Application of cognitive radio in smart grid communication

A Thesis for partial fulfillment of the requirements for completion of course of

M.Tech Dual Degree

In

Electrical Engineering (Electronic System and Communications)

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Certificate

This is to certify that the work in the thesis entitled **Application of cognitive radio in smart grid communication** by **Sidhartha Mohapatra** is a record of an original research work carried out by him during 2015 - 2016 under my supervision and guidance in fulfilment of the requirements for the award of the degree of M.Tech Dual Degree in electrical engineering (electronics System and Communication), National Institute of Technology, Rourkela.

Place: NIT Rourkela **Prof.Susmita Das**

Date: 25 May 2016 Professor

National Institute of Technology ,Rourkela

Declaration

I certify that

1. Project work has been done solely by me under the able supervision of my guide.
2. The work has not been submitted to any other institute for any other degree or diploma.
3. I have followed all the rules and regulations specified by my institute while writing the thesis.
4. In case of usage of materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

Sidhartha Mohapatra

25 may 2016

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Abstract

Wireless communication is fast becoming the most common mode of communication. Invention of bluetooth , Wi-Fi , Wi-Max ,etc have aided in popularizing wireless communication. Now wireless communication is being sought at for achieving communication in smart grid network. In a conventional power distribution system the power which was generated was being transmitted through the transmission link without taking into account the demand of the user. In a smart grid we address that issue. There is a flow of information from both sides. There are devices communicating with each other in sharing information. Advanced metering scheme, dynamic pricing scheme have become new paradigm in smart grid.

Research is going on for application of cognitive radios in smart grid communication. The spectrum used for communication is limited. Out of the channels available some have been licensed to certain users who are known as primary users. The other users are known as secondary users. The secondary users are large in number and the frequency channels available for them to communicate is limited in number. But the primary user use their allotted channels for very small amount of time. So, the secondary users can tap into those frequencies whenever it is idle. This can achieve efficiency in communication and help in reducing communication blockage of secondary users. Cognitive radios help in sensing the availability of the primary users in a channel and relay the data to secondary users so that they could use them. They also perform the task of switching the secondary users into another channel whenever a primary user uses that channel.

In my work I have tried to find out an effective dynamic traffic scheduling scheme for effective communication purposes. First I had taken a scheme in which priority levels were assigned to different groups of secondary users without considering QoS of the channels. Then we took QoS into consideration and calculated the system utilization,blocking probability in both cases for different secondary users. Finally I calculated the end to end delay using an optimal algorithm and compared it with the end to end delay calculated without the algorithm.

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Chapter-1

Introduction

A move for having a smarter system for producing electricity and distributing according to the needs and advice of the consumers are on the move. It would help in efficient and judicious use of energy and also help in incorporating renewable energy sources which would drive our cause for green environment.So, research for effective communication system in these smart grids(SGs) are taking the front seat. Smart grid network would help in forming a dynamic network for energy flow in multiple direction. They are going to help in connecting widely distributed renewable energy systems having small capacity at consumer level and localised power generators of high capacity. They are going to facilitate customer participation for energy production and management , and provide real-time information on the performance of the network and its optimal utilization.

Wireless communication has been the go to technology for communication over the past few years and it is thought of as the future in communication.For communication in smart grid a drive for implementing cognitive radios is going on. The spectrum for communication is accessed by primary users who are the licensed users and secondary users who are the unlicensed users. Cognitive Radio looks for holes in the spectrum i,e when primary users are not utilising the frequency and allows secondary users to communicate in those holes. Channel switching and spectrum sensing becomes important factor in cognitive radio application.

The ongoing chapter dwells on the strategy of spectrum allocation along with negative effect of it on the utilization of spectrum. Cognitive radio has been thought in brief. Objective of and thesis layout conclude the chapter.

1.1 Motivation

As per the data published by the Spectrum Policy Task Force (SPTF) in the purview of Federal Communications Commission (FCC), it has been observed that, some radio recurrence range groups are thickly drawn in while some parts of radio recurrence groups are either tolerably utilized or vacant under the particular geological locale . The electromagnetic spectrum has been a constrained asset and has been under the control of government bodies like Telecom Regulations Authority of India (TRAI) in India, FCC in United States (US).

An altered recurrence task procedure solely designates the particular recurrence band to a specific administration, and unlicensed clients can't get to the band, bringing about spectrum gaps. Spectrum openings are the bands of frequencies assigned to some specific client known commonly as Primary User (PU) or authorized client yet stay empty for quite a while, in an unmistakable topographical district. The spectrum holes are represented in the following figure[1] :

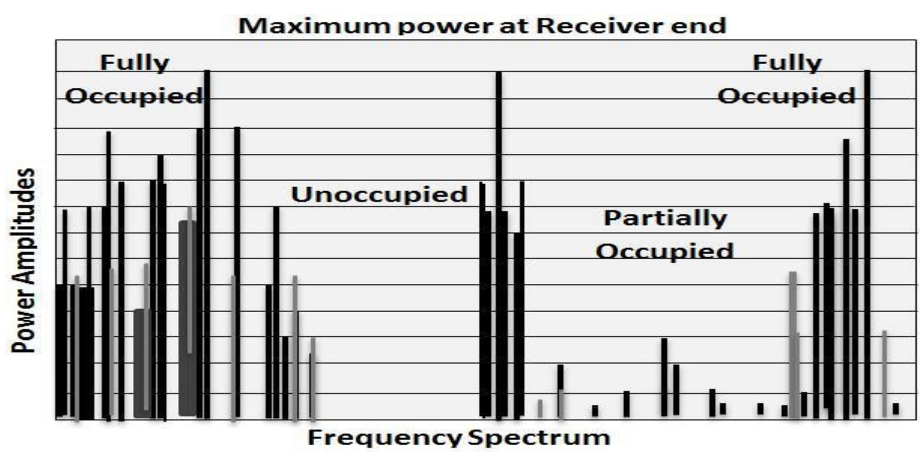

Fig 1.1: Spectrum utilization [1]

To use the accessible spectrum to its highest degree it is obligatory to permit the unlicensed clients to obtain unused authorized radio spectrum bands, with one constraint that it ought not create any hurtful obstruction to the PU. To meet this particular a canny remote correspondence framework is required, which must know about its surroundings and ready to choose the spectrum band and additionally the parameter (for instance, bearer recurrence, balance sort, data transmission, and so on.)

Cognitive radio is positive innovation to manage scarcity of radio recurrence spectrum, and it permits the intelligent users (CUs) or optional clients to use the spectrums openings, additionally CR can adjust the surroundings because of its capacity of changing the parameters . The procedure used for recognizing the nearness or non-appearance of PU, it has to check the radio recurrence range constantly, which is also known as Spectrum Sensing. Spectrum Sensing constitutes the backbone of CR framework. If the intelligent or cognitive user will come to think about the accessibility of the range, it can't get to due to undesirable obstruction to the PU. Toward the starting CR clients will examine the authorized range designated to the particular clients to identify the occupancy condition of the band. Later relying upon the yield of filtering, unlicensed or CR clients will pick their transport approach. If there should be an occurrence of the free authorized spectrum, the CR clients will transmit over the unused channel, yet in the event that PUs are utilizing the dispensed spectrum, CR clients impart the spectrum to the PU by constraining their transmit power until they locate any void spectrum band, and if the band is accessible, the CU will hop into the new spectrum gap promptly.

1.2 Objective of project

- To form a traffic scheduling method for primary and secondary users in the smart grid network so that system utilisation is maximum and blocking probability of secondary users will be reduced.
- To observe all results found out without any scheduling schemes and compare it with a traffic scheduling scheme based on the priority of different users.

- To improve the system utilisation by taking into account the QoS of channels.

1.3 Literature Review

Ruilong Dengg, Jiming Chenn, Xianghuii Cao have found out in their journal **"Sensing-Performance Tradeoff in Cognitive Radio enabled Smart Grid"** about the tradeoff between efficiency and performance issue between good execution control and lowering of correspondence cost, wiping out the path for a green keen framework. An effect intimated with the communication blackout along with execution control of DRM has been likewise examined, which lessens the profit of force supplier along with the welfare of the society of the savvy matrix, despite the fact that it may not generally diminish the masterfit of force buyer .

Jingfang Huang, Honggang Wang, Yi Qian, and Chonggang Wang in their paper **"Priority-Based Traffic Scheduling and Utility Optimization for Cognitive Radio Communication Infrastructure-Based Smart Grid",** in 2013 have developed CR distribution of channels and scheduling of traffic plans taking into thought of switching of channels and mistakes in detection of spectrum, and tackle a framework utility advancement issue for smart grid correspondence framework. In proposed network of Cognitive Radio for SG system the prioritised data have been characterised into 3 groups

1. The vital message
2. Information for system monitoring received from sensors
3. Meter readings

The primary users are given priority level 0 and the secondary users are grouped according to the class of data they possess.

XiaoLu, Ping Wang, Dustin Yato ,ekram Hussain in**"DYNAMIC SPeCTRUM ACCeSS IN COGNITIVe RADIO NeTWORKS WITH RF eNeRGY HARVeSTING"** have addressed issues of efficiency in spectrum as well as in energy. They have focused on procuring energy through RF method for wireless enabled devices.

XU Siya , WeI Lei , LIU Zhu , GUO Shaoyong , QIU Xuesong, MeNG Luming in their paper **"A QoS-Aware Packet Scheduling Mechanism in Cognitive Radio Networks for Smart Grid Applications"** in 2016 improved the priority based traffic scheduling method by taking quality of service of the frequency channel into account and finding the system utilisation and blocking probability.The routine movement planning systems are difficult to give ensured nature of administration for the auxiliary clients. It is on account of that they overlook the impact of different move necessities in heterogenous activity .Consequently, a novel QoS-aware packet scheduling method is proposed to enhance transmission quality for secondary clients. In this system, a QoS-based prioritization model is setup to address information grouping firstly. And after that, channel quality and the impact of channel switch are coordinated into need based packet scheduling system.

1.4 Thesis contribution

In this thesis I have tried to formulate an effective traffic scheduling algorithm for CR based SG system.

- I have tried to implement the system taking all kind of interference in the system along with fading model for different channels.I have tried to incorporate rayleigh fading model while forming the channels and found results for various SNR values for the given channel.
- I have compared the results of probability of blocking and system utilisation for various scheduling methods along with results where no scheduling method was implemented.

1.5 Organisation

This thesis has been sorted out into 5 sections. Ongoing section gives the shorthand prologue to the issue of deficiency in spectrum, spectrum allotment procedure, cognitive radio, and sensing of spectrum. Inspiration along with goal of proposal has been attended to in the following sections, in spite of the fact that the farthest section clarifies the whole theory association and writing study.

Chapter 2: A detailed description of cognitive radio,spectrum sensing in CR , channel switching , interference in CR has been given in this chapter.

Chapter 3: Here a traffic scheduling mechanism based on the priority levels of different users has been proposed and system utilisation for different schemes has been compared.Also the throughput of secondary users have been compared.

Chapter 4: Here we improve upon the priority based method and take QoS of frequency channels in forming the priority levels and analyse the system utilisation for the given method.Also blocking probability and delivery ratio have been calculated.

Chapter 5: This presents the conclusion to my project and sheds some light on the future scope of the work undertaken by me.

Chapter-2

Smart Grids and Cognitive Radios

Introduction:

The power grid is an expansive interconnected framework for conveying power from source of generation all the way to end users. Every Time certain difficulties arise in the conventional network, e.g., rising demands, infrastructures not supported for new technologies, and expanding discharge of greenhouse gases, which have turned into a dire worldwide concern. As broadly thought to be the up and coming era of power grid, the Intelligent and savvy network known as Smart Grid completely overhauls power distribution,generation, transmission, use to enhance nimbleness, unwavering quality, effectiveness, security, economy, and natural agreeableness

It is imagined as a promising innovation to incorporate with renewable environmentally friendly power vitality assets, for example, wind and sun oriented energy. Moreover, it is an open business sector for power suppliers and customers with adaptable estimating techniques and load moving abilities. For instance, these intelligent systems could help in alleviating overload during crest period by the wide usage of vehicles which are hybrid in nature with capacity of connecting themselves with power grids..

Propels in the field of development of smart meters and advanced correspondences elevate the intelligent networks which are smart grid to be a keen closed loop framework where plants generating power and final clients interface closely to accomplish power generation ,distribution and utilization which is both judicious and cost effective. As appeared in Fig. 2.1[2], contribution of the framework is supply given by industries or plants supplying power, whereas the feedback has been sought to be given by end clients demands calculated by smart meters.'Demand Response Management' (DRM) goes about as an unit for control in order to adjust and shape the constant load. Yield produced in the framework is also defined as power conveyed to each client through dissemination and transmission . The way for moving forward is stream of power, and way for the bidirectional movement is data stream, which gives 2-route correspondences in the SG.

Fig 2.1: A system architecture of closed loop smart grid network[3]

2.1 Cognitive Radios

'Cognitive radios' provide solution for the opportunistic access of frequency spectrum.The frequency channels used for communication purposes are limited and some are licenced to certain users known as '*primary users*'.The unlicensed users known as '*secondary users*' are large in numbers and often are blocked.The bands used by PUs are generally idle which could be accessed by SUs.Hence CRs provide the solution for accessing these spectrums when they are idle but switch to other idle channels when a PU tries to access that frequency.So a CR must be able to sense spectrum and switch channels for being effective.

In the following figure a '*cognitive radio sensor network*'(CRSN) architecture for SG has been presented[3]

Fig 2.2: CRSN scheme for SG network[10]

2.2 Spectrum sensing

Spectrum sensing is the heart of cognitive radio.The present writing for spectrum sensing is still in its initial phases of advancement. Various diverse techniques are proposed for recognizing the nearness of signal transmissions. In some methodologies, attributes of the distinguished transmission are recognized for choosing the signal transmission and also recognizing the sign sort. In this area, the absolute most regular spectrum detecting procedures in the CR are clarified

Fig 2.3 Spectrum sensing techniques

2.3 CR WAN FoR Connecting Smart Grid Network

As noted already, WANs in SG have been spread over expansive land zones which need to convey dependable, furthermore, opportune data to a central system. We apply CR innovation taking into account the Ieee 802.22 standard in SG backhaul systems in upgrading adaptability, coverage area ,capacity and diminish cost connected with authorizing range.

Methods Proposed: Taking into account Ieee 802.22 norms concurring to specific or particular instances or applications 2 unique CR frameworks have been proposed .

1) Stand-alone radio: Circumstances in which the number of users per unit area is less or white space are more in number and are accessible by Television groups, we could still get access to broadband if we could use a stand alone radio which uses Ieee 802.22 norms.As groups of TV bands have great spread quality we could get wide spread coverage area if we use stand alone radio.

2) Secondary radio: In case of larger user density also, limit prerequisites ,groups of TV band which are scarcely available, CRs could be used as an optional radio for astute transmission of non-basic information, and give a reinforcement radio in the event of a characteristic fiasco or breach in security.The CRs used must comply with Ieee 802.22 norms. All of the above designs, transmitting time efficient and time basic information in SG is trying because of intrinsic detecting delays also, psychological nature characterized Ieee 802.22. An answer to the above problem is that, we devise a double radio design where one of the radios has been devoted for transmission of information and data gathering and the second one is solely devoted for sensing of spectrum.We have in this scheme , detecting radio continually seeks to find new

accessible channels, so that the handset chain would not defer information correspondence to look for unused transfer speed. This conspire likewise gives higher range proficiency and detecting exactness than a solitary radio engineering that lone allots a particular time opening for spectrum detection.

enhancing Performance

1) Soft limit on capacity: A major attentiveness toward utilities is that their present interests in authorizing transfer speed also, gear will have the capacity to handle future conceivable applications. SG correspondences systems must be intended to oblige the up and coming usage along with the present necessities. Plan which has been vindicated contains a delicate limit as it can artfully as well as powerfully utilize accessible frequency channels in TV band for expanding framework limit. An aggregate information rate of 18 Mbps in a 6 MHz TV channel is currently characterized by norms of Ieee 802.22 giving CPes a level of execution like that of DSL broadband associations. If a higher data rate of 24Mbs is to be given then the norms of Ieee 802.22 suggest that the PHY layer would have to utilise more frequency for channel holding and for receiving and transmitting we would have to use more number of frequency channels of TV band.

2)Wide coverage zone:Ieee 802.22 norms have given a much wider range to the base stations than Ieee 802 norms. For instance, 5Km is the largest coverage area according to Ieee 802.16 but 802.22 norms of Ieee give the maximum range of 33Km for signal power of 4Watts eIRP.These scope may reach out to 100 km if higher force levels are allowed. This implies less Base stations would be required for broad scope.

3)Adaptation to non-critical failure and self-recuperating: The proposed plan is intrinsically powerful to disappointments. On the off chance that one connection is out of administration due to a characteristic debacle or security rupture, another association can be set up to look after availability. Probably the new association would have lower limit, so there ought to be particulars in the catastrophe administration to just transmit basic information that are essential for framework solidness.

4)SDR engineering: CR frameworks are by and large actualized utilizing SDR and thus they are more adaptable what's more, can be effectively changed through programming redesigns. SDR usage has been monetarily accessible in SG availability arrangements both in BSs and switches, especially for effectively tweaking WiMAX radios to particular authorized groups. The upgradability of SDR frameworks is imperative for utility clients since they are worried that their capital speculations on the interchanges framework could turn out to be rashly out of date.

The following figure shows a multi tier network of smart grid

Fig 2.4: Multi-layered SG system [2]

2.4 Scope of the coverage region

Channel modelling has been widely considered in remote interchanges for a considerable length of time. Great expository and experimental methodologies have been created to foresee vast scale scope for remote correspondence framework outline.For estimation purposes path loss model have been used which uses mean of the signal power for receiver as a function of distances, carrier frequencies, and other parameters associated with transmission. For the considered segment, analysis is done about the scope property of TV groups and potential advantages associated with it for SG WAN .We take into consideration a signal with f_c as frequency used for carrying the signal which is transmitted to a collector situated at separation d from it. The signals weakening as per the free space way model for path loss is given by[5]

$$P_{loss} \propto [1/f_{cf}d]^2 \qquad (2.1)$$

For urban areas and rural areas 'Hata model' is used . This model is suitable for frequency ranging from

150 MHz to 1500 MHz. The equation for the above model is given as

$$P_{l,u}(d)dB = 69.55 + 26.16log_{10}(f_{cf}) - 13.82log_{10}(h_{tr}) + a(h_{rr}) + (44.90 - 6.55log_{10}(h_{tr}))log_{10}(d) \qquad (2.2)$$

h_{tr} and h_{rr} are height of transmitter and receiver antenna respectively and $a(h_r)$ is correction factor.

Restriction in parameters for the hata model are

$30m < h_{tr} < 200m$

$1m < h_{rr} < 10m$

$1km < d < 20\ km$

$a(h_{rr})$ is known as correction factor given by

$$a(h_{rr}) = (1.1log_{10}(f_{cf}) - 0.7)h_{rr} - (1.56log_{10}(f_{cf}) - 0.8)dB \qquad (2.3)$$

Pathloss in rural regions could be obtained by adding the following correction factor

$$P_{l,r}(d)dB = P_{l,u} - 4.78[log_{10}f_{cf}^{\ 2} - 1.833log_{10}f_{cf}] - K\,i \qquad (2.4)$$

Where range of Ki is 35.94<Ki<45.94.

The below results [6]show pathloss versus distance model for rural and urban areas with h_{tr}=30m and $h_{rr} = 3m$. We see from below that path loss is low for TV bands with less frequency.As some frequencies in hata model are not relible so we use longley-Rice model which is applicable within 20MHz to 10 GHz.

Fig 2.5 Hata model for path loss (urban region)[2]

Fig 2.6 Hata model for path loss (rural region)[2]

Fig 2.7 Comparisons based on longley rice model[2]

2.5 Conclusion

An usage of CR correspondences for SG WANs was proposed. The CR joins considering the Ieee 802.22 norms is an appealing offer for intelligent Grid frameworks as they don't require starting capital enthusiasm for approved reach. They are moreover versatile, viably upgradable making use of SDR usage, and they give an extended extension domain as a result of the keen use of TV groups.Two particular structures for standing-alone and discretionary CR were proposed considering the Ieee 802.22 policies. Standalone option could give access to broadband for the most part to all spreading customers or end users in rural district. The urban locales, Ieee 802.22 handsets could be associated as a discretionary radio to handle high volumes of non-fundamental data and they can go about as a emergency radio under emergency circumstances.

Chapter-3

A Traffic-Scheduling Method

3.1 Introduction:

Being an intelligent system we would want the SG to be using the resources as efficiently as possible. There are many multimedia data which are being processed in real time environment by the smart grid framework through smart meters and notify us with data about security and health of the network.If there is an outage of power then we could know which component has failed.So, if we have to get better communication among the devices of the smart grid which have to perform a plethora of task at once we have to come up with a strategy to achieve fast communication link and reduced data blockage. In this chapter we provide a priority based scheduling strategy to improve system utilisation in SG network.

3.2 Priority based Network System

The proposed scheme classifies the data traffic into three different categories

- The important messages:- data pertaining to controlling,protection and management of the smart grid network falls under this class.example of this being sudden spike in voltage.These data have highest priority.
- Information regarding monitoring of system from different sensors:- The sensors present in the network constantly send data in the traffic regarding fault locations,temperature,mobility,etc.These data have less priority.
- Data from meters:- Many smart meters and advanced real time metering devices are connected to the network which send important data which could be used for real time pricing schemes.These data form the least priority class.

3.3 System Architecture

Fig 3.1: A network architecture for SG[9]

We consider a spectrum band comprising of 'P' channels which are orthogonal to each other. Both the PUs and SUs have access to these channels.The number of PUs is 'P' and those of SUs is 'N'.We group the SUs into Priorities. It could be seen in the above figure that SUs are sending data to base station.According to the priority level the PUs have priority 0.3 levels of priority classes have been presented in the above figure which are p0,p1,p2.According to the priority level given and based on amount of resources allocated the BS is going to come to a decision and convey to the users the channel resources available to them . every node supposed to be that of SU has queues of information which buffers in the channel. When the SU is accessing a free resource channel it should be aware of the recurrence of PU.

A single-hop cognitive radio system has been considered here supplemented and characterised through topological graph α(P,N), in which the number of PU 'P' have been grouped into $\{p_1, p_2, ... p_p\}$ along with set of SU $\{s_1, s_2, s_3, ..., s_N\}$ which are all connected to base station.

3.4 Interference Characterisation

There are four types of interferences

1. First kind of interference experienced by the SUs is that from primary users. This interference is represented by a matrix Z_n.
2. Secondary users from lower priority class might experience interference from SUs of a higher priority class.This forms the second type of interference and is represented by matrix I_n where

   $I_n = [I_k] \in \{0,1\}^{1\times P}$

   $I_n = 1$,if channel k of node n interferes with secondary users of priority class SU_n

   0 ,otherwise
3. Interference could also be experienced due to channel switching of secondary users.The Matrix for this type is given by SI_n where it is given by

   $SI_n = [SI_k] \in \{0,1\}^{1\times P}$

   $SI_k = 1$,if $P_t P_s > \sigma$ that is channel i at node k interferes with switching channels of priority level class SU_k

   0 ,otherwise
4. Interference of fourth type is due to errors in sensing spectrum.There are two types of Error one of which is if the channel is shown to be busy even if it is idle.This is false alarm.Another error is due to missed detection that is it declares channel idle even if there

Is presence of PU. If we take P_{fa} and P_{md} as probability of false alarm and missed detection Then we represent the matrix as follows

$SR_k = 1,\ if\ P_{md} > \tau$ that is a misdetection happens

0, other wise

After defining these matrix we define available resource matrix as

$$X_n{}^{m.k} = X_n \otimes Z_n \otimes I_{k-1} \otimes I_{k-2} \otimes \ldots \otimes I_1 \otimes SI_{k-1} \ldots \otimes SI_1 \otimes SR_{k-1} \ldots \otimes SR_1 \tag{3.1}$$

3.5 System Utilization in CR enabled SG

We could model the network into three ways.First could be an arrival model for primary users. In this model if a primary user arrives and accesses the channel then it would force the secondary user to loose its data and it would be sending an error message back to the base station.

SUs rate of arrival could be known if we have access to information about source coding. If we take R as the rate of source coding bits and if we keep the number of these bits from user SU as constant which is B ,the time taken for generation of these bits as T then we have arrival rate λ as

$$\lambda = \frac{B}{R \times T} \tag{3.2}$$

But the important model that we take into consideration is the system utilization one.In this model the number of channels that are allocated to each secondary user is different and it depends on priority of the users.For exif SUs are grouped in sets according to their pririty as $\{SU_1, SU_2, \ldots, SU_n\}$ where the subscripts denote the priority class , then the channels allocated would be $\{Ch_1, Ch_2, \ldots Ch_n\}\ where\ Ch_1 > Ch_2 > \ldots > Ch_n$

Then system utilisation is defined as

$$\rho_k = \frac{\lambda_k eff}{c_k \mu_k} \tag{3.3}$$

Where $\lambda_k eff$ is the effective or mean arrival rate of all the SUs and μ_k is the rate of source coding bits.

Now for finding out $\lambda_k eff$ we have to constraints ourselves to three conditions which are

1. There is no blockage along the path during arrival of SUs.
2. No detection of false alarms when SUs are arriving.
3. There are no packets lost from the priority class to which the SU belongs.

According to these constraints $\lambda_k eff$ is calculated as

$$\lambda_k eff = \lambda_k (1 - P_k)(1 - P_{fa}) \prod_{m=1}^{n} (1 - P(m)_{lossk}) \tag{3.4}$$

Where $P(m)_{lossk}$ denotes the probability of loss of packet in the network buffer and P_k is blocking probability.

3.6 Optimising system utilisation model

Formulating the optimisation problem, we have

$A^{\text{opt}} = arg\ max(\alpha_1\rho_1 + \alpha_2\rho_2 + \alpha_3\rho_3 + ... + \alpha_k\rho_k)$

Here $\alpha_1, \alpha_2, ..., \alpha_k$ denote the weights assigned to each factor of system utilisation.

Because of lack of resources in wireless communication networks and great difficulty of the above problem we tend to break the optimisation problem into two parts

$$A_k^{\text{opt}} = arg\ max\ \rho_k$$
$$\text{s.t } E[\triangle D_k(V_k)] \geq \rho \tag{3.5}$$

$E[\triangle D_k(V_k)]$ give reduction in distortion because of lost packets and can be calculated through

$$E_{loss}[\triangle D_k(V_k)] = \sum_{m=1}^{n} (\sum_{p=1}^{k} d_p(r_p)) \prod_k (1 - p_{loss(k)}) P_{loss(k+1)} \tag{3.6}$$

p_{loss} is the packet loss probability and is given by

$$p_{loss} = 1 - (1 - p_e)(1 - p_t p_s)(1 - p_m) \tag{3.7}$$

Blocking Probability for SU_1 **:** It is given by $P_{bs1} = \sum_{j=0}^{N_{s1-1}} \sum_{k=0}^{N_{s2}} P_{N_p,j,k} + (1-P_m) \sum_{k=0}^{N_{s2}} P_{N_p,N_{s1},k}$

$P_{x,y,z}$ denotes there are x PUs ,y $SU_1 s$ and z $SU_2 s$.

3.7 Simulation and Results

For solving optimisation algorithm problem we have used genetic algorithm function in matlab. We calculated system utilisation for both methods that is with optimisation and without optimisation.For the purpose of simulation we have taken 10 PUs and 10 number of frequency channels.There are 24 SUs out of which 8 belong to priority level 1,5 belong to priority level 2,4 belong to priority level 3 and 7 to priority level 4. The frequency channels range from 100MHz to 1100 MHz with bandwidth of each channel being 100MHz.

Table 3.1 Input Data values

Traffic class	Average arrival rate(packets/second)	No.of users	Average source coding rate(kilobits/second)
SU_1	20	8	40
SU_2	15	5	35
SU_3	30	4	45
SU_4	10	7	30

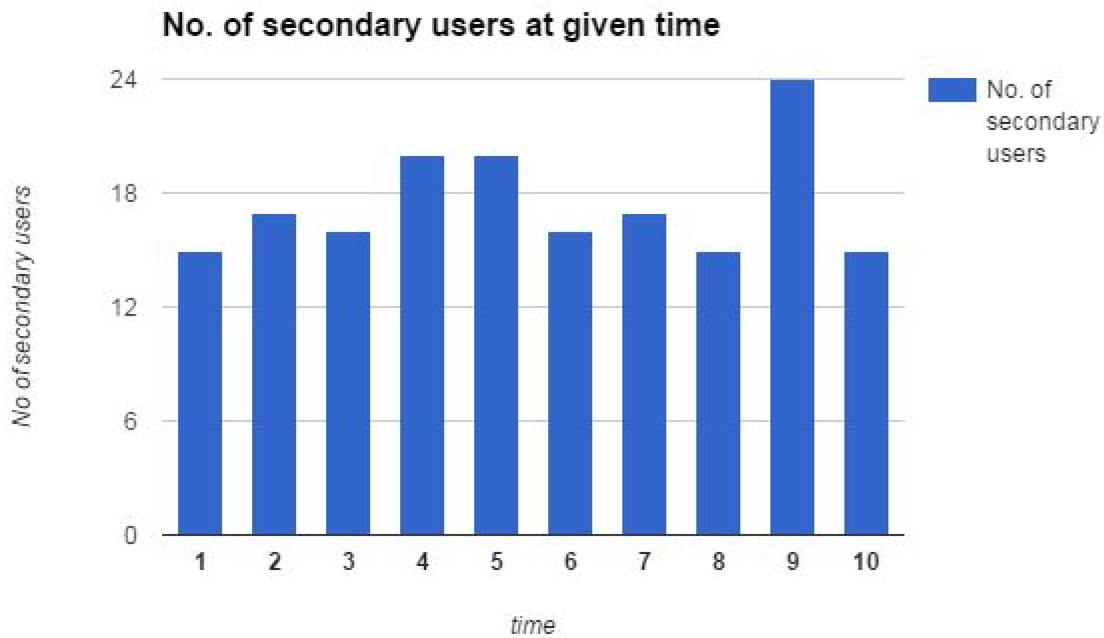

Fig 3.2 No. of secondary users at given time

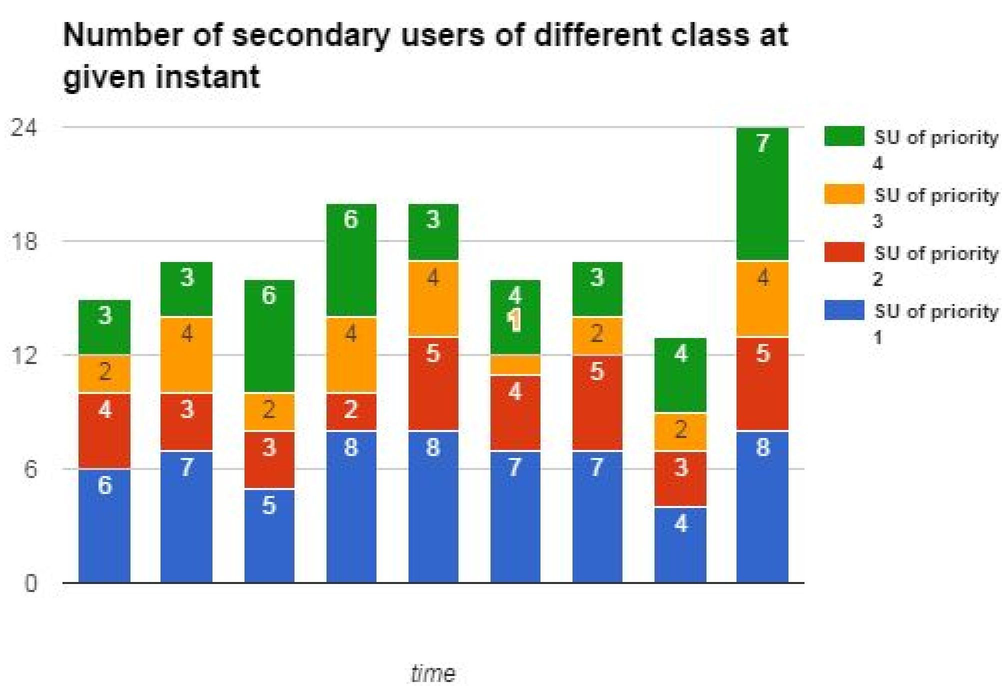

Fig 3.3 Number of secondary users of different classes at given instant

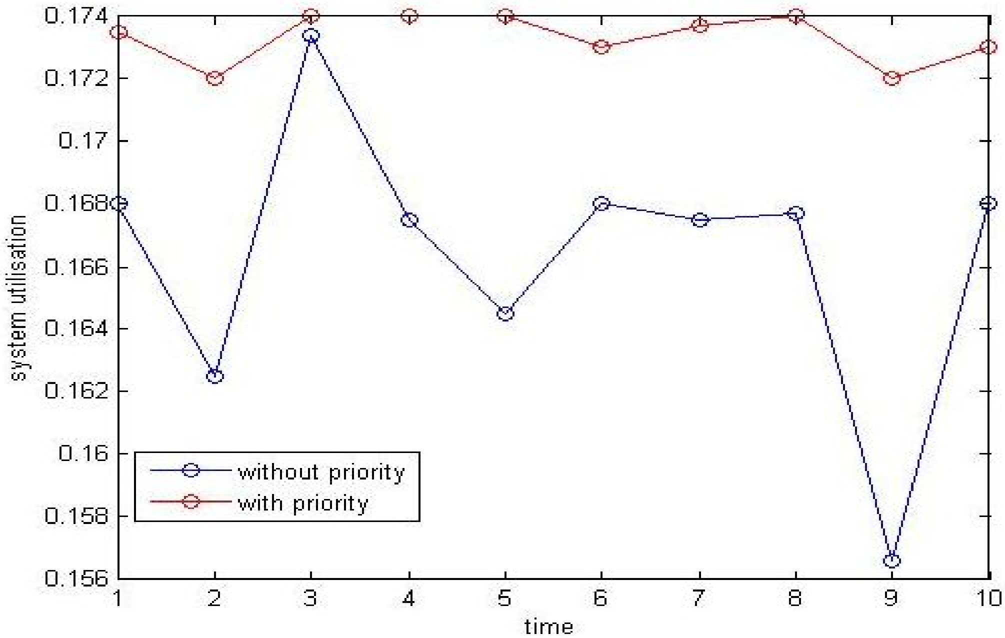

Fig 3.4 Comparison of system utilization before and after optimization

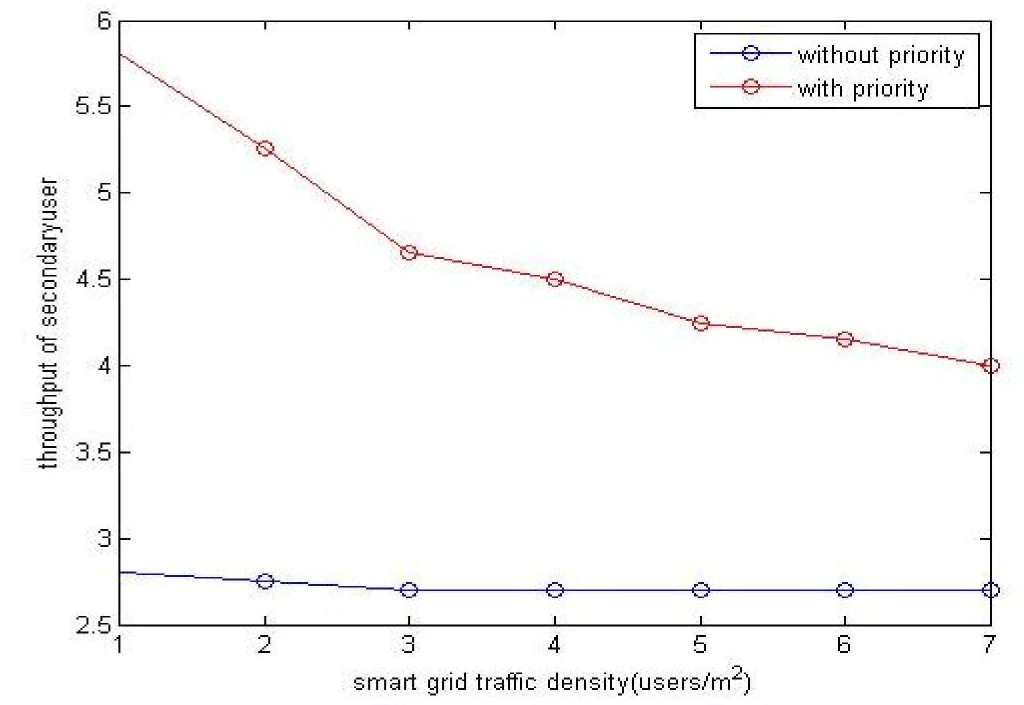

Fig 3.5 Throughput of the SUs over SG system

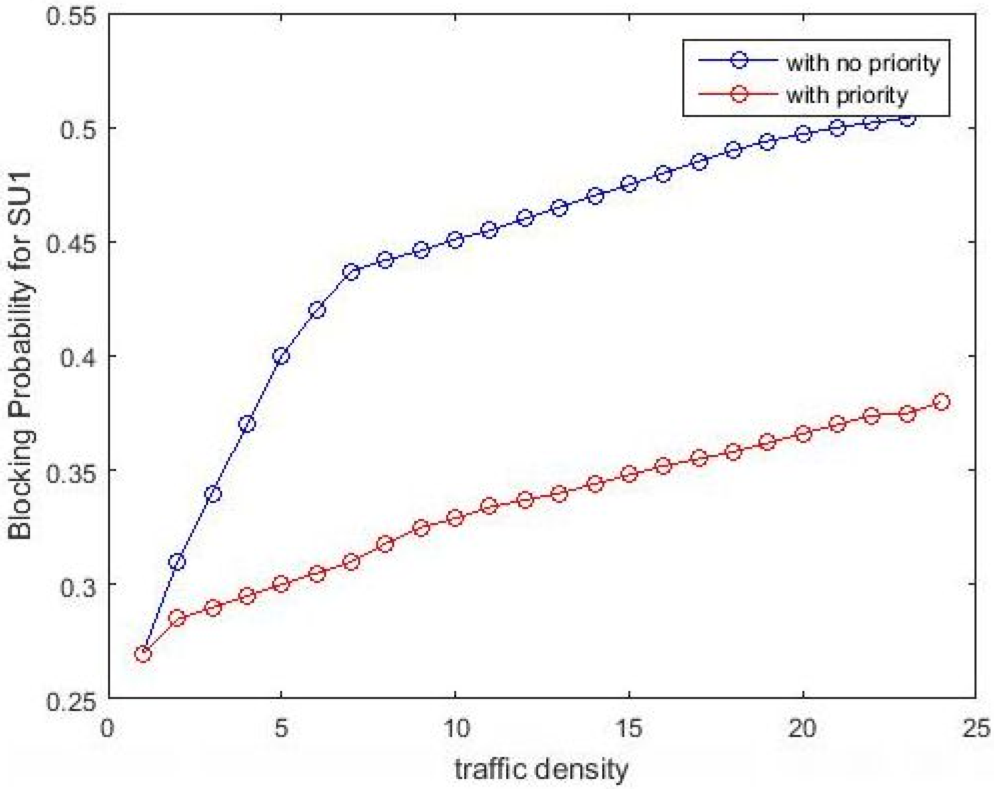

Fig 3.6 blocking probability vs traffic density

From fig 3.4 we see that we get better value of system utilisation parameter if we use optimisation algorithm.From the results above we see that the value of system utilisation depends inversely upon the number of secondary users and depends directly upon the ratio of average packet arrival rate to source coding rate. Also from fig 3.5 it could be clearly seen that the throughput of the SUs is far better when traffic scheduling technique based on priority levels are done. From fig 3.6 we found out the blocking probability for SU with highest priority with respect to traffic density in smart grid.As we can see that the blocking probability decreases enormously when we use priority based model.Also from the graph it is clear that the blocking probability is increasing if more number of users try to access the limited amount of channels.

3.8 Conclusion

From the above results we could clearly see that using a scheduling mechanism for the traffic in the network buffer of a CR enabled smart grid network we effectively reduce the blocking probability in an exponential manner and also increase the throughput of SUs in the system.Also we can improve the data quality for multimedia communication by using an optimised algorithm for system utilization.

Chapter-4

QoS-Aware Cross Layer Scheduling

4.1 Introduction:

In the previous method we did find an efficient method of maintaining traffic in the SG network which is enabled by CR.But in that method we didn't take into account the QoS demanded by each channel.Although we might establish connections between SUs and base stations in those channels but at cost of poor QoS then the data received would be rendered useless.So for better quality data to be received we introduce another scheme where a channel will be allowed to be utilised only if the right values of QoS are adhered to.

4.2 Requirements for QoS

There is a very vast area of application of today's wireless sensors, such as advanced metering infrastructure (AMI),control and monitoring of power from remote sources, fault detection and its diagnosis, acquisition of data and network supervision,monitoring of transmission lines and controlling power distribution . A cognitive radio sensor network based smart grid has been given in the following figure[7].

Fig 4.1: SG structure enabled by CRSN[5]

The table in fig.4.2 defines the QoS values for some of the most important attributes like terms data rate, delay and reliability of different traffics which have been grouped into various classes.More than one class may contain values and function which require similar type of values. The different levels of class or priority level define the extent or flexibility of accessing different channels.The lower the priority higher is the number of channel accessing capability.

Table 4.1:Values of different attributes of different traffic classes.

Traffic Class	β min (kbps)	β max (kbps)	τ min (s)	τ max (s)	α min (%)	α max (%)	Priority level	Application type example
PU	-	-	0	0.25	-	-	0	Protection
SU_1	16	20	0.25	0.75	99	100	1	AMI
SU_2	32	40	1	2	-	-	2	Multimedia

								Surveillance
SU_3	20	28	0.5	1	90	100	3	SCADA
SU_4	-	-	-	-	90	100	4	Meter Reading

4.3 Prioritisation model based on QoS

A heterogenous characteristic based model known as Diffserv model has been used for forming the model of the smart grid of smart grid communication system . Parameters of QoS in the form of α, β, τ have been attributed to each class. There is some priority weights of these attributes and each of those has a threshold value for minima and maxima namely

$\{(\alpha_{min}, \alpha_{max}), (\beta_{min}, \beta_{max}), (\tau_{min}, \tau_{max})\}$.

4.3.1 A strategy based on flexibility in adjustment of priority

In earlier strategies we had a fixed priority order for every data streams but here we are going to dynamically allot priority levels.Every node for secondary user has a sequence of queues of informations for buffering of packets from the source side .A packet from a SU is not allowed to be transmitted only if there are packets from PU or SU of greater priority class and so it enters the information queue buffer waiting in line for the next sequence of batch to be scheduled for transmission. Increase in time for queuing will result in an increased time for blocking probability and also the rate of dropping of packets. Once, the delay in queue reaches a certain value we have to again schedule the priority of different classes so that packets having less priority are not lost.

An estimated level of latency,data rate and reliability is evaluated for the given user class and accordingly we calculate the evaluated value as

$$P = n\alpha_c + l\beta_c + m\tau_c = n(\frac{\alpha}{\alpha_s}) + l(\frac{\beta}{\beta_s}) + m(\frac{\tau}{\tau_s}) \quad (4.1)$$

l, m, n are weighting coefficients and $l+m+n=1$.

β_c=datarate, α_c=reliability, τ_c=communication delay.

For our calculation we have taken $l=m=n=\frac{1}{3}$.

After evaluation value (P) is calculated, we can find the level of priority f(x) as

$$f(x) = \{i | P_{min[i]} \leq P_i \leq P_{max[i]}\} \quad (4.2)$$

If a SU has initial priority class k, communication delay $\tau_k \in (\{\tau_{min[i]}, \tau_{max[i]}\}$ .Then the current priority level of the packet can be defined as(taking queuing delay as Δt_k and scheduling time as t_k)

$$I = k \; if \; \tau_k - \Delta t_k \in (\{\tau_{min[i]}, \tau_{max[i]}\} \text{ or}$$
$$I = k-1 \; if \; P_{min[k-1]} \leq n(\frac{\alpha}{\alpha_s}) + l(\frac{\beta}{\beta_s}) + m(\frac{\tau-\tau_k}{\tau_s}) \leq P_{max[k-1]} \text{ or} \quad (4.3)$$
$$I = k-2 \; if \; P_{min[k-2]} \leq n(\frac{\alpha}{\alpha_s}) + l(\frac{\beta}{\beta_s}) + m(\frac{\tau-\tau_k}{\tau_s}) \leq P_{max[k-2]}$$

These formulas are only applicable for secondary users of priority class 0,1,2 but are not for 3 and 4 as these are not affected by transmission delays.

4.4 Formulating Problem

Users:A single hop network is deployed and there are 2 groups of users $PU = \{pu_1, pu_2, ..., pu_n\}$ and SU= $\{su_1, su_2, ..., su_m\}$ .The priorities of each group have been assigned according to their QoS requirements.For simulation we have taken 5 groups of primary users with each group having 10 members and 4 groups of secondary users with group 1 containing 8,group 2 containing 5,group 3 containing 4 and group 4 containing 7 number of users.

Available Resources: Number of frequency channels available are same as that of the number of groups of primary users which is 5. The frequency channel available range from 100MHz to 600MHz with bandwidth of 100 MHz.These channels are orthogonal in nature.

Modelling Traffic for primary users: The process of arrival of traffic of PUs is modeled as poisson process with average of λ_{puj} and mean time of arrival $\mu_{puj} = 1/\lambda_{puj}$.

Modelling Traffic for secondary users: Consider the avg bitrate of secondary users to be B_r and average rate of arrival of SU be λ_{suj} in frequency channel F_j. If P_{kj} denotes probability of secondary user k using frequency channel F_j then

$$\lambda_{suj} = P_{kj}\frac{B_k}{S_k}$$

S_k is average packet length

System Utility Function: We have previously defined system utility function as

$$U = \sum_{k=1}^{4} \omega_k U_k \text{ where } \omega_1 + \omega_2 + \omega_3 + \omega_4 = 1. \quad (4.4)$$

Also $U_k = \frac{\lambda_k}{N_k \times \mu_k}$ where N_k is the number of secondary users.

Combining the results we have system utilisation as

$$U = \sum_{k=1}^{4} \omega_k\left(\frac{\lambda_k}{N_k \times \mu_k}\right) \quad (4.5)$$

4.5 A Quality based Packet Scheduling Technique

For this scheme to be applicable we have to find the quality of each channel.It could be found out by calculating different parameters which are

Connectivity(C_{kj}): It defines if an user could be connected with BS or not at the given time of scheduling.

$$L_{kj} = \begin{cases} 1, \text{if channel is available} \\ 0, \text{otherwise} \end{cases}$$

Reliability(R_{kj}): It defines whether a channel is reliable for transmitting data or not.It takes into account various interferences and finally calculates reliability.

1. Interference due to primary users is given by Z_j.
2. Higher priority SUs causing interference is given by $1 - G_{kj} = \prod_{Q_x > Q_k} (1 - G_{xj})$ where G_{kj} gives the probability of disturbance of higher priority SUs and Q_x and Q_j give levels of priority.
3. Interference due to errors in sensing is given by $E_{kj} = P_{fa} \langle H_1 | H_0 \rangle + P_{md} \langle H_0 | H_1 \rangle$.
4. Interference due to switching of channels is given by S_j.

Including all these interferences we calculate the reliability factor as

$$R_{ij} = (1 - Z_j) + (1 - R_{ij}) + (1 - E_{ij}) + (1 - S_j) \tag{4.6}$$

Stability(S) : It is given by $W = \frac{\lambda_{puj} + \mu_{puj}}{\lambda_{puj} \mu_{puj} R_{ij}}$ (4.7)

After calculating stability,connectivity and reliability we have the channel evaluation value as

$$EV_{ij} = C_{ij}(aR_{kj} + (1 - a)W) = C_{ij}(a(1 - Z_j)(1 - G_{kj})(1 - E_{kj})(1 - S_j) + (1 - a)W) \tag{4.8}$$

4.6 Steps for QoS based Traffic scheduling Mechanism

1. From the start of transmission determine if there are packets available in the queue for transmission.
2. Priorities are given to various data packets.
3. We find out the channel evaluation factor.
4. The channel with highest channel evaluation factor is assigned to SU with highest priority and thus we assign the channels in decreasing order of channel evaluation factor to subsequent SU with decreasing priority.
5. There is in place , a strategy for backoff for secondary users if a PU accesses the given channel.A SU has to wait once a PU or high priority SU starts accessing the given channel.

The figure below shows a flow diagram for the above mechanism[8]

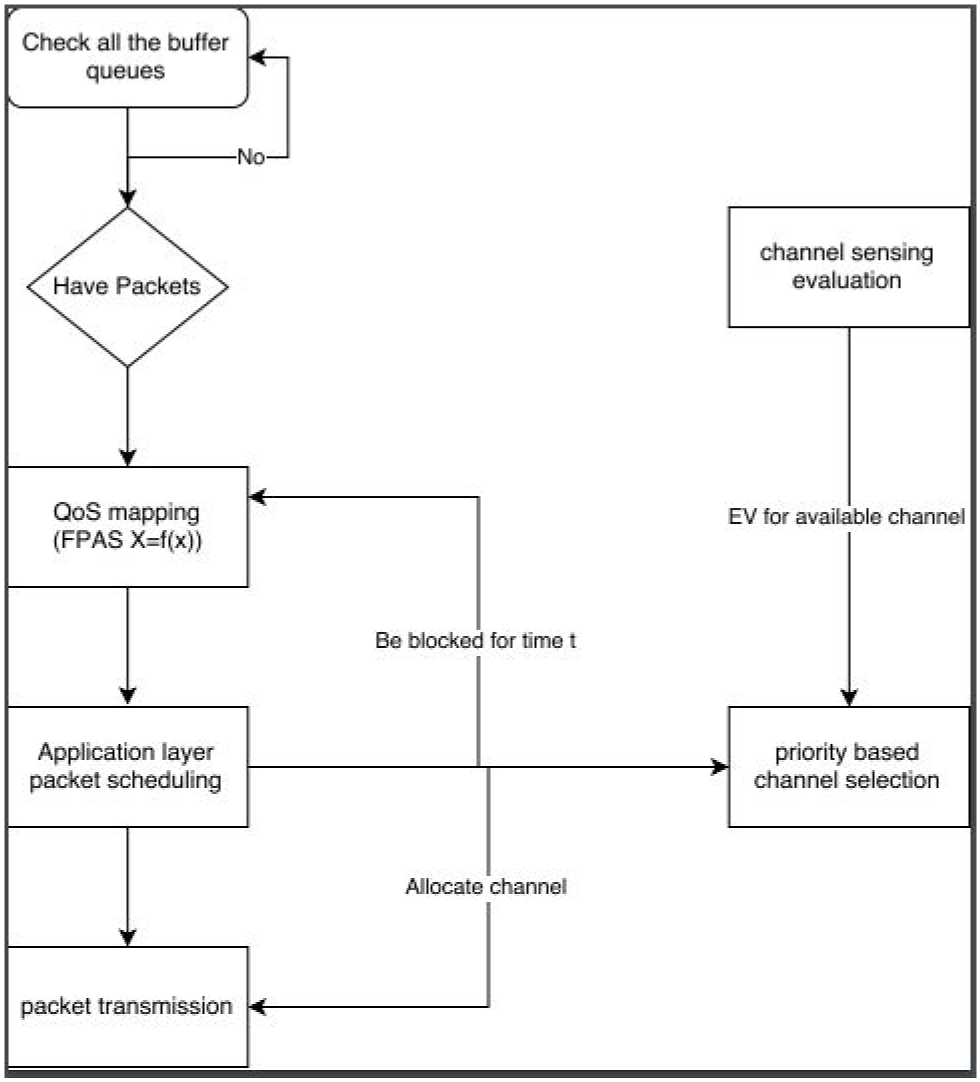

Fig 4.3 Flow chart for QoS aware packet scheduling mechanism

4.7 Simulation and Results:

We took the same system that was taken in the previous chapter.We simulate to find out the delivery ratio of SUs of priority level 1 and 2 with respect to number of channels.We also try to find out the blocking probability of these two groups of users with respect to number of channels using the QoS aware packet scheduling scheme.

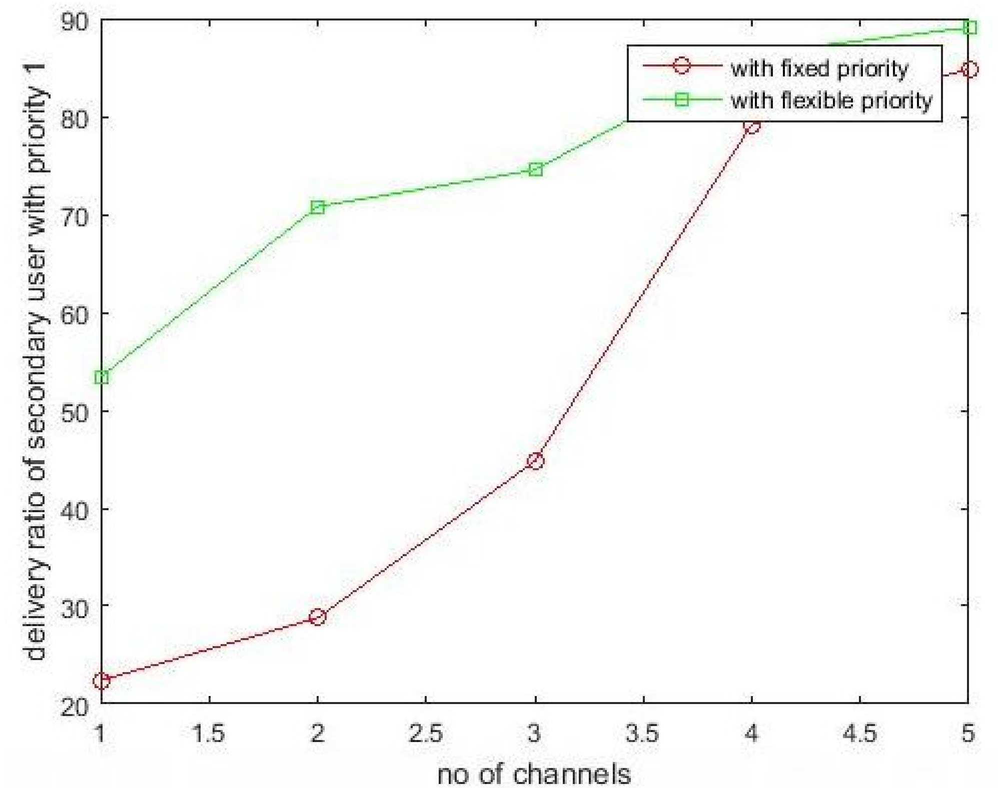

Fig 4.4 Delivery ratio of secondary user with priority level 1 vs number of channels

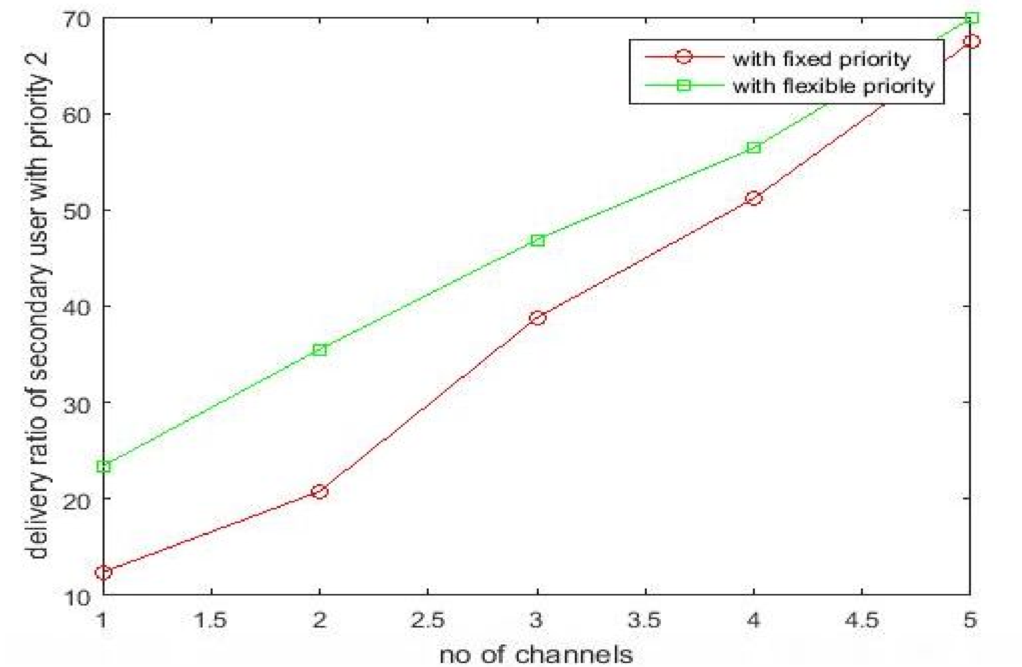

Fig 4.5 Delivery ratio of secondary user with priority level 2 vs number of channels

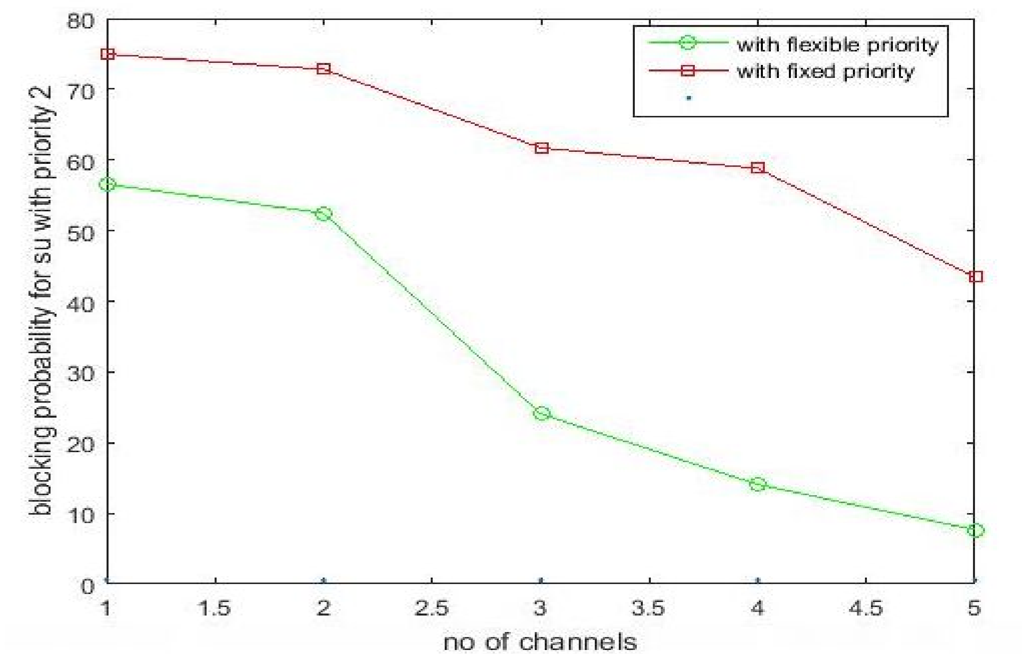

Fig 4.6 Blocking Probability of secondary user with priority level 2 vs number of channels

We see from above impact of increasing the number of channels on delivery ratio of the SU.We could see that the delivery ratio increases as number of channels increases and the value of delivery ratio is better for flexible priority scheme than that of fixed priority scheme.We also see from fig 4.6 that the blocking probability increases on increasing the number of channels and blocking probability is considerably less for flexible priority scheme.

4.8 Conclusion

For accommodating the real time changes in CR networks QoS aware packet scheduling mechanism was introduced.Other conventional strategies have neglected the relative priorities of SU but this method provides a heterogenous model with different and varied QoS services.From simulation we found out that this strategy was much more efficient than traditional strategies.

Ch-5

Conclusion and Future Scope

5.1 Conclusion:

- Various ways in which CR could be used for wireless communication in SG was presented.An outline of the system architecture which could be used practically was discussed and some characteristics of cognitive radio was studied briefly
- Main focus was on formulating a traffic scheduling scheme for better communication.We developed some methods for arranging PUs and SUs such that the blockage of data is decreased and the number of packets being lost in transmission and during queuing delay is reduced.
- We found that the scheduling mechanism based on awareness of QoS yielded the best results.The introduction of flexible priority allotment reduced the blocking probability drastically and helped in increasing system utilisation factor.

5.2 Future Scope:

- Research in Cognitive Radio enabled smart grid is in its infancy . There is a huge scope of improvement in this field.Security Analysis is a burning topic under research in this field. There has also been a strive for forming new set of regulatory rules for CR so that the spectrum could be used more efficiently.Also research is going on in developing new technologies for detecting or sensing spectrum efficiently and accurately which is a bit difficult using today's technology.Also methods are being devised for creating a real time pricing scheme which would help the customers to use the resources judiciously.

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