Chapter VII

Keeve Information Identification Technique for Spectrum Sharing Based on Geo-location, Time and Frequency
7.1 Introduction

Spectrum sharing evolves in wireless communication due to the necessity of extra bandwidth. As the number of wireless device increases, the bandwidth crisis needs a solution for the efficient and fair usage of the spectrum and thus the concept of spectrum sharing emerges. Spectrum sharing and spectrum sensing differs from each other as in the case of sharing, both PUs and SUs can be accommodated in a single channel (Underlay/Overlay/ or any other method), while spectrum sensing searches the vacant spectrum to accommodate SUs. Depending on the application level, Geo-space information and other network provider issues, one has to first choose between both and then decide for their respective implementation. The state of the art in the coexistence of the communication system and bandwidth sharing is very important. In spectrum sharing, the licensed bandwidth involves PUs and if the SUs utilizes the same spectrum, it has to ensure no interference [251]. Some of the technical challenges include precise sensing of radio environment and accordingly transmitting the signals and maintaining the band gap with PUs. Some of the issues with spectrum sharing have been discussed in [251, 252].

The dynamic spectrum access in CR results in efficient spectrum utilization. With the research based on 5G for enhanced bandwidth and high data rates, it is highly essential to enable the spectrum sharing aspect of IoT based devices. CR enters the domain of spectrum sharing by a mutual collaboration with the available networks or the white space based frequency bands. The basic work starts with spectrum sensing (in physical layer) where the vacant channels are found out based on different algorithms and the result is then forwarded to spectrum decision at the network and transport layer of the OSI. The spectrum sharing concept emerges as one of the feasible solution for CR networks and especially for 5G where the amount of beam-width and directionality are the most important parameters because of millimeter wave technology. Spectrum sharing is one of the most effective solutions for eliminating spectrum scarcity issues as it allows unlicensed users or the CR transceivers to coexist along with the licensed users. Efficient spectrum usage through CR has been elaborated using the two proposed methods: i) dynamic spectrum access based on the spectrum sensing outputs [253, 254] where the secondary or the CR user sense the channel and occupies only when the PUs or licensed users are not present and, ii) spectrum sharing using Underlay or Overlay schemes [253, 254, 255] where the CR user coexist with PUs based on a separation gap in power levels without interfering the later.
Further spectrum sharing in architecture level includes Centralized and Decentralized [254] approach. In centralized approach the spectrum allocation and access procedure has been governed by a central entity and in Decentralized approach it is governed on a local basis. In case of cooperative spectrum sharing, the individual channel nodes consider the status of every other nearby node and try to formulate a smooth sharing among them. In case of non-cooperative spectrum sharing, the individual nodes or channels have been considered and underlay or overlay operations are performed. Previously, a lot of research has been focused on different strategies for capacity enhancing of spectrum sharing based on optimal power allocation which maximizes the ergodic capacity using average interference and power constraints [255, 256].

The research has also been carried out for spectrum sensing and sharing based on frequency, time and Geo-space location. In our proposed model, we have proposed a sharing model, where the motion and different sharing parameters are considered based on the Poisson process. The model has been designed considering spectrum sharing issues that may arise in 5G. Massive MIMO and millimeter wave concept is expected to improve the spectrum efficiency and transmission bandwidth. Here, the model proposes a design based on the mobility of CR, i.e., Geo-space information availability and Network’s contribution towards sharing with CR for a continuous or instantaneous time scale. In section 7.2, the proposed KIIT model has been explained and section 7.3 highlights the mathematical implementation of the algorithm based on the likelihood of occurrence of sharing. In general, the work considers the PSD of a same channel at different positions and at different time instants. These make the input parameters of the algorithm independent of each other and later the likelihood is found out using optimized set and minimum search algorithms. The analysis of the model and the simulation result shows a positive likelihood of the sharing performance.

The chapter proposes the spectrum sharing based operation for CR users and network based on the observation of pre-information on a location or the nature of the CR users. A new empirical technique, i.e., KIIT is used to estimate the information based sharing for a mobile CR with respect to time and frequency band availability. The study uses the Geo-space or location
information in sharing to determine the likelihood of getting shared by networks at two different location and time.

The novel aspect of the spectrum sharing on the basis of three basic parameters is designed. These are the Geo-space, time and the network (frequency bands), where a CR transceiver is considered as moving or entering any location asks for spectrum sharing. The whole process can be categorized in terms of the information of CR available to the network or not and in terms of the information of the network available to CR or not. The different parameters for calculation are taken as uninformed and informed CR, and Geo-space based information available. The likelihood function is analyzed based on ED method where the PSD of the channel is considered as parameters for informed and uninformed CR, independent of time and location. The mobility of the CR user generates the likelihood of spectrum sharing with the available networks. The overall operations are assumed to be in the form of the Poisson distribution.

7.2 KIIT

The model assumes different instants and continuous sharing modes with respect to time, and other cases of Geo-space based dependability on sharing parameters. The motivation behind the model come from the word “KEEVE” which means a large bucket or tub. The tub is compared with a Geo-space where the uninformed or informed CR transceivers enter into.

The corresponding behavior after entering the KEEVE is shared with the network available in a continuous or instantaneous manner. With the standard model, the sharing is being decided by the actions of informed and uninformed CR mobility in a Geo-space and the sharing priority changes. The model focuses on the mobility of CR transceivers arrival to a particular location for continuous sharing, keeping the frequency allotment constant with respect to that Geo-space. Our main aim is to calculate empirically the sharing attributes. Assuming single CR shares with an available network in a single available channel for \( i=1, \ldots, I \) time. For any single continuous day and time should be \( i \in [0, T] \). The networks are ready to share with CR based on CR information.

Prior to sharing operation, the study of the nature of Geo-space database and network sharing of the region is mandatory. Location based information is very important with respect to a fixed day or time for initialization of the sharing process.
The model is based on the assumptions that the CR transceiver observes the sharing in a given area as it is on move and for a particular day as \( \alpha \). When the location update takes place, the available networks not ready to share has a probability \( \delta \). Informed CR enters a geographical area with probability \( \mu \) and uninformed CR participates in sharing with a probability \((1- \mu)\). \( \lambda \) denotes the uninformed sharing instantly while as \((1- \lambda)\) is the probability of uninformed sharing continuously between the CR and the network. Assuming the presence of an uninformed CR, who is waiting for the sharing availability with a probability of sharing instantly as \( \varepsilon_s \) and no sharing as \((1-\varepsilon_s)\). Uninformed CR is sharing with a network ready for sharing continuously and not sharing as \((1-\varepsilon_g)\).

Let \((V_i)_{i=1}^I\) be the variables, which provides the sharing parameters at the end of each sharing processes \(i=1,\ldots,I\). Assuming the Geo-space location information is available to CR and the network present is ready to share at time \( I \) with parameter value be \( \tilde{V_i} \) and similarly network not ready for sharing case at the time \( i \) as \( (V_i) \). For no sharing condition for a particular time \( i \) is given by \((V^*_i)\). Assuming the case that \((\tilde{V_i})<((V^*_i))< (\tilde{V_i})\).

Sharing is performed by both informed and uninformed CR and an uninformed CR transceiver arrival is assumed to follow the Poisson distribution. The uninformed CR and the uninformed network exist in \( \varepsilon \) which is the rate of sharing per unit time. For a particular instance when sharing is performed, another informed CR may also arrive. If the CR observes good sharing conditions, it may start its own process without being cared for the other CRs present in that Geo-space.

When an uninformed CR comes in a Geo-space and tries to convert itself to informed CR the process follows a Poisson distribution. The rate of arrival of this uninformed CR is \( \mu \). The arrival of these CRs is assumed to be independent. The tree diagram in Fig 7.2 shows the sharing model based on Geo-space network behaviors and time.
First, segregation is based upon availability of Geo-location of the CR user. Further, it is divided based on network’s readiness to share resources with CR user. Subsequent, division is based on information about CR supplied with the networks or not. As per the node which is selected, for a particular time, the CR arrival rate is assumed to follow a Poisson distribution. For Geo-space based information available to the CR and positive sharing conditions, the CR arrival rates are given by $\mu$, when the network has information about the CR. The other cases are as follows: when the network is ready to share and it is not having CR information, the arrival rate is given by $(1 - \mu + \lambda + \epsilon_s)$ for instant sharing; when the network is ready to share and it is not having CR information, the arrival rate is given by $(1 - \mu + 1 - \lambda + \epsilon_g)$ for continuous sharing.

Fig 7.1 Proposed tree diagram of model
When Geo-space based information not available to CR, the CR arrival rate is given by \((\lambda + \varepsilon_g)\) in case of continuous sharing and \((1 - \lambda + \varepsilon_s)\) for instantaneous sharing. Finally, for non-sharing conditions, the uninformed CR arrives at a rate of \((1 - \lambda + 1 - \varepsilon_s)\) for continuous and \((\lambda + \varepsilon_g)\) instantaneous sharing.

### 7.3 Likelihood Function Analysis

Defining the parameter vector \((\theta) = (\alpha, \delta, \varepsilon, \mu)\) where parameter \(\alpha\) and parameter \(\delta\) define the conditional probability of Geo-space information available with network ready to share and Geo-space information available but the network is not ready to share. The informed CR states are denoted using \(\varepsilon\) and \(\mu\) where, \(\varepsilon\) is uninformed CR sharing with network and \(\mu\) is the informed CR not sharing with the network. Only by observing the sharing, it is not possible to identify the uninformed and informed CRs. Thus, the parameters can be extracted using any standard model.

When the Geo-space information is not available to the CR, there is no informed CR in that particular location and may be some of the uninformed or informed CR may arrive any time. Considering the first case of Geo-space information available and networks ready to share, the arrival rate of uninformed CR is \((\mu + \varepsilon)\). The likelihood of observing any sharing with Geo-space \((G)\) location, Share \((S)\) and No Share \((N)\) available for a particular time \(T\) is given by

\[
L_{G, S, N|s} = e^{-\epsilon T} \frac{(\epsilon T)^G}{G!} e^{-(\mu + \varepsilon) T} \frac{((\mu + \varepsilon) T)^S}{S!}
\]  \hspace{1cm} (7.1)

Which can be written in terms of probability as:

\[
prob(G, S, N|s = share) = [\mu + (1 - \mu) \lambda \varepsilon]^G [(1 - \mu) \lambda \varepsilon]^S [2(1 - \mu)(1 - \varepsilon) \lambda]^N
\]  \hspace{1cm} (7.2)

Similarly, when Geo-space information is not available, the likelihood of sharing and non-sharing is given by:

\[
L_{G, S, N|ns} = e^{-\varepsilon T} \frac{(\varepsilon T)^G}{G!} e^{-\mu T} \frac{(\mu T)^S}{S!}
\]  \hspace{1cm} (7.3)

Which is:

\[
prob(G, S, N|s = notshare) = [\mu + (1 - \mu) \lambda \varepsilon]^S [(1 - \mu) \lambda \varepsilon]^G [2(1 - \mu)(1 - \varepsilon) \lambda]^N
\]  \hspace{1cm} (7.4)
When Geo-space information is available and with network sharing, the likelihood may be written as:

$$L_{G,S,N|S=0} = e^{-(\mu+\varepsilon)T} \frac{[(\mu+\varepsilon)T]^G}{G!} e^{-\varepsilon T} \frac{(\varepsilon T)^S}{S!}$$

(7.5)

Which is:

$$\text{prob}(G,S,N|S=0) = \lambda^{G+S+N} [\varepsilon^{G+S} (2(1-\varepsilon))^N]$$

(7.6)

Thus, from above Eq. (7.2), Eq. (7.4) and Eq. (7.6), the number of CR entering a particular Geo-space and the sharing occurring is sufficient information for a particular reference time $T$. The likelihood of Geo-space available and sharing, Geo-space information available and non-sharing and no Geo-space information available are given in Eq. (7.6) by taking reference of [257], written as:

$$L((G,S)|\theta) = (1-\alpha) * e^{-\varepsilon T} \frac{(\varepsilon T)^G}{G!} e^{-\varepsilon T} \frac{(\varepsilon T)^S}{S!} + \alpha \delta * e^{-\varepsilon T} \frac{(\varepsilon T)^G}{G!} e^{-(\mu+\varepsilon)T} \frac{[(\mu+\varepsilon)T]^G}{G!} e^{-\varepsilon T} \frac{(\varepsilon T)^S}{S!}$$

$$\alpha(1-\delta) * e^{-(\mu+\varepsilon)T} \frac{[(\mu+\varepsilon)T]^G}{G!} e^{-\varepsilon T} \frac{(\varepsilon T)^S}{S!}$$

(7.7)

The branch-wise likelihood can further be written as:

$$L(\alpha, \delta, \mu, \varepsilon) = \prod_{t=1}^{T} [(1-\varepsilon)N_t(1-\mu)^N_t A^{G_t+S_t}] [\alpha(1-\delta) \left(\frac{\mu}{\lambda} + 1\right)^{G_t} + \alpha \delta \left(\frac{\mu}{\lambda} + 1\right)^{S_t} +$$

$$(1-\alpha)(\frac{1}{1-\mu})^{G_t+S_t+N_t}]$$

(7.8)

Where, $A = \frac{(1-\mu)\varepsilon}{2}$ and $G_t$ is the number of sharing for Geo-space information available, $S_t$ as number of non-sharing when Geo-space information is available and $N_t$ as number of sharing when Geo-space information is not available.

For a particular time, the maximum likelihood of sharing parameters $\alpha, \mu$ and $\delta$ will be 1 or 0, which implies a single sharing event occurs with respect to time.
End likelihood Value: 2.11e-06

End likelihood Value: 3.95e-07

End likelihood Value: 4.05e-07
Fig 7.2 Likelihood of spectrum sharing based on 3 CR transceivers in the morning (a) at 0-100 MHz and (b) 750 MHz-950 MHz, assuming 50% informed CR entering a location (c) 0-100 MHz and (d) 750-850 MHz, assuming uninformed CR entering a location.

The above Fig 7.2 shows the likelihood of occurrence of sharing based on the distribution of random dynamic CR transceivers. Here, the work considers one set of PSD and for some random set of Femto-cells or small irregular size cells in different places and at different time. Thus, one can consider the three basic dimensional elements as independent. The number of iterations has been taken as 140 and the graph converges at 2.117 X 10^-6 dBm that is approximately at 1mW power and 3.954 X 10^-7 dBm, which is also almost 1mW in Fig 7.2 (a) and (b), when considering the probability of number of informed CR entering a location is 0.5 and in Fig 7.2 (c) and (d), there are uninformed CR entering the same location and CR sharing is being performed with its respective frequency set.

For a number of time instances collectively, the respective likelihood of each parameter can be estimated from their respective occurrence time. Thus, for a large number of data, one can predict the sharing implementation for each day based on the proposed model. As the time dimension is taken as independent, the likelihood of sharing data \( M = (G_i, S_i)_{i=1}^I \) over \( I \) continuous time is the product of instantaneous likelihood:

\[
L(M|\theta) = \prod_{i=1}^I L(\theta|G_i, S_i) \tag{7.9}
\]
To calculate vector $\theta$ from given $M$, we maximize the above equation which provides direct estimates of uninformed and informed CR sharing in a fixed location as well as other parameters effecting the sharing.

The probability of informed sharing is defined as the unconditional probability of informed CR sharing (PIS) for a particular time, i.e.

$$ PIS = \frac{\mu_t}{(1 - \mu_t) \epsilon_t + \mu_t} $$  \hspace{1cm} (7.10)

Where, $(1 - \mu_t) \epsilon_t + \mu_t$ is the probability of performing sharing when the Geo-space information is available. The value of PIS is 0.6285 which shows a better feasibility of the model. The Eq. (7.10) illustrates the nature of the spectrum sharing of CR along with the network availability and the moving CR is having a prior knowledge of the Geo-space.

### 7.4 Conclusion

The chapter proposed differential behavior of informed and uninformed mobile CR transceivers spectrum sharing activity. Using the designed algorithm, the Geo-space information can be used to formulate the probability of information and likelihood of sharing. This will be based on the sharing between the CR transceivers. It also shows that the chances of non-sharing for informed CR transceivers during its mobility time in a particular location is less as compared with the uninformed CR transceiver.

The work demonstrates the CR network activity based sharing, especially for 5G as it involves sharing spectrum whenever a licensed and a dedicated channel are not possible in a particular location. This will not only further increase the spectral efficiency, but also the QoS using flexible spectrum usage. The work can be further extended by considering the case of adaptive modulation effects on spectrum sharing for the CR transceivers in a mobile condition and the available networks in a particular location or Geo-space.