Enhancements to cognitive radio based IEEE 802.22 air-interface

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***Abstract*—The IEEE 802.22 standard for wireless regional area network is the first standard for cognitive radio that tries to harness the idle or under-utilized spectrum allocated for TV bands. Two major challenges that are faced by IEEE 802.22 are (i) the issue of self co-existence and (ii) the hidden incumbent problem. In this paper, we discuss these two challenges and provide enhancements to the existing IEEE 802.22 air-interface. We use a graph theoretic technique and propose utility graph coloring for allocating spectrum to different IEEE 802.22 base stations so that they can co-exist. The allocation is done such that objectives such as throughput maximization, proportional fairness, and complete fairness are met. We also propose the use of dynamic multiple broadcast messages that resolves the contention among various consumer premise equipments and alleviates the hidden incumbent problem. Through simulation results, we show that the proposed techniques increase the system spectrum utilization and reduce connection set-up delay.**

I. INTRODUCTION

Recently, FCC defined provisions that allow unlicensed devices to operate in the licensed bands so long the unlicensed devices do not create interference for licensed services [6]. Initially, FCC opened sub–900 MHz TV band to unlicensed services because of high under-utilization of these bands. However, for unlicensed devices to gain access to these bands, it is mandated that these devices detect licensed users and avoid interference. The newly proposed IEEE 802.22 standard based on cognitive radios (CRs) is seen as the solution to this current problem [1]. A cognitive radio [7] can operate at any unused frequency in the licensed TV band, regardless of whether the frequency is assigned to licensed services or not. The most important regulatory aspect is that cognitive radios must not interfere with primary incumbants (e.g. TV transmitters and receivers) in licensed bands and must identify and avoid such bands in timely manner. CRs continuously perform spectrum sensing, dynamically identify unused ("white") spectrum, and operate in this spectrum band when it is not used by the incumbent radio systems – the primary users of this band. Upon detecting incumbents in any band, cognitive radio must automatically switch to another channel or mode.

The core components of IEEE 802.22 system are the base stations (BSs) and the Consumer Premise Equipments (CPEs) [3]. The operations of BS/CPEs can be divided into two major categories in IEEE 802.22: sensing and transmitting/receiving data. Sensing and avoiding incumbent transmission is the prioritized task of all IEEE 802.22 enabled devices. If any of the channels used by IEEE 802.22 network is occupied by the licensed incumbents, the primary task of IEEE 802.22 devices would be to vacate the channels within channel move time (2 seconds) and switch to some other unused channel. To get the knowledge of the presence of licensed incumbents and their used channels, BS and CPEs perform channel sensing periodically. Another problem is of self co-existence among IEEE 802.22 networks. 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 this paper, we focus on the enhancements to the existing IEEE 802.22 air-interface. Firstly, we address the issue of self-coexistence among multiple overlapping IEEE 802.22 networks. To address this issue, we propose a network controlled spectrum access mechanism where IEEE 802.22 BSs behave collaboratively to minimize the interference and maximize the utility obtained from the system. We show how the collaborative approach among IEEE 802.22 BSs outperforms any other spectrum allocation mechanism. Next, we focus on the problem of hidden incumbent (defined later) sensing and avoidance by IEEE 802.22 networks. We propose a mechanism such that CPEs can tune to the base stations quickly even in the presence of the hidden incumbents and switch channels if needed. We propose enhancements to the existing IEEE 802.22 MAC that improves the performance of the IEEE 802.22 networks. We also address the issue of self-coexistence. Through simulations, we demonstrate that the proposed techniques help IEEE 802.22 systems to detect incumbents quickly and switch channel with less delay. Spectrum utilization for data transmission is also increased with the proposed techniques.

The rest of the paper is organized as follows. In section II, we describe the existing system architecture of IEEE 802.22. In section III, we explain the problem of self-coexistence and propose a collaborative spectrum allocation algorithm. The hidden incumbent problem is presented in section IV. We propose a dynamic multiple broadcasting messaging mechanism here to address this issue. In section V, simulation models and results are presented. Conclusions are drawn in last section.

II. WRAN – THE IEEE 802.22 SYSTEM

The IEEE 802.22 system is a wireless regional area network (WRAN) technology that is based on the concept of cognitive radio (CR). In WRAN, a BS typically manages its own cell by controlling on-air activity within the cell, including access to the medium by CPEs and allocations to achieve quality of service (QoS).

A. MAC of IEEE 802.22

The existing MAC of IEEE 802.22 has most of the features similar to the MAC of IEEE 802.11 and IEEE 802.16. However, few distinguishing features make the IEEE 802.22 MAC worth mentioning.

1) Initial connection establishment: Initial connection establishment in IEEE 802.22 differs from that of the previous IEEE 802 standards such as 802.11 or 802.16. Though connection establishment in a true centralized network, should be simple, it is not so for IEEE 802.22. In IEEE 802.22 there is no pre-defined channel for the CPEs to establish connection with BS as IEEE 802.22 networks share the spectrum band with licensed devices. Thus there is no way for a CPE to know which channel to use to establish the initial connection with a BS as that might introduce interference to an incumbent using the same channel.

In IEEE 802.22, when a CPE is switched on, it follows the mechanism of *listen before talk* by scanning all the channels in the licensed TV band. A spectrum usage report of vacant and used channels is built based on the incumbents in the interference zone. BS on the other hand also follows the same mechanism of sensing spectrum bands and periodically broadcasts OFDMA frame in the unused frequency channel. The broadcast from IEEE 802.22 BS is differentiated from other TV broadcasts by the preamble sent at the start of each OFDMA frame. If a CPE can locate the preamble sent from the BS, it then tunes to that frequency and then transmits the CPE identifier in the uplink direction. BS then becomes aware of the existence of the CPE. Authentication and connection registration is then done gradually. The spectrum usage report is then sent back to the BS from the CPE in the form of feedback. The BS upon acceptance of the feedback takes decision on spectrum usage. When more than one CPE tries to establish an initial connection, then contention-based connection setup similar to that of the 802.11 takes place.

2) Incumbent detection: Much of the standard of IEEE 802.22 is dependent on incumbent sensing and detection. At any point of time, a number of incumbents (TV broadcasting, wireless microphones etc.) may be operating in a region as that of the IEEE 802.22 network. To co-exist with the incumbents, it is mandatory that incumbent sensing is done by both the BS and CPEs. CPEs in turn send their spectrum usage reports to the BS in the form of feedbacks. The general spectrum sensing process in divided into two categories: *fast sensing* and *fine sensing*. Fast sensing is done fairly quickly and it is carried out in-band at the same time while carrying out data transmissions. Though fast sensing is not very accurate, its advantage stems from the fact that data transmission time is not wasted as sensing is done at the rate of 1ms/channel. Fine sensing, on the other hand, is done out-of-band. BS periodically quiets the channel so that no network traffic is generated and incumbents are sensed. This sensing method provides more accuracy.

B. Drawbacks of existing IEEE 802.22 MAC

Self Co-existence: In a system like IEEE 802.22 where unlicensed devices are sharing the spectrum under the presence of licensed incumbents, the issue of self co-existence among multiple IEEE 802.22 operators in an overlapping region is very significant. In areas with high analog/digital TV transmissions and wireless microphone services, unused channels are already commodities of demand. Therefore, when multiple unlicensed operators are operating using a small available band of frequency, there is a chance that the operators will try to act greedy and occupy the available bandwidth. As all the operators will act in the same way, this may result in interference among IEEE 802.22 networks themselves. Thus an efficient channel allocation method needs to be invoked in order to use the channels with least interference. Although the exact methodology for interference mitigation in IEEE 802.22 networks is yet unknown, we propose an algorithm that increases the spectrum utilization.

The hidden incumbent problem: Let us assume that a BS and a CPE are communicating using a specific frequency channel and an incumbent returns to the same frequency channel near the CPE but outside the BS sensing region (refer Fig. 1 – hidden incumbent region). The CPE can detect the incumbent transmission in-band, but the BS can not. The BS will continue transmission and might interfere with the incumbent. The CPE can not report this licensed incumbent as its transmission will cause interference to the incumbent. On the other hand, due to the centralized nature of the IEEE 802.22 network (on-air activities of CPE is controlled by BS), the CPE can not choose any other channel to connect to the BS as it is not permitted to use any other channel unless BS provides the permission. The problem gets worse as the CPEs do not have any reporting period. Instead what they do have is a channel move time (2 seconds) which means that if they sense any incumbent present in the same frequency band they have to move within the stipulated channel move time.

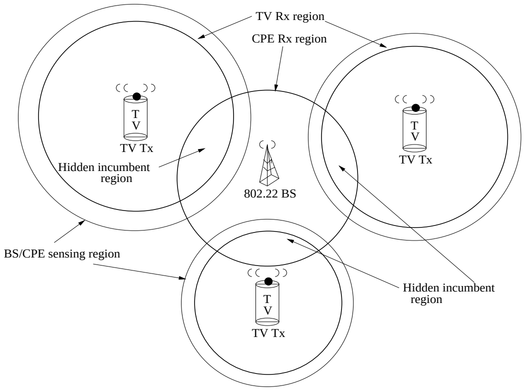

Fig. 1. IEEE 802.22 hidden incumbent scenario

In another similar situation, let us assume that a CPE just turns on and wants to connect to a BS. According to the current MAC proposal, the CPE will then scan all the channels to look for an IEEE 802.22 periodic broadcast. But if there is a nearby incumbent already transmitting with the same frequency as the BS periodic broadcast frequency, and is outside the BS sensing region but inside the CPE receiving region (hidden incumbent region as shown in Fig. 1), the CPE will not be able to decode the BS broadcasting frequency due to the interference from the incumbent. This results in a two-fold problem. The CPE might think that there is no IEEE 802.22 BS transmitting at that time and might switch off. Similarly, if the BS does not receive any feedback, it might think that there is no CPE alive and might stop broadcasting after a certain number of broadcasting periods, thus resulting in wasted control signaling and low spectrum utilization.

III. SPECTRUM ALLOCATION FOR SELF-COEXISTENCE AMONG IEEE 802.22 NETWORKS

When multiple IEEE 802.22 networks (BSs) operate in close proximity in an overlapping region, each BS tries to take as much spectrum as possible to serve its corresponding CPEs without coordinating with other BSs. This greedy approach leads to interference to the operating BS and the neighboring BSs thus degrading the performance of the system.

In this regard, we propose an efficient spectrum allocation algorithm to increase the spectrum utilization and reduce the interference. We frame a *graph coloring* model on spectrum allocation and study the spectrum access problem in a time and space variant manner under different objectives. We study a coordinated spectrum allocation approach instead of the greedy approach taken by the BSs.

A. Assumptions and Problem formulation

We assume that there are N IEEE 802.22 BSs competing for unused licensed spectrum. The amount of the unused spectrum is time variant. The key concept behind spectrum allocation efficiently is to find appropriate chunks of spectrum in such a manner so that BSs can coexist without interfering with neighboring networks and the objectives are met. We discuss the objectives in subsection III-B.

We consider that the utility achieved by the BSs depends directly on the throughput obtained, which in turn depends on the bandwidth of the frequency band the BS is operating on. Thus we define utility achieved by BS i as, $U_i = \sum_j (B_{ij_2} - B_{ij_1})$; where, $(B_{ij_2} - B_{ij_1})$ are the spectrum ranges that BS i is operating on and no other interfering neighbor is using that. B_{ij_1} and B_{ij_2} are the lower and upper bounds respectively of the jth spectrum band.

We follow a simple interference model wherein the transmissions between neighboring networks fail if they are very close to each other and use the same frequency band or overlapping frequency bands. This is governed by the simple path loss model. If the networks are within this proximity, then their utilization is zero. Moreover, we assume if the frequency bands are partially overlapping then the achieved utility will be due to the non-overlapping frequency bands only.

We consider the above scenarios in the multiple overlapping IEEE 802.22 networks using a graph theoretic model. 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. B is the total available spectrum band not used by the incumbents and is usable by the IEEE 802.22 networks. Moreover, without loss of generality, we assume that the topology information of this overlapping region is known to all the IEEE 802.22 BSs (as BSs are static) and the BSs will be honest in providing all their acquired graph model information.

B. Objective functions

We define three objective functions – all in terms of utility.

1) Maximize utility: The aim is to maximize the total utility achieved by all the BSs. We impose a constraint that BS i must get at least a certain amount of spectrum, which we denote as B_{min}. The objective function can be then expressed as

$$\begin{aligned} maximize \quad & \sum_{i=1}^{N} U_i \\ \text{such that} \quad & \sum_{j} (B_{ij_2} - B_{ij_1}) \geq B_{min} \end{aligned} \tag{1}$$

2) Proportional fair utility: The aim here is to divide the spectrum bands under some proportional fairness criteria. The criteria we follow is to prioritize the BSs which interferes with least number of other BSs and thus maximize the utility achieved. This mechanism of allocating spectrum will restrict BSs to be cooperative with other BSs and not follow any greedy approach that may harm the system performance.
3) Complete fairness utility: In this mechanism all the BSs are treated equally. The problem in this approach is known as *tragedy of the commons* [5].

C. Spectrum Allocation through Utility Graph Coloring

We model the appropriate division problem of the whole spectrum band among BSs using the graph coloring technique. Though optimal graph coloring problem is known to be NP-hard in searching and NP-complete in decision, it can be shown easily that at any point of time, in any overlapping region, at most $6-10$ BSs will coexist due to the area coverage capacity of the IEEE 802.22 networks and thus NP-complexity of the graph coloring problem is not a hindrance for the proposed mechanism.

The traditional graph coloring problem is to color each vertex using a color taken from existing color list [4]. The constraint is that if an edge exists between any two distinct vertices, then those two vertices can not have the same color.

With this constraint, the aim of the traditional algorithm is to minimize the number of colors to color all the vertices.

We propose an extension of the above graph coloring algorithm and call it *Utility Graph Coloring* (UGC). The aim is to find divisions of spectrum band under the objective functions defined, such that the system utility achieved can be maximized. In contrast to the traditional graph coloring algorithm where the colors do not carry any value and thus each color is equal in its weightage, in the UGC, we consider heterogeneity in the colors. A color assigned to a vertex (BS) becomes associated with a spectrum band assigned to the BS and the utility achieved by that BS is the bandwidth of that spectrum band if the band is not interfered.

The proposed UGC algorithm is divided into two phases.

Phase 1: In this phase, we follow the principle of traditional graph coloring algorithm to find the minimum number of colors to color all the vertices. We do not associate any value to any color and thus keep colors homogeneous. Let us assume, $C_1, C_2, \cdots, C_m$ are m minimum colors to color all the vertices. With the completion of first phase, we get to know that the graph is m-colorable and the available spectrum band needs to divided into m chunks depending on the objective functions negotiated by the BSs at the beginning.

Phase 2: We follow the mechanism of UGC here. We first find the occurances of the colors in the graph. Let us assume the occurances of the colors $C_1, C_2, \cdots, C_m$ are $N_1, N_2, \cdots, N_m$ respectively, where, $N_1 + N_2 + \cdots + N_m = N$, the total number of base stations. Without loss of generality, let us assume that C_1 has appeared maximum number of times, i.e., N_1 is the highest number among $N_1, N_2, \cdots, N_m$. Then for each of the colors, we run a progressive algorithm as presented in Fig. 2. For each iteration, we keep the information which color has occurred the maximum number of times and note its value. Let us assume that after all the color iterations, we find that, color C_m has the maximum occurrence of N_m^* in iteration i. We then choose this iteration i and redefine the occurances of colors $C_1, C_2, \cdots, C_m$ as, $N_1^*, N_2^*, \cdots, N_m^*$ respectively.

Note that, using traditional graph coloring, we are finding the total minimum number of colors needed. The physical significance is that, we can find out how many minimum divisions one should make from the unused spectrum band to avoid interference. But traditional graph coloring does not maximize the spectrum utilization. What UGC provides us is another hashing of the traditional graph coloring taking traditional graph coloring as the input trying to maximize the number of occurances of a particular color while keeping the total number of colors to the minimum level.

In Fig. 3, we present an illustrative example to explain how the UGC works. With the traditional graph coloring algorithm, we find that the graph under consideration is a 3-colorable graph and we have colored the vertices accordingly. The left-hand graph (traditional graph coloring) in Fig. 3 shows that C_1, C_2 and C_3 appearing 2, 3 and 1 times respectively. After we parse this graph with our utility graph coloring (UGC) algorithm, we find that (right-hand side) C_1 appears once, C_2 appears once, and C_3 appears 4 times. Thus the *re-use* of the spectrum corresponding to one color is increased through UGC. If the bandwidth assigned to this color is more than the rest of the colors, then it is obvious that the maximum chunk of the spectrum is used the most number of times. This implies that UGC maximizes the spectrum reuse.

```
color graph G with traditional graph coloring algorithm
G is m−colorable
for each color i {
    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 ;

    store the information of occurances of each color after this iteration ;
}
Take the iteration with maximum occurance of a color among all iterations
```

Fig. 2. Utility graph coloring algorithm for IEEE 802.22 networks

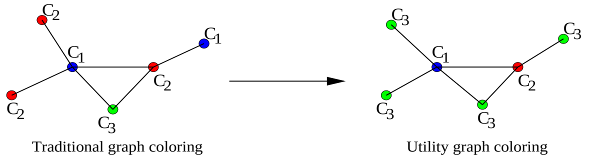

Fig. 3. An illustrative example of UGC for IEEE 802.22 networks

In general, depending on the objective functions, the actions taken for spectrum allocation are as follows:

For objective function 1: The whole spectrum band is divided into m chunks such that the vertices with the color label C_m (maximum number of vertices in the graph) are assigned the maximum possible spectrum as they would interfere least. The essence of UGC under objective 1 is to maximize the system utility only. The rest of the vertices (BSs) will be assigned the minimum threshold frequency (B_{min}) to operate on. This mechanism clearly reduces the interference to the least, as the BSs with interference risk (vertices with existing edge between them) now operate on different parts of the spectrum band. Moreover, as maximum number of BSs in the graph obtain the maximum possible spectrum band, the system utility is maximized. The only drawback in this scheme is that fairness is not maintained and the BSs with color labels $C_2, C_3, \cdots, C_m$ are all treated equally.

For objective function 2: We try to improve the fairness while maximizing the system utility. We divide spectrum bands in m different parts in the ratio of $N_1^* : N_2^* : \cdots : N_m^*$ and assign them to vertices with color bands $C_1, C_2, \cdots, C_m$ respectively. Thus we maintain a proportional fairness criteria through a simple trade-off. As the BSs are now ranked according to number of neighbors they are interfering with, this mechanism will help the BS not to act greedy. This will result in least interference and increased system utility.

For objective function 3: Our aim is to provide complete fairness among all the BSs. Thus in this mechanism, we divide the available spectrum band in m equal parts and assign each part to each of the non-interfering BSs.

Note that, in the study of all three objectives, we assumed the amount of unused spectrum at any instant is such that every BS can be provided the minimum threshold frequency (B_{min}). The study becomes even more interesting when amount of spectrum present for secondary usage (for IEEE 802.22 networks in this case) is such that all the BSs can not be provided their minimum threshold (B_{min}). A TDMA scheme or pricing approach might be suitable in this case.

IV. ENHANCED MAC FOR HIDDEN INCUMBENT PROBLEM

In this section, we propose an enhanced MAC of IEEE 802.22 to address the problem of hidden incumbent situation.

A. *Aggregation / Fragmentation of channel carriers*

Since IEEE 802.22 PHY is capable of bonding channel carriers or fragmenting them to operate over the channels more flexibly and adaptively, we make efficient use of this to utilize the channel bandwidths dynamically. For maximizing data transmission rates, we aggregate 2 to 3 channels, (either contiguous channels in the spectrum bands or separately placed in the band) to provide data rate up to a maximum of 71Mbps. Separate sets of OFDMA carriers are used on each channel to increase the data transmission rate at the time of channel bonding. In general, approximately 2K carriers are used for each channel of 6 MHz, thus making it 6K carriers to transmit data at a high rate while bonding 3 channels together.

We also fragment channel carriers so that IEEE 802.22 devices can operate over channel bandwidths of 1 to 6 MHz. This would allow IEEE 802.22 devices to share the spectrum with incumbent devices such as wireless microphones that only use 1 or 2 MHz of the entire channel assigned. Moreover, this ability of aggregating and/or fragmenting carriers would also allow to selectively tune out partial channels avoiding interference and cross talk and thus making more spectrum utilization. The ability to adapt to the number of carriers dynamically will make IEEE 802.22 more resilient to interference and spectrum utilization efficiency can also be increased.

B. *Dynamic broadcasting with spectrum usage report*

To address the hidden incumbent problem, unlike the existing concept where BS periodically broadcasted using only one single frequency channel, we propose to use dynamic multiple outband broadcasting in different frequencies (*candidate frequencies*) 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 service channel to some other unused band thus overcoming the problem of hidden incumbent.

Another functionality that we add to the IEEE 802.22 MAC is the addition of spectrum usage report inside the periodic broadcasting from BS to the CPEs. Currently, CPEs send the spectrum usage reports to the BS but not the other way. We mirror the spectrum usage report in all the multiple broadcast channels from the BS. This spectrum usage report contains the information of all control frequencies that the CPEs can tune to in the uplink to the BS. Thus, in contrast to the existing connection establishment procedure in IEEE 802.22 where CPEs tune to the single broadcasting frequency and then follow the contention resolving mechanism similar to the IEEE 802.11 for initial connection establishment, we propose that CPEs obtain complete information about all control frequencies that they can utilize in the uplink connection establishment and then follow the contention resolving mechanism.

V. SIMULATION MODEL AND RESULTS

We conducted UNIX based simulation experiments to evaluate the improvements achieved by the enhanced MAC. Evaluations for enhanced and existing schemes were done for a fair comparison. We also present how the utility graph coloring algorithm outperforms other existing spectrum allocation.

A. *Simulation model and parameters*

For the topology, we have assumed a 100 km radius region where multiple overlapping IEEE 802.22 networks and licensed incumbents reside and share the spectrum from the spectrum band. Moreover, we have assumed BS and CPEs use directional antenna for transmission/receiving purpose and omni-directional antenna for incumbent sensing. In table I, we present the simulation parameters for our experiments.

TABLE I
SIMULATION PARAMETERS FOR IEEE 802.22 SYSTEM

Simulation parameters	**Values**
Total licensed spectrum band	54 - 806 MHz
Number of overlapping BSs	8
BS/CPE receiving radius	30 - 50 km
BS/CPE sensing radius	30 - 50 km
TV transmission receiving radius	30 km
$B_{i_{min}}$	30 MHz
Control signal frequency	1 - 2 MHz
Data signal frequency	1 - 18 MHz
Broadcast control signaling interval	20 ms
Number of broadcast control signals	2 - 6

B. *Simulation results*

In Fig. 4, we compare the total system utility achieved by the IEEE 802.22 BSs under UGC spectrum allocation mechanism and greedy non-collaborative spectrum hogging. In the greedy non-collaborative approach, most of the spectrum bands are wasted due to interference among the greedy and selfish base stations, whereas under the collaborative utility graph coloring mechanism, system utility is improved. Moreover, with the increase in usage of the licensed spectrum band, proposed utility graph coloring method provides even better result than the non-collaborative approach. For a comprehensive performance evaluation of the proposed scheme, we present the results under all three objective functions and show that system utility is better with the proposed scheme.

In Fig. 5, we compare the performance of UGC with the traditional graph coloring method of spectrum allocation. It is clear that proposed UGC mechanism outperforms the traditional graph coloring for objective functions 1 and 2. For objective function 3, i.e., the complete fairness, any of the either methods would provide same result.

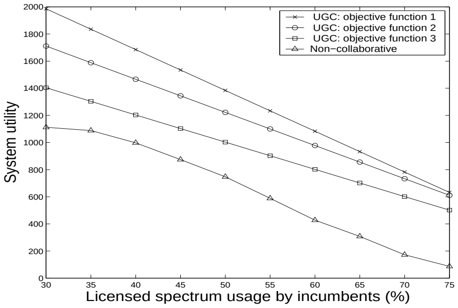

Fig. 4. Total utility achieved by all the BSs under the proposed collaborative approach and greedy non-collaborative approach

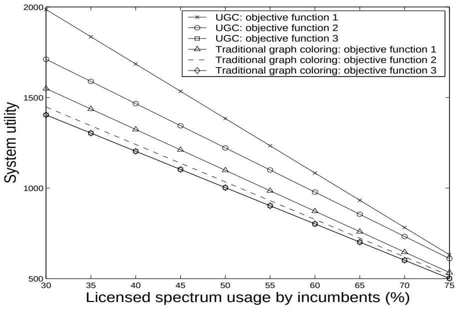

Fig. 5. Total utility achieved by all the BSs under the proposed collaborative approach and greedy, traditional graph coloring approach

Next, we present insights on how our enhanced air-interface would improve the performance for hidden incumbents scenario. In figures 6 and 7, we present a comprehensive result of connection establishment under contention with other CPEs and licensed incumbents together. The average startup delay (delay between switching on and start of data transmission) under the presence of contention is presented for number of CPEs and licensed spectrum usage by incumbents. We calculate the combined delays to tune to a BS broadcasting frequency signal and then successful uplink transmission (transmission of connection identifier and spectrum usage report) through contention resolvement mechanism. It is evident from the figures that enhanced MAC (Fig. 7) provides better result in terms of delay to initiate data transmission.

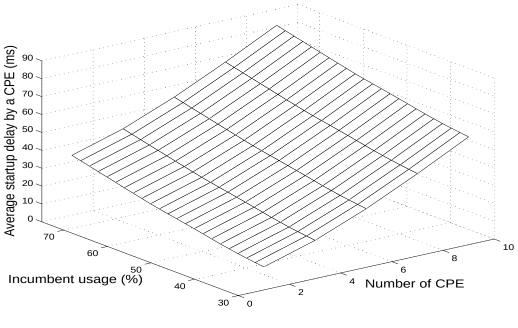

Fig. 6. Average startup delay for existing MAC

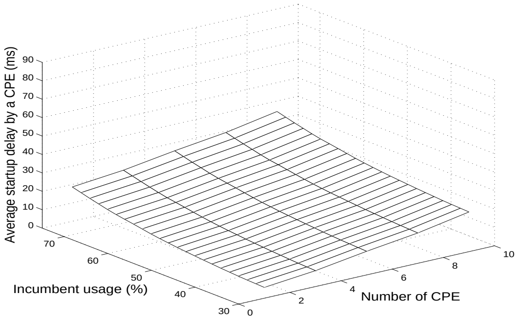

Fig. 7. Average startup delay for proposed MAC

Fig. 8 presents an important result in terms of spectrum utilization for the IEEE 802.22 system. With increase in the usage by licensed incumbents (x-axis), the spectrum utilization for data transmission (y-axis) from the residue spectrum band in the IEEE 802.22 networks is shown in this figure. As evident from the figure, the proposed mechanism increases the spectrum utilization than the existing MAC layer.

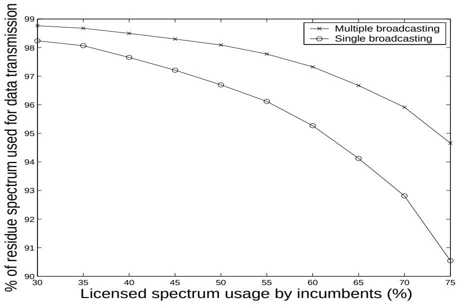

Fig. 8. Spectrum utilization efficiency

VI. CONCLUSIONS

In this research, we provided insights to the cognitive radio based IEEE 802.22 networks. In areas with under–utilization of licensed spectrum bands, IEEE 802.22 based networks are believed to provide the connectivity with efficient usage of these bands. Two major problems – self-coexistence and hidden incumbents, encountered in existing IEEE 802.22 networks are presented. We provided few enhancements to the existing air-interface to improve the performance. Simulation results have demonstrated that the proposed scheme would provide better system utility along with efficient spectrum bands utilization and less connection establishment delay.

REFERENCES

[1] http://www.ieee802.org/22/

[2] M. Buddhikot, P. Kolodzy, S. Miller, K. Ryan and J. Evans, “DIMSUMnet: New Directions in Wireless Networking Using Coordinated Dynamic Spectrum Access”, IEEE Intl. Symp. on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2005, pp. 78-85.

[3] C. Cordeiro, K. Challapali, D. Birru, Sai Shankar, “IEEE 802.22: the first worldwide wireless standard based on cognitive radios”, IEEE International Symposium on Dynamic Spectrum Access Networks, DySPAN, Nov. 2005, pp. 328 - 337.

[4] Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, and Clifford Stein, “Introduction to Algorithms”, 2nd Edition, The MIT Press and McGraw-Hill, 2001.

[5] D. Fudenberg and J. Tirole, “Game Theory”, The MIT Press, 1991.

[6] Federal Communications Commision (FCC), “Notice of Proposed Rule Making”, ET Docket no. 04-113, May, 2004.

[7] DARPA, “Defense advanced research projects agency (DARPA) neXt Generation (XG) communications program”, http://www.darpa.mil/ato/programs/XG/index.htm.

[8] http://www.sharedspectrum.com/inc/content/measurements/ nsf/NYC_report.pdf.