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Abstract. We design an efficient sensing order selection strategy for distributed Cognitive Radio Networks (CRNs), where multiple CRs sense the channels sequentially for spectrum opportunities according to a channel Latin Square. We are particularly interested in the case that CRs' quantity is more than the available channels', where traditional approaches will have high probabilities of collision. We first introduce a system model and an adaptive sensing threshold for available channels which is estimated according to the sensing probability of the specific sequential order. Then, we propose a channel sensing and access strategy that can adjust its sensing and access probabilities based on the crowded degree of sequential order. Last, we conduct extensive simulations to compare the performance of our approach with other typical ones. Simulation results show that the proposed scheme achieves an outstanding performance on channel utilization in the case of heavy channel workload.

1 Introduction

The rapid growth of new wireless communication services is now facing the difficulty of no enough available spectrum resource due to the fact that the fixed spectrums have been granted to some licensed entities exclusively. According to tremendous statistics[1-4], a great deal of allocated spectrums are severely underutilized. According to this fact, a new technology, namely Cognitive Radio (CR), is contrived, which enable wireless services to operate over those licensed but temporally or geographically unused spectrums through secondary opportunistic access. Cognitive Radio Networks, abbreviated as CRNs, are built on the platform of Cognitive Radio, where primary users (PUs), i.e., the licensed users, have arbitrary rights to transmit over those licensed channels whenever necessary. However, the secondary users (SUs) or CR nodes must perform spectrum sensing to attain transmission opportunities under the premise of protecting PUs' communications. Due to the hardware advancement, most of the wireless terminals are able to sense more than one channel within a same transmission slot, which is also our concern in this paper.

For the arbitrary PUs' rights to use licensed channels, a proper sensing mechanism should be designed to ensure a lower rate of transmission collisions among CRs. This mechanism can also evacuate the occupied channels immediately once some PU reclaims them, even if there are some SUs' communications over them. Provided a centralized coordinator and a common control channel (CCC), every CR may achieve a high efficiency of channel sensing and allocation. Otherwise, each of them has to sense the spectrum opportunity independently and then accesses an idle channel depending on the sensed results. In this case, each CR hunts for the opportunities of access channel by periodic or sequential channel sensing. In the first approach, each CR senses a specific channel first and then transmits over it if available. Otherwise, the CR has to wait until the next transmission slot and repeat this process periodically. In the second one, in order to find some available channels, each CR has to sense the channels sequentially according to an elaborated order designed in advance. After spectrum sensing, each CR makes its own decision on whether to sense the next channel continually or to start transmission based on the sensed results. Contrast to the periodically sensing strategies, the sequential approach allows a CR to identify an idle channel quickly by sensing more than one channel successively. If the sensed channel is occupied by other entities currently, there is little time delay before sensing the successive channels. Due to the above justifications, sequential channel sensing is of our concern in this paper.

Traditional researches have mainly focused on improving the throughput of CRNs. However the majority of them have a common assumption or implied assumption that the temporal idle channels could accommodate the majority of CRs, and only in this case some scheduling approaches could achieve a better performance. For example, Khan's work[1] has an excellent performance under the condition that the channel's quantity is not less than the CRs', which has been demonstrated in our experiment in Section 5, but Khan's contribution inspires our work greatly. On the basis of Latin Square utilized in [1], we are interested in the sequential channel sensing strategy without a centralized coordinator under the case of heavy channel workload, i.e., more CRs but fewer available channels.

In this paper, we propose a distributed and sequential sensing approach in a decentralized CRN on the basis of Khan's approach and random access. The contributions of our work are summarized as follows. First, a dynamic sensing threshold for available channels is proposed, which can reflect the crowded degree of a specific sequential channel order. In consideration of the CRs' computation capabilities, the threshold adjustment should be simple, dynamic and low complicated. Once the quantity of sensed available channels reaches the threshold, the related CR will randomly make a decision on whether to choose one channel or to observer continuously. If lots of CRs are crowded on a common sequential order, our approach prefers observation to transmission. Otherwise, there will be a mass of collisions among those CRs, resulted in all the frames invalid as well as a whole transmission slot wasted. Furthermore, if a CR gets a spectrum opportunity and transmits successfully, its access probability to the sequential channel order will be increased; otherwise it will be decreased correspondingly at the next transmission slot. Meanwhile, the sensing threshold of available channel is updated based on the transmission result, i.e., success or failure on this sequential channel order.

The remainder of the paper is organized as follows. In Section 2, we introduce the related work of interest. In Section 3, we design a distributed system model, including the system process mechanism, the stop condition of sensing, the threshold of available channels required to sense, and the collision avoidance approach. In Section 4, we evaluate our proposed design at different channel workload through numerical experimental results. Finally, Section 5 concludes the paper.

2 Related Work

To solve the open problem of spectrum sensing and channel access in distributed CRNs, lots of researches have been conducted and some typical frameworks have been proposed, such as the work in [2-4], where the issue of Opportunistic Spectrum Access, abbreviated as OSA, is still a hot issue.

In order to attain more spectrum opportunities, each CR has to perform periodic sensing or sequential sensing under the premise of protecting PUs' transmission. Centralized and decentralized approaches are two typical branches in dealing with such problems. In centralized ones, a coordinator is required to schedule all CRs' sensing and transmission activities, such as in [5, 6]. The work in [5] takes the statistical features of channel availabilities into consideration, and attains an optimal sensing sequential order with the assistance of coordinator, but this scheme is only suitable for two CRs existed. If lots of CRs are desired to communicate simultaneously, a heavy workload on channels will definitely deteriorate the network performance due to massive collisions. The work in [6] is established on an assumption that CRs and PUs cooperate with each other, where each CR reports its channel sensing result to a centralized Dynamic Spectrum Access (DSA) base station. Therefore, the overall throughput will be maximized through scheduling each CR's transmission opportunity by the DSA. In consideration of DSA unknowing all the operation parameters of PUs, this work proposed a sequential channel sensing order based on estimated traffic. However, all CR devices may not be managed by the same service provider in actual scenarios, and hence it is impossible to attain an optimal scheduling strategy with several different coordinators.

Sensing channel in CRNs with a distributed manner is another branch. Traditional researches are mainly focused on studying periodical sensing strategies, which are easy to implement especially only one authorized channel existed[7]. Moreover, these approaches are easily extended to multi-channel scenarios. In other words, in a given slot, a CR selects a channel to sense in a random way or according to its prior knowledge, and then it accesses this channel to transmit if available. Otherwise, this CR should stay quiet in the whole transmission slot. In this point, a distributed learning and allocation approach is investigated in the work [8, 9], where an adaptive random selection strategy on orthogonal channels is employed. The implementation of this approach is simple but high collision probability.

Using sequential channel order to sense spectrum opportunity has become a hot issue[10], in which a CR probes multiple channels one by one with an elaborated order in a given time slot. Generally, high throughput and low collision are two main objectives of system optimization [11-17]. In the work[11, 12], a low-load approach jointing transmission optimization is proposed to sense channels sequentially. The priori knowledge of authorized channels is not necessary in this approach but requires perfect bandwidth and data rate. The work [13] proposes a simple channel sensing order in multi-channel CRNs without the prior knowledge of PUs' activities, where all CRs sense the channels according to the descending order of their achievable rates. However, this approach is only suitable for OFDM surroundings, and also requires all channel gains in advance.

In the work[14], the statistics characteristics of Signal-to-Noise Ratio for each channel are explored using pilot signals and PU's activities. Based on the fluctuating nature of heterogeneous channels as well as the QoS requirements of various applications, two approaches for channel sensing order are proposed, which are suitable for real-time and best-effort applications respectively. Nevertheless, a Cognitive Pilot Channel, abbreviated as CPC, is required to exchange control information between CRs and the base station. The work[15] is focused on identifying the sensing order and sensing-access strategy such that it can achieve the maximum of energy efficiency. This problem is formulated as a stochastic sequential decision-making process and solved by means of dynamic programming. In addition, the long-term statistical features and short-term diversity features[16], as well as the fast channel sharing[17] are taken into account.

Recently, an efficient strategy for sensing order selection in distributed CRNs surroundings is proposed in Khan's work[1], where two or more autonomous CRs sense the channels sequentially (in some sensing order) for spectrum opportunities. The key contribution of this work is the adaptive persistent sensing order selection strategy in the case that CRs with false alarms autonomously select the sensing orders. This approach may achieve a better performance only when the quantity of CRs is not more than the quantity of available channels.

Different with existing work, we propose a novel sequential order strategy for sensing multiple channels in distributed CRNs jointing Khan's work and random access, but the two works have essential differences. Given that the sensing duration for a single channel is much shorter than the transmission duration, it is worth to attain a much lower collision probability at the cost of part transmission time, which is the foundation of this work.

3 An Adaptive Model for Multiple Channels Sensing

3.1 System Model

In a distributed CRN, M CRs and N authorized channels are coexisted, which are denoted as $\mathbf{CR} = \{CR_1, CR_2, \cdots, CR_M\}$ and $\mathbf{C} = \{C_1, C_2, \cdots, C_N\}$ respectively. If some channels are idle and sensed simultaneously by some CRs, they could transmit over those channels. In this case, if a PU reclaims one of the channels occupied by some CR, it will be evacuated by the related CR at once, which is consistent with the basic principle of Cognitive Radio. Given that all PUs and CRs employ the same time slot system as figure 1 shown, a CR maybe have experienced *i* sensing sub-slots when *k* idle channels are found, where *k* is the sensing threshold of available channels, i.e., a CR is required to find *k* idle channels and then makes a decision on whether to transmit or sense continually. The maximum of sensing duration is an allowable sensing interval, and the sensing process will be stopped and stay quiet if there is no any idle channel found until this upper bound. A PU's communication activity starts only in the beginning of a time slot and last to its end.

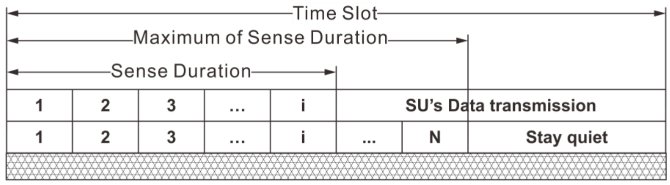

Fig. 1. Multiple channels access with the same time slot system

Similar to Khan's approach, all channels are organized as a form of Latin Square such as in(1):

$$\mathbf{CS} = \begin{bmatrix} C_1, C_2, C_3, \cdots, C_{N-1}, \ C_N \\ C_2, C_3, C_4, \cdots, C_N \ , \ C_1 \\ C_3, C_4, C_5, \cdots, C_1 \ , \ C_2 \\ \vdots \quad \vdots \quad \vdots \quad \ddots \quad \vdots \quad \vdots \\ C_N, C_1, C_2, \cdots, C_{N-2}, C_{N-1} \end{bmatrix} \tag{1}$$

where there are $N*N$ elements and each row CS_i (i=1,2,…,N) stands for a sequential channel order whose elements are consisted of CS_{ij} (j=1,2,…,N). Every CR maintains a sensing probability for each CS_i, i.e., $P^{(CS)} = \{p_i^{(CS)}, i = 1, 2, ..., N\}$, which the CR senses sequential channel order CS_i according to. At the beginning, each CR will select some CS_i according to the probability $p_i^{(CS)} - 1/N_{CS} = 1/N$. With the process going, the $p_i^{(CS)}$ will be updated according to its transmission and collision states, the objective of which is lowering the sensing probability to crowded channel orders. Note that the specific adaptive updating approach for $p_i^{(CS)}$ will be elaborated in next section. Due to the limitation of hardware devices, sensing and transmission could not be conducted simultaneously.

This model is established on the analysis of contending spectrum resource and one CR will make a decision on communicating over an idle channel only when *k* available channels are found. If two or more CRs are crowded at the same sequential channel order, it is required to sensing more available channels before making a transmission decision. Otherwise, a smaller number of available channels can help make a transmission decision. As shown in figure 2, C_1, C_2, C_3 and C_4 four channels are existed in a CRN, whose front part is a Latin Square based on channels, and its columns stand for sensing sub-slots, such as Sense 1 to Sense 4. In a transmission slot, a CR should find some idle channels first and then transmit in the remaining time of this slot. Suppose that CR_1 and CR_2 are crowded at the same CS_1 to perform sequential channel sensing simultaneously. In this case, if both CRs transmit immediately once they find one idle channel, a collision event between them is destined to occur. On the contrary, if they start their transmission when more than one idle channel is found, such as C_1 and C_2 available, they maybe avoid this collision event for CR_1 choosing one idle channel but CR_2 choosing the another idle one. Instinctively, the collision probability at the same sequential channel order is decreased.

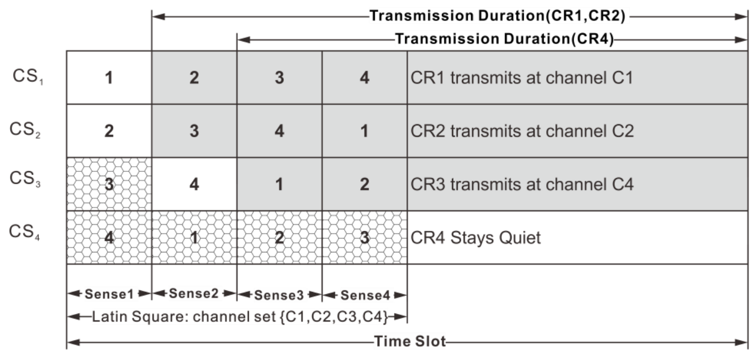

Fig. 2. Schematic diagram of channel sensing

3.2 Stop Condition and Sensing Threshold for Available Channels

In this paper, we mainly concern the distributed approach for sequential channel sensing and there is no possibility of cooperative communications among CRs as well as PUs. Given that the sensing threshold for available channel is k, each CR will sense the sequential channel order CS_i successively, i.e., $\{CS_{i1}, CS_{i2},\ldots,CS_{im}\}$, based on its sensing probability $p_i^{(CS)}$ until k available channels are found. Afterwards, the CR makes a decision on whether to transmit or to sense continuously. In contrast to existing work, we do not consider the traditional stop condition that once an idle channel is found, the process will be transferred to transmission from channel sensing. In the case of heavy channel load, i.e., more CRs but fewer available channels, two or more CRs are crowded at the same sequential channel order which leads to a high rate of collision correspondingly. If we continue to sense until k available channels (at least one) found, each CR on this channel order will have an opportunity to choose a different channel C_j to transmit according to its access probability $p_{CH}(CS_i, C_j)$. Therefore, the value of k is sensitive to the collision probability. If it is too small, more collision will be caused, but on the contrary, the overall sensing time will be increased and the transmission time is shortened correspondingly.

As discussed above, $p_i^{(CS)}$ is the foregoing sensing probability that a CR attends at sequential channel order CS_i, which is estimated according to its transmission success or not on CS_i. A smaller of $p_i^{(CS)}$ stands for a higher collision probability on CS_i. On this basis, the threshold k of available channels could be estimated as (2):

$$k = \min\{\lfloor 1/p_i^{(CS)} \rfloor, C_a\} \tag{2}$$

where C_a is the total quantity of available channels. Therefore, k's value stands for the crowded degree of the current channel order. If k equals to 1, our approach is simplified to Khan's. In conclusion, the stop condition of sensing channel is that k available channels have been found by the current CR.

3.3 Mechanism of Collision Avoidance

In a distributed CRN, collision events will occur frequently due to different CRs contending spectrum opportunities as well as lacking coordinated mechanism among CRs. If two or more CRs are crowded at the same sequential channel order, each CR may attain a similar sensing result and they surely collide with each other even the idle channels being found. In this case, all the transmission frames will be corrupted. To solve those problems, we propose a dynamic collision avoidance mechanism in this paper.

Suppose that a CR senses on sequential channel order CS_i, and do not take transmission activity until k available channels are found, where k is estimated according to section 3.2. If the specific quantity channels are found, the CR will randomly make a choice to transmit or to sense continuously. If continuous sensing is selected, the similar decision will be made in next sensing round. In other words, once k available channels are found, the CR faces two choices:

■ Select channel C_j to transmit based on $p_{CH}(CS_i, C_j)$ that denotes the probability of selecting channel C_j:

$$p_{CH}(CS_i, C_j) = {2 \times r_j}/{(1+k) \times k} \tag{3}$$

where k is the sensing threshold of available channels and r_j is the index number of channel C_j in current available channel set. As shown in(3), the last available channel in sensing result set has the highest access probability. Let r ($r=1,2,\ldots,k$) denotes the index number in available set, and I_r is the subscript of some channel, i.e., $C_{Ir} \in \mathbf{C}$. Therefore, C_{Ik} is the last element and $p_{CH}(CS_i, C_{Ik})$ is

$$p_{CH}(CS_i, C_{Ik}) = {2 \times k}/{(1+k) \times k} = {2}/{(1+k)} \tag{4}$$

To sum up, the access probability of each element in the available set is sensitive to its index number in this set as well as the total quantity k.

■ Continue to sense at the current sequential channel order CS_i.

If the first choice is selected, i.e., transmit over channel C_j, the following two cases maybe happen.

Case 1：If there is no collision over channel C_j during the transmission interval, this time of transmission is successful, which can be inferred from whether the related ACK is correctly received or not. In this case, the sensing probability CS_j, whose first item is C_j, is increased correspondingly:

$$\begin{cases} p_j^{(CS)} = p_j^{(CS)}{}' + \sigma_j \\ p_{k\neq j}^{(CS)} = \dfrac{1-p_j^{(CS)}}{\sum\limits_{q\neq j} p_{q\neq j}^{(CS)}{}'} \times p_{k\neq j}^{(CS)} \end{cases} \quad \text{, if } \; p_j^{(CS)}{}' + \sigma_j < 1 \tag{5}$$

where $p_j^{(CS)}{}'$ is the sensing probability of CS_j at the last transmission slot and $\sigma_j \geq 0$ denotes the augmentation of sensing probability to CS_j at this transmission slot. The value of σ_j should meet the requirement $\lceil 1/p_j \rceil - \lceil 1/p_j{}' \rceil \geq K^{(CS_j)}$, which means that the sensing threshold of available channels should be increased by $K^{(CS_j)}$ such that the hit rate of channel C_j will be increased correspondingly. In this updating process, if $p_j^{(CS)}{}' + \sigma_j \geq 1$ holds true, the sensing probability to CS_j will be set to 1 and other one be set to 0, i.e., $p_{k\neq j}^{(CS)}$ =0.

Case 2：If the ACK is not received correctly, it is deemed that a collision occurs on channel C_j. In this case, the sensing probability to sequential channel order CS_j will be decreased, but others will be increased as shown in(6):

$$\begin{cases} p_j^{(CS)} = p_j^{(CS)}{}' - \sigma_j \\ p_{k\neq j}^{(CS)} = \dfrac{1-p_j^{(CS)}}{\sum\limits_{q\neq j} p_{q\neq j}^{(CS)}{}'} \bullet p_{k\neq j}^{(CS)} \end{cases} \text{, s.t., } \; p_j^{(CS)}{}' - \sigma_j \geq 0 \tag{6}$$

Similarly, the value of $\sigma_j \geq 0$ should meet the requirement $\lceil 1/p_j{}' \rceil - \lceil 1/p_j \rceil \geq K^{(CS_j)}$ such that the hit rate of CS_j and C_j will be decreased. If there is a contradictory between the two inequalities $p_j^{(CS)}{}' - \sigma_j \geq 0$ and $\lceil 1/p_j{}' \rceil - \lceil 1/p_j \rceil \geq K^{(CS_j)}$, the former one should be assured first.

In case 1, it is possible that a CR continues to sense at the current sequential channel order CS_i. In this case, this CR starts to sense from the first element in CS_i in next sensing round, but those channels that have been found busy in the first sensing round will be omitted. Similarly, the process will transfer to transmission or selection decision when k available channels are found. When the whole time of sensing rounds reaches to the upper bound, i.e., the maximum of sensing duration, the sensing process will be stopped at once. As an example shown in figure 3, in the first sensing round (Round 1), CR_1, CR_2, CR_3 and CR_4 employ the same order CS_1<C_1, C_2, C_3, C_4, C_5> to sense k (k=3) available channels. As a result, C_2 is busy and C_1、C_3 and C_4 are idle. In this case, if CR_1 selects channel C_1 to transmit but others decide to sense continuously, C_3, C_4 and C_5 are found available and C_1 is observed in this round. In this case, if CR_2 and CR_3 make a decision on transmission over C_3, a collision happens. Therefore, in the next transmission slot, CR_2 and CR_3 will decrease the sensing probabilities to CS_3< C_3,C_4,C_5,C_1,C_2,>, and meanwhile increase the others. Instinctively, what we do can lower the collision probability in contrast to immediately transmission while one available channel is found.

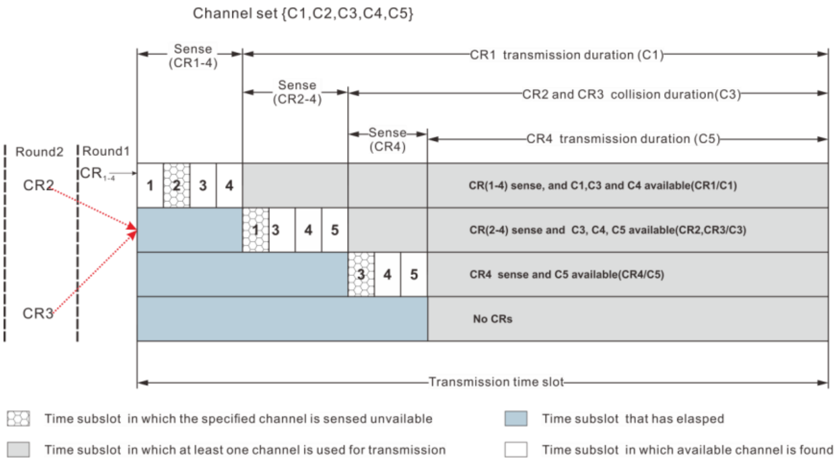

Fig. 3. Illustration of sense, collision and transmission in a transmission slot

Our proposed adaptive multiple channels sensing strategy can be summarized as the following pseudo-code algorithm CRN_MCST, which is executed in each CR independently and there is no any information exchanging among them.

Each CR will execute algorithm CRN_MCST one time in every single transmission slot. In initialization stage, the sensing probabilities to all sequential channel order are identical. With the iterating of transmission, each CR independently make a judgment on whether the current sequential channel order is crowded or not, and then adjust its sensing probability accordingly. In line 2-3, the threshold k of available channels sensing is calculated based on the sensing probability, and meanwhile a sequential channel order is selected from the channel Latin Square, i.e., CS_i. In line 4-8, the CR senses the sequential channel order successively, in which all the available channels are stored into the pre-allocated buffer. This process will be executed repeatedly until k available channels found or all the items in CS_i have been checked. Thus, the complexity of line 4-8 is proportional to the total channel quantity, i.e., O(n). In the process of line 9-20, the CR makes a decision on which channel should be selected for transmission, and the sensing probability and access probability are also updated according to the transmission result. The time complexity is proportional to buffer size, thus it is O(k) and k<=n. In line 21-22, it is the case that no available channels are found and the CR will stay quietly in the whole transmission slot. To sum up, the time complexity in a transmission slot is O(n).

```
Algorithm: CRN_MCST
Initialization: The sensing probability vector P^(CS), and each p_i^(CS) = 1/n, i = 1,2,...,n
     The channel matrix CS with Latin Square form;
     buffer_free is empty;// used for store the available channels sensed
     transmit_flag=false;
1.   BEGIN
2.     CS_i is selected from CS based on p_i^(CS)
3.     Calculate k based on E.q.(2)
4.     WHILE ! endof(CS_i) && sizeof(buffer_free)<k //k is the threshold of free channels
              sensed by the current CR
5.       IF CS_ij is busy THEN j++;
6.       ELSE
7.         Store the CS_ij into the buffer_free;
8.     END WHILE
9.     WHILE sizeof(buffer_free)>0
10.      Make a decision on whether to transmit or continue to sense randomly;
11.        IF deciding transmission THEN
12.          Select C_j from buffer_free to transmit based on E.q.(3)
13.          Set transmit_flag=true and Transmit at the remaining transmission slots
14.          IF transmission is successful at C_j in CS_i THEN
15.            Increase the probability CS_j based on sensing probability E.q.(5) ;
16.          ELSE decrease the probability CS_j based on sensing probability E.q.(6);
17.                Evacuate the buffer_free; // CR will transmit at the remaining period
18.        ELSE //continue to sense the free channel in buffer_free
19.          Goto step 2；
20.    END WHILE
21.    IF transmit_flag=flase THEN
22.      Stay quiet until next transmission slot
23.    END
```

Fig. 4. Algorithm CRN_MCST: multiple channel sense and transmission

4 Experiments and Analysis

In order to verify the performance and compare with other typical approaches, some numerical experiments has been conducted in this section, where the mainly parameters in our experiment are similar to Khan's approach. The channel busy probability *Pu* is set 0.0, 0.1, 0.3 and 0.5, such that we can check the performance of different approaches at different channel workloads. The total channel quantity is 10 and the quantity of CRs are various from 2 to 20. The performance of channel utilization can be inferred from the wasted ratio of transmission slot, including collision interval and idle interval. Moreover, we set 50 transmission slots in each time experiment and total 10 experiments are conducted. Thus, we have attained 100 times experimental data. Meanwhile, we set 11 sub-slots as a transmission slot, i.e., if a CR has sensed the last item in current sequential order, there is only one sub-slot for transmission. The experimental results are shown in figure 5 - figure 8.

Figure 5 and figure 6 are the comparisons between our approach and Khan’s. Khan’s approach has an excellent performance under the case that there is a light load with a fewer number of CRs on the channels, where the wasted ration of transmission is no more than 20%. While the CR quantity is more than 10, the wasted ratio is soaring. Even all the channel are not occupied by PUs, i.e., *Pu*=0.0, the wasted ratio reaches 60% with 20 CRs. But in the case of *Pu*=0.5, the wasted ratio is about 33% in Khan’s approach. Figure 6 shows the experimental result of our approach. It is obvious that the proposed approach has a better overall performance compared with Khan’s, and the wasted ratio is constrained about 10% at different probabilities of *Pu*s. Only when the CR quantity is 2 or 3, the performance is not superior to Khan’s.

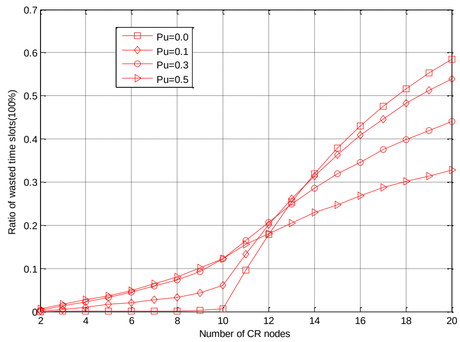

Fig. 5. Khan’s method at different busy probabilities of channels with various CR quantities

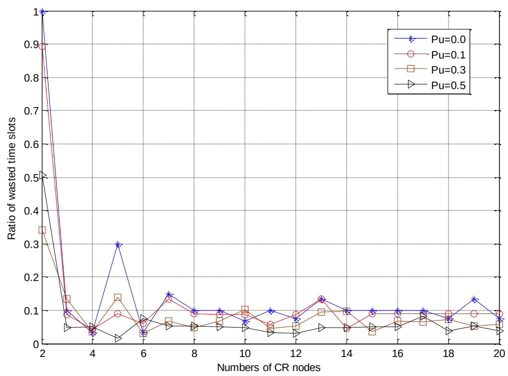

Fig. 6. The proposed method at different *Pu*s with various CR quantities

Figure 7 shows the comparison at the channel busy probability *Pu*=0.1. Only when the CR quantity is less than channel quantity, Khan’s method has a better performance. After that point, this approach has an intolerable increasing on channel wasted ratio. On the contrary, our approach remains a comparative stable wasted ration about 10%, only when the CR quantity is 2 or 3, the performance is poor. In the case of heavy channel workload, our proposed approach will be a quite effective complement to Khan's approach. In those three approaches, the Random LS strategy[13] has the least performance and the channel wasted ratio is reached 70% when there are 20 CRs in the network.

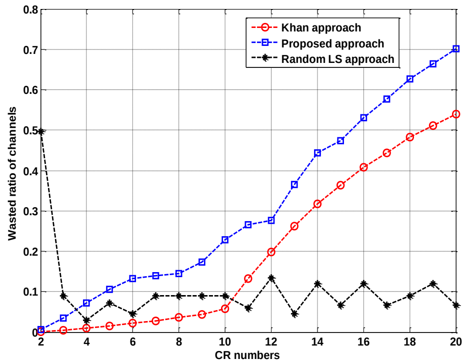

Fig. 7. The comparison between different approaches

When there are 10 CRs, each CR could attain an almost equitable transmission chance about 10% in all those three approaches, and all of them have achieved a well fairness, as shown in Figure 8.

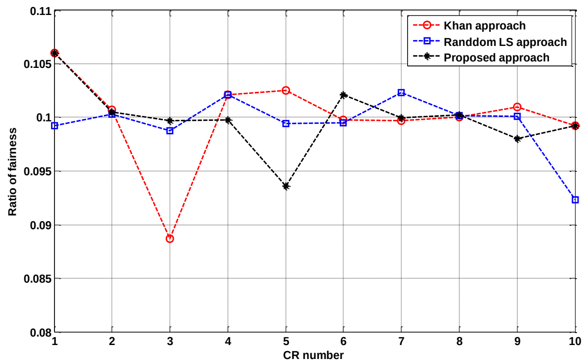

Fig. 8. The comparison in transmission ratio of different CR nodes

5. Conclusion

In this paper, we have investigated the distributed channel sensing strategy in a CRN environment with heavy load channels and obtained some important observations. In the system model, a sensing threshold for available channels is estimated based on the crowded degree of the current sequential channel order. On this base, each CR can adjust its sensing probability to sequential order and access probability to a channel according to whether this transmission success or not. Moreover, we presented an algorithm with low computational complexity, in which the process of each CR sensing the sequential channel order and deciding channel to transmit is elaborated in detail. Simulation results demonstrate the effectiveness of our proposed approach.

Acknowledgments. This work was supported in part by the Research Fund for the Doctoral Program of Higher Education of China under Grant 20122304130002, the Natural Science Foundation in China under Grant 61370212, the Natural Science Foundation of Heilongjiang Province under Grant ZD 201102 and F201037, the Fundamental Research Fund for the Central Universities under Grant HEUCFZ1213 and HEUCF100601, and Postdoctoral Science Foundation of Heilongjiang Province under Grant LBH-210204.

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