An overview of the IEEE 802.22 Standard

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Abstract – The IEEE 802.22 standard is the first standard based on Cognitive Radios (CR) for Wireless Regional Area Networks (WRAN). This standard was proposed in November/2004, by the IEEE 802.22 Working Group (WG) and published in a 2005 IEEE paper and was accepted and used by FCC (Federal Communication Commission). It's an air interface which is defined for allowing unlicensed users to work in TV bands when the incumbents (primary users) are not present in the network. To achieve enough flexibility and adaptability the CR techniques are used in this standard. This standard is considered in the design of the PHY (PHYsical) and the MAC (Media Access Control) layers of the network. In this research, we present an overview of this standard, its considerations, applications, advantages and disadvantages and methods to overcome its problems.

Keywords: ***Cognitive Radio, incumbent, IEEE 802.22, WRAN, PHY, MAC*****.**

I. INTRODUCTION

Today with proliferation of wireless services, the optimum usage of spectrum in order to respond to all services without any harmful interference to other services is a very important problem. Such that we can say the most important resource in our modern era is the radio frequency spectrum. A proposed way is the use of higher frequency bands which are not used yet, but this has some problems will be discussed in this paper. So in order to utilize the spectrum resources appropriately, the FCC makes some new rules to allow unlicensed users to use the allocated spectrum for incumbents, in time and places that incumbents are not present in the network. This results in defining some network standards like PANs / LANs / MANs. To this goal the IEEE 802.22 WG took the idea in using the allocated spectrum for TV bands in order to define a new standard for Wireless Regional Area Networks (WRAN) in MAY/2004.

The previous standards are able to be used in urban/suburban areas and their geographical coverage is not enough large to service the remote/rural areas, while the researches show that in the US and in many other countries more than the half of the population of the country are located in remote/rural areas. The IEEE 802.22 standard is a WRAN standard which can be used for these areas. So the FCC accepted this standard as its defined standards for servicing these areas. This standard can also be used for urban/suburban areas and can be defined for the range of frequencies which are allocated to the TV bands in most of the regimes. This standard has many other advantages which will be described in this paper. To achieve the expected flexibility and adaptability, CR techniques should be used for spectrum sensing, measurements, management to service the secondary users as well as possible without any harmful interference with the incumbents. To imply the CR techniques we should use Software Defined Radios (SDR).

The IEEE 802.22 standard is a useful standard which provides appropriate features to service WRAN networks without any harmful interference with the incumbents in TV bands. It can be defined in the TV frequency range in most of the regimes. So it is a suitable standard to service the rural/remote areas. One of the most important feature of this standard which is not considered well in the previous standards is self-coexistence in addition to the coexistence with the incumbents. i.e., several overlapping 802.22 networks can coexist without any harmful interference to each other. In this research we provide a detailed overview of this standard and explain an enhanced version of this standard to solve some problems such as self-coexistence and hidden incumbent problem.

The rest of this paper is organized as follows. In section II we present a report about the measurements of the frequency usage in TV bands in different places and times and the idea of implying the IEEE 802.22 in the vacant frequencies in these bands. In section III we

consider the TV bands and explain the reason of selecting these bands for defining the IEEE 802.22 standard and the thresholds which would be considered to avoid interference with the incumbents. In section IV some advantages and disadvantages of this standard will be explained. In section V we summarized some considerations about the market of this standard. In section VI the technology of this standard and the enhanced version will be described. In the last section we conclude all the paper.

II. THE FREQUENCY USAGE IN TV BANDS AND THE IEEE 802.22 ISSUES

The spectrum for broadband wireless access is becoming increasingly overcrowded by the developments of new wireless technologies and by the proliferation of wireless devices.
Based on the reports of FCC & other reports, in contrast to high requirements to frequency spectrum, the spectrum utilization is not optimum.
For example the measurements for the frequency bands below 3GHz from January/2004 to August/2005 showed that only about 5.2% of the spectrum is actually in use in the US. [1]
The most of this utilization takes place in unlicensed bands while licensed bands often experience low (e.g., TV bands) or medium (e.g., some cellular bands) utilization.
Fig.1. shows the probability (y-axis) of vacancy of the N adjacent (x-axis) TV channel in time and place in the US [3].
Fig.2. similarly shows the probability (y-axis) of vacancy of the total N (x-axis) TV channels [3].
As we can see in these figures, transmission opportunities (i.e., time during which a channel is vacant) usually experience a random behavior It can be also seen in Fig.3.
So if we can allow secondary users to use some licensed bands when the incumbents are not present, the utilization of the spectrum becomes very appropriate and useful.
Therefore in May/2004 FCC began to introduce a standard to allow users to use the TV bands without any interferences in incumbents.
To achieving the goals of this standard, the use of Cognitive Radio techniques is necessary in order to having enough adaptability, reliability and flexibility.
This standard called the IEEE 802.22 standard introduced in November/2004 and is defined in PHY (PHYsical) & MAC (Medium Access Control) layers of a networ

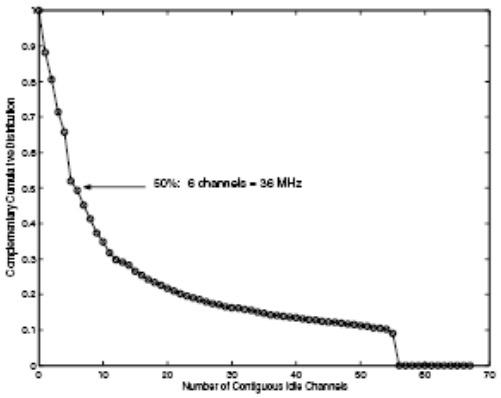

Fig.1. Statistics of Contiguous Idle TV Channel

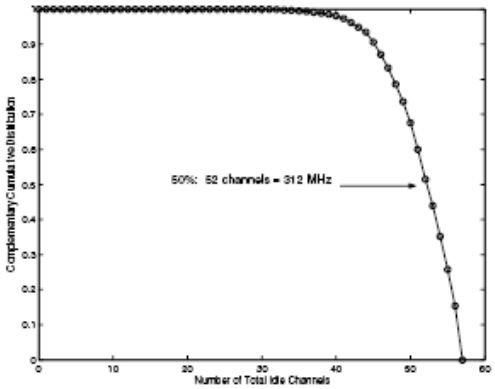

Fig.2. Statistics of Total TV Channels

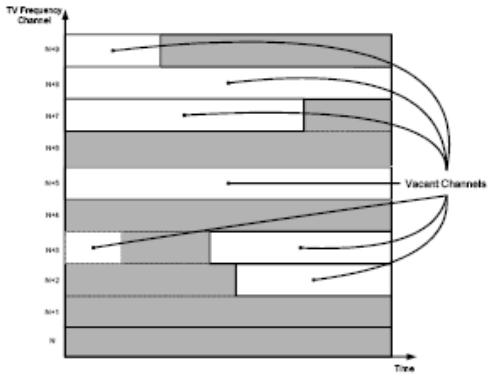

Fig.3. Example of TV band occupancy over time and frequency

III. THE OPERATION IN TV BANDS

In this section we first explain the features of TV bands that are suitable for defining our standard in part A. In the next subsection we determine the thresholds of the incumbents

whenever sensed, the channel should be vacant for the incumbents.

A . Why TV bands?!

In TV bands , in addition to the TV services, other services such as wireless microphones are also allowed by FCC to operate on vacant TV channels on a non-interfering , and so are Private Land and Commercial Mobile Radio Services (PLMRS/CMRS). These are incumbents in TV bands [5]. But FCC by 802.22 standard allows secondary users to use these bands, too.
Maybe someone asks why did the IEEE 802.22 WG choose the TV bands for defining this standard. Here we bring three reasons:
The first reason is the broadband access of this standard in remote and rural areas. Because this lower spectrum of frequencies features very favorable propagation characteristics which would allow far out users to be serviced and hence provide a suitable business case to service these areas. In addition, it has been realized that many TV channels are largely unoccupied in many parts of the US [3], given that most households and businesses rely on cable and satellite TV services. Last, another added advantage is that 802.22 devices in the TV bands will be unlicensed, which further lowers cost and is conducive to providing a more affordable service

B. Sensing thresholds for detecting incumbent

In this subsection we determine the thresholds of the incumbents whenever sensed, the channel should be vacant for the incumbents.

- Digital TV (DTV): -116 dBm over a 6 MHz channel.
- Analog TV: -94 dBm measured at peak of sync of the NTSC (National Television System Committee) picture carrier (different threshold values may be needed to protect the various analog TV systems).
- Wireless microphones: -107 dBm measured in a 200 KHz bandwidth.

IV. SOME ADVANTAGES & DISADVANTAGES OF THE IEEE 802.22 STANDARD

In this part we present some of the advantages and disadvantages of this standard.

A . The advantages

Here we note some advantages of this standard as compared to the others.
Some of previous standards may use the higher frequency bands which are more available. For example 802.11 uses the 5GHz , or 802.15.3.c uses the 57-64 GHz. But the use of high[4]. frequencies has some disadvantages:

- The cost of electronics for a given transmit power is higher.
- The attenuation of the signal even in free space is increased.
- The Doppler effect on mobile transmissions is exacerbated.

But the IEEE 802.22 users are secondary users in the TV bands which are in lower frequencies. For example in the US, TV stations operate from channels 2 to 69 in the VHF and UHF portion of radio spectrum. All these channels are 6GHz and cover 54-72 MHz, 76-88 MHz,174-216 MHz, and 470-806 MHz i.e. IEEE 802.22 standard is used for unlicensed users by sharing the VHF/UHF TV broadcast bands between 54 and 806 MHz for transmissions over 17 – 32 Km. To this goal this standard uses the Dynamic Spectrum Access (DSA) techniques.
The terminology, Wireless *Regional* Area Network (WRAN) for 802.22 implies that the coverage area is much larger than that of other IEEE 802 standards e.g. personal, local and metropolitan area networks: PAN, LAN , & MAN respectively. The coverage area of these standards are shown in Fig.4.

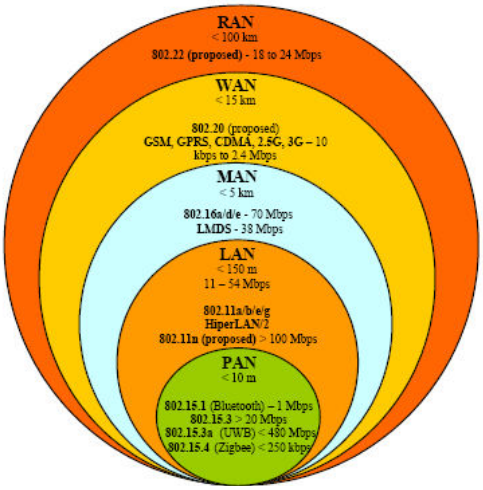

Fig.4. 802.22 wireless RAN classification as compared to other popular wireless standards

The IEEE 802.22 standard can provide various type of services like data, voice, audio & video with appropriate Quality-Of-Service (QOS) support.
IEEE 802.22 users are unlicensed users in TV bands and this decreases the cost of this

standard in comparison to some other standards like 802.16 which does not include incumbent protection techniques necessary to operate in licensed bands. Therefore the utilization of spectrum is much higher than the other standards, especially with techniques for self-co-existence and hidden incumbent detection which will be discussed later in section VI.
The 802.22 system specifies spectral efficiencies in the range of 0.5 bit/(sec/Hz) up to 5 bit/(sec/Hz).

B. Disadvantages

An important consideration in the design of the 802.22 MAC is the propagation delay it must support. Because the geographical coverage of this standard is in the range up to 100 Km as shown in Fig.4., the propagation delay is more considerable in this standard in comparison to the others. Also, such large delays may prohibit the use of access schemes that would otherwise be highly desirable in an environment.
Another disadvantage of this standard is the self-coexistence and hidden incumbent problem which will be described later.

V. THE MARKET FOR THE IEEE 802.22

We can say the most important reason for developing technologies like WRAN 802.22 standard is the availability of broadband access in rural and remote areas as well as that in urban and suburban areas. As mentioned in section III, the coverage area of this standard is much larger than that of the other 802 standards.
We should know that in the US and some other countries especially South America, Africa and Asia about half of the population are located in rural and remote areas. So the wireless broadband access in these areas is as important as urban and suburban areas. The IEEE 802.22 standard is then an international standard that may operate in any regular regime.
But we can't say the market of this standard is restricted to rural and remote areas. Because the IEEE 802.22 standard has defined in such way that can be used in other applications with appropriate costs and so this standard is a suitable business case to provide wireless broad band access for geographical ranges up to remote and rural areas.
We can say that two reasons for considering this standard as a suitable business case is providing wireless broadband access in large geographical coverage and incumbent considerations. Thus, members of the IEEE 802.22 WG include the more traditional corporations (e.g., Philips, Intel, Motorola, ST Micro, CRC, Samsung, Nokia) as well as delegates from the incumbent world (e.g., Fox, CBS, NAB, MSN, Shure Inc.).

VI. TECHNOLOGY OF THE IEEE 802.22 & ENHANCED IEEE 802.22 SYSTEMS

In this section we try to explain the Technology of this standard. As mentioned earlier, this standard is defined in PHY and MAC layers in a network. Then we introduce an enhanced version of this standard to resolve the disadvantages mentioned in section IV.
So we explain the definitions and the topology of this standard, the technology of PHY and MAC layers, and finally the technology of the enhanced IEEE 802.2 standard in three different subsections.

A. The definitions & the topology of IEEE 802.22 standard

An IEEE 802.22 cell is formed by a single Base Station (BS) and zero or more Consumer Premise Equipments (CPEs) which are under the control of the BS. See Fig.5.
The operations of BS/CPEs can be divided into two major categories in IEEE 802.22: sensing and transmitting/ receiving data.
The relations between these components is a master/slave relation. It means that the control of the whole cell is done by the BS (master) and no CPEs (slaves) can transmit before receiving authorization from the BS.
Both BS and the CPEs have to do spectrum sensing to determine whether an incumbent comes to the network. BS does this spectrum sensing periodically itself and by the reports receiving from the CPEs, chooses the appropriate vacant channel to communicate with CPEs.
So each CPE has two antennas: one directional for communicating with the BS and the other omni-directional for sensing and performing measurements.

B. The PHY & MAC systems

As mentioned earlier the IEEE 802.22 standard is defined in PHY and MAC layers of the network. Because the random behavior of the vacancy of the TV channels as described in section II, PHY and MAC both should be considered in our design. The design of the physical and media access control layers is less

innovative, and builds instead upon the structures already developed in IEEE 802.16.[4]

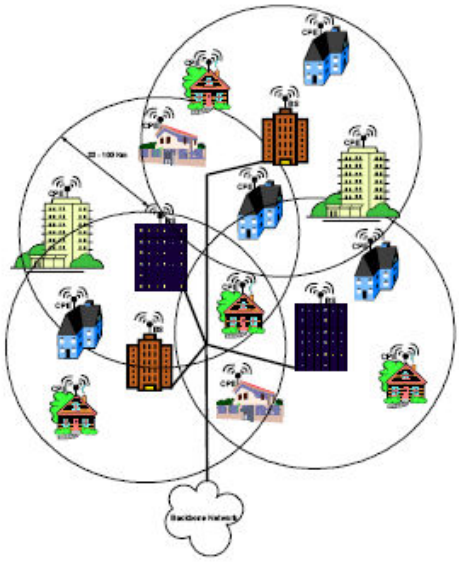

Fig.5. Exemplary 802.22 deployment configuration

B.1 The PHY considerations

The design of the 802.22 PHY should be high performance and low cost and complexity. It has also to provide high flexibility in terms of modulation and coding. Because each CPE based on its distance from the BS and its required SNR has to perform in different coding or modulation scheme.
Another important consideration in the 802.22 PHY layer, is the Transmission Power Control (TPC) and frequency agility. The power is an important issue in order to avoiding or minimizing the interference in incumbents and also self –interference.

B.2 The MAC consideration

In the MAC layer we should consider the master role of the BS in an IEEE 802.22 cell. It means that no CPE can initialize, continue or stop communication without the authorization of the BS.
The BS and its associated CPEs do the spectrum sensing process in the network periodically. Whenever a CPE is switched on , it should scan all the TV channels to determine the vacant frequencies. We can name this mechanism as *listen before talk.* This process is very time-consuming. A spectrum usage report of vacant and used channels is built based on the incumbents in the interference zone.

Then the CPE should find a proper channel to look for and aware the BS of its presence in the network. This step is not also very straightforward, because in this standard there isn't a pre-determined channel a CPE can look for a BS. When the BS becomes aware of the existence of the CPE, according to its periodic spectrum sensing as mentioned earlier and also based on the feedback about the vacant frequencies received from the CPEs, selects the appropriate channel to communicate with a CPE if there is any. Then the BS allows the CPE to start communication. This process i.e., periodic spectrum sensing by the BS and receiving the feedback from the CPEs continues during the communication in order to change the channel appropriately in any time, so that the spectrum utilization becomes maximized and interference to the incumbents and also existing CPEs becomes minimized.
Note that the message that the BS broadcasts to the CPEs in a cell is differentiated from other TV broadcasts by the preamble signal sent at the start of each frame , so that is determinable by the CPEs.
So, we can say that spectrum measurements and spectrum sensing is one of the most important issues should be considered in the MAC design. This process is done by both the CPEs and the BS in a master/slave manner.

C. The enhanced IEEE 802.22 standard

In this subsection we introduce an enhanced version of the IEEE 802.22 standard in which two major problems: self-coexistence and the hidden incumbent problem have been solved. These two problems and their solutions in the enhanced IEEE 802.22 are described here.

C.1 Self-coexistence

One of the most important features of the IEEE 802.22 standard is coexistence with the incumbents as shown in Fig.6. [4] and self-co-existence between the overlapping 802.22 networks as shown in Fig.5.
The coexistence with the incumbents is achieved by accurate and fast spectrum sensing, measurements, detection algorithms, and spectrum management, which are done by the CPEs and the BS. So the flexibility and adaptability becomes very high with these techniques. But the self-coexistence isn't sometimes well considered in the IEEE 802.22.
In areas with significant high incumbents (licensed services), proper allocation of open channels among IEEE 802.22 BSs will be important so that the interference among the users under these base stations can be

minimized. In areas with high analog/digital TV transmissions and wireless microphones (i.e., the incumbents) there is a chance that the secondary operators will try to act greedy and occupy the available bandwidth. This may result in interference among IEEE 802.22 networks themselves. This problem has solved in the enhanced version of this standard.

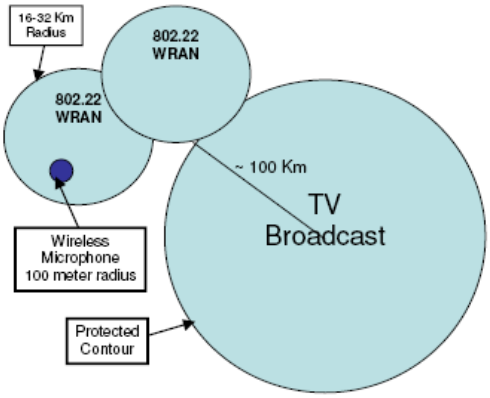

Fig.6. Coexistence Between 802.22 and Incumbent Licensees
(not to scale)

To overcome this problem we consider not a greedy but a coordinated behavior for the BSs of the networks, by the *graph coloring model.*
To this purpose we define an undirected graph $G = \{V, E,B\}$, where V is the set of vertices denoting all BSs in the region. E is the set of all undirected edges denoting the interference constraints among the BSs, i.e., if any two distinct vertices have an edge in between them, they are in the risk of interfering each other if using the same frequency band at the time of transmission.
Then we color the vertices with minimum number of colors such that no two adjacent vertices have the same color. Each color shows the bandwidth of its corresponding BS. Then we use the algorithm described below to change the colors, such that without the change of the number of the colors, one color has a maximum number. The algorithm is as follows: [2]

- G is m-colorable

check each node in G if it can be made color i without conflict to the other nodes' color
made by traditional graph coloring algorithm ;
for each color i {
store the information of occurrences of each color after this iteration ;
}
color graph G with traditional graph coloring algorithm
Take the iteration with maximum occurrence of a color among all iterations

An example is shown in Fig.7. In this example we see that the green color has the most number in the graph, so we consider the most of the available bandwidth for this color. Because the maximum probability of instant working of BSs without interfering to each other is for this color. So by this method [2] the channel utilization increases while the self-coexistence is considered as well as possible

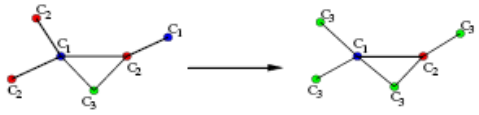

Fig.7. An illustrative example of the algorithm

C.2 The hidden incumbents

Another problem of the IEEE 802.22 standard that has solved in the enhanced version, is the hidden incumbent problem which will be discussed in this section.
We can say hidden incumbents are the primary users which can be sensed by the CPE but not by the BS. It means that hidden incumbents are in the sensing region of the CPE but not the BS's. In this case suppose that while the CPE and the BS are communicating, the hidden incumbent becomes present in the network. The CPE becomes aware of the existence of the incumbent, but the BS not. The CPE can't stop the communication, because for the master/mind behavior of the 802.22 network as mentioned earlier, no CPEs can do anything without the permission of the BS. Also the CPE can't aware the BS of the incumbent presence from the communicating channel, because the CPE senses the incumbent and don't want to interfere to its communication based on the definition of the standard. And also there is not any other channel for the CPE for this purpose, So the BS continues to communicate with the CPE without awaring of the incumbent.
In another manner, suppose that the CPE is switched on while an hidden incumbent is present in the channel, because of the presence of the hidden incumbent the CPE can't aware the BS of its existence, so the BS thinks the CPE is not present and switch off.
To address the hidden incumbent problem, unlike the 802.22 standard where BS

periodically broadcasted using only one single frequency channel, in the enhanced version we use dynamic multiple broadcasting in different frequencies (candidate frequencies). [2] periodically. The number of broadcast messages by BS is updated dynamically depending on the feedback received from the CPEs. BS decreases the number of candidate channels if all the candidate channels are decodable by the CPEs (implying less probability of hidden incumbent situation) and increases the number of broadcasting channels changing the candidate frequencies, if most of the previous candidate channels are not tuned up by CPEs. The reason behind broadcasting at multiple frequencies is that even if a CPE encounters an in-band licensed incumbent transmission (hidden to the BS), it still has ways to report this incumbent transmission to the BS using other candidate channels. The BS then changes the channel to some other unused band thus overcoming the hidden incumbent problem.

VII. CONCLUSION

In this research, we provide a detailed overview of the IEEE 802.22 standard, a based CR standard for WRANs, which is defined as unlicensed users in TV bands. We explained its applications, market, advantages and disadvantages. As this standard is defined in the PHY and MAC layers of the network, The design of these layers for this standard was considered. Then we explained the enhanced version of the IEEE 802.22 standard for solving two major problems: coexistence and the hidden incumbent problem.

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