Multiple service providers sharing Spectrum dynamically via Cognitive Radio in a Heterogeneous Wireless Networks

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Abstract

The current utilization of the spectrum is quite inefficient; consequently, if properly used, there is no shortage of the spectrum that is at present available. Therefore, it is anticipated that more flexible use of spectrum and spectrum sharing between radio systems will be key enablers to facilitate the successful implementation of future systems. Cognitive radio, however, is known as the most intelligent and promising technique in solving the problem of spectrum sharing. In this paper, we consider the problem of spectrum sharing among users of service providers to share the licensed spectrum of licensed service provider. We formulated the problem based on bandwidth sharing in which each service provider's users makes use of the amount of spectrum and each primary user may assign the spectrum among secondary users by itself according to the information from secondary users without degrading its own performance. Service provider central systems suffer from low *utility* performance defined in terms of spectrum efficiency, blocking rate, and free spectrum.

Keywords: Call blockage, Channel allocation, Spectrumscarcity, Spectrum sharing, Spectrum utilization

1. Introduction

The demand for spectrum is increasing and many frequency bands are becoming more congested especially in densely populated urban centers. All nations share the electromagnetic spectrum and reserve their right to its unlimited use. However, to facilitate international telecommunications cooperation to support trade, transportation, communications, and mutual protection against interference, all countries have agreed to an International Telecommunications Convention. Growths in mobile communications have exposed the scarcity of radio spectrum but it is not clear how serious this demand really is and especially, what is the future growth rate of service demand.

Spectrum scarcity has emerged as a primary problem encountered when trying to launch new wireless services. Scarcity is not one-dimensional, since there can be differences between urban and rural areas with spectrum most likely being highly congested in urban areas. In spite of this scarcity problem, recent spectrum utilization measurements have shown that the available spectrum opportunities are severely underutilized i.e. left unused. The spectrum scarcity leads many industrial and academic research groups to explore spectrum sharing in a multiple access environment. Spectrum Sharing is the answer to Scarcity in Licensed Spectrum Utilization.

Spectrum sharing closes the gap between contention-based. In order to solve the conflicts between spectrum scarcity and spectrum under-utilization, Cognitive radio technology was recently proposed dynamic multiple access in terms of using the available spectrum efficiently. A cognitive radio can be considered as a system which continuously interacts with its environment to evaluate the availability of resources and needs of users so as to efficiently utilize the spectrum available. It does so by changing its operation parameters like frequency of operation, modulation and coding technique etc.

In this paper, we introduce the cooperative spectrum sharing across multiple service providers and also determine the call blocking rate, various operations of CR nodes and infrastructures for the technique and also we focus on the problem of Spectrum scarcity in wireless networks. This issue is very important for efficient and reliable utilization of the spectrum. The main goal is to provide the maximal number of Service providers to use the licensed Spectrum with service capabilities in wireless networks.

The spectrum consists of channels which are dynamically allocated to the network users upon request, i.e., during a call set-up. If there are no available channels, a new call is rejected. This rejection rate can be reduced by an effective channel allocation strategy. In addition to the limited number of radio channels, radio interference represents another restriction in communications within cellular networks.

Paper Organization

The rest of the paper is organized as follows. In Section 2&3, the related work and spectrum sharing are briefly introduced. Infrastructure of CR based Spectrum sharing is discussed in section 4. Channel availability in CR nodes and Channel determination are derived in Section 5 as problem description. In section 6, the performance measures of Spectrum sharing is presented. Finally, we draw our conclusions in Section 7.

2. Related Work

Recent studies show that most of the assigned spectrum is under-utilized while the increasing number of wireless applications leads to a spectrum scarcity. An introduction to cognitive radio was provided in [1] where cognitive radio was defined as an intelligent wireless system and the fundamental cognitive tasks as well as the behaviors of cognitive radio were discussed. In [2], a comprehensive survey of the functionalities and research challenges in cognitive radio networks (also referred to as NeXt Generation (xG) networks) was presented.

Cognitive Radio is proposed as a technology to solve the imbalance between spectrum scarcity and spectrum underutilization. Primary-secondary spectrum sharing has the potential to substantially alleviate the growing problem of spectrum scarcity [3-4]. Most current work, e.g. [5-7], have focused on allowing secondary devices to transmit when and where the strength of primary transmissions is so weak that spectrum is considered “unused”. The spectrum sharing opportunities are not affected by the increase in the field size even if the field size grows to infinity[8]. For a CR network consisting of one primary user and multiple secondary users sharing the same frequency using Nash equilibrium[9] based on the auction theory. Markets for spectrum assets would allow the same spectrum to be allocated to different applications across locations and times, according to demand[10]. Using traditional spectrum sharing techniques the potential for such sharing is limited giving the requirement of high confidence protection of the Federal usage. However, more sharing that could enable new private sector systems and economic growth is possible if certain types of future Federal systems were designed to facilitate sharing by letting the private sector users have real time information about spectrum use[11-12]. A service provider (SP) operating a base station will not have to pay any licensing fees. It would share a total spectrum with other SPs in a geographical region and further allocate this spectrum to users efficiently[13-14].

In this paper, sharing of CR nodes to maintain spectrum sharing among multiple service providers in a geographical and cooperative manner which reduces the call blocking rate, cost and battery power consumption of user devices and also improves the spectrum utilization efficiently.

3. Spectrum Sharing

Spectrum can also be shared in several dimensions; time, space and geography. Limiting transmit power is also a factor which can be utilized to permit sharing. Low power devices in the spectrum commons operate on the basis of that principal characteristic: signal propagation which takes advantage of power and interference reduction techniques.

Spectrum sharing enables operators to lease their surplus/unused spectrum to other operators on commercial terms, which consequently results in more efficient allocation and optimal utilization of the spectrum, which is already a scarce resource. It also allows the operators to share each other’s spectrum in a mutually beneficial manner in order to improve the overall trunking efficiency.

Spectrum sharing may be needed when:

- Demand for spectrum exceeds the supply;
- There is congestion and the potential for harmful interference;
- The technical means exist to permit different users to share; and
- Other means for adjusting spectrum use and assignment (such as re-farming) have become burdensome and costly, undermining the goals of economic and technical efficiency.

Spectrum sharing can be categorized as :

- Unlicensed transmitters to operate in the licensed bands at locations where the spectrum is temporally unused.
- Unlicensed spectrum: A Spectrum ie free from centralized control where anyone can transmit without a license while complying with rules that are designed to limit/avoid interference(Eg: Leasing, Trading & Spectrum commons).
- Spectrum transfers: Spectrum can be assigned nationally or on a regional or local basis; a given assignment can be partitioned & shared by users at different locations.

In this paper, Cooperative spectrum sharing across different service providers are discussed with cost and risk of operating CR nodes. The spectrum can be shared among multiple connections (i.e., other Primary users) in which the base station (BS) governs the radio transmission on the allocated spectrum.

4. CR based Spectrum Sharing

Major problem of spectrum sharing comes into picture ie there may be multiple CR nodes trying to access the spectrum, this access should also be coordinated in order to prevent multiple users colliding in overlapping portions of the spectrum. CR nodes are regarded as ‘‘visitors’’ to the spectrum they allocate. Hence, if the specific portion of the spectrum in use is required by a licensed user, the communication needs to be continued in another vacant portion. As a result, spectrum mobility is also important for successful communication between CR nodes[15-16].

In CR networks, where a large portion of the wireless spectrum is considered, the neighbors of a node may change as the operating frequency changes. This technique: (a) removes the sensing function in each user and infrastructure of service providers; thus, reduces the cost, complexity and power consumption of user devices while implementing the spectrum sharing based on CR techniques; (b) improves the spectrum utilization efficiency; (c) can be applied to the current wireless networks to reduce call blocking rate and (d) supports prioritizing spectrum allocation for public safety and other emergency services.

When one or more infrastructures (eg. Base stations) of service providers are overloaded, they use extra available channels which are licensed to other service provider in the same geographical locations in a particular time. The channel availability of the service provider is obtained by the surrounding CR nodes. Channel availability and channel utilization are estimated by deploying CR nodes of a service provider as in Fig. 1.

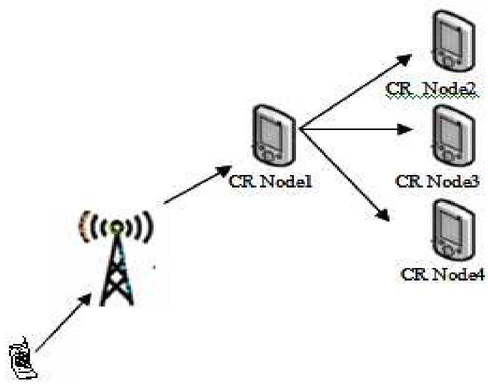

Fig. 1 CR nodes sensing the available channels

Channel utilization is provided on the request of the overloaded service providers. Approaches for the overloaded infrastructures to find out the channel availability of licensed service providers can be given by means of monitoring the near by available channels and CR nodes used to sense the available channels within its coverage area. The cell radii of each service provider differs and are not located at the same location. This could lead to co-channel Interference. (Interference depends on various parameters, such as cell shape, size, layout, defined protection ratio, etc).

To reduce the co-channel interference, CR nodes are distributed regularly within an area and each CR node senses the surrounding environment and monitors the channel usage within its sensing area. This technique can be used on shared spectrum to assign channels automatically based solely on activity by users monitors for potential interference to co-channel users (Fig. 2).

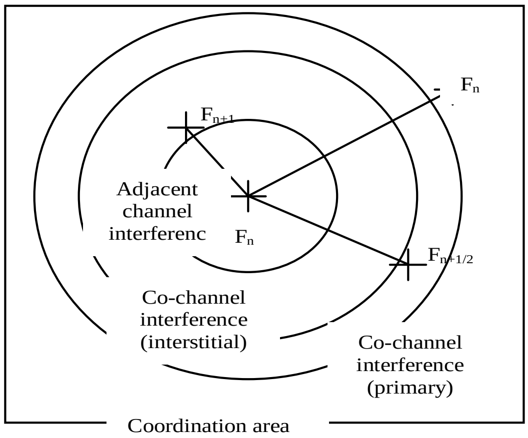

Fig. 2Co-channel Interference

Users have the freedom of selecting and joining a service provider at any time instance and geographical location. In this system, mobiles are made intelligent enough to select an *optimum service provider* via a cost function defined in terms of: (a) channel availability, (b) congestion rate, (c) the service provider quality of service in terms of bit-error rate (BER) performance, (d) cost-per-second, and (e) signal power.

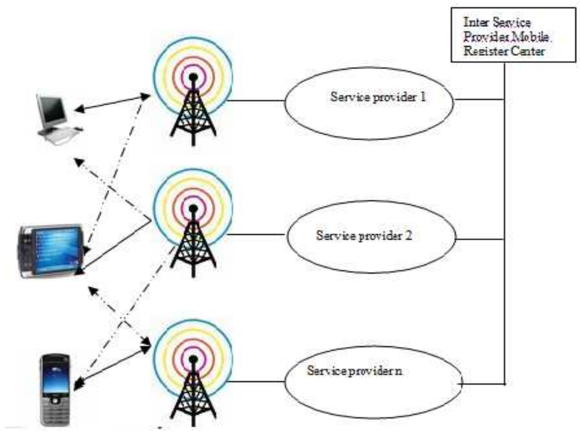

Fig. 3 Multiple Users in CR

Mobile Registration Center (MRC)works as a center which manages all mobiles independent on service providers and records all available service providers that can reach a mobile user at any time, and it can be deployed centrally or distributed in the network(Fig.3). In user-central wireless systems, mobiles are not required to subscribe to any service provider; they become legal users of wireless network as long as they register to the MRC.

The use of non-uniform channels by different CR users makes topology discovery difficult. From Fig. 4a, we see that the CR users A and B experience different PU activity in their respective coverage areas and thus may only be allowed to transmit on mutually exclusive channels. The allowed channels for CR A (1,2) being different from those used by CR B (3) makes it difficult to send out periodic beacons informing the nodes within transmission range of their own ID and other location coordinates needed for networking.

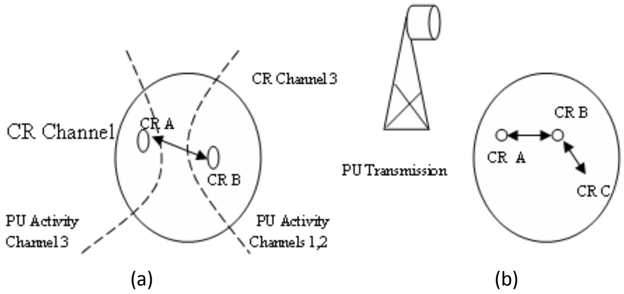

Fig. 4Spectrum sharing challenges in Cognitive radionodes

From Fig. 4b, if CR nodes communicate with each other wirelessly, it requires extra wireless resources and this will increase the overhead of wireless networks. Furthermore, the shared channels should be allocated to specified wireless services in order to avoid malicious use. An agreement among those service providers is necessary.

5. Problem Description

Here, we analyze the problem of channel availability and allocation as a general problem of assigning one sort of object (channels) to another sort of object (cells) subject to a set of constraints.

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. When the infrastructure of one service provider is overloaded, it requests the channel usage information in its coverage area from an adjacent CR node. The CR node coordinates with other relevant CR nodes to find available channels for the overloaded infrastructure[13].

5.1 Dynamic Channel Allocation

Dynamic Channel Selection(DCS) as presented in [17-18], is a fully distributed algorithm for flexible mobile cellular radio resource sharing based on the assumption that mobiles are able to measure the amount of interference they experience in each channel. In DCS, each mobile station estimates the interference probability and selects the base station which minimizes its value. The interference probability is a function of a number of parameters such as the received signal power from base stations, the availability of channels, and co-channel interference. Dynamic channel/spectrum allocation (DCA) techniques improve wireless system spectral efficiency via sharing the available spectrum in cell domain, i.e., within the cells of a service provider, or, in service provider domain, i.e., within the service providers of a cell.
In order to evaluate the interference probability, specific models[19-21] for each of the above parameters should be developed. The strategy for dynamic channel assignment should be sensitive to the load of the system and yields an important insight in that the dynamic channel assignment should be disallowed in certain situations even if channels are free. The dynamic strategies allow assignment of channels in a dynamic fashion only if a minimum number of channels are free. This number depends on the value of the measured load.

5.2 Determination of Channel availability

The traditional fixed block allocation process implies some trunking inefficiencies in the use of the spectrum. Spectrum blocks can be considered as traffic servers where economies of scale are present; basic traffic theory states that a common group of channels will make more efficient use of the available spectrum than if it is divided up among many partitions.

The efficiency losses of allowing multiple service providers to utilize fragmented spectrum instead of sharing a common allocation can be expressed by the following formula:

$$h_e(\%) = 100 * (A_1 - A_N)/A_1$$

where h_e= percent efficiency loss,
A_1= traffic load served by a single operator with *B* channels and
A_N= traffic load handled by *N* operators with *BIN* channels each.

The quality of service (blocking rate) is assumed to be the same for each operator. Fixed block allocations for multiple providers lead to another form of inefficient spectrum utilization.

To check the channel availability in the co-channel cell is determined based on the cell radii and relative positions of infrastructures of service providers involved. CR node determines unused available channels based on the probability on the channel, cost of using the channel, etc.

5.3 Channel Determination

The total channel utilization η is defined as the ratio of the mean number of occupied channels to the total number of channels.

$$\eta = \frac{1}{N}\left\{\sum_{n_1=0}^{N}\sum_{n_2=0}^{N-n_1}(n_1+n_2)\pi(n_1,n_2)+\sum_{n_1=1}^{N}\sum_{n_2=N-n_1+1}^{N}N\pi(n_1,n_2)\right.$$

The total carried traffic (TCT) is defined as the total traffic (both PT and ST) that the system supports in the given service area.

6. Parameters for Evaluation

To evaluate the performance of the proposed scheme, the impact of spectrum sharing on the service providers include call blocking rate, system efficiency, cost, etc.

6.1 Blocking rate

The call blocking rate (*i*) is defined for user *i* that corresponds to the number-of-blocked calls till time *t* for user *i*, and the number-of-initiated calls till time *t* for user *i*. Obviously, the call blocking rate for a user drops because the user has a freedom to select a service provider with available channels. Here, the call would be only blocked, if all service providers are over-loaded. Call blocking occurs if the service provider is fully loaded in the neighboring cells to avoid high co-channel interference.

6.2 System efficiency

The spectrum efficiency is defined as the number of channels used at time *t* for service provider and the number of total channels owned by service provider. Higher spectrum efficiency is anticipated compared to service provider, because the call blocking rate of user-central system is lower; thus, more calls can contribute to the spectrum utilization.

6.3 Spectrum utilization efficiency

Efficient use of spectrum is achieved by the isolation obtained from antenna directivity, geographical spacing, frequency sharing and time-sharing or time division. Therefore, the measure of spectrum utilization factor, *U*, is defined to be the product of the frequency bandwidth, the geometric space and the time denied to other potential users.

6.4 Revenue Efficiency

The accumulative revenue earned by service provider at time *t* is defined as the revenue earned by service provider within the time period [*t* -1, *t*], the number of channels assigned to user *i* by service providerand used for the duration. The total revenue for service providers would be higher. This is a direct result of the lower blocking rate and higher spectrum efficiency.

6.5. Free Spectrum Calculation

Number of n users in service providers calls in the system at time *t* will be negligible when compared with overall performance. We classify the channel occupancy of the system in state (n_1, n_2) as *pre-full* if $n_1 + n_2 < N$, *just-full* if $n_1 + n_2 = N$, and *post-full* if $n_1 + n_2 > N$.

7. Simulation Results

The main simulation parameters used in this work is shown in TABLE 1.The call arrivals are modeled using the Poisson distribution, while the call holding times are exponentially distributed with a mean of 120 seconds.

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.

TABLE 1
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

Fig. 5 shows that at higher traffic rates, the call blocking rate is higher when the traffic rates of different service providers

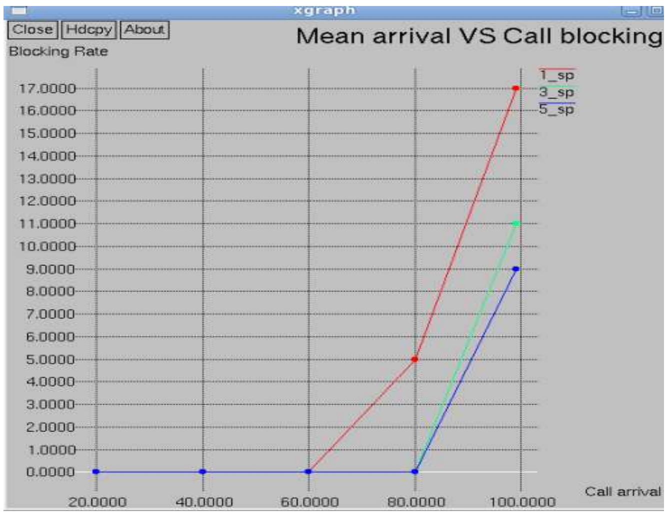

Fig. 5 Mean arrival vs Call blocking

Here, all the service providers might be under loaded or overloaded simultaneously. 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.

If the call arrival rate is found to be lower, then the heavy traffic load obtains the channels that are licensed to the other providers have lower traffic load. Hence, the low correlation of call arrival rate reduces the call blocking rate.

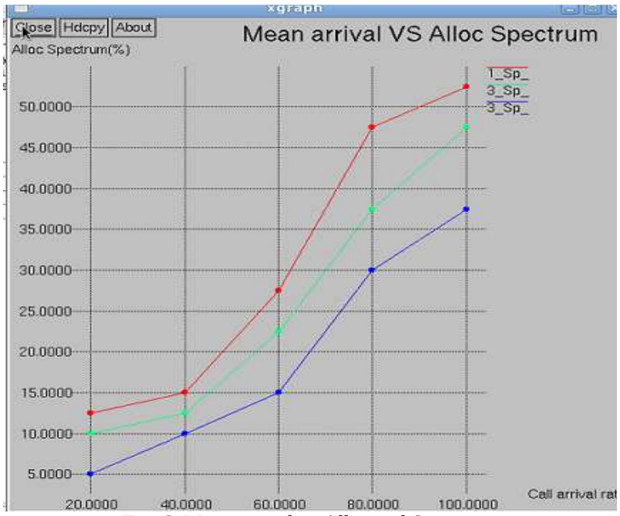

Fig. 6 Mean arrival vs Allocated Spectrum

Fig. 6 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.

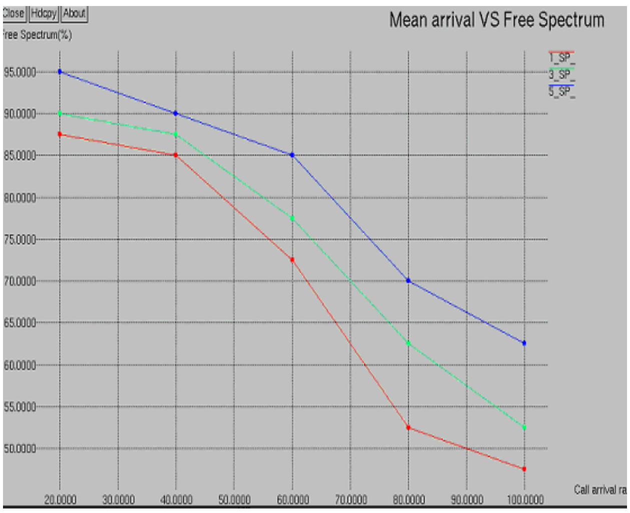

Fig. 7 Mean arrival vs Free Spectrum

Fig. 7 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.

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.

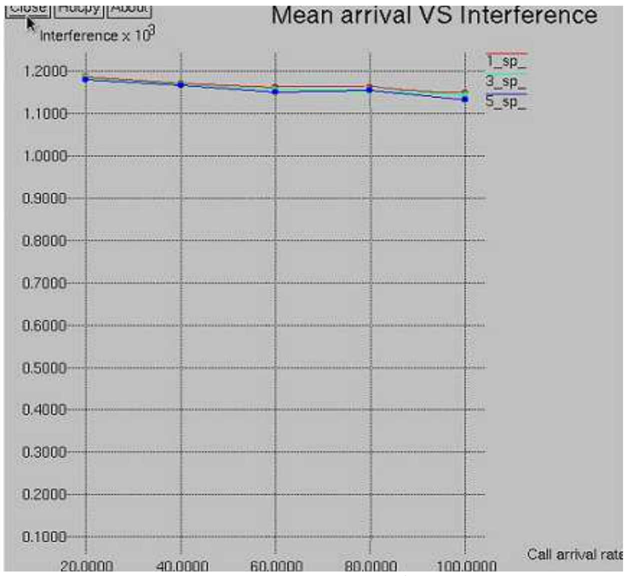

Fig. 8 Mean arrival vs Interference

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. 8.

As the mean call arrival increases the channel utilization also increases as in the Fig. 9. Higher Spectrum efficiency is estimated because the call blocking rate is lower; thus, more calls can contribute to the spectrum utilization. Therefore, the total utilization of the spectrum increases.

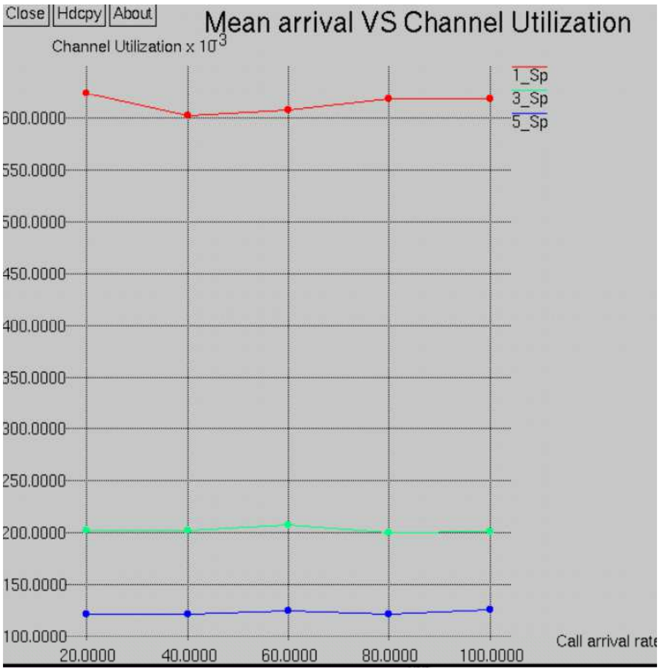

Fig. 9 Mean arrival vs Spectrum Efficiency

8. Conclusion

Extending the availability of today's radio spectrum is a natural interest of nationwide operators. With a more flexible regulatory framework, cognitive radios will improve coverage, capacity, and quality of service of future radio networks. With cognitive radio, spectrum assignment and licensing will become more dynamic.

Scarcity of available spectrum is limiting the growth of wireless products and services. This scarcity comes largely from our use of outdated spectrum policies and wireless technologies.

This paper is concerned with the efficient utilization of the resources (spectrum) of deployed wireless communication systems, based on a bandwidth sharing approach. The spectrum assigned to different service providers is not utilized with the same efficiency: some service providers may fully use their available spectrum and even need more, whereas others may not.

It discusses the operation of CR nodes and infrastructures of service providers for the spectrum sharing, the CR node sensing range decision and optimal channel selection in an infrastructure. In addition, the paper defines some metrics to measure the spectrum sharing performance and investigates the relationship between these metrics. This technique highly enhances the utility performance of wireless systems in terms of blocking rate, spectrum efficiency and calculating the free spectrum.

This work can extend with working advocate operation frequency aware spectrum sharing techniques due the direct interdependency between interference and radio range. It would be much efficient to select control channels in the lower portions of the spectrum where the transmission range will be higher and to select data channels in the higher portions of the spectrum where a localized operation can be utilized with minimized interference or avoiding the Interference by applying OFDM.

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