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A Novel Dynamic Spectrum Access Network in Wireless Communication to Increase the Efficiency of Spectrum Usage

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ABSTRACT: Wireless networks are characterized by fixed spectrum policy. With increasing demands for wireless communication efficiently using the spectrum resources has become an essential issue. Cognitive radio is a form of wireless communication which is used to sense the spectrum and find the free spectrum. It is used by unlicensed users without causing interference to the licensed user. Cognitive radio with the dynamic spectrum access is key technology which provides the best solution by allowing a group of Secondary users to share the radio spectrum originally allocated to the primary users. Dynamically accessing the unused spectrum is known as dynamic spectrum access (DSA) which becomes a promising approach to increase the efficiency of spectrum usage. In this paper, DSA models are discussed along with different methods such as game theory based method, a measurement-based model, network coded cognitive control channel, Markovian Queuing model, the Delay performance of threshold policies, fuzzy logic based method and spatio-temporal spectrum management model.

I. Introduction

The ever-increasing demand of the wireless communication applications and services affirms the importance of the effective usage of the limited radio spectrum. Each user is assigned a license to operate in certain frequency bands. Most of the time spectrum remains unused and it is very difficult to find the unused spectrum. The allocated spectrum has not been utilized properly and it varies with time, frequency and geographical locations. For the removal of the spectrum scarcity and the unutilized spectrum band, Cognitive radio and Dynamic spectrum access technology has been introduced.

Cognitive radio is a figure of wireless communication in which a transceiver can perceive, which communication channels are in use and which are not, and accordingly switch into empty channels while avoiding busy ones. This optimizes the use of available radio-frequency spectrum while minimizing interference to other users. It is a hybrid technology involving software defined radio as applied to spread spectrum communication.

The concept of cognitive radio was first officially presented by “Joseph Mitola” III, at the Royal Institute of Technology in 1998 and published later in an article by Mitola and Gerald Q. Maguire, Jr in 1999: As defined by Haykins, the cognitive radio is an “intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world) and uses the methodology of understanding by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF spur by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind, highly reliable communication whenever and wherever needed; efficient utilization of the radio spectrum”. The FCC (Federal communication commission) ruled in November 2008, in which unused part of RF spectrum (known as white spaces) made available for public use. White Space Device Technology prevents interferences, such as spectrum sensing and geolocations capabilities. The parameter can altered on the basis observations of multiple factors from external and internal environment of cognitive radio environment, like radio frequency spectrum, user behaviour, and network state. Spectrum in 400-1000MHz range is shown in Figure1.

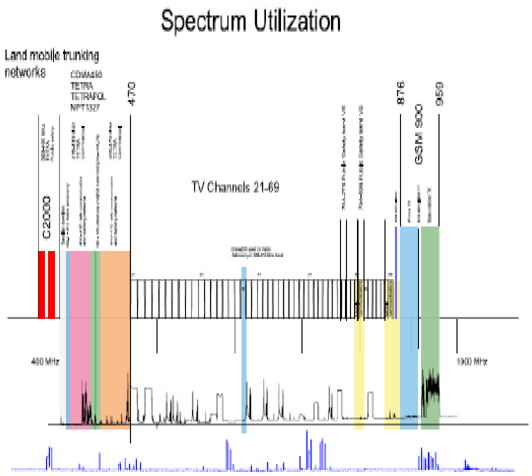

Figure 1. Spectrum Utilization.

Efficient utilization of spectrum improves by allowing a secondary user (SU) to utilize a licensed band when the primary user (PU) is absent. So the detection of spectrum hole is important as shown in Figure 2.

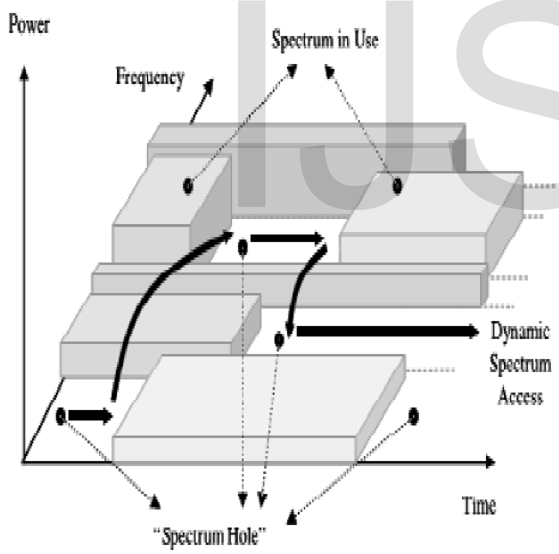

Figure 2. Spectrum Hole Concept.

Spectrum holes is basically a concept which correspond to the latent opportunities for safe use of spectrum i.e. non-interfering and considered as multidimensional regions within frequency, time, and space. The main challenge for secondary radio systems is to be able to robustly sense when they are within such a spectrum hole. To agree to a amalgamated discussion of the core issues in spectrum sensing, the "Weighted Probability of Area Recovered (WPAR)" metric is introduced where the performance of a sensing strategy and the "Fear of Harmful Interference" are evaluated. Cognitive radio is such a inimitable radio technology where user has to decide which part of the spectrum is available. When a user function in a approved (licensed) band (i.e. spectrum sensing), the best available channel is selected (i.e. spectrum management), other users access this channel (i.e. spectrum sharing) and the channel is vacated when a licensed user is detected (i.e. spectrum mobility). Regulatory bodies in various countries (including the Federal Communications Commission (FCC) in the United States, and Ofcom in the United Kingdom) found that most of the radio frequency spectrum was inefficiently utilized.

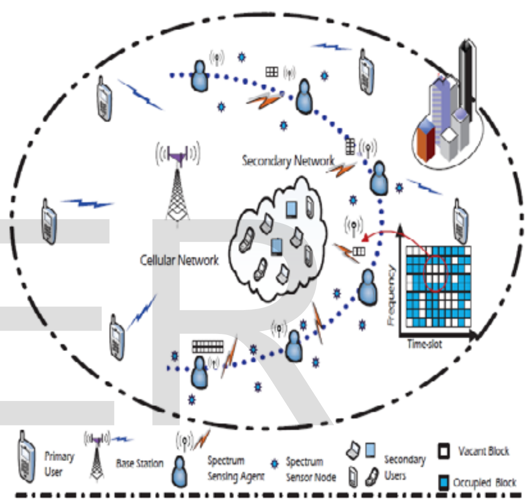

Figure 3. Coexistence scenario with cellular network and unlicensed network

Considering the time-frequency variation of detected resource blocks, those TFBs can be classified into two types according to the TFBs size: massive sized blocks and small sized blocks; and the "wholesale" sharing and "aggregation" sharing approaches are proposed accordingly. Particularly, in the "wholesale" sharing approach, the cooperation among the SUs is utilized for maximizing the utilization of massive sized blocks, while in "aggregation" sharing approach the external sensing agents cooperate with each other for minimizing the underutilized small sized blocks. Finally, we devise a distributed fast spectrum sharing (DFSS) algorithm to realize both the "wholesale" sharing and "aggregation" sharing approaches based on the heuristic packing method. The main contributions of our work are summarized as follows,

• We propose a scalable DSA model and novel associated resource management rules, which can provide a thread for efficiently utilizing the unused spectrum resources in cellular bands in a distributed and flexible way.

• We introduce a dynamic spectrum supply-demand matching strategy for the dynamic spectrum access networks, which can significantly improve the utilization of cellular bands, while helping to alleviate the spectrum scarcity.

• We develop the DFSS algorithm to reduce the delay in the spectrum allocation for resource management in cellular DSA applications, which can be helpful to accelerate the spectrum access process in the real applications.

II. DYNAMIC SPECTRUM ACCESS

Dynamic spectrum access(DSA) is a technique by which a radio system dynamically adapts to available spectrum holes with limited spectrum use rights, in response changing circumstance and objectives: interference created changes the radio's state, changes in environmental constraints. The main objective of DSA is to overcome two types of interference concern: harmful interference caused by malfunctioning device and harmful interference caused by malicious user.

Dynamic spectrum management is also referred to as dynamic spectrum access. DSA that was first demonstrated in 2006 by the Defense Advanced Research Project Agency (DARPA) and Shared Spectrum Company (SSC) of Vienna, VA. In, DSA is such an advanced approach to spectrum management which is closely correlated to other management techniques such as flexible spectrum management and spectrum trading. This allows users to access a particular piece of spectrum for a defined time period or defined area which they cannot exceed without re-applying for the resources. A DSA procedure would follow the following steps:-

• Monitor spectrum to see which frequencies have no other radio activity (i.e. they are not being used by anyone).

• Agree with other dynamic spectrum access devices in the network which frequencies will be used, via same previously agreed common channel.

• Being communicating on the agreed frequency band.

• Continue to monitor the spectrum for attempts other user to access this spectrum.

• Change frequency bands and adjust power as necessary.

The monitoring and managing of the radio resources are done by a single device in the network (centrally managed network) or by each of the devices individually and cooperatively (autonomous network).

III. PROBLEM FORMULATION

3.1. Dynamic Spectrum Access Service Model We consider a dynamic spectrum access scenario which consists of a cellular network as a primary network, a local spectrum sensing network and a secondary network as shown in Fig. 3. In the cellular network, the base station (BS) manages the resource scheduling to serve mobile stations (MSs) that are referred to as PUs. Due to different communication requirements of PUs, the statically pre-assigned time-frequency resource blocks are different. In the meantime, the MSs have different characteristics of spectrum usage behaviors, such as the frequent variations in time and space domain. Similar to, the secondary network is self-organized in the same area. Once a transport link is requested for a real-time bulk data flow transmission between two SUs, e.g., video conference, data forwarding and multi-media service, etc., SUs will apply to external sensing agents for the DSA opportunities with appropriately sized bandwidths and spectrum access durations. The local spectrum sensing network is composed of the common sensor nodes and sink sensor nodes. The sink sensor nodes can obtain the real time channel prediction information and provide the dynamic spectrum access opportunities for SUs. Once PU turns on in the free spectrum bands, the real-time spectrum usage update made by sensor nodes will inform SUs to stop transmission tasks to avoid the interference to PUs.

3.2. Problem formulation

For practical resource sharing in the spectrum market, the application rule of TFB demanders at time *t* is as follows, In practice, due to the time-frequency variation of TFBs supply and different demanded TFB sizes, there exists a supply-demand resource matching problem in the spectrum trading market. On one hand, if the sizes of some TFBs are larger than the resource demands of SUs, the improper allocation of TFBs may make the TFBs underutilized. On the other hand, if the sizes of some TFBs are smaller so that they cannot meet the need of any individual SU, those smaller sized TFBs will be wasted. Considering those two cases, the TFB supply function set RB*t* can be divided into two subsets, i.e., *RBtp* and *RBtd*.

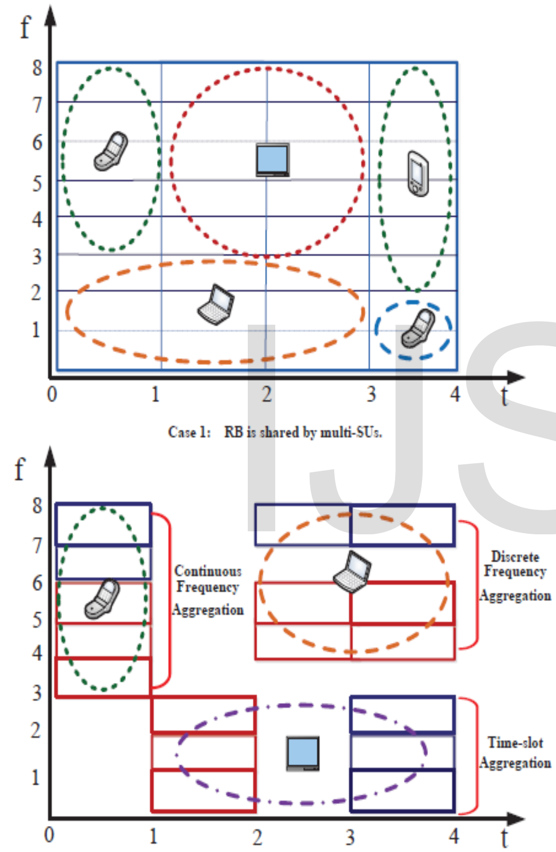

Fig. 4. Two cases in the supply-demand resource matching problem

• **Case 1:** If the time-frequency size of one individual TFB is larger than any current applicant's demand, it will be leased as a whole and allowed to be re-divided among multiple applicant SUs for required sub-channels and sub-slots. We name this approach as "wholesale" sharing, where the SUs will be charged for the whole value of applied resource blocks.

• **Case 2:** If the time-frequency size of one individual TFB cannot meet the needs of users, the multiple small sized blocks will be aggregated. We name this approach as "aggregation" sharing. To encourage SUs to apply for small TFBs in *Btd* , the applicants will be only charged for the practical applied block sizes.

Fig.4 demonstrates the examples to effectively share the provided TFBs in the two cases. Case 1 illustrates that one TFB can be shared via the optimal combination of multiple SUs to increase the TFB's utilization. Case 2 shows that if either the bandwidth or time-slot requirement cannot be met by SUs, the multiple TFBs have to be aggregated for the resource usage. The resource aggregation approach requires the SUs to use the spectrum switch technology for resource sharing and the proposed charging policy will be an incentive for them to use the small sized resources. Based on SUs' transmission rates and data capacity, at time *t*, SU μj can select any of the two resource subsets for the TFB leasing, i.e., *RBtp*or *RBtd*. Before the resource selection, the SU μj will evaluate the value of spectrum resource of *pi*, according to the specific wireless communication parameters, i.e., the allowed transmission power ρmax,*tpi* on the demanded channel, the available channel bandwidths $\kappa t\ pi$, channel gain g*tpi*, and the noise variance (σtpi)2.

IV. RESULTS AND PERFORMANCE EVALUATION

In this section, we evaluate the performance of DFSS algorithm using Matlab. To verify the effectiveness of the proposed dynamic resource demand-supply matching approach, the simulation scenario is simplified by setting $\omega t\ i$ and $\omega t\mu j$ to be constant.To specify the simulation results, Fig. 5 and Fig.6 show the packed results under random packing strategy and our proposed DFSS algorithm for Case 1. In the two figures, there are two provided RBs for the SUs' sharing. For the random packing, we do not consider the minimal surplus strategy in the packing process. Obviously, the DFSS algorithm can minimize the surplus space in the time-frequency block of RBs. Furthermore, Fig. 7 shows that the achieved utilization ratio by three typical packing approaches. Specifically, by DFSS algorithm, the highest spectrum utilization ratio is about 96.09%, and the lowest utilization ratio can also reach up to 88.48%, which is at least 25.75% higher than the utilization ratio achieved by the random packing. Compared with one typical two-dimensional packing algorithm, i.e., SHELFBWF algorithm in, which considers the strategy that the remaining width of the shelf space is minimized, the DFSS algorithm can achieve nearly the same average packed ratio. However, the time complexity of SHELF-BWF algorithm is $O(n2)$, hence, the dynamic spectrum matching time of DFSS algorithm can be greatly reduced. More importantly, as a fast convergence algorithm, the DFSS algorithm can quickly find the optimal SUs to form coalitional group for the spectrum sharing. Fig.8 shows that DFSS algorithm can reach 95% packed ratio with roughly 1/3 of the packing time by random packing. We also present the simulation results on the performance of TFB providers' cooperation case. Via the packing process of DFSS algorithm, different scattered small sized TFBs can be aggregated to meet the resource requirement of one specifical individual SU, as shown in Fig. 8. To compare the performance of packing process in Case 2 among the SHELF-BWF algorithm, DFSS algorithm, and random packing strategy, the detailed packed results under different number of TFB demanders are illustrated in Fig. 9. From the physical meaning of packed results for TFBs aggregation in Case 2, the less overpacked TFB space, the higher utilization that the TFBs will have. The data shows that, for the DFSS algorithm, the packed TFB units nearly meet the requirement of the demanded TFB units. Specifically, the maximal surplus ratio of DFSS algorithm is only about 1.76% more than that of the SHELFBWF algorithm. However, for random packing strategy, at least 43.08% time-frequency TFB capacity is wasted which indicates the significant performance improvement provided by the DFSS algorithm for the two sides matching problem.

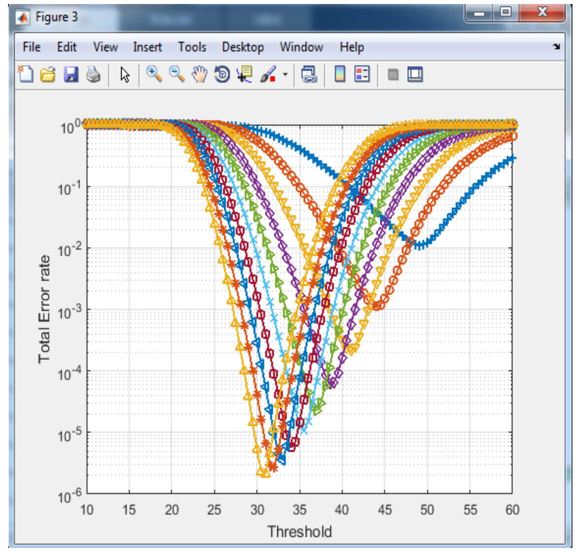

Fig.5. Shows the Threshold Vs Total Error rate for signal streanth.

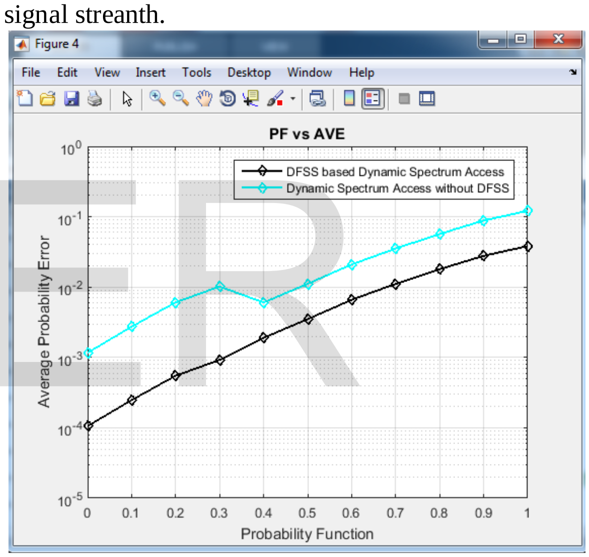

Fig.6. PF vs AVE.

To specify the simulation results, Fig. 6 show the packed results under random packing strategy and our proposed DFSS algorithm for Case 1. In the two figures, there are two provided RBs for the SUs' sharing. For the random packing, we do not consider the minimal surplus strategy in the packing process. Obviously, the DFSS algorithm can minimize the surplus space in the time-frequency block of RBs.

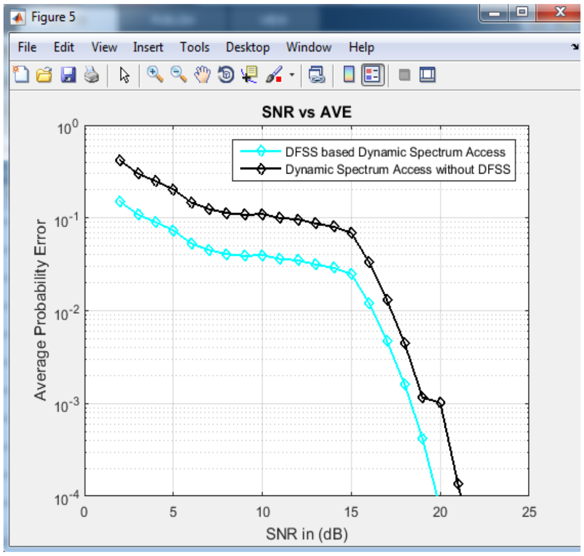

Fig.7. Snr vs AVE

Furthermore, Fig. 6 shows that the achieved utilization ratio by three typical packing approaches. Specifically, by DFSS algorithm, the highest spectrum utilization ratio is about 96.09%, and the lowest utilization ratio can also reach up to 88.48%, which is at least 25.75% higher than the utilization ratio achieved by the random packing.

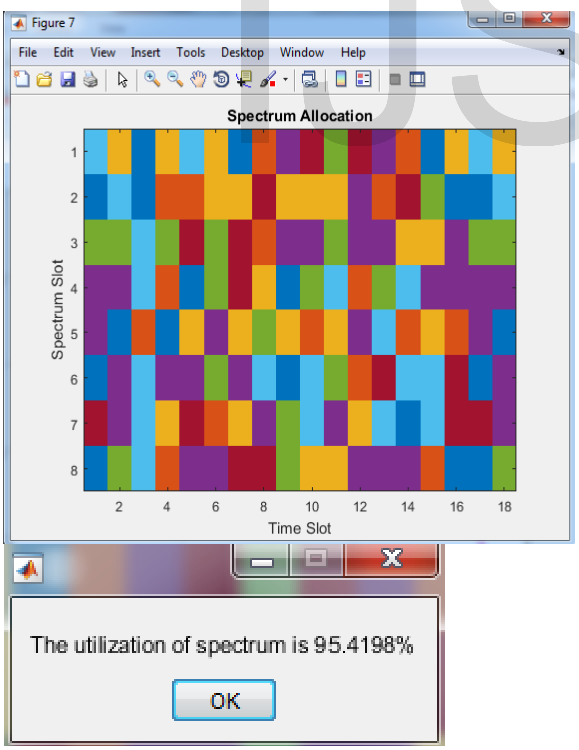

Fig.8. An illustration of cooperation.

DFSS algorithm, different scattered small sized TFBs can be aggregated to meet the resource requirement of one specifical individual SU, as shown in Fig. 8. To compare the performance of packing process in Case 2 among the SHELF-BWF algorithm, DFSS algorithm, and random packing strategy, the detailed packed results under different number of TFB demanders are illustrated in Fig. 9. From the physical meaning of packed results for TFBs aggregation in Case 2, the less overpacked TFB space, the higher utilization that the TFBs will have. The data shows that, for the DFSS algorithm, the packed TFB units nearly meet the requirement of the demanded TFB units.

CONCLUSION

In this paper, we have investigated the resource management problem for DSA in cellular networks using external sensing agents, and formulated the resource management problem as a dynamic spectrum supply-demand matching problem. The time and frequency domains are jointly considered to improve the utilization of unused spectrum in cellular networks, which has made the dynamic spectrum resource management and sharing approach more rational and effective. Furthermore, we have discussed the massive sized and small sized TFB matching cases, and the “wholesale” sharing approach and resource“aggregation” sharing approach are proposed, respectively.

Finally, we have designed a distributed fast spectrum sharing algorithm which can be applied in the real external sensing agents aided dynamic spectrum access scenarios. For future work, the effects of imperfect sensing on the DSA services will be considered. Furthermore, we will design the marketing competition scheme for DSA in the cellular networks.

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