A Probabilistic Study of Spectrum Mobility:Time Relationship Model of Spectrum Handoff

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ABSTRACT
Spectrum utilization is very poor in the present schemes of frequency allocation. Spectrum is not completely used on the terrestrial level. Spectrum assets become high priced on some of the business frequency channels. Discussion and focus are primarily on the policies of spectrum management and dynamic spectrum access(DSA) technology yet, spectrum handoff and spectrum mobility are the new challenges in cognitive radio. Very few research workshave been carried out in these fields till now. In this paper methods are carried out on spectrum mobility or spectrum handoff along with the probability models relating to the spectrum holes and behaviour of the secondary user. We are proposing a time relationship model in handoff process. Studies are also being carried out on the performance and effect of spectrum mobility along with the duration of service of secondary user and probability of spectrum handoff. Lastly, output results are obtained considering the theoretical values and terrestrial environments.

Keywords
cognitive radio; spectrum handoff; spectrum mobility; departure rate

1. INTRODUCTION
The need of non-wired service has increased in a dramatic manner in the recent past. The use of spectrum by conventional, licensed and unlicensed users has increased exponentially. Due to very limited Spectrum and a large number of users, radio spectrum has become a scarce resource. In some of the countries of Europe and US all the Spectrum has been allocated to the users. Expenditure on purchasing the Spectrum licensed for 2G and 3G services has increased to a large extent in Asia and Europe.

Survey shows that there are a lot of white apace in the spectrum bands which are allocated and according to Federal Communication Committee (FCC) they must be used in order to make an efficient use of the Spectrum. Study shows that in cities which are highly populated, total Spectrum band occupancy is 12.9% and occupancy of radio frequency below 3GHz is less than 34% in commercially populated cities like Washington DC. According to the study of National Radio Astronomy Observatory in different parts of the world the minimum spectrum occupancy is 1%. Spectrum allocated for analogue transmission below300MHz is widely and constantly used. Bands allocated for industries, medical (ISM) band, and for scientific purpose at 2.4 GHz and 5.1 GHz shows a shortage in bandwidth, it means that a lot of spectrum is being wasted in these areas.

In other words, we can say that scarcity of spectrum that we are facing now is a result of the inefficient policies undertaken bythe spectrum managing bodies. Many of the research work is focused on the Dynamic Spectrum Access technology using the cognitive radio.

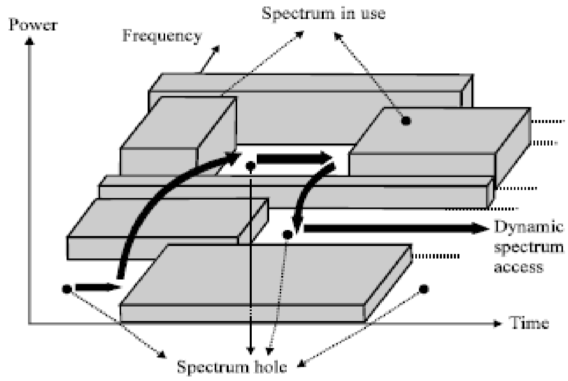

Fig.1. Detection of spectrum hole

Two systems having distinct bandwidth requirement, and using the same spectrum resource is one of the issue that has been studied. Assumption is that, there is limited number of wideband users and they don't wait in queue, whenever two systems are accessing or sharing the same spectrum resources, analysis of block rate is done using the Markov Model. Another dynamic spectrum access configuration is presented previously for sharing the spectrum among a number of networks. In order to increase the utility of licensed spectrum an Ad hoc Secondary Medium Access Control (AS-MAC) protocol[1] is presented by the Authors. Block rate, efficiency of the system, spectrum or bandwidth sharing probability were further studied by the authors from the different traffic rates of distinct operators.

In cognitive wireless network, spectrum handoff and spectrum mobility has been a challenging problem in managing the available wireless resources. With the implementation of DSA technology these issues are to be resolved. Till date, a very few research work has been carried out in these areas. Particularly in this paper, we will be discussing about the detection of Spectrum holes and their probability and behaviour of the Cognitive or secondary user. We will be also discussing about the effect of spectrum mobility on spectrum handoff during a particular call. The simulation result will be compare with the theoretical concepts and result.

Discussions are carried out as follows. In section II, we discuss the basic concept behind spectrum mobility and spectrum handoff. We represent a time relationship model insection III. Theory of spectrum handoff probability and obtained simulation outputs are presented in section IV. Lastly in section V, we conclude our final output results, and discuss the works in future.

2. LITERATURE STUDY

2.1 Spectrum Handoff and Spectrum Mobility

In a cognitive radio, whenever the performance of channel fall apart and any licensed user comes to the picture, spectrum mobility show up. Secondary user communicates with the help of spectrum holes. As the licensed user's appearance and departure is random, it leads to randomness of both appearance and departure of the spectrum holes. With the course of time, the spectrum constantly shifts. To continue a smooth communication, handoff must be done by the secondary user. OFDM is the favoured modulation technique in cognitive radio. It is always preferred due to flexibilities in modulation and easy calculation.

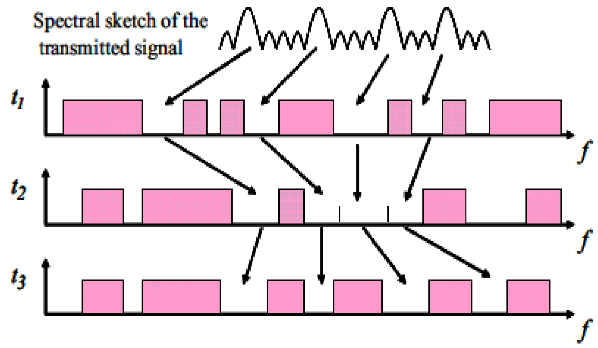

Fig.2.Handoff and spectrum mobility process

Let us take a condition of 4-subcarrier which is depicted in the figure 2. It allows the handoff process of the spectral holes with respect to time (t1<t2<t3). The pink coloured blocks indicate the occupied spectrum by the licensed user, and the white space indicates the spectrum holes which are being used by the cognitive or secondary users.

2.2 Spectrum Handoff Probability

Software and hardware costs are directly affected by the Spectrum handoff in Cognitive radio. So it is necessary and important to outline and analyse the management regarding present wireless assets. In this section, we calculate and determine Spectrum handoff probability in a single call interval of the Cognitive radio.

2.3 Few Considerations

2.3.1 Cognitive User's Consideration

It is assumed that the Secondary user's locationdoes not change in a single call interval and spectrum holes are present during that time segment. Arrival of service call and Cognitive user's departure are Poisson random process. So each service call durationrepresents negative exponential distribution. If $\frac{1}{\alpha}$ is the mean time of every call duration, then the probability density function and the distribution function of secondary user's call duration are respectively:

$$h(x) = \begin{cases} \alpha e^{-\alpha x}, & t \geq 0 \\ 0 \quad , & t < 0 \end{cases}, \qquad (1)$$

$$H(x) = \begin{cases} 1 - e^{-\alpha x}, & t \geq 0 \\ 0 \quad , & t < 0 \end{cases}, \qquad (2)$$

2.3.2 Spectrum holes consideration

In one call duration, Spectrum holes utilized by the Secondary user are sequentially numbered as #0, #1, #2, #3,.... Holding time Ti is a continuous random variable and has an identical independent distribution i.e., i = 0,1,2,3... .g(x), G(x) and $\overline{G}(x)$= 1- G(x) are the representation of the probability density function (PDF), distribution function and divisor function. So, mean and variance are as follows,

$$\begin{cases} E[T_i] = 1/\beta < \infty \\ Var[T_i] < \infty \end{cases} (i = 0,1,2,3, \dots) \qquad (3)$$

Laplace transformation of g(x) can be written as:

$$g^*(s) = \int_0^\infty g(x)\, e^{-sx}\, dx = \int_0^\infty e^{-sx}\, dG(x) \qquad (4)$$

2.3.3 Spectrum hole number assumption

Spectrum holes accessed in current time whenever at the initialization of a new service call is designated as #N0 and the next spectrum holes which are being experienced by the Secondary user as #N1, #N2, #N3, ...

3. MATHEMATICAL MODEL

3.1 Spectrum handoff probability calculation

Time relationship model in one service call holding time is shown in fig3. Residual time after the beginning of one service call is denoted by Tr. Holding period of white space which is engaged by secondary user is denoted by Ti. Duration of call is denoted by D0. A total time span in which a call is initiated till it is finished occupying the spectrum hole is denoted by Di. Di also obeys the negatively exponential distribution.

$$g_r(x) = \frac{1 - G(x)}{E[T_0]} = \beta\big(1 - G(x)\big) \qquad (5)$$

According to density function, we get,

$$\int_0^\infty g_r(x) dx = 1, \qquad (6)$$

In fig.3, we can see that in one call duration time D0, 'n' time spectrum handoff occur. we will be calculating spectrum handoff probability for 'n' time i.e., Pn during time D0.

(1) n=0

Here P0 represents the zero occurring probability of spectrum handoff in time D0 , which gives the Cognitive radio's time duration of one call which occupy one spectrum hole. So, probability P0 is,

$$P_0 = P_r\{D_0 \leq T_r\} = \iint_{u \leq v} h(u)\, g_r(v) du dv$$

$$= \iint_{u\le v} \alpha e^{-\alpha u} g_r(v)dudv = \int_0^\infty g_r(v)dv \int_0^v \alpha e^{-\alpha u}\, du$$

$$= \int_0^\infty g_r(1-e^{-\alpha v})dv \qquad (7)$$

$$= \int_0^\infty g_r(u)dv - \int_0^\infty g_r(v)e^{-\alpha v}dv$$

$$= 1 + \frac{1}{\alpha}\int_0^\infty g_r(v)de^{-\alpha v}$$

$$= 1 - \frac{\beta}{\alpha}\,(1 - \int_0^\infty e^{-\alpha v}dG(v) = 1 - \frac{\beta}{\alpha}\,(1 - g^*(\alpha))$$

(2) n>0

Here we calculate the probability of 'n' time spectrum handoff in time D0 which occurs simultaneously.

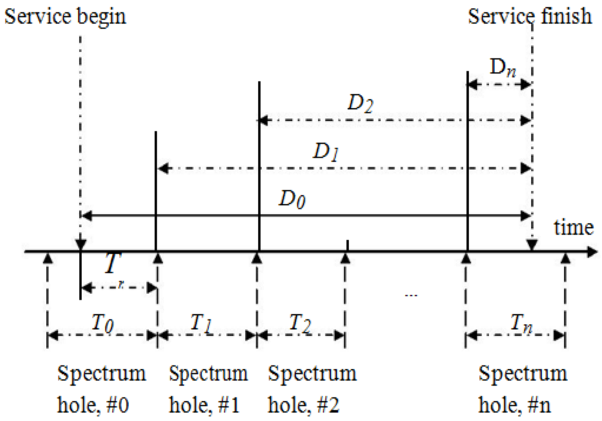

Fig.3. Time relationship model

Here Ti (i=1,2,3,...) is an independent distribution function. So, we obtain:

$$P_n = P_r\{T_r < D_0, T_1 < D_1, T_2 < D_2, \ldots, T_{n-1} < D_{n-1}, T_n > D_n\}$$

$$= P_r\{T_r < D_0\}.P_r\{T_1 < D_1\}.P_r\{T_2 < D_2\}\ldots.P_r\{T_{n-1} < D_{n-1}\}.P_r\{T_n > D_n\} \qquad (8)$$

$$= P_r\{T_r < D_0\}(P_r\{T_1 < D_1\})^{n-1}P_r\{T_n > D_n\}$$

$$= (1 - P_r\{D_0 \le T_r\})(P_r\{T_1 < D_1\})^{n-1}(1 - P_r\{T_n \le D_n\})$$

$$= (1 - P_0)(P_r\{T_1 < D_1\})^{-1}(1 - P_r\{T_n \le D_n\})$$

also,

$$P_r\{T_1 < D_1\} = 1 - P_r\{T_1 \ge D_1\} = 1 - \iint_{y\le x} h(y)g(x)dxdy$$

$$= 1 - \iint_{y\le x} \alpha e^{-\alpha y} g(x)dxdy$$

$$= 1 - \int_0^\infty g(x)dx \int_0^x \alpha e^{-\alpha y}dy$$

$$= 1 + \int_0^\infty g(x)\,(e^{-\alpha x} - 1)dx \qquad (9)$$

$$= 1 + \int_0^\infty e^{-\alpha x}g(x)dx - \int_0^\infty g(x)dx = \int_0^\infty e^{-\alpha x}g(x)dx$$

$$= g^*(\alpha)$$

Simultaneously, we can also obtain,

$$P_r\{T_n \le D_n\} = g^*(\alpha) \qquad (10)$$

From (8),(9),(10), we can get (11),

$$P_n = \frac{\beta}{\alpha}(1 - g^*(\alpha)(g^*(\alpha))^{n-1}\big(1 - g^*(\alpha)\big) \qquad (11)$$

$$= \frac{\beta}{\alpha}(1 - g^*(\alpha))^2(g^*(\alpha))^{n-1}$$

We can obtain probability of handoff in one service call duration using (7) and (11);

$$P_n = \begin{cases} 1 - \frac{\beta}{\alpha}\big(1 - g^*(\alpha)\big), & n = 0 \\ \frac{\beta}{\alpha}(1 - g^*(\alpha))^2(g^*(\alpha))^{n-1}, & n > 0 \end{cases} \qquad (12)$$

Where, $\frac{1}{\beta} = \int_0^\infty xg(x)\,dx$

Spectrum holes arrival and departure follows Poisson distribution. If we consider, effect of primary user activities on the spectrum hole, the above Poisson distribution is reasonable.

If 1/λ is considered as each hole's mean time then density function and distribution of Ti can be determined as:

$$g(x) = \begin{cases} \beta e^{-\beta x}, & t \ge 0 \\ 0, & t < 0 \end{cases} \qquad (13)$$

$$G(x) = \begin{cases} 1 - e^{-\beta x}, & t \ge 0 \\ 0, & t < 0 \end{cases} \qquad (14)$$

solving (4) and (13)we get (15),

$$g^*(\alpha) = \int_0^\infty g(x)\,e^{-\alpha x}dx = \int_0^\infty \beta\, e^{-\beta x}e^{-\alpha x}\,dx$$

$$= \beta\int_0^\infty e^{-(\beta+\alpha)x}\,dx = \frac{\beta}{-(\beta+\alpha)}(e^{-\infty} - e^0)$$

$$= \frac{\beta}{\beta+\alpha} \qquad (15)$$

Solving (15) and (12), we can get (16),

$$P_n = \begin{cases} \frac{\alpha}{\beta+\alpha}, & n = 0 \\ \frac{\alpha\beta^n}{(\beta+\alpha)^{n+1}}, & n > 0 \end{cases} \qquad (16)$$

Where β indicates the spectrum holes departure rate and α indicates the cognitive service call departure rate.

4. RESULTS AND DISCUSSIONS

To observe the effect of α and β on the probability of spectrum handoff, we make changes in the value of one parameter and fix the other parameter and get the probability graph. In order to generate a random variable use Poisson distribution.

4.1 Simulation process

4.1.1 Effect of α on probability of spectrum handoff

Step 1: A random variable with α mean is generated to simulate the Cognitive call.

Step 2: A series of random variable with β mean is generated to simulate the Spectrum holes.

Step 3: One variable from step 1 and one variable from step 2 is compared.

Step 4: Spectrum handoff will take place if cognitive call variable is greater than the Spectrum holes variable;

Step 5: If spectrum handoff take place, we add the first and second variable from Step-2 and compare it with the variable from step-1. If the cognitive call variable is greater than the sum of the spectrum holes variable, spectrum handoff take place.

Step 6: Different probability of spectrum handoff can be obtained when we repeat the process from step-1 to step-5, and with the repetition better result are obtained and it resembles the Poisson distribution.

4.1.2 Effect of β on probability of spectrum handoff

Step 7. By exchanging β and α different series of probability of spectrum handoff can be obtained by repeating the steps from 1 to 6.

Case 1: Fixed cognitive call variable and changing spectrum holes variable.

Here we do not make any changes in the value of cognitive call variable but we make changes in the value of spectrum holes variable. Let we take α = 140 calls per hour β = 20-340 spectrum holes per hour. Figure 4 is the corresponding simulation result. When we keep α constant, we can observe that the probability of spectrum handoff increase sharply with respect to increase in the value of β. This happens due to the greater value of β, which corresponds that the spectrum holes are moving with a faster rate. Therefore it can be calculated that the white space detected by a single service call is more whenever holding time average of white space is shorter. Thus, more number of handoff will occur naturally.

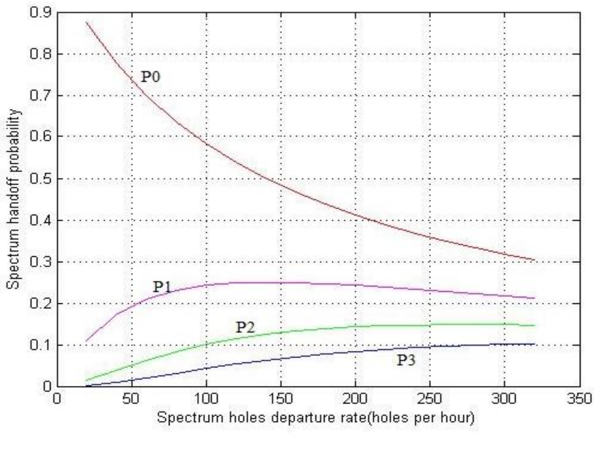

Fig.4. Effect of β on probability of spectrum handoff

Case 2: Fixed spectrum holes variable and changing cognitive call variable

Here we fix the value of spectrum holes variable and change the value of Cognitive call variable. Let we take α = 1-820 calls per hour, β = 160 spectrum holes per hour. Figure 5 is the corresponding simulation result. When we kept β constant, it can be observed that the probability of spectrum handoff increase sharply with respect to increase in the value of α. This happens due to the greater value of α, which corresponds that the service call duration time is shorter and the spectrum holes moving rate is slower. We can also say that during one service call the spectrum holes detected is very small. Thus naturally less number of handoff will occur.

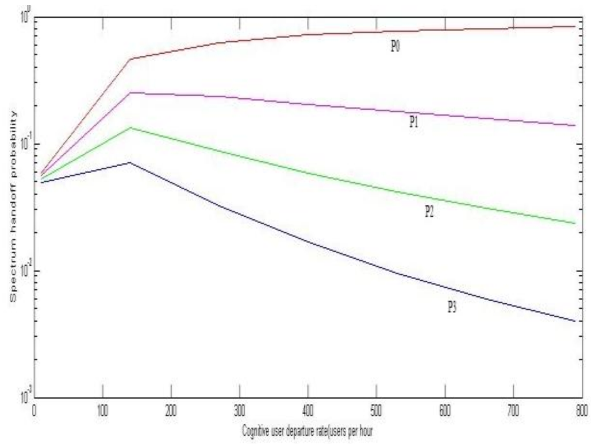

Fig. 5.Effect of α on probability of spectrum handoff

From the simulation result, it can be observed that, some individual point deviates and is not in continuous manner. This happens because we are using Monte Carlo simulation method and the observation window is very small as compared to actual area under observation.

5. FUTURE WORK

Spectrum mobility depends upon the spectrum handoff probability which is a vital factor. Spectrum mobility holds a major and necessary are of spectrum resource management. Success rate of secondary user, handoff success rate, call dropping rate and network indicators will be the future work for us. These factors will be greatly influenced by the spectrum mobility/handoff. With the help of actual measurement information in current scenario occupancy of spectrum from 30Mhz to 3Ghz are also to be investigated in the future work. This will help us to improve the result of this paper work.

6. CONCLUSION

We discuss the concept of spectrum handoff and spectrum mobility in the cognitive radio. As the spectrum is a very scarce resource, it must be utilized very efficiently. Systems must be optimised to get better results. We successfully propose a time relationship model in spectrum handoff. Spectrum handoff probability is concluded and factor which influence the spectrum mobility are studied successfully. Using the Monte Carlo simulations, the theoretical concepts and spectrum management policies the simulation results are obtained successfully.

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