Spectrum Sharing in a Long Term Spectrum Strategy via Cognitive Radio for Heterogeneous Wireless Networks

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Abstract—**In this paper, Spectrum sharing technique among service providers to share the licensed spectrum of the licensed service providers for Heterogeneous wireless networks in a dynamic manner is proposed. Here, we could analyze and sense out the unoccupied bands, free bands, allocated bands by calculating the free spectrum metric. Hence, providing the opportunistic access to the licensed spectrum for unlicensed users ie other service providers try to access the available spectrum without causing interference to the primary users.**

Keywords- allocated bands, CR, call blockage, system efficiency, spectrum efficiency, free spectrum

I. INTRODUCTION

Nowadays, there are a lot of wireless applications sharing the same medium. This overload leads to a lack of spectrum in given frequency bands. The purpose of this work is to present another approach of sharing the same medium by means of a dynamic allocation of the spectrum instead of the static allocation which is believed to cause spectrum inefficiency and scarcity, since the wireless users demands change both temporally and spatially.

Dynamic spectrum sharing is a promising approach for reusing the underutilized spectrum, in which the spectrum is shared among primary and secondary (unlicensed) users (SUs) to improve spectrum flexibility and, therefore, efficiency. The cognitive radio (CR) provides a solution to this dynamic spectrum access (DSA). CR technology is a key enabler for both real time spectrum markets and dynamic sharing of licensed spectrum with unlicensed devices.

The CR device is able to perform spectrum acquisition, either through purchasing (in cleared spectrum) or sensing (in vacant channels of geographical interleaved spectrum), over a range of frequency bands and operate in this spectrum at times and locations where it is able to transmit in a non-interfering basis.

The overall spectral efficiency of a system can be improved with good coexistence properties, good spectrum sharing capabilities, as well as with flexibility in the spectrum use. Capabilities to share spectrum with other systems will significantly increase the efficiency as well as acceptability of the system. The overall spectral efficiency of the work can be also increased with a flexible use of spectrum that adapts to the spatial and temporal variations in the traffic and environment characteristics. The flexibility and scalability of the system is also important in order to simplify the network deployment under spectrum arrangements that may vary from region to region. Built-in capabilities for flexibility and sharing may significantly ease the task of spectrum identification for the system.

In this paper, we propose a scheme about the efficient spectrum utilization(ie spectrum sharing) among service providers via static CR nodes where the under utilized spectrum of a particular service provider can be shared by the overloaded service providers with a coordination among them. This also proposes deploying a network of fixed cognitive radio (CR) nodes to maintain spectrum sharing across multiple service providers operating in the same geographical area. These CR nodes estimate the spectrum utilization in a given area, and cooperate to provide the spectrum usage information for the overloaded infrastructures of service providers.

This work is done with a long term spectrum assignment scheme inorder to estimate the spectrum efficiency in a long term process. Many research works were carried out in a short term spectrum assignment basis. If the spectrum, is assigned in a long term basis, cost should be calculated along with the spectral and system efficiency.

The paper is organized as follows; Section 2 and 3 defines cognitive radio and proposes a spectrum sharing in Cognitive Radio Networks. In section 4, Proposed Spectrum Sharing Techniques are discussed. In Section 5, Performance analysis has been investigated to improve the system efficiency. Section 6 presents the simulation results and implementation issues. Finally, conclusions are presented in Section 7.

II. COGNITIVE RADIO

Cognitive Radio(CR) is of a new concept of Wireless communication paradigm that improves the spectrum utilization by exploiting the existence of spectrum holes. Cognitive radio, has the reconfigurability and capacity to detect the unoccupied spectrum holes. The basic functionalities of CR is to observe and sense the spectrum, to identify and analyze the spectrum and the last is to share the spectrum information and execute the spectrum assignment.

Thus, CR is defined as a radio that can autonomously change its transmission parameters based on interaction with the complex environment (radio scene, application and user requirements) in which it operates.

A. Proposed CR nodes Sensing

With the capability of sensing the environment and finding the available spectrum dynamically, CR technique can help to implement spectrum sharing and improve the spectrum utilization efficiency. In the proposed work, CR engines such as learn and decision does the work of Spectrum Sensing. Here, CR nodes helps to provide the list of available channels and it checks the availability of the channels. Mobile nodes get the information of availability of channels and sends it to BS through the CR nodes as shown in Fig. 1.

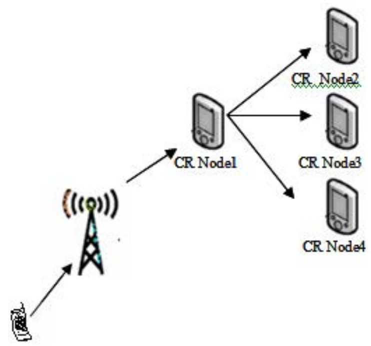


Fig. 1. CR Nodes sensing the available channels

When CR nodes monitor channels in a given area, economically, the number of deployed CR nodes should be minimal, and, meanwhile, these CR nodes can fully cover the given area and properly estimate the channel utilization.

III. SPECTRUM SHARING IN COGNITIVE RADIO NETWORKS

Spectrum Sharing techniques have been classified based on the various factors like architectures, access behavior, access technology. The first classification of spectrum sharing in CR networks is based on the architecture and it can be described as follows:

- Centralized Spectrum Sharing: The spectrum allocation and access procedures are controlled by a central entity. Moreover, a distributed sensing procedure can be used such that measurements of the spectrum allocation are forwarded to the central entity, and a spectrum allocation map is constructed. Furthermore, the central entity can lease spectrum to users in a limited geographical region for a specific amount of time.
- Distributed Spectrum Sharing: Spectrum allocation and access are based on local (or possibly global) policies that are performed by each node distributively. Distributed solutions also are used between different networks such that a base station (BS) competes with its interferer BSs according to the QoS requirements of its users to allocate a portion of the spectrum.

The second classification of spectrum sharing is based upon the spectrum allocation strategy. The spectrum access can be either cooperative or non-cooperative.

- Cooperative Spectrum Sharing: It is a technique which gives the interference measurements of each node from one node to other nodes communication.
- Non-cooperative Spectrum Sharing: Considering only one node for communication. This techniques may reduce spectrum utilization because do not require frequent message exchanges between neighbours as in cooperative solutions.

The third classification of spectrum sharing is based upon the access technology. Methods can be classified as Spectrum Overlay and Spectrum Underlay.

- Spectrum Overlay: A node accesses the network using a portion of the spectrum that has not been used by licensed users. This tries to minimizes interference to the primary network. Here, only one user or system can use a frequency band at particular space and time, and the secondary users have to backoff when a primary user is present. However, when no primary user is present, the secondary user can opportunistically use a frequency band. So this technique is also referred to as Opportunistic spectrum access.
- Spectrum Underlay: The spread spectrum techniques are exploited such that the transmission of a CR node is regarded as noise by licensed users. Here, a secondary user can transmit in an already occupied band if this transmission doesn't increase the interference to the primary user above a given threshold.

Finally, spectrum sharing techniques are generally focused on two types of solutions: spectrum sharing inside a CR network (*intranetwork spectrum sharing*) and among multiple coexisting CR networks (*internetwork spectrum sharing*), as explained[6] in the following:

- Intranet Spectrum Sharing: These solutions focus on spectrum allocation between the entities of a CR network, as shown in Fig. 2. Accordingly, the users of a CR network try to access the available spectrum without causing interference to the primary users. Intranetwork spectrum sharing poses unique challenges that have not been considered previously in wireless communication systems.
- Internetwork Spectrum Sharing: The CR architecture enables multiple systems to be deployed in overlapping locations and spectrum, as shown in Fig. 2. So far the internetwork spectrum sharing solutions provide a broader view of the spectrum sharing concept by including certain operator policies.

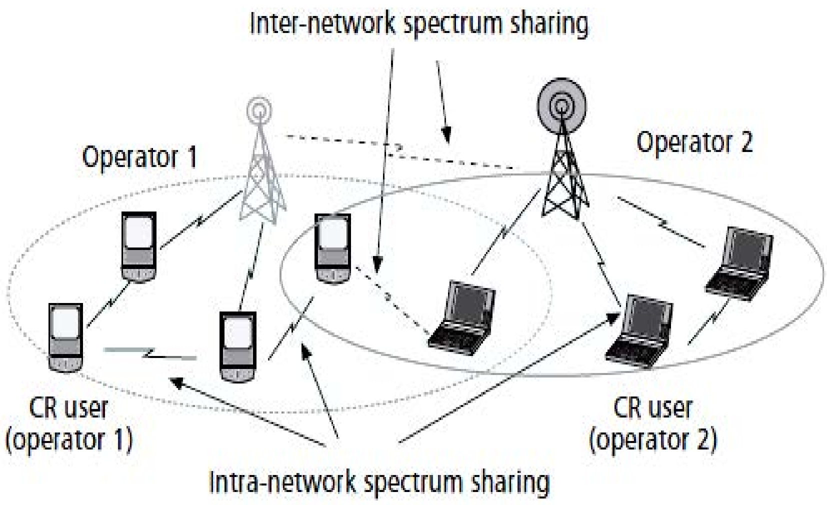
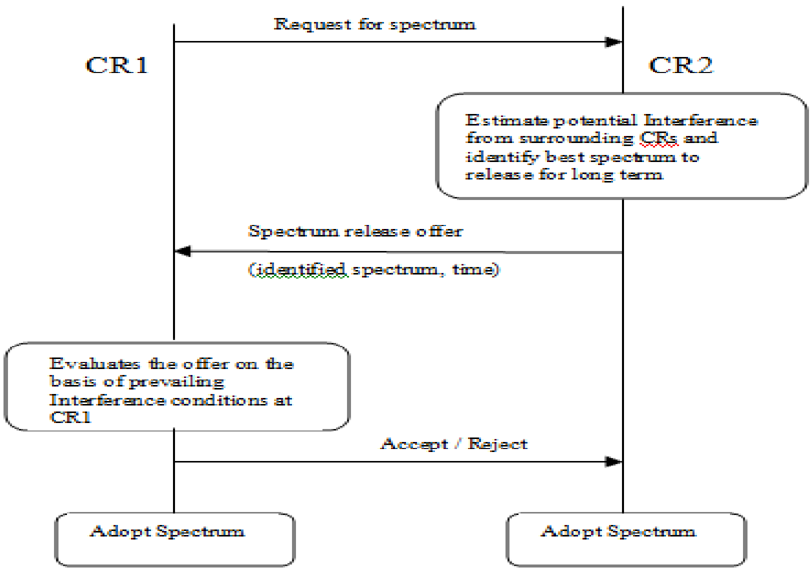


Figure 2. Inter-network and Intra-network spectrum sharing in CR networks

The proposed work, considers the Distributed spectrum sharing architecture, Cooperative spectrum sharing as the spectrum allocation behavior and Spectrum Overlay as the access technology. Similarly, both Intra-network and Inter-network spectrum sharing techniques are considered in this work. Hence, provides the opportunistic access to the licensed spectrum for unlicensed users and the users of an CR network try to access the available spectrum without causing interference to the licensed users.

Here, the process of spectrum sharing is carried out in a long term spectrum assignment method which access the spectrum for a long period. If the spectrum is accessed in a long term, then there should be a pre-agreed amount consideration among the service providers. The following flowchart (Flowchart 1.) depicts the long term spectrum assignment strategy among service providers.



Flowchart 1. Long term Spectrum Assignment, the amount of spectrum considered for release against each request is a pre-agreed amount

IV. PROPOSED SPECTRUM SHARING TECHNIQUES

A. Process of Spectrum Sharing

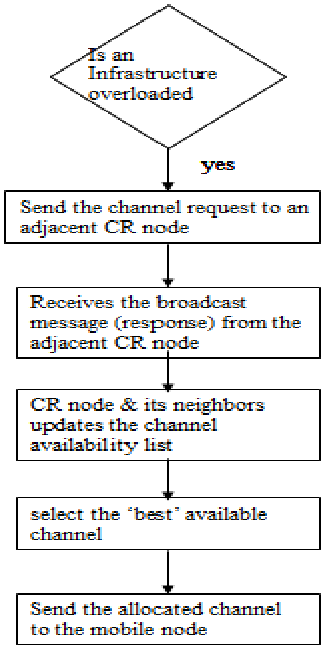
During the peak hours, the communication of the users will be blocked due the number of active users is greater than the maximal number of users ie the infrastructure is found to be overloaded (because of the channel scarcity). At the same time, infrastructure of the other service providers might be in the under-loaded status. Hence, the available channels of the under-loaded service providers can be utilized by the overloaded service providers. This may vary according to the services offered by the customers example Wireless internet for laptops, mobile communications and so on. So this may lead to the difference in the traffic of the active users across service providers. Here, both of these two service providers operate cell-based wireless networks. Therefore implementing spectrum sharing among service providers would highly improve the spectrum efficiency and it also reduces the call blocking rate and Co-Channel Interference.

In order to reduce the Co-Channel Interference and to remove the need of equipping CRs in each infrastructure of service providers, we propose a method that implements a spectrum sharing among service providers via CR nodes in a long term spectrum assignment scheme. These CR nodes are distributed regularly within an area of interest.

Each CR node senses the surrounding environment and monitors the channel usage within its sensing range of different service providers. To avoid co-channel Interference, CR nodes provides the list of the channel availability of each cell for the overloaded infrastructure of service provider. CR nodes are connected to each other via wire or they communicate wirelessly to form a network. This network is called as spectrum management network and it coexists with the wireless networks operated by different service providers.

In this technique, only a limited number of CR nodes are required, and neither users nor service providers need to sense the environment for available spectrum. In the proposed technique, each user subscribes to a specific service provider that is assigned fixed frequency bands. When one or more infrastructures (e.g. base stations) of a service provider are overloaded, they use extra available channels (for communication) which are licensed to other service providers.

The overloaded infrastructures obtain the channel availability information from surrounding CR nodes. CR nodes are deployed to estimate the channel utilization and provide the channel usage information for infrastructures upon their requests. The infrastructures process the information received from CR nodes to select the optimum channels based on the channel associated metrics such as interference level, cost and the probability of channel being available for a certain time duration. The process of spectrum sharing among service providers based on infrastructure is depicted in the following flowchart (Flowchart 2).



Flowchart 2. Process of spectrum sharing among service providers based on Infrastructures

B. Operations of CR Nodes

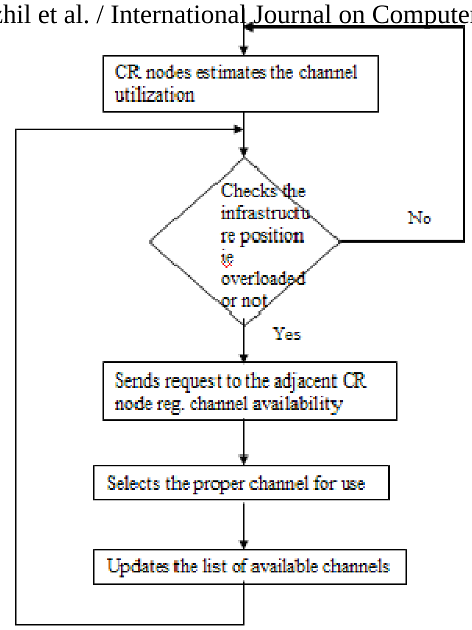
Suppose, if the infrastructure of one service provider is found to be overloaded, it sends the request to the adjacent CR nodes regarding the channel usage availability in its coverage area. It gives the list of available channel from the relevant adjacent CR nodes and it also provides the relevant information associated with each channel such as the average signal to noise–plus interference. The overloaded infrastructure now selects the proper channel to use. Thus, users can communicate with the overloaded infrastructure over the new channels after they are informed with the channel availability. This requires both infrastructure and users to be equipped with radios capable of operating over different frequency bands. If the infrastructure is not found to be overloaded or the traffic is free, then the channels should be released ie users would stop using these channels.

The main operation of CR nodes is to periodically sense the environment and estimate the channel utilization within their sensing range. Once it receives the channel availability information from infrastructures, CR nodes would response to these infrastructures with a set of available channels and relevant information. The main challenges that we facing during the spectrum sharing are:

(i) How to decide the availability of a channel – for a CR node ?

(ii) How to select the optimum channels for usage based on the information provided by CR nodes – for the infrastructure?

The process of spectrum sharing among service providers based on infrastructure is depicted in the following flowchart (Flowchart 3).



Flowchart 3. Process of spectrum sharing among service providers based on CR nodes

C. Channel Selecion Method for Sensing using CR Nodes

In the proposed work, the channel assignment scheme accounts for the interference conditions and the power constraints at different bands. Channel availability can be determined by sending service request to the BS. BS receives service request from the mobile nodes and it will send the channel request to the CR node. CR node receives the channel request and sends the broadcast message to the adjacent CR node. A neighbor CR node receives the broadcast message and also sends the available channel list to the BS. CR node and its neighbors, updates the channel availability list and sends response to the BS. If BS receives the response from the CR node, it selects the available channel and sends service reply with the allocated channel to the mobile nodes. This shows the maximize utilization of a channel and it offers several services such as internet service, call service, multimedia service and so on to the mobile nodes. Our scheme, identifies 'available' channel list for each CR node. Such a list shows which channel is available to use depending on the distance among the CR node and High frequency band. Within a given neighborhood, multiple CR nodes may contend for access to one or more of the available channels.

In the proposed work, priority will be given to the primary user. It shows that if one service provider is found to be overloaded, it checks out the available channel using neighborhood CR nodes. If the service provider is found to be under-loaded, it accepts the other service providers to gain access the available channels in its region.

Thus, implementing those CR nodes and deploying them as a network should be done with the negotiation between service providers based on the cost and the network management policy. This successful deployment provides the risk and the cost of operating the CR network. It founds to be a challenging task of deploying the CR network with the coexistence with the current wireless networks in a geographical situation. It also increases the cost and complexity of wireless network management. If CR nodes communicate with each other wirelessly, then it requires extra wireless resources and it also increases the overhead of wireless networks.

D. Simulation Results

If the infrastructure of one service provider is found to be overloaded, it sends the requests to the adjacent CR Nodes regarding the availability of Channel. Channel availability can be determined by sending service request to the BS. BS receives service request from the mobile nodes and it will send the channel request to the CR node. Fig.3 shows the BS before sending request to the CR Nodes.

CR node receives the channel request and sends the broadcast message to the adjacent CR node. A neighbor CR node receives the broadcast message and also sends the available channel list to the BS.

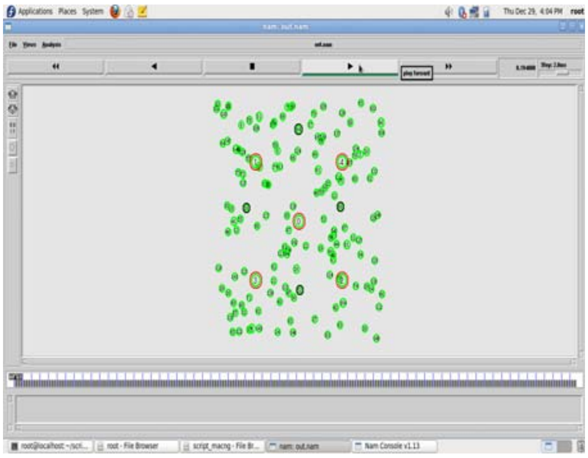


Fig. 3. Before sending request to the CR Nodes

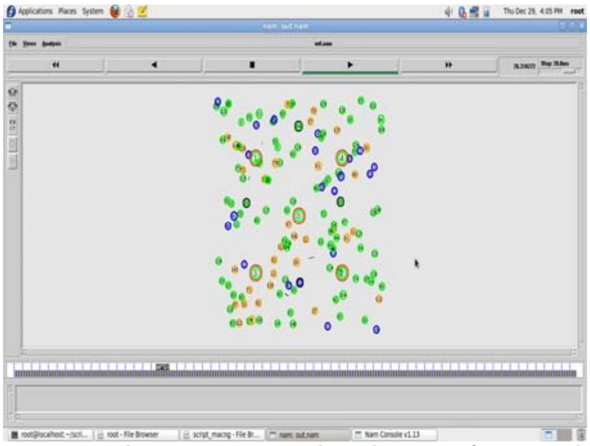


Fig. 4. Sending request to CR Nodes and response from CR nodes

CR node and its neighbors, updates the channel availability list and sends response to the BS. Fig.4. shows the sending and receiving the request and response from CR nodes.

If BS receives the response from the CR node, it selects the available channel and sends service reply with the allocated channel to the mobile nodes. This shows the maximize utilization of a channel and it offers several services such as internet service, call service, multimedia service and so on to the mobile nodes. Fig.5 shows the maximum utilization of channel by sending the response to the BS regarding the channel availability.

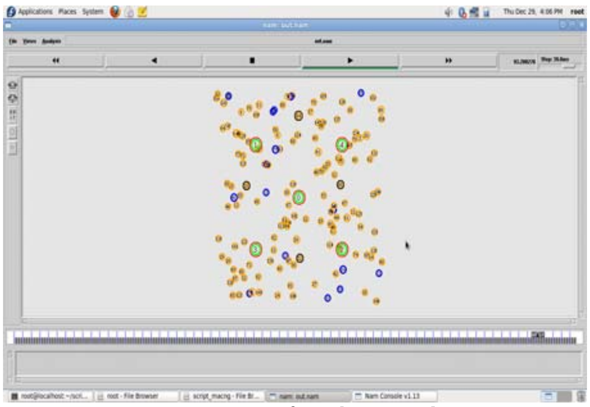


Fig. 5. Response from the CR Nodes

Our scheme, identifies 'available' channel list for each CR node. Such a list shows which channel is available to use depending on the distance among the CR node and High frequency band. Within a given neighborhood, multiple CR nodes may contend for access to one or more of the available channels.

V. Performance Metrics

In this section, we discuss about the performance metrics study the impact of spectrum sharing on the service providers include call blocking rate, system efficiency, Revenue efficiency, etc.

A. Call Blocking rate

The call blocking rate R_{BL} is defined as the ratio of total blocked calls over total calls processed by all service providers and corresponds to:

$$R_{BL} = \lim \frac{n_{BL}^{(total)}(t)}{n_{processed}^{(total)}(t)}$$

where total blocked calls at time t by all service providers is given by

$$n_{BL}^{(total)}(t)=\sum_{i=1}^{n_{sp}} n_{BL}^{(i)}(t)$$

and the total calls processed is:

$$n_{processed}^{(total)}(t)=\sum_{i=1}^{n_{sp}} n_{processed}^{(i)}(t)$$

where n_{sp} is the number of service providers. Here, the call would be blocked, if all the service providers are over-loaded.

B. System Efficiency

The System efficiency $\eta_{sys}^{(i)}$ is defined as Probability efficiency metric for service provider is determined by the processed traffic intensity and the total traffic loaded to service provider within the observation time. Thus, $\eta_{sys}^{(i)}$ is calculated by

$$\eta_{sys}^{(i)} = \frac{E_p^{(i)}}{E_{in}^{(i)}}$$

where $E_p^{(i)}$ is the processed traffic intensity in Erlang for service provider i and $E_{in}^{(i)}$ is the total traffic loaded to the service provider i within the observation time t.

C. Spectrum Utilization Efficiency

The Spectrum Efficiency $\eta_s^{n_{(sp)}}$ is defined as the ratio of average busy channels over total channels owned by service providers. It corresponds to

$$\eta_s^{n_{(sp)}} = \lim \frac{1}{t}\int_0^t \frac{n_{busy}^{n_{(sp)}}(t)}{N_{ch\text{-}total}^{n_{(sp)}}(t)}dt$$

where $n_{busy}^{n_{(sp)}}(t)$ is the number of channels used at time t for service provider $n_{(sp)}$ and $N_{ch\text{-}total}^{n_{(sp)}}(t)$ is the total number of total channels owned by service provider $n_{(sp)}$. Higher Spectrum efficiency is estimated because the call blocking rate is lower; thus more calls can contribute to the spectrum utilization.

D. Revenue(Cost) Efficiency

Within the observation time, cost is determined by the number of processed calls and the length of call holding time. We define the metric $c_e^{(i)}$ to reflect the cost efficiency. $c_e^{(i)}$ is the ratio of the cost earned within the observation time t over total input traffic intensity for service provider sp, is defined as

$$c_e^{(i)} = c^{(i)}/E^{(i)} = \alpha^{(i)}.E_p.t^{(i)}/E^{(i)} = \alpha^{(i)}.t^{(i)}.\eta_s^{(sp)}$$

where $\alpha^{(i)}$ is the unit price ($/second/channel) for service provider sp and $c^{(i)}$ is the average income within the observation time.

E. Free Spectrum Calculation

Free Spectrum can be calculated using the allocated spectrum and limited allocated spectrum values. Maximum users, process service request, allocate spectrum, allocate limited spectrum, lookup unoccupied band, is spectrum free, set user priority and occupy band are the measures to find out the free spectrum.

Free Spectrum will be calculated using the allocated spectrum and limited allocated spectrum values. Maximum users, process service request, allocate spectrum, allocate limited spectrum, lookup unoccupied band, is spectrum free, set user priority and occupy band are the measures to find out the free spectrum.

1. Setting the maximum users per channel.
2. Service request: allocate band for user based on the allocate limited spectrum for primary user and secondary user.
3. Allocate spectrum: Occupy the band after checking free band with maximum user and also indicate the node which occupies the band at which level. Sensing is carried out inorder to find out the free band. It

gives the results with spectrum id, users with channel user, time in and time out.

4. allocate limited spectrum: By using the learn and decision of CR, find out the unoccupied band. Then, we can allocate limited bands for secondary users.
5. lookup unoccupied band: This is to check out the free bands for maximum users.
6. set user priority: priority has been set to the primary user.

Based upon the time in and time out values, the allocated spectrum can be measure.

VI. SIMULATION RESULTS

Using NS2 simulation the performance of the overall system efficiency has been evaluated. The call arrivals are modeled using the Poisson distribution, while the call holding times are exponentially distributed. The main simulation parameters used in this work is shown in TABLE 1.

TABLE I. SIMULATION PARAMETERS

Parameters	Values
Energy model	Energy Model
Channel	Wireless Channel
Propagation Model	TwoRayGround Model
Initial energy	100
Number of nodes	150
X Value	1000
Y value	1000
Number of channels	4
Number of Base stations	5
Number of Primary user	10
Pause time	12.00
Maximum Speed	0.00
Queue length	100
rxPower	0.3
txPower	0.6
Service Types	Call Service, Internet service, Multimedia service

In this section, we present simulation results on the performance of our proposed sensing framework. Channel assignment mechanisms in the traditional multi-channel wireless networks typically select the 'Best' channel for a given transmission. In the proposed work, we are choosing the available channel with the high probability and high-frequency band. To generate utility performance measures, we assume:

1) Maximal five service providers share their spectrum, and 150 nodes are chosen. Maximum limit of user per channel is 10.

2) Call arrival of each service provider is the heterogeneous process.

3) Traffic rates are correlated jointly-Gaussian random variables.

4) The infrastructures for different service providers are located at the same position and the cell radii is also the same.

5) The CR nodes are present at the vertices of the cells of the service providers.

6) Each CR node has the ability of sensing its range within the coverage limits.

7) CR nodes have the capability of detecting all the available channels that are licensed to the other service providers.

8) Channel parameters such as interference level, the probability of being available for a given time period and cost are the same for all available channels.

We conduct simulations to verify the potential of the call arrival rate for different service providers in terms of utility performance measures.

Fig. 6 shows that at higher traffic rates, the call blocking rate is higher when the traffic rates of different service providers are highly correlated. Here, all the service providers might be under loaded or overloaded simultaneously.

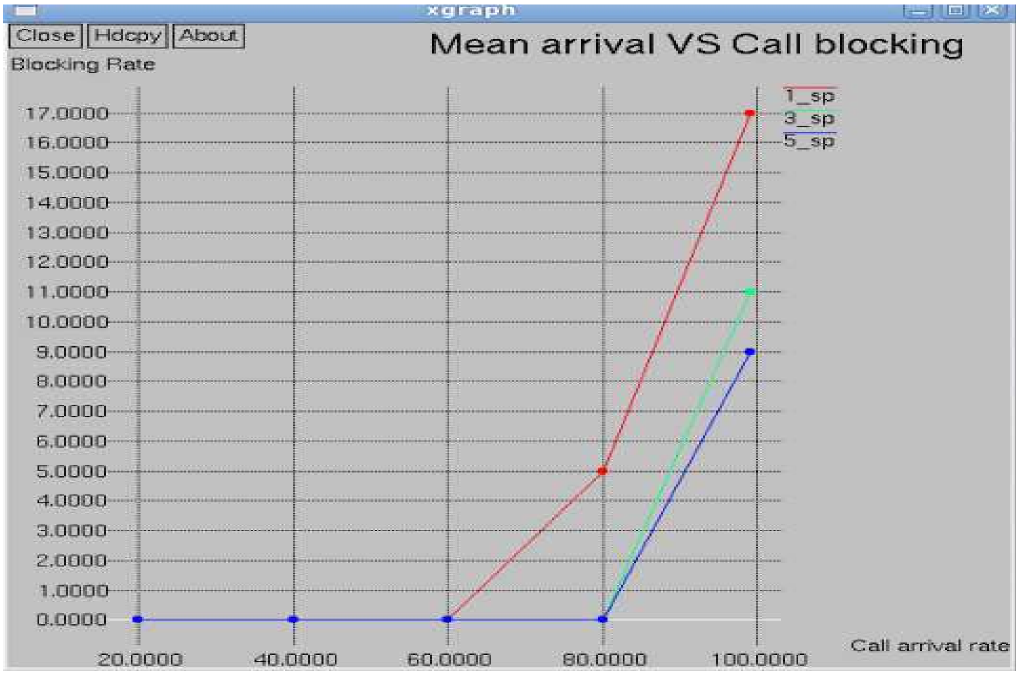


Fig. 6. Mean arrival vs Call blocking

Hence, if the call arrival rate is found to be higher, then the probability of that overloaded service provider successfully obtains the channels that are licensed to the other service providers which is low, because other service providers may experience the same heavy traffic load as well. This will leads to a call blocking rate.

Fig. 7 shows that it depends upon the call arrival rate, so the allocated spectrum get varies among service providers. It depicts that for maximum service provider limited portion of a spectrum is occupied and it also shows that the free spectrum available for further spectrum utilization.

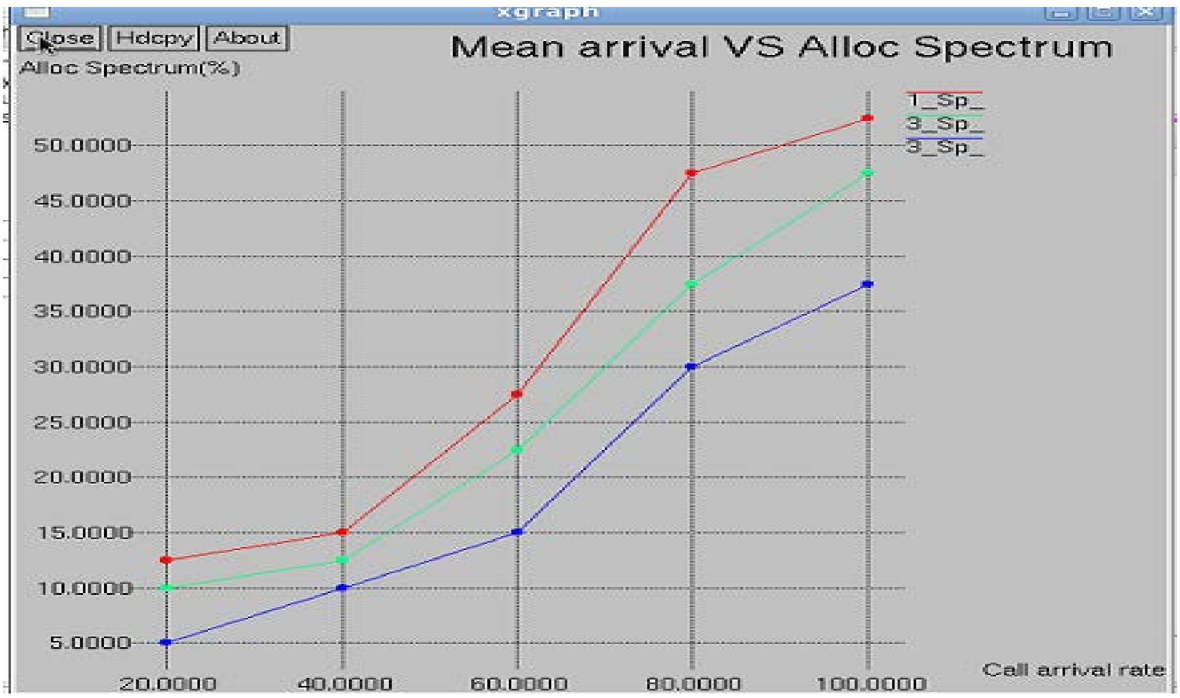


Fig. 7. Mean arrival vs Allocated Spectrum

Fig. 8 shows that the occupied band after calculating the free spectrum. The call blocking rate decreases when the number of service providers increases: in this case, more channels are available for sharing.

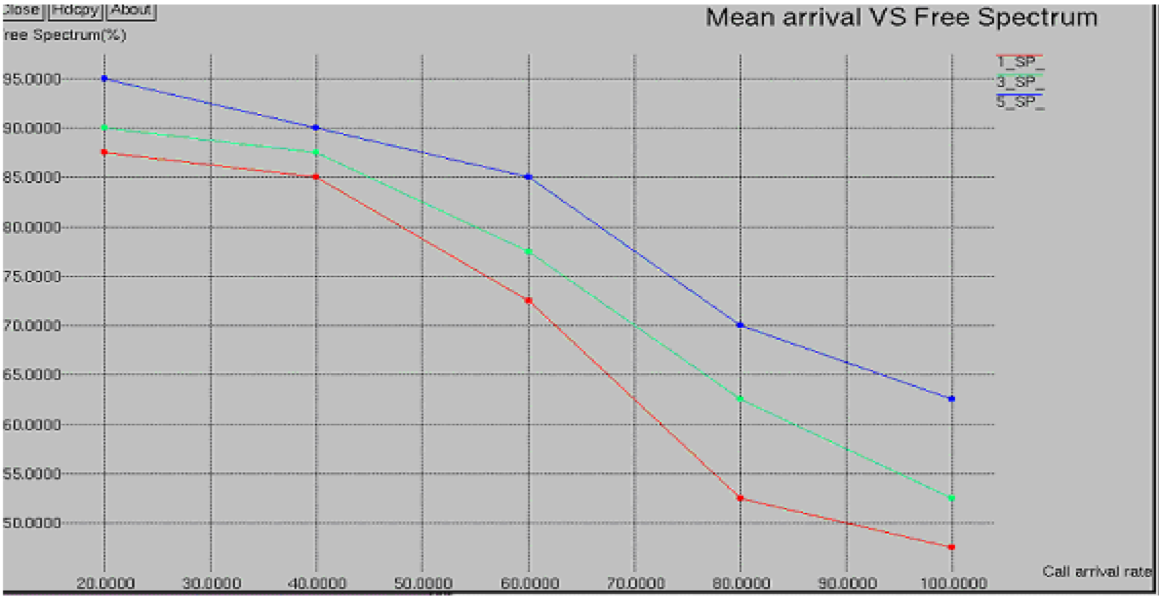


Fig. 8. Mean arrival vs Free Spectrum

Interference is the key factor that limits the performance of wireless networks. Spectrum managers are fundamentally concerned with managing interference and in establishing the methods, techniques, information and processes needed to protect users and uses from harmful interference. Harmful interference arises in radio systems when a transmitter's ability to communicate with its intended receiver(s) is limited because of the transmissions of other transmitters. The problem may be thought of as arising from the limitations of the receiver: better receivers are more able to extract the desired signal from a noisy environment of background radiation and other transmitters.

$$interference = |\, frmax - frmin \,|$$

It dynamically minimizes the inter-cell interference and significantly improves the system performance. As the mean call arrival increases the Interference gets decreased and there will be a minute variations in the Interference as shown in the Fig. 9.

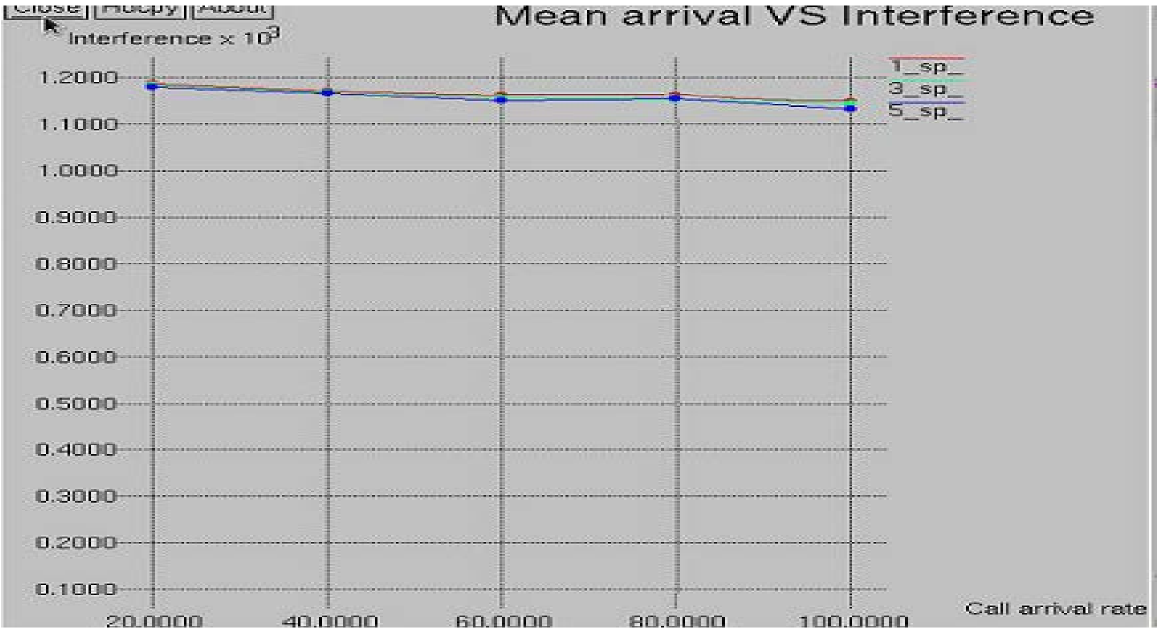


Fig. 9. Mean arrival vs Interference

As the mean call arrival increases the channel utilization also increases as in the Fig. 10. Higher Spectrum efficiency is estimated because the call blocking rate is lower; thus, more calls can contribute to the spectrum utilization.

Fig. 11. shows that, at high-traffic rates, the system efficiency is lower when the traffic rates of different service providers are highly correlated.

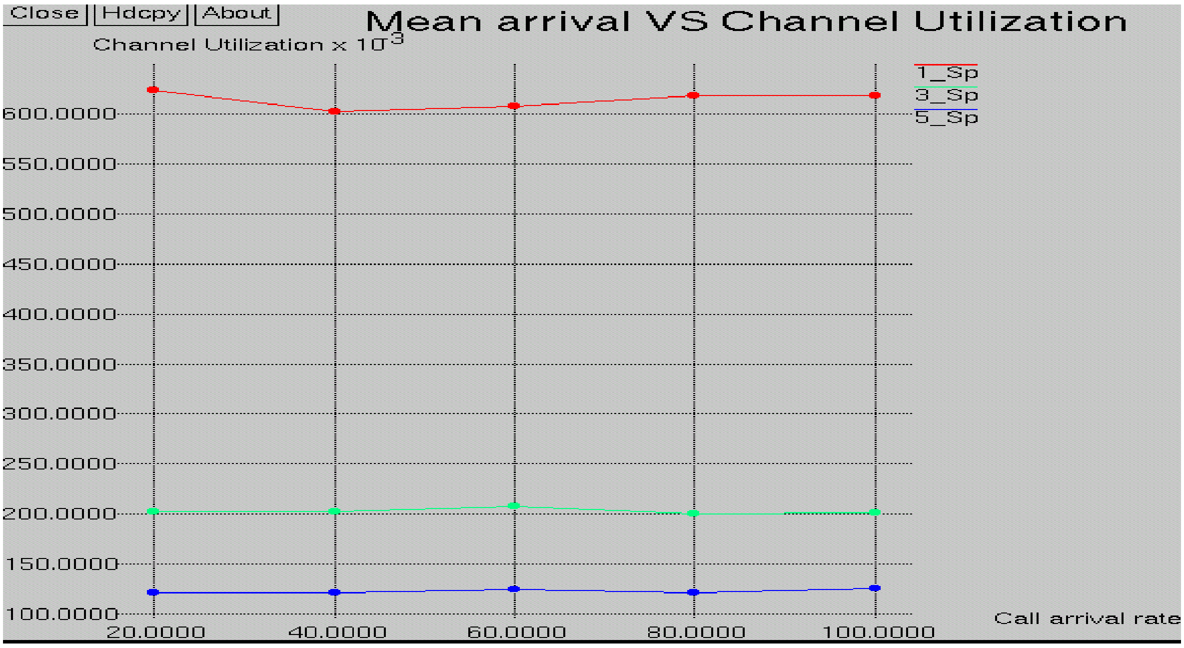


Fig. 10. Mean arrival vs Spectrum Efficiency

When the correlation is lower, based on Fig. 11, as the dropped calls decrease, thus, the total processed calls increase. The system efficiency decreases when the traffic rate is beyond the system capacity.

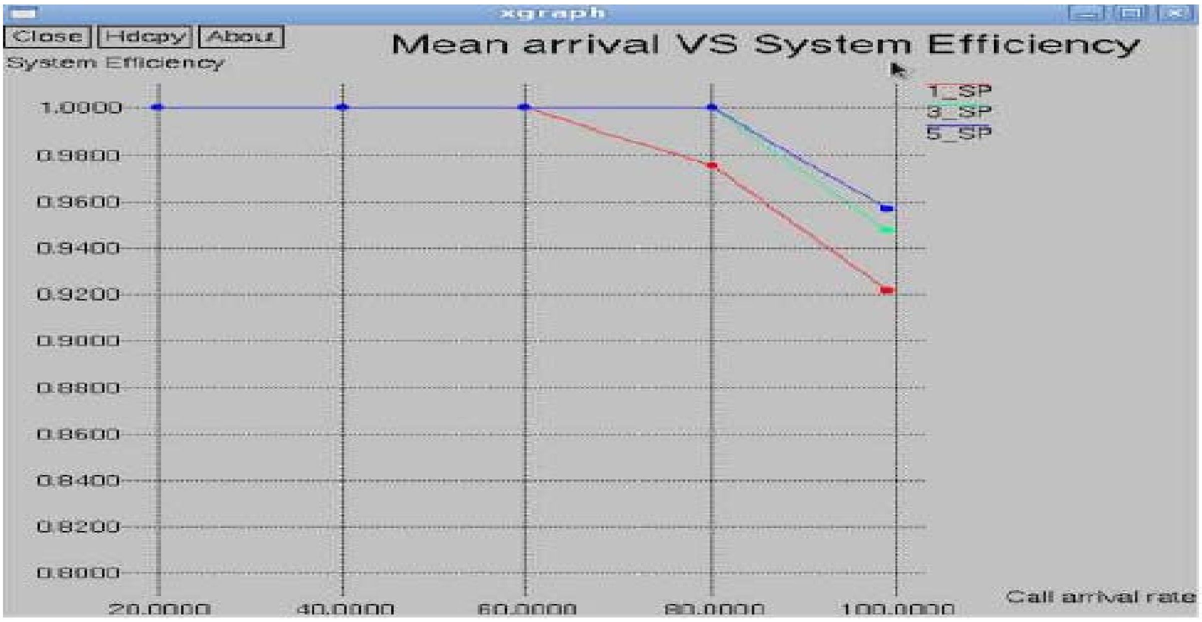


Fig. 11. Mean arrival vs System Efficiency

VII. Conclusion

This paper, provides an efficient way to utilize the unused spectrum of the licensed users. The spectrum assigned to one service provider is not utilized efficiently, then that unutilized spectrum of licensed user can be shared among the other service providers when there is a need for the other service providers in a licensed manner.

Here, we discussed the operations of CR nodes sensing and infrastructure sharing of service providers. From this work, wee can sense the range of CR node and decide the optimal channel for spectrum sharing.

In addition to this work, we calculated the allocated spectrum and unused(free) spectrum which is used to allocate the spectrum for other service providers(unlicensed users of licensed spectrum) during the sharing process. This gives an idea regarding the unoccupied bands, limited allocated spectrum, user priority and so on.

Here, we predicted the call blocking rate, interference among users during sharing, channel utilization and system efficiency. Spectral utilization, probability efficiency of sensing are increased, minimizes the interference and reduces the call blockage. In the future work, avoiding Interference will be carried by applying OFDM.

Acknowledgment

The First Author extends her gratitude to UGC as this work was supported in part by Basic Scientist Research (BSR) Non SAP Scheme, under grant reference no.11-142/2008(BSR) UGC XI Plan.

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