map. This will also contribute to reducing decoding latency. The upstream bursts will be allocated progressively across symbols to minimize the number of subchannels used by CPE, hence reducing the instantaneous effective isotropic radiated power (EIRP) to mitigate interference to incumbent systems. The upstream bursts can also be mapped on a 7-symbol column basis, as shown in Fig. 3.

The physical subcarriers in each subchannel in IEEE 802.22 are distributed across the channel to increase frequency diversity. Transmitting a cluster of adjacent subcarriers is not supported in the IEEE 802.22 standard because it would increase the potential for harmful interference to narrowband wireless microphones.

MAC LAYER

The IEEE 802.22 MAC provides mechanisms for flexible and efficient data transmission, and supports cognitive capabilities for both reliable protection of incumbent services in the TV band and self-coexistence among 802.22 systems. The IEEE 802.22 MAC is applicable to any region in the world and does not require country specific parameter sets.

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DATA TRANSMISSION

An IEEE 802.22 system is a point-to-multipoint network in which a central BS controls the medium access of a number of associated CPE units for broadband wireless access applications. In the downstream direction data are scheduled over consecutive MAC slots, while in the upstream direction the channel capacity is shared by the CPE units based on a demand-assigned multiple access (DAMA) scheduling scheme. The concept of a connection plays a key role in the 802.22 MAC. The mapping of all services to connections, as performed in the convergence sub layer, facilitates bandwidth allocation, QoS and traffic parameter association, and data delivery between the corresponding convergence sublayers. While each 802.22 station has a 48-bit universal MAC address that serves as the station identification, the 12-bit connection identifications (CIDs) are primarily used for data transmissions within an 802.22 system.

SUPERFRAME AND FRAME STRUCTURE

The 802.22 MAC employs a superframe structure in order to efficiently manage data communication and facilitate a number of cognitive functions for licensed incumbent protection, WRAN synchronization, and self-coexistence. As depicted in Fig. 3, a superframe transmitted by a BS on its operating channel begins with a special preamble, and contains a superframe control header (SCH) and 16 MAC frames.

Each MAC frame, with a 10 ms frame size, comprises a downstream subframe and an upstream subframe with an adaptive boundary in between. While the DS subframe only contains a single PHY protocol data unit (PDU), the US subframe may have a number of PHY PDUs scheduled from different CPE units, as well as contention intervals for initialization, bandwidth request, UCS notification, and self-coexistence. Because the DS traffic for CPE located far from the BS can be scheduled early in the DS subframe, such a data layout allows the MAC to absorb the round-trip delay for large distances. In order to absorb the propagation delay for a distance of up to 100 km, a time buffer of one symbol is included before and after the self-coexistence window. Similarly, in order to absorb the round-trip delay in the initial ranging process, a time buffer of two symbols is included before and after the ranging burst.

NETWORK ENTRY AND INITIALIZATION

Unlike other existing wireless access technologies, the network entry and initialization procedures in the 802.22 MAC not only define processes such as synchronization, ranging, capacity negotiation, authorization, registration, and connection setup, but also explicitly specify the operations of geolocation, channel database access, initial spectrum sensing, internetwork synchronization, and discovery.

BSs and CPE will be required to use satellite-based geolocation technology, which will also facilitate synchronization among neighboring networks by providing a global time source. The list of available TV channels is obtained by referring to an up-to-date TV channel usage database and augmented by spectrum sensing performed both by BSs and CPE.

SELF-COEXISTENCE

In a typical deployment scenario, multiple 802.22 systems may operate in the same vicinity. Mutual interference among these collocated WRAN systems due to co-channel operation could degrade the system performance significantly. To address this issue, the 802.22 MAC specifies a self-coexistence mechanism based on the CBP and consisting of spectrum sharing schemes that address different coexistence needs in a coherent manner.

The CBP is a communication protocol based on beacon transmissions among the coexisting WRAN cells. A CBP packet, delivered in the operating channel through the beacon transmission in a dedicated self-coexistence window (SCW) at the end of some frames, comprises a preamble, an SCH, and a CBP MAC PDU. Its purpose is to convey all necessary information across TV channels to facilitate network discovery, coordination, and spectrum sharing. Note that the beacon transmissions which deliver CBP packets are integral to IEEE 802.22 OFDMA transmissions and therefore different from the IEEE 802.22.1 beacon transmissions that need to be transmitted continuously by the 802.22.1 devices to signal the presence of licensed wireless microphone operations.

During a SCW that is synchronized across the TV channels of interest, a WRAN station (BS or CPE) can either transmit CBP packets on its operating channel or receive CBP packets on any channel For efficient intercell communications, each WRAN system is required to maintain a minimum repeating pattern of SCWs in transmit (or active) mode, although the SCWs can also be scheduled on an on-demand basis.

Each WRAN system can reserve its own SCWs on the operating channel for exclusive CBP transmission or share the active SCWs with other co-channel neighbors through contention- based access. By knowing the SCW patterns of its neighbors, a WRAN system can schedule receiving operation at the appropriate moment to capture the CBP packets transmitted from the neighboring systems of interest.

The IEEE 802.22 MAC provides mechanisms for flexible and efficient data transmission and supports cognitive capabilities for both reliable protection of incumbent services in the TV band and self-coexistence among 802.22 systems.

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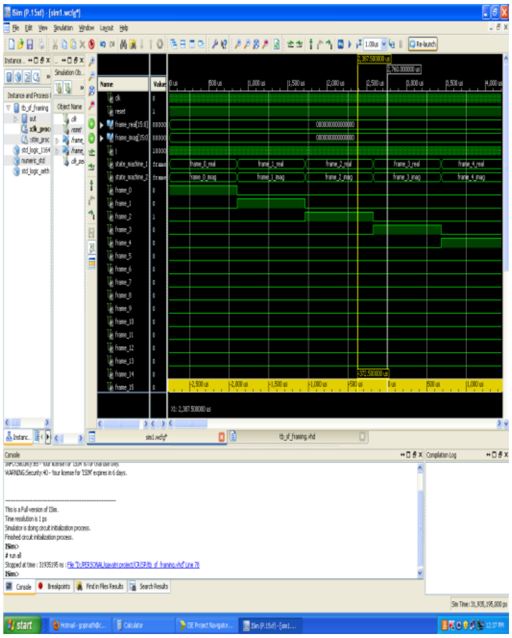
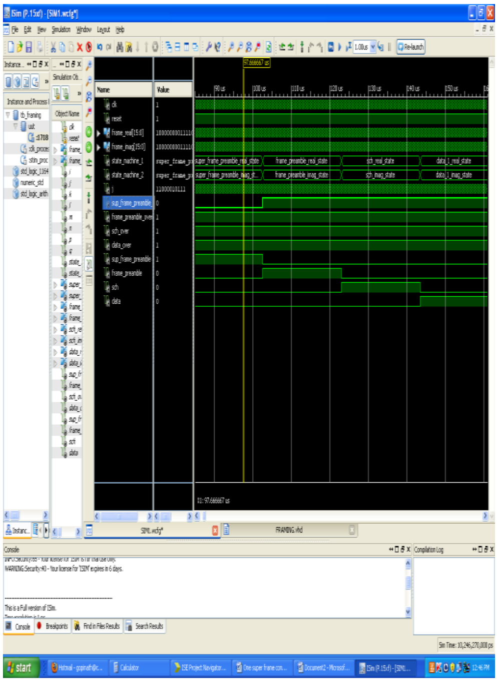
Simulation of a super frame



One super frame consists of 16 frames.

Simulation of a frame



Each frame consists of a super frame preamble, frame preamble, SCH and burst data.

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The super frame structure has been simulated and implemented on VIRTEX 6 board and the data on the frame has been tested using the logic analyzer.

The IEEE 802.22 draft standard requires all devices in the network to be installed in a fixed location and the BS is required to know its location and the location of all of its associated CPEs. The location of the BS must be known to within a 15 m radius while the location of a CPE must be known to within a 100 m radius.

Cognitive Functions

In order to operate in TV broadcast bands without affecting digital TV, analog TV, and licensed wireless microphones operated by TV broadcasters and other eligible licensees, 802.22 systems will have to be cognizant of all incumbent operations in their vicinity.

The necessary tools are being included in the standard to fulfill these cognitive functions. First, the location of each BS and CPE unit will be accurately established. This is described in detail in the geo location section below. The second tool is access to a channel availability database that will provide reliable information on channel availability for WRAN use at any given location. The third tool is the sensing capability included in the standard to sense the presence and identify the type of the incumbent signals in channels of interest.

These capabilities will, by allowing the BS to control channel usage and CPE maximum EIRP, constitute the set of cognitive functions needed to allow operation of 802.22 systems in the TV broadcast bands on a non-interference basis with the incumbents.

The spectrum manager is the cognitive function at the BS that will use the inputs from the spectrum sensing function (SSF), geo location and the incumbent database to decide on the TV channel to be used by the WRAN cell as well as the EIRP limits imposed to the specific WRAN devices.

CONCLUSION

The IEEE 802.22 standard allow broad band access to be provided in sparsely populated areas that cannot be economically served by wire-line means, or other wireless solutions at higher frequencies, by using cognitive radio techniques to allow operation on a non-interfering basis in the VHF/UHF TV broadcast bands. This paper presents the simulations and FPGA implementation of the super frame structure of the MAC layer with all cognitive radio capabilities.

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