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Research Article

The Optimization Algorithm for CR System Based on Optimal Wavelet Filter

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5G network is a heterogeneous large-scale network. Cognitive Radio (CR) technology can be used to realize selection based on the communication time, communication resources, and communication requirement so as to improve the system performance of the whole communication system. Cognitive Radio (CR) system based on wavelet packet owns better flexibility and bandwidth efficiency. The optimal wavelet packet filter optimization algorithm is proposed in the paper for guaranteeing un-licensed user's (un-LU) data transmission rate and optimizing the performance of system. The intelligent search algorithm is used to obtain the optimal wavelet filter. The simulation results show that the Intercarrier Interference (ICI) and bit error rate (BER) performance of the new optimal wavelet filter algorithm without sacrificing any un-LU's subcarriers is better than other three masking subcarriers algorithms.

1. Introduction

The demand of various services on APP and network terminals is increasing with the continuous popularization of new network intelligent terminals. The future wireless network energy efficiency and spectrum resources utilization need to be improved urgently [1]. In the research process of 5G, some traditional communication performance indicators (such as the utilization of spectrum resources and the data capacity of the network system) should be improved much more. And the interference caused in the communication process should be further reduced [2, 3]. As one of the key candidate technologies of 5G communication technology, Cognitive Radio (CR) technology has great advantages in improving communication efficiency and the utilization of spectrum resources. As a very effective application model, the spectrum pooling (SP) can merge the spectrum of different users (military, cluster wireless communications, etc.) into a public spectrum resources pooling. The demand for this spectrum allocation model is shown in the literatures [4]. The un-licensed users (un-LU) can rent spectrum resources which are temporarily not used by LU from the public spectrum pooling [5]. The key of SP is to ensure all kinds of un-LU cannot influence the LU's communication when the un-LU accesses current idle resources. The LU need not change their software and hardware to adapt to the emergence of un-LU.

In the traditional SP system based on Orthogonal Frequency Division Multiplexing (OFDM), the sidelobe interference of OFDM signal leads to huge power spectrum out of band radiation power of SP. The SP system modulates and demodulates orthogonal signals by IFFT/FFT operation that can cause serious mutual interference between the LU and un-LU [6]. Wavelet Packet Modulation (WPM) uses wavelet packet basis to modulate the signals. It can improve the bandwidth utilization and reduce the sidelobe interference because it does not need the cyclic prefix and pilot. It has many advantages, such as intersymbol interference, inter-channel interference, high spectrum utilization, and high secrecy. So, CR system based on wavelet packet owns better flexibility and bandwidth efficiency [7, 8]. Murroni, Maurizio also proposed a robust multirate modulation algorithm for Cognitive Radio communications [9].

Table 1: The number of possible tree structures with modulation lever J.

j	0	1	2	3	4	5	...
γ_j	1	2	5	26	677	458330	...

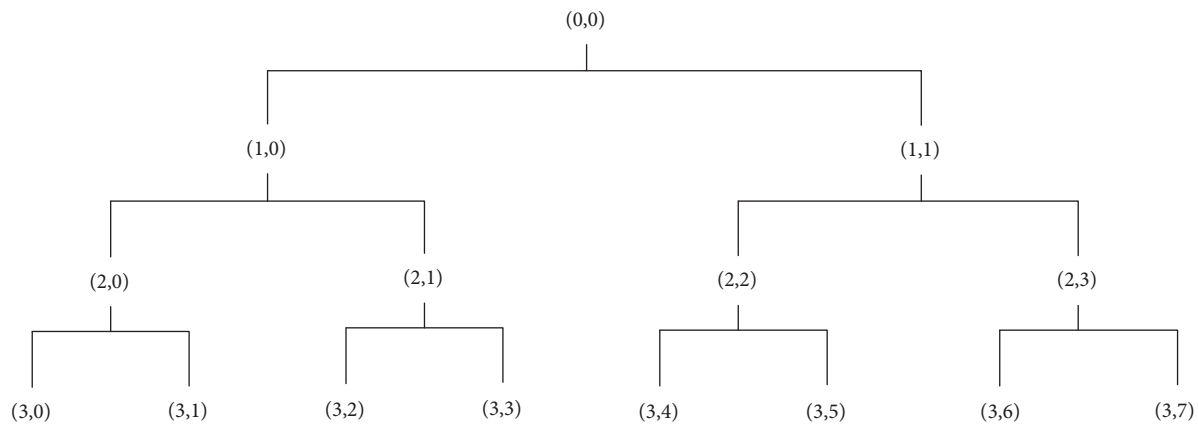

Figure 1: 3 level wavelet packet tree.

The two parameters need to be focused on all the time for all CR technologies. The first is the guarantee of high reliable communication quality. The other is to ensure the maximum utilization of spectrum resources at any time. In order to ensure and improve the communication quality of LU, researching the optimizing algorithms of SP based on WPM to suppress interferences is very meaningful. The traditional interferences suppression method deactivated the adjacent subcarriers of LU. This method is simple, but the transmission bandwidth of un-LU is wasted [10]. For reducing wasting the transmission bandwidth of un-LU, the optimal deactivated subcarriers algorithm is proposed. It can locate the maximum ICI subcarriers and choose to deactivate them according to the data transmission rate requirement of LU [11]. The machine learning algorithm also is designed to obtain the optimal interference subcarriers. Masking the optimal interference subcarriers can suppress ICI [12]. All these three algorithms realize ICI suppression by sacrificing the bandwidth of the un-LU. In order to improve the spectrum utilization, a new SP system optimization algorithm based on optimal wavelet filter is proposed in the paper. It can suppress ICI and optimize performance of SP without wasting any bandwidth of un-LU.

The paper is organized as follows: the system model is provided in Section 2; in Section 3, the system optimizing algorithm is proposed; the simulation results are described in Section 4; Section 5 concludes the paper.

2. The System Model

The whole SP is designed as a WPM system. The spectrum of LU matches with the integer times of the WPM system's subcarrier interval. The SP resources can be used and controlled according to the advantages of WPM flexibly. There are several LU. The un-LU and all users can cross exist and make full use of all spectrum bands. During communication, the whole system communication environment needs to be detected. The occupation of each frequency point can be obtained. The idle subcarriers are expressed by vector "0". The occupied frequency point is described as vector "1". A detailed frequency occupation map can be obtained. The un-LU can utilize all the spectrum resources with vector "0".

The interference of SP based on WPM is caused because the orthogonality of the LU and un-LU is destructed. In the SP, the average ICI energy which influences subcarrier j of LU can be deduced as [10]

$$\sigma_{RU_j}{}^2 = \frac{1}{N_l}\sum_{i=1}^{N_l}\left(\sum_{n=-\infty}^{+\infty}\left|\sum_{m=-\infty}^{+\infty} h_{l_i}(m-p)\, h_{r_j}^*\left(m-2^{D_i}n\right)\right|^2\right) \quad (1)$$

3. System Optimizing Algorithm Design

3.1. The Wavelet Packet Tree Structure. For wavelet packet modulation, the wavelet packet modulation tree structure has diversity with certain level J. The number of wavelet packet modulation tree structure γ_j approximates to the increase of the 2 power with modulation lever J increasing [13].

$$\gamma_j = \gamma_{j-1}^2 + 1 \quad (2)$$

$$\gamma_0 = 1 \quad (3)$$

Table 1 provides the number of possible tree structures with different modulation levers.

There are 26 wavelet packet modulation structures with $J = 3$. Figure 1 gives the full tree wavelet packet modulation structure with $J = 3$. The other modulation tree structures are called the unfull tree structures or the pruning structures of full tree structure. Each wavelet packet tree structure corresponds to a wavelet filter structure. It is shown that the average ICI energy produced by the wavelet filters with different structures is also different from formula (1). The target of optimizing the SP performance can be achieved if the wavelet filter which produces the minimum average ICI energy can be found.

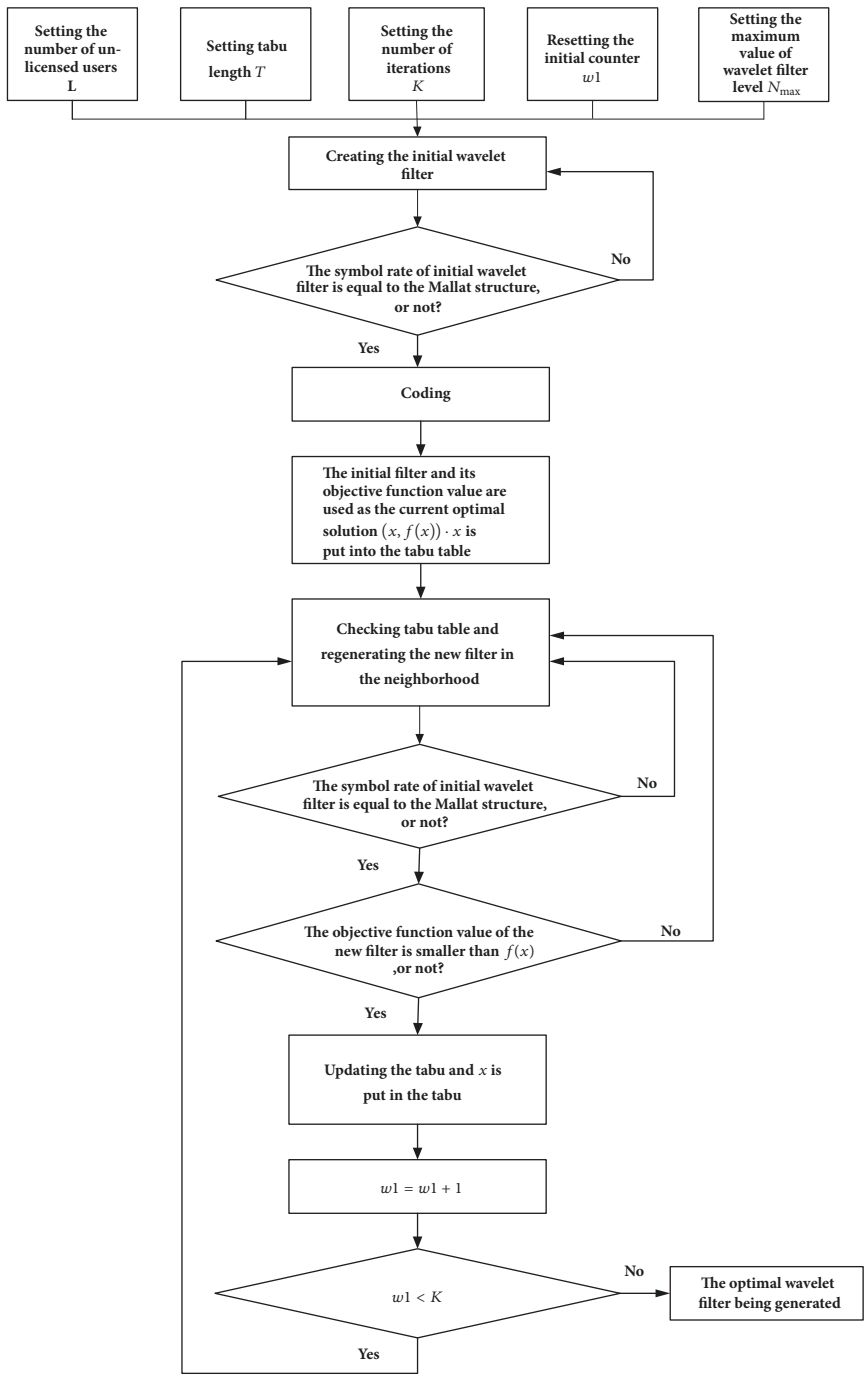

Figure 2: The flowchart of optimization algorithm.

3.2. Optimizing Algorithm Design. For obtaining the wavelet filter with minimum average ICI energy, the Tabu search algorithm is used in the paper to find the optimal wavelet filter. Tabu search algorithm is a metaheuristic random search algorithm. It starts from an initial feasible solution and chooses a series of specific search directions (moving) as a trial. In order to avoid falling into local optimum, Tabu search adopts a flexible "memory" technology to record and select the optimization process that has been carried out and guide the next search direction. In order to find the "global optimal solution", we should not stick to a particular region. The disadvantage of local search is that it is too greedy to search a local area and its neighborhood. Tabu search is to find a part of the local optimal solution, consciously avoiding it (but not completely isolated), so as to obtain more search intervals [14]. The optimal wavelet filter utilized to modulate SP signal can suppress multiusers' interference effectively and improve the performance of SP without sacrificing any transmission bandwidth of un-LU. Figure 2 is the flowchart of the algorithm.

The complexity of algorithm is $O(N^2)$.

4. Simulation Results

4.1. Simulation Scenes

4.1.1. Simulation Scene 1. The algorithm initial values proposed in the paper are set as follows:

Db(6) wavelet and QPSK are used to modulate signals. The number of LU's subcarrier is 64 and the number of un-LU's subcarrier is 16. The maximum value of wavelet filter level is 8. The number of iterations is 200 and the Tabu length is 4. The modulation filter of the masking subcarrier algorithm uses a wavelet filter of the Mallat structure (the 0-15 nodes of the 4 level filter are selected to organize the wavelet filter).

4.1.2. Simulation Scene 2. The algorithm initial values proposed in the paper are set as follows:

Db(6) wavelet and QPSK are used to modulate signals. The number of LU's subcarrier is 128 and the number of un-LU's subcarrier is 32. The maximum value of wavelet filter level is 10. The number of iterations is 500 and the Tabu length is 8. The modulation filter of the masking subcarrier algorithm uses a wavelet filter of the Mallat structure (the 0-31 nodes of the 5 level filter are selected to organize the wavelet filter).

To simulate we use the two path wireless channel model as the wireless channel environment. The impulse response of channel is defined as follows [12]:

$$h_{ch}(n) = \delta(n) + \delta(n - pp)\, e^{j\theta_1} \tag{4}$$

where pp is a positive integer; it represents additional delay of channel and is normalized as symbol period. θ_1 is the random phase, and the range of θ_1 is $[0, 2\pi)$.

4.2. Simulation Results and Analysis. In the simulation scene 1, the optimal wavelet filter structure is obtained by using optimization algorithm to choose optimal wavelet filter. The nodes of the optimal wavelet filter include (4,0)(4,1)(5,4)(5,5)(5,6)(5,7)(2,1)(4,8)(4,9)(3,5)(4,12)(4,13) (5, 28)(5,29)(5,30)(5,31). The ICI energy of system using our optimization algorithm is compared with deactivating the adjacent subcarriers algorithm [10], the optimal deactivated subcarriers algorithm [11], and the ICI suppression algorithm based on genetic algorithm (GA) [12] in Figure 3. It is shown that these masking subcarriers algorithms and our optimal wavelet filter algorithm all can reduce the ICI energy of system and the ICI energy is decreased with the number of masked subcarriers increasing. From Figure 3, the ICI suppression effect of our new optimal wavelet filter algorithm is better than other three masking subcarriers algorithms with masking 2 un-LU's subcarriers. That means the ICI performance of new optimization algorithm without sacrificing un-LU's bandwidth is better than the other three masking subcarriers algorithms with the 12.5% transmission bandwidth of un-LU wasted. The ICI suppression effect of GA with masking 4 un-LU's subcarriers is better than the new optimal wavelet filter algorithm, but the other two algorithms with masking 4 un-LU's subcarriers are still worse than new optimal wavelet filter algorithm. That means the ICI performance of new optimization algorithm without sacrificing un-LU's bandwidth is better than deactivating the adjacent subcarriers algorithm and the optimal deactivated subcarriers algorithm with the 25% transmission bandwidth of un-LU wasted.

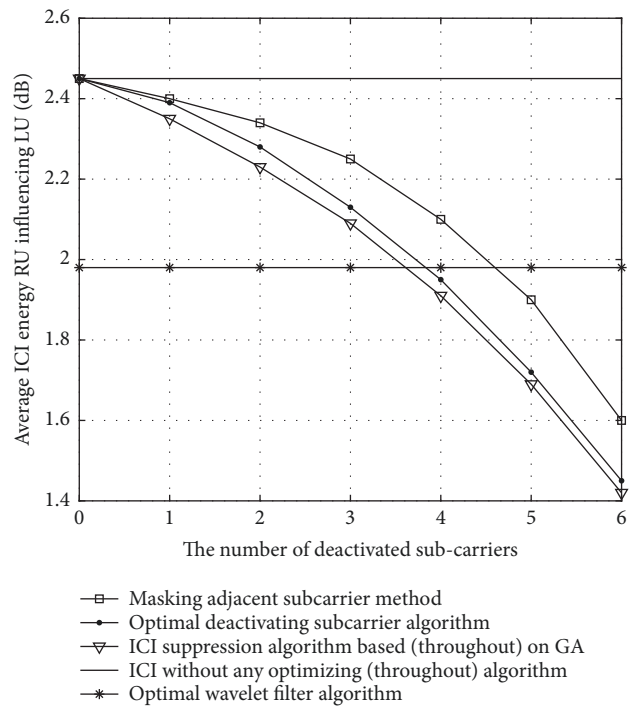

Figure 3: The system ICI energy comparison with various algorithms under Scene 1.

In the simulation scene 2, the optimal wavelet filter structure is obtained by using optimization algorithm to choose optimal wavelet filter. The nodes of the optimal wavelet filter include (5,31)(5,30)(6,59)(6,58)(6,57)(6,56)(5, 27)(5,26)(4,12)(2,2) (6,31)(6,30)(6,29)(6,28)(6,27)(6,26)(5,12) (6,23)(6,22)(6,21)(6,20)(4,4)(3,1)(6,7) (6,6)(6,5)(7,9)(7,8)(5, 1)(6,26) (7,3)(7,2)(6,0). The ICI energy of system using our optimization algorithm is compared with deactivating the adjacent subcarriers algorithm [10], the optimal deactivated subcarriers algorithm [11], and the ICI suppression algorithm based on GA [12] in Figure 4. It is shown that these masking subcarriers algorithms and our optimal wavelet filter algorithm all can reduce the ICI energy of system and the ICI energy is decreased with the number of masked subcarriers increasing. From Figure 4, the ICI suppression effect of our new optimal wavelet filter algorithm is better than other three masking subcarriers algorithms with masking 4 un-LU's subcarriers. That means the ICI performance of new optimization algorithm without sacrificing un-LU's bandwidth is better than the other three masking subcarriers algorithms with the 12.5% transmission bandwidth of un-LU wasted. The ICI suppression effect of three masking

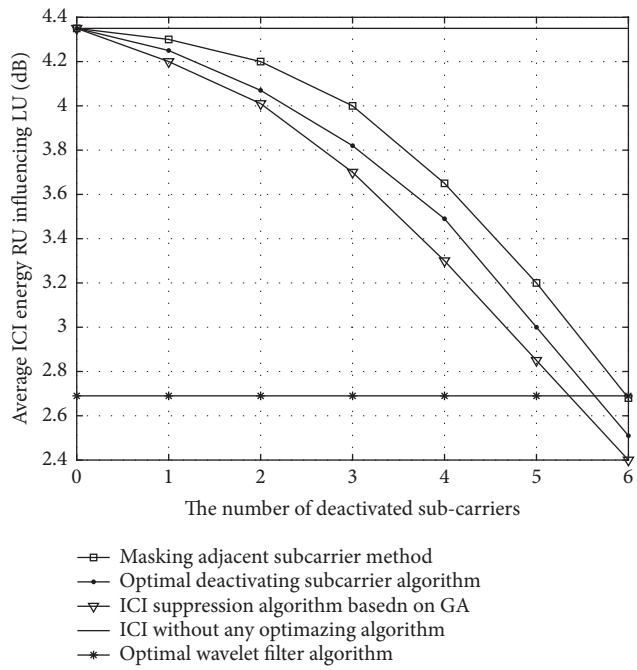

Figure 4: The system ICI energy comparison with various algorithms under Scene 2.

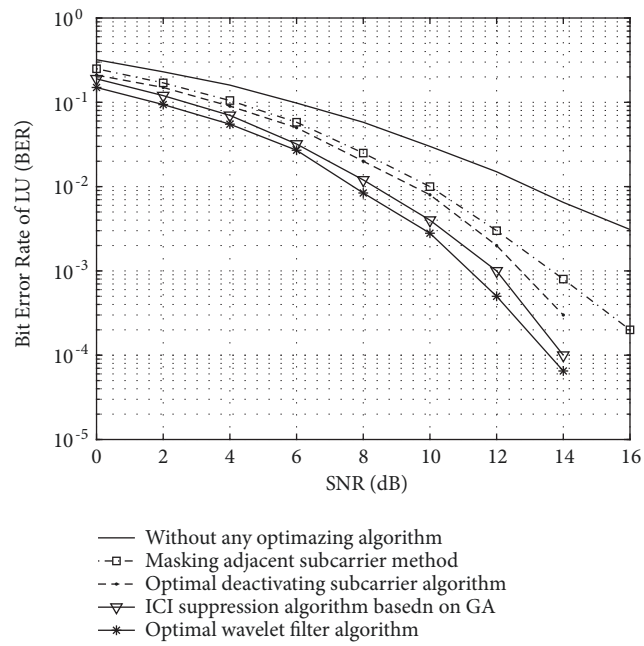

Figure 5: The system BER performance comparison with various algorithms under Scene 1 (masking 4 subcarriers).

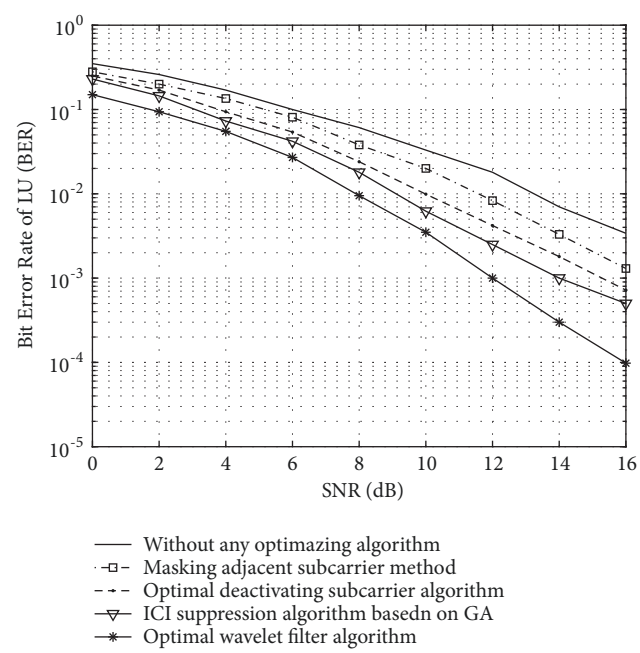

Figure 6: The system BER performance comparison with various algorithms under Scene 2 (masking 6 subcarriers).

subcarrier algorithms with masking 6 un-LU's subcarriers is little better than the new optimal wavelet filter algorithm. But the advantage of new optimal wavelet filter algorithm proposed in the paper does not need to sacrifice any bandwidth of un-LU.

For scene 1, the BER performance of system using our optimization algorithm is compared with deactivating the adjacent subcarriers algorithm [10], the optimal deactivated subcarriers algorithm [11], and the ICI suppression algorithm based on GA [12] with 4 subcarriers masked in Figure 5. It is shown that the BER performance of the new optimal wavelet filter algorithm without sacrificing any un-LU's subcarriers is better than other three masking subcarriers algorithms with 4 subcarriers of un-LU wasted.

For scene 2, the BER performance of system using our optimization algorithm is compared with deactivating the adjacent subcarriers algorithm [10], the optimal deactivated subcarriers algorithm [11], and the ICI suppression algorithm based on GA [12] with 6 subcarriers masked in Figure 6. It is shown that the BER performance of the new optimal wavelet filter algorithm without sacrificing any un-LU's subcarriers is better than the other three masking subcarriers algorithms with 6 subcarriers of un-LU wasted.

From the simulation results above, it is shown that the previous three algorithms can also optimize the ICI performance of CR, but these need to waste much more un-LU's subcarriers. But the optimization algorithm proposed in the paper can suppress the system ICI effectively and improve the system BER performance without sacrificing any bandwidth of un-LU.

5. Conclusions

5G network infrastructure will realize technological innovation and reform. The software radio network (SDN) and the network function virtualization (NFV) are used in the infrastructure platform of 5G network architecture. The CR based on wavelet owns better flexibility and bandwidth efficiency. The optimal wavelet filter algorithm is proposed in

the paper. It is based on an intelligent search algorithm. The new optimization algorithm can not only guarantee communication data transmission rate of un-LU but also suppress the ICI of CR. In the future, 5G communication technology will eventually achieve a universal terminal and the more efficient CR technologies will decide which communication technology can be used in the terminal flexibly. So, more flexible CR technologies should be researched next.

Data Availability

We declare that materials described in the manuscript, including all relevant raw data, will be freely available to any scientist wishing to use them for noncommercial purposes, without breaching participant confidentiality.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Miao Liu conceived and designed the study. Zhenxing Sun performed a part of experiments. Miao Liu performed the most part of experiments and wrote the paper. Yanchang Liu and Cun Zhao edited the manuscript. All authors read and approved the manuscript.

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References

[1] A. Aijaz, M. Dohler, A. Hamid Aghvami, V. Friderikos, and M. Frodigh, "Realizing the Tactile Internet: Haptic Communications over Next Generation 5G Cellular Networks," *IEEE Wireless Communications Magazine*, vol. 24, no. 2, pp. 82–89, 2017.

[2] G. A. Akpakwu, B. J. Silva, G. P. Hancke, and A. M. Abu-Mahfouz, "A Survey on 5G Networks for the Internet of Things: Communication Technologies and Challenges," *IEEE Access*, vol. 6, pp. 3619–3647, 2017.

[3] M. Shafi, A. F. Molisch, P. J. Smith et al., "5G: A tutorial overview of standards, trials, challenges, deployment, and practice," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 6, pp. 1201–1221, 2017.

[4] P. Anker, "Cognitive Radio: The Need to Align Regulations with Technology," in *Handbook of Cognitive Radio*, pp. 1–21, 2017.

[5] A. E. Omer, "Probability-based model for unlicensed spectrum utilization in cognitive radio networks," in *Proceedings of the International Conference on Information and Communication Technology Convergence (ICTC '17)*, pp. 495–500, Jeju, South Korea, October 2017.

[6] M. Srilatha, R. Hemalatha, and K. S. Ramesh, "An improved technique to mitigate interference between adjacent bands in cognitive radio system," in *Proceedings of the 7th IEEE International Advanced Computing Conference, (IACC '17)*, pp. 292–296, India, January 2017.

[7] M. Chafii, J. Palicot, and R. Gribonval, "Wavelet modulation: An alternative modulation with low energy consumption," *Comptes Rendus Physique*, vol. 18, no. 2, pp. 156–167, 2017.

[8] H. Hosseini, A. Anpalagan, K. Raahemifar, and S. Erkucuk, "Wavelet-based cognitive SCMA system for mmWave 5G communication networks," *IET Communications*, vol. 11, no. 6, pp. 831–836, 2017.

[9] M. Murroni, V. Popescu, M. Fadda, and D. Giusto, "Robust multi-rate modulation for cognitive radio communications over land mobile satellite channel at Ku-band," *International Journal of Satellite Communications and Networking*, vol. 35, no. 5, pp. 503–515, 2017.

[10] A. Yazar, M. Elkourdi, and H. Arslan, "Waveform Designs for Cognitive Radio and Dynamic Spectrum Access Applications," in *Handbook of Cognitive Radio*, pp. 1–24, 2017.

[11] L. Miao, L. Na, and Z.-X. Sun, "Optimal deactivated subcarriers guard bands for spectrum pooling systems based on wavelet-based orthogonal frequency division multiplexing," *IET Communications*, vol. 8, no. 7, pp. 1117–1123, 2014.

[12] L. Miao, Z. Sun, and Z. Jie, "The Parallel Algorithm Based on Genetic Algorithm for Improving the Performance of Cognitive Radio," *Wireless Communications and Mobile Computing*, vol. 2018, Article ID 5986482, 6 pages, 2018.

[13] G. Navarro, "Wavelet trees for all," *Journal of Discrete Algorithms*, vol. 25, pp. 2–20, 2014.

[14] Y. Xia and Z. Fu, "A tabu search algorithm for distribution network optimization with discrete split deliveries and soft time windows," *Cluster Computing*, pp. 1–11, 2018.