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Effect of Dynamic Spectrum Aggregation and Allocation Algorithms in Cognitive Radio Networks

N. Suganthi, S. Meenakshi

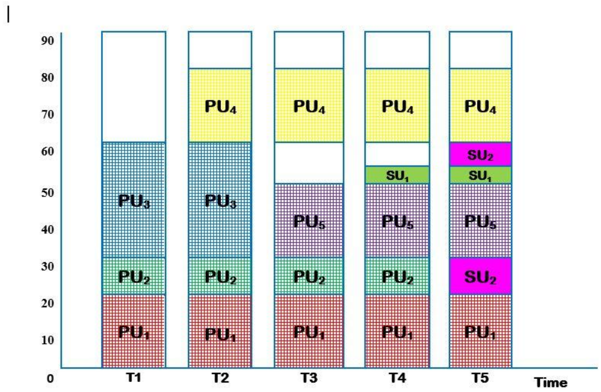
***Abstract:** With rapid proliferation of radio technology, discontinuous spectrum aggregation and access in a single radio has become conceivable. When the bandwidth of the spectrum fragment is narrow, then spectrum aggregation can be utilized to bundle multiple small fragments in one radio. This can positively improve the efficiency of the spectrum utilization. Though, aggregation of fragmented segments leads to improved spectrum utilization it results in further spectrum fragmentation leading to practical hardware constraints. As a solution, we use the popular memory allocation techniques to perform spectrum aggregation so that further fragmentation can be reduced. We derive at an efficient Spectrum Aggregation Algorithm based on Memory Allocation techniques.*

***Keywords:** Cognitive Radio, Spectrum Aggregation, Channel Fragments, Memory Allocation.*

I. INTRODUCTION

Cognitive Radio is an intellectual Wireless Communication System. It is a radio aware of its environment and capable of modifying its operating parameters according to its surroundings in real time with the goal of providing consistent anywhere anytime efficient wireless spectrum communication [1]. Hence, Cognitive Radio is used to improve spectrum usage by exploiting underutilized spectrum. The spectrum utilization efficiency of licensed users is very low. Thus, the unlicensed users in Cognitive Radio Networks can detect and utilize the portion of underutilized spectrum by licensed users in an opportunistic manner [2]. The spectrum bands detected by unlicensed users can be too small and discontinuous and hence it does not support high data rate and high-speed communications. In such cases, spectrum aggregation is a good solution that uses multiple spectrum fragments [3].

In [4], an aggregation aware spectrum assignment algorithm is proposed in which many isolated spectrum fragments are aggregated. The spectrum aggregation is carried out by searching the spectrum from lower to higher frequency to satisfy the required bandwidth of the user. In [5], an admission control spectrum assignment strategy is proposed that considers spectrum aggregation and channel switch based on the dynamics of the channel availability. The spectrum aggregation algorithms are proposed in [3] [4] and [5] with the objective of increasing spectrum utilization. Many Channel Aggregation methods are proposed in MAC protocols [6] to support high data rate SU services. In [7], the authors derived at the capacity upper bound on the number of channels that can be used for channel aggregation in cognitive radio network based on PU and SU activities and channel available conditions. In most of the studies, the channel aggregation is carried out in the spectrum that are channelized i.e. they have fixed bandwidth. However, aggregation can also be applied on fragments of different sizes [8].



Request	PU₄ 200 MHz	PU₄ 200 MHz	PU₄ 200 MHz	PU₄ 200 MHz	......
Departure		PU₃		PU₂	......

Fig. 1. – Example of Spectrum/Channel Fragmentation

The spectrum/ channel fragmentation is illustrated in the figure1. At each time interval T_i, the user request for the spectrum and the available spectrum is searched from the lower frequency and if the frequency is available then the spectrum is allocated to the user. Once the user has completed its service, it releases the spectrum. As and now when the user releases the spectrum, the spectrum fragmentation takes place. When a user requests spectrum and if the spectrum is not free contiguously, then multiple non-contiguous spectrum fragments can be aggregated and allocated. The fragmented spectrum usage leads to channel fragmentation [9] where a single channel consists of multiple spectrum holes.

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* Correspondence Author
N. Suganthi*, Research Scholar, Sathyabama University, Assistant Professor, Department of Information Technology, Jeppiaar SRR Engineering College, Chennai, India. Email: sugasureshdd@gmail.com
Dr. S. Meenakshi , Professor and Head of the Department, Department of Information Technology Jeppiaar SRR Engineering College, Chennai, India. Email: drmeenakshisrr@gmail.com

II. SPECTRUM AGGREGATION

The figure shows sample of spectrum where plain white spaces indicate available spectrum and hatched parts are already allocated and hence, they are unavailable. For example, if 3 transmissions request bandwidth of 4 MHz then C and D can be utilized for two requests and the third request cannot be granted. But if spectrum aggregation is used bands A and B can be aggregated and given to the third request.

Fig. 2. – Spectrum Allocation

A major limitation of the spectrum aggregation is that the maximum span of the aggregated bands is limited due to the limitations of the transceivers[10][11].For example if a transceivers maximum span is 20MHz, then all the aggregated spectrum bands for the transmission must be within 20MHz band range. Another limitation of spectrum aggregation is that on spectrum assignment using aggregation, there are more chances to generate new fragments that cannot be aggregated [12] within the maximum range. When aggregation leads to high fragmentation, it increases system complexity. When more fragments are generated, the bandwidth of each fragment becomes too narrow and hence extra guard bands are needed to protect adjacent users. When more fragments are aggregated, it increases the maintenance overhead of the channel including channel switching [13].

Thus, the aggregation schemes should set a lower bound on the spectrum holes size and the maximum aggregation span range used for spectrum aggregation. The proposed work in this paper uses the well-known memory allocation schemes best fit, first fit and worst fit to analyze the effect of spectrum aggregation on the spectrum fragments. The main objective of the proposed scheme is to improve spectrum utilization and to reduce further spectrum fragmentation.

III. SYSTEM MODEL

We consider a Cognitive Radio Network with M number of Primary users, N number of secondary users and a base station. The Primary users have high priority compared to secondary user for accessing the spectrum since they are licensed users. Secondary users opportunistically access the spectrum in the absence of Primary user and switches when it detects the presence of primary user. The base station has the capability to identify the spectrum holes using spectrum sensing methods. The base station performs spectrum aggregation of unused spectrum bands and allocates it to the secondary user for data transmission. The base station aggregates M number of sub channels to get one aggregated channel.

The aggregated channel C_i allocated to SU_i has a bandwidth of B_i. It is denoted by $SB_{i,j}$ where j denote the number of sub channels aggregated, j<[1,2,…M]. Every sub channel in the aggregated channel allocated to secondary user is identified by $[f_s, f_e]_{i,j}$ where $f_s$denote the start frequency and f_e denote the end frequency of the sub channel. The cognitive radio can dynamically change the center frequency and due to hardware limitations only the spectrum holes within the maximum aggregation range BW_{MAR} can be aggregated and utilized.

IV. SPECTRUM AGGREGATION METHODS

The familiar memory allocation algorithms on computers best fit, first fit and worst fit algorithms are used to perform spectrum aggregation and to analyze the effect of spectrum utilization. All these algorithms use a predefined maximum aggregation range BW_{MAR} within which the spectrum aggregation is done according to the bandwidth requirements of SUs. All the three algorithms search for the spectrum holes from lower to higher frequency in the spectrum band.

A First fit aggregation method

The first fit algorithm uses the first spectrum aggregation within the maximum aggregation range that can accommodate the user request. Assume BW_{MAR} is 30MHz and the user request BW_{req} is 15MHz. In the figure 3 there are 3 portions P_1, P_2, P_3 that shows maximum aggregation range with unused spectrum of 18,30 and 17 MHz respectively. The first fit algorithm chooses the portion P_1 since it gets that portion first on linear scan that can accommodate the user request.

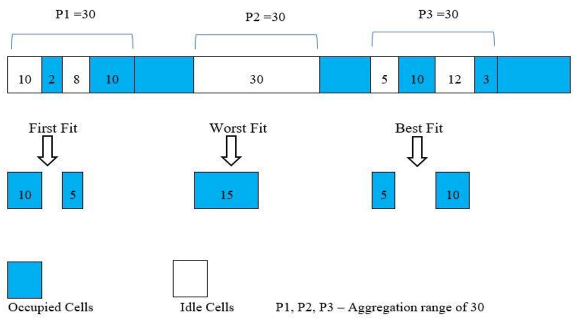

Fig. 3. – Spectrum Allocation by Aggregation Methods

B. Best fit aggregation method

Unlike first fit, the best fit algorithm searches the entire spectrum and gets the list of available spectrums within all the aggregation range. It allocates the spectrum that leaves small spectrum hole upon satisfying the user's request. In the example, the best fit algorithm chooses 15MHz from the portion P_3 which leaves remaining spectrum hole of 2MHz.

C. Worst fit aggregation method

The worst fit algorithm allocates the spectrum that leaves large spectrum hole upon satisfying the user's request. In the example, the worst fit algorithm chooses 15MHz from the portion P_2 which leaves remaining spectrum hole of 15MHz.

V.NUMERICAL RESULTS AND DISCUSSION

The main objective of Spectrum Aggregation is to maximize the spectrum utilization and to minimize further channel fragmentation.

The Spectrum Utilization can be formulated as

$$SPU = \max \sum_{i=1}^{N} (a_i * BW_i)$$

Where a_i represents the channel allocation of SU_i. $a_i$is one if the corresponding SU_i is allocated with spectrum and zero otherwise.

$$a_i \in (0,1), where\ i = 1, \dots, N$$

BW_i represents the channels CH_i allocated for SU_i. CH_i is composed of M_i sub-channels

$$BW_i = \sum_{j=1}^{M_i} [f_s, f_e]_{i,j}$$

Where $f_e^{i,Mj} - f_s^{i,1} \leq BW_{mar}$.

To minimize the number of sub channels and to minimize further spectrum fragmentation, can be formulated as

$$SF_{min} = min\left\{\frac{1}{\sum_{i=1}^{N} a_i} \cdot \sum_{i=1}^{N} M_i\right\}$$

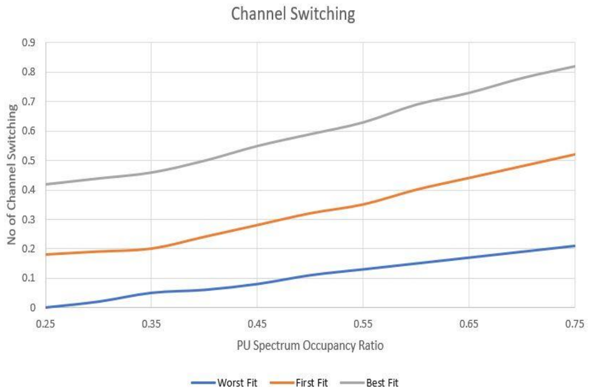

Fig. 3. – Channel Switching

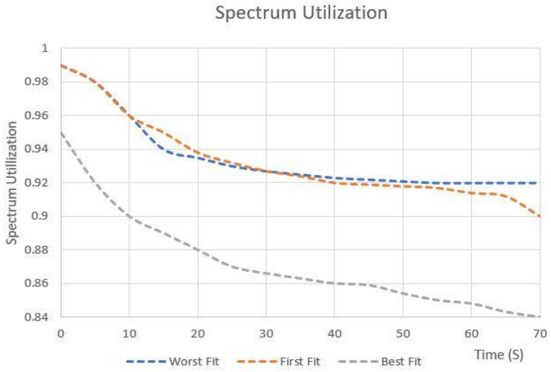

Fig 4 – Spectrum Utilization

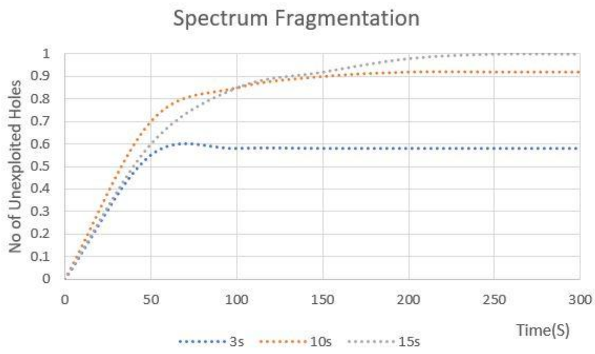

Fig 5 – Spectrum Fragmentation

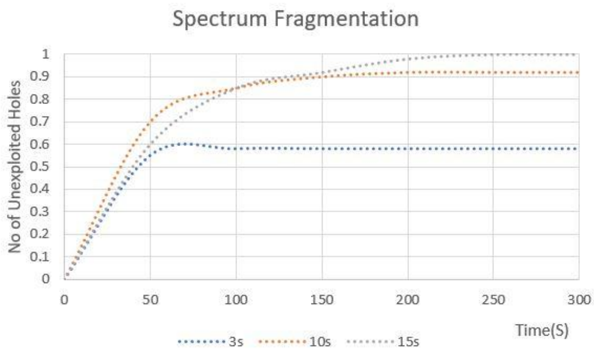

Fig. 6. – Spectrum Fragmentation

Fig 3 shows the effect of channel switching on different channel fragmentation levels. The number of sub-channels chosen for aggregation is less in worst fit algorithm. Hence it generates least number of channels switching. Fig 4 shows the amount of spectrum utilized by three spectrum aggregation methods. Since worst fit algorithm leaves less number of narrow holes, it leads to better spectrum utilization.

The effect of requested bandwidth and service time for first fit algorithm is shown in Fig 5 and 6. In Fig 5, as the bandwidth size decreases, the number of unexploited hole increases, leading to lower spectrum utilization. As depicted in Fig 6, as service time decreases the number of unexploited holes also decreases, leading to better spectrum utilization and reduced channel fragmentation.

VI. CONCLUSION

In this paper, three spectrum aggregation methods based on memory allocation techniques is discussed. It exploits the spectrum allocation methods based on hardware complexity. The aggregated channel is best if it is composed of less sub-channels and the worst fit scheme provides less sub-channels by choosing spectrum holes of large bandwidth. To reduce channel fragmentation compromise between spectrum utilization and channel fragmentation should be considered. Two traffic parameters, bandwidth request and service time are analyzed. Large bandwidth request leads to better spectrum utilization level and small service times provide short spectrum hole in spectrum allocation process. To conclude, to reduce further channel fragmentation and better spectrum utilization, high priority should be provided to wider spectrum band, large requested bandwidth and small service time.

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AUTHORS PROFILE

N.Suganthi, received her B.Tech degree in Information Technology from Pondicherry Engineering College, Pondicherry University, Pondicherry, India in 2005 and M.Tech degree in Information Technology from Sathyabama University, Chennai, India in 2008. Currently, she is pursuing a PhD in the area of Cognitive Radio Networks under Sathyabama University, Chennai, India. Her research interest includes Cognitive Radio Network, Wireless Communication and Networks.

Dr.S. Meenakshi, received her B.E degree in Computer Science and Engineering from Bharathidasan University in 1993, M.E degree in Computer Science and Engineering from Sathyabama University in 2002 and a PhD from Sathyabama University in 2010. She has 22 years of teaching experience in various Engineering Colleges. Currently, she is Professor and Head of Information Technology Department, Jeppiaar SRR Engineering College, Chennai, India. She has published 31 papers in various journals and conferences. Her research areas include Network Security and Wireless Sensor Networks.