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Power Efficient Bandwidth Allocation for Cognitive LTE Networks

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Abstract*—*IEEE 802.22 standard is based on cognitive radio network (CRN).It allows opportunistic use of TV white space as spectrum holes by secondary user. The existing methods used for spectrum access in cognitivethird generation partnership project (3GPP) long term evaluation (LTE)network based on IEEE 802.22 standard are not power efficient. In this paper power efficient dynamic spectrum access (DSA) method in cognitive third generation partnership project (3GPP) long term evaluation (LTE) network based on IEEE 802.22 is proposed. This method enhances the transmission power efficiency along with spectral efficiency. The work is simulated by using NS2. The performance of the proposed method is evaluated in terms of transmission power, packet loss and end to end delay by compared with the performance of existing method called power control and spectrum access (PCSA) approach.

Index Terms*— *IEEE802.22, 3GPP LTE, Spectrum Access, Energy efficiency, QBC1, QBC2

I. INTRODUCTION

Wireless spectrum is basically allocated statically for different radio services in applications like military, government, commercial, private and public safety systems. Though such long-termstatic allocations have certain advantages in terms of oversight and management, it has beendemonstrated through experimental studies that spectrum utilization is time and space variant.

Existing static spectrum allocation methods suffer from spectrum underutilization problem [1]. Due to technology advancement digital television has replaced analog television broadcasting. The current digital television requires 50% less bandwidth as compared to old analog television broadcasting , this saves 50% bandwidth in very high frequency (VHF) and ultra high frequency (UHF) bands reserved for television broadcast.

Such studies over spectrum allocation resulted to spectrum usage and access policy reforms [3] and *dynamic spectrumaccess* (DSA) based on *cognitive radio* (CR) [4] is seen as a viable option that can help thecurrent reforms.

One of the efforts that are seen as a solution to the current spectrum scarcity problem isthe proposition of the *IEEE 802.22* standard. IEEE 802.22 is a cognitive radio-based wirelessregional area networks (WRANs) standard that would allow the unused, licensed sub–900 MHzTV bands to be used by unlicensed users on a non-interfering basis [5]. To protect the licensedservices (primary incumbents), IEEE 802.22 devices are required to perform periodic spectrumsensing and evacuate promptly upon the return of the licensed users.

Even though the primary user protection mechanisms (primary-secondary spectrum etiquettes)have been predominantly studied and designed in IEEE 802.22 standard [6], the critical issue ofensuring quality of service (QoS) among IEEE 802.22 networks themselves, in other words,maintaining *self-coexistence* (secondary-secondary spectrum etiquettes) have not been addressed.In a system where unlicensed devices share the spectrum under the presence of licensed users,the issue of self-coexistence among multiple CR operators in an overlapping region isvery significant. In areas with analog/digital TV transmissions and wireless microphone services,unused channels are already commodities of demand. The challenge of self-coexistence becomeseven tougher as the networks do not have information about which bands other secondary CRnetworks will choose. Different from other IEEE 802 standards where self-coexistence issuesare only considered after the specification essentially is finalized, it is required for IEEE 802.22to take the proactive approach and mandate to include self-coexistence protocols and algorithmsfor enhancing the medium access control (MAC) as a revision to the initial standard [8]-[10].

In this paper we are investigating the performance of recently presented power efficient and scalable dynamic spectrum allocation method for LTE networks. This method is basically focusing on power efficient resource allocation. The size of the node buffers is controlled by this method in the system using the queue stabilityconstraints [12] in order to prevent potential network congestion(which may result in longer delays and large losses).The practical evaluation of this protocol is compared against existing PCSA method using different network scenarios. In below sections, section II take review of different spectrum allocation methods in cognitive networks.In section III, IEEE 802.22 is discussed along with its different layers and components. Concepts of proposed spectrum sensing methods are discussed along with its algorithm. In section V, practical results and analysis have been introduced. Finally, section VI shows the conclusion and future work.

II. RELATED WORKS

Over the years, dynamic spectrum sensing and allocation is becoming interesting research area for research panels with considering different decision making aspects, problems, and challenges in LTE networks.

In [11]-[14], energy detection has been largely used to monitorprimary spectrum usage activity. Spectral correlation based signal detection for primary spectrumsensing in IEEE 802.22 WRAN systems is presented in [15].

In [16], signature-based spectrum sensingalgorithms are presented in order to investigate the presence of Advanced Television SystemsCommittee (ATSC) DTV signals.

In [17], sequential pilot sensing of AdvancedTelevision Systems Committee (ATSC) DTV signals is carried out to sense the primaryusage in IEEE 802.22 cognitive radio networks.

In [18], new channel sensing method isproposed called as dynamic frequency hopping (DFH). In DFH, neighboring WRAN cells formcooperating communities that coordinate their DFH operations where WRAN data transmissionis performed in parallel with spectrum sensing without interruptions. The aim here is to minimizeinterrupts due to quiet sensing.

In [19], a novel metric called Grade-of-Service (GoS) is defined and the trade-off between miss-detection and false alarm is studied for optimizing spectrumsensing performance.

Above all methods presented in [11]-[19] are targeting on sensing of primary spectrum usage, but research problem of self-coexistence among multiple CR networks are not considered.

A broad survey on resource allocation in cellular networks and WLAN thoughgraph coloring mechanisms can be found in [20], [21], [22], [23], [24] and in the referencestherein. However, most of these works do not consider the dynamic availability of spectrumbands due to the presence of primary users and thus cannot be directly applied to IEEE 802.22network spectrum sharing.

In [25], an author investigates the channel assignment problem ina multi-radio wireless mesh networks using graph-coloring such that a given set of flow rates areschedulable.

In [26], an author presented the dynamic channel allocation problem is formulated as graph coloringproblem where dynamic channel availability is observed by the secondary users.

In [27], spectrumallocation and scheduling problems are studied jointly in cognitive radio wireless networks withthe objectives of achieving fair spectrum sharing. However, all channel divisions are treatedequally here.

In [28], a distributed, real-time spectrum sharing protocol called On-DemandSpectrum Contention (ODSC) is proposed that employs interactive MAC messaging among thecoexisting 802.22 cells. However, control signaling is greatly increased through extensive MACmessaging. Game theoretic approaches are recently being investigated in [29], [30] for distributedcoexistence.

III. INTRODUCTION TO IEEE 802.22

The IEEE 802.22 standard defines a system for a Wireless Regional Area Network, WRAN that uses unused or white spaces within the television bands between 54 and 862 MHz, especially within rural areas where usage may be lower. To achieve its aims, the 802.22 standard utilizes cognitive radio technology to ensure that no undue interference is caused to television services using the television bands. In this way 802.22 is the first standard to fully incorporate the concept of cognitive radio. The IEEE 802.22 WRAN standard is aimed at supporting license-exempt devices on a non-interfering basis in spectrum that is allocated to the TV Broadcast Service. With operating data rates comparable to those offered by many DSL / ADSL services it can provide broadband connectivity using spectrum that is nominally allocated to other services without causing any undue interference. In this way IEEE 802.22 makes effective use of the available spectrum without the need for new allocations.

3.1. Background of IEEE 802.22

The IEEE 802.22 standard for a Wireless Regional Area Network or WRAN system has been borne out of a number of requirements, and also as a result of a development in many areas of technology. In recent years there has been a significant proliferation in the number of wireless applications that have been deployed, and along with the more traditional services this has placed a significant amount of pressure on sharing the available spectrum. Coupled to this there is always a delay in re-allocating any spectrum that may come available.

In addition to this the occupancy levels of much of the spectrum that has already been allocated is relatively low. For example in the USA, not all the TV channels are used as it is necessary to allow guard bands between active high power transmitters to prevent mutual interference. Also not all stations are active all of the time. Therefore by organizing other services around these constraints it is possible to gain greater spectrum utilization without causing interference to other users. Despite the fact that the impetus for 802.22 is coming from the USA, the aim for the standard is that it can be used within any regulatory régime. One particular technology that is key to the deployment of new services that may bring better spectrum utilization is that of cognitive radios technology. By using this radios can sense their environment and adapt accordingly. The use of cognitive radio technology is therefore key to the new IEEE 802.22 WRAN standard.

3.2. IEEE 802.22 Concepts

There are a number of elements that were set down for the basis of the 802.22 standard. These include items such as the system topology, system capacity and the projected coverage for the system. By setting these basic system parameters in place, the other areas fall into place.

- ***System topology:*** The system is intended to be a point to multipoint system, i.e. it has a base station with a number of users or Customer Premises Equipments, CPEs located within a cell. The base station obviously links back to the main network and transmits the data on the downlink to the various users and receiver's data from the CPEs in the uplink. It also controls the medium access and addition to these traditional roles for a base station; it also manages the "cognitive radio" aspects of the system. It uses the CPEs to perform a distributed measurement of the signal levels of possible television (or other) signals on the various channels at their individual locations. These measurements are collected and collated and the base station decides whether any actions are to be taken. In this way the IEEE 802.22 standard is one of the first cognitive radio networks that has been defined.

- ***Coverage area:*** The coverage area for the IEEE 802.22 standard is much greater than many other IEEE 802 standards - 802.11, for example is limited to less than 50 meters in practice. However for 802.22, the specified range for a CPE is 33 km and in some instances base station coverage may extend to 100 km. To achieve the 33 km range, the power level of the CPE is 4 Watts EIRP (effective radiated power relative to an isotropic source).
- ***System capacity:*** The system has been defined to enable users to achieve a level of performance similar to that of DSL services available. This equates to a downlink or download speed of around 1.5 Mbps at the cell periphery and an uplink or upstream speed of 384 kbps. These figures assume 12 simultaneous users. To attain this overall system capacity must be 18 Mpbs in the downlink direction.

3.3. IEEE 802.22 Specifications

The basic specification parameters of the IEEE 802.22 standard can be seen in the table below:

Table 3.1: Specifications of IEEE 802.22 standard [3]

PARAMETER	SPECIFICATION
Typical cell radius(km)	30-100 KM
Methodology	Spectrum sensing to identify free channels
Channel bandwidth (MHz)	6,7,8
Modulation	OFDM
Channel capacity	18 Mbps
User capacity	Downlink:1.5 Mbps Uplink :384 kbps

3.4. IEEE 802.22 PHY Layer

The PHY layer must be able to adapt to different conditions and also needs to be flexible for jumping from channel to channel without errors in transmission or losing clients (CPEs). This flexibility is also required for being able to dynamically adjust the bandwidth, modulation and coding schemes. It use OFDMas the modulation scheme for transmission in up and downlinks. With OFDMA it will be possible to achieve this fast adaptation needed for the BS's and CPEs. By using just one TV channel the approximate maximum bit rate is 19 Mbit/s at a 30 km distance. The speed and distance achieved is not enough to fulfill the requirements of the standard. The feature *Channel Bonding* deals with this problem. Channel Bonding consists in using more than one channel for Tx / Rx. This allows the system to have higher bandwidth which will be reflected in a better system performance.

3.5. IEEE 802.22 MAC layer

This layer is based on cognitive radio technology. It also needs to be able to adapt dynamically to changes in the environment by sensing the spectrum. The MAC layer consists of two structures: Frame and Superframe. A superframe formed by many frames. The superframe will have a superframe control header (SCH) and a preamble. These will be sent by the BS in every channel that it's possible to transmit and not cause interference. When a CPE is turned on, it will sense the spectrum, find out which channels are available and will receive all the needed information to attach to the BS. Two different types of spectrum measurement will be done by the CPE: *in-band* and *out-of-band*. The in-band measurement consists in sensing the actual channel that is being used by the BS and CPE. The out-of-band measurement will consist in sensing the rest of the channels. The MAC layer will perform two different types of sensing in either in-band or out-of-band measurements: *fast sensing* and *fine sensing*. Fast sensing will consist in sensing at speeds of fewer than 1ms per channel. This sensing is performed by the CPE and the BS and the BS's will gather all the information and will decide if there is something new to be done. The fine sensing takes more time and it is used based on the outcome of the previous fast sensing mechanism.

IV. METHODOLOGY INVESTIGATED

In this section we are presenting the architecture and algorithm of proposed power efficient dynamic spectrum allocation method. Below figure 4.1 showing the basic architecture of proposed algorithm as per given in [1].

From figure below, end users gets allocated with network resources and the evolved NodeBs (eNBs) by the spectrummanager (SM) using some optimalresource allocation strategy. Basically this method proposed to allocate the bandwidth and transmissionpower to the uplink and downlink of LTE system with goal of total transmission power isminimized subject to capacity constraints, queue stability constraints, and some integerrestrictions on the bandwidth. To find the buffer occupancy in the system, use modifiedShannon expression which depends on signal-to-noise ratio (SNR) and modulation and codingscheme (MCS).

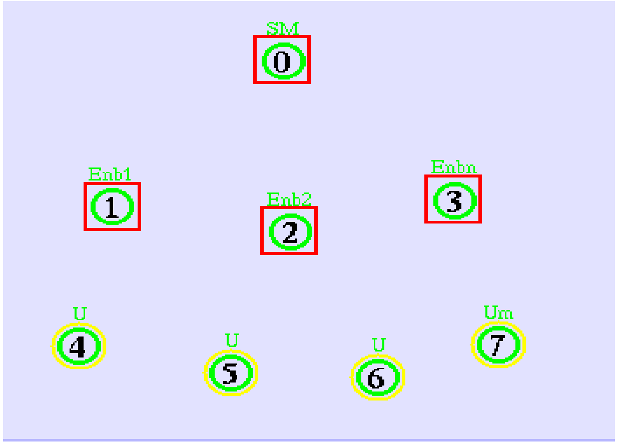

Figure 4.1: A typical CRN model based on LTE standard network.

Based on above architecture below is algorithm for LTE-based networkarchitecture. The objective of the algorithm is to assign thespectrum and transmission power to the uplink and downlinkchannel between the users and the eNBs to minimizethe total transmission power. Thecorresponding algorithm can be described as follows.

Attime t:

– each users/eNB collects the values QUj(t)/QeNBi(t), AUj(t)/AeNBi(t) and sends them to SM;

– SM finds the optimal (or near-optimal) resource allocationvectors $b_j^{UL}, P_j^{UL}, P_i^{DL}, b_i^{DL}$ and sends this informationto corresponding eNBs;

– the eNBs assign the resources to the uplink and downlinkchannels of the users.

The maximal threshold buffer size is assumed to beequal to the average arrival rate of the respective eNB/user,and is calculated using constantly updated values from

$$Q_{eNBi}^{max} = A_{eNBi}(t) = \sum_{t=0}^{t} A_{eNBi}(\tau) \ , \ \forall i \in I \ (1)$$

$$Q_{Uj}^{max} = A_{Uj}(t) = \sum_{t=0}^{t} A_{Uj}(\tau) \ , \ \forall j \in J \qquad (2)$$

BelowAlgorithm Name: Branch &Bound (B & B) Algorithm for QBC-1 and QBC-21 spectrum allocation methods:

Input Set

RPk = relaxed sub-problem at node **k**

(bk, pk)= solution of RPk

yk= value of the objective function at **(bk, pk)** which corresponds to the lower bound of node k

(bMIP, pMIP) = best obtained MIP solution of the primary **MIP** problem;

yMIP= best obtained value at **(bMIP, pMIP)** which corresponds to the upper bound of the primary MIP problem.

The node k has no branches in the following cases:

RPk=**h**as no feasible solutions

bk = is integer;

bk= non-integer and worse than the best obtained integer solution **(bMIP, pMIP)(yk>yMIP** for minimization problem).

Main Algorithm Steps:

Step 1:

Initialize yMIP to last (infinity)

set MIP' equal to MIP

Initialize L

Step 2:

If (all node is present == theta)

{

go to step 3

} else

{

go to step 4

}

Step 3:

yMIP* is optimal value

if (check yMIP* < infinity/infinity+)

{

Optimal_Solution =[bMIP* , pMIP*]

}

Step 4:
Select node k and set L = L / {'k'}
Step 5:
Solve RP to get bMIP and pMIP
Step 6:
If (RPk ==true)
{
go to step 7
} else
{
go to step 2
}
Step 7:
if (yk > yMIP)
{
go to step 8
} else
{
go to step 9
}
Step 8:
Confirm k is fathom node, go to step 2
Step 9:
if (isint (bk))
{
go to step 10
} else
{
go to step 12
}
Step 10:
set yMIP* = yk
set (bMIP,pMIP) = (bK,pK)
Step 11:
for each s node in L set :
if (yk > yMIP*)
{
set L = L of S set
}
Step 12:
Select branch node bk and pk
create two new nodes k1,k2
set yk1=yk and yk2=yk
RPk1=RPk+constraint bi , where biis <= integer bk of Numbers i
RPk2=RPk+constraint bi , where biis => integer (bk of Numbers i)+1
set L to union of L with k1 and k2 set
go to step 2
End

V. SIMULATION RESULTS AND ANALYSIS

5.1 Simulation Platform: For the simulation of this work we have to need the following setups requirement for the same

1) Cygwin: for the windows XP
2) Ns-allinone-2.31.

5.2 Network Scenarios: For CRNs, different network scenarios with varying mobile end users required to be prepared.PCSA (PowerControl and Spectrum Access) for the scheme considered as existing method; QBC (Queue Based Control) for the scheme investigated in this paper.

MACProtocol: IEEE802.22 Standards
Scenarios-1:50/100/150/200/250/300 Number of users
Routing Protocols: AODV
Spectrum Allocation Methods: PCSA/QBC1/QBC2

5.3 Performance Metrics:

- Transmission Power (dbm) vs. number of users
- Loss (%) vs. number of users
- Delay (ms) vs. number of users

Table 5.1 shows the simulation parameters used in this practical analysis for the proposed work.

Table 5.1 Network Configuration for Simulation

Number of Nodes(users)	50/100/150/200/250/300
Traffic Patterns	CBR (Constant Bit Rate)
Network Size (X x Y)	1000 x 1000
Max Speed	5 m/s
Simulation Time	100s
Transmission Packet Rate Time	10 m/s
Pause Time	1.0s
Routing Protocol	AODV
MAC Protocol	802.11
Spectrum Sensing	PCSA/QBC1/QBC2
Number of Flows	5
PDCCH symbols per subframe	3
UL loading facto	1
DL loading factor	1
Inactive bearer timeout	20s
Periodic timer	5 sub fames
Retransmission timer	2560 subframes
Reserved size	2 RBs
Starting RBP for Format 1 messages	0
Allocation periodicity	5 sub frames
Operation mode	FDD
Cyclic prefix type	Normal (7 Symbols per Slot)
EPC bearer definitions	348 kbit/s (Non-GBR)
Subcarrier spacing	15 kHz
Transmitter/receiver antenna gain	10 dBi (pedestrian), 2 dBi (indoor)
Receiver antenna gain	10 dBi (pedestrian), 2 dBi (indoor)
Receiver noise figure	5 dB
Number of preambles	64
Number of RA resources per frame	4

5.4 Simulation Results

Figure 5.1 shows transmission power performance for information network configuration. It gives comparative performance for PCSA, QBC1 and QBC2. It shows transmission power consumption as a function of number of users. The required transmission power increases as the number of users increase.QBC2 method achieves better energy efficiency as compared to QBC1 and existing PCSA method.

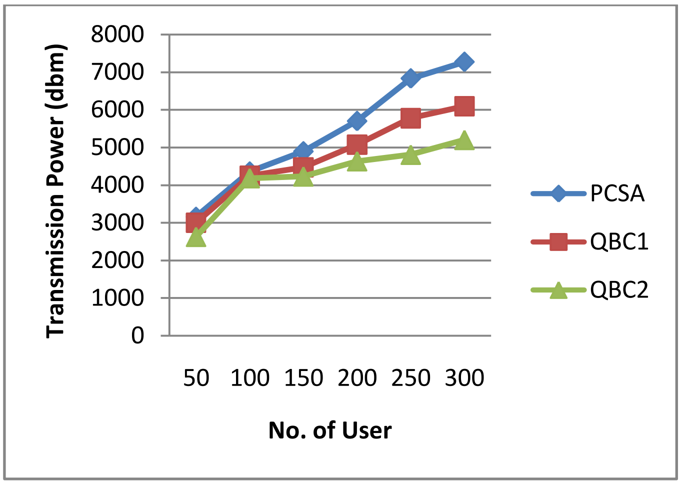

Figure 5.1: Transmission Power Performance

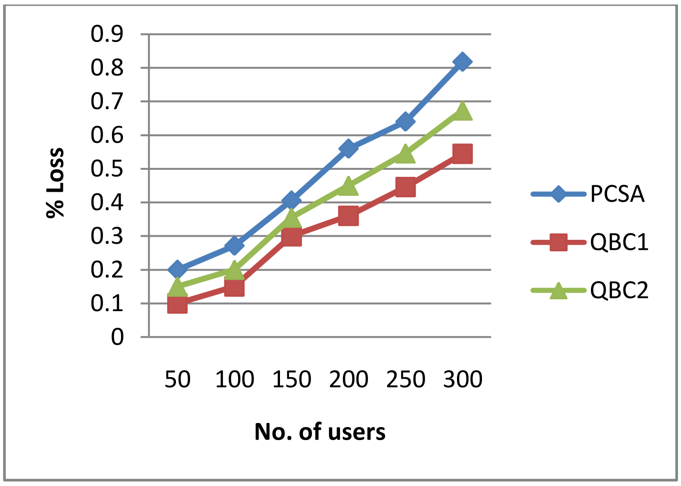

Figure 5.2: Loss Performance

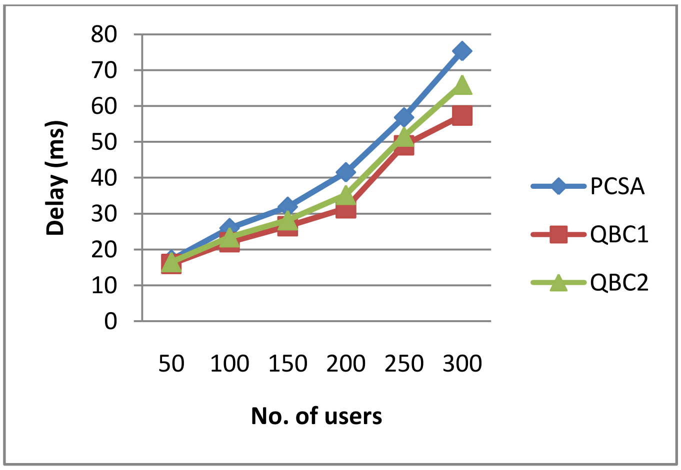

Figure 5.3: Delay Performance

Figure 5.2 depicts percentage packet loss as a function of no of users. Packet loss increases as the number of users increase.

From the figure 5.2 and 5.3, it is clear that QBC1 outperforms existing PCSA method and QBC2. The contradiction between QBC1 and QBC2 is that, QBC2 gives better energy efficiency while QBC1 giving better packet loss and delay performance.

VI. CONCLUSION AND FUTURE WORK

In this paper basic architecture of IEEE 802.22 standard for LTE network is presented. The Proposed work has investigated power efficient bandwidth allocation method for LTE cognitive radio networks based on 802.22 frameworks.

Presented work is simulated using NS2.Resultes shows that QBC1 gives better performance for packet loss and delay as compared with PCSA and QBC2 methods whereas QBC2 performance better for transmission power. Improving the transmission power utilizationefficiency for QBC1 is the future work.

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