Subcarrier and Power Allocation for OFDMA-Based Optimized Cognitive Radio Systems with JOUSAM for Tele Medicine Application

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Abstract
In wireless communication, the need for Radio spectrum is growing rapidly to sustain high-data-rate applications such as telemedicine over wireless systems. Cognitive Radio (CR) is suggested as a technique to enhance the effectiveness of spectrum utilization as it offers an adaptable access to the idle/underutilized spectrum to unlicensed users. To utilize idle as well as underused spectrum bands, two methods of dynamic spectrum access mechanism: Underlay Spectrum Access Mechanism (USAM) & Overlay Spectrum Access Mechanism (OSAM). Orthogonal Frequency-Division Multiplexing (OFDM) is utilized as a prospective air interface technology for CR systems. Besides, its intrinsic benefits that made it an effective standard for traditional wireless systems, OFDM offers agility in allotting spectrum resources in dynamic spectrum access. In an Orthogonal-Frequency-Division Multiple-Access (OFDMA)-based system, distinct subcarriers may be allotted to separate users to efficiently use the varied nature of channel quality across users in a given subcarrier. In this work, a design for resource-allocation technique for a Joint Overlay and Underlay Spectrum Access Mechanism (JOUSAM) is presented. Particularly, it is important to develop subcarrier-and-power-allocation algorithms for telemedicine systems.

Keywords: Cognitive Radio (CR), Orthogonal-Frequency-Division Multiple-Access (OFDMA), Joint Overlay and Underlay Spectrum Access Mechanism (JOUSAM).

Introduction

Telemedicine applications are fast developing healthcare system where medical information is transmitted through telecommunication networks to facilitate consulting, and examinations. This helps in providing medical consultation in remote areas, for diagnosis and learning through wireless channel. This paper presents the concept of implementing reliable transmission and reception of signals related to the medical information (images and videos) with considerable interference rejection using OFDMCR for reliable transmission in telemedicine applications.

Cognitive Radio (CR) is a methodology, which permits Secondary Users (SUs) in identifying and availing the spectrum holes within licensed spectrums. The CR technique consist of four important operations. Successive sensing of the spectrums is carried out by the CR users along with construction of spectrum pools. This comprises all identified spectrum holes during the spectrum sensing phase and chooses a specific channel from the pool to conduct transmissions during the spectrum decision stage. CR users may mutually use accessible channels with other CR clients via appropriate spectrum sharing policies to improve the abilities of the channel. Moreover, according to spectrum mobility policies, CR customers are expected to withdraw from the channel they are utilizing upon the return of the Primary Users (Pus) to ensure priority of Pus and to protect the PU transmission[1]. From the above mentioned usages, it is clear that CR users can use the unutilized licensed bands in a productive way to meet their transmission needs. Conversely there are certain setbacks that prevent the enhancement capability of CR systems. It is necessary to research regarding the prediction technique in order to minimise these drawbacks.

In spectrum mobility that is derived from prediction, CR customers approximate the prospective time in which the PUs appear as well as pull out from the channel prior to the start of PUs' communications. Prediction based spectrum sharing help in the prediction of requests of CR users in time, space and even in frequency domains based on which the spectrums can be pre-designated to efficiently share prior to the onset of CR request. This process can efficiently use the abilities of the channels as well as reduce the delays in responses. All prediction based techniques have ascertained that predictions are an effective approach to improve the performance of CR networks.

Spectrum prediction is a superior method to distinguish CR functions. It is a great opportunity for future endeavors. However this might arise as a difficult issue in CRNs as it includes several subtopics such as the activities of PU predictions, channel status as well as predictions broadcasted in a radio environment. The users can select from a range of prediction techniques among which markov as well as neural networking models are mostly chosen rather than Bayesian interference-based, average-based predictions, Auto-Regressive Model (ARM) as well as Static Neighbor Graph (SNG) -based predictions. The operations of CR vary from preparing forwarded signals if the predicted outputs are inactive as well as clearing channels in circumstances where the predicted results are active.

The scientific community is keenly concentrating on developing techniques to obtain knowledge, to make decisions as well as to learn in CR networks. Since the functional environment for CR networks is assumed to be extremely dynamic as well as adaptable, these methods must be applied to wide range of situations as well as conditions. The time period to adapt in dynamic as well as complicated functional environment with inconsistent needs can be compressed. Consequently conventional numerical methods may not assure to attain optimal solutions to primary optimization problem in a fast as well as scalable manner. So, the design objective changes as to identify better solutions with minimal computational complexity [2].

Consequently, heuristic algorithms have become more popular to confront this performance-complexity trade-off in CR networks. This was mainly because of its experience-based operation methodology as well as self-learning abilities, which offer near-optimal solutions at a considerably minimal computation cost. A number of optimization problems associated to CR have greatly benefitted through the application of heuristic techniques. For example, the genetically-inspired Evolutionary Algorithms (EAs) were used in the simultaneous multi-objective optimization of throughput, Bit Error Rate (BER) as well as in interference level in point-to-point CR communications. Rate as well as power assignment in multiuser OFDM networks was optimized through a heuristic successive user integration protocol, on resource allocation heuristic methods for this specific OFDM scenario.

Another proficient method for distributed Cooperative Spectrum Sensing (CSS), dynamic bandwidth allocation, cross-layer design as well as reconfiguration is Fuzzy logic. The harmony among heuristics as well as resource allocation in CR networks is also evident through the contributions obtained by applying PSO as well as Simulated Annealing (SA) to this communication paradigm. This work deals with the spectrum channel allocation problem in which the broadcast channels for the links in a CRN are assigned to each node based on optimizing an overall system performance metric, while parallel reducing the quantity of interference among nearby nodes. For the given numerical intractability, if the network size increases, then the optimization paradigm can be easily handled by using genetically-inspired optimization approaches [3].

The significant aspects of Particle Swarm Optimization (PSO) are as follows: it has easy implementation process; an effective global search, it does not largely depend upon initial solution, the algorithm has quick response as well as has minimal variable for tuning. The drawbacks of PSO are: The algorithm is found to be weak with respect to local search, very slow convergence rate and in case of tough optimization problems there is a chance of getting trapped in local minima [4].

The potency of a Genetic Algorithm (GA) mainly depends upon its ability to identify a suitable solution for a problem, in which the iterative solution is too restrictive in time as well as the mathematical solution is not achievable. The working method of GA permits it to determine solutions rapidly. Further, the most important aspect of GA approach is that there may be several unique restrictions to the problem based on the particulars of the solution for which one is probing. Likewise, another striking importance of this algorithm is the Schema Theorem as it illustrates the relationship that exists among groups of analogous 'chromosomes' as well as their fitness. The theorem depicts that a group with above average fitness must prolong to maximise its fitness over subsequent generations. Additionally, in this theorem, there is a proof of convergence for an exclusive type of the GA. Though GA is not conceptually complicated, the individual variables as well as the execution process require a huge amount of tuning[5].

The demerits of GA are: it is not possible for GA to offer global optimum for all problems especially when the whole solution has several populations. A tool largely depends on the speed of the computer while only real time application is capable of generating rapid response time [6].

Chen et al[7] proposed a Joint Spectrum Sensing and Resource Allocation (JSSRA) scheme in a CRN to deal with Spectrum Sensing Data Falsification (SSDF) attacks and to incentivize SUs to behave well. Moreover, a user-selection method based on reinforcement learning was presented to select reliable SUs for CSS. In addition, the SU's trust degree is updated according to its behavior in CSS and is used in the sensed resource-allocation process. Comprehensive performance evaluation is conducted by computer simulation. It is showed that the proposed JSSRA scheme deals with the SSDF attack well in cooperative sensing process to improve system robustness and achieved a significant system utility gain in resource allocation.

Wang et al[8] investigated the spectrum allocation as well as the relay selection problem. A spectrum allocation algorithm has its basis on the given number of SUs while a relay selection scheme with fewer complications is suggested to improve the utility of the PU while ensuring the data rate of the PU as well as the fairness among the SUs. Numerical outputs reveal that the suggested relay selection scheme is most feasible and authentic. This work proposes subcarrier-and-power-allocation schemes for JOUSAM. In this work, for pragmatic reasons, it is assumed that the instantaneous channel quality among the CR transmitter and the PUs' receiver is unknown. Section 2 describes various methods employed in the work. Section 3 illustrates the simulation outputs and Section 4 concludes the work.

Methodology

With reference to the OSAM, the spectrum utilization may be improved by allowing secondary customers to strategically exhaust idle frequency bands of PUs. So, the SUs and PUs can co-exist in the side-by-side along spectral bands. There are common interferences among the PUs as well as secondary customers because of non-orthogonality of the broadcasted signals. Conversely, according to USAM, the PUs as well as CR users can coexist in similar spectral band. It could be stated as, that the USAM permits parallel sharing of idle frequency bands by the SUs as well as the PUs. In such circumstances, the interference is mostly due to the coexistence that occurs in similar spectral band. Forgiven interference restrictions enforced by the PUs' system, and thus the CR transmitter may forward reasonably larger transmit power for the OSAM, while in the USAM, it may forward comparatively less power.

This work proposes an optimum power-and-subcarrier-allocation scheme for an OFDMA based CR network with a JOUSAM. The transmission rate of CR customers is maximized for a specific power budget, while the interference carried into the PUs' receiver is retained lesser than the acceptable limits with a specific probability. Since the complications of the optimum power-and-subcarrier-allocation strategy can be larger.

In the optimum strategy proposed for processing the optimum power according to (1),

$$p_{u,k} = \left[\frac{1}{\alpha_l f(d_{k,l}) + \gamma} - \frac{\sigma^2 + j_{k,u}}{|h_{u,k}^{ss}|^2} \right]^+ , \ for\ k \in \Omega_u \tag{1}$$

Here αl and γ represents Lagrange constants respectively.

It needs to process Lagrange parameters by means of a numerical method. Therefore, the optimum strategy can have complications in processing. Specifically, the difficulty of the subcarrier-allocation strategy is O (KZ), whereas the difficulty of the power-allocation strategy is exponential in Z and is O (Z3). To achieve the sub-optimal strategy, the sub-carrier allocation stays the same as mentioned in (2).

$$u^* = \arg\max_u \frac{|h_{u,k}^{ss}|^2}{\sigma^2 + j_{k,u}}, \ for\ k = 1, 2, ..., Z. \tag{2}$$

Moreover, it proposes a sub-optimal power-allocation strategy having fewer complications. The underlaying sub-carriers presents higher interference to the PU receivers when compared to the overlay sub-carriers, it suggests to assign lesser power to the underlay sub-carriers. The details pertaining to the proposed sub-optimal power-allocation strategy is given below. To avoid ambiguity, the index u is eliminated as the power allocation in a specific sub-carrier after it has been allocated to a certain customer.

According to the sub-optimal strategy[9], it is suggested to allocate similar quantity of power to each of the underlay sub-carrier. Conversely, the overlay sub-carriers are allocated with power with respect to ladder profile. The ladder profile is inspired from the heuristic in which the sub-carriers that are close by PU band, increased interference is provided to the PU band, even though they are assigned with comparatively meagre amount of power. The power profile for underlay sub-carriers that are assigned with similar amounts of power can be given by (3):

$$p_l^{subopt,un} = P^{un}, \ \ l \in S_U. \tag{3}$$

The overlay sub-carriers are assigned with power as per ladder fashion, in which the step size is not varying. Basically it is suggested to allocate P^{ov} power to the overlay sub-carrier, which is nearer to the PU band [10]. Later, it is suggested to allocate $2P^{ov}$ power to the immediate overlay sub-carrier. The power profile for overlay sub-carriers can be denoted as (4):

$$p_n^{subopt,ov} = P^{ov} \times i_n, \ \ n \in S_O. \tag{4}$$

Where $i_n \triangleq \left\lfloor \frac{\Delta_n}{\Delta f} \right\rfloor$ and Δ_n denotes the spectral distance among the nth overlay sub-carrier and the nearby PU band. Later, a design factor x is presented, through which the power in an underlay sub-carrier is fewer when compared to the power in the overlay sub-carrier that is nearby a PU band, and it can be denoted as (5):

$$P^{ov} = x \times P^{un} \tag{5}$$

The suitable value of x is found using PSO. Then, the power profile can be computed if P^{un} is known which is computed using (6):

$$\sum_{u=1}^{K} \sum_{k \in \Omega_u} p_{u,k} \leq P_T \tag{6}$$

As well as L interference constraints in (7) are fulfilled.

$$\sum_{u=1}^{K} \sum_{k \in \Omega_u} p_{u,k} f(d_{k,l}) \leq \frac{I_{th}^{(l)}}{2\lambda_l^2 (-\ln(1-a))}, l \in S_U \tag{7}$$

Generally, for every (L + 1) constraints, a corresponding value of P^{un} is measured. From the available (L + 1) power values, the minimum value is selected as it can satisfy all the (L + 1) constraints.

The power values in the CR subcarriers that fulfils the overall power constraint can be stated as

$$\sum_{l=1}^{L} p_l^{subopt,un} + \sum_{n=1}^{N} p_n^{subopt,ov} = P_T \tag{8}$$

Using (3), (4), and (5) in (8), it can be written as:

$$P_{(1)}^{un} \times L + x \times P_{(1)}^{un} \times \sum_{n=1}^{N} i_n = P_T \tag{9}$$

Now, determine the value of $P_{(1)}^{un}$ by solving (9).

The power profile (denoted by $P_{(l+1)}^{un}$) that fulfils the lth interference constraint in (7) is given by:

$$P_{(l+1)}^{un}\sum_{k=1}^{L} f(d_{k,l}) + xP_{(l+1)}^{un} \times \left(\sum_{k=L+1}^{N+L} f(d_{k,l}) \times i_{(k-L)}\right) = \frac{I_{th}^{(l)}}{2\lambda_l^2(-\ln(1-a))} \quad (10)$$

Now, from (10), the value of $P_{(1)}^{un}$ can be calculated as (11):

$$P_{(l+1)}^{un} = I_{th}^{(l)} \begin{bmatrix} -2\lambda_l^2 \ln(1-a) \\ \times\left(\sum_{k=1}^{L} f(d_{k,l}) + x\sum_{k=L+1}^{N+L} f(d_{k,l}) \times i_{(k-L)}\right) \end{bmatrix}^{-1} \quad (11)$$

Finally, the value of P^{un} is chosen as (12):

$$P^{un} = \min\left\{P_{(1)}^{un}, P_{(2)}^{un}, ..., P_{(L+1)}^{un}\right\} \quad (12)$$

Results and Discussion

In the results given here, the values of T_s and Δf are taken to be 4 µs and 0.3125 MHz, correspondingly. It is presumed that there are K = 4 CR users, N = 8 overlay sub-carriers, and L = 8 underlay sub-carriers. Additive White Gaussian Noise (AWGN) power per sub-carrier $\sigma^2 = 1.2944 \times 10^{-15}$ W, while the values of interference are $j_{k,u} = \sigma^2$ (k = 1, 2. . . Z). It is considered that the value of probability a, with which the interference introduced to the lth PU receiver stays lesser than a certain threshold $I_{th}^{(l)}$, is equal to 0.95.

The channel fading amplitude gain between the CR transmitter and the uth CR receiver in the kth sub-carrier $|h_{u,k}^{ss}|$ is presumed to be Rayleigh distributed with a mean of −52.39 dB (related path loss of 103.73 dB). For the results given here, it is presumed that the path loss for the CR users is equal. Table 1 & 2 and figure 1 & 2 shows the transmission rate for power in milli watts and interference threshold in pico watts.

Table 1
Transmission Rate (Power in Milli Watts)

Power in milli watts	Transmission rate in Mbps JOUSAM	Transmission rate in Mbps proposed JOUSAM
1	0.92	1
2	7.6	8.1
3	9.1	9.6
4	10.1	10.6
5	11.3	12.1
6	11.9	12.6
7	12.1	12.9
8	12.2	13
9	12.3	13

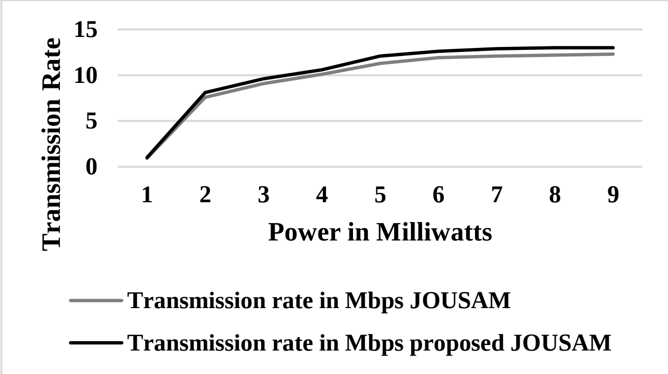

Figure 1: **Transmission Rate (Power in milli watts)**

From the figure 1, it is mentioned that the transmission rate in Mbps suggested JOUSAM has higher transmission rate by 8.33%, 5.34%, 6.83%, 6.4% and 5.53% for transmission rate in Mbps JOUSAM when compared with 1, 3, 5, 7 and 9 power in mill watts.

Table 2
Transmission Rate
(Interference threshold in Pico Watt)

Interference threshold in pico watt	Transmission rate in Mbps JOUSAM	Transmission rate in Mbps proposed JOUSAM
0.5	11.8	12
0.6	12	12
0.7	11.5	12.3
0.8	11.6	12.2
0.9	11.7	12.4
1	11.5	12.5
1.1	11.9	11.9
1.2	11.6	12.5

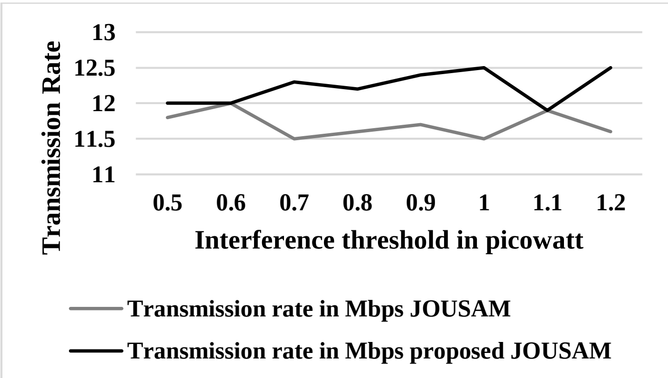

Figure 2: **Transmission Rate (Interference threshold in pico watt)**

From the figure 2, it is mentioned that the transmission rate in Mbps suggested JOUSAM has higher transmission rate by 1.63%, 6.72%, 5.8% and 7.46% for transmission rate in Mbps JOUSAM when compared with 0.5, 0.7, 0.9 and 1.2 interference threshold in pico watt.

Conclusion

This work proposes a sub-carrier-and-power allocation problem for an OFDMA-based CR network, which utilizes a JOUSAM. Specifically, for such a CR system, it builds an optimum sub-carrier-and-power-allocation protocol. As such, the total transmission rate of CR customers for a specific communication power budget is maximized when keeping the introduced interference to the PU receivers lesser when compared to specific thresholds with a particular probability. As the optimum strategy is very complex, it also proposes as low-complexity sub-optimal strategy whose functional execution is faster than the optimum strategy. Results illustrate that the transmission rate in Mbps suggested JOUSAM has greater transmission rate by 8.33%, 5.34%, 6.83%, 6.4% and 5.53% for transmission rate in Mbps JOUSAM when compared with 1, 3, 5, 7 and 9 power in mill watts. The transmission rate in Mbps proposed JOUSAM has higher transmission rate by 1.63%, 6.72%, 5.8% and 7.46% for transmission rate in Mbps JOUSAM when compared with 0.5, 0.7, 0.9 and 1.2 interference threshold in pico watt.

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